DELTAIC PROCESSES AND EPISODES:
THE INTERPRETATION OF PRODUCTIVE COAL MEASURES
OCCURRING IN THE EAST MIDLANDS, GREAT BRITAIN

Fourth Presidential Address to the East Midlands Geological Society, February, 1969

by

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Summary

A review of the history of cyclothem generation theory, as applied to coal-bearing sequences, is concluded by emphasising the amateur work of Strickland (1940) on the Ganges delta. Nine productive coal measures facies, described in the preceding address, are compared with the essential features of deposits accumulating in a similar number of environments within vegetated deltas. Gradients of coal-seam splits are compared with the thickness of coal lying immediately beneath the split-strata; variation is attributed to penecontemporaneous compaction, and model-sections illustrating infra-intradeltaic compaction and water depths are discussed. The inevitable relaxation of deltaic processes during the ageing of a sub-delta is then described in detail. Evidence relating to continual debouching of parent rivers, impermanent distributary banks and random sediment distribution upon a deltaic plain is enlisted to derive a new episodal concept replacing the traditional cyclic concept. An artificial random sequence of prodeltaic-interdistributary, intradistributary, and swamp deposits is compared with two actual borehole sequences. Eight phenomena, including episodal deposition, sedimentation successions, and random superposition of deposits from these three environment-groups, are listed as contributing towards the accumulation of East Midland productive coal measures sequences located in non-peripheral parts of the basin of deposition. Two maps are presented illustrating distributaries traversing at least twenty to thirty miles.

A history of cyclothem genesis theory

It has been widely appreciated for well over a century that thick sequences of sedimentary rocks usually require long continued subsidence to accommodate them during deposition, and that the depth of this subsidence is approximately equal to the undisturbed thickness of the rocks, as now observed. As soon as evidence for shallow water deposition was accepted, including that of stratified coal seams overlying stigmarian roots in clastic rocks, a concept of continuous "topping-up" of the sedimentary pile was established. Belief in the in-situ origin of some coal seams, as opposed to a drifted origin, was expressed in the nineteenth century, but this theory did not become generally accepted as the mode of origin of most British carboniferous coals until the first or second decade of the present century. At about the same time interest began to develop in the details of coal-measure sedimentation using a generalised rhythmic or cyclic repetition of lithologies as a convenient basis for discussion. Such interest was exercised in both America and Europe.

Because coal measures sequences often contain reiterations of coal, seat-earth, sandstone and finer grained fossiliferous beds, many authors were of the opinion that these rocks accumulated in water of varying depths, and debate on this variation ensued. The great majority of authors (Duff et al., 1967, table XXVII) seeking to explain the origin of coal-bearing cycles or rhythms, have referred the supposed variation of water depth to either fluctuating rates of subsidence or to subsidence, fluctuating or otherwise, supplemented by eustatic changes of sea-level. These eustatic changes have in turn been referred to tectonic or geodetic origins and also to climatic cycles, especially those controlled through glaciation. All these theories are conditioned by a principal theme, that of varying the depth of water within which the sediments were deposited, and enlisted little or no attention to lateral variations within the Coal Measures; though such do exist (Elliott, 1968).

Although the water-depth based theories have been revived, with modifications or embellishments, in important papers right up to the present decade, there has been a marked tendency in the last twenty years for a sedimentological approach to develop (Duff et al., 1967, table XXVII). This evolution of thought has been contemporaneous with considerable advances in the science of sedimentology and especially with studies of the growth of modern deltas. One aspect has been a greater appreciation of the importance of lateral facies changes and a realisation that there is a much less reliable indication of relative water-depth from the evidence of clastic rocks and their fossil content alone than was previously supposed. Investigations of modern environments have shown that rock-type variations are just as likely to be due to contemporaneous lateral changes in current strength, sediment load, salinity or pH value as due to water-depth, and that many if not all of these parameters are interdependent to some degree. Goodlet (1959, pp. 232-233) and Calver(1968) have recently referred variations of faunas in Carboniferous cyclic deposits to lateral changes.

Authors promoting a sedimentological approach to the origin of coal measures sequences have laid varying emphasis on factors controlling the disposition or extent of basins of deposition and on others likely to cause a cessation or slowing down of plant growth or of peat accumulation. Robertson (1948) suggested that sand-bars may have kept marine waters from invading Carboniferous swamps and likewise modern distributory levees subdivide a deltaic plain into distinct basins within which the processes of clastic, including floriclastic, accumulation are active to infinitely varying degrees. Furthermore, distributary bank crevassing, leading to "delta-switching" and sub-delta development (Scruton, 1955), as Moore (1958), Goodlet (1959) and Coleman and Gagliano (1964) have suggested, forms a mechanism contributing to the localisation of cyclothem deposition. The efficacy of coal-bearing cyclothem deposition in maintaining the 'topped-up' condition of the basin of sedimentation has been emphasised during the last two decades by several studies which show that, in some cases at least, there are proportionally more cyclothems in the thicker sequences towards the basin centre than in the thinner sequences nearer the basin edge. Duff and Walton (1964) established that there is a high positive correlation between these two variables in the Modiolaris zone of the East Pennine Coalfield.

The cessation of swamp vegetation growth and hence coal-peat accumulation has been attributed to several factors which might adversely affect conditions of plant growth; thus, sand-barriers may break down and give rise to flooding by marine waters (Robertson, 1948) or fresh water flooding may follow severe levee crevassing. Thiadens and Haites (1944) suggested that subsidence arising from the compaction of peat could be accelerated by deposition of clastics from temporary floods and thereby significantly increase swamp water depth and end vegetation growth. Also, climatic and edaphic changes, perhaps causally linked and involving an increased severity of fungal and bacterial attack on both living and dead vegetation, might determine the end of swamp peat accumulation.

When considering this problem of the origin of cyclothems in general terms, subsidence must be assumed to accommodate sediments below base level and, in the first analysis at least, it is convenient to assume a more or less uniform rate of subsidence. Then, as Delmer (1952) did, it is sufficient to demonstrate that cyclothems are generated if a periodic process, an auto-entertained oscillation of relaxation, is superimposed upon the uniform subsidence. Duff et al. (1967) in their summary remarks take the view that after localisation of deposition by "delta-switching", edaphic changes triggered-off unstable plant-growth conditions at a late stage in the deposition of that cyclothem, thus leading to the cessation of peat accumulation. Any of the factors mentioned in the previous paragraph may have contributed to this end.

Strickland (1940), a doctor of medicine, who studied the Ganges Delta, appreciated that deltaic processes relaxed as the delta 'aged', giving rise to a reduced topographic relief and a more sluggish drainage system. He reported the considerable frequency of distributary channel changes by crevassing and other means. He also knew of sub-delta formation at changing locations and how jungle vegetation covers old silted-up river courses. His book also contains topographic and hydrographic data and refers to the effects of floods, tides and subsidence. Strickland observed many processes having a direct bearing on the generation of cyclothems as now envisaged in modern theories involving sensibly uniform subsidence and the relaxation of deltaic processes. This work was necessarily independent, and it pre-dated the modern sedimentological approach; as such it is invaluable, but he unfortunately remains little known to the sedimentologists of today.

It is against this historical background that any interpretation of the origin of East Midland productive coal measures must proceed.

Environments of deposition

In the previous address to this society (Elliott, 1968) ten sedimentary facies from the East Midlands coal measures were described in some detail. They are listed again in Table 1, together with suggested environments of origin.

The interpretations of facies 1 and 2 in particular are adequately summarised in Elliott (1968) from previous literature. Environments of origin of facies 3 to 9 inclusive must be considered in relation to reviews of modern delta studies (Shirley and Ragsdale, 1966; Van Straaten, 1960) and especially in relation to the accumulated knowledge of the Mississippi delta (Fisk et al., 1954; Coleman, Gagliano and Webb, 1964, and Coleman and Gagliano, 1965). From these five works and others it is feasible to establish a general concept of the elemental processes that are essential to the growth of any large vegetated sub-delta. Those significant factors appertaining to the more active parts of a delta and relevant to this discussion are presented in precis on text-fig. 1a. They are there referred to environments of deposition which are linked by sediment flow lines.

A strong current, confined to a distributary channel, floods outwards towards environments of vertical sedimentation by one of three routes across a zone in which there occurs an abrupt decrease in sediment-carrying capacity. This decrease is related to the current fanning-out over a subaerial levee bank, a subaqueous levee bank or a mouth bar. The seven environments of text-fig. 1a each yield characteristic sedimentary structure assemblages due to varied factors essential to these flood paths. The important elements of these assemblages are compared in Table II, with appropriate features of coal measure facies 3 to 9. Only those sedimentary structures or features that are judged to be strongly related to the generalised delta flow pattern and topography should be considered.

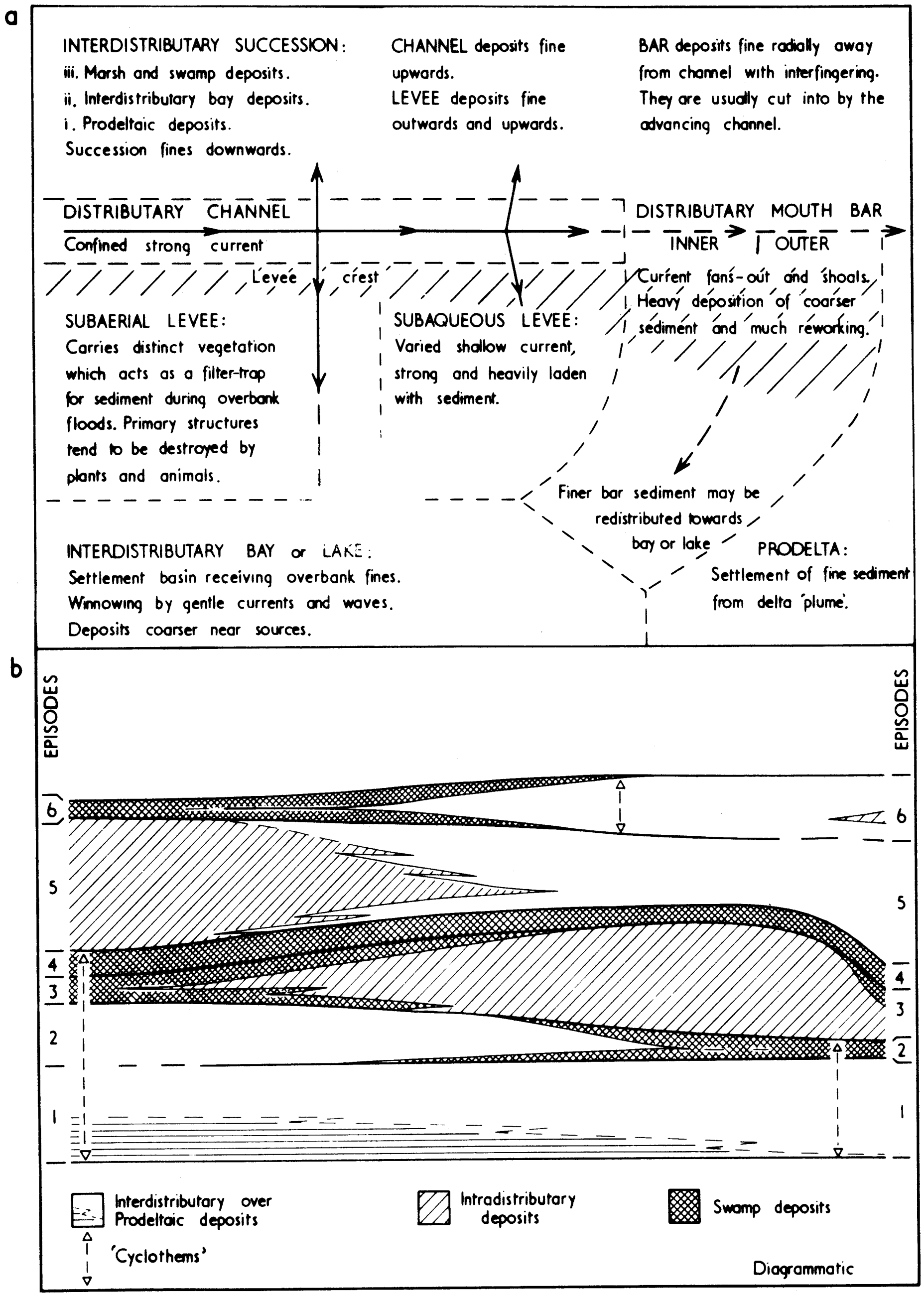

a
INTERDISTRIBUTARY SUCCESSION:
iii. Marsh and swamp deposits.
ii. Interdistributary bay deposits.
i. Prodeltaic deposits.
Succession fines downwards.
CHANNEL deposits fine upwards.
LEVEE deposits fine outwards and upwards.
BAR deposits fine radially away from channel with interfingering.
They are usually cut into by the advancing channel.
DISTRIBUTARY CHANNEL
Confined strong current
DISTRIBUTARY MOUTH BAR
INNER
OUTER
Levee
crest
Current fans-out and shoals.
Heavy deposition of coarser sediment and much reworking.
SUBAERIAL LEVEE:
Carries distinct vegetation which acts as a filter-trap for sediment during overbank floods. Primary structures tend to be destroyed by plants and animals.
SUBAQUEOUS LEVEE:
Varied shallow current, strong and heavily laden with sediment.
Finer bar sediment may be redistributed towards bay or lake
INTERDISTRIBUTARY BAY or LAKE:
Settlement basin receiving overbank fines.
Winnowing by gentle currents and waves.
Deposits coarser near sources.
PRODELTA:
Settlement of fine sediment from delta 'plume'.
b
EPISODES
EPISODES
6
5
4
3
2
1
Interdistributary over Prodeltaic deposits
Intradistributary deposits
Swamp deposits
'Cyclothems'
Diagrammatic

Fig. 1.

TABLE I

	Coal measure facies	Environments of origin
1.	Coals:	
	a) Macrolithic coals.	Anaerobic swamps.
	b) Microlithic coals, durite dominant.	Swamps with some degree of selective decomposition.
	c) Microlithic coals, cannel coals.	Stagnant water lakes.
2.	Seat-earths:	Hydromorphic soils.
	a) Grey with sideritic nodules.	Submerged; negligible drainage.
	b) Brown with sphaerosiderite.	Periodic emergence.
	c) Red spotted seat-earths.	Periodic emergence; some drainage.
3.	Massive siltstones:	Subaerial levees; possibly with some channel fills.
4.	Complex silt-sandstones:	Subaqueous levees.
5.	Layered sand-siltstones:	Inner distributary mouth-bars.
6.	Washout sandstones:	Distributary channel fills.
7.	Rippled sandstones:	Outer distributary mouth-bars.
8.	Flaser silt-sandstones:	Interdistributary bays (or lakes).
9.	Faunal mudstones:	Prodeltaic deposits.
	a) Marine mudstones.	
	b) Trace-fossil mudstones.	
	c) Non-marine lamellibranch mudstones.	
	d) Others including dark or carbonaceous fissile mudstones.	
10.	Miscellaneous rocks:	
	Tonsteins; 'kaolin oolith bands'; and tuffaceous siltstone.	

The rank vegetation generally accepted to have been present in coal swamps may have been paralleled by relatively lush vegetation on distributary levee banks. Disturbance by the roots of this vegetation probally helps to account for the scarcity of lamination in the massive siltstones. The literature indicates that comparable subaerial levee deposits are in the minority on the distal parts of the Mississippi delta and subaerial levees with prominent wavy lamination are more frequent. Wavy laminated sandy siltstones are present in the East Midlands coal measure sequence but they only form a very small percentage of all rocks and tend to occur outside the stratigraphical range covered by this and the previous address.

The same lush levee vegetation could have reduced the frequency of river bank collapse. This might explain the absence of collapse structures in the washout sandstones, although some

TABLE II

Mississippi sub-delta deposits and East Midland productive coal measures facies

Modern deposits and their salient features	Features of Productive coal measures facies selected from Elliott (1968)
Distributary channel fill: Mainly sands are preserved. Confined to a channel. Linguoid and straight dune-sets.	Washout sandstones: Fine to medium-grained sandstones. Ribbon-geometry; channel base. Dune-sets up to several feet thick.
Sub-aerial levee deposits: Support woody plants. Finer grade than contemporary channel sediments. Primary structures tend to be destroyed by plants and animals. Ferric nodules up to over 2 cms. dia. Shrinkage cracks. Distinctive vegetation.	Massive siltstones: Entombed vertical and oblique trunks and branches. Siltstones, sometimes with muddy layers. Relatively structureless sediments. Ferruginous patches. Small-scale soft-sediment faults. Pinnularian roots are almost confined to this facies. Fronds of fern-like genera are more common than in any other facies.
Sub-aqueous levee deposits: Finer grade than contemporary channel sediments. Overlie or grade laterally into bar deposits. Ripple-drift and other complex cross-lamination structures. Scattered burrows.	Complex silt-sandstones: Siltstones with subordinate fine sandstone. Pass into layered sand-siltstones and rippled sandstones. Often overlie faunal mudstones. Ripple-drift and "Train drift" are characteristic. Varied burrows; usually infrequent.
Inter-distributary bay (or lake) deposits: Usually overlie prodeltaic deposits. Highly plastic clays Even parallel laminae. Contain sand lenses up to a few centimetres wide; flaser structure. Lenses reveal wave and current ripple marks. Undifferentiated contorted structures.	Flaser silt-sandstones: Usually overlie faunal mudstones. Vertical transposition structures indicate original hydroplastic clays. Even parallel, laminae where not disturbed. Very fine sandstone lenses; exactly comparable flaser structure. Symmetrical and asymmetrical ripple marks. Vertical transposition structures; sometimes with crumpled bedding.
Inner distributary mouth-bar: Sediment grade comparable with channel. Diastems. Linguoid dune-sets. Gas-heave structures.	Layered sand-siltstones: Sandstone with subordinate siltstone. Diastems. Low-angle cross-stratification within certain layers; truncated. Very rare gas-heave structures.
Outer distributary mouth-bar: Sediment grade comparable with channel. Linguoid and straighter ripple-sets. Interbedded with silts. Sands increasingly dominant towards mouth.	Rippled Sandstones: Sandstone, fine. Linguoid ripple-sets. Often intercalated with flaser silt-sandstones. Thicker beds are often associated with washout sandstones.
Prodeltaic deposits (including those in large lakes): Clays or clayey silts. Even parallel, grade or colour laminae. Up to 100 laminae per inch. Fossiliferous.	Faunal mudstones: Claystones or fine siltstones. Silt grade or light and dark, even parallel laminae. Sometimes very finely laminated. Body and/or trace fossils.

breccio-conglomerates may represent the product of such collapses. Structures due to bank collapse are found in distributary channel fills of the Mississippi delta. Channel fills composed of siltstones probably occur in the East Midlands coal measures as in the Mississippi delta, but no means of separately diagnosing such a facies has as yet been recognised, and some may be included under Massive Siltstones. Mudstones with abundant coal laminae, macrolithic coals and cannel coals occupy chanels known locally as 'swilleys', that is of the type described by Elliott (1965) and also lesser channel-like ribbons (Elliott, 1968, text-fig. 1).

A facies of coal-bearing strata similar to the flaser silt-sandstones has been interpreted by Hemingway (1968) as representing tidal-flat deposits comparable with those of the Wadden Sea. The particular measures considered here lack recognisable tidal-channel structures, and being associated with other deltaic facies, are considered to be interdistributary. Other measures with similar characteristics, but with considerably more trace-fossils and occurring in coal measures with marine bands, could well have a tidal-flat origin.

Faunal mudstones are here equated with prodeltaic deposits; this interpretation is intended in the broadest possible sense. Prodeltaic deposits are here assumed to include all vertically sedimented fines beyond sands and silts accumulated under the influence of deltaic traction currents, whatever the size of the sub-delta concerned. Smaller deltas may develop 'upon the backs of' larger deltas, they may advance into an interdistributary bay or large lake which owes its existence to a larger delta. Thus there can be a hierarchy of deltas and therefore also of some of their respective environments of deposition.

Factors such as water depth, light penetration and salinity must play a part in determining the sub-facies deposited, and each of these factors is likely to be dependent upon situation with respect to the main delta. The smaller and more remote a prodeltaic environment is from the larger expanses of open water, the smaller the number of animal species it is likely to support and the greater is likely to be the importance of organic matter of plant origin in its bottom sediments. Marine mudstones, trace-fossil mudstones, non-marine lamellibranch mudstones, dark or carbonaceous fossil mudstones, canneloid shales and cannel coals appear to represent such a range of sub-facies.

The first nine facies of Table 1 are grouped together in later parts of of this address to form the deposits of three major environments: coal and seat-earths are referred to as "swamp deposits"; washout sandstones, complex silt-sandstones, massive siltstones, layered sand-siltstones and rippled sandstones are referred to as "intradeltaic deposits", and flaser silt-sandstones and faunal mudstones are grouped as "prodeltaic-interdeltaic deposits".

Many coal seams in the East Midlands can be subdivided into leaves of coal (Elliott, 1968, text-fig. 3) and the horizons of the intervening seam splits can be traced within composite seams over major parts of the coalfield, but rarely over the whole field. The mudstone intercalated with the seam in the zone of splitting can usually be traced as a thin wedge for some miles (text-fig. 6) and may pass laterally into a subsection of the seam relatively high in ash content. Alternatively or in addition, the split-horizon may be traceable as the top of a subsection high in sulphur; such features may persist over some tens of square miles. Still further afield from the actual split, the horizon may sometimes be recognised within coal-type (sub-facies) sequences, and generally speaking united seams are significantly thicker than the sum of their constituent leaves measured in the split regions. The additional coal sometimes passes into the split strata as a coal-finger, or occasionally may be seen to intercalate on a small scale with the split strata (for example: Elliott, 1965, p. 134, and text-fig. 2). For these and other reasons developed later in this account, extensive coal swamps are here considered to have existed contemporaneously with intradeltaic and prodeltaic-interdeltaic environments.

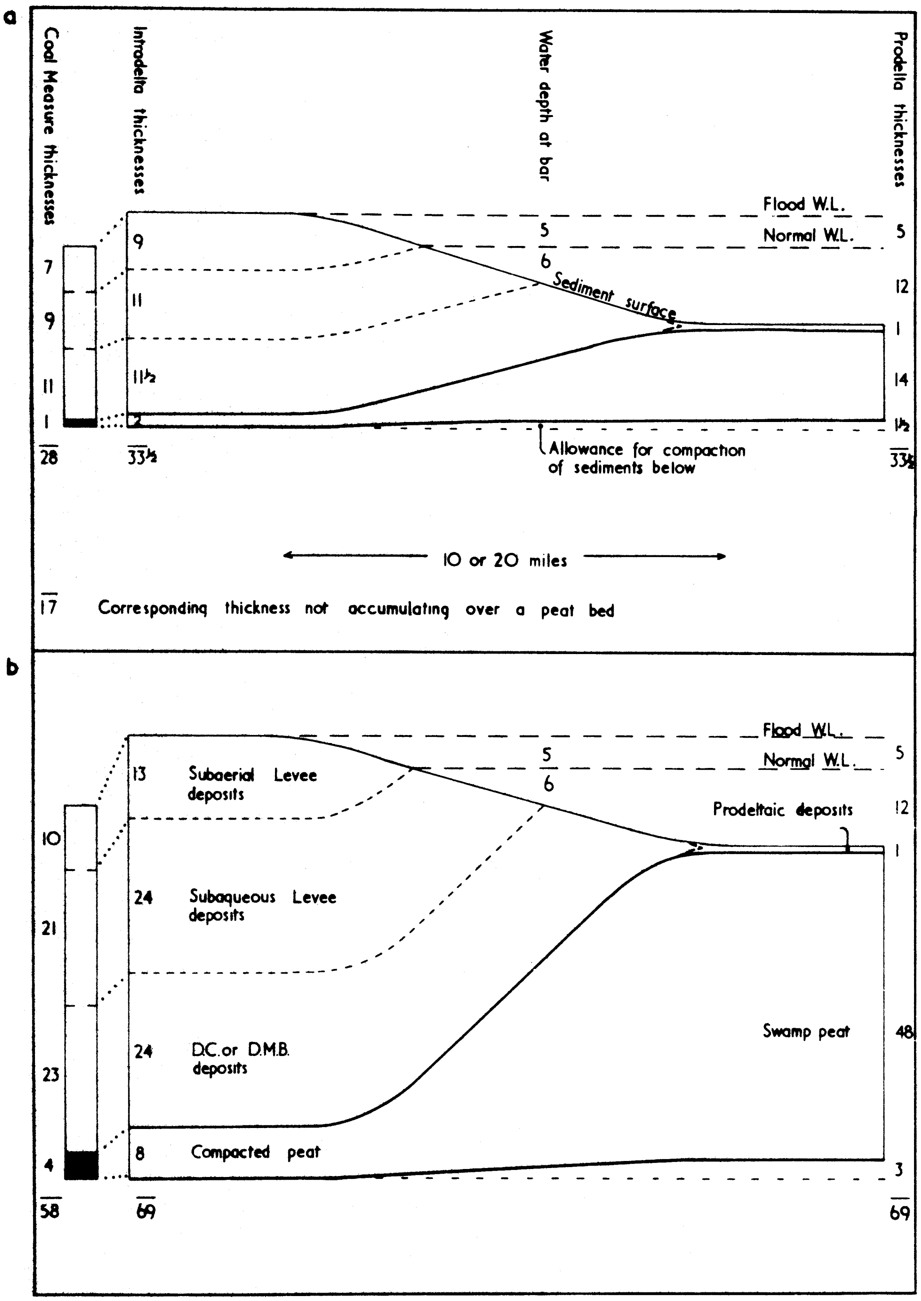

a
Coal Measure thicknesses
Intradelta thicknesses
Water depth at bar
Prodelta thicknesses
Flood W.L.
Normal W.L.
Sediment surface
7
9
11
1
28
9
11
11½
2
33½
5
6
5
12
1
14
1½
33½
Allowance for compaction of sediments below
10 or 20 miles
17 Corresponding thickness not accumulating over a peat bed
b
Flood W.L.
Normal W.L.
Subaerial Levee deposits
Subaqueous Levee deposits
D.C. or D.M.B. deposits
Compacted peat
Prodeltaic deposits
Swamp peat
10
21
23
4
58
13
24
24
8
69
5
6
5
12
1
48
3
69

Fig. 2.

Infra-intradeltaic compaction and water depths

On text-fig. 6 and in the appendix to this address, detail of coal-seam split gradients is presented and discussed. In general, splits overlying thick coal beds open-out at a greater rate of change of gradient than splits overlying thin coal beds. It is concluded that the sediment within the splits was probably deposited upon peat contemporaneously with the growth of swamp vegetation and that this initiated marked compaction of the peat.

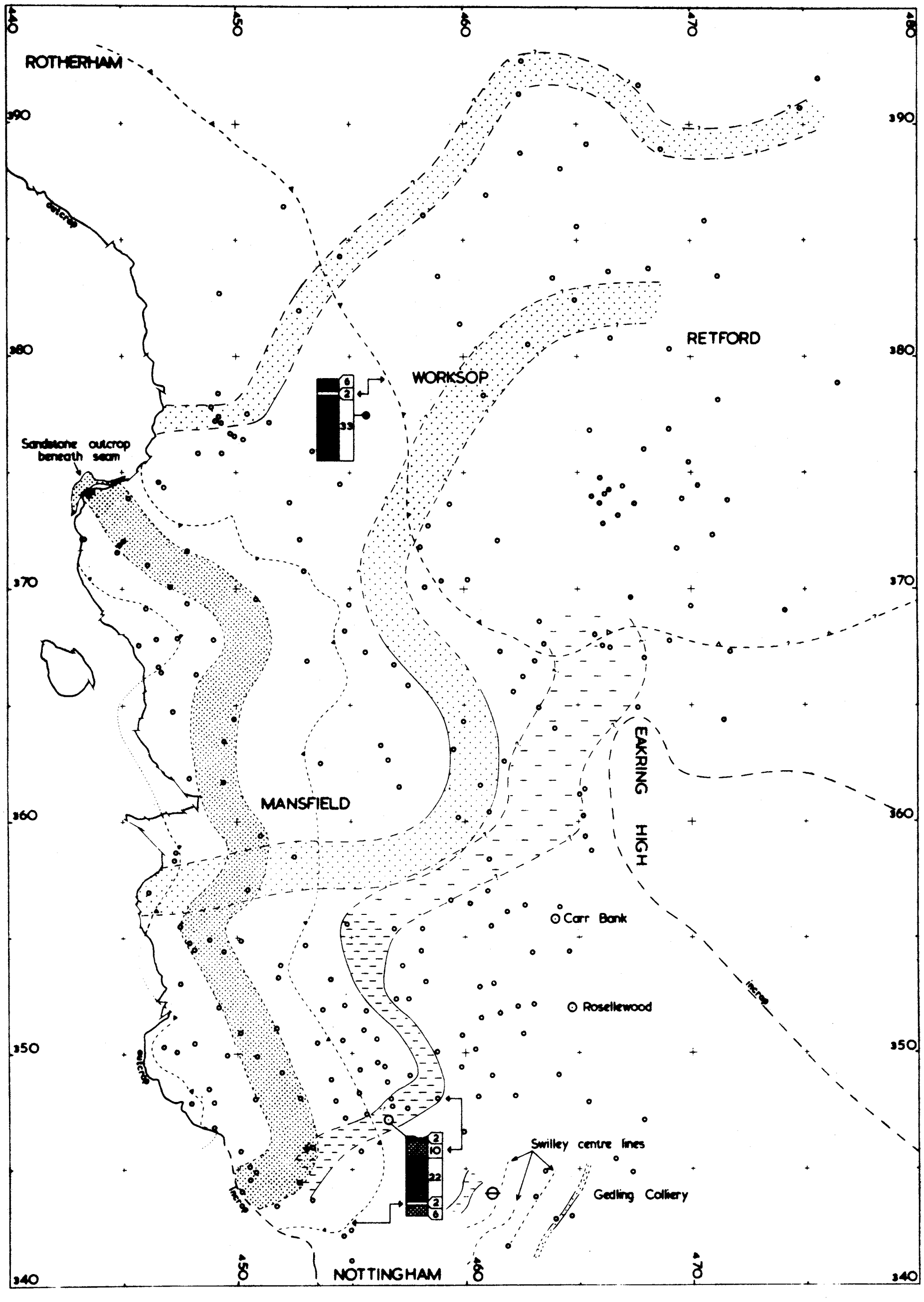
The likely compaction of peat under the weight of intradeltaic deposits is diagrammatically illustrated in text-figs. 2a and 2b. Furthermore the compact nature of peat from the base of thick modern peat beds is the result of consolidation in response to the weight of peat itself; such auto-compaction is likely to be minimal, however, in the case of subaqueous or thoroughly water-logged peats. Up to 90% of water may be present in young surface peat bringing its specific gravity to very near unity. A study of densities and water contents led Ashley (1907) to conclude that deeply buried peat assumed a thickness of about 1/10th of its original thickness, but he was not concerned with water and gases entrapped in the peat by a covering of muddy sediment or with peat which remained below water level.

Ashley continued to calculate from analyses, reduction in thickness associated with the physico-chemical transformation of compacted peat into coal and deduced a ratio of 3 to 1. He recommended further study of the relationship of coal thickness to original topography. By means of this latter method Elliott (1965) deduces a compaction-ratio of 12 to 1 between a thick coal-swamp peat and bituminous coal. A 1/12th reduction is assumed for the overall compaction of the thick peat in text-fig. 2b but, taking some account of relatively greater auto-compaction of the lower layers of a thick peat, an overall compaction of 1/14th is assumed for the compaction of the thinner peat of text-fig. 2a.

The base of the larger natural levees in the Mississippi delta subsides to about 20 ft. below mean sea level as a result of compaction, and it is assumed in the construction of the text-figs. the weight of thick intradeltaic sediments will compress peat to a significantly greater degree than that due to auto-compaction. Supporting this argument the author has seen material with a lignitic appearance in marsh deposits exhumed by local erosion of high dunes on Scolt Head Island, Norfolk. Repeating Ashley's calculation for the transformation of peat/lignite to bituminous coal, of comparable rank to that of the East Midlands, gives a ratio nearer to the 2 to 1 utilised in text-figs. 2a and 2b.

The heights of normal and flood water levels in a main distributary channel, indicated on the diagrams under discussion, relative to lateral and prodeltaic water levels, are taken as comparable to those operating in active Mississippi sub-deltas. The very gradual increase in height of flood water level upstream within such a sub-delta (1 in 20,000, say) is not significant to the present discussion.

An approximate check on the total compacted thickness of peat and intradeltaic deposits in a model constructed as above, is possible by making a comparison with maximum thicknesses of actual coal measure cyclothems developed within nearby seam splits. Such maximum thicknesses, composed of facies representing intradeltaic deposits, range from about 20 ft up to 60 ft. Thicknesses of palaeo-levees around 20 to 25 ft. are listed by Elliott (1965, table 1) from above a coal bed less than one foot thick. Sections of 60 ft., or rather less, are known at several localities where sandstones and siltstones occur above a 4-ft. Blackshale seam in the vicinity of Markham Colliery (text-fig. 4). These measures are overlain by another leaf of coal with characteristics strongly suggesting correlation with the top bed of a united Silkstone seam (Elliott, 1968, fig. 3) one mile to the north-west. Many other examples, usually involving



440
450
460
470
480
ROTHERHAM
390
380
370
360
350
340
outcrop
Sandstone outcrop beneath seam
RETFORD
WORKSOP
6
2
33
MANSFIELD
EAKRING HIGH
Carr Bank
Rosellewood
Swilley centre lines
Gedling Colliery
2
10
22
2
6
NOTTINGHAM

Fig. 3.

intermediate thicknesses, are known. Equivalent coal measure thicknesses are suggested on the left of text-figures 2a and 2b allowing for slight compaction of coarse clastics and somewhat greater compaction of muddy siltstones near the top of the successions. These adjusted sections, derived from the models, compare favourably with the actual coal measure sections quoted above, thereby establishing the approximate check referred to.

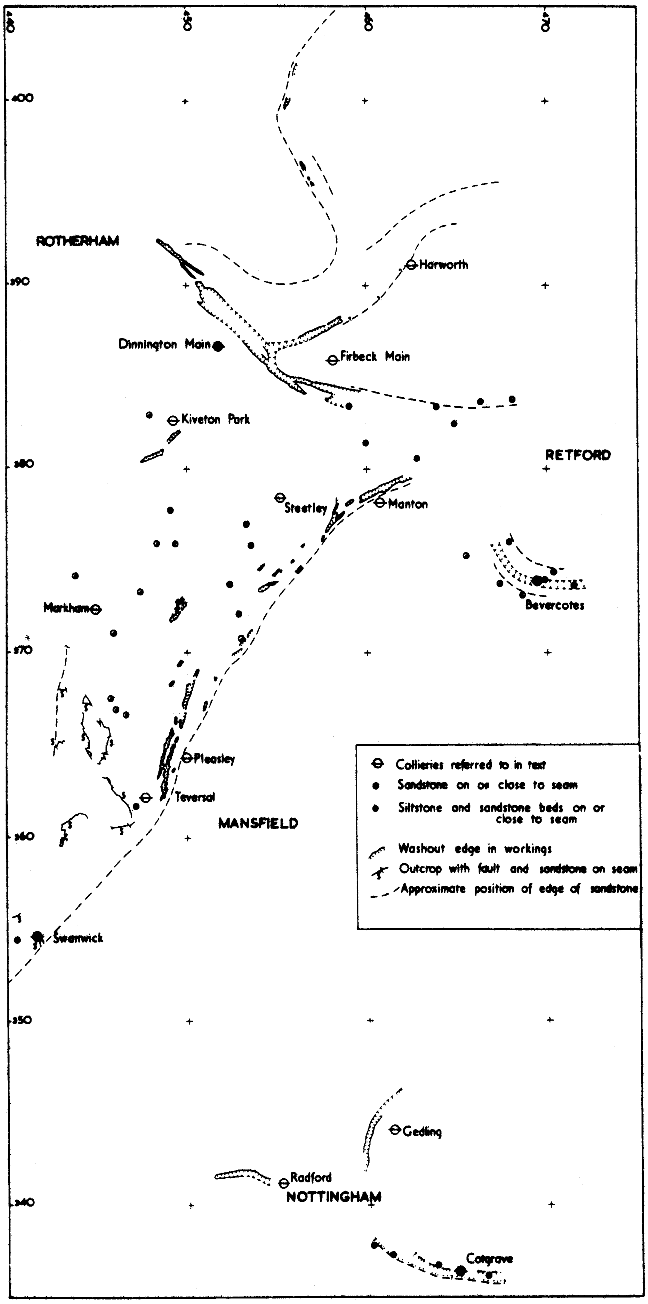
The variation in roof and floor coal split gradients (text-fig. 6 and the appendix) supports the hypothesis that the thickness of intradeltaic sediments varies with underlying seam thickness. Other factors, such as the rate of epeirogenetic subsidence between the time of accumulation of one seam and the next or variation in the compactibility of sediments in the underlying cyclothem, are likely to affect water depths within limits. These are probably relatively small because limits are set by the sedimentation requirements of continued levee building for distributary survival and the maximum contemporaneous peat accumulation rate possible beyond the cyclothem (sub-delta) seam-split boundaries.

The succession of deposits indicated in the models includes a full range of intradeltaic facies in a likely order. Variation upon this order and upon the number of facies present in any one vertical record could be affected by changing water depths, especially regarding subaerial and subaqueous levee deposits, but is more likely to be accounted for by geographical position relative to distributary axes and the relative importance of each distributary as a drainage channel during its active life.

The relaxation of deltaic processes

Levee banks subside due to the compaction of underlying peat and to a minor extent because of regional tectonic subsidence. Such levees are moreover increased in height at any one locality because the channel mean water level, with respect to the mean water level of the pro-deltaic water body, rises as the sub-delta advances. If the stream is to remain confined to its channel, deposition on the levee from flood waters must keep pace with the algebraic sum of these three factors. Assuming the inner and outer slopes of a levee remain essentially constant (or flatten) during its functional life, the greater the height to which the levee is built, the greater is the volume of sediment required to add a height increment. Yet at the same time, as the sub-delta ages, progressively less sediment is available for levee accretion, and Strickland (1940) discusses in some detail reasons for a decreasing volume of sediment available for this purpose. He points out that as a delta advances there is an increase in the area of distribution of sediment and hence a volume decrease at any one locality. Also, he reminds us of an increase in sub-surface drainage by seepage; certainly there is likely to be increased seepage through levees and hence a reduction in water available to carry sediment over their summits.

Levee growth therefore requires an increasing sediment volume for geometrical reasons and yet is starved progressively more and more for largely distributive reasons. At some stage in the history of the levee, accretion fails to meet the requirements of subsidence, flooding is likely to increase eventually causing erosion to dominate over accretion, and this reversal may be accelerated by associated failure of levee vegetation in places and by an increased frequency of crevassing. Once these destructive processes are well under way delta-building processes are finally relaxed in the sub-delta concerned. Other smaller deltas one stage further down the heirarchy may be fed from the crevasses but are shorter lived than their parents, because as the old distributary levees subside towards the mean water level of prodeltaic waters the hydrological fall necessary for crevassing is eliminated. The area throughout which this occurs is deprived of efficient sediment transport arteries and all distributary channels are likely to become infilled by coarse or fine, mineral or vegetable, clastics.



440
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ROTHERHAM
Harworth
Dinnington Main
Firbeck Main
Kiveton Park
RETFORD
Steetley
Manton
Bevercotes
Markham
Pleasley
Teversal
MANSFIELD
Swanwick
Gedling
Radford
NOTTINGHAM
Cotgrave
Collieries referred to in text
Sandstone on or close to seam
Siltstone and sandstone beds on or close to seam
Washout edge in workings
Outcrop with fault and sandstone on seam
Approximate position of edge of sandstone

Fig. 4.

Whether or not peat accumulation completes the relaxation of deltaic sedimentation is likely to depend upon a slow rate of regional subsidence and the extent to which waning sediment transport is able to prepare a surface of very low topographic relief below water only a very few feet deep and hence suitable for invasion by swamp vegetation. In the final stages of swamp establishment shallow hollows appear to have been filled either by organic muds, now represented by cannel lenses (Elliott, 1965); or by muds with abundant plant fragments, probably floated into position and now represented by numerous coal laminae or lenticles set in mudstone, that is "branch" or "bat" in the still convenient local miner's terminology. Cannels and "bats" are common, for example, below the Deep Hard and Top Hard seams in Nottinghamshire and Derbyshire.

When distributive deltaic processes became completely relaxed virtual stagnation probably gave rise to toxic waters arresting microbic and fungal activity and allowing the preservation of peat, later to become macrolithic coal. This stage probably continued whilst the rate of regional subsidence was less than the rate of accumulation of peat. At a still later stage the peat surface may eventually have risen above an anaerobic level to a periodic or partial aerobic level, probably giving rise to microlithic coals dominated by durite.

The best available estimate of the time taken for Westphalian B to accumulate is 15 to 20 million years (Francis and Woodland, 1964). As a proportion of this period, based on maximum known thicknesses of sediments, the sequence between the Blackshale and Main Bright horizons in the East Midlands may have taken 4 to 5 million years to accumulate. Within this sequence there are, say, 120 to 150 episodes (see later parts of this address for definition) of deposition during each of which one or more sub-deltas were active more or less contemporaneously. This latter estimate is based upon a count of coal-leaves illustrated on text-fig. 3 of Elliott (1968), with reasonable allowance for additional episodes represented by the thicker persistent prodeltaic facies in the East Midlands. Calculation then allows some 20 to 40 thousand years per sub-delta. This type of calculation leaves considerable room for error. However, recent sub-deltas within the Mississippi delta complex, averaging about 2000 sq. miles in area and thus of the same order of size as the entire East Pennine Coalfield, took only about 1000 years each (Kolb and Lopik, 1966) to advance to their full extent and then be cut-off by crevassing up-stream. Indeed, some of these sub-deltas advanced into Gulf of Mexico waters up to 150 ft. deep and even deeper, whilst the productive coal measures sub-deltas probably advanced onto a pre-existing deltaic plain. Thus these carboniferous sub-deltas appear to have had well over 20 times more time available for their full development than their recent equivalents. There was ample time available for the basin to be kept continually replete by sub-delta deposition even allowing, in the later stages of each episode, for a relatively lengthy period of relaxation, including thick peat growth. On the other hand, during the early stages of each episode the intradeltaic sediments were probably deposited very rapidly; evidence suggesting this was summarised in the previous address (p. 361) and the distributaries of modern deltas advance at rates of up to 800 ft. a year.

Distributary deposits

Distributary deposits in the East Midlands productive coal measures include all beds of intradeltaic facies and also 'ribbons' of cannel, mudstone and inferior coal within coal seams whose geometrical form and nature strongly suggest that they represent swamp drainage features. Every gradation exists between sediments apparently associated with short-lived swamp 'creeks' to thick 'shoestrings' recording major distributaries. It is now convenient, before passing on to the more theoretical passages of this address, to collect together a list of the examples recorded here and in two previous publications by the author:

1) High Hazles seam, inferior top coal ribbon (text-fig. 3).

2) Low Tupton seam, cannel belt in upper part of seam (Elliott, 1968, text-fig. 1).

3) Blackshale seam, cannel belt in upper part of seam, extending W.S.W. from Mansfield for over seven miles (unpublished).

4-9) Sandstone-siltstone belts associated with seam-splits towards the top of the Parkgate, First Waterloo, Dunsil, Blackshale and High Main seams (text-fig. 6).

10,11) Sandstone-siltstone belts associated with seam-splits towards the base of the Deep Soft and Two Foot seams (text-fig. 6).

12) Sandstone-siltstone belt (text-fig. 3) associated with a seam-split (text-fig. 6) towards the base of the High Hazles seam.

13) 'Swilley' near the base of the Top Hard seam (Elliott, 1965).

14-16) 'Swilleys' near or at the bases of the Deep Hard, Deep Soft and Low Bright (Abdy) seams (Elliott, 1965).

17) 'Swilleys' at the base of the High Hazles seam at Gedling colliery (text-fig. 3).

18) Sandstone-siltstone belts known as the Top Hard 'rock' immediately overlying the Top Hard - Barnsley seam and laterally replacing more than one cyclothem (text-fig. 4).

19) A sandstone-siltstone belt known as the Tupton 'rock', immediately overlying the Low Tupton seam and about 110 ft. thick and laterally replacing several cyclothems (Elliott, 1968, text-fig. 1).

20) A dominantly sandstone and a dominantly siltstone belt, both about 70 ft. thick and immediately overlying the High Hazles seam (text-fig. 3).

Many other deposits similar to the above are referred to in the memoirs of the Institute of Geological Sciences, previously known as the Geological Survey; details of others remain unpublished but have been mapped by National Coal Board Geologists for economic reasons. The examples listed above suffice to illustrate the variety of distributary deposits present in the productive coal measures. They have relationships indicating that they accumulated contemporaneously with all prodeltaic, interdeltaic and swamp facies, suggesting that drainage was active at all stages of the relaxation of deltaic processes. At no horizon is there any evidence which indicates that a distributary deposit is diachronous, even where they are known along lengths of over 20 miles. A fast rate of distributary advance, as mentioned at the end of the preceding section of this account, is consistent with this fact.

This essentially non-diachronous and continuously represented drainage deposit system cannot be reconciled with delta-rejuvenation or cyclothem repetition due to epeirogenetic or eustatic pulsations on a significant scale.

The Top Hard 'washouts' at the base of sandstone and cutting down into the almost completely worked coal seam (text-fig. 4) provide a good illustration of the multi-channel appearance of an extensive coal-measures sandstone-siltstone belt. Good evidence of this complex of channel bases is recorded on large-scale mine plans in the vicinity of Teversal and Pleasley collieries and also northwards towards Steetley and Manton collieries. Similar, less extensive evidence is shown north of Dinnington Main colliery and near to Firbeck Main colliery. Multi-channel sandstone bases are certainly infrequent or rare in the East Midlands productive coal measures, but it appears that a few major 'shoestring' deposits were deposited by rivers flowing in shifting

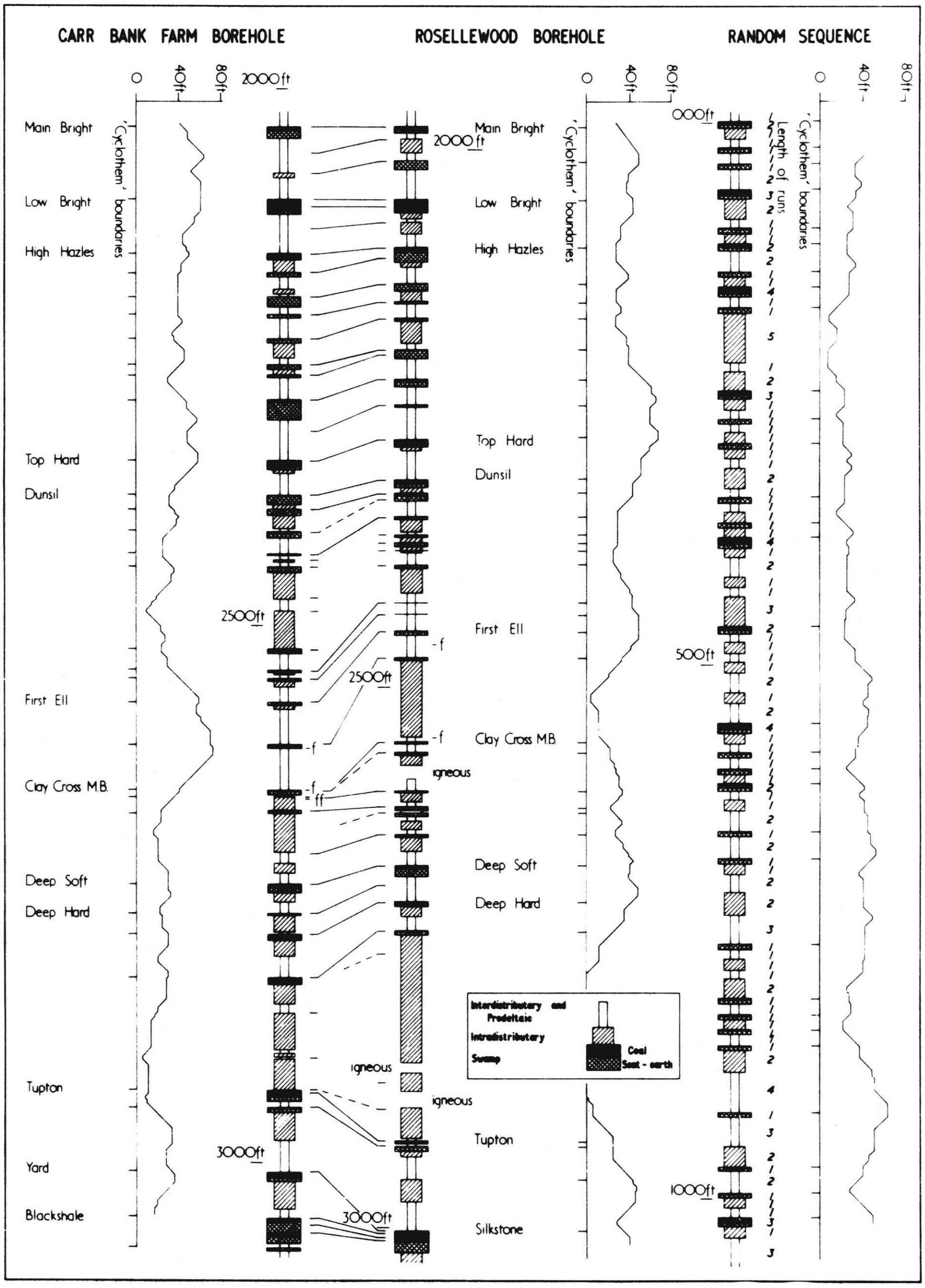

CARR BANK FARM BOREHOLE
ROSELLEWOOD BOREHOLE
RANDOM SEQUENCE
0
40ft
80ft
2000ft
'Cyclothem' boundaries
Main Bright
Low Bright
High Hazles
Top Hard
Dunsil
First Ell
Clay Cross M.B.
Deep Soft
Deep Hard
Tupton
Yard
Blackshale
2500ft
3000ft
igneous
Silkstone
Length of runs
000ft
500ft
1000ft
Interdistributary and Prodeltaic
Intradistributary
Swamp
Coal
Seat - earth

Fig. 5.

channels. Where this is the case, the arguments advanced above for the failure of levees, as part of deltaic relaxation processes, do not apply. These deposits may perhaps represent main-distributary reaches proximal of most contemporaneous delta-switching and feeding a series of sub-deltas. This interpretation is consistent with the relatively static location of these sandstone-siltstone belts, indicated by their lateral equivalence to several cyclothems.

The traditional cyclic concept replaced by an episodal concept

Nine facies from productive coal measures in the East Midlands contain sedimentary features which link them with each of the principal environments of an active sub-delta. This comparison is supported by the relationships between these facies described by Elliott (1968).

A hierarchy of sub-deltas, smaller deltas developing 'upon the backs' of larger deltas, and a series of prodeltaic sub-facies linked to this hierarchy was suggested in a previous section of this address. Each sub-delta is constructed by sedimentation following four facies successions (Elliott, 1968, p. 370): a 'laterally developing clastic succession' followed by 'a washout-fill succession', which together operate in intradistributary zones, whilst 'an upwards developing clastic succession' fills interdistributary zones. A progressive relaxation of delta-building processes takes place as the sub-delta heirarchy devolves, and the whole sub-delta may be crowned by the fourth, or 'hydrologically controlled succession'.

East Midland coalfield correlation studies have shown that in the vicinity of coal seam-splits, intradeltaic deposits commonly wedge-in and are demonstrably contemporaneous with part of the seam (Elliott, 1965). These seam-splits occur at all horizons within coal beds, dividing them into 'leaves' (text-fig. 6). The geometry and relationships of seam-splits strongly suggest that the sediments within them were deposited upon uncompacted peat contemporaneously with the growth of swamp vegetation. The discussion of text-fig. 6 presented in the appendix and consideration of the models depicted in text-figs. 2a and 2b indicate that a major factor determining the thickness of intradeltaic deposits is early compaction of underlying peats. Their base is lowered by compaction whilst levee summits must be maintained at or near flood water level if the distributary concerned is to survive. This conclusion is supported by the fact that those facies interpreted as levee deposits, massive siltstones and complex silt-sandstones, are frequently directly overlain by seat-earths (Elliott, 1968) and very rarely by faunal mudstones.

In spite of epeirogenetic subsidence being sometimes accompanied by considerable compactional subsidence over thick peats, the distributary system appears to have been competent to carry sufficient sediment to maintain its river banks. Such competence must have inevitably led to delta-plain conditions associated with a relaxation of deltaic processes as described by Strickland (1940). The seat-earths on levee summits marked the high points of a very low topography often progressively and completely covered by peats as the 'hydrologically controlled succession' replaced clastic successions then in obsolescence. Elsewhere, however, another sub-delta replaced the relaxed one by crevassing and delta-switching.

It is essential for the continuation of this analysis that the river(s) feeding the delta(s) be regarded as always present and always debouching water and sediment at a more or less similar rate throughout the period of deposition of productive coal measures. The repeated horizons of seat-earth and coal testify that the basin was always "topped-up" and the constancy of the fossil floras and also the limitation of brown seat-earths to the outer parts of the basin (Elliott, 1968, text-fig. 2) and the scarcity of reddened seat-earths in productive coal measures (op.cit., p.354-5) support a view that climatic conditions did not vary in essentials. This contraposed evidence suggests that the parent river(s) neither substantially decreased nor substantially increased during the period under review.

Coal-swamps were probably always present; successive coal-beds are united locally or widely (Elliott, 1968, text-fig. 3) and furthermore the location of these unions varies throughout the coalfield. Probably only on rare occasions did the coal-swamps retreat entirely to the margins of the basin; that is when the most widespread faunal mudstones, especially marine bands of continental extent, were deposited. These events are likely to be due to temporary increases in the rate of epeirogenetic subsidence or to temporary eustatic rises, as Duff et al. (1967, p. 156) suggest. Rare occasions apart, coal-swamps existed alongside localised sub-deltas which may be placed in time-order by documenting the horizons of their lateral limits within the coal seam sequence (text-fig. 6, and Elliott, 1968, text-fig. 3). It is found as already demonstrated that these splits can occur at any horizon within a major coal seam.

The relationships of all facies were recorded and summarised on text-fig. 4 of the previous address. Those relationships and the above analysis together indicate that during the period of deposition of productive coal measures in the East Midlands, in areas now occupied by coal-fields and in adjacent areas from which coal measures have subsequently been eroded, three major environment groups co-existed at all times with sediments accumulating in accordance with the four successions, namely:

a) coal-swamps (hydrologically controlled succession),

b) Prodeltaic and interdistributary areas (upwards developing clastic succession),

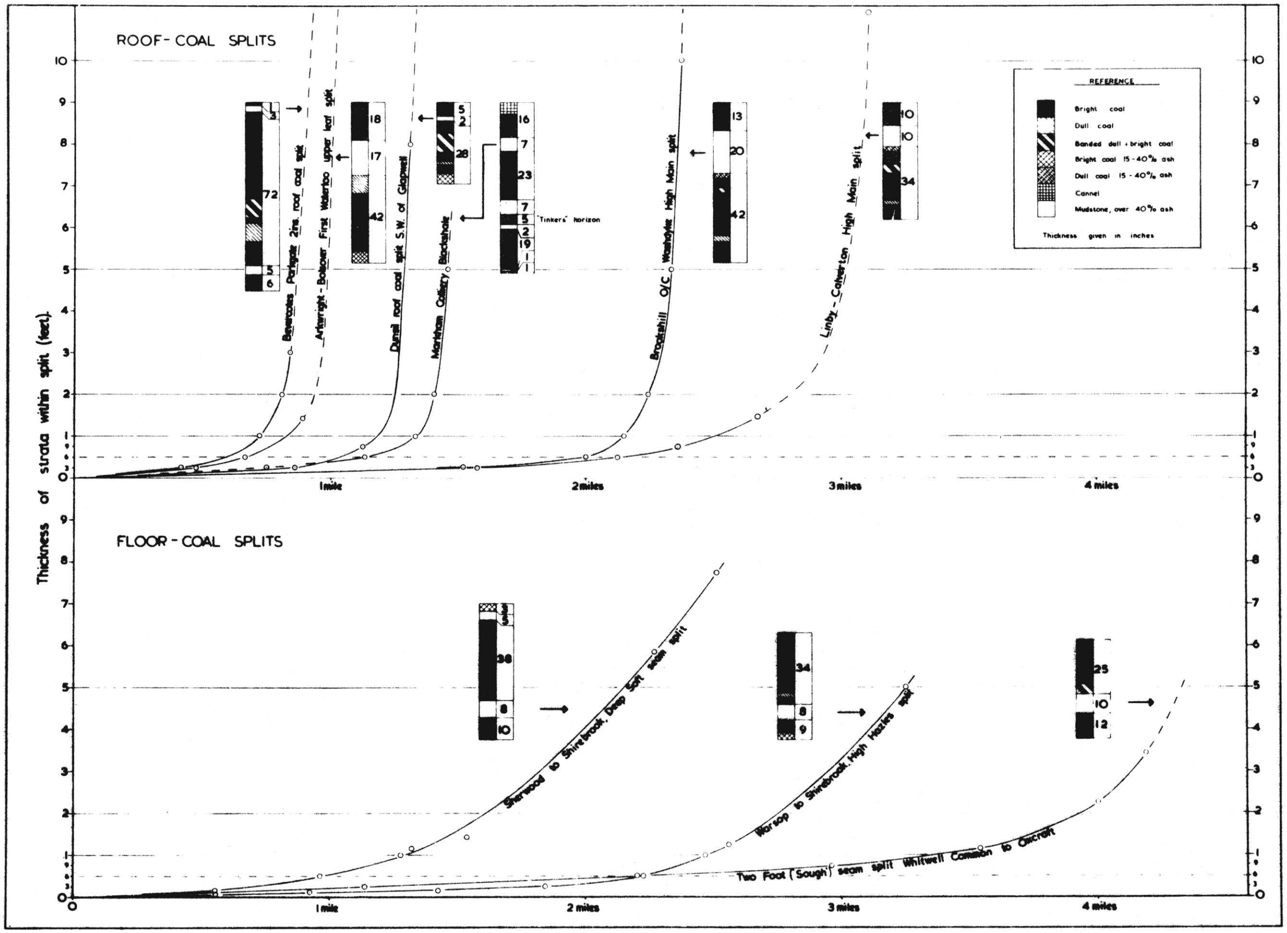
c) Intradistributary areas (laterally developing clastic and washout-fill successions).

Each delta-switching event marked the beginning of a new episode and sub-delta, continuing the accumulation of this complex of deposits (text-fig. 1b). Before and after these events coal swamps continued to exist beyond the reach of the active sub-deltas concerned. Intradistributary deposits spread rapidly into shallow water and faunal mudstones accumulated well beyond them but within the associated flood area. This flooding followed or was a factor in the final arresting of local coal-swamp vegetation growth.

In non-peripheral parts of the basin of deposition (Wills, 1951) the three major environment-groups may be assumed, as a first approximation, to have on average occupied roughly similar percentages of the deltaic plain and to have been equally likely to occur at any one locality during any one episode. On these assumptions a sequence of environment-group deposits was derived from a table of random numbers and is illustrated on text-fig. 5 alongside two actual borehole-core sequences from Nottinghamshire.

The ratio of runs, representing the three environment-group deposits in this random sequence, is adjusted to proportions similar to those between like deposits in the borehole sequences. This was achieved by eliminating a small random selection of terms representing intradistributary deposits; the other two being present in approximately equal numbers of beds in both the Carr Bank and Rosellewood cores. The thicknesses allotted to each deposit in the random sequence are also calculated so as to total to proportions similar to those found in the borehole cores.

Chance runs of several terms representing swamp deposits are drawn as thick coals over seat-earths of normal thickness, and likewise runs of several terms representing intradeltaic deposits appear as thick sandstone-siltstone beds. Account is not taken of erosion of sediments below washout sandstones, of thick successions due to compaction over thick peats, or of chance thick sections simply due to the geometry of levees and channel-fills. If these additional factors were built into the random sequence, one or two still thicker and more continuous sandstone-siltstone sequences would occur. Examples of both thick coals comprising four or five leaves and thick sandstone-siltstone sequences are present in the actual sections of text-fig. 5, but the



ROOF-COAL SPLITS
FLOOR-COAL SPLITS
Thickness of strata within split (feet).
1 mile
2 miles
3 miles
4 miles
Bevercotes Parkgate 2ins. roof coal split
Arkwright - Bolsover First Waterloo upper leaf split
Dunsil roof coal split S.W. of Glapwell
Markham Colliery Blackshale
'Tinkers' horizon
Brookshill O/C Washdyke High Main split
Linby - Calverton High Main split
Sherwood to Shirebrook Deep Soft seam split
Warsop to Shirebrook High Hazles split
Two Foot (Sough) seam split Whitwell Common to Clowne
REFERENCE
Bright coal
Dull coal
Banded dull + bright coal
Bright coal 15-40% ash
Dull coal 15-40% ash
Cannel
Mudstone, over 40% ash
Thickness given in inches

Fig. 6.

latter occur up to 150 feet thick and occupy the positions of several cyclothems; they may not be fully explained as chance long-runs supplemented by thickening associated with erosion, pene-contemporaneous compaction and levee geometry, but also embody sediments accumulating under shifting channel conditions as mentioned above. They may lie proximal to most contemporaneous sub-delta switching.

Chance runs of four or five terms representing the prodeltaic-interdistributary deposits and groupings of these deposits (see graphs on text-fig. 5) are also likely to be present if the principle of random occurrence of major environments operates; support for the existence of such multi-episode beds is found in the detailed description of borehole cores. Faunal mudstones and flaser silt-sandstones occasionally alternate without intervening facies, and detailed coalfield correlation indicates that some coal-seatearth horizons pass into such alternations or into faunal mudstones with carbonaceous or canneloid horizons. About thirty horizons pass-out across text-fig. 3 of Elliott (1968). The correlation of Carr Bank and Rosellewood boreholes on text-fig. 5 of this address further illustrates a few examples.

Intradeltaic deposits in the random sequence rest upon swamp deposits about 60% more frequently than in the actual borehole sections of text-fig. 6. This can be readily accounted for by consiering the devolution of each sub-delta hierarchy: due to the branching development of a distributary pattern this devolution must have the effect of progressively increasing the chance of intradeltaic deposition at any one locality during the course of one episode.

Generally speaking, each term in this artificial sequence represents a locally deposited facies group, and the ability of such a sequence to simulate the productive coal measures, especially if modifications to the intradeltaic content were built-in, seems highly probable. To this extent an episodal concept is supported by the trial random sequence.

Conclusions

East Midland productive coal measures sequences located in non-peripheral parts of the basin of deposition, probably result from the operation of the following phenomena:-

1) Deposition during episodes of essentially stable geography but when sub-delta advance, devolution and relaxation progressed more or less uninterrupted.

2) Four sedimentation successions: a hydrologically controlled succession, an upwards developing clastic succession, a laterally developing clastic succession, and a washout-fill succession, together develop rather like botanical successions unless halted by a major event terminating an episode.

3) Random superposition of major environment groups: Swamp, prodeltaic-inter-distributary, and intradistributary, present at any one locality within successive episodes: long chance-runs of similar environments in particular districts yielding thick coal-seams, compound dominantly mudstone-siltstone sequences or thick dominantly sandstone-siltstone sequences.

4) Devolution of a sub-delta hierarchy progressively increasing the chance of intra-deltaic deposition at any one locality and during any one episode.

5) Successions accumulating during any one episode can become extra thick due to exceptional contemporaneous compaction of underlying deposits: this mechanism operates particularly where intradeltaic deposits accumulate over multi-episode peats.

6) Processes which determine the geometry of levees; also to a lesser extent, other phenomena relating to the form of other deposits.

7) Erosion beneath washout-fill successions.

8) Accumulation of a few 'shoestring' sandstone-siltstone bodies representing the deposits of long-life (multi-episode) distributaries probably located proximal of most contemporaneous sub-delta switches.

It should be possible to improve significantly upon the random section of text-fig. 5 by preparing a more sophisticated simulation programme taking account of all the phenomena (1 - 8), and subsequently test the improved simulated sequence by making comparisons with statistics derived from actual borehole sections.

The traditional cyclothem may cut across the deposits of several episodes (text-fig. 1b) and is not coupled directly to a clear conception of sedimentological processes. The frequently quoted 'typical cyclothems' having lithological patterns of the type: coal seam/seatearth/sandstone and siltstone/mudstone often represent a hydrologically controlled succession overlying an upwards developing clastic succession. One or both of these successions may be interrupted by a sudden change in drainage conditions and therefore be deposited during more than one episode. Only detailed description of coal types and thin mudstone layers within the coal seam and of lithology, sedimentary structures and fossils within the clastic succession, can lead to a correct interpretation of the sequence in relation to laterally adjacent sections.

The author, on reflection, would like to rescind the suggestion made in the previous address that the term 'cyclothem' should be redefined three-dimensionally, primarily because this term is also used in connection with completely different formations where it might be more appropriate to use it in its traditional one-dimensional sense. The imperfect rhythmic pattern found in sequences comparable with the East Midlands productive coal measures sequence is, as here concluded, best considered as episodal (text-fig. 1b) and due to deposition in accordance with four successions, thus dispensing with the cyclothem concept.

Episodes commencing with widespread flooding due primarily to epeirogenetic or eustatic pulsations are to be discounted when considering the greater part of the East Midlands productive coal measures sequence. Flooding, except where resulting in deposits extending well beyond the limits of one river's delta (e.g., the Clay Cross marine band; Calver, 1968), follows without special cause, from deltaic relaxation processes. That intradeltaic facies wedge into sequences at all horizons, sometimes at coal-seam splits and sometimes within upwards developing clastic successions; that intradeltaic facies sometimes lie immediately upon the top of coal seams and extend right across the Nottinghamshire and Derbyshire coalfield for at least twenty to thirty miles (text-figs. 3 and 4) without evidence of rising higher within a prodeltaic facies; and that seam splits are more or less equally common in all parts of this coalfield; appears to be sufficient indication that a large part of the basin was continuously "topped-up" by distributary systems virtually unaffected by relative base level to land-surface level pulsations. This theme is supported by Duff and Walton's (1964) conclusion that there are proportionately more cyclothems in the thicker sequences towards the basin centre than in the thinner sequences nearer to the basin edge. Epeirogenetic or eustatic pulsations are not compatible with the episodal theory developed in this address, and appear not to have occurred in sufficient strength to destroy distributary flow regimes. Drainage gradients of up to only 10 or 15 seconds of arc, a surfeit of sediment and a continuously maintained depositional plain are the essence of a large delta-complex; this is compatible with evidence from the productive coal measures presented in this and the previous address.

EXPLANATION OF TEXT-FIGURES

Text-figure 1. (a) Principal delta environments and associated key sedimentological features. Important current flow paths are shown bold with arrows, broken where they extend into large bodies of water. Depositional environments are arbitrarily partitioned by less-bold broken lines and the shaded zone represents the region across which currents decrease abruptly in sediment-carrying capacity.

(b) A diagrammatic comparison of cyclothems and those sedimentary units deposited during individual episodes. Laterally equivalent interdistributary, prodeltaic, intradistributary and swamp deposits occur in each episode, some outside the limits of the figure. The traditional coal measures cyclothem is defined only in a vertical sense, as indicated by the open arrows, and is not necessarily equivalent in two nearby vertical sections.

Text-figure 2. Model sections illustrating the dependence of thicknesses of intradeltaic deposits upon thickness of swamp peat; a: yielding one foot of coal, and b: yielding four feet of coal. All thicknesses are in feet. W.L. = Water level; D.C.=Distributary channel fill; and D.M.B. = Distributary mouth bar deposit. Coal is shown black and thicknesses resulting from compaction below several thousand feet of rock are suggested on the left. For further explanation see text.

Text-figure 3. Distributary deposits and splits known at the horizon of the High Hazles coal seam. Lines are based on point evidence except where solid indicating trends partially based on colliery underground information and also seam outcrops in the west. The location of borehole and shaft records contributing to the construction of the map are indicated by circles. Ribbons decorated by widely spaced dots are sandstone-siltstone belts resting upon the seam; that decorated by closely spaced dots wedges into the basal part of the seam at the floor coal split horizon of text-fig. 6. One-foot isopachytes of this split are shown east and west of this latter belt, decorated by solid "teeth". A one-foot isopachyte of a regional split is decorated by open "teeth" pointing towards the widely split region, an additional cyclothem, extending north into Yorkshire. Ribbons decorated by horizontal bars represent zones of inferior top coal 9 in. to 12 in. thick and containing up to 25% ash. Two coal-seam sections illustrate the general stratigraphical relationships of the features within the seam; symbols are as on text-fig. 6. National Grid lines are numbered at 10,000 metres intervals.

Text-figure 4. Washouts at the base of, and extent of, the prominent sandstone immediately overlying the Top Hard - Barnsley coal seam. Proved by underground and opencast workings except in the vicinity of the Bevercotes and Cotgrave collieries. Most and probably all the sandstone belts indicated lie between the Top Hard seam and its upper roof coal, known as the Upper Coombe coal. The Lower Coombe coal has occasionally been seen to feather-out against these sandy measures. National Grid lines are numbered at 10,000 metres intervals.

Text-figure 5. Vertical sequences of swamp, intradistributary and interdistributary-prodeltaic deposits. Two Nottinghamshire borehole sections, with correlated swamp deposit horizons, are compared with an artificial random sequence constructed as explained in the text. Graphs illustrate variation in a moving average of interdistributary-prodeltaic deposit thicknesses, that is, variation in thicknesses of this group of deposits within an 80-foot unit of strata moved progressively through the sequences. For the location of the boreholes see text-fig. 3. M.B. = marine band, and f = fault.

Text-figure 6. Graphs relating thicknesses of strata within coal-seam splits and distances away from, and measured perpendicular to, the general trend of the split isopachytes. Petrographic sections illustrate the position of each split within the coal seams. The vertical scale of the sections is three-fifths of that of the graphs. The data for each split was compiled from the vicinity of the following locations:

Seam-split	National co-ordinates
Bevercotes colliery, Parkgate seam:	East: 469, North: 375
Arkwright-Bolsover, First Waterloo seam:	East: 446, North: 371
Glapwell colliery, Dunsil seam:	East: 445, North: 366
Markham colliery, Blackshale seam:	East: 444, North: 373
Brookshill opencast - Washdyke boreholes, High Main seam:	East: 450, North: 350
Linby - Calverton collieries, High Main seam:	East: 464, North: 353
Sherwood - Shirebrook collieries, Deep Soft seam:	East: 454, North: 366
Warsop - Shirebrook collieries, High Hazles seam:	East: 455, North: 367
Whitwell Common - Oxcroft, Two Foot seam:	East: 449, North: 374

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Acknowledgements

The author is indebted to many geologists and others, especially colleagues within the National Coal Board, for discussion over the past twenty years or so, of the numerous data assemblies and interpretations upon which this address is necessarily based. Mr. D.W. Turner of the East Midlands Geological Outstation, National Coal Board, has been particularly helpful with detailed correlation matters.

Mr. R.F. Goossens, of the Yorkshire Geological Outstation, National Coal Board, provided information necessary for the extension of text-fig. 4 across and beyond the Nottinghamshire-Yorkshire boundary; Mr. E. Skipsey, of the East Midlands Geological Outstation, National Coal Board, kindly read the draft manuscript and offered helpful criticism; and Mr. G. Armstrong, Chief Geologist, gave permission on behalf of the National Coal Board for the address to be offered for publication.

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APPENDIX

Coal-seam splits

The thickness of strata within certain well-documented coal-seam splits is plotted on text-fig. 6 against approximate distances measured at right-angles to the line of split from the feather-edge of the non-coal strata. The horizontal distance is approximate for two reasons: firstly, the point of zero thickness is not readily ascertained because records either show zero or ½ inch thicknesses and very rarely an intermediate value: secondly, because non-coal strata isopachytes usually show some irregularities. Each error could be anything up to about ¼ mile, but to some extent they are reduced by taking into account isopachytes up to a few miles in length, not confining the information to a particular line of section. Local isopachyte irregularities have been smoothed out, especially those indentations which could be due to original erosion features.

It must be noted that the splits depicted on text-fig. 6 are not representative of all splits. There are a few in the East Midlands which are not known to widen out to more than about 3 ft. or even less. A split within the Deep Hard seam at Pleasley Colliery (Elliott, 1968, text-fig. 3) is traceable east-north-east to the edge of the well-explored coalfield, a matter of 13 miles, and over an area of 100 or 200 sqaure miles. It is often recognisable as 1 - 3 ft. of mudstone between coals or cannels, and containing non-marine lamellibranchs, but becoming unrecognisable at certain localities because the coal leaves pass into cannel and eventually into dark mudstone. This presence of lamellibranchs between two closely spaced coal seams is a feature very rarely found in the East Midlands Coal Measures. The Blackshale splits above and below the "tinkers" horizon (text-fig. 6) are also not known to thicken to more than about 3 feet. A third, extreme example, is that of the clay layers immediately above and below the Top Hard seam cannel in the vicinity of Hucknall, north-west of Nottingham (Elliott, 1965, p. 136 and text-fig. 1) which only attain a thickness of 4 inches.

Of these thin-splits, the Top Hard example certainly represents brief clastic phases of deposition in a normally stagnant lake; the Deep Hard split appears to represent a marginal zone of a large open-water body, and the Blackshale splits may represent flood deposits from a very minor watercourse which has been mapped over some 7 miles for National Coal Board purposes.

In contrast to these thin-splits the strata within the thick-splits of text-fig. 6 pass laterally from clay-grade rocks into siltstones and sandstones and occur alongside linear bodies of the coarser clastics. In many cases these linear features are probably directly associated with paleo-river courses; the facies of the sediments suggest this conclusion, though the details recorded do not always suffice for a satisfactory interpretation.

In spite of data shortcomings, certain features of these graphs are irrefutable. A region of maximum curvature is often located on the curves around a thickness of 1 ft., and is especially pronounced in the case of the roof-coal splits. Moreover, the distance of this point from the origin varies considerably among both roof and floor coal splits.

The graphs are a function of time and the location of an edge-zone transitional between a region of swamp-peat accumulation and a region of clay, silt and sand accumulation. Several factors could affect the shape of these curves:-

a) overall variation in the rate of accumulation of sediment now forming the split strata, compared with the rate of peat accumulation.

b) lateral change in the rate of sediment accumulation related to a 'filtering' effect of vegetation, thought by some authors to operate in swamp-vegetation edge-zones.

c) the frequently observed passage from sands and silts to clays, accumulating in the widely-split and narrowly-split zones respectively.

d) changes with respect to time, of the vegetation's density and character in the edge-zone; likely to be related to (a) and water-depth. The swamp plants needed a certain depth of water for normal growth; sediment deposition is likely to either allow further colonisation or to overwhelm the edge-zone vegetation.

e) lateral variation of the vegetation's density and character in the edge-zone; likely to be related to (b), (c) and (g).

f) compaction of peat under the weight of sediments now forming the split-strata. Thaidens and Haites (1944) suggested that the weight of sediment deposited upon peat quickly initiated peat compaction.

g) delayed compaction of peat beneath the clayey sediments of (c) compared with that of peat beneath the sandy sediments; due to the clay forming a seal against gas and water contained in the peat.

h) greater compaction of the clays than of the silts and sands; related to (c).

Factors (a) and (d) would be likely to give rise to irregular curves and will not be considered further. Factor (b) might be expected to promote a convex-upwards curve similar to the cross-section of the edge of sand dunes encroaching upon a forest. Factors dependent upon (c), especially (h) and perhaps (e), together with (g) are likely to give rise to concave-upwards curves. The general shape of the graphs suggests that (g) and (h) did operate.

Only factor (f) could produce a more pronounced region of maximum curvature in the graphs representing roof-coal splits than in those representing floor-coal splits. Flooding, and hence sedimentation, would be greatest where compaction of peat most frequently necessitated the immediate restoration of natural levee heights. This mechanism would be more active in the case of roof-coal splits than in the case of floor-coal splits, due to a greater thickness of underlying peat.

The thickness at the point of maximum curvature, that is, around 1 ft. (text-fig. 6), probably represents the thickness of sediments accumulating more or less at the extreme fringe of swamp or marsh. This comprised something of the order of 4 ft. of watery sediment immediately prior to the progressive re-colonisation of the area.

The horizontal distance from zero to the same point of maximum curvature varies from 2/3 of a mile up to nearly 4 miles in the examples illustrated. Other cases may cover greater distances. These wedges of sediment are analogous to the ½ mile-wide 'clay flange' associated with the Top Hard swilley of Elliott (1965).

It therefore can be concluded from the geometry of coal-seam splits that the sediments within them were probably deposited upon peat contemporaneously with the growth of swamp vegetation, and that this initiated marked compaction of the peat.

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Manuscript received 7th March, 1969.

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.