SIMULATION OF A PRODUCTIVE COAL MEASURES SEQUENCE

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by

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Summary

The episodal theory, as presented in the previous address, is briefly summarised. A scheme for the simulation of a productive coal measures sequence, based on this theory, is then described. Episode strata-columns representing generalised facies successions and typical of zones within a simple schematic coal measure delta are selected randomly, subject to predetermined availabilities. The content of each such column is largely theoretical, whereas its thickness and availability are based upon statistics derived from modern borehole logs. A series of episode-column selections builds into a full sequence, and an example over 1000 feet thick is illustrated. This sequence is tested by means of the simple mathematical device suggested by Selley (in the press), and an assessment of the model is made.

Introduction

This account presents a semi-random method of productive coal measures sequence simulation based upon the episodal theory developed in the previous addresses (Elliott, 1968 and 1969). To recapitulate, this theory states that:

1) Deposition took place during successive episodes of gradual sub-delta advance, devolution and relaxation, which were more or less uninterrupted.

2) Devolution consisted of major distributaries and associated environments of deposition giving way, in part, to lesser but collectively more extensive branching distributary systems and smaller scale environments. Devolution thus increased the chance of intra-deltaic deposition at any one locality.

3) Relaxation of deltaic processes accompanied devolution and led to a reduction of sub-delta topographical relief, stagnation giving rise to toxic waters and, at a late stage, to a spread of seat-earth and peat forming conditions wherever the relief was suitable and whilst subsidence was accommodating.

4) Four sedimentation successions operated: an upwards developing clastic succession (faunal mudstones to flaser silt-sandstones) typical of interdistributary regions; a clastic succession laterally and terminally associated with distributaries (massive siltstones, complex silt-sandstones, layered sand-siltstones and rippled sandstones); a washout-fill succession (washout sandstones to rippled sandstones) filling distributary channels; and finally, a hydrologically controlled succession (seat-earths to coals) originating in swamp regions.

5) Episodes were terminated by major geographical changes frequently associated with delta-switching up-stream of the sub-delta concerned. In regions geographically outside the influence of

these events, coal-swamps continued to flourish or open-water deposition was uninterrupted. So terminated, many episode columns have different boundaries to "cyclothems" (Elliott, 1969, text-fig. 1).

6) Three extensive environment-groups are recognised as having existed during each episode (swamp, prodeltaic-interdistributary, and intradistributary environments) and the major geographical changes referred to above are regarded as giving rise to a random superposition of successive episode deposits. Thus, by chance, a coal seam at one locality may have arisen from several episodes of deposition within a swamp region and, likewise, a prodeltaic environment may have persisted during more than one episode.

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

8) The regional epeirogenetic rate of subsidence varied within narrow limits and to that extent contributed to variations in the general thickness of deposits accumulating within each episode.

9) The geometry of levees and other palaeogeographical features was important in determining local thickness variations of certain facies.

The aim of this account is to build at least the more important elements of the above theory into a sequence simulation model.

There is an appreciable variation of the coal content of sequences throughout the Central England basin (text-fig. 1) and sandstones are more prominent in some parts than in others. The sequence containing the Thick Coal of Warwickshire and South Staffordshire gives way northwards, by splitting, to one having about 4% coal, and the paucity of sandstone in Leicestershire contrasts with a variable but significant sandstone content at the northern margin of text-fig. 1. For this reason simulation must be based on facies proportions found within a restricted district. The district chosen is in Nottinghamshire, where a number of recent borehole logs are available, and those utilised are named on text-fig. 1. From one to seven of these have been used to establish the design-parameters of the model; the number used depending upon the accuracy required for each parameter. The stratigraphical range of the Productive Coal Measures simulated is the same as that studied in the two previous addresses, namely, from the roof of the Blackshale seam to the roof of the Main Bright seam. Above and below this range the facies assemblage is detectably different except within certain short sequences.

General description of the model

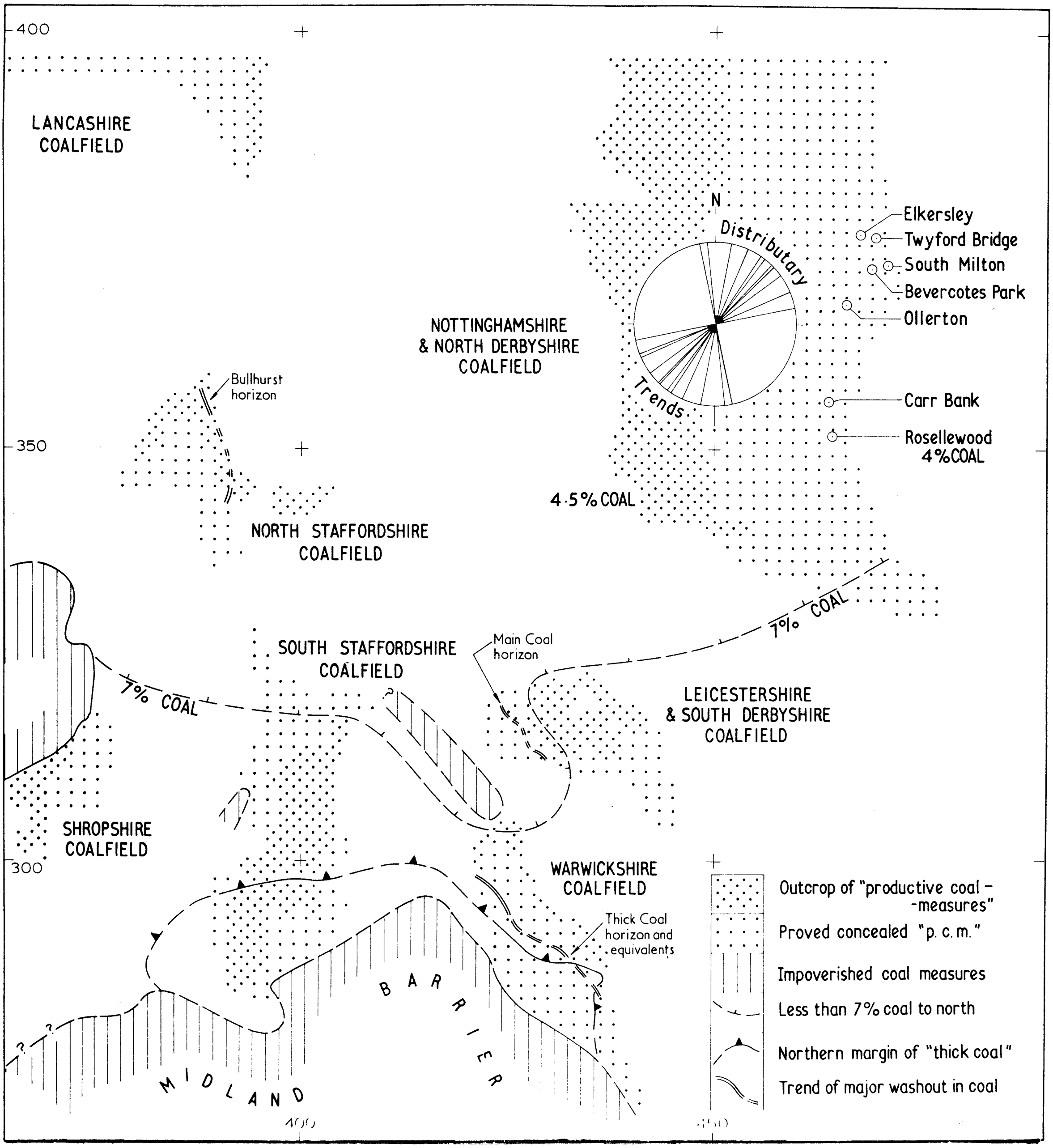
The essentials of the model from which a simulated sequence can be obtained are, as a matter of convenience, set out below:-

a) A schematic map (text-fig. 2) showing sedimentation zones.

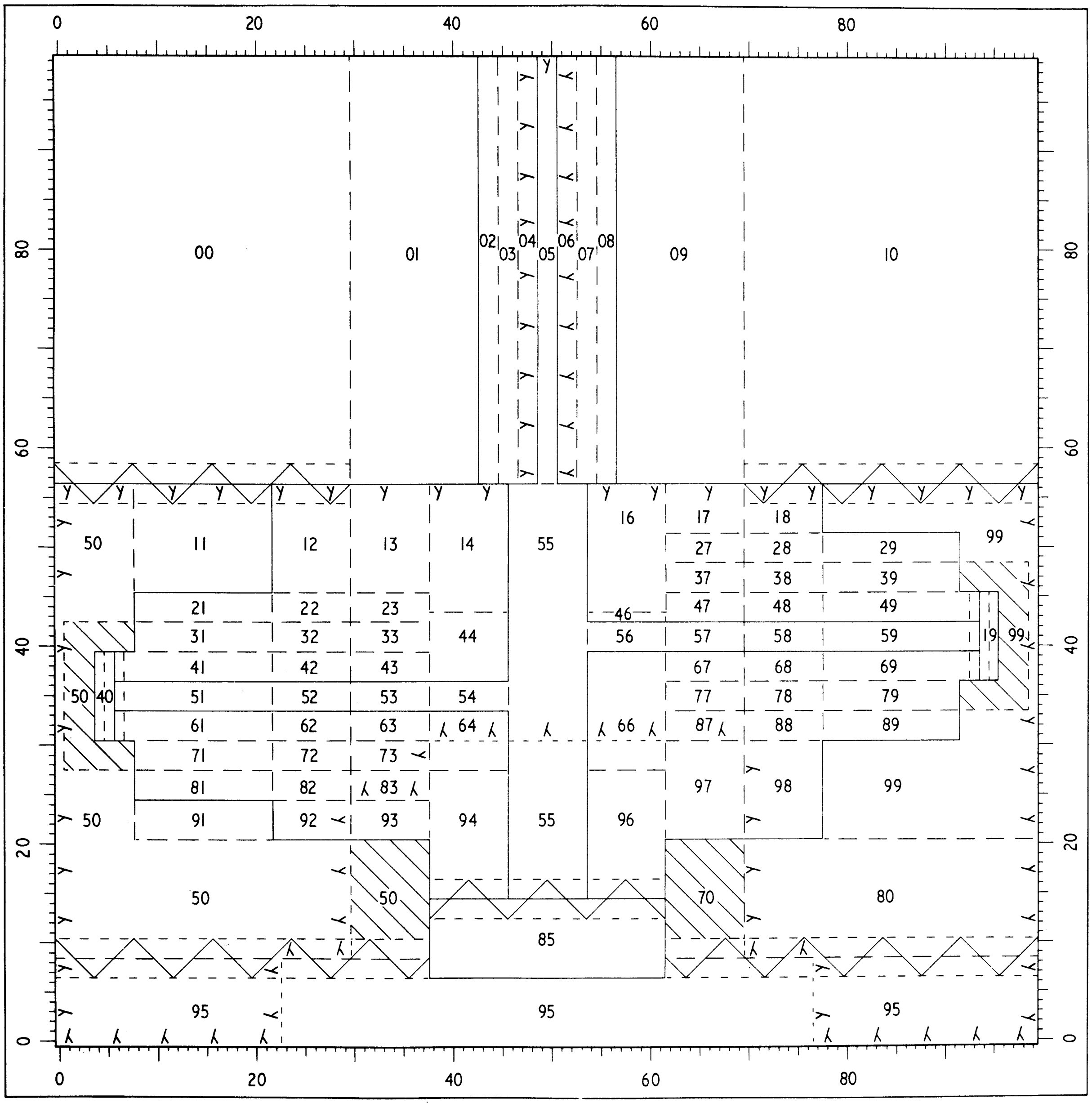
b) A series of 45 columns (text-fig. 3) with cross-references to zones on the map; each depicting a facies or sequence of facies deposited during one episode.

c) Two histograms (text-fig. 4), the columns of which represent thicknesses and their probabilities, one concerning episodal deposits (columns of text-fig. 3) and the second concerning seat-earths to be developed upon sediments included in the first thickness.

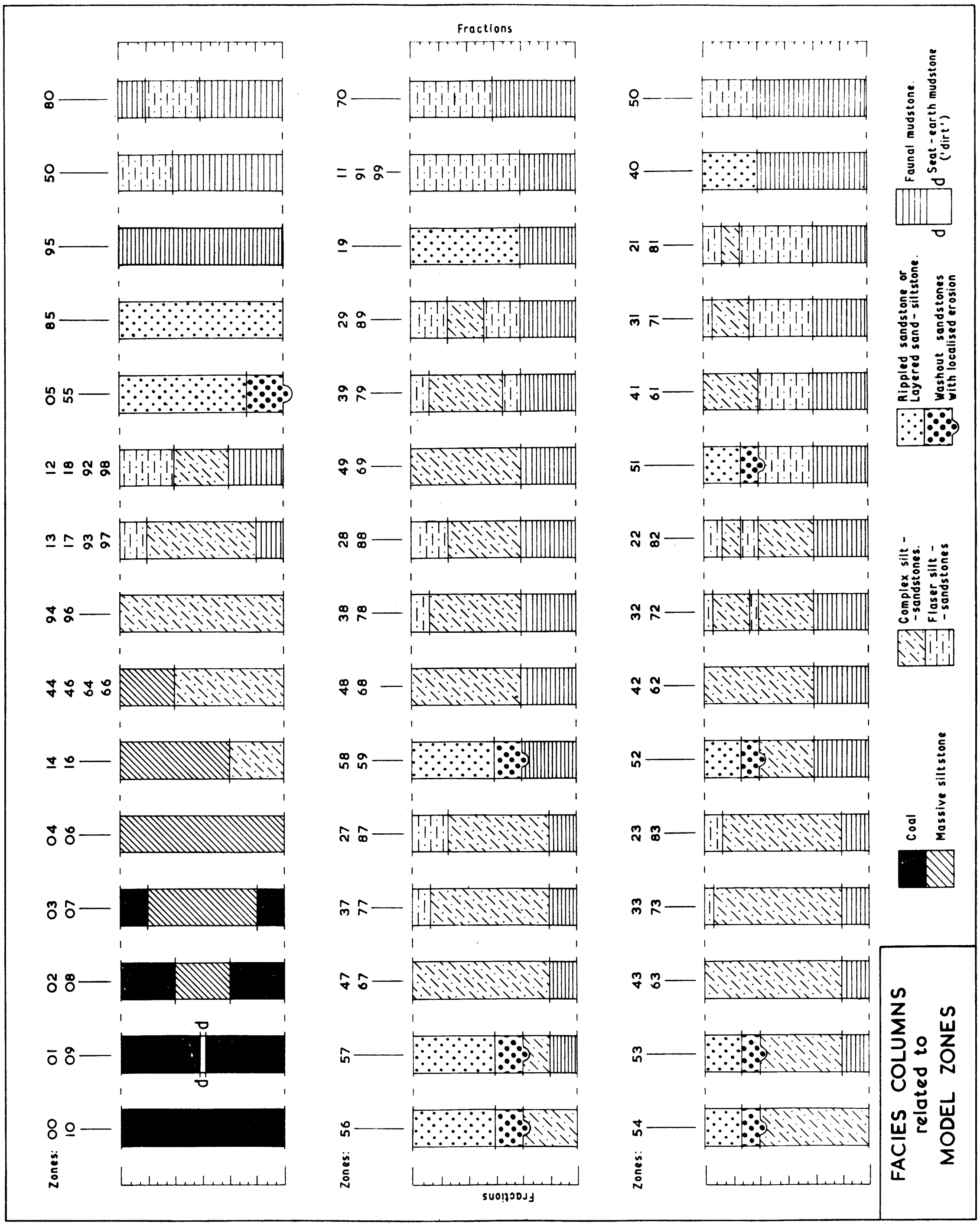
d) Tables or other source of random numbers.



Text-figure 1 Some elements of productive coal measures facies in the Midlands of Great Britain and the location of seven boreholes from which data was obtained for this address. The generalised trends of intradistibutary facies belts from the twelve best known horizons in the Nottinghamshire and North Derbyshire Coalfields are shown. National Grid lines are indicated at 50 kilometre intervals.



Text-figure 2 A schematic map showing sedimentation zones. Co-ordinate scales for the plotting of random numbers are indicated around the margins. A full explanation appears in the text under "The geometry of facies distribution built into the model".



Text-figure 3 Sequence columns related to the zones of text-fig. 2. Each column depicts a facies or sequence of facies deposited during any one episode. The scale of fractions, in terms of sixths and eighteenths, is used for the calculations of thicknesses as described in the text.

Percentage statistics controlling gross facies proportions within the model are given in table 1. The percentage volume of each of nine facies, calculated from summations of the products of zone areas on text-fig. 2 and thicknesses on text-fig. 3, are listed. These are designed to represent closely the thickness proportions of facies (Elliott, 1968 and 1969) encountered in boreholes in the Nottinghamshire sequence between the Blackshale and Main Bright horizons. This design correlation is dependent upon the hypothesis that delta-switching and branching gives rise to a random distribution of environments through time. Approximate correlations are likewise designed between the areas of episode-top facies on text-fig. 2 (those at the top of the corresponding columns on text-fig. 3) and the frequency of episode-top facies in the borehole records, and also between those areas on the same figure not supporting seat-earths and the frequency of episode-tops not supporting seat-earths in the same borehole records. These latter correlations can and need only be very approximate because of the difficulties of consistently recognising episode boundaries within multi-storey beds (for example, a coal seam which splits widely into two or more beds elsewhere) and of placing some "immature" or ill-defined seat-earths in one of the two categories; seat-earth or non-seat-earth.

These statistics and, in turn, the volumes and areas representing them, determine the gross weighted occurrences of facies available for selection. Successive selections are made in order to build a simulated facies sequence in the manner described later in this account.

The geometry of facies distribution built into the model

The schematic map (text-fig. 2) and sequence columns (text-fig. 3) show in a very generalised form the geography and geometry of the sedimentation regimes and units necessary to build a Productive Coal Measures sequence.

On the map, only proportions are essential to the operation of the model: the arrangement illustrated is presented as a matter of descriptive convenience and as such does not depict an intricate geography. The sequence columns (with the addition of seat-earths explained later) incorporate the essentials of sub-delta devolution, the four sedimentation successions, and facies cross-section geometry. Complex interfingering and most facies details, necessarily represented by beds less than about one foot thick, are omitted.

Zones 00 to 10 (text-figs. 2 and 3) represent two coal-swamp regimes separated by an intradistributary facies belt whose massive siltstones (zones 02 to 04 and 06 to 08) wedge laterally into the coal-swamp deposits, either side of a central sandstone belt (zone 05). A sub-delta occupies the major part of the map "south" of zones 00 to 10, leaving only the columns relating to zones 11, 50, 70, 80, 91, 95 and 99 occupied wholly by prodeltaic-interdistributary facies and of these only 95, in advance of the sub-delta, is entirely prodeltaic.

The sub-delta consists of facies associated with a main distributary extending "southwards" and two subsequent distributaries, that to the "east" being the earlier and that to the "west" being the later. To represent this simple 3-stage growth, intradistributary facies associations occupy the whole, the upper two-thirds and the upper third of the relevant facies columns respectively. In the main, these appear on text-fig.3 in the upper, middle and lower rows respectively.

Each intradistributary facies association contains central zones (Nos. 51 to 59) with columns incorporating washout-fill facies and a proportion of layered sand-siltstones. The correct relationships of these minority facies are not completely represented and further statistics are required. This especially applies to the layered sand-siltstones which, as some recent underground observa-

TABLE 1. Percentage statistics controlling gross facies proportions within the model.

FACIES	Thickness in North Notts. sequence (Elliott '68)	Thickness in Rosellewood drilled 1969	(1) Volume built into model	(3) Frequency of episode top facies in boreholes	(3) Areas of episode - top facies on text fig.2.	(3) Frequency of episode tops not supporting seat earths in boreholes	(3) Areas on text - fig.2 not supporting seat-earths
Seat-earth	10 to 20	13	14.0	-	-	-	-
Faunal M	33	27	32.0	20	14	26	34
Flaser Z-S	15	13	14.5	29	42	21	23
Coal	2 to 7	4	(2) 4.5	-	-	-	-
Complex Z-S	15 to 20	20	18.0	26	19	31	14
Layered S-Z	5	6	5.5	7	9	14	15
Massive Z	5 to 10	4	6.0	13	10	3	4
Rippled S	3	4	3.5	5	6	5	10
Washout S	1	9	2.0	0	0	0	0
Totals	89 to 114	100	100.0	100	100	100	100

M = Mudstone; Z = Siltstone; S = Sandstone.

(1) Sums of zone areas (text fig. 2) multiplied by thicknesses of facies in episode columns (text - fig. 3).

(2) Percentage after compaction to 1/12th., relative to other facies.

(3) Coal facies excluded to avoid decompacting coal thickness prior to calculation of these percentages.

tions suggest, may occur as remnants of bar-deposits largely eroded during the prolongation of channel and levees. Other bar facies are represented by the terminal zones (Nos. 19, 40 and 85). In both the terminal and central zones rippled sandstones and layered sand-siltstones are not differentiated on text-figs. 2 and 3: their proportions are randomly chosen and diagrammatically plotted during the operation of the model as described below.

The columns relating to three lateral zones, on either side of each of the central zones, contain a wedge of intradeltaic facies equal to the whole, two-thirds and one third the thickness of the corresponding central zone intradeltaics (*e.g.*, zones 61, 71 and 81). The "east" and "west" distributary wedges consist entirely of composite silt-sandstones, whilst the main distributary wedges consist of massive siltstones to the "north" passing, by increments of a third, into complex silt-sandstones to the "south" and laterally.

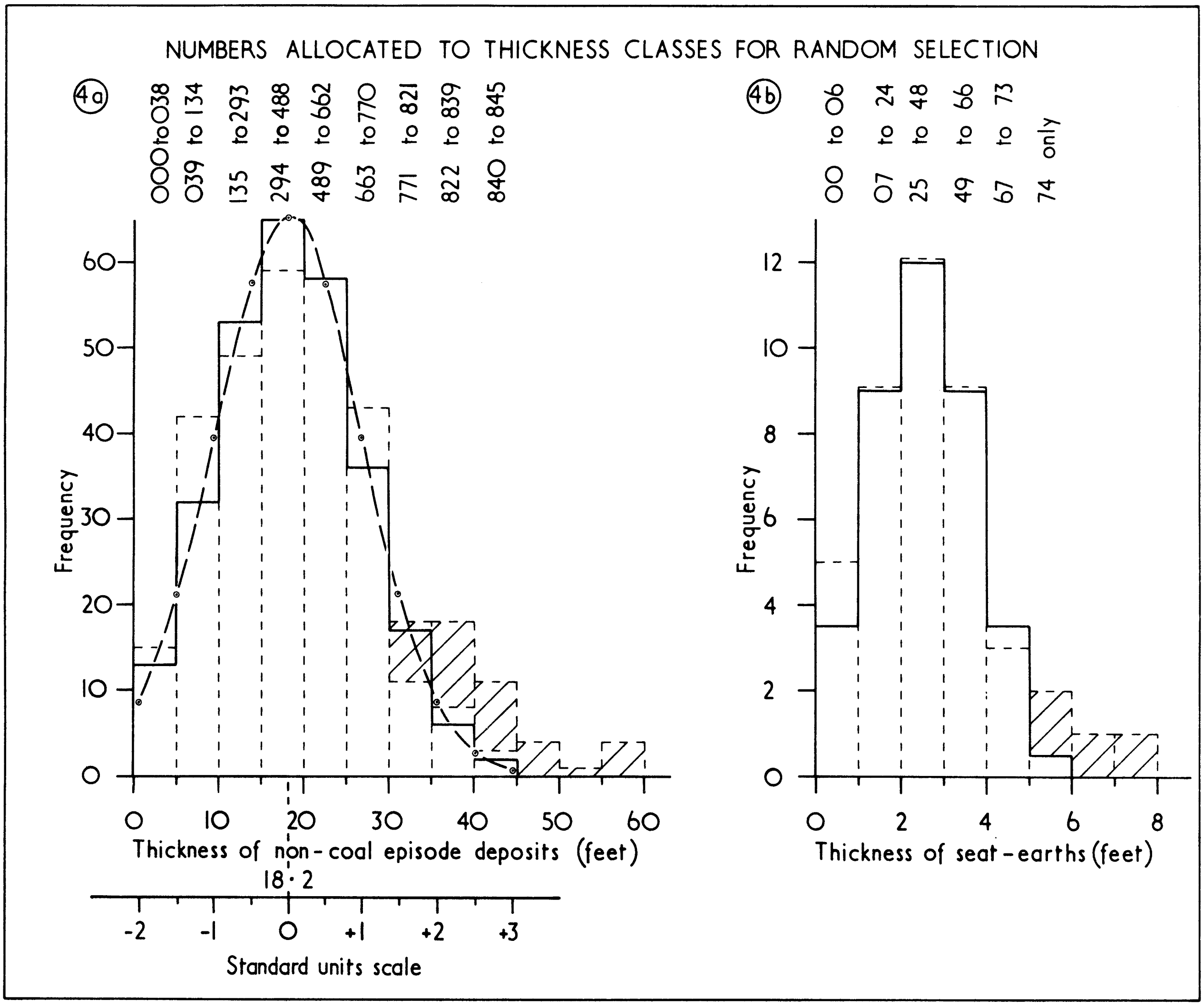
Apart from the wedge relationships referred to and the small-scale interfingering discounted, there is some interdigitation between facies in the seven boreholes (text-fig. 1). The occurrence and non-occurrence of facies alternations, involving beds from one to four feet thick and present in the boreholes at multiples of 40 feet in depth, was counted. The proportionate representation, on a volume basis, of these alternations involving the same specific facies is approximately indicated on text-fig. 2 by oblique and zig-zag lines. The oblique lines (zones 70 and parts of 50 and 99) indicate a 2-ft. bed of rippled sandstone within flaser silt-sandstones. The zig-zag lines decorate intercalation sub-zones wherein the column contains two separate sixths of the more proximal facies split by two-thirds of the more distal facies.

In accordance with the statistics presented in table 1, the approximate proportion of non-coal episode columns supporting a seat-earth is represented on text-fig. 2 by the area outlined by inverted 'γ' symbols. As already mentioned, greater accuracy is not feasible.

Thickness variation built into the model

Thicknesses of single episode strata columns, not involving coal, are recorded from seven boreholes in histogram form on text-fig. 4a. Some thick records destroying the symmetry of this histogram are assumed to represent more than one episode; this is likely on general grounds, backed by detailed correlation experience. After discounting these multi-storey thicknesses, an equivalent "normal frequency curve" was calculated by the method described by Krumbein and Graybill (1965, pp. 181-183). This curve, together with a theoretical histogram deduced from it, is shown on text-fig. 4a superimposed upon the factual histogram. The theoretical histogram is used for the operation of the model. Numbers in true sequence are allotted to each histogram column in proportion to the height of the column; three to each unit of frequency on text-fig. 4a. These numbers serve as the basis for random selection of episode column thickness within the observed normal frequency ranges. The thicknesses of facies beds within each column are derived as proportions of the whole thickness using the fractions plotted on text-fig. 3.

Episode boundaries within coal can in some cases be correlated with precision and in some cases only in an approximate manner, whilst in other cases they remain unrecognised. For this reason, and because they are probably controlled by the same general delta water levels, episode deposits involving coal and those not containing coal are assumed to have a comparable thickness range subject to a correction for gross differential compaction. Gross differential compaction between peat to coal and sediment to other rocks is therefore allowed for by dividing those thicknesses related to coal in columns on text-fig. 3 by a factor of 12 (Elliott, 1969, p. 119 and text-fig. 2). Differential compaction between mud to mudstone and sand to sandstone is not allowed for in this way. However, the percentage statistics upon which the facies proportions in the model



Text-figure 4 Thickness frequency distributions of deposits comprising an episode and of seat-earths. Broken-line histograms are based on borehole data, a proportion of which is discarded and shown cross-hatched. Full-line histograms are hypothetical; they are equivalent in area to the un-hatched factual histograms and represent a normal distribution. The normal curve was plotted from calculated values to a standard units scale prior to construction of the corresponding hypothetical histogram. For further explanation see text.

are based (Table 1) were derived from borehole log measurements, that is, from thicknesses of compacted sediments. A "dirt-layer" (a mining term for any non-coal layer within coal; often seat-earth mudstone) within the columns for zones 01 and 09, and forming the "flange" extending laterally from an intradistributary facies belt, is, as a matter of convenience only, reduced by the same factor.

Seat-earths are not represented in the columns of text-fig. 3; when required by the operating rules (see below) they are superimposed on whichever facies occurs at the sediment surface to a depth within that facies determined from text-fig. 4b. As in text-fig. 4a both factual and theoretical histograms are plotted; some thick records are discounted as being multi-storey and a normal distribution histogram is fitted approximately. No elaborate calculation was considered necessary to achieve this fit and the frequencies were derived directly from the 'Pascal triangle'. Two numbers are allotted to each unit of frequency as a basis for random selection of seat-earth thicknesses. The factual histogram is plotted from seat-earth thicknesses at Rosellewood borehole (text fig. 1), and both histograms have means very close to 2½ft. This thickness, spread over all relevant zones on text-fig. 2, provides the 14% required by the statistics of Table 1.

Model operating procedure

The episode column selection procedure to be described is one of 'Monte Carlo' type selection, or sampling from a stochastic model (Chorley and Haggett, 1967, p.582), that is, with predetermined 'odds'. The sampling is operated by the method of random grid plots (Cole and King, 1968) using the scales around the margin of the schematic map of text-fig. 2. This is followed by further controlled selection of stratigraphic features and of thicknesses.

In detail the procedure is as follows, and gives rise to a record as exemplified in table 3 and a plot therefrom such as text-fig. 5:

1. Select a pair of two-digit numbers from a random number table and plot as co-ordinates on the schematic map (text-fig. 2); the first as an abscissa, the second as an ordinate.

2. Read-off the zone number so located and identify the corresponding facies-column on text-fig. 3.

3. Select a three-digit random number, locate the same number on text-fig. 4a and read-off the corresponding thickness of episode deposits.

4. Plot the facies-column from 2 (above) using the thickness from 3 (above) apportioned out to each bed according to fractions read-off text-fig. 3. Plot any thickness of coal or "dirt" (the latter refers only to zones 01 and 09) as inches instead of feet.

5. If the facies column contains a bed referred to as "rippled sandstone or layered sand-siltstone" select a single-digit random number and calculate and plot the proportion of rippled sandstone listed in table 2:

Table 2

Digit	Proportion	Digit	Proportion	Digit	Proportion
0	8/9	3	4/9	6	2/9
1	6/9	4	3/9	7	1/9
2	5/9	5	2/9	8	1/9
				9	0/9

Layered sand-siltstone forms the remainder of the bed; the distribution is arbitrary.

6. If a washout sandstone is present in the selected facies-column, select a further single digit random number from the tables and plot an undulating base to the sandstone if the number is 7, 8 or 9 and the underlying facies is coal or if the number is 0, 1, 2, 3, 4, 5 or 6 and the underlying facies is other than coal.

7. If the co-ordinate plot fell within the area outlined by the inverted "γ" symbols on text-fig.2, superimpose seat-earth symbols on the top part of the episode column without plotting an extra thickness of deposits. Select a two-digit number and determine the thickness of this seat-earth by reference to text-fig. 4b.

8. If the co-ordinate plot fell within zones 02, 03, 07 or 08, or within the intercalated sub-zones to the "south" of zones 00 and 10, superimpose seat-earth symbols on the top part of the non-coal facies within the column. Select a two-digit number and determine the thickness of this seat-earth by reference to text-fig. 4b.

9. If coal, by chance under instruction 10 below, is to follow as the next facies in this model sequence and no seat-earth was required by the preceding instructions 7 or 8, allow for the accretion of a plant-bearing mudstone or passage facies and the development of a seat-earth theron prior to the plotting of the coal.

   Select a single-digit random number, between one to five inclusive, to represent directly the thickness in feet of the plant-bearing mudstone or passage facies and plot. Select the thickness of the seat-earth as under instruction 7 and superimpose its symbols on the plant-bearing mudstone overlapping them onto the underlying facies if necessary.

10. Consider the next episode by commencing again at instruction 1 above and using those random numbers that occur next in line in the particular tables used; and so on.

Testing the model against actuality

A test can be applied to the model, comparing facies relationships as they appear in the model sequence (table 3 and text-fig. 5) with those actually present in the Ollerton and Rosellewood (text-fig. 1) borehole logs. Such a test may be based on the simple mathematical device suggested by Selley (in the press).

For each sequence a data array is prepared listing the observed number of boundaries between each possible facies pair, and a similar array lists calculated frequencies of the same possible facies pairs assuming a completely random distribution. In the latter case the boundary frequencies depend only upon the numbers of beds of each facies that occur in the sequence, whereas, in actuality boundary frequencies depend, in addition, on any non-random feature that may be present in the arrangement of facies forming the sequence. This non-random contribution takes the form of episode facies columns in the model.

A third series of arrays records algebraic differences between the observed and randomised arrays, that is, they record the deviation of the observed numbers of each facies boundary class from the theoretical random equivalent. These deviation arrays are then compared.

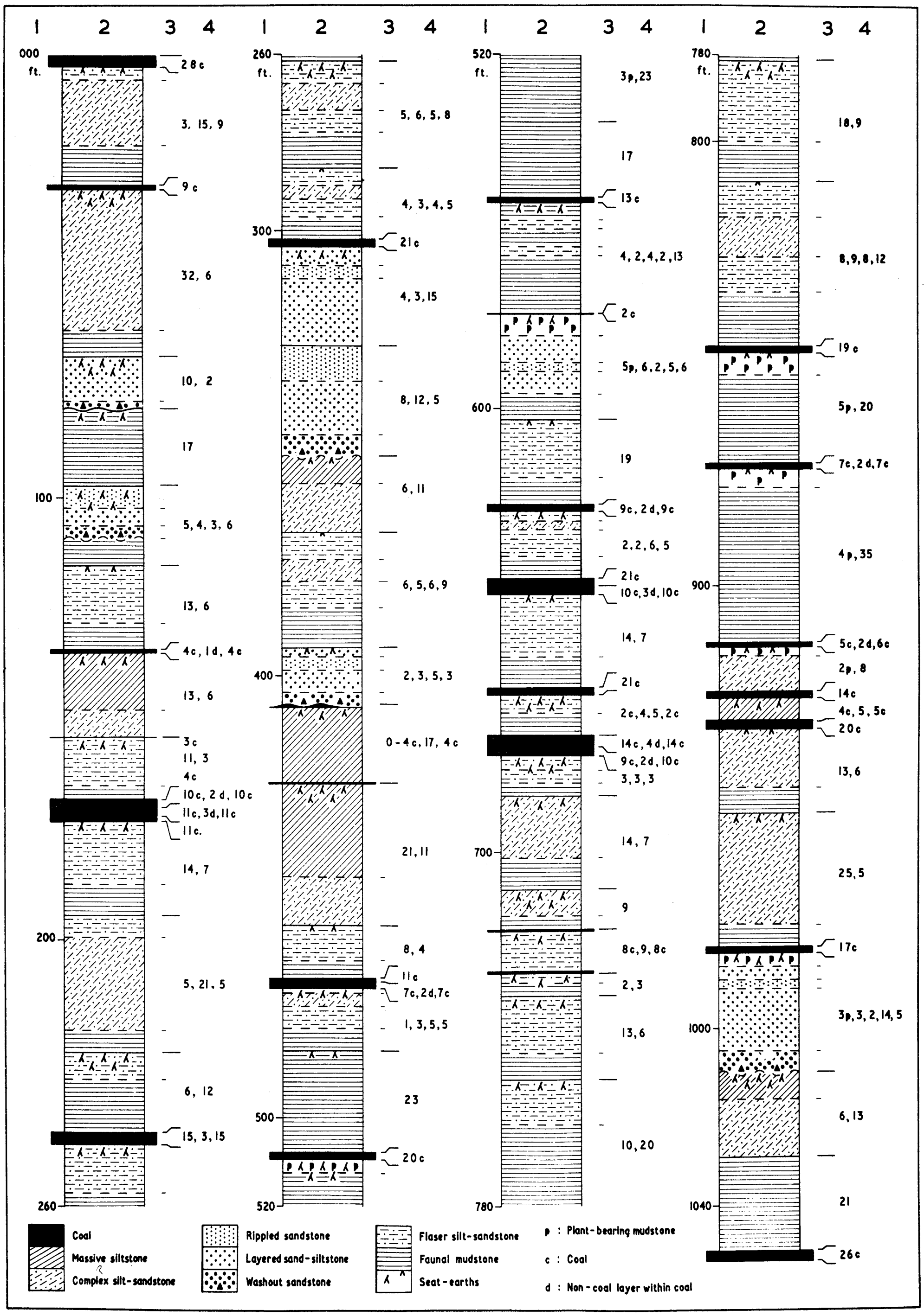
This test shows that the extent and distribution of deviations from the theoretical random facies boundary frequencies is similar in each of the three sequences. The extent to which model deviations differ from Rosellewood deviations is very similar to the extent to which Ollerton deviations differ from Rosellewood deviations.

TABLE 3 : MODEL SEQUENCE DATA

Random Digits	Zone on text-Fig.2.	Random Digits	Episode Thickness Ft.	Random Digits	Seat-earth Thickness Ft.	Minor random selections and general remarks
12,88	00	737	28	--	-	Coal, divide thickness by 12.
72,46	38	692	27	17	1.6	
79,78	10	118	9	--	-	Coal, plot as 1/12 thickness.
35,33	63	834	38	66	4.0	
48,90	05	195	12	54	3.3	9 - No rippled sandstone; 1 - erosive base.
21,03	95	385	17	30	2.2	
71,47	58	418	18	74	5.5	2 - 5/9 rippled sandstone; 3 - erosive base.
83,21	99	463	19	10	1.2	
68,74	09	110	9	--	-	Coal and ‘dirt’, plot as 1/12 thickness
41,46	14	451	19	37	2.5	
94,55	99/10	527	21	38	2.6	Intercalation sub-zone; plot coal as 1/12.
41,61	01	572	22	--	-	Coal and ‘dirt’, plot as 1/12 thickness.
69,91	09	654	25	--	-	Coal and ‘dirt’, plot as 1/12 thickness.
09,89	00	175	11	--	-	Coal, plot as 1/12 thickness.
19,52	11	525	21	25	2.0	
67,24	97	784	31	--	-	No seat-earth.
05,24	50	401	18	65	3.9	
60,58	09	801	33	--	-	Coal and ‘dirt’, plot as 1/12 thickness.
19,50	11	344	16	36	2.5	
91,49	29	634	24	64	3.8	
80,33	89	326	16	05	0.7	
21,81	00	509	21	--	-	Coal, plot as 1/12 thickness.
44,10	85	567	22	39	2.6	7 - 1/9 rippled sandstone.
50,27	55	651	25	--	-	4 - 3/9 rippled sandstone; 5 - erosive; no seat earth.
41,39	44	380	17	07	1.0	
88,49	29	695	26	04	0.6	
51,47	55	241	13	14	1.4	5 - 2/9 rippled sandstone; 7 - erosive base.
53,85	07	670	25	51	3.1	Intercalation sub-zone; plot coal as 1/12.
56,46	16	794	32	69	4.3	
96,29	99	208	12	08	1.1	
24,63	00	156	11	--	-	Coal, plot as 1/12 thickness.
30,93	01	331	16	--	-	Coal and ‘dirt’, plot as 1/12 thickness.
08,42	31	273	14	27	2.1	
99,01	95	590	23	13	1.3	
12,80	00	497	20	--	-	Coal, plot as 1/12 thickness.

TABLE 3 : MODEL SEQUENCE DATA

66,06	95	582	23	72	4.7	plot 3 ft. plant-bearing M. to support S.E.
31,06	95	374	17	--	-	No seat-earth.
22,88	00	218	13	--	-	Coal, plot as 1/12 thickness.
83,08	95/80	645	25	32	2.3	Intercalation sub-zone.
19,61	00	017	2	--	-	Coal, plot as 1/12 thickness
39,14	85	466	19	19	1.7	8 - 1/9 rippled S., 3 ft. plant-bearing M., seat-earth.
85,26	99	461	19	11	1.2	
64,75	09	505	20	--	-	Coal and 'dirt', plot as 1/12 thickness.
16,44	21	299	15	31	2.2	
92,90	00	541	21	--	-	Coal, plot as 1/12 thickness.
60,79	09	595	23	--	-	Coal and 'dirt', plot as 1/12 thickness.
78,21	99	540	21	10	1.2	
03,99	50/00	467	19	--	-	Coal, plot as 1/12 thickness.
03,55	09	233	13	54	3.3	Intercalation sub-zone; plot coal as 1/12.
63,57		796	32	--	-	Coal and 'dirt', plot as 1/12 thickness.
39,73	01	514	21	--	-	Coal and 'dirt', plot as 1/12 thickness.
13,32	61	108	9	60	3.7	
22,39	42	536	21	49	3.0	
77,45	49	117	9	66	4.0	
81,58	10/99	673	25	44	2.8	Intercalation sub-zone; plot coal as 1/12.
29,10	50/95	036	5	47	2.9	Intercalation sub-zone.
94,50	99	431	19	43	2.7	
95,14	50	764	30	64	3.8	
99,51	99	704	27	66	4.0	
88,51	29	828	37	07	1.0	
93,75	10	435	19	--	1.3	Coal, plot as 1/12 thickness.
57,03	95	482	20	06	-	plot 5 ft. plant-bearing M. to support S.E.
62,68	09	352	16	--	2.5	Coal and 'dirt', plot as 1/12 thickness.
32,05	95	817	35	10	-	plot 4 ft. plant-bearing M. to support S.E.
35,95	01	216	13	--	1.0	Coal and 'dirt', plot as 1/12 thickness.
55,26	96	102	8	12	1.3	plot 2 ft. plant-bearing M. to support S.E.
92,93	10	268	14	--	-	Coal, plot as 1/12 thickness.
44,73	02	266	14	36	2.5	plot coal beds as 1/12 thickness.
23,71	00	504	20	--	-	Coal, plot as 1/12 thickness.
91,45	49	430	19	06	1.0	
69,45	47	773	30	24	2.0	
85,93	10	384	17	--	-	Coal, plot as 1/12 thickness.
48,19	55	624	24	35	2.4	8 - 1/9 rippled S.; 5 erosive; 3 ft. plant - bearing M., seat-earth.
39,31	64	448	19	55	3.3	
68,05	95	516	21	--	-	No seat-earth.
29,95	00	675	26	--	-	Coal, plot as 1/12 thickness.



Text-figure 5 A plot of a simulated sequence derived according to the model operating rules. The columns headed 1 to 4 are:- 1: scale of feet; 2: facies sequence; 3: episode and facies boundaries; and 4: facies thicknesses within each episode, coal in inches, non-coal facies in feet.

It appears from this test that facies boundary frequencies can vary just as much between two factual sequences, 10 miles apart in Nottinghamshire, as they do between the model sequence and a factual sequence.

Boundaries between the deposits of two episodes but between two beds of the same facies (within "multi-story" beds), such as some of the horizons of "splitting" within composite coal beds, cannot always be recognised in borehole cores. All were ignored when compiling the observed data arrays for the sake of consistency. Since, however, multi-story boundaries within the model sequence have also been ignored for the purposes of the test, and there is an approximately similar number of boundaries listed from all three sequences, the result of the test should justify the above general conclusion.

Assessment of the model

By design the model has built into it:

1) non-coal episode thicknesses based directly upon borehole data;
2) facies proportions based directly upon borehole data;
3) the four sedimentation successions suggested by Elliott (1968);
4) simplified sub-delta devolution (Elliott, 1969);
5) schematic facies-body relationships and geometry, incorporating items 2, 3, and 4, and from which thicknesses of facies-beds forming part of an episode may be calculated and
6) seat-earth location and thicknesses based very approximately upon statistical borehole data.

Non-coal thicknesses being based upon borehole data are post-compactional measurements. All coal thicknesses selected according to the operating rules, are obtained as are those for non-coal facies and then divided by a differential compaction ratio of twelve (Elliott, 1969) A comparison of the range of thicknesses of coal in the Rosellewood and Ollerton boreholes and the model tends to support this procedure. Whilst coals less than one foot thick are more frequent in actuality than in the model, those from one to two feet thick are correspondingly less frequent, and other frequencies up to the six to seven feet class agree well.

The model assumes that Monte Carlo selection of episode columns from text-fig. 2 is constant for all selections, that is as it were for "all time". It might be suggested that the relative likelihood of selection of proximal columns and distal columns should vary, since the rate of epeirogenetic subsidence of the basin is likely to have varied, although within narrow limits. A visual comparison of the plotted model sequence with those of the borehole sequences does not reveal any need to vary episode column relative likelihoods. The longest run of distal columns compares well with the longest run in reality namely, that associated with Clay Cross Marine Band, and the thickest coal seam is the correct order of thickness, namely 5 - 7 ft. In fact the model section is readily correlated, on a lithological basis, with a generalised Nottinghamshire sequence! Delta switching theories in general and the episode theory upon which this address is based are supported by the realism of the model sequence illustrated here. A constant weighting of episode - column selection appears adequate and this mitigates against theories involving repeated crustal subsidence or spasmodic eustatic rises.

The test based on Selley's "simple mathematical device" gives results indicating that facies boundary frequencies are reasonably realistic in the model sequence.

A number of features which play a part in the building of actual detailed sequences are not built-into the model. In general, these appear to be of relatively minor consequence and include the following:-

1) The modification of facies-body geometry by local sedimentation processes such as erosion of levee flanks, lateral channel migration and the vertical extent of erosion preceding washout sandstones.

2) The detailed nature of the relationship between rippled sandstones and layered sand-siltstones.

3) The occurrence of minor sub-facies such as cannel coal, of probable transitional facies such as evenly laminated siltstones with no particular diagnostic sedimentary structures or fossils, and the infrequent occurrence of beds which might be separated out as facies not described in Elliott, 1969; for example, the ostracod lagoonal facies of Pollard (1969).

4) Random small-scale thickness variations superimposed upon those more determinate variations which are built in.

5) Thickness modification related to abnormal penecontemporaneous compaction of underlying deposits.

6) Intercalations of thin beds, generally less than one foot thick and representing two facies or, more commonly, one facies within a second thicker facies.

7) Abnormally thick 'shoestring' sandstone-siltstone bodies are not incorporated; these probably represent the deposits of multi-episode distributaries located proximally of a series of sub-delta switches (Elliott, 1969, pp. 128-129). Over 100 feet thicknesses of near continuous sandstone occur locally in the Nottinghamshire productive coal measures, but these are infrequent and only occur once in five boreholes each yielding details of about 1000 feet of measures.

Further study will reveal other features which should be listed here, but it appears that the shortcomings of the model are confined to the degree of detail exemplified in 1 to 7 above. Regarding point 5, thickenings due to abnormal penecontemporaneous compaction are incorporated in the statistical borehole data used and hence built into the model as part of the random episode thickness variation. However, this feature is not related to particular underlying lithologies in the model.

Conclusions

The model section thus appears to represent adequately the gross features of a mid-Nottinghamshire productive coal measures sequence, so far as this can be achieved conveniently, without utilising the services of a computer. Several refinements might be worth while and feasible if the model were computerised. Since the model is based on a constant weighting of episode-column selection, representing a steady state or equilibrium, its realism mitigates against theories involving irregular crustal subsidence or spasmodic eustatic rises.

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