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# REPEATED TETHYAN INFLUENCES IN THE EARLY CAMPANIAN TO MIDDLE LATE MAASTRICHTIAN SUCCESSIONS OF FOLX-LES-CAVES AND ORP-LE-PETIT (EASTERN BRABANT MASSIF, BELGIUM)[1]

by

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(9 figures, 7 tables).

**ABSTRACT.**- A preliminary study of the macrofossils (belemnites in particular), benthic forams and ostracodes in the Late Cretaceous chalk deposits at Folx-les-Caves and Orp-le-Petit (eastern Brabant Massif, Belgium) suggests that the sequence at Folx-les-Caves is of early Campanian (post *lingua/quadrata* Zone) age. The «craie blanche» and the «tuffeau jaunâtre» at Orp-le-Petit were deposited during the late Campanian and middle late Maastrichtian, respectively.

The sedimentation of these chalks under shallow to very shallow subtidal conditions was temporarily interrupted by periods of emergence (conglomerate at Folx-les-Caves; hardground at Orp-le-Petit).

The fossil assemblages of the early Campanian and middle late Maastrichtian comprise several distinctive Tethyan elements amongst macrofauna, forams and ostracodes which are rare in or absent from the late Campanian to early late Maastrichtian in Belgium and the SE Netherlands. Possible causes of these repeated Tethyan incursions are discussed.

**RESUME.**- Une étude préliminaire des macrofossiles (en particulier des Bélemnites), des foraminifères benthiques et des ostracodes trouvés dans les dépôts de craie du Crétacé récent à Folx-les-Caves et à Orp-le-Petit (Massif de Brabant oriental, Belgique) suggère que la séquence à Folx-les-Caves est d'âge Campanien ancien (post *lingua/quadrata* Zone). La craie blanche et le tuffeau jaunâtre à Orp-le-Petit ont été déposés pendant le Campanien récent et le Maastrichtien récent moyen, respectivement.

La sédimentation de ces craies sans conditions subtidal peu à très peu profonde, a été temporairement interrompue par des périodes d'émersion (conglomérat à Folx-les-Caves; «hardground» à Orp-le-Petit).

Les assemblages fossils du Campanien ancien et du Maastrichtien récent moyen, comprennent plusieurs éléments Téthysien distincts parmi la microfaune, les foraminifères et les ostracodes qui sont rares ou absents à partir du Campanien récent jusqu'au Maastrichtien récent ancien, en Belgique et dans le sud-est des Pays-Bas. Les causes possibles de ces incursions téthysiennes répétées sont discutées.

## 1.- INTRODUCTION

The Late Cretaceous deposits of Folx-les-Caves and Orp-le-Petit outcrop along the eastern slope of the valley of the Petite Gette, about halfway between Brussels and Liège (figure 1). The location of the outcrops is of prime importance: in between the classic Late Cretaceous outcrops of the Maastricht-Aachen-Liège area (referred to as MAL area henceforth) to the ENE and of the Mons area (Cuesmes, Ciply, Harmignies) to the WSW, which is the reason why they form an important link in correlating these areas.

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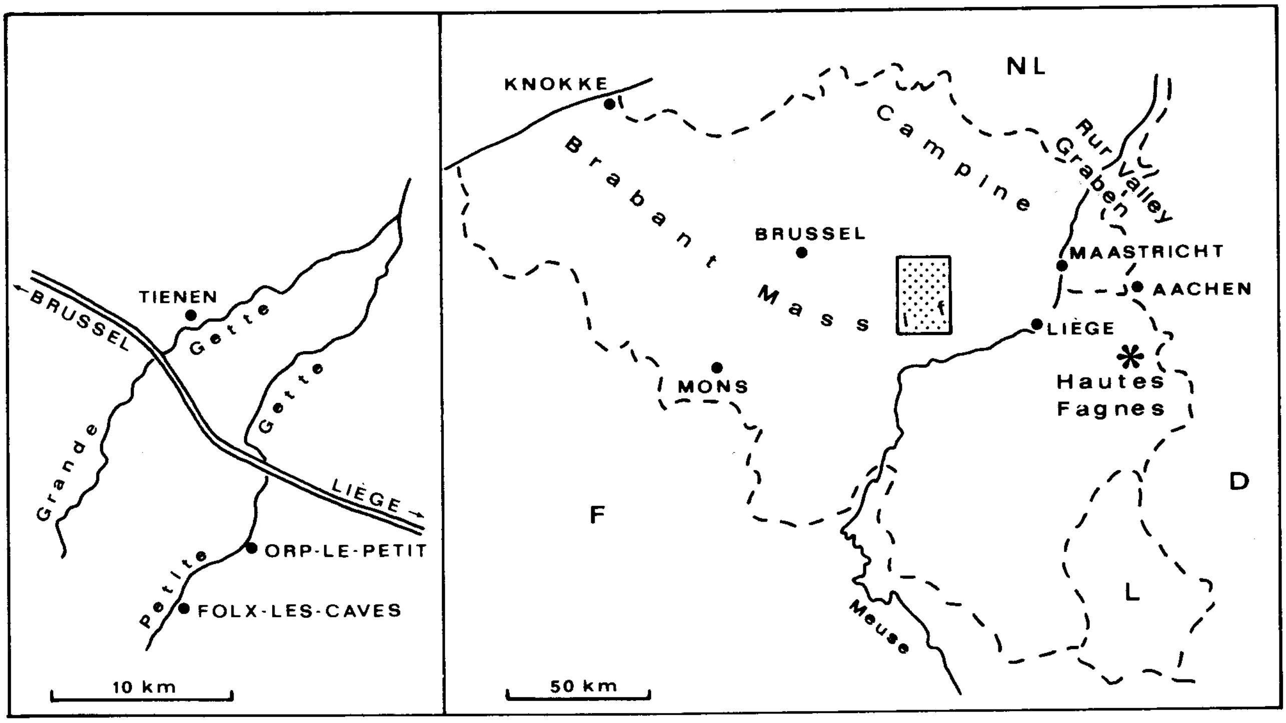

Fig.1.- Map showing the location of the late Cretaceous outcrops at Folx-les-Caves and Orp-le-Petit. Other localities and areas mentioned in the text are also indicated.

The first attempts to date the deposits were made by Rutot & Van den Broeck (1887) and Ubaghs (1888). These authors compared the lower portion of the Folx-les-Caves section with the «Craie blanche» of the Mons and MAL areas, or rather with the «facies arénacée de la craie blanche» in the Kunrade-Ubachsberg-Benzenrade area (eastern part of southern Limburg; see Felder & Bless, 1989), which is late Campanian (Robaszynski *et al.,* 1985; Robaszynski & Christensen, 1989). The upper part of the Folx section (and also that of Orp-le-Petit) was considered to represent the «Maestrichtien proprement dit de Maestricht» (Ubaghs, 1888, p. 57), which is nowadays dated middle-late Late Maastrichtian (Bless *et al.,* 1987).

More recently, Hofker (1961, 1963) has studied the foram assemblages of the same deposits. At Folx-les-Caves, he distinguished a late Santonian «craie arénacée», a possibly middle Campanian conglomerate, and a middle Campanian «tuffeau jaunâtre». However, at Orp-le-Petit the «tuffeau jaunâtre» yielded a late Maastrichtian (foram zone F) assemblage. The underlying «craie grossière» was assigned an early Maastrichtian age, and the «craie blanche» at the base of the section was dated late Campanian.

A revision of the material collected previously from these outcrops and housed in the collections of *e.g.* the Institut royal des Sciences naturelles de Belgique (Brussels) was not considered, since the exact provenance of (many of) the fossils may be doubtful. A good example are specimens of *Pachydiscus colligatus* (Binkhorst) recorded by Ubaghs (1888, pp. 55, 56) from the top of the «tuffeau siliceux» (= «craie arénacée») at Folx-les-Caves. One of these was illustrated by Van den Binkhorst (1861 [1873], pl. 8). Kennedy (1987) reviseed this species and designated lectotype the specimen referred to above, which is said to have come from Jauche (c. 3 km further to the north) and not from Folx-les-Caves, and which is late Campanian on foram evidence. One of the paralectotypes is from Folx-les-Caves (mentioned by Van den Binkhorst, 1861, p. 29); it is illustrated by Kennedy (1987, pl.3, pl.4, figs.4, 5), who stated that it is also late Campanian, although he mentioned that preliminary studies of the belemnites by W.K. Christensen suggested a condensed sequence at Folx probably corresponding to most of the early Campanian; a conclusion matching the one reached herein.

According to Marlière (1954, fig.2) and Robaszynski & Dupuis (1983, fig.39), the eastern part of the Brabant Massif («seuil brabançon») forms the structural limit between the Mons basin to the SW and the Campine/Maastricht-Aachen-Liège basin to the NE. Following this interpretation, Folx-les-Caves and Orp-le-Petit are located on the northern flank of the massif.

This paper presents a revision of the stratigraphy and palaeogeographic position of these deposits. Moreover, special attention is paid to the presence of Mediterranean biota in the early

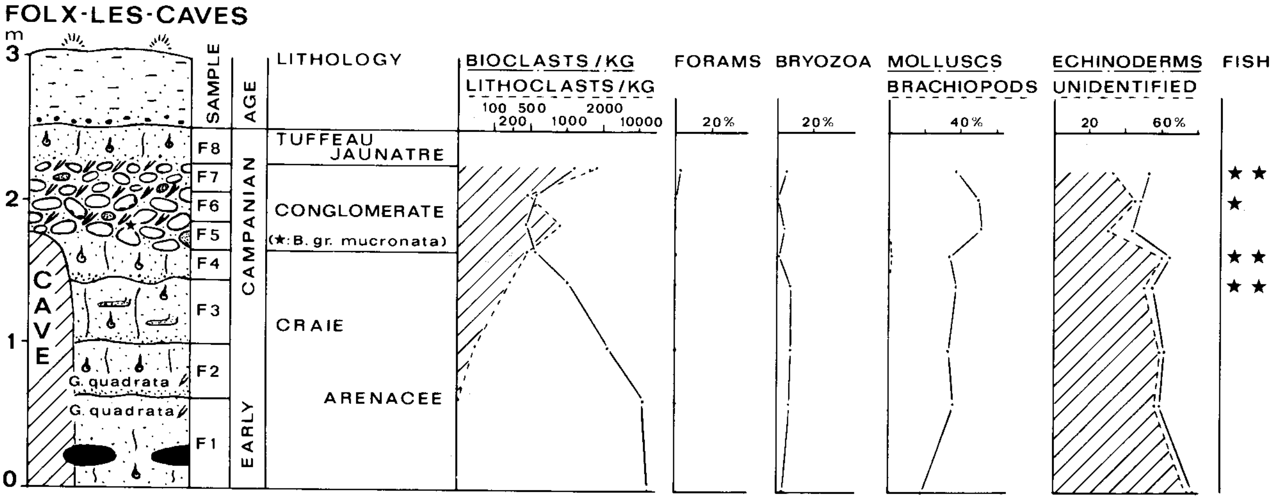

Fig.2.- Lithological section of the outcrop Folx-les-Caves (entry to cave of former subterraneous chalk/flint quarry; flint nodules shown in the figure in subunit F1 do not occur in the outcrop itself but *c.* 2 m into the cave) with frequency profiles for bioclasts and lithoclasts (1.0-2.4 mm sieve fraction). Names of lithological units after Hofker (1963). The position of the key index belemnites *Gonioteuthis quadrata* and *Belemnitella* gr. *mucronata* is indicated in the lithological column.

Campanian of Folx-les-Caves and the late Maastrichtian of Orp-le-Petit.

## 2.- LITHOLOGY AND STRATIGRAPHIC SETTING

### 2.1.- FOLX-LES-CAVES

This outcrop is accessible at the entry of an abandoned subterraneous quarry («cave»), in which chalk and flint (paving, see Ubaghs, 1888) were extracted in the past century. Three lithological units can be distinguished, in ascending order (fig.2):

- «*craie arénacée*» (Rutot & Van den Broeck, 1887) or «*tuffeau siliceux*» with flint nodules (Ubaghs, 1888), containing reworked Triassic boulders and pebbles in the basal portion overlying Triassic quartzite (Hofker, 1961). Thickness about 3-6 m. Only the upper 1.75 m are accessible at present. The sediment is a coarse-grained biocalcarenite with well-rounded (and consequently often hardly recognisable) bioclasts (compare large amounts of unidentified echinoderm clasts, fig.2), with upward-increasing amounts of coarse-grained (> 1 mm) lithoclasts (quartzite and quartz). Four subunits (F1-F4) are distinguished, with coarse fossil debris at their bases and separated by undulating (erosive) contacts. Large flint nodules occur in subunit F1 about 2 m. into the cave.
- *conglomerate or «amas de blocs de tuffeau durci»* (Ubaghs, 1888), consisting of well-cemented biocalcarenite pebbles and subordinate quartzite and shale pebbles. The base of this unit is highly irregular. Thickness 0.5-0.6 m. Three subunits are distinguished (F5-F7), which show increasing amounts of (broken) belemnite guards at their tops. The cement consists of a sandy, coarse-grained biocalcarenite, similar to that of the lower unit (F1).
- «*tuffeau jaunâtre*» («grossier et graveleux», Ubaghs, 1888), a coarse-grained biocalcarenite with well-rounded bioclasts and large amounts of coarse-grained (> 1 mm) lithoclasts (quartz, quartzite and reworked fragments of hard, well-cemented chalk). Irregular, erosive base. Thickness 0.25-0.50 m. This unit is overlain by sandy silt and clay with a basal conglomerate of black flints yielding late Palaeocene (Thanetian) foram assemblages.

The presence of the key index belemnite *Gonioteuthis quadrata* in subunits F1 and F2 would suggest an early Campanian age for at least the upper part of the «crai arénacée». The few specimens available from subunit F1 (Measurements in Table 1) are reffered to *G. quadrata quadrata* (ranging from the *lingua/quadrata* to the *papillosa* Zone *sensu germanico;* compare Christensen, 1988). The latest early Campanian *G. q. gracilis* (ranging from the *conica/gracilis* to the *gracilis/mucronata* Zone) generally shows higher figures for «Riedel-quotient» and «Schlankheits-quotient» (Christensen, 1988). The presence of a guard referred to *Belemnitella* gr. *mucronata* (Table 2) (in co-occurence with *G. quadrata;* see Hofker, 1963) in subunit F5 would indicate a late early Campanian age for the conglomerate. The «tuffeau jaunâtre» has not yielded any macrofossils allowing a more precise age assignment (Table 3).

Contrary to Hofker's (1961, 1963) views the foram assemblages do not show any important changes in these three lithological units. This is

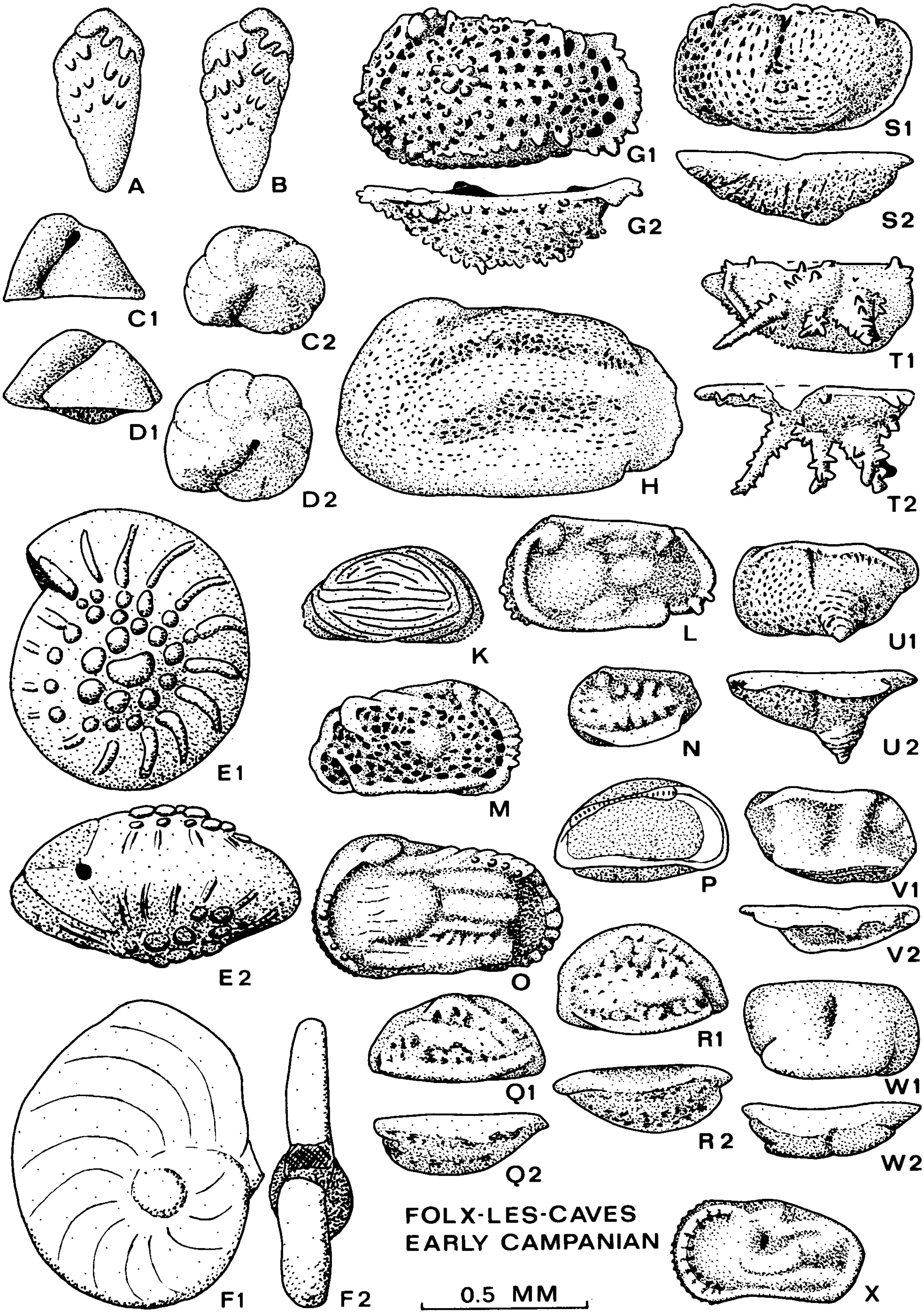
A
B
G1
G2
S1
S2
C1
C2
T1
D1
D2
H
T2
E1
K
L
U1
M
N
U2
E2
O
P
V1
V2
R1
W1
Q1
R2
W2
F1
F2
Q2
FOLX-LES-CAVES
EARLY CAMPANIAN
0.5 MM
X

Table 1.- Measurements and ratios of three well-preserved guards of *Gonioteuthis quadrata* (de Blainville) from the top of subunit F1 (0.60 cm) at Folx-les-Caves (measurements follow Christensen & Schmidt, 1987).

| specimen | 1 | 2 | 3 |
|---|---|---|---|
| L (total length, in mm) | 62.6 | 65.3 | 68.3 |
| D (depth pseudoalveolus, in mm) | 15.8 | 15.5 | 16.9 |
| DVDAE (dorso-ventral diameter at alveolar end, in mm) | 11.4 | 12.8 | 12.7 |
| 'Riedel-quotient' | 4.0 | 4.2 | 4.0 |
| 'Schlankheits-quotient' | 5.5 | 5.1 | 5.4 |

[Riedel-quotient = total length of guard *vs* depth of pseudoalveolus.
Schlankheits-quotient = total length of guard *vs* dorso-ventral diameter at alveolar end]

Table 2.- Measurments of a rather poorly preserved guard of *Belemnitella* gr. *mucronata* (von Schlottheim) from subunit F5 at Folx-les-Caves (measurements follow Christensen & Schmid, 1987). This specimen is slightly lanceolate in ventral view, and high conical in lateral view. Apical angle acute, mucro poorly delimited. Vascular markings are hardly visible. The ratio LAP/DVDP is 3.3. In view of its co-occurrence with *Gonioteuthis quadrata* (see Hofker, 1963), this specimen is here placed in the late early Campanian (*gracilis/mucronata* Zone *sensu germanico*).

| | |
|---|---|
| LAP (length from apex to protoconch, in mm) | 46.2 |
| DVDP (dorso-ventral diameter at protoconch, in mm) | 13.8 |
| LDP (lateral diameter at protoconch, in mm) | 14.8 |
| SD (Schatzky distance, in mm) | *c.* 7.5 |
| AA (alveolar angle) | *c.* 20° |
| FA (fissure angle) | *c.* 21° |

illustrated by the fact that small specimens of «*Siderolites*» *miscella* and *Daviesina primitiva* occur also in the upper portion of the succession (subunits F5-F8), Whereas *Bolivinoides* (specimens here referred to as B. gr. *granulata)* is also common in the subunits F2-F4 of the «craie arénacée» (fig.3). These distinctive species are at present unknown in the earliest Campanian strata with *Bolivinoides strigillata* in the Belgian Campine or with *G. quadrata* and *Belemnitella praecursor* (*lingua/quadrata* Zone) in the MAL area, neither have they been observed in the late Campanian of Belgium or the SE Netherlands. The same holds true for the ostracode assemblages which show little variation within this succession, and which are characterised by the common occurrence of some very distinctive species, such as *Oertliella* gr. *ingerica, Mosaeleberis* sp. A, «*Parapokornyella*» preciosa and *Mauritsina* gr. *hieroglyphica* (fig.3). These are virtually absent (except for a single valve of «*P.*» *presiosa* in the late Campanian of Orp-le-Petit) in the early or late Campanian of Belgium or the SE Netherlands (compare Van Veen, 1932-1938; Deroo, 1966; Nuyts, 1989).

Fig.3.- Selected forams (A-F) and ostracodes (G-X) from the early Campanian of Folx-les-Caves, Belgium.
A-B: *Bolivinoides* gr. *granulatus* HOFKER, F3
C: *Globorotalites* gr *micheliniana* (ORBIGNY), F1
D: *Globorotalites* gr *hiltermanni* KAEVER, F4
E: «*Siderolites*» (=*Miscellanea*) *miscella* (HAYNE & ARCHIAC), F1
F: *Daviesina primitiva* HOFKER, F1
G: *Oertliella* gr. *ingerica* DAMOTTE, F1
H: *Mosaeleberis* sp. A, F1
K: *Veenidea* (?) sp. A, F7
L: «*Curfsina*» (= *Hazelina*?) sp., F7
M: *Oertliella binkhorsti* (VAN VEEN), F3
N: *Amphicytherura* gr. *chelodon* (MARSSON), F2
O: *Mauritsina* gr. *hieroglyphica* (BOSQUET), F3
P-R: «*Parapokornyella*» (= *Parataxodonta*) *preciosa* (VAN VEEN), F2
S: «*Bythoceratina*» (= *Crassacythere*) sherborni (JONES & HINDE), F3
T: «*Bythoceratina*» (= *Nemoceratina*) *tricuspidata (JONES & HINDE), F7*
U: *Bythoceratina* gr. *hispida* (VAN VEEN), F1
V: *Bythoceratina compressa* (VAN VEEN), F3
W: «*Bythoceratina*» (= *Crassacythere*) sp., F3
X: *Cytherelloidea* sp., F7

The co-occurrence of *G. quadrata* and these forams and ostracodes in subunits F1-F2 suggests an early Campanian age for the «craie arénacée», younger than the *lingua/quadrata* Zone and older than the *conica/gracilis* Zone. The co-occurrence of *Gonioteuthis quadrata, Belemnitella* gr. *mucronata* and these forams and ostracodes in subunit F5 establishes a late early Campanian age (*gracilis/mucronata* Zone) for the conglomerate and overlying «tuffeau jaunâtre».

Table 3.- Selected macrofossils from the early Campanian succession at Folx-les-Caves

| **subunit** | **species** | **remarks** |
|---|---|---|
| F1 | *Gonioteuthis quadrata* (de Blainville) | early Campanian; see table 1 for measurements |
| | *Gryphaeostrea canaliculata* (J. Sowerby) | Aptian-Maastrichtian |
| | *Brachylepas naissanti* (Hébert) ? | Campanian-late Maastrichtian |
| F2 | *Gonioteuthis quadrata* (de Blainville) | fragment of rostrum cavum |
| | *Hyotissa ? semiplana* (J. de C. Sowerby) ? | Cenomanian-Maastrichtian |
| | *Neithea (Neithea) quinquecostata* (J. Sowerby) | Barremian-Maastrichtian |
| | *Cretiscalpellum* cf. *glabrum* (Roemer) | late Albian-Maastrichtian |
| | *Cretiscalpellum striatum* (Darwin) | Cenomanian-Maastrichtian |
| | *Arcoscalpellum maximum* var. *solidulum* (Steenstrup) | late early Campanian-late Campanian; perhaps also Maastrichtian of Belgium, compare Withers (1935) |
| | *Arcoscalpellum maximum* (J. de C. Sowerby) | early Santonian-Maastrichtian |
| | *Arcoscalpellum* cf. *gracile* (Bosquet) | ? Campanian-Maastrichtian |
| | *Pseudoptera coerulescens* (Nilsson) | Campanian-Maastrichtian |
| F3 | *Neithea (Neithea) quinquecostata* (J. Sowerby) | |
| | *Pseudoptera coerulescens* (Nilsson) | |
| F5 | *Belemnitella* gr. *mucronata* (von Schlottheim) | latest early Campanian-late Campanian; see table 2 for measurements |
| F7 | *Gryphaeostrea canaliculata* (J. Sowerby) | |
| | *Baculites* cf. *vertebralis* (Lamarck) | where well dated this species is always late Maastrichtian.<br>Although poorly preserved, whorl section and details of suture match specimens described by Kennedy (1986, 1987). In view of the difference in stratigraphic age, the specimen is referred to this species with a query |
| F8 | *Gryphaeostrea canaliculata* (J. Sowerby) | |
| | *Neithea (Neithea) striatocostata* (Goldfuß) | Cenomanian-Maastrichtian |
| | *Isocrania* gr. *costata* (J. Sowerby). | species of *Isocrania* are invariably referred to *I. egnabergensis* (Retzius) in the older literature, *e.g.* Ubaghs (1888). |

## 2.2.- ORP-LE-PETIT

The outcrop is situated in the village of Orp-le-Petit behind the castle on the left-hand side of the road to Wansin. It occurs to the letf of and above a wall of broken lints with an entry to an abandoned subterraneous quarry. Two lithological units can be distinguished, in ascending order:

- «*craie blanche*» (Ubaghs, 1888; Hofker, 1963), a succession of 0.4 to 1.0 m thick beds (subunits OK, OF-OA) of friable white calcisiltite separated by slightly undulating contact planes. Very small (5-10 cm long, 0.5-2 cm thick) flints occur in subunit OF. An important admixture of quartz (and subordinate quartzite) grains (partly exceeding a diameter of 1 mm, compare fig.4) characterises the subunits OD, OB and OA, which also contain brownish phosphate grains of similar size. Subhorizontal burrows occur in subunits OB and OA. The top of this unit is formed by a hardground capping a *c.* 65 cm thick chalkstone with small phosphate nodules and a few small flints and burrows. This hardground is marked by a distinct erosion surface. The number of bioclasts in the 1.0-2.4 mm fraction is small. They are usually well preserved as is indicated by the low percentages of unidentified echinoderm clasts. Fish remains (teeth, bones

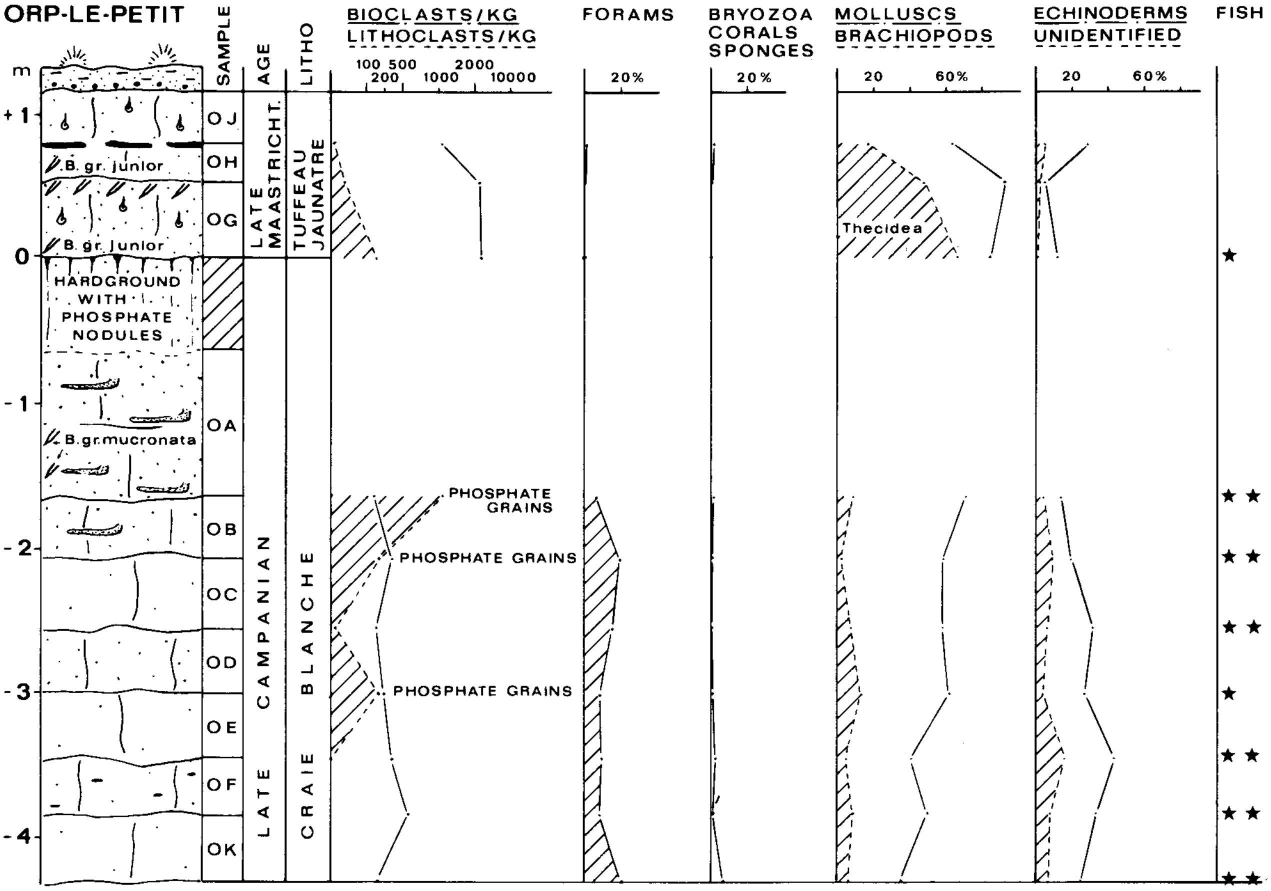

Fig.4.- Lithological section of the outcrop Orp-le-Petit (behind castle on left-hand side of road to Wansin) with frequency profiles for bioclasts and lithoclasts (1.0-2.4 mm sieve fraction). Names of lithological units after Hofker (1963). The position of the key index belemnites *Belemnitella mucronata* and B. junior is indicated in the left-hand column.

and scales) are relatively common in all samples. Only the upper 4.3 m of this succession is accessible in the outcrop.

- «*tuffeau jaunâtre*» with *Thecidea papillata* or «*tuffeau à Thécidées*» (Ubaghs, 1888; Hofker, 1963), a coarse-grained biocalcarenite, in the 1.0-2.4 mm fraction largely consisting of brachiopod (*e.g. Thecidea papillata*) and molluscan clasts, with a small admixture of lithoclasts (quartzite and subordinate quartz). Three subunits (OG-OJ) are distinguished. The top of subunit OG is marked by an increased amount of belemnite guards and is capped by an erosion surface. Large, tabular flints (30 cm diameter, 8 cm thick) separate subunits OH and OJ. This unit has a total thickness of only 1.15 cm. It is overlain by sandy silt and clay with a basal conglomerate of flints, deposited during the late Palaeocene (Thanetian; compare Hofker, 1963).

The presence of *Belemnitella* gr. *mucronata* in subunit OA establishes a late Campanian age for the «craie blanche». The specimen collected at -1.20 m (Table 4) would suggest a correlation with the late late Campanian Beutenaken Member in the MAL area and the Craie de Spiennes of the Mons basin (compare Robaszynski & Christensen,

Table 4.- Measurements of a poorly preserved belemnite guard from the «craie blanche», subunit OA (-1.20 m), at Orp-le-Petit (measurements follow Christensen & Schmid, 1987). The guard is corroded at the apical end and at the protoconch. It is slightly lanceolate in ventral view and cylindrical in lateral view. Dorso-lateral depressions and furrows are distinct, as are vascular markings and longitudinal striae. For the time being, this specimen is referred to as *Belemnitella* gr. *mucronata* (von Schlottheim). It is quite possible that further study of more and better preserved specimens will indicate that it is better assigned to latest Campanian forms, such as *Belemnitella* cf. *najdini* Kongiel.

| | |
|---|---|
| LAP (length from apex to protoconch, in mm) | *c.* 50 |
| DVDP (dorso-ventral diameter at protoconch, in mm) | 11.4 |
| LDP (lateral diameter at protoconch, in mm) | 11.7 |
| SD (Schatzky distance, in mm) | *c.* 8.4 |
| AA (alveolar angle) | *c.* 22° |
| FA (fissure angle) | > 30° |

1989). In addition, the «craie blanche» has yielded several macrofossils (Table 5) that are common in and/or characteristic of the late Campanian Zeven Wegen Member in the MAL area.

The foram assemblages (fig.5) are characterised by many specimens of *Bolivinoides decorata* (3-4 pustules on the last chamber) and (especially in subunits OE to OA) subordinate numbers of *B. australis* (only specimens with 5 pustules on the last chamber were observed). Each sample yielded a few specimens of *Neoflabellina leptodisca*. This association characterises the Zeven Wegen Member in the MAL area (Hofker, 1966; Robaszynski *et al.*, 1985) and the top of the Craie de Trivières, the Craie d'Obourg and the Craie de Nouvelles in the Mons basin (Robaszynski & Christensen, 1989).

The ostracode assemblages in subunits OK, OF-OA are characterised by small numbers of *Cytherelloidea* spp. and *Bythoceratininae* (compare fig.6). This is a typical feature of the assemblages in the Zeven Wegen Member of th MAL area (Deroo, 1966; Bless, 1988), the late Campanian in the Mons basin (Nuyts, 1989) and the late Campanian in the Hautes Fagnes area (Bless *et al.*, 1990).

The relative abundance of *Globorotalites* gr *micheliniana* in the various subunits of the «craie blanche» confirms this correlation. However, the co-occurence of this species with specimens referable to either «*Eponides beisseli*, forme primitive» (*sensu* Hofker, 1963, 1966) or *Globorotalites* gr *hiltermanni* (fig.7) poses a problem. In the Mons basin (Robaszynski & Christensen, 1989), the Hautes Fagnes area (Bless *et al.*, 1990) and the MAL area (Hofker, 1966; Robaszynski *et al.*, 1985) *G.* gr. *micheliniana* disappears prior to the first appearance of *G.* gr. *hiltermanni* and/or «*Eponides beisseli*, forme primitive». Even more problematic is the association of these species in the early Campanian of Folx-les-Caves (fig.7). Their occurrence is possibly dependent on special environmental conditions.

Several specimens of the key index belemnite *Belemnitella* gr. *junior* (Table 6) in subunits OG and OH of the «tuffeau jaunâtre» establishes a late Maastrichtian age for this deposit, and the association of *e.g. Thecidea papillata, Crania antiqua, Isocrania* gr. *costata* (= *I. egnabergensis sensu* Kruytzer, 1969) and *Sclerostyla regia* (Table 7) permits a firm correlation with the Tuffeau de Saint-Symphorien of the Mons basin and the Lanaye Member in the MAL area.

The relative abundance of *Bolivnoides giganteus* and *B.* gr. *draco* in all samples from the «tuffeau jaunâtre» corroborates this correlation, which had already been proposed by Hofker (1963). Remarkable is the common occurrence of specimens closely related to «*Siderolites*» *miscella* and *Daviesina* sp. (figure 5). These forms would indicate a depositional environment similar to that of the early Campanian strata at Folx-les-Caves. Hofker (1963) did not mention these species, nor did he note the presence of *Neoflabellina reticulata*, which was recognised in a sample from subunit OJ.

The ostracode assemblages are characterised by the common occurrence of *Mosaeleberis macrophthalma* (fig.6), a species typical of the Lanaye Member or deposits representing foram zone F in the MAL area and in the Belgian Campine (Felder *et al.*, 1985). Common is also «*Parapokornyella*» *speciosa*, mentioned by Deroo (1966) for the Tuffeau de Saint-Symphorien in the Mons basin and for the Kunrade and Maastricht Chalks in the MAL area.

## 3.- DEPOSITIONAL ENVIRONMENT

### 3.1.- Folx-les-Caves

The early Campanian sediments at Folx-les-Caves were deposited in extremely shallow subtidal, high-energy environments, invariably well above wave base. This is illustrated by:

- the well-rounded, frequently poorly recognisable, micritised bioclasts in the coarse-grained biocalcarenites, and,
- the erosive contacts between the subunits in the «craie arénacée».

The conglomerate of blocks and pebbles of well-cemented chalk in a more friable sandy chalk matrix presumably represents one or several (three?) periods of emergence, marked by

Fig.5.- Selected forams from the late Maastrichtian (A-G) and late Campanian (H-R) of Orp-le-Petit, Belgium.
A-B: *Bolivinoides giganteus* HILTERMANN & KOCH, 6-7 pustules on last chamber, OJ
C: *Bolivinoides* gr. *draco* (MARSSON), OH
D: *Bolivinoides giganteus* HILTERMANN & KOCH, 7 pustules on last chamber.
E: *Neoflabellina reticulata* (REUSS), OJ
G: *Daviesina* sp., OH
H: *Bolivinoides decoratus* (JONES), 4 pustules on last chamber, OA
K: *Bolivinoides australis* EDGELL, 5 pustules on last chamber, OA
L-M: *Bolivinoides decoratus* (JONES), 3-4 pustules on last chamber, OF
N-O: *Bolivinoides decoratus* (JONES), 3-4 pustules on last chamber, OK
P: *Citharinella* cf. *elongata* MARIE, OA
Q: *Neoflabellina leptodisca* (WEDEKIND), OA
R: *Flabellina radiata* (ORBIGNY), OE

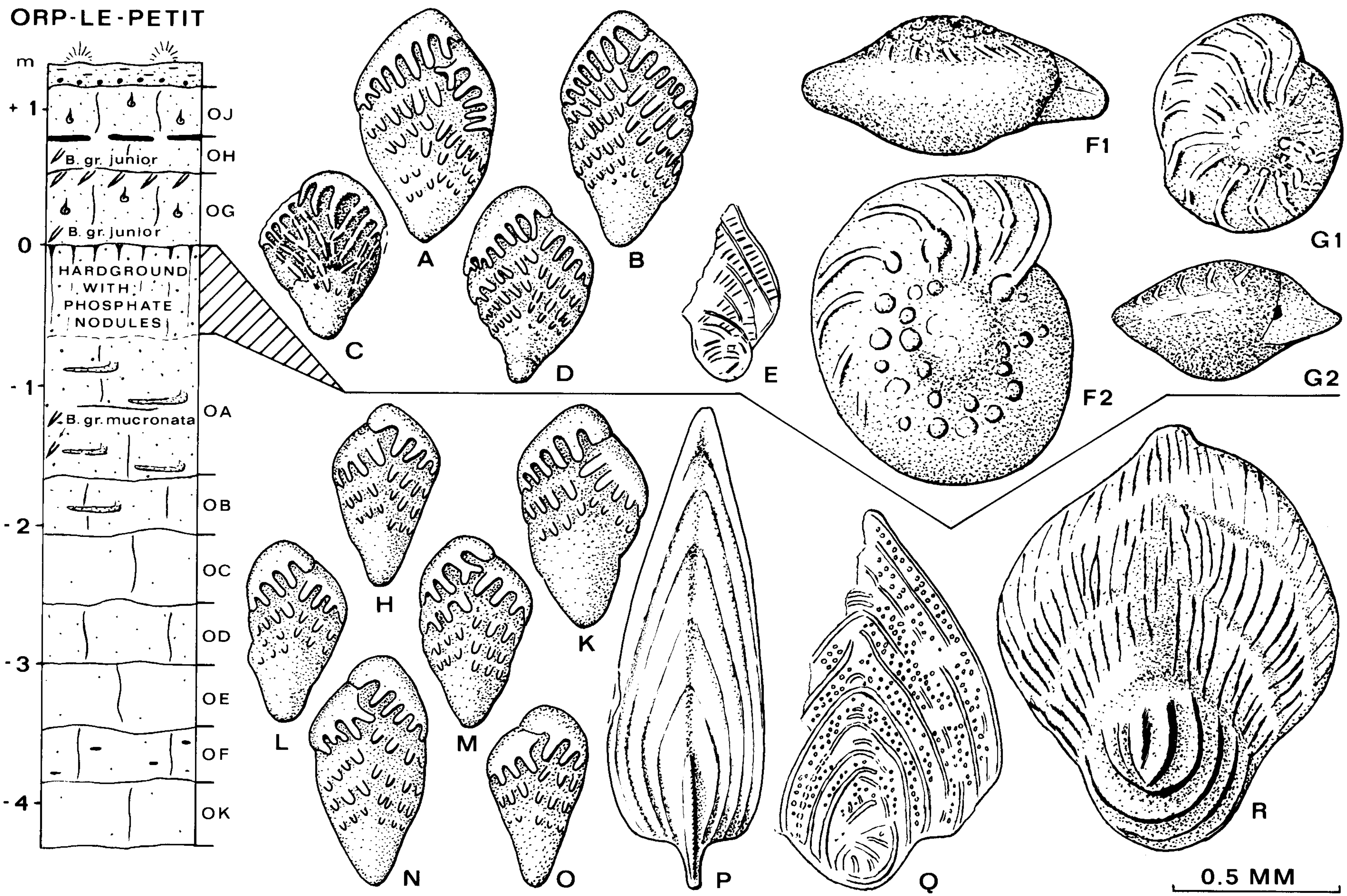
ORP-LE-PETIT
m
+ 1
0
- 1
- 2
- 3
- 4
OJ
OH
OG
OA
OB
OC
OD
OE
OF
OK
B. gr. junior
B. gr. junior
HARDGROUND WITH PHOSPHATE NODULES
B. gr. mucronata
A
B
C
D
E
F1
F2
G1
G2
H
K
L
M
N
O
P
Q
R
0.5 MM

Table 5.- Selected macrofossils from the late Campanian «craie blanche» at Orp-le-Petit

| subunit | species | remarks |
|---|---|---|
| OK | *Rugia spinicostata* Johansen & Surlyk | Campanian |
| | *Ophiomusium* gr. *subcylindricum* (von Hagenow) | Campanian-Maastrichtian |
| | *Ophiura ? hagenowi* Rasmussen | conspecific with forms found in late Campanian Zeven Wegen Member in MAL area |
| | *Temnocidaris (Stereocidaris) serrata* (Desor) | late Campanian |
| | *Atreta nilssoni* (von Hagenow) | Albian-Maastrichtian |
| | *Micrabacia* sp. | this genus occurs quite commonly in late Campanian Zeven Wegen Member and lateral time equivalent of Benzenrade sandy chalk in the MAL area |
| | *Pycnodonte (Phygraea) vesiculare* (Lamarck) | Cenomanian-Maastrichtian |
| | *Mimachlamys cretosa* (Defrance) | Turonian-Maastrichtian |
| | *Glomerula gordialis* (von Schlottheim) | Jurassic-Palaeocene |
| | *Nymphaster* cf. *peakei* Gale | *N. peakei* is a late Campanian species in southern England |
| | *Arcoscalpellum maximum* var. *sulcatum* (J. de C. Sowerby) | late Campanian-Maastrichtian |
| | *Bourgueticrinus* aff. *hureae* (Valette) | specimen very similar to material from late Campanian Zeven Wegen Member in the MAL area |
| | *Limea (Pseudolimea) granulata* (Nilsson) | Turonian-Maastrichtian |
| | *Gryphaeostrea canaliculata* (J. Sowerby) | Aptian-Maastrichtian |
| | *Magas* sp. | this form appears to be identical with Christensen *et al.*'s (1975) species from late Campanian in England and NW Germany |
| | *Isocrania* gr. *costata* (J. Sowerby) | |
| OF | *Magas* sp. | |
| | *Pycnodonte (Phygraea) vesiculare* (Lamarck) | |
| OE | *Magas* sp. | |
| | *Glomerula gordialis* (von Schlottheim) | |
| | *Pseudoptera coerulescens* (Nilsson) | Campanian-Maastrichtian |
| | *Limea (Pseudolimea) granulata* (Nilsson) | |
| | *Pycnodonte (Phygraea) vesiculare* (Lamarck) | |
| | *Temnocidaris (Stereocidaris) serrata* (Desor) | |
| OD | *Magas* sp. | |
| | *Glomerula gordialis* (von Schlottheim) | |
| | *Pycnodonte (Phygraea) vesiculare* (Lamarck) | |
| | *Temnocidaris (Stereocidaris) serrata* (Desor) | |
| OC | *Magas* sp. | |
| | *Pycnodonte (Phygraea) vesiculare* (Lamarck) | |
| OB | *Temnocidaris (Stereocidaris) serrata* (Desor) | |
| | *Porosphaera globularis* (Phillips) | Turonian-Maastrichtian |
| OA | *Belemnitella* gr. *mucronata* (von Schlottheim) | see table 4 |
| | *Pycnodonte (Phygraea) vesiculare* (Lamarck) | |
| | *Mimachlamys cretosa* (Defrance) | |
| | *Cretirhynchia* gr. *woodwardi* (Davidson) | form comparable to specimens from late Campanian Zeven Wegen Member in MAL area (see also Christensen *et. al.*, 1975) |
| | *Sclerostyla* cf. *polyforata* Jäger | Maastrichtian |
| | *Gyropleura inaequirostrata* (Woodward) | Campanian |

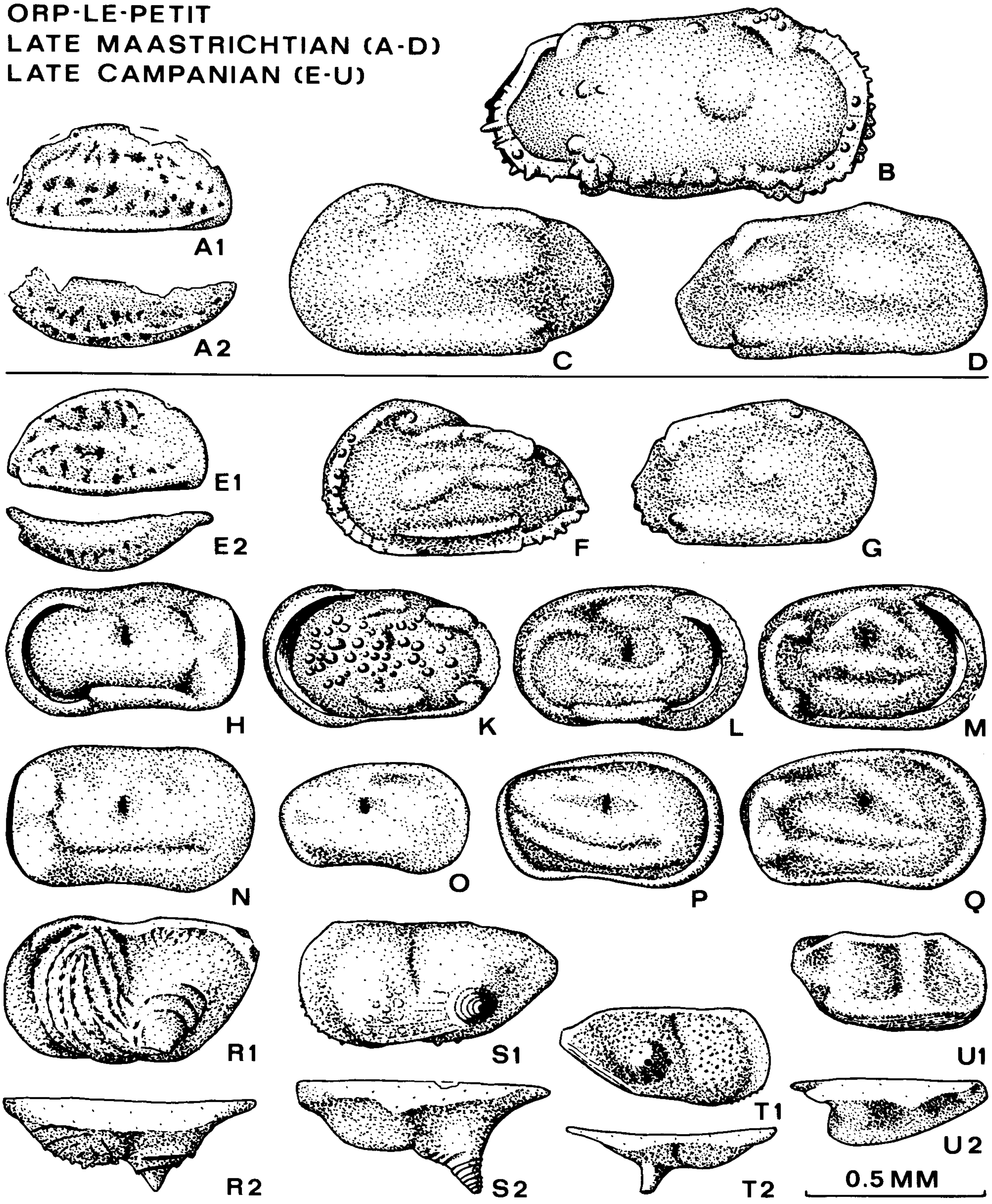

Fig.6.- Selected ostracodes from the late Maastrichtian (A-D) and late Campanian (E-U) of Orp-le-Petit, Belgium.

- A: «*Parapokornyella*» (= *Parataxodonta*) *preciosa* (VAN VEEN), OG
- B: *Cythereis joergensi* CLARKE, OJ
- C-D: *Mosaeleberis macrophthalma* (BOSQUET), OJ
- E: «*Parapokornyella*» (= *Parataxodonta*) *preciosa* (VAN VEEN), OB
- F: *Phacorhabdotus lonsdaleianus retunsus* HERRIG, OD
- G: *Mosaeleberis rutoti* DEROO, OF
- H: *Cytherelloidea levigata levigata* HERRIG (female, left valve), OF
- K: *Cytherelloidea granulosa* (JONES), OF
- L-M: *Cytherelloidea obliquirugata (JONES &HINDE) (L* = male, OE; M = female, OC)
- N-O: *Cytherelloidea levigata levigata* HERRIG (N = female, right valve, OC; O = juvenile, OA)
- P-Q: *Cytherelloidea auricularis* (BOSQUET) (P = male, OK; Q = female, OB)
- R: «*Bythoceratina umbonatoides* (KAYE), OE
- S: «*Bythoceratina marssoni* (VAN VEEN), OB
- T: *Veeniceratina howensis* (SZCZECHURA), OD
- U: «*Bythoceratina compressa* (VAN VEEN), OK

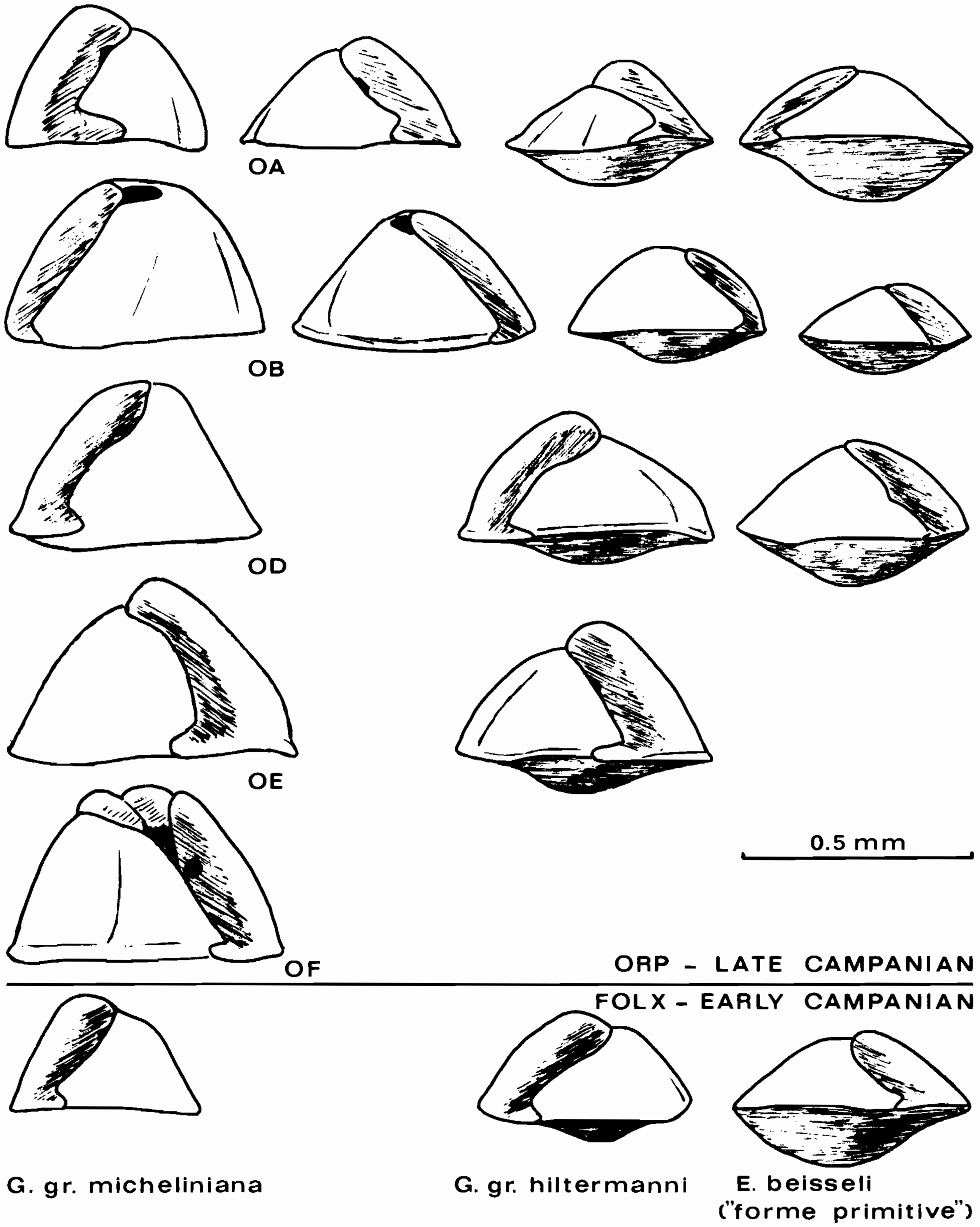

Fig.7.- Co-occurrence of the benthic forams *Globorotalites* gr *micheliniana* (ORBIGNY), *G.* gr. *hiltermanni* KAEVER and «*Eponides beisseli,* forme primitive» (HOFKER, 1956. 1963, 1966) in the (middle-late) early Campanian of Folx-les-Caves and the late Campanian of Orp-le-Petit. Only the slightly schematized lateral views are shown. In the MAL area (Hofker, 1966; Robaszynski *et al.,* 1985), the Hautes Fagnes area (Bless *et al.,* 1990) and the Mons basin (Robaszynski & Christensen, 1989) *G.* gr. *micheliniana* disappears before the late late Campanian (Beutenaken Member, Craie de Spiennes) when *G.* gr. *hiltermanni* and «*Eponides beisseli,* forme primitive» appear. Robaszynski & Christensen (1989) suggested that *G. hiltermanni* is «probably *Eponides beisseli primitiva* of Hofker». However, Kaever (1961, p. 419) explicitly mentioned the co-occurrence of *G. hiltermanni* and «flache rotaliide Foraminiferen... die diese Art sehr ähnlich sind... Es handelt sich hierbei um einen *Globorotalites* nahestehenden *Eponides.*»

Table 6.- Measurements of a poorly preserved guard of *Belemnitella* gr. *junior* Nowak from the «tuffeau jaunâtre», subunit OG (0.2 m above hardground), at Orp-le-Petit (measurements follow Christensen & Schmid, 1987). The specimen is very slightly lanceolate in ventral view and cylindrical in lateral view. Dorso-lateral furrows and depressions, vascular markings and longitudinal striae are well developed, as is the whitish layer.

| | |
|---|---|
| LAP (length from apex to protoconch, in mm) | *c.* 50 |
| DVDP (dorso-ventral diameter at protoconch, in mm) | 11.9 |
| LDP (lateral diameter at protoconch, in mm) | 11.7 |
| SD (Schatzky distance, in mm) | 7.9 |
| AA (alveolar angle) | *c.* 20° |
| FA (fissure angle) | > 50° |

interrupted sedimentation, cementation of superficial chalk, break-up of this crust into individual blocks by desiccation/dissolution during emergence, and reworking and rounding of blocks by wave and current action. The upward-increasing admixture of frequently poorly rounded quartz and quartzite grains and pebbles points to a nearby island or shoal.

The relative diversity and frequency of planktonic forams (with or without well-developed keels, and *Guembelina*) and bythoceratinid ostracodes (amongst others, *Bythoceratina, Nemoceratina, Crassacythere, Monoceratina;* compare fig.3) in all samples is remarkable but not unique. The same phenomenon has been observed in the late Cretaceous strata of the Hautes Fagnes area (eastern Belgium), where planktonic forams and bythoceratinids are common in the sandier (and glauconitic) nearshore deposits (Bless *et al.,* 1990). Presumably, the planktonic forams were introduced into this nearshore environment by tides and currents. The same may be true for the bythoceratinids and the well-preserved specimens of the kymatophobe ostracode genus *Pterygocythereis* (not figured). Alternatively, some of these ostracodes may have lived in sheltered low-energy micro-environments protected by *e.g.* seagrass (*Thalassia*) or algae, or even by sponges, sea anemones or holothurians (compare also Nohara & Tabuki, 1990) within an otherwise high-energy nearshore facies. This assumption is supported by the peculiar distribution pattern of an extremely spiny form such as *Nemoceratina tricuspidata* (figure 3T) in the late Cretaceous of Belgium and the SE Netherlands. This species has been recognised only in the coarse-grained early Campanian biocalcarenites at Folx-les-Caves (this paper), in the sandy, glauconitic sponge-bearing late Campanian deposits in the Hautes Fagnes area (Bless *et al.,* 1990) and in the coarse-grained biocalcarenites of the late Maastrichtian Meerssen Member in the MAL area (Van Veen, 1936).

In addition to the relative frequency of fish remains in the upper portion of the succession (subunits F4-F8; fig.2), these features suggest a nearshore, shallow subtidal deposit in which both autochthonous and allochthonous biota stranded and accumulated.

The nearshore position of the Folx-les-Caves deposits is emphasised by the widespread (tectonically induced) sedimentation gap almost immediately towards the north. Part of the Craie de Trivières of the Mons basin may represent the more offshore (deeper ?) time equivalent (fig.8, 9). This means that Folx-les-Caves was the northern margin of the Mons basin rather than the southern limit of the Campine Basin.

### 3.2.- Orp-le-Petit: «craie blanche»

The late Campanian «craie blanche» at Orp-le-Petit does not differ significantly from coeval deposits in the Mons basin (top Trivières, Obourg, Nouvelles and Spiennes) and in the MAL area (Zeven Wegen, Beutenaken). The «craie blanche» presumably represents a relatively shallow subtidal, «warm water», low-energy offshore environment.

The sediment consists mainly of coccolith debris with some well-preserved forams (partially larger than 1 mm; compare fig.4) and ostracodes, and small numbers of equally well-preserved bioclasts derived from molluscs, brachiopods, echinoderms and fishes (fig.4). The excellent preservation of all these fossils (which may be broken but not abraded) illustrates the low-energy facies. The relative frequency and diversity of the thermophilic ostracode genus *Cytherelloidea* (fig.6H-Q) is considered strong evidence of relatively shallow, «warm» water conditions (Bless, 1988) similar to those in the modern Belize lagoon (Simien, 1987). Analysis of the late Cretaceous palaeorelief in the Hautes Fagnes area (Bless *et al.,* 1990) suggests a maximum water depth of (much) less than 45-65 m.

Remarkable is the presence of occasionally up to 2 mm large, well-rounded quartz and quartzite grains, especially in subunits OD, OB and OA (fig.4). Such comparatively large grains occur also in the coeval Zeven Wegen Member of the MAL area and of the Campine. They were possibly

Table 7.- Selected macrofossils from the late Maastrichtian «tuffeau jaunâtre» at Orp-le-Petit

| subunit | species | remarks |
|---|---|---|
| OG | *Belemnitella* gr. *junior* Nowak | see table 6 |
| | *Thecidea papillata* (Von Schlottheim) | Maastrichtian; in the MAL area this species appears in the Lanaye Member, where it reaches its acme. It is common again in the latest Maastrichtian Meerssen Member (see Backhaus, 1959). In the Mons basin it occurs in the early Maastrichtian «craie phosphatée de Ciply» and in the late Maastrichtian Tuffeau de Saint-Symphorien |
| | *Atreta nilssoni* (von Hagenow) | Albian-Maastrichtian |
| | Mosasauridae | |
| | *Neithea (Neithea) striatocostata* (Goldfuß) | Cenomanian-Maastrichtian |
| | *Pseudoptera coerulescens* (Nilsson) | Campanian-Maastrichtian |
| | *Microchlamys pulchella* (Nilsson) | Turonian-Maastrichtian |
| | *Sclerostyla regia* (Regenhardt) | late Maastrichtian; in the MAL area, this species appears in the Lixhe 3 Member and reaches its acme in the Lanaye Member |
| | *Isocrania* gr. *costata* (J. Sowerby) | this form is conspecific with specimens occurring commonly in the Lanaye Member and the lower Maastricht Formation in the MAL area |
| | *Cretiscalpellum striatum* (Darwin) | Cenomanian-Maastrichtian |
| | *Baculites* sp. | |
| | *Gryphaeostrea canaliculata* (J. Sowerby) | Aptian-Maastrichtian |
| OH | *Crania antiqua* Defrance | late Campanian-late Maastrichtian; the highest occurrence of this species in the MAL area is in the Lanaye Member (see Kruytzer, 1969) |
| | *Sclerostyla regia* (Regenhardt) | |
| | *Thecidea papillata* (Von Schlottheim) | |
| | *Belemnitella* gr. *junior* Nowak | |
| | *Baculites* sp. | |
| | *Isocrania* gr. *costata* (J. Sowerby). | |
| | *Pseudoptera coerulescens* (Nilsson) | |
| | *Atreta nilssoni* (von Hagenow) | |
| | *Limea (Pseudolimea) granulata* (Nilsson) | Turonian-Maastrichtian |
| | *Rhyncolites minimus* (van den Binckhorst) | late Maastrichtian |
| OJ | *Thecidea papillata* (Von Schlottheim) | |
| | *Isocrania* gr. *costata* (J. Sowerby). | |
| | *Crania antiqua* Defrance | |
| | *Sclerostyla regia* (Regenhardt) | |
| | *Microchlamys pulchella* (Nilsson) | |
| | *Atreta nilssoni* (von Hagenow) | |
| | *Pseudoptera coerulescens* (Nilsson) | |
| | *Chomataster acules* Spencer ? | latest Campanian-early Palaeocene |

transported by fish feeding on biota that lived in the shallow sandy substrate of the pre-Valkenburg/Benzenrade deposits to the NE (fig.8, 9). Alternatively, they may have drifted into the basin adhering to floating plants.

### 3.3.- Orp-le-Petit: «tuffeau jaunâtre»

The late Maastrichtian «tuffeau jaunâtre» at Orp-le-Petit roughly matches the lithofacies of the relatively coarse-grained («craie grossière» facies) Tuffeau de Saint-Symphorien of the Mons basin and the Lanaye Member in the MAL area. Like these, it is characterised by flint bands. Together they constitute the offshore equivalent of the (nearshore) basal Kunrade Chalk (compare Felder & Bless, 1989).

In the Mons basin, at Orp-le-Petit and in several boreholes on the line Brussels-Liège (Pécrot, Lande, Velm, Diets-Heur), the deposition of the «tuffeau jaunâtre» and coeval strata (characterised by foram assemblages of zone F of highest zone E) followed upon a period of non-deposition (fig.8). On the Rur Valley block, deposits of this age directly overlie Triassic to early Cretaceous sediments and mark the onset of relaxation of active inversion tectonics during the early Campanian to early late Maastrichtian (Bless, 1988, 1989). Therefore, it is assumed that this transgression was linked to a major change in the palaeogeographic/palaeotectonic setting of the area.

The may coarse bioclasts (1.0-2.4 mm fraction; fig.4) in the «tuffeau jaunâtre» point to a subtidal environment above wave base. They are frequently slightly abraded and/or micritised. The low amount of lithoclasts in the 1.0-2.4 mm fraction (fig.4) matches the reduction of the Rur Valley Block shoal in the north (fig.9).

## 4.- TETHYAN INFLUENCES AND POSSIBLE CAUSES

The early Campanian succession at Folx-les-Caves is characterised by the presence of some unmistakably Tethyan immigrants (fig.8). These include the reptiles *Mosasaurus gracilis* (? = *Plioplatecarpus marshi*) and *Allopleuron hoffmanni* see Ubaghs, 1888), the benthic forams «*Siderolites*» *miscella* and *Daviesina primitiva* (fig.3E-F; compare Hofker, 1961, p.551), and the ostracodes *Mauritsina* gr. *hieroglyphica* and «*Parapokornyella*» *preciosa* (fig.30-R). Several of these biota occur also in the late Maastrichtian «tuffeau jaunâtre» at Orp-le-Petit (Mosasauridae, «*Siderolites*», *Daviesina* and «*P.*» *preciosa*).

In the MAL area, Mosasauridae and *Allopleuron* first appear in the middle late Maastrichtian Lanaye Member (foram zone F) and coeval lower part of the Kunrade Chalk together with numerous other Tethyan immigrants (*e.g. echinoids, forams, ostracodes, serpulids). The foram genera Siderolites* and *Daviesina* and the ostracode species *Mauritsina* gr. *hieroglyphica* and «*Parapokornyella*» *preciosa* also appear in the lower part of the Kunrade Chalk, whereas they are absent from or remain extremely rare in the coeval Lanaye Member and the lower Maastricht Formation. *Siderolites* and *Daviestina* become larger and more diverse in the upper Maastricht Formation, where *M.* gr. *hieroglyphica* and «*P.*» *preciosa* are common. Mosasauridae and *Allopleuron* apparently also reach their acme (and Mosasauridae also their greatest diversity) in the upper Maastricht Formation.

The Mediterranean origin of *Siderolites* and *Daviesina* was stressed by Hofker (1961), and that of *M.* gr. *hieroglyphica* by Bless (1988, 1989). Although «*P.*» *preciosa* has so far been described only from the middle-late late Maastrichtian in the MAL area and in the Mons basin (Deroo, 1966), it is assumed to have had its origin in the Tethys, where the genus *Parapokornyella* appears as early as the Cenomanian (Babinot *et al.*, 1985).

The above list of Mediterranean immigrants in the early Campanian at Folx-les-Caves can be extended with several additional examples. Hofker (1961) mentioned the forams *Pararotalia tuberculifera* and *Distyopsella tenuissima* (both reappear in the middle-late late Maastrichtian in the MAL area; Hofker, 1966), and *Eponides ornatissimus* and *Neoflabellina pachydisciformis* (both restricted to the Campanian). The ostracode *Oertliella* gr. *ingerica* (fig.3G) appears to be a Tethyan element.

The co-occurrence of the six selected taxa convincingly demonstrates the pronouced Tethyan influence in Belgium and the SE Netherlands during the early Campanian and middle-late late Maastrichtian. These taxa are unknown in the early early Campanian *lingua/quadrata* Zone deposits in the Campine and MAL areas, and are virtually absent in the late Campanian (except for a single valve of «*P.*» *preciosa* in the «craie blanche» at Orp-le-Petit), early Maastrichtian (except for *Mosasaurus lemonnieri* and other species (see Lingham-Soliar & Nolf, 1990) in the Craie phosphatée de Ciply in the Mons basin) or early late Maastrichtian.

Naturally, it is realised that these six taxa do not occur in all samples from the early Campanian at Folx-les-Caves. As in the middle late late Maastrichtian, their presence/absence/relative abundance must have been influenced by local

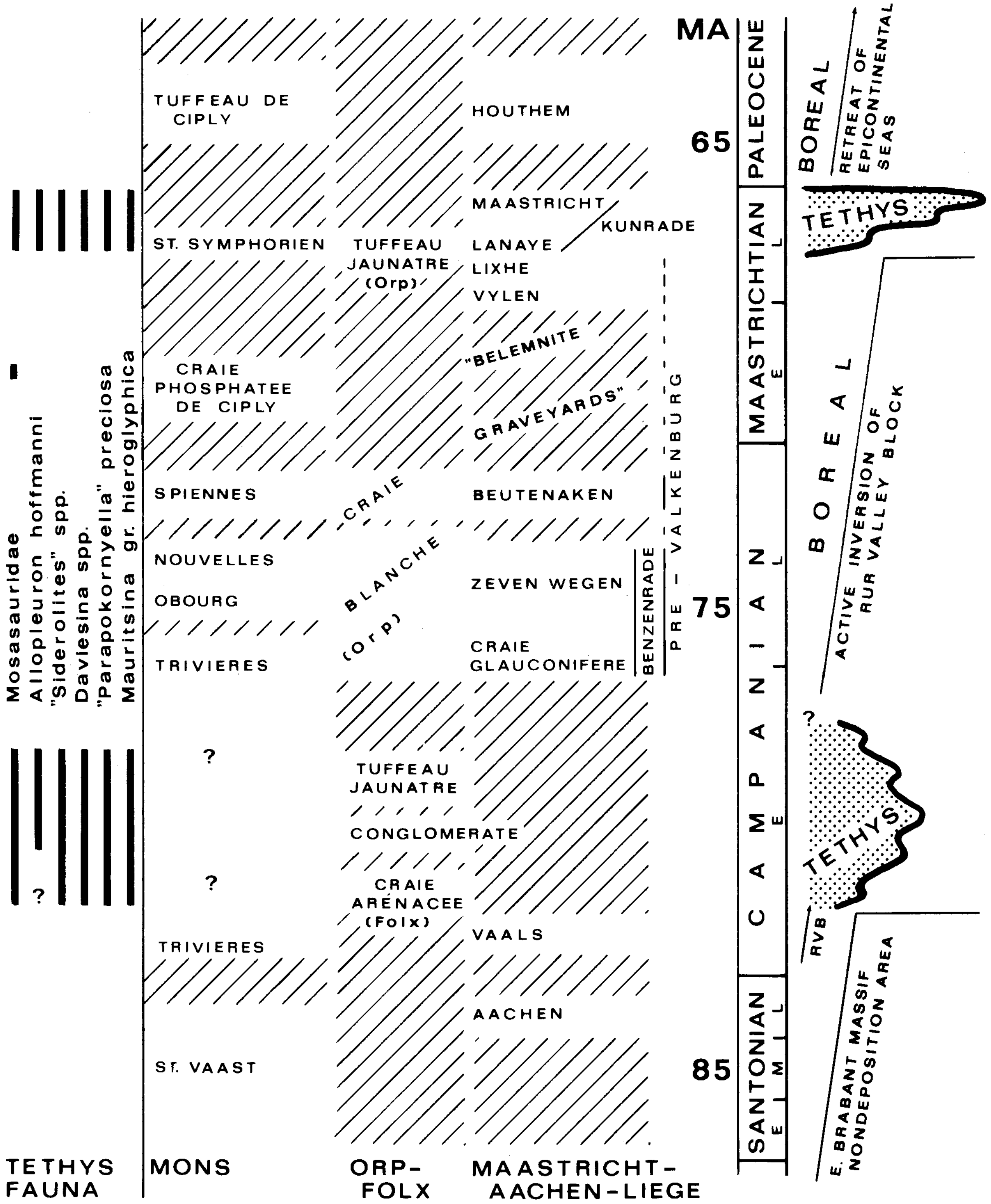

Fig.8.- Schematic distribution of some selected Mediterranean reptiles, forams and ostracodes in the late Cretaceous of Belgium and the SE Netherlands. The two brief, major Tethyan incursions in this region coincide with periods of downwarp or at least relaxation of tectonic activity of various structural blocks. Correlation of late Cretaceous deposits in the Mons basin is based on Marlière (1954) and Robaszynski & Christensen (1989), in Folx-les-Caves and Orp-le-Petit on the present paper, and in the MAL area on Jagt (1988).

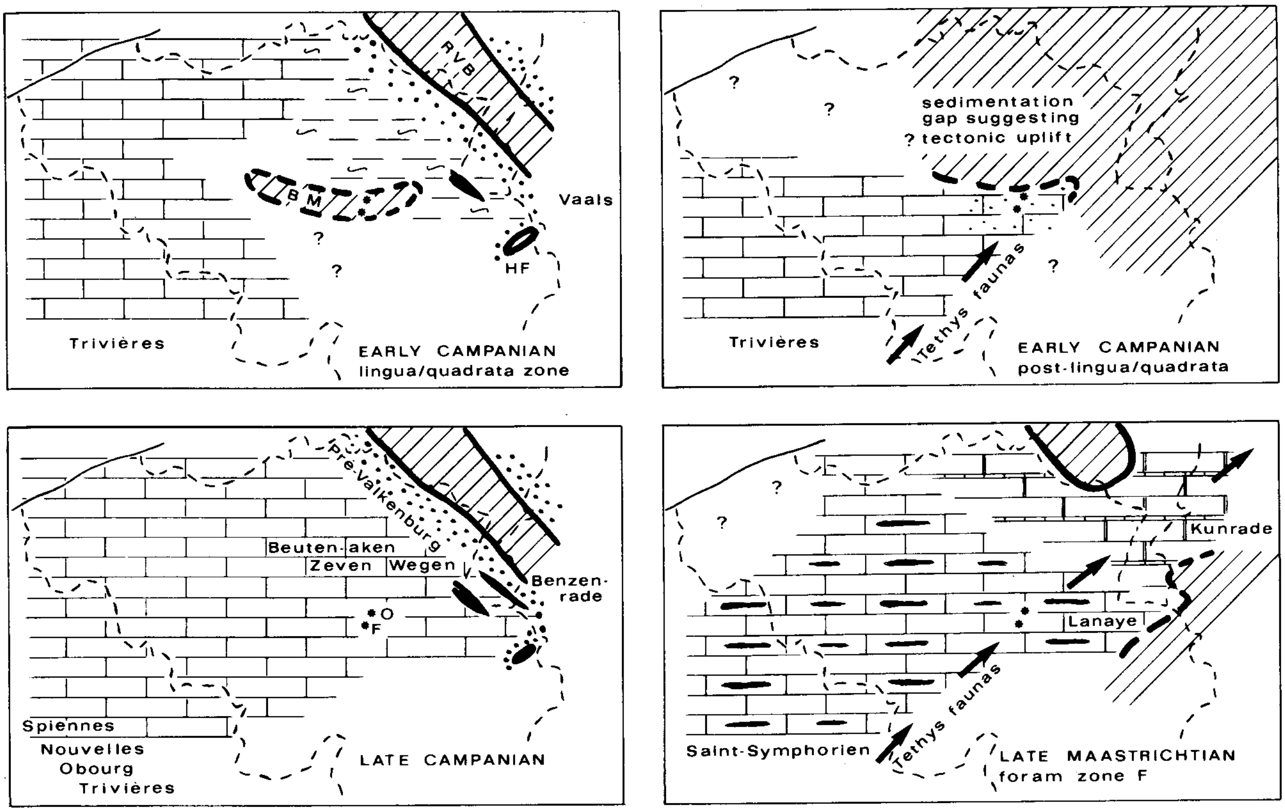

Fig.9.- Palaeogeographic evolution of Belgium and the southern Netherlands during the Campanian and Maastrichtian. Non-depositional areas are indicated by diagonal hatching. RVB: Rur Valley Block. BM: Brabant Massif. HF: Hautes Fagnes area. F: Folx-les-Caves. O: Orp-le-Petit.

environmental conditions which must have varied considerably in time and space. However, their virtual absence in the late Campanian to early late Maastrichtian appears to be highly significant. The exceptions cited above would indicate that there was really no impassable barrier between the Tethys and temperate NW Europe. In principle, all Mediterranean biota would have been able to migrate into the temperate (boreal) realm. However, only two major migratory waves have so far been recognised during such a relatively long timespan (about 15 MA according to Haq & Van Eijsinga, 1987; compare fig.8).

Three possible explanations can be offered:

- palaeoecological conditions (water depth, temperature, energy, substrate) in this area favoured settlement of these biota only temporarily.
- the boundary between the two climatic zones that characterised the Mediterranean and northern Europe was fairly pronouced and stable during most of the time, thus inhibiting the northward migration of Tethyan biota.
- the northward spread of Mediterranean waters (and faunas) over the boreal realm was possible only under very special conditions linked to the palaeogeographic/palaeotectonic setting of northern Europe.

Local palaeoecological conditions were undoubtedly of prime importance for the settlement of Mediterranean biota. This is illustrated by the qualitative/quantitative differences in the fossil content of the Lanaye Member and coeval basal Kunrade Chalk in the MAL area (Bless, 1988, 1989; Felder & Bless, 1989). However, at least on a local scale, water depth, temperature, energy level and substrate conditions during the late Campanian to early late Maastrichtian were similar to those during the early Campanian and/or middle-late late Maastrichtian. For instance, the frequency and diversity of *Cytherelloidea* in the late Campanian point to shallow warm-water conditions, whereas the substrate varied from fine-grained chalk ooze («craie blanche» facies) deposited under low-energy conditions, to coarse-grained sandy deposits with glauconite (Benzenrade and Pre-Valkenburg facies) and even with up to 20 cm large pebbles (Hautes Fagnes area) laid down under high-energy conditions. Therefore, it seems reasonable to assume that the immigration of Tethyan biota was primarily determined by other factors.

The warm-water conditions during the late Campanian - as witnessed by the frequency and diversity of the thermophilic ostracode *Cytherelloidea* in the Mons basin (Nuyts, 1989), the Hautes Fagnes area (Bless *et al.*, 1990) and the MAL area

(Bless, 1988, 1989) - suggest fluctuations in palaeotemperature in the boreal realm during the Campanian and Maastrichtian. However, these need not match (at least not during the late Campanian) Tethyan migratory waves.

There is ample evidence that both the early Campanian transgression at Folx-les-Caves and the Saint-Symphorien/Lanaye/basal Kunrade Chalk transgression (fig.8, 9) coincide with major changes in the palaeogeographic/palaeotectonic setting of the area.

During the early early Campanian transgression (*lingua/quadrata* Zone) in the Campine and MAL areas, the central part of the eastern Brabant Massif was a non-depositional high (island or shoal). This is indicated by the results of studies of the Late Cretaceous in the Pécrot, Landen, Velm and Diets-Heur boreholes (unpublished data by P.J.F.), and presumably by the succession at Folx-les-Caves (base of the late Cretaceous sequence virtually unknown, but most likely of the same age as the studied interval; compare fig.9).

The early Campanian post-*lingua/quadrata* Zone transgression at Folx-les-Caves cannot be explained by a simple rise of eustatic sea level, because the inundation of that part of the Brabant Massif coincides with a regression (marked by an important sedimentation gap) in the area immediately to the north (fig.9).

The middle late Maastrichtian (foram zone F) transgression in Belgium and the SE Netherlands (Saint-Symphorien in the Mons basin, «tuffeau jaunâtre» at Orp-le-Petit and Lanaye and basal Kunrade in the MAL area) is correlated with the onset of relaxation of active inversion (uplift) of the Rur Valley Block (Bless, 1988, 1989). The inundation of the central portion of the Rur Valley Block coincides with the start of the major invasion of Tethyan biota into northern Europe extending to northern Germany (Voigt, 1951) and Poland (Szczechura, 1965).

Thus, there is a strong correlation between the onset of change in tectonic activity (presumably overprinting eustatic sea level changes) and palaeogeographic setting on the one hand and the immigration of Mediterranean biota on the other. Naturally, this mechanism may have triggered off other processes. The northward spread of warm-water Tethyan currents may have improved the climate in the boreal realm. Even so, the actual settlement of these immigrants must have controlled primarily by local conditions.

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