

**POSSIBLE CAUSES FOR THE CHANGE IN OSTRACOD ASSEMBLAGES
AT THE MAASTRICHTIAN-PALAEOCENE BOUNDARY IN SOUTHERN LIMBURG,
THE NETHERLANDS**

by

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Bless, M.J.M. Possible causes for the change in ostracod assemblages at the Maastrichtian-Palaeocene boundary in southern Limburg, The Netherlands.—Meded. Werkgr. Tert. Kwart. Geol., 25(2-3): 197-211, 6 figs, 1 tab. Leiden, October 1988.

In southern Limburg (SE Netherlands) and adjacent areas, the Maastrichtian-Palaeocene (Cretaceous-Tertiary) boundary is marked by, among other phenomena, an almost complete change in ostracod faunas at the (sub)specific level; moreover, the number of cytheracean and other ostracod taxa decreases drastically at this boundary. Analysis of this and other events in the Late Cretaceous to Early Tertiary succession of ostracod assemblages suggests that this change was induced by the Early Danian sea level fall and concomitant regressions of epicontinental sea margins, by the closure of seaways linking the Mediterranean (Tethyan) and Boreal faunal provinces, and by the subsequent Late Danian transgressions with accompanying influx of cold upwelling water from the Atlantic Ocean, bringing about the return of 'boreal' elements in the ostracod faunas.

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SAMENVATTING

Mogelijke oorzaken voor de verandering in ostracodenassociaties op de Maastrichtien-Paleoceengrens in zuidelijk Limburg (Nederland).

In Zuid-Limburg en het aangrenzende gebied wordt de grens Maastrichtien-Paleoceen (Krijt-Tertiair) onder andere gekenmerkt door een vrijwel complete verandering op soort- of ondersoort-niveau in ostracodenfauna's. Daarnaast neemt het aantal taxa uit de Cytheracea, maar ook uit andere ostracodengroepen, drastisch af op deze grens. Op basis van een analyse van deze 'events' en van andere soortgelijke 'events' in het Laat Krijt en Vroeg Tertiair voor wat ostracodenfauna's betreft, wordt gesuggereerd dat deze omwenteling veroorzaakt werd door de daling van de zeespiegel tijdens het Vroeg Danien, door het wegvallen van verbindingen tussen de Mediterrane (Tethys) en boreale faunaprovincies en door de daarop volgende transgressies tijdens het Laat Danien, die gepaard gingen met toevoer van koud, opwellend water uit de Atlantische Oceaan, waardoor 'boreale' elementen in de ostracodenfauna's opnieuw geïntroduceerd werden.

INTRODUCTION

The only publication on Early Tertiary (Palaeocene) ostracods from the 'chalk' deposits in southern Limburg (The Netherlands) to have appeared thus far is the one by Deroo (1966), who described thirty species of Cytheracea. Two of these had been reported earlier from the Eocene of France (*Mosaeleberis canaliculata*; see Apostolescu, 1956, and *Trachyleberis aculeata*; see Bosquet, 1850), and ten from the 'Montian' of SW Belgium (Marlière, 1958). No descriptions have yet been published of ostracod taxa other than Cytheracea from the Palaeocene Houthem Chalk in southern Limburg. These include *Bairdia*, *Bairdoppilata*, *Cytherella*, *Cytherelloidea* and '*Paracypris*', among other genera.

Within the Palaeocene Houthem Chalk in southern Limburg three ostracod zones are distinguished (Deroo, 1966), which can be correlated into the Mons Basin in SW Belgium (Marlière, 1958). According to Deroo, the lower zone represents the Late Danian, whereas the two upper zones are of Montian age. This subdivision will not be considered here any further, but it should be noted that the Early Tertiary sequence in the former Curfs quarry at Geulhem (near Valkenburg aan de Geul, The Netherlands) was referred entirely to the Late Danian by Deroo (1966). Hofker (1966) attributed this interval to his benthic foraminifer zone P and the base of zone Q.

The relatively low diversity in cytheracean ostracod taxa in the Palaeocene of southern Limburg is in sharp contrast with the profuse cytheracean faunas known from the latest Maastrichtian in the same area. Deroo (1966) listed as many as 116 species from these strata. Many of these had already been described by Bosquet (1847, 1850, 1854), and by van Veen (1932, 1934-1938). None of these 116 cytheracean taxa ranges into the Palaeocene, and none of the Palaeocene taxa appears already in the underlying Maastrichtian.

This radical change in the composition of ostracod faunas at the specific or subspecific level occurring at the Cretaceous-Tertiary (K-T) boundary presupposes some sudden, brutal event causing mass extinction followed by a (gradual ?) re-appearance of new life forms. This contribution is meant as an analysis of this phenomenon in southern Limburg.

QUALITATIVE AND QUANTITATIVE DATA

Deroo's (1966) data on the distribution of cytheracean ostracods around the Maastrichtian-Palaeocene boundary have largely been confirmed by a study of spot samples from boreholes in southern Limburg and NE Belgium, and by a more detailed investigation of 53 closely spaced

(approximately every 0.50 m) samples from the former Curfs quarry at Geulhem (southern Limburg). In Fig. 1 some easily distinguished taxa from the uppermost Maastrichtian and lowermost Palaeocene in this area are illustrated. The analysis was limited to small numbers of ostracods per sample. Usually, only the first thirty to fifty specimens encountered in a sample were picked for further study. In this way, only the statistically most abundant taxa are found. Therefore, the data so obtained may also be used for a broadbrush quantitative analysis of the ostracod assemblages. Taxa that are usually rare (*i.e.* normally less than 1% of the assemblages) are found only occasionally, whereas taxa that occur frequently in relatively large numbers (say, at least 3-5% of the assemblages) are found in almost every sample.

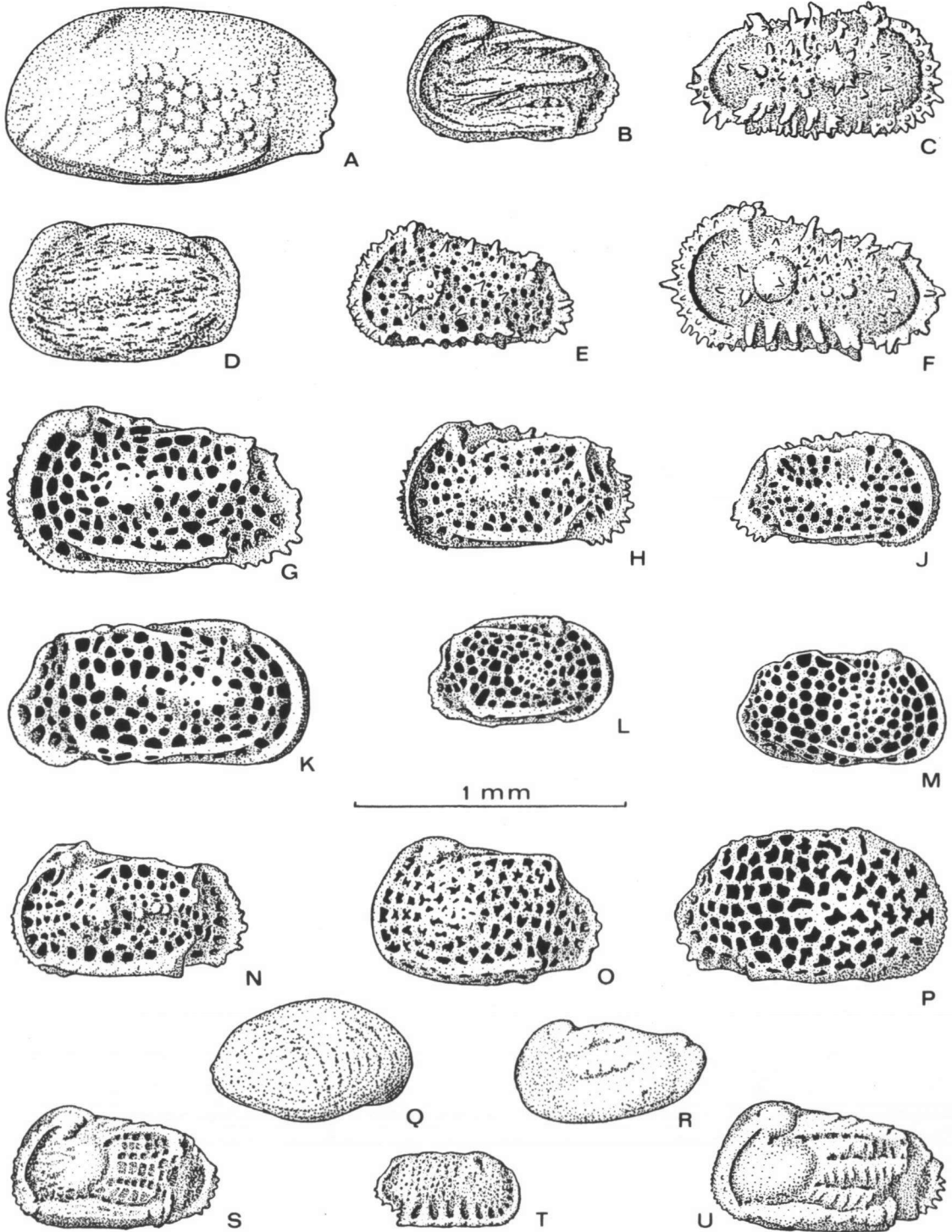
The results of the method applied here are comparable with those obtained by Deroo (1966) for the Curfs quarry. For example, Deroo found the relatively rare species, *Kikliocythere labyrinthica* (Bosquet, 1854) only twice near the base of his 'partie supérieure du Tuffeau de Maastricht' (Deroo, 1966, tab. 4, section 18, samples 419 and 421), which is some 15 m below the Vroenhoven Horizon, and only once in the Vroenhoven 'hardground' (sample 429). In the present study, this species was recognized in two samples near the base of the section studied (at 9.8 and 15.1 m below the Vroenhoven Horizon, respectively).

The more common species, *Mauritsina hieroglyphica* (Bosquet, 1847), was found in four samples near the base of the section studied by Deroo (1966, samples 419, 421, 422 and 423), as well as in two samples from the Vroenhoven 'hardground' (samples 428 and 429). This is six out of eleven samples, or 55%. In the present study, 20 out of 34 samples from below the Vroenhoven Horizon yielded this species (compare Fig. 3), which means 59% of the Late Maastrichtian samples in that section. Similar figures were obtained for other taxa.

In this way, the rather abrupt change in the qualitative composition of the ostracod assemblages around the Maastrichtian-Palaeocene boundary in the former Curfs quarry, as established by Deroo (1966), could be confirmed (Fig. 2). However, in the section studied here, the Vroenhoven 'hardground' was only poorly developed and did not yield any mixed assemblages of both Maastrichtian and Palaeocene taxa. Such mixed assemblages have however been recognized in the Vroenhoven 'hardground' along the Albert Canal near Vroenhoven (see Jagt, 1986).

The ostracod faunas collected at the former Curfs quarry can be considered representative of the uppermost Maastrichtian and Palaeocene deposits in this area. Of the 116 cytheracean species listed by Deroo (1966, tab. 6) for the upper Late Maastrichtian, 80 were found by him in the former Curfs quarry. In the same section he collected 13 of the 16 species listed by him for the 'Upper Danian'.

The question now arises whether the sudden change and impoverishment in the ostracod assemblages at the Maastrichtian-Palaeocene boundary in this area was a unique event or not. Two different approaches will here be considered: firstly, the change in the number of taxa at the boundary was preceded by another, almost as dramatic a turnover during the Late Maastrichtian. The stratigraphical distribution of ostracods in the upper Cretaceous-Palaeocene deposits of southern Limburg (Deroo, 1966, tab. 6; complemented by personal observations) illustrates that only limited numbers of cytheracean species (say up to 30 species) characterize the Early and Late Campanian, Early and early Late Maastrichtian, as well as the Palaeocene (Dano-Montian) deposits, whereas large numbers of species occur exclusively in the Middle and late Late Maastrichtian sediments (Tab. 1). Thus, if some event induced the disappearance of so many species, another equally important event may have brought about the incoming of new species.



Age		lithostratigraphic units	foram zones (Hofker, 1966)	number of cytheracean species
Montian	Late	Houthem	P-S	22
	Early			22
Danian	Late			16
Maastrichtian	late Late	Nekum-Meerssen	K-M	116
	middle Late	Lanaye-Emael (Kunrade)	F-I (J, O)	123
	early Late	Vijlen-Lixhe	C-E	36
	Early	Beutenaken	B	30
Campanian	Late	Zeven Wegen (Pre-Valkenburg)	A (A'-upper)	24
	Early	Vaals <i>s.str.</i>	A'-lower	10

Table 1. Variations in the number of cytheracean ostracod (sub)species in the Late Cretaceous and Palaeocene of southern Limburg, after Deroo (1966) and Bless *et al.* (1987).

Fig. 1. Selected ostracods from the Early Palaeocene Houthem Chalk (A-M) and latest Maastrichtian Maastricht Chalk (N-U) in southern Limburg (SE Netherlands) and NE Belgium. Metres in Curfs quarry refer to the position of samples above or below the Vroenhoven Horizon (VH), the lithological boundary between the Maastrichtian and the Palaeocene. All illustrated specimens are deposited in the collections of the Natural History Museum at Maastricht.

- A-*Ruggieria pustulosa* (Marlière, 1958). Curfs quarry, 8 m above VH.
 B-*Mosaeleberis canaliculata* (Apostolescu, 1956). KS 17 borehole, 370 m.
 C, F-'*Cythereis' ciplensis* (Marlière, 1958). Curfs quarry, 2.5 m and 0.5 m above VH, respectively.
 D-*Cytheretta nerva montensis* Marlière, 1958. Molenbeersel borehole, 1248.1 m.
 E-*Trachyleberis aculeata* (Bosquet, 1850). Curfs quarry, 4.5 m above VH.
 G, K-*Limburgina ornatoidella fissurata* Deroo, 1966, 'forme géante' of Deroo (1966, pl. 24, figs 734-736). G from KS 16 borehole, 333 m; K from Curfs quarry, 7.5 m above VH.
 H, J-*Limburgina ornatoidella fissurata* Deroo, 1966 (pl. 24, figs 743-746). H from Curfs quarry, 2 m above VH; J from Kastanjelaan-2 borehole, Maastricht, 12 m.
 L, M-*Limburgina bilamellosa bilamellosa* (Marlière, 1958). L from Kastanjelaan-2 borehole, Maastricht, 12 m; M from KS 17 borehole, 370 m.
 N-*Limburgina ornata* (Bosquet, 1847). Curfs quarry, 2.8 m below VH.
 O-*Limburgina bilamellosa depressa* Deroo, 1966. Curfs quarry, 4.8 m below VH.
 P-*Spongicythere celleporacea* (Bosquet, 1854), Curfs quarry, 3.3 m below VH.
 Q-*Sphaeroleberis mosaensis* Deroo, 1966. Curfs quarry, 4.8 m below VH.
 R-*Veentia foersteriana* (Bosquet, 1847). Curfs quarry, 2.8 m below VH.
 S, U-*Mauritsina hieroglyphica* (Bosquet, 1847). Curfs quarry, 1.8 m and 7.8 m below VH, respectively.
 T-*Kingmaina hagenowi* (Bosquet, 1854). Curfs quarry, 0.8 m below VH.

CURFS - SELECTED OSTRACODS

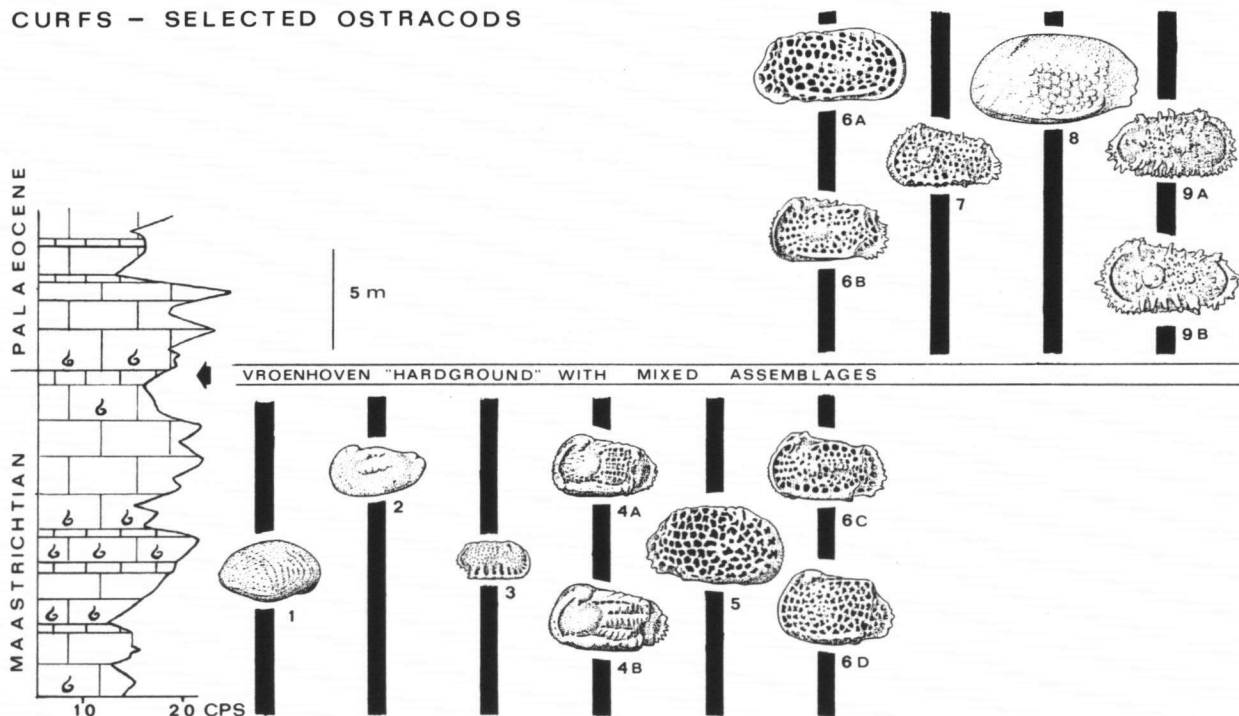


Fig. 2. Distribution of selected ostracod taxa at the M-P (Maastrichtian-Palaeocene) boundary in the former Curfs quarry at Geulhem (near Valkenburg aan de Geul, southern Limburg), based on data from Deroo (1966) and personal observations. Simplified lithological column shows approximate position of main (sometimes rapidly wedging) 'hardgrounds', hard limestones, fossil grit layers and gamma-ray log (in counts per second) according to P.J. Felder & Boonen (1988).

- 1-*Sphaeroleberis mosaensis* Deroo, 1966 (genus disappears at M-P boundary).
- 2-*Veenia foersteriana* (Bosquet, 1847) (genus disappears at M-P boundary).
- 3-*Kingmaina hagenowi* (Bosquet, 1854) (genus re-appears in Eocene of Belgium, see Keij, 1957).
- 4-*Mauritsina hieroglyphica* (Bosquet, 1847), characteristic of the Mediterranean influence in southern Limburg during the Late Maastrichtian (genus disappears at M-P boundary).
- 5-*Spongicythere celleporacea* (Bosquet, 1854) (genus reappears in the Eocene of North America, see Howe, 1951).
- 6-*Limburgina* spp. (genus common in both Maastrichtian and Palaeocene strata in southern Limburg, but represented by different taxa at specific or subspecific level).
 - 6A-B-*Limburgina ornatoidella fissurata* Deroo, 1966.
 - 6C - *L. ornata* (Bosquet, 1847).
 - 6D - *L. bilamellosa depressa* Deroo, 1966.
- 7-*Trachyleberis aculeata* (Bosquet, 1850) (genus possibly already present in Late Maastrichtian, see Deroo, 1966).
- 8-*Ruggieria pustulosa* (Marlière, 1958) (genus appears in Palaeocene, see Deroo, 1966).
- 9-'*Cythereis*' *ciplyensis* (Marlière, 1958) (generic position not clear, species characterizes Palaeocene in southern Limburg and adjacent areas, as well as in the Mons area and in Denmark).

Mixed assemblages of Maastrichtian and Palaeocene species in the Vroenhoven 'hardground' are explained by the presence of burrows with an infill of overlying Palaeocene sediment in this latest Maastrichtian indurated chalk.

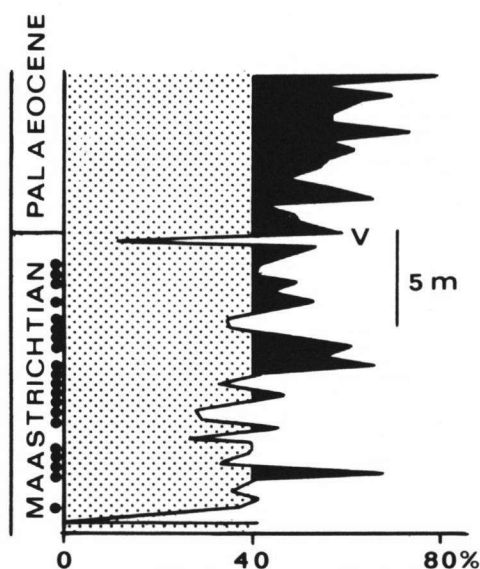


Fig. 3. Frequency profiles of ornamented ostracods (in percentages) in assemblages in the section of the former Curfs quarry at Geulhem.

Note that the relative abundance of ornamented specimens does not markedly change at the boundary, although there is a radical change in the qualitative composition of the assemblages at the specific or subspecific level.

Black dots to the left indicate presence of *Mauritsina hieroglyphica* (Bosquet, 1847) in the latest Maastrichtian. 'Hardgrounds' below the Vroenhoven Horizon (V) at the K-T boundary and near the base of the section are marked by very small numbers of ornamented ostracods indeed.

The second approach consists in a comparison of the mean percentage of ornamented species in the ostracod assemblages, a method developed by Bless *et al.* (1983). It is based on the assumption that ornamented ostracods¹ may occur in larger numbers in nearshore and/or shallow facies than in offshore and/or deep facies, because their test might be more resistant to high-energy environments than that of smooth-shelled (and often also thinner shelled) ones. It is of course realized that such statements are oversimplifications; but, whatever the cause may be, it has been demonstrated statistically that the relative number of ornamented specimens in the ostracod assemblages (expressed in percentages) tends to increase in glauconitic, siliciclastic and/or more coarse-grained carbonate deposits in the Late Cretaceous and Palaeocene of this area.

This variation in the percentage of ornamented ostracods is independent of the variation in the species diversity of the assemblages. For example, the number of ornamented taxa diminished dramatically at the Maastrichtian-Palaeocene boundary in southern Limburg, even when compared with that of the smooth-shelled ones. However, in this same interval, the relative number of ornamented specimens remains constant and even tends to show a slight increase (Fig. 3).

Similarly, the absolute and relative number of ornamented ostracod taxa increases distinctly at the boundary between the Early and Late Campanian, but the relative number of ornamented

¹ One might argue that it is sometimes difficult to distinguish between ornamented and smooth-shelled ostracod taxa. Therefore, a list of genera which are 'by definition' smooth or ornamented was presented by Bless *et al.* (1983, 1987), with the aim of creating a repeatable method.

specimens usually drops remarkably (see Bless, 1988; Bless *et al.*, 1988). Apparently, this change is linked to an important change in the sedimentary environment, as illustrated by the 'Vaals Greensand' and 'Zeven Wegen Chalk' in the CPL quarry at Haccourt, some 8 km South of Maastricht (Bless, 1988, fig. 2). It is only within the Late Maastrichtian sequences, at the boundary between the early and middle Late Maastrichtian (Bless *et al.*, 1987), that a distinct increase in both species diversity and the relative number of ornamented ostracod specimens can be noted.

Thus, it can be concluded that the abrupt change in the composition of the ostracod assemblages at the Maastrichtian-Palaeocene boundary is certainly not a unique event in the Late Campanian-Palaeocene sequence in southern Limburg and contiguous areas.

POSSIBLE CAUSES FOR EVENTS IN SOUTHERN LIMBURG

As discussed above, three major events affected the ostracod assemblages in southern Limburg during the Late Cretaceous-Early Tertiary (Fig. 4). The first event (Event 1) took place somewhere between the Early and Late Campanian, and is marked by an important sedimentary gap (several macrofaunal zones are missing; Jagt, 1988), by an increased diversity of ostracod taxa (increased number of cytheracean species, appearance of at least six species of *Cytherelloidea*; compare Deroo, 1966 and Bless, 1988), and by a decrease in the relative number of ornamented specimens in assemblages despite the higher diversity of ornamented taxa (Bless, 1988; Bless *et al.*, 1988). In the Early Campanian 'Vaals Greensand' of southern Limburg (glauconitic clays and marls), assemblages are frequently dominated by specimens of the ornamented taxa *Cythereis*, *Veenia* and *Pterygocythere*. These taxa may also be present in the Late Campanian of the region, but in much smaller numbers and then especially in the so-called 'Pre-Valkenburg' deposits (glauconitic, marly to occasionally sandy sediments). In the Late Campanian 'Zeven Wegen Chalk' of this area (fine-grained calcilitites to calcisiltites), the assemblages are usually dominated by (increasing percentages of) smooth-shelled taxa such as *Cytherella*, *Bairdia*, 'Paracypris' and *Sphaeroleberis* (*sensu* Deroo, 1966 = *Physocythere sensu* Herrig, 1966), although there is a markedly higher diversity amongst ornamented taxa such as *Bythoceratina*, *Cuneoceratina*, *Curfsina*, *Mosaeleberis*, *Limburgina*, *Cytherelloidea* and other taxa (Deroo, 1966; Bless, 1988).

These Early and Late Campanian ostracod assemblages are also found elsewhere in the Late Cretaceous boreal realm. Compare, for instance, the frequency and diversity of *Bythoceratina* and *Cytherelloidea* in chalk deposits of the Germanies (Hemmoor: Clarke, 1983; Rügen: Herrig, 1966) and the frequent association of *Cythereis*, *Veenia* and *Pterygocythere* in glauconite-rich marls and clays of the West-German Münster Basin (Bless & Robaszynski, 1988).

The second event (Event 2 in Fig. 4) took place during the Late Maastrichtian, and is marked by the massive invasion of cytheracean taxa in particular, with many of them having Mediterranean or Tethyan affinities, and by a distinct increase in the relative number of ornamented specimens (Deroo, 1966; Liebau, 1978; Bless *et al.*, 1987). This sudden appearance of Mediterranean elements can be noted in ostracod assemblages, as well as among benthic foraminifers (Hofker, 1966), echinoids (van der Ham *et al.*, 1987; Jagt, 1988), serpulids (Jäger, 1988) and reptiles [giant turtles, such as *Allopleuron hoffmanni* (Gray, 1831)]. This rapid reorganisation from exclusively boreal into mixed boreal-Mediterranean faunas is somewhat difficult to pinpoint in the sedimentary record. However, it seems reasonable to place the onset of this faunal turnover somewhere between the times

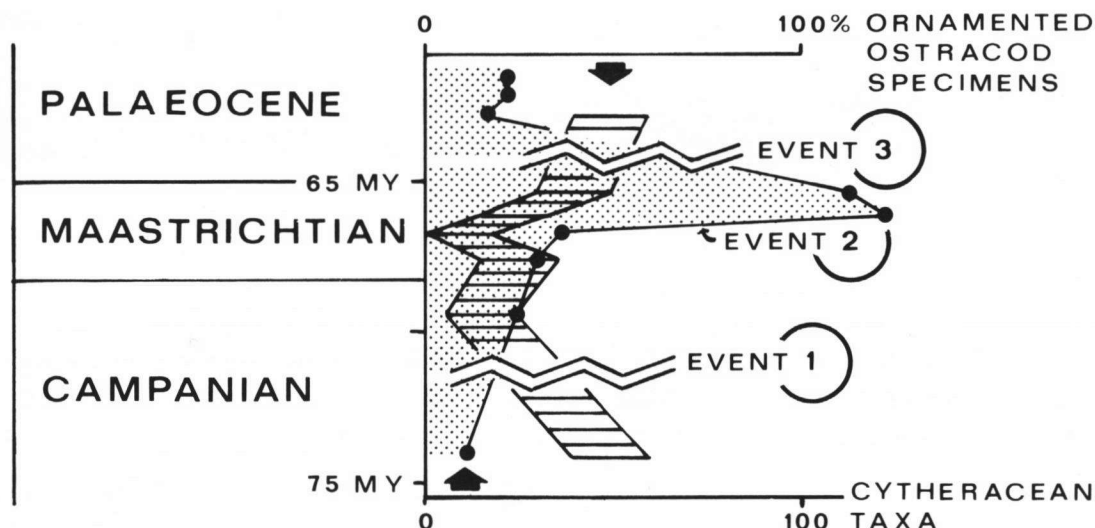


Fig. 4. Graph showing the change in diversity of cytheracean ostracod taxa from the Early Campanian into the Palaeocene in southern Limburg (after Deroo, 1966 and Bless *et al.*, 1987) compared with the variation in mean percentage of ornamented specimens in assemblages (based on personal observations). Three main ecostratigraphic events are distinguished.

Event 1 took place between the Early and Late Campanian and resulted in a distinct reduction in the percentage of ornamented specimens, although the number of cytheracean (and also other, such as *Cytherelloidea*) taxa increased considerably. This event is marked by an important gap in the sedimentary record.

Event 2 occurred during the Late Maastrichtian (time of deposition of upper Lixhe and lower Lanaye Chalks, *Belemnitella* junior Zone), and is characterized by the sudden, massive appearance of Mediterranean taxa, such as *Mauritsina hieroglyphica*, as well as by an increase in the mean percentage of ornamented specimens in the assemblages. Presumably, this event is distinguished more clearly in the so-called Kunrade facies than in the Gulpen-Maastricht facies.

Event 3 is situated at the K-T boundary and is distinguished by a dramatic impoverishment in the diversity of cytheracean taxa as well as by a total change of these taxa at the specific or subspecific level. There is no noticeable change in the percentage of ornamented specimens. The geological time table used here is after van Eijsinga (1978).

of deposition of the upper Lixhe Chalk and the lower Lanaye Chalk (*sensu* W.M. Felder, 1975), as applied in the ENCI quarry at Maastricht. This faunal change is assumed to have been completed earlier in the so-called Kunrade environment than in the classic (and possibly more offshore) Maastricht facies.

Most astonishingly, Event 2 is not characterized by an apparent depositional interruption, at least not in the Maastricht area (ENCI quarry). However, there are indications that the Mediterranean invasion coincided with the moment that the influx of siliciclastics from the, at that time inverted, Rur Valley Block came to an end (Bless *et al.*, 1987, 1988). It is quite possible that this and other inverted blocks in The Netherlands and in Germany had become drowned to such an extent that they no longer functioned as active sources for siliciclastics, and that an open connection had been created between the boreal and Mediterranean realms from the Aquitaine and Paris Basins in the South, through southern Limburg and adjacent areas into Denmark in the North (Kauffman, 1984).

The massive northward migration of Mediterranean elements at the end of the Maastrichtian is well illustrated by the ostracod genus *Mauritsina*. In the Mediterranean realm, this genus is already present in the Albian or Cenomanian, but it does not invade southern Limburg until the Late Maastrichtian (Fig. 5). The type species, *M. hieroglyphica* (Bosquet, 1847) lived much earlier in the Aquitaine and Paris Basins than in southern Limburg. One might suggest that this was due to less favourable (colder ?) conditions in the boreal realm. However, the frequent presence of at least six different species of the distinctly thermophilic (see e.g. Clarke, 1982, 1983; Kemper, 1987) ostracod genus *Cytherelloidea* in the Late Campanian of this area (Fig. 6, compare also Bless, 1988) illustrates that the water temperature may have been high enough for Mediterranean faunas. Apparently, physical barriers—such as the ones created by inversion tectonics in The Netherlands (Rur Valley Block etc.)—prevented their northward migration until these were inundated during the Late Maastrichtian. Whether this inundation was caused by relaxation of active (upward) inversion move-

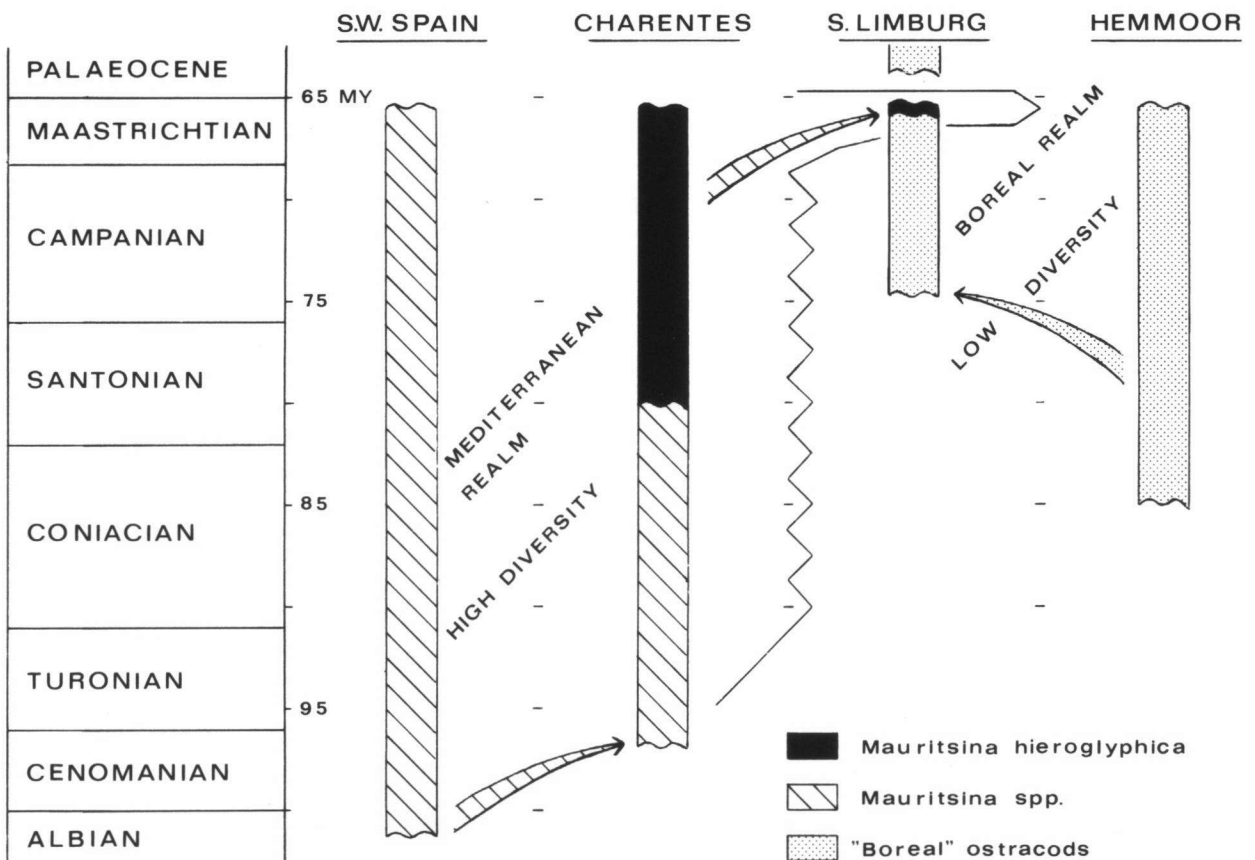


Fig. 5. Transitory northward extension of Mediterranean influence into the Limburg basin during the latest Maastrichtian, illustrated by the distribution of the ostracod genus *Mauritsina*.

In the Mediterranean realm, the genus appeared near the Albian-Cenomanian transition. In the Charentes (SW France), *M. hieroglyphica* occurred already during the Early Santonian, but it did not invade southern Limburg until the latest Maastrichtian, in spite of the fact that the epicontinental sea had presumably extended from the Charentes through the Paris Basin into Limburg since the Early Campanian (see Babinot *et al.*, 1985, figs 30-31). *Mauritsina* disappeared at the start of the Palaeocene when epicontinental seas became strongly reduced in their lateral extension, and Mediterranean influence and connections were replaced by oceanic (Atlantic) ones. The geological time table used here is after van Eijsinga (1978).

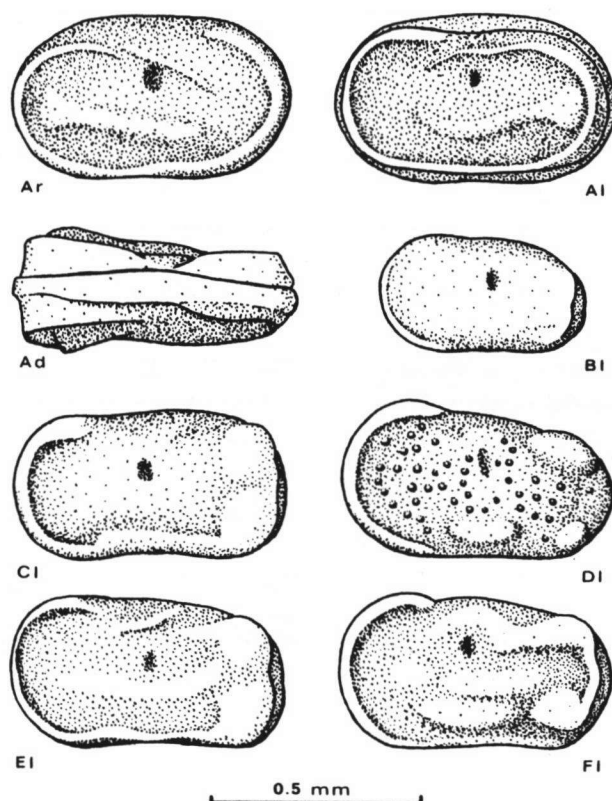


Fig. 6. *Cytherelloidea* species from the Late Campanian of southern Limburg and NE Belgium. Abbreviations used: r = right view, l = left view; d = dorsal view.

A-*Cytherelloidea binkhorsti* van Veen, 1932. Merksplas borehole, 967.12 m.

B-*C. levigata* Herrig, 1963. Diets-Heur borehole, 49-51 m.

C-*C. sp.* Hombourg borehole, 43 m.

D-*C. granulosa* (Jones, 1849). CPL quarry, Haccourt, 5 m above base of Zeven Wegen Chalk.

E-*C. obliquirugata* (Jones & Hinde, 1890). Hombourg borehole, 37 m.

F-*C. aff. binoda* Clark, 1982. Hombourg borehole, 43 m.

All specimens are housed in the collections of the Natural History Museum at Maastricht.

ments, by transitory downwarp of inverted blocks, by eustatic sealevel rise, or by a combination of these mechanisms remains an open question.

Whether or not this event was strengthened by improving climatic conditions is impossible to establish on the basis of the present analysis. However, it is felt that the model as here proposed does not need the support of palaeoclimatic variations, as unhindered northward-moving currents from the Mediterranean into the boreal realm might have been sufficient in this case.

The third event (Event 3 in Fig. 4) is situated at the boundary between the Maastrichtian and the Palaeocene. Just like Event 1, it is marked by an important stratigraphic gap, covering the latest Maastrichtian and at least part of the Early Danian (Hofker, 1966; Deroo, 1966; Jagt, 1988). The timespan involved in this gap is of the same order as that of the first event between the Early and Late Campanian, irrespective of the chronological scales used as reference. The time table of van

Eijsinga (1978) is here used (Figs 4 and 5), but it should be noted that, according to other authors, the Maastrichtian lasted a few millions years longer, whereas the Coniacian in particular had an extremely short duration (Odin, 1983; Palmer, 1983).

In southern Limburg and contiguous areas, there is no sign of a clayey deposit at the Maastrichtian-Palaeocene boundary (Vroenhoven Horizon). The gamma-ray log of the former Curfs quarry (Fig. 2) does not show any remarkable changes near this horizon. Therefore, comparisons with the famous iridium-rich clay beds at the K-T boundary in *e.g.* Spain (Playa de Zumaya) or Italy (Gubbio), which have been attributed to extraterrestrial causes by some authors (see *e.g.* Alvarez *et al.*, 1980) are not possible.

As stated above, the passage from the Maastrichtian into the Palaeocene in southern Limburg and adjacent areas is also characterized by a drastic reduction in the number of cytheracean ostracod taxa (116 species in the uppermost Maastrichtian deposits and only 16 in the basal part of the Palaeocene Houthem Chalk), and a total change in the cytheracean ostracod assemblages at the (sub)specific level. However, the relative number of ornamented ostracod specimens slightly increases above this boundary (Fig. 3).

The rather low diversity and relatively large number of ornamented specimens in these Palaeocene assemblages show a strong resemblance to those of the Early Campanian of this area (Fig. 4), in spite of the differences in their qualitative composition or in the sediments in which they occur (Houthem Chalk *versus* Vaals Greensand).

The small number of species in the Campanian to early Late Maastrichtian has above been interpreted as a 'boreal' character. Consequently, the small number of Palaeocene taxa would illustrate the return of 'boreal' conditions during this interval. This implies that seaways linking the cold-water boreal and the warm-water Mediterranean realms during the latest Maastrichtian, must have been closed again. Presumably, this was induced by Early Danian sea level fall, coupled with tectonic (early laramid) movements and regional regressions in western Europe, thus again creating physical barriers between these domains. As a result, the northward-moving warm water currents from the Mediterranean were cut off. The influence of the Russian Platform seas and the North Atlantic rapidly increased instead.

The Atlantic influence is particularly illustrated by the relative frequency of globular and keeled planktonic foraminifers (*Globigerina*, *Globorotalia*; see Hofker, 1966) in the Houthem Chalk. In this context, it should be noted that planktonic foraminifers are also common in certain Late Cretaceous strata, notably in glauconitic greensand facies (Santonian of the West-German Münster Basin and the Early Campanian of southern Limburg; see Bless & Robaszynski, 1988), but also in the early Late Maastrichtian Vijlen Chalk of southern Limburg (Robaszynski, 1988). The regular incursion of planktonic foraminifers in the Late Cretaceous and Early Palaeocene carbonate platforms of western Europe is most likely due to the upwelling of cold water from the Atlantic [possibly induced by tectonic pulses of the spreading sea-floor (?)] (Robaszynski, 1988). The relatively large number of ornamented ostracods in the Palaeocene Houthem Chalk is here interpreted as denoting that the water energy during its deposition was roughly comparable to that during the latest Maastrichtian or Early Campanian in the same area. This does not, however, necessarily imply comparable water depths !

CONCLUSIONS

Whatever may have happened at the K-T boundary, the extinction of many ostracod taxa at this level may be simply explained by the rapid eustatic sea level fall during the Early Danian, causing worldwide regressions and related extreme reduction or disappearance of many shallow-marine, warm water ecological niches. The transitory Late Danian transgressions must have been associated with widespread upwelling of cold, oceanic water from the Atlantic, leaving its mark in the form of rich planktonic foraminifer assemblages and 'boreal' ostracod faunas of low diversity.

The three events distinguished here in the Campanian-Palaeocene sequence in southern Limburg are not necessarily linked to global climatic variations. The changes in the ostracod fauna during the first event can be explained by regional changes in the sedimentary environment within the boreal realm, presumably induced by differential movements of the block-faulted basin. Increased diversity of the ostracod assemblages (with appearance of several species of the thermophilic genus *Cytherelloidea*) in the Late Campanian Zeven Wegen Chalk suggests the establishment of a shallow-marine, warmer carbonate environment at some distance from the inverted Rur Valley Block during the Late Campanian.

Planktonic foraminifers, which are relatively common in the glauconitic greensands of the Early Campanian Vaals Formation, are rather rare in the Zeven Wegen Chalk. This suggests that cold upwelling water from the Atlantic could, for some reason or other, no longer reach this area.

The second event during the Late Maastrichtian was caused by the opening of a seaway between the Mediterranean and boreal realms, permitting the massive northward migration of many Mediterranean or Tethyan ostracods such as *Mauritsina hieroglyphica*. Because of the gradual shallowing of the sedimentary environment in southern Limburg during the latest Maastrichtian, more and more Mediterranean taxa could occupy a suitable niche in the increasingly warmer water.

Finally, the third event at the K-T boundary caused the closure of the marine connection with the Mediterranean, the destruction of practically all shallow-marine, warm-water niches and the extinction of their occupants. The Late Danian transgressions were coupled again with widespread upwelling of cold, oceanic water, as illustrated by the relative abundance of planktonic foraminifers in the Houthem Chalk, and by the low diversity of the ostracod assemblages, resembling those of the Campanian-Maastrichtian boreal deposits in the same area. In this context, it may be appropriate to point out the more diverse Eocene ostracod assemblages in Belgium (Keij, 1957), since these include taxa such as *Kingmaina*, a genus that disappeared at the end of the Maastrichtian in southern Limburg, but returned in the Eocene, when the seaway to the South was restored again (compare Ziegler, 1982).

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