Updating Frasnian miospore zonation from the Boulonnais (Northern France) and comparison with new data from the Upper Palaeozoic cover on the Brabant Massif (Western Belgium)

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ABSTRACT. Accurate palyno-analysis by S. Loboziak (from 1980 to 1983) of 28 samples from the Upper Givetian to the Middle Frasnian Blacourt, Beaulieu and Ferques Formations and of 44 samples of the Upper Frasnian to the Lower Famennian Hydrequent Formation are re-evaluated. Chelnospora concinna, Verrucosisporites bulliferus, Cirratiradites jekhowskyi, Lophozonotritiles media first occurrences are major criteria for Lower and Middle Frasnian, well calibrated by conodonts. Cymbosporites acanthaceus, Rugospora bricei, Grandisporea gracilis, Diducites pleabiulis, Corbulispora viminalis first occurrences allow to subdivide the Upper Frasnian where conodonts are poorly present. Samarispores triangulatus versus Aureonaspora pseudocrucia taxonomy and stratigraphic significance are discussed.

The reconnaissance borehole Nieuwkerke-De Seule (95W152), near the limit of the Upper Palaeozoic subcrop on the Brabant Massif (West Flanders, Belgium, 75 km east of the Boulonnais), which has intersected conodont-dated Givetian/Frasnian boundary at the transition between the Bois de Bordeaux and Bovesse Formations, contained poorly preserved miospores attributed to the triangulatus–concinna (TCo) Oppel Zones. In the nearby Nieuwkerke-Noordhoek borehole (95W153), strata also assigned to the Bovesse Formation yielded better preserved miospores which demonstrate a close succession of triangulatus–concinna (TCo) and bulliferus–jekhowskyi (BJ) Oppel Zones at the transition Lower–Middle Frasnian, also known in the Beaulieu Formation in the Boulonnais.

Samples from the Heuvelland groundwater monitoring well (95W175), 10 km north of Nieuwkerke, contain the bricei–acanthaceus (BA) Oppel Zone suggesting a late Frasnian age, also known in the Hydquent Formation in the Boulonnais area and in the Booischot Formation in the Booischot borehole (59E146) from the Campine Basin (Belgium).

International correlation using Frasnian miospore zonation is attempted between the Pripyat Depression in Belarus, the Timan–Pechora province in Russia and North-West China.

KEYWORDS: biostratigraphy, Oppel Zones, Boulonnais, Flanders, Russia, China.

1. Introduction

Former accurate palyno-analysis from the Upper Givetian to the Lower Famennian in the Boulonnais (Northern France), made some forty years ago, had to be re-evaluated. Consequently, stratigraphic correlations, across the French–Belgium Boundary, between the Boulonnais and boreholes in West and East Flanders have to be revised. Some international correlations with Central and Eastern Europe and North-West China will also be made possible.

1.1. History

Frasnian miospores from the Boulonnais (Northern France) were first described and illustrated from one sample collected in the Beaulieu Formation Belonging to the Lower Frasnian (Taugourdeau-Lantz, 1960). Most taxa were tentatively identified by comparison with the rich Upper Devonian miospore drawings from the Russian Platform (Naumova, 1953). Several species were updated and re-illustrated in further papers (Taugourdeau-Lantz, 1967a, b), a first palynostratigraphic chart covering the whole Frasnian being given in Taugourdeau-Lantz (1967a). The stratigraphic chart, illustration and description of miospores were again updated (Taugourdeau-Lantz, 1971).

A new section showing in succession the Blacourt Formation and the Beaulieu Formation was then made available in the railway track Cailliers–Ferques allowing, among other fossils, ten conodont faunas to be identified (Brice et al., 1979). These new detailed stratigraphic data have encouraged us to restudy the miospores produced in three papers concerning respectively the Givetian–Lower Frasnian (Loboziak & Streel, 1980) and the Middle–Upper Frasnian to Lower Famennian (Loboziak & Streel, 1981; Loboziak et al., 1983). All taxa received an identification number (from 1 to 79, see Table 1) reused in a next paper (Loboziak & Streel, 1988) establishing a succession of four formal Oppel Zones: Samarispores triangulatus–Rhabdosporites langi (TLa) renamed (Streel et al., 1987), S. triangulatus–Ancyrospora ancryea ancryea (TA), S. triangulatus–Chelnospora concinna (TCo), Verrucosisporites bulliferus–Cirratiradites jekhowskyi (BJ), V. bulliferus–Lophozonotritiles media (BM) and two informal Zones (IV and V), that were not defined in that paper. These two informal zones were characterised and subdivided by Streel (2009) as Rugospora bricei–Cymbosporites acanthaceus (BA) and Knossispores dedalus–Diducites versabilis (DV) Oppel Zones.

The former TLa Zone, now renamed TA Zone, is typified by the composition of sample G-02 at the base of the Blacourt Formation in the Griset quarry; the TCo Zone is typified by the composition of sample H26 in the upper part of the same formation in the Ferques railroad trench; the BJ Zone is typified by the composition of sample sequence Q52 to Q56 in the Beaulieu Formation in the Ferques railroad trench; the BM Zone is typified by the composition of samples VW5 and VW8 in the Ferques Formation in the Bois quarry (Loboziak & Streel, 1981). The BA Zone, mainly studied in the 23 m of shales above the dolomitic bed (Loboziak et al., 1983, fig. 1) in the Hydquent Formation in the “Briqueterie de Beaulieu” quarry, is more complex, requiring probably several characteristic samples to typify the subdivisions A to E (Fig. 1). The base of the DV Zone in the same quarry, could be typified by sample 109 (this paper).

1.2. Correlation with other microfossils

The basis of TA Zone probably occurs in or below the conodont Middle varcus Zone (FIV on Fig. 1), the base of the TCo Zone ranging from the conodont (FV) Upper varcus to the Lower asymmetricus Zone (Bultynck in Streel et al., 1987). BJ and BM

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Figure 1. 1: chronostratigraphy; 2, 3: conodont faunas (Brice et al., 1979); 4, 5, 6: lithostratigraphy (note that there is no scale for the thickness of the formations); 7: samples with miospores; 8: period of miospores analysis by S. Loboziak; 9: miospore zones. Taxa 56 and 71 are not displayed.
### Table 1. Identification numbers of taxa recorded on Figure 1, sorted by number. Taxa are sorted by names in Appendix.

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<th>Identification number</th>
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<td>Aurospora macro Sullivan 1968</td>
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<td>Retusotriletes planus Dolby &amp; Neves 1970</td>
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<td>Grandispore gracilis (Kodo) Streele 1974</td>
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<td>U-Samarisporites sp. B in Lobozia, Streele &amp; Vanguestaine 1983</td>
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<td>Diductes mucronatus (Kodo) Van Veen 1981</td>
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<td>Aneurospora sp. B in Lobozia, Streele &amp; Vanguestaine 1983</td>
</tr>
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<td>79</td>
<td>Samarispores sp. D in Lobozia, Streele &amp; Vanguestaine 1983</td>
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</table>
Zones range from the conodont Lower asymmetricus Zone to as far as the conodont Ancyronathus triangularis Zone (Brice et al., 1981).

We had attempted to provide a stratigraphic control of the Frasnian/Famennian Boundary (conodonts being poorly present in the Upper Frasnian of the Bouloznais), using acritarchs “dated” by conodonts in the type region from the Ardenne (Vanguesteaine, 1986; Martin, 1993; Stree et al., 2000a). The conclusion was that the higher part of the BA Oppel Zone (BA plie Subzone, starting with the first occurrence of Didicites plicabilis in Stree, 2009) ranges from the conodont upper Palmaetoplis gissza Zone to the upper Palmaetoplis triangularis Zone and contains therefore the base of the Famennian Stage (Ziegler & Sandberg, 1990).

The acritarch Vipsysphaera (?) secunda (VI) Zone occurs in samples 217-216 of the Upper Frasnian Hydrequent Formation (Loboziak et al., 1983). The Famennian acritarch Villopspsula globosa (Vg) Zone is not recorded in that section. If one accepts the synonymy (Vanguesteaine et al., 1983) of Herkomorphytae sp. A and V.? occulata, as a good marker for the earliest Famennian in Belgium (Martin, 1993), then sample 213 of the Hydrequent Formation might be Famennian. A Frasnian/Famennian boundary drawn between samples 216 and 213 would match the top of several miospore species recorded in the Upper Frasnian Hydrequent Formation, i.e. Cymbosporites sp. C (75), Aneurospora sp. A (77), A. sp. B (78) and Samarispores sp. D (79), illustrated and briefly described by Loboziak et al. (1983).

1.3. Comments on the first occurrence (FOB) of main taxa

Most of these papers show the range of each taxon by a line joining the first and last occurrences. This failed in not showing the quantity of data these ranges were built upon and did not enable us to evaluate the likelihood of the “presence” criterion. Figure 1 shows (according to data still available and unmodified), the presence of the selected taxa in each sample (28 samples of the Upper Givetian to the Middle Frasnian Blacourt, Beaulieu and Ferques Formations and 44 samples of the Upper Frasnian to the Lower Famennian Hydrequent Formation, all slides scanned by Stanislas Loboziak at Lille. The corresponding slides have not been revised for the present paper). One can observe then that C. concinna (38), V. bulliferus (45), C. jekhowskyi (39), L. media (50) first occurrences are major criteria for the Lower and Middle Frasnian, and that C. acanthaceus (57), R. bricei (58), G. gracilis (69), D. plicabilis (64) first occurrences allow the subdivision of the Upper Frasnian.

It might seem surprising that Samarispores triangularus Allen 1965 (syn.: S. egryphus Taugourdeau-Lantz, 1967b, Crisstaffspores triangularus (Allen) McGregor & Camfield, 1982), the eponym species of TA and TCopp Zones, is not retained among the taxa listed here above. Its first occurrence is indeed controversial (Richardson & McGregor, 1986, fig. 6; Stree, 2009, fig. 3). It might be, in part, the result of differences of palynologist acception of the degree of the equatorial flange reaching its maximum width radially even if it is hardly perceptible in the inter-radial regions (Allen, 1965, p. 706). Compare, for instance, Allen (1965) plate 99, Richardson & McGregor (1986) plate 15, Loboziak et al. (1991) plate 2. It might also be that Geminospora lemurata (40) was not recognised in the few samples studied in the Blacourt Formation (Loboziak & Stree, 1980, fig. 1) or maybe confused with Aneurospora Greggii (24) (see Stree & Loboziak, 1987, p. 100) showing why Geminospora lemurata is recorded as being older than Samarispores triangularus in the Eifel (Loboziak et al., 1991) as in Canada and European Russia according to Richardson & McGregor (1986).

The stratigraphic range of S. triangularus is also questionable. According to Richardson & McGregor (1986), it occurs in their optivus-triangulatus and ovalis-bulliferus assemblage Zones corresponding to the TA, TCo, BJ, BM and the lower part of BA Oppel Zones. Allen (1982, figs 2 and 3) has recorded many occurrences of this species and possible synonyms in the Northern hemisphere and suggests they range from Upper Givetian to Middle Frasnian.

However, in the Bouloznais, we had noted S. triangularus as high as the top of the Frasnian.

Allen (1982) explains that its stratigraphic value is enhanced by the fact that the characteristic zona with a maximum width radially, can usually be identified even in poorly preserved specimens. It should be noted that such poorly preserved specimens might as well correspond to Aurosospora pseudocrista Ahmed 1980 ranging from the uppermost Frasnian into the Famennian and which often demonstrates one or more maximum width radially.

2. The reconnaissance boreholes Nieuwerkerke-De Seule (95W152, renamed 110W7) and Nieuwerke-Noordhoek (95W153)

These partly cored boreholes were drilled near the limit of the Upper Palaeozoic subcrop on the Brabant Massif (West Flanders, Belgium, 75 km east of the Bouloznais) (Figs 2 and 3). They are north of the Brabant Parautochthon, and within the Upper Palaeozoic cover of the Brabant Massif unaffected by the Variscan orogeny (Belanger et al., 2012). All facies indications and correlations with the Tournai, Vieux-Leuze and Annape brosholes suggest a correlation to the lower part of the Bovesse Formation (or Beaulieu Formation in the Bouloznais) of the Frasnian strata in the Nieuwerkerke boreholes (Coen-Aubert et al., 1980; Legrand, 1981; Dusar & Loy, 1986).

Nieuwerkerke-De Seule (95W152) which has penetrated conodont-dated Givetian/Frasnian boundary at the transition between the Mazy Member and the Bovesse Formation (Fig. 4), contained poorly preserved miospores attributed to the Samarispores triangularus–Chelinospora concinna (TCo) Oppel Zone (Tourneur et al., 1989). They are listed on Table 2. Nieuwerke-Noordhoek (95W153) provided three samples from the Bovesse Formation with rather well preserved miospores listed also on Table 2, suggesting proximity to the Lower/Middle Frasnian boundary.

The youngest sample (219 m) contains Cirratiradites jekhowskyi (39) with Chelinospora concinna (38), both taxa coexisting in the lower part of the Verrucosisporites bullifers–Cirratiradites jekhowskyi (BJ) Oppel Zone.

In the sample at 221.5 m, Retusotretilites rugulatus (30) and Verrucosisporites bulliferus (45) suggests a close proximity to the top of the Samarispores triangularus–Chelinospora concinna (TCo) Oppel Zone and the base of the Verrucosisporites bulliferus–Cirratiradites jekhowskyi (BJ) Oppel Zone.

In the sample 223.7 m, Grandispora velata (22) and Coryostisporites multifurcatus (42) belong to the Samarispores triangularus–Chelinospora concinna (TCo) Oppel Zone.

3. The Heuvelland groundwater monitoring well (95W175), in Westouter, 10 km north of Nieuwerkerke

This well has also penetrated Frasnian shales covering the Brabant Massif, albeit in a north dipping position resulting in the subcrop of younger strata. One cuttings sample from the interval 260.00–262.00 m, assigned to the Franc-Waret Formation, contains the taxa recorded on Table 3.

Didicites plicabilis (64) and Grandispora gracilis (69) belong to the upper part (BA plie) of the Oppel Zone BA.
Figure 2. Location of studied boreholes and sections on a tectono-stratigraphic map showing their position in the Devonian cover sequence on the Lower Palaeozoic Brabant Massif (reprinted from Belanger et al., 2012, with permission of Geologica Belgica). A: Ferques section in the Palaeozoic core of the Boulonnais; B: Nieuwkerke boreholes on the margin of the Brabant Parautochthon south of the Brabant Massif; C: Booischot borehole in Devonian half-graben on the margin of the Variscan Campine basin north of the Brabant Massif.

Figure 3. Schematic N-S profile between Brabant Massif and the Variscan Front (reprinted from Belanger et al., 2012, with permission of Geologica Belgica). Ferques section (A on Fig. 2) corresponds to the deformed zone 2; the Nieuwkerke boreholes (B on Fig. 2) are located in the nearly undeformed northern margin of the Brabant Parautochthon at number 1; Booischot borehole (C on Fig. 2) is located north of the Brabant Massif outside this scheme but in an approximately symmetrical position to the undeformed zone 1 of the Brabant Parautochthon.
underlined.

2. Main taxa recorded in the boreholes Nieuwkerke-De Seule (95W152) and Nieuwkerke-Noordhoek (95W153). A: Identification numbers of taxa, B: List of taxa, C: Taxa recorded in Nieuwkerke (95W152) after Tourneur et al. (1989). D, E, F: Taxa recorded in the present paper in Nieuwkerke (95W153): D = 223.7 m, E = 221.5 m, F = 219 m, this paper. FOB key species presences are underlined.

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In conclusion the sample contains the *bricei-acanthaceus* (BA) Oppel Zone suggesting an Upper Frasnian age, also known in the Hydherent Formation in the Boulonnais (France) and in the Boosichot Formation in the Boosichot borehole (59E146) from the Campine Basin (Belgium) (see Coen-Aubert, 2014).

4. The Boosichot borehole (59E146) from the Campine Basin (Belgium)

The Boosichot geological reconnaissance borehole (59E146), drilled in the Campine Basin, north of the Brabant Massif (Figs 2 and 4), encountered at the base of Upper Palaeozoic a thick sequence of red and green conglomerates, assigned to the Boosichot Formation (Lagrou & Coen-Aubert, 2017). The upper part of the Boosichot Formation had been investigated by Streel (1965) and Streel & Loboziaik (1987). Between 1002 and 994.5 m, the *Vernuosisporites bullierus*-Lophozonotriletes media (BM) Oppel Zone recognised by Streel & Loboziaik (1987) is correlated in the Boulonnais, with the conodont zones occurring between the Middle *Polygnathus asymmetricus* and *Ancyrognathus triangularis* Zones. Higher in the borehole, Streel & Loboziaik (1987) identified between 940 m and 900.5 m the miospore interval Zones IV A, C and E present in the upper part of the Hydherent Formation from the Boulonnais. Their miospore zonation as well as the distribution of characteristic miospores and acritarchs have been reviewed by Streel et al. (2000a, p. 131, fig. 13). In this paper, the authors correlated the miospore Zones IV B, C and partly D with the upper part of the Hydherent Formation from the Boulonnais. The opportunity is now taken to regularise their status.

5. Nomenclatural notice

Several species of *Samarisporites* first occurring in the BA Zone were illustrated but left in open nomenclature by Loboziaik & Streel (1981), Loboziaik et al. (1983) and Streel & Loboziaik (1987). The opportunity is now taken to regularise their status.

*Samarisporites* sp. A (54) in Loboziaik & Streel, 1981, plate II: 7, 8.


Thick, often dark, spherical central body and thin narrow equatorial wing, sometimes slightly expanding in front of the trilete rays. Ornaments are mainly composed, on the distal and equatorial surfaces, of narrow spines, 2-3 µm high. Comparable with *Samarisporites* sp. 2 in Breuer & Steemans (2013), which differs in being significantly bigger.

*Samarisporites* sp. B (73) in Loboziaik, Streel & Vanguestaine 1983, plate 1:11.

Rounded central body and a reticulate ornamentation with a broad mesh (fields are 10 µm in diameter) and high (2-5 µm high) diaphanous muri which might be confused with the equatorial thin membrane and the high lips of the trilete mark. The generic identification remains doubtful.

*Samarisporites* sp. C (76) in Loboziaik, Streel & Vanguestaine 1983, plate 2: 4-6.


Rounded central body and equatorial wing reaching up to
Figure 4. Formation names and lithology after Bouvain et al. (1999), Bultynck et al. (1991), Lagrou & Coen-Aubert (2017), Mansy et al. (2007). Miospore Zones extensions in the Boulonnais between samples (x) located on Figure 1 (lithostratigraphy); in W Brabant, depth in boreholes (this paper); in Campine Basin, depth in Booischot Borehole, miospores after Streel (1965), Streel & Loboziax (1987); acritarch data for Falisolle Formation after Vanguestaine et al. (1983). Green arrows locate after Legrand (1964) abundant fronds of Archaeopteris fimbriata versus A. macilenta.
one third of the spore radius, expanding in front of the trilete rays. Ornaments are mainly composed, on the distal and equatorial surfaces, of coni reaching sometimes 2–3 µm high and 2 µm wide. This taxon might well be part of a *S. triangulatus sensu lato* morph yet to be defined (see also Allen, 1982).


Equatorial margin subtriangular. Ornament of coni (up to 2 µm high and wide) borne on irregular crests that are more or less fused in an imperfect reticulum (mesh 3–6 µm). Ornamentation denser on polar area than on the zona which reaches sometimes to one half of the spore radius.


Non *Samarisporites triangulatus* Allen 1965 in Loboziak & Streel 1981, plate II: 4-5.

Rounded central body and equatorial margin subtriangular. Ornament of small verrucae and sometimes coni (up to 2 µm high and wide) borne on irregular crests to form a more or less fused imperfect reticulum (smaller mesh than in *Samarisporites* sp. D.). Compare with *Samarisporites inusitatus* Allen 1965 (see Breuer & Steemans, 2013, fig. 40: B-C) which has an equatorial margin that is less triangular in shape and with rare spines on the verrucae.


Rounded central body with thin smooth equatorial zona showing small typical radial expansions.

This taxon might as well (see also *S. sp. C*) be part of a *S. triangulatus sensu lato* morph yet to be defined (see also Allen, 1982).

Better definition of some taxa formerly attributed to *Samarisporites triangulatus* Allen 1965 (21) suggest that the range of this species in the BM and BA Zone should be revised. Two taxa (without identification number in Fig. 1) should obviously be added to the BM Zone: *Samarisporites* sp. E in Streel & Loboziak (1987) and *Cristatisporites deliquescens* (Naumova) Arkhangelskaya, both occurring in the Ferques Formation from the Boulonnais.

6. International correlations using Frasnian miospore zonations

International correlations using Upper Devonian miospore zonations have been attempted between far-away basins (Stree et al., 2000b). For instance, comparison of the Boulonnais miospores with the Amazon Basin (Melo & Loboziak, 2003), allowed, for the first time, to correlate, using microfossils, SW Gondwanaland and Laurussia.

At a smaller scale, Frasnian and Lower Famennian deposits, containing miospores, are widespread on the territory of the Pripyat Depression in SE Belarus and the Timan–Pechora Province in Russia. Biostratigraphy of these deposits is based also on conodonts in the Timan–Pechora.

A palaeophytogeographic reconstruction (Fig. 5) after Streel et al. (1990) shows, during Frasnian time, Eastern Europe centred on the equatorial belt and Western Europe in the tropical belt. It explains, to some extent, why different miospore zonations can be found in these regions (Stree et al., 2000a). Correlation charts between Western Europe and Eastern Europe have been tentatively published by Loboziak & Streel (1981, 1988) but the most documented chart was published by Avkhimovitch et al. (1993) for the Middle and Upper Devonian and Obukhovskaya et al. (2000) for the Upper Frasnian and Famennian boundary deposits.

Correlations from the Late Givetian until the Mid Frasnian are shown on these charts to be obvious from the *varcus* to *punctata* conodont Zones (Obukhovskaya, 2000; Streel et al., 2000a; Tel’nova, 2008; Telnova et al., 2019) but less obvious from Middle Frasnian to the Lower Famennian within the *Archaeoperiakoccus ovalis–Verrucosporites grimosus* (OG), *Cristatisporites deliquescens–Verrucosporites evlanensis* (DE) and *Corbulispora vinicuus–Geminospora vsiamica* (VV) Assemblage–Acme Zones of Eastern Europe.

Subzone SB, in the lower part of the OG Zone, contains *Cristatisporites deliquescens* and is associated with the...
Frasnian miospores from northern France and Western Belgium

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conodont Upper *Polygnathus asymmetricus* and *Ancyrognathus triangularis* Zones i.e. more or less the *hassi–janiaeae* level of the “standard” conodont zonation (Ziegler & Sandberg, 1990). Subzone CVe, in the middle part of the OG Zone, contains *Grandispora gracilis* (69) and is associated to the conodont Lower *gigas* Zone or early *rhenana* level. Subzone MR in the upper part of the OG Zone, contains *Diducites mucronatus* (74) associated with the conodont *gigas* Zone.

Subzone AS, in the lower part of the DE Zone, contains *Cymbosporites acanthaceus* (57) and is associated with the conodont *gigas* Zone. Subzone GS, in the upper part of the DE Zone is referred to the conodont Uppermost *gigas* Zone or *linguiformis* level (see Fig. 6).

VV Zone shows the appearance of the first index species *Corbulispora vimineus* (61) and is correlated with conodonts of the *Palmatolepis triangularis* Zone.

Consequently it is proposed here (Table 4) that a correlation exists between part of the *Verrucosisporites bulliferus–Lophozonotriletes media* (BM) Oppel Zone, all of the

Rugospora bricei–Cymbosporites acanthaceus (BA) Oppel Zone and part of the *Knossisporites dedaleus–Diducites versabilis* (DV) Oppel Zone in Western Europe with the *Archaeoperisaccus ovalis–Verucosisporites grumosus* (OG), *Cristatisporites deliquescentes–Verrucosisporites ovalesisi* (DE) and part of the *Corbulispora vimineus–Geminispora vasjamica* (VV) Assemblage–Acme Zones of Eastern Europe, covering the range from the conodont *hassi* Zone to the *triangularis* Zone.

The transition from the Rugospora bricei–Cymbosporites acanthaceus (BA) Oppel Zone and the *Knossisporites dedaleus–Diducites versabilis* (DV) Oppel Zone of Western Europe crossing the Frasnian–Famennian Boundary is tentatively recognised in the lowermost part of the Honggelelung Formation in the Bulongguoer section of the Junggar Basin in NW China (Stachacz et al., 2020). The Frasnian/Famennian Boundary is dated by Zircon-U-Pb (371.5 ± 0.9 Ma) immediately below the Honggelelung Formation, in the Zhulumute Formation in the same region (Zheng et al., 2020).

7. Conclusions

The correlation proposed on Table 4 at the transition BM/BA dated Upper Frasnian by the *rhenana* conodont Zone in Eastern Europe points to the inability in the Ferques and Hydrequent Formation succession between the La Parisienne Member (or Gris Member?) and the Dolomitic Beds (Brice et al., 1981) to trace the exact base of the Upper Frasnian in the Boulonnais. An initial examination at the many recorded ranges of taxa (Fig. 1) suggests, first of all, a sampling gap between these formations. Obviously, it suggests also a significant change in the vegetation cover occurring at that level which introduces the basal Famennian miospores characteristics of the DV Zone. Such a deep change in the vegetation cover might well have a climate origin (Streel et al., 2000a; Huang et al., 2018) corresponding more or less to the Lower Kellwasser Event (LKW) starting at the base of the Upper *rhenana* conodont Zone (Becker et al., 2016).

8. Acknowledgements

We would like to thank Alexandre Lambion (Department of Geology, Uliège) for technical assistance in preparing the samples from the Nieuwkerke-Noordhoek borehole. Marleen De Ceukelaere, Geo-collections manager of the Royal Belgian Institute of Natural Sciences is thanked for making the core available. We are grateful to the two reviewers, Prof. J. Marshall (Southampton) and Dr M. Coen-Aubert (Brussels) for their suggestions which greatly improved the manuscript. P.S. is a NFSR Senior Research Associate.

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**Table 4.** Correlation between late Frasnian miospore assemblages in Western and Eastern Europe.

<table>
<thead>
<tr>
<th>Miospore zonation Western Europe</th>
<th>Conodont (Fig. 6) Eastern Europe</th>
<th>Ages</th>
<th>FO key species?</th>
</tr>
</thead>
<tbody>
<tr>
<td>DV</td>
<td>VV</td>
<td>triangularis</td>
<td>Famennian</td>
</tr>
<tr>
<td>BA plc-E</td>
<td>VV</td>
<td>triangularis</td>
<td>Famennian</td>
</tr>
<tr>
<td>BA grac</td>
<td>DE GS</td>
<td>linguiformis</td>
<td>Upper Frasnian</td>
</tr>
<tr>
<td>BA pregrac</td>
<td>DE AS</td>
<td>rhenana</td>
<td>Upper Frasnian</td>
</tr>
<tr>
<td>BM/BA ?</td>
<td>OG MR</td>
<td>rhenana</td>
<td>Upper Frasnian</td>
</tr>
<tr>
<td>BM/BA ?</td>
<td>OG CVe</td>
<td>Early rhenana</td>
<td>Upper Frasnian</td>
</tr>
<tr>
<td>BM</td>
<td>OG SB</td>
<td>hassle</td>
<td>Middle Frasnian</td>
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</tbody>
</table>

**Figure 6.** Conodont zonations after Klapper & Ziegler (1979), Ziegler & Sandberg (1990). Redrawn from Avkhimovitch et al. (1993, fig. 4).
9. References


Appendix. Identification numbers of taxa recorded on Figure 1, sorted by taxa name.

Acinosporites lindlarensis Riegel 1968 = 1
Acinospora cf. heterodonta (Naumova) Streel 1972 = 2 = Acinosporites lindlarensis Riegel 1968 = 1
Acinospora ancyrea var. brevisipina Richardson 1962 = 14
Acanthotriletes cf. horridus Haasquebard 1957 sensu Richardson 1965 = 10
Acinospora ancyrea var. ancyrea Richardson 1962 = 13
Acinospora angulata Tiwari & Scharaechmidt 1975 = 37
Acinospora angulata (Taugoude-Lantz) Allen 1965 = 31
Acinospora logani McGregor 1973 = 15
Acinospora lysi (Taugoude-Lantz) Loboziaik &Streel 1981 = 52
Acinospora goensis Streel 1964 = 2 = Geminospora expansa (Naumova) Gao in Obukhovskaya 2000 = 11
Acinospora greggii (McGregor) Streel 1974 = 24
Acinospora sp. A in Loboziaik, Streel &Vanguestaine 1983 = 77
Acinospora sp. B in Loboziaik, Streel &Vanguestaine 1983 = 78
Archaeozonotriletes variabilis (Naumova) Allen 1965 = 2
Auroraspora hyalina (Naumova) Streel 1974 = 62
Auroraspora macra Sullivan 1968 = 63
Auroraspora macromanifesta (Haasquebard) Richardson 1960 = 16
Auroraspora micromanifesta (Haasquebard) Richardson 1960 = 17
Auroraspora solisorta Hoffmeister, Stalpin & Malloy 1955 = 70
Auroraspora sp. A in Loboziak & Streel 1989 = 66
Bioraumispora reticulata Lelo & Streel 1969 = 25
Brototriletes sp. = 3
Bullotriletes aff. bullatus Allen 1965 = 18
Chelinospora concina Allen 1965 = 38
Cirratriradites disstus Allen 1965 = 19
Cirratriradites jehokovskij Taugoude-Lantz 1967b = 39
Contagiosporites optius var. vorobjevensis (Chibrikova) Owens 1971 = 12
Convolatiospora cf. subtilis Owens 1971 = 43
Convolatiospora disparitilis Allen 1965 = 4
Convolatiospora paraverrucacuta McGregor 1964 = 5
Convolatiospora tegula Allen 1965 = 48
Corbaliyspora sp. in Loboziak & Streel 1981 = C. viminea (Nekriata) Obukhovskaya &Nekriata in Obukhovskaya et al. 2000 = 61
Corbaliyspora viminea (Nekriata) Obukhovskaya & Nekriata in Obukhovskaya et al. 2000 = 61
Corysiosporites multispinosus Richardson 1965 = 42
Cymbosporites acanthaceus (Kedo) Obukhovskaya in Obukhovskaya et al. 2000 = 57
Cymbosporites cf. cyathis Allen 1965 = 20
Cymbosporites sp. A in Loboziaik & Streel 1981 = 68
Cymbosporites sp. B in Loboziaik & Streel 1981 = C. acanthaceus (Kedo) Obukhovskaya in Obukhovskaya et al. 2000 = 57
Cymbosporites sp. C in Loboziaik, Streel &Vanguestaine 1983 = 75
Densosporites sp. Loboziaik & Streel 1981 No records = 71
Dibolosporites cf. gisserosus (Naumova) Richardson 1965 = 6
Dibolosporites echinosus (Eisenack) Richardson 1965 = 28
Dibolosporites sp. C Lophotriletes atrinus (Naumova) sensu Streel 1974 = 41
Diducites mucronatus (Kedo) Van Veen 1981 = 74
Diducites plicabilis Van Veen 1981 = 64
Diducites polycissus (Kedo) Van Veen 1981 = 55
Diducites versabilis (Kedo) Van Veen 1981 = 65
Emphasiosporites spp. = 29
Geminospora lemara Butlme 1962 = 40
Geminospora expansa (Naumova) Gao in Obukhovskaya 2000 = 11
Grandispora cf. tennispinosa (Haasquebard) Playford 1971 in Streel 1974 = 53
Grandispora douglastownense McGregor 1973 = 7
Grandispora gracilis (Kedo) Streel 1974 = 69
Grandispora incluta Allen 1965 = 21
Grandispora sp. A in Loboziaik & Streel 1981 No records = 56
Grandispora tomentosa Taugoude-Lantz 1967b = 32
Grandispora velata (Eisenack) McGregor 1973 = 22
Hystricosporites multifurcatus (Winslow) Mortimer & Chaloner 1967 = 47

Hystricosporites spp. = 33
Knoxiysporites cf. hederae (Ishenko) Playford 1963 = 60
Knoxiysporites dedalus (Naumova) Streel 1977 = 59
Lophozonotriletes media Taugoude-Lantz 1967b = 50
Perotriletes erugatus Allen 1965 = 34
Planisporites scaber Taugoude-Lantz 1967b = 49
Pustulatisporites rugosus (Taugoude-Lantz) Loboziaik &Streel 1981 = 51
Retusotriletes planus Dolby & Neves 1970 = 67
Retusotriletes rugosus Riegel 1973 = Scylaspora rugulata (Riegel) Breuer et al. 2007 = 30
Rhabdosporites langi (Eisenack) Richardson 1960 = 8
Rhabdosporites parvulus Richardson 1965 = 35
Rugospora bricei Loboziaik & Streel 1989 = 58
Rugospora cf. flexuosa (Juschko) Streel 1974 = R. bricei Loboziaik & Streel 1989 = 58
Samarisporites inaequus (McGregor) Owens 1971 = 23
Samarisporites sp. A in Loboziaik & Streel 1981 = 54
Samarisporites sp. B in Loboziaik, Streel & Vanguestaine 1983 = 73
Samarisporites sp. C in Loboziaik, Streel & Vanguestaine 1983 = 76
Samarisporites sp. D in Loboziaik, Streel & Vanguestaine 1983 = 79
Samarisporites triangularus Allen 1965 = 36
Scylaspora rugulata (Riegel) Breuer et al. 2007 = 30
Scylasporites diplophorus (McGregor) Owens 1971 = 9
Scylasporites sp. A in Loboziaik, Streel & Vanguestaine 1983 = 72
Scylasporites sp. cf. grandis McGregor 1960 = 44
Scylasporites sp. cf. uncatus (Naumova) Richardson 1965 = 27
Scylasporites premnosus Richardson 1965 = 26
Plate 1a. Miospores recorded in the borehole Nieuwkerke-Noordhoek (95W153).
1, 2: Ancyrospora angulata (37) 1:223, 7, H50-3-4, 2:219,0, G45-2.
3: Aneurospora greggsii (24) 221, 5 L36-0.
5: Chelinospora concinna (38) 219,0, N43-4.
6, 7: Cirratiradites jekhowskyi (39) 219,0, 6:M42-3. 7:T52-4.
8: Corystisporites multispinosus (42) 223, 7, F55-4.
9: Dibolisporites echinaceus (28) 219,0, R43-0.
10: Emphanisporites spp (29) 219,0, W41-4.
11, 12: Geminospora lemurata (40) 11:221,5, M4-0. 12:223,7, H53-1-2.

Scale bar = 10 µm.
Plate 1b. Miospores recorded in the borehole Nieuwkerke-Noordhoek (95W153) (continued).
14: Grandispora velata (22) 223,7, G57-0.
18: Scylaspora rugulata (Riegel) Breuer et al. 2007 (30) 221,5, G33-0.
23, 24: Verrucosisporites bulliferus (45) 221,5, 23:G48-3;24:T46-3.
Scale bar = 10 µm.
Plate 2a. Miospores recorded in the Heuvelland groundwater monitoring well (95W175).

All figures are at a magnification 700x unless otherwise stated.
Plate 2b. Miospores recorded in the Heuvelland groundwater monitoring well (95W175) (continued).
12: Diducites plicabilis (64), E47-3.
15: Grandispera gracilis (69), O46-4.

All figures are at a magnification 700x unless otherwise stated.