Mededelingen
Nederlands Instituut voor
Toegepaste Geowetenschappen TNO

Biostratigraphy of Cretaceous/Tertiary boundary strata in the Curfs quarry, the Netherlands

Editor: G.F.W. Herngreen

Nr61 1998

The "Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen TNO" is a publication medium for collaborators of the Netherlands Institute of Applied Geoscience TNO - National Geological Survey. Manuscripts by other authors may be also accepted if these deal with topics of interest for the Institute. Responsibility for the opinions and interpretations given rests with the authors. Each volume may comprise several separate issues.

Editorial address:
Board of Editors of the "Mededelingen Nederlands
Instituut voor Toegepaste Geowetenschappen TNO"
c/o NITG TNO
P.O. Box 157
2000 AD Haarlem
The Netherlands
Fax: 31-23-5300283

Design:
J.A.M. Bruinenberg

Prepress and printing:
Boom Planeta de Grafische, Haarlem
the Netherlands

The "Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen TNO", is issued since 1997 by the Netherlands Institute of Applied Geoscience TNO and succeeds the:
"Mededeelingen van de Rijksopsporing van Delfstoffen" (issued between 1908 and 1917),
"Mededeelingen van 's Rijks Geologischen Dienst", Serie A (issued between 1922 and 1944),
"Mededeelingen van 's Rijks Geologischen Dienst", Serie B (issued in 1923)
"Mededeelingen van de Geologische Stichting", Serie C (issued between 1941 and 1975),
"Mededeelingen van de Geologische Stichting", Serie D (issued in 1942)
"Mededelingen van de Geologische Stichting", Nieuwe Serie (issued between 1944 and 1965)
"Mededelingen Rijks Geologische Dienst", Nieuwe Serie (issued between 1968 and 1977).
"Mededelingen Rijks Geologische Dienst" (issued between 1978 and 1997).

Kette

Nederlands Instituut voor Toegepaste Geowetenschappen TNO
Netherlands Institute of Applied Geoscience TNO
- National Geological Survey

The Netherlands Institute of Applied Geoscience TNO - National Geological Survey was created in 1997 by joining:
1. Geological Survey of the Netherlands (Rijks Geologische Dienst)
2. TNO Institute of Applied Geoscience (TNO Grondwater en Geo-Energie).

The Institute is the central geoscience institute in the Netherlands for information and research to promote the sustainable management and use of the subsurface and its natural resources.

The Institute is part of the Netherlands Organization for Applied Scientific Research TNO (4000 staff). TNO is a statutory organization, established in 1932, and operates on an international scale. Its fields of activities also include environment and energy, construction, transport and infrastructure.

Netherlands Institute of Applied Geoscience TNO
- National Geological Survey

Richard Holkade 10
P.O. Box 157
2000 AD Haarlem
The Netherlands
Phone +31 23 530 03 00
Fax +31 23 535 16 14

Schoemakerstraat 97
P.O. Box 6012
2600 JA Delft
The Netherlands
Phone +31 15 269 71 52
Fax +31 15 256 48 00

Biostratigraphy of Cretaceous/Tertiary boundary strata in the Curfs quarry, the Netherlands

G.F.W. Herngreen, H.A.H.M. Schuurman and J.W. Verbeek
Netherlands Institute of Applied Geoscience - National Geological Survey, P.O. Box 157, 2000 AD Haarlem, the Netherlands

H. Brinkhuis
Laboratory of Palaeobotany and Palynology, University of Utrecht, Budapestlaan 4, 3584 CD Utrecht, the Netherlands

J.A. Burnett
Department of Geological Sciences, University College London, Gower Street, London, WC1E 6BT, United Kingdom

W.M. Felder
c/o Netherlands Institute of Applied Geoscience - National Geological Survey, district South, P.O. Box 126, 6400 AC Heerlen,
the Netherlands

M. Kedves
Cell Biological and Evolutionary Micropaleontological Laboratory of the Department of Botany, J.A. University, P.O. Box 993, H-6701,
Szeged, Hungary

Abstract

Samples from the Maastricht Formation and the Houthem Formation, latest Maastrichtian to earliest Danian, exposed in the Curfs quarry, southern Limburg, the Netherlands have been examined micropalaeontologically. Foraminiferal, nannoplankton and palynomorph studies, emphasizing dinoflagellate cysts and sporomorphs, were carried out mainly on the same sampled section. With the exception of sporomorphs, this classic Dutch Cretaceous/Tertiary boundary (KTB) section contains rich and well preserved assemblages.

The stratigraphically diagnostic dinoflagellate cysts and foraminifers confirm that the lower part of the succession represents the latest Maastrichtian, and that an Early Danian age may be assigned to sediments from the base of the Berg en Terblijt Horizon upwards. Positioning of the KTB at this horizon is supported by the presence of detrital clays just above it. The Vroenhoven Horizon, previously thought to represent the KTB is now placed in the Lower Danian.

On the basis of the quantitative palynological evidence it is suggested that the lithological succession represents relatively marginal marine, probably inner neritic, conditions, with most of the hardgrounds marking periods of sea-level lowstand. A 'second-order' deepening trend from the latest Maastrichtian into the Early Danian can be inferred. Superposed on this trend, three 'third-order' sea-level cycles may be recognized, one in the uppermost Maastrichtian and two in the Lower Danian. The KTB, represented by the Berg en Terblijt Horizon falls within the third-order cycle TA1.1 of Haq et al. (1988) and is characterized by the first occurrences (FOs) of Senoniasphaera inornata *and* Lanternosphaeridium reinhardtii *and a distinct influx of bryophyte spores. The KTB succession can be well correlated with the time-equivalent interval in the Geulhemmerberg caves.*

Some benthic foraminifer marker species, as well as the ostracod Dumontina stellata, *indicate a Danian age for the interval above the Berg en Terblijt Horizon. Neither the numbers of the predominant* Pararotalia tuberculifera *nor the species diversity suggest a major change at or around the KTB. A considerable number of reworked Upper Maastrichtian forams is found in the youngest unit of the Maastricht Formation between the Berg en Terblijt and Vroenhoven Horizons.*

Controversially, the nannofossil data indicates that the entire examined section around the KTB is of Danian age, with standard zone NP1 extending from 2.5 m below the Berg en Terblijt Horizon to 0.1 m above the Vroenhoven Horizon. This hypothesis is partly based on the presence of Neobiscutum *spp. throughout the sequence, although there is a possibility that these forms evolved in the Maastrichtian. However, the additional presence of* Cruciplacolithus *spp., also from the base of the sequence, lends weight to the argument that the section around both hardgrounds is Danian. Incontrovertible nannofossil evidence for the later Early Danian occurs above the Vroenhoven Horizon, which explains why this was originally interpreted as representing the KTB. Two cycles of reworking can be demonstrated, the first involving Upper Maastrichtian to lowest Campanian sediments, the second, the basal Paleocene and Upper Maastrichtian.*

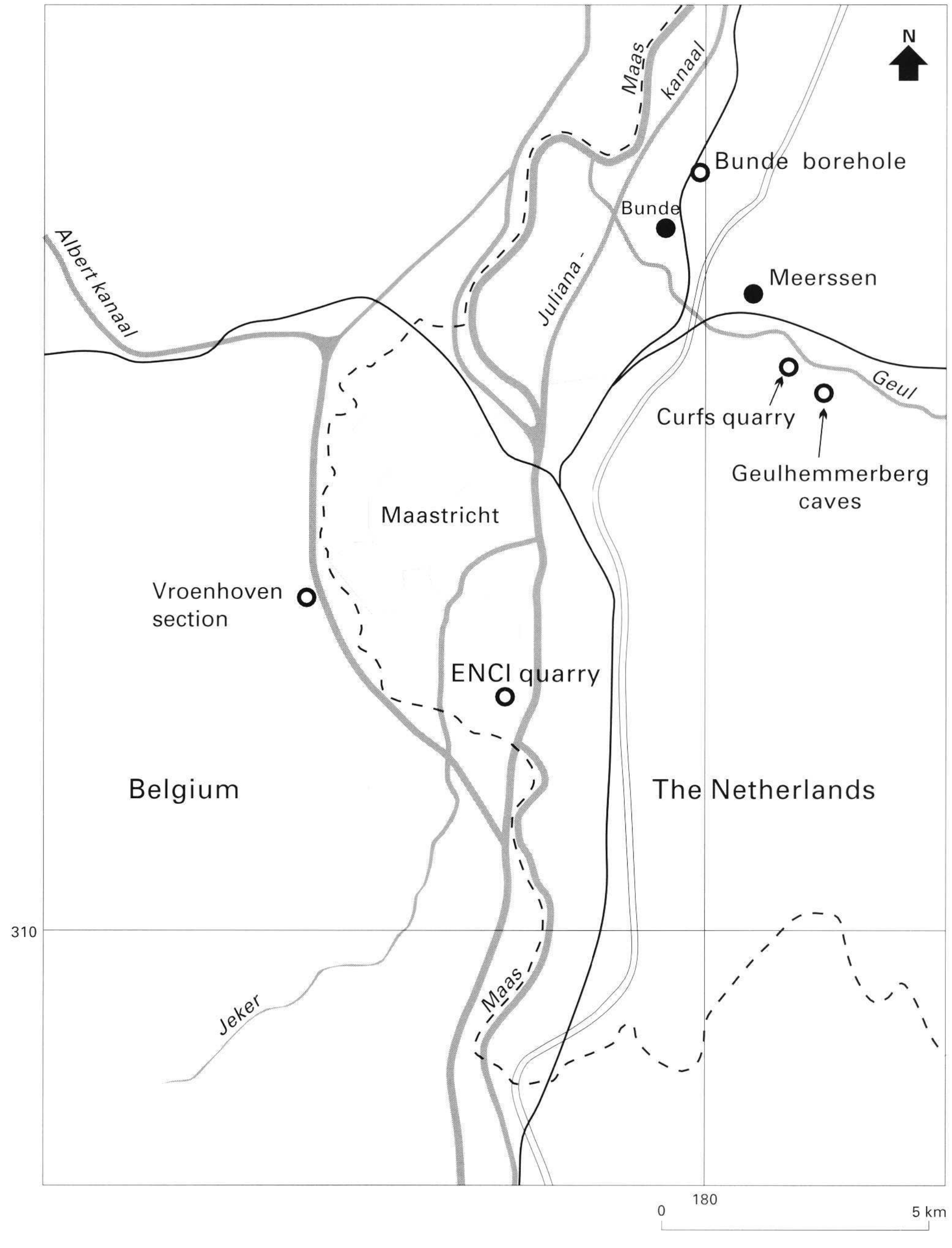
The sporomorph data do not indicate a drastic change at the KTB. There is a distinct decrease in the Upper Cretaceous Eunormapolles taxa in the Houthem Formation, whereas the so-called Tertiary Postnormapolles pollen grains increase in this formation. Species of Pseudotrudopollis *proved to be useful index fossils for the Maastrichtian, while* Jarzenipollenites trinus *is a good marker species for the Danian. Changes in the sporomorph assemblages indicate a cooler latest Maastrichtian.*

Introduction

The sporomorph results from the Gulpen and the lower part of the Maastricht Formations have been dealt with in two previous publications, respectively Kedves & Herngreen (1980) and Herngreen et al. (1986). In order to complete this research programm, which was set up fifteen years ago to study the palynofloral changes around the Cretaceous/Tertiary boundary (KTB), samples from KTB transitional strata were taken in the Curfs quarry, near Maastricht, the Netherlands (Figures 1 and 2).
As much micropalaeontologic information as possible, other than sporomorphs, has been incorporated in previous studies and has been used in the present paper.

For many years, the KTB in the Maastrichtian type-area was thought to be represented by an unconformity, marked by a well-defined hardground, the Vroenhoven

Figure 1
Map showing localities mentioned in this paper.



Horizon (e.g. Felder 1975). Although not present at the ENCI quarry, the Maastrichtian type-locality, where the topmost Maastrichtian is missing, this horizon is well-exposed in the nearby Curfs quarry located some 7 km NE of Maastricht (Figs 1 and 2). Recently, however, a relatively complete KTB section was found for the first time in the man-made Geulhemmerberg caves (see papers in Brinkhuis & Smit 1996; Fig. 1). Here the KTB is represented by another hardground, named the Berg en Terblijt Horizon (Felder & Bosch, in press), which occurs upto 5 m below the Vroenhoven Horizon.

The entire section exposed in the Curfs quarry was originally referred to as a single lithological unit, the Md (Uhlenbroek 1912). Following Hofker (1955) and Felder (1975) the Curfs quarry exposes the topmost Maastrichtian members (Nekum Chalk and Meerssen Chalk of the Maastricht Formation), as well as part of the Lower Danian (Geulhem Chalk Member of the Houthem Formation) above the Vroenhoven Horizon (Figs 3 and 4). A few metres below the Vroenhoven Horizon, another hardground can be observed, recently described as the Berg en Terblijt Horizon at Curfs by Felder & Bosch (in press), Figs 5 and 6. Slightly above the base of this horizon, thin isolated clay layers occur, comparable to those found in the Geulhemmerberg caves above this horizon. These are thought to represent remnants of the 'boundary' clay (Smit & Brinkhuis 1996). Near the base of the quarry, the Caster Horizon is developed, a hardground separating the Nekum and Meerssen Chalks (Felder 1975).

P.J. Felder (1988) extensively studied the lithology of the entire quarry and concluded that, with the exception of the Vroenhoven Horizon which is easily distinguished by its thick hardground and a fossil grit layer, no distinct changes in lithology, bioclast assemblages and gamma radiation occur across the KTB.

Figure 7 illustrates the position of the Berg en Terblijt and Vroenhoven hardgrounds around the KTB, at various locations in the Maastricht type-area.

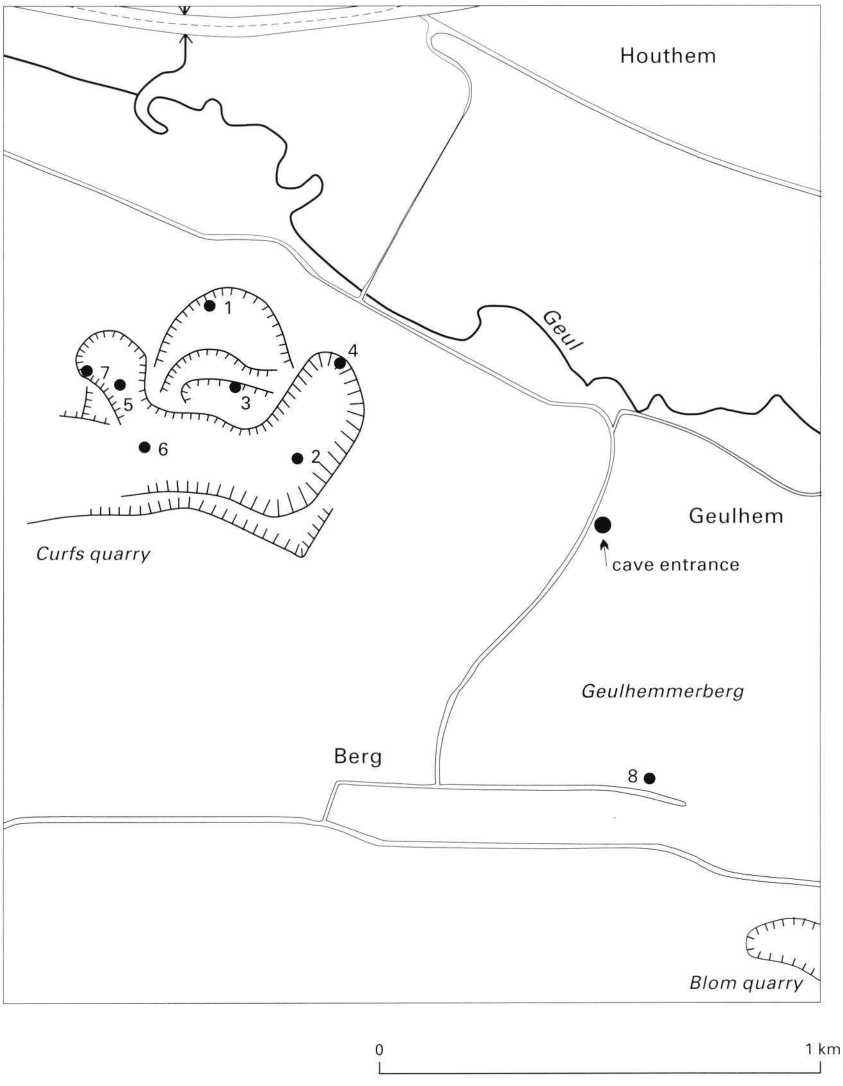


Figure 2
Plan of the Curfs quarry with location of the Cretaceous/Tertiary boundary sections.
1-4 Position of localities sampled by Hofker (1966):
1. 182.000-320.200,
2. 182.200-319.920,
3. 182.100-320.030,
4. 182.320-320.080;
5-6 Location of RGD sites for detailed sampling at the KTB transition:
5. 1985 181.800-320.020 and
6. the 1996 site 181.840-319.930;
7 Position of LPP sampling site 1992, 181.740-320.050;
8 Location of the main sampling site within the Geulhemmerberg caves (papers in Brinkhuis & Smit 1996).

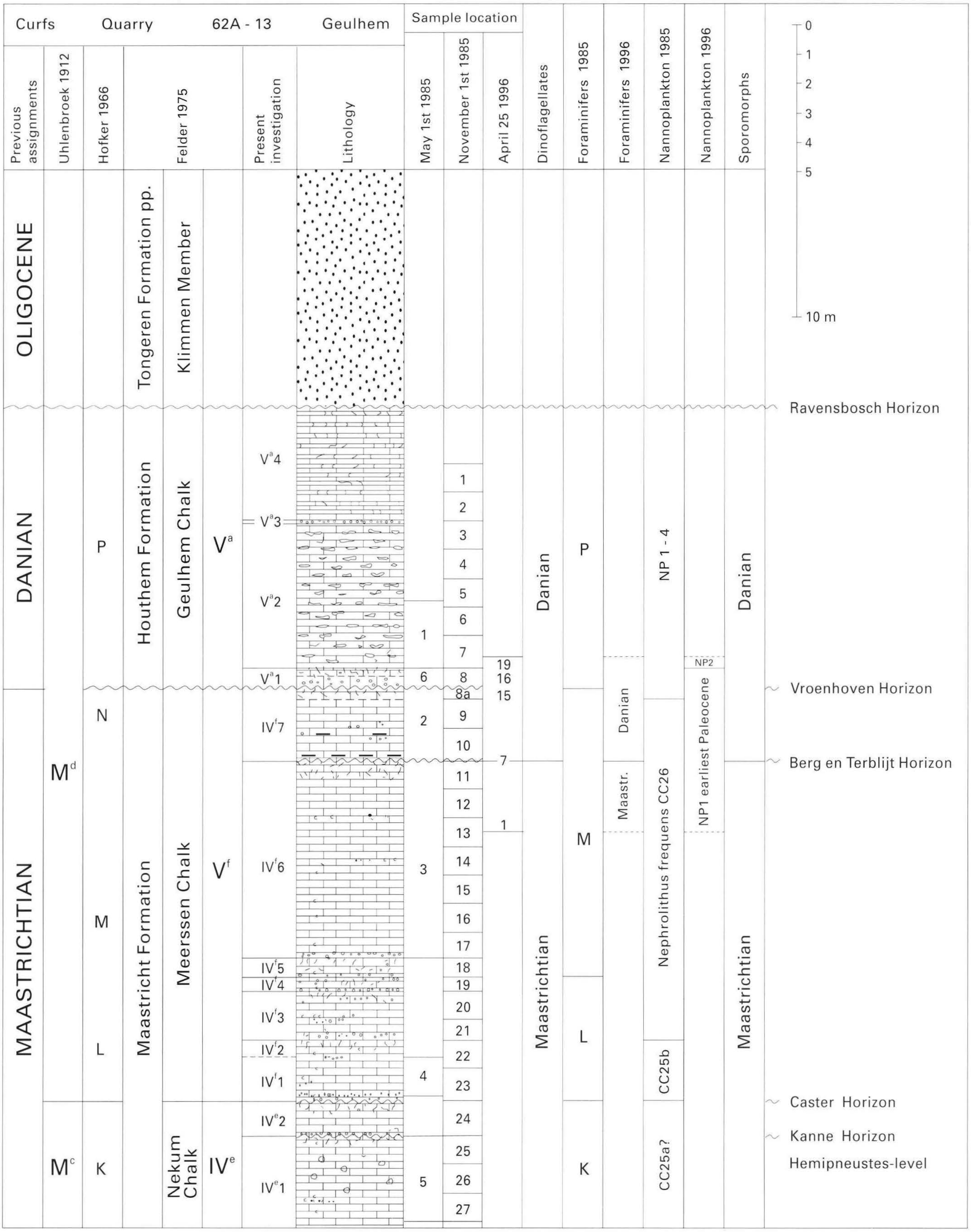


Figure 3

Lithology and bio- and lithostratigraphic units distinguished in the Curfs quarry. The numbers indicate the position of the samples taken in the 1985 (May and November) and 1996 sample campaign.

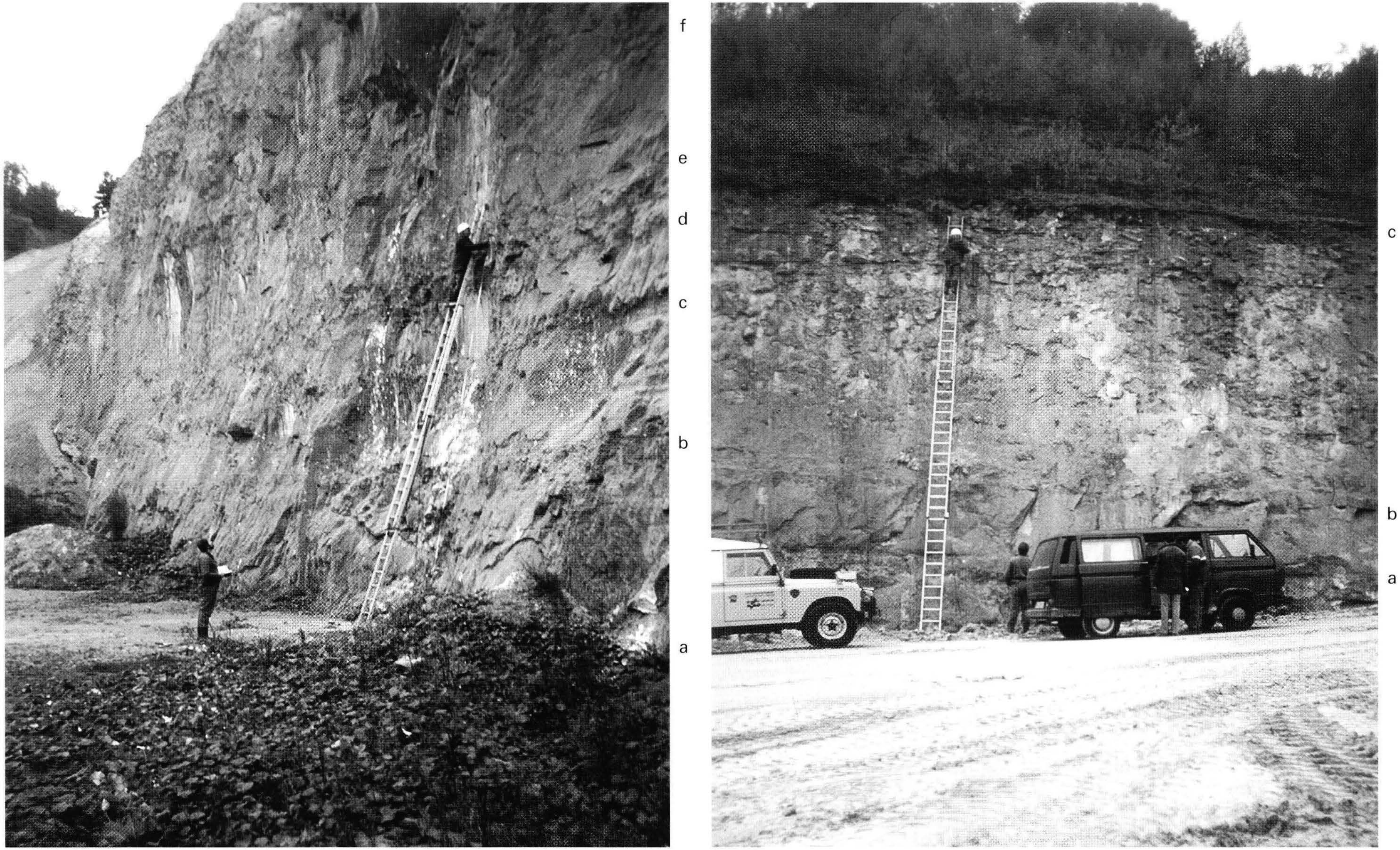
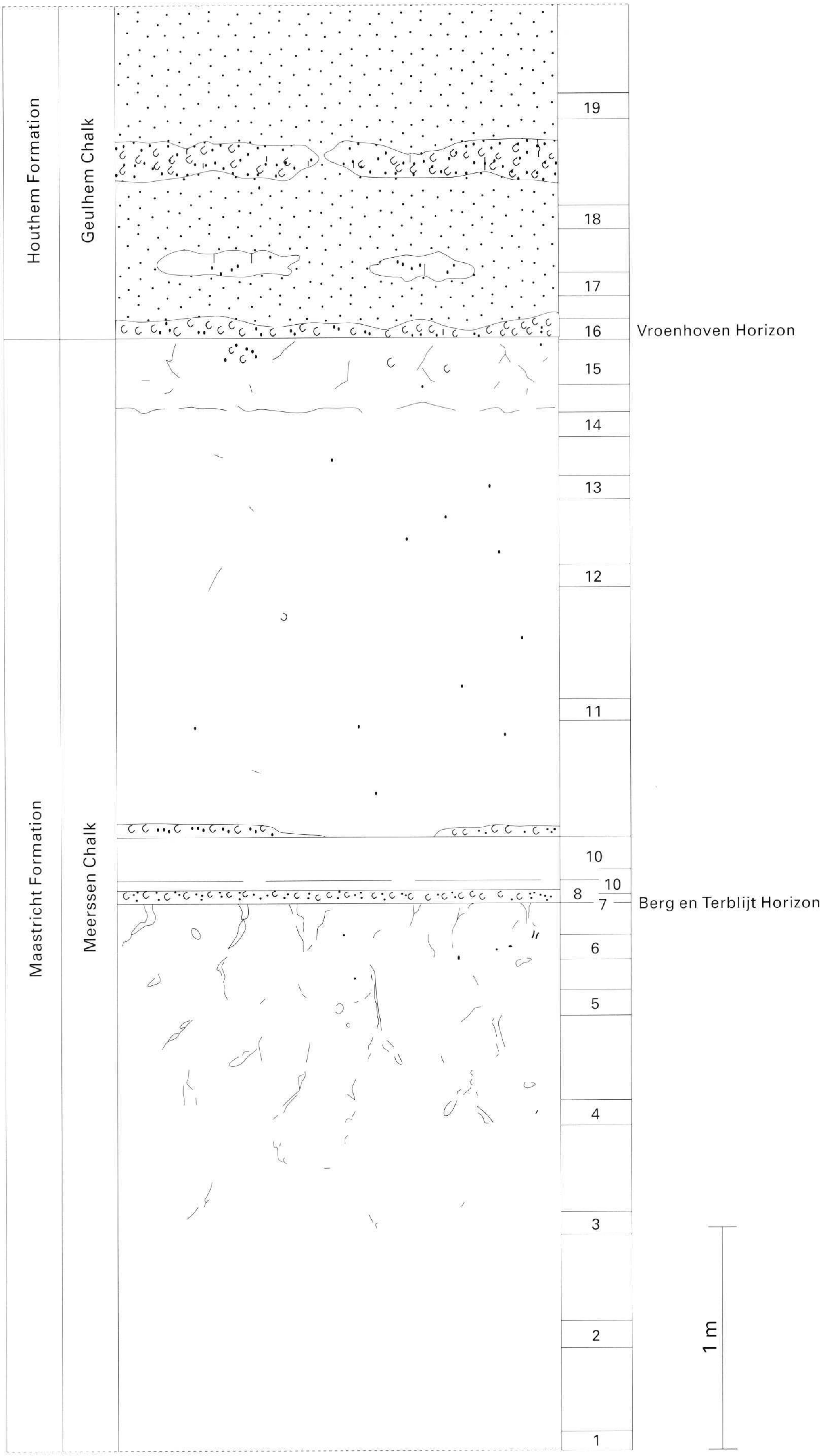


Figure 4
Overview of Curfs quarry, WMF on the ladder; photo's taken by GFWH November 1st, 1985.

4.1 Meerssen Chalk Member (Maastricht Formation) between the Mc/Md boundary (a) and Berg en Terblijt Horizon (f). The Mc/Md boundary is covered by debris and plant overgrowth; b-e hardgrounds.

4.2 Top of the Meerssen Chalk Member with Berg en Terblijt Horizon (a), Vroenhoven hardground (b), Geulhem Member (Houthem Formation) and overlying Oligocene strata of the Klimmen Member (Tongeren Formation) above the Ravensbosch Horizon (c).

Figure 5
Lithology and sample position around the KTB in the Curfs quarry; sampling carried out April 25, 1996.



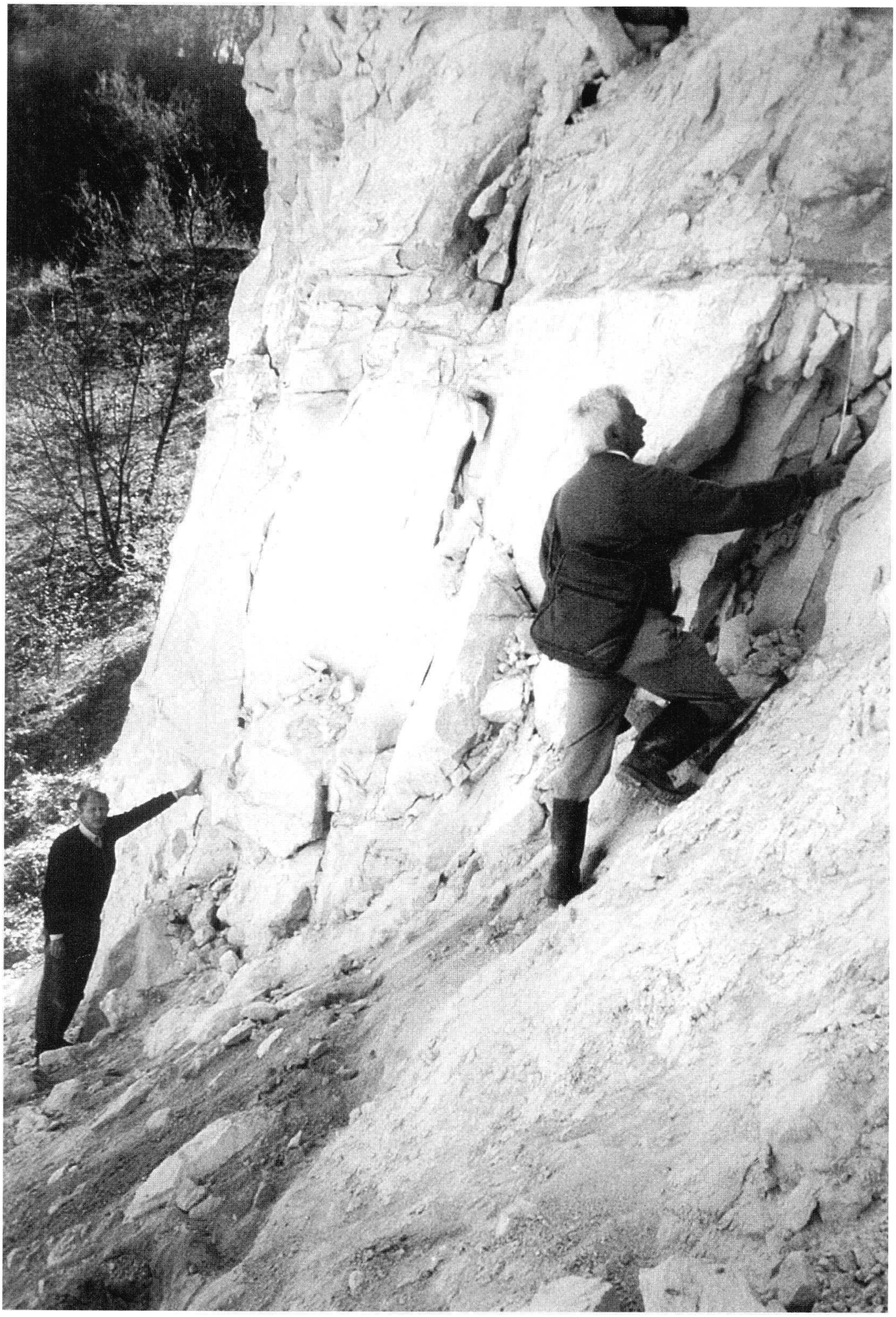
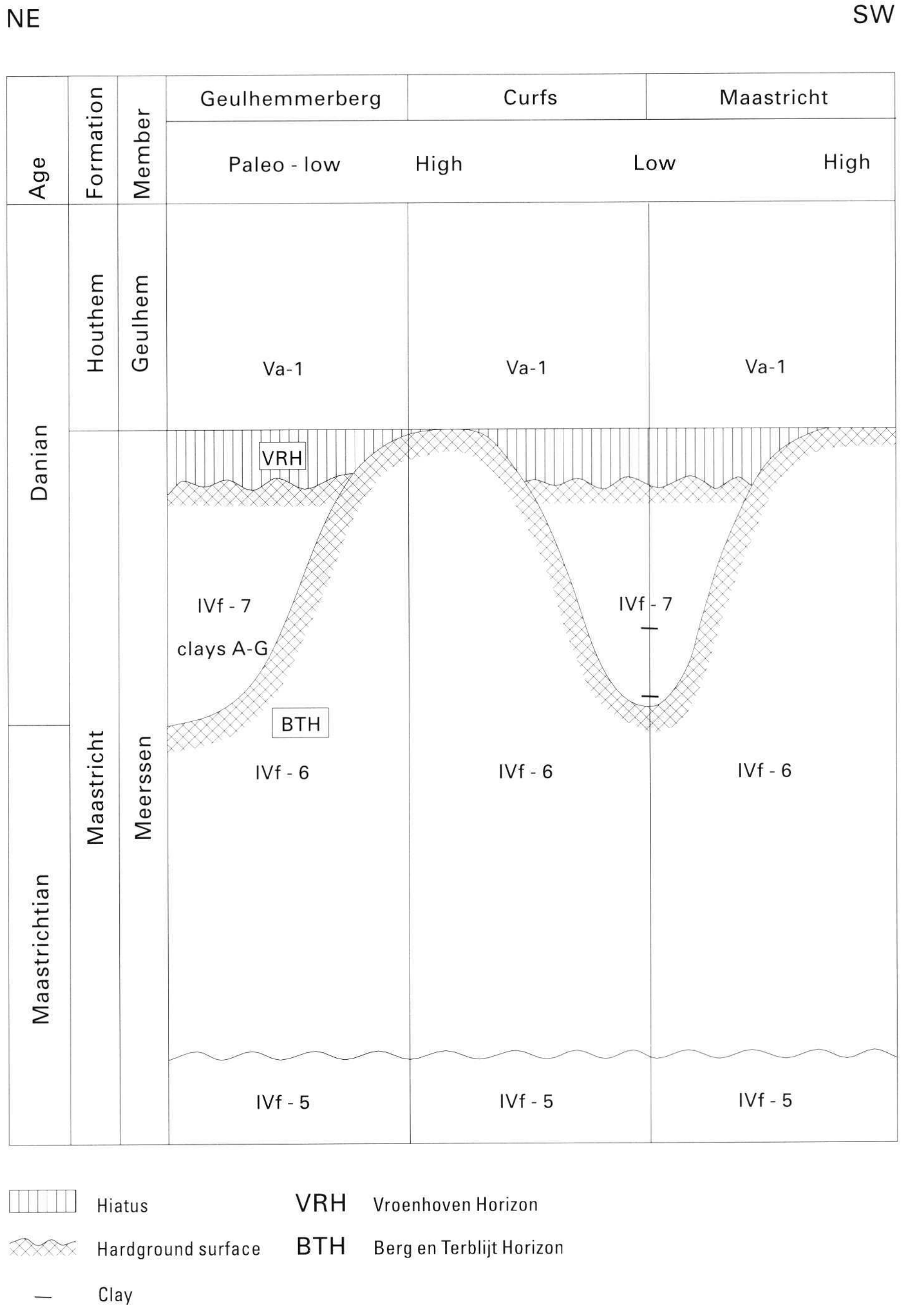


Figure 6
KTB section in Curfs quarry at Geulhem; photo taken by GFWH April 25, 1996. The hand of the figure in the background lies on the Berg en Terblijt hardground, the IVf-7 unit (topmost Meerssen Chalk Member, Maastricht Formation) and WMF measuring the distance to the Vroenhoven hardground (a). Note change in colour between Meerssen Chalk Member and overlying Geulhem Member (lowermost unit of the Paleocene Houthem Formation).

Figure 7
Generalized overview of the stratigraphy around the KTB in South Limburg.



Material and methods

The first series of samples, originally intended for a large-scale palynomorph (dinoflagellates and sporomorphs) study - with foraminifera and nannoplankton support - of the uppermost Maastrichtian deposits, was taken by GFWH and WMF during two sessions. On the first occasion, May 1st 1985, six samples were collected for a provisional sporomorph examination. The preliminary results showed that a detailed examination would be justified and a more complete set of 27 samples was taken on November 1st, 1985 (Fig. 3). JWV examined these samples for nannofosils.

In the mid-nineties, it became clear in the light of the results obtained from the Geulhemmerberg caves (papers in Brinkhuis & Smit 1996) that the section around the KTB in the Curfs quarry might be more complete than previously thought. Moreover, the exposures in Curfs are well accessible and occupy a key position, geographically as well as stratigraphically, between the Maastricht type-section in the ENCI quarry and the nearly complete Cretaceous/Tertiary transition in the Geulhemmerberg caves. For this reason, an additional set of 19 closely-spaced samples from 2.5 m below the Berg en Terblijt Horizon to 1 m above the Vroenhoven Horizon was taken on April 25th, 1996 by GFWH and WMF (Fig. 5). This set of samples was examined for forams and ostracods (HAHMS) and nannoplankton (JAB).

In addition to the November 1985 sampling campaign by the Geological Survey, the Laboratory of Palaeobotany and Palynology, University of Utrecht, collected material from crucial intervals around the KTB in the Curfs quarry in 1992, for dinoflagellate analysis (Figs 8-10). The results of both integrated sample sets are reported by HB.

Dinoflagellates

Introduction

Brinkhuis & Schiøler (1996) described the rich palynological associations of the Geulhemmerberg KTB section in detail, emphasizing dinoflagellate cysts. Their results indicate that the lowermost Danian may be characterized by the first occurrences (FOs) of the dinoflagellate cysts *Senoniasphaera inornata* and *Lanternosphaeridium reinhardtii*, as well as massive occurrences of presumed bryophyte spores. Although several studies have described the palynology of parts of the Upper Cretaceous and Lower Danian succession in the southern Netherlands and its immediate surroundings (e.g. Wilson 1971, 1974; Schumacker-Lambry 1977; Robaszynski et al. 1985; Herngreen et al. 1986; Batten et al. 1988; Bless & Streel 1988; Schiøler et al. 1997), no such studies are available from the Curfs quarry, the classic Dutch KTB section, relatively close to the Geulhemmerberg locality. Only Wilson (1974) briefly described a single sample from the western part of the quarry immediately below the contact with Foraminifera Zone P. In this sample, which correlates well with his sample AC1 (top Md; top of Zone M) from the Albert Canal section, marginate and chorate cysts predominate (93%) with *Areoligera coronata, A. senonensis* and *Hystrichosphaeridium tubiferum* being the most abundant species.

The present study is therefore aimed at (1) a palynobiostratigraphical analysis of the KTB transition at Curfs, complemented by (2) palaeoenvironmental interpretations, and (3) correlation to the Geulhemmerberg KTB section.

For the present study, use is made of two sets of samples derived from the succession exposed in the Curfs quarry. The first set encompasses 27 samples taken by the Geological Survey of the Netherlands (RGD) in 1985, labled 'RGD'. A second set of 14 samples was taken from crucial intervals in 1992, labled 'CURF' (Figs 8-10). Approximately 10-15 g of sample was processed following standard palynological techniques. Heavy liquid separation ($ZnCl_2$) was applied in all cases. Residues were sieved using a 10µm precision sieve. After extensive mixing to obtain homogeneity, two to eight slides were prepared using glycerine jelly as the mounting medium. Where possible, approximately 250 palynomorphs were counted per sample; dinoflagellate cysts were counted on species level while other palynomorphs were counted in broad categories (e.g. bisaccate pollen, other pollen, spores, different groups of prasinophyte algae, acritarchs, inner walls of foraminifera). The remaining material was scanned for additional dinoflagellate cyst taxa.

The taxonomy of dinoflagellate cysts follows that cited in Lentin & Williams (1993). Previously undescribed taxa and those not included in that index are briefly treated in the taxonomic section which, also includes a list of recorded taxa. Characteristic taxa are illustrated on Plates 1-4. Light-photomicrographs were taken from permanent scatter mounts, using a Leitz Orthoplan/Orthomat combination and interference-contrast illumination. England Finder coordinates are provided for photographed specimens. All material is filed in the collection of the Laboratory of Palaeobotany and Palynology, University of Utrecht, the Netherlands.

Results

Palynomorph distribution

The relative distribution of the recorded categories of palynomorphs within the main section is plotted in Figure 9. The aquatic component mainly consists of dinoflagellate cysts and representatives of the acritarch genus *Paralecaniella*. The latter are particularly pronounced in the lowermost and uppermost parts of the succession. The terrestrial component, only common above the Berg en Terblijt Horizon, is dominated by well-preserved, simple, spherical or spiny spores, momentarily attributed to bryophytes (compare with Brinkhuis & Schiøler 1996).

Dinoflagellate cysts

Rich and diverse dinoflagellate cyst associations were recovered from the majority of samples. The dinoflagellate cyst distribution within the samples from the main section is plotted in Figure 8. Typically, however, only a few groups of morphologically related taxa consistently make up about 80% of the associations. These are (1) the *Spiniferites* complex (mainly consisting of subspecies of *Spiniferites ramosus*), grouped herein together with species of the morphologically similar genus *Achomosphaera*, (2) *Areoligera* spp. and *Glaphyrocysta* spp. (mainly *Areoligera senonensis* and *Glaphyrocysta perforata*, but also including the morphologically similar *Senoniasphaera inornata* and *Glaphyrocysta pastielsii*), (3) *Hystrichosphaeridium* spp., here combined with the few occurring *Oligosphaeridium* spp. and *Hystrichokolpoma bulbosa*, (4) *Cribroperidinium* spp., and (5) *Disphaerogena carposphaeropsis* and morphologically related forms such as *Cordosphaeridium, Carpatella, Fibrocysta, Thalassiphora*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Samples	Depth	A. wilsonii SLIMANI 1994	C. intermedia SLIMANI 1994	I. rigidaseptatum SLIMANI 1994	A. buccinum	A. cf. reticulata B&S 1996	A. circumtabulata	A. ramulifera	Areoligera/Glaphyrocysta spp.	BISACCATE POLLEN	Bryophyte sphaerical	Bryophyte spiny	C. aceras	C. cf. fibrospinosum	C. cornuta	C. diebelii	C. discreta	C. fibrospinosum	C. fimbriata	C. speciosum	C. striolatum	C. wetzelii	Caligodinium? sp.	Carpatella? sp.	Cleistosphaeridium spp.	Cribroperidinium sp. A B&S 199	Cyclopsiella spp.	D. californicum	D. carposphaeropsis	D. cf. carposphaeropsis	D. colligerum	DINOCYSTS INDET	Dinogymnium spp.	E. bifidum	Exochosphaeridium spp. (pars.)	F. axialis	F. ferox	F. ovalis	Fibrocysta sp. A B&S 1996	Fibrocysta spp. (pars.)
CURF 13	0,2	2	0	0	0	0	0	3	68	0	0	0	0	0	0	0	0	6	1	0	0	0	0	0	*	1	6	0	*	0	0	21	0	0	0	1	0	*	0	1
RGD01	2,1	0	0	0	0	0	0	0	36	0	*	*	0	0	0	0	0	1	0	0	0	0	0	0	0	1	2	0	*	0	0	35	0	1	0	0	0	0	0	0
RGD02	3,1	0	*	0	0	0	0	0	5	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	6	0	0	0	0	2	0	0	0	0	0	0	0	0
CURF 12	3,6	0	0	0	0	0	0	*	14	2	0	0	1	*	0	0	0	1	*	1	0	0	0	0	1	*	4	*	*	0	3	5	0	2	0	*	*	0	0	*
RGD03	4,5	*	0	0	0	0	0	0	22	4	0	1	0	0	*	0	*	*	1	0	0	0	*	0	0	1	8	*	*	0	*	95	0	*	0	*	0	*	0	*
CURF 11	4,6	0	0	0	0	0	0	*	49	3	3	0	1	*	*	0	0	2	*	0	0	0	0	0	0	*	3	*	0	*	0	55	0	*	0	1	0	*	0	*
RGD04	5,5	1	*	0	0	0	0	0	75	0	8	1	0	*	0	0	0	1	2	0	0	0	0	0	0	9	2	0	0	0	0	100	0	0	0	2	1	0	0	2
RGD05	6,5	0	*	0	0	0	0	0	69	*	3	10	*	1	0	0	0	2	*	0	0	0	0	0	0	3	1	0	0	0	0	110	0	1	6	1	0	0	0	0
RGD06	7,3	0	0	0	0	0	0	0	41	2	*	9	0	0	0	0	0	*	2	*	*	0	*	0	0	2	1	0	0	0	1	100	0	1	3	2	0	0	0	0
RGD07	8,1	0	0	0	0	0	*	0	53	4	*	6	0	1	0	0	*	3	3	*	0	0	0	0	0	4	*	0	0	*	1	70	0	2	5	4	0	0	0	*
CURF 10	9,3	0	*	0	0	*	*	*	20	1	1	2	*	*	*	*	0	*	*	*	0	0	0	0	0	2	1	*	*	*	*	25	0	*	0	3	1	*	0	*
RGD08	9,4	*	0	0	0	0	0	0	24	4	4	2	0	1	0	0	0	0	0	0	0	0	*	0	0	2	1	*	0	0	0	85	0	*	0	2	*	0	0	*
CURF-DL(9)	9,8	0	*	0	*	*	*	*	21	4	2	*	*	*	*	0	1	2	*	*	*	0	0	0	0	*	1	0	*	*	*	15	*	*	0	1	*	0	0	*
CURFS-DL	10	0	*	*	2	*	*	1	11	3	3	1	*	0	0	0	*	3	*	*	*	0	0	0	0	5	1	0	*	*	0	17	*	0	0	*	1	0	0	*
CURF 8	10,4	0	0	0	*	*	0	1	20	3	2	3	*	0	0	0	0	9	1	*	0	0	0	0	*	4	2	0	2	0	2	40	0	*	0	1	*	*	*	1
RGD09	10,5	*	0	0	1	*	0	0	15	7	6	6	1	0	0	0	1	1	1	1	0	*	0	0	0	4	*	0	2	*	*	25	0	2	0	2	3	0	0	0
CURF 7A-B	10,9	*	*	*	1	*	0	*	8	3	5	1	*	0	0	0	0	2	*	*	1	0	0	*	*	2	1	0	*	0	*	20	0	1	0	*	1	0	0	*
CURF 6	11,25	0	*	*	1	0	0	2	21	4	1	1	0	0	0	0	0	2	1	0	1	0	0	0	*	2	2	0	1	0	0	8	0	*	0	*	1	0	0	0
RGD10	11,5	0	*	0	1	0	0	0	22	3	20	2	0	0	0	0	0	1	0	*	0	*	0	0	0	6	1	0	*	*	1	47	0	1	0	2	*	0	0	0
CURF 5	11,75	0	0	0	*	0	0	0	22	*	1	2	0	0	0	0	0	2	0	4	0	0	0	0	0	6	3	0	*	0	0	3	1	*	0	*	*	0	0	0
CURF 4	11,9	0	0	0	1	0	0	0	56	0	0	0	0	0	0	0	0	1	*	2	*	0	0	0	3	1	1	0	*	0	0	18	1	1	0	*	*	0	0	0
RGD11	12,5	0	0	*	3	0	0	*	31	*	0	0	0	0	0	0	0	2	0	0	*	*	0	0	0	1	5	0	*	0	0	15	0	*	*	1	0	0	0	0
RGD12	13,3	0	0	0	*	0	0	0	33	0	0	1	0	0	0	0	0	1	1	0	0	*	0	0	0	2	6	0	*	0	*	17	*	*	*	4	0	0	0	*
RGD13	14,5	3	0	*	1	0	0	0	18	*	0	0	0	0	0	0	0	3	0	1	*	1	0	0	0	2	17	0	0	0	0	15	0	*	*	1	0	0	0	0
CURF 3	15	0	*	0	1	0	0	0	14	1	0	0	0	0	0	0	0	1	*	*	*	0	0	0	0	*	*	0	*	0	0	1	0	*	0	1	0	0	0	*
RGD14	15,5	0	0	*	1	0	0	0	7	1	1	0	0	0	0	0	0	1	0	*	0	0	0	0	0	*	11	0	0	*	0	25	0	0	0	1	0	*	0	*
RGD15	16,4	5	*	0	*	0	0	0	9	*	0	0	0	0	0	0	0	*	*	*	*	*	0	0	0	*	5	0	0	0	0	20	0	1	*	4	0	0	0	0
RGD16	17,3	0	0	0	*	0	0	0	6	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	*	11	0	0	0	0	16	0	*	0	*	0	0	0	0
RGD17	18,1	*	0	0	*	0	0	0	5	1	*	0	0	0	0	0	0	1	*	0	0	0	0	0	0	2	10	0	0	1	0	25	0	0	0	*	0	0	0	*
CURF 2	18,5	0	0	0	*	0	0	*	15	1	0	0	0	0	0	0	0	1	1	*	0	0	0	0	0	3	15	0	0	0	0	10	0	*	0	1	0	0	0	0
RGD18	19	0	0	0	*	0	0	0	18	1	0	1	0	0	0	0	0	2	1	0	0	0	0	0	0	0	12	0	*	0	0	20	0	1	*	1	0	*	0	0
RGD19	19,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	0	*	0	0	0	0
RGD20	20,5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
RGD21	21	0	0	0	*	0	0	0	6	0	0	0	0	0	0	0	0	*	*	0	*	0	0	0	0	0	8	0	*	0	0	2	0	*	0	*	0	0	0	0
CURF 1	21,25	0	0	0	1	0	0	*	7	1	0	0	0	0	0	0	0	*	1	0	0	0	0	0	0	1	23	0	0	0	0	17	0	*	0	1	0	0	0	0
RGD22	21,8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RGD23	22,75	0	0	0	*	0	0	0	18	0	0	0	0	0	0	0	0	*	1	0	*	0	*	0	0	0	23	0	0	*	0	12	0	*	0	*	0	0	0	0
RGD24	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RGD25	25,3	0	0	0	2	0	0	0	24	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	8	0	0	0	0	22	0	5	0	0	0	0	0	0
RGD26	26,3	0	0	0	*	0	0	0	14	0	0	0	0	0	0	0	0	*	*	0	0	0	0	0	0	0	4	0	0	0	0	6	0	2	*	*	0	0	0	0
RGD27	27,2	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	*	0	0	1	0	0	0	0	1	6	0	0	0	0	6	0	0	*	0	0	0	0	0

Figure 8

Distribution chart of dinoflagellates in the Curfs quarry.

40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84
H. bulbosum	H. coninckii	H. duplum	H. tubiferum cpx	Indet. Skolochorates	K. truncatum	Kiokansium? sp.	L. filosa	L. globosa	L. reinhardtii	Leiosphaeridia spp.	M. polycladiata	M. tenella	Micrhystridium spp.	Microdinium group	N. perforatum	O. complex	O. pulcherrimum	OTHER POLLEN & SPORES	Operculodinium spp.	P. grallator	P. maastrichtiense	P. pyrophorum	P. silicorum	PALYNOMORPHS INDET.	Palaeocystodinium spp.	Palambages spp.	Paralecaniella spp.	R. borussica	R. granulata	Reworked Upper Cretaceous	S. bicavatum	S. cornutus	S. inornata	S. ramosus cpx	Spongodinium sp.	T. bononiensis	T. cf. pelagica	T. patula	T. pelagica	Tanyosphaeridium spp.	Turbiosphaera sp. A B&S 1996	X. reticulatum	X. rugulatum	Xenikoon sp.
0	*	1	12	10	0	0	0	0	0	10	0	0	0	0	0	0	0	9	2	0	0	*	0	84	*	0	50	0	0	3	0	0	2	35	0	0	0	0	0	*	0	0	0	0
*	0	1	7	8	0	0	0	0	0	5	0	0	0	0	0	0	*	2	1	0	0	0	0	55	*	0	40	0	0	1	0	0	0	18	0	0	*	0	0	*	0	0	0	0
0	0	0	5	0	0	0	0	0	0	10	0	0	0	0	0	0	0	4	0	0	0	0	0	20	0	0	200	0	0	*	0	0	0	2	0	0	0	0	0	*	0	0	0	0
*	*	0	5	*	0	0	*	0	*	15	0	0	0	0	0	0	0	5	2	0	0	*	0	15	0	0	187	0	0	*	0	0	0	9	0	0	*	0	*	2	0	0	*	0
*	1	*	14	28	0	0	0	0	1	15	0	0	0	0	0	0	*	6	0	0	0	*	*	70	*	0	52	0	0	*	0	0	*	38	0	0	*	*	0	3	0	0	*	0
1	*	*	6	20	0	0	0	0	*	25	1	0	10	0	0	0	0	2	2	0	0	*	0	40	0	0	37	0	0	*	0	0	*	10	0	0	0	0	*	*	0	0	*	*
1	0	1	28	20	0	1	0	0	0	20	0	0	0	0	0	0	0	2	0	0	0	0	2	70	*	0	70	0	0	0	0	0	0	22	1	0	*	0	0	3	0	0	0	0
0	*	*	30	0	0	0	0	0	0	10	0	0	1	0	0	0	0	4	2	0	0	*	5	55	0	0	33	0	0	*	0	0	3	20	*	0	0	0	0	2	0	0	0	0
*	1	1	22	0	0	0	0	0	0	15	0	0	0	0	0	0	*	3	0	0	0	*	11	75	0	0	45	0	0	0	0	0	*	35	2	0	0	0	*	4	0	0	*	0
1	*	*	18	5	0	2	0	0	*	15	*	0	3	*	0	0	0	5	1	0	0	*	2	85	*	0	86	0	0	*	0	0	*	48	*	0	0	0	1	3	0	0	*	*
*	*	2	16	20	0	0	*	0	*	20	0	0	0	*	0	1	*	2	1	0	0	*	5	35	*	0	30	0	0	2	0	*	*	35	0	0	*	*	*	1	*	0	*	*
1	*	0	10	3	0	4	0	0	*	3	0	0	3	1	0	*	2	*	2	0	0	*	3	70	0	1	46	0	0	1	0	0	*	46	0	0	0	0	*	2	0	0	0	*
*	*	*	14	8	*	1	*	0	*	2	0	*	0	*	0	*	*	*	*	0	*	4	2	35	*	*	19	*	*	2	0	0	*	50	*	*	0	*	*	*	*	*	*	0
0	*	*	5	4	0	0	*	*	*	30	*	*	0	1	*	0	*	1	1	*	0	0	*	60	*	0	63	*	0	*	0	0	0	41	0	*	0	*	*	4	*	0	0	0
1	3	*	9	12	1	2	0	0	*	10	1	0	5	*	0	0	*	1	1	*	0	2	*	55	*	0	27	*	0	1	0	0	*	37	0	1	0	*	*	*	0	0	0	0
*	1	*	11	0	0	3	0	0	0	4	0	0	2	5	*	*	*	1	*	0	0	0	7	55	2	1	78	0	0	2	0	0	0	64	0	1	0	0	0	1	0	0	0	*
*	*	*	5	4	*	1	0	0	0	5	*	0	0	2	*	*	*	2	2	*	*	0	1	24	*	0	6	*	0	2	*	0	0	26	0	1	0	*	*	2	*	0	0	*
0	1	*	6	*	1	0	0	0	0	12	1	0	0	2	0	0	0	1	1	2	0	0	0	20	0	0	31	*	0	6	0	0	0	36	0	1	0	*	4	2	1	0	0	0
0	0	0	2	0	*	0	0	6	0	10	0	0	7	6	0	0	0	7	*	0	0	0	2	105	*	*	73	0	0	4	0	0	0	47	0	*	0	*	0	0	0	0	0	0
0	1	0	2	1	0	0	0	0	0	3	0	0	0	0	0	0	0	1	3	0	0	0	0	25	0	0	40	0	0	*	0	0	0	16	0	*	0	0	*	0	0	0	0	*
0	0	0	6	*	*	0	0	0	0	5	0	0	0	1	0	0	0	2	3	2	0	0	0	20	0	0	15	0	0	*	0	0	0	41	0	0	0	0	0	0	0	0	0	0
1	*	1	12	0	0	*	0	0	0	8	*	0	0	1	0	0	0	1	5	*	0	*	1	45	*	0	56	0	0	*	0	0	0	45	0	0	0	0	0	0	0	0	0	0
1	2	2	30	0	0	0	1	0	0	*	0	0	0	0	0	0	0	0	2	2	0	0	2	45	0	0	80	0	0	0	0	0	0	62	0	0	0	0	0	0	0	0	0	0
0	1	*	10	0	0	2	*	0	0	*	1	0	0	*	0	0	0	0	1	*	0	*	3	50	*	0	109	0	0	*	0	0	0	36	0	0	0	*	0	0	0	0	0	1
0	*	0	3	1	0	0	0	0	0	2	0	0	0	1	0	0	0	0	*	*	0	0	1	10	0	0	5	*	0	*	0	0	0	16	0	0	0	0	*	0	*	0	0	0
*	*	1	7	0	0	*	0	0	0	5	1	0	2	0	0	0	0	2	*	0	0	0	0	50	0	0	124	0	0	0	0	0	0	20	0	0	0	0	*	0	0	0	0	0
0	1	1	15	0	0	0	0	0	0	10	0	0	2	*	0	0	0	0	1	*	0	0	1	40	0	0	118	0	0	0	0	0	0	30	0	0	0	0	0	0	0	0	0	*
0	0	0	7	0	*	0	0	0	0	10	0	0	0	1	0	0	0	0	2	*	0	0	5	65	0	0	125	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0
0	1	0	3	0	0	0	0	0	0	5	0	0	0	0	0	0	0	1	*	*	2	0	22	85	*	0	147	0	0	*	0	0	0	35	0	0	0	0	0	0	0	0	0	0
0	1	*	5	2	0	0	*	0	0	20	0	0	0	0	0	0	0	1	*	*	0	*	0	60	0	0	82	0	0	*	0	0	0	14	0	0	0	*	0	0	*	0	0	*
0	0	*	16	0	0	3	0	0	0	3	0	0	2	0	0	0	0	3	1	1	0	0	2	65	0	0	42	0	0	0	0	0	0	37	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	30	0	0	114	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	*	*	6	3	*	0	*	0	0	30	0	0	0	1	*	0	0	*	*	*	0	0	2	105	0	0	93	0	0	3	0	0	0	4	0	0	0	0	*	0	0	0	0	*
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	*	0	9	0	0	0	*	0	0	2	*	0	0	0	0	0	0	0	*	0	0	0	0	40	0	0	99	0	0	*	0	0	0	9	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	*	5	0	0	2	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	5	55	0	0	70	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0
0	*	0	1	0	0	3	1	0	0	*	0	0	0	*	0	0	0	0	0	0	1	0	2	30	0	0	130	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
0	0	1	3	2	0	0	0	0	0	12	0	0	1	1	0	0	0	1	*	0	3	0	8	65	0	0	92	0	0	*	0	0	0	15	0	0	0	0	0	0	0	0	0	0

and *Damassadinium* spp., all placed in the '*Cordosphaeridium* group'. The relative distributions of these groups are plotted in Figure 10. All other taxa have been grouped together in the category 'others'.

Representatives of the *Spiniferites* complex dominate the associations in the middle and upper parts of the succession, showing an optimum just above the Vroenhoven Horizon. In the relatively poorly diversified samples from the lower part of the succession, the *Areoligera-Glaphyrocysta* group is dominant. It may be noted that dinoflagellate cysts presumably derived from heterotrophic dinoflagellates, viz. the peridinioids, are not quantitatively pronounced in any of the investigated samples.

Biostratigraphic analysis

Perhaps not surprisingly, the recovered dinoflagellate cyst associations from Curfs are very similar to those recently described by Brinkhuis & Schiøler (1996) in their study of the nearby Geulhemmerberg KTB section. They primarily compared their associations with the available data from relatively nearby Denmark, referring to the studies of, for example, Hansen (1977, 1979), Kjellström & Hansen (1981), Hultberg (1985, 1986), Hansen et al. (1986), Damassa (1988), and Schiøler & Wilson (1993). All these papers stress the importance of the last occurrence (LO) of *Palynodinium grallator* at the KTB, and the FOs of *Damassadinium californicum*, *Senoniasphaera inornata* and *Carpatella cornuta* above the boundary. The uppermost Maastrichtian succession in Denmark is characterized by the co-occurrence of *Thalassiphora pelagica* and *Palynodinium grallator* (e.g. Hansen 1977). According to Hansen (1977, 1979) and Hultberg (1985, 1986), the upper part of the Lower Danian may be characterized by the successive FOs of several *Xenicodinium* or *Tectatodinium* species (see also Powell 1992). Notably, the FOs of *Damassadinium californicum* and *Carpatella cornuta* are thought to be of global significance for the recognition of the KTB, as evidenced from sections from Denmark, Tunisia and the USA (e.g. Brinkhuis & Zachariasse 1988; Damassa 1988; Habib et al. 1992; Moshkovitz & Habib 1993; Habib et al. 1996). Moshkovitz & Habib (1993) recently introduced *Lanternosphaeridium reinhardtii* as an additional Danian marker (see also Habib 1994; Habib et al. 1996). In addition, Brinkhuis & Schiøler (1996) suggested that the FO of *Disphaerogena carposphaeropsis* characterizes the uppermost Maastrichtian, its inception possibly being younger than that of *Thalassiphora pelagica* (compare also, for example, Benson 1976; Brinkhuis & Zachariasse 1988; Moshkovitz & Habib 1993; Habib 1994; Habib et al. 1996). They furthermore suggested that the FO of the morphologically similar *Thalassiphora patula* may be of additional importance for characterisation of the uppermost Maastrichtian.

However, Habib (1994), Habib et al. (1996), Brinkhuis & Schiøler (1996) and Brinkhuis et al. (1998) pointed out that, although it has long been believed that the FOs of *Senoniasphaera inornata, Damassadinium californicum* and *Carpatella cornuta* at the KTB are simultaneous (e.g. Hansen 1977), only the FO of *Senoniasphaera inornata* more or less coincides with the boundary, or occurs slightly higher, calibrated against planktonic foraminifer zone P0. According to Habib (1994), Habib et al. (1996) and Brinkhuis et al. (1998), the FOs of *Damassadinium calfornicum* and *Carpatella cornuta* occur significantly higher, calibrated against planktonic foraminifer zones Pα or P1a. Furthermore, Habib et al. (1996) as well as Brinkhuis et al. (1998) claim that the LO of *Palynodinium grallator* occurred in the Early Danian rather than at the KTB, at a horizon calibrated against the basal part of planktonic foraminifer zone P1a.

Most of the above-mentioned stratigraphically important taxa, viz. *Palynodinium grallator, Senoniasphaera inornata, Thalassiphora pelagica, Thalassiphora patula, Disphaerogena carposphaeropsis, Carpatella cornuta, Damassadinium californicum* and *Lanternosphaeridium reinhardtii* as well as *Xenicodinium rugulatum* have been recorded from one or more samples from Curfs (Fig. 8). When analyzing the distribution pattern of these stratigraphically important taxa, it may be noted that (1) *Palynodinium grallator* and *Disphaerogena carposphaeropsis* types co-occur in the lowest samples above the Caster Horizon, rapidly joined upwards by *Thalassiphora pelagica*, (2) the LO of *Palynodinium grallator* occurs at the Vroenhoven Horizon, (3) *Senoniasphaera inornata* and *Lanternosphaeridium reinhardtii* first occur just above the Berg en Terblijt Horizon, (4) *Damassadinium californicum, Carpatella cornuta* and *Xenicodinium rugulatum* first occur directly above the Vroenhoven Horizon, and (5) no stratigraphically significant events appear to occur in the overlying Danian part of the succession.

It may thus be confirmed that, indeed, (1) the lowermost part of the Curfs succession represents (part of) the latest Maastrichtian (upper part of the *Palynodinium grallator* Zone, possibly *Thalassiphora pelagica* Subzone of Hansen, 1977), but that (2) an early Early Danian (not necessarily earliest Danian) age may already be assigned to sediments slightly above the base of the Berg en Terblijt Horizon, significantly below the Vroenhoven Horizon, based on the FOs of *Senoniasphaera inornata* and *Lanternosphaeridium reinhardtii.* The assignment of the Nekum and the lower part of the Meerssen Chalk to the *Palynodinium grallator* Zone is in line with results from Wilson (1974) from the Maastrichtian type-section (his Vb Subzone), and with the results of Schiøler et al. (1997) in their re-study of the same section. The sediments from directly above the Vroenhoven Horizon, containing *Damassadinium californicum, Carpatella cornuta* and *Xenicodinium rugulatum*, may be assigned to the *Xenicodinium rugulatum* zonule of Hansen (1977), of Early Danian age. No further subdivision of the Danian interval is possible as no significant LOs or FOs of species are recorded. Of interest may be the occurrence of *Spongodinium* sp., a taxon morphologically very similar to *Spongodinium reticulatum* described by Hultberg (1985).

Of further interest is that the associations from above the Berg en Terblijt Horizon at Curfs are virtually identical to those recovered by Brinkhuis & Schiøler (1996) from just above this horizon at the Geulhemmerberg. Conspicuously, the occurrences of *Thalassiphora bononiensis, Fibrocysta* sp. and *Alisocysta* cf. *reticulata* appear to be confined to the interval between the Berg en Terblijt and Vroenhoven horizons (compare Brinkhuis & Schiøler 1996). Moreover, the presumed bryophyte spores are common from the base of the Berg en Terblijt Horizon upwards, declining above the Vroenhoven Horizon, further confirming the correlation between the Geulhemmerberg KTB section and Curfs at this level. The combined evidence from Geulhemmerberg and Curfs furthermore suggests that *Palynodinium grallator, Adnatosphaeridium buccinum* and *Northidinium perforatum* cross the KTB only to become extinct during the early Early Danian. Their LOs may thus be added to the list of stratigraphically important dinoflagellate events around the KTB in NW Europe.

Palaeoenvironmental interpretation

The relative distribution pattern of the broad categories of palynomorphs indicate that the assemblages can be characterized as being either relatively poor and dominated by *Paralecaniella* spp., or as rich assemblages dominated by dinoflagellate cysts. The boundaries between these assemblages may be placed (1) in the uppermost Maastrichtian just above the Caster Horizon between samples RGD18 and 19, and (2) in the Lower Danian succession between samples RGD03 and CURF12. Conspicuously, the hardgrounds close to the KTB, the Berg en Terblijt and Vroenhoven Horizons, are not marked by a pronounced change in overall composition.

In their review of the possible palaeoecological significance of abundances of *Paralecaniella* spp., Brinkhuis & Schiøler (1996) suggested that these probably indicated extremely marginal marine environments, and possibly even stressed, brackish conditions. The encountered dinoflagellate cysts are most probably all of marine origin. Taxa typically representing relatively offshore and/or oceanic conditions (e.g. *Impagidinium* spp., *Nematosphaeropsis* spp.; see, e.g., Wall et al. 1977, papers in Head & Wrenn 1992) have only been recorded in trace amounts and could be reworked. The most abundant groups of morphologically related taxa recorded from the Curfs succession (Fig. 10) are usually found in similar abundances in relatively marginal marine successions throughout the Mesozoic and Cenozoic (compare, e.g., Downie et al. 1971; Hultberg & Malmgren 1986; Brinkhuis & Zachariasse 1988; Brinkhuis 1994; Brinkhuis & Schiøler 1996; Schiøler et al. 1997). Of these groups, only representatives of the *Spiniferites* complex still occur today. They typically occupy outer neritic waters (e.g. Wall et al. 1977, papers in Head & Wrenn 1992). They may be regarded as the most 'offshore' category of dinoflagellate cysts present in the Curfs succession.

In summary, the relative abundance of *Paralecaniella* spp. may indicate marginal marine to restricted marine influence, or may reflect increased transport from such settings. Alternatively, as suggested by Brinkhuis & Schiøler (1996), relative abundances of *Paralecaniella* spp. may also be related to sediments deposited under hydrodynamically higher energy conditions, relative to those dominated by dinoflagellate cysts. The assemblages characterized by rich and well-diversified dinoflagellate cyst associations may be expected to reflect outer neritic conditions, or hydrodynamically lower energy deposits. In both models, however, the alternation of the two assemblage types may be explained in terms of relative sea level fluctuations. Considering the probable amount of time involved (some 2 m.y., at least), these fluctuations may be compared to the third-order sea-level changes of Haq et al. (1988). Combining the sedimentological and quantitative information, and realizing the overall marginal marine nature of the investigated deposits, the succession may be subdivided in an alternation of successive transgressive (TST) and highstand (HST) system tracts (the corresponding lowstands being absent and marked by hardgrounds). A first sequence boundary may be placed at the Caster Horizon, separating HST and TST deposits (Figs 9 and 10). A subsequent maximum flooding surface (mfs) may be placed some 4m higher, around sample CURF2, characterized by a dinoflagellate and a *Spiniferites* optimum. The overlying deposits, including those above the Berg en Terblijt Horizon, are placed in the subsequent HST. The Vroenhoven Horizon, a well-marked hardground with dissolution features, is regarded as the subsequent early Early Danian sequence boundary, underlying TST deposits (Figs 9 and 10). Again, the lowstand deposits are missing. The Vroenhoven Horizon sequence boundary seems to have been associated with a major sea-level fluctuation, as it is clearly diachronous across the Maastrichtian type-area (cf. Felder 1975) and underlying deposits have often been removed. The overlying mfs is tentatively placed around sample RGD05, the subsequent dinoflagellate optimum. A subsequent sequence boundary is proposed to occur just below sample CURF12, associated with the Va-3 hardground. Overlying deposits are again characterized by a *Paralecaniella* dominance, placed in the subsequent TST. Superposed on the third-order trends, general deepening seems to have occurred, since *Paralecaniella* spp. do not become as dominant as they are around the Caster Horizon in overlying deposits. The proposed successive alternation of TST and HST can be well reconciled with the distribution pattern of the individual dinoflagellate groups. The distribution pattern of the more marginal marine *Areoligera-Glaphy-*

Curfs (NL) Palynomorph Groups

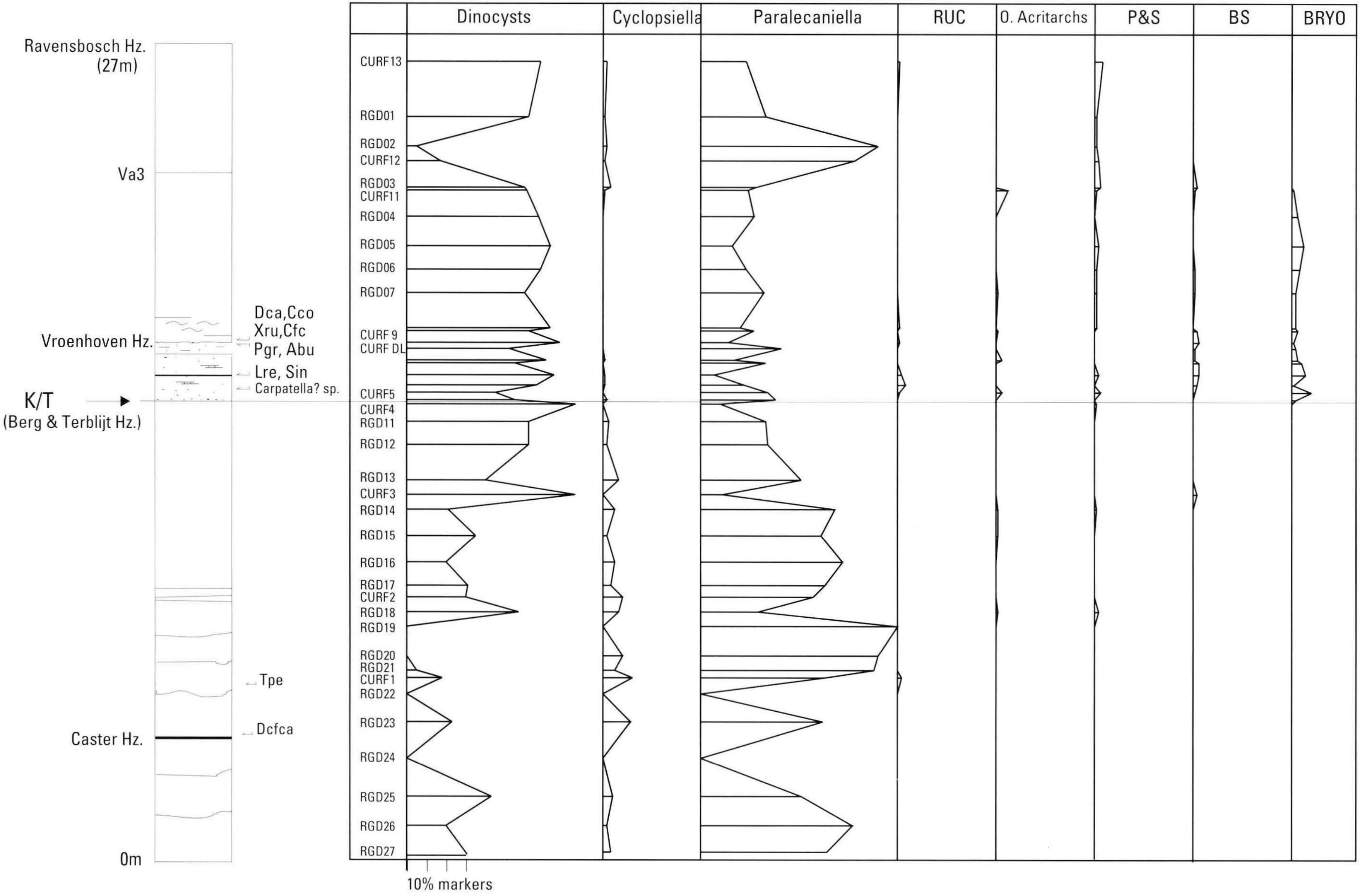


Figure 9

Diagram of palynomorph groups in the Curfs quarry.

ktwwcur3.cdr

Curfs (NL) Dinocyst Groups & Sequence Stratigraphy

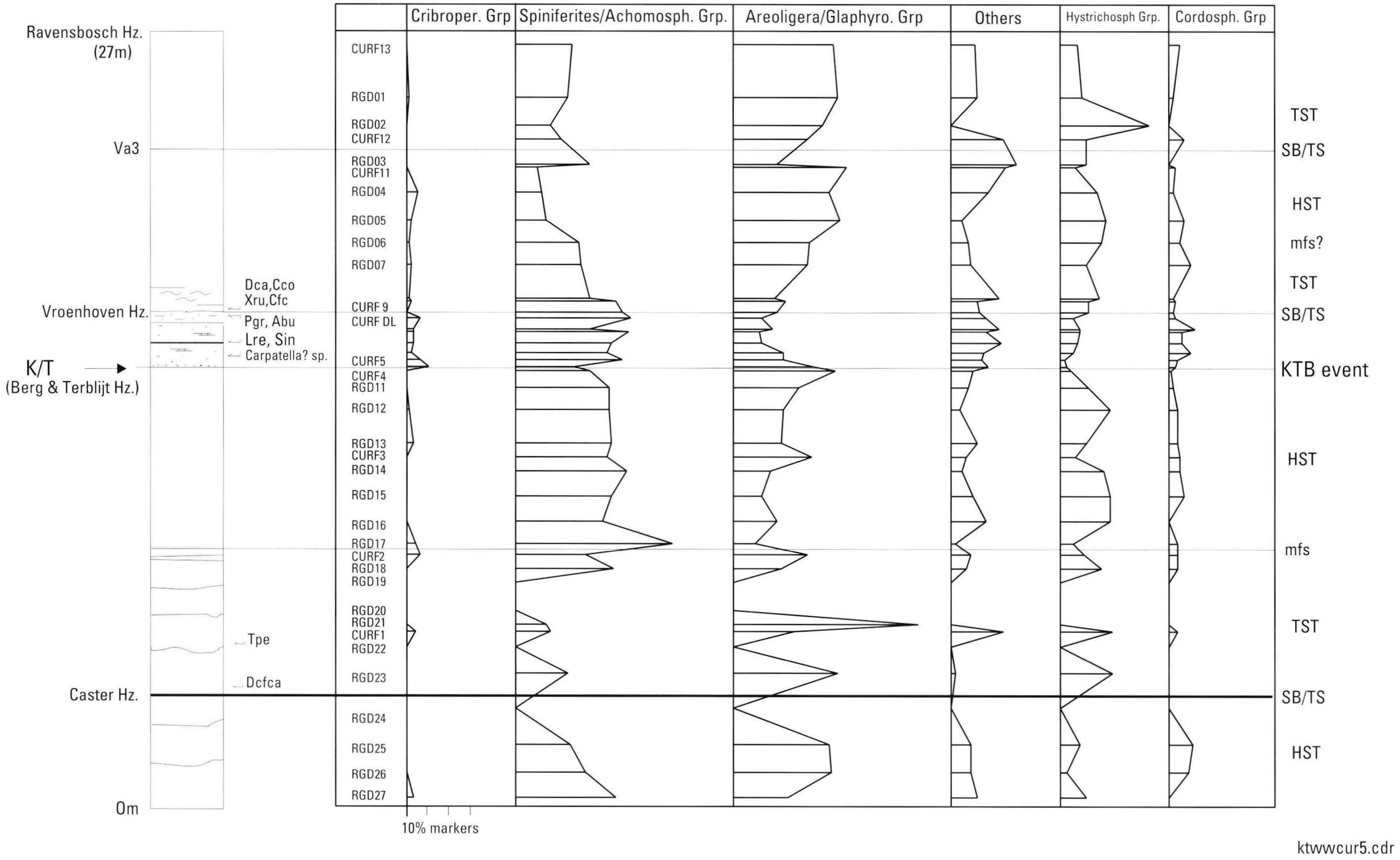


Figure 10
Diagram of dinocyst groups in the Curfs quarry and sequence stratigraphy.

rocysta and *Hystrichosphaeridium* groups, relative to the slightly more offshore *Spiniferites* group, is similar to the overall pattern of *Paralecaniella* spp. vs. dinoflagellate cysts (compare Brinkhuis & Schiøler 1996; Schiøler et al. 1997). Pattern differences only occur in the interval between the Berg en Terblijt and Vroenhoven Horizons. In this interval, dominated by the *Spiniferites* group, the *Areoligera-Glaphyrocysta* and *Hystrichosphaeridium* groups have decreased relative abundances, while other groups, notably *Cribroperidinium* spp. and the *Cordosphaeridium* group, are more abundant. Since *Areoligera-Glaphyrocysta* spp. dominances are often described from marginal marine, high-energy deposits (see, e.g., Powell et al. 1995), this may be explained by proposing a more shielded, possibly back-barrier environment for this interval, as a result of continuing sea-level fall. A similar interpretation was proposed for the sediments above the Berg en Terblijt Horizon at the Geulhemmerberg (papers in Brinkhuis & Smit 1996). In the latter volume, it was suggested that the formation of the Berg en Terblijt hardground itself is related to the KTB event(s).

A comparison to Haq et al. (1988) and the revised version of the (Paleocene-Eocene part of the) sea-level chart presented by Hardenbol (1994), using the available age-control, leads to the conclusion that the three third-order sequences recognized at Curfs may well be reconciled with their data. The sequence boundary placed at the Caster Horizon may be correlated to their latest Cretaceous sea-level fall (cycle TA1.1 of Haq et al. 1988), the one associated with the Vroenhoven Horizon to cycle Da-1 of Hardenbol (1994; formerly the latest Cretaceous cycle TA1.2 of Haq et al. 1988, now placed in the lower Lower Danian), and the one in the overlying 'middle' Lower Danian to Da-2 of Hardenbol (1994). The KTB occurs within cycle TA1.1, just below the Da-1 sequence boundary.

Conclusions

The KTB succession at Curfs generally contains rich and well-preserved palynological assemblages. From the recorded stratigraphically diagnostic dinoflagellate cysts, it is suggested that the lowermost part of the succession represents the latest Maastrichtian, and that an Early Danian age may be assigned to sediments from the base of the Berg en Terblijt Horizon upwards. On the basis of the quantitative palynological evidence it is suggested that the succession represents relatively marginal marine, probably inner neritic, conditions throughout, with most unconformities marking periods of sea-level lowstand. A 'second-order' deepening trend from the latest Maastrichtian into the Early Danian can be inferred. Superposed on this trend, three third-order sea-level cycles may be recognized, one in the uppermost Maastrichtian and two in the Lower Danian. These cycles appear to be correlatable to those proposed by Haq et al. (1988) and Hardenbol (1994) in the same timeslice. The KTB, represented by the Berg en Terblijt Horizon, falls within third-order cycle TA1.1 of Haq et al. (1988) and is characterized by the FOs of *Senoniasphaera inornata* and *Lanternosphaeridium reinhardtii* and the sharp incoming of bryophyte spores. The KTB succession can be well correlated to the time-equivalent interval in the Geulhemmerberg caves.

Selected taxonomy

Characteristic dinoflagellate cysts are illustrated on Plates 1-4. An alphabetic list of recorded taxa is provided below. Only previously undescribed taxa are briefly treated in this section. Most taxonomic citations may be found in Lentin & Williams (1993). Citations for described species not included in Lentin & Williams (1993) are referenced herein. The material is filed in the collection of the Laboratory of Palaeobotany and Palynology, University of Utrecht, the Netherlands.

List of taxa

Dinoflagellate cysts
A.? wilsonii Slimani, 1994
Achomosphaera ramulifera
Adnatosphaeridium buccinum
Alisocysta circumtabulata
Alisocysta sp. cf. *A. reticulata* in Brinkhuis & Schiøler 1996
Areoligera-Glaphyrocysta spp.
Caligodinium aceras
Caligodinium? sp.
Carpatella cornuta
Carpatella? sp.
Cassiculosphaeridia? *intermedia* Slimani 1994
Cerodinium diebelii
Cerodinium speciosum
Chlamydophorella discreta
Conneximura fimbriata
Cordosphaeridium fibrospinosum
Cordosphaeridium cf. *fibrospinosum*
Coronifera striolata
Cribroperidinium wetzelii
Cribroperidinium sp. A in Brinkhuis & Schiøler 1996
Damassadinium californicum (Drugg) Fensome et al. 1993
Dinogyminium spp.
Diphyes colligerum
Disphaerogena carposphaeropis
Disphaerogena cf. *carposphaeropsis*
Exochosphaeridium bifidum
Exochosphaeridium spp. (pars.)
Fibrocysta axialis
Fibrocysta ovalis
Fibrocysta sp. in Brinkhuis & Schiøler 1996
Fibrocysta spp. (pars.)
Florentinia ferox
Hystrichokolpoma bulbosa

Hystrichosphaeridium duplum
Hystrichosphaeridium tubiferum plexus
Hystrichostrogylon coninckii
Impagidinium rigidaseptatum Slimani 1994
Kiokansium? sp.
Kleithriasphaeridium truncatum
Lanternosphaeridium filosa
Lanternosphaeridium reinhardtii Moshkovitz & Habib 1993
Lejeunecysta globosa
Membranilarnacia polycladiata
Membranilarnacia tenella
Microdinium group
Northidinium perforatum in Wilson 1974
("*Neonorthidium perforatum*' Marheinecke 1992)
Oligosphaeridium complex
Oligosphaeridium pulcherrimum
Operculodinium spp.
Palaeocystodinium spp.
Palaeoperidinium pyrophorum
Palynodinium grallator
Rottnestia borussica
Rottnestia granulata
Senegalinium bicavatum
Senoniasphaera inornata
Spiniferites cornutus
Spiniferites ramosus plexus
Spongodinium sp.
Tanyosphaeridium spp.
Thalassiphora bononiensis
Thalassiphora patula
Thalassiphora pelagica
Thalassiphora pelagica sensu Hansen 1977
Turbiosphaera filosa
Turbiosphaera sp. A in Brinkhuis & Schiøler 1996
Xenicodinium lubricum
Xenicodinium reticulatum
Xenicodinium rugulatum

Acritarchs
Cyclopsiella spp.
Leiosphaeridia spp.
Michrystridium spp.
Palaeotetradinium maastrichtiense
Palaeotetradinium silicorum
Palambages spp.
Paralecaniella spp.
Xenikoon sp. A in Foucher & Robaszynski 1977

Taxonomic remarks

Caligodinium? sp., Plate 1:7

This taxon is provisionally assigned to *Caligodinium*, but differs from typical *Caligodinium* in having a distinct multi-angular outer wall, and thus being distinctly cavate.

Carpatella? sp., Plate 2:1

This taxon is provisionally assigned to *Carpatella*, and is characterized by an extremely thick, irregular fibrous outer wall, and is perhaps also related to *Thalassiphora pelagica* sensu Hansen 1977.

Cordosphaeridium cf. *fibrospinosum*

This taxon is distinguished from *Cordosphaeridium fibrospinosum* (Plate 2:2) by the development of distinct apical and antapical horns. This is a typical feature of forms in the *Disphaerogena-Cordosphaeridium-Damassadinium-Thalassiphora-Carpatella-Fibrocysta* complex close to, and most notably above the KTB.

Disphaerogena cf. *carposhaeropsis*

This taxon is distinguished from *Disphaerogena carposphaeropsis* by the development of distinct apical and antapical horns. See also remarks under *Cordosphaeridium* cf. *fibrospinosum*, and the comments by Brinkhuis & Schiøler (1996) on `the *Disphaerogena carposphaeropsis* complex'.

Hystrichosphaeridium tubiferum plexus

This complex is introduced to accomodate all subspecies of *Hystrichosphaeridium tubiferum* (Plate 3:4), and also includes the closely related, if not synonymous, species recently described by Marheinecke (1992), viz. '*Hystrichosphaeridium arborispinum*' sensu Marheinecke (1992), '*Hystrichosphaeridium proprium brevispinosum*', '*Hystrichosphaeridium proprium proprium*' and '*Hystrichosphaeridium tenuitubatum*'. *Hystrichosphaeridium salpingophorum* is also included in this complex.

Kiokansium? sp.

This taxon may be characterized by being an *Operculodinium*-type of cyst with a 2P archaeopyle.

Microdinium group

This group is introduced to accomodate all species belonging to either *Microdinium, Phanerodinium, Cladopyxidium* and *Fibradinium* and morphologically closely related genera, since LM is not sufficient for accurate species identification.

Spiniferites ramosus plexus

This complex is introduced to accomodate all subspecies of *Spiniferites ramosus.*

Thalassiphora pelagica and *Thalassiphora pelagica* sensu Hansen 1977 (Plate 4:7)

Thalassiphora pelagica sensu Hansen 1977 is separated from *Thalassiphora pelagica* by having endophragmal apical and antapical horns, similar to the development in *Lanternosphaeridium reinhardtii* (Plate 3:5-6). Note that specimens assigned here to *Thalassiphora pelagica* sensu Hansen 1977 differ markedly from the typical Eocene *Thalassiphora pelagica*, which are closer to the holotype.

Those recovered during the present study show a closer resemblance to *Lanternosphaeridum lanosum*, by having the rather spongious to fibrous outer wall loosely draped around the entire inner wall, and lacking the camocavation of more typical *T. pelagica.* They are nevertheless placed here in *'Thalassiphora pelagica'* since Hansen (1977) based his Maastrichtian zonal scheme partly on this taxon, and also because we have confirmed the presence of this type in the Danish Maastrichtian. As has already been discussed above, we believe that these taxa are part of what Brinkhuis & Schiøler (1996) called the '*Disphaerogena carposphaeropsis* complex', more or less the single group of dinoflagellate cysts that show morphological changes across the KTB.

Foraminifers and ostracods

The Curfs quarry is one of the classic sites for micropalaeontologic examinations, especially with regard to benthic foraminifera, of Maastrichtian chalks and Cretaceous/Tertiary transitional strata (Hofker 1966). The location of his samples (year of sampling 1958; see fig. 102 in Hofker 1966) in relation to the current plan of the quarry is indicated in Figure 2.

The Nekum Chalk Member represents Hofker's Zone K. The uppermost unit of the Maastricht Formation, the Meerssen Chalk Member, is identified by his Zones L and M. Hofker's samples H733 and H765 (his fig. 102) are from unit IVf-7, between the Berg en Terblijt and Vroenhoven Horizons and represent Zone M. The basal unit of the Houthem Formation, the Geulhem Chalk Member, is equated with Zone P. Hofker recognized his Zone N, of Danian age, in the eastern section of the quarry, and thought this zone to be absent in the western section.

Nekum, Meerssen and Geulhem Chalk Members

The 1985 sample set (Fig. 3), covering the upper part of the Nekum Chalk Member, the Meerssen Chalk Member and a major part of the Geulhem Chalk Member, as exposed in the Curfs quarry, were examined by J.P.M.T. Meessen (ex-RGD) in 1986 for benthic foraminifers (inhouse notes). Identification of species, zonation and dating are according to Hofker (1966).

Foram Zone P

The following characteristic species were recognized in samples 1-8: *Karreria fallax, Dentalina fissicostata, Nodosaria affinis, Robulus discus, R. klagshammensis, Sigmomorphina paleocenica, S. pseudoregularis, Gavelinella lellingensis* and *Pararotalia globigeriniformis*. This assemblage is assigned to the Early Paleocene Foraminifera Zone P.

Foram Zone M

In samples 9-18, marker species include *Tremastegina roestae* (large specimens with radiate striae on the dorsal side), *Siderolites laevigata* and *Daviesina ornamentata*. This association is characteristic of Zone M.

Foram Zone L

Species which characterize Foraminifera Zone L were encountered in samples 19-23 and include *Linderina visserae, Rotalia trochidiformis, Tremastegina roestae* (small specimens without radiate striae on the dorsal side) and *Daviesina fleuriausi* (A2-form).

Foram Zone K

The following markers for Foraminifera Zone K were recognized in samples 24-27: *Lituola senoniensis, Linderina visserae, Pseudoparrella alata, Pararotalia tuberculifera* and *Daviesina fleuriausi* (B-form).

Conclusions

The 1986 interpretations of the Curfs quarry foraminifer assemblages, viz. the Maastrichtian Zones K, L and M for the Maastricht Formation and the Paleocene Zone P, recognized in the Houthem Formation, fully agree with the classic zonal scheme of Hofker (1966). Neither Hofker nor Meessen mention Early Tertiary forams (Zone N in Hofker 1966) from the topmost Meerssen Chalk, unit IVf-7, in the western part of the quarry.

KTB interval: the Berg en Terblijt to Vroenhoven Horizons

The KTB interval, viz. the top of the Meerssen Chalk and the entire Geulhem Chalk Members, was reinvestigated in greater detail using a selected number of samples collected in 1996 (Figs 5 and 11). The quantitative method was used which means that, in a split of the sample, all specimens and fragments of determinable species were counted. Afterwards it proved that in this particular case this method was less suitable for photo-documentation. Therefore an additional examination was carried out for sample 11, this time applying a qualitative study of several size-fractions.
Determination of the ostracods is after Deroo (1966).

Benthic foraminiferal faunas predominate, while planktonic forams and ostracods are rare. Among the benthics, *Pararotalia tuberculifera* is dominant; milioliids and larger foraminifera are scarce. This indicates troubled shallow-water conditions in an inner neritic setting of less than 30 m depth (Haynes 1981; Lecalvez 1970).

Meerssen Chalk below Berg en Terblijt Horizon

In general, only smaller foram specimens were found and the preservation is poor. The joint occurrence in sample 6 of *Tremastegina roestae, Daviesina ornamentata, D. fleuriausi, Gavelinopsis bembix* and *Textularia faujasi* indicates a Late Maastrichtian age. The number of indeterminate forams is fairly high and reworking can not be excluded. A fairly rich ostracod association in sample 2, with *Kingmaina decocki, Spongicythere koninckiana, Kikliocythere labyrinthica, Amphicytherura limburgensis, Limburgina uhlenbroeki, Veenia pulchella, Limburgina ornata* and *Tumidoleberis laevis* confirms this age.

Uppermost Meerssen Chalk above Berg en Terblijt Horizon

As in the preceding samples, the forams are small and poorly preserved. The associations are comparable to those described by Hofker (1966) from his Zone N. Characteristic species include *Angulogerina europaea, Gavelinella lellingensis, Rosalina brotzeni* and *Rotalia saxorum/perovalis*, which indicate a Danian age. The ostracods *Dumontina stellata* and *Limburgina bilamellosa bilamellosa* confirm this age. Quite a number of Upper Maastrichtian forams, and a single specimen of the ostracod *Limburgina ornatoidella ornatoidella*, are found in this interval; they are considered reworked specimens.

Conclusions

Above the Berg en Terblijt Horizon, distinctive Danian foram faunas are found which represent Hofker's (1966) Zone N. This interval has not been previously recognized from the western wall of the quarry (see, for example, Hofker 1966, fig. 102). Moorkens (1982) and Doppert & Neele (1983) also assigned Zone N to the Danian. No drastic faunal change has been observed in the benthic foraminiferal contents. The same observation was recently made by Witte & Schuurman (1996) from the nearby Geulhemmerberg caves. A considerable number of Maastrichtian forams were encountered above the

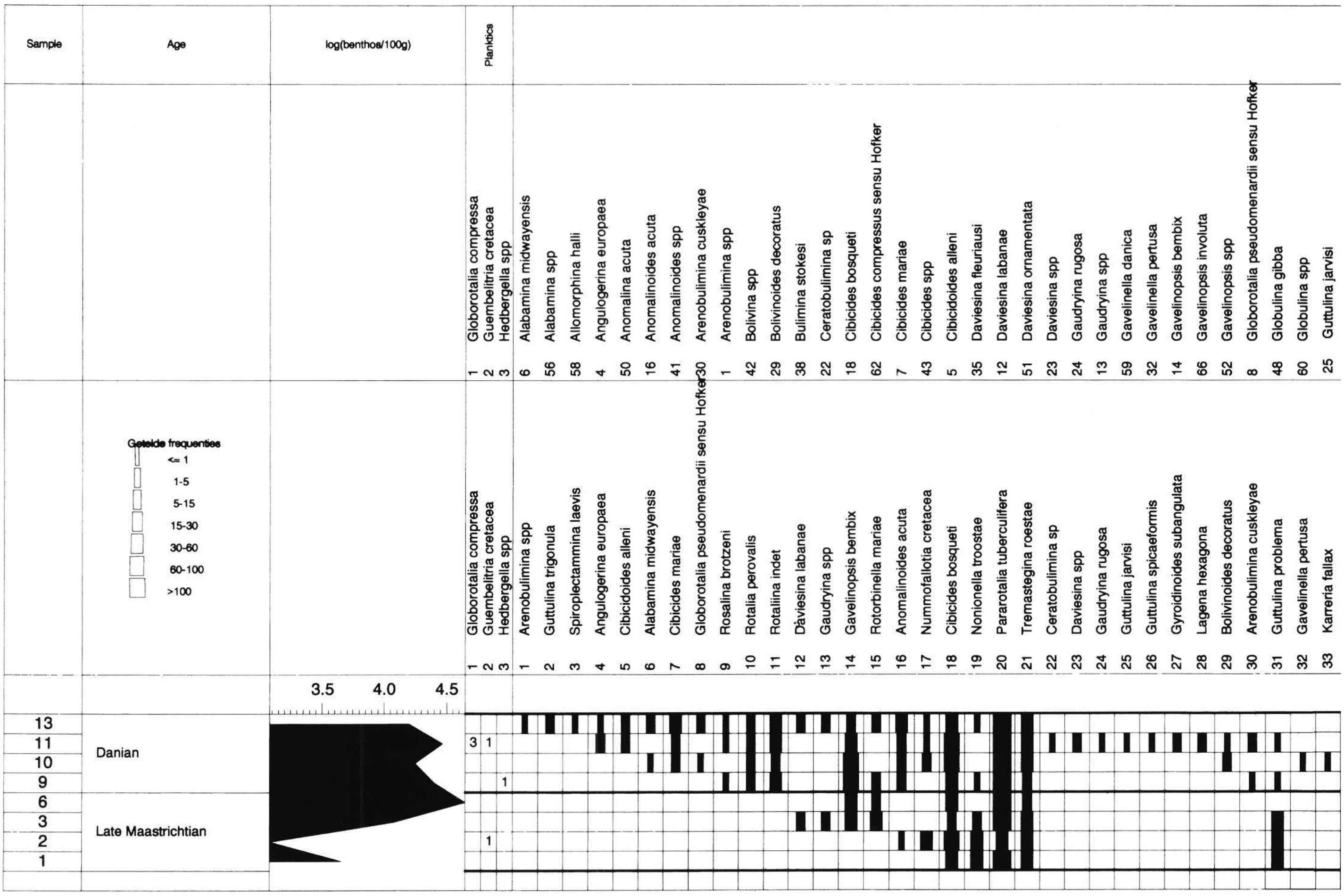
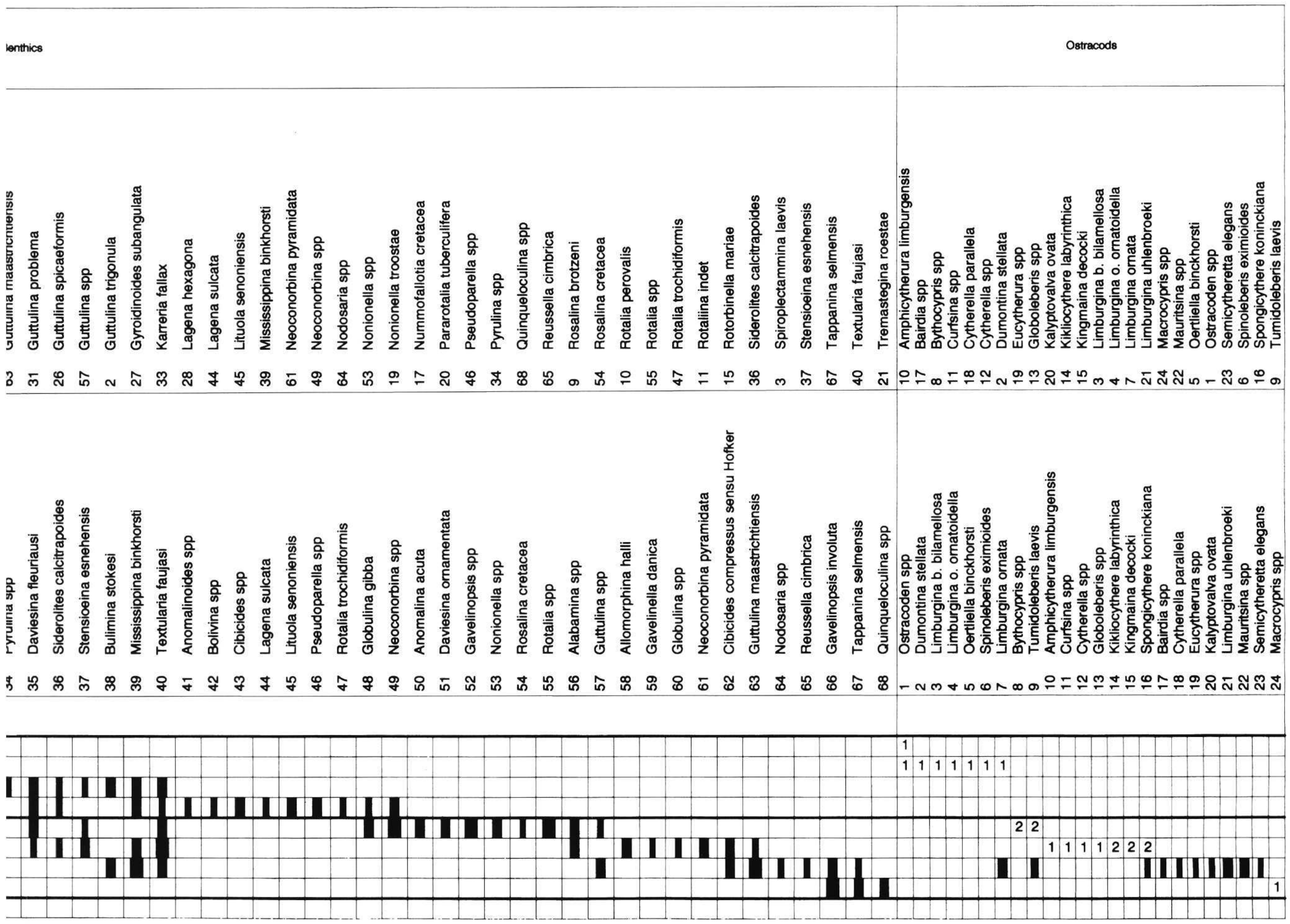


Figure 11
Distribution chart of foraminifers and ostracods in the Curfs quarry around the KTB.

Berg en Terblijt Horizon and most likely represent reworked faunas. A major difference between the Curfs and Geulhemmerberg sections is seen in the composition of the predominant benthic forams. At Geulhemmerberg the *Cibicides* group and sometimes *Tappanina selmensis* are very common (Kuhnt 1996; Kuhnt & Kaminski 1996; Witte & Schuurman 1996) while at Curfs *Pararotalia tuberculifera* is dominant. These divergent observations reflect different palaeodepths: a shallower inner neritic (<30 m), higher-energy environment at Curfs versus a middle (30-100 m) to outer (100-200 m) neritic setting at Geulhemmerberg.



Nannoplankton

Nekum, Meerssen and Geulhem Chalk Members

In the youngest sediments of the Maastricht Formation the nannofloras decrease in quantity and quality towards the Vroenhoven Horizon, probably as a result of diagenesis (Cepek & Moorkens 1979). Such diagenesis seems to be less distinct in the Curfs quarry than in the nearby Vroenhoven section (Verbeek 1986), although the sample intervals at Vroenhoven are more closely spaced through this interval. Reworking of Campanian and Early Maastrichtian nannoplankton occurs frequently in the marls of the Curfs quarry. The distribution of the flora is given in Figure 12.

The nannofloral associations (for position of samples see fig. 3) in the uppermost part of the Nekum Chalk and the lower part of the Meerssen Chalk at Curfs, samples 27 through 19, show a low diversity and are not rich in numbers. Solution-resistent species such as *Micula decussata* (= *Micula staurophora*) and *Watznaueria barnesae* occur most frequently. These assemblages are similar to the poorly preserved floras in the youngest part of the ENCI quarry where the uppermost unit, IVf-7 of the Maastricht Formation, is absent (Felder 1975).
The species diversity of the nannofloras in the younger part of the Meerssen Chalk Member is much higher, with a predominance of *Micula decussata, Prediscosphaera cretacea* and *Eiffellithus* spp. Such nannofloras are comparable to those found in the Vroenhoven section.
In the youngest sediments of the Meerssen Chalk, the assemblages are moderately preserved due to strong overgrowth with secondary calcite. On the basis of the biostratigraphically significant species, *Lithraphidites quadratus, Nephrolithus frequens* and *Arkhangelskiella cymbiformis*, this interval is assigned to the latest Maastrichtian standard zone, CC26 (*Nephrolithus frequens* Zone). This is in agreement with results obtained by Verbeek (1983), who dealt with the Campanian to Maastrichtian of southern Limburg and adjacent Belgium, and who concluded that the upper part of the Maastricht Formation correlates with the *N. frequens* Zone, now Nannofossil Zone CC26. The poor nannofloras of the lower part of the Meerssen Chalk Member, Maastricht Formation, are provisionally assigned to CC25b and CC26 because *L. quadratus* comes in at sample 23 and *N. frequens* appears at sample 21. This may suggest that the likewise poor nannofloras of the Nekum Chalk Member are CC25a.

Samples 1 through 8 are from the Geulhem Member, Houthem Formation. As usual in this formation, the sediments contain a considerable amount of reworked Cretaceous nannofossils and the floras are poorly preserved. Only in sample 2 and 8 were stratigraphically useful species found. These include *Biantholithus sparsus* (FO NP1), *Cruciplacolithus tenuis* (FO NP2) and *Neocrepidolithus fossus* (FO NP2) according to Perch-Nielsen (1985) and Martini & Müller (1986). These species are indicative of a combination of NP1 through NP4. The relatively high abundances of *Braarudosphaera bigelowii, Markalius inversus* and *Thoracosphaera operculata* are another indication for this zonal assignment because similar high numbers of *B. bigelowii* and *M. inversus* were found in NP1 and NP3-4 of the Vroenhoven section (Verbeek 1986).

KTB interval: the Berg en Terblijt to Vroenhoven Horizons

Introduction

In a recent work on nannofloras from a supposedly complete KTB section from Geulhemmerberg by Romein et al. (1996, presented as part of a major multidisciplinary work: Brinkhuis & Smit, 1996) it was intimated that the Maastricht Formation, which contains the Berg en Terblijt Horizon, is at least partly of Early Paleocene age, not entirely Late Maastrichtian as previously thought. This raises a serious question concerning the validity of the Maastrichtian stratotype. In order to test this, nannofossil analysis of nineteen samples from the nearby Curfs quarry was carried out (Fig. 5). The examined section contains the Berg en Terblijt and Vroenhoven Horizons, the latter previously being thought to represent the KTB (e.g. Cepek & Moorkens 1979; Verbeek 1986). The nannofossil succession in Curfs quarry revealed an interesting pattern of reworking. The presence of reworked material is not particularly surprising since the section lies within a region of laterally extensive hardground and hiatus formation. However, the most intensely reworked zone occurs within the Maastricht Formation.

Nannofossil succession

As explained by Burnett, Bown & Young (in MacLeod et al. 1997, especially fig. 4), the nannofloral succession across the KTB has been well-documented from numerous successions, and the sequence of events is well-established. However, nannofossil biostratigraphic interpretation was not particularly straightforward in the Curfs quarry, and at least six traverses of each slide were made to try to ensure that all elements of the nannofloras were recorded. This intensive approach was prompted by the findings of Romein et al. (1996) in their examination of samples from the Geulhemmerberg section, just east of Curfs quarry. It seems that the small, rare Tertiary elements (e.g. *Neobiscutum*) of their three 'Maastrichtian' samples were not picked up with LM analysis but were eventually revealed by SEM analysis of the same samples, although they dismissed a single LM-observed occurrence of *Neobiscutum romeinii* in their lowermost sample as the result of bioturbation. Romein et al. (1996) placed little weight on the SEM analyses, intimating that these Tertiary taxa either were bioturbated down-section, represented contamination, evolved in the Maastrichtian, or were exhibiting diachroneity, since there was no evidence of them having evolved in the Maastrichtian of the complete boundary-stratotype at El Kef, from which they were originally described (Perch-Nielsen 1981). Since then, however, communications from various colleagues indicate that *Neobiscutum* (but not *Cruciplacolithus*) may indeed first occur (albeit very rarely) in the Maastrichtian elsewhere.

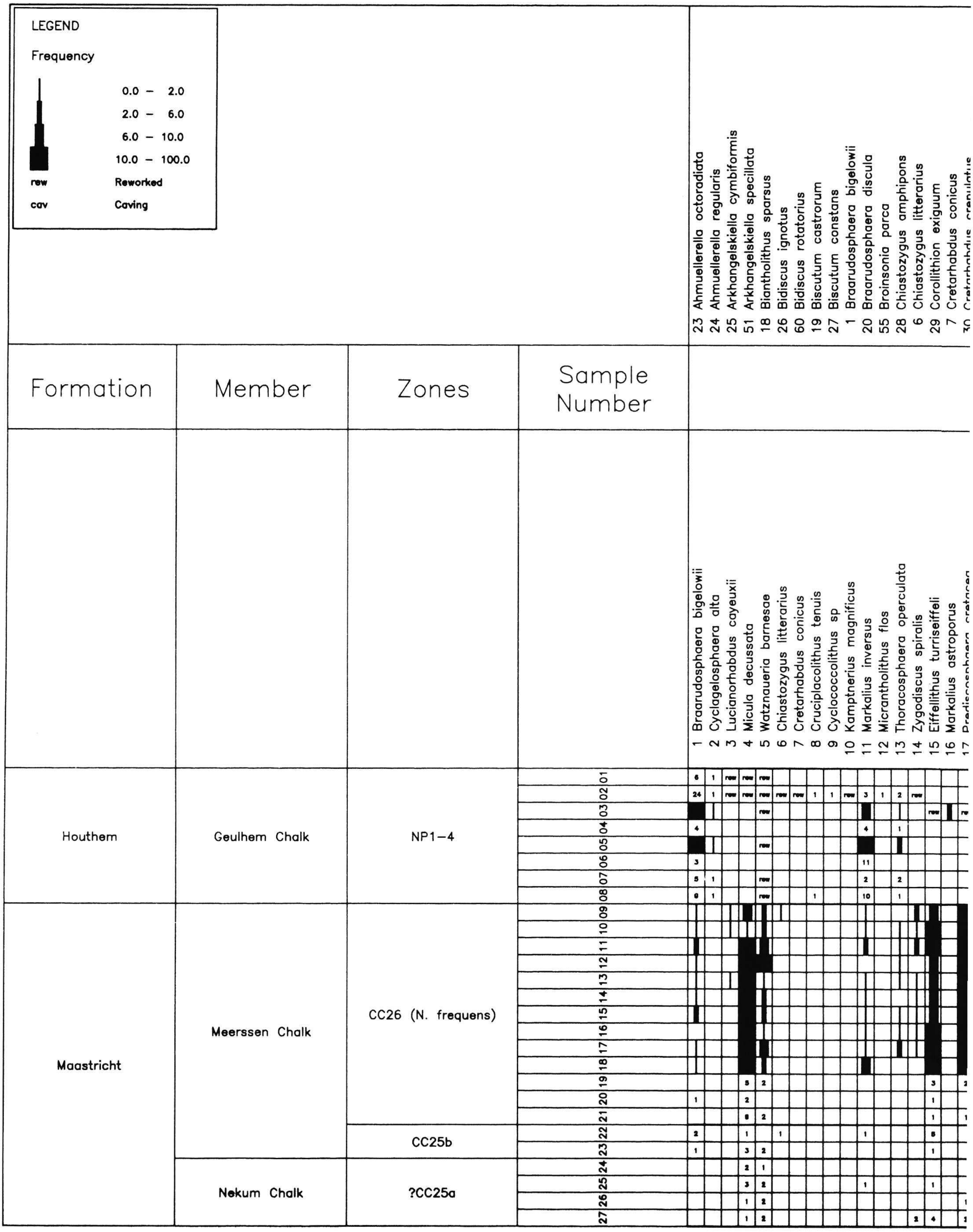
The nineteen samples analysed from Curfs quarry are calcareous sandstones. Although no evidence of bioturbation was observed in the nannofossil whole-rock samples, this cannot be ruled out. It should also be borne in mind that this sequence has been interpreted elsewhere in this paper as a shallow-water, high-energy deposit. Since nannofossils are the smallest component of the assemblages, they are the most likely to have been extensively, and most obviously, reworked. Preservation of the nannofloras is predicatably poor to moderate, although this did not generally affect identification of the taxa. Calcareous sandstones typically contain etched and overgrown nannofossils due to the ease with which pore-waters can circulate through such lithologies, dissolving and redepositing calcite. It is therefore possible that certain relatively delicate nannofossils may have been removed from the assemblages. This is critical, since these are commonly the forms which typify the earliest Paleocene, however this did not particularly affect the interpretation presented herein. It should be noted, however, that the tiny size of these earliest Paleocene coccoliths combined with the incredible dilution of the assemblages with reworked Cretaceous taxa observed here, makes them extremely difficult to find with the LM.

Figure 13 is a comprehensive range-chart of the nannofossils recorded from the Curfs quarry KTB section. Age-indicative Tertiary taxa are highlighted, as are (partially) reworked age-indicative Cretaceous forms. Figure 14 summarises the sequence of events which are described below. Nannofossil taxonomy herein follows that presented in Bown (1998) and illustrations of all of these taxa can be found in Burnett (in Bown, 1998).

Small forms of *Cruciplacolithus primus* occur sporadically throughout the section. This taxon has been used by a number of authors (e.g. Romein 1979; Perch-Nielsen 1981; Varol 1989) to define the base of a zone or subzone in the lowest Paleocene but not immediately above the KTB. Thus, it appears that the section lies entirely within the lowest Paleocene (i.e. Nannofossil Zones NP1 of Martini 1971; D2 of Perch-Nielsen 1979; CP1a of Okada & Bukry 1980; NTp1B of Varol 1989). This is in agreement with Romein et al.'s (1996) tentative SEM conclusions from the Geulhemmerberg section. Additionally, coccospheres and coccoliths of tiny *Neobiscutum* spp. occur throughout the section. These also have been used to define subzones in the basal Tertiary (e.g. Perch-Nielsen, 1981). *Futyania petalosa* was not found in this section, which constrains the youngest age to NTp1B.

The KTB itself is commonly marked by both the LO of abundant Cretaceous taxa (discounting reworked forms) and the FOs of *Biantholithus sparsus* and/or *Cyclagelosphaera alta*, often accompanied by a succession of 'blooms' of non-coccolithophore survivor taxa such as *Thoracosphaera* spp. and *Braarudosphaera* spp. Although both of these latter taxa were consistently present throughout, 'blooms' were not encountered in the Curfs quarry section. The FO of *Cyclagelosphaera alta* in the Curfs quarry section lies in sample 8, just above the Berg en Terblijt Horizon, although it does not occur consistently until sample 16. The only occurrence of *Biantholithus sparsus* (8-rayed form) lies in sample 17, along with the first consistent occurrence of *Neocrepidolithus cohenii* (a Cretaceous 'survivor' species which increases in abundance above the KTB). These events seem to be out of place with respect to the presence of *Cruciplacolithus primus*, and suggest that either the immediately post-KTB basal Paleocene is not represented here or has been reworked into slightly younger Paleocene sediments (ignoring the distribution of *Neobiscutum* and *Cruciplacolithus* below this level). The pattern of Cretaceous nannofossil reworking gives some impetus to this speculation; or that *Biantholithus sparsus*, particularly, cannot be used as a marker taxon here (it is rare in most KTB sections), and that reliance should thus be placed more heavily on the presence of *Cruciplacolithus*.

Cretaceous nannofossils form the bulk of the nannofloras in the Curfs quarry section. A sequence of Cretaceous nannofossil events are shown in Figure 14. Each of these events represents a well-established marker with virtually global applicability (they constitute part of the standard biozonation scheme of Sissingh (1977) and Perch-Nielsen (1985)). Interestingly, the events occur upsection in a retrograde sequence. This is interpreted here as reworking and redeposition of successively older sediments from an adjacent part of the basin. So, sample 1 is Lower Paleocene with a CC25b (lower Upper Maastrichtian)


LEGEND
Frequency
0.0 – 2.0
2.0 – 6.0
6.0 – 10.0
10.0 – 100.0
rew Reworked
cav Caving
23 Ahmuellerella octoradiata
24 Ahmuellerella regularis
25 Arkhangelskiella cymbiformis
51 Arkhangelskiella specillata
18 Biantholithus sparsus
26 Bidiscus ignotus
60 Bidiscus rotatorius
19 Biscutum castrorum
27 Biscutum constans
1 Braarudosphaera bigelowii
20 Braarudosphaera discula
55 Broinsonia parca
28 Chiastozygus amphipons
6 Chiastozygus litterarius
29 Corollithion exiguum
7 Cretarhabdus conicus
Formation
Member
Zones
Sample Number
1 Braarudosphaera bigelowii
2 Cyclagelosphaera alta
3 Lucianorhabdus cayeuxii
4 Micula decussata
5 Watznaueria barnesae
6 Chiastozygus litterarius
7 Cretarhabdus conicus
8 Cruciplacolithus tenuis
9 Cyclococcolithus sp
10 Kamptnerius magnificus
11 Markalius inversus
12 Micrantholithus flos
13 Thoracosphaera operculata
14 Zygodiscus spiralis
15 Eiffellithus turriseiffeli
16 Markalius astroporus
Houthem
Geulhem Chalk
NP1–4
Maastricht
Meerssen Chalk
CC26 (N. frequens)
CC25b
Nekum Chalk
?CC25a
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27

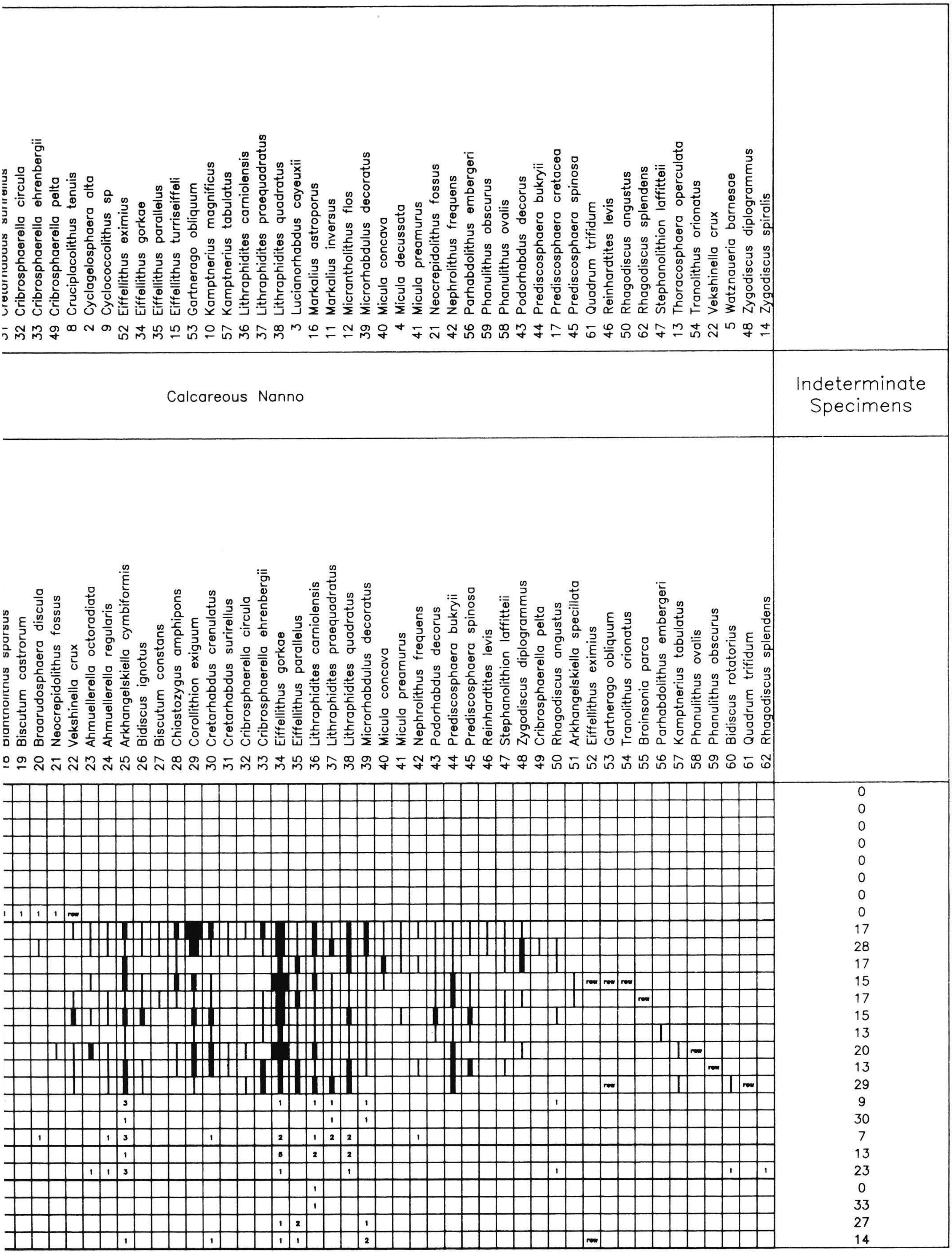


Figure 12

Distribution chart of nannoplankton in the Curfs quarry (JWV, herein).

component, sample 2 has a CC24 (Lower/Upper Maastrichtian) component, samples 3 to 6 have a CC23b (Lower Maastrichtian) component, sample 7 has a CC23a (Campanian/Maastrichtian) component, and sample 8 has a CC22c to CC16-17 (Upper Campanian to Santonian/Campanian) component.

Sample 8, lying immediately above the Berg en Terblijt Horizon, is unusual. This sample also contains the first indubitable earliest Paleocene component (*Cyclagelosphaera alta*). So, the controversial interpretation here is that, just above the Berg en Terblijt Horizon, oldest Campanian to Upper Maastrichtian sediments were continuing to be redeposited, and oldest Paleocene deposits were starting to be reworked, presumably from a different part of the basin, and redeposited at the Curfs quarry location. Possible confirmation of this is provided by following the reworking pattern higher up the section. Between samples 7 and 11/12, the abundance of nannofossils as a component of the sediment is higher than anywhere else in the section, as is the total number of Cretaceous taxa, possibly suggesting increased bulking of the sediment with a

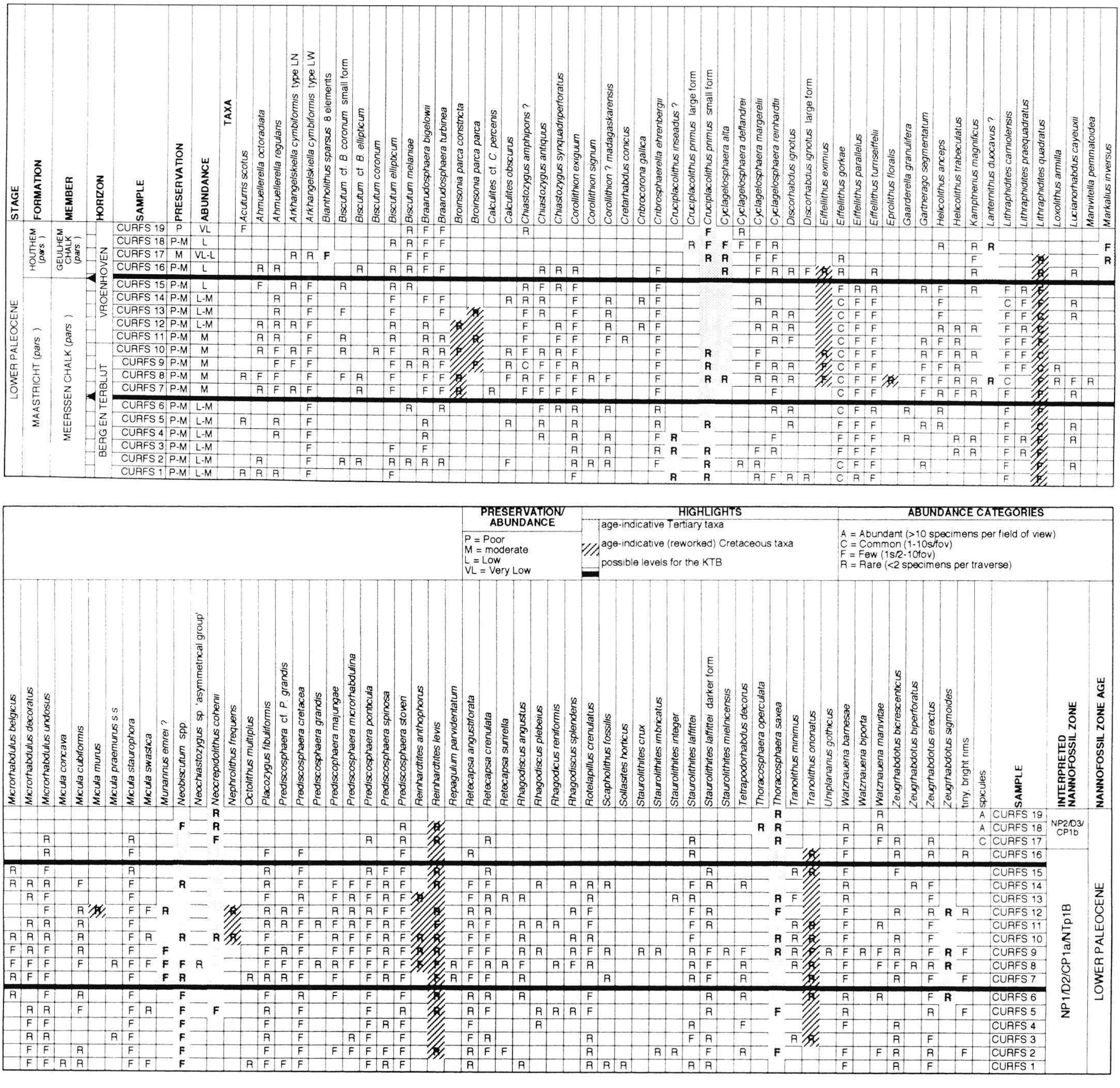


Figure 13

Distribution chart of nannoplankton in the Curfs quarry around the KTB (JAB, herein).

greater amount of nannofossils from a wider stratigraphical range (this does not affect individual abundances of the taxa, which remain constant at the abundance categories used). Reworking of obviously Upper Campanian nannofossils continues into sample 16 but younger events (FOs of *Nephrolithus frequens* and *Micula murus*) start to appear in the interim succession. Thus a new, additional cycle of reworking appears to have been established, involving zone NTp1A (lowest Paleocene) in sample 8, to CC26 (uppermost Maastrichtian) in samples 10 and 11, CC25c (Upper Maastrichtian) in sample 12, and CC25b (Upper Maastrichtian) in samples 13 to 15.

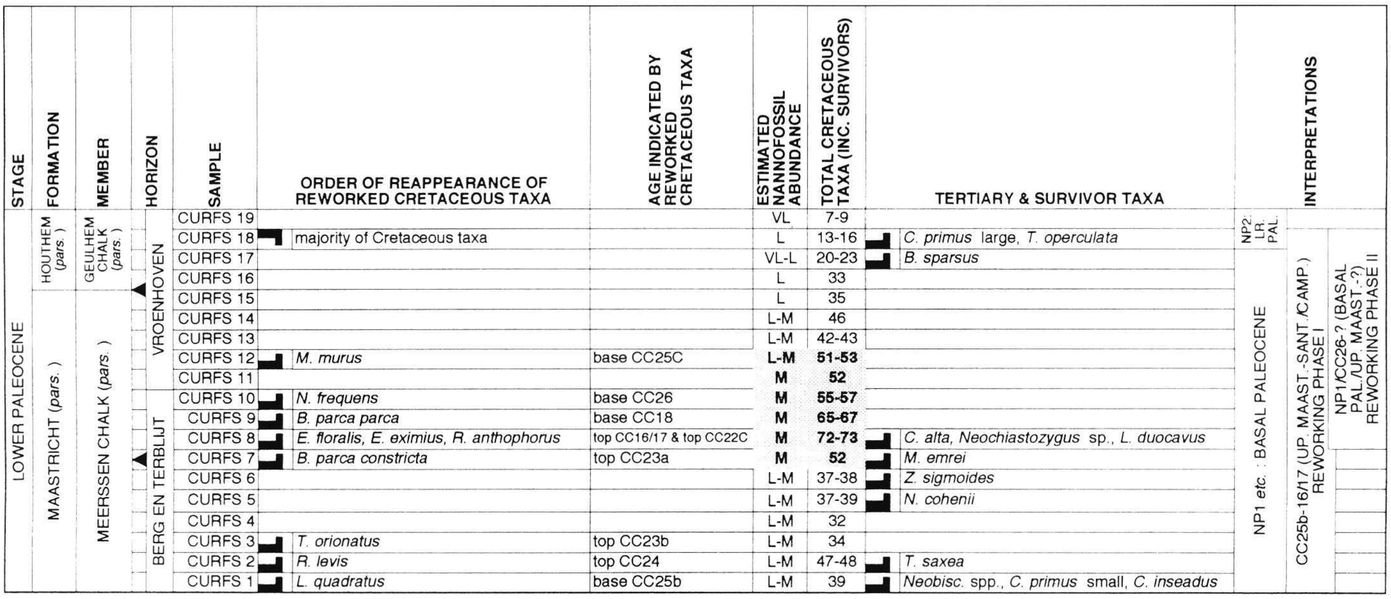
Sample 15 marks the start of a low to very low nannofossil component of the sediment. There is a marked reduction in the number of Cretaceous taxa being reworked into samples 15 to 19, possibly indicating the slowing of erosion and redeposition of Upper Campanian to Lower Maastrichtian nannofossils. From sample 17, a Lower Paleocene assemblage becomes more obvious, probably because the abundances of these taxa are no longer being extremely diluted by the Cretaceous component. A large form of *Cruciplacolithus primus* was found in sample 18, which indicates a higher Lower Paleocene zone: NP2 of Martini (1971), D3 of Perch-Nielsen (1979), and CP1b of Okada & Bukry (1980). Sample 18 contains the last of the majority of Cretaceous taxa.

Discussion

The nannofloral record in the Curfs quarry sequence has been disrupted by extensive reworking in what has been interpreted elsewhere herein as a high-energy, shallow-water environment. Because nannofossils are so small, it seems likely that this reworking will have manifested itself most obviously and extensively in the nannofossil component. The nannofossil record shows that there is no doubt that virtually the entire section from Curfs (1996 samples Curfs2-19) contains reworked components.

The nannofossil biozonation of the Curfs sequence hinges on the presence throughout of *Neobiscutum* and *Cruciplacolithus*. It is possible that *Neobiscutum* is naturally present in the Maastrichtian but often overlooked because of its extremely small size. It is unlikely that *Cruciplacolithus* evolved in the Maastrichtian, however. The topmost Maastrichtian marker taxa, *Micula murus, Nephrolithus frequens* and *Lithraphidites quadratus* are all present at Curfs, the latter occurring virtually throughout the sequence, whilst *N. frequens* debuts at Curfs10 (above the newly-proposed KTB) and *M. murus* first occurs in Curfs12. Thus, if one were to ignore the *Neobiscutum/Cruciplacolithus* evidence, it might be inferred that the Curfs section is of Late Maastrichtian age upto Curfs13 (where *N. frequens* and *M. murus* both disappear). Incidentally, the distributions of both of these taxa would lend greater weight to the argument that the KTB might lie at the Vroenhoven Horizon, rather than at the Berg en Terblijt Horizon. However, Verbeek (1986 and Figure 12), found *N. frequens* to first occur well below this level (1985 sample Curfs21) towards the base of the Meerssen Chalk and well below the Berg en Terblijt Horizon.

The KTB was originally thought to lie at the level of the Vroenhoven Horizon (Cufs16). Possible nannofossil arguments to support this might include the LO of most Creta-



STAGE	FORMATION	MEMBER	HORIZON	SAMPLE	ORDER OF REAPPEARANCE OF REWORKED CRETACEOUS TAXA	AGE INDICATED BY REWORKED CRETACEOUS TAXA	ESTIMATED NANNOFOSSIL ABUNDANCE	TOTAL CRETACEOUS TAXA (INC. SURVIVORS)	TERTIARY & SURVIVOR TAXA	INTERPRETATIONS		
LOWER PALEOCENE	HOUTHEM (*pars.*)	GEULHEM CHALK (*pars.*)	VROENHOVEN	CURFS 19			VL	7-9		NP2: LR. PAL.		
				CURFS 18	majority of Cretaceous taxa		L	13-16	*C. primus* large, *T. operculata*		CC25b-16/17 (UP. MAAST.-SANT./CAMP.) REWORKING PHASE I	NP1/CC26-? (BASAL PAL./UP. MAAST.-?) REWORKING PHASE II
				CURFS 17			VL-L	20-23	*B. sparsus*	NP1 *etc.* : BASAL PALEOCENE		
				CURFS 16			L	33				
	MAASTRICHT (*pars.*)	MEERSSEN CHALK (*pars.*)		CURFS 15			L	35				
				CURFS 14			L-M	46				
				CURFS 13			L-M	42-43				
				CURFS 12	*M. murus*	base CC25C	**L-M**	**51-53**				
				CURFS 11			**M**	**52**				
			BERG EN TERBLIJT	CURFS 10	*N. frequens*	base CC26	**M**	**55-57**				
				CURFS 9	*B. parca parca*	base CC18	**M**	**65-67**				
				CURFS 8	*E. floralis, E. eximius, R. anthophorus*	top CC16/17 & top CC22C	**M**	**72-73**	*C. alta, Neochiastozygus* sp., *L. duocavus*			
				CURFS 7	*B. parca constricta*	top CC23a	**M**	**52**	*M. emrei*			
				CURFS 6			L-M	37-38	*Z. sigmoides*			
				CURFS 5			L-M	37-39	*N. cohenii*			
				CURFS 4			L-M	32				
				CURFS 3	*T. orionatus*	top CC23b	L-M	34				
				CURFS 2	*R. levis*	top CC24	L-M	47-48	*T. saxea*			
				CURFS 1	*L. quadratus*	base CC25b	L-M	39	*Neobisc.* spp., *C. primus* small, *C. inseadus*			

Figure 14

Sequence of nannofossil events in the Curfs quarry around the KTB (JAB, herein).

ceous taxa (at Curfs17), along with the FO of *Biantholithus sparsus* (at Curfs17), the regular occurrences of *Cyclagelosphaera alta* (from Curfs16), and *Markalius inversus, Neocrepidolithus cohenii* and *Thoracosphaera* spp. (from Curfs17). This interpretation however ignores the presence of *Cyclagelosphaera alta, Neobiscutum* spp., *Cruciplacolithus* spp., *Neochiastozygus* sp., *Munarinus emrei* and *Lanternithus duocavus* below this level.

Evidence from other micropalaeontological groups presented herein indicates that the Berg en Terblijt Horizon (Curfs7) represents the KTB. Nannofloral evidence to include this hypothesis might include the FOs of *Cyclagelosphaera alta, Neochiastozygus* sp. and *Lanternithus duocavus* (in Curfs8), and possibly the FO of *Munarius emrei* (in Curfs7). These latter two species are solution-prone holococcoliths, and it should be noted that their FOs at this level coincides with an increase in abundance of coccoliths which may have produced a buffering effect in the system so that they were not removed from the assemblages above this level. Neither species is particularly useful as a marker taxon but both are considered to be Tertiary-restricted. Nannofloral evidence against the Berg en Terblijt Horizon being the level of the KTB include the presence of *Cruciplacolithus* and *Neobiscutum* below this horizon, and the lack of interruption in the distribution patterns of numerous Cretaceous taxa across this horizon (the 'normal' pattern being one of reduced abundance of Cretaceous taxa above the boundary). The apparent FOs of *Micula murus* and *Nephrolithus frequens* above this horizon cannot be used because this distribution is not supported by the data presented by Verbeek (1986 and Figure 12).

Conclusions

Virtually the section in Curfs quarry, from 2.5 m below the Berg en Terblijt Horizon to 0.1 m above the Vroenhoven Horizon, belongs to Lower Paleocene Nannofossil Zone NTp1B of Varol (1989) and NP1 of Martini (1971). The top 1 m of the section probably belongs to Lower Paleocene zone NP2 of Martini (1971). The sediments contain reworked major Cretaceous and possibly minor earliest Paleocene components. Nannofossil events through the Maastricht Formation appear to provide evidence of two phases of reworking. First, a cycle of progressively retrograde remobilisation and redeposition, from an adjacent part of the basin, of Campanian to Upper Maastrichtian nannofloras was established, then, from the level of around the Berg en Terblijt Horizon, a second, additional cycle of remobilisation and redeposition of lowest (NTp1A) Paleocene to Upper Maastrichtian sediments became overprinted on the (continuing) first cycle.

At least part of the Maastricht Formation, and definitely the Berg en Terblijt Horizon, in this area appears to be Tertiary in nannofossil terms. This is in partial agreement with the findings of Romein et al. (1996), based on their SEM study of their samples, which revealed the presence of small *Cruciplacolithus primus* and *Neobiscutum* spp. throughout the section they studied from the Geulhemmerberg caves, but is not in agreement with evidence presented for the other micropalaeontological groups herein.

The nannofossil data seems to pose more questions than it answers and, in nannofossil terms at least, it is obvious that further, and more stratigraphically extensive, work needs to be carried out in the Maastrichtian type-region, and that direct comparisons should be made with the KTB type-section at El Kef. In particular, it is vitally important that the precise FOs of the *Neobiscutum* spp. and *Cruciplacolithus* spp. be established in both areas, so that the nannofossil interpretations presented herein can be either strengthened or revised.

Sporomorphs

Introduction

The present work deals with the sporomorphs of the Curfs quarry, and is the last contribution of an inventory series documenting the Campanian-Maastrichtian chalks of South Limburg, the Netherlands. Previous results have been reported from the Gulpen Formation, as exposed in the ENCI quarry near Maastricht, by Kedves & Herngreen (1980) and from the Maastricht Formation of the Bunde borehole by Herngreen et al. (1986). The pollen and spore counts of a provisional examination of six samples (for position see Fig. 3) from the Curfs quarry are shown in Figure 15. Although the number of sporomorphs was fairly low, varying between 2 and 44 per slide, a detailed examination on a second set of 27 samples (Figs 3 and 16) was thought worthwhile.

During the Curfs examinations, no new taxa in addition to those already described were encountered, nor were supplementary taxonomic remarks necessary. Therefore, for all taxonomic details, reference is made to both abovementioned papers. The sporomorphs determined during the present investigation are listed, together with their abundances and the number of investigated slides, and summarized in two diagrams (Figs 15 and 16).

Sporomorph stratigraphy

The new results may be summarized as follows.

Species limited to the Maastricht Formation below the Berg en Terblijt Horizon

Gleicheniidites circinidites
Inaperturopollenites hiatus
Cycadopites cycadioides
Oculopollis minoris
Semioculopollis croxtonae
Semioculopollis maastrichtiensis crassiexinus
Trudopollis lativerrucatus
Trudopollis maestrichtiensis
Pseudotrudopollis cf. *competitor*
Pseudotrudopollis crassiexinus
Pseudotrudopollis pseudoalnoides

These three *Pseudotrudopollis* species have been found only up to the Nekum Chalk. On the basis of the present investigation, and bibliographical data, the form-genus *Pseudotrudopollis* is a good index fossil for the Maastrichtian strata of the Boreal Normapolles sporomorph province (Herngreen et al. 1996). *P. crassiexinus* is characteristic of the Gulpen Formation and the lower part of the Maastricht Formation, and consequently it seems to be the most important marker of the Maastrichtian. The significance of the number of apertures was emphasized and discussed in Herngreen et al. (1986). The so-called typical forms with five apertures appear first and are characteristic of the Gulpen Formation. The four-aperturate forms appear in younger sediments of the Maastricht Formation.

Kriegeripollenites laevigatus
Pseudosculapollis tschudyi
Elsikipollenites convexus
Pompeckjoidaepollenites daniensis
Magnoporopollenites krutzschii
Subtriporopollenites anulatus maestrichtiensis

Species of the Maastricht Formation above the Berg en Terblijt Horizon and the Houthem Formation

Species marked with an asterisk (*) appear in the Houthem Formation.

*Leiotriletes triangulus**
*Psilatricolpites parmularius** - a characteristic Lower Paleogene species
Felderipollenites triangulus
Nudopollis endangulatus - this species is very characteristic of the Lower Paleocene spore-pollen assemblages of Europe
Nudopollis terminalis cretacicus
Jarzenipollenites trinus - taking into consideration previous data (Stanley 1965; Bratzeva 1969; Jarzen 1976; Kedves 1979), this species can be used as an important index pollen grain for Lower Danian strata, not only in the Normapolles, but in the *Aquilapollenites* Province too.
*Plicapollis pseudoexcelsus semiturgidus**
Vacuopollis pflugii
*Triatriopollenites conspicuus**
*Triatriopollenites podagrarius**
*Momipites quietus**
Triporopollenites spackmanii
*Rugutriporites balinkaense minor**
*Subtriporopollenites palaeogenicus**
*Subtriporopollenites facilis**
*Portniaginaepollenites maastrichtiensis**
*Caryapollenites triangulus**
Ericipites sp.*

Assemblages around the Berg en Terblijt Horizon

Unfortunately, most of the above-mentioned species with top or base occurrences at the Berg en Terblijt Horizon are

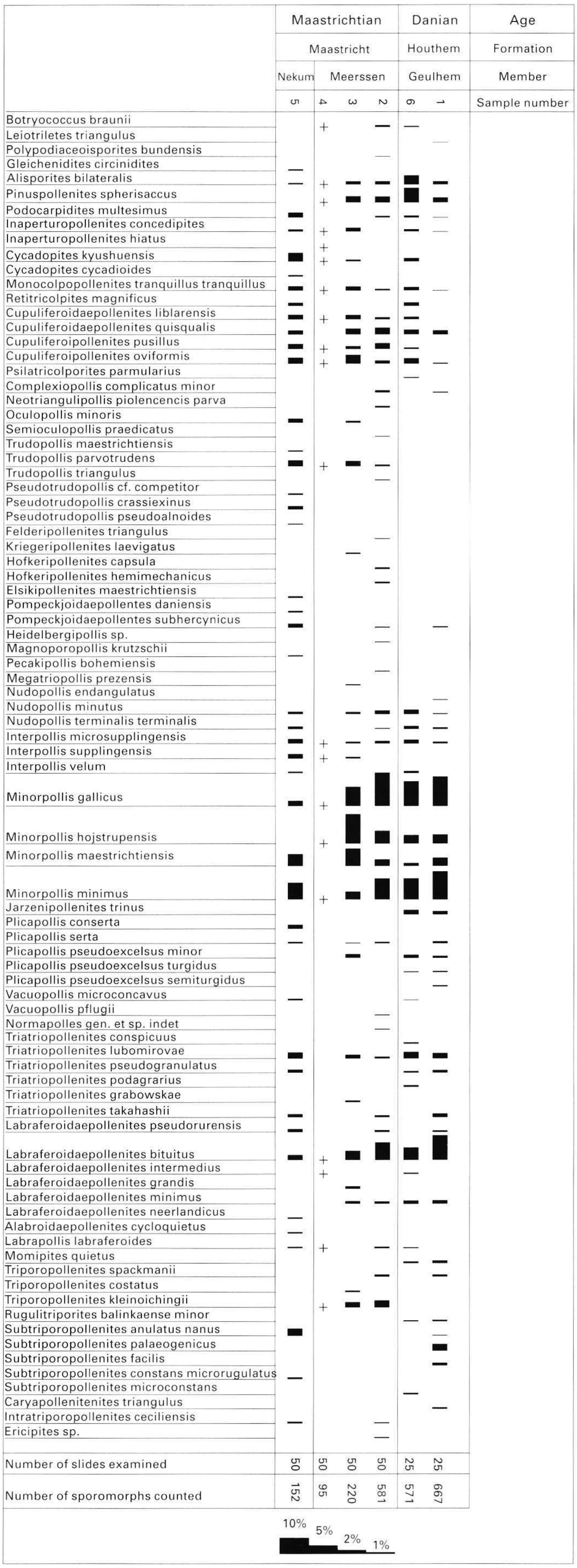


Figure 15
Sporomorph diagram of six samples from the Curfs quarry: a reconnaissance examination.

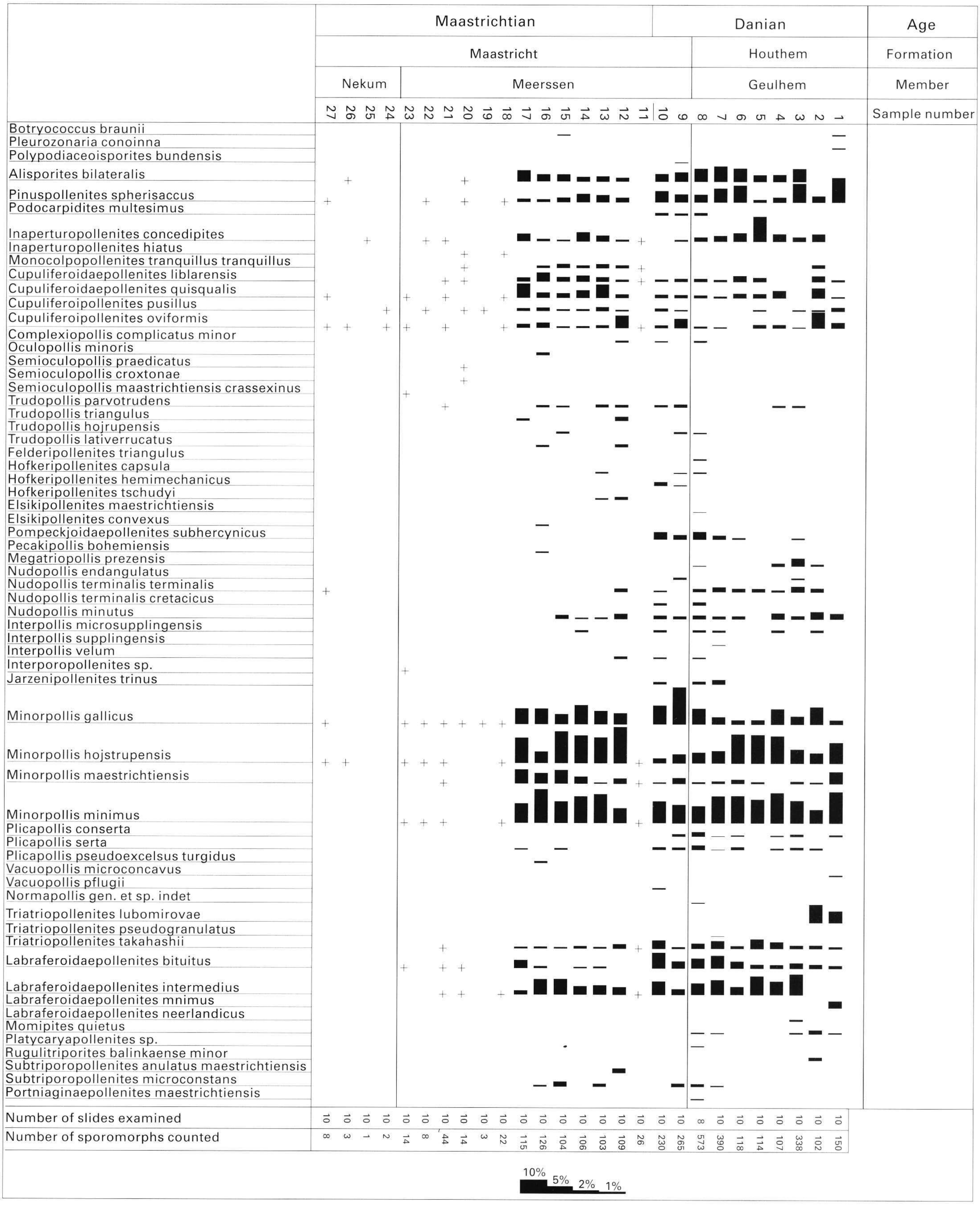


Figure 16

Sporomorph diagram of the Curfs quarry: the definite investigation.

rare or occur irregularly. Also, with respect to the general scarcity of sporomorphs, it cannot be excluded that future examinations may slightly extend their range.

From a quantitative point of view, an increase of bisaccate pollen (*A. bilateralis, P. spherisaccus* and *P. multesimus*) can be observed, together with more common and regular finds of *Pompeckjoidaepollenites subhercynicus* and a temporary increase of *Labraferoidaepollenites bituitus*. Within the genus *Minorpollis*, marked frequency changes are observed.

Brevaxonate pollen

The occurrence of Brevaxonate angiosperm pollen grains in the Maastricht Formation (Md) and the Houthem Formation, the Netherlands, and the Fish Clay Formation, Denmark, is summarized below.

	Md	Houthem Fm.	Fish Clay Fm.
Complexiopollis complicatus minor	+	+	
Neotriangulipollis piolencensis parva	+		
Oculopollis minoris	+		+
Oculopollis sp.			+
Semioculopollis praedicatus	+		
Semioculopollis croxtanae	+		+
Semioculopollis daniensis			+
Semioculopollis maastrichtiensis crassiexinus	+		
Trudopollis parvotrudens	+	+	
Trudopollis triangulus	+		
Trudopollis maestrichtiensis	+		
Trudopollis bangii			+
Trudopollis hojrupensis	+	+	+
Trudopollis lativerrucatus	+		
Cf. Hungaropollis sp.			+
Pseudotrudopollis cf. competitor	+		
Pseudotrudopollis crassiexinus	+		
Pseudotrudopollis pseudoalnoides	+		
Felderipollenites triangulus	+	+	
Kriegeripollenites laevigatus	+		
Hofkeripollenites capsula	+	+	
Hofkeripollenites hemimechanicus	+		
Pseudosculapollis tschudyi	+		
Elsikipollenites maastrichtiensis	+	+	
Elsikipollenites convexus	+		
Pompeckjoidaepollenites stockmarrii			+
Pompeckjoidaepollenites subhercynicus	+	+	+
Pompeckjoidaepollenites daniensis			+
Pompeckjoidaepollenites hojrupensis			+
Heidelbergipollis sp.	+		
Pecakipollis bohemiensis	+		
Megatripollis prezensis	+	+	
Nudopollis endangulatus	+	+	
Nudopollis terminalis terminalis	+	+	+
Nudopollis terminalis cretacicus	+	+	
Nudopollis minutus	+	+	
Interpollis microsupplingensis	+	+	+
Interpollis supplingensis	+	+	+
Interpollis velum	+	+	+
Interporopollenites sp.	+		
Minorpollis gallicus	+	+	+
Minorpollis hojstrupensis	+	+	+
Minorpollis maestrichtiensis	+	+	
Minorpollis minimus	+	+	
Jarzenipollenites trinus	+	+	+
Jarzenipollenites sp.			+
Plicapollis conserta	+	+	

	Md	Houthem Fm.	Fish Clay Fm.
Plicapollis serta	+	+	
Plicapollis pseudoexcelsus minor	+	+	+
Plicapollis pseudoexcelsus turgidus	+	+	+
Plicapollis pseudoexcelsus semiturgidus		+	
Plicapollis pseudoexcelsus luteticus			+
Vacuopollis microconcavus		+	
Vacuopollis pflugii		+	+
Triatriopollenites conspicuus		+	
Triatriopollenites lubomirovae	+	+	
Triatriopollenites pseudogranulatus		+	
Triatriopollenites podagrarius		+	
Triatriopollenites grabowskae	+		+
Triatriopollenites takahashii	+	+	
Labraferoidaepollenites rurensis			+
Labraferoidaepollenites pseudorurensis	+	+	
Labraferoidaepollenites bituitus	+	+	
Labraferoidaepollenites intermedius	+	+	
Labraferoidaepollenites grandis	+		
Labraferoidaepollenites minimus	+	+	
Labraferoidaepollenites neerlandicus		+	
Alabroidaepollenites cycloquietus			+
Labrapollis labraferoides	+	+	+
Labrapollis globosus			+
Labrapollis rotundoides			+
Momipites quietus		+	
Platycaryapollenites sp.		+	
Myrtaceidites sp.			+
Sparganiaceoipollenites cf. cuvillieri			+
Triporopollenites undulatus			+
Triporopollenites robustus robustus			+
Triporopollenites festatus			+
Triporopollenites spackmanii	+	+	
Triporopollenites costatus	+		
Triporopollenites kleinoichingii	+		
Rugulitriporites balinkaense minor		+	
Subtriporopollenites constans constans			+
Subtriporopollenites anulatus anulatus			+
Subtriporopollenites anulatus nanus		+	+
Subtriporopollenites anulatus maestrichtiensis	+		
Subtriporopollenites palaeogenicus		+	
Subtriporopollenites facilis		+	
Subtriporopollenites microconstans	+	+	
Caryapollenites triangulus		+	
Intratriporopollenites ceciliensis		+	
Portniaginaepollenites sp.			+
Portniaginaepollenites maestrichtiensis		+	

The above-mentioned pollen grain data are summarized as follows:

Restricted to the Maastricht Formation Md	20
Md + Houthem Fm.	21
Md + Houthem Fm. + Fish Clay	12
Restricted to the Houthem Fm.	14
Houthem Fm. + Fish Clay	2
Restricted to the Fish Clay	21
Md + Fish Clay	3

Evaluation of the quantitative sporomorph data

Maastricht Formation, Nekum Member

Only one sample was suitable for quantitative palynological study (Fig. 15). The dominance of *Minorpollis* suggests a Juglandaceae vegetation. Other pollen grains indicate Cycadales, Palmae, Fagaceae and Myricaceae.

Maastricht Formation, Meerssen Member

The samples from the lower part of this member are not suitable to reconstruct the vegetation type on a palynological basis. The sporomorphs from the middle and upper parts indicate an early Juglandaceae-Myricaceae-Fagaceae assemblage. The saccate and inaperturate gymnospermous pollen grains are quantitatively also worth mentioning.

Danian Houthem Formation

The quantitative sporomorph data are essentially identical with those from the upper part of the Meerssen Member. It may be concluded that, quantitatively speaking, the character of the vegetation type, as based on pollen and spore investigations, has not changed across the boundary between the Maastricht and Houthem Formations.

Comparison with Gulpen and Maastricht Formation assemblages

A comparison of data from the present examination of the upper(most) part of the Maastricht Formation with previous results obtained from the Maastrichtian type area viz the Gulpen Formation (Kedves & Herngreen 1980) and the lower part of the Maastricht Formation (Herngreen et al. 1986), reveals some distinct trends:

1. Spores: in the Gulpen and lower part of the Maastricht Formation spores occur in fair diversity, however in low percentages. In the upper part of the Maastricht Formation a strong decrease in species variety and in numbers is found.
2. *Classopollis* spp.-*Classoidites*: this plexus reached maximum values up to 30% in the Gulpen Formation and decreased to 5% in the overlying lower(most) part of the Maastricht Formation. The present investigation shows that representatives of this complex are virtually absent in the upper part of the Maastricht Formation.

Both of these changes in the sporomorph assemblages reflect a cooling trend in the latest Maastrichtian of the SE Netherlands.

Comparison with other areas from the Northern Hemisphere

Comparison with other areas is difficult because most studies deal with assemblages characteristic of other sporomorph provinces than the Normapolles Province found at Curfs quarry.

The best-studied terrestrial sections spanning the KTB are in the Western Interior of North America, and are within the *Aquilapollenites* Province. Compilations of many earlier papers by Nichols (1990), Sweet & Braman (1992) and Frederiksen (1996) reveal the following:

- At the KTB, representatives of the *Aquilapollenites*-plexus and oculata morphogroup (*Azonia* and *Wodehouseia*) become extinct in northern areas, and *Proteacidites* and *Tilia wodehouseia* have range tops in the southern areas.
- Generally, a "fern spike" occurs in a short interval immediately above the KTB where spores are dominant below the boundary. Where angiosperms are conspicuous below the boundary, an angiosperm spike characterized by one or two dominant species occurs above the boundary. The dominant opportunistic taxa are interpreted to indicate a pioneer vegetation that dominated the flora following devastation which may have resulted from the impact of an extra-terrestrial body.
- There is strong evidence that the KTB event coincides with a period of increased wetness over most of western North America which resulted in extensive peat formation. The temperature curve in Sweet (1990) indicates a short-term cooling phase at the KTB.

Sporomorph assemblages around the KTB and belonging to the Normapolles Province were studied by Tschudy (1970, 1975) and Jarzen (1978) from the Mississippi Embayment region. This area yields *Araucariacites, Rugubesiculites* and *Zlivisporis*, which are restricted to the Cretaceous, and several genera belonging to the Normapolles group which decline in Early Tertiary times, becoming totally extinct in the Early Oligocene. New Paleocene taxa include *Interporopollenites turgidus, Momipites, Triatriopollenites, Polyporopollenites* and brevitricolporate pollen. These pollen floras show greater similarities to those from Europe than to those from the North American Western Interior. Tschudy (1970) thought the sharp change in sporomorph floras, with the extinction of many Cretaceous species and the appearance of Paleocene floras impoverished in species diversity, to be the result of environmental changes. Jarzen (1978) interpreted the marked change at the KTB in Alabama as a result of the marine transgression.

Beeson (Beeson 1992; Beeson et al. 1993; Beeson et al. 1994) discussed the detailed quantitative analyses of terrestrial palynomorphs across a (?nearly) continuous marine KTB at the Brazos River locality, Texas. He concluded that the KTB is not marked by extinctions; the sporomorph signature across the KTB interval shows a series of species disappearances before and after the boundary. A majority of fern spore spikes are associated with an extinction interval beginning about 50,000 years after KTB time, these extinctions are similar in composition to those at the KTB in continental sections. Kumar (1992), likewise dealing with outcrop sections in Texas, suggested the changes in the composition of the sporomorphs to be more due to ecological than evolutionary changes.
Unfortunately there are no complete KTB sections on the Gulf and Atlantic Coastal Plains, where sporomorph biostratigraphy has been carried out, with one possible exception: the dissertation by Beeson (1992) mentioned above (pers. comm., N.O. Frederiksen, USGS, to GFWH, October 21, 1997).

In addition to North America, the KTB section at El Kef, Tunisia was studied in detail by Méon (1990, 1991). In Maastrichtian times, northern Africa was at the transition between the boreal Normapolles and the equatorial Palmae provinces (Herngreen et al. 1996). Until the end of the Maastrichtian the spores and Araucariaceae pollen (*Araucariacites australis* and *Inaperturopollenites undulatus*) were the most abundant. The Danian shows an increase in monolcolpates (Palmae), triporates (particularly Juglandaceae) and Normapolles pollen. There is an impoverishment of species diversity during the Late Maastrichtian: the extinctions are not compensated for by appearances. Below the KTB, the assemblages have a mixed character of species recorded from tropical Africa-South America and species of boreal Laurasian affinity. The Paleocene microfloras are dominated by European taxa, especially Normapolles species. Méon (1990, 1991) concluded that the climatic influence on the vegetation is clear, however the changes become manifest over a long period. In her opinion, the palynofloral change appears to have been gradual and catastrophic events were not recorded.

In the tropical regions, there is a gradual change rather than a catastrophic elimination of taxa across the KTB (Tschudy 1984; Herngreen, 1998). The assemblages from northern South America and Central Africa are characterized by Palmae and mangrove taxa such as *Mauritiidites, Proxapertites* and *Spinizonocolpites*.

Dealing with land plant evidence Hickey (1981) concluded that geographically uneven and generally moderate levels of extinction and diversity change in the land flora contradict the hypotheses that universal biotic catastrophic events, caused by an asteroid, cometary impact or a supernova terminated the Cretaceous. Similarly, Herman & Spicer (1997) reported that the floral change near the KTB is gradual and may in all likelihood be due to long-term climatic fluctuation and evolutionary change. The evidence from North American leaf floras (Wolfe & Upchurch 1986) points to a sudden, dramatic event at the KTB. Data from the land biota support, in their opinion, a brief low-temperature excursion, resulting from a bolide impact. The pattern of change across the boundary seems to indicate climatic changes rather than extinctions.

Conclusions

The aim of this research program was to establish the sporomorph characteristics of the upper part of the Maastrichtian in the type area near Maastricht, the Netherlands.
The limestone layers are generally poor in spores and pollen grains. However, by investigating a number of slides, the most important taxa from a stratigraphical and palaeoecological point of view have been recorded.
The sporomorph data are sufficient to characterize the Maastrichtian and Danian sediments. As index fossils for the Maastrichtian and for the Danian *Pseudotrudopollis* spp. and *Jarzenipollenites trinus* can be mentioned, respectively.
There is a gradual change in the composition of the Brevaxones pollen group from the base of the Maastrichtian up to and including the Danian. However, there is no indication for a drastic change in the character or composition of the vegetation at the KTB. The number of so-called Tertiary elements increases during the span of time represented by the Maastricht and Houthem Formations.
The decrease of spores and disappearance of the *Classopollis-Classoidites* plexus in the upper(most) Maastricht Formation are interpreted as a cooler phase. Similar cooling trends were found in the Northern Hemisphere in western North America (Sweet 1990), northern Africa (Méon 1990, 1991) and southeast China (Song Zhichen & Huang Fei 1997).

Summary of results

Typical Cretaceous/Tertiary boundary (KTB) clay layers were recently described from the Geulhemmerberg caves, South Limburg, the Netherlands (papers in Brinkhuis & Smit 1996), for location see Figures 1 and 2. In that multidisciplinary (micro)palaeontological, sedimentological, geochemical and paleomagnetic study the KTB is positioned at the Berg en Terblijt Horizon. In the nearby Curfs quarry some thin and pale clay layers occur in a similar stratigraphic position just above the Berg en Terblijt hardground Horizon (Felder & Bosch, in press) in the basal part of unit IVf-7 of Felder (1975), see Figure 5. IVf-7 is the topmost unit of the Meerssen Chalk Member and is bounded at its top by the well known Vroenhoven Horizon, a hardground separating the Maastricht and Houthem Formations and traditionally considered to represent the Cretaceous/Tertiary boundary in Limburg. In addition to a biostratigraphical examination of widely-spaced samples of the entire Curfs section, a detailed micropalaeontological investigation was carried out on the interval around the Berg en Terblijt to the Vroenhoven Horizons.

Stratigraphically diagnostic dinoflagellates, benthic foraminifera and some ostracods indicate a Late(st) Maastrichtian age of the sediments below the Berg en Terblijt Horizon and an Early Danian age above the hardground. This horizon is furthermore characterized by the sharp influx of bryophyte spores and the first appearance of the Paleocene sporomorph *Jarzenipollenites trinus*. The nannofossil results are difficult to interpret and suggest that the section from 2.5 m below the Berg en Terblijt Horizon to 0.1 m above the Vroenhoven Horizon should be attributed to the Lower Paleocene NP1 Zone of Martini (1971) and NTp1B Zone of Varol (1989). A similar disagreement between nannoplankton and other micropalaeontological groups about the precise biostratigraphic position of the KTB was apparent in the Geulhemmerberg section (see in particular Romein et al. 1996 and Smit & Brinkhuis 1996). The Curfs palynomorph assemblages and the benthic foraminifera faunas point to a relatively marginal marine inner neritic depositional setting. Particularly *Pararotalia tuberculifera* is indicative of a high-energy environment at less than 30 m waterdepth.

The present biostratigraphic results from all disciplines involved suggest a gradual change across the KTB, there is no proof for the often alleged mass extinction at the end of the Cretaceous.

Foraminifera and nannoplankton analysis show considerable reworking. The nannoflora evidence is most detailed and indicates two phases. First, a cycle of progressively retrograde remobilisation of Upper Maastrichtian to Campanian nannofloras observed from 2.5 m below the Berg en Terblijt Horizon and upwards. The second cycle of lowest Paleocene to Upper Maastrichtian sediments is from around the Berg en Terblijt Horizon and is superimposed on the continuing first cycle. It is thought that this reworking reflects differential tectonic movements of the block-faulted basement as demonstrated by Bless (1991) in NE Belgium and the SE Netherlands, in particular the Lixhe-Voeren and Thermae Blocks.

The sequence boundary at the Caster Horizon is correlated to the sea-level fall of cycle TA1.1, and at the Vroenhoven Horizon to cycle TA1.2 of Haq et al. (1988).

Sporomorph results from the Maastricht Formation indicate a distinct cooling trend towards the KTB.

Finally, it should be stressed again that the biostratigraphic KT boundary falls within the topmost part of the Maastricht Formation. The lithostratigraphic boundary between the Maastricht and Houthem Formations, which was thought for decades to coincide with the Cretaceous/Tertiary boundary, is within the earliest Danian.

Acknowledgements

We are grateful to the Director of the Netherlands Institute of Applied Geoscience - National Geological Survey (NITG-TNO) for giving permission to publish the Curfs results in the Mededelingen. We appreciate the use of NITG in-house foraminiferal data, reported by J.P.M.T. Meessen. Mrs. S.J. Kerstholt kindly corrected the manuscript, Th. Lissenberg made the SEM-pictures and R.R. van der Kraan drew the figures. HB wishes to thank J.C. Leereveld-van Steenbergen and J. van Tongeren (LPP, Utrecht) for technical assistance, and he acknowledges support from The Netherlands Foundation for Geological, Oceanographical and Atmospherical Research (GOA) and financial aid from The Netherlands Organization for the Advancement of Scientific Research (NWO) and the LPP Foundation. This is publication 98001 of The Netherlands Research School of Sedimentary Geology (NSG). JAB thanks Dr. P.R. Bown (University College London) for confirming some of her observations with his better-quality microscope! GFWH is indebted to Dr. N.O. Frederiksen, U.S. Geological Survey at Reston, for helpful information and supplying abstracts.

References

Batten, D.J., Dupagne-Kievits, J. & Lister, J.K., 1988: Palynology of the Upper Cretaceous Aachen Formation of northeast Belgium. - p. 95-103 in: Streel, M. & Bless, M.J.M. (eds): The Chalk district of the Euregio Meuse-Rhine. Joint publ. Natuurhistorisch Museum Maastricht and Lab. Paléont. Univ. d'Etat à Liège. - Plumhans Publishers, Verviers, Belgium.

Beeson, D.C., 1992: High-resolution palynostratigraphy across a marine Cretaceous-Tertiary boundary interval, Falls County, Texas. - Ph.D. Dissertation, Pennsylvania State University, 390 pp.

Beeson, D.C., Gartner, S., Keller, G., MacLeod, N., Médus, J., Rocchia, R., & Robin, E., 1993: Stratigraphy and depositional environment across the Cretaceous/Tertiary boundary, Brazos River, Falls County, Texas. - Geological Society of America, Abstracts with Programs, 25 (6), p. 297.

Beeson, D.C., Gartner, S., Keller, G., MacLeod, N., Médus, J., Rocchia, R., & Robin, E., 1994: The KT boundary along the Brazos River, Falls County, Texas: multidisciplinary stratigraphy and depositional environment. - p. 9-10 in: New developments regarding the KT event and other catastrophes in earth history. - Lunar and Planetary Institute, Houston, Contribution 825.

Benson, D.G., 1976: Dinoflagellate taxonomy and biostratigraphy at the Cretaceous-Tertiary boundary, Round Bay, Maryland. - Tulane Stud. Geol. Paleontol, 12, p. 169-233.

Bless, M.J.M, 1991: Eustatic sea level and depth of the Late Cretaceous epicontinental sea: an example from NW Europe. - Geologie en Mijnbouw, 70, 339-346.

Bless, M.J.M. & Streel, M., 1988: Upper Cretaceous nannofossils and palynomorphs in South Limburg and northern Liège: a review. - p. 105-117 in: Streel, M. & Bless, M.J.M. (eds): The Chalk district of the Euregio Meuse-Rhine. Joint publ. Natuurhistorisch Museum Maastricht and Lab. Paléont. Univ. d'Etat à Liège. - Plumhans Publishers, Verviers, Belgium.

Bown, P.R., 1998: Calcareous nannofossil biostratigraphy. - British Micropalaeontological Society Series. - Chapman & Hall, London, 315 pp.

Bratzeva, G.M., 1969: Palynological studies of the Upper Cretaceous and Paleogene of the Far East. - Tr. Geol. Inst. Akad. Nauk SSSR, 207, 56 pp. (in Russian).

Brinkhuis, H., 1994: Late Eocene to Early Oligocene dinoflagellate cysts from the Priabonian type-area (Northeast Italy); biostratigraphy and palaeoenvironmental interpretation. - Palaeogeogr., Palaeoclimatol., Palaeoecol., 107, p. 121-163.

Brinkhuis, H., Bujak, J.P., Smit, J., Versteegh. G.J.M. & Visscher, H., 1998: - Dinoflagellate-based sea surface temperature reconstructions across the Cretaceous - Tertiary boundary. - Palaeogeogr., Palaeoclimatol., Palaeoecol., 141, p. 67-84.

Brinkhuis, H. & Schiøler, P., 1996: Palynology of the Geulhemmerberg Cretaceous/Tertiary boundary section (Limburg, SE Netherlands). - p. 193-213 in: Brinkhuis, H. & Smit, J. (eds): The Geulhemmerberg Cretaceous/Tertiary boundary section (Maastrichtian type area, SE Netherlands). - Geol. Mijnb., 75.

Brinkhuis, H. & Smit, J. (eds), 1996: The Geulhemmerberg Cretaceous/Tertiary boundary section (Maastrichtian type area, SE Netherlands). - Geol. Mijnb., 75, p. 101-293.

Brinkhuis, H. & Zachariasse, W.J., 1988: Dinoflagellate cysts, sea level changes and planktonic foraminifers across the K/T boundary at El Haria, Northwest Tunisia. - Mar. Micropaleontol., 13, p. 153-191.

Burnett, J.A., 1998: Upper Cretaceous. - p. 132-199 in: Bown, P.R. (ed.): Calcareous nannofossil biostratigraphy. - Chapman & Hall, London.

Cepek, P. & Moorkens, Th., 1979: Cretaceous/Tertiary boundary and Maastrichtian-Danian biostratigraphy (coccoliths and foraminifera) in the Maastrichtian type area. - Proceedings of the Cretaceous-Tertiary Boundary Events Symposium, Copenhagen, 2, p. 137-143.

Damassa, S.P., 1988: *Carpatella cornuta* Grigorovich 1969 (Dinophyceae) - a member of the *Aptiana-Ventriosum* complex. - Palynology, 12, p. 167-177.

Deroo, G., 1966: Cytheracea (Ostracodes) du Maastrichtien de Maastricht (Pays-Bas) et des régions voisines; résultats stratigraphiques et paléontologiques de leur étude. - Mededelingen Geologische Stichting, Ser. C, 2(2), 197 pp. (27 plates and 42 pp. plate description; 9 tables).

Doppert, J.W.Chr. & Neele, N., 1983: Biostratigraphy of the marine Paleogene deposits in the Netherlands and adjacent areas. - Mededelingen Rijks Geologische Dienst, 37 (2), p. 3-79.

Downie, C., Hussain, M.A. & Williams, G.L., 1971: Dinoflagellate cyst and acritarch associations in the Paleogene of southeast England. - Geosci. Man 3, p. 29-35.

Elsik, W.C., 1977: *Paralecaniella indentata* (Deflandre and Cookson 1955) Cookson and Eisenack 1970 and allied dinocysts. - Palynology, 1, p. 95-102.

Felder, P.J., 1988: Maastrichtian-Early Tertiary strata in the SE Netherlands (Curfs quarry, Rur Valley Graben) and the Campine Mining District (NE Belgium): lithology, gamma radiation and bioclast assemblages. - Meded. Werkgr. Tert. Kwart. Geol., 25 (2-3), p. 115-125.

Felder, W.M., 1975: Lithostratigrafie van het Boven Krijt en het Dano-Montien in Zuid-Limburg en het aangrenzende gebied. - p. 63-72 in: Zagwijn, W.H. & Van Staalduinen, C.J. (eds). - Toelichting bij geologische overzichtskaarten van Nederland, Rijks Geologische Dienst, Haarlem.

Felder, W.M. & Bosch, H.W. (in press): Afzettingen uit het Boven-Krijt en Danien van Zuid-Limburg en omgeving. - Geologie van Nederland, nr. 4.

Fensome, R.A., Taylor, F.J.R., Norris, G., Sarjeant, W.A.S., Wharton, D. & Williams, G.L., 1993: A classification of living and fossil dinoflagellates. - Micropaleontology, Special Publ. 7, 351 pp.

Foucher, J.-C. & Robaszynski, F., 1977: Microplankton des silex du Bassin de Mons (Belgique) (Dinoflagellés Crétacés et Daniens). - Ann. Paléontol. Invertébr., 63 (1): 19-58.

Frederiksen, N.O., 1996: Uppermost Cretaceous and Tertiary spore/pollen biostratigraphy. - p. 831-841 in Jansonius, J. & McGregor, D.C. (eds): Palynology: principles and applications. - American Association of Stratigraphic Palynologists Foundation.

Habib, D., 1994: Biostratigraphic evidence of the KT boundary in the eastern Gulf coastal plain north of the Chicxulub Crater. - p. 45-46 in: New developments regarding the K/T event and other catastrophes in Earth history. - Lunar and Planetary Institute Contrib., 825, Houston, Texas, USA.

Habib, D., Moshkovitz, S. & Kramer, C., 1992: Dinoflagellate and calcareous nannofossil response to sea-level change in Cretaceous-Tertiary boundary sections. - Geology, 20, p. 165-168.

Habib, D., Olsson, R.K., Liu, C. & Moshkovitz, S., 1996: High-resolution biostratigraphy of sea-level low, biotic extinction, and chaotic sedimentation at the Cretaceous-Tertiary boundary in Alabama, north of the Chicxulub crater. - p. 243-252 in: Ryder, G., Fastovsky, D. & Gartner, S. (eds): The Cretaceous-Tertiary event and other catastrophes in Earth history. - Geol. Soc. Am., Special Paper, 307.

Hansen, J.M., 1977: Dinoflagellate stratigraphy and echinoid distribution in Upper Maastrichtian and Danian deposits from Denmark. - Bull. Geol. Soc. Denmark, 26, p. 1-26.

Hansen, J.M., 1979: A new dinoflagellate zone at the Maastrichtian-Danian boundary in Denmark. - Dan. Geol. Unders., Arbog 1978, p. 131-140.

Hansen, H.J., Gwozdz, R., Hansen, J.M., Bromley, R. & Rasmussen, K.L., 1986: The diachronous C/T plankton extinction in the Danish Basin. - p. 381-384 in: Walliser, O. (ed.): Global Bioevents - Lecture notes on Earth Sciences, 8. - Springer Berlin, Heidelberg.

Haq, B.U., Hardenbol, J. & Vail, P.R., 1988: Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change. - p. 71-108 in: Wilgus, C.K. & Hastings, B.S. (eds): Sea Level Changes; An Integrated Approach. - Soc. Econ. Paleontol. Mineral., Special Publication, 42.

Hardenbol, J., 1994: Sequence stratigraphic calibration of Paleocene and Lower Eocene continental margin deposits in NW Europe and the US Gulf Coast with the oceanic chronostratigraphic record. - GFF, 116, p. 49-50.

Haynes, J.R., 1981: Foraminifera. - Macmillan Publ., London, 433 pp.

Head, M.J. & Wrenn, J.H. (eds), 1992: Neogene and Quaternary dinoflagellate cysts and acritarchs. - Am. Assoc. Stratigr. Palynol. Found., Publishers Press, Salt lake City, USA, 438 pp.

Herman, A.B. & Spicer, R.A., 1997: The Koryak flora: Did the Early Tertiary deciduous flora begin in the Late Maastrichtian of northeastern Russia? - p. 87-92 in: Herngreen, G.F.W. (ed.): Proceedings 4th European Palaeobotanical and Palynological Conference. - Mededelingen Rijks Geologische Dienst, 58.

Herngreen, G.F.W., 1998: Cretaceous sporomorph provinces and events in the equatorial region. - Proceedings 5th International Cretaceous Symposium, Freiberg, Sachsen, 1996. - Zbl. Geol. Paläont., Teil I, 1996, H. 11/12, p. 1313-1323.

Herngreen, G.F.W., Felder, W.M., Kedves, M. & Meessen, J.P.M.T., 1986: Micropaleontology of the Maestrichtian in borehole Bunde, The Netherlands. - Rev. Palaeobot. Palynol., 48, p. 1-70.

Herngreen, G.F.W., Kedves, M., Rovnina, L.V. & Smirnova, S.B., 1996: Cretaceous palynofloral provinces: a review. - p. 1157-1188 in Jansonius, J. & McGregor, D.C. (eds): Palynology: principles and applications. - American Association of Stratigraphic Palynologists Foundation.

Hickey, L.J., 1981: Land plant evidence compatible with gradual, not catastrophic, change at the end of the Cretaceous. - Nature, 292, p. 529-531.

Hofker, J., 1966: Maestrichtian, Danian and Paleocene Foraminifera. The foraminifera of the Type Maestrichtian in South Limburg, Netherlands, together with the foraminifera of the underlying Gulpen Chalk and the overlying calcareous sediments; the foraminifera of the Danske Kalk and the overlying greensands and clays as found in Denmark. - Palaeontographica, Suppl. (A), 10, 376 pp.

Hultberg, S.U., 1985: Dinoflagellate studies of the Upper Maastrichtian and Danian in southern Scandinavia. - Ph.D. dissertation, Department of Geology, University of Stockholm, Stockholm, Sweden, 189 pp.

Hultberg, S.U., 1986: Danian dinoflagellate zonation, the C-T boundary and the stratigraphical position of the Fish Clay in southern Scandinavia. - J. Micropaleont., 5, p. 37-47.

Hultberg, S.U. & Malmgren, B.A., 1986: Dinoflagellate and planktonic foraminiferal paleobathymetrical indices in the boreal uppermost Cretaceous. - Micropaleontology, 32 (4), p. 316-323.

Jarzen, D.M., 1978: The terrestrial palynoflora from the Cretaceous-Tertiary transition, Alabama, U.S.A. - Pollen et Spores, 20, p. 535-553.

Kedves, M., 1979: Palynological investigations on sediments of the Lower Danian (Fish Clay, Denmark) I. - Acta Miner.-Petr., Szeged, 24, p. 167-186.

Kedves, M. & Herngreen, G.F.W., 1980: Palynology of the stratotype of the Maestrichtian and the Gulpen Formation, ENCI section, Maastricht, The Netherlands. - Pollen et Spores, 22, p. 483-544.

Kjellström, G. & Hansen, J.M., 1981: Dinoflagellate biostratigraphy of the Cretaceous-Tertiary boundary in southern Scandinavia. - Geologiska Förenigens i Stockholm Förhandlingar, 103, p. 271-278.

Kuhnt, W., 1996: Early Danian benthic foraminiferal community structures, Geulhemmerberg, SE Netherlands. - Geologie en Mijnbouw, 75, p. 163-172.

Kuhnt, W. & Kaminski, M.A., 1996: The response of benthic foraminifera to the K/T boundary event - a review. - p. 433-442 in Jardiné, S. et al. (eds): Géologie de l'Afrique et de l'Atlantique Sud (Compte-rendu des Colloques de géologie d'Angers 1994), Bull. Centres Rech. Explor.-Prod. Elf Aquitaine, Mem. 16.

Kumar, A., 1992: Palynological study of the sediments across the K/T boundary in Texas, U.S.A. - Geophytology, 21, p. 83-97.

Lecalvez, Y., 1970: Contribution à l'étude des foraminifères Paléogènes du Bassin de Paris. - Cah. Paléontol., 48, p. 1-70.

Lentin, J.K. & Williams, G.L., 1993: Fossil dinoflagellates: index to genera and species, 1993 edition. - Am. Assoc. Stratigr. Palynol., Contrib. Series, 28, 856 pp.

MacLeod, N., Rawson, P.F. et al., 1997: The Cretaceous-Tertiary biotic transition. - J. Geological Society, London, 154, p. 265-292.

Marheinecke, U., 1992: Monographie der Dinozysten, Acritarcha und Chlorophyta des Maastrichtium von Hemmoor (Niedersachsen). - Palaeontographica, B, 227, p. 1-173.

Martini, E., 1971: Standard Tertiary and Quaternary calcareous nannoplankton zonation. - p. 739-785 in: Farinacci, A. (ed.): Proceedings of the 2nd Planktonic Conference, Roma, 1970.

Martini, E. & Müller, C., 1986: Current Tertiary and Quaternary nannoplankton stratigraphy and correlations. - Newsl. Stratigr., 16, p. 99-112.

Méon, H., 1990: Palynologic studies of the Cretaceous-Tertiary boundary interval at El Kef outcrop, northwestern Tunisia: Paleogeographic implications. - Rev. Palaeobot. Palynol., 65, p. 85-94.

Méon, H., 1991: Etudes sporopolliniques à la limite Crétacé-Tertiaire: la coupe du Kef (Tunisie nord-occidentale); étude systématique, stratigraphie, paléogéographie et évolution climatique. - Palaeontographica, B, 223 (4-6), p. 107-168.

Moorkens, Th.L., 1982: Foraminifera of the Montian stratotype. - Mém. Explic. Cartes Géologiques et Minières de la Belgique, 17, 2, 186 pp.

Moshkovitz, S. & Habib, D., 1993: Calcareous nannofossil and dinoflagellate stratigraphy of the Cretaceous-Tertiary boundary, Alabama and Georgia. - Micropaleontology, 39 (2), p. 167-191.

Nichols, D.J., 1990: Geologic and biostratigraphic framework of the non-marine Cretaceous-Tertiary boundary interval in western North America. - Rev. Palaeobot. Palynol., 65, p. 75-84.

Okada, H. & Bukry, D., 1980: Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). - Marine Micropaleontology, 5, p. 321-325.

Perch-Nielsen, K., 1979: Calcareous nannofossils from the Cretaceous between the North Sea and the Mediterranean. - IUGS Series A, 6, p. 223-272.

Perch-Nielsen, K., 1981: New Maastrichtian and Paleocene calcareous nannofossils from Africa, Denmark, the USA and the Atlantic, and some Paleocene lineages. - Eclogae Geologicae Helvetiae, 74, p. 831-863.

Perch-Nielsen, K., 1985: Mesozoic calcareous nannofossils. - p. 329-426 in: Bolli, H.M., Saunders, J.B. & Perch-Nielsen, K. (eds): Plankton Stratigraphy, Cambridge University Press.

Powell, A.J. (ed.), 1992: A Stratigraphic Index of Dinoflagellate Cysts. - British Micropaleont. Soc. Publ. Ser., Chapman and Hall, London, 325 pp.

Powell, A.J., Brinkhuis, H. & Bujak, J.P., 1995: Upper Paleocene - Lower Eocene dinoflagellate cyst sequence biostratigraphy of SE England. - p. 145-183 in: Knox, R.W.O'B, Corfield, R. & Dunay, R.E. (eds): Correlation of the early Paleogene in Northwest Europe. - Geol. Soc., Special Publ., 101.

Robaszynski, F., Bless, M.J.M., Felder, P.J., Foucher, J.-C., Legoux, O., Manivit, H., Meessen, J.P.M.T. & van der Tuuk, L.A., 1985: The Campanian-Maastrichtian boundary in the chalky facies close to the type-Maastrichtian area. - Bull. Cent. Rech. Explor.-Prod. Elf-Aquitaine, 9 (1), p. 1-113.

Romein, A.J.T., 1979: Lineages in early Paleogene calcareous nannoplankton. - Utrecht Micropaleontological Bulletins, 22, p. 1-231.

Romein, A.J.T., Willems, H. & Mai, H., 1996: Calcareous nannoplankton of the Geulhemmerberg K/T boundary section, Maastrichtian type area, the Netherlands. - Geologie en Mijnbouw, 75, p. 231-238.

Schiøler, P. & Wilson, G.J., 1993: Maastrichtian dinoflagellate zonation in the Dan Field, Danish North Sea. - Rev. Palaeobot. Palynol., 78, p. 321-351.

Schiøler, P., Brinkhuis H., Roncaglia, L. & Wilson, G.J., 1997: Dinoflagellate biostratigraphy and sequence stratigraphy of the Type Maastrichtian (Upper Cretaceous), ENCI Quarry, The Netherlands. - Mar. Micropaleont., 31 (1/2), p. 65-95.

Schumacker-Lambry, J., 1977: Microfossiles végétaux?

planctoniques. - p. 45-49 in: Streel, M. & Bick, H. (eds): Macro- et microfossiles végétaux dans le contexte litho- et biostratigraphique du Sénonien-Paléocène de la rive gauche de la Meuse au nord de Liège, Belgique. - Handout APLF/PK-meeting, Liège.

Sissingh, W., 1977: Biostratigraphy of Cretaceous calcareous nannoplankton. - Geologie en Mijnbouw, 56, p. 37-65.

Slimani, H., 1994: Les dinokystes des Craies du Campanien au Danien à Halembaye, Turnhout (Belgique) et à Beutenaken (Pays-Bas). - Mém. Expl. Cartes Géol. et Min. Belgique, 37, 173 pp.

Smit, J., 1982: Extinction and evolution of planktonic foraminifera after a major impact event at the Cretaceous/Tertiary boundary. - Geol. Soc. Am., Spec. Pap., 190, p. 329-352.

Smit, J. & Brinkhuis, H., 1996: The Geulhemmerberg Cretaceous/Tertiary boundary section (Maastrichtian type area, SE Netherlands); summary of results and a scenario of events. - p. 283-293 in: Brinkhuis, H. & Smit, J. (eds): The Geulhemmerberg Cretaceous/Tertiary boundary section (Maastrichtian type area, SE Netherlands. - Geol. Mijnb., 75.

Song Zhichen & Huang Fei, 1997: Comparison of palynomorph assemblages from the Cretaceous/Tertiary boundary interval in Western Europe, northwest Africa and southeast China. - Cretaceous Research, 18, p. 865-872.

Stanley, E.A., 1965: Upper Cretaceous and Paleocene plant microfossils and Paleocene dinoflagellates and hystrichosphaerids from northwestern South Dakota. - Bull. American Paleontol., 49 (222), p. 179-384.

Sweet, A.R., 1990: Palynofloras and climates of the Santonian to Paleocene of midcontinental North America. - p. 99-103 in Knobloch, E. & Kvacek, Z. (eds): Proceedings, Symposium on paleofloristic and paleoclimatic changes in the Cretaceous and Tertiary. - Geological Survey Publisher, Prague.

Sweet, A.R. & Braman, D.R., 1992: The K-T boundary and contiguous strata in western Canada: interactions between paleoenvironments and palynological assemblages. - Cretaceous Research, 13, p. 31-79.

Tschudy, R.H., 1970: Palynology of the Cretaceous-Tertiary boundary in the northern Rocky Mountain and Mississippi Embayment regions. - p. 65-111 in Kosanke, R.M. & Cross, A.T. (eds): Symposium on Palynology of the Late Cretaceous and Early Tertiary. - Geological Society of America, Special Paper 127.

Tschudy, R.H., 1975: Normapolles pollen from the Mississippi Embayment. - U.S. Geol. Survey, Prof. Paper 865, 42 pp.

Tschudy, R.H., 1984: Palynological evidence for change in continental floras at the Cretaceous-Tertiary bounday. - p. 315-337 in Berggren, W.A. & Van Couvering, J.A. (eds): Catastrophes and earth history. Princeton University Press, Princeton.

Uhlenbroek, G.D., 1912: Het Krijt van Zuid-Limburg. Toelichting bij eene geologische kaart van het Krijtgebied van Zuid-Limburg. - Jaarverslag Rijksopsporing van Delfstoffen (1911), p. 48-57.

Varol, O., 1989: Palaeocene calcareous nannofossil biostratigraphy. - p. 267-310 in: Crux, J.A. & van Heck, S.E. (eds): Nannofossils and their applications. Proceedings of the INA Conference, London 1987. British Micropalaeontological Society Series/Ellis Horwood Limited, Chichester.

Verbeek, J.W., 1983: The calcareous nannofossils from the Campanian and Maastrichtian rocks of Southern Limburg (The Netherlands) and the adjacent Belgium area. - Abstracts Symposium on Cretaceous Stage Boundaries, Copenhagen, p. 197-200.

Verbeek, J.W., 1986: Calcareous nannoplankton at the Cretaceous-Tertiary boundary in the region near Maastricht in the Province of Limburg (the Netherlands). - Proceedings Kon. Ned. Akad. Wetensch., ser. B, 89 (4), p. 357-365.

Wall, D., Dale, B., Lohmann, G.P. & Smith, W.K., 1977: The environmental and climatic distribution of dinoflagellate cysts in modern marine sediments from regions in the North and South Atlantic oceans and adjacent seas. - Mar. Micropaleontol., 2, p. 121-200.

Wilson, G.J., 1971: Observations of European Late Cretaceous dinoflagellate cysts. - p. 1259-1275 in: Farinacci, A. (ed.): Proceedings of the 2nd Planktonic Conference, Roma, 1970.

Wilson, G.J., 1974: Upper Campanian and Maastrichtian dinoflagellate cysts from the Maastricht region and Denmark. - Unpublished Ph.D. dissertation, Dept. of Geology, University of Nottingham, Nottingham, UK, v + 601 pp.

Witte, L. & Schuurman, H., 1996: Calcareous benthic foraminifera across the Cretaceous/Tertiary boundary in the Geulhemmerberg (SE Netherlands). - Geologie en Mijnbouw, 75, p. 173-186.

Wolfe, J.A. & Upchurch, G.R., 1986: Vegetation, climatic and floral changes at the Cretaceous-Tertiary boundary. - Nature, 324, p. 148-154.

Plate 1

In the description of the dinoflagellates (photoplate 1-4) the following data are presented: species name, sample, slide number, coordinates, magnification, focus and remarks.

1-2
Adnatosphaeridium buccinum, *CURF07B, 6, 3791025, 250x, high-low*

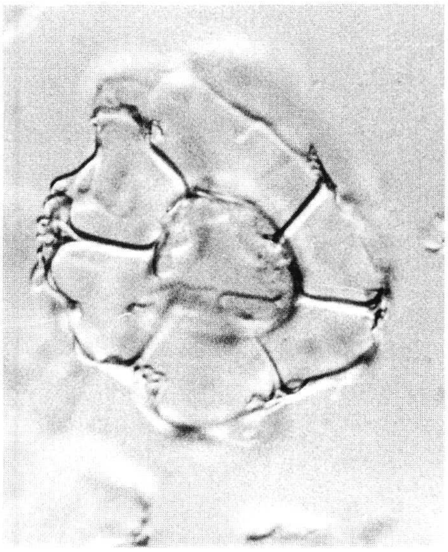
3
Alisocysta *cf.* reticulata, *CURF10, 6, 4631068, 400x, high*

4-5
Areoligera *spp., RGD03, 2, 3991032, 250x, high-low*

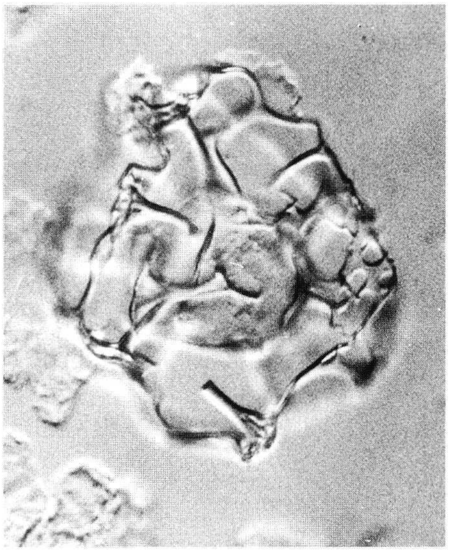
6
Caligodinium aceras, *CURF10, 5, 3101080, 400x, mid*

7
Caligodinium*? sp., RGD23, 1, 433991, 400x*

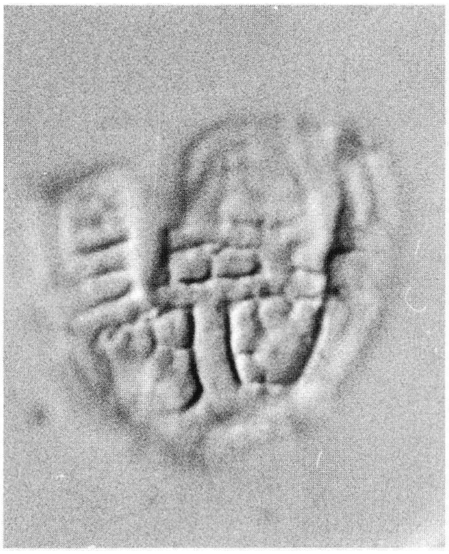
8-9
Carpatella cornuta, *CURF11, 1, 4001020, 400x, high-low*



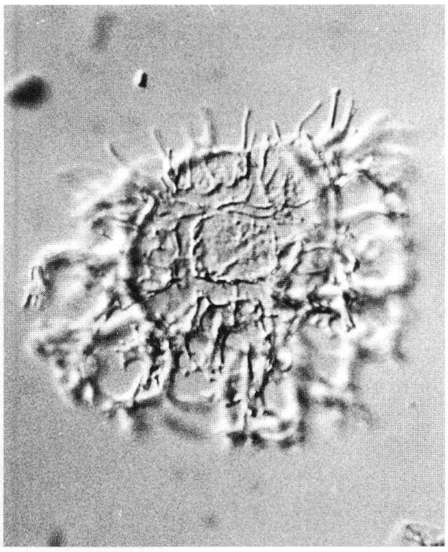
1



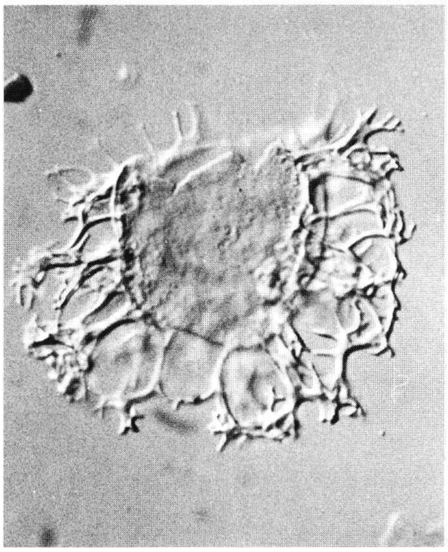
2



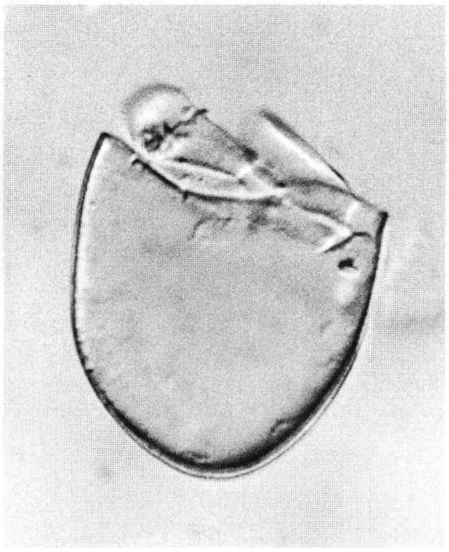
3



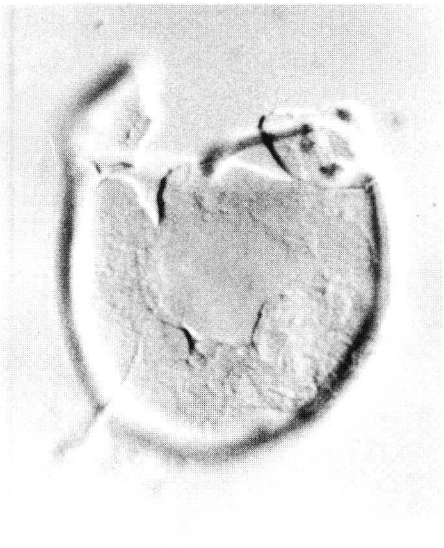
4



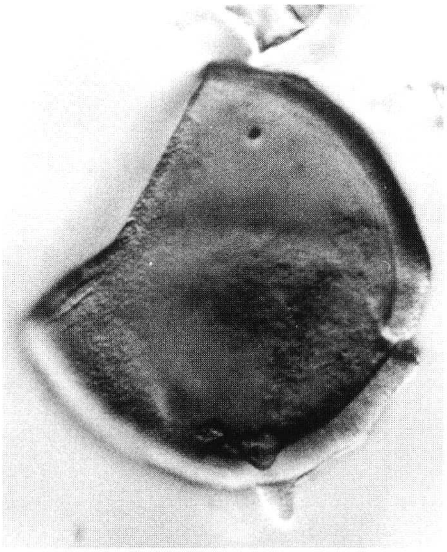
5



6



7



8

9

Plate 2

1
Carpatella*? sp., CURF07B, 1, 437982, 400x, precingular archeopyle*

2
Cordosphaeridium fibrospinosum, *RGD03, 2, 3901073, 250x, mid*

3
Cribroperidinium wetzelii, *RGD15, 1, 4081082, 400x, mid*

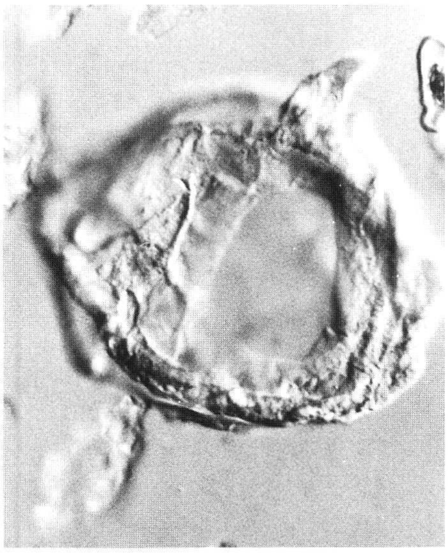
4
Cribroperidinium *sp. A in Brinkhuis & Schiøler, 1996, RGD15, 1, 443977, 400x, mid*

5
Cyclapophysis monmouthensis, *CURF03, 2, 379939, 250x, mid*

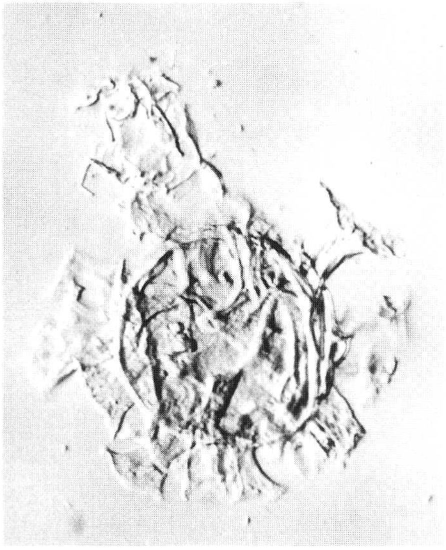
6-7
Cyclapophysis *cf.* monmouthensis, *RGD17, 1, 3821036, 250x, high-low*

8
Damassadinium californicum, *CURF10, 1, 3851080, 250x, high*

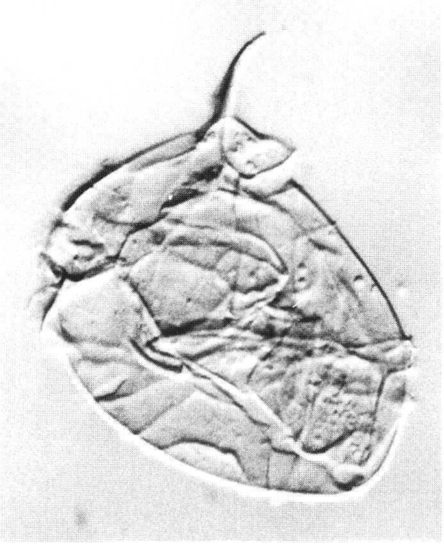
9
Damassadinium californicum, *CURF10, 3, 400997, 250x, high*



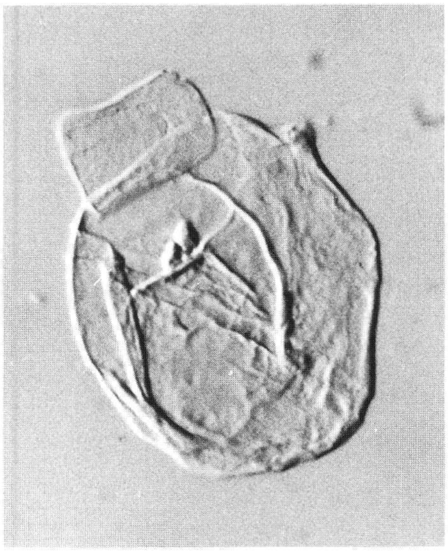
1



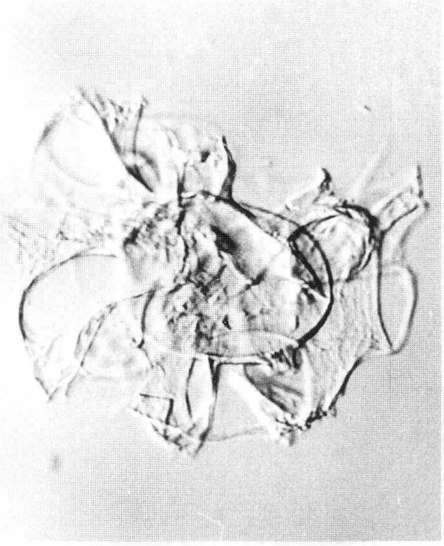
2



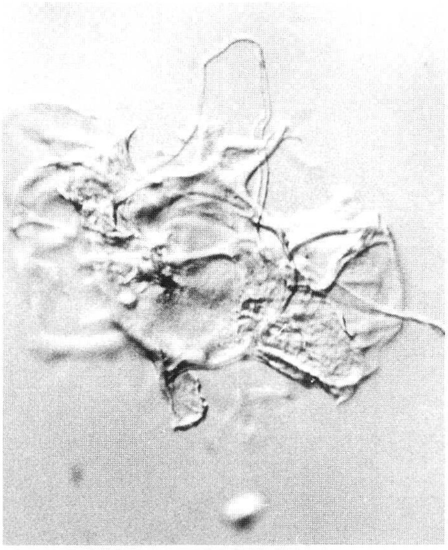
3



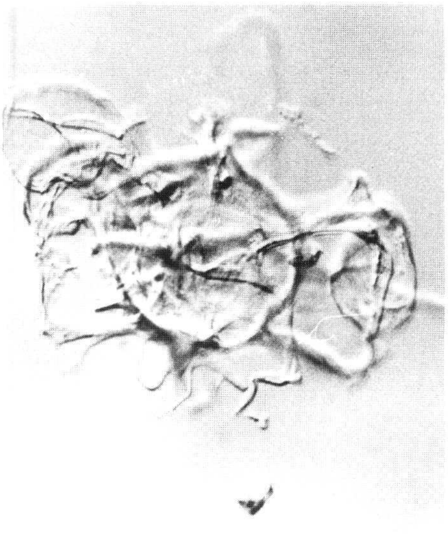
4



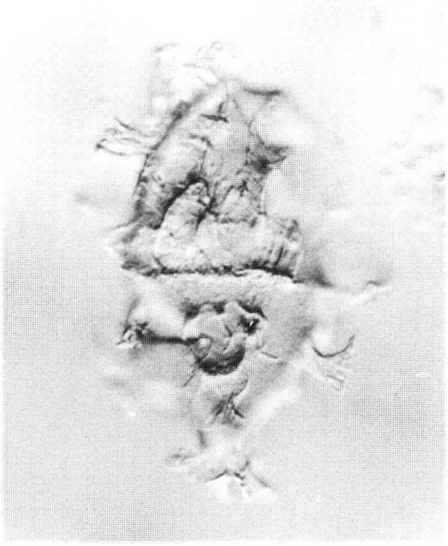
5



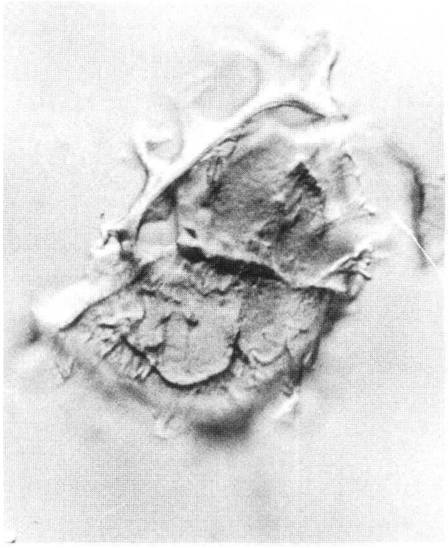
6



7



8



9

Plate 3

1
Damassadinium californicum, *CURF10, 3, 400997, 250x, low*

2
Fibrocysta axialis, *CURF10, 1, 3601040, 250x, mid*

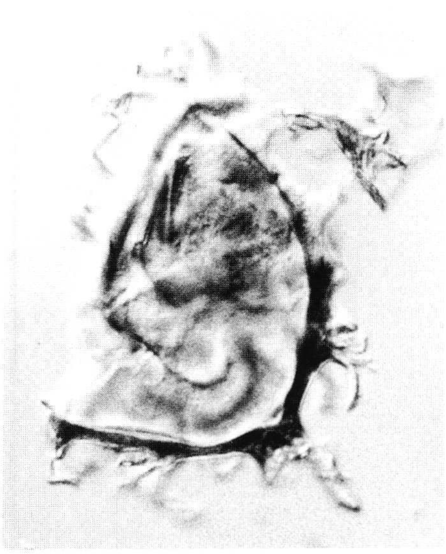
3
Glaphyrocysta perforata *and* Hystrichokolpoma bulbosa, *RGD03, 2, 3991038, 250x, mid*

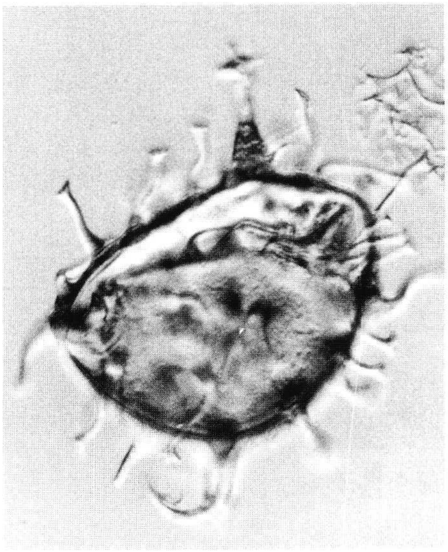
4
Hystrichosphaeridium tubiferum, *CURF03, 2, 3231005, 400x, low, dorsal view*

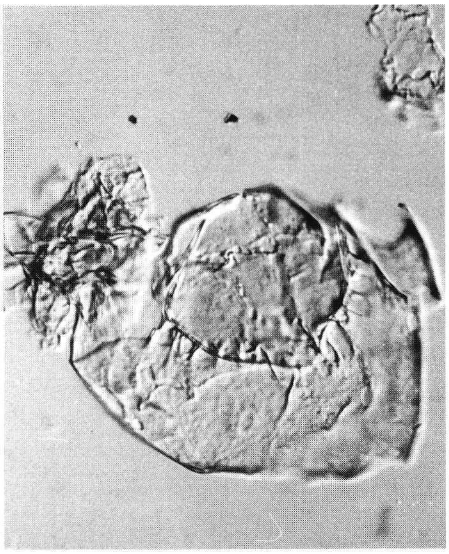
5-6
Lanternosphaeridium reinhardtii, *CURF10, 2, 362982, 250x, high-low*

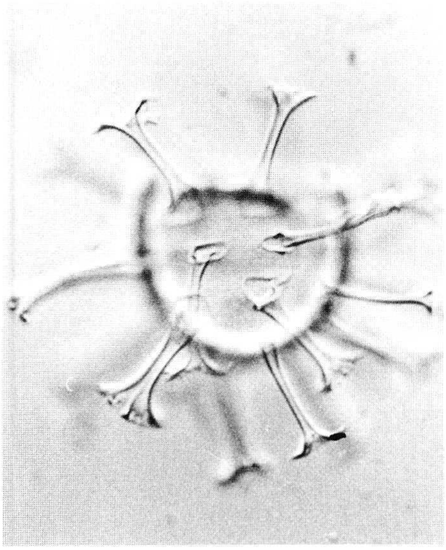
7
Northidinium perforatum *in Wilson, 1974 (=*'Neonorthidium perforatum' *Marheinecke 1992), CURF07A, 6, 285991, 400x, high*

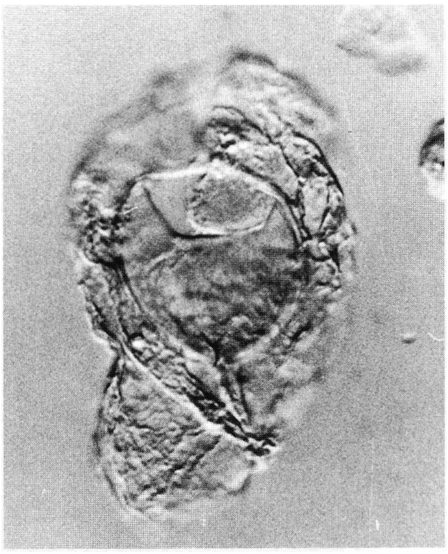
8-9
Palynodinium grallator, *RGD15, 1, 4191042, 400x, high-low*

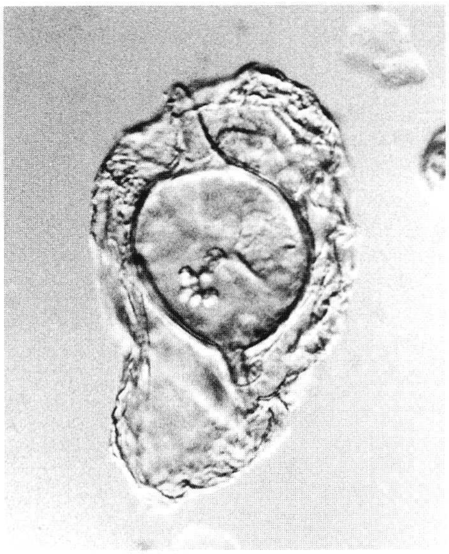

1


2

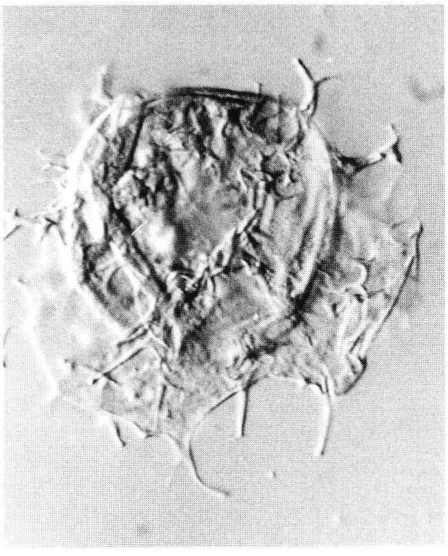

3


4


5


6


7


8

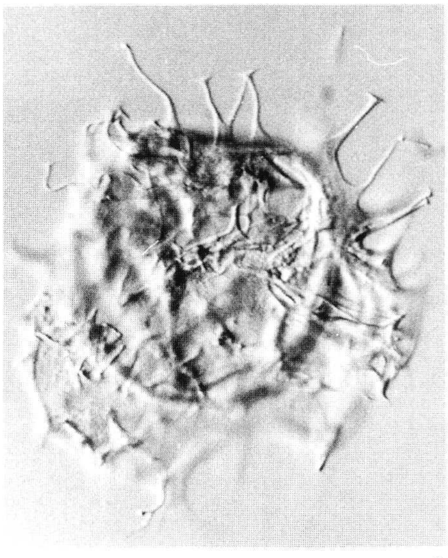

9

Plate 4

1

Paralecaniella indentata, *CURF07A, 6, 4121088, 400x, mid*

2

Oligosphaeridium pulcherrimum, *RGD08, 1, 4231012, 400x, high*

3-4

Senoniasphaera inornata, *CURF08, 1, 441972, 400, high-low*

5

Spongodinium *sp., RGD05, 2, 3991078, 250x, mid*

6

Thalassiphora bononiensis, *CURF07B, 1, 4251061, 250x, mid*

7

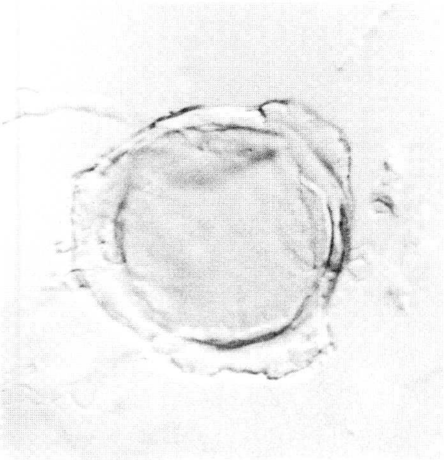
Thalassiphora pelagica *sensu Hansen 1977, CURF10, 1, 410965, 250x, mid*

8-9

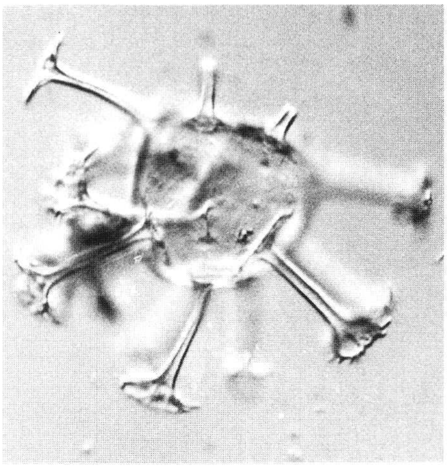
Dinocyst provisionally assigned to the Xenicodinium-Tectatodinium *plexus, CURF10, 6, 290988, 400x, optical section and archeopyle*

10

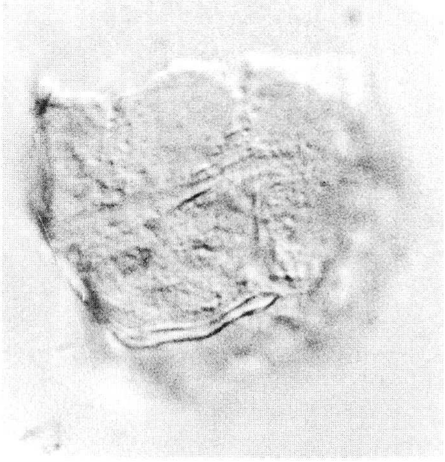
Cassiculosphaeridia*?* intermedia, *RGD05, 2, 3251041, 250x, mid*



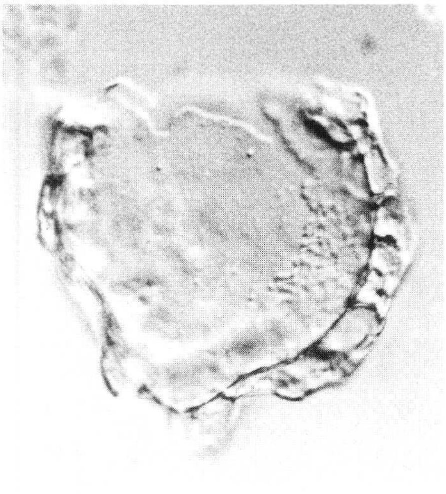
1



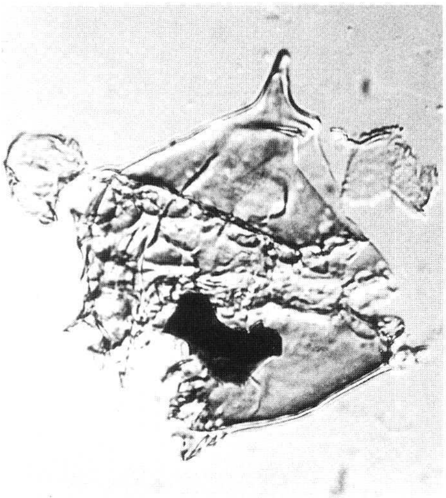
2



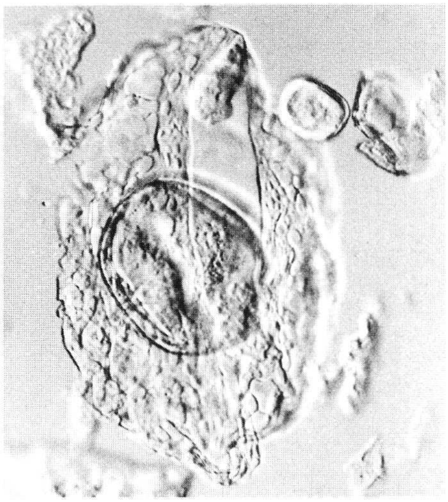
3



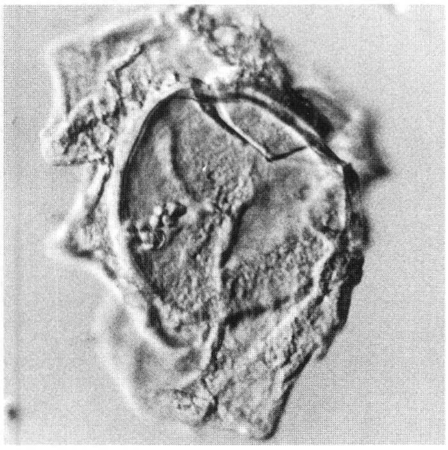
4



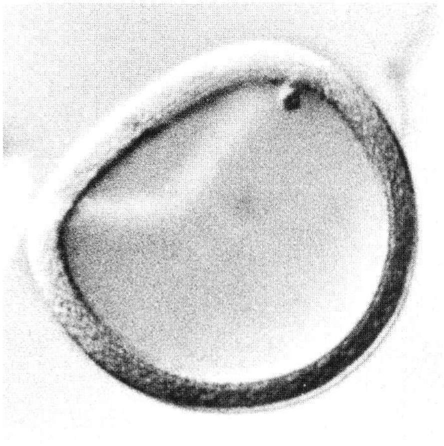
5



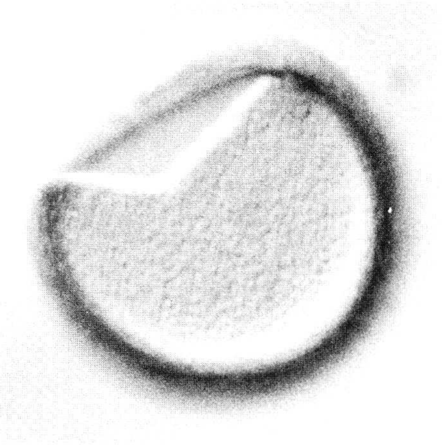
6



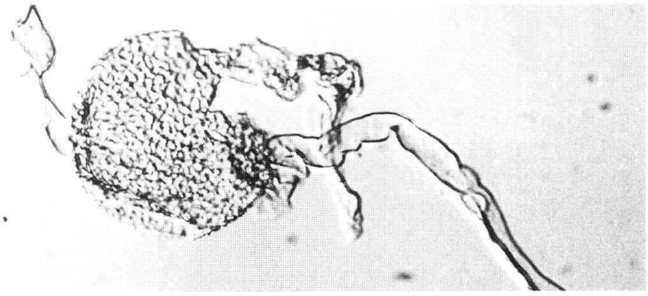
7



8



9



10

Plate 5

All foraminifers and ostracods as illustrated in plates 5 and 6 are mounted in a single slide, number FO-97-001. The numbers as listed after the species name and author indicate, respectively, sample number (see Fig. 5), cellule of the Plummer distribution slide and magnification.

1
Textularia faujasi *Reuss 1861; 2, 01, 70x*

2
Arenobulimina cuskleyae *Brotzen 1948; 11, 02, 70x*

3-4
Mississippina binkhorsti *(Reuss 1862); 2, 03, 70x; 2, 04, 70x*

5
Nummofallotia cretacea *(Schlumberger 1899); 10, 05, 70x*

6
Pararotalia tuberculifera *(Reuss 1862); 3, 06, 70x*

7
Reussella cimbrica *(Troelsen 1937); 11, 07, 140x*

8-9
Tremastegina roestae *(Visser 1950); 2, 08, 70x; 2, 09, 70x*

10
Gavelinella danica *(Brotzen 1940); 3, 10, 70x*

11
Bulimina stokesi *Cushman & Renz 1946; 10, 11, 140x*

12
Rotorbinella mariae *(van Bellen 1946); 1, 12, 70x*

13
Gavelinopsis bembix *(Marsson 1878); 11, 13, 70x*

14
Anomalinoides acuta *(Plummer 1926); 11, 14, 70x*

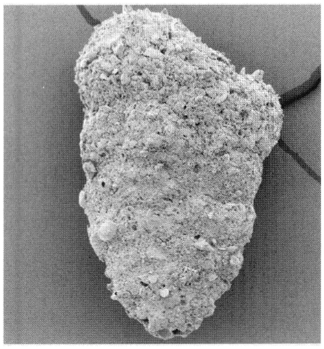
15
Tappanina selmensis *(Cushman 1933); 2, 15, 140x*

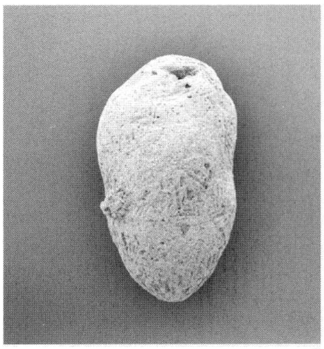
16
Bolivinoides australis *Edgell 1954; 11, 16, 140x*

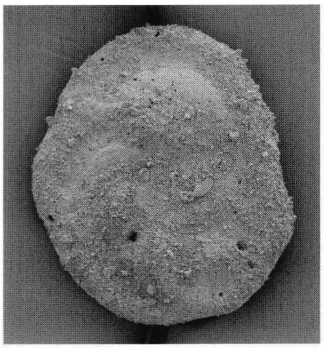
17
Cibicidoides alleni *(Plummer 1926); 11, 17, 70x*

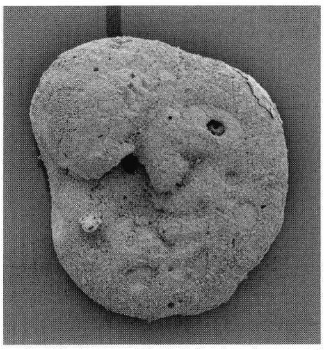
18
Nonionella troostae *(Visser 1950); 13, 18, 70x*

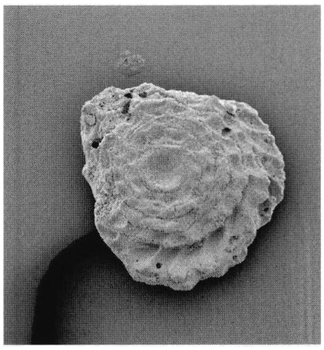
19
Cibicides mariae *(Jones 1852); 11, 19, 70x*

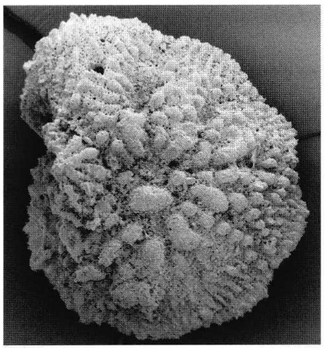

1

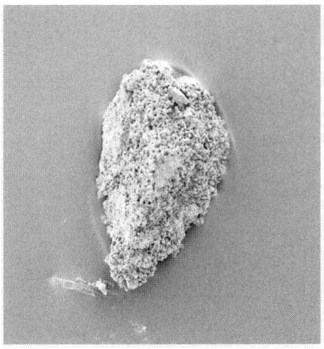

2

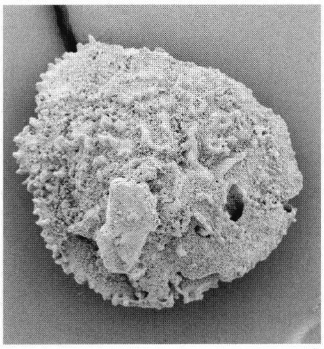

3

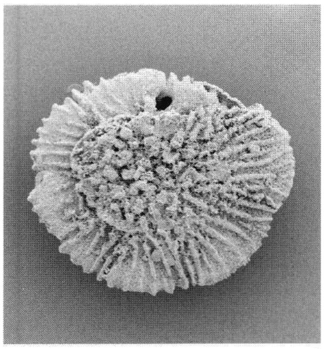

4

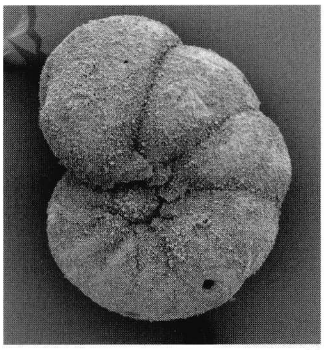

5

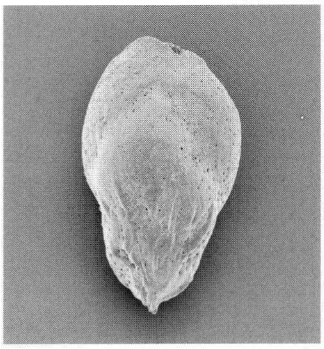

6

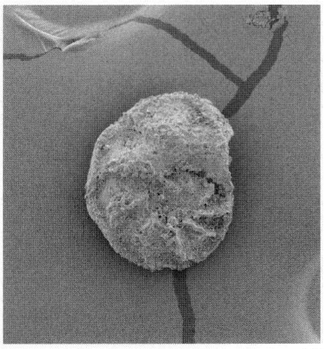

7

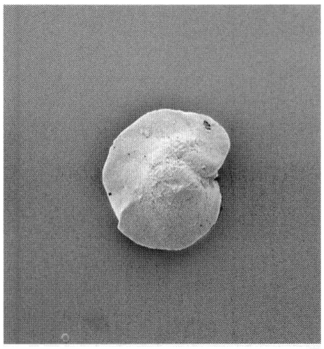

8

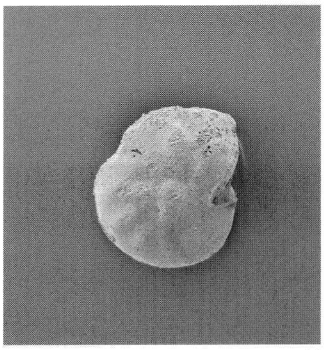

9

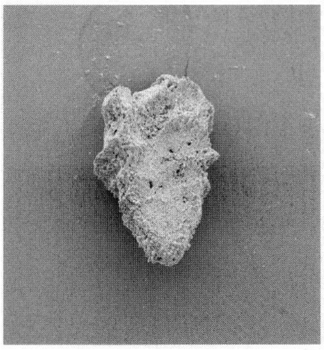

10

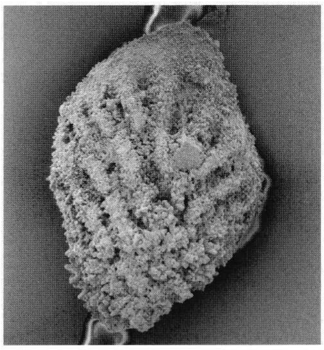

11

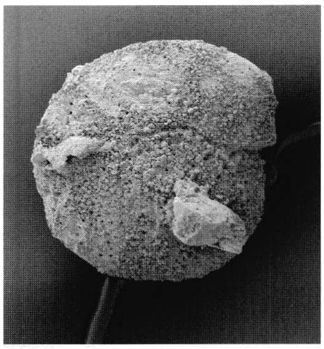

12

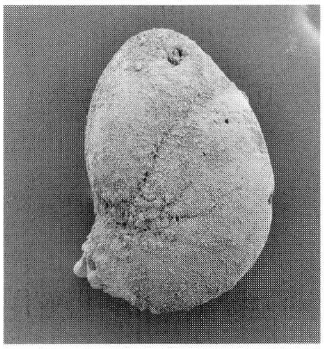

13


14


15


16


17


18

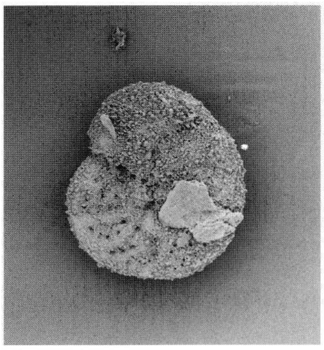

19

Plate 6

1
Allomorphina halli *Jennings 1936; 2, 20, 70x*

2
Rosalina brotzeni *Hofker 1961; 11, 21, 140x*

3
Guembelitria cretacea *Cushman 1933; 11, 22, 140x*

4
Daviesina ornamentata *Hofker 1962; 10, 23, 70x*

5
Rotalia perovalis *(Terquem 1882); 11, 24, 140x*

6
Ceratobulimina *sp.; 11, 25, 70x*

7
Daviesina fleuriausi *forma B (d'Orbigny 1826); 11, 26, 70x*

8
Dumontina stellata *Deroo 1966; 11, 27, 70x*

9
Spongicythere koninckiana *(Bosquet 1847); 2, 28, 70x*

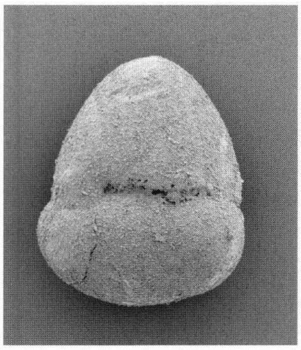
10
Limburgina ornata *(Bosquet 1847); 11, 29, 70x*

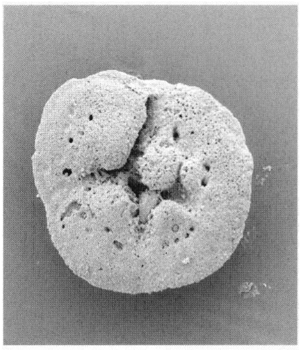
11
Semicytheretta elegans *(Bosquet 1847); 2, 30, 70x*

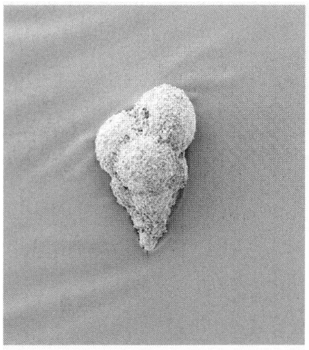
12
Tumidoleberis laevis *(van Veen 1935); 2, 31, 70x*

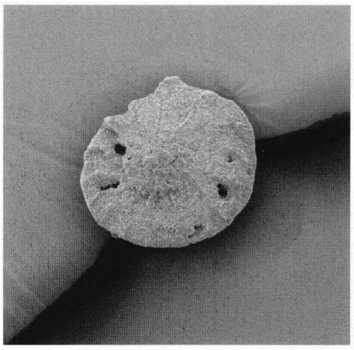
13
Spinoleberis eximioides *(van Veen 1936); 11, 32, 70x*

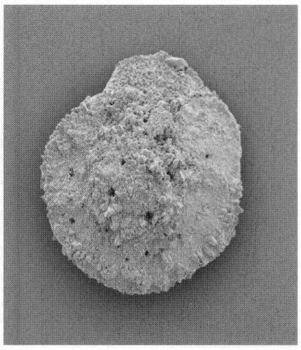
14
Oertliella binkhorsti *(van Veen 1936); 11, 33, 70x*

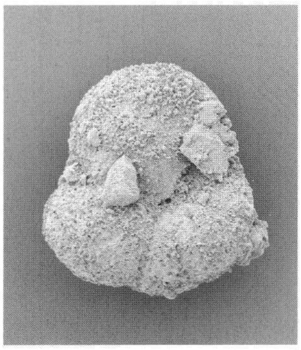

1

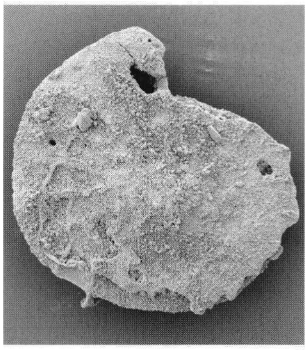

2

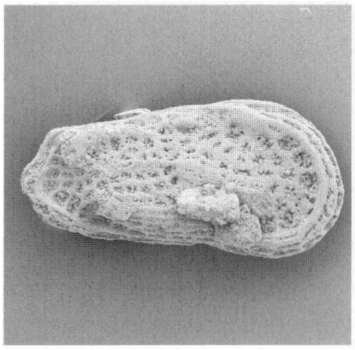

3

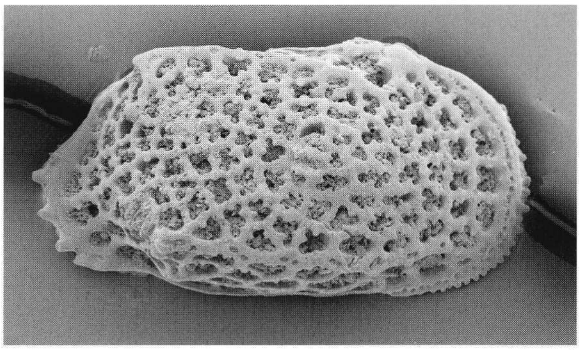

4

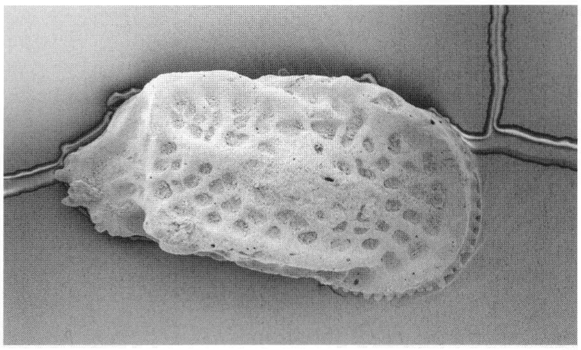

5

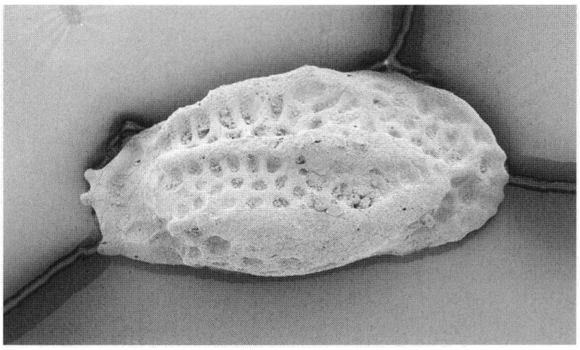

6

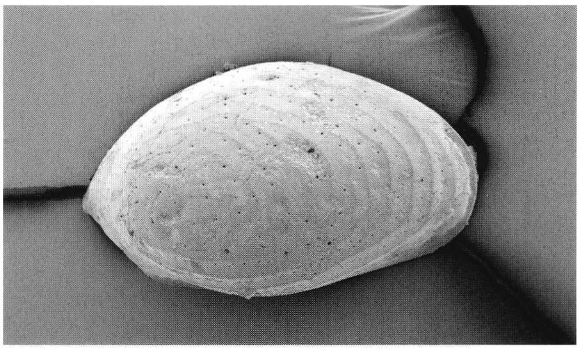

7

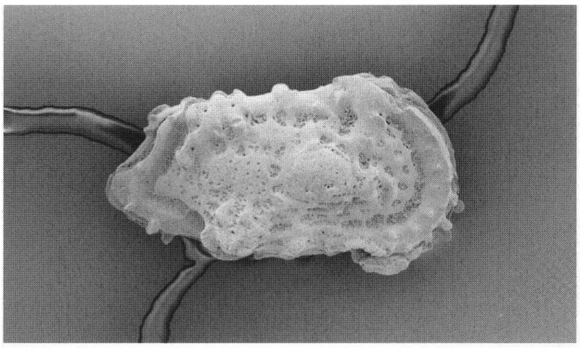

8

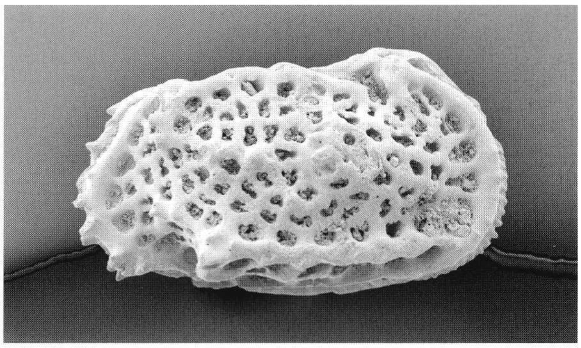

9


10


11


12


13


14

Instructions to authors

General remarks

Typewritten manuscripts should be submitted in triplicate to the Editor-in-Chief, Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen TNO , PO Box 157, 2000 AD Haarlem, The Netherlands.
Manuscripts should be typed on standard A4 (29.7 x 21 cm) paper, double-spaced with a widez margin on one side. All manuscripts should be accompanied by a 3.5" diskette (MS DOS system) containing the identical text in a current word-processing program, preferably WordPerfect or MSWord, labelled properly, indicating the operating system and software used.
Do not use justified alignment and turn off automatic hyphenation. Start numbering pages with the title page. Diacritical marks should be used in a consistent way. For words that have to be printed in italics, use the italic command. To indent paragraphs or separate columns in tables, use the TAB key (not the space bar).
Manuscripts should be in English. In special cases, German or French may be accepted after consultation with the Editor-in-Chief. Author(s) who submit a manuscript written in a language which is foreign to them are advised to have the text translated or edited by a sworn translator or skilled native speaker.
Metric (SI) units should be used throughout the manuscript. The author(s) should indicate in the margin of the manuscript where figures and tables are to be inserted. Please refer to recent issues of the Mededelingen to copy the journal's standard structural hierarchy.

Manuscript order

The order of the various parts of the manuscript should be:

- Title page (see below)
- Introduction
- Main text
- Acknowledgements
- References
- Appendix(es) (if any)
- Explanations to plates
- Captions of illustrations

The title page should comprise:

- Informative but concise title of paper
- Name(s) of author(s)
- Affiliation(s) and professional address(es) of author(s)
- Date of submission
- Key words (up to 8 key words may be listed)
- Abstract in English, not exceeding 200 words. If additional abstracts in other languages are required, they will be moved to the next page.

Illustrations

Illustrations include line drawings, photographs and tables. These should be referred to as Figures (written Figure, not abbreviated and with capital F), and numbered in order of appearance. Lettering in illustrations should be distinct, preferably in Universe font. The legends to the figures must be explanatory in a single step. The captions of all illustrations should be listed on a separate page at the end of the manuscript.
All line drawings should be submitted digitally, preferably made in CoralDraw (for MS-DOS) or Adobe Illustrator (for MS-DOS or Apple Macintosh). Different programs may occasionally be acceptable after consultation with the Editor-in-Chief.
Photographs should be of good, contrast-rich quality, printed on glossy paper. Illustrations must conform with the journal's page format, the maximum height of a full-page illustration being 250 mm and width 184 mm. Make sure to leave sufficient space for the relevant caption. Widths of 70 and 146 mm are also acceptable.
Several related drawings or photographs may be grouped into a composite figure on one page (216 x 184 mm). The parts of such composites may be numbered separately, e.g. Figure 1.1, Figure 1.2. If placed at the end of the paper, composite illustrations may be called Plates.
Tables should be submitted on separate sheets. Avoid large tables, fly-outs can only be accepted in exceptional cases. Large amounts of data should preferably be grouped in several tables. The number of auxiliary horizontal and/or vertical ruled lines should be kept to a minimum.

Italics

Use italic characters for genus and species names only. For other latin words, for example: et al., e.g., ibid., sensu, etc., use normal characters. A consistent use of italic characters for headings or paragraphs is acceptable.

Abbreviations

Do not type full stops between the capital letters of an abbreviation, e.g. RGD (Rijks Geologische Dienst), AAPG (American Association of Petroleum Geologists), BP (before present). An abbreviation should not be followed by a full stop if the last letter of the abbreviation is the same as the last latter of the entire word, e.g. dr (doctor) and eds (editors), but ed. (editor).

Equations

Equations should form part of the typed text, leaving ample space around it. Subscripts and superscripts should be distinguished clearly. Special care should be taken to show the difference between the number zero (0) and the capital letter O, and between one (1) end the lower-case letter l. The meaning of all symbols should be given immediately following the equation in which these are used for the first time.
In general, equations should be numbered sequentially with the number in parentheses near the right margin. When referring to equations by number in the text, put the numbers in parentheses, e.g. 'as shown in equation (10)'.

Cross references

Try to avoid cross references to page numbers as the page number cannot be inserted until the final proof is available. If necessary, type: 'see page 000', and indicate the page number of that cross reference in pencil in the margin of your manuscript.

References

Literature citation within the text should be by author(s) and year of publication. In the List of References an alphabetical order is required (De Groot under D, Van Amerom under V, etc.). The following reference style should be used:

- for references to papers in journals:
  Zagwijn, W.H., 1973: Pollenanalytic studies of Holsteinian and Saalian beds in the northern Netherlands. - Meded. Rijks Geol. Dienst, N.S. 24, p. 139-156.
  Names of journals should be abbreviated as is done in the journal itself or according to 'Documentation - International list of periodical title word abbreviations' (International Standard ISO 833). Do not quote the issue number, unless each issue of a volume is paginated individually.
- for references to articles in books:
  Bodenhausen, J.W.A. & Ott, W.F., 1981: Habitat of the Rijswijk oil province, onshore The Netherlands. - p. 301-309 in: Illing, L.V. & Hobson, G.D. (eds): Petroleum Geology of the Continental Shelf of NW Europe. - Heyden & Son, London.
- for references to books:
  Ziegler, P.A., 1989: Evolution of Laurussia, a study in Late Paleozoic tectonics. Kluwer Academic Publ., Dordrecht, 102 pp.

Proofs

Authors will receive one set of proofs (together with their manuscript). Errors should be marked clearly and proofs returned to the Editor-in-Chief. Major alterations in the text of proofs, other than printer's errors will not be accepted.

Offprints

Hundred (100) offprints of each paper are supplied to the (first) author free of charge. No additional copies can be ordered.

Issued November, 1998

ISSN 1388-3453

Netherlands Institute of Applied Geoscience TNO

- National Geological Survey