Geologie en Mijnbouw **75:** 107–118, 1996.

The Cretaceous/Tertiary boundary in the Maastrichtian type area (SE Netherlands, NE Belgium); a historical account

John W.M. Jagt[1], Werner M. Felder[2], Rudi W. Dortangs[3] & Jacques Severijns[4]
[1] *Natuurhistorisch Museum Maastricht, Postbus 882, 6200 AW Maastricht, the Netherlands;* [2] *Rijks Geologische Dienst, Geologisch Bureau, Postbus 126, 6400 AC Heerlen, the Netherlands; present address: Oude Trichterweg 26, 6294 AL Vijlen, the Netherlands;* [3] *Hoofdstraat 36, 6436 CG Amstenrade, the Netherlands;* [4] *Volderstraat 67, 6231 LB Meerssen, the Netherlands*

Key words: Danian, K/T boundary, southern Limburg

Abstract

In view of the renewed interest in the Cretaceous/Tertiary (K/T) boundary in the type area of the Maastrichtian Stage, a historical account is presented of the litho- and biostratigraphy of the strata below and above this boundary, as well as the position of the boundary itself. Localities exposing uppermost Maastrichtian and lowermost Palaeocene deposits are reviewed and for some of them, including the recently discovered Geulhemmerberg site, lithologic logs are provided.

Introduction

The position of the Cretaceous/Tertiary (K/T) boundary in the type area of the Maastrichtian Stage remains controversial, even at the present day. Recently, a presumably relatively complete K/T boundary section was discovered in the Geulhemmerberg caves. This section is reported on in extenso in other contributions to this issue (see Brinkhuis and Smit, this issue, for an introduction). In order to set the stage for the results coming from the Geulhemmerberg material, we present a brief historical account of the litho- and biostratigraphy of the strata associated with the K/T boundary in the area. A few mid-nineteenth century sources are quoted in detail since they are not easily accessible.

The history of the K/T boundary in the Maastrichtian type area

Nineteenth century

One of the earliest detailed records of latest Maastrichtian and possibly earliest Palaeocene deposits in the Valkenburg–Geulhem area (i.e. the Maastrichtian type area) is by Binkhorst van den Binkhorst (1859: 29–31), who presented the following description of his 'Coupe de Heunsberg près de Fauquemont' (in descending order);

> '. . . e. Craie tuffeau, friable, sablonneuse avec quelques rares fossiles de la couche qu'elle couvre. Epaisseur $1^1/_2$ mètres.
> f. Une couche très-riche en fossiles qui traverse un peu irrégulièrement l'assise supérieure et a 60 centimètres d'épaisseur. Nous y avons recueilli:
> *Hemiaster prunella*, d'Orb, en grand nombre.
> *Cassidulus lapis cancri*, Lam.
> *Cassidulus marmini* très rare, Desm.
> *Cidaris regalis*, Goldf.
> *Cidaris Faujasii*, Desor.
> *Asterias quinqueloba*, Goldf.
> *Belemnitella mucronata*, d'Orb.
> *Exogyra conica*, Sow.
> *Exogyro auricularis*, Goldf.
> *Exogyro decussata*, Ed.
> *Natica (neritina) rugosa*, Goldf.
> *Lima semisulcata*, id. abondant
> *Pecten lævis*, Nilss.
> *Pecten arcuatus*, Defr.
> *Trochosmilia Faujasii*, Edw. et Hai.
> *Moltkia Isis*, Steenstr.
> *Rhyncholithus Buchii*, Mull.
> *Rhyncholithus Debeyi*, id.
>
> Cette couche est caractérisée principalement par le grand nombre d'exemplaires de *Hemiaster prunella*, par *Rhyncholithus Buchii, Rh. Debeyi*, etc.

g. Craie tuffeau $^1/_2$ à 1 mètre; cette couche au-dessus de la 1re couche de bryozoaires a, près de Geulhem, à la montagne St-Pierre derrière Slavante, une plus grande épaisseur; au Heunsberg elle devient fort dure. A Geulhem où elle a une puissance de plus de 12 mètres, à une demi-lieue de Fauquemont, aux bords de la Geul, nous avons trouvé dans cette couche beaucoup de fossiles à l'état de moules. Nous croyons que c'est elle que M. le professeur Hébert a désignée comme représentant la calcaire pisolitique de France.

Nous y avons receuilli l'ammonite que nous avons indiquée dans le catalogue comme se rapprochant d'*Ammonites pedernalis*, F. Roemer, mais qui est une espèce nouvelle, et probablement le dernier de ces céphalopodes.

Scaphites constrictus, d'Orb.
Baculites Faujasii, Lam.
toute une faune de gastéropodes non encore décrits
Cardita Goldfussii, Mull.
Perna, sp. très-abondant.
Natica (Neritina) rugosa d'Orb., très-abondant
Hemipneustes radiatus, Ag.
Hemiaster prunella. Desor. en très-grand nombre dans le tuffeau qui remplit les crevasses de cette couche endurcie. Dans une seule de 3 pouces de largeur, nous en avons trouvé jusqu'à 15 individus . . .'

A year later, Binkhorst (1960: 61, 62, 65; cf. Binkhorst, 1863) reported having discovered new interesting layers ('nouvelles couches intéressantes, par la faune spéciale que l'une d'elles enferme'), which he described as follows:

'. . . 5. Presque immédiatement sous le sable tertiaire, à Genchen (read: Geulhem), près Meerssen, où la craie supérieure est de plusieurs mètres plus puissante qu'à Saint-Pierre et Fauquemont, une première couche fossilifère la traverse; elle est formée de petites cailloux entremelés de débris de bryozoaires, fragments de *Cidaris Faujasi*, etc.

6. Trois mètres plus bas, une seconde couche fossilifère traverse d'une manière irregulière la craie jaune. Elle est épaisse de 3 à 4 pouces, et est facile à reconnaître par ses taches vertes de glauconie. Elle forme une agglomération de baguettes de *Cidaris Hardouini*, Desor, par milliers d'individus, de dents de Requin, *Corax, Lama* [sic], *Otodus virgulina, Notidanus*, et de petites dents de *Sphaerodus* rappelant l'espèce tertiaire *Sphaerodus parvus*, Ag. Tous ces fossiles, à peu exceptions près, ont beaucoup souffert par le transport. Elle contient aussi des bryozoaires, et une espèce d'*Isis* nouvelle pour notre craie . . .'

The underlying layer, 'couche 7', is reported to have yielded large numbers of typically latest Maastrichtian echinoids; it represents the uppermost part (unit IVf-7) of the Meerssen Member of the Maastricht Formation in the current nomenclature introduced by W.M. Felder (1975a, b; Table 1). Binkhorst's units 5 and 6 are now known as the Geulhem Member of the Houthem Formation (cf. W.M. Felder, 1975a, b). A comparable section for the Curfs-Ankerpoort quarry, usually referred to as Curfs quarry, at Geulhem was later described by W.M. Felder (1968, 1973).

Triger (1860: 106) reacted quite strongly to Binkhorst's (1860) claim of having discovered strata not previously recognised in the type Maastrichtian area, and explicitly stated that Binkhorst's 'couche 6',

'. . . n'est pas plus nouvelle que la première, puisque je l'ai signalé depuis un an à la Société géologique, comme terminant la série des dépôts crétacés des environs de Maestricht, n'attachant pas, du reste, à cette couche, une autre importance que celle d'être un fait de plus, entre mille, constatant la parfaite identité qui existe entre la craie supérieure de Maestricht et la craie de Ciply, où les mêmes radioles de *Cidaris* abondent à la partie supérieure . . .'

Triger thus appears to have been the first to correlate the Geulhem Member with the Tuffeau de Ciply of the Mons Basin (southern Belgium).

Ubaghs (1879: 89–92) described for the Geulhem section ('une des plus belles coupes de la partie supérieure du tuffeau de Maastricht', his 'Coupe de Geulhem') the following units:

'. . . c. Craie tuffeau, immédiatement sous le sable tertiaire, laquelle, principalement là où elle est en contact avec le sable superposé, est à demi décomposée, et contient de l'oxyde de fer. Elle renferme ici des bancs durs et fendus, de 0,20 mètres, des concrétions de structure oolithique. Dans les couches plus dures se trouvent en grande partie des fossiles à l'état de moules et des empreintes creuses, comme *Cardita, Arca, Tellina, Nucula, Pectunculus, Venus, Pholadomya, Turritella, Rostellaria, Aporrhais Limburgensis*, etc. Le tuffeau entre les parties dures est friable et d'un blanc grisâtre; l'*Hémiaster prunella* s'y trouve en abondance. Puissance: 4 mètres.

d. Couche à *Cidaris Hardouini*, Desor. Celle-ci a une puissance de 10–15 centimètres, est friable, de structure oolithique et renferme beaucoup de concrétions calcaires; les aiguillons de *Cidaris Hardouini* (1) sont surtout en grande abondance dans cette mince couche; on en trouve par milliers. Ces aiguillons sont très rares dans la partie plus profonde du tuffeau. Nous y trouvâmes en outre des aiguillons de *Cidaris Faujasii, Pentatagonaster* [sic] *quinqueloba, Trochosmilia Faujasii, Molkia* [sic] *Isis, Crania Hagenowi, Mitella lithotryodes* Bosquet, et une quantité de dents de requins.

[(1) Cette couche fut d'abord découverte par le savant géologue français M. Triger, qui nous la fit observer dans une excursion que nous fîmes ensemble. Bullet. de la Soc. Géol. de France, II série, t. XVII. Séance du 5 déc. 1859, Lett. de M. Triger, rel. à une communication faite par M. Binkhorst sur la craie de Maastricht]

e. Puis viennent des tuffeaux alternant avec des bancs endurcis et fendillés et des concrétions lenticulaires; les parties dures contiennent une quantité de Conchylifères à l'état de moules, comme *Baculites Faujasii, Ammonites pedernalis* Roemer, *Scafites* [sic] *constrictus* d'Orbigny, *Cardita, Arca, Tellina, Fistulana* et une foule de Gastéropodes, parmi lesquels *Nerita Subrugosa* d'Orbigny, celles-ci seulement avec les tests conservés; dans les parties plus friables *Hemipneustes radiatus, Hemiaster prunella, Cassidulus Lapiscancri, Ostrea vesicularis* (petite variété). Puissance 12 mètres.

On a exploité cette partie autrefois, cependant elle ne fournit qu'une pierre de médiocre valeur, le tuffeau étant trop friable et trop entrecoupé de couches plus dures . . .'

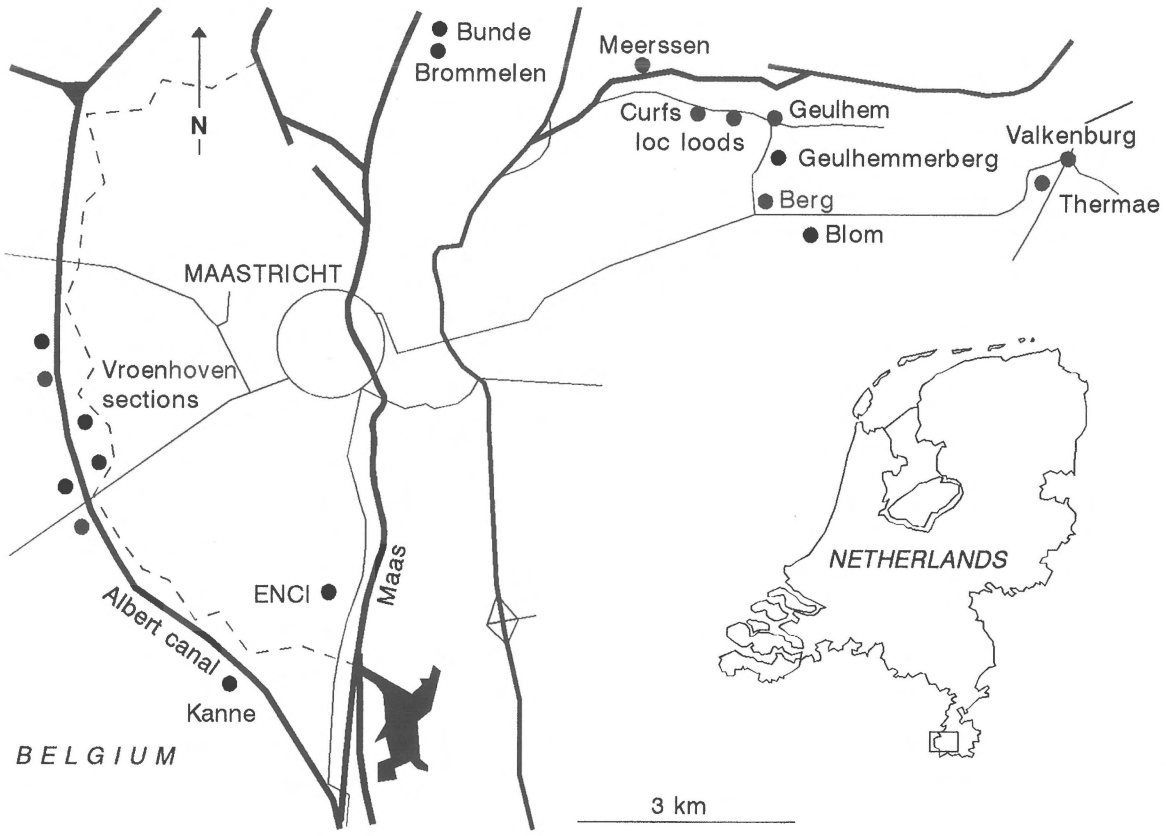

Figure 1. Location of sections (black dots) in the Maastrichtian type area mentioned in the text.

Ubaghs' unit 'd' clearly corresponds to the above-mentioned layer 6 of Binkhorst (1860). Ubaghs considered the entire Geulhem section to be of Maastrichtian, i.e. Cretaceous, age.

Uhlenbroek (1912) combined strata now referred to the Meerssen and Geulhem members in his 'Md', and considered them to be of Cretaceous age. The 'Md' comprised the entire section between the top of the underlying 'Mc' (= Nekum Member in current nomenclature) and the Oligocene sand cover. The K/T boundary was thus not considered at all.

1955–1975

Some 75 years later, Hofker (1955) discovered in the Curfs-Ankerpoort quarry near Geulhem a yet undescribed unit, characterised by a foraminiferal fauna distinct from that of the underlying Maastrichtian (Md sensu Uhlenbroek, 1912). He compared this unit with the Tuffeau de Ciply, thus following Triger (1860). The following year, Hofker (1956) recorded a number of additional localities from where this unit had then become known and referred to it as 'Onder-Paleoceen' (= Lower Palaeocene), and in 1957 he described from the eastern part of the Curfs quarry on top of the slightly indurated 'boven-Md' (= upper Meerssen Member, unit IVf-6 in current nomenclature) thin clayey films, often limonitic and brownish, often greyish, containing many abraded bioclasts. Above this he found a greyish friable glauconitic limestone (his 'Me', c. 2–3 m thick; unit IVf-7), capped by an indurated horizon yielding many Palaeocene molluscs. The strata above this horizon yielded a mixture of Palaeocene faunal elements and species known from the 'Me'. To explain lithologic differences occurring within the 'Post-Maastrichtian' or 'Me' as exposed in the eastern and western corners of the Curfs quarry, Hofker (1957) assumed the presence of a fault.

In a series of papers (1960a, b, 1962, 1966a) which culminated in his 1966(b) monograph, Hofker attempted to provide arguments in favour of a correlation of the type Maastrichtian with the type Danian. Berggren

Table 1. Lithostratigraphy of Upper Maastrichtian (Maastricht Formation) and Lower Palaeocene (Houthem Formation) strata in the type area of the Maastrichtian Stage (W.M. Felder, 1975b), showing Uhlenbroek's (1912) lithostratigraphic units and Hofker's (1966b) benthic foraminifera zones. The Berg en Terblijt Horizon, not shown, defines the boundary plane between units IVf-6 and IVf-7 of the Meerssen Member (Felder and Bosch, 1996). Hofker's (1957) 'Me' unit corresponds to unit IVf-7; it was introduced because Uhlenbroek (1912) lumped uppermost Maastrichtian and lowermost Danian strata together in his 'Md'.

		W.M. Felder 1975b	Uhlenbroek 1912	Hofker 1966
	Lutterade Horizon			
	Geleen Mbr	Vc		R
Houthem Fm	Bunde Mbr	Vb		Q
	Geulhem Mbr	Va		P
	Vroenhoven Horizon		Md	N
	Meerssen Mbr	IVf		M L
	Nekum Mbr	IVe	Mc	K
Maastricht Fm	Emael Member	IVd		I J
	Schiepersberg Mbr	IVc	Mb	
	Gronsveld Mbr	IVb		H
	Valkenburg Mbr	IVa	Ma	G
	Lichtenberg Horizon			

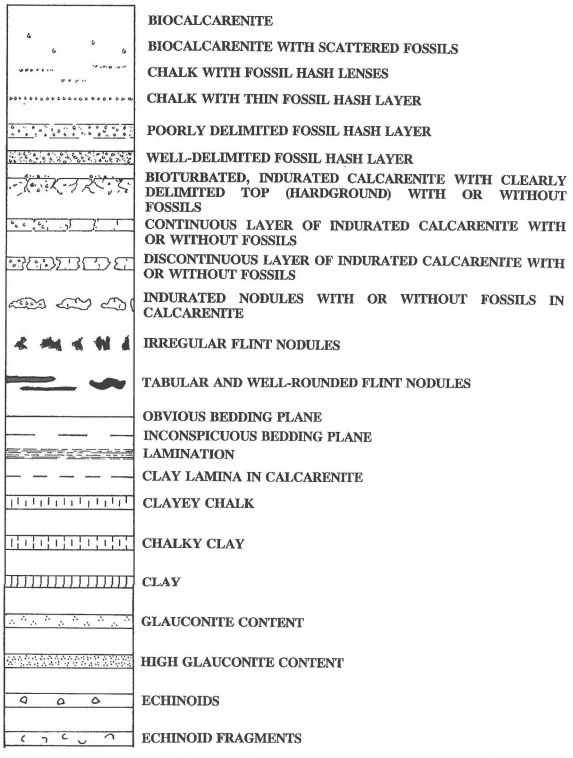

Figure 2. Legend to the lithologic logs illustrated in Figures 3–9.

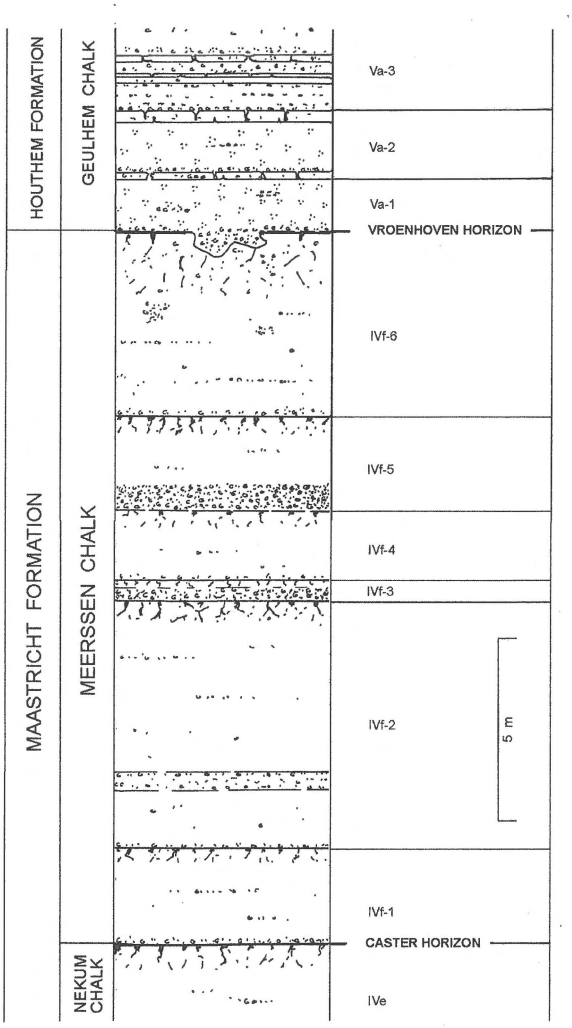

Figure 3. Section (exposures 61F-15 and -107) formerly exposed along the Albert Canal, between Kanne and Vroenhoven (Belgium). Approximate location and legend in Figures 1 and 2, respectively. Deroo's (1966) 'tuffeau glauconieux' (= coarse-grained glauconitic calcarenite) corresponds to units Va-1 to Va-3 of the Geulhem Member.

(1964), however, showed that Hofker had misidentified the planktonic foraminifera from the type Maastrichtian on which he had based his Danian age assignment. He also showed that the Maastrichtian and Danian stages were not time equivalent.

Meijer (1959, 1965) also refuted Hofker's identifications and demonstrated on the basis of planktonic foraminifera and echinoids that the entire unit between the Maastrichtian Md (= Meerssen Member sensu W.M. Felder, 1975b) and the Lower Oligocene sandy cover was of Danian age (cf. Kruytzer and

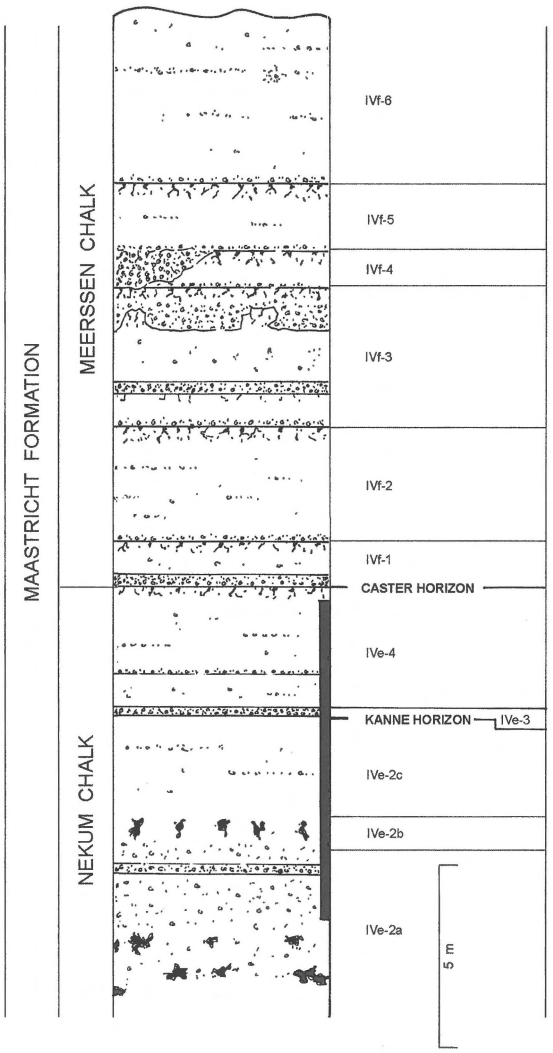

Figure 4. Section 61F-19 exposed at the quarry of the ENCI Nederland BV cement factory, Maastricht. Note that the upper part of the Meerssen Member and the Lower Palaeocene strata are eroded. Location and legend in Figures 1 and 2, respectively. The solid black bar to the right denotes the position of the underground galleries as exposed in the northern quarry face.

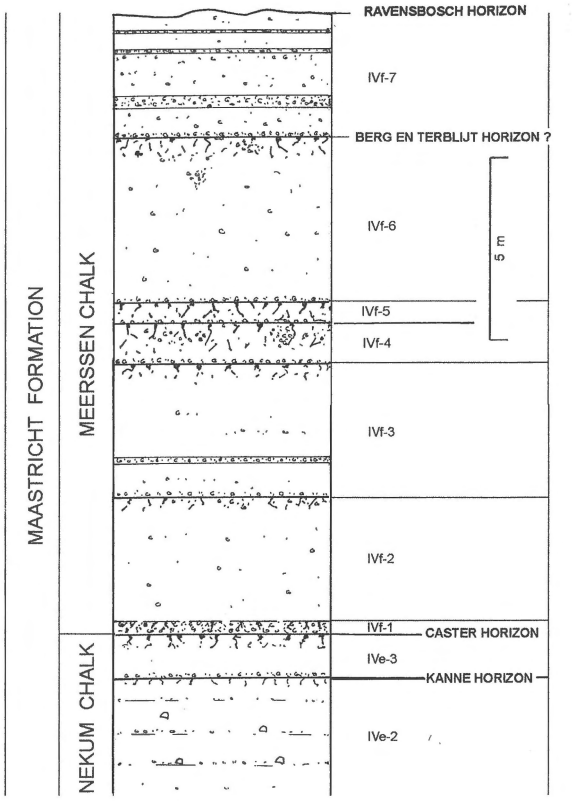

Figure 5. Section exposed at Blom quarry (62A-19), Berg en Terblijt. Location and legend in Figures 1 and 2, respectively. Units IVf-6 and IVf-7 and the Berg en Terblijt Horizon compare fairly well with correlative strata at the Curfs-Ankerpoort quarry. The Vroenhoven Horizon is missing; the Ravensbosch Horizon is the base of Oligocene sands.

Meijer, 1958). Meijer retained Hofker's Me unit and referred to Hofker's 'Lower Palaeocene' as 'Pa' (cf. Romein, 1963). During the same period, Rasmussen (1964, 1965) pointed out unmistakable faunal relationships between the Belgian Tuffeau de Ciply, the 'Post-Maastrichtian' of the Maastricht area and the Danish type Danian, referring in particular to echinoderm faunas (cf. W.M. Felder, 1963). Subsequent to Rasmussen's 1965 paper there appears to have been a general consensus as to the Early Palaeocene, Danian age of the 'Post-Maastrichtian'. Many publications, even of recent date, still refer to the 'Post-Maastrichtian' as Dano-Montian.

In a general stratigraphic overview of Cretaceous–Palaeocene deposits in the Maastricht area, Deroo (1966: 33) noted for the Albert Canal and Curfs-Ankerpoort sections a coarse-grained glauconitic limestone ('tuffeau glauconieux'). Both lithologically and palaeontologically, this unit, which corresponds to units Va-1 to Va-3 in Figure 3, was reported to be easily distinguished from the underlying Meerssen Member. Deroo made reference to Hofker's interpretation of the evolutionary stages of the planktonic foraminifera, and thus also accepted a late Danian age for the unit. On ostracod evidence, Deroo correlated the 'tuffeau glauconieux' with the Tuffeau de Ciply of the Mons Basin.

Vangerow and Schloemer (1967) analysed samples from Meijer's (1959) unit Pa, as exposed along the

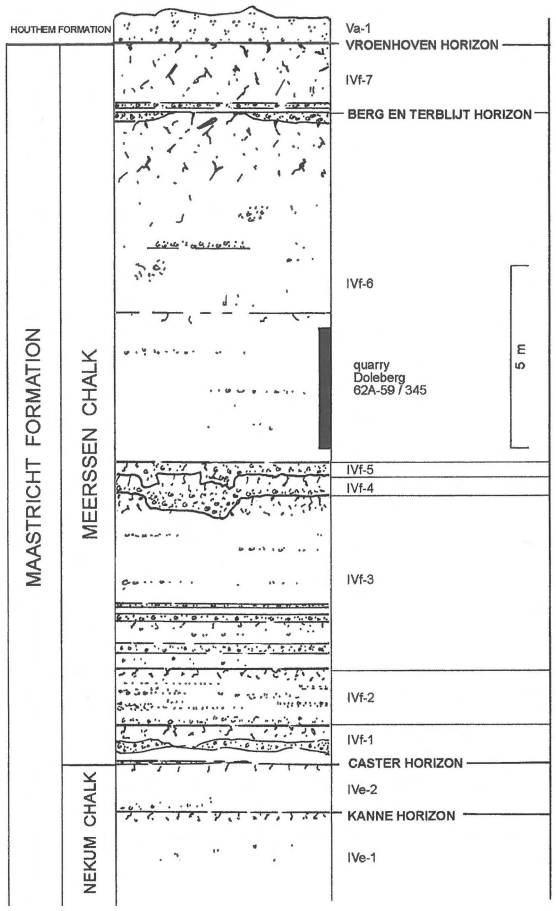

Figure 6. Section 62A-59 and 62A-345 exposed at the disused Doleberg quarry, just north of the entrance to the Curfs-Ankerpoort quarry tunnel. Location and legend in Figures 1 and 2, respectively. The solid black bar to the right denotes the position of underground galleries.

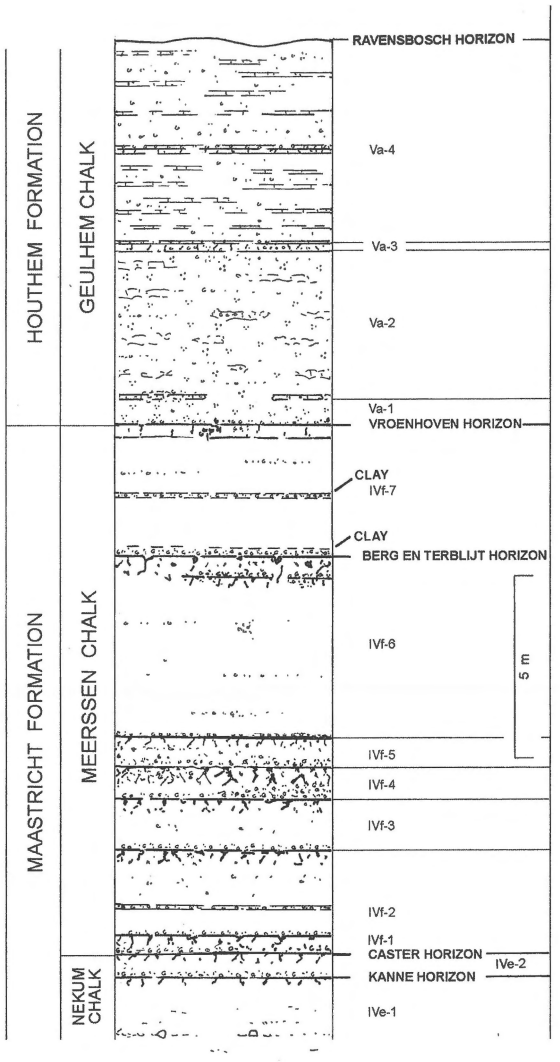

Figure 7. Section 62A-13 exposed at the Curfs-Ankerpoort quarry. Location and legend in Figures 1 and 2, respectively. The Ravensbosch Horizon is the base of Oligocene sands.

Albert Canal at Vroenhoven and at the Curfs quarry, and concluded on nannofossil evidence that this unit, their 'Houthem Kalk', might indeed be of Danian age.

Moorkens (1971: 850) described foraminifera from a cored borehole at Mechelen aan de Maas (Belgium, 18 km NW of Maastricht), noting a hiatus to occur '... above the "hardground"' which generally forms the top of the 'Tuffaceous Chalk of Maastricht' (= Vroenhoven Horizon). He also corroborated Berggren's (1964) re-identifications of Hofker's allegedly Danian planktonic forams from the type Maastrichtian.

1975–1994

It was not until 1975 that a formal lithostratigraphy became available for the type area of the Maastrichtian Stage. W.M. Felder (1975a, b; cf. Albers and Felder, 1979) assigned Hofker's and Meijer's units Me and Pa together to the Geulhem Member of the Houthem Formation. He called the lower boundary plane of this member the Vroenhoven Horizon. Felder subdivided the Houthem Formation into three members: Geulhem, Bunde and Geleen. The stratotypes of the Geulhem Member (the equivalent of Hofker's 1966b zone P) and the Bunde Member (equivalent of zone Q) were desig-

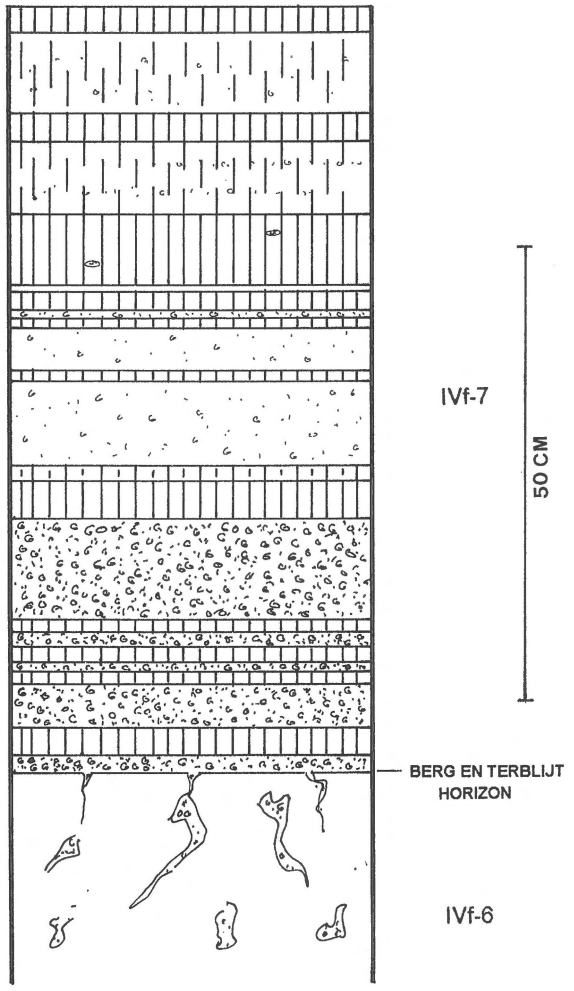

Figure 8. Composite section 62A-354 across the Berg en Terblijt Horizon exposed at points 110 to 119 in the Geulhemmerberg underground workings. Location and legend in Figures 1 and 2, respectively.

nated at Geulhem (Curfs-Ankerpoort quarry, exposure 62A-13) and in Borehole 61F-2 at Brommelen near Bunde (depth below surface 30–53 m, lower limit not reached), respectively. The stratotype of the Geleen Member, equivalent to Hofker's zone R, was designated in shaft 3 of the colliery Staatsmijn Maurits at Geleen (7.5 km NE of Bunde, borehole 60C-249), at 169.20–185.50 m depth below surface. W.M. Felder (1975b: fig. 2.3.3) mapped the areal extent of the Houthem Formation.

Villain (1977) presented a good summary of earlier contributions on the age of the Geulhem Member and provided regional and long-distance correlations between the type Maastrichtian and the Late Maastrichtian Kunrade facies in southern Limburg with strata exposed in the Mons Basin (cf. Robaszynski, 1979).

W.M. Felder et al. (1978) briefly discussed the section exposed at the Curfs-Ankerpoort quarry, indicating the thickness of the Geulhem Member there to vary between 5 and 8 m. In their fig. 4-3, unit IVf-7, which is capped by the Vroenhoven Horizon, i.e. the base of the Geulhem Member, is assigned to the Late Maastrichtian Meerssen Member (Maastricht Formation).

Albers et al. (1978) in their field guide briefly discussed the temporary exposures along the Albert Canal near Vroenhoven and referred to Meijer (1959) for a more detailed discussion, noting that former exposures were virtually all overgrown (cf. W.M. Felder, 1975a). The Vroenhoven Horizon was taken to mark the boundary between the Meerssen and Geulhem members, and thus to correspond to the K/T boundary.

On the basis of nannofossil and foraminiferal studies, Čepek and Moorkens (1979) concluded that the onset of Danian sedimentation in the Maastricht area did not start until the *Globigerina daubjergensis* Zone, and that sediments documenting the older *Globoconusa eugubina* Zone as recognised in the Danian type area are absent. They also suggested that their 'post *Nephrolithus frequens* interval' might be younger than the top of the Maastrichtian in the Stevns Klint section in Denmark.

For the Valkenburg–Meerssen area and the environs of Maastricht, W.M. Felder (1979, 1981) provided details as to the stratigraphy of sections exposed in underground workings, including those exposing Geulhem Member sediments. He assumed the Vroenhoven Horizon to correspond to the K/T boundary.

Bless et al. (1981) showed a thin cover of Geulhem Member sediments to occur above the Maastricht Formation in a few boreholes in the Maastricht area. Selected benthic foraminifera and echinoid spines are cited as characteristic faunal elements for this cover, which they considered to be Early Palaeocene (Danian) in age (equivalent of Hofker's 1966 zone P).

Moorkens (1982: 31) described the section along the Albert Canal near Vroenhoven, and followed earlier authors in considering the hardground at the top of the Maastrichtian (= Vroenhoven Horizon) to represent the K/T boundary. The top 3 m of the section he studied were referred to as 'Bunde Kalk' (= Bunde Limestone), and correlated with the 'Calcaire de Mons' on the basis of lithology and foraminiferal assemblages.

Doppert and Neele (1983: encl. 1) assigned the Houthem Formation to their benthic foraminifer zone

FK (*Pararotalia globigeriniformis–Rotalia saxorum* Zone; cf. Van Bellen, 1946). They referred to this zone as 'Paleocene, lower part: partly Montian and Danian', and designated a reference section at the Curfs-Ankerpoort quarry near 'Geulkens' [sic = Geulhem].

P.J. Felder (1984: 101) discussed Hofker's Me unit (= W.M. Felder's IVf-7) at the Curfs-Ankerpoort quarry and noted that, on the basis of bioclast content, it is impossible to determine whether or not this unit consists of reworked sediments, but that it should be included in the Meerssen Member. In his view, the Vroenhoven Horizon thus represented the K/T boundary.

P.J. Felder et al. (1985) distinguished a 'bioclast ecozone 7' for Houthem Formation sediments, representing Hofker's zones P, Q and R. They noted that the Houthem Formation shows similar lithologic features as the upper part of the Maastricht Formation, and that but few correlations are possible within the former, its limits, however, being very clear.

Verbeek (1986) studied part of the section exposed along the Albert Canal near Vroenhoven, analysed calcareous nannofossil assemblages and concluded that the sedimentary record indicates a hiatus of short duration at the Cretaceous/Tertiary boundary and a more extensive one within the Early Palaeocene part of the section. He assigned an early Danian age to the basal part, and a late Danian or early Thanetian age to the uppermost part of the Geulhem Member as exposed at Vroenhoven.

Unfortunately, the cored section between 26.10 and 60.50 m in Borehole Bunde 61F-312, north of Maastricht, described by Herngreen et al. (1986), was dated only by benthic foraminifera: Hofker's (1966b) benthic foraminifer zones P, Q and R were recognised, thus demonstrating the Palaeocene age of this interval.

In a detailed discussion of bryozoan faunas of the classic 'Dano-Montien' of Mons in southern Belgium, Voigt (1987) referred to localities in the Maastricht area. He noted that the higher part of the Geulhem Member as exposed at Vroenhoven bears a strong resemblance to the type Tuffeau de Ciply, which is of middle Danian age.

Krings et al. (1987) discussed the stratigraphy of the strata penetrated in the Thermae boreholes at Valkenburg. Deposits of the Houthem Formation were recovered from depths of 30.25–30.35 m in Thermae 2000 and of 31.5–33.5 m in Thermae 2001. The benthic foraminifera encountered were typical of Hofker's (1966b) zone P, of Danian age (cf. Bless et al., 1986).

P.J. Felder (1988) provided data on lithology, gamma radiation and bioclast content of Late Maastrichtian and Early Palaeocene deposits in southern Limburg, the Belgian Campine coal-mining district, and the Roer Valley Graben (cf. P.J. Felder and Boonen, 1988). He stressed that in southern Limburg bed-by-bed correlations are difficult because of the lenticular nature of the sediments (cf. Bless et al., 1987), and that there are no apparent changes in lithology, gamma radiation or bioclast content across the Vroenhoven Horizon (= K/T boundary in his interpretation) at the Curfs-Ankerpoort quarry. Correlations between the section at this quarry and boreholes in Belgium relied heavily on foraminifer zonal assignments.

Jagt and Collins (1988) and Jagt and Janssen (1988) commented on earlier papers with regard to the biostratigraphy of the Geulhem Member and agreed with Rasmussen (1965) and Verbeek (1986) in correlating the lower part of this member with the lower part of the type Danian of Denmark and southern Sweden. The reader is referred to Jagt (this issue) for further details.

Van der Ham (1988) listed all echinoid species known from the Geulhem Member and noted that species occurring in the upper part of this member correspond closely to 'Montian' (i.e. Palaeocene) faunas of southern Belgium and the Paris Basin. He also indicated that the echinoid fauna of the member contains a considerable endemic element.

On the basis of the files of the Geological Survey of the Netherlands (Heerlen), Jagt (1990) made an inventory of all known occurrences of Houthem Formation sediments, which he considered to be of Danian (i.e. Early Palaeocene) age.

Bless et al. (1993) described Palaeocene and Late Maastrichtian carbonates penetrated in borehole Molenbeersel (NE Belgium) at depths between 1223 and 1283.17 m. Their units 5, 6 and 7 are assigned to the Geulhem, Bunde and Geleen members, respectively. Their proposed correlations with the Maastricht area rely mainly on ostracod and foraminiferal species.

Zijlstra (1994), following Albers and Felder's (1979) stratigraphic interpretation, discussed sedimentological aspects of the uppermost Cretaceous–lowermost Palaeocene carbonates in the Maastrichtian type area, summarising earlier data.

Current research

In the autumn of 1992 the section at the Curfs-Ankerpoort quarry (Figure 7) was sampled for dinoflagellate cyst and calcareous nannoplankton

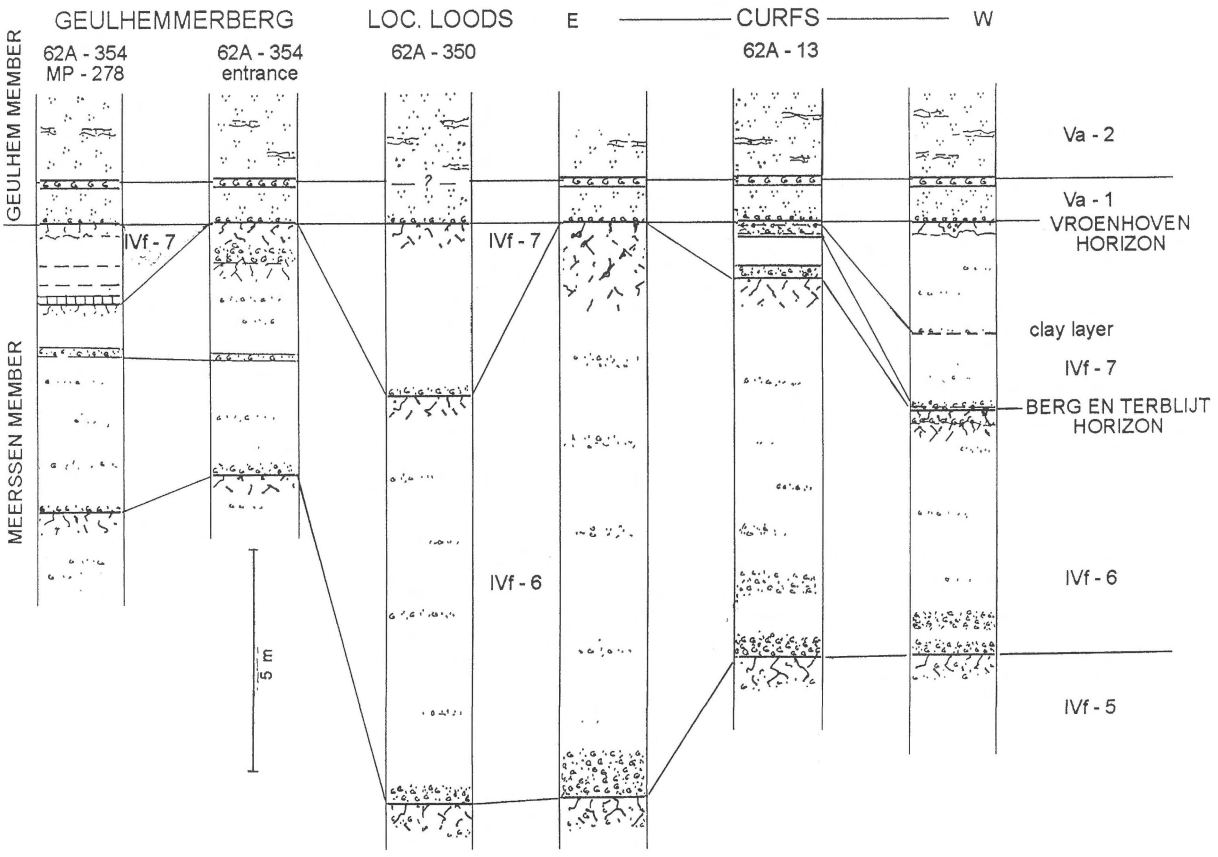

Figure 9. Correlation of Geulhemmerberg sections (62A-354, Figure 8, entrance and point MP 278), Locomotief loods section (62A-350), and of three sites within the Ankerpoort-Curfs quarry (62A-13; Figure 7). Location and legend in Figures 1 and 2, respectively. 62A-numbers refer to archives of the Rijks Geologische Dienst (Afd. Kartering).

analyses. At this occasion, the uppermost part of unit IVf-6 of the Meerssen Member was shown to yield comparatively numerous *in situ* ammonoids. The fossil hash forming the base of the overlying unit IVf-7 contains reworked, but comparatively well-preserved belemnites. It should be noted that belemnite guards collected from immediately above the Vroenhoven Horizon are much more heavily abraded and fragmentary. The hardground separating units IVf-6 and IVf-7 was labelled 'Berg en Terblijt Horizon' and formally defined in the Curfs-Ankerpoort quarry in a recent paper by W.M. Felder and Bosch (1996). At the base and in the middle part of unit IVf-7, thin clay films were noted, and these were tentatively correlated with the better developed clay layers in the underground Geulhemmerberg section studied in this issue. Similar to the results from the Geulhemmerberg (Brinkhuis and Schiøler, this issue), the dinoflagellate associations from the calcarenites and clays of unit IVf-7 from Curfs-Ankerpoort are reported to be Danian in nature (H. Brinkhuis, in preparation). Hence, these results indicate that the traditional interpretation of the Vroenhoven Horizon (sensu W.M. Felder, 1975a, b) as representing the K/T boundary must be revised. The K/T boundary in the area is in this issue equated with the aforementioned, recently established Berg en Terblijt Horizon (Brinkhuis and Smit, and Smit and Brinkhuis, this issue), marking the base of unit IVf-7. The various sections across the newly interpreted K/T boundary as exposed at the Geulhemmerberg are shown in a composite log in Figure 8, and correlated with nearby sections in Figure 9.

Further fieldwork of the present authors concentrated mainly on attempts to provide detailed correlations between the various occurrences of the Meerssen Member (ENCI, Blom, Geulhem-Doleberg and Curfs-

Ankerpoort quarries, Figures 4–7). The first appearance datum (FAD) of the coleoid cephalopod *Belemnella (Neobelemnella) casimirovensis* (cf. Jagt, 1993, this issue) was determined and used as a datum line for biostratigraphic correlation between the various sections.

Conclusions

The historical account presented above makes clear that age assignments for the uppermost part of the Maastrichtian and for the overlying Palaeocene, and the positioning of the K/T boundary have varied considerably. In addition, resolution was comparatively poor until recently. However, the results of most recent studies, including those reported in the present issue, indicate that the K/T boundary may in fact be equated with the recently established 'Berg en Terblijt Horizon'. This horizon, and the overlying sediments (unit IVf-7) up to the Vroenhoven Horizon are, however, still regarded as part of the Maastricht Formation (W.M. Felder and Bosch, 1996).

Acknowledgements

We acknowledge the assistance of Wiel Miseré (Staatstoezicht op de Mijnen, Rijswijk/Heerlen), Peter W. Bosch (Rijks Geologische Dienst, Geologisch Bureau Heerlen) and Frans Bergsteyn (Stichting De Rotswoning, Geulhem). This is contribution no. 960808 of the Netherlands Research School of Sedimentary Geology (NSG).

References

Albers, H.J. & W.M. Felder 1979 Litho-, Biostratigraphie und Palökologie der Oberkreide und des Alttertiärs (Präobersanton-Dan/Paläozän) von Aachen-Südlimburg (Niederlande, Deutschland, Belgien) – Int. Union Geol. Sci. Series A 6: 47–84

Albers, H.J., W.M. Felder, P.J. Felder, O.S. Kuyl, H.W.J. van Amerom, P.W. Bosch & J.P.M.T. Meessen 1978 Lithology and stratigraphy of Upper Cretaceous of the Belgium-Dutch borderland west of the river Meuse. Joint Annual Meeting, Paläont. Ges./Palaeont. Assoc., Maastricht 1978, Excursion C: 50–100

Berggren, W.A. 1964 The Maestrichtian, Danian and Montian Stages and the Cretaceous-Tertiary boundary – Stockh. Contr. Geol. 11: 103–176

Binkhorst van den Binkhorst, J.T. 1859 Esquisse géologique et paléontologique des couches crétacées du Limbourg, et plus spécialement de la craie tuffeau, avec carte géologique, coupes, plan horizontal des carrières de St.-Pierre, etc. Van Osch-America et Cie, Maastricht, xviii + 268 pp

Binkhorst van den Binkhorst, J.T. 1860 Sur la craie de Maestricht et sur les fossiles de cette localité – Bull. Soc. Géol. France (2) 17: 61–66

Binkhorst van den Binkhorst, J.T. 1863 Course à Geulhem et à Fauquemont, le 2 septembre 1863 – Bull. Soc. Géol. France (2) 20: 804–811

Bless, M.J.M., P. Boonen, J. Bouckaert et al. 1981 Preliminary report on Lower Tertiary-Upper Cretaceous and Dinantian-Famennian rocks in the boreholes Heugem-1/1a and Kastanjelaan-2 (Maastricht, The Netherlands) – Meded. Rijks Geol. Dienst 33: 333–415

Bless, M.J.M., J. Bouckaert, P.J. Felder, H.R. Langguth & J.P.M.T. Meessen 1986 Gesteenten, fossielen en water van de proefboring Thermae 2000 te Valkenburg aan de Geul. Valkdruk, Valkenburg: 40 pp

Bless, M.J.M., M. Dusar, P.J. Felder & R. Swennen 1993 Lithology and biostratigraphy of Upper Cretaceous-Paleocene carbonates in the Molenbeersel borehole (NE Belgium) – Geol. Mijnbouw 71: 239–257

Bless, M.J.M., P.J. Felder & J.P.M.T. Meessen 1987 Late Cretaceous sea level rise and inversion: their influence on the depositional environment between Aachen and Antwerp – Ann. Soc. Géol. Belg. 109 (1986): 333–355

Brinkhuis, H. & P. Schiøler (this issue) Palynology of the Geulhemmerberg Cretaceous/Tertiary boundary section (Limburg, SE Netherlands)

Brinkhuis, H. & J. Smit (this issue) The Geulhemmerberg Cretaceous/Tertiary boundary section (Maastrichtian type area, SE Netherlands); an introduction

Čepek, P. & T. Moorkens 1979 Cretaceous/Tertiary boundary and Maastrichtian-Danian biostratigraphy (coccoliths and Foraminifera) in the Maastrichtian type area. In: W.K. Christensen & T. Birkelund (eds): Cretaceous-Tertiary Boundary Events Symposium, 2. Proceedings, University of Copenhagen, Copenhagen: 137–142

Deroo, G. 1966 Cytheracea (Ostracodes) du Maastrichtien de Maastricht (Pays-Bas) et des régions voisines: résultats stratigraphiques et paléontologiques de leur étude – Meded. Geol. Sticht. C(V)2(2): 1–197 + 1–42

Doppert, J.W.C. & N.G. Neele 1983 Biostratigraphy of marine Paleocene deposits in The Netherlands and adjacent areas – Meded. Rijks Geol. Dienst 37: 3–79

Felder, P.J. 1984 Mesofossielen-onderzoek in de groeve Curfs en de stratigrafische typering van de vindplaats van enkele Hadrosaurierbotten uit deze groeve – Natuurhist. Maandbl. 73: 99–104

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: 115–125

Felder, P.J. & L.G.M. Boonen 1988 Gamma-ray measurements of Upper Cretaceous to Pleistocene deposits in South Limburg (SE Netherlands) and northern Liège (NE Belgium). In: M. Streel & M.J.M. Bless (eds): The Chalk District of the Euregio Meuse-Rhine. Selected papers on Upper Cretaceous deposits, Natuurhist. Museum Maastricht/Laboratoire Paléontologie, Université Liège: 17–24

Felder, P.J., M.J.M. Bless, R. Demyttenaere, M. Dusar, J.P.M.T. Meessen & F. Robaszynski 1985 Upper Cretaceous to early Tertiary deposits (Santonian-Paleocene) in northeastern Belgium and South Limburg (The Netherlands) with reference to the Campanian-Maastrichtian – Belg. Geol. Dienst, Prof. Paper 1985/1 (214): 1–151

Felder, W.M. 1963 Krijtontsluitingen ten zuiden van Maastricht – Grondboor Hamer 17: 162–190

Felder, W.M. 1968 Sphenodiscus binckhorsti Boehm 1898 in het Krijt van Zuid-Limburg – Grondboor Hamer 22: 75–95

Felder, W.M. 1973 Kalksteengroeven in het Boven-Krijt van Zuid-Limburg. De groeve Curfs te Geulhem – Sprekende Bodem 17: 2–9

Felder, W.M. 1975a Lithostratigraphische Gliederung der Oberen Kreide in Süd-Limburg (Niederlande) und den Nachbargebieten. Erster Teil: Der Raum westlich der Maas, Typusgebiet des 'Maastricht' – Publ. Natuurhist. Gen. Limburg 24: 1–43

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

Felder, W.M. 1979 De stratigrafische plaats van de ondergrondse kalksteengroeven in het Boven-Krijt van Zuid-Limburg. 2 De groeven tussen Valkenburg en Meerssen – Natuurhist. Maandbl. 68: 42–45

Felder, W.M. 1981 De stratigrafische plaats van de ondergrondse kalksteengroeven in het Boven-Krijt van Zuid-Limburg. Deel 5: de groeven in en nabij de Cannerberg bij Maastricht – Natuurhist. Maandbl. 70: 56–59

Felder, W.M. & H.W. Bosch 1996 Afzettingen uit het Boven-Krijt en Danien in Zuid-Limburg en omgeving – Geologie van Nederland (Rijks Geol. Dienst, Haarlem) (in press)

Felder, W.M., P.J. Felder, O.S. Kuyl, H.W.J. van Amerom, P.W. Bosch & J.P.M.T. Meessen 1978 Lithology and stratigraphy of the Maastrichtian chalks in the type areal [sic] on both sides of the river Meuse. Joint Annual Meeting, Paläont. Ges./Palaeont. Assoc., Maastricht 1978, Excursion G: 65–94

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

Hofker, J. 1955 Ontdekking van een nog niet bekende geologische formatie in Zuid-Limburg – Natuurhist. Maandbl. 44: 78

Hofker, J. 1956 Het Onder-Paleoceen van Zuid-Limburg – Natuurhist. Maandbl. 45: 132–133

Hofker, J. 1957 Een nieuwe laag in het Bovenste Krijt van Zuid-Limburg – Natuurhist. Maandbl. 46: 121–123

Hofker, J. 1960a Le problème du Dano-Paléocène et le passage Crétacé-Tertiaire – Rev. Micropaléont. 3: 119–130

Hofker, J. 1960b The type localities of the Maestrichtian (Maestrichtian Chalk Tuff) and of the Montian (Tuffeau du Ciply, Calcaire de Mons, lagunar, and lacustre Montian) – J. Paleont. 34: 584–588

Hofker, J. 1962 Correlation of the Tuff Chalk of Maestricht (type Maestrichtian) with the Danske Kalk of Denmark (type Danian), the stratigraphic position of the type Montian, and the planktonic foraminiferal faunal break – J. Paleont. 36: 1051–1089

Hofker, J. 1966a La position stratigraphique du Maestrichtien-type – Rev. Micropaléont. 8: 258–264

Hofker, J. 1966b Maestrichtian, Danian and Paleocene Foraminifera – Palaeontographica, Suppl. A 10: 1–376

Jagt, J.W.M. 1990 Voorkomens van de Formatie van Houthem, en de Kalksteen van Geulhem in het bijzonder, op de kaartbladen 60C (Sittard), 61F (Maastricht) en 62A (Valkenburg) – Rijks Geol. Dienst, Afd. Kartering, Heerlen, unpubl. rept. OP 6965, 29 pp

Jagt, J.W.M. 1993 K/T boundary sections in the type area of the Maastrichtian Stage (The Netherlands, Belgium). In: Reg. Comm. Northern Palaeog. Stratigr. – Reg. Comm. Northern Neog. Stratigr., 4th Bi-annual Joint Meeting, 11–15th October 1993, Niedersächs. Landesamt Bodenforschung, Hannover: 29, 30

Jagt, J.W.M. (this issue) Late Maastrichtian and Early Palaeocene index macrofossils in the Maastrichtian type area (SE Netherlands, NE Belgium)

Jagt, J.W.M. & J.S.H. Collins 1988 The biostratigraphy of the Geulhem Member (Early Palaeocene), with reference to the occurrence of *Pycnolepas bruennichi* Withers, 1914 (Crustacea, Cirripedia) – Meded. Werkgr. Tert. Kwart. Geol. 25: 175–196

Jagt, J.W.M. & A.W. Janssen 1988 The Danian in the Maastrichtian type area (SE Netherlands, NE Belgium): past, present and future research – Meded. Werkgr. Tert. Kwart. Geol. 25: 213–223

Krings, S., M.J.M. Bless, R. Conil, P.J. Felder & J.P.M.T. Meessen 1987 Stratigraphic interpretation of the Thermae boreholes (Valkenburg a/d Geul, The Netherlands) – Ann. Soc. Géol Belg. 110: 9–38

Kruytzer, E.M. & M. Meijer 1958 On the occurence [sic] of Crania brattenburgica (v. Schlotheim 1820) in the region of Maastricht (Netherlands) (Brachiopoda, Inarticulata) – Natuurhist. Maandbl. 47: 135–141

Meijer, M. 1959 Sur la limite supérieure de l'étage Maastrichtien dans la région-type – Bull. Acad. Roy. Belg. Sci. 5 (45): 316–338

Meijer, M. 1965 The stratigraphical distribution of echinoids in the Chalk and Tuffaceous Chalk in the neighbourhood of Maastricht (Netherlands) – Meded. Geol. Sticht., n.s. 17: 21–25

Moorkens, T.L. 1971 Some Late Cretaceous and Early Tertiary planktonic foraminifera from the Maastrichtian type area. In: A. Farinacci (ed.): Proc. 2nd Plankt. Conf. Roma 1970, Tecnoscienza, Roma: 847–877

Moorkens, T.L. 1982 Foraminifera of the Montian stratotype and of subjacent strata in the 'Mons Well 1969' with a review of Belgian Paleocene Stratigraphy. In: R. Marlière (ed.): Etudes sur le Stratotype du Montien à Mons réalisées sous la direction de René Marlière Professeur à la Faculté Polytechnique de Mons – Mém. Expl. Cartes Géol. Min. Belg. 17: 1–186

Rasmussen, H.W. 1964 Les affinités du Tuffeau de Ciply en Belgique et du Post-Maestrichtien 'Me' des Pays-Bas avec le Danien – Mém. Bur. Rech. Géol. Min. 28: 865–873

Rasmussen, H.W. 1965 The Danian affinities of the Tuffeau de Ciply in Belgium and the 'Post-Maastrichtian' in The Netherlands – Meded. Geol. Sticht., n.s. 17: 33–40

Robaszynski, F. 1979 Paléocène et Eocène inférieur de la région de Mons et du Nord de la France: arguments actuels de corrélations – Bull. Soc. Belge Géol. 87: 239–247

Romein, B.J. 1963 Present knowledge of the stratigraphy of the Upper Cretaceous (Campanian-Maastrichtian) and Lower Tertiary (Danian-Montian) calcareous sediments in southern Limburg – Verh. Kon. Ned. Geol.-Mijnb. Gen., Geol. Ser. 21: 93–104

Smit, J. & H. Brinkhuis (this issue) The Geulhemmerberg Cretaceous/Tertiary boundary section (Maastrichtian type area, SE Netherlands); summary of results and a scenario of events

Triger, J. 1860 Une lettre rélative à une communication faite dans la séance précédente par M. Binkhorst, sur la craie de Maestricht – Bull. Soc. Géol. France (2) 17: 103–107

Ubaghs, C. 1879 Description géologique et paléontologique du sol de Limbourg, avec catalogue général des fossiles du terrain crétacé, coupe de la superposition des couches, et description de quelques grands vertébrés de la craie supérieure de Maastricht. Romen & Fils, Roermond, 275 + ii pp

Uhlenbroek, G.D. 1912 Het Krijt van Zuid-Limburg. Toelichting bij eene geologische kaart van het Krijtgebied van Zuid Limburg – Jaarversl. Rijksopsp. Delfst. 1911: 48–57

Van Bellen, R.C. 1946 Foraminifera from the Middle Eocene in the southern part of the Netherlands province of Limburg – Meded. Geol. Sticht. (C)5(4): 1–144

Van der Ham, R.W.J.M. 1988 Echinoids from the Early Palaeocene (Danian) of the Maastricht area (NE Belgium, SE Netherlands): Preliminary results – Meded. Werkgr. Tert. Kwart. Geol. 25: 127–161

Vangerow, E.F. & W. Schloemer 1967 Vergleich des 'Vetschauer-Kalkes' der Aachener Kreide mit dem Kreide-Profil von Süd-Limburg anhand von Coccolithen – Geol. Mijnbouw 46: 453–458

Verbeek, J.W. 1986 Calcareous nannoplankton at the Cretaceous-Tertiary boundary in the region near Maastricht in the Province of Limburg (The Netherlands) – Proc. Kon. Ned. Akad. Wet. B 89: 357–365

Villain, J.-M. 1977 Le Maastrichtien dans sa région type (Limbourg, Pays-Bas). Etude stratigraphique et micropaléontologique – Palaeontographica A157: 1–87

Voigt, E. 1987 Die Bryozoen des klassischen Dano Montiens von Mons (Belgien) - Mém. Expl. Cartes Géol. Min. Belg. 17: 1–161

Zijlstra, J.J.P. 1994 Sedimentology of the Late Cretaceous and Early Tertiary (tuffaceous) chalk of northwest Europe – Geol. Ultraiectina 119: 1–192