Meded. Werkgr. Tert. Kwart. Geol. | 25(2-3) | 175-196 | 2 figs, 1 pl. | Leiden, oktober 1988

THE BIOSTRATIGRAPHY OF THE GEULHEM MEMBER (EARLY PALAEOCENE), WITH REFERENCE TO THE OCCURRENCE OF *PYCNOLEPAS BRUENNICHI* WITHERS, 1914 (CRUSTACEA, CIRRIPEDIA)

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Jagt, J.W.M., & J.S.H. Collins. 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(2-3): 175-196, 2 figs, 1 pl. Leiden, October 1988.

Valves of the brachylepadomorph cirripede *Pycnolepas bruennichi* Withers, 1914 are reported from the Early Palaeocene of the environs of Maastricht (The Netherlands and NE Belgium). The occurrence of this distinctive species provides additional proof of a correlation of the Danish Danian with the Early Palaeocene in the Maastricht area. A discussion of the biostratigraphy of the Geulhem Member (Houthem Formation) from which the cirripede remains were collected is presented. It is concluded that *P. bruennichi* is restricted to strata of Early Palaeocene (Danian) age in Denmark as well as in the Maastrichtian type area (SE Netherlands, NE Belgium).

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Contents

SAMENVATTING

De biostratigrafie van de Geulhem Kalksteen (Vroeg Paleoceen) naar aanleiding van het voorkomen van *Pycnolepas bruennichi* Withers, 1914 (Crustacea, Cirripedia).

Geisoleerde platen van de eendemossel *Pycnolepas bruennichi* worden gemeld uit het onderste en bovenste deel van de Geulhem Kalksteen van de Houthem Formatie (Vroeg Paleoceen, Danien) zoals die ontsloten is in twee sleutelprofielen in de omgeving van Maastricht, te weten de voormalige groeve Curfs bij Geulhem (gemeente Valkenburg aan de Geul) en de secties die bij de verbreding van het Albertkanaal bij Vroenhoven-Riemst (Belgisch Limburg) toegankelijk waren. *P. bruennichi* is een soort die tot nog toe alleen uit het Midden Danien van Fakse, Sjaelland, Denemarken gemeld werd. Het optreden in het Vroeg Paleoceen van Maastricht en omgeving is een bijkomend argument om de Geulhem Kalksteen te correleren met het Danien uit het type gebied. In dit kader wordt hier ook een vrij uitvoerige discussie gepresenteerd over verschillende fossielgroepen die voor de biostratigrafie en correlaties over grotere afstanden van belang zijn. Deze fossielgroepen zijn de volgende: planktonische en benthonische foraminiferen, echinodermen, ostracoden, kalkschalig nannoplankton, dinoflagellaten/sporomorfen en enkele kleinere groepen (bryozoen, serpuliden). Geconcludeerd wordt dat voor een betrouwbare biostratigrafische indeling van de Geulhem Kalksteen, en zodoende van het Danien in de omgeving van Maastricht, uitgebreid èn gecombineerd onderzoek nodig is van alle bovengenoemde groepen in zoveel mogelijk profielen, die van te voren op lithologische en op andere gronden (bv. gamma ray logging) aan elkaar gekoppeld zijn.

INTRODUCTION

In 1839 Steenstrup described and figured a cirripede scutum, tergum and carina from the Danian Bryozoan Limestone of Fakse, Denmark, as *Pollicipes rigidus* J. de C. Sowerby, 1836. These elements were subsequently described by Darwin (1851) as a new species, *Pollicipes elegans*, but this name had already been used by Lesson (1830) for a Recent cirripede species. Maintaining Darwin's name, however, Brünnich Nielsen (1912) published additional information, although some of his figured specimens attributed to the species were later referred to *Calantica (Scillaelepas) dorsata* (Steenstrup, 1839) by Withers (1914, 1935).

When Withers (1914) came to include this species, to which he gave the name *brünnichi*, in his newly erected genus *Pycnolepas*, the original specimens studied by Steenstrup and Darwin could no longer be found and he 'reluctantly' selected as type a scutum (Withers, 1914, pl. 7, fig. 6) from a large number of elements recently collected by Brünnich Nielsen from the Bryozoan Limestone of Fakse. In 1935, Withers included *Pycnolepas* in his suborder Brachylepadomorpha (Withers, 1923) and thoroughly reviewed the description of *P. bruennichi.*

The species is now known from several new localities. It is considered opportune, therefore, to amend the occurrences of this species as they are known now.

The presence of this distinctive species of cirripede provides an opportunity to critically review the stratigraphy of the Geulhem Member of the Houthem Formation in the Maastrichtian type area, and a discussion of several groups of fossils of biostratigraphic value occurring with the cirripede is presented.

SYSTEMATIC DESCRIPTION

Ordo Thoracica Darwin, 1854
Subordo Brachylepadomorpha Withers, 1923
Familia Brachylepadidae Woodward, 1901
Genus *Pycnolepas* Withers, 1914

Type species—*Pollicipes rigidus* J. de C. Sowerby, 1836, by original designation.

Diagnosis—See Withers (1914, 1935) and Newman *et al.* (1969).

Pycnolepas bruennichi Withers, 1914
Plate 1

1839 *Pollicipes rigidus* J. de C. Sowerby.—Steenstrup, p. 404, pl. 5, figs 24-26 (non Sowerby).
1851 *Pollicipes elegans* Darwin, Darwin, p. 76, pl. 4, fig. 9 [non *Pollicipes elegans* Lesson, 1830 (Cirripedia)] (Partim, not the specimens from Ignaberga, Sweden = *Pycnolepas ignabergensis* Carlsson, 1953).
1912 *Pollicipes elegans* Darwin—Brünnich Nielsen, p. 32, pl. 1, figs 18-20; pl. 2, figs 1-8, 11, 12 [*non* pl. 2, figs 9, 10, 13-18 = *Calantica (Scillaelepas) dorsata* (Steenstrup, 1839)].
1914 *Pycnolepas brünnichi* Withers, p. 181, pl. 7, figs 5-9; pl. 8, fig. 6 (with synonymy).
1935 *Pycnolepas brünnichi* Withers—Withers, p. 47, 73, 359, pl. 47, figs 7-15 (with synonymy).
1953 *Pycnolepas brünnichi* Withers—Carlsson, p. 24.
1980 *Pycnolepas brunnichi* Withers—Collins, p. 21, 25.

Type—Withers (1914, pl. 7, fig. 6; 1935, pl. 47, fig. 8) designated a scutum from the Middle Danian Bryozoan Limestone of Fakse, Sjaelland, Denmark, as 'type specimen', which has to be considered the holotype. It is kept in the British Museum (Natural History), Department of Palaeontology, London, catalogue number I. 16.625.

Material studied—The material studied for this paper was collected at three localities in the Maastricht area (Fig. 1).

—34 scuta, 43 terga, 15 rostra/carinae, 1 imbricating plate and several fragments of valves from the western bank of the Albert Canal at Vroenhoven (municipality of Riemst, Belgian Limburg), c. 1000 m N of the bridge, from the lowermost 0.5 m of the Geulhem Member (Houthem Formation). Locality 4 in Fig. 1. Jagt and Collins collections.

—29 scuta, 17 terga, 21 rostra/carinae, 4 imbricating plates and 2 fragmentary upper latera from the eastern bank of the Albert Canal at Vroenhoven, c. 2000 m N of the bridge, from c. 8- 9 m above the Vroenhoven Horizon (see Fig. 2), upper part of Geulhem Member. Locality 5 in Fig. 1. Jagt and Collins collections.

—1 fragmentary, worn tergum from the uppermost metre of the Geulhem Member in the former Curfs quarry at Geulhem (municipality of Valkenburg aan de Geul, The Netherlands). Locality 1 in Fig. 1. Jagt collection.

Description—The reader is referred to Brünnich Nielsen (1912) and Withers (1914, 1935) for comprehensive descriptions of *P. bruennichi.*

Remarks—Only isolated elements are present in the samples studied. They are at times more or less strongly worn, but some are of excellent preservation. Some elements are fragmentary, but this is partly due to the method of sample processing. Several growth stages were found.

The number of lateral valves present in a sample of *Pycnolepas* is, almost invariably, disproportionate to the number of other capitular elements. So far, no reasonable explanation for this can be given. The minimum number of individuals present in a sample can be assessed by counting the number of the more common side (*i.e.* left or right) of the most common valve - usually a scutum or tergum. The collection made by one of us (JWMJ) from locality 5 along the Albert Canal (see Fig. 1) contains 18 scuta of several growth sizes, yet both left and right latera together number only 2. This proportion appears to be much the same as encountered in similar samples of *P. rigidus*.

STRATIGRAPHIC AND GEOGRAPHIC DISTRIBUTION OF *P. BRUENNICHI*

Withers (1935) reviewed the taxonomic history of *P. bruennichi*, thoroughly revised the description and documented the geological and stratigraphical data as known at that time. Since 1935 the stratigraphy of the Late Cretaceous and its boundary with the Danian has been considerably revised and Withers's recorded occurrences for *P. bruennichi* are all of Danian age, as will be discussed below.

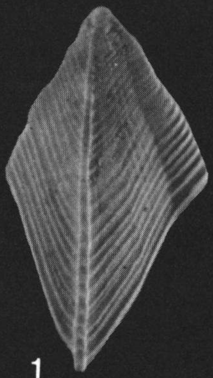
P. bruennichi was first recorded (as *Pollicipes rigidus*) from the Bryozoan Limestone of Fakse by Steenstrup (1839). Subsequently, Darwin (1851) united, under the new taxon *Pollicipes elegans*, two species of totally different stratigraphic provenance, viz. Fakse (Danian Bryozoan Limestone) and Ignaberga (Skåne, Sweden; latest Early Campanian, see Christensen, 1975, 1986).

The specimens from Fakse were later rightly isolated and described by Withers (1914) as *P. bruennichi* [= *Pollicipes rigidus* Steenstrup, 1839 non J. de C. Sowerby, 1836; *Pollicipes elegans* Darwin, 1851 (partim)]. The Ignaberg material was renamed in 1953 by Carlsson as *Pycnolepas ignabergensis*. Thus the inclusion by Withers (1914, and, with reservation, 1936) of Ignaberga among the localities for *P. bruennichi* no longer applies.

Plate 1. *Pycnolepas bruennichi* Withers, 1914.

Capitular valves and imbricating plates. Temporary exposures along the Albert Canal (exposure 61F-15), N of Vroenhoven bridge, Vroenhoven, municipality of Riemst, province of Limburg (Belgium). Geulhem Member, Houthem Formation (Early Palaeocene, mid-Early to Middle Danian). All specimens illustrated are deposited in the collections of the Natural History Museum Maastricht (abbreviation NHMM and registration numbers) (leg. J.W.M. Jagt). Figs 1-2, 4-9 from locality 5 in text-fig. 1; Fig. 3 from locality 4 in text-fig. 1

Fig. 1. Left tergum, outer view, x 4; NHMM 198842.
Fig. 2. Right tergum, outer view, x 5; NHMM 198843.
Fig. 3. Left tergum, inner view, x 3; NHMM 198844.
Figs 4a-b. Right scutum, outer and inner views, x 5; NHMM 198845.
Fig. 5. Left scutum, outer view, x 5; NHMM 198846.
Fig. 6. Carina, outer view, x 7; NHMM 198847.
Fig. 7. Rostrum, outer view, x 7; NHMM 198848.
Figs 8a-b. Imbricating plate, outer and inner views, x 8; NHMM 198849.
Figs 9a-b. Imbricating plate, outer and inner views, x 12; NHMM 198850.



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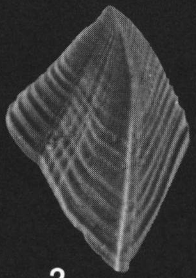

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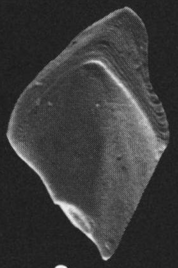

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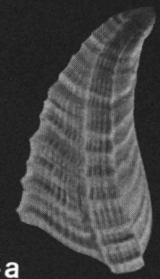

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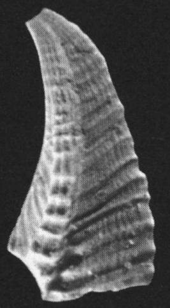

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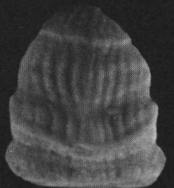

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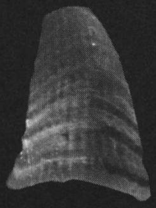

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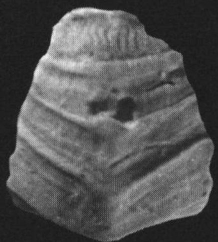

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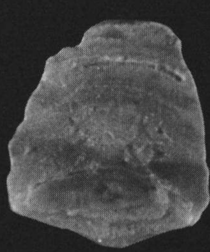

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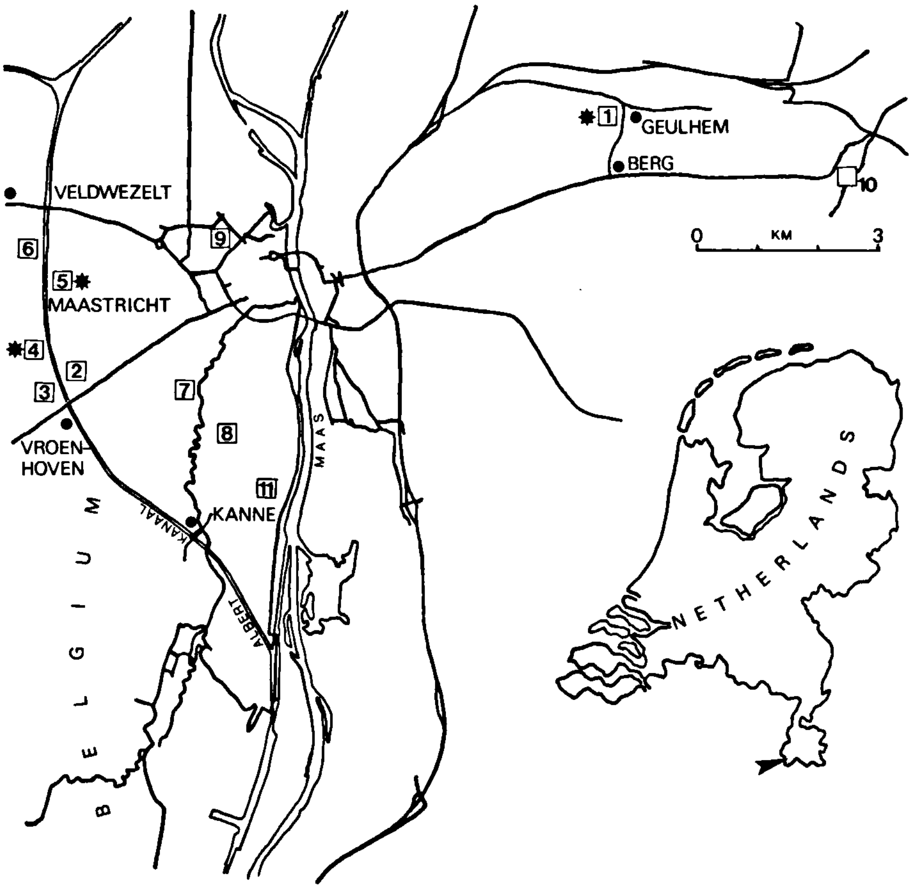

Figure 1. Location map of the environs of Maastricht (SE Netherlands, NE Belgium) with outcrops and boreholes from which Early Palaeocene strata have been reported.

Localities:

1. Ankersmit Holding B.V. (former Curfs quarry, Geulhem, Valkenburg aan de Geul, stratotype of the Geulhem Member *sensu* W.M. Felder, 1975b);

2-6. Sections along the Albert Canal between Vroenhoven bridge and Veldwezelt bridge, Riemst, Limburg [section 2 is the locality mentioned in Jagt (1986), section 3 is the one in Verbeek (1986), sections 4 and 5 are the ones described in the text here, section 6 is the one described in van der Ham (1988)];

7. Louwberg (Meijer, 1959, p. 327);
8. Former van der Zwaan quarry in the Sint Pietersberg (Meijer, 1959, p. 327);
9. Borehole Kastanjelaan-1, Maastricht (Bless *et al.*, 1981);
10. Boreholes Thermae 2000-2001, Valkenburg aan de Geul (Bless *et al.*, 1986; Krings *et al.*, 1987);
11. ENCI N.V. quarry, stratotype of the Maastrichtian Stage, as presently defined.

Sections that have yielded the material of *Pycnolepas bruennichi* here described are marked with an asterisk.

It is evident, that the taxa *P. rigida* (J. de C. Sowerby, 1836) (Albian-Cenomanian), *P. ignabergensis* Carlsson, 1953 (latest Early Campanian) and *P. bruennichi* Withers, 1914 (Danian) together form an evolutionary lineage, although *elegans* is, according to Carlsson (1953) somewhat closer to *P. rigida*. Withers (1935) recorded *P. bruennichi* from the Danian of Denmark, and doubtfully from the Maastrichtian of Bemelen (Maastricht area, The Netherlands) and Ciply (Mons Basin, SW Belgium). These latter records undoubtedly go back to Bosquet (1857, p. 14, pl. 3, fig. 3), who des-

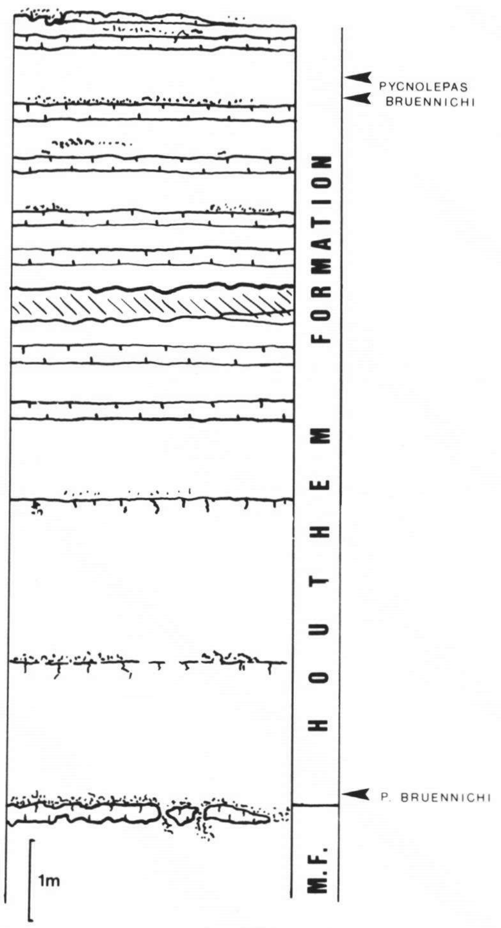

Figure 2. Schematic lithologic log (modified from Meijer, 1959) of a section along the Albert Canal near Vroenhoven, Riemst, Belgian Limburg.

The underlying Maastricht Formation (M.F.) is of late Late Maastrichtian age, with the hardground capping this unit yielding typically Cretaceous fossils, such as the ammonite *Hoploscaphites constrictus* (J. Sowerby, 1817) and the bivalves *Tenuipteria argentea* (Conrad, 1858) and *Pinna cretacea* (von Schlotheim, 1813). The contact between the Maastricht and Houthem Formations is known as the Vroenhoven Horizon. The shaded area in the middle of the log represents in all probability a stratigraphic gap. With arrows the stratigraphic provenance of the material of *Pycnolepas bruennichi* here described is indicated.

cribed and illustrated a fragmentary left tergum from 'une couche à Bryozoaires appartenant au Système Maestrichtien' at Bemelen, and who also noted 'Je viens de receuillir dans une poignée de terrain Maestrichtien de Ciply en Belgique un petit fragment d'un scutum qui appartient presque indubitablement à la même espèce' (Bosquet, 1857, p. 16; see also Bosquet, 1860, 1868). In Bosquet's days it was still common practice to include strata of Early Palaeocene age directly overlying the Maastrichtian deposits in the Maastricht area into the Système Maestrichtien of Dumont (1849). It is therefore quite possible that the tergum Bosquet illustrated came from the Geulhem Member in the neighbourhood of Geulhem: his locality Bemelen should then be considered in a broad sense. A study of the actual specimen (possibly still preserved in the Bosquet collection at the Institut royal des Sciences naturelles de Belgique, Brussels) will be necessary to pinpoint its identification. As far as the specimen from Ciply is concerned it should be noted that we have not found, apart from that of Withers, any subsequent reference to this species in the literature.

As pointed out above, Steenstrup's and Brünnich Nielsen's material came exclusively from the Bryozoan Limestone of Fakse, Denmark [Brünnich Nielsen, 1912, p. 33: Bryozokalk i Faxe (Bry XI og Bry I); see his fig. 1 on p. 29]. The large quarry at Fakse constitutes together with the section at Stevns Klint (Sjaelland) the stratotype of the Danian stage as introduced by Desor (1847). There is a general consensus in the recent literature that the strata exposed in the Fakse quarry are Middle Danian in age (see *e.g.* Floris, 1979). Perch-Nielsen (1979a) refers the strata to the lower part of nannoplankton zone NP 3, the Chiasmolithus danicus Zone, which corresponds to the P 1c planktonic foram zone, the Subbotina trinidadensis Zone (see Cavelier & Pomerol, 1986, tab. 1). In macrofaunal terms the strata are referred to the Tylocidaris bruennichi Zone (see Brotzen, 1959).

The material of *P. bruennichi* described here was collected almost exclusively in the outcrops along the Albert Canal, in the lowermost 0.5 m and in the upper part (c. 8-9 m above the Vroenhoven Horizon) of the Geulhem Member. As will be pointed out below, the specimens from low in the Geulhem Member are associated with typically Early Danian echinoderms, whereas those from the upper part are associated with spines of *Tylocidaris bruennichi* Ravn, 1928. The same holds true for the single tergum collected in the former Curfs quarry. From these data it can be concluded that *P. bruennichi* is not restricted to Middle Danian strata as it is in Denmark, but that it already occurred during the Early Danian in the Maastricht area.

STRATIGRAPHY OF THE GEULHEM MEMBER

A formal lithostratigraphy for the Late Cretaceous-Early Tertiary strata in the Maastrichtian type area meeting internationally agreed recommendations was proposed by W.M. Felder (1975b). In this scheme the glauconitic, rather coarse-grained biocalcarenites directly overlying the lithologically similar Meerssen Member of the Maastricht Formation (Late Maastrichtian) and separated from this by a locally well-developed hardground (Vroenhoven Horizon) is known as the Geulhem Member [Kalkstein von Geulhem *sensu* W.M. Felder, 1975b; Zone XI^{w} *sensu* W.M. Felder, 1975a; Kalksteen van Geulhem (V^{a}) *sensu* Albers & W.M. Felder, 1979], the basal unit of the Houthem Formation of Early Tertiary age. Stratotype of the Geulhem Member is the former Curfs quarry (exposure 62A-13 in the files of the Geological Survey at Heerlen), now Ankersmit Holding B.V., at Geulhem, The Netherlands (W.M. Felder, 1975b; Albers & W.M. Felder, 1979) (see Fig. 1). The section exposed here comprises the upper part of the Maastricht Formation (Nekum and Meerssen Members) and a sequence of c. 8 m in thickness of Early Palaeocene strata (Geulhem Member) on top of which rest Oligocene and Pleistocene deposits (W.M. Felder *et al.*, 1978, figs 4-2 and 4-3). W.M. Felder (1973) stressed that within the Geulhem Member two lithological subunits can be distinguished: a lower of coarse-grained, greyish glauconitic calcarenites with scattered concentrations of bioclasts, and an upper of coarse-grained greyish-brownish, less glauconitic calcarenites with distinct layers of hard chalkblocks. These units appear to be separated by an incipient hardground. This separation on lithological grounds may also be biostratigraphically significant (see below).

Sections that can complement the stratotype of the Geulhem Member in several respects were, up to recently, well accessible along the Albert Canal N of Vroenhoven bridge (Fig. 1), at Riemst, Belgian Limburg. Here again (W.M. Felder, 1963; 1975a, p. 42, fig. 38) two distinct units can be distinguished within this member. Over a period of several years a number of very interesting sections could be sampled. Unfortunately, the method of excavation hampered the construction of a detailed lithostratigraphic log, because a complete section of the Geulhem Member (with the Vroenhoven Horizon at the base and an unknown horizon at the top) was never exposed in any one section. From field observations it is concluded that c. 12 metres of Early Paleocene biocalcarenites are present along this canal, which means that these sections are more complete than the stratotype section at Geulhem. This is also apparent when one considers the highly distinctive echinoid fauna that was recently discovered in the uppermost part of the Geulhem Member along this canal. This fauna includes elements that have never been reported from the stratotype (van der Ham, 1988).

Time-equivalent strata have been reported in the literature from a number of small outcrops at and near the Sint Pietersberg, close to the Maastrichtian stratotype (ENCI N.V. quarry, see Fig. 1), from several boreholes in southern Limburg (Kastanjelaan-1/Maastricht; Thermae 2000 and 2001/Valkenburg aan de Geul; Bunde) and from the Campine Mining District (province of Brabant, Belgium) (see also Hofker, 1955, 1956b, 1957).

Of the sections mentioned above, those of the Albert Canal and of the former Curfs quarry are the most important for several reasons. Accessibility is one of the major requirements; highly diversified faunal assemblages are absolutely essential for a thorough and reliable biostratigraphy, which would preferably be based on the analysis of as many groups of micro- and macrofossils as possible, and so on. In view of this, most (if not all) of the studies on the fossil contents of the Early Palaeocene in the Maastricht area were carried out in these two sections.

Below, discussions of a number of fossil groups of particular stratigraphic value will be presented, so as to arrive at an up-to-date picture of the biostratigraphy of the Geulhem Member in the environs of Maastricht. Seeing that the biozonation of the Early Palaeocene is based mainly on the stratigraphic ranges of planktonic foraminifers and nannoplankton taxa, these two groups will be treated first.

—Planktonic foraminifers

Hofker (1956a, 1959a-c, 1960a-b, 1962a-b, 1964, 1965, 1966a-b, among other papers) extensively dealt with planktonic forams from the Early Palaeocene and the underlying Maastrichtian strata in the Maastrichtian type area. It should be borne in mind that he correlated the Maastrichtian (*sensu* Dumont, 1849) with the Danish Danian, a correlation that was subsequently rightly challenged, amongst others by Berggren (1962, 1964). Meijer (1959) supplied detailed data on several outcrops in the Early Palaeocene in the environs of Maastricht and studied the planktonic foram fauna. He rejected Hofker's views on planktonic foram taxonomy and stratigraphy and stressed that the assemblages in the Early Palaeocene calcarenites were totally different from those of the underlying Maastrichtian. For the sections along the Albert Canal Meijer (1959, p. 326) recorded an assemblage with abundant *Globoconusa daubjergensis* (Brönnimann, 1953), fairly common *Heterohelix* ex gr. *striata* (Ehrenberg, 1840) and rare *Rugoglobigerina* ex gr. *rugosa* (Plummer, 1926) with associated *Subbotina pseudobulloides* (Plummer, 1926) and/or *Guembelitria cretacea* (Cushman, 1926). *S. pseudobulloides* becomes more common higher in the section. Meijer stressed that typical representatives of *Chiloguembelina morsei* (Kline, 1943) and *Subbotina triloculinoides* (Plummer, 1926) are apparently absent, and that *Planorotalia compressa* (Plummer, 1926) vanishes abruptly, and remarked that the presence of Maastrichtian forms at the very base of the Palaeocene strata must be the result of reworking. *G. daubjergensis* is the species that Meijer (1959, p. 327-328) recorded for the Louwberg and the Sint Pietersberg (see Fig. 1). At Geulhem (Curfs quarry) the same assemblage was demonstrated by

Meijer, with typical forms such as *G. daubjergensis* and *S. pseudobulloides*. El-Naggar (1967, p. 106) also mentioned the occurrence of species of the P. compressa/G. daubjergensis Zone in NE Belgium and SE Netherlands. *G. daubjergensis* is recorded for the lower part of the FK foram zone (see below) by Doppert & Neele (1983), with *Planorotalites pseudomenardii* (Bolli, 1957) and *P. pusilla laevigata* (Bolli, 1957), species characterising the P3b and P4 planktonic foram zones respectively (Late Palaeocene, Thanetian) (see Cavelier & Pomerol, 1986, table 1) for the middle part of the zone. The species *G. daubjergensis* (Brönnimann, 1953) has turned out to be *the* index fossil for the Danian stage (see *e.g.* Koch, 1977; H.J. Hansen, 1970; Pożaryska, 1965).

The type Danian, as presently defined (Cavelier & Pomerol, 1986), comprises three planktonic foram zones, viz. from base to top, the Globigerina eugubina Zone (P 1a), the Subbotina pseudobulloides Zone (P 1b) and the S. trinidadensis Zone (P 1c), with the strata on top of this last zone being characterized by the *Morozovella* lineage (see *e.g.* Corfield & Granlund, 1988). Berggren (1972) included the G. uncinata-G. spiralis Concurrent Range Zone (P 2) in his scheme of the Danian (figs 4 and 5) and distinguished the P 1 G. daubjergensis-G. pseudobulloides Partial Range Zone, which is subdivided into four subzones: P 1a/eobulloides, P 1b/triloculinoides, P 1c/pseudobulloides and P 1d/compressa-inconstans/trinidadensis. Salaj (1980) presented the same biozonation, although the zonal names differ somewhat: he distinguished (tab. 8) for his Danian *s.l.* from base to top: Globigerina taurica-Globoconusa daubjergensis Zone (corresponding to the Globigerina eugubina Zone of Luterbacher & Premoli-Silva, 1964, and the Globigerina eobulloides Zone of Berggren, 1972, among others), and the Globigerina trinidadensis Zone with three subzones as follows: Globigerina pseudobulloides Subzone, Planorotalia compressa Subzone and Turborotalia (Acarinina) inconstans Subzone. The lowermost Danian in the type area in Denmark is characterized by an assemblage of the Eoglobigerina danica Zone (Bang, 1971, 1979a-b, 1980), the upper boundary of which is defined by the first appearance of *G. daubjergensis*, which is itself a constituent of the *Eoglobigerina eobulloides* assemblage (Bang, 1979a).

In the Mons Basin (southern Belgium) an assemblage comparable to the one recorded from the Maastricht area (Meijer, 1959) with *G. daubjergensis*, *P. compressa*, *P. triloculinoides* and *S. pseudobulloides* is found in the Tuffeau de Ciply, correlated with the Middle Danian (Meijer, 1967; Robaszynski, 1979a-b)

Summing up, it may be stated that the planktonic forams indicate that the equivalents of the Danish E. danica Zone are absent in the environs of Maastricht and that the Geulhem Member is early Middle to Late Danian in age on planktonic foram evidence (S. pseudobulloides Zone, middle part of the range zone of *G. daubjergensis*). Cepek & Moorkens (1979, p. 141) reached the same conclusion: they recorded numerous *G. daubjergensis* associated with rare and strongly recrystallized specimens of *Rugoglobigerina* and *Globotruncana* (reworking) at the base of the Geulhem Member. Assemblages characterising the eugubina Zone (and its Danish counterpart) are absent; the Danian sedimentation starts in the G. daubjergensis Zone, which indicates an important stratigraphic gap between the underlying Late Maastrichtian and the Geulhem Member. Hofker (1960a, see also 1960c) suggested a Late Danian age for the Geulhem Member on the basis of the orthogenetic development stage of *G. daubjergensis* (see also Berggren, 1962; H.J. Hansen, 1970).

—Calcareous nannoplankton

Vangerow & Schloemer (1967) were among the first to study the coccoliths of the Geulhem Member. Their samples came from the sections along the Albert Canal between km marks 18 and 24 (see fig.

5-1 in Albers *et al.*, 1978) and from the former Curfs quarry. They noted in particular the presence of *Markalius inversus* (Deflandre, 1954) Bramlette & Martini, 1964, and *Braarudosphaera bigelowi* (Gran & Braarud, 1935) emend. Deflandre, 1947 in addition to other species (Vangerow & Schloemer, 1967, tab. 1 and fig. 8), concluding that the 'Houthem Kalk' is apparently of Danian age.

Verbeek (1986) described the calcareous nannoplankton flora of a section along the Albert Canal, immediately N of Vroenhoven bridge. Unfortunately he sampled only c. 2.8 m of strata belonging to the Geulhem Member, in which he noted a distinct lithofacial change: a lower, heavily glauconitic part, and an upper part with far less glauconite. As already noted above, such a subdivision in lithology is often accompanied by a biostratigraphic subdivision. Verbeek recorded for his lower part an abundant occurrence of *B. bigelowi*, *B. discula* Bramlette & Riedel, 1954, and *M. inversus* in addition to other species, suggesting the NP 1 (Biantholithus sparsus Zone, Martini, 1971, emend. Romein, 1979b). A different assemblage was recorded by Verbeek for the upper metre or so of the studied section: *Chiasmolithus danicus* (Brotzen, 1959) and *Cruciplacolithus tenuis* (Stradner, 1961) Hay & Mohler, 1967, are among the important species, with the former defining the base of the NP 3 Zone.

On the calcareous nannoplankton evidence Verbeek referred the lower part to the Early Danian and the upper part to the Late Danian or Early Thanetian (Late Palaeocene). He explicitly stated that *Biantholithus* cf *sparsus* of Cepek & Moorkens (1979), who recorded this species for the base of the Geulhem Member in the former Curfs quarry, was not found by him. Verbeek (1986) supposed that a hiatus of only short duration characterizes the Maastrichtian-Danian boundary along the Albert Canal, and that a much more extensive gap exists between the two lithological units he distinguished in the studied section. Unfortunately, his findings cannot be applied without any reservation to the other sections along the canal. It would have been especially important to have studied the calcareous nannoplankton of the upper and uppermost part of the Geulhem Member closer to the Veldwezelt bridge (see below), on both sides of the canal. The same holds true for the upper part of the stratotype section at Geulhem, where just as in the sections along the Albert Canal, this part of the Geulhem Member is characterized by species held to be indicative of Middle Danian (the echinoid *Tylocidaris* gr. *bruennichi* in particular).

The type Danian comprises ten subzones (D 1 to D 10) of four zones, from bottom to top: NP 1 Markalius inversus Zone (= D 1 and D 2), with the index taxon and *B. sparsus*, NP 2 Cruciplacolithus tenuis Zone (= D 3 and D 4), NP 3 Chiasmolithus danicus Zone (= D 5–D 9) and NP 4 Ellipsolithus macellus Zone (= D 10), to which part of the type Danian seems to belong (Perch-Nielsen, 1979a, p. 119), although other authors (see *e.g.* Cavelier & Pomerol, 1986; Martini, 1977) refer the NP 4 Zone to the lower part of the Selandian. Martini's (1971) NP zonation can be matched with Bukry's (1973) CP zonal scheme.

For detailed discussions of the calcareous nannoplankton zonation of the Maastrichtian-Danian boundary strata and of the type Danian the reader is referred to Bramlette & Martini (1964), Perch-Nielsen (1979b-c), Gartner & Keany (1979), Romein (1979a), Smit (1979) and Monechi (1979).

—Benthic foraminifers

Hofker (1966b) introduced a foram zonation using letters for the Maastrichtian type area. His zone P corresponds to the Geulhem Member (Albers & W.M. Felder, 1979, fig. 4). The FK foram zone for assemblages with the benthic species *Pararotalia globigeriniformis* (van Bellen, 1946) and *Rotalia saxorum* d'Orbigny, 1826, was proposed (see Jaarverslag Rijks Geologische Dienst, 1976). To this FK

Zone Doppert & Neele (1983) assigned the Houthem Formation and illustrated a number of characteristic species. In their view, the FK Zone is partly Danian, partly Montian in age, but a subdivision of this zone has never been proposed. Among the species they mentioned are *G. daubjergensis*, *P. pusilla laevigata* and *P. pseudomenardii*, all planktonic species, of which the first is indicative of Danian and the other two are of Thanetian age (see above). Most of the benthic species of the FK Zone are also known in other parts of NW Europe (see *e.g.* Pożaryska, 1965; Brotzen, 1948). In an attempt at unifying the biostratigraphic scheme based on foraminifers, Letsch & Sissingh (1983) suggested a new zonation in which the FK Zone corresponds to the Anomalinoides danica Zone, with a lower Globoconusa daubjergensis Subzone and an upper Bulimina trigonalis Subzone, FT 1a and FT 1b respectively.

In boreholes in the Campine Mining District and in southern Limburg time-equivalent strata of the Geulhem Member in its stratotype are mainly recognized on the basis of forams. Meessen (*in* P.J. Felder *et al.*, 1985; *in* Herngreen *et al.*, 1986; *in* Bless *et al.*, 1986) recorded as characteristic species of foram zone P *Lenticulina discus* (Brotzen, 1948), *Pseudopolymorphina paleocenica* Brotzen, 1948, *Nodosaria affinis* Reuss, 1846, *Protelphidium brotzeni* Hofker, 1966, and *Lenticulina klagshamnensis* (Brotzen, 1948).

The reader is referred to Hofker (1966, with additional references) for a more detailed discussion of the benthic foram faunas.

—Echinoderms

The Danian stage in its type area has traditionally been subdivided by means of primary spines of the psychocidarid echinoid genus *Tylocidaris* Pomel, 1883 (see *e.g.* Ødum, 1926; Ravn, 1928; Rosenkrantz, 1937; Brünnich Nielsen, 1938; Wind, 1954). This zonation was applied to and refined for an outcrop of Danian strata in southern Sweden (Skåne, Limhamn) by Brotzen (1959), who based his zonal scheme on successive *Tylocidaris* 'populations' from this locality (see also Holland & Gabrielson, 1979). Up to now, this echinoid zonation has never been really questioned. However, J.M. Hansen (1977) has shown that, when compared to the dinoflagellate zonation, the *Tylocidaris* zonal scheme is slightly diachronous within the Danish basin, being influenced by facies (see also Asgaard, 1979). Hansen (1977, p. 9) stressed that there is a trend showing progressively younger occurrences of *Tylocidaris* zones towards the NW of the basin, and explained this with the general regression that is assumed to have taken place during the Danian. His sedimentary model of the Maastrichtian/Danian transition and the Danian of the Danish basin is an excellent example of what can be achieved by combining data from various fossil groups with biostratigraphic potential (J.M. Hansen, 1977, fig. 6).

The *Tylocidaris* zonal scheme comprises the following zones, from bottom to top (J.M. Hansen, 1977; Brotzen, 1959): T. oedumi Zone, including *T. abildgaardi* Ravn, 1928 (Early Danian), T. rosenkrantzi and T. bruennichi Zones (Middle Danian) and T. herupensis Zone (= T. vexillifera Zone) (Late Danian).

Representatives of the genus *Tylocidaris* have also been recorded for Early Paleocene strata in other parts of NW Europe. Kongiel (1958) for example described and illustrated a new variety *T. pomifer* var. *masoviensis* Kongiel, based on material from Poland which he analysed morphologically and biometrically. It must be stressed that biometric analyses of Danish populations of *Tylocidaris* have not been carried out: it is therefore extremely difficult to state how species recognized outside the Danish-Swedish basin fit into the zonation applied to that basin. Only on the basis of detailed, biometric studies of populations can it be decided if the Polish and Dutch-Belgian species of *Tylocidaris* are to be looked upon as migrants from the Danish basin or as endemic species of similar morphology as a result of homeomorphy. In this respect it is very interesting that Rosenkrantz (1970) recorded from the Early Palaeocene of West Greenland *T.* aff. *vexillifera* Schlüter, 1892, and *T.* aff. *oedumi* Brünnich Nielsen, 1938, and that the same author (1964) illustrated (pl. 5, fig. 3) a primary spine referred to *T. masoviensis* Kongiel, 1958, from the Middle Danian of Fakse, Denmark.

In the Maastricht area only two distinct types of *Tylocidaris* spines seem to characterize the Geulhem Member. *T. hardouini* (Desor, 1855), a species originally described from the Craie phosphatée and Poudingue de la Malogne in the Mons basin in southern Belgium, appears to be typical of the lower part of the Geulhem Member in which it is extremely abundant locally. The upper part of the Geulhem Member (including the uppermost part as described by van der Ham, 1988) yields another type of spine usually referred to *T. bruennichi* Ravn, 1928. It would be very important to check the stratigraphic ranges of these two species (it is significant to note that they can only be separated on spine characteristics and not on details of the tests; see van der Ham, 1988). The sections along the Albert Canal are certainly unsuitable for the construction of a biozonation by means of biometrically characterized *Tylocidaris* populations, for reasons outlined above. The best possibilities for such a zonation would obviously be offered by a continuous section, such as the one in the former Curfs quarry. W.M. Felder (1973) noted the occurrence of *T. hardouini* immediately below an incipient hardground that separates the lower from the upper part of the Geulhem Member in that quarry. *T. bruennichi* is occasionally found in the upper part but its exact vertical range is unknown. The fact that the uppermost part (as recognized in the Albert Canal sections) is apparently missing in the stratotype of the Geulhem Member poses another problem.

Seeing that the *Tylocidaris* zonation is the only zonation, macrofaunally speaking, that has been proposed for the Danish Danian, it would be of the greatest importance to study the *Tylocidaris* populations of the Mons basin (see Smiser, 1935; Rasmussen, 1965), the Maastricht area and Poland, so as to arrive at a detailed picture of the evolutionary lineage(s) of this genus in the NW European Early Palaeocene. In this respect it is essential to note that it has been suggested in the literature (Brotzen, 1959, p. 44; Wind, 1954) that *T. hardouini* may be conspecific with *T. abildgaardi* Ravn, 1928 and that Lambert's (1911) and Smiser's (1935) *Balanocidaris schlueteri* Lambert may be the same as *T. vexillifera*. Moreover, Kongiel (1958) reported some spines from Poland and referred to them as cf *Balanocidaris ? hardouini* (Desor).

What is stratigraphically the most important is the fact that there is a general consensus in the literature to consider *T. bruennichi* as index echinoid for the Middle Danian (see *e.g.* Rasmussen, 1964, 1965), which would mean that the upper and uppermost part of the Geulhem Member are Middle Danian in age.

The occurrence of additional echinoids in the Early Palaeocene of the environs of Maastricht is strongly lithofacially controlled. When one compares the echinoid assemblages of the Danish-Swedish basin (see *e.g.* Ravn, 1927, 1928; Asgaard, 1979; Gravesen, 1979) with those of the Maastricht area (Meijer, 1965; van der Ham *et al.*, 1987; van der Ham, 1988) it becomes immediately clear that a number of genera (for instance, *Echinocorys*, *Globator* and *Cyclaster*) characterizing the Danian in the type area are absent from the Geulhem Member. Numerous other examples could be cited here, but it seems best to defer a thorough discussion of the echinoid faunas of the Mons area, the Maastricht region and the Danish type area to another paper.

In addition to numerous echinoids the echinoderm fauna of the above mentioned areas comprises crinoids, asteroids and ophiuroids. A certain number of these echinoderms has stratigraphic potential, as has been shown by Rasmussen (1964, 1965, 1972, 1979). Of importance, stratigraphically speaking, among the crinoids is *Nielsenicrinus obsoletus* (Brünnich Nielsen, 1913), a species confined in Denmark to the Late Danian (Brünnich Nielsen, 1913; Rasmussen, 1961, 1972) and reported by Rasmussen (1965, tab. 1) for the Maastricht area. Species of the genera *Bourgueticrinus* and *Democrinus* that are characterized by having large axial canals in their columnals [*B. danicus* Brünnich Nielsen, 1913, and *D. maximus* (Brünnich Nielsen, 1915)] are confined to the Danian, according to Rasmussen. It must be stressed, however, that there are also Maastrichtian species with similar columnal structure and that the presence of this type of columnal alone is not enough proof of Danian age. The crinoid fauna of the Geulhem Member is still rather poorly known: comatulid crinoids are also known and a future treatment of these echinoderms should also include a discussion of their correlative value.

Among the asteroids there are three species of the genus *Metopaster* that deserve attention. Rasmussen (1965) recorded the typically Early Danian *M. spenceri* Brünnich Nielsen, 1943, *M. kagstrupensis* Brünnich Nielsen, 1943, and the typically Late Danian *M. carinatus* (Brünnich Nielsen, 1943) for the Geulhem Chalk of the Albert Canal and Geulhem. Material recently collected in the sections along the Albert Canal by private collectors has yielded large numbers of dissociated ossicles of *M. spenceri* in particular and it would therefore be of importance to pinpoint the exact range of this species within the Geulhem Member. Rasmussen (1965) mentioned a number of other species and field observations by one of us (JWMJ) have brought to light important new data, especially on asteroids of the Astropectinidae of the type recorded by Rasmussen (1945, 1950, 1972) for the Danish Danian. Dissociated ossicles of this type of asteroid are among the commonest echinoderm remains in the Geulhem Member. Here again an exhaustive discussion of the taxonomy and the stratigraphic potential must await the study of large collections.

Among the ophiuroids there are very few species of correlative value. Most of the taxa recorded by Rasmussen (1950, 1972, 1979) are long-ranging and cross the Maastrichtian/Danian boundary morphologically unchanged. The ophiuroid fauna of the Geulhem Member is very poorly known; only *Amphiura ? senonensis* Valette, 1915, a species with an enormous geographic and stratigraphic distribution, has been reported (Jagt, 1986).

Summing up, the following can be said about the echinoderm fauna of the Early Palaeocene of the environs of Maastricht: echinoids and asteroids are among the stratigraphically important echinoderms, but a thorough understanding of their ranges within the Geulhem Member and their relationship with taxa previously recorded from the type Danian is essential to make them more useful in a macrofaunal zonation.

—Ostracods

Deroo (1966) was the first to comprehensively describe and illustrate ostracod faunas from the Late Maastrichtian and Early Tertiary of the Maastrichtian type area and beyond. He introduced a scheme of ostracod zones, in which the Geulhem Member (Tuffeau Glauconieux) is correlated with the Tuffeau de Ciply of the Mons basin on the basis of ostracod assemblages. Deroo also stressed the lithologic similarity between the Geulhem Member and the underlying Meerssen Member, suggesting comparable conditions of deposition. His '5ème faunizone (Tuffeau Glauconieux = couches à *Cytherelloidea*)' contains an ostracod assemblage utterly different from the underlying Late

Maastrichtian one, with characteristic species such as *Alatacythere heerlenensis* Deroo, 1966, *Ruggieria pustulosa* (Marlière, 1958) and *Curfsina geleenensis* Deroo, 1966, in addition to a number of other species (Deroo, 1966, p. 42). Deroo accepted Hofker's (1960a) views on the orthogenetic development of the foram *Globoconusa daubjergensis*, which would suggest that the Geulhem Member is of Late Danian age. The ostracod faunas of the Tuffeau de Ciply in the Mons area as described by Marlière (1958) are nearly identical to the ones of the Geulhem Member, thus suggesting their time equivalence.

The most recent sections along the Albert Canal have not been sampled for ostracods; however, Jagt (1986) mentioned an assemblage of reworked Maastrichtian and redeposited Danian species, among which *R. pustulosa*, *A. heerlenensis*, *Limburgina calciporacea* Deroo, 1966 and *L. longiporacea* Deroo, 1966, were noted.

For a more detailed discussion of ostracod assemblages and their stratigraphic potential the reader is referred to Bless (1988).

—Brachiopods

The brachiopod fauna of the Geulhem Member is, with some exceptions, very poorly known, Craniids in particular have been systematically revised (Kruytzer, 1969) and the occurrence of *Crania brattenburgica geulhemensis* (Kruytzer & Meijer, 1958) is of particular importance for the stratigraphy of this member. This taxon, now known as *Danocrania geulhemensis* (see Rosenkrantz, 1964; Lee & Brunton, 1986) is closely related to *D. tuberculata* (Nilsson, 1827) of Late Danian age. Rosenkrantz (1964, p. 518) referred *D. geulhemensis* to the Middle Danian, which is understandable in the light of Meijer's (1959) data on planktonic forams and from the fact that this craniid is much more abundant in the upper part of the Geulhem Member (in its stratotype as well as in the Albert Canal sections) where it is associated with the echinoid *Tylocidaris bruennichi*. It must be stressed that it also occurs at the very base of the member, which suggests that it may already be present in the Early Danian of the area.

Backhaus (1959) exhaustively treated the thecideid brachiopods of the Late Cretaceous and reported *Bifolium longirostris parva* (Backhaus, 1959) from the Geulhem Member.

From field observations by one of us (JWMJ) it has become clear that the brachiopod fauna of the Geulhem Member is particularly characterized by numerous craniids of the genera *Ancistrocrania* and *Danocrania*, and representatives of the genera *Terebratulina* [especially *T. chrysalis* (von Schlotheim, 1813)], *Argyrotheca* and an unidentified terebratulid. It would no doubt be stratigraphically rewarding to treat the brachiopod fauna of this member in a similar fashion as Johansen (1987) has done for an important Cretaceous-Tertiary boundary section at Nye Kløv, Jylland, Denmark. A thorough systematic framework is needed before attempts can be made to test the stratigraphic value of brachiopods of the Early Palaeocene of the Maastricht area.

—Dinoflagellates and sporomorphs

The literature on these two groups of microfossils is extremely scanty. Herngreen *et al.* (1986, p. 45), in describing the micropalaeontology of the Bunde borehole (The Netherlands), explicitly stated that '... the results of an examination of the Danian Houthem Formation in the Maastricht area may contribute to a better understanding of the changes in palynomorph composition (and vegetation) around the Cretaceous/Tertiary boundary. These analyses will be carried out in the near future by examining samples from quarry Curfs (topmost Mc, Md and Houthem Fm.) near Maastricht and by re-investigating the Danian strata of Denmark which together may throw more light on the mentioned similarity between the Danish (Danian) and Dutch (uppermost Maestrichtian) palynomorph assemblages.' Unfortunately, Herngreen *et al.* (1986) did not supply any data on Early Palaeocene (foram zone P) dinoflagellates from this borehole.

The type Danian corresponds to the zone of the dinoflagellate species *Danea mutabilis* Morgenroth, 1968 (see Cavelier & Pomerol, 1986). J.M. Hansen (1977) studied the dinoflagellate assemblages of a number of key localities in Denmark, including Kjølby Gard, which is considered to be one of the most complete Maastrichtian-Danian boundary sections in the Danish basin.

Hansen introduced the Danea mutabilis Zone with two subzones, the Chiropteridium inornatum Subzone and the Hafniasphaera cryptovesiculata Subzone. The first of these subzones is again subdivided into four zonules which are correlated with the *Tylocidaris* zonation as follows: the Carpatella cornuta Zonule corresponds to strata yielding *T. oedumi*, the Xenocodinium rugulatum Zonule includes sediments referred to the T. oedumi, T. abildgaardi and T. bruennichi Zones and the X. lubricum Zonule includes strata yielding *T. abildgaardi* and *T. bruennichi*.

It is to be hoped that a study of the dinoflagellates and the sporomorphs of the key sections of the Geulhem Member in the Maastricht area will yield similarly promising results, especially so as J.M. Hansen (1977, p. 5) stressed that the first occurrence in dinoflagellate stratigraphy has turned out to yield a high level of biostratigraphic resolution in the Palaeogene of NW Europe.

—Other groups

In addition to the above mentioned groups several others may turn out to possess stratigraphic potential when thoroughly studied. Yet others may be too strongly facies dependent to grow out to be more than just locally or regionally important index taxa. Here the enormous numbers of the small serpulid *Ditrupa schlotheimi* Rosenkrantz, 1920 should be mentioned from especially the upper part of the Geulhem Member. This species was originally described from the uppermost Danian of Denmark (Rosenkrantz, 1920) and was subsequently reported from Dano-Montian strata in Poland (Pugaczewska, 1967).

In the literature it has occasionally been suggested that bryozoans may be of correlative and biostratigraphic value as well. The reader is referred to discussions in Voigt (1979) and Wiesemann (1963), among other papers.

CONCLUSION

From data presented above it soon becomes clear that the Geulhem Member of the Houthem Formation is really Early Palaeocene in age, but that precise correlations with the Danish-Swedish type area are as yet impossible for the most part. In order to be able to determine the exact stratigraphic ranges of key index fossils from all the above mentioned groups of nanno-, micro- and macrofossils multidisciplinary investigations are essential. These should be carried out in the two key sections of the Geulhem Member, viz. the former Curfs quarry and the sections along the Albert Canal. In this respect it is very unfortunate that most of the latter sections are no longer accessible at the moment and that large quantities of material have been collected over the past six years or so by private collectors who often were not aware of the importance of acquiring stratigraphically well-documented samples. It is therefore to be hoped that in the near future the sections that are still accessible for sampling will be studied in the greatest detail so that a thorough presentation of all aspects of the Danian (sedimentology, palaeoecology, biostratigraphy and lithostratigraphy) can be given.

It will, however, not be possible to correlate exactly the Geulhem Member with the type Danian until such a proper picture is obtained.

ACKNOWLEDGEMENTS

We wish to thank Mr A.W. Janssen, Dr P.A.M. Gaemers (both Rijksmuseum van Geologie en Mineralogie, Leiden) and Mr J.J. Bellen (Venlo) for their invaluable help with the photography. Dr W.K. Christensen, Mr S.L. Jakobsen (both Geological Museum, Copenhagen) and Mr J.C. van Veen (Teylers Museum, Haaqrlem) supplied an item of literature, for which we are grateful.

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Manuscript received 17 August 1988