

# High resolution miospore stratigraphy of the Upper Famennian of eastern Belgium, and correlation with the conodont zonation.

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**ABSTRACT.** The Ourthe valley in eastern Belgium provides the most complete exposures of the upper Famennian Condroz Group. A detailed miospore stratigraphy has been established for this succession. The lower three miospore biozones of the Upper Famennian (GF, VCo and VH Opper Zones) are re-defined and subdivided into five new interval zones. The GF Opper Zone which spans the Middle and Upper Famennian boundary was previously subdivided into three interval zones is now reduced to two. The highest *Retispora macroreticulata* (Mac) Interval Zone is now removed (due to its very sporadic occurrence) which results in the *Grandispora microseta* (Mic) Interval Zone of the GF Opper Zone now being the lowest miospore interval zone of the Upper Famennian. The overlying VCo Opper zone is subdivided into two new interval zones, the *Rugospora radiata* (Rad) and overlying *Grandispora cornuta* (Cor) interval Zones. A detailed study based on new and published material of the two nominal zonal taxa of the VCo Zone has clarified their morphology and resolved identification problems with other closely related Upper Devonian taxa. Furthermore, a biometric comparison of *Grandispora cornuta* with *Grandispora tamarae* has resulted in the specific diagnosis of *G. cornuta* being emended to increase its minimal spine length to 8 µm. The biostratigraphic implications for intercontinental correlations with the Upper Famennian of North America are discussed. The overlying VH Opper Zone is subdivided into two new interval zones, the *Apiculiretusispora verrucosa* (Ver) Interval Zone and the overlying *Vallatisporites hystricosus* (Hys) Interval Zone. All of the new miospore interval zones are closely correlated with the well established conodont zones occurring in five sections of the Ourthe Valley. The new integrated data sets provide a high resolution biostratigraphy for the Upper Famennian stratigraphic interval in eastern Belgium.

**KEYWORDS:** lithostratigraphy, biostratigraphy, guide fossils, Upper Devonian

## 1. Introduction.

In Belgium, Famennian deposits comprise a 600 m thick predominantly siliciclastic sedimentary sequence which has been subdivided into two lithostratigraphic groups (Thorez et al., 2006). The lower Famennian is represented by the predominately pelitic Famenne Group and this is succeeded by the more arenaceous Upper Famennian Condroz Group.

The Condroz Group is best developed in the eastern part of the Dinant Synclinorium, where it shows the most complete suite of constituent formations (Fig. 1). In the classic Ourthe Valley section, Murlon (1875 – 1886) made the first detailed lithostratigraphical division of the Condroz sandstones and described a succession of units that comprised the Esneux, Souverain-Pré, Montfort and Evieux ‘assises’, which later were formalised to formation status. More recently, new coeval formations have been introduced that include the Beverire and Comblain-la-Tour Formations (Bouckaert et al., 1968). The sediments of the Condroz Group originated during an important progradation of deltaic complexes into a shallow epicontinental sea. As a result, a whole spectrum of alluvial, estuarine, restricted marine (lagoonal) and shallow marine siliciclastic depositional settings were developed (Thorez et al., 2006, fig. 6). The mainly regressive Upper Famennian is interrupted by two short transgressive events. The first is represented by the Bon Mariage Shale which occurs at the boundary between the sandstone dominated Montfort Formation and the sandstone/siltstone dominated Evieux Formation in the Comblain-la-Tour section. This thin (meter scale) black shale horizon has been correlated with the *annulata* event (Thorez et al., 2006). The second transgressive pulse, occurs within the Evieux Formation and is represented by a restricted marine or peritidal carbonates (the Fontin Event, Dreesen & Jux 1995). These deposits together with conspicuous ball-and-pillow levels and pedogenic red beds, serve as important lithostratigraphic tools in the Condroz Group, where block faulting and regional irregularities of the sea floor were responsible for a strong lateral variability (Thorez et al., 2006, fig. 7).

**Figure 1:** Famennian lithostratigraphy and substage divisions of the Famennian after Thorez et al 2006, fig. 4.

Bev: Beverire Formation; CBT: Comblain-la-Tour Formation, L: Lower; M: Middle; U: Upper; U+: Uppermost

| BIOSTRATIGRAPHY |    | LITHOSTRATIGRAPHY            |                  |
|-----------------|----|------------------------------|------------------|
| Conodonts       |    |                              |                  |
| sulcata         |    | TOURN.                       | Hastière         |
| praesulcata     | U  | UPPERMOST FAM.<br>(STRUNIAN) | Comblain-au-Pont |
|                 | M  |                              |                  |
|                 | L  |                              |                  |
| expansa         | U  | UPPER FAMENNIAN              | Bev Evieux       |
|                 | M  |                              |                  |
| postera         | L  | UPPER FAMENNIAN              | CBT Montfort     |
|                 | U  |                              |                  |
| trachytera      | L  | UPPER FAMENNIAN              | Souverain-Pré    |
|                 | U  |                              |                  |
| marginifera     | U+ | MIDDLE FAMENNIAN             | Esneux           |
|                 | U  |                              |                  |
| rhomboidea      | L  | MIDDLE FAMENNIAN             | Mariembourg      |
|                 | U  |                              |                  |
| crepida         | U  | LOWER FAMENNIAN              | Senzeille        |
|                 | M  |                              |                  |
|                 | L  |                              |                  |
| triangularis    | U  | LOWER FAMENNIAN              | Senzeille        |
|                 | M  |                              |                  |
|                 | L  |                              |                  |
| linguiformis    |    | FRASN.                       |                  |

A detailed biostratigraphical framework for the Upper Famennian interval has been established based mainly on conodonts, foraminifera and spores. Initially, it provided biostratigraphical control of the former Upper Famennian Fa2b, Fa2c and Fa2d lithostratigraphical subdivisions (Bouckaert et al., 1969). However, these divisions are now obsolete and have been replaced by a formal subdivision of the Famennian Stage into four substages: the Lower, Middle, Upper and Uppermost Famennian substages (Thorez et al., 2006).

## 2. Palynology

Streel et al. (1987) described a miospore biozonation scheme for the classic marine Devonian of the Ardenne – Rhenish regions. The biozonation scheme comprised a series of Opper and Interval zones. An Opper Zone is characterized by the association or aggregation of selected taxa of restricted and largely concurrent range chosen as indicative of approximate contemporaneity (After Hedberg 1976, p.58, judgement may vary however as to how many and which of the selected diagnostic taxa need to be present to identify the zone). Interval Zone, on the contrary, is an interval between two distinctive biostratigraphical horizons. Accurate correlation with the conodont biostratigraphy needs the definition of reliable interval zones. The Middle, Upper and Uppermost Famennian parts of the miospore zonation scheme is based predominately on well studied sequences of the Condroz Group in the area of eastern Belgium. Four successive miospore Opper zones (GH, GF, VCo, LV) were established by Streel et al. (1987) for the Upper Famennian interval. Maziane et al. (1999) subsequently revised this zonation scheme by erecting a new *Vallatisporites hystricosus* - *Apiculiretusispora verrucosa* VH Zone (which was equivalent to the upper part of the original VCo Opper Zone), replacing the LV Zone by the *Retispora lepidophyta* - *Knoxisporites literatus* LL Zone and establishing the *Retispora lepidophyta* - *Indotridadites explanatus* (LE) Zone. Streel (2009) redefined the Middle and lowermost Upper Famennian GH (now DV) and GF Opper Zones.

The principal aims of the present paper are to:

- (1) Redefine and subdivide the Upper Famennian GF, VCo and VH Opper Zones into five successive interval range zones.
- (2) Clarify the morphological characteristics of some key zonal spore taxa and to morphologically discriminate these taxa from other closely related Upper Devonian forms.
- (3) Accurately correlate the Upper Famennian spore zones with the established conodont biostratigraphy.

To achieve these objectives, a detailed palynological study has been carried out on some 200 palynological samples from five sections of the Condroz Group exposed in the Ourthe Valley. (Fig. 2). Most of the material studied is from the research slide collections of Kievits (1977) and Maziane (1993 and 1999) stored in the Palaeopalynology Unit, Department of Geology, University of Liege.

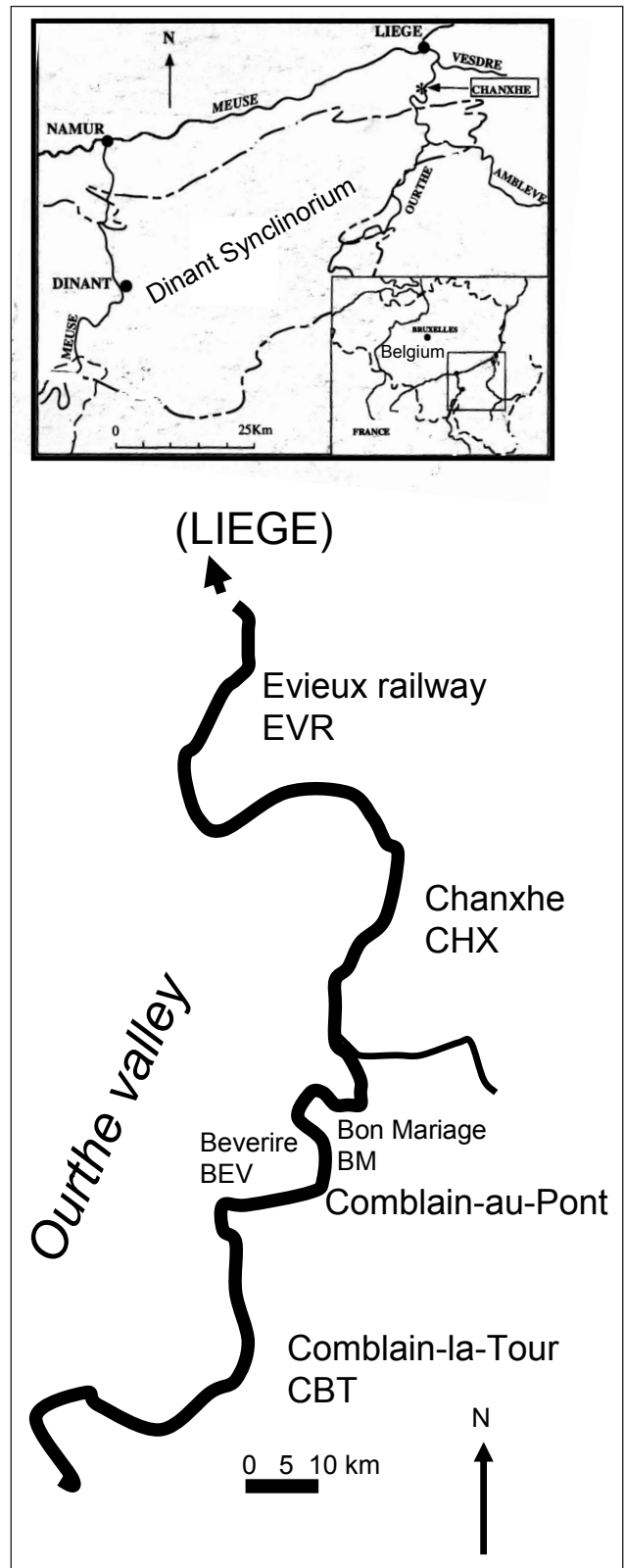
### 2.1. Miospore zonation scheme

*Grandispora gracilis* – *Grandispora famenensis* GF Opper Zone.

This zone is considered to span the Middle and Upper Famennian boundary and was divided into three Interval Zones by Streel (2009), in ascending stratigraphic order. These were the pre-*Grandispora microseta* (Premic), the *Grandispora microseta* (Mic) and the *Retispora macroreticulata* (Mac) subzones. Due to the sporadic first occurrence of *Retispora macroreticulata*, the highest Mac Interval Zone is here considered obsolete. Consequently, the *Grandispora gracilis* - *Grandispora famenensis* GF Opper zone is now subdivided in only two zones, the younger one being based solely on the first occurrence of *Grandispora microseta*. The upper Mic interval zone occurs in the lowermost part of the Upper Famennian.

*Diducites versabilis* – *Grandispora cornuta* VCo Opper Zone

The base of the original *Diducites versabilis* – *Grandispora cornuta* (VCo) Opper zone was originally defined by Streel et al., 1987 (p. 220, fig. 9) by the co-occurrence of the three taxa *Grandispora cornuta*, *Rugospora flexuosa* (now *R. radiata*) and *Retusotriletes phillipsii*. However, Streel and Loboziak (1996, p.580), were reluctant to define formal First Occurrence



**Figure 2:** Localities studied in the Ourthe Valley, and location in Eastern Belgium (Dinant Synclinorium).

Biohorizons for these three zonal taxa due to insufficient biostratigraphical control of their respective inceptions. In addition, *Retusotriletes phillipsii* was originally nominated as a zonal species due to the importance given to this species in the Famennian of eastern North America (Clendening et al., 1980; Richardson & McGregor, 1986). However, its occurrence in the late Famennian of the Ourthe valley, was not established; therefore it is proposed that this species should no longer be used as a diagnostic species for the VCo Zone in western Europe. It is proposed that the VCo Opper Zone be redefined by the occurrence of *Rugospora radiata* and *Grandispora cornuta*, and that the

staggered first appearances of these two taxa within the VCo Oppel Zone now define two new interval zones: the *Rugospora radiata* (Rad) interval zone succeeded by the *Grandispora cornuta* (Cor) interval zone.

*Apiculiretusispora verrucosa* - *Vallatisporites hystricosus*. VH Oppel Zone

This zone was first described by Maziane et al. (1999) from the Chanxhe section in the Ourthe Valley, and was defined by the first appearance of *Apiculiretusispora verrucosa* and *Vallatisporites hystricosus*. Other taxa mentioned as appearing in this zone included, *Endoculeospora gradzinskii*, *Spelaeotriletes crenulatus* and *Grandispora echinata*. However, revision of the slides from the Evieux-railway cutting (EVR) shows that these three species first appear at level well below the base of the zone and so can no longer be considered as a characteristic species of the VH Oppel Zone. Furthermore, *A. verrucosa*, one of the zonal nominal species has been now recorded below the first occurrence of *V. hystricosus* in the Ourthe Valley section. Consequently the staggered first appearances of these two taxa within the VH Oppel Zone allows the definition of two new interval zones, the *Apiculiretusispora verrucosa* (Ver) interval zone followed by the *Vallatisporites hystricosus*. (Hys) interval zone. The taxonomic distinction of *Vallatisporites hystricosus* from the Russian taxon *Vallatisporites pusillites* was clarified by Avchimovitch et al. (1988) who showed that *V. hystricosus* is a much more coarsely ornamented form with spines 3-16 µm in length whereas the stratigraphically younger *V. pusillites* normally has small spines 1-2 µm in length. Richardson and Ahmed (1988) recorded the *Apiculiretusispora verrucosa* (as *A. fructicosa*) and *Vallatisporites hystricosus* (as *V. pusillites*) assemblage zone from the lower part of the Cattaraugus Formation of western New York State. This assemblage zone broadly correlates with the VH Oppel Zone of Belgium; however the two zonal taxa appear in a reversed stratigraphic order to that observed in eastern Belgium.

2.2. Systematics

A taxonomic review has been carried out of *Rugospora radiata* and *Grandispora cornuta* to provide a clear understanding about the morphological features of these two zonal species and a better discrimination with other closely related Upper Devonian taxa.

*Grandispora cornuta* Higgs 1975 emend  
Plate 1, Figs. A-F; Plate 3, Figs. K and N

- 1962 *Acanthotriletes acutus* Caro-Moniezi, in Caro-Moniezi, pl. XVI fig. 11.
- 1966 *Spinozonotriletes* cf. *uncatus* Hacquebard 1957 in Streel pl. II fig. 27.
- 1968 *Spinozonotriletes* cf. *uncatus* Hacquebard 1957 in Streel. pl. I: 7.
- 1971 *Spinozonotriletes* cf. *conspicuus* Playford 1964 in Combaz & Streel. pl. 3 fig. 8.
- 1973 *Spinozonotriletes* sp. cf. *S. uncatus* Hacquebard 1957 sensu Bouckaert, Streel, Thorez & Mound 1969 in Gayer et al., 8, pt 2, pl. 14 fig. B.
- 1975 *Grandispora cornuta* Higgs, pp.398-399, Pl.4, 4-6.
- 1976 *Spinozonotriletes uncatus* Hacquebard 1957 in Coquel et al., pl. IV fig 23.
- 1996 *Grandispora cornuta* Higgs 1975 in Streel & Loboziak. pl. 1 fig. 25.

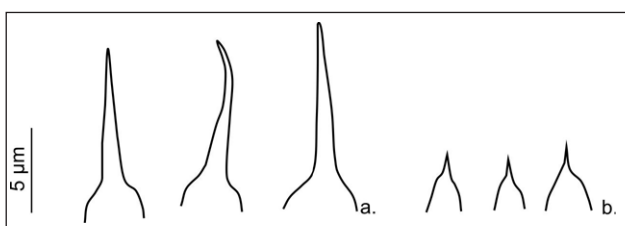


Figure 3: Comparison of spine length and shape in a. *Grandispora cornuta* and b. *G. tamarae*

Remarks: The diagnosis of this species is emended in light of the present biometric study of *G. cornuta* and *G. tamarae* from Upper Devonian material from eastern Belgium and Ireland (described below). The size range of the spines for *G. cornuta* is changed from 5-16 µm to 8-16 µm in length (see Fig. 3)

*Grandispora tamarae* Loboziak in Higgs et al., 2000  
Plate 1, Figs. G-N; Plate 2, Figs. A-F; Plate 3, Figs. I-J

- 1962 *Acanthotriletes loricatus* Caro-Moniezi, in Caro-Moniezi pl. XVI fig. 13.
- 1969 *Spinozonotriletes* cf. *S. uncatus* Hacquebard 1957 in Bouckaert et al., pl. 93 figs. 7 and 8
- 1969 *Spinozonotriletes* cf. *S. tenuispinus* Hacquebard 1957 in Bouckaert et al., pl. 93 fig. 6.
- 1969 *Hymenozonotriletes microsetus* Kedo 1965 in Bouckaert et al., pl. 93 fig. 9.
- 1973 *Spinozonotriletes* sp. cf. *S. uncatus* Hacquebard 1957 sensu Bouckaert, Streel, Thorez & Mound 1969 in Gayer et al., 8, pt 2, pl. 14 fig. A.
- 1977 *Grandispora* cf. *tenuispina* (Hacquebard) Playford 1971 in Clayton et al., pl. 2 fig. 15.
- 1986 *Grandispora cornuta* Higgs 1975 in Richardson & McGregor pl. 20 fig. 1.
- 1988 *Grandispora cornuta* Higgs 1975 Richardson & Ahmed, pl. 1 fig. 5.
- 1992 *Grandispora cornuta* Higgs 1975 in McGregor & Playford pl. 15 fig. 9.
- 1992 *Grandispora cornuta* Higgs 1975 in Grey pl. 16 fig. 6.
- 1993 *Grandispora* cf. *tenuispina* (Hacquebard) Playford 1971 in Hartkopf-Fröder & Streel pl. 7 fig. H.
- 1997 *Grandispora cornuta* Higgs 1975 in Loboziak et al., pl. 2 fig. 11.
- 2003 *Grandispora cornuta* Higgs 1975 in Melo & Loboziak. pl. IV fig. 7.

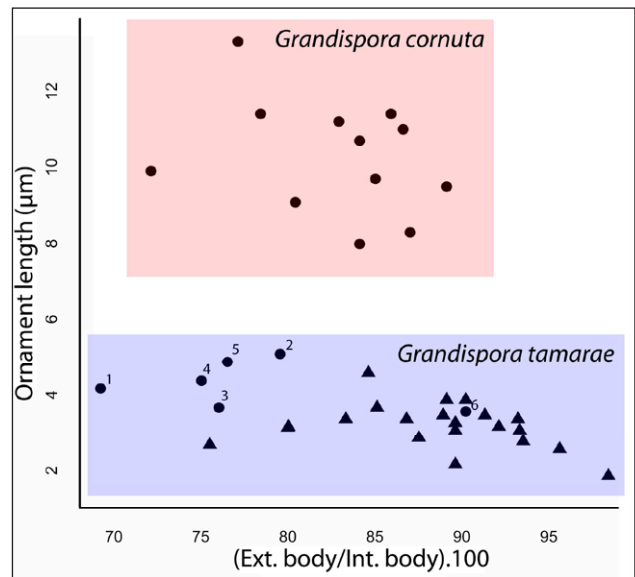


Figure 4: Ornament length compared to the ratio external body/internal body in *Grandispora cornuta* and *G. tamarae*. Black dots were all referred to belong to *G. cornuta*, black triangles to *G. tamarae*. Numbered specimens are now transferred to *G. tamarae*  
1 : Unpublished specimen previously considered to mark the base of the VCo Zone, Bon Mariage 12/54.  
2 : *Spinozonotriletes* cf. *S. uncatus*, Beverire 55 in Bouckaert et al., 1969 pl 93 fig.7.  
3 : *Grandispora cornuta*, Pennsylvania (USA) in Richardson & McGregor 1986 pl 20 fig. 1.  
4 : *Spinozonotriletes* cf. *S. uncatus*, Beverire 45 in Bouckaert et al., 1969 pl 93 fig. 8.  
5 : Unpublished specimen previously considered to mark the base of the VCo Zone, Bon-Mariage 11/54.  
6 : *Hymenozonotriletes microsetus*, Chera E 9 in Bouckaert et al., 1969 pl 93 fig. 9.



### 2.3. Biometric analysis of *Grandispora cornuta* and *G. tamarae*

A morphological analysis of Famennian *Grandispora* species was carried out by Higgs et al. (2000), and thirteen individual species were discriminated on the basis of exoexine wall thickness, exoexine/intexine ratio, and ornament type, size and distribution. In this study, *Grandispora cornuta* was defined as having a spine length of 5-16  $\mu\text{m}$  whereas *G. tamarae*, a form that appears in the Upper Frasnian but is common in the Upper Famennian assemblages, has a spine length of 2-5  $\mu\text{m}$ . This overlap in ornament size has presented some difficulty for the identification of the smaller ornamented forms of the zonal taxon *G. cornuta*. In the present study a morphological analysis of *G. cornuta* and *G. tamarae* specimens was carried out on both published and unpublished material. This included unpublished data from the Upper Famennian of the Namur Syncline in Belgium (plate 2) and Hook Head, Ireland, the type locality for the two species (plate 1), as well as data from 38 published records of these two taxa. The principal parameters measured in the analysis of the *Grandispora* specimens are, ornament length, ornament basal width and the exoexine/intexine size ratio. A summary of the results is given below.

Fig. 4 shows the length of ornaments (in  $\mu\text{m}$ ) plotted against exoexine/intexine ratio (given as %). It shows that two populations are clearly distinguished, *G. cornuta* (dots) and *G. tamarae* (triangles). This analysis also shows that some specimens previously identified as *G. cornuta* in the literature plot within the *G. tamarae* group (see the dots numbered 1-6 in Fig. 4). These include the specimen illustrated in Richardson & McGregor (1986) and Richardson & Ahmed (1988), specimens from the Beverire section (Bouckaert et al., 1969), sample 55 (pl. 93 fig. 7) and 45 (pl. 93 fig. 8) and one specimen from Chera in the Vesdre Valley attributed (Bouckaert et al., 1969, pl. 93 fig. 9) to *Hymenozonotriletes microsetus*. On the basis of this evidence we suggest all of these specimens to be transferred into *G. tamarae*. Two additional unpublished specimens, formerly believed to mark the base of the *G. cornuta* interval Zone at level 54 of the BM section (see fig. 7), should also be assigned *G. tamarae*.

The second morphological analysed feature was the relationship of ornament length and overall spore diameter. Fig. 5 shows the plot of spine length against exoexine diameter, and again two distinct groups can be differentiated. However, it also shows that in the *G. cornuta* group there is an obvious trend for the spine length to increase with increased exoexine diameter. Based on these analyses, we propose that the minimal size limit for the *G. cornuta* spine length be increased from 5  $\mu\text{m}$  to 8  $\mu\text{m}$ ; this will provide a much clearer morphological distinction between the two species.

The third morphological analysed feature was the shape and width of the ornament bases. In *G. cornuta*, the base of spines

was described as 2-6  $\mu\text{m}$  in width, often swollen or bulbous in shape, tapering uniformly or sharply to pointed and occasionally curved tips. (Higgs et al., 2000). In *G. tamarae* cones and spines are described as 2-5  $\mu\text{m}$  in basal diameter, typically possessing decurrent sides and sharply pointed tips, often bent over (Fig. 3). Unpublished specimens of both species with homologous specimens taken from the literature are illustrated in plate 1. In addition, unpublished specimens of *G. tamarae* from the Upper Famennian of the Namur Syncline are also shown on Plate 2.

The number of spines projecting at the equator in both species was analysed; although the number is slightly more in *G. tamarae*, it was not considered significant enough to be used to discriminate the two taxa.

Taking into account all these characters, it appears that several specimens previously identified in the literature as *G. cornuta* are now more appropriately assigned to *G. tamarae*. For instance, the specimen figured as *G. cornuta* from the lower Cattaraugus Fm (U.S.A.) named by Richardson & McGregor (1986) and Richardson & Ahmed (1988) now belongs to *G. tamarae*. This taxonomic re-evaluation has biostratigraphic consequences for international correlations and might partly explain the much debated diachronic correlations between European and American palynozones (e.g. Richardson and McGregor 1986; Streef and Marshall 2007).

### 2.4. *Rugospora radiata* (Juschko) Byvscheva 1985

Plate 3, Figs A-B

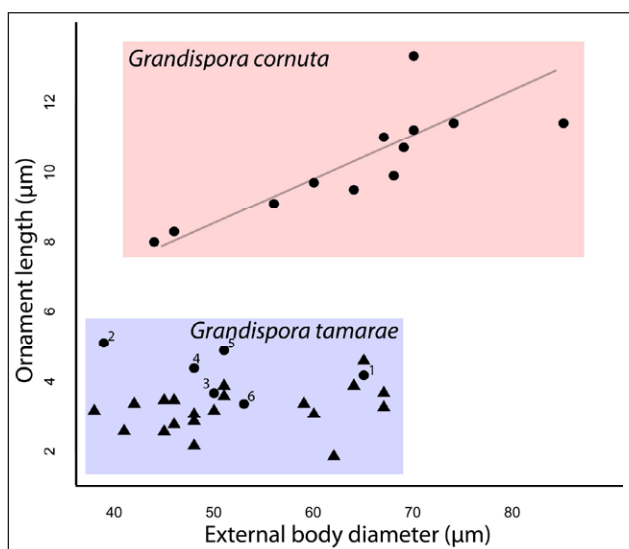
1960 *Camptotriletes radiata* Juschko, p.128, pl. 2, fig. 26

1974 *Trachytriletes radiata* (Juschko) Kedo p.7, pl. 1, fig.1

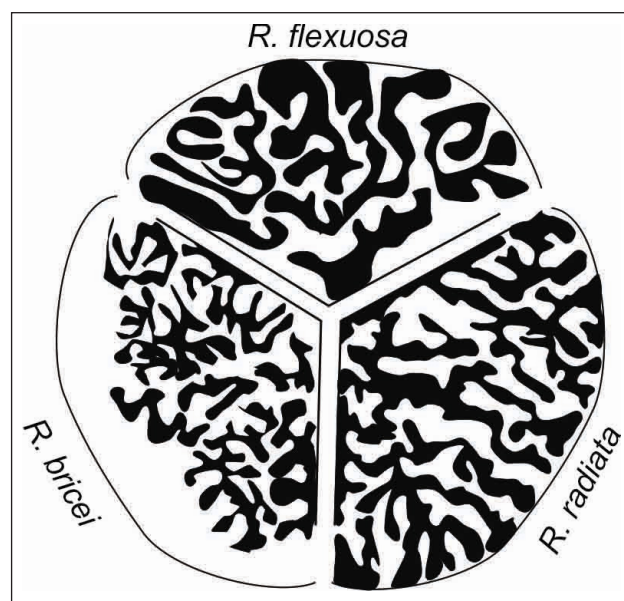
1985 *Rugospora radiata* (Juschko) Byvscheva 1985

1988 *Synorisporites flexuosus* (Jushko) Richardson & Ahmed (pl. 2 figs. 1-3)

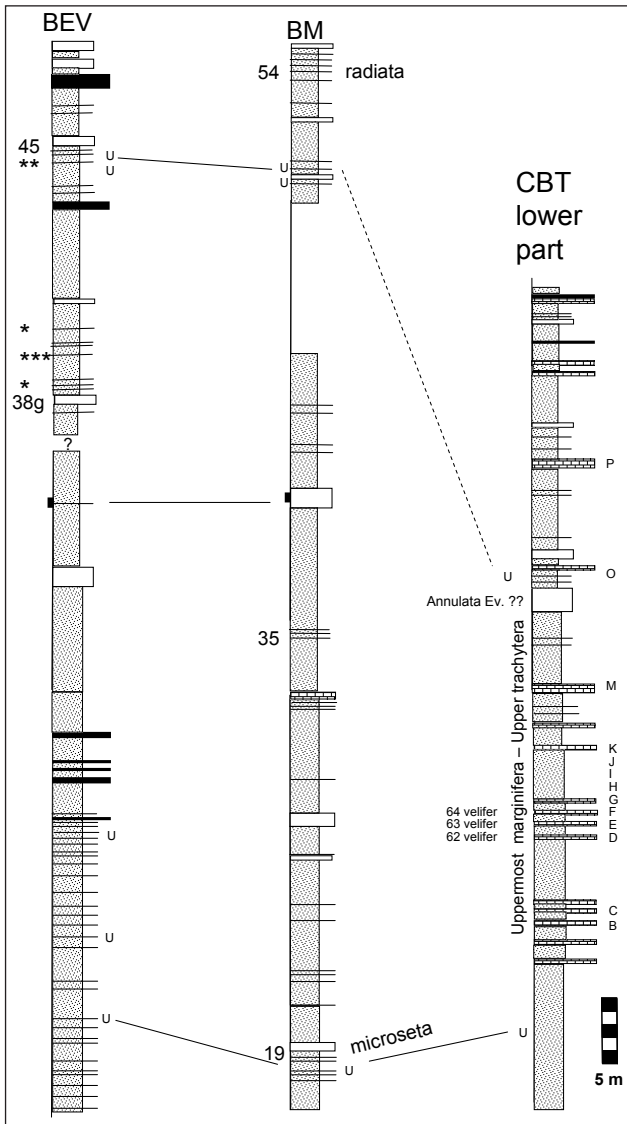
*Rugospora radiata* is morphologically similar to *Rugospora bricei* (Loboziak & Streef 1989) a stratigraphically important species that first appears in the Frasnian. Identification difficulties between these species have resulted in the stratigraphical extension downwards of the VCo Opper Zone range in some regions, particularly in New York and Pennsylvania (Richardson & McGregor 1986). The main morphological differences are in the size and arrangement of the rugulae. In *R. bricei* the distal rugulae are small (1-1.5  $\mu\text{m}$  wide) and randomly (rarely radially) arranged. By comparison, *R. radiata* has thicker and longer rugulae, most commonly radially arranged on and adjacent to the disto-equatorial margin. In addition, the rugulae in *R. bricei*, rarely reach the equator whereas in *R. radiata* the rugulae distinctly cross the equatorial border (Fig. 6). *Rugospora*



**Figure 5:** Ornament length compared to the external body diameter in *Grandispora cornuta* and *G. tamarae*. (the black dots, triangles and numbers are the same as in Fig. 4).



**Figure 6:** Comparison of ornamentation in *Rugospora radiata*, *R. flexuosa* (syn.? *S. variegatus*) and *R. bricei*.



**Figure 7:** Lithology and guide fossils in the lower part of sections studied in Comblain-la-Tour (CBT) and Comblain-au-Pont (Beverire BEV and Bon-Mariage BM). See legend on Fig. 8.

*explicata* Gonzalez et al. (2005) from the Upper Famennian (VCo Zone) Pyrite Belt of southwest Spain, differs from *R. radiata* and *R. bricei* in possessing sinuously arranged ornament of rugulae that bear very small conical baculi, and pila (1-2 µm in size)

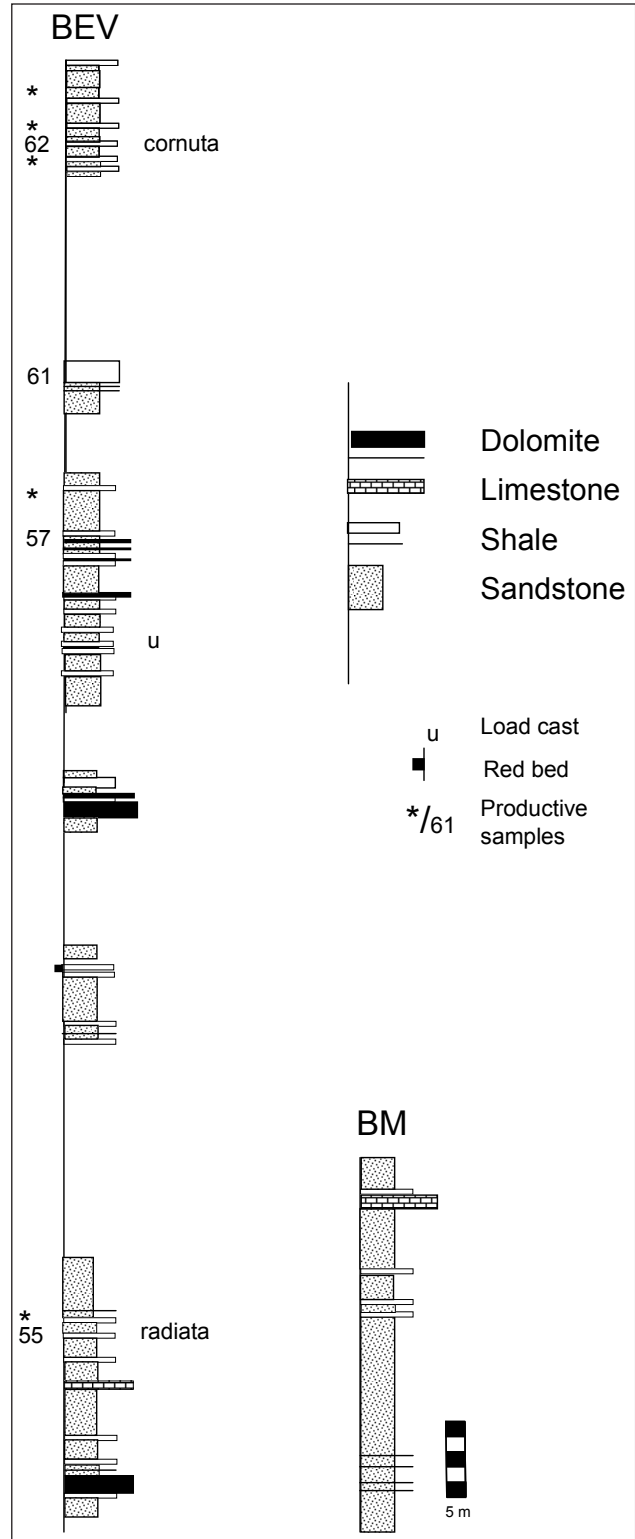
**3. Correlation of the Upper Famennian miospore zones with the conodont biostratigraphy in the Ourthe valley sections.**

The Ourthe Valley provided excellent outcrops of the Upper Famennian Condros Group where a composite stratigraphy has been established based on five sections. These sections are shown on Figure 2; from the south to the north these are: Comblain-la-Tour (upper and lower parts), Comblain-au-Pont composed of a right bank section (Bon-Mariage) and a left bank section (Beverire), Chanxhe and Evieux railway sections. Bed-by-bed sampling for micropaleontological and palynological investigations has resulted in a detailed biostratigraphical framework for the Upper Famennian interval based on conodonts and miospores. (Thorez et al., 2006 : 10. Biostratigraphy). The following section provides a correlation of the new miospore zonation with the conodont biostratigraphic data. Fig. 10 shows the Famennian miospore and conodont zonation schemes and the respective zones mentioned in the next section.

The Upper to uppermost *Marginifera* Conodont Zone (Bode 1991; Dreesen & Thorez 1994) occurs in the lower part of the Comblain-au-Pont section (about 45 m above the top of

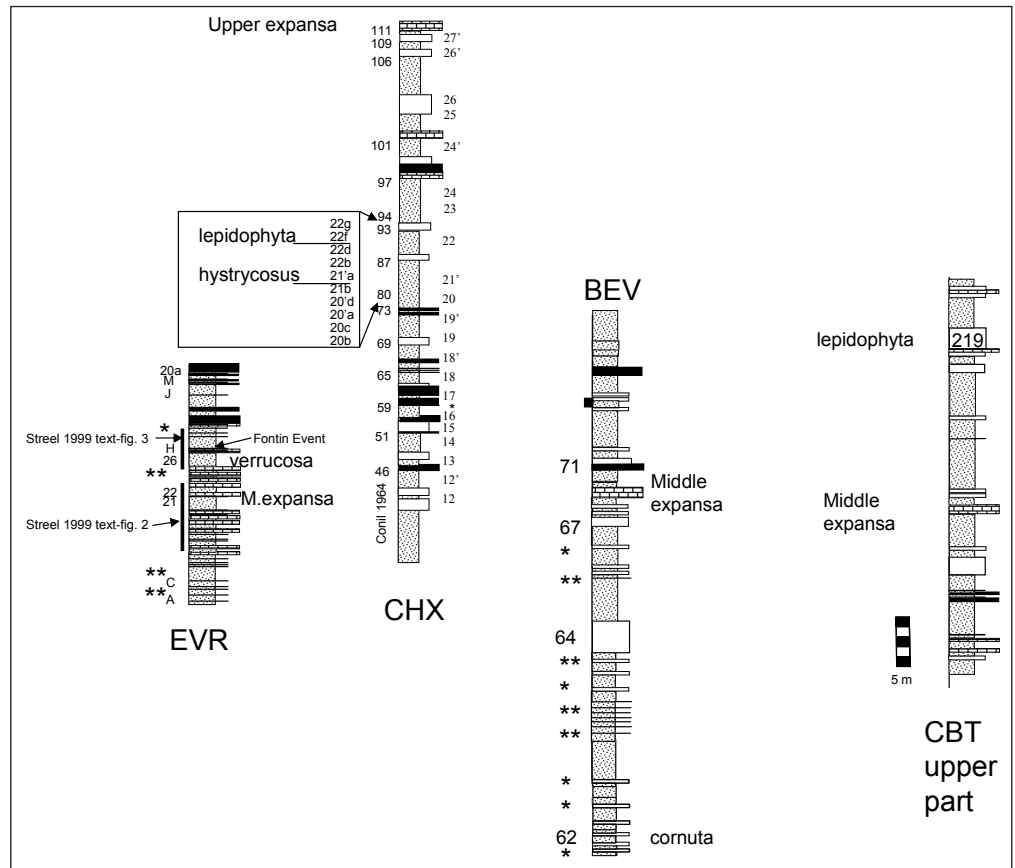
the Souverain-Pré Formation (Fig. 7). Some 15 m higher in the section, limestone beds 62, 63 and 64 (= beds D, E, F) contain the index species *Scaphignathus velifer* that indicates the uppermost *marginifera* or Lower *trachytera* Conodont Zone. However, conodonts in levels E and O (Dreesen & Thorez 1994) indicate a slightly higher stratigraphic position i.e. the Upper *trachytera* Zone (former Upper *Velifer* Zone). Level O is just above the shales presumed to correlate with the “*annulata*” Event (Thorez et al., 2006). Unfortunately, the lower part of the Comblain-la-Tour is very poor in terms of miospore preservation so no direct correlation could be made with the conodont zones.

The lower part of the Comblain-la-Tour section can be lithologically correlated using red beds and ball-and-pillow levels



**Figure 8:** Lithology and miospores in the middle part of sections studied in Comblain-au-Pont (Beverire BEV and Bon-Mariage BM).

**Figure 9:** Lithology and guide fossils in the upper part of sections studied in Comblain-la-Tour (CBT), Comblain-au-Pont (Beverie BEV), Chanxhe (CHX) and Evieux railway (EVR) See legend on Fig. 8



with the two sections at Comblain-au-Pont (Bon Mariage BM and Beverie BEV). The *Grandispora microseta* first occurrence biohorizon (the base of the Mic Subzone of the *gracilis-famenensis* GF Opperl Zone, see Fig. 7) occurs at level 19 in the BM section; this correlates with one of the *marginifera* conodont zones. Higher in the same section level 54 is the first occurrence of *Rugospora radiata* which marks the base of the Rad Interval Zone of the VCo Opperl Zone (Fig. 7), and this correlates with position close to the transition between *trachytera* and *postera* conodont zones. At a higher level in the BM section at Bed 62 is the entry of *Grandispora cornuta* and the base of the Cor Interval Zone of the VCo Opperl Zone (Fig. 8). The Lower *expansa* Zone is not recorded so far in the Ourthe Valley sections because of unfavourable facies; however it is considered to more or less correspond to the lower part of the Cor Interval Zone

The Middle *expansa* Zone is recorded in the Comblain-la-Tour, Beverie (BEV) and Evieux-rail (EVR) sections being

coeval with the Fontin Event in the latter section. The Fontin Event is shown in detail in Stree1 (1999, fig. 3) after data from Lafleur (1991) and Maziane (1993). This transgressive horizon correlates with the middle *expansa* conodont zone (Fig.9) and the first appearance of *Apiculiretusispora verrucosa* which marks the base of the Ver Interval Zone of the VH Opperl Zone. The Fontin Event has been correlated by Kaiser et al. (2008) with the Dasberg Event in Germany and indirectly to a late Famennian isotopic excursion (ALFIE) in Western USA by Myrow et al. (2011).

In the Chanxhe(CHX) section *Vallatisporites hystricosus* appears in bed 21a (Maziane et al., 1999) thus marking the base of the Hys interval zone of the VH Opperl Zone ( Fig. 9) followed a short distance by *Retispora lepidophyta* in bed 22 defining the base of the overlying LL miospore Biozone (Fig. 9). These two miospore zonal bases correlate with the Middle *expansa* conodont zones. The lower part of the LL biozone was

| Miospore zonation   |                                  |                                      | Conodont zonation                 | Events     |
|---|----------------------------------|--------------------------------------|-----------------------------------|------------|
| Opperl Zones  | Interval zones                   | Acme zones                           |                                   |            |
| Retispora lepidophyta<br>Knoxisporites literatus<br>LL              | literatus                        | R. lep. minor<br>R. lep. lepidophyta | Upper expansa                     | Avesnelles |
| Apiculiretusispora verrucosa -<br>Vallatisporites hystricosus<br>VH | hystricosus HYS<br>verrucosa VER |                                      | Middle expansa                    | Fontin     |
| Diducites versabilis -<br>Grandispora cornuta<br>VCo                | cornuta COR<br>radiata RAD       | Diducites versabilis                 | ? Lower expansa                   | annulata   |
| Grandispora gracilis-<br>Grandispora famenensis<br>GF               | microseta MIC<br>minuta          | Grandispora gracilis                 | ? postera<br>trachytera           |            |
| Knoxisporites dedaleus<br>Diducites versabilis<br>DV                | dedaleus                         |                                      | marginifera                       |            |
|   |                                  |                                      | ? rhomboidea<br>to ? triangularis |            |

**Figure 10:** Correlation of Famennian Miospore, Conodont zonations and events in eastern Belgium.



demonstrated by Streeel and Hartkopf-Fröder (2005) to correlate also with the Middle *expansa* conodont zone. Approximately 18 m above the entry of *R. lepidophyta*, conodonts of the Upper *expansa* Zone marking the base of the Uppermost Famennian substage are recorded in bed 111 of the Chanxhe (CHX) section (Dreesen et al., 1993). This horizon corresponds to a quantitative change (acme zones) from *Retispora lepidophyta lepidophyta* to *Retispora lepidophyta minor* (Maziane et al., 2002) (Fig. 10).

#### 4. Conclusions

- The VCo Opperl Zone is more appropriately defined on the occurrence of *Rugospora radiata* and *Grandispora cornuta*. Furthermore, the staggered first appearance of these two taxa within the VCo Opperl Zone allows the definition of two new interval zones: the *Rugospora radiata* (Rad) interval zone, succeeded by the *Grandispora cornuta* (Cor) interval zone.
- A biometric study of coeval populations of *Grandispora cornuta* and *G. tamarae* has shown that the two species can be clearly separated on spine length and shape. The specific diagnosis of *G. cornuta* is emended to a new minimum spine length of 8 µm.
- Close correlation of miospore and conodont zones in the Condroz Group succession in five sections of the Ourthe Valley now provide a close integrated biostratigraphy for the Upper Famennian interval in eastern Belgium.
- The *Grandispora gracilis*-*Grandispora famensis* GF Opperl zone is now subdivided only into two subzones, the higher one being based on the first occurrence of *Grandispora microseta* within the upper part of the *marginifera* conodont zone. The *Retispora macroreticulata* Mac Subzone characterized by the sporadic first occurrence of *R. macroreticulata* is now considered obsolete.
- The base of the *Diducites versabilis*-*Grandispora cornuta* VCo Opperl zone, now fixed at the first occurrence of *Rugospora radiata*, most probably correlates with the *trachytera* zone.
- The base of the *Grandispora cornuta* interval zone, as understood from this new definition of *G. cornuta*, has to be found in the *postera* or Lower *expansa*.
- The transition between the Lower and the Middle *expansa* corresponds more or less to the Fontin/Dasberg Event and can be correlated with the base of the *Apiculiretusispora verrucosa* Interval zone, a new base for the *Apiculiretusispora verrucosa*-*Vallatisporites hystricosus* VH Opperl zone.
- The base of the Upper *expansa* zone has been demonstrated by Maziane et al. (2007) to correlate with the change from the acme zones of *Retispora lepidophyta lepidophyta* to *Retispora lepidophyta minor*; and should correspond to the major increase in sea-surface temperature demonstrated at the same level by Kaiser et al. (2011)

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#### 6. References

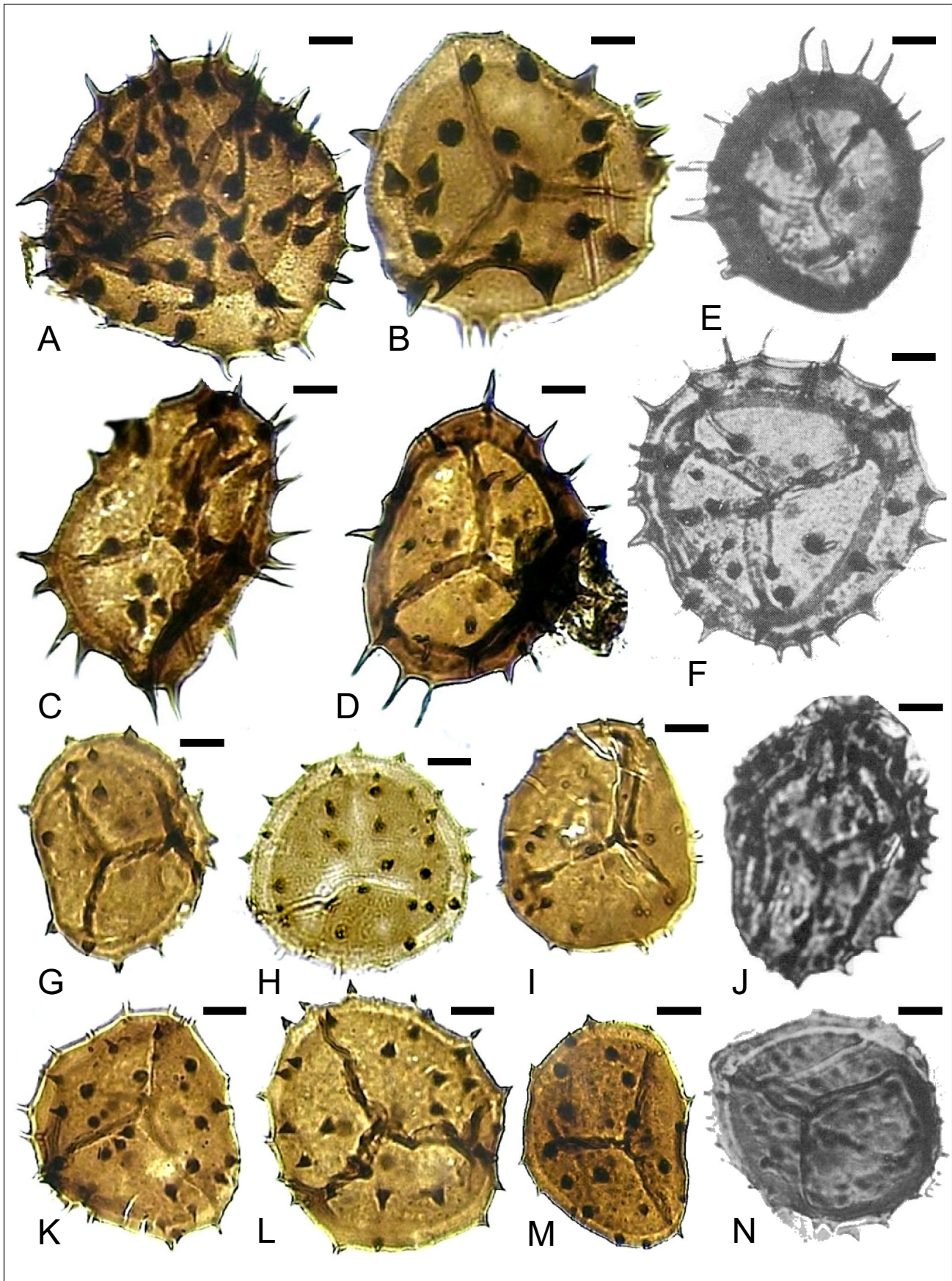
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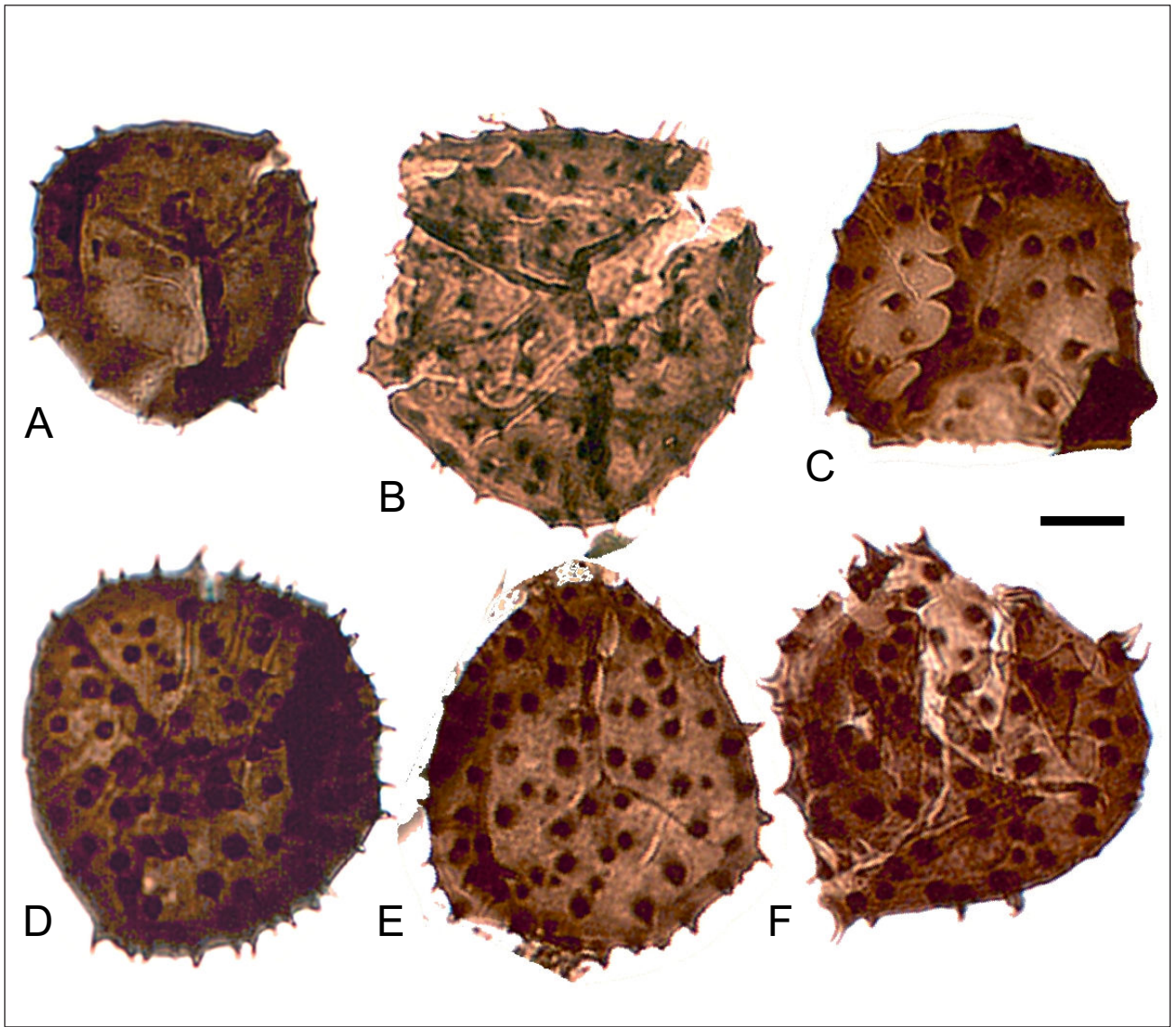
**Plate 1:** Comparison of unpublished material of *Grandispora cornuta* and *G. tamarae* with homologous material described in the literature.

A to F: *Grandispora cornuta* Higgs 1975

A: HK41/S35; B: HK41/P11; C: HK44/U19; D: HK42/U19; E: Tournai borehole 316 m, Belgium, 3010/01. (Syn. *Spinozonotriletes* cf. *uncatus* Hacquebard 1957 in Streeel 1966, plate 1: 7). See also Clayton et al., 1977 plate 3, fig.15; F: HOLOTYPE, Hook Head, Eire, ML1104. See also Clayton et al., 1977 plate 3, fig.16.

G to N: *Grandispora tamarae* Loboziak in Higgs et al., 2000

G: HK44/H12; H: HK44/W13; I: HK43/T40; J: La Gombe, Ourthe Valley, Belgium, Go37 2393/679. (Syn. *Spinozonotriletes* cf. *S. tenuispinus* Hacquebard 1957 in Bouckaert et al., 1969, plate 93, fig. 6) ; K: HK41/C59; L: HK41/G48; M: HK41/E29; N: HOLOTYPE, Hook Head, Eire, ML 1106 (Syn. *Grandispora* cf. *echinata* Hacquebard 1957 in Higgs 1975, plate 4, fig. 12).



**Plate 2:** unpublished specimens of *Grandispora tamarae* from the Upper Famennian of the Namur Syncline, Evieux Formation, Huy Citadelle Mbr. Upper Famennian (Thorez et al., 2006).



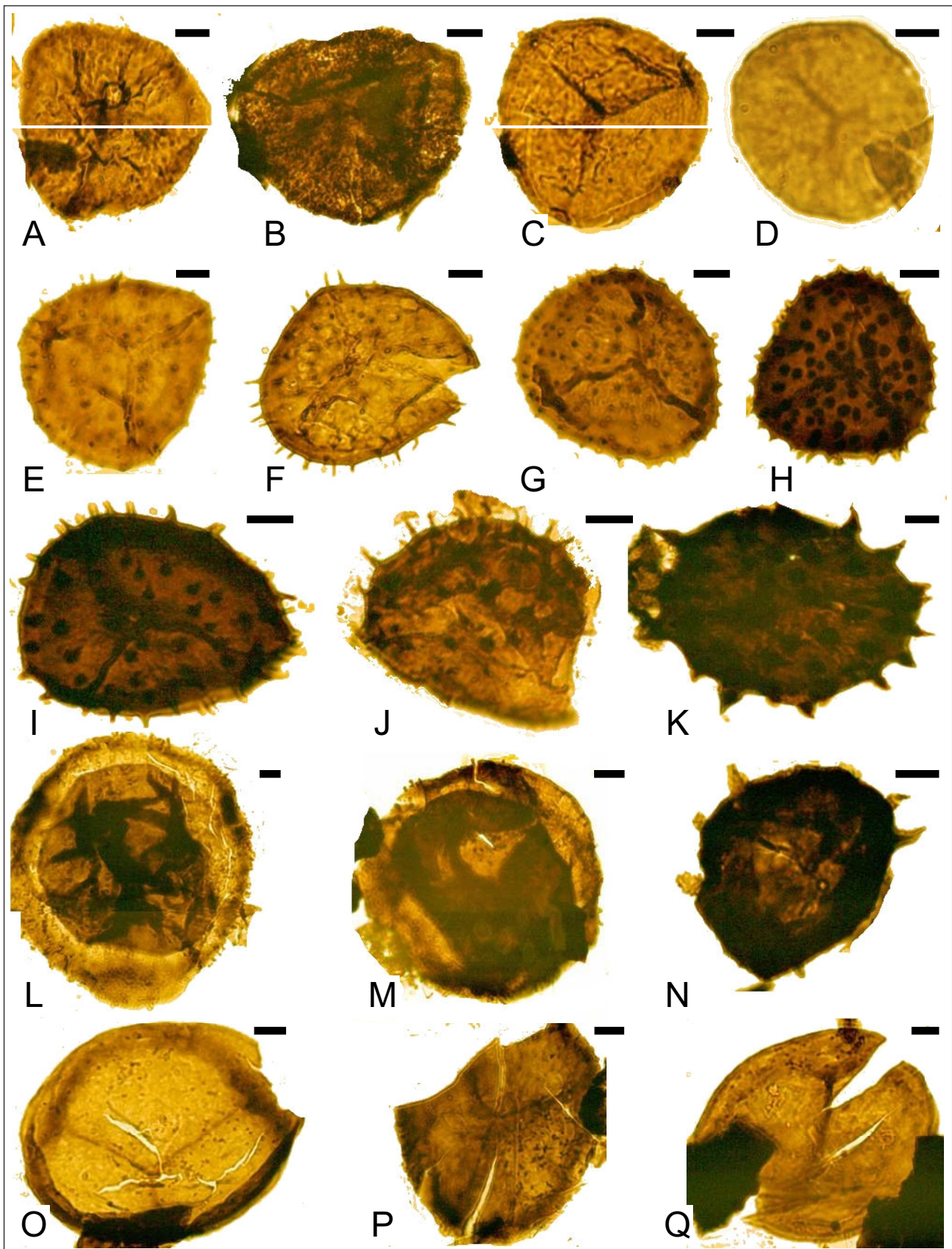


Plate 3: Other characteristic taxa

A and B: *Rugospora radiata* (Juschko) Byvsheva 1985.

A: Beverire 55-4, slide 2460, J34/2 ; B: Bon-Mariage 54-5, T24/4

C and D: *Rugospora bricei* Loboziak & Streel 1989.

C: Beverire 55-4, slide 2460, G29; D: Bon-Mariage 54-5A, H21/1

E and F: *Grandispora microseta* (Kedo) Streel in Becker et al., 1974.

E: Bon-Mariage 19A, H22/4; F: Bon-Mariage 54-5A, R38/3

G: *Grandispora echinata* Hacquebard 1957, Bon-Mariage 35A2, H21/4

H: *Grandispora famenensis* (Naumova) Streel 1974 var. *minuta* Nekriata 1974, Evieux-rail, slide 33291, G31/2

I and J: *Grandispora tamarae* Loboziak in Higgs et al., 2000.

I: Beverire 45-6, slide 15638, K46; J: Beverire 71, slide 2490, T25

K and N: *Grandispora cornuta* Higgs 1975.

K: Beverire 62-64-2, slide 15375, S38/2; N: Evieux-rail, slide 33217, R25/1

L and M: *Endoculeospora gradzinskii* Turnau 1975.

L: Evieux-rail, slide 31378, Q24/2 ; M: Evieux-rail, slide 33277, H21/4

O, P and Q: *Apiculiretusispora verrucosa* (Caro-Monie) Streel in Becker et al 1974.

O: Evieux-rail, slide 31378, E22/4 ; P: Evieux-rail, slide 31388, K40 ; Q: Evieux-rail, slide 31388, M23/2-4