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Palynology of the Ballagan Formation in the Birnieknowes and Splimersford boreholes of the Midland Valley of Scotland

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Palynology of the Ballagan Formation in the Birnieknowes and Splimersford boreholes of the Midland Valley of Scotland

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Summary

This report records the results of palynological analysis of 54 samples from the Spilmersford and Birnieknowes boreholes, National Grid Reference NGR [NT 4570 6902] and [NT 7373 7546]. respectively

Overall the palynological yield from the Spilmersford Borehole is very poor; many of the samples were barren, and those that yielded palynomorphs, contained mainly leiospheres or rare spores. Very few palynomorphs of biostratigraphic significance were recorded and no specimens of *Lycospora pusilla*, the zonal index of the Viséan Pu Biozone were recorded, which is surprising since the studied section in Spilmersford includes the CM–Pu transition as determined by Neves and Ioannides (1974) and Neves et al. (1973).

Although no specimens of *Lycospora pusilla* were recorded in the present study of the Spilmersford Borehole, the occurrence of an 'upper Ballagan' assemblage (see Stephenson et al. 2002) at a depth of 2732.5 feet, and a probable 'upper Ballagan' assemblage at a depth of 2794.5 feet, is consistent with the placing of the CM-Pu biozonal boundary at a depth of 2628.5 feet as determined by Neves and Ioannides (1974) and Neves et al. (1973).

In comparison to the assemblages of the Spilmersford Borehole, those of the Birnieknowes Borehole are diverse and well preserved, and contain the zonal indices of the CM and Pu biozones. On the basis of the presence of *Lycospora pusilla*, the upper part of the borehole section (at a depth of 938.33 feet), can be assigned to the earliest Viséan Pu Biozone of Clayton et al. (1977).

The evidence of this study, of *Lycospora pusilla* first appearing at a depth of 938.33 feet, supports the view given in the text of Neves et al. (1973), which places the CM/Pu biozonal boundary at that depth. However the common occurrence of *Schopfites claviger* in the highest samples (such as MPA 51099, depth 898.25 feet) and the absence of *Perotrilites tesselatus* and *Schulzospora campyloptera* in those samples suggests that the age of the highest part of the studied section does not extend into the younger TC biozone, as suggested in the text of Neves et al. (1973).

This study has highlighted problems in the stratigraphic placement of the CM/Pu biozonal boundary. According to the present analysis, the Birnieknowes Borehole contains only one sample from which specimens of *L. pusilla* were recovered. The 11 samples above (within the range 934.91–892.5 feet depth) contained no specimens of *L. pusilla*, and several of these assemblages are indistinguishable from typical CM Biozone assemblages in that they contain *S. claviger* and *A. macra*. If the horizon at a depth of 938.33 feet had not been sampled, it is probable, in the absence of other evidence, that the whole studied section would have been assigned to the CM Biozone. This difficulty highlights the importance of continued joint ostracod/palynology biostratigraphic studies and the need to investigate other essentially non-biostratigraphic methods such as $\delta^{13}C_{org}$ stratigraphic studies of sedimentary kerogen (see Stephenson, Leng et al., 2002).

1 Introduction

This report records the results of palynological analysis of 54 samples from the Spilmersford and Birnieknowes boreholes, National Grid Reference NGR [NT 4570 6902] and [NT 7373 7546] respectively. The palynology of the boreholes was reported on by Neves and Ioannides (1974), Neves et al. (1973) and Clayton (1971), and where possible, the results of these previous studies have been incorporated in this report. Recent work of Williams (2002) on the ostracods of the Spilmersford Borehole is also incorporated in this report. The Birnieknowes Borehole is yet to be studied for ostracods.

The objective of the study is to investigate the potential for high precision correlation within the Ballagan Formation in the Midland Valley of Scotland, following detailed work at the Heads of Ayr section, Ayrshire (Stephenson, Williams et al., 2002) and on the Glenrothes, Blairmulloch and East Dron boreholes (Stephenson, 2002a, b, c), and to investigate the palynological transition between the CM and Pu biozones in the boreholes.

2 Spilmersford Borehole [NT 4570 6902]

The ranges of palynomorphs and the quantitative characteristics of palynomorph assemblages in this section are shown in Figure 1. Selected occurrence of palynomorphs recorded by Neves and Ioannides (1974), as well as ranges and palaeoecological associations of ostracods (after Williams, 2002) are also shown.

2.1 DESCRIPTION OF ASSEMBLAGES

2.1.1 SAMPLE MPA 51032, DEPTH 2284 FEET

The sample yielded a very sparse organic residue containing no age-diagnostic palynomorphs.

2.1.2 SAMPLE MPA 51033, DEPTH 2334.75 FEET

This sample yielded a sparse organic residue containing common poorly preserved palynomorphs including:

Aurorasopora cf. *macra* (narrow margin)

Auroraspora sp.

Colatisporites spp.

Dibolisporites sp.

Large *Leiosphaeridia* sp.

Leiosphaeridia sp. A

Leiosphaeridia sp. B

Retusotriletes spp.

Rugospora cf. *polyptycha*

Rugospora minuta

Rugospora polyptycha

Spelaeotriletes sp.

2.1.2.1 INTERPRETATION

The assemblage contains no age diagnostic palynomorphs, but the presence of *Aurorasopora* cf. *macra* (narrow margin), *Rugospora minuta* and *Rugospora polyptycha*, suggests a general Late Tournaisian to Viséan age. No specimens of *Lycospora pusilla* were recorded.

2.1.3 SAMPLE MPA 51034, DEPTH 2335.5 FEET

This sample yielded a sparse organic residue consisting almost entirely of algal palynomorphs including: *Leiosphaeridia* spp. and *Leiosphaeridia* sp. A, though spores such as *Auroraspora macra* and *Rugospora* sp. also occur. The assemblage contains no age diagnostic palynomorphs, but purely on the basis of the presence of *Auroraspora macra*, a maximum age range of Devonian to earliest Viséan can be suggested (Clayton et al., 1977).

2.1.4 SAMPLES MPA 51035–51040, DEPTH 2344.25–2478.5 FEET

This group of samples yielded sparse organic residues consisting almost entirely of algal palynomorphs including *Leiosphaeridia* spp. and indeterminate spores. No age determination can be made.

2.1.5 SAMPLES MPA 51041–51042, DEPTH 2497.50–2500.25 FEET

These samples yielded sparse organic residues consisting almost entirely of algal palynomorphs including: *Leiosphaeridia* spp., *Leiosphaeridia* sp. A and indeterminate spores. Of note is the occurrence, in both samples, of the probably algal spore Cf. *Peltacystia* sp. 1, first recorded from the Glenrothes Borehole (Stephenson 2002c). In the absence of age-diagnostic palynomorphs, no age determination can be made.

2.1.6 SAMPLES MPA 51043–51047, DEPTH 2529.5–2615.5 FEET

These samples yielded sparse organic residues consisting almost entirely of algal palynomorphs including: *Leiosphaeridia* spp. and *Leiosphaeridia* sp. B, though *Colatisporites* sp. and indeterminate spores were also recorded. In the absence of age-diagnostic palynomorphs, no age determination can be made.

2.1.7 SAMPLES MPA 51048, DEPTH 2640.16 FEET

This sample yielded a sparse organic residue containing: *Colatisporites* sp., *Retusotriletes* spp., *Rugospora minuta*, *Leiosphaeridia* spp., *Aurorasopora* cf. *macra* (narrow margin) and *Apiculiretusispora* spp.. In the absence of age-diagnostic palynomorphs, no age determination can be made.

2.1.8 SAMPLES MPA 51049–51051, DEPTH 2664–2718.5 FEET

These samples yielded sparse organic residues consisting almost entirely of algal palynomorphs including: *Leiosphaeridia* spp., *Leiosphaeridia* sp. A, *Leiosphaeridia* sp. B and *Chomotriletes* sp., though *Colatisporites* spp. and indeterminate spores are also present. In the absence of age-diagnostic palynomorphs, no age determination can be made.

2.1.9 SAMPLE MPA 51052, 2732.5 DEPTH FEET

This sample yielded a rich organic residue containing common poorly preserved dark coloured palynomorphs including:

?*Knoxisporites* spp.

Acanthotriletes cf. *macrogaleatus*

Anaplanisporites baccatus

Auroraspora cf. *macra* (narrow margin)

Auroraspora cf. *macra*

Cf. *Spelaeotriletes microspinosus*

Colatisporites spp. (common)

Convolutispora sp.

Dictyotriletes cf. *submarginatus*

Discernisporites cf. *micromanifestus*

Discernisporites micromanifestus

Discernisporites sp.

Retusotriletes spp. (common)

Rugospora minuta

Rugospora polyptycha

Verrucosisporites sp.

2.1.9.1 INTERPRETATION

The presence of *Auroraspora* cf. *macra* and *Acanthotriletes* cf. *macrogaleatus* suggest a correlation with the upper part of the Ballagan Formation at the heads of Ayr, though the lack of zonal taxa from the CM or Pu biozones precludes certain age assignment.

2.1.10 SAMPLES MPA 51053–51054, DEPTH 2737.66–2746.33 FEET

These samples yielded very sparse organic residues. Only rare dark-coloured, non-diagnostic palynomorphs are present.

2.1.11 SAMPLE MPA 51055, DEPTH 2794.5 FEET

This sample yielded a rich organic residue containing common, poorly preserved, dark-coloured palynomorphs including:

'Monolete spore' of McLean and Neves 2001

Acanthotriletes spp.

Anaplanisporites baccatus

Apiculiretusispora spp.

Aurorasopora cf. *macra* (narrow margin)

Auroraspora macra

Cf. *Spelaeotriletes microspinosus*

Colatisporites sp.

Convolutispora spp.

Densosporites spp.

Discernisporites micromanifestus

Grandispora echinata

Perotrilites sp.

Plicatispora scolecophora

Punctatisporites spp.

Retusotriletes spp.

Rugospora minuta

Rugospora polyptycha

Verrucosisporites nitidus

2.1.11.1 INTERPRETATION

The presence in this assemblage of *Auroraspora macra*, and an occurrence stratigraphically above (Sample MPA 51052, depth 2732.5 feet) of an assemblage of probable 'upper Ballagan' age suggests that this assemblage is of CM Biozone age, though one of the zonal taxa for this biozone, *Schopfites claviger*, is not present.

2.1.12 SAMPLE MPA 51056 –51057, DEPTH 2817.66–2850.5 FEET

These samples yielded sparse organic residues containing only indeterminate and other non-diagnostic spores.

2.1.13 SAMPLE MPA 51058, DEPTH 2859.25 FEET

This sample yielded a rich organic residue containing common poorly preserved palynomorphs including:

Anaplanisporites baccatus

Auroraspora cf. *macra* (narrow margin)

Auroraspora macra

Calamospora spp.

Colatisporites spp.

Convolutispora spp.

Discernisporites micromanifestus

Leiotriletes sp.

Plicatispora scolecophora

Retusotriletes spp.

Schopfites claviger

Stenozonotriletes sp.

2.1.13.1 INTERPRETATION

This assemblage contains both the zonal taxa of the CM Biozone of Clayton et al. (1977) and hence is likely to be of Late Tournaisian (Tn3C age).

2.1.14 SAMPLE MPA 51059, DEPTH 2865.08 FEET

This sample yielded a sparse organic residue containing poorly preserved palynomorphs including: *Colatisporites* spp., *Rugospora polyptycha*, *Schopfites claviger*, *Auroraspora macra*, *Retusotriletes* spp. and *Rugospora minuta*. The assemblage can be assigned to the CM Biozone of Clayton et al. (1977).

2.1.15 SAMPLE MPA 51060, DEPTH 2966.5 FEET

This sample yielded a sparse organic residue containing poorly preserved palynomorphs including:

Acanthotriletes socraticus

Auroraspora cf. *macra* (narrow margin)

Camptotriletes sp.

Colatisporites spp.

Convolutispora spp.

Cristatisporites sp.

Dictyotriletes spp.

Discernisporites micromanifestus

Grandispora sp.

Kraeuselisporites hibernicus

Leiotriletes sp.

Plicatispora scolecophora

Retusotriletes spp.

Schopfites claviger

Stenozonotriletes sp.

Verrucosisporites nitidus

2.1.15.1 INTERPRETATION

CM Biozone of Clayton et al. (1977).

2.1.16 SAMPLE MPA 51061, DEPTH 2992.75 FEET

This sample yielded a sparse organic residue containing no recognisable palynomorphs.

2.2 ASSEMBLAGES REPORTED FROM THE CM –PU TRANSITION BY NEVES

AND IOANNIDES (1974)

Only 14 samples were reported from the CM-Pu Biozone interval in the Spilmersford Borehole by Neves and Ioannides (1974) and Neves et al. (1973). According to plate 4 of Neves and Ioannides (1974), *S. claviger* and *A. macra*, the zonal indices of the CM Biozone, were reported between 3013 feet 6 inches and 2306 feet 6 inches and *L. pusilla*, the zonal taxon of the Pu Biozone was reported from two samples within the interval 2306 feet 6 inches and 2628 feet 6 inches. No indication of numbers of specimens are given in plate 4 of Neves and Ioannides (1974), only presence and absence.

In the text of Neves and Ioannides (1974), *L. pusilla* is reported as being present in 'small numbers' from a sample at 2449 feet, though the presence of *L. pusilla* in this sample is not indicated in plate 4 of the same paper. In the text, *L. pusilla* is also described as occurring in small numbers in the sample from 2628 feet 6 inches depth. Neves and Ioannides (1974) note that '….it was often difficult to distinguish between certain specimens of *Anaplanisporites delicatus* and *L. pusilla* at these horizons'.

Apparently, information from the Neves and Ioannides (1974) study was available to Neves and his co-authors before the publication of Neves and Ioannides (1974) since Neves et al. (1973) display the same sample positions as those shown in the Splimersford study. Figure 8 of Neves et al. (1973) shows the presence of *L. pusilla* at 2628.5, 2563, 2504.75, 2449, 2342.5 and 2306.5 feet in the Spilmersford Borehole.

On the basis of these occurrences, the CM-Pu biozonal boundary was drawn by Neves et al. (1973) at a depth of 2628.5 feet (see Figure 1). The position of this boundary cannot be confirmed by the data from the present study.

2.3 DISCUSSION

Overall the palynological yield from the Spilmersford Borehole is very poor; many of the assemblages were barren and those that yielded palynomorphs contained mainly leiospheres or rare spores. Very few palynomorphs of biostratigraphic significance were recorded and no specimens of *Lycospora pusilla*, the zonal index of the Viséan Pu Biozone were recorded, which is surprising since the studied section includes the CM –Pu transition as determined by Neves and Ioannides (1974).

Although no specimens of *Lycospora pusilla* were recorded in the present study, the occurrence of an 'upper Ballagan' assemblage (see Stephenson, Williams et al., 2002) at a depth of 2732.5 feet, and a probable 'upper Ballagan' assemblage at a depth of 2794.5 feet, is consistent with the placing of the CM-Pu biozonal boundary at a depth of 2628.5 feet as determined by Neves and Ioannides (1974) and Neves et al. (1973).

3 Birnieknowes Borehole [NT 7373 7546]

3.1 DESCRIPTION OF ASSEMBLAGES

The ranges of palynomorphs and detailed quantitative data are shown in Figure 2.

3.1.1 SAMPLE MPA 51097–51098, DEPTH 892.5–895.25 FEET

These samples yielded very sparse organic residues with no age diagnostic palynomorphs.

3.1.2 SAMPLE MPA 51099, DEPTH 898.25 FEET

This sample yielded a very sparse organic residue containing a few palynomorphs including: *Schopfites claviger* (common), *Colatisporites* spp., *Apiculiretusispora* sp., *Auroraspora* cf. *macra* (narrow margin), *Retusotriletes* sp. and *Auroraspora macra*.

3.1.2.1 INTERPRETATION

In the absence of *Lycospora pusilla* this assemblage could be assigned to the CM Biozone of Clayton et al. (1977), but the presence of *L. pusilla* in stratigraphically lower samples in this section indicates that, by superposition, this sample may be Pu Biozone in age (i.e. Viséan). The common occurrence of *Schopfites claviger* and the absence *Perotrilites tesselatus* and *Schulzospora campyloptera* suggests that the age of this sample horizon does not extend into the younger TC biozone.

3.1.3 SAMPLE MPA 51100, DEPTH 902.5 FEET

This sample yielded an organic residue rich in well-preserved, medium to dark brown palynomorphs. The assemblage contains: common *Schopfites claviger*, common *Colatisporites* spp., as well as *Retusotriletes* spp., *Auroraspora macra*, *Auroraspora* cf. *macra* (narrow margin), *Rugospora minuta*, *Plicatispora scolecophora*, *Leiosphaeridia* sp. B, *Leiosphaeridia* spp., *Verrucosisporites* sp., *Retusotriletes incohatus*, *Convolutispora* sp., *Rugospora polyptycha*, *Schopfites delicatus*, *Calamospora* spp. and *Discernisporites micromanifestus*.

3.1.3.1 INTERPRETATION

As for Sample MPA 51099, depth 898.25 feet.

3.1.4 SAMPLE MPA 5110, DEPTH 903.4 FEET

This sample yielded a rich and unusual organic residue consisting of common terrestrially derived spores and pollen, a diverse aquatic algal palynomorph assemblage and common sheet cellular material of probable land plant origin. The plant debris and palynological content is closely similar to that of an assemblage recorded from the Glenrothes Borehole at a depth of 357.80 m (Stephenson, 2002c). The present assemblage contained:

?Colpate pollen

'Monolete spore' of McLean and Neves 2001

Apiculiretusispora spp.

Auroraspora cf. *macra* (narrow margin) (common)

Auroraspora macra

Auroraspora sp. 1

Auroraspora spp.

Botryococcus spp.

Calamospora spp.

Chomotriletes spp.

Colatisporites spp. (common)

Convolutispora spp.

Grandispora cf. *cornuta*

Large monolete spores

Leiosphaeridia spp. (common)

Plicatispora scolecophora

Reduviasporonites catenulatus

Reduviasporonites chalastus

Retusotriletes incohatus

Retusotriletes spp.

Rugospora minuta

Rugospora polyptycha

Schopfites claviger (common)

Spelaeotriletes cf. *microspinosus*

Spelaeotriletes microspinosus (common)

Spelaeotriletes sp. C

Spelaeotriletes sp. D

3.1.4.1 INTERPRETATION

In the absence of *Lycospora pusilla* this assemblage could be assigned to the CM Biozone of Clayton et al. (1977), but the presence of *L. pusilla* in stratigraphically lower samples in this section may indicate that, by superposition, this sample is of Pu Biozone age.

A number of the taxa in the assemblage are likely to be of zygnemataceaen algal origin; this and the presence of *Botryococcus*, a green alga, suggests fresh or brackish water palaeoenvironmental conditions. The similar assemblage from a depth of 357.8 m in the Glenrothes Borehole is associated with the brackish or freshwater ostracod *Shemonaella* cf. *scotoburdigalensis* (Williams, 2001; Stephenson, 2002c).

3.1.5 SAMPLES MPA 51102–51106, DEPTH 905.08–915.58 FEET

These samples yielded very sparse organic residues that were either barren, or yielded non-diagnostic palynomorphs.

3.1.6 SAMPLE MPA 51107, DEPTH 934.91 FEET

This sample yielded a rich organic residue containing poorly preserved palynomorphs as well as common sheet cellular material of probable land plant origin. The form of this plant debris is similar to that present in sample MPA 51101. The assemblage contains:

Apiculiretusispora multiseta

Apiculiretusispora spp.

Botryococcus spp.

Chomotriletes sp.

Colatisporites spp.

Prolycospora claytonii

Retusotriletes spp.

Rugospora minuta

3.1.6.1 INTERPRETATION

The presence of zygnemataceaean algae and *Botryococcus* suggests a fresh or brackish water environment, as in Sample MPA 51101. No age diagnostic palynomorphs are present; it should be noted, however, that *Prolycospora claytonii* is present. In lower samples in this section *Prolycospora claytonii* appears to be part of a group of forms that are, at least in this borehole section, transitional with *Lycospora pusilla* and *Anaplanisporites baccatus,* and hence the presence of *P. claytonii* may be weak evidence for a Pu Biozone age.

3.1.7 SAMPLE MPA 51108, DEPTH 938.33 FEET

This sample yielded a rich organic residue containing common moderately preserved palynomorphs. The assemblage contained:

Lycospora pusilla

?*Schopfites claviger*

Anaplanisporites baccatus (common)

Apiculiretusispora multiseta

Apiculiretusispora spp.

Cf. *Lycospora pusilla*

Colatisporites spp.

Plicatispora cf. *scolecophora*

Plicatispora scolecophora

Prolycospora claytonii

Prolycospora claytonii/*A. baccatus*/ *L. pusilla* transitional form

Retusotriletes incohatus

Retusotriletes spp.

Rugospora minuta

Tetraporina sp.

3.1.7.1 INTERPRETATION

The assemblage contains only a few specimens that can, without doubt, be assigned to *Lycospora pusilla*; however many specimens in the assemblage are closely similar to that taxon, and many appear to be similar to the forms described by Neves and Ioannides (1974) as being transitional between *Anaplanisporites* spp. and *Lycospora pusilla*. Specimens of *L. pusilla*, and other transitional forms are illustrated in detail in Plate 2. In view of the presence of *L. pusilla*, this sample (and therefore by superposition, the samples above this, at least to a depth of 892.5 feet), are assigned to the early Viséan Pu Biozone of Clayton et al. (1977). Although the characteristics of the palynostratigraphy of the Birnieknowes Borehole are not described in detail, the text of the paper by Neves et al. (1973) appears to support the placement of the base of

the Pu Biozone at the depth suggested here.

3.1.8 SAMPLE MPA 51109, DEPTH 942.25 FEET

This sample yielded a rich organic residue containing common moderately preserved palynomorphs. The assemblage contained:

Anaplanisporites baccatus (common)

Anaplanisporites baccatus/ *L. pusilla* transitional form

Apiculiretusispora multiseta

Baculatisporites fusticulus

Convolutispora spp.

Grandispora sp. E

Plicatispora scolecophora

Prolycospora cf. *claytonii*

Prolycospora claytonii

Punctatisporites spp.

Retusotriletes spp.

Rugospora minuta

Verrucosisporites cf. *nitidus*

3.1.8.1 INTERPRETATION

The presence of transitional specimens between *Anaplanisporites baccatus* and *Lycospora pusilla* indicates the proximity of this sample to CM-Pu biozonal boundary. Since *L. pusilla* is not present, this assemblage must be assigned tentatively to the CM Biozone despite the absence of the CM Biozone indices *S. claviger* and *A. macra.*

3.1.9 SAMPLE MPA 51110, DEPTH 947.16 FEET

This sample yielded a rich organic residue containing common moderately preserved palynomorphs. The assemblage contained:

Anaplanisporites baccatus (common)

Apiculiretusispora multiseta (common)

Apiculiretusispora spp.

Auroraspora macra

Baculatisporites fusticulus

Botryococcus spp.

Calamospora sp.

Colatisporites spp.

Convolutispora spp.

Grandispora sp. E

Plicatispora scolecophora

Prolycospora cf. *claytonii*

Prolycospora claytonii

Punctatisporites spp.

Retusotriletes spp.

Rugospora minuta

Rugospora sp.

Schopfites claviger

3.1.9.1 INTERPRETATION

The lack of *L. pusilla* and forms transitional between *Prolycospora claytonii*, *Anaplanisporites baccatus* and *Lycospora pusilla*, and the presence of *Schopfites claviger* and *Auroraspora macra* suggests assignment to the CM Biozone of Clayton et al. (1977) (Tournaisian Tn3c).

3.1.10 SAMPLE MPA 51111, DEPTH 1027.5 FEET

This sample yielded a very sparse organic residue containing a few palynomorophs including: *Anaplanisporites baccatus* and *Retusotriletes* spp. No age diagnostic palynomorphs are present.

3.1.11 SAMPLE MPA 51112, DEPTH 1136.5 FEET

This sample yielded a rich organic residue containing common moderately preserved palynomorphs. The assemblage contained:

'Monolete spore' of McLean and Neves 2001

Acanthotriletes socraticus

Anaplanisporites cf. *baccatus*

Apiculiretusispora multiseta (common)

Apiculiretusispora spp.

Auroraspora cf. *macra*

Auroraspora cf. *macra* (narrow margin) (common)

Auroraspora macra

Chomotriletes sp.

Colatisporites spp. (common)

Convolutispora spp.

Dictyotriletes spp.

Diducites sp.

Discernisporites cf. *micromanifestus*

Discernisporites micromanifestus

Knoxisporites spp.

Murospora sp.

Plicatispora scolecophora

Retusotriletes incohatus

Retusotriletes spp. (common)

Rugospora polyptycha

Schopfites claviger

Vallatisporites spp.

Verrucosisporites nitidus

3.1.11.1 INTERPRETATION

As for Sample MPA 51110, depth 947.16 feet.

3.1.12 SAMPLE MPA 51113, DEPTH 1162.33 FEET

The sample yielded an extremely sparse organic residue containing no identifiable palynomorphs.

3.1.13 SAMPLE MPA 51114, DEPTH 1165.16 FEET

This sample yielded a rich organic residue containing common poorly preserved palynomorphs. The assemblage contained:

Anaplanisporites baccatus

Apiculiretusispora multiseta (common)

Apiculiretusispora spp.

Aurorasopora cf. *macra* (narrow margin) (common)

Auroraspora cf. *macra*

Auroraspora macra

Calamospora sp.

Colatisporites spp.

Convolutispora spp.

Dibolisporites distinctus

Discernisporites micromanifestus

Knoxisporites sp.

Leiotriletes spp.

Murospora sp.

Plicatispora scolecophora

Retusotriletes spp.

Schopfites claviger

3.1.13.1 INTERPRETATION

As for Sample MPA 51110, depth 947.16 feet.

3.1.14 SAMPLE MPA 51115, DEPTH 1173.75 FEET

This sample yielded a rich organic residue containing common poorly preserved palynomorphs. The assemblage contained:

Apiculiretusispora multiseta

Apiculiretusispora spp. (common)

Aurorasopora cf. *macra*

Auroraspora cf. *macra* (narrow margin)

Auroraspora macra

Botryococcus spp.

Calamospora spp.

Colatisporites spp. (common)

Convolutispora spp.

Diducites sp.

Discernisporites micromanifestus

Grandispora echinata

Grandispora sp.

Knoxisporites spp.

Leiosphaeridia spp.

Plicatispora scolecophora

Punctatisporites spp.

Retusotriletes spp.

Schopfites claviger

Spelaeotriletes tuberosus

3.1.14.1 INTERPRETATION

CM Biozone (Clayton et al., 1977).

3.1.15 SAMPLE MPA 51116, DEPTH 1175.25 FEET

This sample yielded a rich organic residue containing common poorly preserved palynomorphs. The assemblage contained:

Acanthotriletes cf. *socraticus*

Apiculiretusispora sp.

Aurorasopora cf. *macra*

Aurorasopora cf. *macra* (narrow margin)

Aurorasopora macra

Botryococcus spp.

Colatisporites sp. (common)

Convolutispora spp.

Discernisporites micromanifestus

Grandispora spp.

Knoxisporites triangularis

Perotrilites sp.

Punctatisporites sp.

Retusotriletes sp.

Rugospora minuta

Schopfites claviger

Spelaeotriletes pretiosus

Vallatisporites spp.

Verrucosisporites cf. *nitidus*

Verrucosisporites nitidus

3.1.15.1 INTERPRETATION

CM Biozone (Clayton et al., 1977).

3.1.16 SAMPLE MPA 51117, DEPTH 1198.58 FEET

This sample yielded a rich organic residue containing common poorly preserved palynomorphs. The assemblage contained:

'Monolete spore' of McLean and Neves 2001

Anaplanisporites baccatus

Auroraspora cf. *macra*

Auroraspora cf. *macra* (narrow margin) (common)

Auroraspora macra

Colatisporites spp. (common)

Convolutispora spp.

Kraeuselisporites hibernicus

Plicatispora scolecophora

Punctatisporites spp.

Retusotriletes incohatus

Retusotriletes spp. (common)

Rugospora minuta

Schopfites claviger

Single isolated cells of *Reduviasporonites chalastus*

Spelaeotriletes sp.

Vallatisporites spp.

3.1.16.1 INTERPRETATION

CM Biozone (Clayton et al., 1977).

3.1.17 SAMPLE MPA 51118, DEPTH 1246.5 FEET

This sample yielded a rich organic residue containing common poorly preserved palynomorphs. The assemblage contained:

Anaplanisporites baccatus

Auroraspora cf. *macra* (narrow margin)

Auroraspora macra

Chomotriletes sp.

Colatisporites spp. (common)

Convolutispora spp.

Densosporites spp.

Discernisporites crenulatus

Discernisporites micromanifestus

Grandispora sp.

Retusotriletes incohatus

Retusotriletes spp.

Schopfites claviger

Spelaeotriletes pretiosus

Verrucosisporites nitidus

3.1.17.1 INTERPRETATION

CM Biozone (Clayton et al., 1977).

3.1.18 SAMPLE MPA 51119, DEPTH 1259.75 FEET

This sample yielded a rich organic residue containing common moderately preserved palynomorphs. The assemblage contained:

Anaplanisporites baccatus (common)

Auroraspora cf. *macra*

Auroraspora cf. *macra* (narrow margin)

Auroraspora macra

Baculatisporites fusticulus

Botryococcus spp.

Colatisporites sp. (common)

Convolutispora spp.

Discernisporites crenulatus

Discernisporites micromanifestus

Murospora/*Knoxisporites* sp.

Punctatisporites sp.

Retusotriletes incohatus

Retusotriletes spp.

Schopfites claviger

Verrucosisporites nitidus

Verrucosisporites sp.

3.1.18.1 INTERPRETATION

CM Biozone (Clayton et al., 1977).

3.1.19 SAMPLE MPA 51120, DEPTH 1269.08 FEET

This sample yielded a rich organic residue containing common moderately preserved palynomorphs. The assemblage contained:

Acanthotriletes sp.

Anaplanisporites baccatus (common)

Auroraspora cf. *macra*

Auroraspora cf. *macra* (narrow margin)

Baculatisporites fusticulus

Calamospora spp.

Colatisporites spp. (common)

Convolutispora spp.

Discernisporites cf. *micromanifestus*

Discernisporites crenulatus

Discernisporites micromanifestus

Lophotriletes sp.

Murospora sp.

Plicatispora scolecophora

Proprisporites undosus

Retusotriletes incohatus

Retusotriletes spp.

Unknown palynomorph 1

Verrucosisporites cf. *nitidus*

Verrucosisporites nitidus

3.1.19.1 INTERPRETATION

CM Biozone (Clayton et al., 1977).

3.2 DISCUSSION

In comparison to the assemblages of the Spilmersford Borehole, those of the Birnieknowes Borehole are diverse and well preserved, and contain the zonal indices of the CM and Pu biozones. On the basis of the presence of *Lycospora pusilla* in the sample from a depth of 938.33 feet, the upper part of the borehole section (at less than depth 938.33 feet depth) can be assigned to the earliest Viséan Pu Biozone of Clayton et al. (1977).

The Birnieknowes Borehole was studied by Clayton (1971) and Neves et al. (1973). Clayton (1971) described assemblages from the borehole section between 1276 feet and approximately 1150 feet depth, wholly below the base of the Horse Roads Sandstone (see Figure 2) and did not record specimens of *Lycospora pusilla*, a finding consistent with the present study. Neves et al. (1973) studied the borehole section between approximately 140 and 1276 feet depth, although the depths of samples studied cannot be accurately discerned since Figure 11 of Neves et al. (1973) does not show sample depths, but merely schematic sample positions.

The findings of Neves et al. (1973) are presented inconsistently. In the text of the paper, the section from 1276 to 1096 feet depth is assigned to the CM Biozone, whereas that between 938.5 to 914 feet depth is assigned to the Pu Biozone. In Figure 11 of the same publication, the CM-Pu biozonal boundary is shown at approximately the base of the Horse Roads Sandstone (at the position of sample B22 of Neves et al. 1973); according to the BGS Birnieknowes Borehole log (dated 1968), the depth of this horizon is approximately 1085 feet. These discrepancies are shown in Figure 2.

The evidence of this study, of *Lycospora pusilla* first appearing at a depth of 938.33 feet, tends to support the view given in the text of Neves et al. (1973), placing the CM-Pu biozonal boundary at that depth. However the common occurrence of *Schopfites claviger* in the highest samples (such as Sample MPA 51099, depth 898.25 feet) and the absence of *Perotrilites tesselatus* and *Schulzospora campyloptera* suggests that the age of the highest part of the studied section does not extend into the younger TC biozone, as suggested in the text of Neves et al. (1973).

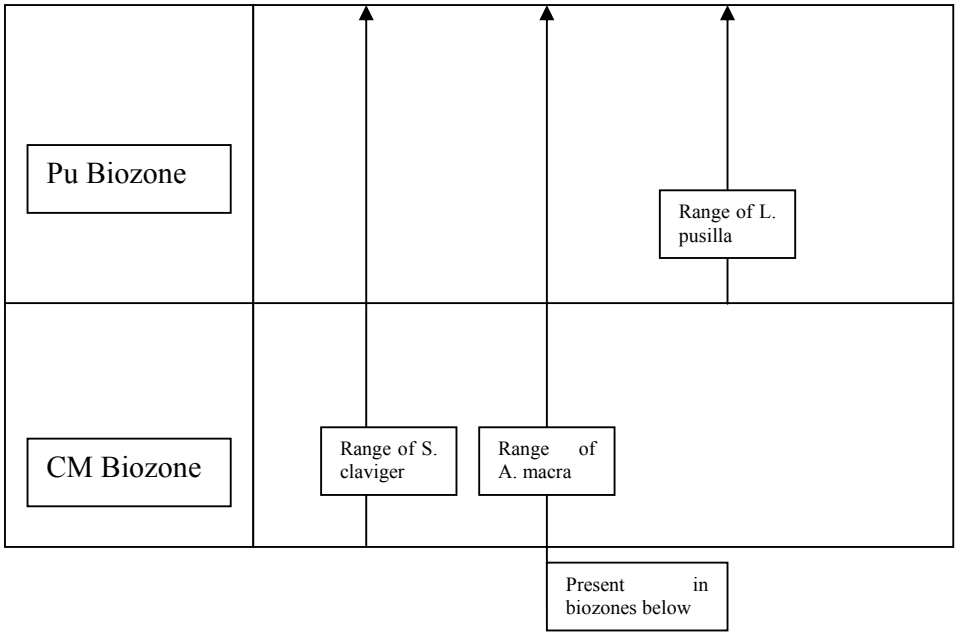
4 Comment on the definition of the base of the Pu Biozone

The base of the Pu Biozone has been defined in two ways (Owens et al., 1977; Higgs et al., 1988).

1. At the incoming of the first specimen of *L. pusilla*
2. At the incoming of 'significant' numbers of *L. pusilla*

Higgs et al. (1988) suggested that the first definition should be adopted since this is more practically applied. Adopting this definition, the CM and Pu biozones and the ranges of definitive taxa can be illustrated as in Figure 3.

Fig. 3 Range of selected palynomorphs at the CM/Pu Biozone boundary



Though this definition is now clear, the stratigraphic placement of the boundary can still be problematic. In this study, the Birnieknowes Borehole contains only one sample from which specimens of *L. pusilla* were recovered. The 11 samples above (within the range 934.91–892.5 feet depth) contained no specimens of *L. pusilla*, and several of these assemblages are indistinguishable from typical CM Biozone assemblages in that they contain *S. claviger* and *A. macra*. If the horizon at a depth of 938.33 feet had not been sampled, it is probable, in the absence of other evidence, that the whole studied section would have been assigned to the CM Biozone. This difficulty highlights the importance of continued joint ostracod/palynology biostratigraphic studies and the need to investigate other essentially non-biostratigraphic methods such as $\delta^{13}C_{org}$ stratigraphic studies of sedimentary kerogen (see Stephenson, Leng et al., 2002).

5 Further work

- Continued joint ostracod-palynology biostratigraphic studies
- $\delta^{13}C_{org}$ stratigraphic studies of sedimentary kerogen
- Final correlation of the MVS boreholes studied

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WILLIAMS, M. 2001. Ostracods form the Ballagan Formation (Tournaisian; lower Carboniferous) of the Glenrothes Borehole. *BGS Report* IR/01/63.

6 Appendix 1, Charts

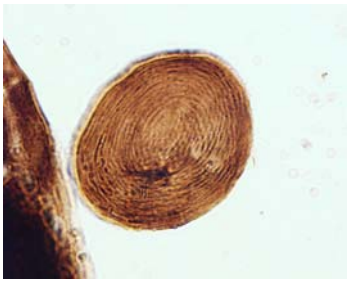
7 Appendix 2, Plates

Plate 1, Palynomorphs from the Birnieknowes Borehole,

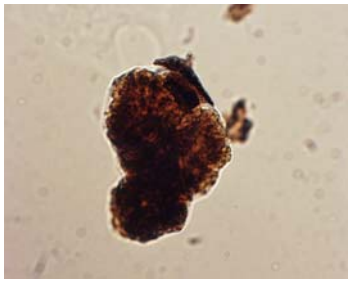
R. chalastus, 019/4, 51101

?R. chalastus, F20/2, 51101

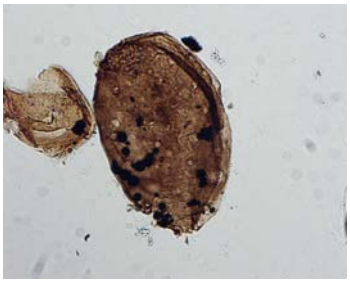
?R. chalastus, F26, 51101



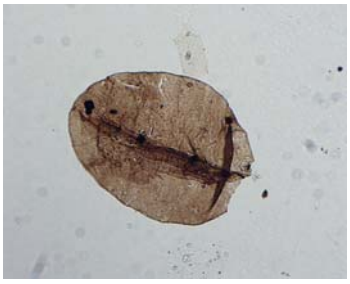
Chomotriletes sp. F30, 51101



Botryococcus sp. F24/1, 51101

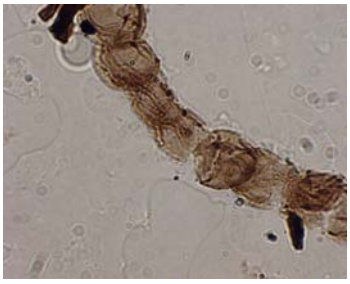


'Monolete spore' of McLean and Neves, H21/2, 51101



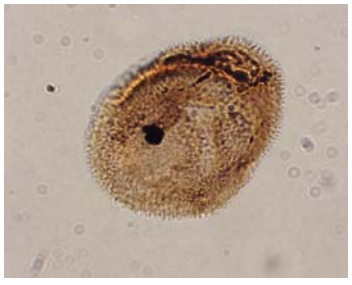
'Monolete spore' of McLean and Neves, O13/3, 51101

'Monolete spore' of McLean and Neves, Y9, 51101

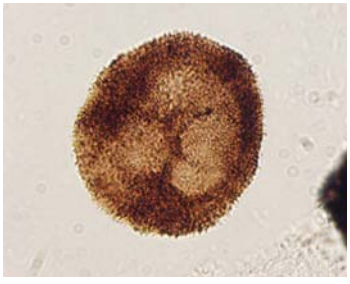


R. catenulatus, U31/4, 51101

Leiosphaeridia sp., G3/3, 51101



A. multiseta, D34, 51108



A. multiseta, G21/3, 51112

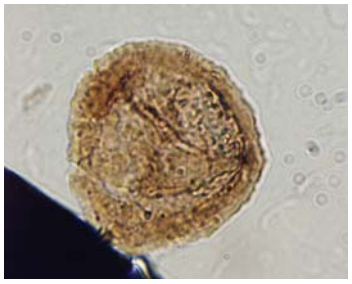
D. crenulatus, E31, 51118

D. crenulatus, E33, 51118

D. crenulatus, M12, 51118

Plate 2, Palynomorphs from the Birnieknowes Borehole

L. pusilla, T7/4, 51108



Cf. L. pusilla, O11, 51108

Cf. L. pusilla, P24/1, 51108

Cf. L. pusilla, Q9, 51108

P. claytonii/A. baccatus/ L. pusilla transitional form, G12/4, 51108

P. claytonii/A. baccatus/ L. pusilla transitional form, J31/1, 51108

P. claytonii/A. baccatus/ L. pusilla transitional form, J21, 51108

P. claytonii/A. baccatus/ L. pusilla transitional form, N28/3, 51108

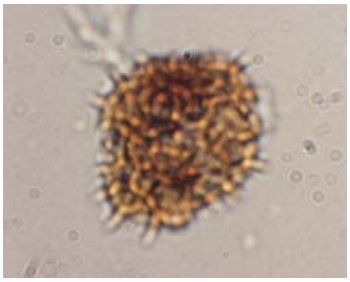
P. claytonii, N26/4, 51108

Unknown palynomorph 1, N8, 51120

P. undosus, N33/1, 51120

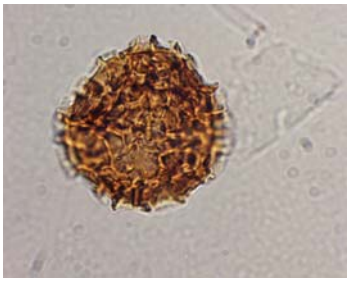
Unknown palynomorph 1, N8, 51120

Plate 3, Palynomorphs from the Spilmersford Borehole

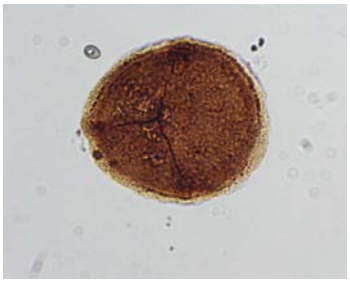


Acanthotriletes socraticus, D35/2, 51060

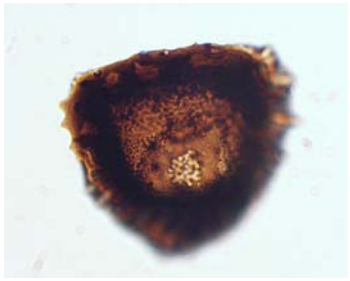
Leiosphaeridia sp. A, F20, 51039



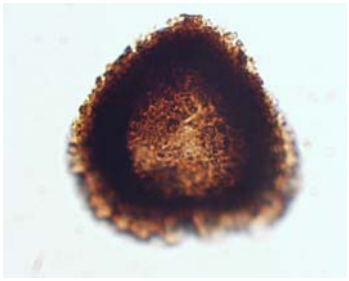
Dictyotriletes sp., N14, 51060



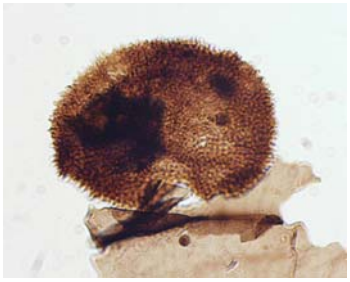
A. cf. macra (narrow margin), N26/3, 51055



Densosporites sp. L29/3, 51055

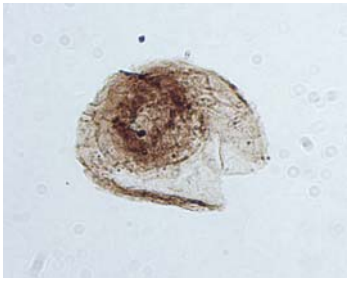


Densosporites sp. R13/3, 51055

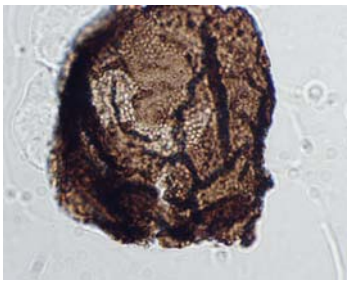


S. cf. microspinosus, D28/2, 51052

A. cf. macrogaleatus, J10/2, 51052



Leiosphaeridia sp. B, X30/2, 51051



Leiosphaeridia sp. A, E7, 51041

Cf. Peltacystia sp. 1, J32, 51041

Cf. Peltacystia sp. 1, W36/1, 51041