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BIOSTRATIGRAPHY AND ECOSTRATIGRAPHY OF LATE CRETACEOUS DEPOSITS IN THE KUNRADE AREA (SOUTH-LIMBURG, SE NETHERLANDS)[1]

by

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(9 figures)

RESUME.- Les dépôts du Crétacé récent dans la région de Kunrade dans le Limbourg méridional (sud-est des Pays-Bas) se distinguent des affleurements classiques autour de Maastricht par leur lithofaciès et leur contenu en fossiles. Sur la base de données bio- et écostratigraphiques dans 24 coupes (2 sondages et 22 affleurements), une subdivision écostratigraphique en cinq écozones est proposée. Cette écozonation est corrélée avec des coupes situées à Valkenburg a/d Geul (Sondages Thermae), Maastricht (Sondage Kastanjelaan), Hoepertingen et Diets-Heur.

ABSTRACT.- The Late Cretaceous deposits in the Kunrade area in South-Limburg (SE Netherlands) differ from the classic outcrops around Maastricht in their lithofacies and fossil content. On the basis of biostratigraphic and ecostratigraphic data from 24 sections (2 boreholes and 22 outcrops), an ecostratigraphic subdivision into five ecozones is proposed. This ecozonation is correlated with sections at Valkenburg a/d Geul (Thermae Borehole), Maastricht (Kastanjelaan Borehole), Hoepertingen and Diets-Heur.

INTRODUCTION

Since the beginning of the nineteenth century, geologists have studied the Late Cretaceous deposits in the now classic outcrops of the Kunrade area (South-Limburg, SE Netherlands; fig. 1). Despite all these efforts, their exact dating and correlation with the Vaals, Gulpen and Maastricht Formations in the Maastricht area (some 20 km to the west) has remained problematic because of the differences in lithofacies and fossil content. This is illustrated in the following historical review that considers some of the earlier opinions and problems.

One of the first geologists to discuss the Late Cretaceous deposits in the Kunrade area was Staring (1860). He distinguished in this area his «laag 18 : Kwartskrijt, en laag 18′: Kalkmergel van Kunraad» (layer 18 : quartz chalk or «craie siliceuse» and layer 18′ : chalky marl of Kunrade), which he correlated with the Maastricht Chalk («Kreidetuff von Maastricht und Valkenberg und Mergel von Kunraad»). Staring also recognized the existence of the «Zandig Krijt van Benzenraad, waarschijnlijk overeenstemmende met den Kalkmergel van Kunraad en dus laag 18′» (Sandy Chalk of Benzenrade, presumably correlating with the chalky marl of Kunrade and thus with layer 18′) at the localities Daalhof (our section 16, De Dael), Benzenraadhof (section not studied here) and Eemsterhof (possibly our section 24, Imstenraderhof). However, he also stated that this might be correlated with the underlying «Herve Greensand».

The distinction between Kunrade Chalk and underlying Sandy Chalk of Benzenrade was also made by Van Rummelen (1923). In his description

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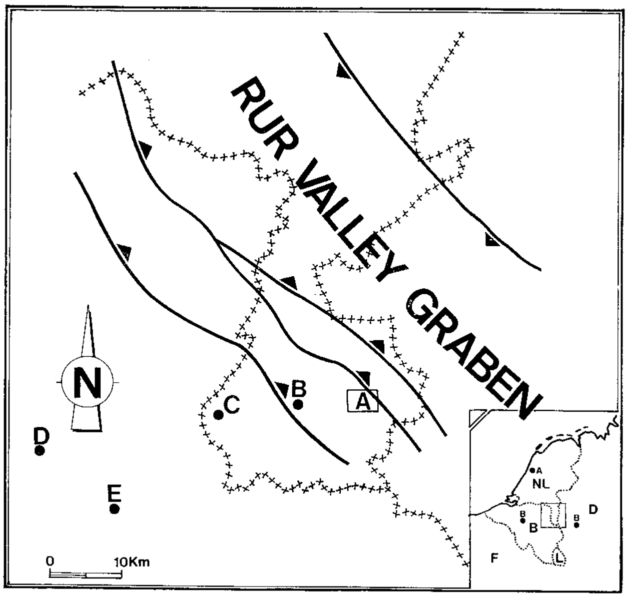

Fig. 1.- Map of South-Limburg (SE Netherlands) and contiguous parts of Belgium, showing location of Kunrade area (square marked «A»; for details see fig. 2) and of some relevant boreholes (B: Thermae 2000, Valkenburg aan de Geul; C: Kastanjelaan, Maastricht; D: Hoepertingen; E: Diets-Heur), wich are discussed in this report.

of the Wingerdsberg Quarry (our section 12, Wingerd; quarried in 1914-1918), this author stated that the Sandy Chalk of Benzenrade has yielded the bivalve «*Ostrea goldfussi*», at that time considered to be a guide for the Herve Greensand. Van Rummelen could trace the Sandy Chalk of Benzenrade from the Wingerdsberg Quarry (our section 12, lower portion of 12') to the De Dael Farm (our section 16). *Ostrea goldfussi* Holzapfel, 1889 is traditionally considered as an Early Campanian species. However, Jagt *et al.* (1987) recorded comparable specimens from the De Dael outcrop (section 12) as *Acutostrea* sp.

In his description of the «Groeve aan de Welterberg» (possibly our section 12, Wingerd; presumably not our section 5, sunken lane on Welterberg), Umbgrove (1925) mentioned the existence of «reworked boulders of Gulpen Chalk» within the «Vaals Greensand, some 5 m below the Vaals-Kunrade boundary». The Vaals Greensand is the local name for the Herve Greensand. Umbgrove believed that these «boulders of Gulpen Chalk» might have been buried in the Vaals Greensand «during the Kunrade transgression». He stated that he has observed similar phenomena in the Maurits Shaft («between 178 and 180 m NAP, this is immediately below the Kunrade Chalk»).

This review clearly shows the ambiguity of the data available at that time for dating and correlating the Sandy Chalk of Benzenrade. Staring (1869) obviously hesitated between assigning this deposit to the Kunrade Chalk or rather to the underlying Herve or Vaals Greensand. Van Rummelen (1923) correlated it with the Herve Greensand on the basis of the misidentification of an oyster as recently suggested by Jagt *et al.* (1987). And finally, Umbgrove (1925) recognized «boulders» of the stratigraphically younger Gulpen Chalk «buried in the Herve Greensand during the (still younger) Kunrade transgression». In this way, he implicitly emphasized the unique lithofacies of the Sandy Chalk of Benzenrade. A similar solution was proposed by Romein (1963), who assumed (for another section) fault activities during deposition of the Gulpen Chalk «causing the upper part of the Herve Greensand to be re-agitated and mixed with Gulpen Chalk».

Still later, Hofker (1966) assigned the Sandy Chalk of Benzenrade to the Early Campanian Vaals Formation («Herve Greensand or Chalk of Benzenrade»), for example in his picture of the «Welterberg Quarry» (our section 12', Wingerd; Hofker, 1966, fig. 12). Although this was not stated explicitly; he possibly recognized a foram assemblage indicating his foram zone A' or A'-upper, at that time considered to be indicative of the Early Campanian (cf. Hofker, 1957). Kuyl (1980) and W.M. Felder *et al.* (1984) also placed these sediments in the Vaals Formation.

During the past few years, cephalopod finds (*Belemnitella mucronata* and «*Pachydiscus stobaei*») in section 16 (De Dael outcrop) have irrefutably proved the early-Late Campanian age (*conica-senior* or *basiplana-spiniger* zone; cf. Jagt *et al.*, 1987; Jagt, 1988) of these strata. Along with the presence of the foraminifer *Bolivinoides decorata* (with a mean number of pustules on the last chamber of 3.2-3.3) these cephalopods allow a correlation of the Sandy Chalk of Benzenrade with the basal part of the Late Campanian Zeven Wegen Chalk at Halembaye (Jagt, 1988). Likewise it reinforces the hypothesis of P.J. Felder *et al.* (1985) that Hofker's (1957) foram zone A'-upper matches his (1966) foram zone A.

The exact correlation between the Kunrade Chalk and the Maastricht Chalk also appeared to be rather complicated. The benthic foram assemblages of the Kunrade Chalk, which differ significantly from those of the Maastricht Chalk at Maastricht, were assigned by Hofker (1966, e.g. fig. 123) to his foram zones J and O. He equated foram zone J of the Ubachsberg-Kunrade area with foram zones H-I in the Maastricht area, and foram zone O with the foram zones K-L (Hofker, 1966, e.g. fig. 55). As stated by Hofker (1966, p. 267), there are both «fresh, well-preserved specimens» and «more or less eroded, opaque specimens». This suggests that at least part of the

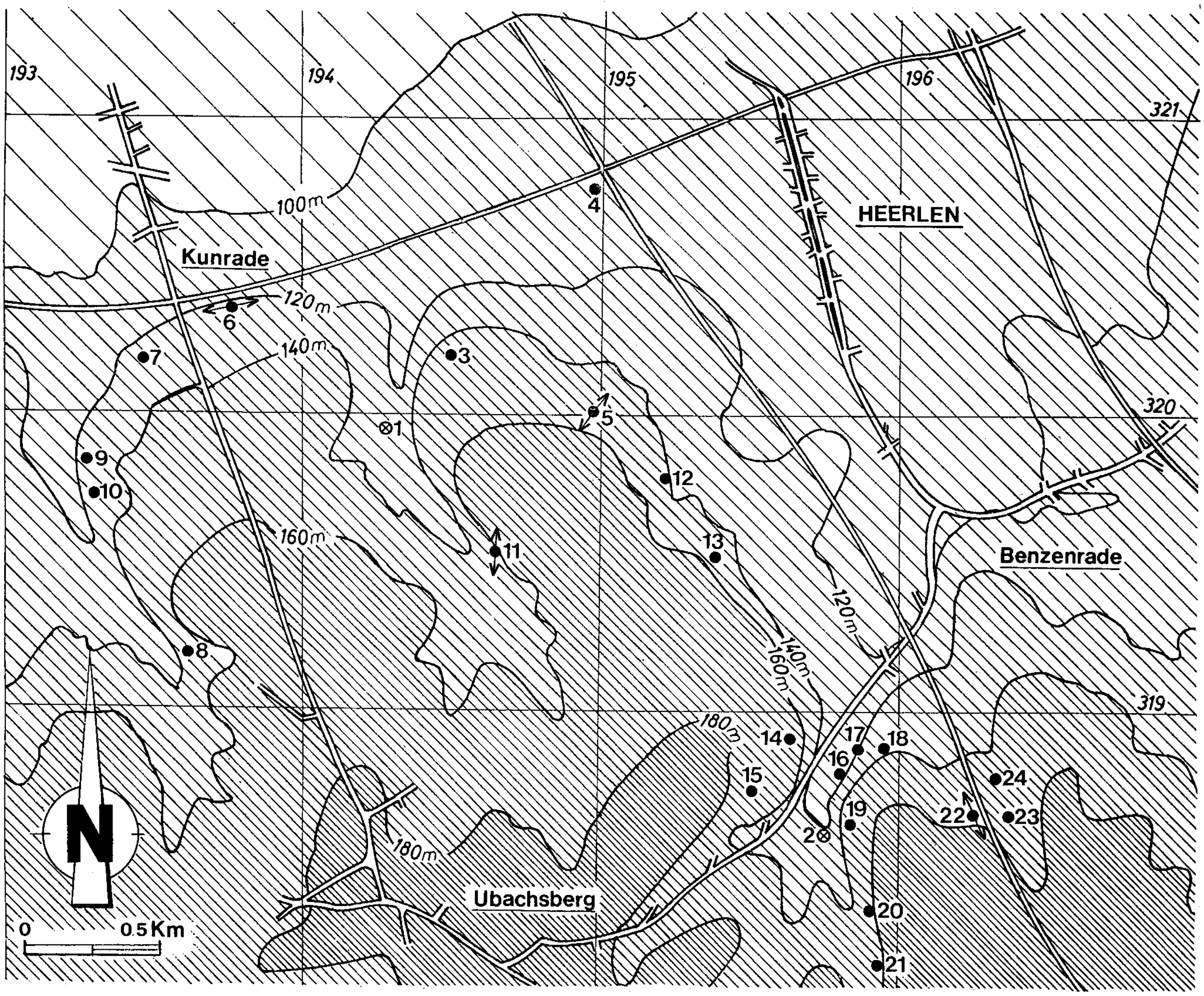

Fig .2.- Map of Kunrade area (for general location see fig. 1), showing location of boreholes (1-2) and outcrops (3-24) with Late Cretaceous deposits, which have been analyzed for the present report. Names of the reference sections are indicated in fig. 3 and in the text.

Kunrade Chalk has been deposited above wave base or derived from facies above wave base.

W.M. Felder (1975, 1977) correlated the Kunrade Chalk facies with the lower portion of the Maastricht Chalk in the Maastricht area. According to him, the «Koraalbank van Kunrade» near the top of the Kunderberg Quarry (our section 3) should be correlated with the Romontbos Horizon in the ENCI Quarry. This implies that he correlated the upper part of Hofker's (1966) zone O with the upper part of Hofker's zone H ! This suggestion was later followed by P.J. Felder *et al.* (1985) and Bless *et al.* (1987), who studied bioclast and ostracode assemblages.

The study of ostracode and benthic foram assemblages from the lower half of the Kunrade Chalk (our section 22, Highway 76 Benzenrade) by Romein *et al.* (1977) did not yield new viewpoints. These authors correlated section 22 with the Mb or Mc of Uhlenbroek (1912), which roughly matches Hofker's (1966) foram zones H-I-K. The recent find of cephalopods (*Belemnitella junior* and «*Baculites vertebralis*») in section 22 has confirmed the Late Maastrichtian age of the strata (*junior* belemnite zone; Jagt, 1988).

Thus, there are in fact two interpretations of the relative position of the Kunrade Chalk in its type area. On the one hand, there is the opinion based on benthic foraminifera and ostracodes (Hofker, 1966; Romein *et al.*, 1977) that assumes the Kunrade Chalk to be more or less the equivalent of the larger part of the Maastricht Formation (foram zones H, I, K and L). On the other hand, the study of lithofacies, bioclasts and ostracodes (W.M. Felder, 1975, 1977; P.J. Felder *et al.*, 1985; Bless *et al.*, 1987) rather suggests a correlation with the lower portion of the Maastricht Formation (foram zone H).

The present report is based on the analysis of two boreholes (sections 1-2) and twenty-two outcrops (sections 3-24) in the Kunrade area (figs 1 and 2). These include several of the classic outcrops previously described by Staring (1860), Van Rummelen (1923) and Hofker (1966). Five different parameters (here presented in order of descending importance) have been used. These are :

1. Cephalopods (described in Jagt *et al.*, 1987; Jagt, 1988) from sections 16 (De Dael) and 22 (Highway 76 Benzenrade).
2. Benthic foraminifera (partly described in Hofker, 1966; Romein *et al.*, 1977; Jagt *et al.*, 1987) from all sections.
3. Ostracoda (partly described in Deroo, 1966; Romein *et al.*, 1977; Jagt *et al.*, 1987; Bless, 1988; Bless *et al.*, 1988) from all sections.
4. Bioclast (only 1.0-2.4 mm) assemblages (partly described in P.J. Felder *et al.*, 1985a,b; Jagt *et al.*, 1987; Bless *et al.*, 1988) from all sections.
5. Lithology of all sections.

Combination of these data has provided the basis for a subdivision of the Late Cretaceous deposits in the Kunrade area into ecozones, and also for a correlation of the twenty-four studied sections within this area with the reference section here proposed (figs 3-4).

ECOZONES IN KUNRADE AREA

Five ecozones are distinguished in the Kunrade area (fig. 3-4) which are characterized as follows.

ECOZONE I

Medium- to coarse-grained sand with phytoclasts (megaspores and diminutive plant debris), suggesting a correlation with the Santonian Aachen Formation. Only recognized in section 2 (De Dael Borehole, 143-160 m). Ecozone easily distinguished by presence of phytoclasts.

ECOZONE II

Glauconitic, silty, fine- to medium-grained sand with a few gravel beds. Bioclasts are relatively rare and consist predominantly of molluscs (bivalves). Ostracode assemblages characterized by frequent presence of *Veenia, Cythereis* and *Pterygocythere,* and by large numbers of ornamented specimens. Rare benthic foraminifera include *Neoflabellina sphenoidalis* and *Lenticulina multinodosa* (in section 2, 115-120 m), indicating Hofker's (1957) foram zone A'-lower and allowing correlation with the Early Campanian Vaals Formation at Halembaye, in Kastanjelaan-2 Borehole (166.2-198.2 m) and in Thermae 2000 Borehole (167-195.5 m). The top of this ecozone has been drawn arbitrarily at the top of the interval with large numbers of ornamented ostracode specimens (in section 2 at 80 m). Only recognized in section 2 (De Dael Borehole, 80-143 m). Ecozone readily distinguished by relatively large number of ornamented ostracode specimens, including *Veenia, Cythereis* and *Pterygocythere.*

ECOZONE III

Silty, fine- to medium-grained sand in the lower portion (in section 2, 65-80 m) or fine- to coarse-grained sand, slightly glauconitic, with hard limestone nodules and lenses in the upper part (the «Sandy Chalk of Benzenrade»), where also a gravel bed has been recognized in sections 1 and 2.
The number of bioclasts (1.0-2.4 mm) gradually increases upwards. Mollusc clasts predominate, along with small amounts of echinoderm (crinoid) clasts and (near the top) clasts of solitary corals. Three small, complex serpulid peaks occur, each of them marked by the presence of the coiled tubes of the genus *Glomerula.* These suggest correlation with three comparable serpulid peaks (with *Glomerula*) in the Late Campanian Zeven Wegen Chalk in Diets-Heur Borehole and Kastanjelaan-2 Borehole. Ostracode assemblages contain relatively small numbers of ornamented specimens, including *Mosaeleberis rutoti* and *Cytherelloidea* spp., as well as smooth-shelled «*Xestoleberis*» *bidentata.* Benthic foraminifera in the upper portion of this ecozone (in sections 1, 12' and 16) include *Bolivinoides decorata* (with mean number of pustules on last chamber is 3.2-3.3) and *Neoflabellina leptodisca,* characterizing Hofker's (1957, 1966) foram zone A or A'-upper. Cephalopods finds in section 16 (De Dael outcrop) comprise *Belemnitella mucronata* and «*Pachydiscus stobaei*» indicating an early-Late Campanian age (*conica-senior* to *basiplana-spiniger* zones) of the upper portion of Ecozone III and correlation with the basal part of the Zeven Wegen Chalk at Halembaye (Jagt *et al.*, 1987; Jagt, 1988).

Recognized in section 1 (Kunderberg Borehole, 8.5-50 m), section 2 (De Dael Borehole, above 80 m), section 12' (Wingerd, only lower half), 13, 16 (De Dael outcrop, except top of section), 17 and 24. Ecozone III is easily distinguished by relatively

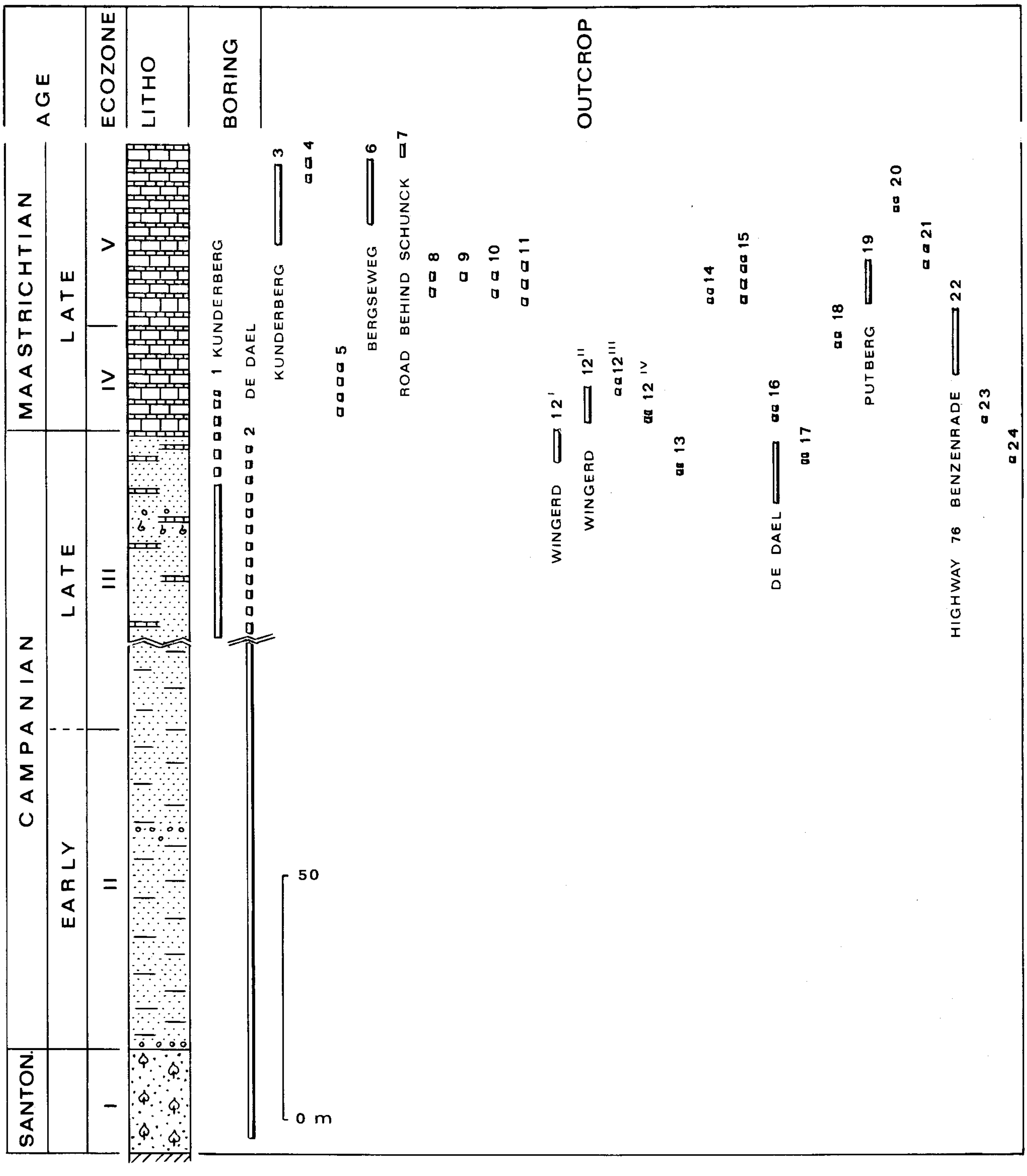

Fig. 3.- Simplified lithostratigraphic column for Kunrade area showing relative position of studied sections. Full-drawn lines indicate (named) reference sections. Ecozones I to V are defined in this report.

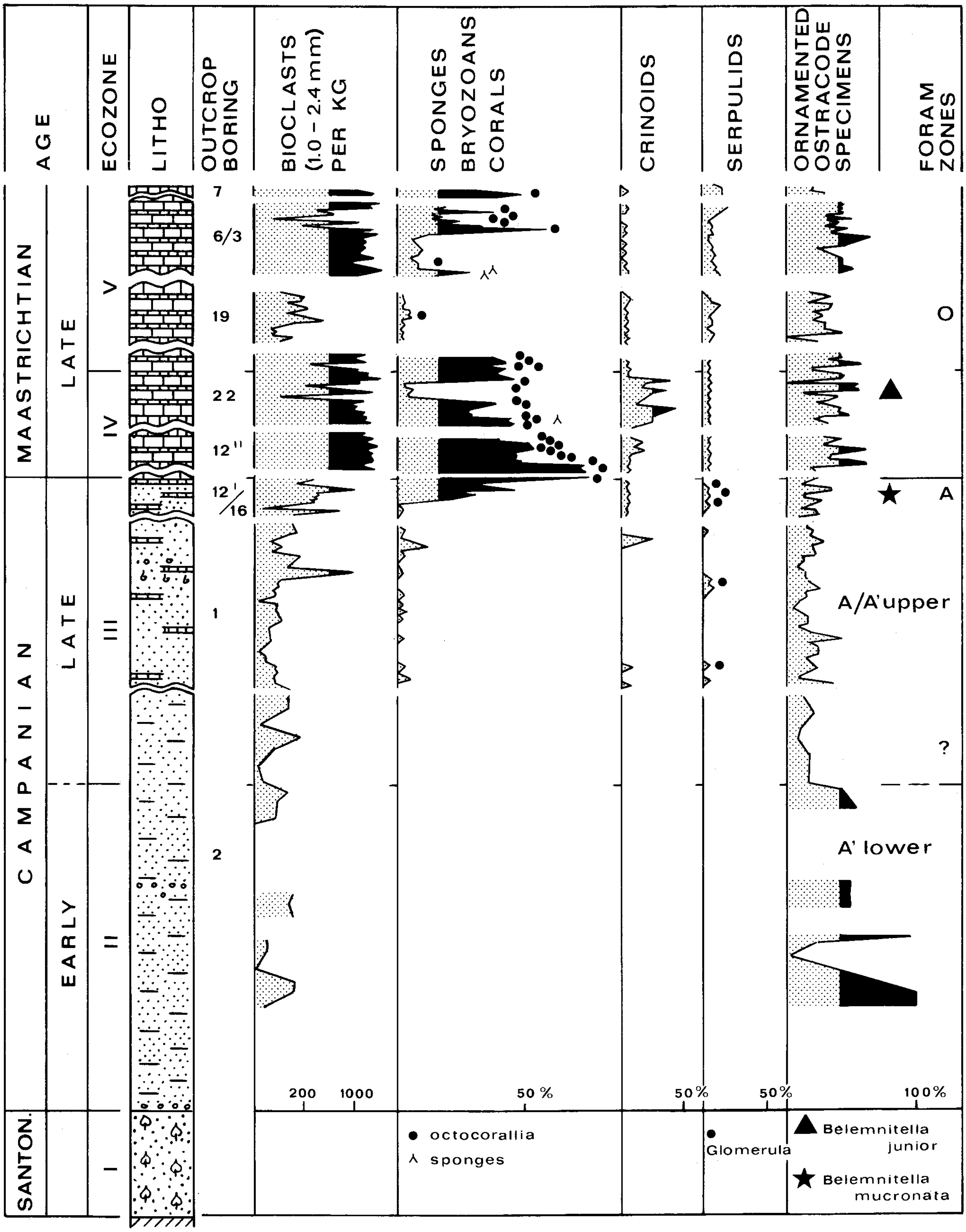

Fig. 4.- Simplified lithostratigraphic column for Kunrade area showing biostratigraphic and ecostratigraphic characteristics. Asterisk marking position of *Belemnitella mucronata* also stands for occurrence of ammonite «*Pachydiscus stobaei*» (both recognized in section 16, De Dael outcrop; cf. Jagt *et al.*, 1987).

small number of ornamented ostracode specimens including *Mosaeleberis rutoti* and *Cytherelloidea*, by repeated occurrence of small numbers of serpulid *Glomerula*, and by presence of foraminifera *Bolivinoides decorata* and *Neoflabellina leptodisca*.

ECOZONE IV

Hard limestone lenses and nodules in soft chalk, both consisting of medium- to coarse-grained biocalcarenites («Kunrade Chalk»). The number of bioclasts (1.0-2.4 mm) is high to very high and usually exceeds 2000/kg. Echinoderm and bryozoan clasts predominate, but mollusc clasts are also common. Characteristic are the presence of relatively large numbers of crinoid clasts (up to 22 %) and the frequent occurrence of Octocorallia rods (genera *Moltkia* and *Graphularia*). The ostracode assemblages contain large amounts of ornamented specimens, including *Limburgina, Mosaeleberis, Imhotepia* and *Mauritsina*. Benthic foraminifera, characterizing Hofker's (1966) zones J or O, include isolated specimens of *Bolivinoides australis* and rare, rather small specimens of *Siderolites calcitrapoides, Mississippina binkhorsti* and *Orbitoides* sp., suggesting a correlation with Hofker's (1966) foram zones F-H-I in the Maastricht area. The find of *Belemnitella* gr. *junior* (in section 22, Highway 76 Benzenrade) indicates Late Maastrichtian age. Recognized in top of section 1 (Kunderberg Borehole, 2.8-8.5 m), as well as in sections 5, 12 (Wingerd, except lower portion of 12'), 16 (De Dael outcrop, only top of section), 18, 22 (Highway 76 Benzenrade) and 23. Ecozone easily distinguished by frequent large numbers of crinoid clasts and common presence of Octocorallia rods. Correlation of this ecozone is discussed further on.

ECOZONE V

Hard limestone lenses and nodules in soft chalk, both consisting of medium- to coarse-grained biocalcarenites («Kunrade Chalk»). The number of bioclasts (1.0-2.4 mm) is high to very high as in Ecozone IV. However, the composition of the bioclast assemblages differs from that in Ecozone IV by the relatively small number of crinoid clasts (rarely exceeding 5 %) and the lower frequency of Octocorallia rods. The ostracode assemblages are similar to those in Ecozone IV. The benthic foram assemblages also resemble those of Ecozone IV with the exception of *Bolivinoides australis* which is missing here. There are no relevant macrofossil finds allowing a more precise biostratigraphic dating of this ecozone. Recognized in sections 3 (Kunderberg Quarry), 4, 6 (Bergseweg), 7 (Road behind Schunck), 8, 9, 10, 11, 14, 15, 19 (Putberg), 20 and 21. Ecozone V is distinguished from the underlying Ecozone IV by the very small number of crinoid clasts. Correlation with other areas is discussed below.

CORRELATIONS WITH OTHER AREAS

The correlation of these five ecozones with the Late Cretaceous deposits elsewhere in the SE Netherlands and NE Belgium is based on the same parameters as used for their distinction.

The highest dating and correlative value is attributed to the cephalopods. Although these have so far been collected at only a few localities (sections 7, 16 and 22), their occurrence in section 16 (De Dael) has been decisive for the dating (early-Late Campanian, or *conica-senior* to *basiplana-spiniger* zones; Jagt, 1988) and correlation (equivalent of basal portion of Zeven Wegen Chalk at Halembaye) of the «Sandy Chalk of Benzenrade». In fact, this explains the «boulders of Gulpen Chalk buried in the Vaals Greensand» observed by Umbgrove (1923). Presumably, what this author saw was nothing more than lenses of chalk in a sandy matrix. Apparently, some 50-60 years ago, it was extremely difficult to imagine a predominantly sandy («Vaals-like») deposit with chalky intercalation; and hence it seemed easier to believe that these represented reworked Gulpen boulders incorporated into an older sediment during a younger transgression !

Of course, the Kunrade Chalk has also yielded some cephalopods, as shown by the discovery of *Belemnitella* gr. *junior* (cf. Jagt, 1988) and «*Baculites vertebralis*» in section 22 (Highway 76 Benzenrade), and by the find of a possible *Belemnitella junior* in section 7 (Road behind Schunck) by the Belgian collector J. Reinders (J. Jagt, pers. comm.). However, these have not improved the correlation with other areas. Perhaps, a careful check of amateur collections in this region will help to find other useful macrofossils from the Kunrade area, enabling a more precise dating and correlation.

In the following paragraphs we will briefly comment on the use of the benthic foraminifera, ostracodes and bioclasts for a detailed correlation with other Late Cretaceous sections in South-Limburg and contiguous parts of Belgium.

FORAMINIFERA

At first sight, two assemblages of benthic foraminifera can be distinguished in the Kunrade area :

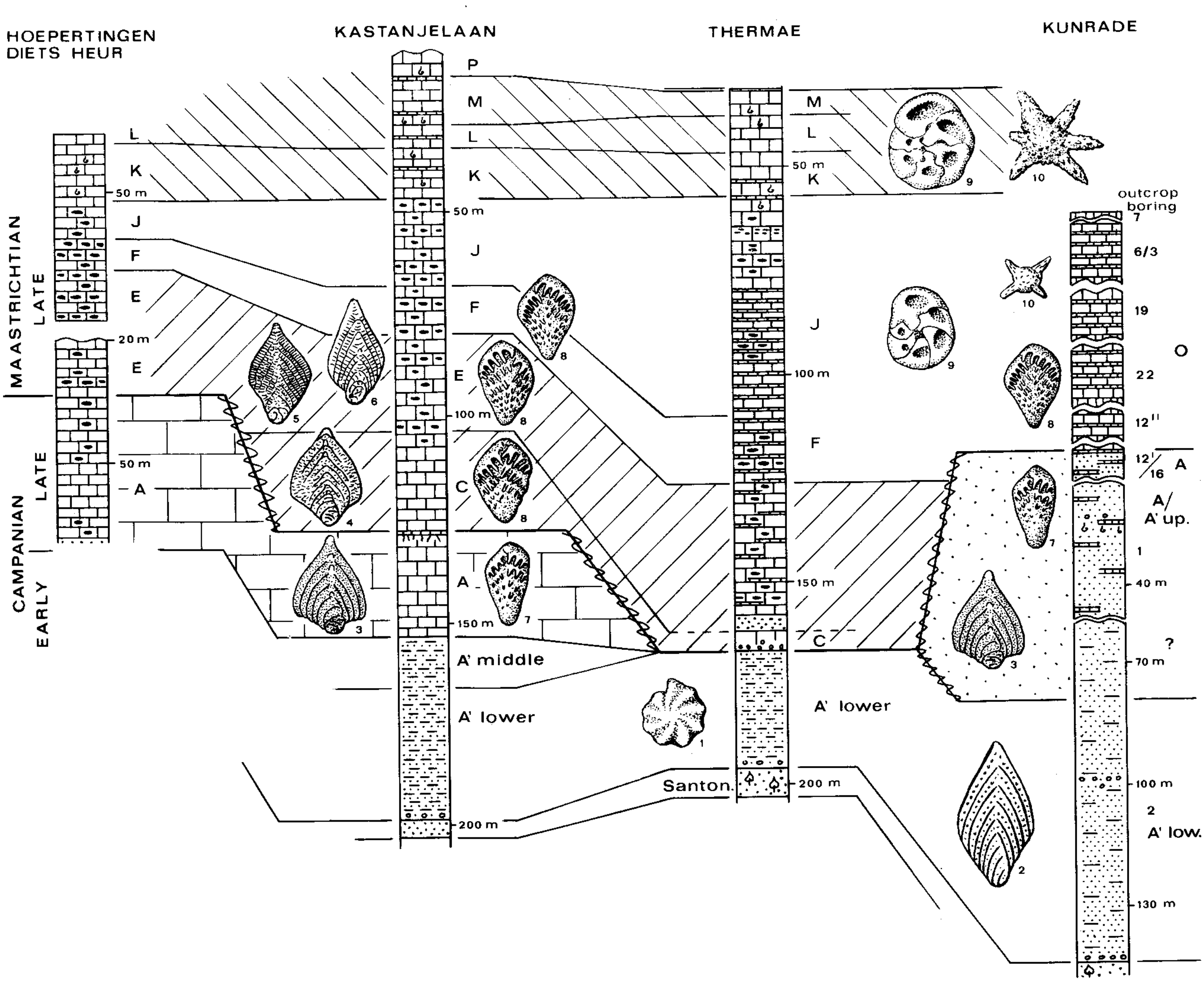

Fig. 5.- Correlation of Late Cretaceous deposits in boreholes Hoepertingen, Diets-Heur, Kastanjelaan (Maastricht) and Thermae (Valkenburg a/d Geul) with reference section for Kunrade area. For location of sections see figs. 1-2. To the right of the lithostratigraphic columns, the benthic foram zonation of Hofker (1957, 1966) is shown (partly based on P.J. Felder *et al.*, 1985; Bless *et al.*, 1981, 1986; Jagt *et al.*, 1987). The foram zonation forms the basis for the correlation of the rather different lithologies in these sections. Some relevant benthic foraminifera are illustrated, including the evolutionary trends in *Bolivinoides decorata-australis* (7-8), *Neoflabellina sphenoidalis-postreticulata* (2-6), *Mississippina binkhorsti* (9) and *Siderolites calcitrapoides* (10).

1: *Lenticulina multinodosa;* 2: *Neoflabellina sphenoidalis;* 3: *N. leptodisca;* 4: *N. praereticulata;* 5: *N. reticulata;* 6: *N. postreticulata;* 7: *Bolivinoides decorata* (3-4 pustules on last chamber); 8: *B. australis* (4-7 pustules on last chamber); 9: *Mississippina binkhorsti* (small in foram zones F-J-O, large in zones K-L-M); 10: *Siderolites calcitrapoides* (small in foram zones F-J-O, large in zones K-L-M).

- rather monotonous Campanian assemblages, characterizing either foram zone A/A'-upper or foram zone A'/A'-lower of Hofker (1957, 1966), with regularly occurring small numbers of e.g. *Nodosaria, Dentalina, Lenticulina, Vaginulina trilobata, Gavelinella clementiana* and *Globorotalites micheliniana;* and

- a more diverse Late Maastrichtian assemblage, characterizing either foram zone J or foram zone O of Hofker (1966), with isolated specimens of *Siderolites* gr. *calcitrapoides* (small form with only four spines), *Mississippina binkhorsti* (small, relatively flattened form), *Daviesina fleuriausi, Orbitoides* sp. (small form) and *Gavelinopsis* spp. In the lower portion of the sequence, rare specimens of *Bolivinoides australis* and *B. gigantea* occur (e.g. in section 22, Benzenrade RW 76; cf. Romein *et al.*, 1977).

Usually, the Campanian faunas are extremely poor in specimens and species. However, some assemblages allow the distinction between Early and Late Campanian. Typically Early Campanian foraminifera are restricted to the lower portion of section 2 (De Dael Borehole), where *Neoflabellina sphenoidalis* and *Lenticulina multinodosa* occur between 115 and 120 m. Characteristic Late Campanian foraminifera such as *Stensiöina pommerana, Neoflabellina leptodisca* and *Bolivinoides decorata,* have been found for instance in the sections 1 (Kunderberg Borehole), 12'

(Wingerd) and 16 (De Dael; cf. Jagt *et al.*, 1987). The boundary between Early and Late Campanian must be located somewhere in the De Dael Borehole (section 2); its position cannot be determined on the basis of the extremely poor foram assemblages.

The Late Maastrichtian foram assemblages of Hofker's (1966) zones J and O are characterized by the presence of rather small and primitive specimens of *Orbitoides, Siderolites* and *Mississippina,* suggesting a correlation with Hofker's (1966) foram zones H-I in the ENCI Quarry at Maastricht. The presence of *Bolivinoides australis-gigantea* (6 or more pustules on the last chamber) in section 22 (Highway 76 Benzenrade) along with small *Siderolites, Mississippina* and *Orbitoides* correlates with Hofker's (1966) foram zones F-H in the ENCI Quarry and the foram zones F and basal part of J in the Thermae 2000 Borehole (fig. 5).

This points to a correlation of the Kunrade sections with the mid-Late Maastrichtian foram zones F-H-I in the ENCI or F-J in Thermae 2000. There is no sign of an equivalent of the late-Late Maastrichtian foram zones K-L-M as defined in the ENCI Quarry (with relatively large *Siderolites, Mississippina* and *Orbitoides*). Moreover, there is no equivalent of the foram zones B-C-E (Early to early-Late Maastrichtian), which are marked by the *Bolivinoides australis-gigantea* (with 4 to 7 pustules on the last chamber) and the *Neoflabellina praereticulata-reticulata-postreticulata* lineages.

The boundary between the Campanian and Late Maastrichtian is easily seen in section 12' (De Wingerd). It also occurs in section 1 (Kunderberg Borehole) and 16 (De Dael Outcrop). However, the exact position of this boundary could not be established there.

In this report (fig. 5), the Late Maastrichtian deposits in the Kunrade area are all assigned to Hofker's (1966) foram zone O. According to the data now available, foram zone O in the Kunrade area roughly matches the lower portion of foram zone J and the upper portion of foram zone F. If the ecostratigraphic/lithostratigraphic correlation of the «Koraalbank van Kunrade» near the top of the Kunderberg sequence (section 3) with the Romontbos Horizon in the ENCI Quarry is correct (W.M. Felder, 1975; P.J. Felder *et al.*, 1985), the top of the succession in the Kunrade area would match the top of foram zone H in the ENCI Quarry. However, this does not exclude the possibility that elsewhere foram zone O would also correlate with younger foram zones (I-K-L-M) as suggested by Romein (1963) and Hofker (1966).

OSTRACODES

Three ostracode assemblages are distinguished in the Kunrade area (fig. 6) :

- A lower one (only present in section 2, De Dael Borehole, 80-125 m), characterized by frequently rather high percentages of ornamented specimens (not species !) and by the common occurrence of the genera *Veenia, Cythereis* and *Pterygocythere.*

- A middle one with relatively low percentages of ornamented specimens and in the upper portion (e.g. section 1, Kunderberg Borehole, 8.5-50 m; section 2, De Dael Borehole, above 65 m; section 12', Wingerd, lower portion with Sandy Chalk of Benzenrade; section 16, De Dael, lower portion with Sandy Chalk of Benzenrade; section 24) frequently *Mosaeleberis rutoti, Cytherelloidea* spp. and «*Xestoleberis*» *bidentata* (Jagt *et al.*, 1987; Bless *et al.*, 1988).

- An upper one with frequently rather high percentages of ornamented specimens, including *Mosaeleberis* spp., *Imhotepia* spp., *Mauritsina hieroglyphica* and *Kingmaina* spp.

The lower assemblage is characteristic of the Early Campanian foram zone A'-lower of Hofker (1966) at e.g. Halembaye and in numerous boreholes, such as Kastanjelaan and Thermae (Jagt *et al.*, 1987; Bless *et al.*, 1988). At least in some cases it also matches the (presumably Early Campanian) foram zone A'-middle (e.g. in Kastanjelaan Borehole). The boundary with the middle assemblage is drawn arbitrarily at the top of the interval with high percentages of ornamented specimens. A similar procedure was followed in Bless *et al.* (1988), since no other criteria were available (e.g. presence/absence of Late Campanian markers; see below).

The frequent presence of *Mosaeleberis rutoti* and *Cytherelloidea* spp. forms the principal argument for correlation of the middle ostracode assemblage with on the one hand the Zeven Wegen Chalk (e.g. in Halembaye, Kastanjelaan, Diets-Heur) and on the other the sandy marls of the «Pre-Valkenburg» facies (e.g. in Walem, Campine mining area; cf. P.J. Felder *et al.*, 1985; Jagt *et al.*, 1987; Bless *et al.*, 1988). It should be noted that the percentage of ornamented specimens can be rather high in the basal part of these sequences. The genera *Veenia, Cythereis* and *Pterygocythere* also occur in the Sandy Chalk of Benzenrade, but they tend to be rare or even absent in the Zeven Wegen Chalk.

Remarkable is the presence of «*Xestoleberis*» *bidentata.* This smooth-shelled species can be used as a regional marker for the Late Campanian sandy marls of the Pre-Valkenburg facies and

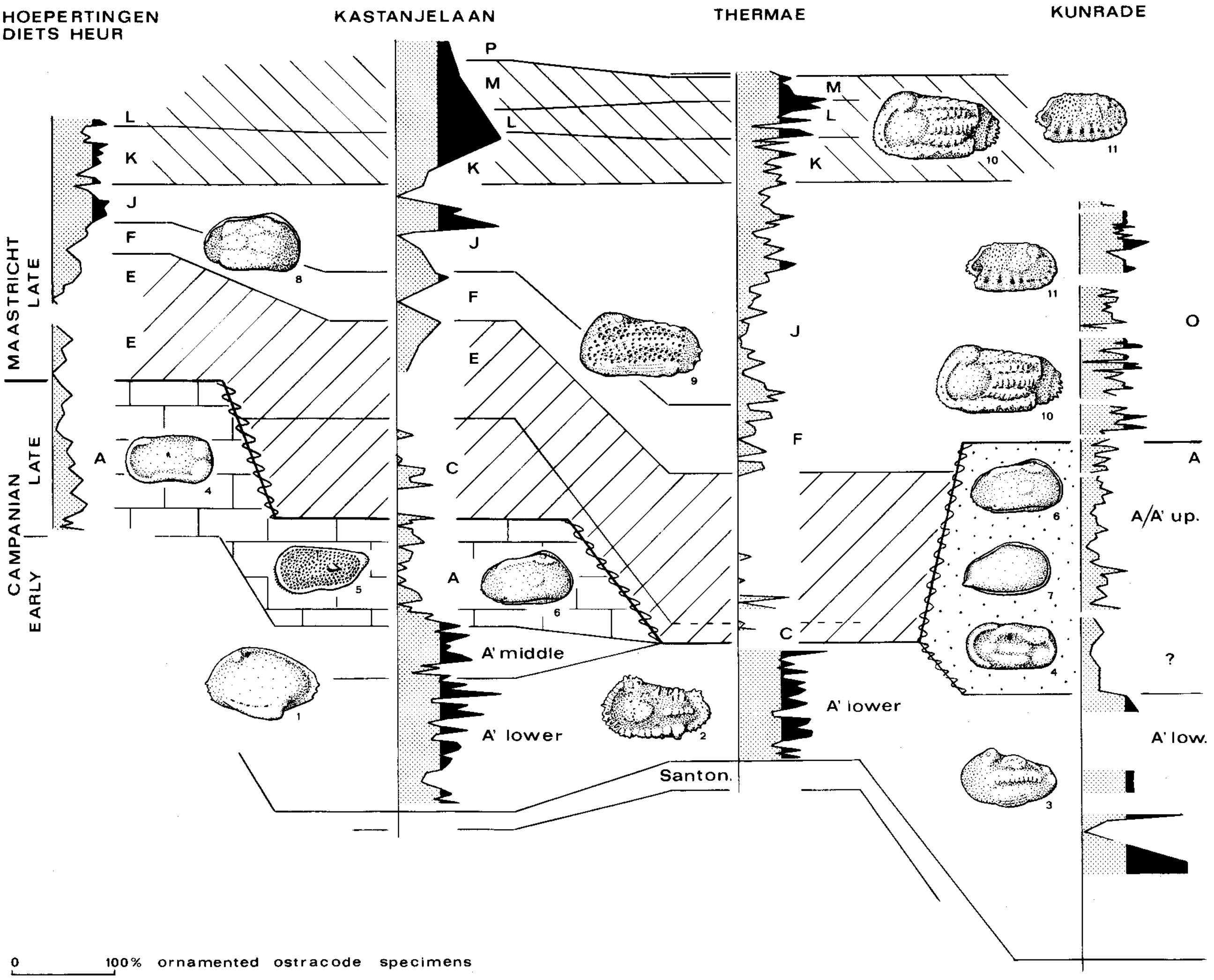

Fig. 6.- Comparison of frequency profiles for ornamented specimens in Late Cretaceous ostracode assemblages in boreholes Hoepertingen, Diets-Heur, Kastanjelaan and Thermae, and in reference section for Kunrade area. For location of sections see figs. 1 - 2. Correlation of sections based on benthic foram zonation as in fig. 5. Some relevant ostracodes are illustrated.
1: *Pterygocythere;* 2: *Cythereis;* 3: *Veenia;* 4: *Cytherelloidea;* 5: *Cuneoceratina;* 6: *Mosaeleberis rutoti;* 7: *«Xestoleberis» bidentata;* 8: *Mosaeleberis macrophthalma;* 9: *Imhotepia interruptoidea;* 10: *Mauritsina hieroglyphica;* 11: *Kingmaina.*

Sandy Chalk of Benzenrade. It is absent, however, in the Zeven Wegen Chalk facies, in which *Bythoceratina* and *Cuneoceratina* are common, two genera which are practically not found in the sandy marls.

The basal portion of the succession with the middle ostracode assemblage has been arbitrarily assigned to it because of the small number of ornamented specimens, although it had not yielded any characteristic taxa. This is of course a rather unsatisfactory solution. It follows the pragmatic approach adopted already for other sections in the Campine mining area (Jagt *et al.,* 1987; Bless *et al.,* 1988).

The rather high percentages of ornamented specimens in the upper assemblages match those observed in e.g. the ENCI Quarry and Kastanjelaan Borehole at Maastricht, and in the Thermae Borehole at Valkenburg a/d Geul, where these charaterize the upper part of foram zone E through foram zone M (Bless, 1988).

The common presence of *Imhotepia* spp. (and notably *I. interruptoidea*) and *Mosaeleberis* spp. (especially *M. macrophthalma*) clearly points to a correlation of the upper ostracode assemblage with those in the foram zones F-H-I of the ENCI Quarry, or F-J in the boreholes Hoepertingen, Kastanjelaan and Thermae. The presence of Tethyan immigrants such as *Kingmaina* and *Mauritsina* in the Kunrade Chalk (which in the Maastricht Chalk facies appear only in the foram zones K-L-M) suggests a possibly shallower (and warmer ?) environment for the Kunrade Chalk than for the flint-bearing Maastricht Chalk facies.

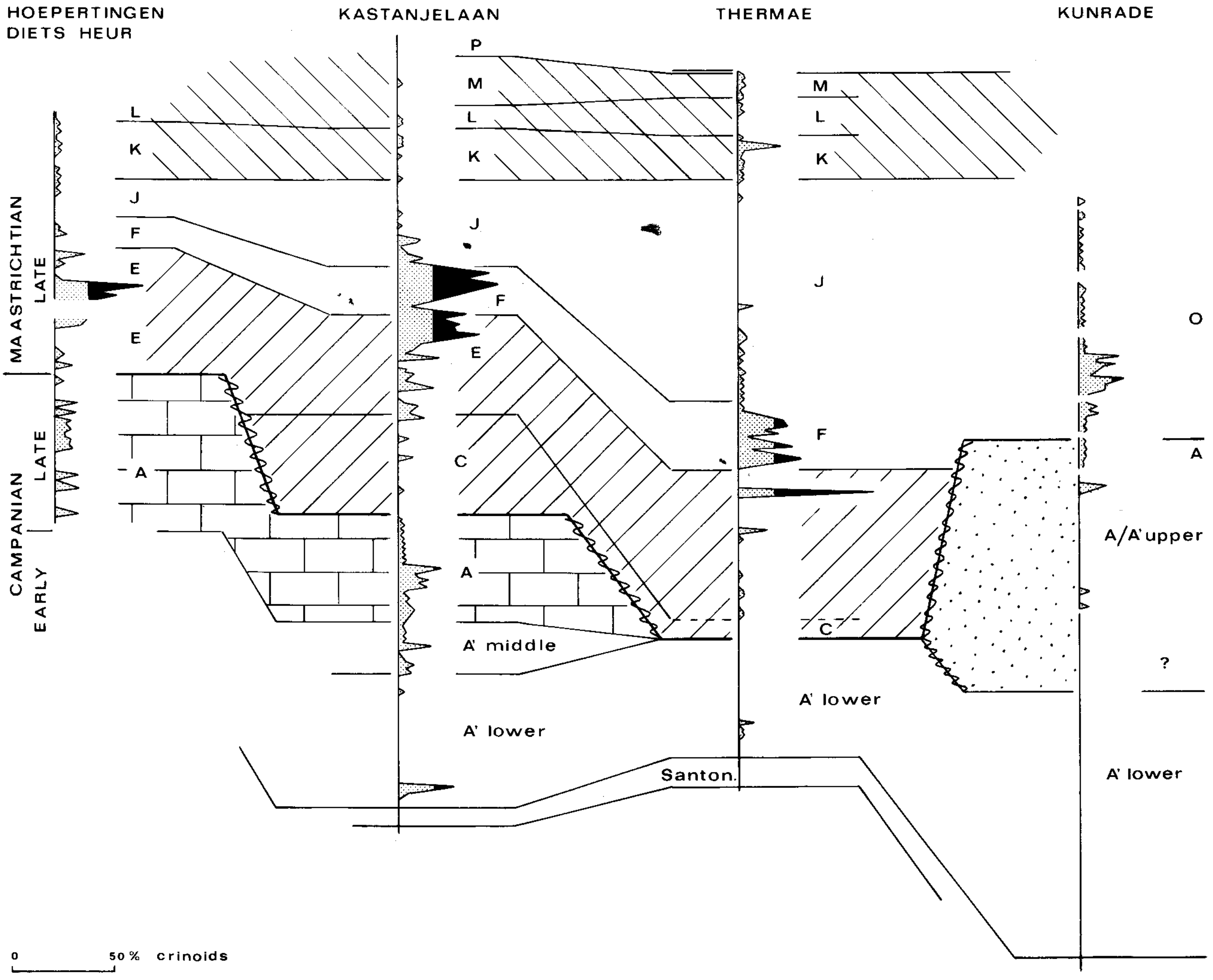

Fig. 7.- Comparison of frequency profiles for crinoid clasts in Late Cretaceous bioclast (1.0-2.4 mm) assemblages in boreholes Hoepertingen, Diets-Heur, Kastanjelaan and Thermae, and in reference section for Kunrade area. For location of sections see figs 1-2. Correlation of sections based on benthic foram zonation as in fig. 5.

BIOCLASTS

Frequently, the Late Cretaceous bioclast assemblages in the SE Netherlands and NE Belgium can be used for a refinement or confirmation of the correlations based on benthic foraminifera and ostracodes. They are also successfully applied in best-fit correlations between sections when no determinations of foraminifera and ostracodes are available (cf. P.J. Felder *et al.*, 1985; Jagt *et al.*, 1987; Bless *et al.*, 1987, 1988). The ecostratigraphic value of four different groups of bioclasts is discussed here : crinoid clasts, serpulids, Octocorallia rods and sponge spicules. The remnants of crinoids, serpulids and Octocorallia have been studied in the sieve fraction 1.0-2.4 mm (the «normal» bioclast assemblages discussed here), whereas the sponge spicules were found in the sieve fraction 0.125-1.0 mm.

Small amounts of crinoid clasts occur throughout the Campanian and Maastrichtian deposits, but distinct peaks of 10-25 % of the bioclast (1.0-2.4 mm) assemblages are largely restricted to the foram zones A'-lower through F (P.J. Felder *et al.*, 1985; Felder, 1988). Usually, two complex and variably developed crinoid maxima in the upper portion of foram zone E and in foram zone F mark the top of the succession with rather high crinoid percentages. Crinoid peaks are quite exceptional in the foram zones H-I-J-K-L-M. Therefore, the well-developed, complex crinoid maximum (up to 22 %) in the lower portion of the Kunrade Chalk (fig. 7) suggests correlation with one of the two crinoid peaks in foram zones E or F in the boreholes Kastanjelaan or Thermae (cf. Jagt, 1988). The resemblance of the vertical range and the configuration of the Kunrade crinoid maximum (in section 12", Wingerd, and section 22, Highway 76 Benzenrade) with the crinoid peak in foram zone F

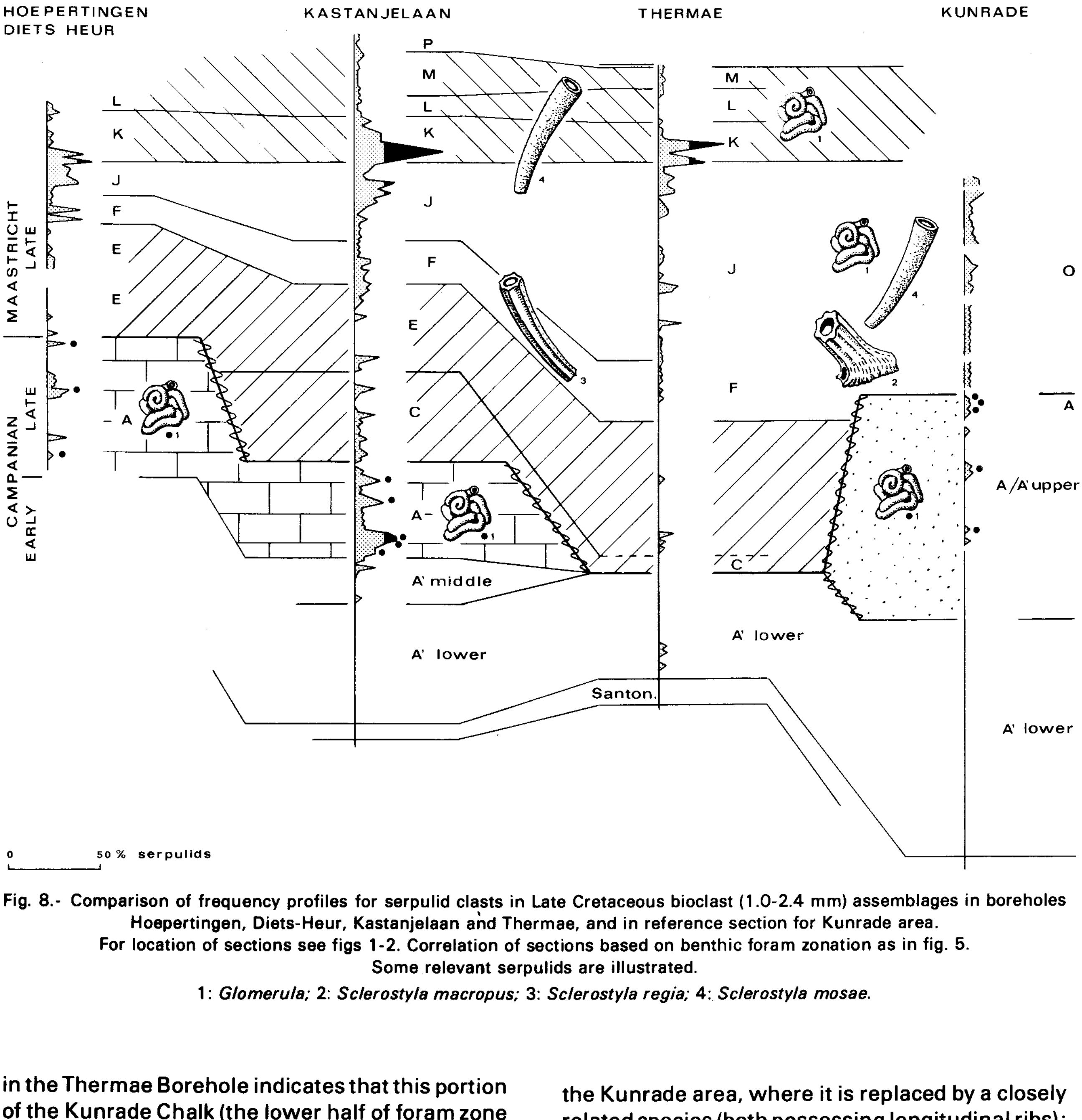

Fig. 8.- Comparison of frequency profiles for serpulid clasts in Late Cretaceous bioclast (1.0-2.4 mm) assemblages in boreholes Hoepertingen, Diets-Heur, Kastanjelaan and Thermae, and in reference section for Kunrade area.
For location of sections see figs 1-2. Correlation of sections based on benthic foram zonation as in fig. 5.
Some relevant serpulids are illustrated.
1: *Glomerula;* 2: *Sclerostyla macropus;* 3: *Sclerostyla regia;* 4: *Sclerostyla mosae.*

in the Thermae Borehole indicates that this portion of the Kunrade Chalk (the lower half of foram zone O) is best correlated with the foram zone F in the Valkenburg and Maastricht area.

In the ENCI Quarry at Maastricht, the highest percentages of serpulid clasts occur in foram zones I and K (Emael and Nekum Chalk). This matches the complex serpulid peaks near the top of foram zone J and foram zone K of the boreholes Hoepertingen, Kastanjelaan and Thermae (fig. 8). The maxima relate to the massive occurrence of *Sclerostyla mosae* (cf. Jäger, 1987). Presumably, the absence of these serpulid maxima in the Kunrade area indicates that the Kunrade Chalk is older than the foram zones I (or top of J) and K.

The serpulid *Sclerostyla regia,* which characterizes the flint-bearing chalk facies of foram zones F-H in the Maastricht area does not occur in the Kunrade area, where it is replaced by a closely related species (both possessing longitudinal ribs): *Sclerostyla macropus* (cf. Jäger, 1988). According to Jäger (1988), *S. macropus* is common in boreal Cretaceous shallow-water environments. This may be an indication that the Kunrade Chalk was deposited in a shallower environment than the Lanaye-Valkenburg-Gronsveld Chalk of foram zones F-H in the Maastricht area.

The three very small, complex serpulid peaks in the Sandy Chalk of Benzenrade (foram zone A/A'-upper) are marked by the presence of the coiled tubes of the genus *Glomerula.* This suggests a correlation with three similar peaks in the Zeven Wegen Chalk of Diets-Heur and Kastanjelaan. Rare specimens of *Glomerula* also occur randomly in the Kunrade Chalk and in the foram zones K-L-M of Hoepertingen, Kastanjelaan and Thermae.

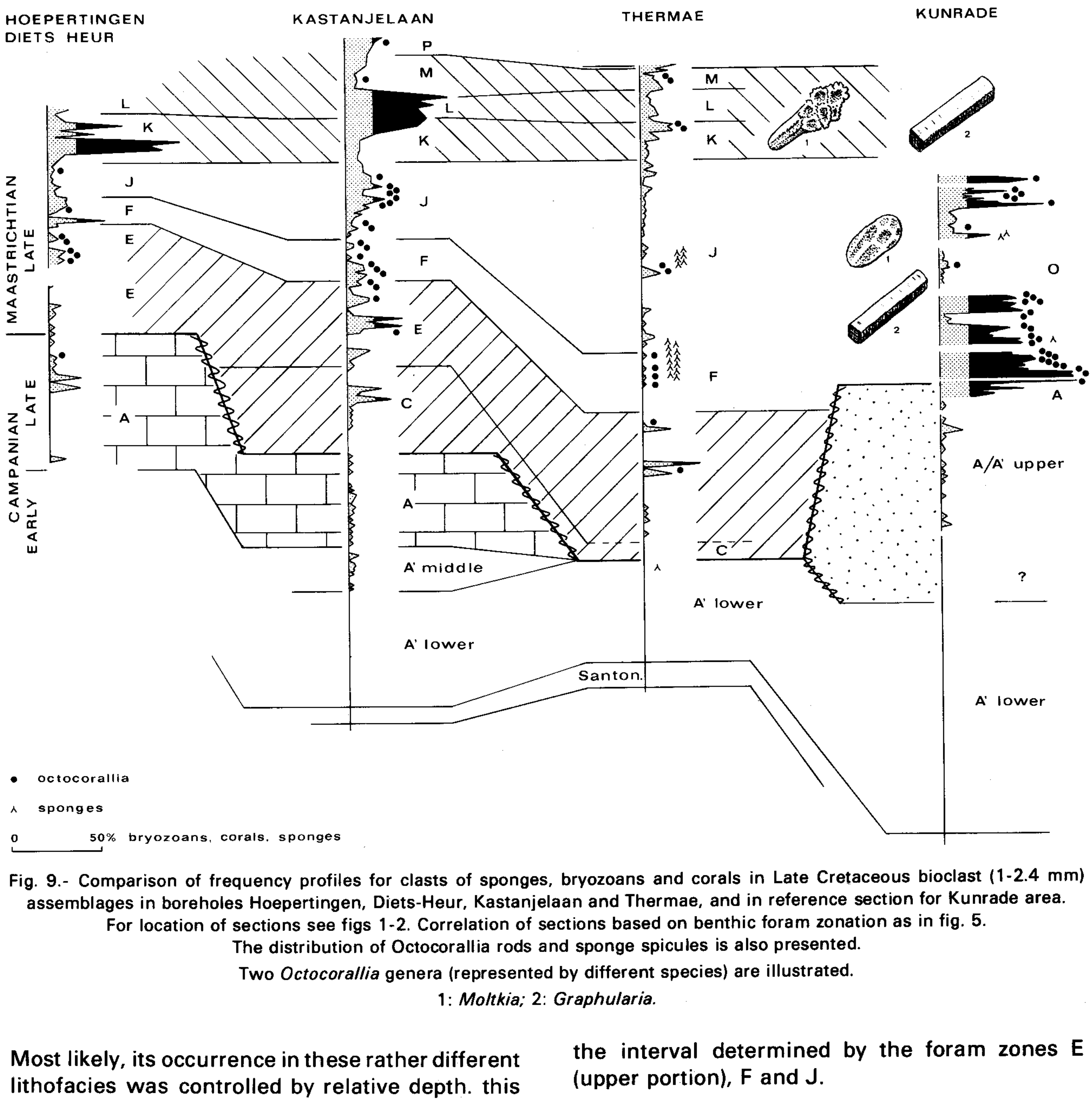

Fig. 9.- Comparison of frequency profiles for clasts of sponges, bryozoans and corals in Late Cretaceous bioclast (1-2.4 mm) assemblages in boreholes Hoepertingen, Diets-Heur, Kastanjelaan and Thermae, and in reference section for Kunrade area. For location of sections see figs 1-2. Correlation of sections based on benthic foram zonation as in fig. 5. The distribution of Octocorallia rods and sponge spicules is also presented. Two *Octocorallia* genera (represented by different species) are illustrated. 1: *Moltkia;* 2: *Graphularia.*

Most likely, its occurrence in these rather different lithofacies was controlled by relative depth. this may be an indirect argument for the shallow depositional environment of the Zeven Wegen Chalk !

The maxima in the frequency profiles for the group of sessile benthos (sponges, bryozoans and corals) are rather randomly distributed (fig. 9). Therefore, these have little ecostratigraphic value. On the other hand, however, some taxa within this group may be useful for correlation purposes. This is shown by the occurrence of Octocorallia rods (marked by black dots in fig. 9). These are common in the bioclast (1.0-2.4 mm) assemblages of the Kunrade Chalk. In the boreholes Hoepertingen, Diets-Heur, Kastanjelaan and Thermae, Octocorallia rods are practically restricted to the foram zones E (upper portion) through J. They are relatively rare in foram zones K-L-M. Thus, the Kunrade Chalk in its type area best corresponds to the interval determined by the foram zones E (upper portion), F and J.

The Octocorallia are represented by the genera *Moltkia* and *Graphularia* with different species for, on the one hand, the foram zones E, F, J and O, and, on the other hand, the foram zones K, L and M (cf. P.J. Felder, 1981). In the foram zones O and K-L-M, rods of *Moltkia* dominate; in the foram zones E-F-J, rods of *Graphularia* are more common.

Two intervals within the Kunrade Chalk (base of section 22, Highway 76 Benzenrade, and base of section 3, Kunderberg) have yielded a very rich and diverse assemblage of siliceous sponge spicules. The foram zones F and J of the Thermae Borehole also contain two intervals with abundant sponge spicules (fig. 9). A best-fit correlation between these sections implies that the sponge level at the base of section 22 would match the sponge interval in the upper half of foram zone F or base of foram zone J, whereas the level at the base of section 3 would correlate with the interval halfway foram zone J. This is in agreement with Hofker's (1966, fig. 55) model of a «sponge facies» in the eastern half of South-Limburg that ranges from the top of foram zone F to the top of foram zone J. Further to the west (Maastricht area), this sponge facies seems to be absent or at least less well developed.

LITHOFACIES

Four Late Cretaceous lithofacies can be distinguished in the Kunrade area. The lowermost one corresponds to Ecozone I and consists of phytoclast-bearing, medium- to coarse-grained sand with a thickness of about 17 m in section 2 (De Dael Borehole, 143-160 m). It is assigned to the Aachen Formation *sensu* W.M. Felder (1975).

The second lithofacies consists of glauconitic silty, fine- to medium-grained sand with some gravel beds, one of these forming the base of the sequence. This lithology corresponds to Ecozone II and the lower part of Ecozone III, and has a total thickness of 78 m in section 2 (De Dael Borehole, 65-143 m). Presumably, this is a local variant of the Vaals Formation *sensu* W.M. Felder (1975). Note that the boundary with the overlying lithofacies does not match the boundary between ecozones II and III. Future studies should substantiate this.

The third lithofacies consists of fine- to coarse-grained, slightly glauconitic sand with hard limestone nodules and lenses and some isolated gravel beds. This is the «Sandy Chalk of Benzenrade» *sensu* Staring (1869) and corresponds to the upper portion of Ecozone III. The total thickness is some 60-70 m (in section 2, De Dael Borehole, above 65 m). To the SW (e.g. in the Maastricht area), this lithofacies passes into the calcilutites of the Zeven Wegen Chalk *sensu* W.M. Felder (1975), and to the NW (e.g. Campine Mining area) into the lower portion of the Pre-Valkenburg facies *sensu* P.J. Felder *et al.* (1985a). It is proposed here to retain the name «Sandy Chalk of Benzenrade» as a local variant of the Pre-Valkenburg facies. The top is well defined by a hard limestone bed in section 12' (Wingerd).

The fourth and uppermost lithology is formed by the «Kunrade Chalk» : hard limestone nodules and lenses in soft chalk, both consisting of medium- to coarse-grained biocalcarenites, sometimes with some glauconite in the soft chalk, and with isolated flint nodules near the top of sections 3 and 22. The Kunrade Chalk corresponds to the Ecozones IV and V. The estimated total thickness is 50-60 m. To the SW (e.g. in the Maastricht area), the Kunrade Chalk passes into the flint-bearing chalk of the upper portion of the Gulpen Formation (Lanaye Chalk as recognized in the ENCI Quarry *sensu* W.M. Felder, 1975) and lower portion of the Maastricht Formation (Valkenburg, Gronsveld, Schiepersberg and base of Emael Chalk as recognized in the ENCI Quarry *sensu* W.M. Felder 1975). The equivalent of the Lichtenberg Horizon in the ENCI Quarry (the boundary between the Gulpen and Maastricht Formations) might be bed 39 in section 22 (Highway 76 Benzenrade), some 5 m below the top of the interval with high crinoid percentages, as suggested by the study of foram, ostracode and bioclast assemblages (cf. Bless *et al.,* 1986, 1988).

CONCLUSIONS

The Late Cretaceous deposits in the Kunrade area have been subdivided into five ecozones, which are correlated with the classic outcrops of Halembaye and ENCI in the Maastricht area, and with the boreholes Hoepertingen, Diets-Heur, Kastanjelaan (Maastricht) and Thermae (Valkenburg a/d Geul). These correlations are based on the following arguments.

Ecozone I : The exclusive presence of phytoclasts is characteristic of the Santonian Aachen Formation.

Ecozone II : The Early Campanian age is well established only for a short interval in section 2 (115-120 m) and based on benthic foraminifera. The relatively monotonous ostracode assemblages with high percentages of ornamented specimens permit correlation with similar sequences in the Vaals Formation throughout the SE Netherlands and NE Belgium. The top of the ecozone is arbitrarily drawn at the top of the interval with high percentages of ornamented ostracode specimens.

Ecozone III : The Late Campanian age is proved by cephalopods, which also allow correlation with the lower part of the Zeven Wegen Chalk. Benthic foraminifera, ostracodes and serpulids confirm this correlation. The stratigraphic position of the lower portion of this ecozone in section 2 (65-80 m) has not yet been established with certainty.

Ecozone IV : The Late Maastrichtian age is illustrated by cephalopods. Benthic foraminifera, ostracodes, crinoid clasts, Octocorallia rods, serpulids and sponge spicules all suggest a best-fit correlation with the foram zone F (or maybe base of foram zone J) in the boreholes Thermae, Kastanjelaan and Hoepertingen. The boundary with Ecozone III is well marked by a change in the ostracode and foram assemblages, and by a change in the lithofacies.

Ecozone V : The Late Maastrichtian age is also illustrated by cephalopods. Benthic foraminifera, ostracodes, Octocorallia rods, serpulids, sponge spicules and lithofacies («Koraalbank van Kunrade») all indicate a best-fit correlation with the lower half of foram zone J in the boreholes Thermae and Kastanjelaan, and with foram zone H in the ENCI Quarry. There are no arguments for a correlation with the foram zones I-K-L-M.

The interpretation of the stratigraphy of the Late Cretaceous deposits in the Kunrade area here presented differs in three aspects from those formulated by former authors. First, the Late Campanian age of the Sandy Chalk of Benzenrade (Ecozone III) was firmly established by Jagt *et al.* (1987), whereas earlier authors (Romein, 1963; Hofker, 1966; W.M. Felder, 1975; Kuyl, 1980) suggested an Early Campanian age.

Secondly, the lower half of the Kunrade Chalk (Ecozone IV) is here correlated with foram zone F in the Maastricht area, whereas e.g. Romein (1963), Hofker (1966), W.M. Felder (1975) and Romein *et al.* (1977) correlated this with the foram zones H-I-K.

Finally, the top of the Kunrade Chalk in its type area corresponds to the top of foram zone H in the ENCI Quarry, as indirectly proposed by W.M. Felder (1975 : «Koraalbank van Kunrade matches Romontbos Horizon in ENCI Quarry at Maastricht»). This contradicts the opinion of Hofker (1966, fig. 55), who believed that the upper part of the Kunrade Chalk in the Kunrade area should be correlated with foram zone K in the Maastricht area.

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