FACIES, SEDIMENTATION SUCCESSIONS AND CYCLOTHEMS IN PRODUCTIVE COAL MEASURES IN THE EAST MIDLANDS, GREAT BRITAIN

by

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Summary

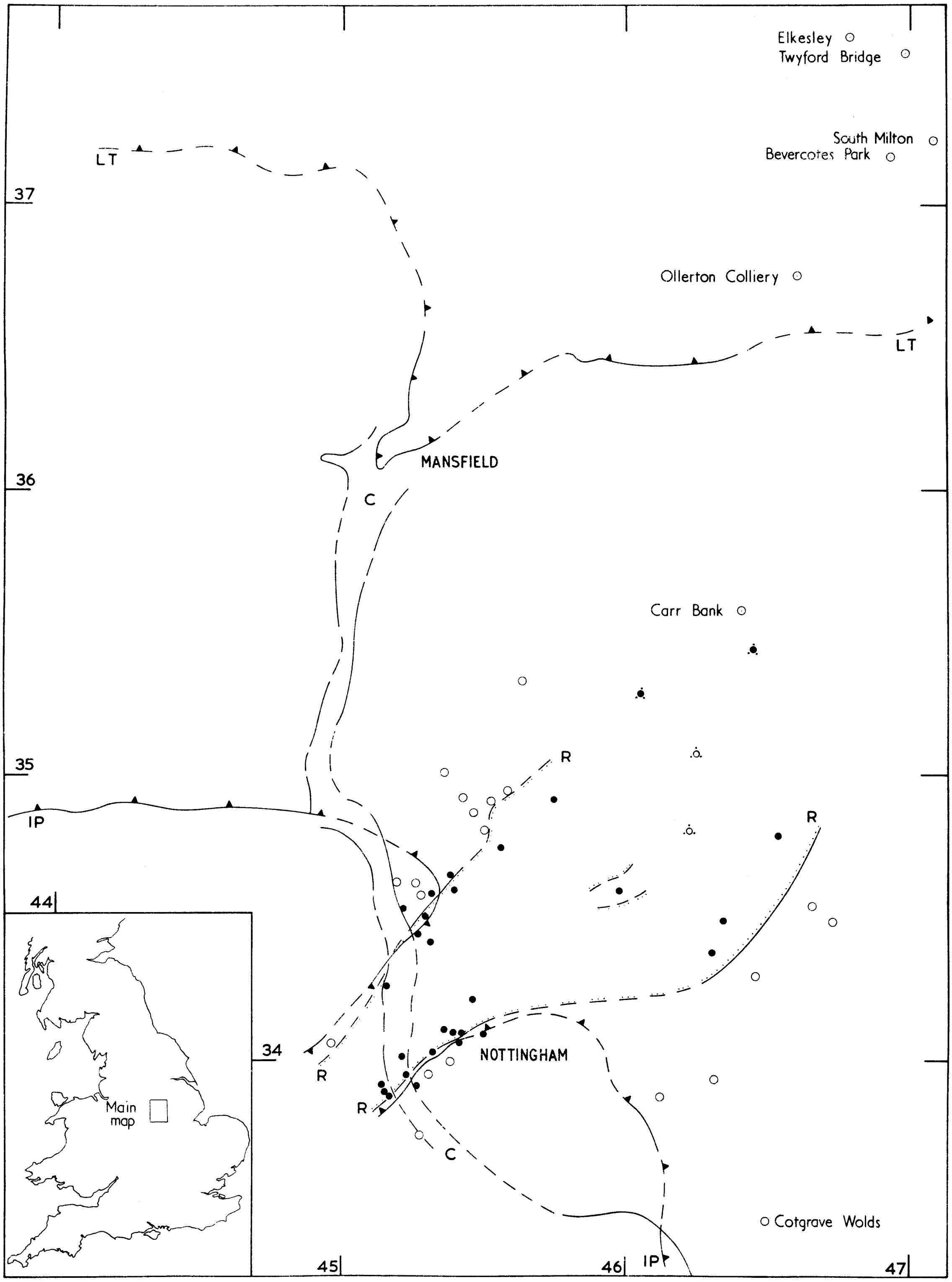
Ten facies, comprising the rocks between the Blackshale and Main Bright horizons in the Coal Measures of the East Midlands, are described in terms of lithology, sedimentary structures, body-fossils, trace-fossils and other features of palaeo-environmental significance. It is suggested that the much abused cyclothem concept should be rationalised using an ancillary one of sedimentation successions, four of which operate and interfere to produce the considerable cyclothem variation between the Blackshale and the Main Bright. The complexities of coal seam splitting are figured, a borehole sequence is discussed and a synthesis of coalfield horizon mapping experience is also brought to bear on the understanding of geometrical relationships between productive coal measures facies.

Introduction

Productive coal measures have usually been described in terms of a few lithological types, qualified only by words relating to colour, gradation and interstratification, sometimes with the addition of a broad assessment of fossil content. There exist large numbers of stratigraphic successions published in these broad terms and general conclusions regarding repeated rhythms or "cyclothems" have frequently been drawn. One such "cyclothem" is given by Edwards (1951, p. 15) for the concealed coalfield of Yorkshire and Nottinghamshire; he describes it as a normal upward succession averaging 30 to 40 feet thick of the following beds: coal, dark mudstone with shells, grey mudstone, sandy mudstone or sandstone, seatearth. A statistical study of successions between seatearths in the Modiolaris zone of the same coalfield by Duff and Walton (1962), revealed that there was a variety of orders in which similar simply connotated beds occur.

The Edwards (1951) "cyclothem", and others comparable, are crudely representative of part of a mixed population of successions in any one deep borehole through the productive coal measures. Close examination of complete cores from coal borings in Britain during the last two decades has suggested that there are recurring strata types which though recognisable as an entity cannot be unequivocally described in the traditional largely lithological terms. There are for instance several strata types in which both siltstone and sandstone play a part.

This address sets out to distinguish the facies present in the productive Carboniferous coal measures of the East Midlands, particularly of Nottinghamshire. The detail is derived from the records of lithology, sedimentary structures, body-fossil genera, trace-fossils and other features in the cores from six deep boreholes, namely, Elkesley, Twyford Bridge, South Milton, Bevercotes Park, Ollerton Colliery and Carrbank



Text-fig. 1. Two selected palaeographical features from the Lower Coal Measures. LT. = Split within the Low Tupton seam; an intra-seam "dirt" isopachyte of 1 foot opening out northwards. C = Cannel belt within the Low Tupton seam; lines are 6 ins. isopachytes of cannel which dies out very rapidly east and west; maximum cannel thickness is over 1 ft. 1 P = split and line of deterioration within the lower part of the First Piper seam. K = approximate limits of thick sandstone belt below the First Pipe seat-earth (Tupton rock). Solid circle locations are boreholes with brown seat-earths at the First Piper horizon and in the vicinity of the sandstone belt. Open circles locate nearby boreholes with grey seat-earths at the First Piper horizon. The six surface boreholes providing the main facies information for this address are named. National Grid lines are numbered at 10,000 metre intervals.

boreholes (Text-fig. 1), drilled between Retford and Farnsfield in 1962 and 1963 and examined by the author together with other geologists. This primary data is backed by other records accumulated over two to three decades within the coal industry and by the author and his associates now at the National Coal Board East Midlands Geological Outstation.

This study is limited to strata between the Blackshale and Main Bright horizons and is thus essentially concerned with non-marine coal-bearing measures. The succession of coal beds is shown on Text-figure 3. The clastic rock terms, mudstone, siltstone and sandstone are used here as defined by Elliott and Strauss (in press) and essentially as used by the majority of geologists when examining cores from Nottinghamshire coal-boreholes. Terminology relating to sedimentary structures is taken, when relevant, from Elliott (1964 and 1965a).

Description of facies

The coal measures referred to above may be conveniently discussed under ten readily distinguished main facies, some of which may be sub-divided.

1. Coal facies

Coal beds form only 2 - 7% of the East Midland productive coal measures, and are the one facies group in the Coal Measures which have been studied intensively from most of the aspects open to the earth scientist. Only a few matters of sedimentological interest are pertinent here and the reader is referred to the vast literature available. The microscopical information given in the following is largely taken from Smith (1962).

There are three main sub-facies with transitional types or intercalated beds occurring between any two:

(a) Macrolithic coals: clarite and vitrite dominant;

(b) Microlithic coals: durite dominant;

(c) Microlithic coals: cannel coal.

The macrolithic coals contain a large proportion of relatively large constituents and almost always make up the greater part of any particular coal seam section, frequently to the exclusion of the other two sub-facies. These coals are layered, each such layer being up to 3/8 inch thick, and exceptionally as much as 2 inches. Each dense black layer of vitrain represents a fragment of wood or bark in a considerably compressed condition, often many feet in length; these fragments are often Lycopod remains. As a broad generalization the macrolithic coals yield a miospore assemblage referable to Lycopods, the large arborescent plants of Westphalian times, but a few layers bear poorly-preserved spores some of which are attributable to 'fern-like' plants; these represent the 'incursion phase' of Smith (1962). The finer laminae within clarain, contain disintegrated leaf and other tissues. Fungal remains are at a minimum in the macrolithic coals, except in the 'incursion phase'. Mineral sediment and pyrite may be present in significant quantities.

The microlithic durite-rich coals contain a high proportion of fine-grained constituents; layering is less pronounced than in the previous sub-facies but is often clear upon close examination, especially under a low magnification. Degraded fragmentary plant material is common and only the more resistant plant parts are recognisable, such as mega- and miospores. The typical miospore assemblage is referred to as the densospore phase and probably represents a herbaceous or mixed herbaceous and arborescent flora, though too few parent plants are known to be conclusive. Probable fungal mycelia are common and mineral sediment and pyrite are at a minimum.

The cannel coals are composed of very finely comminuted plant debris with a sometimes appreciable admixture of inorganic clay-sediment. The debris is ordinarily too fine to identify and cannel coals may be described as organic muds. They are lenticular deposits frequently unrelated to seat-earths and without visible laminae, and often with occasional fish debris, especially scales, and phosphatic lenticles. They occur in three situations (Text-fig. 4), associated with a regional split, as a long narrow cannel belt (Text-fig. 1) and associated with a "swilley" or palaeo-river course (Elliott, 1965b). Rocks are found intermediate in character between cannel coals and faunal mudstones.

The great majority of non-cannel coal beds overlie seat-earths and underlie a faunal mudstone. Interdigitation may be present between coal and seat-earth but usually involving only coal laminae; the top junction is almost invariably the sharper. Most facies may overly coal on occasions but the faunal mudstones are by far the most common in that situation.

2. Seat-earth facies

Seat-earths are readily sub-divided into two principal sub-facies, a grey one with nodular 'ironstone', that is sideritic nodules, and a brown one with sphaerosiderite. Both sub-facies consist of unlaminated mudstone or siltstone and rarely sandstone; the more clay-rich examples being always traversed by numerous listric surfaces. Thicknesses average about 40 inches and may range up to about 60 inches; greater thicknesses involve more than one seat-earth. They form 10 - 20% of the East Midlands productive coal measures and pass down into any of the other facies.

Grey seat-earths with nodular ironstone may vary from pale to very dark grey in colour and contain carbonised stigmarian roots. The nodular siderite concretions have irregular to twisted elongate shapes and can often be seen to be associated with stigmarian root branches in the lower part of the bed. These have often been referred to as 'root-nodules' and 'rootlets' respectively, in East Midlands coalfield borehole records. Many root-nodules have a white 'kaolin' core.

Brown seat-earths with sphaerosiderite occur much less frequently than grey seat-earths and vary from very pale to dark brown, are typically devoid of carbonaceous matter, and the stigmarian roots and 'rootlets' are only represented by casts which are sometimes vague. Sphaerosiderite is usually present and may be scattered or aggregated, particularly in the lower part of the bed. Comparisons show that coal seams over brown seat-earths tend to be thinner than where the same seams overlie grey seat-earths.

Composite seat-earths having characters attributable to both sub-facies take several forms. Occasionally a seat-earth contains both nodular and sphaero-siderite or the seat-earth is mottled grey and brown or is grey tinted brown with especially small ironstone nodules. Moreover a thin grey-brown layer may overlie a grey seat-earth. In each of these composite forms *Stigmaria* may be carbonised.

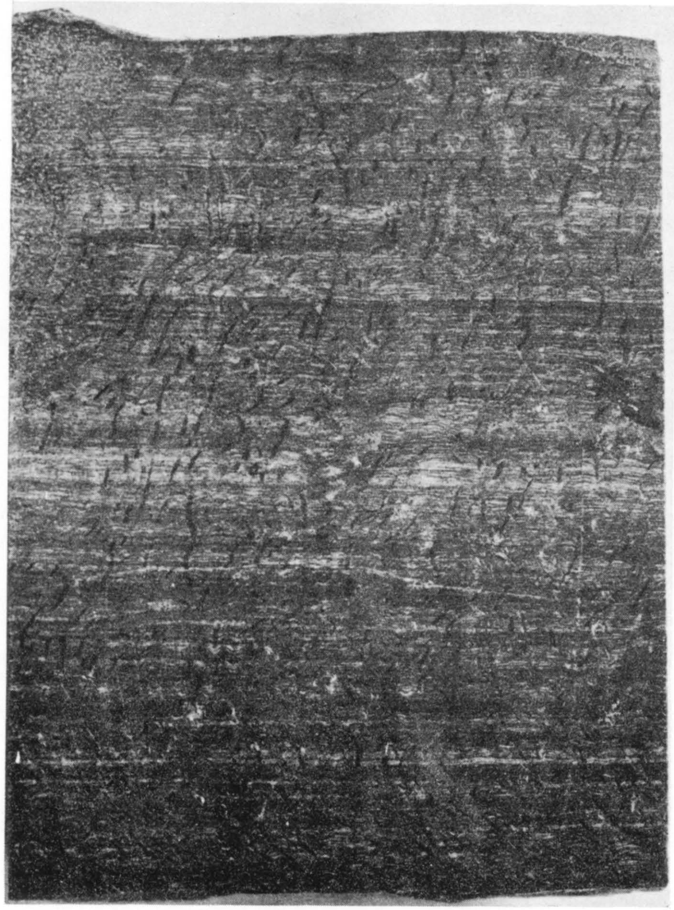
Other variants of these seat-earth facies include rare beds with a high quartz content and somewhat laminated beds transitional with other facies. These laminations are usually disturbed around and near transecting stigmarian roots. Seat-earths may be unusually thick due to repetition, having more than one siderite horizon, or thin due to truncation by a sharp irregular surface so that only the siderite horizon is present.

Reddened seat-earths, which are best developed in non-productive coal measures, may be classed as a third sub-facies but only very rare red-mottled sphaerosiderite-bearing seat-earths are known in the East Midland productive coal measures; for example,

at the Second Ell horizon (1438 ft.) in Cotgrave Wolds borehole (Text-fig. 1) (E.4649, N.3343),

at the Two-foot horizon (904 ft.) in King's Mill borehole (Text-fig. 2) (E.4513, N.3595),

A. <u>Complex silt-sandstone facies.</u> Laminated silt-stone and very fine sandstone with multiple sets of "train-drift" (one inch from top and base) and a solitary set of a larger ripple-drift structure (two to three inches from top of core). Twyford Bridge borehole: 2499 ft. 0 ins. to 2499 ft. 6 ins. Core diameter: $4\frac{1}{2}$ ins. Original cylindrical surface.



B. <u>Complex silt-sandstone facies.</u> Laminated and layered silt-stone and very fine sandstone with "colonial burrows". Salterford Farm borehole: 2410 ft. 5 ins. to 2410 ft. 10 ins. Core diameter: $3\frac{1}{2}$ ins. Prepared flat smooth surface.

at the Brown Rake horizon (1964 ft.) in Ollerton Colliery borehole (Text-fig. 2) (E.4659, N.3675,

at 17 feet below the Mansfield Marine Band (109 ft.) in Bestwood 100's borehole (E. 4587, N. 3480),

and at the Mansfield Marine Band Horizon (78 ft.) in Calverton 1's borehole (E.4605, N. 3481)

In each of these cases no coal, apart from a few thin laminae, occurs above the seat-earth.

3. Massive siltstone facies

Relatively structureless siltstones of variable grade comprise the massive siltstone facies. They often contain anastomosing small-scale soft-sediment faults and well-preserved plants in all attitudes. The facies forms 5 - 10% of the East Midlands productive coal measures and thicknesses range up to 40 feet but are commonly less than 20 feet.

Lamination is often difficult to detect or absent, never dominant, but may be distinct in a few layers such as a muddy layer with a concentration of plant material or a sandstone-rich layer displaying deformation. Such bedding is usually discordant to adjacent beds by up to about 35 degrees. Thin mudstone-pellet layers are rare but typical; these pellets are usually greenish or pale brownish grey and may be accompanied by roughly rectangular fusain fragments. Ferruginous patches or dispersed ironstone may be present and occasionally sporadic sphaerosiderite is locally developed.

This facies will often yield many well-preserved pinnules and fronds of Neuropteris, Alethopteris and other fern-like genera. Pinnularia is virtually confined to and universal in these siltstones and is associated with finely grooved plant 'stalks' and Calamites stems, both often embedded obliquely. Also near-vertical large Lycopod trunks, standing on a coal bed below, may be entombed and remain relatively undeformed. The well-known group of such stumps preserved in Victoria Park, Glasgow, is a striking example and many have been seen in the East Midlands. Lycopod stems, if present, are usually confined to the muddy layers.

With increasing layering or lamination, associated with a higher sandstone content, this facies grades into the complex silt-sandstones. It is often located immediately below a seat-earth and occasionally with a few stigmarian roots may appear somewhat seat-earth like; it more rarely lies below a bed of flaser silt-sandstone. On the other hand it may overlie most facies but is rarely intercalated with them and then usually with complex silt-sandstones.

4. Complex silt-sandstone facies

This facies occurs in beds up to 25 feet thick forming between 15 and 20% of the sequence, and composed of thinly interlaminated siltstone and very fine sandstone in varying proportions but with siltstone dominant on average. Layers in which siltstone or sandstone are dominant often alternate regularly and the lamination is usually pronounced, even to gently undulating with slight wedging in places. The layer dips are sometimes low but may be up to 25 degrees and discordant with respect to adjacent beds. Stratification surfaces are often finely micaceous and minor diastems are common where sandstone is dominant.

Two varieties of ripple-drift type structures with arcuate plan forms are frequently present. One has uneroded stoss sides with a wave length of several inches and occurs as a solitary 'migrating' wave form with ill-defined limits, grading into more clayey sediments. The second is compound and very small scale; it consists of many rather sharply defined sub-sets within which are convex-upward cross-laminae. It is found confined to a few cubic inches of sediment and has been recorded as "Train-drift" (Plate 17a) in many Nottinghamshire coal-bore logs during the past five years. Minute, straight and very shallow, sand-filled grooves of unknown classification are occasionally detectable and are probably cross-laminated in sections perpendicular to their axes. Some few thin layers may be deformed, crumpled or corrugated, with perhaps minor soft-sediment faults. Such faults occur occasionally throughout the facies.

Trace fossils are abundant locally and occur in certain layers to the extent of fairly advanced bioturbation. Solitary, small cup-shaped and other burrows are fairly well but spasmodically distributed. Large laminated burrows with pronounced down-dragged laminae and colonies of long thin parallel tubular burrows, with well-defined walls, occur very occasionally but are confined to this facies. The latter are recorded in borehole logs as "colonial burrows" (Plate 17b). Also, very rarely, thin layers of this facies contain shallow almond-shaped traces referable to Pelecypodichnus (Seilacher, 1953).

The wealth of biokinematic structures typifies one sub-facies; a second contains less trace-fossils and more examples of the exokinematic structures described above together with orientated plant remains, entrapped plant stems at oblique angles, and small amounts of comminuted plant debris. Still-united Calamites stems oblique to the bedding are known.

It is the exokinematic sub-facies which is sometimes markedly discordant but it grades into and interfingers intimately with the trace-fossil sub-facies. The facies as a whole grades by intercalation into layered sand-siltstones and flaser silt-sandstones, and with loss of lamination into massive siltstones. It frequently underlies a seat-earth, or less commonly massive siltstones, and usually overlies a shelly or trace-fossil mudstone.

5. Layered sand-siltstone facies

This facies, which forms about 5% of the the sequence, consists of beds up to 25 feet thick in which there is a pronounced alternation of sandstone and siltstone layers, each up to about 3 inches thick. Micaceous and comminuted plant debris planes may be present. These beds are generally unfossiliferous apart from a few varied burrows.

Minor diastems between the layers are typical and frequent, and the layer dip may be notably discordant to adjacent beds. The layers often show low-angle cross-stratification and the diastems are sometimes associated with strings of small siltstone clasts or discontinuous siltstone laminae.

Normally sandstone is dominant but the facies intergrades with the complex silt-sandstones, within which siltstone is usually dominant, and also possibly with the washout sandstones.

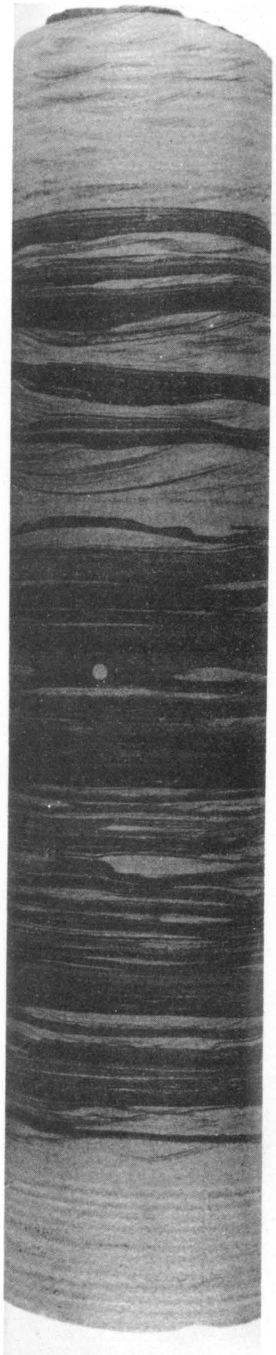
6. Washout sandstone facies

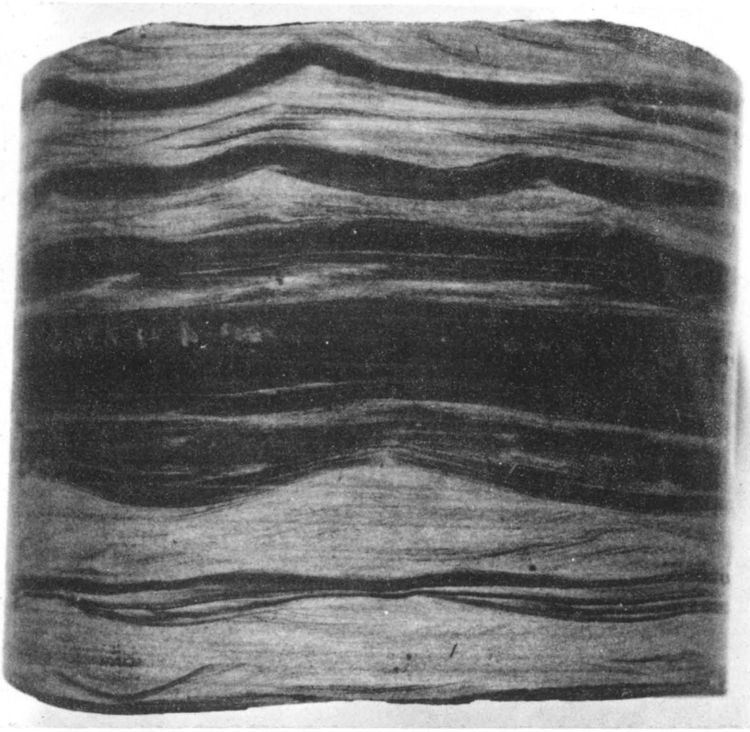
These rocks form less than 1% of the sequence and comprise fine to medium-grained sandstones; are unfossiliferous, with mica and comminuted plant debris in laminated parts; are up to 36 ft. thick and divisible into two sub-facies:-

(a) Dune-set sandstones: cross-laminated, having dune-sets up to 6 ft. thick;

(b) Massive sandstones: massive with clasts, that is without continuous lamination and containing angular to sub-angular fragments, often crowded and in bands of up to 5 ft. thick (breccio-conglomerates). These clasts consist of either laminated siltstone, sometimes identifiable as from the complex silt-sandstone facies, ferruginous siltstone, coal or more infrequently ironstone of fine-silt or mud grade, the latter being apparently from the trace-fossil or shelly mudstone sub-facies. Sizes range up to 5 or 10 inches diameter and are either to be measured in inches or as flakes less than ½ inch diameter. The clasts are usually spaced discretely and are rarely bedded one on another with a sand infilling.

Washout sandstones have a ribbon-geometry. Their bases almost invariably show signs of erosion and where studied in three dimensions in colliery workings are often channelled in a shallow fashion with





A. Flaser silt sandstone facies between beds of rippled sandstone facies. Salterford Farm borehole: 2416 ft. 3 ins. to 2417 ft. 8 ins. Core diameter: $3\frac{3}{4}$ ins. Original cylindrical surface.

B. Flaser silt-sandstone facies. Laminated and layered silt-stone and very fine sandstone with asymmetrical ripple marks surmounted by symmetrical ripple cappings a few laminae thick. Twyford Bridge borehole: 2605 ft. 6 ins. to 2605 ft. 10 ins. Core diameter: $4\frac{1}{2}$ ins. Original cylindrical surface.

"boat-hull" shaped lows cutting into the underlying stratum. This surface of disconformity usually lies upon coal, flaser silt-sandstone or a mudstone facies.

The upper layers of the washout sandstones are often intercalated with the rippled-sandstones or underlie, usually without alternation, flaser silt-sandstones. Other relationships include lateral passage by interdigitation into the rippled sandstone or the layered sand-siltstone or either silt-sandstone facies. The two sub-facies may alternate but, in general, cross-laminated beds lie above massive beds and the basal bed of a washout sandstone is a massive one if that sub-facies is present at all.

7. Rippled sandstone facies (Plate 18a)

This is a fine grained sandstone facies characterised by linguoid ripple-sets which are usually delineated by micaceous sedimentary surfaces bearing comminuted plant debris. Both trace and body fossils are always absent.

This facies occupies less than 3% of the measures and is usually thin, less than 5 feet; it is often intercalated within the flaser silt-sandstones, the complex silt-sandstones or the dune-set sandstone sub-facies, but infrequently within others and never within massive siltstones. Occasionally it overlies dune-set sandstones as a relatively thick bed of up to 15 feet. Its top and bottom boundaries are usually sharp.

8. Flaser silt-sandstone facies (Plate 18)

Siltsone, very fine sandstone and, less frequently, sandy siltstone are interlayered; together comprising about 15% of the East Midlands productive coal measures in beds up to 12 ft. thick and exceptionally up to 20 ft. where not juxtaposed with other siltstone-sandstone facies. Many finely micaceous sedimentary surfaces with comminuted plant debris, ironstone lenses, and thin ironstone layers may be interposed, the ironstones being infrequent.

Most layers are laminated and the whole is readily sub-divided into sets. The sandstone sets are often built of more-or-less isolated ripple-marks whose roughly lens-like cross-sections provide the facies name here adopted. These ripple-marks are basically asymmetrical and straight but are sometimes surmounted by a symmetrical ripple capping, only one or two laminae thick. The siltstone sets show even laminae and the sandy siltstone layers are less distinctly or unlaminated. The latter often reveal vertical transposition, load mark and pouch structures involving an overlying sandstone set. Occasionally they exhibit crumpled bedding, especially at or towards their base. Similar layers with more complex kinematic structures are on rare occasions seen to rest on an inclined surface truncating the layers below (Bevercotes Park borehole, Text-fig. 1: 2156 ft. 5 in. in first core, 2157 ft. 6 in. in diversion core). Also rarely, a thin layer of small siltstone fragments may be found in this facies.

Occasional small burrows are usually the only records of animal life. Likewise, plant stem fragments are infrequent and isolated pinnules are very rare.

This facies, wherever present, nearly always occupies the same place in the succession: faunal mudstone, flaser silt-sandstone, seat-earth, coal; irrespective of any other facies that may be interposed. It passes down to the mudstones by alternations and gradation, and the complex silt-sandstones, layered sand-siltstones and rippled sandstones frequently interdigitate with or occur in the position of the flaser facies. It occasionally overlies washout sandstones.

9. Faunal mudstone facies

There are a variety of faunal mudstones found in the East Midlands productive coal measures with some small degree of intergradation and intercalation. Thicknesses range up to 30 ft. though they are commonly less than 20 feet; they represent about a third of all strata in the Coal Measures. The three principal sub-facies are marine mudstones including Lingula bands, trace-fossil mudstones and non-marine lamellibranch mudstones. Each of these may be silty or be represented by fine siltstones, probably as a passage to one of the siltstone or silt-sandstone facies. A few, occasionally many, sideritic ironstone layers or lenses may be present.

Marine mudstones are usually vaguely laminated or unlaminated and may contain mollusca, especially goniatites, Dunbarella, Myalina, and gastropods; horny brachiopods, especially Lingula; foraminifera and trace-fossils. Details have frequently been published: see particularly Edwards and Stubblefield (1948).

Trace-fossil mudstones are usually very well laminated on a fine scale, alternately light and dark. The more silty variants show alternations of clayey and more quartzose laminae. Body fossils are absent or rare, and trace-fossils are well represented though difficult to reveal by a clean split precisely along a sedimentation surface. Such a split is more readily achieved when the rock is broken by tension than by compression and these fossils are most easily found in borehole cores of less than 3 in. diameter. The traces include a small form of burrow similar to Planolites ophthalmoides (Jessen, 1949), regularly meandering traces known as Cochlichnus kochi, small bi-lobed traces referred to as Gyrochorte carbonaria, other minute-burrows and other undescribed forms which are difficult to expose intact. C. kochi was described and discussed in detail by Michelau (1955) but unfortunately under the genus Belorhaphe. It has frequently been recorded in the East Midland Coal Measures as Belorhaphe, Sinusites or in early records as "sineoids". For elucidation of this taxonomy see Michelau (1955) and Moore (1962).

Non-marine lamellibranch mudstones may be laminated but usually are not if very shelly. These are the well-known "mussel"-bearing mudstones typified by the genera Anthracosia, Carbonicola, Anthraconaia or Anthracosphaerium. Ostracods and Spirorbis sometimes accompany these lamellibranchs. Palaeontological details are to be found in the coalfield memoirs by Edwards (1951), Eden et alia (1963) and Smith, E. G., et alia (1967), and a general review of the non-marine lamellibranch succession was given by Calver (1955).

Other faunal mudstone sub-facies are to be found sparingly distributed in the Coal Measures of the East Midlands. They include dark fissile beds with Planolites montanus (Richter, 1937), fissile beds with Euestheria ("Estheria"), or more carbonaceous fissile beds with fish and phosphatic remains. Each of these sub-facies usually underlies one of the main sub-facies.

Faunal mudstones commonly overlie either coal or seat-earth and occasionally the flaser silt-sandstones or the rippled sandstone facies. They may underlie most facies, but most frequently the flaser or complex silt-sandstones. They are found intercalated with the flaser silt-sandstones, but rarely with other facies.

10. Miscellaneous rocks

A few rock types in the East Midland coal measures between the Main Bright and Blackshale horizons are not embraced by the above nine facies, but they account for only a small fraction of one per cent of the measures. These rocks include tonsteins, 'kaolin oolith bands' and a calcareous tuffaceous siltstone.

The tonsteins are mudstones low in illite and containing appreciable amounts of kaolinite, often with an "unglazed earthenware" texture and without listric surfaces. They usually occur as poorly laminated layers less than 5 cm. thick, and are associated with seat-earths or coals (Text-fig. 3) At least some have microscopic features reminiscent of volcanic sediments and some have a matrix showing gell-like features containing kaolinite pseudomorphs and evidence of considerable fungal attack on plant remains. They have been described collectively by Eden et alia (1963) and Strauss (in the press), whilst Moore (1964) and many continental authors have debated the origin of examples outside the

East Midlands. Whatever the primary origin of the sediment, Moore argued that the level of the swamp water table in conjunction with particular biochemical conditions, was the controlling factor in the diagenetic development of a particular well-developed tonstein layer. To this extent, his theories may well apply to most, if not all true tonsteins.

'Kaolin oolith bands', as described by Deans (1934-5) occur at a number of horizons on top of a coal bed or a seat-earth, but are usually quite local. One, however, extends over the southern half of Nottinghamshire on top of the First Ell coal seam (Text-fig. 3). These rocks are sideritic layers containing a variable proportion of 'kaolin' ooliths and coaly fragments. They have characteristic irregular top and bottom margins. Deans held the view that the ooliths were originally produced by gentle agitation from bottom currents, as is traditionally held in connection with other ooliths from other formations.

A calcareous tuffaceous siltstone occurs throughout southern Nottinghamshire and the adjacent parts of Derbyshire within a non-marine lamellibranch mudstone at the Black Rake horizon (Text-fig. 3). This is described by Francis et alia (in the press), and it has long been recognised as a speckled pale ferruginous layer which is often laminated and which effervesces with dilute hydrochloric acid. The layer varies from a fraction of an inch up to a foot or so, and passes into a thicker deposit with lapilli in the vicinity of Epperstone where a borehole at Wash Bridge (Text-fig. 2) probably passed close to a contemporaneous volcanic neck. Isopachytes of the layer show a relatively thicker belt extending due west of Epperstone as far as the outcrop, suggesting as Francis (et alia) point out, that the prevailing wind of the time was from the east.

Each of these three miscellaneous rock types are utilised as marker bands to improve detailed correlation of borehole and other sections.

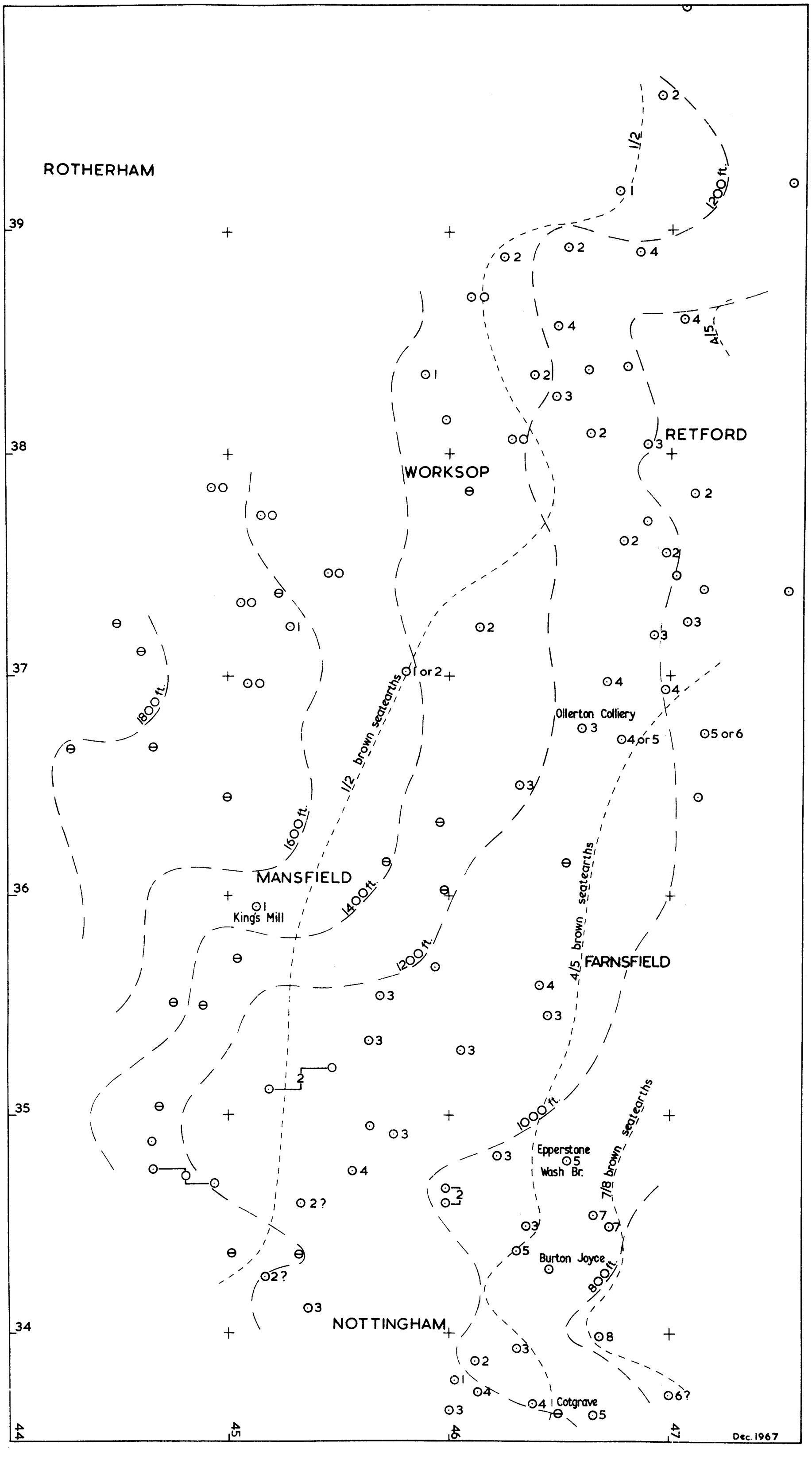
Interpretation of facies

Coals and Seat-earths: facies 1 and 2

The very large fragments of plants, including trees, that are found in coal seams, the occasional in-situ stumps in the immediately overlying sediments, the almost invariable roots or root-casts found in underlying seat-earths, the relatively uniform thickness of coal layers and the lack of appreciable clastic sediment mixed with them at the majority of locations all help to testify to the growth of vegetation in place with suitable conditions for its preservation. This is usually taken to indicate accumulation within water shallow enough for plants to grow, yet deep enough and de-oxygenated sufficiently for preservation, and in general this swamp-environment thesis has stood the test of time as applied to the coal seams of the Coal Measures of Great Britain. Rarely is coal deposit found to be at variance with the above, with the probable rare exception of local and thin drift coals.

The above discussion refers to the non-cannel coals; cannels are, and usually have been, recorded as indurated vegetable mud accumulated in lakes and ponds: see, for example, the large cannel-lenses recorded by Elliott (1965b).

Variation within and especially between the coal types is nowadays normally attributed to changes in factors controlling the degree of selective decomposition. These factors include those leading to weak oxygenation of the water cover: shallow depths of water, agitation of water, and some aspects of climate. Smith and Butterworth (1967, pp. 84-89 and fig. 59), give an explanation of miospore phase successions, which are broadly related to coal types, in terms of successive increments of peat in relation to the water table. Essentially the macrolithic coals are regarded as accumulated near but below the free water-table under anaerobic conditions and the durite-rich coals as being accumulated near that level under aerobic conditions for part of the time, preserved to a degree by water retained by the capillary-like properties of the peat bogs.



Text-fig. 2. Numbers of brown seat-earths within and thickness of measures between the Blackshale and Main Bright horizons. The isopachytes are at 200 feet intervals and the seat-earth frequency lines are at a 3 seat-earths interval. Numbers alongside borehole location points refer to brown seat-earths recorded. Thicknesses at all location points shown, both boreholes and shafts (with horizontal bar), were used to define the isopachytes. National Grid Lines are numbered at 10,000 metre intervals.

These views accord well with the sedimentological features of these coals as outlined earlier in this address. Subaqueous preservation was balanced against the attack of fungi and bacteria under the prevailing, probably sub-tropical but somewhat variable climatic conditions. Fungal remains increase from the macrolithic to the microlithic, durite-rich coals, that is with some degree of emergence from protective swamp waters.

The sub-facies of seat-earths are probably also related to drainage conditions. The distribution of brown seat-earths is shown on Text-figure 2 where it is compared with the Blackshale to Main Bright interval. A negative correlation exists between the number of these seat-earths in the succession and the thickness of the measures. Some irregularities exist in the occurrence of brown seat-earths at any one horizon, and in at least one or two cases they are located on probable slight palaeo-topographic highs. There is for instance a belt of this sub-facies at the First Piper horizon, overlying a Tupton-rock belt which extends from west of Nottingham north-eastwards (Text-fig. 1). Increase in frequency towards the edge of the productive coal measure basin and localisation over relatively un-compactable sands both suggest that the brown sub-facies developed in slightly emergent areas. Further into the basin of deposition or on more compactable deposits the grey seat-earths probably developed in areas with poorer drainage. The rare red-mottled seat-earths appear to have been more emergent than the brown seat-earths, allowing some oxidation.

Massive siltstones, complex silt-sandstones and layered sand-siltstones: facies 3, 4 and 5

These three facies are related in several ways: they intergrade between themselves, they can often be mapped as ribbon deposits or in juxtaposition with washout sandstone ribbons, they each may show discordant dips and they yield diverse structures attributable to moderately strong currents or rapid deposition.

The crude and sparse bedding of the massive siltstones suggests a lack of sorting. Entombed large plants and even upright tree trunks are present. To explain the occurrence of similar upright fossil trees, Teichmüller (1956) advocates rapid burial by sediments deposited by heavily laden floodwater from nearby watercourses. The complex silt-sandstones contain steep-climbing ripple-drift structures, the larger of which have features in common with Walker's type 3 (1963, Fig. 6) as found in turbidites: the straight sand-filled grooves may be tool-marks due to dragged half-floating plants, now sometimes found in oblique attitudes as in the massive siltstones. The layered sand-siltstones have eroded dune-sets and small clasts.

When fully developed these facies, together or singly, often occupy the full thickness between coal-seat-earth horizons, and the massive siltstones may contain roots throughout. Plants are common, large and occasionally in the position of growth. All this leads to the conclusion that these facies have a proximal situation within or alongside drainage channels that were extending rapidly.

Where these deposits are represented by relatively thin, more nearly concordant beds they probably lie towards the distal or lateral edges of their distribution. This includes the trace-fossil sub-facies of the complex silt-sandstones. Here, less exokinematic structures and abundant evidence of life-activity suggest weaker currents but sufficient to bring in ample food particles. The rate of sedimentation was low enough to permit a rich colonisation causing bioturbation, but punctuated by periods of rather more rapid deposition causing the "colonial-burrow" inhabitants to extend their "burrows" upwards considerably. These were probably escape-burrows, the Fluchtbahnen of Reineck (1958).

Washout sandstones: facies 6

The breccio-conglomerates suggest deposition from stronger currents of the upper flow regime, whereas the dune-sets (large ripples) indicate deposition in the upper part of the lower flow regime. After cutting the original channels, the currents, though varying in strength, weakened as deposition proceeded, usually until an overlying facies with ripple-sets or ripple marks accumulated. A very similar fining upwards succession from the Old Red Sandstone is described by Allen (1963).

Flaser silt-sandstones and rippled sandstones: facies 7 and 8

The isolated ripple marks and general lenticular nature of the very fine sandstone layers bear witness to the paucity of sand arriving at the site of deposition of the flaser silt-sandstones. Symmetrical and asymmetrical ripple marks indicate current intensities fluctuating within the lower part of the lower flow regime. The relative paucity of plant remains coupled with weak currents suggest that this facies accumulated distally of facies 3, 4 and 5.

The rippled sandstones and the flaser silt-sandstones have generally similar relationships to other facies. The thicker beds of rippled sandstone may be found in juxtaposition with the dune-set sandstones and, unlike the flaser silt-sandstones, may be intercalated with them. Evidence of life and recognisable plant debris is absent.

These features suggest that the rippled sandstones were deposited when and where sand was available in plenty, and the flaser silt-sandstones when and where clay was available for deposition in a relatively large proportion to sand. They are sometimes intercalated and may be regarded as largely contemporaneous and related facies, but with the rippled sandstones occurring in closer relationship to the washout sandstones.

Faunal mudstones: facies 9

Each of the faunal mudstone sub-facies, except some pyritic blackshales, provided evidence of a bottom fauna. This indicates a rate of sedimentation sufficiently gentle for living organisms to flourish; moreover, an extremely fine shades-of-grey lamination is often present suggesting quiescent conditions. These features and the fine clayey sediment, though sometimes mixed with a small proportion of fine quartz, support a conclusion that these sub-facies lie distally of all those preceding. Pyritic black-shales are normally accepted as being deposited under stagnant conditions and the thin beds found in these coal measures often only contain a fauna of fish remains: in this extreme case bottom currents were probably insignificant.

Cyclothem theory

The facies described above can be readily recognised in borehole cores. The sequence at Ollerton Colliery borehole (Text-fig. 1), for example, is given below from the author's records. All beds less than 4 inches thick are discounted unless they are important to the sequence; thus isolated thin coal beds are included but thin interfingering at a facies junction and all beds in the miscellaneous group 10 are excluded.

The digits used are those numbering the preceding sections of this address: they are repeated here as a matter of convenience:-

1	Coal facies
2	Seat-earth facies
3	Massive siltstone facies
4	Complex silt-sandstone facies
5	Layered sand-siltstone facies
6	Washout sandstone facies
7	Rippled sandstone facies
8	Flaser silt-sandstone facies
9	Faunal mudstone facies

Facies sequence recorded at Ollerton Colliery borehole

(Main Bright) 1 2 3 4 5 9 (Two Foot) 1 2 8 9 1 2 4 3 4 3 2 4 3 2 3 2 5 4 3 4 8 4 5 4 1 2 5 4 9 (High Hazles) 1 2 1 2 3 1 2 4 9 2 8 9 1 2 1 2 8 9 2 3 2 3 2 4 5 7 4 9 1 2 8 7 8 9 (Main Smut) 1 2 8 9 1 2 5 6 4 9 1 2 (Top Hard) 1 2 4 9 1 2 4 7 8 9 (Dunsil) 1 2 4 1 2 3 4 9 1 2 4 9 8 9 2 8 7 8 9 1 2 7 8 4 8 4 9 8 9 1 7 8 7 8 9 4 7 8 9 (First Ell) 1 2 4 7 9 2 8 9 8 9 (Second Ell) 1 2 4 7 8 7 8 9 2 8 4 8 9 (Joan) 1 2 9 1 2 9 1 2 4 8 9 1 2 4 7 8 7 5 4 9 (Deep Soft) 1 2 8 2 4 5 4 8 7 2 7 8 7 8 7 8 9 1 2 8 9 2 4 3 4 5 4 5 4 7 5 7 4 (Parkgate) 1 2 4 9 2 4 7 8 9 1 2 4 9 (Low Tupton) 1 2 9 (Threequarters) 1 2 4 7 4 7 4 9 4 5 7 8 9 (Yard) 1 2 4 3 4 3 (Blackshale) 1.

This sequence appears complex and is not readily divisible into cyclothems following a reasonbly regular pattern. Statistical tests by the 'method of runs' show it to be random or borderline non-random. The median for such tests may be varied in its position relative to the facies, thus taking account of a possible circular nature of the sequence, and certain facies may be grouped as one. Those grouped in trial tests were 1 and 2, 7 and 8, and 3, 4, 5 and 6. Neither shifting the median, nor grouping the facies, yielded sequences that were decisively non-random.

Sedimentological considerations, as discussed in the interpretation of facies earlier in this paper, suggest that an East Midlands productive coal measures sequence is compounded of four sedimentation successions, distinct in origin.

The faunal mudstones, deposited in quiescent conditions are most frequently overlain by and intercalated with the flaser silt-sandstones, deposited under gentle but intermittent currents; probably as a distributary extended towards and by the site of deposition. Where uninterrupted by other facies this may be regarded as an upwards-developing clastic succession. Faunal phases are often present in the mudstones adding a biological aspect to this succession.

The seat-earths, whose sub-facies appear to be related to drainage conditions, are likely to represent a hydromorphic soil series modified to a greater or lesser degree by post-depositional mineralogical changes. Miospore phases and coal-type successions are considered to be controlled by the position of the water-table together with related factors such as rainfall, humidity and evaporation. Swamp waters were essential to the preservation of coal-forming peat but on the other hand a degree of aerobic fungal and bacterial decay probably promoted the accumulation of the durite rich coals. Coal almost always overlies a seat-earth and this forms a hydrologically controlled succession with phases within each facies.

The washout sandstones are often overlain by rippled-sandstones or flaser silt-sandstones and together these facies form a third succession generated by the decreasing strength of currents, from the upper flow regime to the lower part of the lower flow regime.

Fourthly, a laterally developing clastic succession is represented by the layered sand-siltstones the complex silt-sandstones and the massive siltstones. Their frequent high discordant dips indicate lateral-deposition with flatter dips in some beds probably deposited further downcurrent.

These four sedimentation successions appear to operate and interfere to produce considerable vertical section variation. Such a four-fold genesis of the productive coal measure sequence can account for its complex nature and can be recognised to a fair degree in the Ollerton Colliery borehole sequence. Separating out facies 1, 2, 7, 8 and 9 and inserting punctuation where facies are omitted, the sequence reads:

(Main Bright) 1 2 . 9 1 2 8 9 1 2 . 2 . 2 . 2 . 8 . 1 2 . 9 1 2 1 2 .
1 2 . 9 2 8 9 1 2 1 2 8 9 2 . 2 . 2 . 7 . 9 1 2 8 7 8 9 1 2 8 9 1 2 .
9 1 2 1 2 . 9 1 2 . 7 8 9 1 2 . 1 2 . 9 1 2 . 9 8 9 2 8 7 8 9 1 2 7 8
. 8 . 9 8 9 1 7 8 7 8 9 . 7 8 9 1 2 . 7 9 2 8 9 8 9 1 2 . 7 8 7 8 9 2 8
. 8 9 1 2 9 1 2 9 1 2 . 8 9 1 2 . 7 8 7 . 9 1 2 8 2 . 8 7 2 7 8 7 8 7 8
9 1 2 8 9 2 . 7 . 7 . 1 2 . 9 2 . 7 8 9 1 2 . 9 1 2 9 1 2 . 7 . 7 . 9 .
7 8 9 1 2 . 1 (Blackshale)

Facies 7 and 8 may be regarded as related, as suggested in the paragraphs concerning their interpretation. Of the twenty-two instances of facies 7, only six are not associated with 8, six lie above 8, five are interposed between two beds of facies 8 and only two lie below 8.

Allowing for interdigitation and for a lateral equivalence of 7 and 8 there are no reversals of the cycle 1 2 8 (or 7) 9 in the Ollerton sequence. That is, three consecutive digits do not occur in reversed order, i.e. as 198, 982, 821 or 219, or their equivalents with 7 substituted or added. This suggests that the first two sedimentation successions are operating consistently. It is equally true that they are probably operating to some extent independently. The upwards-developing succession 8 9, with or without 7 substituted or added, is repeated at five horizons without 1 or 2 intervening, and likewise the hydrological succession is repeated frequently without 7, 8 or 9 intervening. Both may also be incomplete and represented by only one facies.

Facies 6 only occurs once in the Ollerton sequence and rarely occurs at more than a few horizons in any one borehole sequence in Nottinghamshire. However, the succession:

Rippled sandstones of flaser silt-sandstones (facies 7 and 8)

Dune-set sandstones (facies 6)

Massive sandstones with clasts; breccio-conglomerates (facies 6):

is well established. Like the two preceding sedimentation successions it may be repeated, reduced to two or, more rarely, one facies, or both repeated and reduced. Such variety is found in twenty-four instances in the siz boreholes listed in the introduction.

The remaining, lateral-developing, sedimentation succession separated out of the Ollerton sequence reads as follows with punctuation inserted where facies are omitted:

(Main Bright) . 3 4 5 . 4 3 4 3 . 4 3 . 3 . 5 4 3 4 . 4 5 4 . 5 4 . 3 . 4 .
3 . 3 . 4 5 . 4 . (Main Smut) . 5 4 . 4 . 4 . 4 .3 4 . 4 . 4 . 4 .4 . 4 .
4 . 4 . 4 . 4 . 5 4 . 4 5 4 . 4 3 4 5 4 5 4 . 5 . 4 .4 . 4 . 4 . 4 . 4 . 4 .
. 4 5 . 4 3 4 3 . (Blackshale)

When facies 3, 4 or 5 are juxtaposed they do not occur in any preferred order; alternative orders occur with almost equal frequency. Facies 4, the complex silt-sandstones, is commonly isolated in the above sequence abstract but when combined, it is usually with either 3 or 5, the massive siltstones or the layered sand-siltstones, rarely with both. There is also a tendency for facies 4 to be combined with the silt-dominant facies 3 in one part of the sequence and with the sand-dominant facies 5 in another part. Further inspection of the full Ollerton sequence shows also that facies 3 and 7 never or rarely occur within the same group of siltstones and sandstones and are distributed in distinct parts of the sequence as follows:

(Main Bright) 3 . 3 . 3 .3 . 3 . 3 . 3 . 3 . 3 .7 . 7 . (Main Smut)
. 7 . 3 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 7 . 3 . 7 .
7 . 7 . 7 . 7 . 7 . (Yard) . 3 . 3 (Blackshale).

These generalisations hold true for the other boreholes listed in the introduction. Thus facies 3, 5 and 7 have strong tendencies to occur repeatedly in particular parts of the stratigraphic sequence. This is also true of the "washout" facies 6, though it is less common and its distribution cannot be adequately demonstrated in a small group of sections. Facies 6 occupies the position of more than one "cyclothem", for example between the Parkgate and Deep Soft horizons at Elkesley borehole, between the Top Hard and Kents Thick horizons at Twyford Bridge borehole, between the Tupton and Parkgate horizons at Carr Bank borehole, within the Tupton rock of Nottinghamshire (Text-fig. 1), and within many other thick local sandstones or 'rocks' mentioned by Edwards (1951), Eden et alia (1957) and Smith, E.G. et alia (1967).

Mapping of sandstones and siltstones of facies 6 and 3, at many horizons for National Coal Board purposes, has clearly shown that these rocks occur in linear or 'shoestring' forms, and also that facies 4 is often laterally related to them. The tendency for most sandstone and siltstone facies to be better represented in particular parts of the stratigraphic sequence at any one locality has been referred to as a kind of "inheritance" phenomenon. This appears to indicate a tendency for certain "shoestrings" to be located in the same general belt of country throughout the deposition of a continuous sequence of cyclothems (see definition at the end of this address).

Synthesis

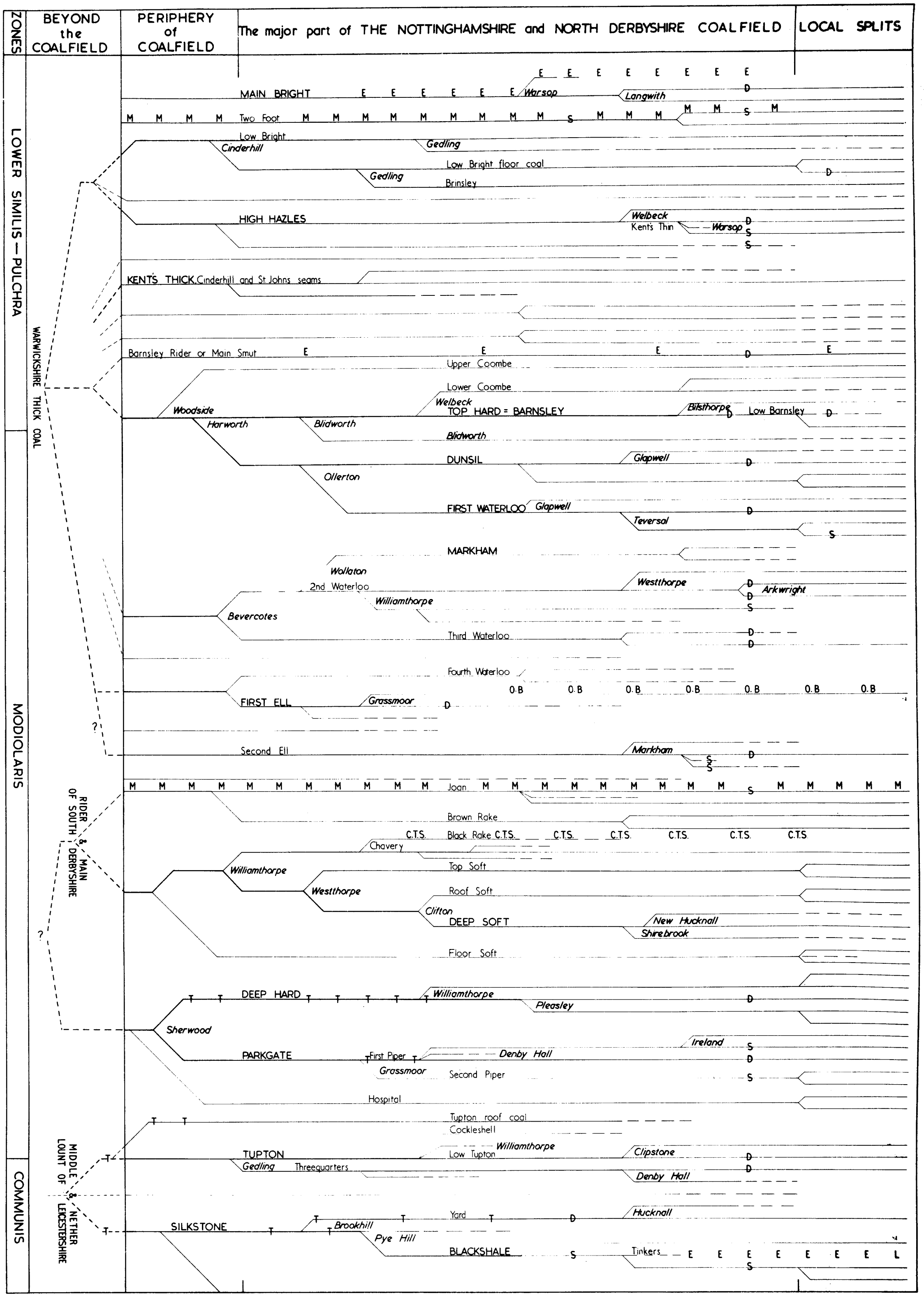
Figure 3 shows some hundred coal-seat-earth horizons within the Blackshale to Main Bright sequence of Nottinghamshire and North Derbyshire, all of which form a hierarchical system culminating in thicker coals on the periphery of and beyond the coalfield; particularly to the south. The left to right ordinate represents area as a proportion of the whole coalfield, not one dimension such as north-south; local split seams are shown to the right and local or peripheral seam unions are shown towards the left. Because of the overlapping of coal seam split-lines or thin inter-seam isopachytes a few compound seams cannot be named on the figure. These include: the Top Barnsley comprising all coal above the Low Barnsley and below the Barnsley rider; the Haigh Moor, a combination of the Second Waterloo and one or two beds below, but without the Markham; the Flockton which is believed to be the Top Soft plus Roof Soft, but not including the Deep Soft; and the Clay Cross Soft which comprises the Chavery and Flockton.

Figure 3 represents the present state of knowledge within the National Coal Board, but additional seam-splits would undoubtedly come to light if the un-economic seams could be studied in the same detail as the economic ones. It is, however, clear that cyclothems vary greatly in their known extent, from the many within the local splits to the few without any known lateral boundaries. Not shown on Text-figure 3, but equally clear is the very varied general geographical location of successive cyclothems. This suggests that, in part, the sequence may be built from localised cyclothems deposited as sub-deltas similar to the six or seven recognised in the post-glacial Mississippi delta (Scruton, 1955). Maps of economic coal seam were published by Collinson and Elliott (1960) and, although they were prepared on an economic basis, they give an idea of the varied distribution of coal swamps.

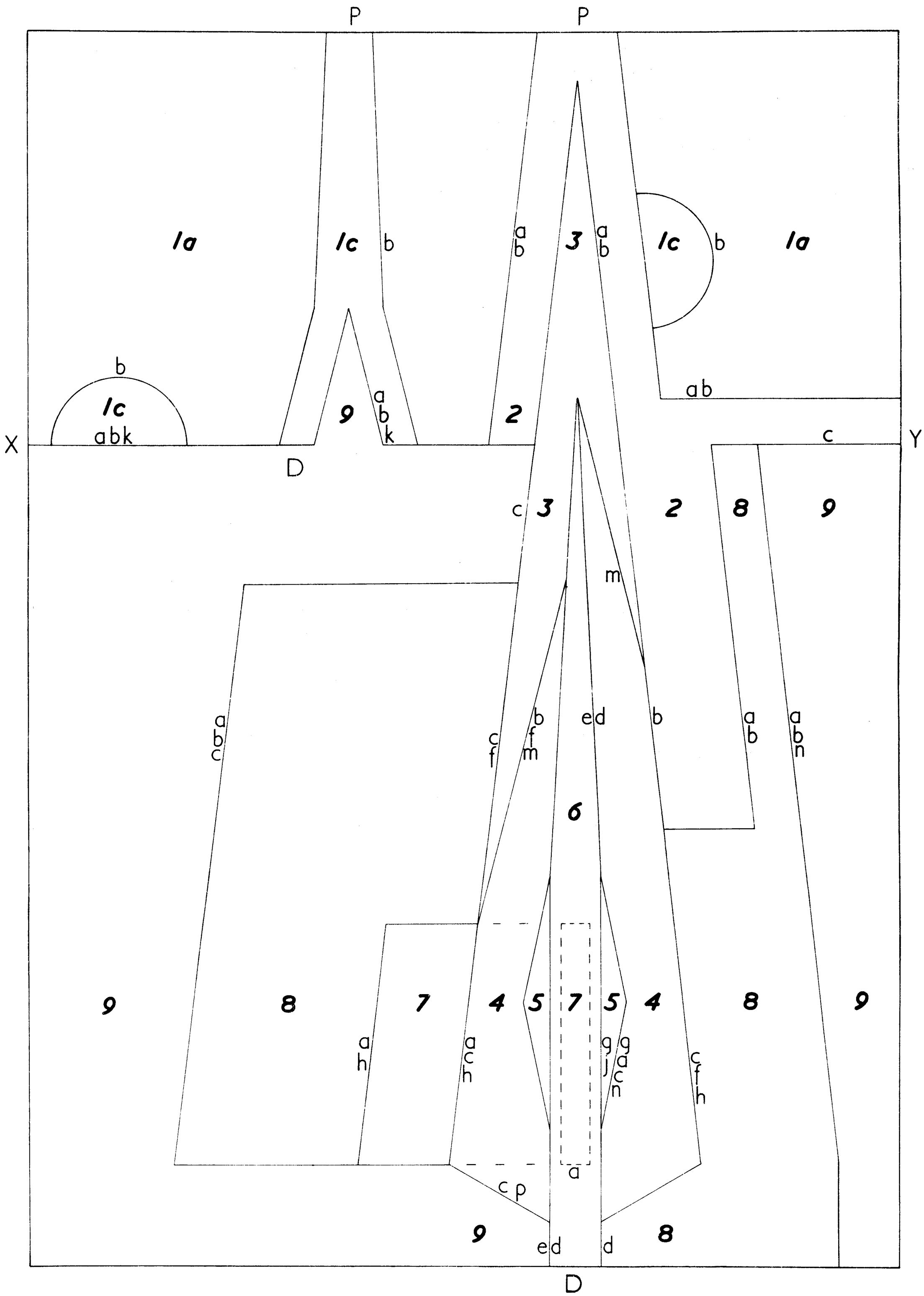
Over the last 15 years coal seam and seam-environment studies, by coal scientists and geologists working for the National Coal Board in the East Midlands, have yielded a detailed knowledge at 15 horizons. This work, together with the results of borehole sequence studies including relationships between and features common to adjacent facies, formed the basis for construction of Text-figure 4.

Cannel-belts as shown schematically on Text-figure 4 (top middle-left: 1c) are known in two seams, one of which appears on Text-figure 1. Cannel-pools associated with regional splits (Text-figure 4, left: 1c) occur at least at four horizons and those adjacent to linear clastic bodies (top-right 1c) are as described from the Top Hard seam (Elliott, 1965 b). Regional coal-seam splitting (Text-figure 4: X-Y) with at least several tens of square miles of contemporaneous clastics beyond are well-known at over ten horizons. Linear clastic facies are proved to interrupt a regional split (Text-figure 4, top-middle-right) at eight horizons, one of which is shown on Text-figure 1. A general lateral relationship of facies 3, 4 or 5 to "shoestrings" is known at about six levels.

Text-figure 3 The frequency and extent of splitting within coal seams in the East Midlands. This figure is diagrammatic and not to scale. Non-marine lamellibranch zones, coal seams and other horizons are named with upright letters. Each horizon line represents a coal bed, seat-earth or in a few cases one of these traced into a region where the horizon is represented by a faunal mudstone resting on a sandstone-siltstone facies. The more important economic coal seams appear in upper case: these together with some of the adjacent lesser seams are well known from ample data. All the lesser seams are in lower case and knowledge of those more separated from the major ones is imperfect; some splitting must remain undetected. Localities at which many of the splits are well known are named with sloping letters. Horizontally, the probable area over which each pair of adjacent coal beds is separated by other sediments is plotted as an approximate proportion of the whole coalfield, local splitting being confined to the right hand side and more widespread splitting being shown progressively further to the left. The union of seams outside Nottinghamshire and North Derbyshire, particularly to the south in the adjacent coalfields, is suggested on the extreme left. E = "Estheria" band, M = marine band, O.B. = "Kaolin" oolith band, C.T.S. = Calcareous tuffaceous siltstone, T = tonstein, D = coal bed with a prominent "dull" or durain-rich layer and S = coal bed with a significantly high sulphur content having a correlation value.


ZONES
BEYOND the COALFIELD
PERIPHERY of COALFIELD
The major part of THE NOTTINGHAMSHIRE and NORTH DERBYSHIRE COALFIELD
LOCAL SPLITS
LOWER SIMILIS—PULCHRA
MODIOLARIS
COMMUNIS
WARWICKSHIRE THICK COAL
RIDER OF SOUTH & MAIN DERBYSHIRE
MIDDLE LOUNT OF & NETHER LEICESTERSHIRE
MAIN BRIGHT
Warsop
Langwith
Two Foot
Low Bright
Cinderhill
Gedling
Low Bright floor coal
Gedling
Brinsley
HIGH HAZLES
Welbeck
Kents Thin
Warsop
KENTS THICK, Cinderhill and St Johns seams
Barnsley Rider or Main Smut
Upper Coombe
Lower Coombe
Welbeck
TOP HARD = BARNSLEY
Woodside
Bilsthorpe
Low Barnsley
Harworth
Bildworth
Bildworth
DUNSIL
Glapwell
Ollerton
FIRST WATERLOO
Glapwell
Teversal
MARKHAM
Wollaton
2nd Waterloo
Westthorpe
Arkwright
Williamthorpe
Bevercotes
Third Waterloo
Fourth Waterloo
O.B
FIRST ELL
Grassmoor
Second Ell
Markham
Joan
Brown Rake
C.T.S.
Black Rake
Chavery
Top Soft
Williamthorpe
Westthorpe
Roof Soft
Clifton
DEEP SOFT
New Hucknall
Shirebrook
Floor Soft
DEEP HARD
Williamthorpe
Pleasley
Sherwood
Ireland
PARKGATE
First Piper
Denby Hall
Grassmoor
Second Piper
Hospital
Tupton roof coal
Cockleshell
Williamthorpe
TUPTON
Low Tupton
Clipstone
Gedling
Threequarters
Denby Hall
Yard
Hucknall
SILKSTONE
Brookhill
Pye Hill
BLACKSHALE
Tinkers

Text-figure 4. The relationships of East Midland productive coal measures facies in schematic map form (not to scale, proportions distorted). The bold sloping characters indicate areas of accumulation of the facies as labelled in the text: 1 = Coal facies; 2 = Seat-earth facies; 3 = Massive siltstone facies; 4 = Complex silt-sandstone facies; 5 = Layered sand-silt stone facies; 6 = Washout sandstone facies; 7 = Rippled sandstone facies; 8 = Flaser silt-sandstone facies; 9 = Faunal mudstone facies. The lower case letters refer to features associated with particular inter-facies boundaries; a = interfingering common; b = beds of intermediate character common; c = beds of intermediate character rare; d = erosional contact; e = derived clasts of recognisable origin from adjacent facies; f = deformed layers in both facies; g = diastems in both facies; h = small-scale cross-stratification in both facies; j = large-scale cross-stratification in both facies; k = similar body-fossils in both facies but with very different frequencies; m = exceptionally large plant remains in both facies; n = similar trace-fossils in both facies but with very different frequencies; p = rare *Pelecypodichnus* in coarser facies probably related to non-marine lamellibranchs in finer facies. P = proximal end of linear facies; D = distal end of linear facies, and X - Y = regional coal seam split.


P
P
1a
1c
b
a
b
3
a
b
1c
b
1a
b
1c
abk
9
a
b
k
2
ab
X
D
c
Y
c
3
2
8
9
m
a
b
c
c
f
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f
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ed
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h
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ed
d
8
D

From the theoretical sections of this address there emerges a workable re-definition of the term cyclothem, as far as it applies to productive coal measures:

A cyclothem is a volume of rock between two coal seat-earth horizons or laterally equivalent junctions between faunal mudstones and siltstones or sandstones. Where a boundary horizon is marked by a coal seat-earth succession the top of this hydrological succession should be taken as the strict boundary because this is frequently a sharp boundary and usually marks the most radical facies change. In plan view, such a cyclothem is limited by a regional split on the one side and the limit of recognition of top or bottom boundaries on the other; one or both being, sinuous and arcuate to enclose an area. Within the volume of such a cyclothem up to about 9 facies are recognisable and four sedimentation successions operate and interfere to produce a wide range of variation in vertical sections through the cyclothem. These successions are:

A) A hydrologically controlled succession: facies 2 ⟶ 1

B) An upwards developing clastic succession: facies 9 ⟶ 8 (with 7)

C) A washout-fill succession: facies 6 ⟶ 7 (or 8)

D) A laterally developing clastic succession: facies 3, 4 and 5.

So defined, as a volume and generated by these successions, many productive coal measures cyclothems are probably comparable with the sub-deltas of the Mississippi delta; others are more widespread.

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ALLEN, J.R.L. 1963. Henry Clifton Sorby and the sedimentary structures of sands and sandstones in relation to flow conditions. Geol. en Mijnbouw, vol. 42, pp. 223-228.

CALVER, M.A. 1955. Die stratigraphische Verbreitung der nicht-marinen Musheln in den penninishen Kohlenfeldern Englands. Z. deutsch. Geol. Ges, vol. 107, pp. 26-29.

COLLINSON, P.L. and ELLIOTT, R.E. 1960. Proving coal reserves in the Nottinghamshire and North Derbyshire Coalfield. Trans. Inst. Min. Eng., vol. 119, pp. 537-560.

DEANS, T. 1934-5. Some oolitic ironstones from the Coal Measures of Yorkshire. Trans. Leeds Geol. Ass., vol. 5, pp. 161-187.

DUFF, P. McL.D. and WALTON, E.K. 1962. Statistical basis for cyclothems; a quantitative study of the sedimentary succession in the East Pennine Coalfield. Sedimentology, vol. 1, pp. 235-255.

EDEN, R.A., STEVENSON, T.P. and EDWARDS, W. 1957. Geology of the country around Sheffield. Mem. Geol. Surv. Gt. Brit., 238 pp.

EDEN, R.A., ELLIOT , R.W., ELLIOTT, R.E. and YOUNG, B.R. 1963. Tonstein bands in the coalfields of the East Midlands. Geol. Mag. vol. 100, pp. 47-58.

EDWARDS, W.N. 1951. The concealed coalfield of Yorkshire and Nottinghamshire. Mem. Geol. Surv. Gt. Brit., 3rd edn., 285 pp.

EDWARDS, W. and STUBBLEFIELD, C.J. 1948. Marine bands and other faunal marker-horizons in relation to the sedimentary cycles of the Middle Coal Measures of Nottinghamshire and Derbyshire. Quart. J. Geol. Soc. Lond., vol. 103, pp. 209-260.

ELLIOTT, R.E. 1964. A classification of cross-stratification structures. Nature, vol. 202, pp. 451-452.

ELLIOTT, R.E. and STRAUSS, P.G. (in the press). A classification of coal measures rocks based on quartz content. 6th Int. Congr. Carb. Strat. and Geol., Sheffield 1967.

FRANCIS, E.H., SMART, J.G.O. and RAISBECK, D.E. (in the press). Westphalian volcanism at the horizon of the Black Rake in Derbyshire and Nottinghamshire. Proc. Yorks. Geol. Soc.

JESSEN, W. 1949. "Augenshiefer" - Grabgänge, ein Merkmal für Faunenshiefernähe im westfalischen Oberkarbon. Z. Deut. Geol. Ges., vol. 101, pp. 23-43.

MICHELAU, P. 1955. Belorhaphe kochi (Ludwig 1869), eine Wurmspur im europäishen Karbon. Geol. Jb., vol. 71, pp. 299-330.

MOORE, L.R. 1964. The microbiology, mineralogy and genesis of a tonstein. Proc. Yorks. Geol. Soc., vol. 34, pp. 235-291.

MOORE, R.C. 1962. Treatise on invertebrate paleontology, part W, Miscellanea. Geol. Soc. Amer. and Univ. Kansas, 259 pp.

REINECK, H.E. 1958. Wühlbau-Gefüge in Abhängigkeit von Sediment-Umlagerungen. Senckenbergiana Lethaea, vol. 39, pp. 1-23; 54-56.

RICHTER, Rudolf 1937. Marken und Spuren aus allen Zeiten. I. Wühl-Gefüge durch kotgefüllte Tunnel (Planolites montanus n. sp.) aus den Ober-Karbon der Ruhr. Senckenbergiana, vol. 19, pp. 151-159.

SCRUTON, P.G. 1955. Sediments of the Eastern Mississippi Delta. Soc. econ. Palaeontologists and Mineralogists, Spec. pub. No. 3, Finding Ancient Shorelines.

SEILACHER, Adolf 1953. Studien zur Palichnologie. II. Die fossilen Ruhespuren (Cubichnia). Neues Jahrb. Geol. Paläont., Abhandl., vol. 98, pp. 87-124.

SMITH, A.H.V. 1962. The palaeoecology of Carboniferous peats based on the miospores and petrology of bituminous coals. Proc. Yorks. Geol. Soc., vol. 33, pp. 423-474.

SMITH, A.H.V. and BUTTERWORTH, Mavis A. 1967. Miospores in the coal seams of the Carboniferous of Great Britain. Special papers in palaeontology No. 1, Palaeon. Assoc., London, 324 pp.

SMITH, E.G., RHYS, G.H. and EDEN, R.A. 1967. Geology of the country around Chesterfield, Matlock and Mansfield. Mem. Geol. Surv. Gt. Brit., 430 pp.

STRAUSS, P.G. (in the press). Kaolin-rich rocks in the East Midlands Coalfields of England. 6th Int. Congr. Carb. Strat. and Geol., Sheffield 1967.

TEICHMULLER, Rolf 1956. Ubër Küstenmoore der Gegenwart und die Moore des Ruhrkarbons. Ged. Landesanst., Geol. Jahrb., vol. 71, pp. 197-217.

WALKER, R.G. 1963. Distinctive types of ripple-drift cross-lamination. Sedimentology, vol. 2, pp. 173-188.

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CORRIGENDUM to ELLIOTT (1968)

p. 351: line 5: for '1967' read: 1968.
p. 352: Text-fig. 1: line 4 of caption: for 'First Pipe seat-earth' read: First Piper seat-earth.
p. 358: line 24: for 'Eden et alia (1963)' read: Eden et alia (1957).
p. 359: line 31: for 'Rarely is coal' read: Rarely is a coal.
p. 365: line 33: for 'coal seam' read: coal seams.
p. 371: insert:

ELLIOTT, R.E. 1965a. A classification of subaqueous sedimentary structures based on rheological and kinematical parameters. Sedimentology, vol. 5, pp. 193-209.

1965b. Swilleys in the Coal Measures of Nottinghamshire interpreted as palaeo-river courses. Mercian Geologist, vol. 1, pp. 133-142.

Plate 18: caption 'A' refers to left-hand illustration and caption 'B' refers to right-hand illustration.

[From *Mercian Geologist*, August 1969, vol. 3, no. 2, p. 135]