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The classic Lower Devonian plant-bearing deposits of northern New Brunswick, eastern Canada: dispersed spore taxonomy and biostratigraphy

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ABSTRACT

This paper describes dispersed spore assemblages recovered from the Lower Devonian Val d'Amour and Campbellton formations exposed along the Restigouche River in northern New Brunswick, eastern Canada. The dispersed spore assemblages were recovered from seven of the nine sampled sections and biostratigraphical analysis suggests that these can be assigned to the polygonalis-emsiensis, annulatus-sextantii and douglastownense-eurypterota Spore Assemblage Biozones. This indicates that these strata range in age from Pragian to late Emsian [or possibly earliest Eifelian]. The new biostratigraphical control enables accurate stratigraphical correlation of the nine sections and provides important age constraints for the famous early land plant megafossil and non-marine invertebrate/vertebrate assemblages recovered from these strata. Two new dispersed spore species are described: Emphanisporites genselae sp. nov. and Emphanisporites morrisae sp. nov.

Key words: Pragian; Emsian; Lower Old Red Sandstone.

1. Introduction

Among the earliest reports of early land plant fossils are those from the Lower Devonian deposits exposed along the Restigouche River in northern New Brunswick, eastern Canada (Dawson, 1882). Subsequent work on these fossiliferous horizons has been critical in developing our understanding of Lower Devonian plants (Gensel and Andrews, 1984). However, placing the plants in a secure stratigraphical context has been hampered because the stratigraphy of the deposits was unclear and they were poorly age-constrained. Recent work on the stratigraphy, sedimentology and palaeoecology of the deposits (Kennedy and Gibling, 2011; Kennedy et al., 2012a,b, 2013), coupled with analysis of their dispersed spore/pollen assemblages (this work), now enables these plant communities to be considered within a rigid stratigraphical/biostratigraphical framework.

2. Geological setting

A narrow belt of Lower Devonian strata belonging to the Campbellton Formation crops out along the southern shore of the Restigouche River in northern New Brunswick (Fig. 1). To the south of it lies a thicker development of volcaniclastic deposits belonging to the Val d’Amour Formation (Fig. 1). The stratigraphy of the Campbellton Formation, and its relationship to the underlying Val d’Amour Formation, is difficult to interpret as in situ exposure is limited due to extensive erosion and slumping along the coastal sections and lack of exposure in the densely forested inland areas. Nonetheless these formations have long been famous due to the rich terrestrial-freshwater biotas they yield, including terrestrial plants

(Gensel and Andrews, 1984) and arthropods (Shear et al. 1996), and freshwater aquatic invertebrates (e.g. Miller, 2007) and fish (e.g. Miller et al., 2003). Recently, Kennedy and Gibling (2011) undertook extensive logging/mapping of the formations that has led to a much better understanding of their sedimentology and stratigraphical relationships (Figs 2-3).

Regionally these deposits form part of the Gaspé Belt whose genesis and history are intimately associated with the Acadian Orogeny. They form the final terrestrial phase of basin infilling following significant uplift. The Val d'Amour Formation comprises volcaniclastic deposits deposited in a shallow marine environment to the east and subaerially to the west. Following a period of uplift, and possible unconformity, the terrestrial fluviatile deposits of the Campbellton Formation were deposited in an intermontane basin surrounded by a rugged mountainous landscape (Wilson et al., 2004, 2005). Deposition took place at approximately 35˚S on the southeast margin of Euramerica near the margin between the arid and warm temperate climate belts.

Radiometric dating of rhyolites near the top of the Val d'Amour Formation give an age of 407.4 +/- 0.8 Ma which indicates a late Pragian age (Wilson et al., 2005). Colin McGregor studied dispersed spore assemblages from the Campbellton Formation but his findings are included in unpublished Geological Survey of Canada reports and published only as personal communications in various papers reporting on the biotas of the deposits. A discussion of this work is included within the descriptions of the various sections examined during the study reported herein (see below).

The boundary between the Val d'Amour and Campbellton formations is difficult to interpret. This is because sedimentary horizons are present in the Val d'Amour Formation volcanics, but towards the boundary with the Campbellton Formation these become more common and sedimentary and volcanic units are intercalated. In places there is clear evidence of sediments overlying volcanic rocks with angular unconformity. However, this may be very local. In other places there is clear interdigitation with sediments and lavas/ash falls.

Kennedy and Gibling (2011) undertook detailed bed-by-bed logging of all of the available coastal exposure of the Campbellton Formation and attempted to produce a composite log from six logged sections (Fig. 3). The eastern outcrop includes a 4 km long coastal exposure that follows strike. Kennedy and Gibling logged 938 m of strata (sections III to VI). Two logs (sections I and II) were undertaken in the western outcrop encompassing 82 m of strata. These strata belong to the basal part of the formation and were considered equivalent to the lower strata logged in section III of the eastern outcrop. Kennedy and Gibling subdivided the strata into six facies associations: (1) restricted lacustrine; (2) marginal lacustrine; (3) near-shore lacustrine; (4) coastal-deltaic; (5) sandy to gravelly alluvial plain; (6) gravelly proximal alluvial environments. Building on this stratigraphical and sedimentological framework Kennedy et al. (2012a,b) undertook a detailed analysis of the palaeoenvironments and biota of the deposits.

3. Materials and methods

Samples for palynological analysis were collected from nine sections (A-I) from throughout the sequence during fieldwork in 1998, 2007, 2013 and 2016. Additional samples from specific plant beds were supplied by Pat Gensel. Details of all analysed samples are provided in Appendix 1 and their geographical and stratigraphical position illustrated in Figs 1 and 3, respectively. Twenty grams of each rock samples was processed using standard HCl/HF/HCl palynological acid maceration techniques followed by heavy liquid separation using $ZnCl_2$. Sieving was undertaken using a 20 µm mesh. Most of the residues are of low thermal maturity and did not require oxidation. However, some samples from adjacent to igneous intrusions or extrusions were coalified and oxidised for between 10 and 20 minutes using Schultz solution. Residues were strew mounted and attached to slides using Petropoxy resin. All materials (rock, residue, slides) are housed in the collections of the Centre for Palynology of the University of Sheffield. Slides of each sample were scanned using a light microscope and all spore taxa present identified (largely using the spore taxonomy established by McGregor (1973, 1977) in his classic monograph on the spores from coeval correlative strata at nearby Gaspé). A semi-quantitative count of 200 fossil spores was undertaken on each productive sample.

4. Systematic palaeontology

4.1. Introduction

All of the taxa encountered in this study are listed in Table 1 and figured (Plates I-VIII). Most of these taxa are well known and described in detail in the monograph of dispersed spores from coeval strata from nearby Gaspé (McGregor 1973, 1977). Two new spore taxa were discovered during the course of this investigation and are described in the brief taxonomic section that follows.

4.2. Description of new taxa

Genus **Emphanisporites** McGregor 1961

Type species: Emphanisporites rotatus McGregor 1961

Emphanisporites genselae sp. nov. (Plate V, 5-8)

Holotype: Plate V, fig. 5, Sample BNB29/1, E.F.No. (K41/3).

Derivation of name: after Pat Gensel who provided samples used in this study and invaluable guidance during field work on the Gaspé and New Brunswick Lower Devonian sequences.

Diagnosis: An Emphanisporites characterised by a prominent, wide equatorial crassitude and proximal face ornamented by radial ribs, which are highly variable in width and often divide, and cover most of the interradial area.

Description: Amb subcircular. Trilete mark distinct. Suturae straight and simple extending to near the spore equator. Equatorial crassitude up to 5 µm wide and very distinct, apparently with a groove on the distal surface demarcating the inner margin of the crassitude. Contact areas ornamented with highly variable, more-or-less radially arranged, muri. The muri are of highly variable width and frequently coalesce in a general direction towards the proximal pole. This leaves irregular, sinuous gaps between muri of <1 µm. The muri finish short of the trilete mark leaving the sutures in a distinct topographic low (indentation). Due to their irregular nature they end near the sutures along their entire length (i.e. they do not all converge on the proximal pole). Distal surface entirely laevigate.

Dimensions: 42(45)46 µm (5 specimens measured).

Occurrence: Present in two samples from the Val d'Amour Formation of New Brunswick, Canada (Pragian-?earliest Emsian polygonalis-emsiensis Spore assemblage Biozone) (Table 1).

Comparison and remarks: The highly irregular nature of the radially arranged proximal muri distinguish this taxon from previously described species of Emphanisporites (reviewed in Taylor et al. 2011).

Emphanisporites morrisae sp. nov. (Plate V, 12-14)

Holotype: Plate V, fig. 12, Sample BNB33/1, E.F.No. (N43).

Derivation of name: after Jenny Morris who provided invaluable assistance in the field working on the Gaspé and New Brunswick Lower Devonian sequences.

Diagnosis: An Emphanisporites characterised by its relatively large size and large number of robust radially-arranged proximal muri.

Description: Amb subcircular to subtriangular. Trilete mark indistinct. In some specimens straight suturae, accompanied by lips ca. 1 µm wide, extend from the proximal pole to the equator. In other specimens the suturae appear to be gaping resulting in a triangular section of the proximal surface, centred on the proximal pole, that is missing. Equatorial crassitude distinct and up to 2 µm wide. Contact areas ornamented with a large number (up to 40) of crowded, radially-arranged muri. Muri robust, thinning from the equatorial margin towards the proximal pole, from 4 to 1 µm in width. Muri occasionally bifurcating. Distal surface entirely laevigate.

Dimensions: 59(73)107 µm (21 specimens measured).

Occurrence: Present in samples from the Val d'Amour and Campbellton formations of New Brunswick, Canada (Pragian-?earliest Emsian polygonalis-emsiensis Spore assemblage Biozone) (Table 1).

Comparison and remarks: The relatively large size and large number of prominent radially-arranged proximal muri distinguish this taxon from previously described species of Emphanisporites (reviewed in Taylor et al. 2011).

4.3. Discussion of spore taxa encountered

4.3.1. Laevigate retusoid trilete spores

McGregor (1973, 1977) subdivided the laevigate retusoid spores he encountered in Gaspé into several genera (Calamospora, Retusotriletes, Deltoidospora) and numerous species. The criteria used to distinguish these taxa were rather subtle, and although we could identify most of them, it was decided to group them together as Retusotriletes spp., with positive identification of only the most distinctive taxa (R. triangulatus, R. cf. rotundus, R. eslae). This is because these taxa are morphologically similar and also because they are not biostratigraphically significant. They are, however, extremely common and comprise up to 90% of spores in the assemblages studied. Plate I figures a selection of laevigate retusoid spores including some of the more distinctive and common taxa encountered.

4.3.2. Ornamented retusoid trilete spores

Apiculiretusispora spp. is abundant in all of the samples studied and is highly distinctive as it is bilayered with the outer ornamented layer often in the process of separating from the inner body and sloughing off. McGregor (1973, 1977) described six species of this genus from Gaspé (as well as similar spores he placed with Apiculatisporis microconus Richardson 1965, Apiculatasporites perpusillus (Naumova) McGregor 1973 and Anapiculatisporites sp.). In this study only four of these taxa were recognised (see Table 1 and Plate I).

Of the five Dibolisporites species recognised by McGregor (1973, 1977) from Gaspé all are present in the New Brunswick sequence except for D. variegatus McGregor 1973 (see

Table 1 and Plate II). Dibolisporites spp. occurs in all samples and is a persistent but low abundance component.

All five Dictyotriletes species recognised by McGregor (1973, 1977) in Gaspé are present in the New Brunswick sequence (see Table 1 and Plate II).

4.3.3. Laevigate crassitate trilete spores

Simple laevigate crassitate spores are present in most samples and are referred to as Ambitisporites spp. (Plate III, fig. 1). They become less common in increasingly younger spore zones. Similar forms from Gaspé were described by McGregor (1973, 1977) as species of Punctatisporites.

4.3.4. Ornamented crassitate trilete spores

Various ornamented crassitate trilete spores were encountered (Table 1). These include forms assigned to Synorisporites (Plate III, figs 4-5,9) those with an ornament of elements with a spatulate tip (Raistrickia sp.) (Plate III, figs 6-7) and rare but distinctive taxa with a distal ornament of anastomosing muri (Plate III, figs 2-3) or an annulus (Amicosporites jonkeri) (Plate III, fig. 8). These all occurred sporadically and in low numbers (Table 1).

Forms with a more prominent equatorial crassitude, verging on patinate structure, were included in Lycopodiacidites ogygius, Verruciretusispora dubia, Verruciretusispora multituburculata, Verrucosisporites devonicus, Verrucosisporites polygonalis? and Verrucosisporites sp. A. (see Table 1 and Plates III-IV).

Other ornamented crassitate spores include five species of Brochotriletes (Plate IV), seven species of Emphanisporites (Plate V) and Camarozonotriletes sextantii (Plate IV, figs 7-8). The latter also occurs within a large laevigate body with a trilete mark (Plate IV, fig.14) as previously reported among in situ spores recovered from the plant Chaleuria cirrosa (Andrews et al. 1974).

4.3.5. Patinate trilete spores

Laevigate patinate spores are represented by the taxa Archaeozonotriletes chulus (Plate VI, fig. 2) and ?Archaeozonotriletes sp. of McGregor 1973 (Plate VI, fig. 1). Ornamented forms are notably rare with only very rare representatives of the genera Cymbosporites and Chelinospora (see Table 1 and Plate VI).

4.3.6. Trilete spores with multiple wall layers

Structurally more complex spores, with distinct inner bodies +/- zona, include Acinosporites lindlarensis (Plate VI, figs 4,7,11), Ancyrospora loganii (Plate VIII, figs 5-7), Camptozonotriletes caperatus (Plate VII, figs 5,8), Grandispora douglastownensis (Plate VIII, figs 1-4), Zonotriletes brevivelatus (Plate VII, figs 1,4,7,10), and other rare forms (Plate VII, figs 2-3,6). A. lindlarensis is highly variable in terms of size and ornament (See Richardson et al. 1993) as has previously been noted based on studies of in situ spores (Richardson et al. 1993; Gensel and Kasper 2005; Gensel and Albright 2006; Wellman et al. 2009). Grandispora douglastownensis is highly variable regarding ornament (Plate VIII, figs 1-4) but this is considered to represent intraspecific variation within a single taxon (see discussion in Wellman and Gensel 2004).

4.3.7. Cryptospores

Cryptospores are very rare in the assemblages and include the pseudodyad Pseudosyadospora petasus (Plate VII, fig. 9) and permanent tetrad Tetrahedraletes medinensis. No true dyads (or hilate cryptospores dissociated from them) were reported.

5. Biostratigraphical analysis

5.1. Introduction

Nine sections (A - I) were sampled (Figs 1-3). Most of the samples yielded assemblages containing abundant and well preserved spores that were either of low thermal maturity or cleared easily using Schultz solution. Details of all samples, including those that were barren, are provided in Appendix 1. The best preserved spore assemblages from each of the nine sampled sections (A – I) were logged and the distribution of recorded taxa is reported in Table 2. Fig. 4 is a summary diagram indicating the spore zonation, ages and correlation of the studied sections.

Previous palynological investigation of these deposits has been reported on by Colin McGregor and Elliot Burden. McGregor's work consists of unpublished Geological Survey of Canada reports and personal communications. These are quoted in various papers concerning descriptions of the palaeontology (e.g. Gensel et al. 1991) and stratigraphy of these beds (e.g. Kennedy and Gibling 2011) and are outlined in the discussion below. The spore assemblages are correlated using the spore zonation scheme of McGregor and Camfield

(1976) and McGregor (1977). It should be noted that this differs somewhat from the later spore zonation of Richardson and McGregor (1986) and cross correlation is difficult (see Figure 1 (insert) of Richardson and McGregor 1986). Burden’s spore-based biostratigraphical interpretations are discussed in Wilson et al. (2004, 2005).

5.2. Section A *(Val d’Amour Formation)*

Wilson et al. (2004, 2005) mapped an outcrop of the Val d’Amour Formation around Dalhousie. It is exposed in coastal sections south and west of Dalhousie, and in the latter it is unconformably overlain by the Campbellton Formation (section III of Kennedy & Gibling 2011). Two samples yielding palynomorphs were recovered in the section south of Dalhousie (Walker Brook Member in Wilson et al. 2005). Sample BNB30 is from a small pocket of sediments intercalated between lavas, with a notable accumulation of pillow lavas stratigraphically above. Sample BNB29 occurs higher in the sequence and is from an exposure of highly fossiliferous sediments rich in marine invertebrate remains. Both samples contain abundant marine and non-marine palynomorphs. The marine palynomorphs consist of diverse assemblages of acritarchs, chitinozoans and scolecodonts, in addition to large fragments of arthropod cuticle. The non-marine palynomorphs consist of abundant, but not diverse, spore assemblages in addition to abundant large fragments of plant debris (including banded tubes and cuticles). The dispersed spore assemblages are virtually identical in both samples (Table 2) and are placed with the PE Spore Assemblage Biozone of Richardson & McGregor (1986), based on the presence of the nominal species of the zones and the overall characteristics of the spore assemblages, indicating a Pragian-?earliest Emsian age. This zone equates to the PoW Oppel Zone of Streel et al. (1987). The presence of D. wetteldorfensis may further constrain the assemblages to the W Interval Zone of Streel et al. (1987). The presence of Acinosporites lindlarensis in sample BNB30 is interesting as this occurrence appears to be earlier than expected.

5.3. Section B *(Val d'Amour Formation)*

There is an excellent section of the Val d'Amour Formation exposed in the road cut either side of Route 11 directly west of Sugarloaf Mountain (logged and described by Kennedy et al. 2013). The strata are more-or-less perpendicular and strike parallel to the road. Moving west along the road, from its junction with Route 270, in the cut on the south side of the road a volcaniclastic sequence is dominated by tuffs. The first significant development of sediments is at N47˚59.177 / W066˚042.027 and consists of an approximately 5m thick sequence from which 4 samples were collected (BNB34 – coal; BNB33 – siltstone with plant fragments; BNB 32 – coaly horizon; BNB 31 – siltstone). Further west, on the north side of the road cut at N47˚59.142 / W066˚42.096, further sediments are exposed from which 5 samples were collected (BNB16 – coal; BNB17 – siltstone; BNB18 – siltstone with fragments of the plant Taeniocrada (see also Kennedy et al. 2013 for a discussion of plant fragments recovered from this section); BNB 19 directly above BNB18; BNB20 directly below BNB18). Slightly further west Sample BNB21 (dark organic rich shale) was collected from the sediments that unconformably overlie a hummocky volcanic surface well exposed in the road cut. A similar horizon was collected (BNB22) on the south side of the road cut.

The samples all yield essentially the same spore assemblage (Table 2). It is dominated by simple Ambitisporites, Retusotriletes, Apiculiretusispora and Dibolisporites but with rare more elaborate spores. The spore assemblage can be equated with the PE Spore Assemblage Biozone of Richardson and McGregor (1986) indicating an early (but not earliest) Pragian - ?earliest Emsian age. It contains both of the eponymous species and numerous other species characteristic of this zone (e.g. Brochotriletes foveolatus?, Dictyotriletes favosus, Clivosispora verrucata). This zone equates to the PoW Oppel Zone of Streel et al. (1987). The presence of Dictyotriletes subgranifer may restrict the assemblage to the Su Interval Zone of Streel et al. (1987) constraining the age to late Pragian - ?earliest Emsian. All of the samples yield only spores and plant fragments with no marine elements suggesting deposition in a subaerial environment.

5.4. Section C *(Val d'Amour* Formation / Campbellton Formation contact)

There is an excellent section purportedly representing the contact between the Val D'Amour and Campbellton formations exposed in the roadcut of Route 134 Beauvista Street that heads northwest from Sugarloaf Mountain towards the Restigouche River. The roadcut exposes mainly tuffs, but contains a thin sedimentary sequence that Miller (2007, p.983) considers to "…sit at the base of the Campbellton Formation in contact with the Val d'Amour Formation Rhyolite.". It is from this section that Doran (1980) described specimens of the trimerophyte plant Psilophyton crenulatum exceptionally preserved by a fall of volcanic ash (plant locality Q of Gensel & Andrews (1984) and Gensel et al. (1991)). McGregor (in Doran 1980) reported on a spore assemblage recovered from the sediments. He equated the spore assemblages with the CE and AL(S) zones of McGregor (1977). This was based on the presence of Brochotriletes hudsonii, Camptozonotriletes caperatus, Dictyotriletes canadensis, D. emsiensis, Emphanisporites erraticus, E. schultzii and ?Enigmophytospora simplex. A sample was collected during this study (Appendix 1) and based on the spores present (Table 2) it is assigned to the AS Spore Assemblage Biozone of Richardson and McGregor (1986) which is equivalent to the AB Oppel Zone of Streel et al. (1987). These designations were based on the presence of all of the nominal species of the zones and also general consideration of the composition of the assemblage. This suggests an early Emsian age. Only terrestrial palynomorphs were recovered suggesting that the sediments accumulated as terrestrial fluvial-lacustrine deposits between ash falls directly onto the land surface.

5.5. Section D (Campbellton Formation Western Belt sections I & II sensu Kennedy & Gibling 2011)

The Western Belt of the Campbellton Formation includes Sections I and II of Kennedy & Gibling (2011). It contains a basal contact between Val d'Amour Formation rhyolites and basal sediments of the Campbellton Formation as described in Wilson et al. (2005) and Kennedy and Gibling (2011, p. 1574). A radiometric age of 407.4 (+/-0.8) Ma has been obtained from the rhyolites (Wilson et al. 2004, 2005). Gensel and Albright (2006) note that spore assemblages recovered from this sequence belong to the AS Spore Assemblage Biozone of Richardson & McGregor (1986) and "The presence of Calyptosporites heisdorfensis indicates an age no older than late Emsian (McGregor, written communication to McCutcheon 1996)".

A rich invertebrate and fish fauna occurs in these beds (Whiteaves 1881; Jones 1889; Woodward 1892; Traquair 1893; Miller et al. 2003; Miller 2007). Kennedy and Gibling (2011) interpreted Section I as a coastal deltaic sequence containing both aquatic fauna and plant remains but noted that it is difficult to decide if the delta was feeding into a lacustrine, brackish or marine environment. Arguments have previously been put forward for the non-marine affinities of various fish (Kennedy and Gibling 2011) and invertebrates (Morris 1985; Gray 1988) recovered from these beds. However, both Blieck and Cloutier (2000) and McGregor (in Gamba 1990) report the presence of marine acritarchs and prasinophcean cysts.

Section II is interpreted as fluvial based on sedimentological grounds (Kennedy and Gibling 2011). Plant locality 3 of Grierson and Hueber (1968) (GH3) occurs low in section I (Figs 3-4).

Samples BNB36-41 are from Section I. BNB36b is the lowest in the sequence and is at the unconformity where a mudstone fills a fissure in the Val d'Amour Formation rhyolites. BNB36a is from indurated sediments directly above this and represents a fish bed. This locality was termed the "Athoville Section" by Miller (2007). Higher in the sequence samples BNB37 and BNB38 are mudstones containing ostracods and sample BNB39 is a mudstone slightly higher in the sequence. Samples BNB40-41 are from another fish/eurypterid bed (Miller 2007). BNB40 is from the actual fish/eurypterid bed and is extremely hard. Sample BNB41 is from directly below this and is a softer plant hash bed. Sample BNB35 is from east and belongs to Section II and probably represents the highest beds exposed in the sequence.

The samples all yield essentially the same spore assemblage (Table 2). It is dominated by simple Retusotriletes, Apiculiretusispora and Dibolisporites but with rare more elaborate spores. The spore assemblage can be equated with the AS Spore Assemblage Biozone of Richardson and McGregor (1986) indicating an early - mid Emsian age. It contains both of the eponymous species and numerous other species characteristic of this zone (e.g. Acinosporites lindlarensis, Dictyotriletes canadensis, Emphanisporites schultzii). The assemblage can be correlated with the AB Oppel Zone of Streel et al. (1987) suggesting a more restricted early Emsian age. Marine palynomorphs, in the form of acritarchs, are relatively common in samples BNB40, BNB41 and BNB35 suggesting some marine influence higher in the sequence.

5.6. Section E (Campbellton Formation Eastern Belt Section III sensu Kennedy & Gibling 2011)

Kennedy and Gibbling (2011)'s section III is a 250m+ section with sediment intermittently exposed that covers the eastern end of the Eastern Belt of the Campbellton Formation. Productive samples in this study are currently restricted to strata in the lower part of the sequence around plant localities N and M of Gensel and Andrews (1984) and Gensel et al. (1991) that include the type localities for Sawdonia acanthotheca (Gensel et al. 1975) and Zosterophyllum divaricatum (Gensel 1982a). A total of 6 samples were collected, from a variety of lithologies, but all yield essentially the same dispersed spore assemblage (Table 2). Previously, for plant locality M Gensel (1982a) reported McGregor pers. com. as suggesting that palynological analysis indicates an Emsian age and Gensel (1991) noted that D. C. McGregor, unpublished Geological Survey of Canada Report #F1-6-1979 suggested an early Emsian age. Gensel and Andrews (1984) and Gensel et al. (1991) indicated that the assemblage belonged to the PE Spore Assemblage Biozone of Richardson and McGregor (1986). We confirm this designation that suggests an early (but not earliest) Pragian - ?earliest Emsian age. The assemblage is dominated by simple Ambitisporites, Retusotriletes, Apiculiretusispora and Dibolisporites but with rare more elaborate spores. It contains both of the eponymous species of the zone and numerous other species characteristic of this zone (e.g. Brochotriletes foveolatus?, Camptozonotriletes caperatus, Dictyotriletes favosus, Clivosispora verrucata). The zone equates to the PoW Oppel Zone of Streel et al. (1987). The presence of Dictyotriletes subgranifer may restrict the assemblage to the Su Interval Zone constraining the age to late Pragian - ?earliest Emsian. All of the samples yield only spores and plant fragments with no marine elements.

Plant localities higher in the sequence (K and L in Andrews and Gensel 1984 and Gensel et al. 1991) are probably younger as they yield spore assemblages considered to belong to the AL(S) zone of McGregor (1977) (Andrews & Gensel 1984; Gensel et al. 1991; Kennedy et al. 2013). Li et al. (2000) reported that spore assemblages belonging to the AS Spore Assemblage Biozone were recovered from this higher sequence in the section. Unfortunately this study failed to recover productive palynological samples from this part of the section.

5.7. Section F (Campbellton Formation Eastern Belt Section IV lower part sensu Kennedy & Gibling 2011)

Kennedy and Gibbling (2011)'s section IV covers the western end of the Eastern Belt of the Campbellton Formation and essentially consists of two separated sections: a lower 28 m section and an upper18 m section separated by ca. 126 m of section. We subdivided these into Section F (lower) and Section G (upper).

Section G is very rich in plant beds including plant localities F, E, A, G and H of Gensel and Andrews (1984) and Gensel et al. (1991). Gensel (1982a) reported that dispersed spore assemblages belonging to the lower Grandispora subzone of McGregor (1977) indicated a late Emsian age for plant locality A (D. C. McGregor, unpublished Geological Survey of Canada Report #F1-6-1979). Gensel (1982b) reported that dispersed spore assemblages belonging to the Grandispora subzone of McGregor (1973) indicated a late but not latest Emsian age for plant locality E (D. C. McGregor, unpublished Geological Survey of Canada Report F1-11-1981). Gensel and Albright (2006) suggested that plant locality F belonged to the AS Spore Assemblage Biozone of Richardson and McGregor (1986). Jensen and Gensel (2013) noted that McGregor, in a 1979 pers. comm. to Gensel, suggested that the three plant localities A, G and H all belonged to the lower Grandispora subzone of McGregor (1977).

Samples were collected from throughout section F including plant beds E and A (Appendix 1). All of the samples yield essentially the same dispersed spore assemblage (Table 2). This can be equated with the AS Spore Assemblage Biozone of Richardson and McGregor (1986) indicating an early - mid Emsian age. It contains both of the eponymous species and other species characteristic of this zone (e.g. Acinosporites lindlarensis and Emphanisporites schultzii). Convincing examples of Grandispora douglastownense are not present in the samples studied precluding assignment to the overlying DE Spore Assemblage Biozone of Richardson & McGregor (1986). The spore assemblage can be equated to the AB Oppel Zone of Streel et al. (1987) suggesting a more restricted early Emsian age (Fig. 4). Marine palynomorphs, in the form of acritarchs, occur rarely in sample BNB12 high in the section.

5.8. Section G (Campbellton Formation Eastern Belt Section IV upper part sensu Kennedy & Gibling 2011)

Section G is from the upper18 m of Kennedy and Gibbling (2011)'s section IV (see above). It contains the important plant localities B and I of Gensel and Andrews (1984) and Gensel et al. (1991). Andrews et al. (1975) reported that McGregor pers. com. suggested plant locality B was late Emsian (uppermost Lower Devonian) based on spore studies. Subsequently, Gensel (1982a) noted that McGregor, unpublished Geological Survey of Canada Report #F1-6-1979, suggested a late Emsian age. Gensel and Andrews (1984) and Gensel et al. (1991) placed plant locality B as the youngest in the Campbellton Formation and belonging to the Grandispora subzone of the annulatus-lindlarensis zone of McGregor (1977). Gensel and Kasper (2005) reported McGregor (pers. comm. 1975) as stating they belong to the Grandispora subzone of the annulatus-lindlarensis zone of McGregor (1977) which is equivalent to high in the AS Spore Assemblage Zone of Richardson & McGregor (1986).

Samples were collected from throughout section G including plant beds I and B (Appendix 1). All of the samples yield essentially the same dispersed spore assemblage (Table 2). They belong to the DE Spore Assemblage Biozone of Richardson and McGregor (1986) suggesting a late Emsian-?earliest Eifelian age. The assemblage is dominated by simple Retusotriletes, Apiculiretusispora and Dibolisporites but with rare more elaborate spores. It contains one of the eponymous species of the zone (Grandispora douglastownense) and other species characteristic of this zone (e.g. Ancyrospora loganii). The zone equates to the Cor and Pro (but not Vel) Interval zones of the AP Oppel Zone of Streel et al. (1987) (Fig. 4). Unfortunately none of the taxa that designate Interval Zones are present in the Canadian spore assemblages so further subdivision is not possible. Marine palynomorphs, in the form of acritarchs, occur rarely in sample BNB48, BNB15, BNB47 suggesting possible marine influence (or reworking).

5.9. Section H (Campbellton Formation Eastern Belt Section V sensu Kennedy & Gibling 2011)

No productive samples were recovered from these strata (Appendix 1).

5.10. Section I (Campbellton Formation Eastern Belt Section VI sensu Kennedy & Gibling 2011)

No productive samples were recovered from these strata (Appendix 1).

6. Discussion

Biostratigraphical analysis of dispersed spore assemblages from the best exposed sections of the Val d'Amour and Campbellton formations of northern New Brunswick enable their age dating and correlation (Fig. 4). It is evident that there is a complex relationship regarding the boundary between the two formations. The Val d'Amour Formation is predominantly volcanic consisting of lavas and ash falls. However, sedimentary intercalations are present throughout. In the east (Section A) they are marine and older (PE SAB/PoW OZ[?W IZ]). In the west (Section B) they are terrestrial and slightly younger (PE SAB/PoW OZ[Su IZ]). Situating the actual boundary between the two formations is problematic as it would appear that sedimentary intercalations increase in frequency but volcanic activity persists. Thus it is impossible to draw a boundary between a solely/predominantly volcanic and a solely/predominantly sedimentary formation. In the west we have Section C, with sediments of (AS SAB/AB OZ) age intercalated among volcanic rocks, in very close vicinity to basal sediments of Section D, apparently unconformably overlying a volcanic sequence of exactly the same spore zone and age. In contrast, however, in the east the thick unit of basal sediments of Section E, that overlies a predominantly volcanic sequence, is older and of (PE SAB/PoW OZ[Su IZ]) age. This sedimentary sequence is relatively thick and possibly extends up into the succeeding spore zone (AS SAB/AB OZ) but without the high proportion of associated volcanic rocks as seen in the west in Section C.

Higher sediments in the sequence, which clearly belong to the Campbellton Formation rather than Val d'Amour Formation, are demonstrably younger. However, their relationships are not as clear cut as previously considered. To the west Sections F and G, previously considered to represent a continuous sequence, are shown to differ in age. Section F is older and of (AS SAB/AB OZ) age. Section G is young and of (DE SAB/AP OZ pars [Cor and Pro IZ]) age. This suggests a significant gap in the sequence between Sections F and G (although the magnitude of this gap may appear exaggerated because of the absence of critical taxa used to identify Oppel and Interval zones in the scheme of Streel et al. 1987). Unfortunately palynomorph assemblages have not been recovered from Section H and I to the east.

The new age dates and stratigraphical correlations have important implications regarding the ages of the important terrestrial plant/animal and freshwater aquatic invertebrate/vertebrate fossil assemblages described from these sequences. Details of the plant assemblages is summarised in Tables 3-4 with their stratigraphical relationships illustrated in Fig. 4. It is noteworthy that the numerous plant localities belong to three different spore zones.

The oldest plant localities (N and M=?H1) belong to the PE SAB (Fig. 4). Sawdonia acanthotheca and Zosterophyllum divaricatum are exclusive this zone (Table 4). The spore assemblages are dominated by Retusotriletes spp. (Table 2) that are produced by these zosterophylls (Table 3).

At least 9 plant assemblages belonging to the AS SAB occur in four of the sections (C,D,E,F) (Fig. 4). They yield rich plant assemblages containing rhyniophytes, zosterophylls, lycopsids, trimerophytes and various plants of uncertain affinity (Bitelaria, Chaleuria, Loganophyton). The spores Retusotriletes spp. and Apiculiretusisporites spp., known to be produced by zosterophylls and trimerophytes (Table 3), dominate these assemblages. The spores of Chaleuria (Camarozonotriletes sextantii) and Leclercqia (Acinosporites lindlarensis) are locally abundant.

Plant assemblages I and B, from section G, belong to the DE SAB (Fig. 4). They yield rich plant assemblages containing rhyniophytes, zosterophylls, lycopsids, trimerophytes and the more complex/advanced plant of uncertain affinity Oocampsa (Andrews et al. 1975) (Table 4). The spores Retusotriletes spp. and Apiculiretusisporites spp., known to be produced by zosterophylls and trimerophytes (Table 3), still dominate these assemblages. The spores of Oocampsa (Grandispora douglastownense) appear for the first time and are relatively abundant. Other more complex spores, such as Ancyrospora loganii with its grapnel-tipped processes, appear for the first time. Spores bearing grapnel-tipped processes are most likely produced by lycopsids (Wellman 2002).

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FIGURE CAPTIONS

Fig. 1. Location map of the study area showing the distribution of the geological formations and the location of the studied sections (A-I).

Fig. 2. Stratigraphical sequence in the region illustrating the relationship of the sections studied (A-I). The location of a radiometric age date is indicated with an asterisk.

Fig. 3. Details of the stratigraphic sequences (modified from Kennedy and Gibling 2012).

Fig. 4. Summary diagram indicating the spore zonation, ages and correlation of the studied sections (A-I).

PLATE CAPTIONS

Plate I. Dispersed spores from the Lower Devonian Val d'Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x1000. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. Retusotriletes sp. [BNB11/1 (Q44)].

2. Retusotriletes triangulatus (Streel) Streel 1967 [BNB45/1 (G46/4)].

3. Retusotriletes cf. rotundus (Streel) Streel 1967 [BNB47/1 (T27)].

4. Retusotriletes eslae Cramer and Diez 1975 [BNB44/1 (O31/1)].

5. Retusotriletes eslae Cramer and Diez 1975 [PG6/1 (N25/3)].

6. Apiculiretusispora plicata (Allen) Streel 1967 [BNB45/1 (Y30/3)].

7. Apiculiretusispora plicata (Allen) Streel 1967 [BNB45/1 (C37/4)].

8. Apiculiretusispora minor McGregor 1973 [BNB11.1 (E50/2)].

9. Apiculiretusispora minor McGregor 1973 [BNB45/1 (D37/2)].

10. Apiculiretusispora minor McGregor 1973 [BNB45/1 (O37)].

11. Apiculiretusispora arenorugosa McGregor 1973 [BNB11/1 (R23)].

12. Apiculiretusispora brandtii Streel 1964 [BNB45/1 (U55)].

Plate II. Dispersed spores from the Lower Devonian Val d'Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x1000 unless otherwise stated. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. Dibolisporites echinaceus (Eisenack) Richardson 1965 [BNB42/1 (W55/3)].

2-3. Dibolisporites quebecensis McGregor 1973 [BNB35/1 (B37/3)].

4. Dibolisporites quebecensis McGregor 1973 [BNB30/1 (C37/2)].

5. Dibolisporites eifeliensis (Lanninger) McGregor 1973 [BNB30/1 (E29/2)].

6. Dibolisporites eifeliensis (Lanninger) McGregor 1973[BNB39/1 (O24)].

7. Dibolisporites wetteldorfensis Lanninger 1968 [BNB29/1 (W29/3)].

8-9. Dibolisporites wetteldorfensis Lanninger 1968 [BNB23 (G37/4)].

10. Dictyotriletes emsiensis (Allen) McGregor 1973 [BNB40/1 (M28/3)].

11. Dictyotriletes subgranifer McGregor 1973 [BNB23/1 (X32)].

12. Dictyotriletes favosus McGregor & Camfield 1976 [BNB42/1 (J28/1)].

13. Dictyotriletes emsiensis (Allen) McGregor 1973 [BNB33/1 (H46/3)].

14. Dictyotriletes ?gorgoneus Cramer 1966 [BNB34/1 (P34)].

15. Dictyotriletes canadensis McGregor 1973 [BNB40/1 (G29)] Magnification x500.

Plate III. Dispersed spores from the Lower Devonian Val d’Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x1000. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. Ambitisporites sp. [BNB33/1 (D38/3)].

2. Crassitate trilete spore with a distal ornament of anastomosing muri [BNB45/1 (J49/3)].

3. Crassitate trilete spore with a distal ornament of anastomosing muri [BNB34/1 (N40/1)].

4-5. Synorisporites cf. verrucatus Richardson & Lister 1969 [BNB33/1 (G30)].

6. Raistrickia sp. [BNB36A/1 (N45/1)].

7. Raistrickia sp. [BNB33/1 (L45/4)].

8. Amicosporites jonkeri Riegel 1973 [BNB33/1 (L29/4)].

9. Synorisporites papillensis McGregor 1973 [BNB33/1 (U40/2)].

10. Verrucosisporites sp. A [PG3/1 (N40/1)].

11. Crassitate trilete spore with a distal ornament of verrucae [BNB40/1 (O46/2)].

12. Lycopodiacidites ogygius McGregor 1973 [BNB23/1 (M40)].

13. Verruciretusispora multituburculata (Lanninger) McGregor 1973 [BNB39/1(Q34/4)].

14. Verrucosisporites sp. A [BNB39/1 (M30/3)].

15. Verruciretusispora dubia (Eisenack) Richardson & Rasul 1978 [BNB47/1 (F50)].

16. Verrucosisporites sp. A [BNB37/1 (Q31)].

17. Verrucosisporites devonicus McGregor 1973 [BNB49/1(U40/4)].

Plate IV. Dispersed spores from the Lower Devonian Val d'Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x1000. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. Verrucosisporites polygonalis? Lanninger 1968 [BNB35/1 (J30/4)].

2. Verrucosisporites polygonalis? Lanninger 1968 [BNB45/1 (D37)].

3. Brochotriletes sp. B [BNB40/1 (T54)].

4. Brochotriletes [PG2/1 (S32)].

5. Clivosispora verrucata McGregor 1973 [PG6/1 (G41.4)].

6. Clivosispora verrucata McGregor 1973 [BNB42/1 (T25)].

7. Camarozonotriletes sextantii McGregor & Camfield 1976 [PG3/1(F31/2)].

8. Camarozonotriletes sextantii McGregor & Camfield 1976 [BNB11/1 (B46.3)].

9. Brochotriletes foveolatus? Naumova 1953 [BNB23/1 (M40)]. Singleton.

10. Brochotriletes bellatulus Steemans 1989 (=Brochotriletes sp. B McGregor 1973) [BNB42/1 (G49/3)].

11. Brochotriletes sp. A McGregor 1973 [BNB48/1 (M52)].

12. Tetrad of Brochotriletes robustus (Scott & Rouse) McGregor 1973 [BNB23/1 (N44/3)].

13. Brochotriletes robustus (Scott & Rouse) McGregor 1973 [PG2/1 (V43)].

14. Camarozonotriletes sextantii McGregor & Camfield 1976 [BNB05/1 (Q34)]. Spore enclosed within a large laevigate body with trilete spore as also reported by Andrews et al. (1974).

Plate V. Dispersed spores from the Lower Devonian Val d'Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x1000 unless otherwise stated. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. Emphanisporites annulatus McGregor 1961 [BNB47/1(M36/4)].

2. Emphanisporites erraticus (Eisenack) McGregor 1961 [BNB35/1 (L37)].

3. Emphanisporites schultzii McGregor 1973 [PG2/1 (T38/1)].

4. Emphanisporites rotatus (McGregor) McGregor 1973 [PG2/1 (T30/2)].

5. Emphanisporites genselae sp. nov. Holotype. [BNB29/1(K41/3)].

6. Emphanisporites genselae sp. nov. [BNB29/2 (R37/2)].

7. Emphanisporites genselae sp. nov. [BNB29/1 (W38)].

8. Emphanisporites genselae sp. nov. [BNB30/1 (Y37/3)].

9. Emphanisporites spp. Singleton. [BNB36A/1(Q37/2)].

10. Emphanisporites spp. Singleton. [PG2/1 (W30)].

11. Emphanisporites micrornatus Richardson & Lister 1969 [BNB29/1 (C30/1)].

12. Emphanisporites morrisae sp. nov. Holotype. [BNB43/1 (Y40/1)]. Magnification x500.

13. Emphanisporites morrisae sp. nov. [BNB20/1 (G36/4)].

14. Emphanisporites morrisae sp. nov. [BNB33/1(N43)].

Plate VI. Dispersed spores from the Lower Devonian Val d'Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x1000. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. ?Archaeozonotriletes sp. McGregor 1973 [PG2/1 (U40/4)].

2. Archaeozonotriletes chulus (Cramer) Richardson & Lister 1969 [BNB30/1 (P40)].

3. Cymbosporites yorkensis McGregor 1973 [BNB23/1 (P25/1)].

4. Acinosporites lindlarensis Riegel 1968 [PG2/1 (044/1)].

5-6. Chelinospora spp. McGregor 1973 [BNB36A/1 (R31/1)].

7. Acinosporites lindlarensis Riegel 1968 [BNB38/1 (E43/1)].

8-9. Chelinospora spp. [BNB45/1 (Y41/1)].

10. Chelinospora spp. [PG6/1 (X41)].

11. Acinosporites lindlarensis Riegel 1968 [BNB11/1 (E33/3)].

Plate VII. Dispersed spores from the Lower Devonian Val d'Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x1000 unless otherwise stated. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. Zonotriletes brevivelatus Breuer and Steemans 2013 [BNB45/1 (M25/3)].

2-3.Camptozonotriletes sp. in McGregor 1973. Singleton. [BNB36A/1 (G46)].

4. Zonotriletes brevivelatus Breuer and Steemans 2013 [BNB45/1 (V28/2)].

5. Camptozonotriletes caperatus McGregor 1973 [BNB45/1 (D24)].

6. Zonate-pseudosaccate spore with conate ornament. Singleton. [BNB32/1 (V42)].

7. Zonotriletes brevivelatus Breuer and Steemans 2013 [BNB45/1 (R31/2)].

8. Camptozonotriletes caperatus McGregor 1973 [BNB38/1 (L43/3)].

9. Pseudodyadospora petasus Wellman & Richardson 1993 [PG6/1 (X31/3)].

10. Zonotriletes brevivelatus Breuer and Steemans 2013 [BNB43/1 (S48/3)].

11. Camptozonotriletes caperatus McGregor 1973 [PG3/1 (U35/1)]. Magnification x500.

Plate VIII. Dispersed spores from the Lower Devonian Val d'Amour and Campbellton formations of New Brunswick (eastern Canada). All spores at magnification x500 unless otherwise stated. Taxon name followed by sample/slide number and England Finder co-ordinates.

1. Grandispora douglastownense McGregor 1973 [PG3TOP/2 (R41/1)].

2. Grandispora douglastownense McGregor 1973 [PG3TOP/14 (U32)].

3. Grandispora douglastownense McGregor 1973 [PG3TOP/14 (V32/2)].

4. Grandispora douglastownense McGregor 1973 [PG3TOP/14 (V32/4)]. Specimen laterally compression.

5-6. Ancyrospora loganii McGregor 1973 [BNB47/1 (K47/4)]. (6) at magnification x1500. Specimen laterally compressed. Close up of ornament illustrates bifurcate-tipped processes.

7. Ancyrospora loganii McGregor 1973 [BNB15/1 (X37)]. Magnification x1000.

TABLES

Table 1. Dispersed spore taxa identified in this study.

Retusotriletes eslae Cramer & Diez 1975 [Plate 1, figs 4-5]
Retusotriletes cf. rotundus (Streel) Streel 1967 [Plate 1, fig. 3]
Retusotriletes triangulatus (Streel) Streel 1967 [Plate 1, fig. 2]
Retusotriletes spp. [Plate 1 fig. 1]
Apiculiretusispora arenorugosa McGregor 1973 [Plate 1, fig. 11]
Apiculirestusispora brandtii Streel 1964 [Plate 1, fig. 12]
Apiculiretusispora minor McGregor 1973 [Plate 1, figs 8-10]
Apiculiretusispora plicata (Allen) Streel 1967 [Plate 1, figs 6-7]
Apiculiretusispora spp.
Dibolisporites echinaceus (Eisenack) Richardson 1965 [Plate 2, fig. 1]
Dibolisporites eifeliensis (Lanninger) McGregor 1973 [Plate 2, figs 5-6]
Dibolisporites quebecensis McGregor 1973 [Plate 2, figs 2-4]
Dibolisporites wetteldorfensis Lanninger 1968 [Plate 2, figs 7-9]
Dibolisporites spp.
Dictyotriletes canadensis McGregor 1973 [Plate 2, fig. 15]
Dictyotriletes emsiensis (Allen) McGregor 1973 [Plate 2, figs 10,13]
Dictyotriletes favosus McGregor & Camfield 1976 [Plate 2, fig. 12]
Dictyotriletes ?gorgoneus Cramer 1966 [Plate 2, fig. 14]
Dictyotriletes subgranifer McGregor 1973 [Plate 2, fig. 11]
Ambitisporites sp. [Plate 3, fig. 1]
Amicosporites jonkeri Riegel 1973 [Plate 3, fig. 8]
Raistrickia sp. [Plate 3, figs 6-7]
Synorisporites papillensis McGregor 1973 [Plate 3, fig. 9]
Synorisporites cf. verrucatus Richardson & Lister 1969 [Plate 3, figs 4-5]
Crassitate trilete spore with a distal ornament of anastomosing muri [Plate 3, figs 6-7]
Crassitate trilete spore with a distal ornament of verrucae [Plate 3, fig. 9]
Lycopodiacidites ogygius McGregor 1973 [Plate 3, fig. 12]
Verruciretusispora dubia (Eisenack) Richardson & Rasul 1978 [Plate 3, fig. 15]
Verruciretusispora multituburculata (Lanninger) McGregor 1973 [Plate 3, fig. 13]
Verrucosisporites devonicus McGregor 1973 [Plate 3, fig. 17]
Verrucosisporites polygonalis? Lanninger 1968 [Plate 4, figs 1-2]
Verrucosisporites sp. A [Plate 3, figs 10,14,16]
Brochotriletes bellatulus Steemans 1989 (=Brochotriletes sp. B McGregor 1973) [Plate 4, fig. 10]
Brochotriletes foveolatus? Naumova 1953 [Plate 4, fig. 9]
Brochotriletes robustus (Scott & Rouse) McGregor 1973 [Plate 4, figs 12-13]
Brochotriletes sp. A McGregor 1973 [Plate 4, fig. 11]
Brochotriletes sp. B [Plate 4, figs 3-4]
Emphanisporites annulatus McGregor 1961 [Plate 5, fig. 1]

Emphanisporites erraticus (Eisenack) McGregor 1961 [Plate 5, fig. 2]
Emphanisporites genselae sp. nov. [Plate 5, figs 5-8]
Emphanisporites micrornatus Richardson & Lister 1969 [Plate 5, fig. 11]
Emphanisporites morrisii sp. nov. [Plate 5, figs 12-14]
Emphanisporites rotatus (McGregor) McGregor 1973 [Plate 5, fig. 4]
Emphanisporites schultzii McGregor 1973 [Plate 5, fig. 3]
Camarazonotriletes sextantii McGregor & Camfield 1976 [Plate 4, figs7-8,14]
Clivosispora verrucata McGregor 1973 [Plate 4, figs 5-6]
Archaeozonotriletes chulus (Cramer) Richardson & Lister 1969 [Plate 6, fig. 2]
?Archaeozonotriletes sp. McGregor 1973 [Plate 6, fig. 1]
Cymbosporites yorkensis McGregor 1973 [Plate 6, fig. 3]
Chelinospora spp. [Plate 6, figs 5-6,8-9,10]
Acinosporites lindlarensis Riegel 1968 [Plate 6, figs 4,7,11]
Ancyrospora loganii McGregor 1973 [Plate 8, figs 5-7]
Zonotriletes brevivelatus Breuer & Steemans 2013 [Plate 7, figs 1,4,7,10]
Camptozonotriletes caperatus McGregor 1973 [Plate 7, figs 5,8,11]
Camptozonotriletes sp. in McGregor 1973 [Plate 7, figs 2-3]
Grandispora douglastownense McGregor 1973 [Plate 8, figs 1-4]
Zonate spp. [Plate 7, figs 2-3,6]
Pseudodyadospora petasus Wellman & Richardson 1993 [Plate 7, fig. 9]
Tetrahedraletes medinensis (Strother & Traverse) Wellman & Richardson 1993

Table 2. Distribution of spore taxa from the sections/samples analysed.

Table 3. Plant taxa reported from the Val d'Amour and Campbellton formations and details of their in situ spores. In terms of localities: SI – SVI refer to the sections of Kennedy & Gibling (2011); A-Q refer to the plant-bearing localities of Gensel & Andrews (1984) and Gensel et al. (1991); GH1-GH3 refer to plant-bearing localities of Grierson & Hueber (1968); H1-H3 refer to plant-bearing localities of Hueber (1968). Facies Associations (FA) are from Kennedy et al. (2012b). The stratigraphical relationship of these localities, some of which represent the same locality, is summarised in Fig. 4.

Table 4. Plant taxa reported from individual localities. Data is from references in Table 3 supplemented by data in Kennedy et al. (2012). In terms of localities: Sections A-H refer to those used in this paper; SI – SVI refer to the sections of Kennedy & Gibling (2011); A-Q refer to plant-bearing localities of Gensel & Andrews (1984) and Gensel et al. (1991); GH1-GH3 refer to plant-bearing localities of Grierson & Hueber (1968); H1-H3 refer to plant-bearing localities of Hueber (1968). Facies Associations (FA) are from Kennedy et al. (2012b). The stratigraphical relationship of these localities, some of which represent the same locality, is summarised in Fig. 4. * refers to spore age constraints reported by McGregor (see Li et al. 2000).

APPENDIX

Appendix 1. Details of samples. Sections A-I refer to sections collected. The number in Parenthesis (I-VI refers to the equivalent section of Kennedy and Gibling 2012). + indicates productive samples that were logged and counted.