THE DISTRIBUTION OF MEGASPORES FROM THE UPPER CARBONIFEROUS (NAMURIAN A) COAL-BEARING SEQUENCE OF DALQUHANDY, DOUGLAS COALFIELD, LANARKSHIRE, SCOTLAND

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Abstract

The Douglas Coalfield of Lanarkshire, Scotland, of early Late Carboniferous age contains a thick sequence of coal-bearing strata of the Limestone Coal Formation. Ten coals occur in an eighty-five meter sequence. Lycopsid megaspores occur abundantly in most of these coals. Ten species of megaspore are recorded from the coals and a discussion of their distribution is presented. The spores are typical of other Namurian A (Pendellian) assemblages and are characterized by the abundance of *Lagenicula subpilosa* forma *major*, *Setosisporites brevispinosus*, *S. hirsutus*, *S. splendidus*, *Zonalesporites brasserti* and *Rotatispotites rotatus*. Comparisons are made with assemblages from the Lower Limestone Formation and other localities in the Limestone Coal Formation.

INTRODUCTION

Namurian megaspores are poorly known in Britain and only a few have previously been described (Dijkstra, 1957; Sen, 1964; Scott, et al. 1993). Our knowledge of Namurian megaspore distribution is rather poor (Scott and Hemsley, 1996). The stratigraphy of the Douglas Basin has been studied in some detail (Lumsden, 1964) so that most of the Namurian A (Pendellian) is known to be represented at the Dalquhandy Opencast Mine. Samples were taken for palynological analysis from most of the coals during 1991 to 1994. In this paper preliminary assessment of the megaspores obtained during this study are presented.

GEOLOGICAL SETTING OF THE SCOTTISH UPPER CARBONIFEROUS COAL-BEARING STRATA

Scotland has long been famous for its coal. Indeed coals are found in the widest age range of rock formations here than in the rest of the British Isles. The British coal industry, and particularly the Scottish Coal Industry, has undergone severe decline over the past ten years and prospects are uncertain despite the fact that over 1000 million tons of good quality bituminous coal is still available for mining. The Midland Valley Basin is a rift basin which underwent major subsidence in the late Palaeozoic. Overlying thick Devonian molasse sediments of Old Red Sandstone facies are Lower Carboniferous (Dinantian) sediments, predominantly non-marine, but with extensive volcanics. The earliest coals are of late Viséan age but they have little significance. The oldest worked coals are from the Limestone Coal Formation of Namurian (Silesian) age which are worked mainly by opencast methods both in the East Lothian region and in the Douglas Coalfield (Text-Figure 1). In the Douglas coalfield nine coals up to two metres thick are worked. These coals were deposited in typical coastal plain/deltaic settings. The other major phase of coal deposition was during the late Namurian Passage Group and the Westphalian Coal Measures. These occur generally as thin seams often less than one metre thick, except unusually in the now closed Westfield mine (Scott et al., 1993), and have been worked both by deep mining and by opencast mining techniques in several coalfields. Most deep mines are now closed and mining appears for the future to be restricted to a few opencast operations.

Palaeogeography and Climate

There has been considerable research over the past twenty years on the position of Carboniferous plates. Scotland formed part of a major continental block variously known as Laurussia (Laurasia) or Euramerica. Despite the variations in reconstructions all show Scotland more or less on the equator as part of the Euramerican Coal Province. It is

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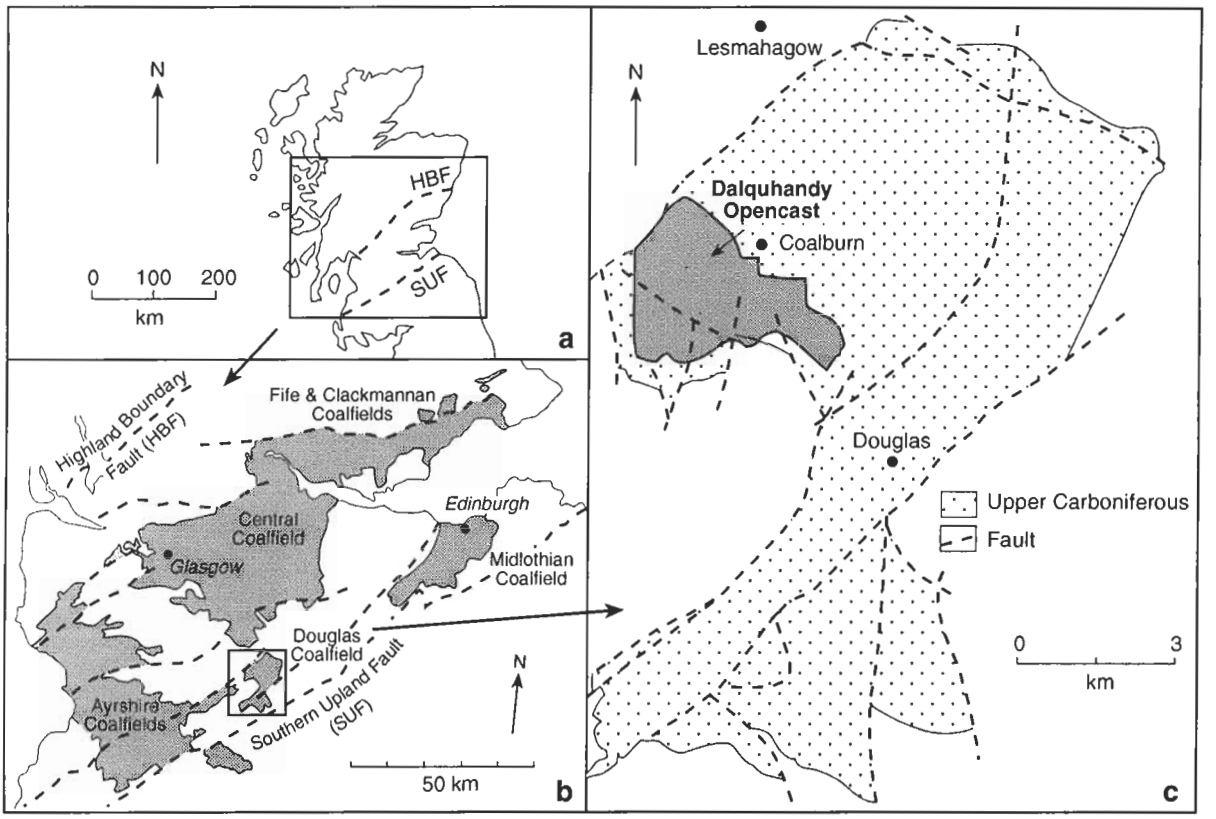

Text-Figure 1. Location maps of the Dalquhandy Opencast Coal Mine, Coalburn, Lanarkshire, Scotland. A Position of the Midland Valley of Scotland. B Coalfields in the Midland Valley of Scotland and the position of the Douglas Coalfield. C Location of the Dalquhandy Opencast Mine in the Douglas Coalfield.

also generally agreed that this equatorial belt was tropical with high rainfall (Calder and Gibling, 1994).

Recent research has suggested that during everwet cycles (i.e. high rainfall for all twelve months in a year) peat may accumulate but little clastic sediment will be transported or deposited (Cecil, 1990). When rainfall is more sporadic peat formation may stop and clastic sedimentation resume. The implication of this model is rather than peats and clastic sediments coexisting in a basin, their alternation implies climatic change. Until recently most modern analogues which had been used to compare with Carboniferous peat-forming systems had been in the

PLATE 1

Scanning Electron micrographs of megaspores from the Limestone Coal Group in the Dalquhandy Opencast Mine, Douglas Coalfield, Scotland.

1 *Lagenicula subpilosa* forma *major* x50, CP1252, 30 inch Coal.
2 detail of 1. x 500
3 *Lagenicula subpilosa* forma *major* x50, CP1256, Gas Coal.
4 detail of 3. x 500
5 *Lagenicula subpilosa* forma *major* x50, CP1260, Ell Coal.
6 detail of 5. x 240
7 ?*Setosispotites indianensis* x50, CP1256, Gas Coal.
8 *Setosisporites clavatus* x50, CP1259, 30 inch Coal.
9 detail of 8. x 400
10 *Cystosporites giganteus*. aborted specimen. x 50, CP1260, Ell Coal.
11 *Cystosporites giganteus*. aborted specimen. x 50, CP1226, 30 inch Coal.


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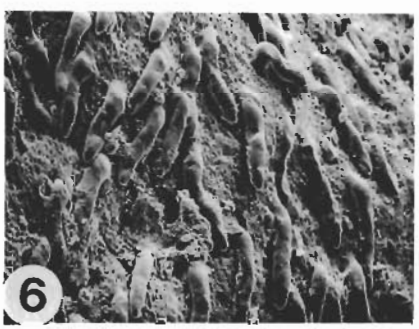
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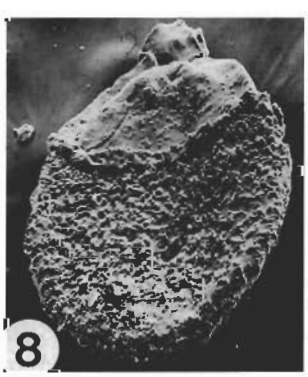
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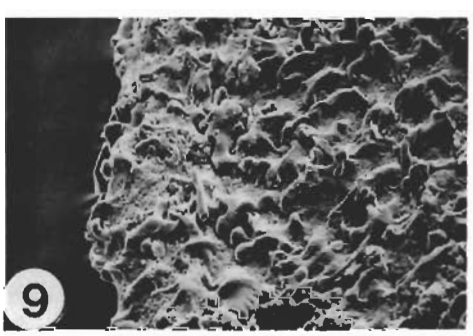
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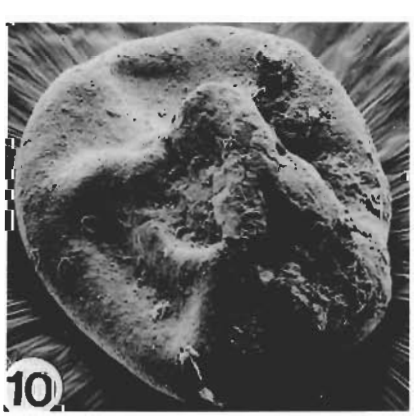
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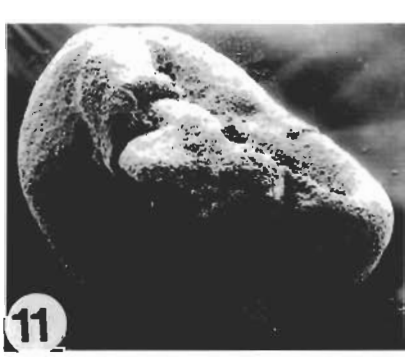
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Southeast United States but research by several workers suggests that the peat-forming systems of Southeast Asia represent better, but not ideal, models. It has been argued that the thick domed peats of these tropical regions are our closest analogues. Despite the idea of continual rainfall it is clear that all was not always peaceful. The occurrence of abundant charcoal (fusain, Scott, 1989b) in many Scottish coals and coal-bearing sequences indicates that fires were an important part of the ecosystem dynamics (Scott and Jones, 1991,1994).

Upper Carboniferous Basins

The major Scottish coalfields occur within the Midland Valley Basin. This basin is one of a series of grabens and half-grabens which occur in northern Britain (Text-Figure 1a). A useful review will be found in Leeder (1982). The Midland Valley Basin is bounded by the Highland Boundary Fault to the north and the Southern Uplands Fault to the south, both trending WSW-ENE. The main faults were probably quiescent during much of the Carboniferous, nevertheless the Midland Valley Basin occupied a tectonically active region of the Northern Megabasin (Grayson and Oldham, 1987), a graben/half graben complex on the southern marginal shelf of Laurasia (Leeder, 1988) that was dissected into W-E elongated tilt blocks by fault controlled hinge belts. The nature of the tensional stresses that generated the crustal dissection is controversial. The fundamental cause of the regional tectonism is also equivocal. The most probable scenarios involve shear zones associated with the opening of the North Atlantic (Hazeldine, 1984) or, more likely, northward subduction of the Iberian-southwest microplate aggregate c. 1100 km to the south of the Midland Valley following the closure of the mid-European Rheic Ocean and narrowing of the proto-Tethys Ocean separating Laurasia from Gondwanaland (Leeder, 1982).

Sedimentation through the Carboniferous in the Midland Valley Basin was ocean-marginal but largely non-marine. The basin received some detritus from the emergent Caledonian hinterland to the north (particularly from deltas in the northwest) and the Southern Uplands Massif (Cockburnland) to the south.

Scottish Carboniferous Stratigraphy and Environments

Carboniferous rocks are widespread in the Midland Valley of Scotland (Text-Figure 1b). Details of their stratigraphy and environments may be found in Francis (1991) but some of the more significant points are outlined here. Most coal-bearing strata is restricted to the Upper Carboniferous (Silesian).

The oldest Coal-bearing sequence is the Limestone Coal Formation of early Namurian age. This sequence has recently been studied by Stedman (1988). The Limestone Coal Formation is widespread in the Midland Valley Basin occurring in several coalfields (Text-Figure 1b). The sequence is usually no more than 250m thick and contains cyclic developments of sandstones, siltstones mudstones and seatearths together with coals of mineable thickness, two prominent marine bands and is generally considered to be deltaic (Browne et al., 1985; Read, 1988) or alluvial in origin (Stedman, 1988).

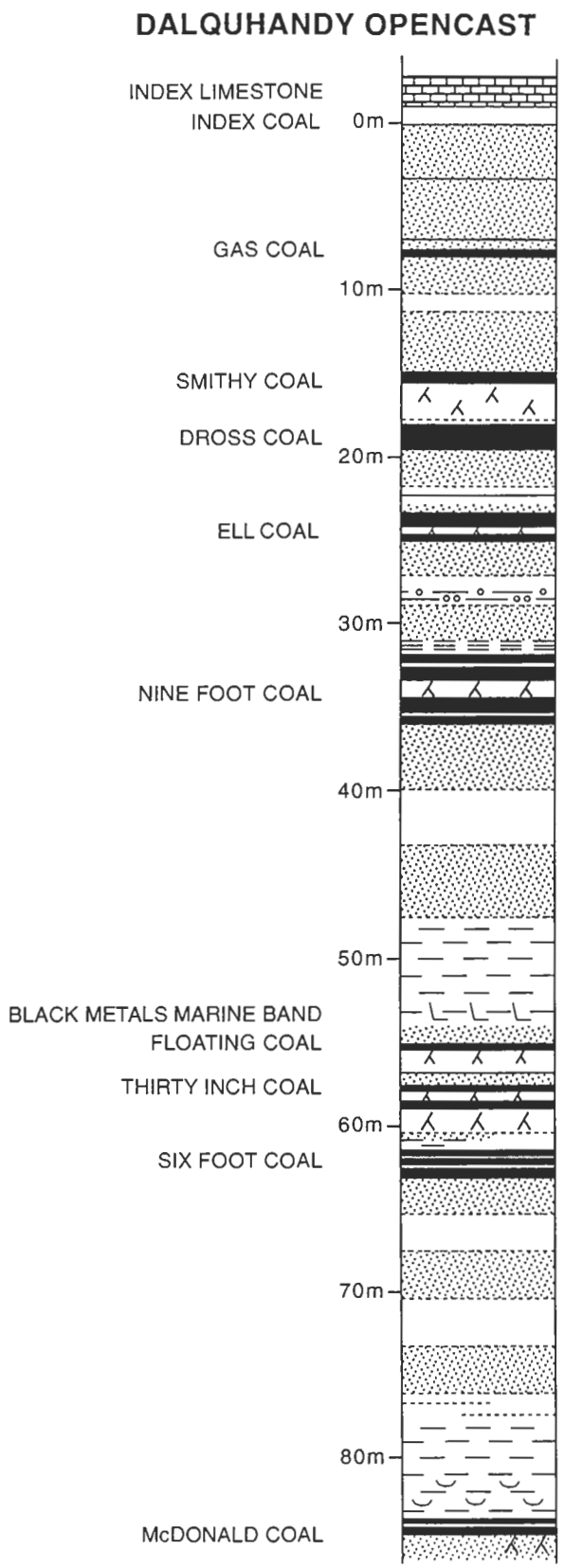
The overlying Upper Limestone Formation, whilst containing some coal-bearing sequences, is more predominantly marine in origin. Deltaic sedimentation occurred throughout much of the basin and the direction of clastic sediment input was predominantly from the north (Cope et al., 1992).

DALQUHANDY

The Dalquhandy Opencast Coal Mine is in the Northwest of the Douglas Coalfield which is an outlier of Carboniferous rocks separated from the Central Coalfield to the North and the Ayrshire Coalfield to the west by rocks of Silurian and Devonian age (Text-Figures 1b, c). The Douglas coalfield is a deep narrow syncline trending NNE-SSW but it broadens out into shallower basins in the south and north. The site is located on the western edge of the northern basin and extends to the southwest as a subbasin structurally continuous with the Muirkirk Syncline. The coal sequence belongs to the Limestone Coal Formation of Namurian A (Pendellian) age and interbeds comprise mainly sandstones, siltstones and shales, some with marine faunas (Text-Figure 2). The complete sequence of the Limestone Coal Formation from the floor of the MacDonald Coal to the base of the Index Limestone is present in the mine. There is a great variation in thickness of the strata and the coal seams across the site. The coal seams tend to be thickest in the west-central part of the site and thin, and in some instances die out completely, to the south-east and to a lesser extent thin to the northwest. In this report only general assemblages of megaspores will be presented - detailed vertical and lateral studies will be presented elsewhere together with a description of the sequence and a more detailed systematic treatment of the megaspores.

AFFINITIES OF CARBONIFEROUS MEGASPORES

It has been well established that in the Upper Carboniferous of tropical Euramerica that the lycopsids were the



main peat (coal) forming vegetation (DiMichele and Phillips, 1994). Studies from North America from the Westphalian equivalent rocks have demonstrated the diversity of such lycopsids and have shown that these plants developed a number of vegetative and reproductive strategies to live in a wide range of wetland environments. All of these lycopsids were heterosporous and hence produced both microspores and megaspores.

These data have been obtained from permineralized plants from coal balls, that is to say permineralized peats (DiMichele and Philips, 1994). In Britain, however, permineralized peats are rare. The lycopsid assemblages forming the coals can, however, be studied using a different approach: that of extracting the megaspores. It has been shown that megaspore assemblages from Upper Carboniferous coals also yield important palaeoecological data and as they are more widespread than coal balls offer complementary data over a wider geographical and stratigraphical range. Bartram (1987) has demonstrated the rapid changes which can occur in a single coal seam.

Most of our knowledge of Carboniferous coal-forming vegetation comes from the Westphalian and later. We have little knowledge of early Upper Carboniferous coal-forming vegetation. Permineralized peat from the late Lower Carboniferous (Dinantian: Viséan) of Scotland from Pettycur has indicated that lycopsids can dominate peat-forming systems (Rex and Scott, 1987), although there are few economic coals of this age. However, megaspore studies from the late Lower Carboniferous and early Upper Carboniferous indicate that there was a major vegetational change in the early Namurian (early Upper Carboniferous) with the peat forming lycopsids indicating a series of extinctions and innovations so that late Namurian assemblages are very similar to later Westphalian assemblages (Scott et al., 1993). Some of these data have been obtained from the Westfield Coal Basin in Scotland, where there are a series of Namurian and Westphalian coals (Scott et al., 1993). However, most of these are of later Namurian age.

All the coals from the Dalquandy Opencast Mine yielded abundant and very well preserved megaspore assemblages. This sequence, offers therefore, the chance to investigate both lateral and vertical changes in lycopsid peat-forming vegetation at an important period of vegetational change. Different seams will be exposed as the mine progresses and it is intended to sample the coals each year.

←

Text-Figure 2. The succession of coals in the Limestone Coal Group (Namurian A, Pendellian), Dalquhandy Opencast Mine, Douglas Coalfield, Lanarkshire, Scotland.

MATERIALS AND METHODS

Samples were originally supplied by British Coal from the site. Subsequently samples were collected by the author in 1992, 1993 and 1994. All samples have a prefix CP. Approximately 10 grams of coals were treated with concentrated HNO_3 for 6 days washed and 10% ammonia overnight. Samples were sieved at 180µm and megaspores picked and stored wet in bottles. Selected spores were dry mounted and representative spores were studied by Scanning Electron Microscopy (Cambridge Stereoscan S100) and some by TEM (Hitachi H-600). On completion of the project all material will be deposited in the Geological Collections of the Royal Scottish Museum of the National Museums of Scotland.

THE MEGASPORES AND THEIR DISTRIBUTION

Megaspores were abundant in most of the coal samples studied. Material was obtained from most splits of the coals and from many parts of the site. In this paper material from the individual coals will be considered together. Ten megaspore taxa have so far been identified from this sequence of coals. All of the megaspores illustrated here have received monographic treatment elsewhere so no formal taxonomic treatment will be attempted in this paper.

Genus *Lagenicula* Bennie & Kidston ex Zerndt, 1934 emend Dybová-Jachowicz et al., 1979

Type Species. *Lagenicula horrida* Zerndt 1934.

Lagenicula subpilosa (Ibrahim) forma *major* Dijkstra ex Chaloner 1954

Plate 1, fig. 2-5

Remarks. This species is described by Spinner (1969) and Dybova-Jachowitz et al. (1982). I prefer to follow Spinner and keep the forma *major*. This species has recently been described in a lycopsid cone from the late Viséan of the Midland Valley of Scotland (Scott and Hemsley, 1993).

Distribution. Six Foot Coal, 30 Inch Coal, Floating Coal, Nine Foot Coal, Ell Coal, Gas Coal.

Genus *Setosisporites* Ibrahim 1933 emend. Dybová-Jachowicz et al. 1979

Type Species. *Setosisporites hirsutus* (Loose 1932) Ibrahim 1933.

Setosisporites brevispinosus (Zerndt) Brzozowska 1968

Plate 2, figs. 5, 8

Remarks. Many authors have used the form *S. hirsutus* var *brevispinosus*. In this species the spines are always characteristically short and I follow Dybova-Jachowitz (1987) in considering this as a distinctive species. It is characteristic of late Viséan and early Namurian assemblages.

Distribution. Six Foot Coal, 30 Inch Coal, Nine Foot Coal, Ell Coal, Dross Coal, Smithy Coal, Gas Coal, Index Coal.

Setosisporites clavatus Brzozowska 1968 emend. Dybova-Jachowitz et al. 1987

Plate 1, fig. 8

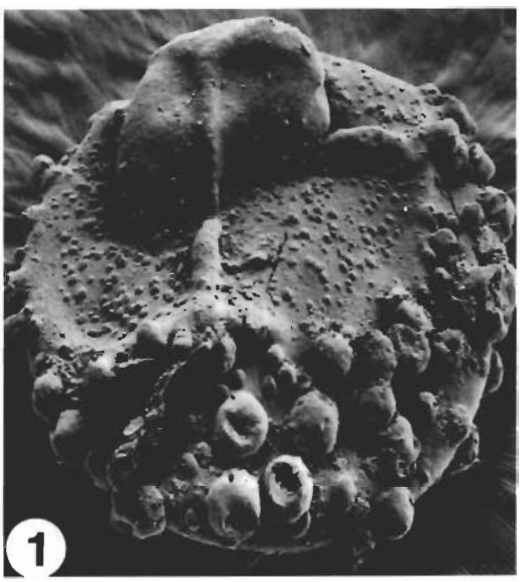
Remarks. This species is rare. Typically the ornamentation is of small pila. Spinner (1969) recorded this as a new species *S. pseudoreticulatus* which Dybova-Jachowitz (1987) place in *S. clavata*. The species is rarely found in deposits of late Viséan and early Namurian age.

Distribution. 30 Inch Coal.

PLATE 2

Scanning Electron micrographs of megaspores from the Limestone Coal Group in the Dalquhandy Opencast Mine, Douglas Coalfield, Scotland.

1 *Setosisporites slendidus* x50, CP1256, Gas Coal.
2 *Setosisporites slendidus* x50, CP1224, Nine Foot Coal.
3 *Setosisporites slendidus* x50, CP1225, 30 inch Coal.
4 *Setosisporites hirsutus*. x50, CP1225, 30 inch Coal
5 *Setosisporites brevispinosus*. x50, CP1257, Ell Coal.
6 ?*Setosisporites indianensis*. x50, CP1259, 30 inch Coal.
7 detail of 6. x 130
8 *Setosisporites brevispinosus*. x50, CP1260, Ell Coal.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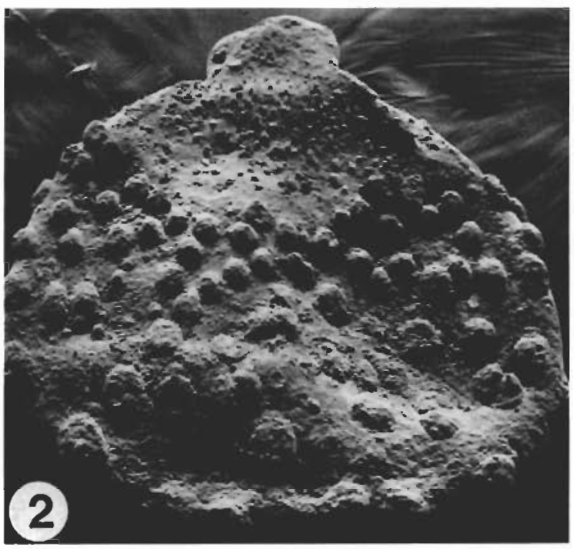
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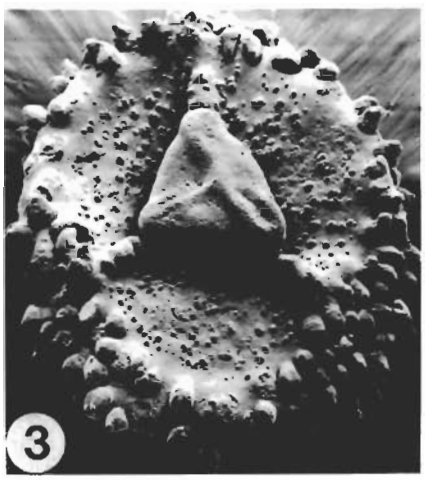
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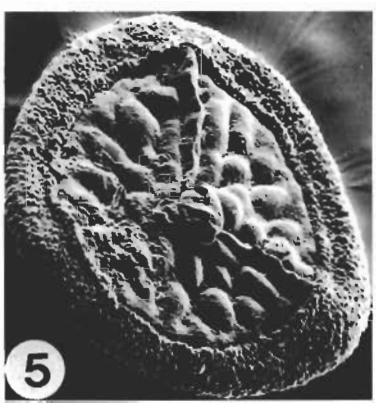
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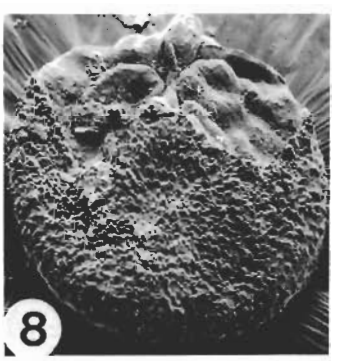
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Setosispories hirsutus (Loose) Ibrahim 1933
Plate 2, fig. 4

Remarks. This is the type species of *Setosisporites*. It is particularly small, often around 500m in diameter. The spines range from 30 to 200m long but in the Dalquhandy specimens are often less than 100m.

Distribution. Six Foot Coal, 30 Inch Coal, Floating Coal, Nine Foot Coal, Ell Coal, Gas Coal.

Setosisporites indianensis (Chaloner) Spinner 1969
Plate 1, fig. 7

Remarks. This species is rare in the Viséan of Scotland and the early Namurian of North America. The ornament is usually subdued and the apical prominence is characteristic (Chaloner, 1954).

Distribution. 30 Inch Coal, Gas Coal.

Setosisporites splendidus (Zerndt) Spinner 1969
Plate 2, fig. 1-3

Remarks. This is a very distinctive spore with large warts. It is a spore characteristic of the late Viséan but has also been reported from the early Namurian. It is common in most of the coals at Dalquhandy.

Distribution. Six Foot Coal, 30 Inch Coal, Nine Foot Coal, Ell Coal, Gas Coal, Index Coal.

Genus *Zonalessporites*

Type Species. *Zonalesporites brasserti* (Stach & Zerndt) Potonié & Kremp 1954 emend. Dybova-Jachowitz et al. 1977.

Zonalesporites brasserti (Stach & Zerndt) Potonié & Kremp 1954 emend. Dybova-Jachowitz et al. 1977
Plate 3, fig. 1, 4, 6

Remarks. This is one of the most distinctive of all Carboniferous spores and has a very long range. It was described by Dijkstra (1956) from the Namurian of Scotland. It has rarely been reported from older strata with any certainty.

Distribution. Six Foot Coal, 30 Inch Coal, Floating Coal, Nine Foot Coal, Ell Coal, Dross Coal.

Zonalesporites sp.
Plate 3, fig. 7

Remarks. The ornament of some specimens is very variable making their specific identification difficult. Illustrated here is one example which is currently being investigated.

Distribution. Six Foot Coal, Dross Coal, Smithy Coal.

Genus *Rotatisporites*

Type Species. *Rotatisporites rotatus* (Bartlett) Potonié & Kremp 1954.

Rotatisporites rotatus (Bartlett) Potonié & Kremp 1954
Plate 3, figs. 2, 3

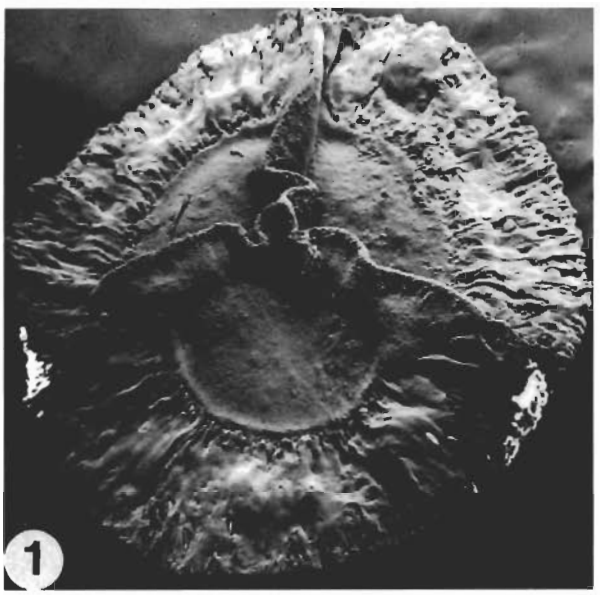
Remarks. The zona of this spore is quite characteristic and it occurs more commonly in the uppermost coals of the Dalquhandy sequence. It has a widespread distribution from the Viséan to the late Westphalian but is characteristic of the early Namurian and has been previously reported from the Limestone Coal Group by Dijkstra (1955, 1957).

Distribution. 30 Inch Coal, Nine Foot Coal.

PLATE 3

Scanning Electron micrographs of megaspores from the Limestone Coal Group in the Dalquhandy Opencast Mine, Douglas Coalfield, Scotland.

1 *Zonalesporites brasserti*. x25, CP1259, 30 inch Coal.
2 *Rotatisporites rotatus*. x25, CP1223, Nine Foot Coal.
3 detail of 2. x 90.
4 detail of 1. x 110.
5 detail of 6. x 75.
6 *Zonalespotites brasserti*. x25, CP1220, Dross Coal.
7 *Zonalesporites* sp. x25, CP1261, Six Foot Coal.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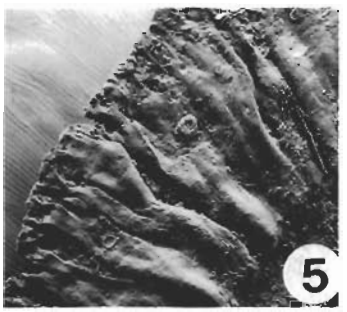
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Genus *Cystosporites* Schopf 1938

Type Species. *Cystosporites brereto nensis* Schopf forma *brereto nensis* Schopf 1936.

Cystosporites giganteus (Zerndt) Schopf, 1938.
Plate 1, figs. 10, 11

Remarks. The specimens recovered in this study were all aborted forms similar to that illustrated by Hemsley (1993). They differ from *C. diabolicus* in the non-fibrous nature of the gula.

Distribution. 30 Inch Coal, Nine Foot Coal, Ell Coal, Dross Coal, Smithy Coal, Gas Coal, Index Coal.

DISCUSSION

There have been relatively few studies of megaspores from early Namurian deposits. Some megaspores were described by Dijkstra (1946) but precise horizons and localities were not provided. Likewise the work of Sen (1964) was general but some data was given for assemblages from the Limestone Coal Formation of the Ayrshire Coalfield which is adjacent to the Douglas Coalfield (Text-Figure 1b). The characteristic spores included: *Setosisporites brevispinosus*, *Zonalesporites brasserti*, *Rotatisporites rotatus*, *Setosisporites praetextus*, *Lagenicula subpilosa* forma *major*, *Lagenicula horrida*, *Setosisporites splendidus* and *Cystosporites giganteus*.

Many spores are in common with Dalquhandy. The only other early Namurian deposit yielding megaspores is Westfield (Scott et al., 1993). Here the Namurian A (Pendellian) sequence is thin and the assemblages poorly preserved and not particularly diverse. Samples near the base of the sequence include *Lagenicula subpilosa* forma *major* Dijkstra ex Chaloner, typical of late Viséan sequences in the Midland Valley of Scotland. Samples from the P Coal yielded mainly *Setosisporites brevispinosus* (Zerndt) Spinner, *Setosisporites praetextus* (Zerndt) Potonié and Kremp, *Zonalesporites brasserti* (Stach and Zerndt) Potonié and Kremp with rare examples of *Setosisporites splendidus* (Zerndt) Spinner, *S. hirsutus* (Loose) Ibrahim, *Lagenicula subpilosa* (Ibrahim) Potonié and Kremp, *C. giganteus* (Zerndt) Schopf, and *Tuberculatisporites mammilarius* (Bartlett) Potonié and Kremp.

It is interesting that *Tuberculatisporites mammilarius* does not occur at Dalquhandy nor in any Viséan deposits from the Midland Valley of Scotland. Megaspores have been described from a number of late Viséan sites by Spinner and the author (Spinner, 1969; Spinner and Clayton, 1973; Scott and Hemsley, 1993, 1996; Scott unpublished). Typically samples yield *Lagenicula subpilosa* forma *major* and *Setosisporites splendidus*, *S. brevispinosus* as well as *Auritolagenicula angulata*. The Dalquhandy assemblages appear to be intermediate in character with the absence of late Viséan forms such as *Auritolagenicula angulata* and later Carboniferous forms such as *Tuberculatisporites mammilarius*.

CONCLUSIONS

The megaspore flora from the Dalquandy coals were generally of moderate diversity. A total of 10 taxa were recorded: *Lagenicula subpilosa* forma *major*, *Setosisporites brevispinosus, Setosisporites clavatus, Setosispories hirsutus, Setosisporites indianensis, Setosisporites splendidus, Zonalesporites brasserti, Zonalesporites sp., Rotatisporites rotatus, Cystosporites giganteus.*

The megaspore assemblages from Dalquhandy are generally of lower diversity than those from Westphalian coals elsewhere in Britain (see for example Bartram, 1987; Scott, 1978; Scott and King, 1981) but of greater individual diversity than those recorded at Westfield (Scott et al., 1993). This may not be surprising, however, as such thick coals from Westfield may have developed as ombrotrophic mires where nutrient supply was low and hence diversity poor (Bartram, 1987; Scott, 1989a). The coals at Dalquandy appear to be more diverse in character from rheotrophic (flow-water fed peats) through to ombrotrophic (rainwater fed peats). From the distribution of megaspores it would appear that the coal-forming vegetation was repeated during each peat depositional episode.

The affinities and palaeoecology of the spores are more problematic. *Lagenicula subpilosa* forma *major* has been reported from the arborescent lycopsid cone *Flemingites scottii* (Scott and Hemsley, 1993), *Setosisporites* is known from the arborescent lycopsid *Bothrodendron* (Stubbefield and Rothwell, 1981), *Zonalesporites* is reported from *Sporangiostrobus* , whose ecology has recently been studied by Wagner (1989). Until more association analysis is undertaken, together with coal petrology, the significance of these results cannot be fully assessed.

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TABLE1. The Distribution of megaspores in the late Viséan and early Namurian of the Midland Valley of Scotland (data from this study, Scott et al., 1993; Sen, 1964; Spinner, 1969; Spinner and Clayton, 1972).

	Lower Limestone Group	Limestone Coal Group		
Taxon	**Spinner**	**This paper**	**Scott et al.**	**Sen**
Auritolagenicula angulata	X			
Bacutriletes pseudocristatus	X			
Cystosporites diabolicus			X	
Cystosporites giganteus		X	X	X
C. sp.	X			
Lagenicula horrida				X
Lagenicula rugosa	X			
Lagenicula subpilosa f.major	X	X	X	X
Rotatisporites dentatus			X	
Rotatisporites rotatus	X	X		X
Setosisporites brevispinosus	X	X	X	X
S.clavatus	X	X		
S.hirsutus		X	X	
S.indianensis	X	X		
S. praetextus			X	X
S. splendidus	X		X	X
Tuberculatisporites mammilarius			X	
Zonalesporites brasserti		X	X	X
Z. fusinatus	X			