LATE FAMENNIAN MIOSPORE ASSEMBLAGES FROM
THE BERGISCH GLADBACH - PAFFRATH SYNCLINE,
RHENISH SLATE MOUNTAINS, GERMANY

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(2 figures & 7 plates)

ABSTRACT. During routine palynological analysis of Devonian sediments of the Bergisch Gladbach-Paffrath Syncline, Rhenish Slate Mountains, late Famennian marine strata hitherto unknown in this region have been recognized. The thermal alteration index (TAI of 2 to 2+) is remarkably low compared to other Upper Devonian sediments in the Ardenne-Rhenish area, indicating that the settings were never deeply buried. Due to the low thermal maturity the miospore preservation is very good to excellent. The miospore assemblages are rich and diverse in composition. Species of the Diducites complex are particularly abundant. Other stratigraphically significant species are Cyrtospora cristifera, Grandispora cornuta, Raistrickia variabilis, and Retispora lepidophyta. The latter species is a near world-wide marker for the late Famennian. The occurrence of Grandispora echinata and Knoxiosporites literatus is still doubtful and hence, the assemblages have been assigned to the Oppel Zone LV. The rather large diameter of the exoexine of Retispora lepidophyta signifies a position close to the base of the Oppel Zone LV. The next older sediments known in the syncline are of lower Nehdenian age. It is still doubtful whether upper Nehdenian, Hemb ergian and Dasbergian sediments are present in this area.

KEYWORDS: miospores, palynostratigraphy, Upper Famennian, Strunian, Rhenish Slate Mountains, Bergisch Gladbach-Paffrath Syncline, regional geology.

RESUME. Assemblages de miospores du Famennien tardif du Synclinal de Paffrath-Bergisch Gladbach, Massif Schisteux Rhénan, Allemagne. A l’occasion d’une analyse palynologique de routine de sédiments dévonien du Synclinal de Paffrath-Bergisch Gladbach, Massif Schisteux Rhénan, des couches marines du Famennien tardif, inconnues jusqu’ici dans cette région, ont été identifiées. L’indice d’altération thermale (TAI de 2 à 2+) est remarquablement faible comparé à d’autres sédiments des régions ardenno-rhénaises, suggérant que l’ensemble n’a jamais été enfoui profondément. Grâce à cette maturité thermale faible, la conservation des miospores est très bonne à excellente. Les assemblages de miospores sont riches et diversifiés. Les espèces du complexe Diducites sont particulièrement abondantes. D’autres espèces stratigraphiquement significatives sont Cyrtospora cristifera, Grandispora cornuta, Raistrickia variabilis, et Retispora lepidophyta. La dernière espèce est un marqueur pratiquement mondial pour le Famennien tardif. La présence de Grandispora echinata et Knoxiosporites literatus est encore douteuse et, en conséquence, les assemblages ont été attribués à la Zone d’Oppel LV. Les diamètres relativement grands de l’exoexine de Retispora lepidophyta indiquent une position proche de la base de la Zone d’Oppel LV. Les sédiments immédiatement plus anciens connus dans le synclinal sont d’âge Néhdénien inférieur. On ne sait pas encore si des sédiments Néhdénien supérieur, Hemb ergien et Dasbergien sont présents dans cette région.


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1. INTRODUCTION

Famennian miospore assemblages have been extensively studied in the Ardenne-Rhenish area (e.g., Higgs & Streel, 1984; Streel, 1986b; Streel et al., 1987; Higgs & Streel, 1994). The miospore zones ranging from the Oppel Zone GF to LV (middle to late Famennian) have been defined in the Dinant Synclinorium where in sediments of the Condroz sandstone facies diverse and rather well preserved palynomorph assemblages are abundant (Streel, 1986b; Streel et al., 1987). However, due to adverse facies conditions latest Devonian miospore-bearing sediments younger than the Oppel Zone LV are rarely recorded in eastern Belgium (Streel, 1986a, b). Instead, a comprehensive miospore zonation has been established in the Irish Famennian - Tournaisian succession comprising LL to CM spore Biozones (Higgs et al., 1988). This zonation has been applied to Devonian/Carboniferous basin sequences in the Sauerland where detailed studies on macro- and microfaunal index fossils and key sections offer independent biostratigraphic control (Higgs & Streel, 1984; 1994; Streel et al., 1987).

The lowermost miospore zone recognized in these sections is the Interval Zone LL. Although in the Dinant and Namur Synclinorium the late Famennian miospore Zones LL, LE and LN have been recorded from separate sections (Paprot et al., 1983; Loboziak et al., 1994; Streel in Dreesen et al., 1993) no single section is yet known in which the transition of the LV/LL Zones has been found.

In connection with a geological and engineering geological mapping program of an area east of Cologne (sheet 5008 Köln-Mülheim of the topographic map 1:25000) numerous samples from shallow boreholes have been dated palynologically. Surprisingly enough, one sample collected from a borehole drilled in the Bergisch Gladbach-Paffrath Syncline yielded a miospore assemblage of late Famennian age. Because the presence of late Famennian strata was hitherto unknown in this region several sections exposing Upper Devonian sediments were sampled. Furthermore, cuttings from two boreholes drilled respectively in 1984 and 1985 were available. It is from these two boreholes that additional late Famennian miospore assemblages were recovered.

The miospores are well to excellently preserved at least compared with assemblages previously described from late Devonian strata of the Ardenne-Rhenish region. The aim of this paper is to document the miospore assemblage and to comment upon its palynostratigraphic significance.

2. GEOLOGICAL FRAMEWORK AND STRATIGRAPHY

The regional geology of the Bergisch Gladbach-Paffrath Syncline or for short Paffrath Syncline is very well known, thanks to the rich fauna of outstanding preservation. Over the years many fossil groups recovered from Devonian sediments of the syncline have been extensively studied making this area a classical source of Devonian palaeontology in the Ardenne-Rhenish regions (for references see Jux, 1991). In fact, research on fossils from the Paffrath Syncline started already in the eighteenth century (Schröter, 1777).

The Paffrath Syncline lies near the northern rim of the Rhenish Slate Mountains, approximately 20 km northeast of Cologne (Fig. 1). Geologically, the syncline is located between the Bechen Anticline which is the southwestern extension of the Ebbel Anticlinorium and the Bensberg Anticline. On the southern flank Middle and Upper Devonian sediments of the syncline are bordered by a very important overthrust fault (Gladbachener Randverwerfung). South of this fault Lower Devonian sediments are widespread. Due to longitudinal and strike-slip faults a complicated tectonic pattern of small-scale thrust fault systems, synforms and fault blocks is produced (Jux, 1982).

Frasnian and lower Famennian sediments varying from 330 to 410 m in thickness crop out in a narrow sector stretching southwest-northeast (Jux, 1991). The Upper Devonian succession starts with lagoonal limestones (Fig. 2) which have yielded a very famous fish fauna (e.g. Örvg, 1960/1961; Jensen, 1973). After deposition of the Refrath Formation reeval limestone production ceased and the overlying strata are dominated by grey fine-grained sediments. At the top of the Sand Formation a distinctive unit (correlated with the upper Kellwasser horizon) marks the base of the Knoppenbießen Formation. The formation is characterized by dark grey marlstones and mudstones very rich in well preserved invertebrate fossils (Jux & Groos, 1967; Jux & Krath, 1974) which date the sediments as lower Nehdenian precisely. Until recently it was believed that the Knoppenbießen Formation terminated the Upper Devonian succession in the Paffrath Syncline. The late Famennian sediments encountered in the three boreholes have not yet been named and it is unknown if Upper Nehdenian, Hembergian and Dasbergian sediments are present. The late Famennian sediments are not exposed and no borehole exists which intersects the complete succession. Therefore our knowledge concerning thickness and facies of the late Famennian in the Paffrath Syncline is extremely limited.
The thermal maturation in the Paffrath Syncline is extraordinarily low compared to the Upper Devonian sediments which crop out at the northern border of the Rhenish Slate Mountains. Paproth & Wolf (1973) report a vitrinite reflectance value of %Ro max = 0.69 for the Knappenbießen Formation indicating that the Knappenbießen Formation was never deeply buried. Apparently, the thickness of overlying and in the meantime eroded sediments did not exceed 200 m.

3. PREVIOUS PALYNOLOGICAL WORK

A number of papers which deal with palynomorphs from Devonian rocks of the Paffrath Syncline have been previously published. Amirie (1984; 1989) described Adorfian acritarch and miospore assemblages, respectively. The acritarch communities from the Upper Devonian were considered by Jux (1975; 1984) including TEM investigations. Referring to determinations by G. Schultz, he also provided a very limited account of six miospore taxa from the Knappenbießen Formation without illustrating or describing the species (Jux, 1975: p. 116). Stratigraphically, the most important one is Retispora lepidophyta. The occurrence of this taxon is striking because its inception marks the base of the Oppel Zone LV which in turn coincide with the base of the Fa2d (Streel et al., 1987). However, faunal data clearly indicate a lower Nehdenian age assignment for the Knappenbießen Formation. Unfortunately, the samples and slides relating to the study of Jux (1975) could not be relocated in the collection of the Department of Geology, University of Cologne (G. Schultz, oral comm.). Therefore 25 samples have been investigated from the Knappenbießen Formation cropping out in the Lerbach section and from a former excavation (locality Kreishaus) southeast of Bergisch Gladbach. In addition, one sample from Cox quarry nearby where the Knappenbießen Formation was temporarily exposed was processed. The samples yielded abundant but poorly preserved miospores severely damaged by the growth of pyrite crystals. However, not a single specimen of Retispora lepidophyta was recovered. Therefore the previous record of *R. lepidophyta* could not be confirmed and the authors believe it might represent a misidentification of strongly corroded camerate spores.

4. SAMPLE DETAILS

This report is based on five samples collected from three boreholes (topographical map 1:25000, sheet 5008 Köln-Mülheim). All samples are housed in the Geological Survey of North Rhine-Westphalia.
<table>
<thead>
<tr>
<th>Nehdenian</th>
<th>Knoppenbießen Fm</th>
<th></th>
<th>cir. 15 m</th>
<th>mudstone, marlstone, diverse invertebrate fauna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand Fm</td>
<td></td>
<td>cir. 20 m</td>
<td>mudstone, marlstone, tentaculites, dendroid graptolites</td>
<td></td>
</tr>
<tr>
<td>Hombach Fm</td>
<td></td>
<td>cir. 50 m</td>
<td>marlstone, anoxic conditions, tentaculites, trilobites</td>
<td></td>
</tr>
<tr>
<td>Tonschiefer Fm</td>
<td></td>
<td>30 – 50 m</td>
<td>mudstone, siltstone goniatites</td>
<td></td>
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<tr>
<td>Refrath Fm</td>
<td></td>
<td>60 – 70 m</td>
<td>reef limestone, diverse brachiopod fauna</td>
<td></td>
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<tr>
<td>Adorfian</td>
<td></td>
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<tr>
<td>Upper</td>
<td></td>
<td>150 – 200 m</td>
<td>lagoonal limestone, olistostromes, eurypterids, diverse fish fauna</td>
<td></td>
</tr>
<tr>
<td>Plattenkalk Fm</td>
<td></td>
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</table>

Figure 2. Lithostratigraphic divisions of Upper Devonian rocks in the Pafrath Syncline.

Borehole Buchenkamp 1985 (coordinates R°76765, H°46930) was drilled for ground-water observation and ended at a depth of 306 m. It penetrated 42 m of Quaternary sediments before it reached late Devonian sediments dominated by dark grey mudstones and marlstones. Marly limestone and medium grey siltstones occasionally occur as thin bands. Due to the deep weathering during Tertiary and Quaternary times at least the upper 60 m of the Devonian sediments are hardly indurated. Only one sample from 60 m (N° 89509) (all depths as measured from surface; sample number in brackets) was available. It consists of medium grey, slightly calcareous mudstone.

Borehole Brücker-Hardt 1984 (coordinates R°76490, H°45760) was drilled by the Geological Survey NW to a total depth of 60 m during a geological mapping program in the Pafrath Syncline. The Devonian sediments are covered by gravel and sand of Quaternary age. Their thickness is 36.5 m. Like in borehole Buchenkamp et al., 1985 the Devonian mainly consists of medium grey mudstones. In the lowermost part of the borehole micaceous fine-grained sandstone layers are present. Three samples have been examined from 42 m (N° 82348), 45 m (N° 82349), and 48 m (N° 82350).

The third borehole KB-33 1983 (coordinates H°79713, R°49002) is very shallow with a total depth of 9 m. It penetrated 4 m of Quaternary. A palynology sample (N° 81227) consisting of dark grey, slightly calcareous, platy mudstone was obtained at the terminal depth.

The samples studied have been processed following conventional palynological preparation procedures. Due to the low thermal alteration oxidation with Schulze reagents was not required.

5. PALYNOLOGY

All samples studied yielded palynomorphs. The best recovery was from three samples from borehole Brücker-Hardt 1984. They contained a diverse and very well preserved assemblage of miospores and microphytoplankton. The two samples from the other boreholes proved to be less productive in terms of numbers and taxonomic diversity. The following
list includes the stratigraphic key taxa which occur in the miospore population encountered in the samples N°. 82348-82350. Species which are of little stratigraphic significance, e.g. smooth trilete spores, are not taxonomically segregated and are not considered in the species list.

Species list

Aneurospora greggsii (McGregor 1964) Streele 1974 (Not figured)
Archaeozonotritiletes micronulatus Kedo 1974 (Plate 1: A, B)
Auroraspora hyalina (Naumova 1953) Streele in Becker et al. 1974 (Plate 1: C)
Auroraspora solisorta Hoffmeister, Staplin & Malloy 1955 (Plate 1: D)
Auroraspora cf. solisorta Hoffmeister, Staplin & Malloy 1955 sensu Higgs, Clayton & Keegan 1988 (Plate 1: F)
Convolutispora sp. (Plate 1: H, I)
Convolutispora cf. usitata Playford 1962 sensu van der Zwan 1980 (Plate 1: G)
Corbulisporina sp. (not figured)
Cytospora cristifera (Luber 1941) emend. van der Zwan 1979 (Plate 1: E)
Diducites mucronatus (Kedo 1974) emend. van Veen 1981 (Plate 2: A, B, H)
Diducites plicabilis van Veen 1981 (Plate 2: C, D, E)
Diducites polfissicus (Kedo 1974) emend. van Veen 1981 (Plate 2: G, I, L)
Diducites versabilis (Kedo 1975) emend. van Veen 1981 (Plate 2: F, K)
Endoculeospora gradzinskii Turnau 1975 (Plate 3: A, B, D, E)
Endoculeospora setacea (Kedo 1971) Avkhimovich & Higgs in Avkhimovich et al. 1988 (Plate 3: C, F, I)
Geminispora lemurata Balme 1962 emend. Playford 1983 (Plate 3: G)
Gorgonispora crassa (Winslow 1962) Higgs, Clayton & Keegan 1988 (Plate 3: K, L)
Grandispora cornuta Higgs 1975 (Plate 3: H; Plate 4: A)
Grandispora aff. echinata Hacquebard 1957 (Plate 4: C, E)
Grandispora gracilis (Kedo 1957) Streele in Becker et al. 1974 (Plate 4: F)
Grandispora cf. tenuispina (Hacquebard 1957) Playford 1971 sensu Streele in Becker et al. 1974 (not figured)
Grandispora cf. tenuispina (Hacquebard 1957) Playford 1971 var. punctata Streele in Becker et al. 1974 (Plate 7: H)
Hystricosporites sp. (Plate 4: B, D, G, H)
Knoxi sporites hederatus (Ischenko 1956) Playford 1963 (Plate 5: A, B, D)
Knoxi sporites aff. literatus (Waltz 1938) Playford 1963 (Plate 5: E)

Lophozonotritiletes lebedianensis Naumova 1953 (Plate 5: C, K, L)
Lophozonotritiletes sp. (Plate 5: F, G, H, I)
Raistrickia minor (Kedo 1963) Neves & Dolby 1967 (Plate 6: E)
Raistrickia variabilis Dolby & Neves 1970 (Plate 6: A, B, C)
Retispora lepidophyta (Kedo 1957) Playford 1976 (Plate 6: F, G, I)
Rhabdospores lanigii (Eisenack 1944) Richardson 1960 (Plate 6: D, H)
cf. Samarisporites sp. (Plate 7: A, B, C)
Spelaetritiletes cf. granulatus (Kedo 1963) Moreau-Benoit 1980 (Plate 7: D, E)
Spelaetritiletes sp. cf. S. pretiosus (Playford 1964) emend. Utting 1987 var. windsoirenis Utting 1987 (Plate 7: G)
Teichertispora turqua (Higgs 1975) emend. McGregor & Playford 1990 (Plate 7: F)

5.1. SELECTED SYSTEMATICS

Information on the abundance of a particular taxon is only given for those species of which less than five specimens have been recovered.

Archaeozonotritiletes micronulatus Kedo 1974 (Plate 1: A, B)

Remarks: Currently, late Devonian taxa of the genus Grandispora are being revised by a CIMP working group. In order not to anticipate the results or to produce nomenclatural confusion in referring to not yet published new taxa or changed generic assignments we therefore continue to use the old names.

Occurrence: one specimen.

Auroraspora cf. solisorta Hoffmeister, Staplin & Malloy 1955 sensu Higgs, Clayton & Keegan 1988 (Plate 1: F)

Comparison: Auroraspora velata (Felix & Burbidge) Ravn 1991 is very similar and differs only on the basis of a thinner, flexuous exoexine parts of which are often folded over the intinece.

Convolutispora cf. usitata Playford 1962 sensu van der Zwan 1980 (Plate 1: G)

Remarks: The specimen recorded conforms closely to those described by van der Zwan (1980b: p. 221, pl. 7, fig. 3, 4). Convolutispora caliginosa Clayton & Keegan in Clayton et al. 1982 is similar but differs by reduced ornamentation in the contact area.

Occurrence: one specimen.

Endoculeospora gradzinskii Turnau 1975 (Plate 3: A, B, D, E)

Remarks: Most specimens recorded clearly belong to variant B of van der Zwan (1980a). Variant A which is smaller in size is not present in the assemblage.
Endocelospora setacea (Kedo 1971) Avkhimovitch & Higgs in Avkhimovitch et al. 1988 (Plate 3: C, F, I)

Remarks and comparison: The exosome is infragranulare, bearing distally and equatorially discrete pilae and baculi with rounded tops and up to 4 μm high. On the proximal surface some rare sculptural elements are present. The species has a similar style of ornament to *E. gradziński*, but differs in possessing a thin, folded intestine which is larger in relation to the total spore diameter. The specimens recorded closely to those figured by Avkhimovitch et al. (1988).

Geminispora lerumata Balme 1962 emend. Playford 1983 (Plate 3: G)

Remarks: The specimen is slightly larger than the size range given by Playford (1983) and the lips are accompanied by laesurae. However, specimens of *G. lerumata* from the type locality (Gneudna Formation, Pelican Hill borehole), which we were able to examine, show a wide range of morphological variation (e. g. depending on the state of preservation, cf. Playford, 1983). Hence we believe that the present specimen is conspecific with that species. At least some taxa of *Geminispora*, figured in Avkhimovitch et al. (1993), appear to be synonymous with *G. lerumata* and should be reconsidered.

Occurrence: one specimen.

Gorgonispora crassa (Winslow 1962) Higgs, Clayton & Keegan 1988 (Plate 3: K, L)

Comparison: *Gorgonispora convoluta* (Butterworth & Spinner 1967) Playford 1976 on the distal surface is rugulate, reticulate and subordinately verrucate whereas in *G. crassa* an imperfect reticulum with widely spaced muri is developed. *Gorgonispora multiplicabils* (Kedo 1965) Tunma 1978 lacks the wide labra.

Occurrence: one specimen.

Grandispora aff. echinata Haquebarg 1957 (Plate 4: C, E)

The Paffrath specimens possess spineae and coni which usually are smaller than 2.5 μm in height. However, on any specimen some spineae up to 3 μm and in some rare cases up to 4 μm are present. The holotype of *G. echinata* bears broad based spineae and coni with a maximum height of 2.5 μm (McGregor & McCutcheon, 1988: fig. 4 f.)). *G. echinata* from sections located in the Dinant Synclinorium where the Interval Zone *Ech.* has been defined also has smaller sculptural elements than the present specimens. We only tentatively assign our material to *G. echinata* until this species has been reviewed by the CIMF working group (see Archaeozonotriletes micronulatus).

Hysticosporites sp. (Plate 4: B, D, G, H)

Description: Amb subcircular, proximal surface flattened, distal surface inflated, hemispherical. Exosome and intestine separated, exosome lavigate to infragranulare, total spore diameter 90 μm (excluding projecting ornament). Overall outline of inner body subcircular, intestine laevigate, partially concentric compression folds developed along periphery of intestine, diameter of inner body 70 μm. Laesurae obscured by high flexuous folds forming an apical prominence at the proximal pole. Contact areas indistinct, delimited by low arcuate ridges and ornamented with 3 or 4 radially oriented thickened ribs in each interradial area. Some ribs vaguely defined. Ribs straight to slightly sinuous, broad and flat, up to 3 μm high, some possessing a median depression, and separated by a furrow. Median depression clearly visible near the proximal pole, disappearing towards the arcuate ridges. Exosome bears distally, equatorially and on the arcuate ridges slender processes with bifurcate terminations. Each process consists of a broad base, a shaft tapering in its lower part but parallel sided in its middle and upper portion, and a laterally extended and reflexed or a laterally extended termination (terminology according to Owens 1971). Length of the processes 12-17 μm, basal diameter 3-6 μm, length of bifurcate spinae 3-8 μm.

Remarks: In the past, more than thirty species originally assigned to *Hysticosporites* have been erected mainly due to differences in size, distribution of ornamentations, process size and profile, nature of terminal bifurcate portion of the processes, development of contact areas and curvatures or presence of proximal radiating ribs. Because the morphology of the ornamentations seems to be fairly variable on one and the same specimen, its taxonomic value may be questionable.

Comparison: The present specimen is characterized by proximal ribbing and sparse, slender processes which are relatively small compared to the spore diameter. *Hysticosporites bulbus* Chi & Hills 1976, *H. elongatus* Chi & Hills 1976, *H. exans* Chi & Hills 1976, *H. furcatus* Owens 1971, *H. grandis* Owens 1971, *H. gravis* Owens 1971, *H. harpagos* Owens 1971, *H. pseudoparatus* Hills et al. 1984, *H. reflexus* Owens 1971, *H. spiralis* Chi & Hills 1976, *H. validus* Chi & Hills 1976, and *Hysticrosporites* sp. of van der Zwan 1960b, p. 224, pl. 10, figs. 1a-c all have radially oriented ribs on the contact area but bear processes considerably different in size, profile or termination. From the Devonian of Russia some more species with radially disposed costae have been described and originally assigned to *Archeaoctelites*. Several of these taxa subsequently have been transferred to *Hysticosporites* but their description and illustration in most cases is still insufficient in order to definitely confirm or deny identity with the present specimen. Also some of the Russian species are considered to be at least very closely comparable if not identical to one another or may prove to be synonymous with taxa mentioned above (Playford & McGregor, 1993: p. 31). Although no radiating ribs on the contact areas are mentioned in the description of *H. corysus* Richardson 1962 the figured holotype clearly shows this feature. *H. corysus* is distinguished from the present specimen by its triradiate mark with greatly elevated, membranous ridges and by its longer spines. *H. costatus* Vigran 1964 differs in having seven or more radially aligned ribs and more densely distributed processes which do not have a parallel sided but a gradually tapering shaft and which have triangular terminations. *H. delectabilis* McGregor 1960 is much larger but the processes are very similar besides that in *H. delectabilis* they are longer and more densely distributed. However, Braman & Hills (1992) report *H. delectabilis* from the Upper Devonian of Canada considerably smaller in size than previously noted. If one accepts a concept of broadly defined taxa within *Hysticosporites* as discussed by Playford & McGregor (1993), the Paffrath specimen may be best assigned to *H. delectabilis*.

Occurrence: one specimen.

Knoxisporites hederatus (Ischenko 1956) Playford 1963 (Plate 5: A, B, D)

Remarks and comparison: According to Bertelsen (1972) and Playford (1976) *K. hederatus* is distinguished from *Knoxisporites pristinus* Sullivan 1968 in having a stronger exine, no proxi-
mal thinning, and simple laesurae whereas *K. pristinus* possesses elevated laesurae lips and a granular exine. In addition, *K. pristinus* is frequently deformed due to the thin exine. However, as Bertelsen (1972), Playford (1976), and Hibbert & Lacey (1969) commented, both species are difficult to distinguish from each other. The differences between *K. hederatus* and *K. pristinus* appear unconvincing to the present authors and hence we consider the two species as synonymous. One specimen recorded in the Paffrath assemblage (pl. 5: D) displays a thin deformed exine but is devoid of any ornaments and lacks lips. Well preserved specimens (pl. 5: A, B) possessing a thick exine are scabrate with microgranulae smaller than 0.5 μm giving the exine a rough appearance. A similar ornamentation was described and figured for *K. pristinus* from the Lower Carboniferous of Denmark (Bertelsen 1972, pp. 51-52, pl. 18, fig. 5). A microgranulate exine was not positively mentioned in former descriptions of *K. hederatus*. Some specimens (e.g. pl. 5: A) show folds along the laesurae superficially giving the impression of broad labra. *Knoxisporites dedalus* (Naumova 1953) Streel 1973 is distinguished from *K. hederatus* by a narrow cingulum and a granulate exine (Avkhimovitch et al., 1988 p. 172).

**Raistrickia minor** (Kedo 1963) Neves & Dolby 1967 (Plate 6: E)

**Remarks:** Combaz & Steele (1971, pp. 231-232, pl. 4, figs. 5 and 9) figured two specimens from the late Famennian of Pas-de-Calais (France) which are very similar to the present material and which they assigned to *Raistrickia variabilis* Dolby & Neves 1970. According to Higgs et al. (1988), these specimens are conspecific with *R. minor*.

**Occurrence:** one specimen.

**Raistrickia variabilis** Dolby & Neves 1970 (Plate 6: A, B, C)

**Remarks:** One specimen (pl. 6: C) is ornamented on both surfaces with a mixture of bacula and small (1-3 μm in basal diameter), closely spaced verrucae, subcircular to irregular in plan view, sometimes coalescent, and with flattened tops. However, the specimen is identical in any other respect with *R. variabilis*.

**Rhabdosporites langii** (Eisenack 1944) Richardson 1960 (Plate 6: D, H)

**Remarks:** The diameter of the exoexine is 85 μm, that of the endexine 62 μm which falls into the size range of *Rhabdosporites parvulus* Richardson 1965. In the original description this species was differentiated from *R. langii* by its smaller size range and by its relatively larger endexine although the size ranges overlap as is clearly shown in the graphical plot of exoexine and endexine diameters (Richardson, 1965: text-fig. 8). Both species were originally described as uniformly covered by densely packed rods which are parallel sided and have truncated tips. In the present specimen the bladder is densely covered with often fused minute coni and spines. However, the different ornamentation may be the result of preservational alteration as it was previously demonstrated to be the case for *R. langii*, too (Lele & Steele, 1969, McGregor & Camfield, 1982). Specimens appearing identical or at least very similar to the present one have been described and tentatively assigned to *Rhabdosporites langii* by Streel (1965), to *Rhabdosporites parvulus* by Lele & Steele (1969) and Higgs & Russell (1981), and to *Rhabdosporites* cf. *parvulus* by Streel in Becker et al. (1974). Possibly, there is a morphographic gradation between the above mentioned taxa, particularly since Marshall & Allen (1982) proved a gradual change in exoexine/endexine diameter and ratio of *R. langii* and *R. parvulus*. Hence, we follow Marshall & Allen (1982) and Balme (1988) and regard these species as synonymous.

**Occurrence:** one specimen

**cf. Samarisporites** sp. (Plate 7: A, B, C)

**Remarks and Comparison:** The specimen superficially resembles *Samarisporites* sp. cf. *Aephotretiloites hirtus* Naumova 1953 sensu Streel in Becker et al. 1974 and the unidentified spore in Chitaley & McGregor (1988: pl. 13, fig. 3). As only one specimen is available and because of the poor preservation, accurate identification is precluded.

**Occurrence:** one specimen.

**Spelaeotritles** cf. *granulatus* (Kedo 1963) Moreau-Benoit 1980 (Plate 7: D, E)

**Description:** Trilete camerate miospore, amb convexly subtriangular with rounded apices and convex sides. Intexine distinct, thin, laevigate, eccentrically placed with respect to the exoexi-
ne, comprising approximately 60 per cent of the total spore diameter. Suturae obscured by ray folds, folds flexuose, reaching equator where they merge with an equatorial darkening of the exooxine forming curvatures. Ornaments consisting of coni, microcon in, and microspinae, superimposed on infragranulate exooxine, some rare coni 1 µm in height, most microconi 0.5 µm or less in height and less than 1 µm in basal diameter, microspin ae less than 0.5 µm in height. Ornaments discrete, hardly discernible on distal surface due to their minute size, readily visible at the equator. Overall diameter of exooxine 100 µm, of inteinxine 60 µm.

Remarks and comparison: Spelaeotritites eccentricus Butte rworth & Mahdi 1982 is similar to the present specimen but dif fers in possessing an intestine ornamented with minute, closely spaced bacula and in being ornamented with coarse grana and some scattered coni/spiniae. Spelaeotritites exiguus Keegan 1977 which Higgins et al. (1986) consider to be synonymous with Spelaeotritites crustatus resembles the Paffrath specimen and bears minute ornaments up to 1µm in height. However, the sculptu ral elements consist of a mixture of microverrucae, microba culae, microconi and microspinae. Spelaeotritites queenslan densis Jones & Truswell 1992 possesses coarser, occasionally fused sculptural elements and a less distinct intestine which is also larger in relation to the exooxine. Generally, the Paffrath specimen is considered conformable to S. granulatus but the rather undifferentiated diagnosis and line-drawn illustrations do not facilitate detailed comparisons. We tentatively assign the specimen to S. granulatus because according to the original dia gnosis, the Russian species is slightly smaller and granulate, not conate/microconata. However, depending on the resolving power of the used objective extremely minute sculptural elements may be misinterpreted. Moreau-Benoit (1980) who encountered the species from the late Famennian of the Rhodames Basin (Western Libya) does not discuss it in detail. She describes it as possessing an exooxine uniformly ornamented with small gran e (une fine granulation uniforme) whereas Coquel & Moreau-Benoit (1989; p. 89) state that S. granulatus is infragranulate. As mentioned before, the coni on the Paffrath specimen are so small that if any ornaments can be detected over-oxidized or med iocrey preserved specimens will at best display grana rather than coni. Cm. Hymenozyonion granulatus Kedo 1963 sensu Chi taley & McGregor (1998) from the latest Famennian of Pennsyl vania, illustrated but undescribed, appears to be similar.

Outside of Russia S. granulatus was rarely found namely in sequences exclusively dated within the Strunian to Tournaisian (Streel in Paris et al., 1985; Moreau-Benoit, 1989). In addition to the records already mentioned the species was also reported to occur in the Strunian of the Ililki basin, eastern Algerian Sahara (Coquel & Lateche, 1989).

The author attributions for Spelaeotritites granulatus are still unclear, especially regarding the first validating author (cf. the differing authorship citation in Moreau-Benoit, 1980: p. 40 but pl. 13, fig. 1; Coquel & Moreau-Benoit, 1986: p. 29; Moreau Benoit, 1989: p. 13) and the validity of the combination made by Moreau-Benoit (1980). As it is not the intention of this paper to unravel nomenclatural problems we continue to use the most customary citation.

Occurrence: one specimen.

Spelaeotritites sp. cf. S. pretiosus (Playford 1964) emend. Utting 1987 var. windsoresensis Utting 1987 (Plate 7: G)

Comparison: The Paffrath specimen closely resembles S. pre ti osus var. windsoresensis, but has a slightly smaller intestine in relation to the exooxine and possesses an equatorial darkening of the exooxine.

Remarks: Higgins et al. (1988) followed the original concept of Pustulatisporis pretiosus Playford 1964 when they defined the late Middle/early Upper Tournaisian PC Biozone whose base is marked by the first appearance of this taxon. The Irish species which is used in their zonal concept is identical with Spelaeotritites pretiosus (Playford 1964) emend. Utting 1987 var. pretiosus Utting 1987 and does not include forms ornamented with small, discrete sculptural elements. Therefore the stratigraphic range of the Irish species is not extended downward into the latest Devonian by the single, questionably identified specimen of S. pretiosus (Playford 1964) emend. Utting 1987 var. windsoresensis Utting 1987.

Occurrence: one specimen.

6. STRATIGRAPHIC SIGNIFICANCE OF THE MIOSPORES

Without doubt the Paffrath miospore assemblage is of late Famennian age.

In the Ardenne-Rhenish regions Grandispora gracilis, Diducites poljessicus, and Diducites plicabilis appear in the upper part of the Frasnian (Streel et al., 1987). In upper Famennian strata of Belgium Diducites is particularly abundant (Streel & Schec kler, 1990). McGregor & Playford (1990) compiled the stratigraphic distribution of Teichertospora for quata in upper Devonian rocks of western Europe and North America where the species ranges from very late Frasnian to latest Famennian. However, in Europe this form seems to be confined to the latest Famennian suggesting that its incoming may not have been synchronous in southern Euramerica. Grandispora cornuta provides one of the eponyms for the Oppel Zone VCo which marks the base of the chrozone Fa2c and within this Oppel Zone Raistrickia variabilis begins, too (Streel et al., 1987). In Ireland and in the Sauerland Endoculesporaspora gra dzinski is first seen in the Interval Zones LE (Higgs et al., 1988) and LL (Higgs & Streel, 1984), respectively but in North America as far as we are aware the oldest recorded occurrence seems to be in the Rugospora flexuosa - Grandispora cornuta Assemblage Zone (Richardson & Ahmed, 1988) which approxIMately equates with the late Famennian.

It is generally assumed that in Europe Cyrtospora cristifera does not appear before the latest Famennian but that in the northern region of the Old Red Continent the species, among others, characterizes the Auroraspora forquata - Grandispora gracilis Assemblage Zone which is of latest Frasnian to early late Famennian age (Richardson & McGregor, 1986; Chitaley & McGregor, 1988; McGregor & McCutcheon, 1988). Indeed, the taxon was reported to occur rarely at the very top of the Devonian of the Northern Rhenish Slate Mountains but to be more abundant in the lowermost Carboniferous of Ireland.
In the Sauerland the species makes its first appearance together with an atypical LN assemblage signifying a position near the top of the Interval Zone LN just below the incoming of *Siphonodella sulcata* (Higgs & Streel, 1984; Higgs *et al.*, 1993; Higgs & Streel, 1994). In Ireland the taxon was reported to range from the Biozone VI to PC (Higgs *et al.*, 1988). However, a single specimen of *C. cristifera* was recovered by us from a sample of the Knoppenbießen Formation (lower Nehdenian) collected in the Lerbach section (see 3.) indicating that the taxon, though very rare, is already present in the lower Famennian of Europe. The species was also reported to occur in the lowermost Famennian of the Boulonnais area of northern France (Lobozia & Streel, 1981) and near the Frasnian/Famennian boundary of North-East Libya (Streel *in Paris* *et al.*, 1985).

By far the stratigraphically most important miospore species recorded is *Retispora lepidophyta* which is a near-cosmopolitan miospore marker for the late Famennian. In the Ardenne-Rhenish regions the incoming of *Retispora lepidophyta* defines the base of the Oppel Zone LV which in turn corresponds to the base of the chronozones Fa2d (Streel *et al.*, 1987). The species became extinct at or near the Devonian/Carboniferous boundary. *Grandispora echinata* and *Knoxiosporites literatus* could not be positively identified. These species characterize the Interval Zone *Ech.* and the overlying Interval Zone *LL*, respectively. At this stage in our knowledge of latest Devonian palynostratigraphy the most reasonable age for the Paffrath assemblage is the lower part of the Oppel Zone LV of Streel *et al.* (1987). As pointed out by Streel *et al.* (1987) and Dreesen *et al.* (1993) the base of the Oppel Zone LV occurs near the limit between the conodont Middle and Late expansa Zones.

Further information on the age of assemblages containing *Retispora lepidophyta* can be deduced from the size range of this species. Streele (1966) applied biometric methods to define zones which he informally named C - F. Zone B is characterized by small numbers of *R. lepidophyta*, in zone C the taxon is represented by abundant and large forms, in zone D small specimens of *R. lepidophyta* appear, zone E lacks any large forms but some specimens are present displaying an atypical development of the distal lumina, and in zone F atypical representatives of *R. lepidophyta* are dominant. In assemblages which contain *R. lepidophyta* populations typical for the zones B and C, *Grandispora echinata* is absent (Paprot & Streel, 1971). In the Paffrath assemblage *R. lepidophyta* is a common element totaling up to 20 per cent. The diameter of the exoexine of *R. lepidophyta* ranges from 45 µm to 100 µm with a mean of 70 µm and therefore the Paffrath assemblages can be best assigned to the biometrically defined zone C.

The presence of *Geminospora lemurata* and *Rhabdosporites langii* is surprising and represents an unusually young occurrence of these two typically Middle and early Upper Devonian miospores in rocks as young as late Famennian. The exine colour of the last-mentioned species does not differ from other species whereas *G. lemurata* is slightly darker. However, this may be due to its thick exine and is not an argument in favour of reworking. Also the good state of preservation does not point to the fact that the two specimens are derived from older strata.

In the Ardenne-Rhenish region *Geminospora lemurata* characterizes the Interval Zone *Lem*. near the Eifelian/Givetian boundary (Streel *et al.*, 1987). The species is very abundant at the Givetian/Frasnian boundary (Playford, 1983). In northwestern Canada it reaches an acme within the lower Famennian (Braman & Hills, 1992). The youngest occurrence was reported by Chitaley & McGregor (1988) who found in situ miospores referable to *G. lemurata* in a heterosporous lycopsid cone collected from the Venango Formation of northwestern Pennsylvania. Dispersed miospores recovered from the matrix around the cone place the rocks into the latest Stuniian within the Interval Zone LN. The presence of *G. lemurata* in the Paffrath assemblage supports the findings previously but rarely reported that *G. lemurata* does occur in strata of late Famennian age.

In Euramerica *Rhabdosporites langii* has a widespread distribution from the lower part of the Eifelian to the Givetian/Frasnian boundary. The upper limit of its range is uncertain but may be as high as the middle Frasnian or the Frasnian/Famennian boundary (Richardson & McGregor, 1986; Traverse & Schuyler, 1994). Streel *in Becker* *et al.* (1974) noted the presence of a similar, and probably identical, form in the lower Famennian (Fa1a) from Belgium and Braman & Hills (1992) reported some very rare miospores from the Frasnian and lower Famennian of northwestern Canada which they tentatively assigned to *Rhabdosporites* cf. *R. langii*. Provided that the Paffrath specimen is correctly identified (discussion see 5.1.) and not reworked, its occurrence represents a considerable upward extension of the previously recognized range.

For the time being, it is impossible to unequivocally decide whether the two specimens are rare but genuine constituents of the late Famennian miospore population or whether they are reworked. In the latter case they may derive from outcropping Givetian/Frasnian sediments eroded not far away from the actual Paffrath Syncline during the late Famennian.
7. PALAEOENVIRONMENTAL INTERPRETATION AND THERMAL MATURETY

All samples contain miospores rich in species, acanthomorph acritarchs and prasinophyte green algae. The presence of the last two is an indication of a marine environment. However, as tetraeds are common the sediments presumably accumulated not far away from the shore. Also in the upper Famennian of the Ourthe Valley, Belgium, diverse miospore assemblages characterize a marine near-shore environment rather than a terrestrial one (Streel & Scheckler, 1990).

The colour of the spore exines in transmitted light is medium orange to light brown indicating a Thermal Alteration Index (TAI) of 2 to 2+ on a five point scale. These values in turn equate with a vitrinite reflectance of %Ro max = 0.6 to 0.9 approximately and thus are within the oil generation zone, namely in the early to peak generation stage of the oil window (Utting & Wielens, 1992). The vitrinite reflectance of latest Devonian sediments at the northern border of the Rhenish Slate Mountains ranges from %Ro max = 2.9 to 4.6 (Wolf, 1972; Paproth & Wolf, 1973), corresponding to a TAI of 4 - 5. Hence, the thermal maturity is remarkably low and suggests that there was never a significant depth of burial in this area.

8. CONCLUSIONS

It is very surprising that in the Paffrath Syncline, which has been thoroughly studied for a long time in respect to Devonian stratigraphy and palaeontology, a completely unknown late Famennian succession was recognized during palynological routine investigations. The occurrence of Retispora lepidophyta dates the assemblage in the Oppel Zone LV and clearly indicates a late Famennian (lower Strunian) age. So far the youngest known Devonian sediments in the syncline were considered to be the KnopenbieBen Formation which on the basis of a rich invertebrate fauna are of lower Nehdenian age. It is not known whether this lithostratigraphy is preserved in the syncline.

Although informations about the facies of the late Famennian settings in the Paffrath Syncline are still limited, the presence of a diverse population of acanthomorph acritarchs and prasinophyte green algae manifest that the sediments were deposited in a marine environment. As late Famennian sediments were unknown in the Paffrath Syncline until recently, this area was believed to be situated south of the northern boundary of the Ardenne-Rhenish shoal (Paproth et al., 1986).

The Oppel Zone LV has been frequently recognized in late Famennian successions of the Dinant and Namur Synclinoria. Whereas from basinal areas the Oppel Zone LV is virtually unknown except of one section in the Dill Syncline (Somers & Streel, 1978). On the other hand, palynologically defined zones overlying the Oppel Zone LV have been extensively studied in the Sauerland. Therefore the late Famennian settings in the Paffrath Syncline represent an important connecting link between the Congro sandstone facies in the Belgian Ardennes and the supposed basinal area east of the Velbert Anticline.

9. ACKNOWLEDGEMENTS

We wish to thank Kenneth T. Higgs (University College, Cork) for helpful and constructive comments. Stephen E. Scheckler (Virginia State University, Blacksburg) improved the English of parts of this paper.

10. REFERENCES


Richardson, J.B., 1965. Middle Old Red Sandstone spore assemblages from the Orcadian basin north-east Scotland. *Palaeontology, 7*: 559-605.


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PLATE 1

Photographs were taken on a Zeiss Axioplan using 63x Plan Apochromat or 100x Plan Neofluar oil immersion objectives and a Konica XG 100 film. All specimens were photographed under Nomarski differential interference contrast which greatly enhances resolution of minute sculptural elements. The figures are magnified approximately x750, except as noted otherwise.

In the explanation of the figures, the species name is followed sequentially by remarks where appropriate, the slide identification number and the England Finder reference system co-ordinates provided that the illustrated specimen is from strewn mounts. Most of the specimens are preserved in single grain mounts indicated by «SG» as part of the slide identification number.

All material relating to this study is stored in the palynological collection of the Geological Survey North Rhine-Westphalia, Krefeld.

A, B: *Archaeozonotriletes micronulatus* Kedo 1974; 82348SG34;
A: Median focus
B: Proximal surface.

C: *Auroraspora hyalina* (Naumova 1953) Streel in Becker et al. 1974; 82350SG14.


E: *Cyrtospora cristifera* (Luber 1941) emend. van der Zwan 1979; 82349SG1.


H, I: *Convolutispora* sp.; 82349SG10;
H: Distal focus
I: Proximal focus.
PLATE 2


B, H: Diducites mucronatus (Kedo 1974) emend. van Veen 1981; 82348SG8; H: showing separation of outer wall layers.

C: Diducites plicabilis van Veen 1981; 82348SG17.

D: Diducites plicabilis van Veen 1981; 82350SG21.

E: Diducites plicabilis van Veen 1981; 82350SG20.


G: Diducites poljessicus (Kedo 1957) emend. van Veen 1981; 82349SG16.

I: Diducites poljessicus (Kedo 1957) emend. van Veen 1981; 82349SG15.

K: Diducites versabilis (Kedo 1957) emend. van Veen 1981; 82348SG16.

L: Diducites poljessicus (Kedo 1957) emend. van Veen 1981; 82350SG15.
PLATE 3


B: *Endoculeospora gradzinskii* Turnau 1975; 82350SG27.


D, E: *Endoculeospora gradzinskii* Turnau 1975; 82349SG18;
D: proximal focus;
E: distal focus.

F, I: *Endoculeospora setacea* (Kedo 1971) Avkhimovitch & Higgs in Avkhimovitch *et al.* 1988; 82350SG29;
F: proximal focus;
I: distal focus.


H: *Grandispora cornuta* Higgs 1975; 82350SG11.

K: proximal focus
L: distal focus.
PLATE 4

A: *Grandispora cornuta* Higgs 1975; tetrad; 82350SG12.

B, D, G, H: *Hystricosporites* sp.; 82349SG9;
   B: proximal focus
   D: median focus
   G: sculptural detail, proximal surface
   H: radiating ribs with median depression near proximal pole.

C, E: *Grandispora* aff. *echinata* Hacquebard 1957; 82348SG31;
   C: median focus
   E: proximal focus.

PLATE 5


B: Knoxisporites hederatus (Ischenko 1956) Playford 1963; sculptural details, distal surface; 82349SG11.

C: Lophozonotriletes lebedianensis Naumova 1953; 82349SG6.


E: Knoxisporites aff. literatus (Waltz 1938) Playford 1963; 82348/5; EF B46/4.

F, G, H, I: Lophozonotriletes sp.; 82349SG5;
  F: proximal focus
  G: distal focus
  H: sculptural details, distal focus
  I: sculptural details, median focus.

K: Lophozonotriletes lebedianensis Naumova 1953; sculptural details, proximal focus; 82349SG7.

PLATE 6


D, H: *Rhabdosporites langii* (Eisenack 1944) Richardson 1960; 82348SG25;
D: median focus
H: distal focus.


PLATE 7

A, B, C: cf. Samarisporites sp.; 82349SG13;
B, C: sculptural details.

D, E: Spelaeotrilites cf. granulatus (Kedo 1963) Moreau-Benoit 1980; 82348SG24;
E: sculptural details; magnification x1200.

F: Teichertospora torquata (Higgs 1975) emend. McGregor & Playford 1990; magnification x480; 82348/5;
EF P47.

82350SG25.

H: Grandispora cf. tenuispina (Hacquebard 1957) Playford 1971 var. punctata Streel in Becker et al. 1974;
magnification x1200; 82350SG10.