



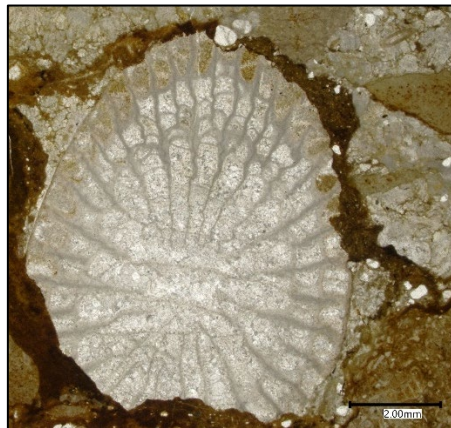
*INTERNATIONAL UNION OF  
GEOLOGICAL SCIENCES  
COMMISSION ON STRATIGRAPHY*

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**SUBCOMMISSION ON  
DEVONIAN STRATIGRAPHY**

**NEWSLETTER No. 37**

**R.T. BECKER, Editor  
WWU Münster  
Germany**



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# SDS NEWSLETTER 37

## Editorial

The SDS Newsletter is published annually by the International Subcommission on Devonian Stratigraphy of the IUGS Subcommission on Stratigraphy (ICS). It publishes reports and news from its membership, scientific discussions, obituaries of Devonian researchers, original science contributions (SDS Documents), scientific reviews, Minutes of SDS Meetings, SDS reports to ICS, general IUGS information, information on past and future Devonian meetings and research projects, and summaries of new Devonian publications.

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**Please ease the editing by strictly keeping the uniform style of references, as shown in the various sections!**

The Newsletter contributions should be quoted as: “SDS Newsletter, 37: x-y.”

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## Quantitative approach by miospores of the Devonian-Carboniferous transition

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### Abstract

The abundance of selected species at geological scale has been noted to be a useful criterium to correlate sedimentary sequences. In this work, we take as an example two groups of species, the *lepidophyta* and *pusillites*, which are noted to characterize the Devonian-Carboniferous transition. From formerly obtained results in rare Famennian coal-beds, it is known that the parent plants of the two groups of spores were living near swamps in deltaic marshes. Spores (miospores), often with diameters around 50 µm, have the advantage, compared to other microfossils, to be produced by each individual terrestrial plant in thousands of specimens, which are transported into the sediments by wind and fluvial or marine currents. In this context, the group *lepidophyta*, the most widespread and stratigraphically narrowest, was chosen to be considered in priority.

We selected the geological sections studied in the northern Rhenish Massif (Sauerland, Germany) as reference because they are the best known for animal microfossils, such as goniatites, in particular those species that had been used to fix the DCB before the use of conodonts (and spores), which prevail to-day. In the reference sections in Sauerland, the extinction of the group *lepidophyta* is observed in two steps. Initially it is most often dominant, with more than 50 % of the total of all spores counted. The first extinction step is characterized by a strong decline of the group *lepidophyta*, which persist to be present in all samples, but rarely exceeds 5 % of the total of all spores counted. The second extinction step led to the complete absence of the group.

These two extinction steps have been noted in several localities in Europe (Ireland, England, Poland, Portugal) but also in Greenland in a sedimentary

sequence in which the extinction of the group *lepidophyta* is linked to warming and humidity increase and the collapse of the final Devonian glacial episode.

We have searched this interval in North and South America, but most of palynological analysis have no quantitative approach, and often the extinction level of the DCB is hampered by the erosion of Upper Devonian deposits or unfavorable lithofacies for palynology. Additionally, the presence of reworked Devonian palynomorphs is frequent and, especially, those from the Upper Devonian were redeposited into Mississippian deposits in South America.

### 1. Introduction

Since the middle of last century (KEDO 1957), attention has been drawn on the significance of Famennian species often designated then as belonging to the genus *Hymenozonotriletes* NAUMOVA, but known, now, as belonging to the genera *Retispora* and *Vallatisporites*. Quantitative studies bearing these taxa were used to approach the definition of the Devonian/Carboniferous boundary (see STREEL 1970, pp. 121-147, and CHIBRIKOVA et al. 1978, fig. 2). In the present contribution, we will focus on the transitional period between the *Retispora* group optimum (4 and 5 in Fig. 1) and the *Vallatisporites* group optimum (6, 7, and 8 in Fig. 1) time-interval, which corresponds more or less to the paleo climatic events called Hangenberg Crisis (STREEL 1999).

Spores (miospores), often with diameters around 50 µm, have the advantage, compared to other microfossils, to be produced by each individual terrestrial plant in thousands of specimens, which are transported into the sediments by wind and fluvial or marine currents. The abundance of selected species at geological scale has been noted to be a useful criterium to correlate sedimentary sequences.

The intention is to consider the stratigraphic correlations available between miospores data and other micro- and macro-fossil groups helpful for age diagnostics, as well as the presence of diamictitic deposits within the postglacial sequence, and the eventual recognition of positive carbon isotope excursions (PCIE).

Most of the biostratigraphic data available for these time-intervals have been displayed in “assemblage zones”, rarely in “concurrent range zones”. Although, correlations with other groups of fossils other than miospores require the latter (STREEL & LOBOZIAK 1996).

Furthermore, the lowest record of any taxon (First Occurrence Biohorizon = FOB) is dependent of the amount of miospores observed below the FOB (ALPERN 1970) and, of course, of a homogenous concept of the involved taxon.

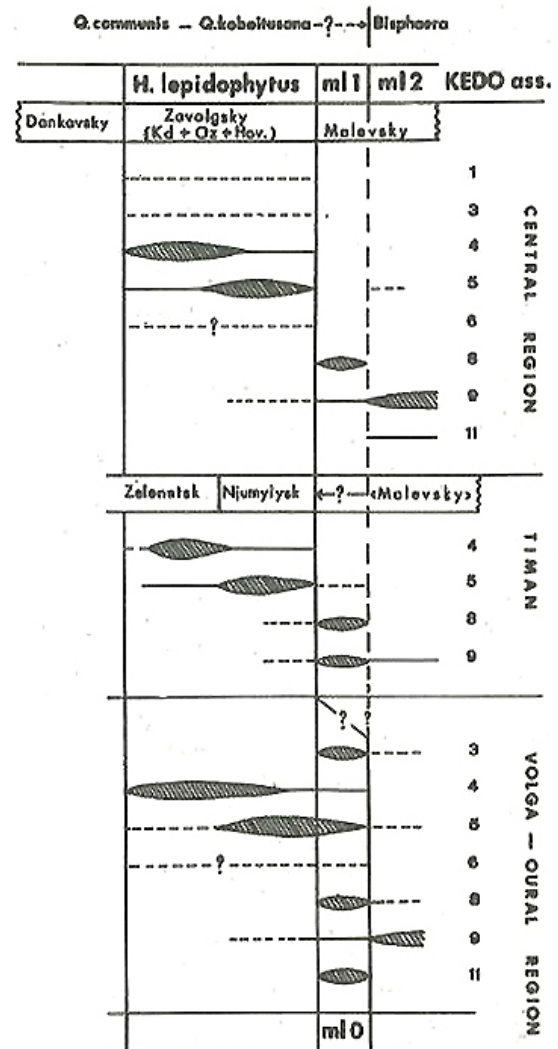
## 2. The *lepidophyta* Group

The *Retispora lepidophyta* FOB, base of the former LV miospore Zone (STREEL et al. 1987), equated to the base of Fa2d chronozone after BOUCKAERT et al. (1968), was recorded in the Chanxhe I section 20 cm higher than the base of Bed 94 of CONIL (1964). One specimen of 127 counted spores was found, followed successively by seven specimens of 224 counted spores, 10/203, 7/103, 28/631, 31/432, and more than 100 specimens in the biometric zone C, one meter higher than Bed 97 (STREEL et al. 1976, p. 29 and pl. 4. *Vallatisporites pusillites* was also first recorded at that last level.

A reexamination, with new slides of the same section (Chanxhe 1), led to the conclusion that the *Retispora lepidophyta* FOB (base of the LL miospore Zone) was about 2 m below the top of the Evieux Formation (in Bed 93 of CONIL 1964) and the first *Knoxisporites literatus* enters immediately above the top (MAZIANE-SERRAJ et al. 1999, 2007).

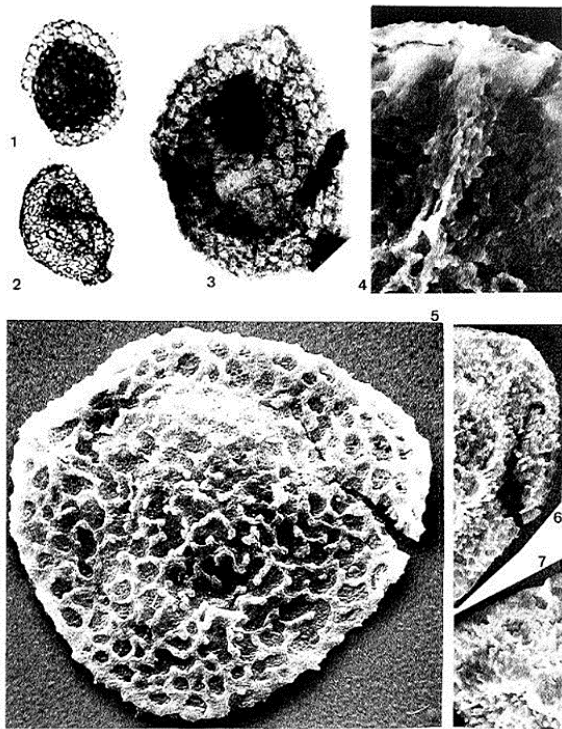
The sedimentary context of these FOBs was displayed in STREEL (1999, figs. 2 and 3) and dated as the Middle *expansa* conodont zone, characterizing the Fontin Event (HIGGS et al. 2013). In the Etroeungt area (northern France), the *Retispora lepidophyta* FOB is found (1/171 counted spores), in unit i of the “Schistes de l’EpINETTE”, i.e. immediately below the *Eoendothyra communis radiata* (Df3d) Zone, marking the base of the EpINETTE Event (CONIL et al. 1974; STREEL et al. 2005). The uppermost Famennian Substage, or Strunian, has been widely used and internationally in a

chronostratigraphic sense based on macrofossils described from the Etroeungt area. A new definition based on microfossils is still proposed for international agreement (STREEL et al. 1998, 2006) but is already widely used.



**Fig. 1.** Distribution of key spores on the Russian platform (CHIBRIKOVA et al. 1978). Data from RASKATOVA, UMNOVA, NASARENKO, BYVSHEVA and KHOLOVAYA (central region), SENNOVA (Timan), and BYVSHEVA (Volga-Ural region).

- 1 = “*macroreticulatus*”
- 2 = “*admirandus*”
- 3 = “*flexuosus-radiatus*”
- 4 = *lepidophytus* “*typicus*”
- 5 = *lepidophytus minor* and *tener*
- 6 = *Vallatisporites* n. sp. (*pusillites* DEL. & NEV.)
- 7 = *verrucosus*
- 8 = “*pusillites*” (*vallatus* HACQ.)
- 9 = “*Dictyotriletes*”
- 10 = *nitidus*
- 11 = *explanatus*



**Fig. 2.** Original reproduction of Plate IV from STEEMANS et al. (1996). **1, 5.** *Retispora lepidophyta* (KEDO) PLAYFORD 1976; 1. Eviex Formation, Langlier Quarry, Dinant Basin, Belgium, x 500; 5. SEM photo showing muri and additional ornament, well visible at the equator, x 2.500. **2, 6, 7.** *Retizonomonoletes hunanensis* FANG et al., 1993; 2. Oujiaichong Formation, Malanbian, Hunan, x 500; 6-7. SEM photo showing density of ornamentation, x 2.500. **3, 4.** *Retispora macroreticulata* (KEDO) BYVSHEVA 1985; 3. Eviex Formation, Eviex railway section, Dinant Basin, Belgium, x 500; 4. SEM photo showing muri and additional apiculate ornament, x 2.500.

The uppermost Famennian starts about at the level of the first occurrence of the Foraminifer *Quasiendothyra kobetusana* (or Df3e). It corresponds to the Upper *expansa* conodont zone (= *Bispathodus ultimus ultimus* Zone) and to the change from larger forms of *Retispora lepidophyta* sensu lato (or typical form) into *R. lepidophyta* var. *minor*.

*Retispora lepidophyta* var. *tener* of KEDO (1957 = *Retispora lepidophyta* type a of STREEL 1966) and *R. lepidophyta* var. *minor* also, appear slightly later than larger forms of *Retispora lepidophyta* sensu lato (or typical form), and increase in frequency closer to the Devonian-Carboniferous boundary. *Retispora lepidophyta*

var. *tener* is more frequently documented just below the DCB. It is distinguished from *Retispora lepidophyta* sensu lato (or typical form) due to its irregular pattern of foveolate/reticulum in distal face. It was attributed to a short event of abnormal spores (*tener* Eent) discussed in detail by FILIPIAK & RACKI (2010) and PRESTIANNI et al. (2016) (see also STREEL & STEEMANS 2020).

The taxonomical context of the FOB is, of course, often easier to control when used by the same researchers. Conflict may arise, however, as from the interpretation on a possible ancestor of *Retispora lepidophyta* named *R. l.* var. *macroreticulata* by KEDO or *Retispora macroreticulata* by BYVSHEVA 1985. These forms occur in the Ardennes area in the Uppermost *marginifera* conodont zone (STREEL & LOBOZIAK 1996), i.e. much below the *Retispora lepidophyta* FOB, as characterized above (Fig. 2). *Retispora archaeolepidophyta* (KEDO) MCGREGOR & CAMFIELD 1982 appearing in the Eifelian-Givetian to Frasnian is another example of a possible ancestor of *Retispora lepidophyta*, occurring much below the *Retispora lepidophyta* FOB.

Following F. L. STAPLIN (personal communication from 7.2.1971), below the larger forms of *Retispora lepidophyta* sensu lato (or typical form), known in the Famennian in Western Canada, specimens again become smaller, and are more granulose-apiculate than reticulate. They seem to represent another species.

Another misinterpretation may arise from the occurrence of malformed spores. This is perhaps the case with the abundant monolete spore named *Retizonomonoletes hunanensis* FANG et al., 1993, which, after GAO (1990), have the same time-range as *Retispora lepidophyta* from biozones LL to VI in the Malabian section (Hunan, South China, Fig. 2). This coincides with the Df3 Foraminifer Zone (HANCE et al. 1994).

*Retispora lepidophyta* was produced by a small, still unknown, annual, herbaceous, short living plant, without a strong vegetative growth,



and producing only sterile spores (MARSHALL 2021). Species of the *lepidophyta* group disappeared at the end of the Devonian (e.g. STREEL et al. 2000; MATIJA et al. 2020; MARSHALL et al. 2020).

### 3. The *pusillites* Group

*Hymenozonotriletes pusillites* KEDO, 1957 is known in the highest Zavolsk and Malevka beds in eastern regions of the Russian Platform (BYVSHEVA 1976) and was then considered to belong to what “western palynologists” were calling *Vallatisporites vallatus* HACQUEBARD, 1957. *Vallatisporites pusillites* (KEDO) DOLBY & NEVES 1970 was considered then to be different (CHIBRIKOVA et al. 1978).

Another confusion aroused with the definition of *Cirratriradites hystricosus* by WINSLOW in 1962, due to a gradual change of ornamentation from *Cirratriradites hystricosus* to *Vallatisporites vallatus* was suggested later by STREEL & TRAVERSE (1978) in DC strata from the Horseshoe Curve section in Pennsylvania, U.S.A.

Spores with the same size, but different sculpture, were described as *Hymenozonotriletes pusillites sensu lato* KEDO & GOLUBTSOV, 1971. KEDO indicated that it would be possible to recognize some variations or even new species within this taxon. The CIMP Working Group *Vallatisporites*, managed then by Bernard OWENS (unpublished, 2002-2006), had recorded 31 different species, which all show the characteristic vacuoles of the genus *Vallatisporites*. RICHARDSON et al. (2022) retained nine of these taxa, their stratigraphic distribution and a list of synonyms based on the analysis by AVCHIMOVITCH et al. (2021).

### 4. Palaeoenvironmental approaches

Coal beds and lateral fluvial mud incursions give obviously the best chance to reconstruct the palaeoenvironment of marsh complexes. Unfortunately, preserved Famennian coal beds are rather rare (e.g. PRESTIANNI et al. 2010).

1. One of these is at the locality of Elkins, Hampshire Formation, West Virginia (USA),

where both large deltaic marshes and smaller upland backswamp are dominated by the prefern *Rhacophyton* and its microspores known to belong to the *Diducites plicabilis-Auroraspora varia* Complex. “Other plants contributed to the swamp peats only as a result of transport during floods and storms or by increased proximity of flood plain communities to swamp as lateral encroachment occurred during ecological succession” (SCHECKLER 1986). Samples collected in and near coals in that locality do not contain *Retispora lepidophyta*, only *Vallatisporites hystricosus* (STREEL & SCHECKLER 1990).

Samples of coal (Samples Hc and Hc pyr on fig. 2 in STREEL & SCHECKLER 1990) contain only 3 or 4 % of *V. hystricosus* among a complete dominance of miospores of the *Diducites plicabilis-Auroraspora varia* Complex. On the contrary, Sample Hd coming from a more shaly part of a hummocky cross-stratified sandstone overlying the coal-bed, contains 34 % of *V. hystricosus* against 39 % of miospores of the *Diducites plicabilis-Auroraspora varia* Complex. The miospore assemblage from Sample Hd might well represent a mixture of the swamp and near-swamp environments. Evidently the plants producing *V. hystricosus* spores were living near the swamp. The Elkins locality corresponds to a deltaic marsh characterized by rare introduction of acritarchs (Sample Hb).

2. Another locality with coal at Rawley Springs (U.S.A.), where no *hystricosus* and no *lepidophyta* spores were recorded, corresponds to a back-swamp on the upstream floodplain characterized by other spores, dominated (66 %) by *Retusotriletes* cf. *coniferus* (SCHECKLER 1986; STREEL & SCHECKLER 1990).

3. In a section of the Catskill Formation, carbonaceous shales including pockets and small beds of pyritic, vitrinitic, high-volatiles, a bituminous “coal” (with > 40 % ash) was uncovered in Centre County, Pennsylvania (WARG & TRAVERSE 1973). The carbonaceous shales and coals contain abundant spores, mostly *R. lepidophyta* and *V. hystricosus*. *Retispora*

*lepidophyta* decreases in size and then disappears toward the top of the Devonian sequence. Only *V. hystricosus* has been found higher. A sample from the top of the section studied yielded an assemblage where *R. lepidophyta*, usually abundant, was missing. Instead, *V. hystricosus* increased in relative abundance by a factor of about 15 times. The complete absence of *R. lepidophyta* was in a sample that came from the “Lower Sandstone Member” of the Pocono Formation (see below).

4. A section of sandstones and shales of the Catskill and Pocono formations spanning the transition Devonian – Mississippian was sampled (STREEL & TRAVERSE 1978) at the famous Horseshoe Curve between Altoona and Gallitzin in Pennsylvania (U.S.A.), 80 km southwest of Centre County, Pennsylvania (WARG & TRAVERSE 1973). Plants recorded from the highest part of the “Middle Sandstone and Shale Member” are representative of the widespread Mississippian *Triphyllopteris* flora of READ & MAMAY (1964).

Samples 1 and 2 from the “Lower Sandstone Member” on top of the Catskill Red Beds have *V. hystricosus* but lack *R. lepidophyta*. They correspond to the HYS Interval Zone of the VH Opperl Zone (= Middle *expansa* conodont Zone, now *Bi. aculeatus aculeatus* Zone) in the Evieux Formation of the Ourthe Valley in Belgium (HIGGS et al. 2013).

Samples 3 and 4 from the “Middle Sandstone and Shale Member” have *R. lepidophyta* (11.500 spores scanned below). Sample 4 has also *Indotriradites explanatus* (20.000 spores scanned below). They correspond, respectively, to the LL and LE Opperl Zones in the Chanxhe reference section in East Belgium.

Sample 5 from the same “Middle Sandstone and Shale Member” has no *R. lepidophyta* but *Vallatisporites verrucosus*, *V. vallatus*, and probable *Spelaotriletes pretiosus* (see pl. I, fig. 3 in STREEL & TRAVERSE 1978). It should correspond to the PC Zone of Middle Tournaisian age (CLAYTON et al. 1977).

Obviously, the plants producing the *pusillites* group started to occupy the Famennian complex of marshes before (in the middle Famennian?) and continue after (in the lower Tournaisian?) the plants producing the *lepidophyta* group.

## 5. Time-interval between the *lepidophyta* group dominance and the *pusillites* group dominance

Detailed spore data are found in the Hangenberg shales and sandstones of the Rhenish Massif in Germany (HIGGS et al. 1993, 2013) but are not mentioned by ARETZ et al. (2021, fig. 2) in their global review on the DCB. Spore stratigraphy can however be related (STREEL 2015) to different intervals of the Hangenberg crisis (BECKER et al. 2021).

## 6. The Devonian – Carboniferous LN-LN\*-VI palynozones in Sauerland (Germany)

The LN-LN\*-VI transition corresponds to the Middle and Upper Hangenberg Crisis intervals ranging from the *Bi. costatus-Pr. kockeli* Interregnum (*cki*) to the *Pr. kockeli* Zone, followed by the *Pr. kuehni-Si. (Eosi.) sulcata* Zone (CLAUSEN et al. 1994; BECKER et al. 2021). We have condensed the Upper Crisis intervals I and II on our correlation chart (Fig. 3). The interval I (a black nodule layer) has been documented from the Drewer section of the Rhenish Massif, but occurs also in the Borkewehr section of the Balve region. (R. T. Becker personal communication 2022).

In the Stockum trench II (HIGGS et al. 1993), the sandy part (Hangenberg Sandstone = HSst) contains an atypical LN assemblage of spores (LN\*), very rich in *Retusotriletes* ssp., and where *R. lepidophyta* is rare (about 1 % - but a consistent element). A quantitative palynological study allows to recognize in the Stockum trench II (STREEL 1999) some changes in the paleoenvironment of the deposits based mainly on the type of palynodebris: more heterogenous, better preserved and more translucent debris suggesting more anoxic conditions in the Hangenberg Shales (HSh)



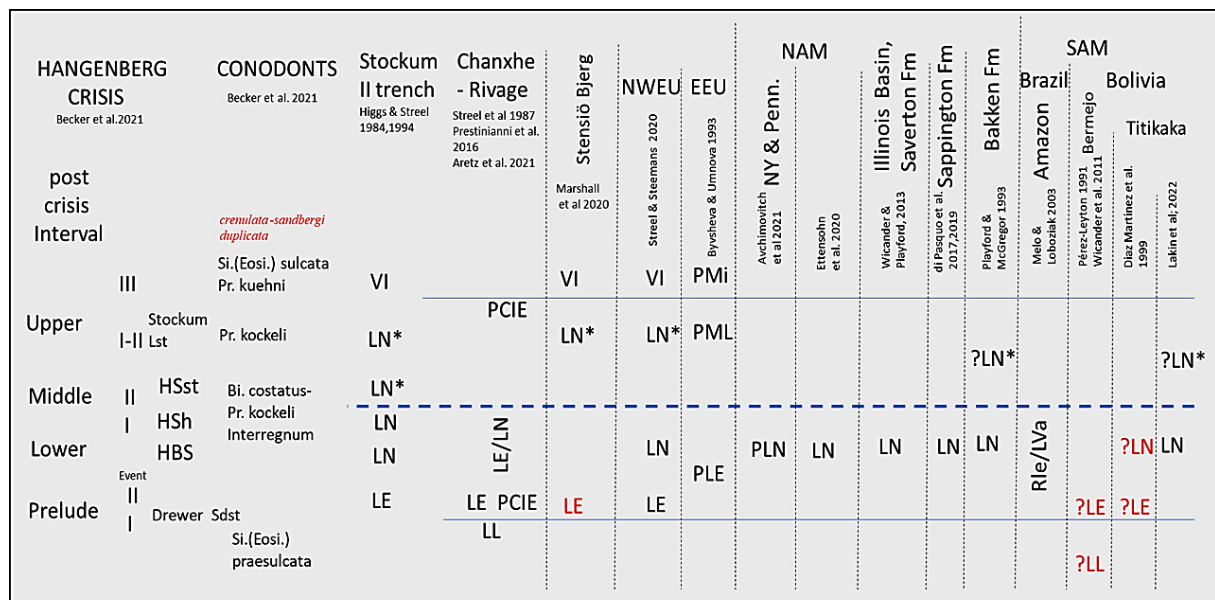
between the HBS (Hangenberg Black Shales) and the HSst.

All studied assemblages never contain acritarchs except immediately above the last sandstone (Sample 94 in HIGGS et al. 1993), where a very abundant single form of *Micrhystridium* occurs, accounting for 70 % of the total palynomorphs. A detailed analysis of the spore content of 21 successive samples (HIGGS et al. 1993, tab. 1) allows to characterize the sequence LN-LN\*-VI. Above the HBS, the LN Zone occurred from samples 150 to 121, the LN\* Zone from samples 118 to 104, and the VI Zone from samples 102 to 94.

The following taxa start in the LN\* informal zone: *Cyrtospora cristifer* in samples 106 and

118 (HIGGS et al. 1993), present also in the Hasselbachtal section samples Hb83, Hb15-17, and Hb 22-23 (HIGGS & STREEL 1983) but absent from the corresponding Hasselbachtal Borehole Bh1 Sample. *Bascaudaspora mischkinensis* (= ?*B. submarginata* PLAYFORD) HIGGS et al. 1988) starts in the LN\* informal zone (samples 106, 110, 113), if one accepts that LN\* starts at the level 29, 40 in the Hasselbachtal Borehole Bh1 (HIGGS et al. 1993).

No spore species starts at the base of the so-called VI Zone: *Vallatisporites verrucosus*, *V. vallatus*, and *Retusotriletes incohatus* are known since the LN Zone in the Stockum trench II (HIGGS & STREEL 1984; HIGGS et al. 1993).



**Fig. 3.** Correlation chart of the Devonian – Carboniferous LN-LN\*-VI palynozones. References and abbreviations: NWEU= North-West Europe (see in Streel & Steemans 2020: South-West England 5.1, 5.2, South-Ireland: 6.1, 6.2, 6.3; South-Poland: 7.1, 7.2; South-Potugal: 8; Germany: 10.5). EEU=East Europe. NAM= North America. SAM= South America. PCIE=Positive Carbon Isotope Excursion. ?LL and ? LE are reinterpreted herein as likely reworked RI assemblages in Tournaisian of Bolivia (for more information see text).

### 7. The Devonian – Carboniferous LN-LN\*-VI palynozones in Ireland

CLAYTON et al. (1974), working in the South Munster Basin (the Cork beds) in southern Ireland, subdivided the NV Zone of NEVES et al. (1972) into two subzones, the LN Subzone and the VI Subzone. They were proposed as Concurrent Range Zone by HIGGS et al. (1988).

The LN (*Retispora lepidophyta-Verrucosisporites nitidus*) Biozone has most of the taxa of the preceding (LE) Biozone. *Lophozonotriletes malevkensis* NAUMOVA (KEDO), *Vallatisporites verrucosus* HACQUEBARD and *Densosporites spitsbergensis* PLAYFORD appear close to the base of the LN Biozone. *Verrucosisporites nitidus* is rather

sparse in the basal LN Zone, usually represented by the smaller verrucate forms (HIGGS et al. 1988).

The VI (*V. verrucosus-Retusotriletes incohatus*) Biozone is marked by the disappearance of *R. lepidophyta*, *V. pusillites*, *Rugospora flexuosa*, species of the genera *Ancyrospora* and *Hystricosporites*, *Diducites versabilis*, and *D. plicabilis*. The basal VI Biozone assemblages, in contrast to the preceding LN assemblage, are very restricted in composition, usually dominated by simple laevigate forms (HIGGS et al. 1988). *Vallatisporites vallatus* was originally considered by CLAYTON et al. (1974) as characterizing the *V. vallatus-R. incohatus* Zone.

An important contribution to the quantitative approach of the transitional Devonian to Carboniferous palynozonation is obviously the descriptive and quantitative analysis, with illustrations of miospores in the Ballycrovane Harbour (VAN VEEN 1981, fig. 2; see also HIGGS et al. 1988) and Bantry Bay (VAN VEEN 1981, fig. 3) sections (County Cork, southern Ireland). It shows that the most distinct DCB palynological change is taking place between the *Retispora lepidophyta-Verrucosisporites nitidus* (LN) and the *Retispora lepidophyta-Cyrtozpora cristifera* (LCr) Phases in the basal part of a widespread pelitic unit: the Castle Slate Member of the Kinsale Formation (STREEL & STEEMANS 2020).

*Cyrtozpora cristifera* var A VAN DER ZWAN 1979 covers the range of phases LCr and NR in southern Ireland (VAN VEEN 1981) across the Coomhola/Kinsale formations transition. It is present until the Courtmascherry Formation according to VAN DER ZWAN (1979). *Cyrtozpora cristifera* is distinguished from other members of the *C. cristifera* morphon in having a distal crassitude. *Cyrtozpora cristifera* var A is distinguished from *C. cristifera* var B, which has a reduced distal crassitude, rosette shaped. Most occurrences of the *C. cristifera* morphon are documented in Euramerica, *Cyrtozpora cristifera* var A being the most often recognized by VAN DER ZWAN (1979, fig. 3). Almost all

occurrences of recorded *C. cristifera* were from marine strata or from continental strata with marine excursions. One may think of an exclusively coastal-deltaic environment for these plant taxa (VAN DER ZWAN 1979).

The *C. cristifera* morphon might be another example of malformed land plant spores due to the destruction of the Ozone layer resulting from direct effects of volcanic gases derived from large igneous province (LIP) eruptions (PISARZOWSKA et al. 2020) or/and UV-B radiations resulting in the loss of that protective Ozone layer (MARSHALL et al. 2020).

## 8. The Devonian – Carboniferous LN-LN\*-VI palynozones in Belgium

The reference section of the Ourthe Valley Chanxhe 1 (MAZIANE et al. 2002, 2007), interrupted by a fault in its upper part, has been duplicated on the left bank of the river at Rivage Pont de Scay (PRESTIANNI et al. 2016). About the same section had been studied by KUMPAN et al. (2014), using the original log of CONIL (1964) and providing correlations with two positive carbon isotope excursions (PCIE in Fig. 3).

The juxtaposition of lithologies indicates that the lower recorded positive excursion (around 3 ‰, equivalent to the unnamed positive excursion in the Upper *expansa* = *Bi. ultimus ultimus* Zone known from the Carnic Alps, after KAISER et al. 2008), is to be searched around the transition LL/LE in the Ourthe Valley sections. The positive excursion is accompanied with increased values of the U/Th palaeoredox proxy, which reached values 0.75 indicative for hypoxia (JONES & MANNING 1994). The positive  $\delta^{13}\text{C}_{\text{carb}}$  excursion in the level of facies progradation may be related to a cooling event, as reported from various glacial periods of the Earth history (e.g. SALTZMAN 2003; personal communication of T. KUMPAN in 2020).

This is also observed at the level of Chanxhe 1, where acritarch diversity regresses significantly and where the level of the first appearance of *I. explanatus* marks the contact of palynozones LL/LE. It is also the level, where

shallow water ostracods enter in this locality (CASIER et al. 2005), arguing for a lowering of the sea level.

The higher recorded positive excursion near the base of the Tournaisian Hastiere Formation, devoid of conodonts and miospores, should correspond to the DC Boundary. It gives also some credibility to the attribution of the last samples (83-94) studied in the Rivage Pont de Scay to a combine LE/LN zone rather than a LE Zone alone. Notably, the occurrence in the highest sample (94) of *Bascaudaspora mischkinensis* and *Vallatisporites vallatus?* is coincident with the first thick shaly beds (Bed 156 after CONIL 1964) of the Hangenberg Black Shale (HBS) in Sauerland.

### **9. The Devonian – Carboniferous LN-LN\*-VI palynozones in Greenland**

The discovery in East Greenland (Stensiö Bierg) of the LN\* Zone allowed to better understand the End-Devonian Mass Extinction (EDME) succeeding a significant arid interval of the LN Zone, and representing warming and humidity increase and the collapse of the final Devonian glacial episode (MARSHALL 2021).

### **10. The Devonian-Carboniferous LN-LN\*-VI in Western, Central and Southern Europe**

A review of localities, where spores had been studied in the range of the DCB was attempted by STREEL & STEEMANS (2020) in order to verify the “practicability” of the new sequence LN-LN\*-VI (Fig. 3). Ten of 25 were positive in that they display the full sequence, notably Kowala (in southern Poland), Burrington Combe and the Barnstaple area (in South-West England), Old Head Kinsale (in southern Ireland), and the Tercenas Formation in southern Portugal.

### **11. The Devonian-Carboniferous LN-LN\*-VI in Eastern Europe**

Based on many boreholes in eastern Europe, the spore zonation near the DCB has been established, and the *Vallatisporites pusillites* (P) Zone, being divided into three Subzones (BYVSHEVA & UMNVA 1993). The lower

*Vallatisporites pusillites* - *Retispora lepidophyta* - *Hymenozonotriletes explanatus* Subzone (PLE) has abundant *Retispora lepidophyta*. The middle *Vallatisporites pusillites* - *Tumulispota malevkensis* - *Retispora lepidophyta* Subzone (PML) may include rare *Retispora lepidophyta*. The upper *Vallatisporites pusillites* - *Tumulispota malevkensis* Subzone (PM) does not contain *Retispora lepidophyta*. The PM Subzone has been changed subsequently into the *Vallatisporites pusillites* - *Bascaudaspora mischkinensis* (PMi) Subzone.

The succession PLE-PML-PMi corresponds to the LN-LN\*-VI sequence (Fig. 3), the PML including rare *Retispora lepidophyta*.

Some boreholes were studied in the central part of the Russian Platform, which cross the DCB limit. Spores of the *Vallatisporites pusillites* - *Bascaudaspora mischkinensis* (PMi) Subzone of the *Vallatisporites pusillites* (P) Zone may be disconformably overwhelming the *Retispora lepidophyta tenera* (Ltn) Subzone of the *Retispora lepidophyta* (L) Zone).

The assemblages of spores of the PMi Subzone and M Zone (*Tumulispota malevkensis* Zone) overwhelming the P Zones are closely comparable in their composition of species. In the assemblage of the PMi Subzone, *V. pusillites* varies from 6 to 58 % but is reduced to near its total disappearance in the M Zone. Neither *Retispora lepidophyta* nor any of its varieties has been found in the PMi Subzone.

### **12. The Devonian – Carboniferous LN-LN\*-VI palynozones in North America (NAM)**

Several publications are available in NAM, which associate palynomorphs and conodonts, such as SANDBERG et al. (1972).

#### *12.1. New York State and Pennsylvania*

The material formerly studied by RICHARDSON & AHMED (1988) from the upper and uppermost Famennian of New York State and Pennsylvania (see also RICHARDSON & MCGREGOR 1986) has been restudied by AVCHIMOVITCH et al. (2021) and compared with

contemporaneous palynozonations in Western Europe and Belarus.

The highest palynozone is named PLN (*V. pusillites*-*R. lepidophyta*-*V. nitidus*). *Retispora lepidophyta* is represented by the var. *tenera* and var. *minor*. *Vallatisporites pusillites* sensu lato are abundant; *V. pusillites* sensu stricto, *V. kedoeae*, and *V. hystricosus* dominate. *Vallatisporites higgsii*, *V. enigmus*, *V. mcgregorii*, *V. drybrookensis*, and *V. dolbii* are present. Typical Carboniferous species are said to occur, such as *Vallatisporites vallatus*, *V. verrucosus*, and *V. splendens*. Also, *Bascaudaspora mischkinensis*, *Camptotriletes paprothii*, *Vallatisporites streelii*, and small amounts of *Verrucosisporites nitidus* occur. All species are known in the highest Famennian.

The PLN Zone is comparable, if not similar, with the lower part of the P Zone of Eastern Europe.

### 12.2. Appalachian Basin (Morehead-Kentucky)

ETTENSohn et al. (2020a, 2020b) gathered the most recent information about a glacial successions recognized by a belt of in situ terrestrial diamictite 400 km long and 40 km wide in the Appalachian Basin. This interval is assigned to the lower Spechtly Kopf Formation, the Rockwell Formation, and the Cussewago Sandstone of Pennsylvania and Maryland, and the Bedford Shale and Berea Sandstone of Ohio (cf. BREZINSKI et al. 2010). The diamictite was deposited during a single glacial advance and retreat sequence as parts of shallow, marginal-marine transgressive sequences, which inundated Hampshire/Catskill alluvial plains, and ended Upper Devonian alluvial sediment accumulation across most of the area. Palynology from this interval indicated that all the diamictites examined occur in the LE and LN miospore zones, following CLAYTON et al. (2010, 2012).

The Logan Hollow section (N38°11'36'', W83°29'37''), located 0.2 miles north of the junction of Bratton Branch and Logan Hollow roads in the east-central part of the Morehead quadrangle, includes the Robinson boulder or

“lonestone” (see OJAKANGAS 1985; ETTENSohn et al. 2009) in the upper Cleveland Member of the Ohio Shale Formation, interpreted as a glacial dropstone removed from the Ordovician (ETTENSohn et al. 2009, 2020a, 2020b).

This shale interval from Cleveland, Bedford and the Berea sandstone are dated as uppermost Famennian *Retispora lepidophyta*-*Verrucosisporites nitidus* (LN) miospore Zone (CLAYTON et al. 2010, 2012), based on these two taxa and others, such as *Densosporites spitsbergensis*, *Indotriletes explanatus*, *Knoxisporites concentricus*, *Latosporites* sp., and *Retusotriletes crassus*. A more quantitative study is not available from the abstracts, which would have allowed a more detailed approach of the LN-VI sequence.

### 12.3. Illinois Basin (Iowa)

The Upper Devonian Saverton Shale Formation is present in outcrop and subsurface in southern Iowa (Iowa Basin), western and southeastern Illinois, as part of the Illinois Basin, and in northeastern Missouri. Three samples of the Upper Devonian Saverton Shale and three of the Lower Mississippian Hannibal Shale were collected along the bluff at Atlas South, Pike County, Illinois (WICANDER & PLAYFORD 2013).

The assemblage of the Saverton Shale yielded prasinophytes, acritarchs, and spores, such as *Punctatisporites hannibalensis*, *Retusotriletes incohatus*, *Emphanisporites rotatus*, *Auroraspora macra*, *Retispora lepidophyta*, and *Verrucosisporites nitidus*, which were assigned to the LN miospore Zone (WICANDER & PLAYFORD 2013). The overlying Hannibal Shale yielded an overall depauperate palynoflora bearing several taxa from the underlying palynoassemblage, such as *M. stellatum* and other species of *Micrhystridium* that are the most frequent acritarchs, and rare appearances of *G. ohioense*, *G. winslowiae*, *S. micropolygonale*, and *Veryhachium trispinosum*. Among the spores, *Punctatisporites hannibalensis*, *Retusotriletes incohatus*, *Auroraspora macra*, and *Verrucosisporites*

*nitidus* are still documented. Instead, *Retispora lepidophyta*, *Grandispora cornuta*, *Vallatisporites hystricosus*, *Indotriradites explanatus*, and species of *Ancyrospora* and *Teichertospora* are absent (WICANDER & PLAYFORD 2013).

A Kinderhookian (Lower Mississippian) age is given based on conodonts of the lower *Siphonodella sandbergi* - lower *S. crenulata* zones (WORK et al. 1988; LANE & BRECKLE 2005). The Hannibal microphytoplankton assemblage contains the same morphologically simple and stratigraphically long-ranging taxa that are found globally in Lower Mississippian strata, together with a few taxa, notably *Gorgonisphaeridium ohioense* and *G. winslowiae*, which possibly extend from the Devonian into the Lower Mississippian. The Saverton miospore assemblage features a number of species known to be restricted to the uppermost Devonian, and that serve as reliable index fossils for that time interval, in particular, *Retispora lepidophyta*. The Hannibal miospore assemblage is both less abundant and diverse than its microphytoplankton counterpart, and is suggestive of a Lower Mississippian age.

The transition between the Saverton Shale and the Hannibal Shale, interrupted by the Glen Park Limestone, has not been studied.

#### 12.4. Sappington Basin (Montana)

The palynology of the green burrowed shale (Unit 4) of the Sappington Formation at Logan Gulch in Montana studied by DI PASQUO et al. (2017) allowed the description of the latest Famennian *Retispora lepidophyta*-*Verrucosporites nitidus* LN Zone. Age-diagnostic taxa include spores (e.g. *Grandispora echinata*, *G. praecipua*, *Endoculeospora setacea*, *Retispora lepidophyta*, *Verrucosporites nitidus* and *Vallatisporites* spp.) and less frequent phytoplankton species (e.g. *Dictyotidium fairfieldense*, *Gorgonisphaeridium winslowiae*, *Maranhites*, *Tasmanites*, *Botryococcus*). This palynoassemblage is correlated with that one at Hardscrabble (Peak 9559) in Bridger Mountain recorded by SANDBERG et al. (1972). A sandstone

bed (Unit 5) over Unit 4 at Logan Gulch, palynologically barren, is unconformably followed by the base of the Mississippian CCM Lodgepole Formation (DI PASQUO et al. 2017).

From the Koch section located in the Madison Range of southwestern Montana (USA), a detailed palynological analysis of the uppermost Devonian Sappington Formation provides a whole association from four samples composed of 87 trilete spore species that dominated over microphytoplankton (13 species) (DI PASQUO et al. 2019a). Among the most representative spore species are *Convolutispora oppressa*, *Cymbosporites loboziakii*, *Cyrtospora cristifera*, *Diaphanospora perplexa*, *Grandispora echinata*, *Knoxiosporites concentricus*, *Knoxiosporites literatus*, *Kraeuselisporites explanatus*, *Punctatisporites hannibalensis*, *Pustulatisporites dolbii*, *Retispora lepidophyta* (very abundant), *Retusotriletes incohatus*, *Spelaeotriletes crustatus*, *Tumulispora rarituberculata*, and *Vallatisporites drybrookensis*. These species are diagnostic of the LN Zone yet documented in Unit 4 shale at Logan Gulch (DI PASQUO et al. 2017, 2019b) and other locations in SW Montana documented by RICE et al. (2016) aforementioned.

The type section for the *Siphonodella (Eosi.) praesulcata* conodont fauna in North America at the Lick Creek locality was revisited and sampled for palynology and conodonts due to its importance as a reference section for ongoing Devonian-Mississippian boundary (DCB) studies within the Sappington Formation and correlative Exshaw and Bakken formations (see ISAACSON et al. 2015, RICE et al. 2017).

As yet discussed by STREEL (2009), the upper Famennian through basal Carboniferous interval embraces six conodont zones (see also KAISER et al. 2015; BECKER et al. 2016), i.e., the Middle *expansa* (= *Bi. aculeatus aculeatus*) through *sulcata* zones, which correspond to the Western European LL, LE, and LN miospore interval zones, and the succeeding *Vallatisporites vallatus* - *Retusotriletes incohatus* (VI) assemblage zone (Fig. 3).

As originally described, the *Si. (Eosi.) praesulcata* conodonts occur in a 2 foot (ft) thick

oolitic grainstone presumed to be at or near the top of the Sappington Formation (in Unit 5), but the exact stratigraphic position within the Sappington is poorly known. RICE et al. (2017) found in Unit 4 the uppermost Devonian *Retispora lepidophyta* spore assemblage, not recorded previously. So, there was concern about the relative age of *Si. (Eosi.) praesulcata* and if the oolitic grainstones, that are part of Unit 5 elsewhere, could possibly be part of the overlying Cottonwood Canyon Member. Detailed stratigraphic studies of the Lick Creek section and other nearby sections resolve much of the uncertainty concerning the stratigraphic position of the *Si. (Eo.) praesulcata* conodonts. The Sappington at Lick Creek consists of a normal Sappington succession from Unit 1 through Unit 5, with the addition of over 8 ft of oolitic grainstones near the top. Unit 4, which has been found beneath a veneer of cover, provides the key evidence to show that the oolitic grainstones occur near the top of Unit 5 based on regional thickness. The overlying Cottonwood Canyon Member is only 4 cm thick at Lick Creek, but at other localities nearby, its correlatives reach more typical thicknesses of 3-4 ft, where it also rests on oolitic grainstones. This suggests that very little of Unit 5 has been eroded at Lick Creek, thus placing the *Si. (Eo.) praesulcata* locality somewhere near the top of Unit 5. This new analysis confirms that the *R. lepidophyta* spore assemblage underlies the *Si. (Eo.) praesulcata* fauna at Lick Creek, although they may overlap. The preliminary results by RICE et al. (2017) indicate that Sappington Unit 4 at Lick Creek, and at some other localities studied, are Devonian in age based on conodonts and other organic microfossils. The transition between the LN Zone sensu stricto (with very abundant *R. lepidophyta*) and the VI Zone being interrupted by a sandstone bed (Unit 5) is still unpublished (RICE 2021; DI PASQUO et al. 2021).

#### 12.5. Williston Basin (North Dakota and Montana)

HOGANCAMP & POCKNALL (2018) documented new paleontological data from the Bakken Formation in the Williston Basin of

North Dakota and combined the new data with those previously published in a revised biostratigraphic framework. From three wells, 81 samples were taken from the Bakken Formation (23 from the lower, 34 from the middle, and 24 from the upper members), and three from the Lodgepole Formation. Palynological data from the Middle Bakken indicates that the historical Devonian-Carboniferous Boundary should be placed at the unconformable contact between the lower Middle Bakken (Middle Bakken 1) and the upper Middle Bakken (Middle Bakken 2), based on the highest stratigraphic occurrence of *Retispora lepidophyta*.

The acritarchs *Gorgonisphaeridium ohioense*, *G. winslowiae*, *Unellium winslowiae*, *Puteoscortum polyankistrum*, and *Stellinium micropolygonale* are only found in the Lower and Middle Bakken. Although *Gorgonisphaeridium absitum* and *G. plerispinosum* are rarely recorded in the Middle Bakken, they are common components of Upper Bakken assemblages. The spores *Lophozonotriletes magnus*, *Retispora lepidophyta*, *R. macroreticulata*, *Vallatisporites splendens*, and *Verrucosisorites nitidus* are restricted to the Middle Bakken.

Although no conodont data were analyzed from the Middle Bakken, the Lower Bakken provided conodonts of the *Pseudopolygnathus granulosus* Zone to the *Bi. ultimus ultimus* Zone, and possibly to the basal Tournaisian *Protognathodus kockeli* Zone, and the Upper Bakken may range from the Tournaisian *Si. (Si.) duplicata* Zone to the *Si. (Si.) quadruplicata* Zone (the utility of the latter has been questioned by BECKER et al. 2021).

DI PASQUO et al. (2018) provided new palynological data from three stratigraphic intervals of the Middle Bakken Formation (Enterprise Archer well core) in the Williston Basin of northeastern Montana. Two samples from the top of the lower Middle Bakken siltstone (Archer 1 = 7,625.0-7,626.7 feet), six samples from silty shale facies above the Middle Bakken sandstone (A2 = 7,600.4-7602.7 ft), and



two samples from the silty shales above a bioclastic lag, below a limestone bed of the upper Middle Bakken (A3 = 7,599.0-7599.8 ft).

*Retispora lepidophyta* is recorded throughout A1-A3 assemblages (A1: 28 spores, 13 phytoplankton, 1 scolecodont; A2: 65 spores, 14 phytoplankton; A3: 30 spores, 4 phytoplankton). These assemblages share 22 spore species (e.g. *Cristatisporites mattheusii*, *Diaphanospora perplexa*, *Grandispora echinata*, *Grandispora senticosa*, *Pustulatisporites dolbii*, *Spelaeotriletes crustatus*, *Tumulispora rarituberculata*, and *Velamispores perinatus*) and few acritarchs/prasinophytes (*Gorgonisphaeridium winslowiae*, *G. absitum*). The “Marine Index” (A1 = 150, A2 = 121.5 and A3 = 113.3) confirms that A1 was deposited in a shallow marine setting whilst A2 and A3 in brackish embayments, as suggested previously from ichnologic and sedimentologic analyses.

A comparison of these assemblages with the Middle Bakken Formation of the Montague Lake core (C-69809-21/26) of southern Canada studied by PLAYFORD & MCGREGOR (1993) and HOGANCAMP & POCKNALL (2018) and also with the Middle Sappington Formation (RICE et al. 2016, DI PASQUO et al. 2017), suggest their correlation possibly coeval with the *R. lepidophyta-Verrucosisporites nitidus* (LN) Zone, based on the occurrence of *Claytonisporites rarisetosa*, *Convolutispora major*, *Cymatiosphaera* sp., *Dictyotriletes flavus*, *Endoculeospora setaceae*, *Grandispora praecipua*, *Knoxisporites literatus*, *Navifusa bacilla*, *Retusotriletes crassus*, *Vallatisporites drybrookensis*, *V. splendens*, *Verrucosisporites mesogrumosus*, and *V. papulosus*, amongst others.

#### 12.6. Western Canadian or South Alberta Basin

The Bakken Formation, in the Williston Basin of Western Canada, constitutes part of a widespread, predominantly black shale sequence that covered much of the North American craton in Upper Devonian and Lower Carboniferous time.

24 samples constitute the base of this study (PLAYFORD & MCGREGOR 1993) from cores of five wells in southern Saskatchewan. Two thirds of the samples are from the Middle Sandstone Member of the Bakken Formation, five are from the Upper Shale Member, and only one from the Lower Shale Member.

Among the acritarchs, *Gorgonisphaeridium winslowiae* is often the most abundant. It is confined to the uppermost Famennian or Strunian in the Ourthe Valley reference sections in Belgium (VANGUESTAINE 1986). Among the miospores, *Retispora lepidophyta* is present everywhere, except in one sample (or two!), of the Upper Shale Member of one of the cores. This might be taken as an indication that *R. lepidophyta* is rare at that level of the Bakken Formation (LN\* Zone?) but it also supports the opinion of the authors that it could be reworked in the next VI Zone.

In Alberta, a total of 23 core samples obtained from Exshaw and Banff formations were analyzed in boreholes by RICHARDS et al. (2002).

From the base of the Lower Black Shale Member of the Exshaw Formation, conodont data of the Lower *expansa* conodont Zone have been documented. From both the lower and upper shale units of the Exshaw Formation, the “*Vallatisporites pusillites* – *Retispora lepidophyta* Zone” is characterized by *Retispora lepidophyta* and other spores (*Cyrtospora cristifera*, *Grandispora echinata*, *G. saurota*, *Pustulatisporites dolbii*, *Spelaeotriletes crustatus*, *Tumulispora rarituberculata*, *Vallatisporites drybrookensis*, and *V. splendens*) and microplancton taxa (*Gorgonisphaeridium winslowiae*, *Stellinium micropolygonale*, *Leiosphaeridia* and rare *Maranhites*).

The *Retispora lepidophyta* – *Verrucosisporites nitidus* Zone was recovered from the Upper Member of the Exshaw beneath the basal Banff Formation. Tuff samples interbedded allowed the recovery of absolute age dates associated with conodont and palynobiostratigraphy, supporting an uppermost Devonian age (e.g. 363.34 ± 0.39 Ma from the

Nordegg tuff) as summarized by RICHARDS et al. (2002) and discussed by BECKER et al. (2020, pp. 777-778).

Conodonts from the overlying Upper Siltstone Member of the Exshaw Fm were not common, but the Mississippian Upper *duplicata* Zone to *crenulata* Zone from the basal black shale of the Banff Formation were indicated in southwestern Alberta (RICHARDS et al. 2002; JOHNSTON et al. 2010).

### 13. The Devonian-Carboniferous boundary in South America (SAM)

Several publications are available for SAM, which associate palynomorphs, diamictites and glacio-marine strata.

#### 13.1. Amazon Basin, northern Brazil

In the Amazon Basin as well as in other Brazilian Palaeozoic basins, uppermost Famennian assemblages are often characterized by the joint occurrence of *R. lepidophyta* and *Indotriletes explanatus*. Two Interval Zones are recognized in the Curiri Formation and are shown between two erosional surfaces in PLAYFORD & MELO (2012). Diamictites and glacio-marine strata are common in these intervals (see Fig. 3).

In the R1e Zone, the FOB of *R. lepidophyta* occur, also containing *Vallatisporites verrucosus* and many additional species of the genera *Convolutispora*, *Corbulispora*, *Cristatisporites*, *Cymbosporites*, *Densosporites*, and *Verrucosiporites*. All these taxa range upwards into the succeeding *R. lepidophyta*-*V. vallatus* (LVa) Interval Zone, containing *Verrucosiporites nitidus*, and many persist even higher (MELO & LOBOZIAK 2003).

The next *Radiizonates arcuatus*-*Waltzispora lanzonii* (AL) Interval Zone, succeeding the LVa Zone in the Oriximana Formation, corresponds to the LOB of important Upper Devonian miospores, headed by *R. lepidophyta*. This unit is characterized by a proliferation of miospores with simple morphology and laevigate forms. In certain AL Zone sections and even in higher Tournaisian and Viséan intervals, *R. lepidophyta*

and some of its uppermost Famennian associates may still persist, usually in reduced numbers, due to recycling processes (MELO & LOBOZIAK 2003).

#### 13.2. Los Espejos Range between Santa Cruz de la Sierra – Cochabamba, Bolivia

The Bermejo river outcrop studied by PÉREZ LEYTON (1990) between Bermejo-La Angostura in the highway connecting Santa Cruz de la Sierra and Cochabamba, revealed a great diversity of spores, acritarchs and chitinozoan species in the Itacua (ex Saipurú) Formation, composed of turbiditic resedimented diamictites with glacial influence, and the unconformably underlying Los Monos/Iquiri formations. A biostratigraphic interpretation is given by PÉREZ LEYTON (1990) and was revised and changed in PÉREZ LEYTON (1991). The main composition of the three samples of the Itacua Fm is as follow.

**M19:** *Colatisporites decorus*, *Rugospora radiata*, *Retusotriletes planus*, *Knoxisporites* sp., and *Cristatisporites* sp. (scarce specimens), whereas reworked spores from the Devonian and acritarchs are abundant, especially *Umbellasphaeridium saharicum*. *Verruciretusispora famenensis* and the absence of *Retispora lepidophyta* were used to attribute this sample to the VCo Zone of STREEL et al. (1987).

**M12-13:** Notably rich in diverse palynomorphs, among them *Retispora lepidophyta*, *Colatisporites decorus*, *Cordylosporites glumaceus* (= *C. marciae*, *Dictyotriletes fimbriatus*, see PLAYFORD & MELO 2012), *Cristatisporites echinatus*, *Cyrtospora cristifera*, *Knoxisporites literatus*, *Kraeuselisporites explanatus*, *Raistrickia spathulata*, *Tumulispora rarituberculata*, *Vallatisporites verrucosus*, and the chlorophycean *Botryococcus*.

This assemblage was akin to the uppermost Famennian LE Zone of STREEL et al. (1987) and a younger age was rejected due to the absence of index taxa, such as *S. balteatus*, *S. pretiosus*, *Umbonatisporites* spp., and *Aratrisporites saharensis*.

Hence, DI PASQUO & AZCUY (1997) indicated with certainty a Lower Carboniferous age, most likely mid-Tournaisian, for the three samples M19, 12 and 13 of this diamictitic deposit of Itacua Formation, and the separation of indigenous and reworked set of palynomorphs. A revision of this outcrop by STREEL et al. (2012) did agree with the presence of Mississippian spores in this diamictitic unit.

From the same area of the Bermejo outcrop described above, more diamictitic deposits are exposed along the La Angostura-Bermejo-Samaipata-Mairana highway in the Espejos Range, west of Santa Cruz de la Sierra. WICANDER et al. (2011) studied the palynological content of a diamictite at Lajas area, and it was correlated to the LL and LE zones due to the absence of *Verrucosisporites nitidus*. STREEL et al. (2012) doubted this zonal correlation and age given to this deposit bearing exotic blocks in view of the doubtful distribution of taxa along the samples.

### 13.2. Sol, Mina Matilde and Hinchaka sections, Titikaka Lake, Bolivia

DÍAZ MARTÍNEZ et al. (1993, 1999) referred to the Famennian glaciation of western Gondwana, based on the palynologic information from diamictites of the Cumaná Formation (VAVRDOVÁ et al. 1991, 1993) at Isla del Sol and in the Mina Matilde and Hinchaka sections.

VAVRDOVÁ et al. (1993) presented the palynologic result of two sections in the Titikaka lake area, and established an upper Famennian age for the samples IS 2 and IS 3 (Isla del Sol) and MM4a and 9a (Mina Matilde), due to the presence of *Retispora lepidophyta* along with *Kraeuselisporites explanatus*, *Raistrickia macrura*, *R. spathulata*, *R. variabilis*, *Retusotriletes incohatus*, and the acritarch *Umbellasphaeridium saharicum*. The samples MM4a and 9a also document important taxa associated to *Retispora lepidophyta*, such as *Verrucosisporites nitidus*, *Lophozonotriletes malevkensis*, *Knoxisporites literatus*,

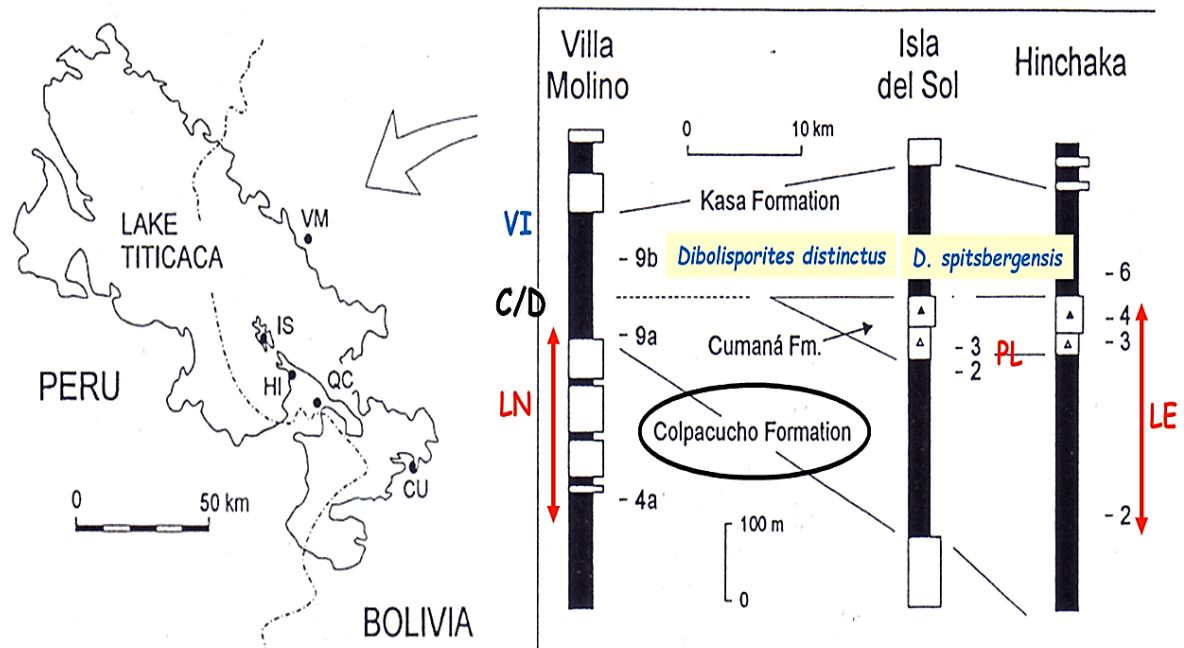
*Cordylosporites marciae*, and *Convolutispora vermiformis*.

In the Sample MM9b, species with Tournaisian ranges, such as *Densosporites spitsbergensis*, *Grandispora conspicua*, *G. echinata*, *Spelaeotriletes obtusus*, *S. pretiosus*, *Rugospora polyptycha*, *Tumulispora rarituberculata*, and *Cyrtoispora cristifera* allowed their attribution to the lowerr Tournaisian VI Zone. Other Devonian species associated to those spore taxa include numerous acritarchs that were considered indigenous. *Retispora lepidophyta* is absent. DÍAZ MARTÍNEZ et al. (1999) cited also the presence of *Dibolisporites distinctus*, another exclusive species of the Tournaisian in Europe and Australia.

DÍAZ MARTÍNEZ et al. (1999) described a section at Hinchaka and its palynological content of samples HI2-HI4 from a diamictite of the Cumaná Formation, characterized as poor in palynomorphs but bearing *Retispora lepidophyta*, *Convolutispora vermiformis*, *Cordylosporites marciae*, *Kraeuselisporites explanatus*, *Raistrickia macrura*, *R. spathulata*, *Spelaeotriletes resolutus*, and *S. obtusus*. It was akin to the *R lepidophyta* – *K explanatus* (LE) Zone. The overlying Sample HI6 yielded *Raistrickia clavata* and *D. spitsbergensis*, and it was assigned to the lower Tournaisian VI Zone.

It must be mentioned that several acritarchs and other palynomorphs recycled from the Devonian *sensu lato* are associated to the indigenous taxa in all the samples of the three localities.

DI PASQUO & AZCUY (1997) and DI PASQUO (2003) warned about the presence of Devonian olistoliths intercalated in Mississippian and Pennsylvanian successions locally, and also, that clasts of very different sizes in the diamictites yielded different Devonian ages through specific palynologic analysis, including *Retispora lepidophyta* and other allied taxa (see also DI PASQUO & STREEL 2022a, with many data presented in abstracts, still unpublished).



**Fig. 4.** Correlation of DCB sections in the Titicaca Lake region after DÍAZ MARTÍNEZ et al. 1999). The “indigenous” taxa in the *Rerispora lepidophyta* and VI assemblages mixed with other reworked from the Devonian s.l., characteristic of the diamictites in South America, could preclude accurate datings of those microfloras.

#### 13.4. Chaguaya, NE shore at Titicaca lake, Bolivia

LAKIN et al. (2021) analyzed an uninterrupted D-C sequence in the Titicaca region, and it was characterized by three palynoassemblages:

AI-1 corresponds to the range of *Retispora lepidophyta*, which comprises up to the third of the total miospore count and is confined to the Colpacucho Formation. Single wall, non-apiculate miospore taxa are common (half of the total miospore count). The assemblage contains *Knoxisporites literatus*, *Indotriradites explanatus*, and *V. nitidus*. The phytoplankton is rich and characterized by a high relative abundance of *Umbellasphaeridium saharicum*.

AI-2 is constrained within the lower unit of the Kasa Formation. The miospore fraction is dominated by single wall, non-apiculate taxa (60% of the total miospore count), but there is a relative increase in single-wall apiculate miospores (*Anapiculatisporites*, *Apiculatisporites*, *Apiculiretusispora*, and *Raistrickia*). Age-diagnostic miospore taxa are extremely rare, and difficult to speciate with

confidence. Only a single age-diagnostic species, *Anapiculatisporites semicuspidatus*, appears. The phytoplankton fraction is relatively impoverished and characterized by a high relative abundance (73 % of phytoplankton) of *Gorgonisphaeridium* spp.

AI-3 is defined by the loss of the phytoplankton fraction and ranges entirely within the upper Kasa Formation. It contains up to 49 % of single wall, non-apiculate taxa, the remaining being single wall apiculate taxa. Phytoplankton are almost nonexistent. Mississippian miospore taxa (including *Anapiculatisporites ampullaceus*, *Indotriradites dolianitii morphon*, *Indotriradites viriosus*, and *Waltzisporea lanzonii*) are extremely rare or limited to single occurrences.

The Assemblage-Intervals 2 and 3 are both attributed by the authors to the Tournaisian. Alternatively, one may consider that at least in part, the basal AI-2 could correspond to the LN\* range with occasional *R. lepidophyta*. Although, the reworked character of the AI-2 and AI-3 of the Kasa Formation is noticed, in coincidence

with other Mississippian deposits in SAM (see DI PASQUO & STREEL 2022a, 2022b).

#### 14. Final remarks

Most, if not all, of the miospore records published around the DCB in North and South America lack the quantitative approach, which allow to identify the LN\* Zone and consequently the VI Zone. Both zones are dependent, by definition, on the low percentage or absence of *Retispora lepidophyta*. This criterium alone is not applicable to characterize a zonal subdivision when one realizes the enormous quantity produced by this taxon, often more than 50 % of the total of miospores, during the millions of years of the upper/uppermost Famennian.

Most of the sections investigated around the DCB in North and South America are hampered by the presence of unfavorable lithofacies for palynology. The probability to have been affected by reworking processes is very important and should not be ignored in DCB studies (cf. STREEL & BLESS 1980; DI PASQUO & STREEL 2022a, 2022b).

Also, we have not recognized in the description of all reviewed assemblages any taxon first occurrence (FOB), which might serve as an alternative criterium. The base of the LN\* Zone, probably the beginning of the collapse of the final Devonian glacial episode, is only recognizable by a quantitative approach.

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