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DISTRIBUTION AND PALEOENVIRONMENT OF DEVONIAN TO PERMIAN OSTRACODE ASSEMBLAGES IN BELGIUM WITH REFERENCE TO SOME LATE FAMENNIAN TO PERMIAN MARINE NEARSHORE TO «BRACKISH-WATER» ASSEMBLAGES DATED BY MIOSPORES[1]

by

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(10 figures, 7 tables and 1 plate)

RESUME.- Les assemblages d' ostracodes dévoniens à permiens en Belgique peuvent être subdivisés en six groupes majeurs caractérisant des environnements non marins, saumâtres, marins peu profonds et de bassins. Une revue à grands traits de leur distribution stratigraphique montre que des faunes marines mixtes sont le plus largement répandues au Dévonien et au Carbonifère. A la suite de l'orogène calédonienne, on constate des tendances vers des assemblages d'«eaux saumâtres» (oligohalins ?) pendant le Dévonien inférieur. Mais à partir du Givétien on trouve aussi des associations de plateforme ouverte sur la mer et même des entomozoaires et des ostracodes de type Thuringien (indicatifs de «plateforme profonde» et de «bassin») dans le Frasnien superieur et la base du Famennien supérieur. Cette succession suggère une tendance transgressive pour l'ensemble de l'environnement sédimentaire, atteignant son acmé au Dévonien supérieur. La tendance régressive qui suit commence au Famennien tardif (Fa2c) et au Dinantien avec l'apparition fréquente d'assemblages marins mixtes qui alternent dans le temps et dans l'espace avec des faunes de plateforme ouverte sur la mer. Cette régression généralisée qui culmine au Westphalien est marquée par l'apparition successive d'assemblages d'ostracodes d'«eaux saumâtres» et non marins suivie par la disparition, respectivement, des faunes marines mixtes (à la base du Westphalien C) et des ostracodes d'«eaux saumâtres» (au Westphalien C supérieur). L'apparition isolée d'un ostracode d'«eaux saumâtres» dans les couches rouges du Thuringien reflète l'existence d'une brève incursion marine pendant cette période.

Quelques exemples d'assemblages littoraux marins de mer peu profonde («marin mixte» et «eaux saumâtres»), datés par miospores du Famennien supérieur au Permien, sont montrés.

ABSTRACT.- The Devonian to Permian ostracode assemblages in Belgium may be subdivided in six major groups characterizing non-marine through «brackish» and shallow marine into deep marine shelf and «basin» environment. A broad-brush review of their stratigraphical distribution reveals that mixed marine faunas are the most widely extended in the Devonian and Carboniferous. Following the Caledonian orogeny there are tendencies towards «brackish-water» (oligohaline?) assemblages during the Lower Devonian. But since the Givetian also open marine shelf associations are found and even Entomozoans

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and Thuringian-type ostracodes (indicative for «deep shelf» to «basin») in the Upper Frasnian and basal Upper Famennian. This succession suggests a transgressive trend for the overall depositional environment, reaching its acme in the Late Devonian. The subsequent regressive tendency starts in the late Famennian (Fa2c) and Dinantian with the frequent occurrence of mixed marine assemblages which alternate in time and space with open marine shelf faunas. The culmination of this overall regression in Westphalian times is marked by the successive appearance of «brackish- water» and non-marine ostracode assemblages followed by the disappearance of, respectively, the mixed marine faunas (base Westphalian C) and «brackish-water» ostracodes (Upper Westphalian C). The isolated occurrence of a «brackish-water» ostracode in the red beds of the Thuringian reflects a short- lived marine incursion during that period.

Some examples of shallow marine nearshore («mixed marine» and «brackish-water») assemblages from the Upper Famennian to Permian are shown, which have been dated by miospores.

INTRODUCTION

The ostracode assemblages in the Devonian to Permian sediments of Belgium can be subdivided in six major groups characterizing different paleoenvironments (Bless 1983). These are the Entomozoans and Thuringian-type ostracodes which may have preferred relatively quiet and usually deep offshore facies (basin or deep shelf), the open marine shelf and mixed marine shelf assemblages which seem to have predominated in more shallow marine conditions ranging from offshore (open marine) to presumably more nearshore (mixed marine), the «brackish-water» ostracodes which are found in sediments suggesting either reduced (oligohaline to polyhaline) or increased (hypersaline) salinities in a littoral to lagoonal or estuarine regime, and finally the non-marine ostracodes which swarmed in lacustrine, fluviatile or deltaic waters.

The taxonomic composition of these groups is difficult to define, even at a suprageneric level, with the exception of the Entomozoans or Entomozoacea (usually distinguished by their delicate ornamentation) and the non-marine ostracodes with only the genera *Carbonita* and *Darwinula*. As a rule however the Thuringian-type faunas are recognized by the presence of many taxa with a rather «spinous» carapace. The open marine shelf assemblages often contain high numbers of Bairdiaceans (frequently more than 50% of specimens and species) but lack taxa with a spinous carapace. Slightly to strongly ornamented (but not spinous) ostracode taxa predominate in the mixed marine assemblages. And finally, the «brackish-water» assemblages display low diversity (often only one or a few species) and sometimes tendencies towards giantism in one or more species (Bless 1983).

This idealized picture is complicated by the frequent occurrence of transitional assemblages and by the recognition of highly specialized associations occurring for example around reefs. A further problem is the paleoecological assessment of the assemblages. This is based on the interpretation of the sediment and associated fauna and flora, and is certainly not always conclusive. But despite all these possible shortcomings and uncertainties it is believed that the recognition of these major ostracode assemblages may constitute a useful «finger-print» method in paleoecological investigations. The present report is restricted to some examples of presumed nearshore (mixed marine shelf and «brackish-water») assemblages in the Upper Famennian to Permian of Belgium, all situated around the Brabant Massif that formed a structural high during the Devonian and Carboniferous (fig. 1).

MIXED MARINE OSTRACODE ASSEMBLAGES

This term is here applied to ostracode assemblages which presumably lived in a somehow restricted marine environment. In most cases, this seems to have been a relatively shallow nearshore shelf (e.g. Montfort-IV and Kooigem-Driehoven). But sometimes the lithofacies and accompanying fossil assemblages have been interpreted as indicative for a rather «deep shelf» (Wervik-2).

The ostracode assemblages of the so-called «restricted shallow nearshore shelf» are marked by the relative (qualitative and quantitative) rarity of Bairdiacean ostracodes (notably *Bairdia* and *Acratia*). In the here shown examples the Bairdiaceans only represent some 2% (Kooigem-Driehoven) to 5% (Montfort-IV) of the total number of ostracode specimens, whereas these make up only some 15-20% of the number of species (tables 1,4; figures 2-7). These figures are well below those observed in more «open marine» (offshore shelf) sediments of the same age, wherein Bairdiaceans may constitute more than 50% of the number of individuals and species. Lethiers &

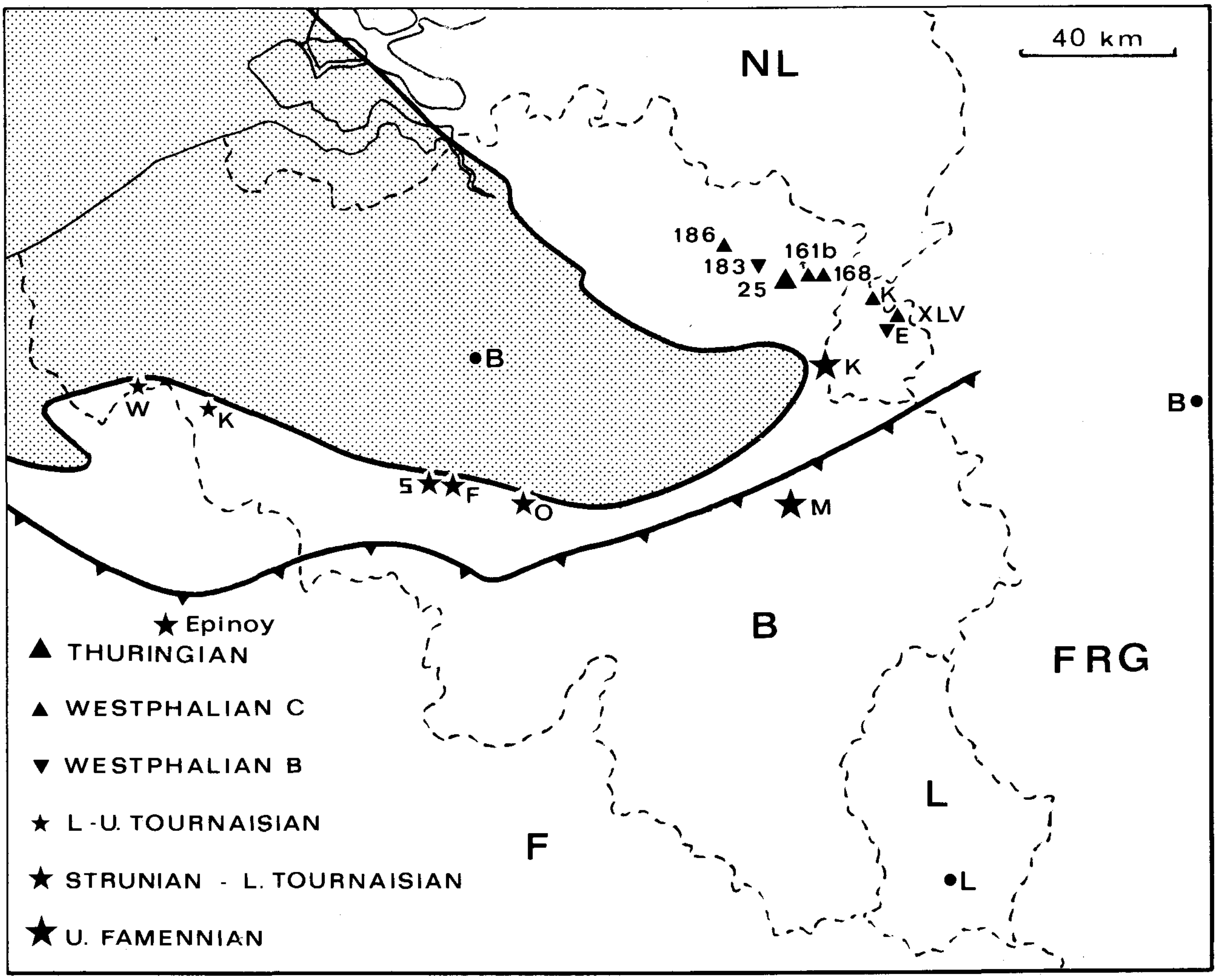

Figure 1.- Map showing the geographical distribution of some Upper Devonian to Permian ostracode assemblages dealt with in this paper. The outline of the Cambro-Silurian rocks of the Brabant Massif (punctate shading) and the Midi-Aachen Overthrust are indicated. The following localities are shown.
- Thuringian : KS 25 borehole (Campine);
- Westphalian C : BGD 161b, BGD 168, BGD 186 boreholes (Campine), XLV and Kemperkoel boreholes (South-Limburg);
- Westphalian B : BGD 183 borehole (Campine), former Emma State Mine (South Limburg);
- Lower to Upper Tournaisian : Wervik-2 and Kooigem-Driehoven boreholes (West Flanders);
- Strunian to Lower Tournaisian : Soignies (C455), Feluy and Onoz outcrops (Namur Basin), Epinoy-1 borehole (N France);
- Upper Famennian : Montfort and other outcrops (a.o. Evieux, Chanxhe, Flagotier) in Ourthe Valley, Kastanjelaan borehole at Maastricht (South-Limburg).

Bouquillon (1986) described ostracode assemblages from the Upper Givetian, Frasnian and Strunian of the Epinoy-1 borehole in northern France, where Bairdiaceans are (practically) absent. According to those authors the assemblages indicate «shallow marine environments with more or less restricted conditions». In several beds, the Epinoy ostracodes are associated with articulate brachiopods. The same observation has been made for Montfort-IV and Kooigem-Driehoven.

Brachiopods also form the associated fauna of an (here not further described) ostracode assemblage without Bairdiaceans from the Lochkovian «schistes de Mondrepuits (southern Belgian Ardenne). In Belgium, the youngest known Paleozoic ostracode assemblages without or with extremely few (qualitatively and quantitatively) Bairdiaceans occur in the Aegir Marine Band equivalent at the base of the Westphalian C (Van den Boogaard & Bless 1985). The associated occurrence of articulate brachiopods, (usually small) goniatites, lamellibranchs and echinoderms has been commonly interpreted as an indication for a «shallow marine offshore shelf with well-aerated bottom conditions». However, because of the absence or rarity of bryozoans, crinoids, complex foraminifera such as fusulinids and Bairdiaceans, it has been presumed that these represent «a less open marine environment» (Van den Boogaard & Bless 1985: 138).

It seems rather difficult to give an exact definition of these «mixed marine ostracode assemblages». The generic composition is extremely variable, both qualitatively and quantitatively as shown by the examples of Montfort-IV and Kooigem- Driehoven. The organic matter in the sediment may be extremely low (well-aerated) to very high (anaerobic). The sediment itself may be a pure carbonate (Kooigem-Driehoven), a marl or a carbonaceous shale (Aegir M.B.), or a mixture of these (Montfort-IV). The water energy may have been rather low (frequent occurrence of complete carapaces, usually fine-grained deposits, sometimes anaerobic conditions). The ostracodes may occur without or with (notably brachiopods, both inarticulate and articulate) other fossil groups. In some instances there is an indication for a reduced salinity: presence of presumed «brackish-water» indicators such as *Cryptophyllus, Beyrichiopsis, Glyptopleura,* relatively poor or monotonous macrofauna assemblages, mixture of marine and «non-marine» elements as in Upper Visean of Epinoy-1 (Lethiers & Bouquillon 1986). In other cases the assemblages occur in lithofacies suggesting unstable, short-lived marine conditions (e.g. Montfort-IV, Aegir M.B.).

Maybe even more problematic is the interpretation of Wervik-2. The carbonate nodules in a shale matrix would suggest a rather «deep» shelf environment. This interpretation is supported by the presence of relatively small corals and crinoids (poorly oxygenated?). The arthropod assemblage of *Shivaella* and conchostracans seems unique. However, «estheriid» conchostracans in the (usually organic-rich) shales and limestones around the Devonian-Carboniferous boundary in the Rheinisches Schiefergebirge (FGR), in the Montagne Noire (France), in the Muhua section of southern China and in the western USA presumably lived in a restricted nearshore environment as indicated by the associated fossil assemblages (inarticulate brachiopods, plant debris, dwarf faunas (Bless *et al.,* 1988). Recent conchostracans preferably live in non-marine to oligohaline environments.

MONTFORT IV

This is a small abandoned quarry on the eastern bank of the Ourthe, south of Esneux, with an outcrop of the Upper Famennian Evieux Formation. The lithofacies is predominated by arkosic and micaceous sandstones with repeated cross stratification, ripple marks and parallel lamination in ascending order, as well as fining upward sequences. Silty to clayey (sometimes micaceous) shales occur on top of these more or

Table 1.- Quantitative composition of ostracode assemblage from Fa2c in Montfort-IV Quarry (numbers refer to, respectively, number of specimens and percentages)

Beyrichiopsis	8 -	1 %
Quasiknoxiella	120 -	23 %
Armenites	6 -	1 %
H. (Keslingella)	2	
Chamishaella	15 -	3 %
Egorovina	150 -	30 %
Lichwinia?	1	
Cryptophyllus	90 -	18 %
Cavellina	55 -	11 %
Gen. nov. et sp. nov.	36 -	7 %
Bairdia	16 -	3 %
Acratia	13 -	2 %
	512 -	99 %

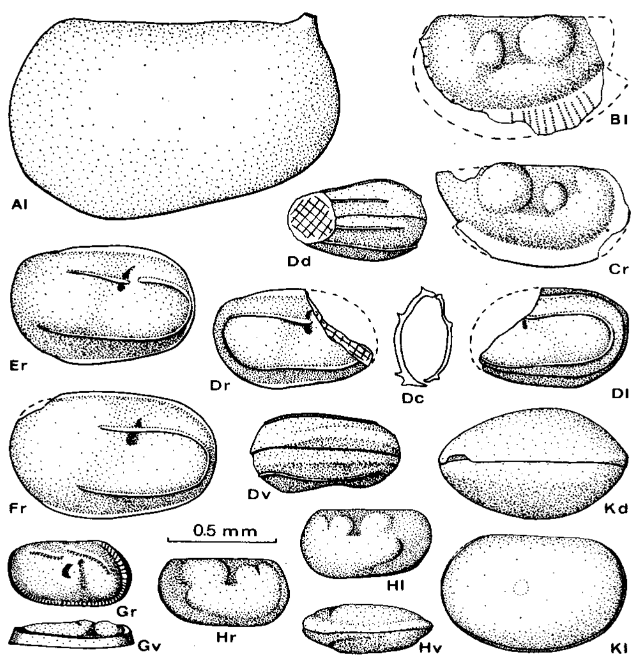

Figure 2.- Upper Famennian (Fa2c) ostracodes; Montfort IV section, Ourthe Valley, Belgium.

A : *Armenites* sp. (cf. *A. compositus* Tschigova 1977 and *A. philippovae* Tschigova 1977);
B-C : *Hollinella (Keslingella)* sp.
D-F : *Beyrichiopsis chovanensis* Posner (in Gurevich 1971). Males with U-shaped lateral crest, females inflated posteriorly and lateral crest forming a closed ring (= *B. glyptopleuroides* sensu Becker *et al.* 1974, non Green 1963).
G : *Lichwinia ?* sp. (cf. Tschigova 1977, pl.39, 13-14)
H : *Marginia* cf. *rauseri* Tschigova 1977
K : *Chamishaella* aff. *lysi* Tschigova 1977

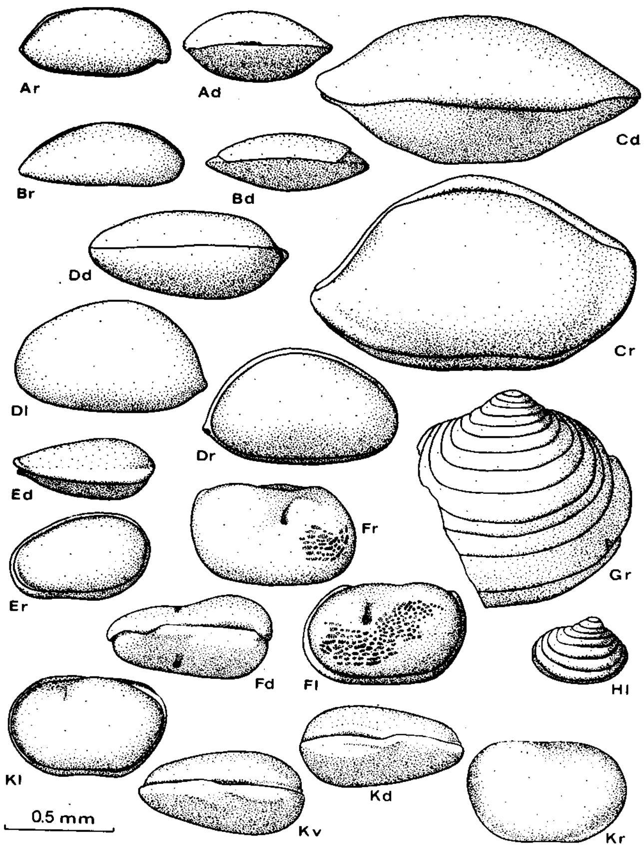

Figure 3.- Upper Famennian (Fa2c) ostracodes; Montfort IV section, Ourthe Valley, Belgium.

A : *Acratia (Cooperuna)* cf. *subobtusa* Lethiers 1974
B : *Acratia* sp.
C : *Bairdia* cf. *sinuosa* Morey 1936
D : gen. et sp. nov.
E : *Cavellina* sp.
F : *Quasiknoxiella* sp.
G-H : *Cryptophyllus* spp.
K : *Egorovia* cf. *egorovi* (Nasarova 1951)

Table 2.- Most characteristic miospores from VCo Zone of Fa2c age in Montfort-IV Quarry.

Aneurospora greggsii (McGregor) Streel *in* Becker *et al.*, 1974
Auroraspora hyalina (Naum.) Streel *in* Becker *et al. 1974*
Diducites plicabilis Van Veen 1981
Diducites poljessicus (Kedo) Van Veen 1981
Diducites versabilis (Kedo) Van Veen 1981
Grandispora cornuta Higgs 1975
Grandispora gracilis (Kedo) Streel *in* Becker *et al.* 1974
Retusotriletes incohatus Sullivan 1964
Retusotriletes planus Dolby & Neves 1969
Rugospora flexuosa (Jusch.) Streel *in* Becker *et al.* 1974
Spelaeotriletes cassiculus Higgs 1975

The section is dated by several spore samples (Table 2) some 8 meters below the limestone interval, which indicate the VCo spore zone (Streel *et al.*, 1987). This suggests that the limestone interval may be correlated with that of Chanxhe beds CH06 to CH13 (Becker *et al.*, 1974, fig. 9) and Evieux-railway (Becker *et al.*, 1974, fig. 10), maybe also with Evieux-grotte (Becker *et al.*, 1974, fig. 10).

The predominance of complete carapaces in the ostracode assemblage suggests rapid sedimentation. The association of *Beyrichiopsis, Quasiknoxiella, Egorovina* and *Cryptophyllus* (making up more than 70 % of the number of specimens) suggests a restricted, mixohaline environment (cf. also Robinson 1978). This fits well with the rather poor, monotonous macrofauna in the same samples.

less rhythmic sequences. Abundant fish remains (scales, bones and teeth) occur in one of these shale intervals near the base of the section. Near the top of the section several thin, dark organic-rich, finely laminated micritic limestones occur with irregularly interbedded (sometimes micaceous) shales. Both the limestone and interbedded shale yield a very rich and diverse ostracode assemblage (table 1, figs. 2-3), as well as rare lamellibranchs and small euomphaloid gastropods. The bioturbated top of the limestone interval contains a wide variety of brachiopods, among which up to 4 cm large specimens of «*Cyrtospirifer*» cf. *pamiricus* (K.V. Simakov, pers. comm.).

The sedimentary setting suggests alluvio-lagoonal to sublagoonal tidal flat environments (cf. Thorez *in* Becker *et al.*, 1974; Thorez & Dreesen 1986). Presumably, these sediments have been deposited during the period of maximum progradation of the «Psammites du Condroz» facies.

WERVIK-2

This borehole is also known as Wervik-Hazebeek (K9, 96E -75; Dusar & Loy 1986). It is located in SW Belgium near the frontier with France, about halfway between Ieper and Kortrijk. The top of the Dinantian occurs at 164 m bore depth. The lithological sequence consists (in ascending order) of :

- red-green sandstones and mudstones (228.9 - 212.2 m), yielding non- marine lamellibranchs and fish near the top, where a paleosol is developed;
- dolostones with dark-grey shale partings (212.2 - 201.9 m), partly silicified, usually with huge amounts of crinoids;
- clayey nodular wackestones with some thin limestone lenses (201.9 - 179.0 m), carbonates partly dolomitized; and
- encrinitic dolostones (179.0 -164 m).

The clayey nodular wackestones between 201.9 m and 179.0 m contain a relatively rich fossil assemblage including crinoids, brachiopods, bryozoans, small corals and fish. Ostracodes (usually Paraparchitacea) occur in several layers. The depositional environment may have been a «relatively deep» marine shelf. The 201.9-179.0 m interval is dated by conodonts of the *Siphonodella* zone (Dusar & Loy 1986).

Miospores have been studied from 185.4 m and 192.0 m (Table 3) which yield evidence that this interval belongs to the HD spore zone (see Higgs & Streel 1984).

Table 3.- Most characteristic miospores of HD Zone from the uppermost Lower Tournaisian in Wervik - 2.

Auroraspora asperella (Kedo) Van der Zwan 1980
Convolutispora vermiformis Hughes & Playford 1961
Kraeuselisporites hibernicus Higgs 1975
Raistrickia corynoges Sullivan 1968
Retusotriletes incohatus Sullivan 1964
Verrucosisporites nitidus (Naum.) Playford 1964.

A limestone nodule from 189.75 m has yielded a small assemblage of ostracodes (*Shishaella* sp.) and conchostracans («*Cryptophyllus*» or «estheriids») (Pl. 1: 4). Similar conchostracans in the Devonian-Carboniferous boundary beds of the Rheinisches Schiefergebirge (FRG), Montagne Noire (France), Muhua (southern China) and the western USA may indicate restricted nearshore conditions because of the there associated fossil assemblages (inarticulate brachiopods, plant debris; Bless *et al.*, 1988).

KOOIGEM-DRIEHOVEN

This borehole (K2, 97E -63) has been briefly described by Dusar & Loy (1986). It is located in SW Belgium about halfway between Kortrijk and Tournai. Top Dinantian occurs at 78 m bore depth. Down to total depth at 160 m the sequence consists of dark-grey wackestones with frequent chert nodules. These contain rich and diverse ostracode assemblages in the upper portion, which are associated with relatively rare crinoid and brachiopod fragments as well as some fish

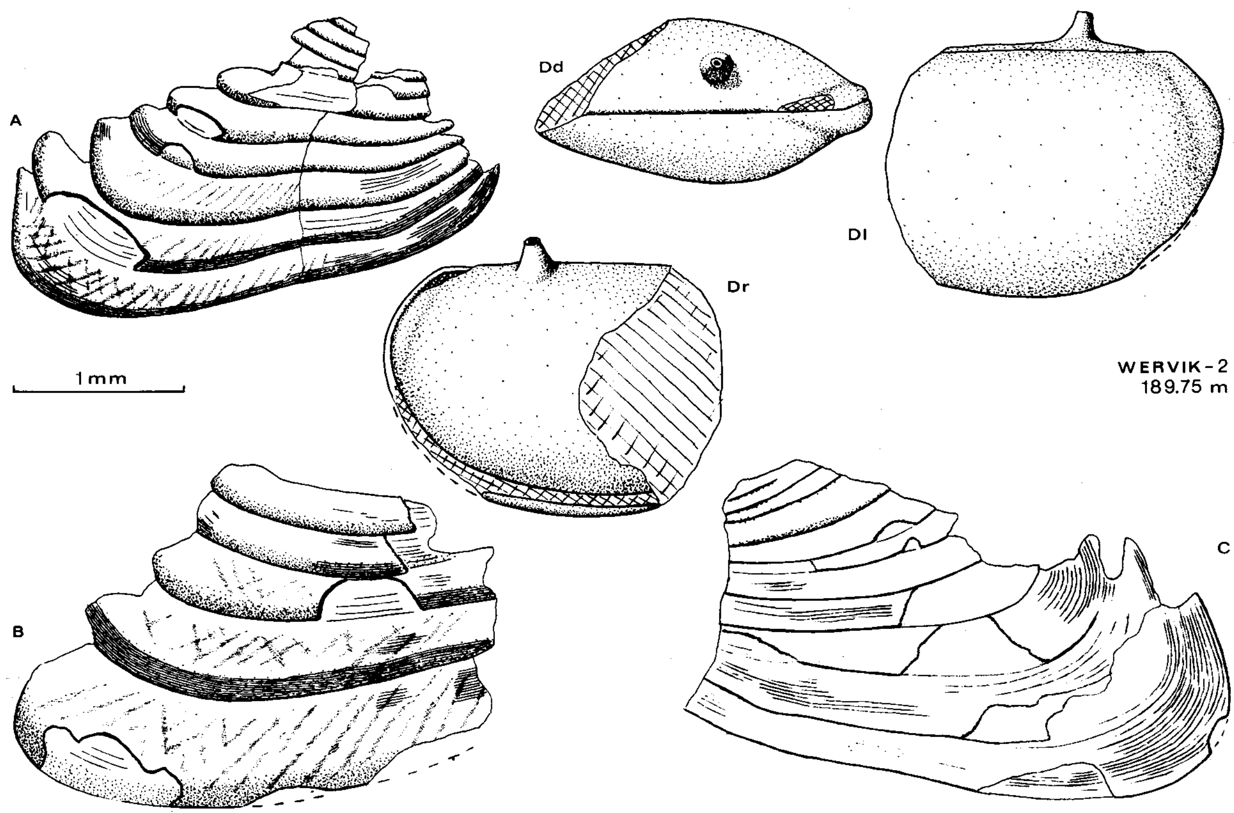

Figure 4.- Uppermost Lower Tournaisian arthropods ; Wervik-2 borehole (189.75 m), SW Belgium.
A-C : Conchostracan shell fragments. Specimens show retention of exuvia as in *Cryptophyllus.* Concentric striae notably occurrin on youngest exuvia resemble ornament in *Estheria*- like specimens described as «*Posidonia*» or «*Guerichia*» in the latest Devonia Hangenberg Shale of the Rheinisches Schiefergebirge (FRG) and as «*Lioestheria*» in the black shales of the latest Devonian Pilo Shale and equivalents in Nevada, Utah and Montana (USA) (cf. Bless *et al.*, 1988). Similar fine striae occur on recent conchostracans (Feist & Flajs 1987). The systematic position of these enigmatic fossils will be dealt with separately (Bless & Flajs, in preparation).
D : *Shishaella* sp.

Table 4.- Quantitative composition of ostracode assemblages from the Upper Ivorian in Kooigem-Driehoven borehole (100.0 m and 100.8 m) (numbers refer to, respectively, number of specimens and percentages)

	100.0 m	100.8 m
Libumella	9 - 2 %	4 - 1 %
Polytylites ?	2	1
Kummerowia	2	-
H. (Keslingella)	19 - 5 %	5 - 1 %
Shivaella	219 - 56 %	287 - 67 %
Glyptopleura	41 - 10 %	22 - 5 %
Beyrichiopsis	27 - 7 %	13 - 3 %
Coryellina	11 - 3 %	10 - 2 %
Selabratina	16 - 4 %	30 - 8 %
Graphiadactylloides	22 - 6 %	12 - 3 %
Paraberounella ?	1	3
Knoxiella	15 - 4 %	25 - 4 %
Cavellina	-	1
Healdia	-	1
Microcheilinella	-	1
Bairdiacea	6 - 2 %	8 - 2 %
ind.	2	5 - 1 %
	393 - 99 %	418 - 97 %

remains. Samples 100.0 m and 100.8 m have been investigated on their ostracode contents (table 4, figures 5-7).

The lithofacies is a fine-grained carbonate mud with abundant burrowing and bioturbation suggesting a somewhat protected (and maybe restricted) nearshore marine environment.
The carbonates have not yielded any spores. But conodont assemblages indicate the CC2γ-δ to CC3 conodont zones (*Eotaphrus bultyncki* to *Scaliognathus* zones). This corresponds to the Upper Ivorian («Tn3c»).

The ostracode assemblages contain high numbers of complete carapaces (more than 75%) indicating rather high rates of sedimentation. The association of *Shivaella, Beyrichiopsis, Glyptopleura* and *Knoxiella* (together making up more

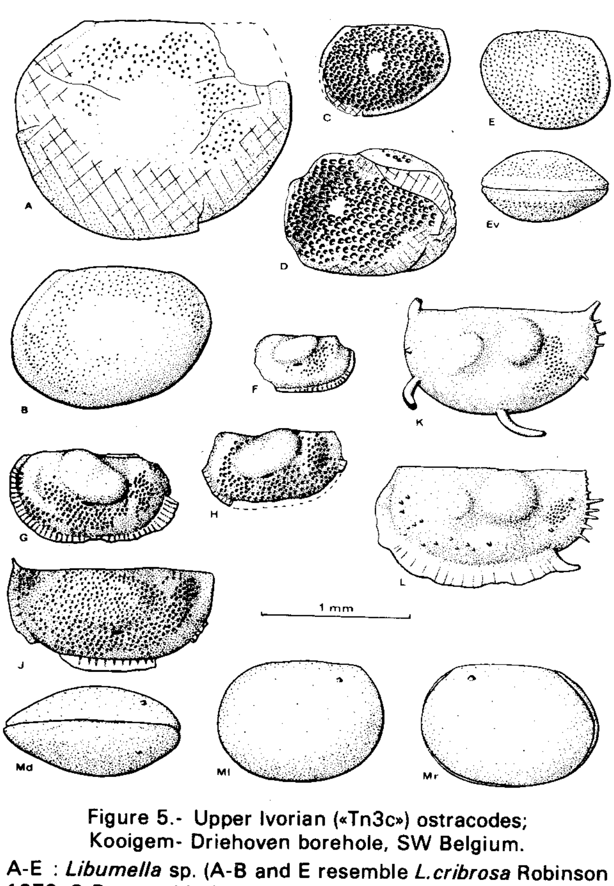

Figure 5.- Upper Ivorian («Tn3c») ostracodes; Kooigem- Driehoven borehole, SW Belgium.

A-E : *Libumella* sp. (A-B and E resemble *L.cribrosa* Robinson 1978, C-D resemble *L. reticulata* Robinson 1978). Variation in ornementation may be due to varying salinity ? (A, B, D, E : 100.0 m ; C : 100.8 m)
F-G : *Polytylites ?* sp.,100.0 m (compare also *Shleesha*)
J : *Kummerowia* sp., 100.0 m
K-L : *Hollinella (Keslingella)* ex gr. *radiata* (Jones & Kirkby 1886), 100.0 m
M : *Shivaella* cf. *macallisteri* Sohn 1972, 100.0 m

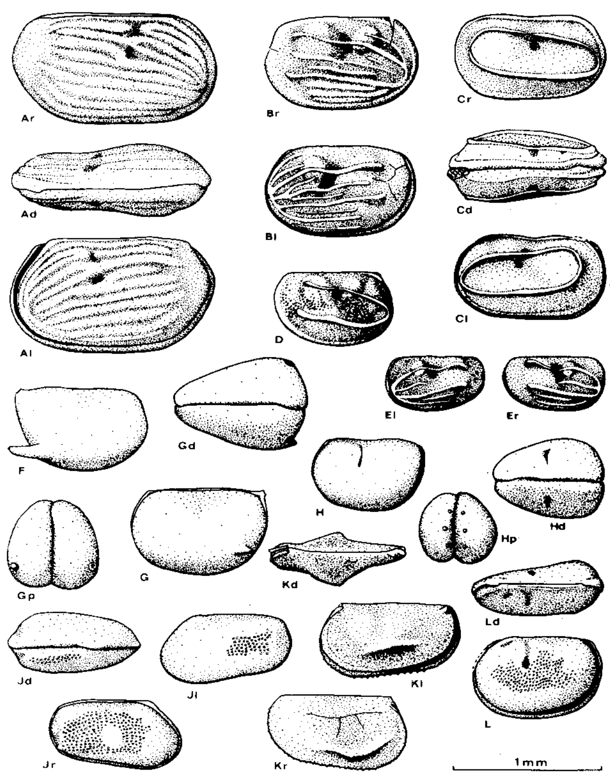

Figure 6.- Upper Ivorian («Tn3c») ostracodes; Kooigem- Driehoven borehole, SW Belgium.

A : *Glyptopleura costata* (McCoy 1844),100.0 m
B : *Glyptopleura* ex gr. *lirata* Robinson 1978, 100.0 m
C-D : *Beyrichiopsis sokolskyae* Egorov 1950, 100.0 m. Males with U-shaped lateral crest, females swollen posteriorly and with ring-shaped lateral crest. Compare also *B. glyptopleuroides* Green 1963 (presumably conspecific). Lateral crest on *B. chovanensis* (Fa2c-Tn1 in Belgium, identified as *B. glyptopleuroides* in Becker *et al.* 1974) is more subdued than in this species.
E : *Glyptopleura* sp., 100.8 m (juvenile ?)
F-G :*Selebratina* sp., 100.0 m
H : *Coryellina cesarensis* Crasquin 1985, 100.0 m
J : *Graphiadactylloides* sp., 100.0 m
K : *?Paraberounella* sp., 100.8 m
L : *Knoxiella* cf. *rugulosa* (Kummerow) sensu Robinson 1978, 100.0 m

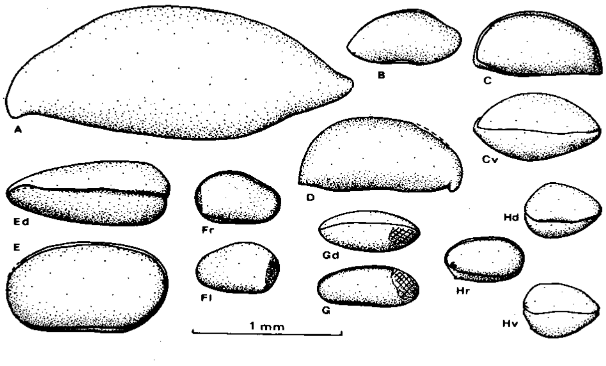

Figure 7.- Upper Ivorian («Tn3c») ostracodes; Kooigem- Driehoven borehole, SW Belgium.

A : *Acratia (Cooperuna)* sp., 100.0 m
B : *Bairdia* sp., 100.8 m
C-D : *Acratia (Cooperuna)* cf. *similaris* Morey 1936 (C - 100.8 m, D - 100.0 m)
E : *Cavellina* ex gr. *attenuata* (Jones & Kirkby 1886), 100.8 m
F : *Healdia* aff. *asymmetrica* (Gründel 1975), 100.8 m
G : Podocopida indet., 100.0 m
H : *Microcheilinella* ex gr. *subcorbuloides* (Jones & Kirkby 1885), 100.8 m

than 75% of the number of specimens) is here taken as an indication for a restricted, mixohaline environment (cf. also Robinson 1978). The practical absence of other fossils (except the abundant burrows and rare brachiopod fragments and crinoid ossicles) supports this interpretation.

«BRACKISH-WATER» OSTRACODES

The most characteristic and well-documented form in this group is the genus *Geisina*. Single valves of this ostracode have been found in finely laminated, black, organic-rich bituminous shales of the Westphalian B-C in the Belgian Campine (fig. 8), where these occur along with fish remains and «non-marine» lamellibranchs and ostracodes (*Carbonita*). Presumably these reflect transitory marine incursions, when sea water was swept deep in the delta by exceptionally high spring tides (maybe enhanced by storms or earth quakes) and stayed behind in ponds and pools of stagnant water that quickly turned into brackish and fresh again.

The «brackish-water» character of *Geisina* is deduced from its frequent association (notably in Westphalian A deposits) with agglutinating foraminifera (*Ammodiscus, Hyperammina*) and «non-marine» lamellibranchs and ostracodes (*Carbonita*), and less commonly with *Lingula* and *Orbiculoidea* (Bless, 1983).

Geisina bands abound in the Westphalian A of Great Britain (Calver 1969), Belgium (Pruvost 1930), the German Ruhr Basin (Kremp & Grebe 1955) and South Limburg (Bless 1967), but appears to be absent in northern France (Pruvost 1930).

Except for Great Britain, these become rare in the (Lower) Westphalian B. In Belgium, only one occurrence (Mons Basin) was mentioned by Pruvost (1930). As far as known, the find of *Geisina* in BGD 183 -Peer is the first known occurrence of the genus in the Lower Westphalian B of the Campine. Also in South Limburg and in the Ruhr Basin, the genus is extremely rare in deposits of that age.

Several *Geisina* bands are known in the Westphalian C of Great Britain (notably below the Top Marine Band at the base of the Upper Westphalian C). These have not been recognized in coeval strata in northern France and SW Belgium (Mons and Charleroi basins), nor in the Ruhr Basin. Bless *et al.* (1972) mention one occurrence in the Westphalian C of South Limburg. Recent finds in the Campine boreholes BGD 161b, BGD 168 and BGD 186 prove the existence of at least two Geisina bands: one at a short distance below the Nibelung Tonstein (correlated with the Top Marine Band by Bless *et al.,* 1977) in the Lower Westphalian C, the other one well above the Nibelung Tonstein in the Upper Westphalian C.

This picture suggests a gradual withdrawal of the marine influence in NW Europe during the Westphalian A-C, starting in northern France (Westphalian A), southern Belgium (Westphalian B) and the Ruhr Basin (Westphalian B), whereas proximal delta environments persisted until late Westphalian C in South Wales as suggested by the presence of at least nine *Geisina* Bands and five marine bands (Carway Fawr, Foraminifera, Five Roads, Lower Cwmgorse and Upper Cwmgorse) above the Aegir Marine Band equivalent (Bless *et al.,* 1972). Deep-reaching brackish events occasionally affected the presumably upper delta regime of the Campine and South-Limburg during the Westphalian C. Most likely, these reflect marine incursions in the proximal delta area of Great Britain.

Apparently, brackish-water ostracode assemblages are restricted to the Upper Carboniferous in Belgium. These may occur however in the Lower Devonian as suggested by the Upper Emsian fauna and flora of Waxweiler in the Eifel area (FRG, Rebske *et al.,* 1985). Presumably the Upper Emsian Klerf Beds at Waxweiler (coarsely cross-bedded sandstones overlain by rather fossiliferous shales and reddish sandstones) have been deposited in an estuarine to proximal delta environment.

Remarkable is the association of the smooth, thin-shelled lamellibranch *Modiolopsis ekpempusa* (morphologically similar to some non-marine lamellibranchs in the Westphalian C!), abundant and diverse plant remains, and giant ostracode species (*Euprimites? koeppeni* up to 2.4 mm, *Rebskeella waxweilerensis* up to about 1 cm, *Herrmannina* over 1 cm !). Giantism amongst ostracodes is common in sediments which presumably have been deposited under restricted nearshore marine (oligohaline to hypersaline) conditions.

The relatively large ostracode (2.6 mm) in the Upper Permian redbeds (fig. 9) of KS 25 - Opglabbeek-Reyndersstraat (Belgian Campine) may also fit in this pattern. The morphology or the unisulcate test roughly resembles that of *Geisina*. An oligohaline or hypersaline paleoenvironment is proposed.

This survey shows that presumed «brackish-water» (oligohaline, but sometimes the term may include in this context also hypersaline) ostracodes only occur in predominantly siliciclastic, plant-bearing sequences, which have been deposited in extended estuarine or deltaic systems (Upper Emsian of Waxweiler, Westphalian of Campine and South- Limburg) or near or at the former shoreline (Zechstein of Campine). These «brackish-water» ostracodes have never been observed in purely non-marine sequences (e.g. in intramontane basins) where only «non- marine» ostracodes belonging to genera such as *Carbonita* and *Darwinula* occur.

BGD 183 -PEER

This borehole is located in the Campine mining area (NE Belgium), some 4 km south of the village of Peer (about 15 km NNW of Genk), west of the village of Linde. The Carboniferous sequence between 1029 m and 1498 m consists of sandstones, shales and coal seams. These have been deposited in a swamp lowland with frequent development of crevasse splay facies (Houlleberghs 1985) and rare incursions of the sea. The latter resulted in thin layers of black, organic-rich (bituminous) shales with a «brackish-water» fossil assemblage of ostracodes (*Geisina* and *Carbonita*) and fish remains. Samples from two of these «brackish-water» levels (at 1382.9 m and 1438.1 m) have been studied in the present context.

The Lower Westphalian B age of these samples is confirmed by one miospore assemblage (table 5) from two samples (at 1430.9 m and 1446.1 m) indicating the NJ (*nobilis-junior*) Zone, more precisely the CP (*costata-pseudoreticulata*) Subzone.

The fact that only single valves of *Geisina* (fig. 8) have been found is interpreted as an indication for very low rates of sedimentation in presumably stagnant water (anaerobic conditions suggested by high organic content of shales).

Table 5.- Most characteristics of the miospore assemblage belonging to the CP subzone of Lower Westphalian B age in BGD 183 - PEER.

Cristatisporites indignabundus (Loose) Staplin & Jansonius 1964

Radiizonates faunus (Ibrahim) Smith & Butterworth 1967

Vestispora costata (Balme) Spode 1967

Vestispora pseudoreticulata Spode 1967

Absence of *Microreticulatisporites nobilis* (Wichner) Knox 1950 and *Vestispora magna* (Butterworth & Williams) Spode 1967

BGD 186 -KERKHOVEN

This borehole is located in the Campine mining area (NE Belgium), immediately east of the village of Kerkhoven, some 5 km north of the village Léopoldsburg. The Carboniferous sequence between 852 m and 1504 m consists of sandstones, shales and coal seams. These have been deposited in an «upper delta» environment (Houlleberghs 1985) marked by the repeated presence of point-bar facies and crevasse splay facies. The presence of «brackish-water» ostracodes of the genus *Geisina* at 1049-1053 m (fig. 8) and 1131.4 m proves the sometimes far-reaching influence of marine incursions in the distal part of the then existing delta system.
The Westphalian C age of these brackish-water beds is confirmed by miospores (table 6) from four samples (at 1038.48 m, 1053.1 m, 1129.1 m, 1131.7 m) indicating the SL (*securis-laevigata*) Zone and more precisely the GS (*granifer-sculptilis*) Subzone.
The presence of the Nibelung Tonstein at 1082 m confirms the age. Moreover, this suggests that the *Geisina* band at 1131.4 m may be correlated with a similar band in BGD 161b (Opglabbeek-Louwelsbroek) at 1297.6-1298.95 m (6 m below Nibelung Tonstein), and in BGD 168 (Opoeteren-Den Houw) at 1157.7-1158.05 m (15 m below Nibelung Tonstein) (Dusar *et al.*, 1986). The *Geisina* band at 1049-1053 m has not yet been recognized elsewhere in the Campine.

Samples from BGD 161b at 1290.9 m and 1303.5 m and from BGD 168 at 1141.2 m and 1159.0 m carry also a miospore assemblage belonging to the GS Subzone.

The fact that only single valves of *Geisina* occur in the finely laminated, black, organic-rich bituminous shales points to extremely low sedimentation rates under anaerobic conditions for both *Geisina* bands.

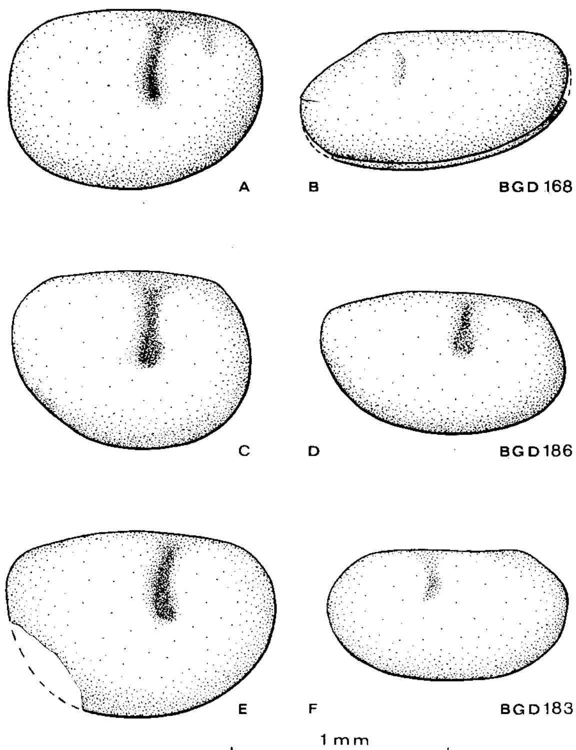

Figure 8.- Westphalian B-C specimens of the brackish-water ostracode *Geisina arcuata/subarcuata* from the Campine mining area (NE Belgium).
Specimens A-B from BGD 168 borehole have been found in the Lower Westphalian C some 15 m below the Nibelung Tonstein at, respectively, 1157.7 m and 1158.05 m (Dusar *et al.* 1986). This brackish-water band has been correlated with Top Marine Band in Great Britain. Specimens C-D from BGD 186 borehole occur in the Upper Westphalian C some 29 m above the Nibelung Tonstein at 1053.0 m. Specimens E-F from BGD 183 borehole come from one of the two brackish- water bands in the Lower Westphalian B in that borehole at 1438.13 m (the other occurs at 1382.9 m).

KS 25 - OPGLABBEEK-REYNDERSSTRAAT

This borehole was drilled in the Campine mining area (NE Belgium), north-west of the village of Opglabbeek, some 8 km north of Genk. Permian Thuringian shales and sandstones occur between 656 m and 693.8 m (fig. 9). Marine lamellibranchs and plant debris abound in the grey, calcareous mudstones between 693 m and 677 m, whereas the red shales and sandstones between 677 m and 656 m are marked by the frequent occurrence of burrows. Burrowing is also noticed at the base of the shale interval near 693 m. Presumably the Zechstein sediments have been deposited during a single depositional cycle. The grey calcareous mudstones in the lower half broadly correspond to the onset and acme of a marine transgression. The red beds with more or less intensive bioturbation may represent repeatedly flooded and dried supratidal lagoons or ponds. Salinity may have varied from extremely

Table 6.- Most characteristics of the miospore assemblage belonging to the GS Subzone of Westphalian C age in BGD 186 - KERKHOVEN.

Cristatisporites solaris (Balme) Butterworth & Smith 1964.
Endosporites globiformis (Ibrahim) Schopf, Wilson & Bentall 1944.
Florinites junior Potonié & Kremp 1956
Microreticulatisporites nobilis (Wicher) Knox 1950
Punctatisporites granifer Potonié & Kremp 1956
Triquitrites sculptilis (Balme) Smith & Butterworth 1967.
Vestispora costata (Balme) Spode 1967
Vestispora pseudoreticulata Spode 1967
Vestispora magna (Butterworth Williams) Spode 1967

Table 7.- Some miospores of the Thuringian assemblage in KS 25

Klausipollenites schaubergeri (Potonié & Klaus) Jansonius 1952
Lueckisporites virkkiae Potonié & Klaus 1954
Striatisaccus div. sp.
Taeniaesporites sp.
Vittatina sp.

low (fresh-water from streams entering the area in the wet season) to extremely high (ponds drying out during the dry season). At 670.9 m an over 2 mm large ostracode was found in a red clayey shale with sand- filled burrows (fig.9).

The Thuringian age is confirmed at the level 679.2 m by miospores (table 7) (See also Demaret-Fairon *et al.,* 1985). The Thuringian age of the ostracode sample at 670.9 m could not be proved by palynomorphs (which are absent in the redbed facies). Theoretically, this could be Triassic. However, the redbeds are here interpreted as the regressive part of the sedimentary cycle. The base of the Triassic is arbitrarily placed at the base of a (grey) sandstone with reworked clay pebbles.

STRATIGRAPHIC DISTRIBUTION OF OSTRACODE ASSEMBLAGES IN BELGIUM

The known stratigraphic range of the six major groups of ostracode assemblages around the Brabant massif is illustrated in figure 10. This shows that Entomozoan ostracodes are largely restricted to the Upper Frasnian/basal Famennian Matagne Shales of the Dinant Nappe (Lethiers 1974), whereas Thuringian-type ostracodes have only been found once in the basal Upper Famennian Baelen-complex (Dreesen *et al.,* 1985).
Acceptance of the paleoecological model wherein these indicate either «basin» or «deep offshore shelf» facies implies that the acme of the transgressions during the Devonian and the

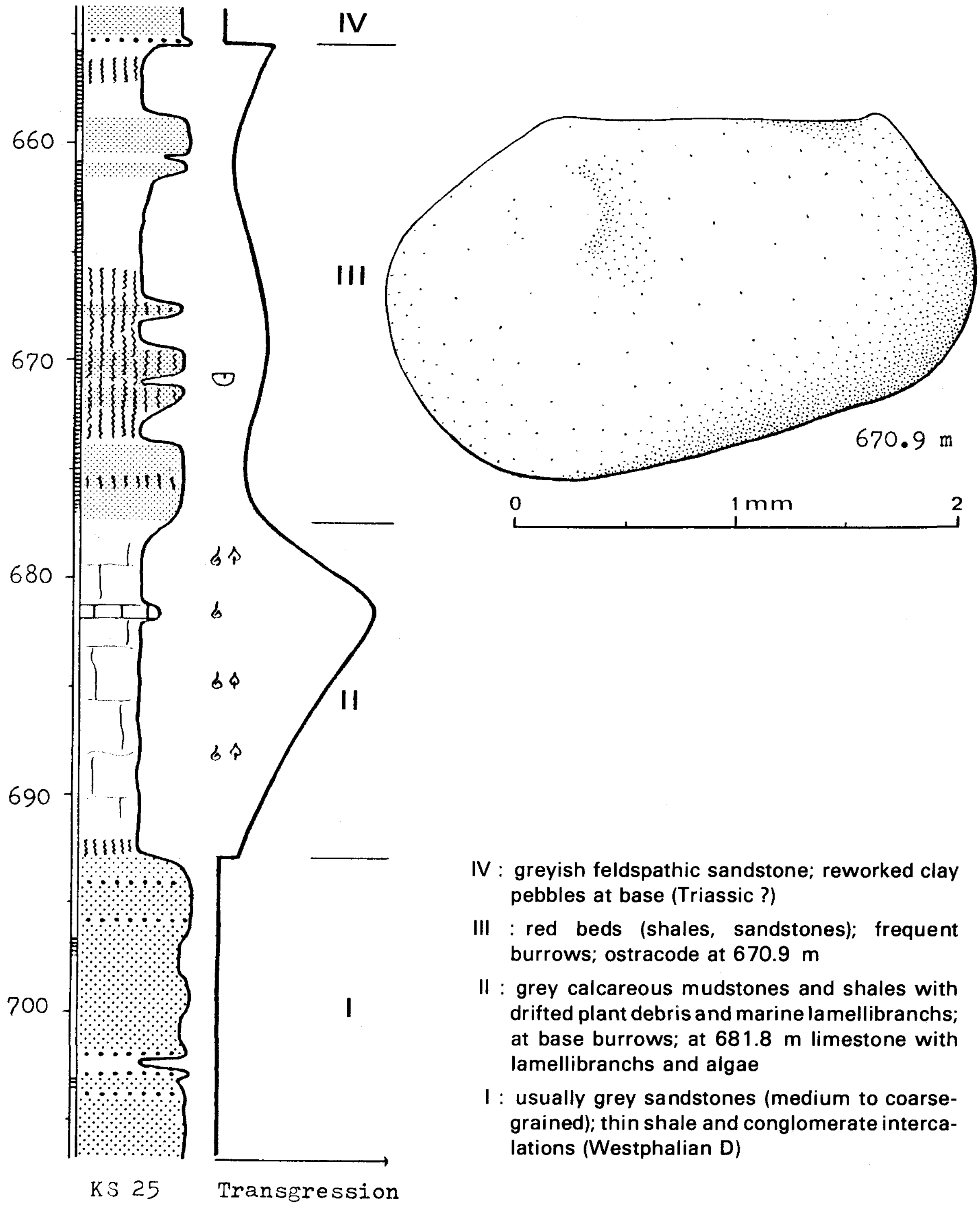

Figure 9.- Lithology and facies interpretation of Upper Westphalian to Triassic in KS 25 borehole (eastern Campine, Belgium). Position of the ostracode in the upper right is shown in red bed facies (marked by horizontal bars in left column) at 670.9 m.

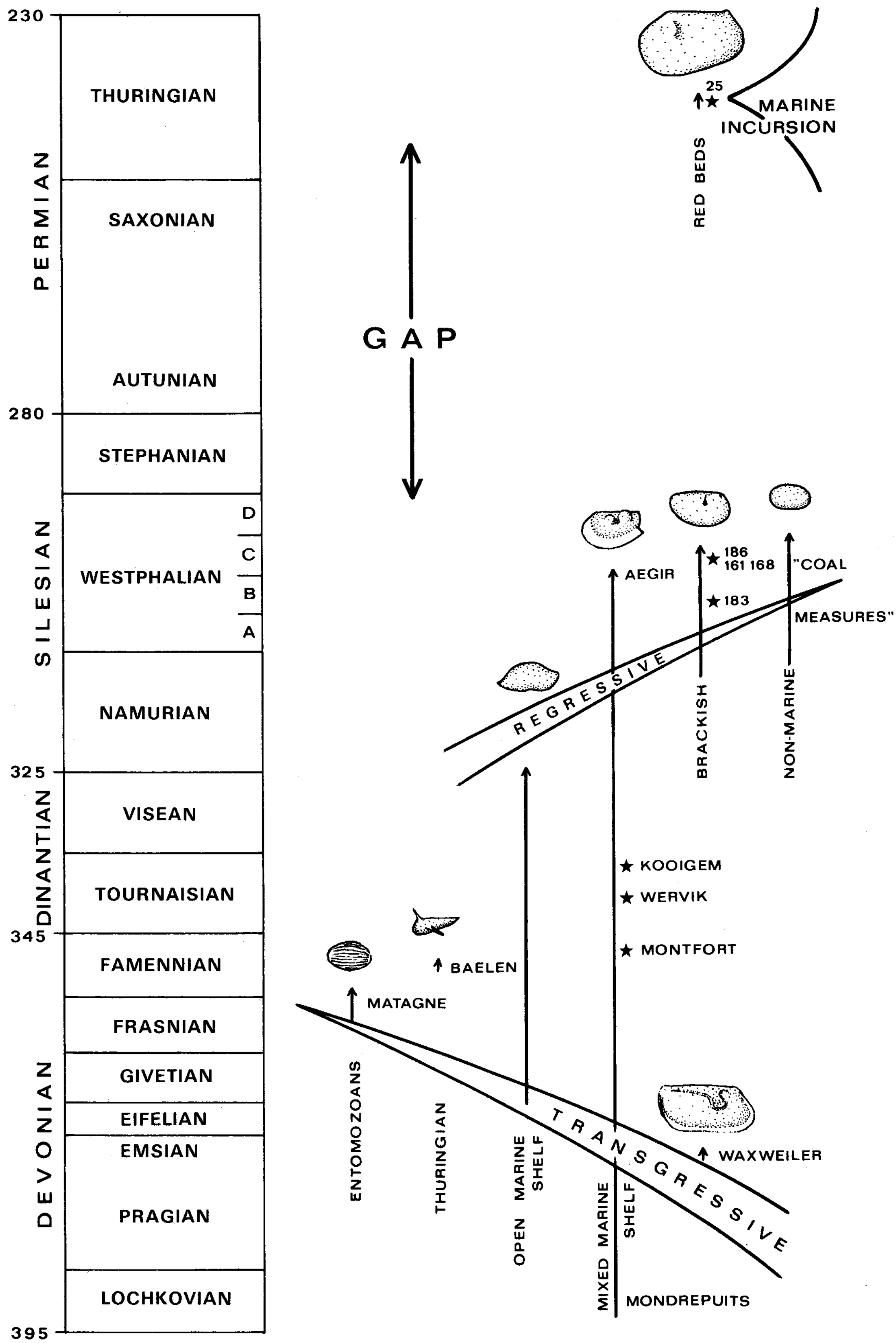

Figure 10.- Cartoon showing stratigraphical distribution of ostracode assemblages in Devonian to *Permian* strata of Belgium Assemblages dealt with in some detail in this paper are marked with an asterisk. Some other relevant occurrences are named as well for better orientation.

Carboniferous in Belgium was during the Late Frasnian and the beginning of the Late Famennian.

The vertical range of open marine shelf ostracode assemblages is distinctly longer that that of the two former groups. The oldest examples in Belgium are found in the Givetian around Givet and Philippeville (Coen 1985), the youngest in the Upper Visean of Visé (Becker & Bless 1974) and the Campine (Bless *et al.,* 1981). It should be noticed that many assemblages from the Middle Devonian and Frasnian in Belgium are transitional to the «mixed marine shelf» and usually highly specialized ones occurring around biostromal or biohermal complexes.

Mixed marine ostracode assemblages already occur in the Lochkovian (schistes de Mondrepuits) of Belgium. Many faunas recognized in the Eifelian to Lower Famennian belong to this group (e.g. Becker 1980) or are transitional to the «open marine shelf» around reef complexes (cf. Becker 1973). Mixed marine ostracode faunas are common in the Upper Famennian of the Ourthe Valley, but also occur in strata of the same age at Maastricht (Kastanjelaan borehole; Bless 1982). These are also known from the Strunian (?) and Lower Tournaisian of Onoz, Feluy and Soignies in the Namur Basin (Becker & Bless 1974, Becker *et al.,* 1974), and in the Strunian of the Epinoy-1 borehole in northern France (Lethiers & Bouquillon 1986). The here described examples from the uppermost Lower Tournaisian of Wervik-2 and Upper Ivorian of Kooigen-Driehoven prove that mixed marine assemblages are common at locations near the Brabant Massif irrespective of their age throughout the Dinantian. This impression is confirmed by the faunas from the Upper Visean of the Epinoy-1 borehole (Lethiers & Bouquillon 1986) where a mixture of marine (*Shemonaella, Beyrichiopsis*) and non-marine (*Carbonita*) ostracodes is interpreted as belonging to this group, although a «brackish-water» environment might be possible as well.

Mixed marine ostracode assemblages of Westphalian age are restricted thus far to the Aegir (=Maurage) Marine Band at the base of the Westphalian C in the Campine (Van den Boogaard & Bless 1985). In South-Limburg (SE Netherlands) these also occur in the Lower Westphalian A Finefrau Nebenbank Marine band (Bless 1973).

In Belgium several beds with «brackish-water» (oligohaline to polyhaline) ostracodes of the genus *Geisina* occur in the Westphalian A north (Campine) and south (Mons, Centre, Charleroi, Liège and Herve) of the Brabant Massif (Pruvost 1930). These are rare in the (Lower) Westphalian B (one find in the Mons Basin, Pruvost 1930; two assemblages in the Campine, BGD 183, this paper). Two *Geisina* bands are known in the Westphalian C of the Campine (BGD 186, this paper). This roughly matches the observations for South-Limburg. Most likely, *Geisina* bands will also be found in the (Upper) Namurian strata of Belgium.

Apparently, «brackish-water» ostracode assemblages do not occur in the Dinantian, and in the Middle and Upper Devonian where more marine conditions prevailed, although restricted marine conditions are frequently recognized in the nearshore shallow shelf facies around the Brabant Massif (see above).

«Brackish-water» (oligohaline ?) assemblages may be expected in the Lower Devonian of Belgium as suggested by the finds at Waxweiler in the nearby Eifel region (Rebske *et al.,* 1985). Whether the ostracode in the red beds of the KS 25 borehole in the Campine should be treated as a true «brackish-water» (oligohaline - polyhaline) one or rather as reflecting a hypersaline environment is open to debate. Anyhow, this is an isolated occurrence in the stratigraphic column.

Non-marine ostracode assemblages have been recognized only in the coal-bearing strata of the Upper Namurian and Westphalian A-C. It is presumed that non-marine ostracode specimens of the genus *Carbonita* in older deposits (e.g. Upper Visean of Epinoy-1 borehole, Lethiers & Bouquillon 1986) had been washed into brackish or nearshore marine environments.

This broad-brush review shows that in Belgium the shallow marine nearshore ostracode assemblages are the most common ones in the Devonian and Carboniferous. In the Lower Devonian and in the Upper Carboniferous these may reflect brackish or even non-marine conditions, whereas in the Middle Devonian to Dinantian also open marine shelf assemblages occur. In the Upper Devonian even faunas characterizing deep shelf to basin facies are found in the Dinant Nappe.

This suggests an overall transgressive tendency for the sedimentary environment in Belgium following the Caledonian orogeny from Early to Late Devonian, with the acme during the deposition of the Upper Frasnian Matagne Shales (drowning of carbonate reefs and platform) and basal Upper Famennian «Souverain-Pré» strata (nodular limestones, Baelen crinoidal mudmound). From the Late Famennian onwards the ostracode assemblages suggest an overall regressive tendency despite the Dinantian transgressions. This overall regressive trend reflects the increasing influence of the Hercynian (or Variscan) orogeny and reaches its acme during the Late Westphalian C (only non-marine ostracode assemblages) and the succeeding periods of Stephanian to Saxonian (sedimentary gap, non-deposition and/or erosion). Eventually, a short-lived Thuringian transgression in the eastern Campine is marked by the «brackish-water» or hypersaline ostracode find in the red beds of the KS 25 borehole.

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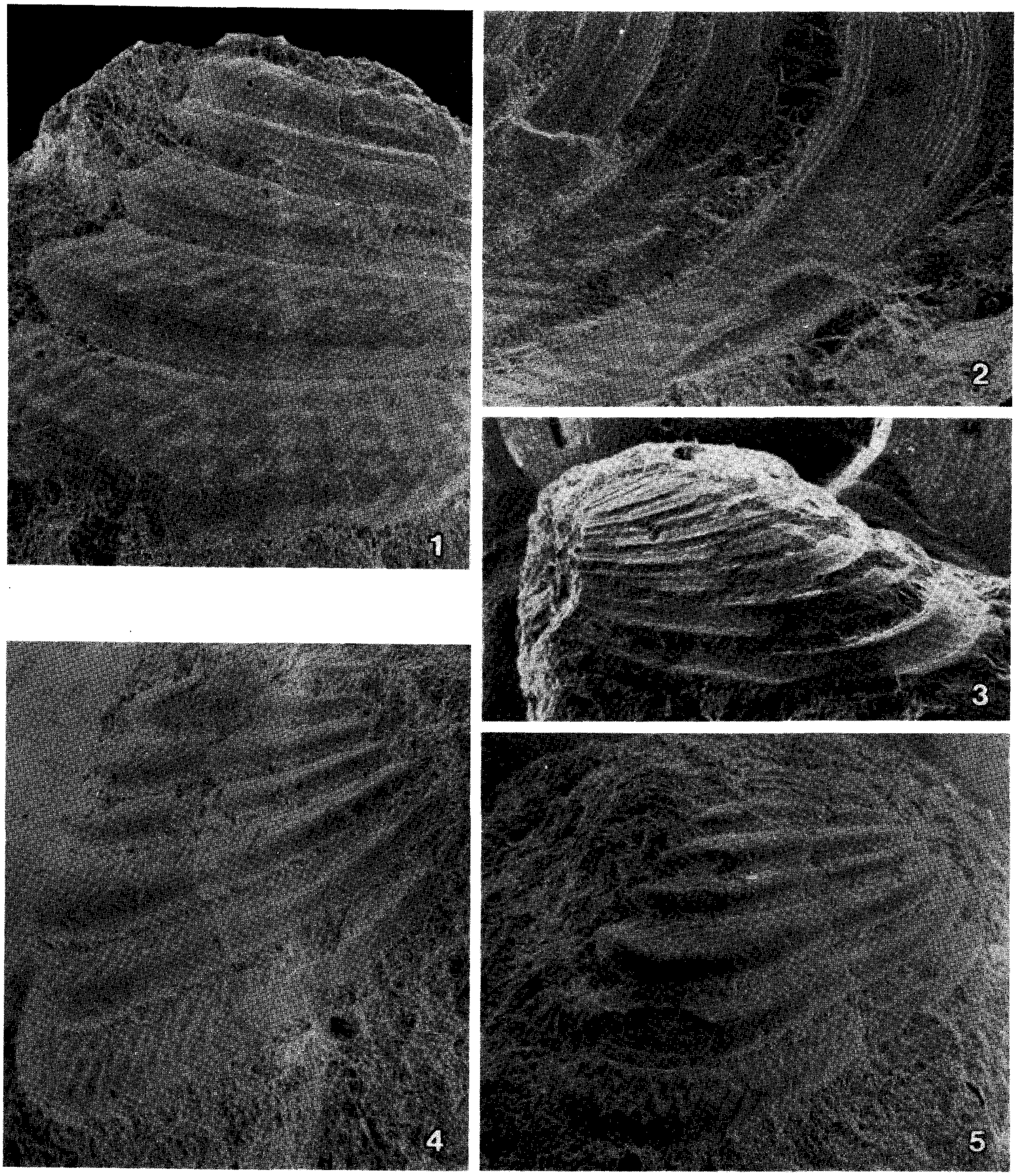
PLATE 1

Conchostracan shells from the uppermost Lower Tournaisian of the Wervik-2 borehole (SW Belgium), 189.75 m, fond in association with *Shishaella* sp. (cf. fig. 4). The general shape of the specimens suggests that these might be related to *Cryptophyllus* (notably the retention of juvenile exuvia). However, the ornamentation (closely spaced concentric striae partly or entirely masked when surface displays ondulating «ribs») rather remembers estheriids.

1.: 40 x; 2.: detail of 3, 40 x; 3.: 17 x; 4 and 5.: same specimen in different views, 22 x.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