

ASSEMBLAGES OF MIOSPORES FROM SOME UPPER CARBONIFEROUS COALS AND THEIR ASSOCIATED SEDIMENTS IN THE YORKSHIRE COALFIELD

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ABSTRACT. An investigation has been made of the miospore assemblages in the coals at the bottom and top of certain Yorkshire seams and in the adjacent seat-earths and roof measures. The assemblages from the sediments are similar and are often richer in numbers of species than those from the adjacent coals. The spores provide no evidence for the existence on the seat-earths of a distinctive type of vegetation differing significantly in composition from that which formed the initial peat layer. Several spore genera do, however, show greater frequency of occurrence in the sediments than in the coals. The investigation suggests the value of seat-earths for the solution of correlation problems when the associated coal is lacking. Four new miospore species from the sediments are described, also remains of the algal genus *Botryococcus*. The miospore species are *Leiotriletes turgidus*, *Punctatisporites arenosus*, *Convolutispora tumulosa*, and *Savitrissporites concavus*.

MANY workers have studied the spores in coal seams and in recent years assemblages have been described from other rocks. There have been few comparative studies of the spores in coal seams and their associated sediments. Hoffmeister, Staplin, and Malloy (1955), Neves (1958), and Staplin (1960) examined short sequences of sediments from single geological horizons.

A more extensive investigation was carried out by Neves (1961) on a series of un-associated sediments and coals of Namurian age from central England. This work confirmed the earlier observations that whereas some species transgress 'facies boundaries' and are present in coal, non-marine shales, and marine shales, others were recorded only from a particular type of rock.

Of particular relevance to the present investigation are the results of Sullivan (1962) who described spore assemblages from coals and shales collected from forty-five horizons within the Coal Measures sequence in South Wales. Sampling through any one cyclothem was discontinuous although the total number of samples included at least one example from each lithological unit within a cyclothem. Preparations from the seat-earths and the sandstones yielded few or no spores. The assemblages from the basal part of the roof shales were comparable both in composition and proportion of species with those from the underlying coal seams. This also applied to some of the shales well above the coals. The differences between the composition of these assemblages are of the same order as those between different coal types from the same seam (Smith 1957, 1962).

No systematic attempt has been made to compare assemblages in the seat-earths and roof measures with those from the adjacent portions of coal seams. Little is therefore known of the precise changes which took place in the vegetation at the beginning and end of peat formation.

Considerable practical advantages to coalfield geology will result from a study of the spores in clastic sediments. Sullivan (1962) has shown that many of the spores which

have been used for zoning the coal-bearing strata of Great Britain (Butterworth and Millott 1960) have similar stratigraphic ranges in the sediments and the coals. In areas where the rank of the coal prohibits the isolation of the spores from the coal, seams can still be placed in their approximate stratigraphic position on the basis of the spores in the associated sediments as suggested by Sullivan.

Seat-earths are worth investigating for their value as a means of correlating horizons where expected coal seams appear to be lacking. In these instances the seat-earths, which are often of considerable lateral extent, may provide the only reliable basis for correlation.

For these reasons a preliminary investigation was made of the assemblages of small spores (miospores) in the coals adjacent to the roofs and floors and in a limited thickness of these immediate roofs and floors from some of the more important seams from the Lower and Middle Coal Measures of the Yorkshire coalfield (Westphalian A, B, and lower C). These seams, the sampling localities, and brief descriptions of samples are given in the Appendix. Ash values are given as a rough guide to the organic content of the samples as well as the colour of each dry powdered rock sample as determined in daylight by reference to the Geological Society of America Rock Color Chart (1951).

Most of the samples were collected specially from underground workings for the present investigation. This imposed a restriction on the thickness of sample which could be collected from below the coal seam. In order to increase the number of seams examined, use was made of certain subsections collected as part of the routine seam-survey programme of the National Coal Board Coal Survey Laboratory at Sheffield. The thickness of some of these samples is not known. Wherever possible, however, the thickness of coal was restricted to a few inches to avoid obvious changes in petrographic type. The distinction between coal, inferior coal, and coaly shale was made subjectively in the present investigation. In most instances the boundary between the coal and the adjacent sediment was readily apparent but there were cases where the transition was gradual and less easily defined. The Swallow Wood seam was sampled at two localities 5 miles apart to examine the nature of lateral variation in spore content.

TECHNIQUES

The coals in this investigation were macerated with fuming nitric acid (S.G. 1.5). A representative sample of each coal was crushed to just pass a 36 BS sieve (aperture 0.42 mm.) and approximately 0.5 g was treated with acid at room temperature for 16 hours. Experience has shown that this method is less liable to result in chemical attack of the spore exines than that using Schulze reagent and alkali.

The sediments were crushed to pass a 14 BS sieve (aperture 1.20 mm.) and depending on the organic content 1–2 g of the powdered rock were pretreated with 40 per cent. hydrofluoric acid for at least 48 hours in a water bath at 40° C. to remove silicates. The organic residue was then macerated by the so-called dry Schulze method. In practice 0.6 g of crystalline potassium chlorate and 20 ml. of concentrated nitric acid were added to the moist residue after removal of the hydrofluoric acid. The alkali-soluble ulmins were removed from the maceration residue by washing with 5 per cent. potassium hydroxide. Schulze reagent was used on the sediments in preference to fuming nitric acid since the reaction is more easily controlled, an important consideration when the amount of organic material requiring oxidation is variable.

In the case of the roof of the Pot Clay coal, it was found that gentle boiling with 100-volume hydrogen peroxide gave better results than the Schulze method.

The maceration residues were subjected to ultrasonic vibrations in a 80/40-watt transistorized 'Soniclean' with tank-type transducer for periods of time which varied with the individual samples. This treatment cleans and disaggregates the spores when this is necessary, generally facilitating subsequent examination.

Finally, two slides were prepared from the spore residue of each sample, one being an open and the other a covered gelatine mount. A count of 500 spores was then made, based on 250 spores from each slide. Frequencies determined in this manner have increased accuracy (Tomlinson 1957). Both slides were then traversed completely for forms not observed during the initial counting. The open slides in each case provided the spores for single grain mounts.

SYSTEMATIC PALAEOLOGY

The terminology employed in the descriptions is that recommended by the nomenclature sub-committee of the International Committee of the Microflora of the Palaeozoic. All type and certain other figured specimens mounted singly in glycerine jelly are referred to by a preparation number. The remaining figured specimens, not so prepared, are referred to by a preparation number followed by the 'east-west' and 'north-south' mechanical stage readings from a Vickers Instruments (Cooke, Troughton, and Simms) biological research microscope. All figured specimens are available for reference at the Coal Survey Laboratory of the National Coal Board, Sheffield.

Anteturma SPORITES H. Potonié 1893
Turma TRILETES (Reinsch) Potonié and Kremp 1954
Subturma AZONOTRILETES Lubert 1935
Infraturma LAEVIGATI (Bennie and Kidston) Potonié 1956
Genus LEIOTRILETES (Naumova) Potonié and Kremp 1954

Leiotriletes turgidus sp. nov.

Plate 99, figs. 1-3

Holotype. Plate 99, fig. 1. Preparation T75/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb triangular to roundly triangular, sides concave, straight or convex, apices narrowly to broadly rounded, margin smooth. Laesurae simple, generally accompanied by folds aligned more or less parallel with the rays and giving the appearance of prominent lips; laesurae and folds extend nearly to equator. Exine thick, 5-7 μ , and laevigate; often pyramidally elevated, culminating in vertex. Single distal compression fold often follows margin.

Size (25 specimens). Maximum dimensions from apex to opposite inter-radial margin 59 (77) 104 μ ; holotype 82 μ . Treatment, dry Schulze and 5 per cent. KOH.

Description. Shape somewhat variable depending on convexity of inter-radial margins. Combined width of 'lips' 10-17 μ . Continuous marginal fold often present, more or less

uniform in width and situated distally from the equator. Presence of fold appears to be related to state of compression of exine; forms with elevated proximal surface appear to lack marginal fold. Exine thickness often visible at spore margin; colour reddish-brown to very dark brown.

Comparison. *Leiotriletes ornatus* Ishchenko 1956 in Playford 1962, p. 575, is morphologically similar but is smaller, 32 (46) 63 μ , with thinner exine (2–3.5 μ) and narrower lips (each 2.5–4.5 μ wide). Spore type 1 described by Love (1960, p. 122) is considered by Playford to be 'undoubtedly representative' of *L. ornatus*. Spore type 2 (*ibid.*) is similar in shape and size to *L. turgidus* sp. nov. but 'shows very strong infrastructure'.

Spore type C of Neves (1958, pl. ii, fig. 6) is morphologically very like *L. turgidus* but is circular with very broad lips (14–20 μ wide).

Genus PUNCTATISPORITES (Ibrahim) Potonié and Kremp 1954

Punctatisporites arenosus sp. nov.

Plate 99, figs. 4, 5

Holotype. Plate 99, fig. 4. Preparation T76/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb circular to subcircular, commonly distorted by compression; margin smooth. Laesurae simple, reaching nearly to amb, infrequent. Exine with granulate infrastructure, generally strongly developed and usually with distinct pseudo-rim, 2–7 μ wide. Compression folds characteristic, randomly orientated, frequently long and narrow.

Size (25 specimens). 82 (104) 126 μ ; holotype 109 μ . Treatment, dry Schulze and 5 per cent. KOH.

Description. Although a tetrad mark is infrequently seen (*c.* 5 per cent. of spores examined) exine commonly shows a triangular tear which has probably resulted from a rupture along a triradiate line of weakness. Laesurae may be obscured by folds more or less parallel to sutures. Pseudo-rim structureless, with ill-defined inner margin; results from viewing the hyaline substance of the exine wall with its internal structure in strongly compressed material.

Comparison. The size, general absence of tetrad mark, distinct infrastructure and characteristic form of the folding are all features which serve to distinguish this species from all other previously described forms of the genus *Punctatisporites*.

Infraturma MURORNATI Potonié and Kremp 1954

Genus CONVOLUTISPORIA Hoffmeister, Staplin, and Malloy 1955

Convolutispora tumulosa sp. nov.

Plate 99, figs. 6–8

Holotype. Plate 99, fig. 6. Preparation T77/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb circular to subcircular, margin more or less undulate to smooth. Laesurae simple or with thickenings parallel to the commissure, often indistinct or not seen, straight or sinuous, two-thirds radius to margin. Proximal and distal ornament of continuous anastomosing ridges, rounded conical to flat-topped in optical section, up to $4\ \mu$ in height and $4\text{--}10\ \mu$ in basal width (measured at margin), maximum width at their confluence, enclosing irregularly shaped lacunae with maximum diameter $2\text{--}10\ \mu$. Ornament, particularly in high focus, gives a reticulate pattern; inner surface of exine shows a distinct reticulum. Number of ridges projecting at margin $20\text{--}25$. One or two random folds may be present. Exine thin in lacunae.

Size (25 specimens). 54 (64) $77\ \mu$: holotype $68\ \mu$. Treatment, dry Schulze and 5 per cent. KOH.

Description. Shape variable, depending on compression, probably originally spherical since there is no preferred orientation. Margin generally, at least in part, strongly undulose. Sides of ridges parallel or converging, usually towards apex. Distinctness of outer reticulum variable due to fluctuating height and width of ridges; generally visible with careful focusing. Inner reticulum positive, distinct and regular; probably a compression feature of the outer reticulum.

Comparison. In *Convolutispora mellita* Hoffmeister, Staplin, and Malloy 1955 (size $60\text{--}85\ \mu$) the ridges are not so broad ($2\text{--}8\text{--}5\text{--}6\ \mu$) and reticulation is less marked. Specimens of *C. mellita* from the type locality were examined by the authors. *Convolutispora* sp. A. Neves 1961 is larger ($122\ \mu$) and has somewhat broader sculptural elements ($6\text{--}10\ \mu$ wide). *Reticulatisporites textilis* Balme and Hassel (1962) is also larger (size 89 (106) $135\ \mu$), has smoother margin, and a more distinct reticulum.

Palaeobotanical affinities. Radforth (1939, pl. i, figs. 2, 6, 7) and W. and R. Remy (1957, pl. 3, figs. 5–7) have figured spores of closely comparable size, 52 (61) $70\ \mu$ (Radforth 1939), and morphology to those of *Convolutispora tumulosa* sp. nov. from the schizaeaceous fern *Senftenbergia pennaeformis* Brongniart. Butterworth and Williams (1958) noticed the close similarity between the spores of *S. sturi* Sterzel and the dispersed spore *Savitrissporites* (*Callisporites*) *nux* (Butterworth and Williams) Sullivan 1964. It is of

EXPLANATION OF PLATE 99

All figures $\times 500$ except where stated. All miospores photographed are from seat-earth of Swallow Wood Seam, Elsecar Main Colliery, Yorkshire.

Figs. 1–3. *Leiotriletes turgidus* sp. nov. 1, Holotype; proximal surface. 2, 3, Proximal view, medium focus; preparations T75/2 and T75/3.

Figs. 4, 5. *Punctatisporites arenosus* sp. nov. 4, Holotype, ? proximal view, low focus. 5, Proximal view, medium focus; preparation T76/2.

Figs. 6–8. *Convolutispora tumulosa* sp. nov. 6, Holotype, medium focus. 7, Proximal surface; preparation T77/2. 8, Low focus showing reticulate inner surface of exine through tear; preparation T77/3.

Figs. 9–12. *Savitrissporites concavus* sp. nov. 9, Holotype, proximal surface. 10, Distal surface; preparation T78/2, $22\cdot0$ $78\cdot0$. 11, Proximal surface; preparation T78/2, $18\cdot5$ $76\cdot5$. 12, Proximal surface; preparation T78/3, $8\cdot1$ $76\cdot8$.

Figs. 13–16. *Savitrissporites nux* (Butterworth and Williams) Sullivan. 13, Distal surface; preparation T78/2, $30\cdot5$ $65\cdot0$. 14, Distal surface; preparation T55/2 (mounted between two cover glasses) ring number 4. 15, 16, Preparation T55/2, ring number 2, $\times 1000$: 15, Proximal surface; 16, Distal surface (preparation photographed from reverse side).

interest that both species of dispersed spores are well represented in the assemblages from the seat-earth of the Swallow Wood seam at Elsecar Main Colliery.

Turma ZONALES (Bennie and Kidston) Potonié 1956

Subturma ZONOTRILETES Waltz 1955

Infraturma CINGULATI Potonié and Klaus 1954

Genus SAVITRISPORITES Bharadwaj 1955

Savitrisorites concavus sp. nov.

Plate 99, figs. 9-12

Holotype. Plate 99, fig. 9. Preparation T78/1.

Type locality. Non-coaly seat-earth of Swallow Wood seam, Elsecar Main Colliery, Yorkshire. Lower Westphalian B.

Diagnosis. Amb triangular, sides straight to strongly concave, margin more or less crenulate to smooth, apices pointed to narrowly rounded. Laesurae simple, straight, reaching inner margin of cingulum, suture often open. Proximal ornament, if present, of ridges bordering laesurae; distal ornament, if present, of irregular thickenings. Apical swellings often developed. Cingulum width often variable on any one specimen.

Size (25 specimens). Maximum dimension from apex to opposite inter-radial margin 29 (34) 43 μ ; holotype 43 μ . Treatment, dry Schulze and 5 per cent. KOH.

Description. Laesurae often appear to have thickened lips owing to a broad, flat-topped ridge bordering each ray and occupying most of central area. Distal ornament, when developed, usually prominent (height 2-4 μ) mainly around distal pole and radiating towards each apex. A pair of apical swellings may be developed from ornament on either surface. Cingulum often widest in radial positions and frequently irregular in profile, possibly as result of corrosion.

Comparison. *Savitrisorites* (*Callisorites*) *nux* (Butterworth and Williams) Sullivan is larger, 30 (47) 60 μ (in Sullivan), its shape is typically convex and it possesses regularly disposed distal ornament. Specimens of *S. nux* are illustrated in Plate 99, figs. 13-16 of this paper for comparison. In the type material a small number of specimens have been observed with features intermediate between *S. concavus* and *S. nux*. *S. asperatus* Sullivan 1964 is of comparable size, but its sides are less concave, the inner margin or the cingulum is less well defined, the irregular distal thickenings cover the whole distal surface, apical thickenings are more prominent and the exine is thicker. *S. triangulus* Bharadwaj 1955 is larger (53-65 μ), has straight sides, and possesses a heavier distal ornament.

ALGAE-XANTHOPHYCEAE

Genus BOTRYOCOCCUS

Plate 100, figs. 1-4

Discussion. The immediate roof of the Shafton seam as collected from Dearne Valley Colliery Drift consists of 5 in. of coaly mudstone. The spore residue obtained by macerating this material contained many branched, hollow structures which, on both size

and morphology, may be grouped with the polymorphic algal species *Botryococcus braunii* Kützing 1849. *Botryococcus* has a stratigraphic range from at least Lower Carboniferous to Recent (Traverse 1955). The forms found in the present work compare closely with the descriptions and illustrations of Blackburn and Temperley (1936) who dealt with both fossil and modern forms of *Botryococcus*.

The Shafton specimens bear closest resemblance to the branched *Pila* colonies shown in Temperley's pl. i, figs. 9, 10, although they are usually more fragmentary. The hollow nature of the branches with a distinct tendency to be incurved at the tips is evident in Plate 100, figs. 2, 3. On some of the axes a ladder-like pitting is visible, Plate 100, fig. 4, and this may be similar in origin to the scalariform structure observed by Blackburn, which she interpreted as the product of 'the separation of the basal portions of the cups and their lamellae' (1936, p. 844). Scattered circular granules may also occur on the branches. Only the cuticular thimbles of *Botryococcus* appear to be preserved in the material examined, the enclosed cells and outer waxy cups being absent. The radial groups of cells which form spherical colonies are commonly preserved but are now compressed to disc-like aggregates.

Thin sections were prepared of the shale from which the algae had been isolated. These sections contained scattered fragments of the alga with the same form as those obtained by maceration. It was therefore evident that no structural changes had taken place during the maceration process.

Further thin sections of the immediate roof of the Shafton seam, from several localities in the Yorkshire coalfield, proved to contain *Botryococcus* of the form illustrated. The persistence and abundance of *Botryococcus* in the Shafton roof may well prove to be a reliable marker for this horizon. It would appear that the conditions suitable for the growth of *Botryococcus* were widespread in Yorkshire immediately above the Shafton seam.

Fragments of the alga have also been found sporadically in separations from seat-earth, roof, and coal samples from the Flockton, Swallow Wood, and Barnsley seams examined during the course of this work.

Records of the occurrence of *Botryococcus* in primarily inorganic sediments of Coal Measures age in the British coalfields are rare. Neves has found *Botryococcus* to be widespread at two principal horizons in the non-marine shales of the southern Pennines, namely the *Carbonicola exporecta* horizon (1961, p. 277) and the roof of the Pot Clay coal (pers. comm.).

MIOspore ASSEMBLAGES IN COALS AND THEIR ASSOCIATED SEDIMENTS

Adequate numbers of miospores were isolated from all the samples so that counting 250 specimens per slide presented no difficulty even with separations from sediments.

EXPLANATION OF PLATE 100

Figs. 1-4. *Botryococcus* isolated from roof measures of Shafton seam. 1, Portion of colony. 2, 3, Fragments of colony with hollow terminal cups; preparation T79/2, 15.1 87.0 and 8.9 72.3. 4, Axes of portion of colony showing characteristic markings; preparation T79/2, 35.0 86.5. All figures $\times 500$.

In general, over the thickness sampled, coaly rocks yielded larger numbers of spores but fewer species than the samples containing less organic material. Therefore the number of species generally tends to increase with distance from the coal. However, the numbers of species in the coals and in the associated rocks of any one seam may differ considerably from the numbers in any other seam (Table 1).

TABLE 1. Number of species per 500 spores in coal and associated sediments.

Seam	Seat-earth				Bottom of Seam		Top of Seam	Roof Measures				
Shafton	40	26			22		54	34	56	43	52*	42
Beamshaw			28		30							
Barnsley	27	28	27	34	24		32	38				
Swallow Wood			54	46	43		40	49				
Swallow Wood			58	49	40		42	41				
Flockton Thick			54		28		33	44				
Silkstone			23		22							
Top Beeston			15		15							
Pot Clay			41			22		19				

Inferior coal*

The true diversity of the microflora is not always apparent from a count of 500 specimens when one species is overwhelmingly dominant in the assemblage. This is true of the seat-earth of the Beeston seam and the roof of the Pot Clay seam from which a large number of species were recorded after examination of the entire slides prepared from these samples.

Table 2 lists the genera and the number of their species recorded from the samples. The occurrence of the genera in seat-earths and roof measures and the number of species in samples of each type are also recorded.

Few genera are recorded exclusively from one type of sample. Genera with species whose abundance exceeds 2 per cent. in any sample are indicated in the table. Very few of such genera consistently attain this level of abundance.

Table 3 shows the abundance of *Lycospora* spp. in the sediments and coals. With four exceptions, two from the Shafton seam and two from the Swallow Wood seam, this genus dominates all the assemblages, exceeding 50 per cent. in most instances and sometimes 80 per cent. of the total spores counted.

The frequencies of the other relatively abundant genera or species in the coals and sediments are shown graphically in text-figs. 1, 2, and 3. Several genera such as *Calamo-*

TABLE 2. Occurrence of genera and representation of species in coals and associated sediments.

Genus	Total number of species	Number of samples containing genus				Number of species in samples			
		Sediments		Coals		Sediments		Coals	
		Seat-earth (total samples 8)	Roof (total samples 5)	Bottom (total samples 8)	Top (total samples 5)	Seat-earth	Roof	Bottom	Top
<i>Reticulatisporites</i> (Ibrahim) Pot. and Kr. 1954*	1	2	3	4	2	1	1	1	1
<i>Granasporites</i> Alpern 1959*	1	6	4	3	3	1	1	1	1
<i>Leiotriletes</i> (Naumova) Pot. and Kr. 1954*	4	8	3	8	5	4	4	4	4
<i>Ahrensia</i> Pot. and Kr. 1954	1	2	2	1	1	1	1	1	1
<i>Punctatisporites</i> (Ibrahim) Pot. and Kr. 1954	3	6	2	1	1	3	1	2	1
<i>Calamospora</i> Schopf, W. and B. 1944*	6	8	5	5	5	6	5	5	5
<i>Granulatisporites</i> (Ibrahim) Pot. and Kr. 1954	6	8	4	7	5	6	5	5	5
<i>Cyclogranisporites</i> Pot. and Kr. 1954*	4	5	4	7	4	4	4	4	3
<i>Verrucosporites</i> (Ibrahim) Pot. and Kr. 1954	3	2	2	2	—	3	1	2	—
<i>Lophotriletes</i> (Naumova) Pot. and Kr. 1954*	6	7	4	7	4	6	4	4	4
<i>Anapiculatisporites</i> Pot. and Kr. 1954	2	2	2	4	2	2	2	2	2
<i>Apiculatisporis</i> Pot. and Kr. 1956*	7	6	5	6	4	6	5	4	6
<i>Planisporites</i> (Knox) Pot. and Kr. 1954	1	5	5	4	3	1	1	1	1
<i>Crassispora</i> Bharadwaj 1954*	1	8	5	8	5	1	1	1	1
<i>Pustulatisporites</i> Pot. and Kr. 1954	1	4	2	3	2	1	1	1	1
<i>Acanthotriletes</i> (Naumova) Pot. and Kr. 1954	4	2	3	1	2	3	3	1	3
<i>Ibrahimisporites</i> Artuz 1957	1	—	1	—	—	1	—	—	—
<i>Raistrickia</i> (Schopf, W. and B.) Pot. and Kr. 1954*	4	8	5	8	5	4	4	3	4
<i>Foveolatisporites</i> Bharadwaj 1955	1	—	1	—	1	—	1	—	1
<i>Dictyotriletes</i> (Naumova) Pot. and Kr. 1954*	4	6	4	4	3	4	3	3	3
<i>Novisporites</i> Bharadwaj 1957*	1	1	1	1	1	1	1	1	1
<i>Reticulatisporites</i> (Ibrahim) Pot. and Kr. 1954	4	2	2	1	1	3	3	1	2
<i>Knoxisporites</i> Pot. and Kr. 1954	2	3	2	2	1	2	2	2	1
<i>Camptotriletes</i> Naumova 1937	2	4	2	4	1	2	2	2	1
<i>Convolutispora</i> Hoffmeister, S. and M. 1955*	1	2	—	1	—	1	—	1	—
<i>Vestispora</i> Wilson and Hoffmeister 1956	3	5	5	5	3	2	3	2	2
<i>Triquitrites</i> (Wilson and Coe) Pot. and Kr. 1954*	3	2	1	2	1	2	3	2	2
<i>Anulatisporites</i> (Loose) Pot. and Kr. 1954*	1	3	4	1	2	1	1	1	1
<i>Densosporites</i> (Berry) Pot. and Kr. 1954*	3	6	3	5	2	3	1	2	2
<i>Cingulizonates</i> Dybova and J. 1957*	3	4	5	2	2	2	3	2	2
<i>Lycospora</i> (Schopf, W. and B.) Pot. and Kr. 1954*	4	8	5	8	5	4	4	4	4
<i>Savitrissporites</i> Bharadwaj 1955*	3	6	4	4	2	3	2	1	1
<i>Cristatisporites</i> Pot. and Kr. 1954	3	2	3	2	2	2	3	1	2
<i>Cirratiradites</i> Wilson and Coe 1940*	4	5	5	3	3	4	2	2	2
<i>Reinschospira</i> Schopf, W. and B. 1944	1	2	1	—	—	1	1	—	—
<i>Laevigatosporites</i> Ibrahim 1933*	2	6	4	7	4	2	2	2	1
<i>Punctatosporites</i> Ibrahim 1933*	2	6	4	7	4	1	2	1	2
<i>Auroraspora</i> Hoffmeister, S. and M. 1955	1	1	1	—	—	1	1	—	—
<i>Endosporites</i> Wilson and Coe 1940*	2	4	4	4	4	2	2	2	2
<i>Florinites</i> Schopf, W. and B. 1944	6	8	5	8	5	6	6	5	5
<i>Alatisporites</i> Ibrahim 1933	1	1	2	3	—	1	1	1	—
<i>Schopfipollenites</i> Pot. and Kr. 1954	1	3	2	2	—	1	1	1	—

* Genera with species whose abundance is greater than 2 per cent. in at least one sample.

spora Schopf, Wilson, and Bentall, *Densosporites* (Berry) Potonié and Kremp, and *Florinites* Schopf, Wilson, and Bentall often show higher values in the seat-earths and sometimes in the roof measures than in the associated coals.

It is interesting that the assemblages from the seat-earth of the Swallow Wood seam in which *Lycospora* spp. are less abundant contain numbers of spores whose palaeobotanical affinities are with the schizaeaceous fern genus *Senftenbergia*. Thus *Convolutispora tumulosa* sp. nov. *Raistrickia saetosa* (Loose) Schopf, Wilson, and Bentall and

TABLE 3. Abundance of *Lycospora* spp. in coals and associated sediments.

Seam	Seat-earth	Bottom of Seam	Top of Seam	Roof Measures
	percentage abundance			percentage abundance
Shafton	69 62	85	8	30 11 37 18* 40
Beamshaw	83	38		
Barnsley	85 87 83 78	86	71	58
Swallow Wood	37 29	38	44	59
Swallow Wood	15 47	27	32	60
Flockton Thick	47	69	54	44
Silkstone	91	95		
Top Beeston	95	95		
Pot Clay	67	63		78

Inferior coal*

Savitrissporites nux (Butterworth and Williams) Sullivan account for 20 per cent. of the assemblages from seat-earth B at Elsecar Main Colliery and from 5 to 7 per cent. of the assemblages from the other samples of seat-earth from this seam.

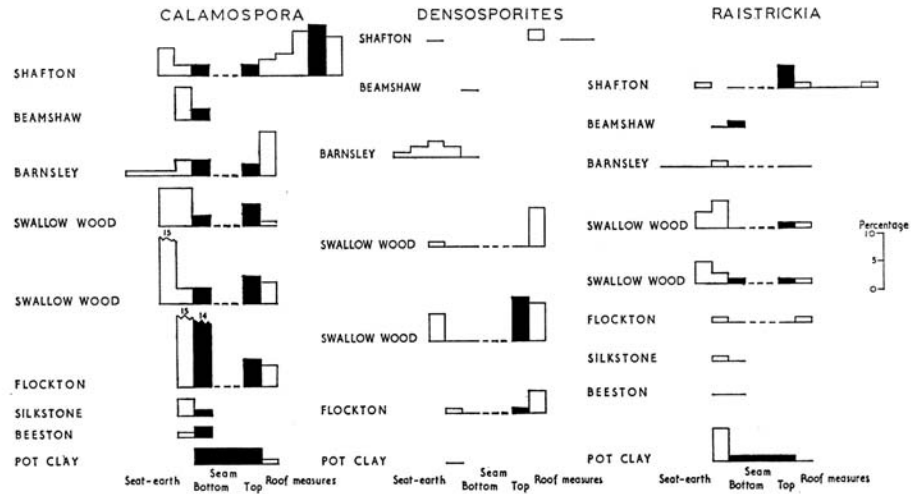
ECOLOGICAL SIGNIFICANCE OF RESULTS

Seat-earths and associated coals

Existing theories concerning the formation of seat-earths are based on general geological considerations and particularly on the mineralogical evidence. These theories are considered by Beerbower (1961) and Huddle and Patterson (1961), who favour the view that seat-earths were probably waterlogged prior to diagenesis and do not represent terrestrial soils subject to long periods of subaerial weathering. The presence of spores in seat-earths does not support either view, since spores can be preserved in waterlogged and drained acid soils in temperate or tropical latitudes for thousands of years (Dimbleby 1961), and probably indefinitely if such soils were subsequently covered by peat.

It may be possible to deduce something of the environment of seat-earth formation from the spore data if it is possible to discriminate between the sources which probably contributed to the spore assemblages.

The spores which were distributed along with the mineral sediment before the establishment of vegetation on these deposits have an allochthonous origin. As plants



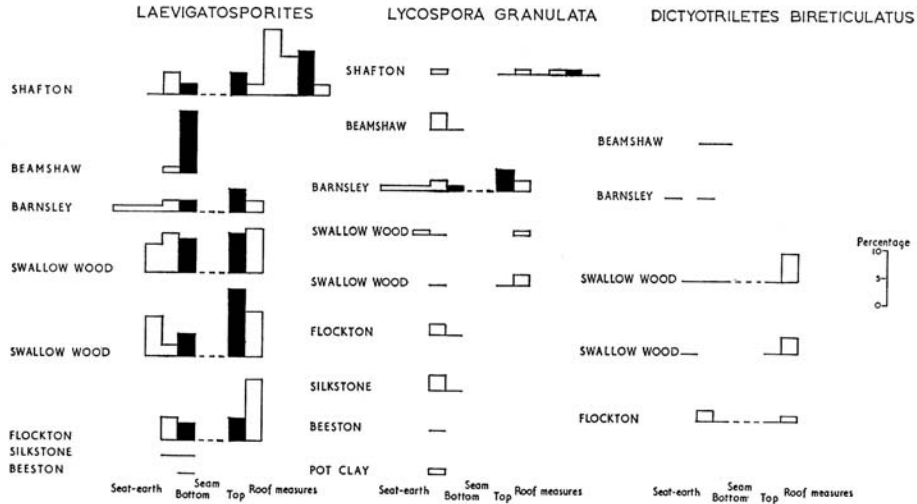
TEXT-FIG. 1. Abundance of certain genera in seat-earths, roof measures, and associated coals of some Yorkshire seams.

began to colonize these sediments the autochthonous element would become progressively more important. The extent to which this latter element is represented in the assemblages would be related to the amount of mineral sediment that continued to be deposited after plants began to grow. It is likely that the proportion of the assemblage attributable to the wind-borne element would also have become much smaller once plant cover had developed, to judge by the small extent to which present-day surface samples are influenced by nearby vegetation types. For discussion of the literature on this aspect reference should be made to Dimbleby (1961).

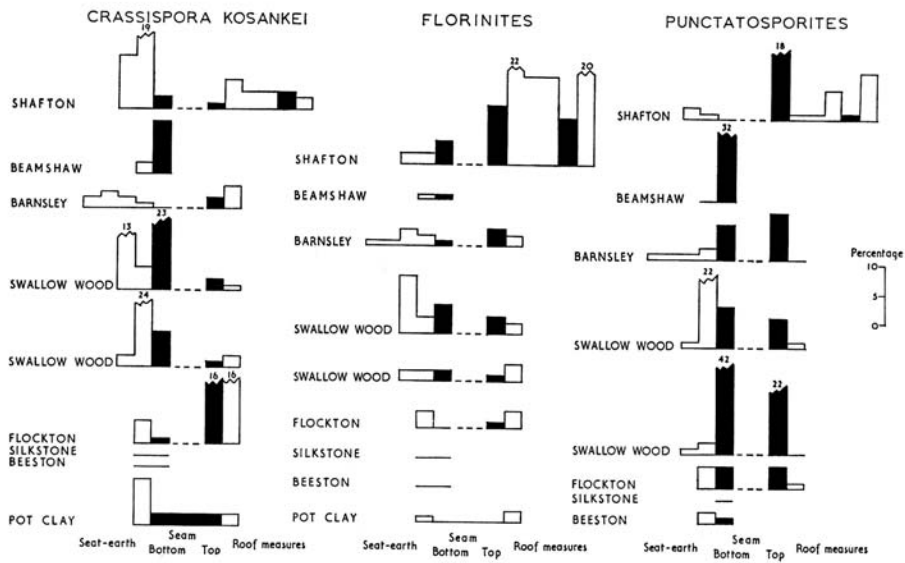
The allochthonous element probably had the following sources:

1. The vegetation of the uplands or regions marginal to the basin of deposition. Very little is known of the detailed composition of these floras.
2. The vegetation of peat bogs within the area of deposition. Except during periods of major marine transgression, peat formation was probably taking place contemporaneously with the deposition of clastic sediment.
3. Older organic or inorganic deposits which were being eroded.

It is possible that the allochthonous spores and the sediments could have been derived from different source areas. The contribution from any one source would depend on the strength and direction of wind and water currents from that quarter (Muller 1959).



TEXT-FIG. 2. Abundance of certain genera and species in seat-earths, roof measures, and associated coals of some Yorkshire seams.



TEXT-FIG. 3. Abundance of certain genera and species in seat-earths, roof measures, and associated measures of some Yorkshire seams.

During deposition of mineral sediments the contributions of the spores from the different sources is likely, therefore, to vary.

The work of Sullivan (1962) suggests that sources (2) and possibly (3) made the biggest contribution to assemblages of non-marine shales. The phase of peat bog development (Smith 1962) in the source areas would largely determine the qualitative composition of the assemblage. This perhaps explains why in the non-marine shales examined by Sullivan the proportion of the common species varied considerably. It does not account for the unusually high proportions of certain species which are normally rare constituents of the assemblages of coal seams. The possibility that some species were preferentially preserved in certain environments cannot be excluded. Any downward water movement through the seat-earths after their deposition would tend to transport the spores from the upper layers into the lower layers of the seat-earths, thereby masking the residual spore assemblage, that is, the assemblage incorporated during the early stages of deposition. The extent to which this happened cannot be determined from the available data, owing to limitations imposed by sampling, which did not extend into the lower layers of the seat-earths or the sediments below. From the study of recent soil profiles it is known that there is a downward movement of pollen grains under the influence of percolating water but that the process is very slow. The distribution curve of each species in suitable recent soil profiles assumes a characteristic form according to the length of time the pollen grains have been in the soil (Dimbleby 1957, p. 27). The greatest concentration of pollen grains is generally near the surface and this is true of the spores in seat-earths. However, it is doubtful whether such a movement would take place in permanently waterlogged soils (Dimbleby, pers. comm.).

If it is assumed that plants were growing on seat-earths before the formation of peat, although the spores provide no evidence of this, it may be inferred from the spores that the vegetation mainly comprised arborescent lycopods. Only if peat formation followed immediately on the colonization of the seat-earths by plants is it necessary to postulate that the bulk of the lycospores in their upper layers were derived from peat vegetation which had already begun to form in the neighbourhood. Very little can be inferred from the presence of rootlets in seat-earths. Their presence in some cases through a considerable thickness of sediment could have resulted from the burying of successive generations of stigmarian rootlets. On the other hand they could include the roots of rhizomes of other plants which grew downwards rather than horizontally but which were established for a relatively short period.

It is interesting to compare the occurrence of certain other spore species which constitute the seat-earth assemblages with their occurrence in coal.

Laevigatosporites Ibrahim is a genus which occurs in small numbers in the assemblages of seat-earths and bottom coals but generally becomes prominent in coal seams at a later stage in their development (Smith 1962). The occurrence of this species contrasts with that of *Densosporites sphaerotriangularis* Kosanke, which occurs consistently in small numbers in seat-earth assemblages but is not common in the assemblages of the bottom coals, although generally it becomes numerically important in the middle or upper portions of coal seams (Smith 1962). This may result from a preference of the parent plants for certain types of environment but it may indicate a different source for the spore. Kremp (1952) has suggested that Densospores of this type are an allochthonous element in coal seams although Smith (1957) does not support this view. It is, however, quite

probable that a peat bog at the appropriate stage of development was the source of this spore in small numbers in the seat-earths.

Other genera such as *Crassispora* Bharadwaj, *Florinites* Schopf, Wilson, and Bentall, and *Punctatosporites* Ibrahim, which occur commonly in seat-earths, are associated in coal seams with the occurrence of allochthonous petrographic constituents (Smith 1962). These species may, therefore, sometimes occur in numbers in the bottom coals. It is probably valid to make a distinction between *Florinites*, which occurs in relatively small numbers, and the other two genera, which are more abundant in seat-earths and certain types of coal. *Florinites* may represent a wind- or water-borne element in both coals and seat-earths, since Neves (1958, 1961) found it abundantly represented in marine deposits. A marine incursion would probably eliminate the swamp-peat vegetation as a source of this genus, which was more likely derived from the vegetation growing on the higher ground (Chaloner 1958).

It is possible that *Crassispora* and *Punctatosporites* are autochthonous elements in the assemblages of seat-earths and coals but their occurrence in a certain type of peat-swamp environment, in which the allochthonous *Florinites* is deposited, is due to a preference for this environment by their parent plant. Possibly this particular peat-swamp environment shared some features in common with that of the seat-earths.

The allochthonous element of seat-earths, therefore, comprised spores from the vegetation of lowland peat swamps (*Densosporites sphaerotriangularis*) and of upland regions (*Florinites*). These spores were mainly water-borne and were deposited along with mineral sediment. As the vegetation became established on the seat-earth and peat began to accumulate the contribution from the water-borne element to the assemblage would diminish, but flood waters would introduce such spores occasionally as an element of the peat-swamp assemblage.

There is another element in seat-earth assemblages, represented by the spores described in this paper which are normally rare in assemblages from autochthonous coal seams. These species may represent plants more or less restricted to the seat-earth vegetation. Had they originated from plants growing outside the basin of deposition it is likely that they would occur in those parts of seams containing allochthonous petrographic constituents including spores (Smith 1962).

There do not appear to be any common species in coal seams which are not represented in seat-earth assemblages, although some of the less common species found in coals have not so far been recorded from the seat-earths.

The present investigation has shown no evidence for the existence on the seat-earths of a distinctive type of vegetation differing markedly in composition from that which formed the initial peat layers. It can be inferred from this that the edaphic conditions were not those of a well-drained, terrestrial soil. The evidence suggests that as peat began to accumulate the vegetation of the seat-earths persisted more or less unchanged, except for slight changes in the relative proportions of the different genera and species and for the elimination of a few species unable to survive in the more specialized environment of a peat bog or in competition with the more successful arborescent forms.

It is also unlikely that the seat-earths were covered by any depth of stagnant water for long periods except in those rare instances where cannel coal occurs now at the bases of coal seams. Maurenbrecker (1944, p. 90) records an example of such an occurrence and it is significant that in this case a seat-earth was not developed beneath the cannel.

Roof measures and associated coals

The spores comprising the assemblages of roof measures were probably partly autochthonous and partly allochthonous. The autochthonous element was probably derived from the vegetation growing *in situ*, rooted in the peat but becoming gradually buried in mineral sediment. The allochthonous spores were probably from the same sources as listed under seat-earths.

As with the seat-earth assemblages, the proportion of the allochthonous species should increase with distance from the coal seam but there is no evidence of this in the one instance where successive samples were available for comparison.

The miospore assemblages in the roof measures immediately adjacent to the coals do not differ significantly from those of the seat-earths. The species comprising these roof assemblages are those found in coal seams although certain species may be more abundant in the roof measures than in the coals immediately in association. This is generally true of the dominant *Lycospora* spp. as well as in some instances of *Laevigatosporites*, *Densosporites sphaerotriangularis*, *Dictyotriletes bireticulatus*, and *Florinites*. It is also interesting to note that the proportions of species of *Lycospora* often differ in the coals at the top of seams and in the adjacent measures.

Whilst these species, with the exception of *Florinites*, may have originated from peat vegetation still forming somewhere within the basin of deposition, it is possible that they were derived from vegetation still growing *in situ*. There is ample evidence in the roof measures of many seams of trunks of arborescent lycopods in position of growth with their stigmata spreading out above the peat surface. Such an environment probably resembled that of the seat-earths just prior to peat formation.

Florinites, it has been suggested, probably represents an allochthonous element. Apart from the high proportion of this genus in the roof measures of the Shafton seam, there is no evidence that the numbers are significantly different in seat-earths and roof measures, which may perhaps indicate that the composition of the upland floras had not changed during the deposition of the coal seams.

The numbers of other species such as *Crassispora kosankei* remain relatively unchanged in the coals at the top of the seams and in the associated measures; high numbers in the coals corresponding to high numbers in the sediments.

One of the more ubiquitous species, *Punctatosporites minutus* Ibrahim, appears to be less abundant in all the roof measures than in the associated coals.

CONCLUSIONS

These preliminary investigations have shown that those portions of seat-earths and roof measures immediately adjacent to seams contain abundant spores. The assemblages are often richer in numbers of species than those from the associated coals; most of the species being those from the different phases of peat development. It is not known how far these assemblages extend into the cyclothem, nor what relationship there may be between lithology and the composition of the assemblages.

The fact that the stratigraphic index spores occur in seat-earths and roof measures together with species rare in the coal seams gives their assemblages potential value for the solution of correlation problems. The assemblages from seat-earths are particularly important in those instances where the associated coal is lacking. This conclusion pre-

supposes that the assemblages in such seat-earths have similar floristic features to those overlain by coal.

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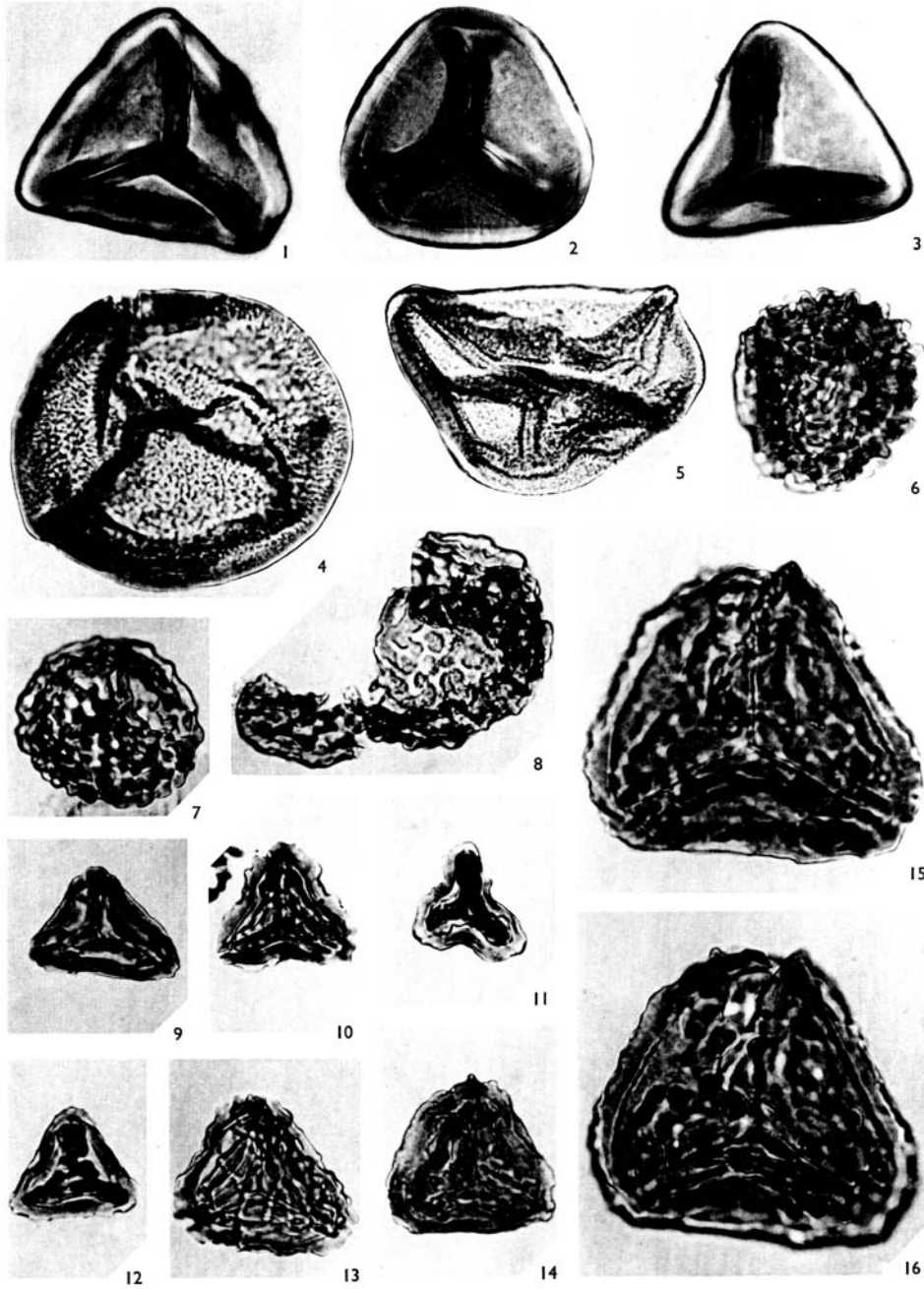
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APPENDIX. SOURCE, DESIGNATION, AND DETAILS OF SAMPLES

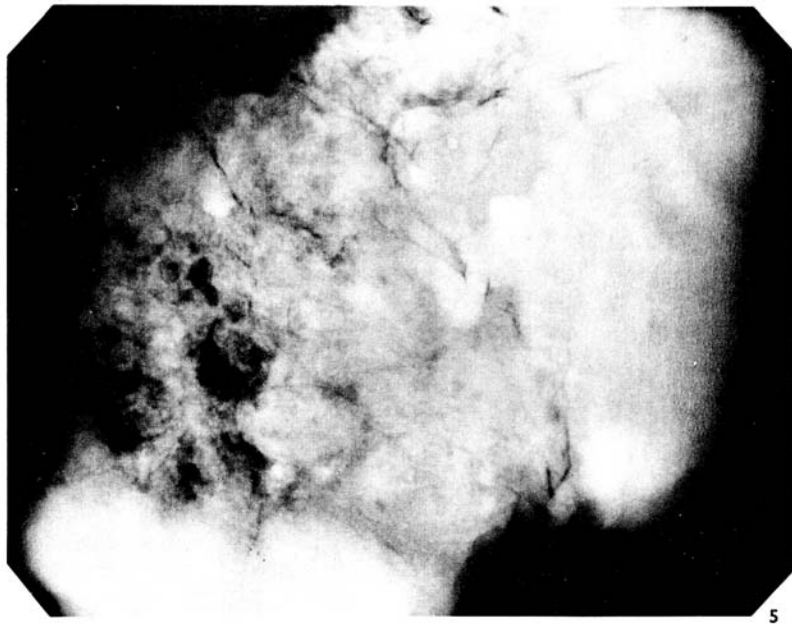
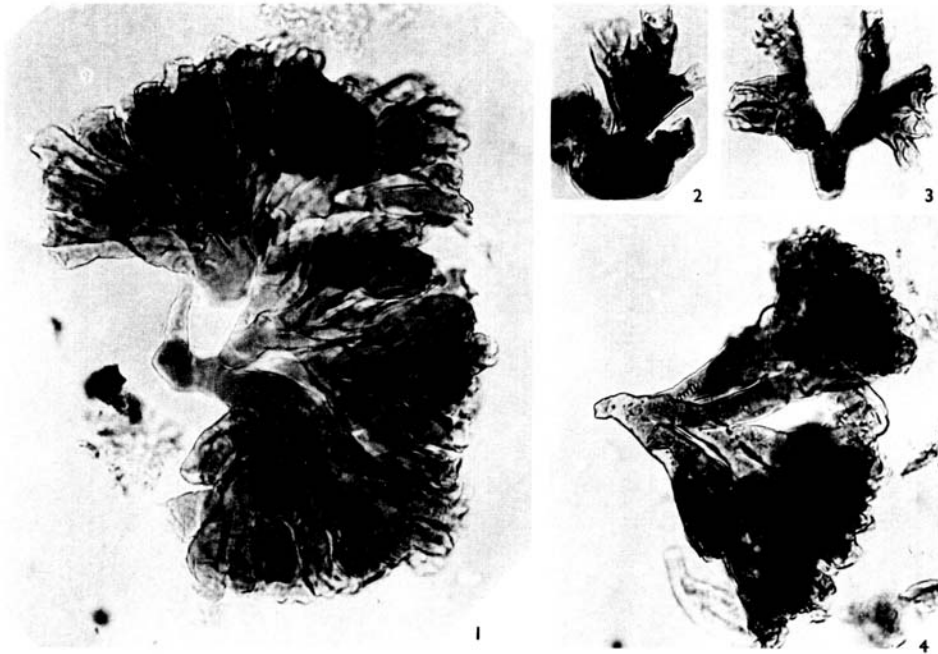
Source and designation (in stratigraphic order)	Thickness of sample (in.)	Description	Ash (per cent.)
Shafton Seam (Dearne Valley Colliery)			
Roof E		Mudstone (5)	89
" D	3-5	Inferior bright coal of canneloid appearance	26
" C	19½	Shaly seat-earth (5/6)	84
" B	3	Shale (3)	73
" A	5	Mudstone (3/4)	74
Top of seam	1	Bright coal	5
Bottom of seam	1	Bright coal	4
Floor A	¾	Seat-earth with thin (< ¼ in.) vitrain bands (4)	71
" B	2	Seat-earth (5/6)	91
		Both Floor A and B are silty and slickensided with rootlets; their junction is irregular.	
Beamshaw Seam (Askern Main Colliery)			
Bottom of seam	10½	4 in. dull and bright coal above 6½ in. mainly bright coal	3
Floor		Seat-earth (4)	78
Barnsley Seam (Yorkshire Main Colliery)			
Roof		Shaly siltstone (3)	82
Top of seam	9½	Bright coal with two ½ in. dull bands	4
Bottom of seam	4	Bright coal	6
Floor A	¾	Coaly shale (4)	69
" B	1½	Coaly shale with vitrain bands (2)	62
" C	1½	increasingly coaly upwards (2)	69
" D	¾	Slickensided shale (4/5)	73

<i>Source and designation (in stratigraphic order)</i>	<i>Thickness of sample (in.)</i>	<i>Description</i>	<i>Ash (per cent.)</i>
Swallow Wood Seam			
(Cadeby Main Colliery)			
Roof		Shale, some mussels (4)	85
Top of seam	2	Bright coal	3
Bottom of seam	1	Inferior bright coal	26
Floor A	1½	Coaly seat-earth (1)	57
„ B		Seat-earth (6/7)	89
Swallow Wood Seam			
(Elsecar Main Colliery)			
Roof		Mudstone, some mussels (4)	84
Top of seam	3½	Interbanded, mainly bright coal with shaly partings	14
Bottom of seam	6½	Mainly bright coal with pyritized fusain; bottom 0-½ in. shaly	9
Floor A	½	Seat-earth with plant structures on upper surface (4/5)	73
„ B		Seat-earth (7)	90
Flockton Thick Seam			
(Glass Houghton Colliery)			
Roof		Mudstone with occasional mussel bands (2)	78
Top of seam	1½	Inferior bright coal with plant remains and small mussels in two shale partings	23
Bottom of seam	1	Mainly bright coal	13
Floor		Seat-earth (7)	90
Silkstone Seam			
(Elsecar Main Colliery)			
Bottom of seam	6	Bright coal	6
Floor		Slickensided seat-earth (2)	73
Top Beeston Seam			
(Kellingley Colliery)			
Bottom of seam	2	Bright coal with dirty streaks in lower part	16
Floor	4	Seat-earth with vitrain streaks (4)	77
Pot Clay Seam			
(Outcrop at Midhopstones)			
Roof	5	Non-marine shale (1)	56
Coal (whole seam)	8	Inferior bright coal	32
Floor	18	Seat-earth (4/5)	79

Figures in brackets refer to colours of Geological Society of America, Rock Color Chart (1951) (1 corresponds to Black, 10 to White).



MARSHALL and SMITH, Upper Carboniferous miospores



MARSHALL and SMITH, Upper Carboniferous *Botryococcus*
HUNTER and LANGSTON, Odontoma in mammoth