

## EVENT-INDUCED CHANGES IN LATE CRETACEOUS TO EARLY PALEOCENE OSTRACODE ASSEMBLAGES OF THE SE NETHERLANDS AND NE BELGIUM<sup>1</sup>

by

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(10 figures)

**RESUME.-** Des assemblages d'ostracodes du Crétacé récent au Paléocène ancien du sud-est des Pays-Bas et d'aires voisines en Belgique ont montré des changements qualitatifs et quantitatifs en relation avec plusieurs événements. Le premier changement a pris place entre les Campaniens ancien et récent et est marqué par l'apparition de plusieurs nouveaux taxa dans cette région, beaucoup appartenant au genre *Cytherelloidea* et aux bythoceratinae. L'événement qui a produit cette évidente diversification peut avoir été soit un approfondissement de la mer, soit un réchauffement de l'environnement marin.

Le deuxième changement important au milieu du Maastrichtien récent semble lié au relâchement de la tectonique d'inversion régionale et à une incursion massive concomitante d'éléments de la Téthys.

Enfin, le troisième événement, à la limite Maastrichtien-Danien (Crétacé-Tertiaire), se reconnaît à un changement pratiquement complet des espèces et à la disparition de quatre-vingt pourcents des genres d'ostracodes du Maastrichtien récent de la région. Cependant, au moins cinquante pourcents de ces genres ont survécu ailleurs dans le nord de la Téthys. Ceci indique que le changement drastique des faunes d'ostracodes du sud-est des Pays-Bas résulte de modifications dans l'environnement régional du nord-ouest de l'Europe et non d'un événement produisant une extinction globale massive.

**ABSTRACT.-** Late Cretaceous to Early Paleocene ostracode assemblages in the SE Netherlands and contiguous areas of Belgium underwent several event-induced changes in their qualitative and quantitative composition. The first change took place between the Early and Late Campanian and is marked by the appearance of several new taxa, many of which belong to *Cytherelloidea* and Bythoceratinae. The event causing this obvious diversification may have been either a deepening of the sea or a warm-up of the marine environment.

The second important change during the mid-Late Maastrichtian seems related to the relaxation of regional inversion tectonics and a concomitant massive invasion of Tethyan elements.

Finally, the third event at the Maastrichtian-Danian (Cretaceous-Tertiary) boundary is distinguished by a practically complete species turnover and the disappearance of eighty percent of the Late Maastrichtian ostracode genera from the area. However, at least some fifty percent of these genera survived elsewhere in the northern Tethys. This illustrates that the drastic change in the ostracode faunas of the SE Netherlands was caused by changes in the regional environment of NW Europe and not by a massive, global extinction event.

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## INTRODUCTION

The intricate interaction of eustatic sea level fluctuations and differential, synsedimentary movements of the block-faulted basement has resulted in frequent lateral changes in thickness and lithofacies, and numerous, important sedimentary gaps in the Late Cretaceous to Early Paleocene deposits of South-Limburg (SE Netherlands) and the Campine area (NE Belgium).

These have been detected by the more refined biostratigraphic (e.g. Jagt, 1988; Batten *et al.*, 1988), ecostratigraphic (e.g. Felder *et al.*, 1985; Dusar *et al.*, 1987; Bless *et al.*, 1987; Bless, 1988a,b) and seismostratigraphic (e.g. Rossa, 1987; Demyttenaere, 1988) methods developed and applied during the past decade.

As a result of this recent research, we now distinguish at least ten different areas in NE Belgium and the SE Netherlands (fig. 1), each of these being characterized by its own structural and depositional history. Comparison of the successions in, for example, the Maastricht, Valkenburg and Kunrade areas in South-Limburg (fig. 2) readily shows these differences. But figure 2 also displays some of the many questions that remain, notably as to the exact biostratigraphic dating of the Danian (foram zone P) and Early Campanian (foram zone A'-middle). Moreover, it should be borne in mind, that the classic biostratigraphic subdivision of the (boreal) Campanian and Maastrichtian in the Hemmoor-Kronsmoor-Lägerdorf area (S of Hamburg, FRG; cf. Schulz *et al.*, 1984) seems to be incompletely represented in the SE Netherlands (fig. 2, column «Hemmoor zones», adapted from Jagt, 1988).

Correlation of this subdivision with the regional ecostratigraphic foram (fig. 2, column «foram zones», adapted from Hofker, 1957, 1966, and Bless *et al.*, 1987) and ostracode (fig. 2, column «characteristic ostracodes», based on Deroo, 1966, and unpublished data of present author) zonation is based on a rather limited number of detailed observations (notably summarized in Jagt, 1988; compare also Bless *et al.*, 1988).

This is easily explained by the fact that only a few outcrops remain from which macrofossils can be collected bed by bed. However, the «Hemmoor» zonation is partly based on the biometric analysis of macrofossils, such as echinoderms and molluscs. For the regional correlations in NE Belgium and the SE Netherlands, microfossils such as benthic foraminifera and ostracodes are used, which often abound in the cores and cuttings of boreholes, as well as variations in the frequency profiles for bioclasts, ostracodes and forams, and changes in the gamma ray logs.

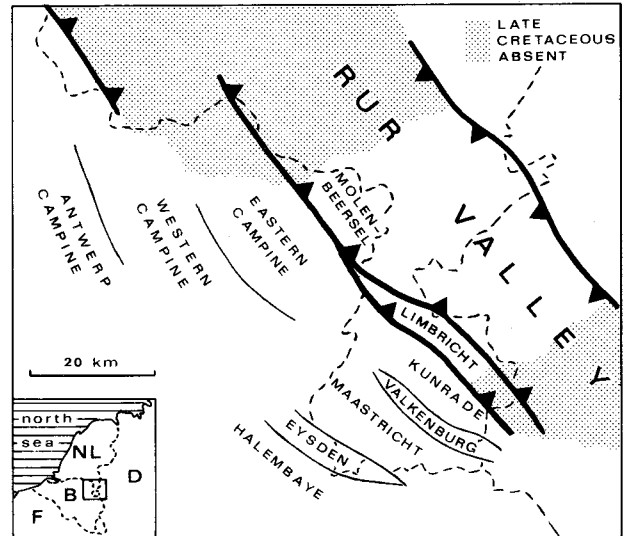


Fig. 1.- Location map of study area in NE Belgium and the SE Netherlands showing segmentation of area south of the Rur Valley Block during the Late Cretaceous (partly after Felder *et al.*, 1985, and Bless, 1988a). Each segment is characterized by its own structural and sedimentary history. Presumably, the limits between these segments were formed by synsedimentary faults.

The objective of this report is to analyse and interpret the three major, qualitative and quantitative changes in the ostracode assemblages (fig. 3), and compare these with changes in the lithofacies, biomass (expressed in terms of relative abundance of special groups of bioclasts in the sieve fraction 1.0-2.4 mm) and foram assemblages.

The first of these changes coincides with the widespread sedimentary gap between the Early and Late Campanian, and is further on referred to as the «Campanian ecoevent».

The equally widespread sedimentary gap between the Campanian and Maastrichtian (the Early Maastrichtian is frequently either missing or incompletely represented as condensed sequences) is only marked by a change at the species level. This minor event (possibly related to deepening of the sea) is not further considered here.

The second major change in the ostracode assemblages occurs within the Late Maastrichtian, in an apparently uninterrupted sedimentary succession, and is referred to as the «Late Maastrichtian ecoevent».

The third change took place near the Maastrichtian-Danian boundary, where there exists again a widespread sedimentary gap of unknown magnitude. This change is referred to as the «Maastrichtian-Danian ecoevent».

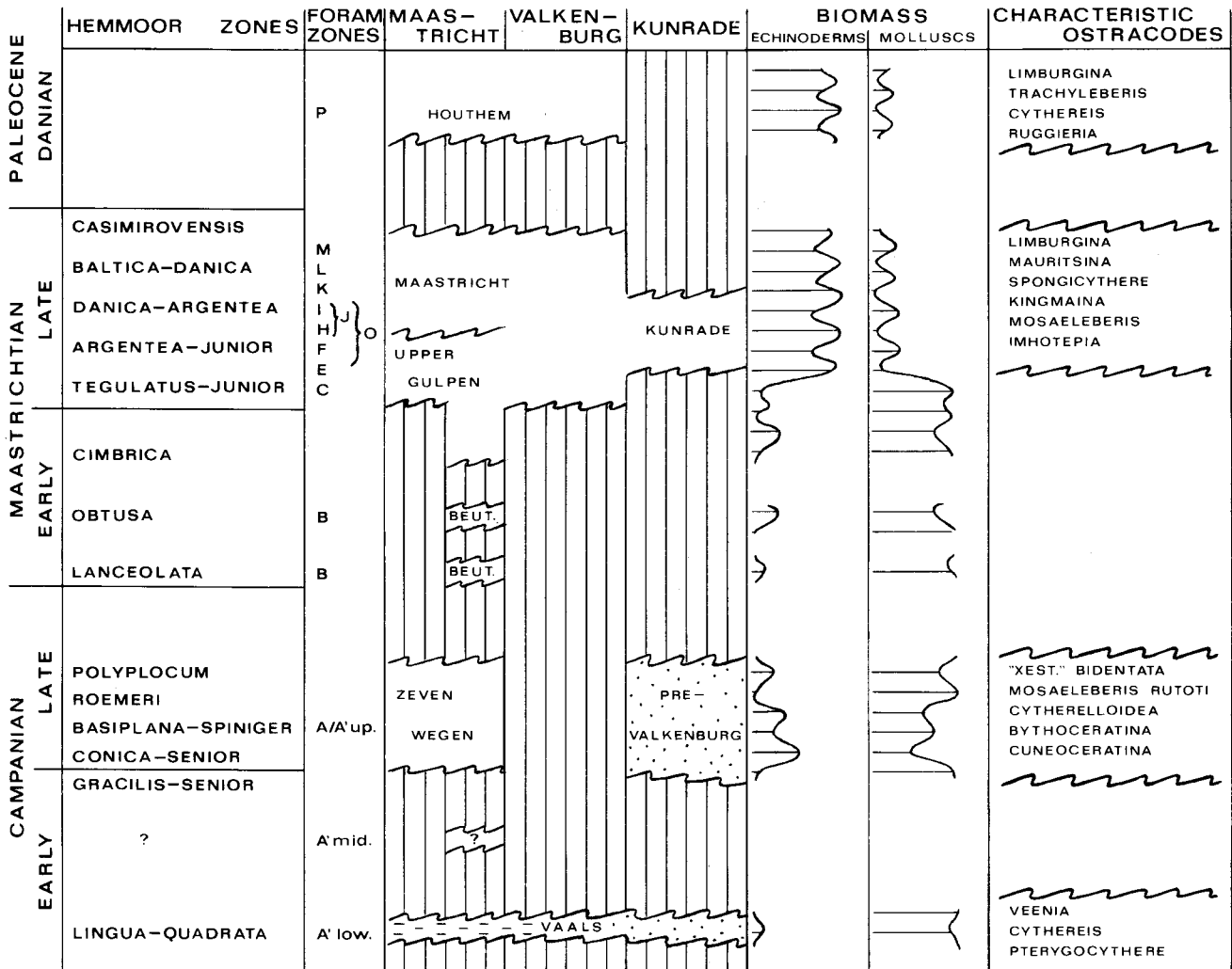


Fig. 2.- Correlation of strata exposed in the SE Netherlands (Maastricht, Valkenburg and Kunrade areas) with the classic biozonation of Hemmoor-Kronsmoor-Lägerdorf («Hemmoor» zones) in NW Germany (only those Hemmoor zones are indicated which have been recognized in SE Netherlands; cf. Jagt, 1988), and with regional benthic foram zones (Hofker, 1957, 1966; Bless *et al.*, 1987). Some characteristic ostracode taxa and variations in the composition of the biomass (here expressed as the sum of all bioclasts between 1.0 and 2.4 mm) are shown. Note that the Houthem Formation is not indicated in the column for the Kunrade area *sensu stricto*, although it is present in the northwestern part (e.g. Maurits Shafts; cf. Deroo, 1966).

## CAMPANIAN ECOEVENT

The first important change in the ostracode assemblages coincides with a sedimentary gap between the Early and Late Campanian, presumably covering some five to six «Hemmoor» zones (*pilula* to *conica-gracilis* or *gracilis-senior* zones; cf. Jagt, 1988). Accepting a total duration of 12 MA for the Campanian (between 83 and 71 MA according to Haq & Van Eijsinga, 1987) and equal duration for each of the fourteen Hemmoor zones, some 4 to 5 MA would be missing in the sedimentary record. Whether or not this gap is locally partly filled by deposits of the A'-middle foram zone (observed e.g. in Maastricht area, Kastanjelaan borehole; cf. Bless *et al.*, 1981) is an as yet unsolved problem.

This gap is usually marked by a change in the lithofacies: glauconitic sands, silts and clays frequently dominate in the Early Campanian, while calcilutites and glauconitic (sometimes sandy) marls characterize the Late Campanian (fig. 4).

There is no apparent change in the biomass, here expressed as the sum of all bioclasts (whether natural or artificial) between 1.0 and 2.4 mm (size limits determined by mesh size of commercially available sieves), notwithstanding the important Late Campanian diversification at the species and genus level of, for instance, the echinoid assemblages (cf. Van der Ham *et al.*, 1987). Alternately, molluscs and echinoderms predominate in both Early and Late Campanian, not only in the number of specimens, but also in

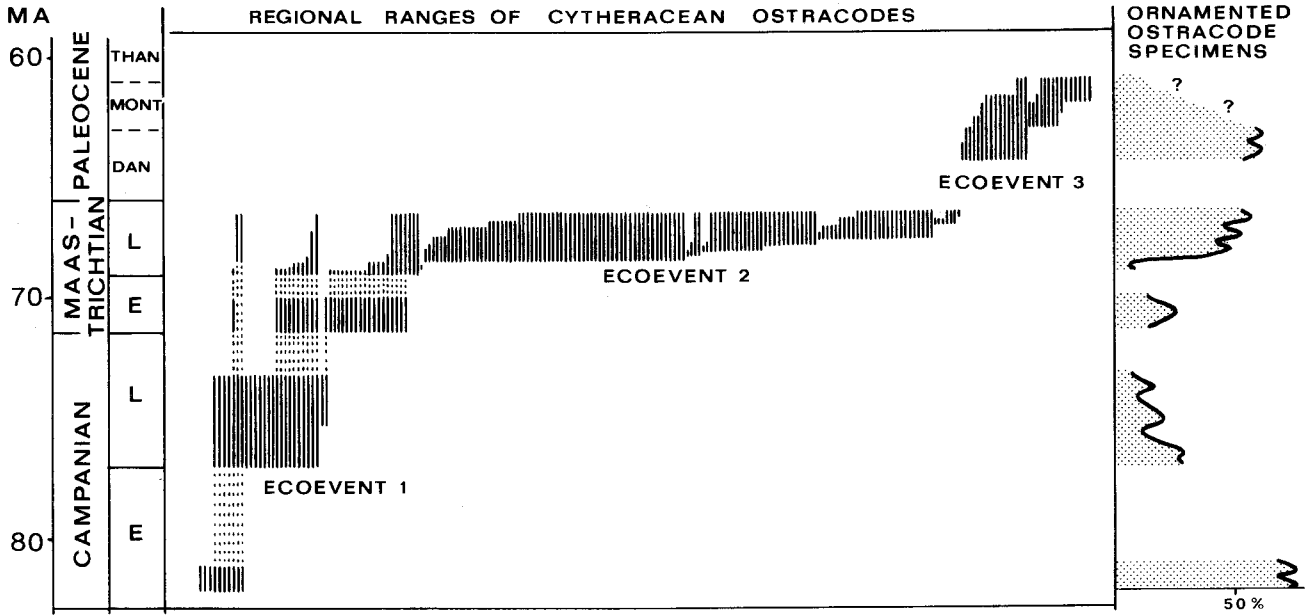


Fig. 3.- Chronoecological graph for Campanian to Paleocene showing durations of Cytheracean ostracode species and subspecies in the SE Netherlands and adjacent areas (partly based on Deroo, 1966), compared with frequency profile for ornamented ostracode specimens. Range lines stand for single ostracode species or subspecies. The species turnover between the Late Campanian and Early Maastrichtian is not considered here as the result of a special event, this in contrast to the appearance of species in the Late Campanian, which is largely due to the entry of genera (notably Bythoceratinae; but also the non-Cytheracean *Cytherelloidea*) which are practically absent in the Early Campanian deposits of this region.  
Time scale from Haq & Van Eijsinga (1987).

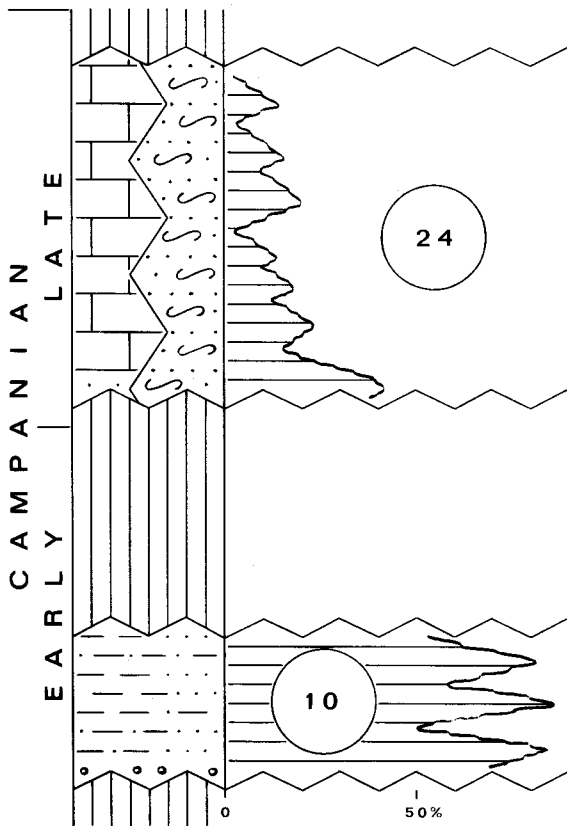


Fig. 4.- Simplified lithostratigraphy of Campanian in NE Belgium and SE Netherlands with idealized frequency profile for ornamented ostracode specimens. Encircled is the number of species or subspecies in the superfamily Cytheracea.

the number of species (Bless *et al.*, 1987). In both the Early and Late Campanian, cephalopods (belemnites, nautiloids and ammonoids) preferably occur concentrated in some beds of condensed sedimentation. Notably the cephalopods and echinoids permit a detailed correlation with the NW European «Hemmoor» biozonation (Jagt, 1988). This indicates that during the entire Campanian timespan the SE Netherlands and NE Belgium formed part of the Boreal province.

The basal conglomerate of the Early Campanian Vaals Formation shows that this represents the onset of the Campanian transgression in this region, and thus that it was probably deposited in a relatively shallow, nearshore environment. This is also indicated by the frequent occurrence of fish remains (cf. Felder *et al.*, 1985). The common presence of small numbers of planktonic foraminifera (both globular and keeled forms) suggests the influx of oceanic upwelling water (Robaszynski, 1988). Kemper (1982, 1987a) believed that many Cretaceous glauconitic «greensands» might have been deposited in a cold, upwelling-water environment.

The Early Campanian ostracodes in this region are characteristic of the glauconitic clays and silts of the NW European Late Cretaceous, irrespective of their age (Bless & Robaszynski, 1988). Among the genera with an ornamented carapace *Veenia*, *Cythereis* and *Pterygocythere* (fig. 2), and among those with a smooth carapace *Bairdia* and

*Cytherella* dominate. Ornamented ostracode specimens (not species) frequently abound, forming up to 80 % of the total ostracode assemblage in some beds (fig. 4). This suggests a rather shallow-water facies, above the «pterygocline» (upper bathymetric limit of distribution for ostracodes which avoid wave action or currents; Liebau, 1980), since the frequently thick-shelled, ornamented ostracodes would be better adapted to high-energy environments (Bless *et al.*, 1983, 1987).

A spectacular change takes place in the ostracode assemblages above the sedimentary gap. The number of species and genera increases considerably (for example, from 10 to 24 species in the superfamily *Cytheracea*), especially that of taxa with an ornamented carapace. However, this relative and absolute increase in the diversity of ornamented species (most of them belonging to the Bythoceratinae and the genus *Cytherelloidea*; fig. 5) is not reflected in the number of ornamented ostracode specimens. On the contrary, their percentage clearly decreases and rarely exceeds 20 % (fig. 4; Bless, 1988a), indicating a quiet-water, possibly sheltered environment.

The genera and species of Late Campanian ostracodes in this region are characteristic of the Late Cretaceous chalk deposits of NW Europe (cf. Herrig, 1966; Jorgensen, 1979; Clarke, 1983). Thus, these confirm the boreal character of the faunas. Therefore, the change in the lithofacies and faunas took place within the Boreal realm.

The passage from glauconitic siliciclastics into marls and calcilutites is commonly interpreted as a transgressive sequence, and therefore related to a deepening of the environment. In favour of this model are the coccolith-rich Late Campanian Zeven Wegen Chalk (cf. Bless & Streel, 1988), the usually rather small number of ornamented ostracode specimens (frequently less than 20 %) and the relative frequency and diversity of the genera *Pterygocythereis*, *Bythoceratina* and *Cuneoceratina*.

Modern *Pterygocythereis jonesii* usually occurs below 60 to 100 m below sea level off the southwestern coast of France (Liebau, 1980) and between 100 and 300 m in several parts of the Mediterranean (Van Harten & Droste, 1988). Modern Bythoceratinae live between 220 and 1034 m off the southeastern coast of the USA (Cronin, 1983).

However, in more protected environments, *Pterygocythereis jonesii* may occur in water depths of less than 30 m, occasionally even less than 10 m (Liebau, 1980). Apparently, the storm wave base determines the upper bathymetric limit of distribution of this and other «cymatophobic»

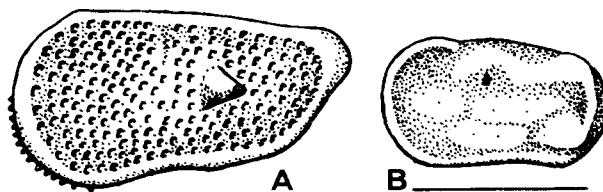


Fig. 5.- Examples of characteristic Late Campanian ostracode taxa.

A: *Cuneoceratina pedata* (Marsson, 1880), a representative of the Bythoceratinae, which preferably live below the «pterygocline» (Liebau, 1980) in low-energy environments. Bythoceratinae are common in the Zeven Wegen Chalk, but practically absent in the Pre-Valkenburg sandy marls. B: *Cytherelloidea* aff. *binoda* Clarke, 1982, a representative of the genus *Cytherelloidea* that has its optimal distribution in shallow (less than 35 m), relatively warm subtropical to tropical seas. *Cytherelloidea* is common in the calcilutites of the Zeven Wegen Chalk and rare in the sandy marls of the Pre-Valkenburg lithofacies.

Bar represents 0.5 mm.

ostracodes (Liebau, 1980). Likewise *Bythoceratina* is not always limited to deep-water facies, as shown by its presence in 10 to 30 m deep water around a recent reef in the Java Sea (Whatley & Watson, 1988). Moreover, Simien (1987) described a modern coccolith-rich carbonate on top of silty to sandy clays from the Southern Belize Lagoon (Caribbean Sea), where water depths are less than 40 m. The small number of ornamented ostracode specimens might rather point to a more or less sheltered environment.

On the other hand, the relative frequency and diversity (at least six species; Bless, 1988a) of the strongly thermophilic (Kemper, 1987b) ostracode *Cytherelloidea* suggests a rather warm (subtropical to tropical according to personal communication of Hartmann in Clarke, 1982) and shallow (optimum depth for modern *Cytherelloidea* less than 35 m in shallow neritic seas; Clarke, 1982) depositional environment for the Late Campanian Zeven Wegen Chalk. *Cytherelloidea* also occurs in less than 1 m deep water on a recent reef in the Java Sea (Whatley & Watson, 1988).

Finally, also the relative frequency of fish remains in both the Early and Late Campanian deposits may be considered as an indication of extremely shallow environments. Such remains are extremely rare higher up in the succession, where possibly deeper facies (chalk with flint) predominated.

Thus, the change in depositional environment and ostracode faunas may not reflect a significant deepening of the sea, but rather an increased water temperature. In this context it seems worthwhile to remember, that planktonic forams are relatively common in the glauconitic siliciclastics of the Early Campanian (indicating cold,

upwelling water ?), whereas these become less frequent in the Late Campanian marls and calcilutites.

Accepting the warm-up of the marine environment as suggested by the genus *Cytherelloidea*, there remains the problem why Tethyan ostracode genera such as *Mauritsina* and *Kingmaina* did not enter this region, although they had been present in the Mediterranean since at least the Turonian and sometimes even since the Albian (Babinot *et al.*, 1985). This seems to imply the existence of some kind of a physical barrier between Tethys and Boreal realm during at least the Late Campanian. Possibly, the water in the Paris Basin was too deep and/or too cold, inhibiting the passage of these Tethyan elements. Alternatively, there was some shoal or landmass preventing their northward migration with Mediterranean currents.

The foregoing arguments permit two alternative interpretations of the ecoevent that produced the change in the Campanian ostracode assemblages;

- This change was either caused by an important deepening of the sea (because of progressive relative subsidence of the basin floor and/or eustatic sea level rise); and in that case the frequency and diversity of the thermophilic *Cytherelloidea* and the frequency of fish remains in both the Zeven Wegen calcilutites and the Pre-Valkenburg marls should be explained as secondarily introduced elements (mud flows?, turbidites?).

- Or it was the result of a warm-up of a possibly only slightly deeper marine environment (the Recent Belize Lagoon model; possibly because cold, upwelling water is more or less linked to the initial phase of transgression?); but in that case we should try and be able to locate a physical barrier between Tethyan and Boreal Europe.

## LATE MAASTRICHTIAN ECOEVENT

Contrary to the Campanian ecoevent, the Late Maastrichtian major change in the fossil assemblages takes place within an apparently uninterrupted, continuous succession of flint-bearing chalk (Gulpen-Maastricht facies), at least in the Maastricht area. However, in the zone fringing the Rur Valley Block, this change more or less matches the passage from the sandy Pre-Valkenburg marls (as defined by Felder *et al.*, 1985) into the chalk alternating with hard limestone lenses of the Kunrade facies. This passage cannot be seen in the Kunrade region, where a sedimentary gap occurs between the Late Campanian Pre-Valkenburg facies and the Late Maastrichtian Kunrade

facies. The practical end of the influx of siliciclastics in the Campine area and the renewed sedimentation in the Kunrade area since the Late Campanian apparently precede the onset of Late Cretaceous deposition in the Molenbeersel and Limbricht segments on top of the Rur Valley Block. This suggests that to the end of the Late Maastrichtian (presumably from top of foram zone «E» onwards) the Rur Valley Block no longer acted as a source for siliciclastics, but gradually became incorporated in the depositional environment.

Presumably, this moment marks the end of the active inversion of the Rur Valley Block and the beginning of a long period of relaxation that was to last until the Middle to Late Oligocene, when renewed downwarp of the Rur Valley Graben started (fig. 6; cf. Rossa, 1987). It is assumed that with the onset of relaxation Tethyan faunas invaded this area, carried northwards by Mediterranean currents now freely passing over the Rur Valley Block into Eastern Germany and Poland (cf. Szczechura, 1965).

With the arrival of Tethyan organisms in the SE Netherlands and NE Belgium, the number of taxa rapidly increased, resulting in more diverse faunas. A major faunal turnover is observed in the biomass (composition of 1.0-2.4 mm bioclast assemblages), where echinoderm clasts dominate in foram zone F and higher, notwithstanding the rapidly increasing diversity of the molluscs (including the appearance of rudists in the K-L-M foram zones). The invasion of Tethyan echinoids in the SE Netherlands has been documented by Van der Ham *et al.* 1987). The rapidly increasing number of ornamented ostracode specimens (fig. 7) is interpreted as an indication of a gradual shallowing of the sea, although this cannot be recognized in the lithofacies.

Amongst the benthic foraminifera, the arrival of the Tethyan genera *Siderolites*, *Orbitoides* and *Mississippina* is noted along with the (gradual) disappearance of «Boreal» genera such as *Bolivina* and *Neoflabellina* (which range up into the latest Maastrichtian in NW Germany and Denmark, where Boreal conditions persisted; compare e.g. Stenestad, 1979; Koch, 1977). In the F-J and I foram zones, these Tethyan immigrants are rare (especially in the Gulpen-Maastricht facies) and relatively small (cf. Felder & Bless, 1989). But with the shallowing of the environment in the K-L-M foram zones, they become larger and more abundant (cf. Hofker, 1966). The fact that these Tethyan representatives tend to be slightly more common in the Kunrade facies than in the Gulpen-Maastricht facies is considered here as an indication of the relatively shallow character of the Kunrade deposits.

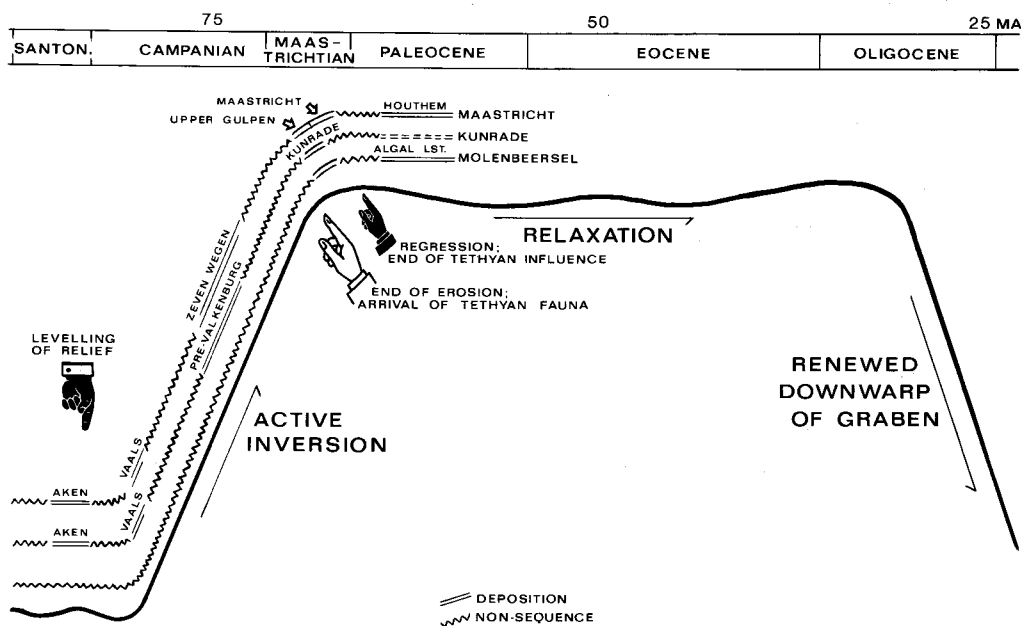


Fig. 6.- Scheme showing relationship between inversion of Rur Valley Block (RVB) during Late Cretaceous and Tertiary and depositional history of three areas on (Molenbeersel), near (Kunrade) and at some distance from (Maastricht) RVB. Heavy line marks structural history of RVB.

- During active inversion of RVB no sedimentation occurred on top of this block. Influx of siliciclastics was more important in areas near RVB (e.g. sandy Vaals and sandy Pre-Valkenburg marls) than in those at some distance from it (clayey Vaals and Zeven Wegen Chalk).
- Erosion on RVB came to an end with the onset of tectonic relaxation. At the same time, sedimentation on RVB started e.g. in Molenbeersel and Limbricht segments, whereas Tethyan organisms invaded Boreal realm of SE Netherlands and Poland.
- The Latest Maastrichtian to Earliest Danian eustatic sea level fall killed off most of the Tethyan faunas. The Paleocene fossil assemblages in this region again have distinct Boreal affinities.
- Renewed downwarp of the RVB started in the Middle Oligocene and has continued to this day.

Near the boundary between foram zones E and F (marked by the Nivelle Horizon in the ENCI Quarry; cf. W.M. Felder, 1975), a rapid species and genus turnover is noted in the ostracode assemblages (fig. 3). More than two-thirds of the existing species (24 out of 35) of the superfamily Cytheracea disappear, whereas some 127 new species and subspecies appear between this boundary and the end of the Maastrichtian deposition in this region (cf. Deroo, 1966). Above the E-F boundary, two ostracode assemblages are distinguished :

- A presumably eurytopic assemblage, consisting of a relatively small number of species (only some 30 Cytheracean taxa; cf. Deroo, 1966), that inhabited the relatively «deep-water» conditions of the flint-bearing (Gulpen-Maastricht) chalk facies, characterized by the frequent (and sometimes abundant) occurrence of *Mosaeleberis macrophthalma*, *Imhotepia interruptoidea* and *Semicytheretta elegans*. Note that the ostracodes of this assemblage also occur with the same frequency in other lithofacies.

- A presumably stenotopic assemblage with a large number of species (including some 116 to

123 Cytheracean taxa; cf. fig. 7), that preferred the relatively «shallow-water» conditions of the Kunrade (chalk with frequent chalkstone lenses) facies and the coarse-grained biocalcarenites of the K-L-M foram zones, marked by *Mauritsina hieroglyphica*, *Kingmaina* spp., *Limburgina* spp. and *Spongicythere* spp.

The Boreal affinities of the ostracodes from the flint-bearing chalk facies are emphasized by the presumably coeval change in the equally rather poor (about 30 Cytheracean species according to Clarke, 1983) ostracode assemblages of the flint-bearing chalk in NW Germany, taking place about halfway the *junior* belemnite zone (*argentea-junior* zone of Schulz *et al.*, 1984; Xb ostracode zone of Clarke, 1983), and characterized by the appearance of *Imhotepia interruptoidea* (possibly not conspecific with the form described by Deroo, 1966) and *Mosaeleberis macrophthalma*.

The stenotopic taxa in the Kunrade chalk and in the biocalcarenites of the K-L-M foram zones are practically all immigrants from the Tethys, where for example the genera *Mauritsina* and *Limburgina* had typified the ostracode assemblages of the northern Tethys since the Albian (Babinot & Colin,

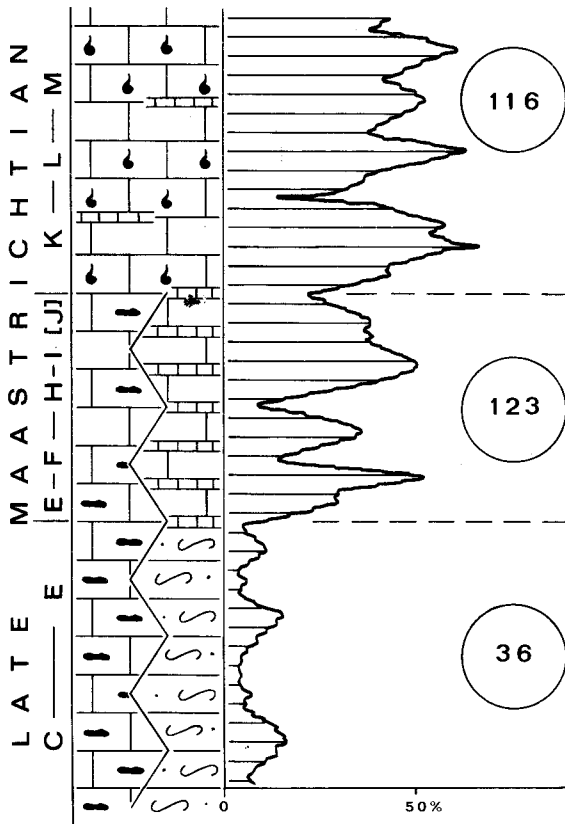


Fig. 7.- Simplified lithostratigraphy of (part of) Late Maastrichtian in NE Belgium and SE Netherlands with idealized frequency profile for ornamented ostracode specimens. Encircled is the number of Cytheracean species and subspecies.

1988). The genera *Kingmaina*, *Spongicythere* and *Kikliocythere* had occurred since the Turonian-Santonian in SW Europe as well (Babinot *et al.*, 1985; Rodriguez Lazaro, 1985). At the species level the immigration of, for example, *Kikliocythere labyrinthica*, *Kingmaina gr. hagenowi* and *Mauritsina gr. hieroglyphica* (fig. 8) should be emphasized. All these species had existed in the northern Tethys since the Turonian, i.e. some fifteen to twenty million years before their arrival in the SE Netherlands and NE Belgium.

This implies the existence of some very effective barriers between Tethyan and Boreal Europe, especially since the frequency and diversity of *Cytherelloidea* in the Late Campanian of the SE Netherlands and environs suggest the presence of warm, shallow seas with at least transitory subtropical to tropical conditions, under which Tethyan ostracodes might well have flourished (see chapter on Campanian ecoevent).

The fact that the immigration of Tethyan ostracodes and other organisms in the SE Netherlands started with the end of the siliciclastic influx in this area and with the onset of sedimentation on the Rur Valley Block, clearly indicates that this and other inverted highs in the

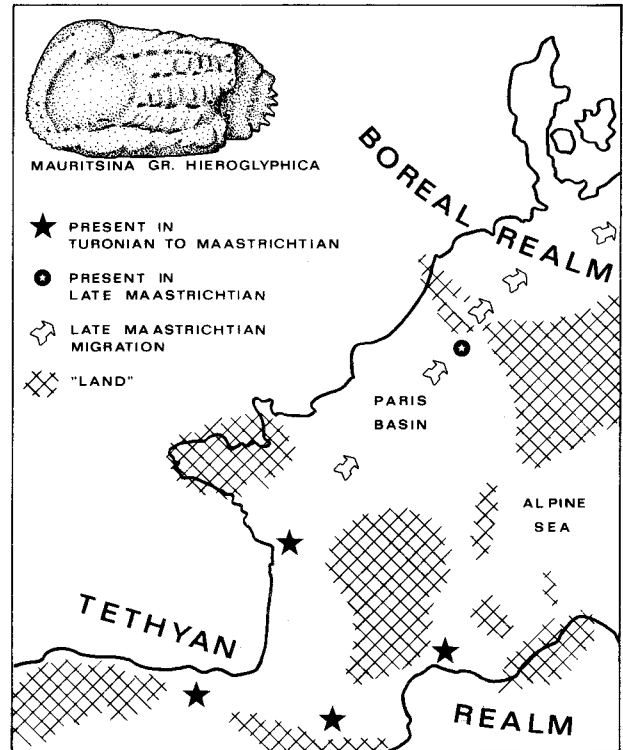


Fig. 8.- Paleogeographic distribution of the ostracode *Mauritsina gr. hieroglyphica* in Western Europe during the Late Cretaceous (based on data in Szczechura, 1965; Deroo, 1966; Jorgensen, 1979; Clarke, 1983; Babinot *et al.*, 1985; Rodriguez Lazaro, 1985).

Netherlands contributed to preventing the development of northward directed currents from the Mediterranean. With the tectonically induced (relaxation of inversion movements) disappearance of this barrier, Tethyan species such as *Mauritsina gr. hieroglyphica* not only invaded the SE Netherlands (fig. 8) but they also migrated deep into the Boreal realm setting down only at places where suitable niches existed, such as in the Late Maastrichtian of Poland (Szczechura, 1965).

Naturally, a mid-Late Maastrichtian eustatic sea level rise can be taken to have enhanced the free passage of this presumed Mediterranean current over the Rur Valley Block and other former barriers. In how far a supposed amelioration and warming of the world climate (cf. Kauffman, 1984) has contributed to the northward migration of Tethyan elements cannot be deduced from the present survey. However, such an amelioration of the global climate is not a prerequisite for explaining this migration into the Boreal realm, since tropical-subtropical conditions existed there earlier (Kemper, 1987a, 1987b). On the other hand, the fact that apparently Tethyan ostracode taxa did not invade NW Germany (cf. Clarke, 1983)



or Denmark (cf. Jorgensen, 1979) is better explained by migration following a distinct current pattern than by a uniform change in the global climate.

This model also explains why the chrono-ecological signal (here taken as the species turnover in ostracode faunas) is weaker in areas such as Denmark (Jorgensen, 1979) or Hemmoor-Kronsmoor-Lägerdorf (Clarke, 1983). Apparently, these were not directly influenced by the south-north circulation of Mediterranean currents, either because these currents did not reach them or because the environmental conditions (water depth ?) were less suitable for the Tethyan elements.

## MAASTRICHTIAN - DANIAN ECOEVENT

The major change in the ostracode assemblages at the Maastrichtian-Danian boundary in NE Belgium and the SE Netherlands is characterized by a sedimentary gap of as yet unknown magnitude (cf. Jagt, 1988; Jagt & Janssen, 1988). The top of the Maastrichtian deposits (Meerssen Chalk Member of Maastricht Formation; W.M. Felder, 1975) frequently consists of a hardground (Vroenhoven Hardground), overlain by a very fossiliferous biocalcarenite (base of Dano-Montian Houthem Chalk). However, where the Vroenhoven Hardground is absent, it may be difficult to distinguish in the field between the Meerssen Chalk and the Houthem Chalk, since both consist of medium- to coarse-grained biocalcarenites with fossil grit lenses and «hardgrounds» of limited lateral extension.

Both the Vroenhoven Hardground and the top of the Meerssen Chalk often contain a concentration of a diverse Late Maastrichtian micro- and macrofauna, suggesting a condensed sedimentation during the Latest Maastrichtian. Usually, the burrows in the Vroenhoven Hardground yield an infill of Danian fossils and chalk, whereas reworked Maastrichtian elements may locally occur in the basal parts of the Houthem Chalk (cf. Deroo, 1966).

Most likely, the sedimentary gap reflects the Latest Maastrichtian to Earliest Danian eustatic sea level fall. But apparently, the subsequent Danian eustatic rise roughly restored the previous (Late Maastrichtian) depositional conditions. This is at least suggested by the similarity of the sediments (medium- to coarse-grained biocalcarenites with comparable  $\text{CaCO}_3$  content, grain-size and gamma radiation) and the almost identical composition of their biomass (expressed in composition of 1.0-2.4 mm bioclast assemblages;

Dusar *et al.*, 1987; P.J. Felder, 1988). The percentage of ornamented ostracode specimens remained more or less constant as well (fig. 9). However, the presence of glauconite in the basal portion of the Houthem Chalk (P.J. Felder, 1988) along with the relative abundance of globular and keeled planktonic foraminifera (Hofker, 1966) indicates that at least the initial phase of the Danian transgression was accompanied by the influx of cold, upwelling oceanic water, similar to the situation postulated for the Early Campanian Vaals Greensand in this area (see above).

Although the Cretaceous-Tertiary boundary in the SE Netherlands is marked by the disappearance of many higher taxa, such as mosasaurs, belemnites, ammonites, inoceramids and rudists, as well as several benthic (e.g. *Orbitoides*, *Siderolites*) and planktonic (e.g. *Globotruncana*) foraminifera, there is no uniform extinction pattern for all groups of organisms. For example, fifty percent (13 out of 26) of the Latest Maastrichtian echinoid genera in this area cross the Maastrichtian-Danian boundary, despite the major species turnover at this level (28 species disappear, 4 cross the boundary and 28 new species appear in the Danian; Van der Ham *et al.*, 1987; Van der Ham, 1988).

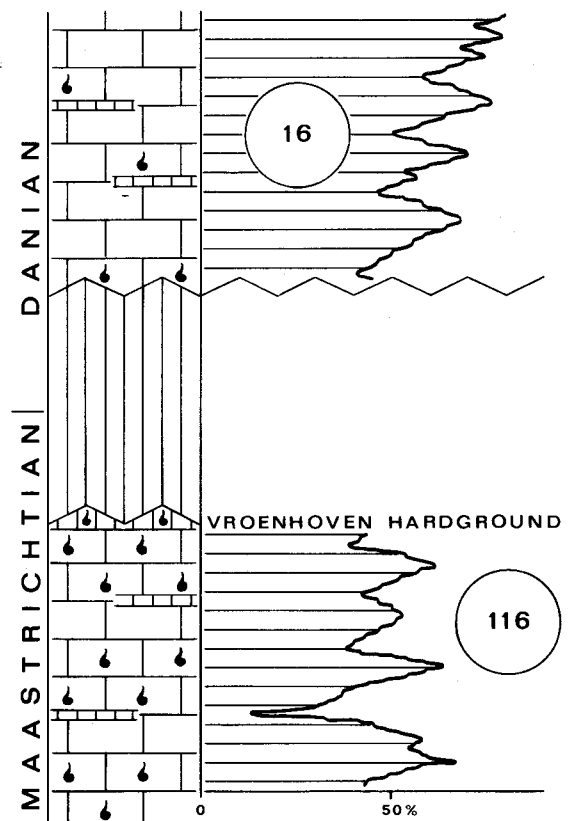


Fig. 9.- Simplified lithostratigraphy of Latest Maastrichtian and Danian in NE Belgium and SE Netherlands with idealized frequency profile for ornamented ostracode specimens. Encircled is the number of Cytheracean species and subspecies.

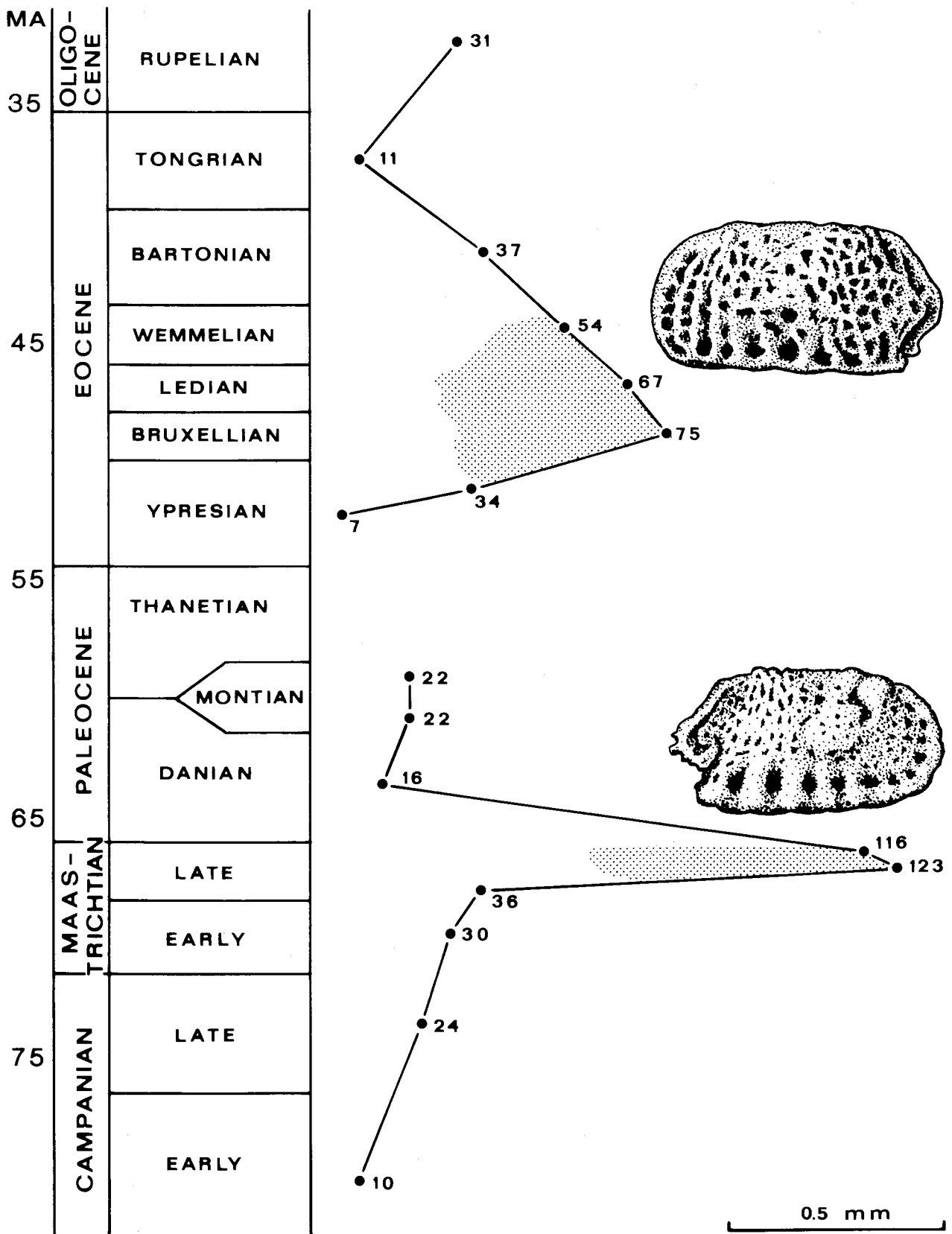


Fig. 10.- Correlation between diversity of ostracode faunas (indicated by number of species) and ecostratigraphic distribution of Cytheracean ostracode genus *Kingmaina* (punctuate shading) in NE Belgium and SE Netherlands. Stratigraphic timetable modified after Haq & Van Eijsinga (1987) and Keij (1957). For the Campanian-Paleocene, the number of Cytheracean species is indicated (after Deroo, 1966; Bless, 1988b). For the Eocene-Oligocene, the total number of ostracode species is given (after Keij, 1957).

The ostracode faunas also show a dramatic change at the species level. apparently, none of the 116 Cytheracean species or subspecies in the Latest Maastrichtian Nekum and Meerssen Chalk crosses the Maastrichtian-Danian boundary (cf. Deroo, 1966; Bless, 1988b). The situation at the genus level seems equally dramatic, considering the fact that eighty percent (44 out of 55) of the Cytheracean genera described by Deroo (1966) for the Campanian-Maastrichtian in the SE Netherlands are not found again in the Danio-Montian deposits of this region. But, on the other hand, no fewer than eleven of the fifteen Cytheracean genera (about 70 %) occurring here in the Danio-Montian sediments existed already in the Maastrichtian, and six of these even in the Campanian or earlier. Moreover, twenty of the Cytheracean genera cited by Deroo (1966) from the Campanian-Maastrichtian in this region, but not recognized here in the Danio-Montian, are found again elsewhere in the Tertiary (cf. Moore, 1961).

A fine example is provided by the ecostratigraphic distribution of the ostracode genus *Kingmaina*. In the northern Tethys, this genus ranges from the Santonian (cf. Rodriguez Lazaro, 1985) to the Latest Eocene (cf. Ducasse *et al.*, 1985). However in the SE Netherlands and NE Belgium, *Kingmaina* is restricted to the Latest Maastrichtian and the Middle Eocene, both periods distinguished by the transitory invasion of Tethyan elements into the Boreal realm of NW Europe and by an increased diversity of the ostracode faunas (fig. 10).

Thus, the disappearance of many ostracode genera at the Maastrichtian-Danian boundary in the SE Netherlands reflects a change in the regional environment rather than an overall extinction event.

Most likely, the Latest Maastrichtian eustatic drawdown strongly reduced the space occupied by the epicontinental seas, causing the disappearance of many shallow-marine, warm-water ecological niches and the extinction of the essentially stenotopic Tethyan faunal communities. The same regression also cut off the seaways linking the warm-water Tethys and the cold-water Boreal realms. Under these circumstances only some eurytopic taxa survived, adapting themselves to the new ecological conditions and eventually evolving into new species or subspecies.

The coupling of the subsequent Danian transgression and the influx of cold, upwelling oceanic water with planktonic foraminifera illustrates that the Latest Maastrichtian communication between Tethyan and Boreal Europe remained closed. The restoration of the Boreal conditions in the SE Netherlands during the

Paleocene is emphasized by the reduced number of ostracode taxa, reminiscent of that occurring here earlier in the Campanian to early-Late Maastrichtian, when Boreal conditions also prevailed.

The impact of the eustatic fall and rise in the Tethys differed from that in Boreal Europe. This is evidenced by the survival in the Tethys of no fewer than twenty of the forty-four ostracode genera which disappear at the Maastrichtian-Danian boundary in the SE Netherlands.

## CONCLUSIONS

The above broad brush analysis of the Late Cretaceous to Paleocene ostracode faunas in the SE Netherlands and NE Belgium suggests that qualitative and quantitative changes in their composition can be explained in terms of regional tectonic or global eustatic events. However, the data available thus far are not always conclusive and sometimes permit alternative interpretations, as illustrated by the Campanian event.

As far as the Cretaceous-Tertiary boundary is concerned, the drastic change in the ostracode faunas seems to have been caused by a simple eustatic sea level fall and rise, coupled with the closure of a transitory Latest Maastrichtian seaway between Tethyan and Boreal Europe. The massive extinction of over a hundred ostracode species and subspecies at this boundary does not seem any more dramatic than the Latest Maastrichtian invasion of a comparable number of Tethyan taxa due to regional relaxation of inversion tectonics.

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