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 Fergus Formations and of 44 samples from the Upper Frasnian to the Lower Famennian Hydrequent Formation are re-evaluated. *Chelinospora concinna*, *Verrucosisporites bulliferus*, *Cirratiradites jekhowskyi*, *Lophozonotriletes media* first occurrences are major criteria for Lower and Middle Frasnian, well calibrated by conodonts. *Cymbosporites acanthaeus*, *Rugospora bricei*, *Grandispora gracilis*, *Diducites pleobilis*, *Corbulispora vimineus* first occurrences allow to subdivide the Upper Frasnian where conodonts are poorly present. *Samarxisporites triangulatus versus Auronaspis pseudocruciat 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* (BI) 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–acanthaeus* (BA) Oppel Zone suggesting a late Frasnian age, also known in the Hydro frequent 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 Believed to belong 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 palyno-stratigraphic 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: *Samarxisporites triangulatus–Rhabdosporites langi* (TLa) renamed (Streel et al., 1987), *S. triangulatus–Anynexaspis ancyrea ancyrea* (TA), *S. triangulatus–Chelinospora concinna* (TCo), *Verrucosisporites bulliferus–Cirratiradites jekhowskyi* (BJ), *V. bulliferus–Lophozonotriletes 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 acanthaeus* (BA) and *Knoxisporites dedaleus–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 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 Hydrequent 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 base 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
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. Leboziak; 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.

| Identification number | Taxa                                                                 |
|-----------------------|---------------------------------------------------------------------|
| 1                     | Anurospora cf. heterodonta (Naumova) Streeł 1972 = Acinosporites lindlarensis Riegel 1968 (Richardson et al., 1993) |
| 2                     | Archaeozonolitites variabilis (Naumova) Allen 1965                 |
| 3                     | Brochotritiletes sp.                                               |
| 4                     | Convolutispora disparilis Allen 1965                               |
| 5                     | Convolutispora paravaccaria McGregor 1964                          |
| 6                     | Dibolisporites cf. gibberous (Naumova) Richardson 1965             |
| 7                     | Grandispora douglasitowense McGregor 1973                          |
| 8                     | Rhabdospores langi (Eisenack) Richardson 1960                       |
| 9                     | Verrucisporites pallidus (McGregor) Owens 1971                      |
| 10                    | Acanthotritiletes cf. horridus Haquebard 1957 sensu Richardson 1965|
| 11                    | Anurospora goenioides Streeł 1964 = Geminospora expansa (Naumova) Gao in Obukhovskaya 2000 |
| 12                    | Contagiosporites optica var. vorobjevovensis (Chiříkova) Owens 1971|
| 13                    | Anurospora ancyra var. ancyra Richardson 1962                      |
| 14                    | Anurospora ancyra var. brevispinosa Richardson 1962                 |
| 15                    | Anurospora longii McGregor 1973                                    |
| 16                    | Aurorospora macromanifesta (Haquebard) Richardson 1960             |
| 17                    | Aurorospora micromanifesta (Haquebard) Richardson 1960             |
| 18                    | Ballatisporites aff. bullatus Allen 1965                           |
| 19                    | Cirratiridites dissitus Allen 1965                                 |
| 20                    | Cymbiosporites cf. cyathus Allen 1965                              |
| 21                    | Grandispora incula Allen 1965                                     |
| 22                    | Grandispora velata (Eisenack) McGregor 1973                       |
| 23                    | Samarisporites inaequus (McGregor) Owens 1971                      |
| 24                    | Anurospora greggsii (McGregor) Streeł 1974                         |
| 25                    | Biornatispora reticulata Lele & Streeł 1969                        |
| 26                    | Verrucisporites premoenas Richardson 1965                          |
| 27                    | Verrucisporites cf. vacuatus (Naumova) Richardson 1965             |
| 28                    | Dibolisporites echniaceus (Eisenack) Richardson 1965               |
| 29                    | Emphanisporites spp.                                               |
| 30                    | Retusotritiletes rugulatus Riegel 1973 = Sylaxspora rugulata (Riegel) Breuer et al. 2007 |
| 31                    | Anurospora langi (Taungourdean-Lantze) Allen 1965                  |
| 32                    | Grandispora tomentosa Taungourdean-Lantze 1967b                   |
| 33                    | Hystricisporites spp.                                              |
| 34                    | Perotritiletes ergato Allen 1965                                   |
| 35                    | Rhabdospores parvulus Richardson 1965                              |
| 36                    | Samarisporites triangulatus Allen 1965                            |
| 37                    | Anurospora angulata Tonari & Schaarschmidt 1975                    |
| 38                    | Cheilinospora concinna Allen 1965                                 |
| 39                    | Cirratiridites jekowskyi Taungourdean-Lantze 1967b                 |
| 40                    | Geminospora lemura Baize 1962                                      |
| 41                    | Dibolisporites sp. cf. Lophotritiletes atratus (Naumova) sensu Streeł 1974 |
| 42                    | Coryxistisporites multispinosus Richardson 1965                    |
| 43                    | Convolutispora cf. subtilis Owens 1971                            |
| 44                    | Verrucisporites cf. grandis McGregor 1960                         |
| 45                    | Verrucisporites bulliferus Richardson & McGregor 1986             |
| 46                    | Anurospora simplex Guenée 1965                                     |
| 47                    | Hystricisporites multifurcatus (Winslow) Mortimer & Chaloner 1967  |
| 48                    | Convolutispora tegula Allen 1965                                  |
| 49                    | Planisporites scaber Taungourdean-Lantze 1967b                    |
| 50                    | Lophozonotriiteles media Taungourdean-Lantze 1967b                 |
| 51                    | Pastalatispores rugulatus (Taungourdean-Lantze) Lobozia & Streeł 1981 |
| 52                    | Anurospora lyti (Taungourdean-Lantze) Lobozia & Streeł 1983        |
| 53                    | Grandispora cf. tenaspinosus (Haquebard) Playford 1971 in Streeł 1974 |
| 54                    | Samarisporites sp. A in Lobozia & Streeł 1981                     |
| 55                    | Diductes polyfossica (Kedo) Van Veen 1981                         |
| 56                    | Grandispora A in Lobozia & Streeł 1981 No records                |
| 57                    | Cymbiosporites sp. B in Lobozia & Streeł 1981 = C. acuminatus (Kedo) Obukhovskaya in Obukhovskaya et al. 2000 |
| 58                    | Bagiosporites cf. flexosa (Huschko) Streeł 1974 = R. bricel Lobozia & Streeł 1989 |
| 59                    | Knotisporites dedalo (Naumova) Streeł 1977                        |
| 60                    | Knotisporites cf. hedaratus (Ishenko) Playford 1963               |
| 61                    | Corbisporites sp. in Lobozia & Streeł 1981 = Corbisporites viminea (Nekrieta) Obukhovskaya & Nekrieta in Obukhovskaya et al. 2000 |
| 62                    | Asororaspores halyne (Naumova) Streeł 1974                        |
| 63                    | Asororaspores macro Sullivan 1968                                |
| 64                    | Diductes plicabilis Van Veen 1981                                 |
| 65                    | Diductes versabilis (Kedo) Van Veen 1981                         |
| 66                    | Asororaspores sp. A in Lobozia & Streeł 1981                     |
| 67                    | Retusotritiletes planus Dolby & Neves 1970                       |
| 68                    | Cymbiosporites sp. A in Lobozia & Streeł 1981                    |
| 69                    | Grandispora gracilis (Kedo) Streeł 1974                         |
| 70                    | Asororaspores solisorta Hoffmeister, Stuplin & Malloy 1955        |
| 71                    | Densisporites sp. Lobozia & Streeł 1981 No records               |
| 72                    | Verrucisporites sp. A in Lobozia, Streeł & Vanguasteine 1983      |
| 73                    | Samarisporites sp. B in Lobozia, Streeł & Vanguasteine 1983       |
| 74                    | Diductes microconutus (Kedo) Van Veen 1981                       |
| 75                    | Cymbiosporites sp. C in Lobozia, Streeł & Vanguasteine 1983      |
| 76                    | Samarisporites sp. C in Lobozia, Streeł & Vanguasteine 1983      |
| 77                    | Anurospa sp. A in Lobozia, Streeł & Vanguasteine 1983            |
| 78                    | Anurospora sp. B in Lobozia, Streeł & Vanguasteine 1983          |
| 79                    | Samarisporites sp. D in Lobozia, Streeł & Vanguasteine 1983      |
Zones range from the conodont Lower asymmetricus Zone to as far as the conodont \textit{Anacyronathus 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 Boulonnais), using acritarchs “dated” by conodonts in the type region from the Ardenne (Vangueristaine, 1986; Martin, 1993; Strel et al., 2000a). The conclusion was that the higher part of the BA Oppel Zone (BA plic Subzone, starting with the first occurrence of \textit{Didicutites plicabilis} in Strel, 2009) ranges from the conodont upper Paltomelopis gigas Zone to the upper Paltomelopis triangularis Zone and contains therefore the base of the Famennian Stage (Ziegler & Sandberg, 1990).

The acritarch \textit{Vishysphaera (?)} \textit{fucund} (VI) Zone occurs in samples 217-216 of the Upper Frasnian Hydrofrequent Formation (Loboziak et al., 1983). The Famennian acritarch \textit{Villocapscula globosa} (Vg) Zone is not recorded in that section. If one accepts the synonymy (Vangueristaine et al., 1983) of \textit{Herkomorphytus} sp. A and \textit{V.?} \textit{occultata}, as a good marker for the earliest Famennian in Belgium (Martin, 1993), then sample 213 of the Hydrofrequent Formation might be Famennian. A Frasnian/ Famiennian Boundary drawn between samples 216 and 213 would match the top of several miospore species recorded in the Upper Frasnian Hydrofrequent Formation, i.e. \textit{Cymbosporites} sp. C (75), \textit{Aneurospora} sp. A (77), \textit{A}. sp. B (78) and \textit{Samarisporites} 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 taxa 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 Fersques Formations and 44 samples of the Upper Frasnian to the Lower Famennian Hydrofrequent 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 \textit{C. concinna} (38), \textit{V. bulliferus} (45), \textit{C. jekhowskyi} (39), \textit{L. media} (50) first occurrences are major criteria for the Lower and Middle Frasnian, and that \textit{C. acanthaceus} (57), \textit{R. bricei} (58), \textit{G. gracilis} (69), \textit{D. plicabilis} (64) first occurrences allow the subdivision of the Upper Frasnian.

It might seem surprising that \textit{Samarisporites triangulatus} Allen 1965 (syn.: \textit{S. egylphus} Taugourdeau-Lantz, 1967b, \textit{Cristatisporites triangulatus} (Allen) McGregor & Camfield, 1982), the eponym species of TA and TCo Oppel Zones, is not retained among the taxa listed here above. Its first occurrence is indeed controversial (Richardson & McGregor, 1986, fig. 6; Strel, 2009, fig. 3). It might be, in part, the result of differences of palynologist acceptance 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 \textit{Geminospora lemura} (40) was not recognised in the few samples studied in the Blacourt Formation (Loboziak & Strel, 1980, fig. 1) or maybe confused with \textit{Aneurospora greggisi} (24) (see Strel & Loboziak, 1987, p. 100) showing why \textit{Geminospora lemura} is recorded as being older than \textit{Samarisporites triangulatus} in the Eifel (Loboziak et al., 1991) as in Canada and European Russia according to Richardson & McGregor (1986).

The stratigraphic range of \textit{S. triangulatus} is also questionable. According to Richardson & McGregor (1986), it occurs in their \textit{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 Boulonnais, we had noted \textit{S. triangulatus} 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 \textit{Aurospora 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 Nieuwkerke-De Seule (95W152, renamed 110W7) and Nieuwkerke-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 Boulonnais) (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 Tournaï, Vieux-Leuze and Annapes boreholes suggest a correlation to the lower part of the Bovesse Formation (or Beaulieu Formation in the Boulonnais) of the Frasnian strata in the Nieuwkerke boreholes (Coen-Aubert et al., 1980; Legrand, 1981; Dusar & Loy, 1986).

Nieuwkerke-De Seule (95W152) which has penetrated conodont-dated Givetian/Famennian boundary at the transition between the Mazy Member and the Bovesse Formation (Fig. 4), contained poorly preserved miospores attributed to the \textit{Samarisporites triangulatus–Chelinospora concinna} (TCo) Oppel Zone (Toureau et al., 1989). They are listed on Table 2.

Nieuwkerke-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 \textit{Cirratriradites jekhowskyi} (39) with \textit{Chelinospora concinna} (38), both taxa coexisting in the lower part of the \textit{Verrucosisporites bulliferus–Cirratriradites jekhowskyi} (BJ) Oppel Zone.

In the sample at 221.5 m, \textit{Retusotriletes rugulatus} (30) and \textit{Verrucosisporites bulliferus} (45) suggests a close proximity to the top of the \textit{Samarisporites triangulatus–Chelinospora concinna} (TCo) Oppel Zone and the base of the \textit{Verrucosisporites bulliferus–Cirratriradites jekhowskyi} (BJ) Oppel Zone.

In the sample 223.7 m, \textit{Grandispora velata} (22) and \textit{Corystisporites multifurcatus} (42) belong to the \textit{Samarisporites triangulatus–Chelinospora concinna} (TCo) Oppel Zone.

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

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.

\textit{Didicutites plicabilis} (64) and \textit{Grandispora gracilis} (69) belong to the upper part (BA plic) 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.
In conclusion the sample contains the *bricei-acanthaceus* (BA) Oppel Zone suggesting an Upper Frasnian age, also known in the Hydrequent Formation in the Boulonnais (France) and in the Boisochot Formation in the Boisochot borehole (59E146) from the Campine Basin (Belgium) (see Coen-Aubert, 2014).

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

The Boisochot 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 Boisochot Formation (Lagrou & Coen-Aubert, 2017). The upper part of the Boisochot Formation had been investigated by Streel (1965) and Streel & Loboziaik (1987). Between 1002 and 994.5 m, the *Vernuosisporites bulliferus–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 *Ancyrogynathus 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 Hydrequent 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 *Palmatolepis rhenana* conodont Zone (see Coen-Aubert, 2014; Lagrou & Coen-Aubert, 2017). Streel (2009) had renamed the IV Regional Zone as the *Rugospora bricei–Cymbosporites acanthaceus* (BA) Oppel Zone and the V Regional Zone as the *Knoxisporites dedaleus–Didicites versabilis* (DV) Oppel Zone.

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.

1965. “Gen. nov.” in Streel 1965, plate 1: 4-6.

1974. *Samarisporites* sp. cf. *Hymenozonotriletes acanthogynosus* Chibrikova 1959 in Becker et al. 1974, pl. 18: 8.

1987. *Samarisporites* sp. A in Streel & Loboziaik 1987, plate 1: 7.

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.

1989. Cf. also *Samarisporites triangulatus* in Loboziaik & Streel 1989, plate IV: 6-8.

Rounded central body and equatorial wing reaching up to

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| 31 | Ancyrospora langii | X | X | X | X |
| 37 | Ancyrospora angulata | X | X | X | X |
| 13 | Ancyrospora ancraea ancraea | X | X | X | X |
| 24 | Ancyrospora greggsii | X | X | X | X |
| 38 | Chelinospora concina | X | X | X | X |
| 39 | Circiradrates jekhowskyi | X | X | X | X |
| 42 | Corysistsporites multispinosus | X | X | X | X |
| 6 | Dipolosporites cf. gibberosus | X | X | X | X |
| 28 | Dipolosporites echinaceus | X | X | X | X |
| 29 | Emphantisporites sp. | X | X | X | X |
| 40 | Geminospora leuromaculata | X | X | X | X |
| 22 | Grandispora leuromaculata | X | X | X | X |
| 21 | Grandispora incisa | X | X | X | X |
| 33 | Hystricosporites sp. | X | X | X | X |
| 34 | Perotriletes sp. | X | X | X | X |
| 30 | Sclayspora rugulata | X | X | X | X |
| 35 | Retinosoritles confossus | X | X | X | X |
| 36 | Samarisporites triangulatus | X | X | X | X |
| 37 | Samarisporites sp. E | X | X | X | X |
| 45 | Vernuosisporites bulliferus | X | X | X | X |

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

**Table 3.** Miospores recorded in the Heuvelland groundwater monitoring well (95W175).

**Miospores**

(14) Ancyrospora ancraea var. brevispinosa Richardson 1962
(31) cf. Ancyrospora langii (Taugourdeau-Lantz) Allen 1965
(24) Ancyrospora greggsii (McGregor) Streel 1974
aff. Archaeoepiphyssus sp.
Auroraspora pseudocrista Ahmed 1980
(42) Corysistsporites multispinosus Richardson 1965
(64) Didicites plicabilis Van Veen 1965
(29) Emphantisporites sp. 
(69) Grandispora gracilis (Kedo) Streel 1974
(33) Hystricosporites sp. 
Pavonisporites costulatus (Taugourdeau-Lantz) Taugourdeau-Lantz 1971
cl. Lophozonotriletes lebiedianensis Naumova 1953 
cl. Retinosoritles crassus Clayton et al. 1980
(36) Samarisporites triangulatus Allen 1965
Samarisporites sp. cf. Acanthotriletes hirtus Naumova 1953
(79) Samarisporites sp. D in Loboziaik, Streel & Vanguestaine 1983 
cf. Teichertospora torquata (Higgs) McGregor & Playford 1990

Samarisporites sp. E and Pavonisporites costulatus 
(Taugourdeau-Lantz) Taugourdeau-Lantz, 1971 are known in the Mid-Late Frasnian from the Boisochot borehole from the Brabant Massif (Streel & Loboziaik, 1987). Pavonisporites costulatus (Taugourdeau-Lantz) Taugourdeau-Lantz, 1971 was originally recorded as Lagenosporites costulatus by Taugourdeau-Lantz (1960) in the Middle Frasnian in the Boulonnais Region.

Auroraspora pseudocrista Ahmed 1980, Teichertospora torquata (Higgs) McGregor & Playford 1990 and Lophozonotriletes lebiedianensis Naumova 1953 belong to the torquata-gracilis assemblage Zone of Richardson & McGregor 1986, ranging from the uppermost Frasnian up to the Famennian.
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 Steer (1965), Steer & Loboziak (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).

Samarisporites sp. D (79) in Loboziak, Streel & Vanguestaine 1983, plate 2: 2-3.
1988. Samarisporites sp. D, in Loboziak & Streel 1988, plate 3: 14.

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). Ornametnation denser on polar area than on the zona which reaches sometimes to one half of the spore radius.

Samarisporites sp. E in Streel & Loboziak 1987, plate 1: 10. 1965. Calyptosporites microspinosis Richardson 1962 in Streel 1965, plate II: 10.
1974. Samarisporites sp. aff. S. inusitatus Allen 1965 in Becker et al. 1974, plate 18: 7.
1981. Samarisporites triangulatus Allen 1965 in Loboziak & Streel 1981, plate II: 3.
1989. Samarisporites sp. E in Loboziak & Streel 1989, plate IV: 9. 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.

Samarisporites triangulatus Allen 1965 in Loboziak & Streel 1981, plate II: 4-5. = Cristatisporites deliquescens (Naumova) Arkhangelskaya, both occurring in the Ferques Formation from the Boullonais.

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 Boullonais 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 (Streel 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 Archaeoperisaccus ovalis–Verrucosisporites grumosus (OG), Cristatisporites deliquescens–Verrucosisporites evlanensis (DE) and Corbulispora virgulata–Geminispora vasjamina (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

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 BA Zone must 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 Boullonais.

**Figure 5.** Global palaeogeography during Middle Devonian time after Heckel & Witzke (1979). The map shows (black thick line) the tropical to equatorial transect of Western to Eastern Europe. Black X correspond to the locality studied in North-West China by Stachacz et al. (2020).
Table 4. Correlation between late Frasnian miospore assemblages in Western and Eastern Europe. Miospore zonation after Avkhimovitch et al. (1993). Conodont after the “standard” zonation of Ziegler & Sandberg (1990). Substage limits based on SDS members votes (SDS Subcommission Devonian Stratigraphy Newsletter 22, 2007).

| Western Europe | Conodont (Fig. 6) | Ages | FOB key species? |
|----------------|-------------------|------|-----------------|
| DV             | VV                 | triangularis | Famennian |
| BA plic-E      | VV                 | triangularis | Famennian |
| BA grac        | DE GS              | linguiformis | Upper Frasnian |
| BA pregrac     | DE AS              | rhenana    | Upper Frasnian |
| BM/BA ?        | OG MR              | rhenana    | Upper Frasnian |
| BM             | OG SB              | hassi      | Middle Frasnian |

Conodont Upper Polygnathus asymmetricus and Ancyrognathus triangularis Zones i.e. more or less the hassi–jamieae 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 Knoxsporites dedaleus–Diducites versabilis (DV) Oppel Zone in Western Europe with the Archaeoperisaccus ovalis–Verrucosporites grumosus (OG), Cristatisporites deliquesces–Verrucosporites evlanensis (DE) and part of the Corbulispora vimineus–Geminisporites vasjanica (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 Knoxsporites 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).

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

Actinosporites lindlarensis Riegel 1968 (Richardson et al. 1993) = 1
Actinospora cf. heterodonta (Naumova) Street 1972 = Actinosporites
Actinospora lindlarensis Riegel 1968 (Richardson et al. 1993) = 1
Ancyrospora ancyrea var. brevipinosa Richardson 1962 = 14
Acanthotirites cf. horrudes Haquebard 1957 sensu Richardson 1965 = 10
Ancyrospora ancyrea var. ancyrea Richardson 1962 = 13
Ancyrospora angulata Tiwari & Schaarschmidt 1975 = 37
Ancyrospora langii (Taugourdeau-Lantz) Allen 1965 = 31
Ancyrospora loganii McGregor 1973 = 15
Ancyrospora lysi (Taugourdeau-Lantz) Loboziaik & Street 1981 = 52
Ancyrospora goensis Street 1964 = Ancyrosporites expansa (Naumova)
Gao in Obukhovskaya 2000 = 11
Ancyrospora greggi (McGregor) Street 1974 = 24
Ancyrospora sp. A in Loboziaik, Street & Vanguestaine 1983 = 77
Ancyrospora sp. B in Loboziaik, Street & Vanguestaine 1983 = 78
Archaeozonotriletes variabilis (Naumova) Allen 1965 = 2
Auroraspora hyalina (Naumova) Street 1974 = 62
Auroraspora macro Sullivan 1967 = 63
Auroraspora macromanifesta (Haquebard) Richardson 1960 = 16
Auroraspora micromanifesta (Haquebard) Richardson 1960 = 17
Auroraspora solisorta Hoffmeister, Staplin & Molloy 1955 = 70
Auroraspora sp. A in Loboziaik & Street 1981 = 66
Biorotisporites reticulata Lele & Street 1969 = 25
Brochantrites sp. = 3
Bullatisporites aff. bullatus Allen 1965 = 18
Chelinospora concinna Allen 1965 = 38
Cirratriradites dissatus Allen 1965 = 19
Cirratriradites jekhowskyi Taugourdeau-Lantz 1967 = 39
Contagiosporites optivus var. vorhjensvensis (Chibrikova) Owens 1971 = 12
Convolatissopora cf. subtilis Owens 1971 = 43
Convolatissopora disparilis Allen 1965 = 4
Convolatissopora paraverrucata McGregor 1964 = 5
Convolatissopora tegula Allen 1965 = 48
Corbilsopora sp. in Loboziaik & Street 1981 = C. vinita (Nekriata)
Obukhovskaya & Nekriata in Obukhovskaya et al. 2000 = 61
Corbilsopora vininea (Nekriata) Obukhovskaya & Nekriata in Obukhovskaya et al. 2000 = 61
Corysistedonites multiispinosus Richardson 1965 = 42
Cymbosporites acanthaceus (Kedo) Obukhovskaya in Obukhovskaya et al. 2000 = 57
Cymbosporites cf. cyathus Allen 1965 = 20
Cymbosporites sp. A in Loboziaik & Street 1981 = 68
Cymbosporites sp. B in Loboziaik & Street 1981 = C. acanthaceus
(Kedo) Obukhovskaya in Obukhovskaya et al. 2000 = 57
Cymbosporites sp. C in Loboziaik, Street & Vanguestaine 1983 = 75
Densosporites sp. Loboziaik & Street 1981 No records = 71
Dibolisporites sp. gibberosus (Naumova) Richardson 1965 = 6
Dibolisporites echinosorus (Eisenack) Richardson 1965 = 28
Dibolisporites sp. C Lophorotrites atratus (Naumova) sensu Street 1974 = 41
Diducites micromutans (Kedo) Veen Van Veen 1981 = 74
Diducites plicabilis Van Veen 1981 = 64
Diducites poleckicus (Kedo) Veen Van Veen 1981 = 55
Diducites versusabilis (Kedo) Van Veen 1981 = 65
Emphanisporites spp. = 29
Geminosporellula lemarata Balme 1962 = 40
Geminosporellula expansa (Naumova) Gao in Obukhovskaya 2000 = 11
Grandispora cf. tennesisnosa (Haquebard) Playford 1971 in Street 1974 = 53
Grandispora douglastownensis McGregor 1973 = 7
Grandispora gracilis (Kedo) Street 1974 = 69
Grandispora inculta Allen 1965 = 21
Grandispora sp. A in Loboziaik & Street 1981 No records = 56
Grandispora tomentosa Taugourdeau-Lantz 1967 = 32
Grandispora velata (Eisenack) McGregor 1973 = 22
Hystricosporites multifurcatus (Wünslow) Mortimer & Chaloner 1967 = 47
Hystricosporites spp. = 33
Knoxisporites cf. heterodota (Ishenko) Playford 1963 = 60
Knoxisporites dedalus (Naumova) Street 1977 = 59
Lophozonotriletes media Taugourdeau-Lantz 1967 = 50
Pterotriletes ergatus Allen 1965 = 34
Planisporites scaber Taugourdeau-Lantz 1967 = 49
Pustulatisporites rugulatus (Taugourdeau-Lantz) Loboziaik & Street 1981 = 51
Retusotriletes planus Dolby & Neves 1970 = 67
Retusotriletes rugulatus Riegel 1973 = Scylasporsa rugulata (Riegel)
Breuer et al. 2007 = 30
Rhabdosporites langi (Eisenack) Richardson 1960 = 8
Rhabdosporites parvulus Richardson 1965 = 35
Rugospora bricei Loboziaik & Street 1989 = 58
Rugospora cf. flexuosa (Juschko) Street 1974 = R. bricei Loboziaik & Street 1989 = 58
Samarisporites inaequus (McGregor) Owens 1971 = 23
Samarisporites sp. A in Loboziaik & Street 1981 = 54
Samarisporites sp. B in Loboziaik, Street & Vanguestaine 1983 = 73
Samarisporites sp. C in Loboziaik, Street & Vanguestaine 1983 = 76
Samarisporites sp. D in Loboziaik, Street & Vanguestaine 1983 = 79
Samarisporites triangulatus Allen 1965 = 36
Sclayspora rugulata (Riegel) Breuer et al. 2007 = 30
Scylasporsa pullido (McGregor) Owens 1971 = 9
Scylasporsa sp. A in Loboziaik, Street & Vanguestaine 1983 = 72
Verrucretisporites bulliferus Richardson & McGregor 1986 = 45
Verrucisporites cf. grandis McGregor 1960 = 44
Verrucisporites cf. unicatus (Naumova) Richardson 1965 = 27
Verrucisporites pretiosus Richardson 1965 = 26

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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.
4: Auroraspora aff. pseudocrista Ahmed 1980: 223,7, R40-1-4.
5: Chelinospora concinna (38) 219,0, N43-4.
6, 7: Cirratriradites 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).
13: Grandispora inculta (21) 223,7, 13-3,
14: Grandispora velata (22) 223,7, 57-5,
15, 16: Hystroicospore spp (33) 15: 219,0, 4-3, 16: 223,7, 39-3,
17: Retusotriletes confossus (Rich.) Streel 1967, 223,7, 5-1,
18: Scylaspora rugulata (Riegel) Breuer et al. 2007 (30) 221,5, 33-3,
19, 20: Samarispores triangulatus (36) 223,7, 19: 37-12, 20: 35-4,
21, 22: Samarispores sp. E, 223,7, 21: 37-0, 22: 38-50,
23, 24: Verrucosisporites bulliferus (45) 231,5, 23: 48-3, 24: 46-3.
Scale bar = 10 µm.
Plate 2a. Miospores recorded in the Heuvelland groundwater monitoring well (95W175).
1: aff. *Archaeoperisaccus* sp. H31-2.
2, 3, 4: *Auroraspora pseudocrista* Ahmed 1980 2: H41-2 4: O48-3.
5, 6, 7: *Samarisporites* sp. D (79) in Loboziak, Streel & Vanguestaine 1983, 5: M33-1, 6: O46-3, 7: E44-2.
8: cf. *Teichertospora torquata* (Higgs) McGregor & Playford 1990, 8: O46-2.
9: *Aneurospora greggsii* (McGregor) Streel 1974 (24), W46-1.

All figures are at a magnification 700x unless otherwise stated.
Plate 2b. Miospores recorded in the Heuvelland groundwater monitoring well (95W175) (continued).
10, 11: Samarisporites triangulatus Allen 1965 (36), 10: U48-4, 11: G44-4.
12: Diducites plicabilis (64), E47-3.
13, 14: Pavonisporites costulatus (Taugourdeau-Lantz) Taugourdeau-Lantz 1971, 13: N46-2, 14: V30; (x250).
15: Grandispora gracilis (69), O46-4.

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