Coal Studies

NUMERICAL DEPOSITIONAL MODELLING OF THE ELK VALLEY COALFIELD* (82G, J)

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INTRODUCTION

With the completion in 1987 of 1:10 000-scale mapping of the north half of the Elk Valley coalfield (Morris and Grieve, 1988 and in preparation), the last stage of the Elk Valley project, preparation of a bulletin, is under way. Statistical analysis of stratigraphic sequences in core logs and measured sections from the coalfield is now in progress. This article summarizes results to date.

The locations of drill cores used in this study are shown in Figure 4-1-1. A total of 3284.4 metres of core was logged, comprising ten separate holes. Some of these were described by Grieve and Elkins (1986). All holes penetrated mainly the Mist Mountain Formation, principal coal-bearing unit of the Jurassic-Cretaceous Kootenay Group (Gibson, 1985). The Mist Mountain Formation averages 500 metres in thickness in the study area. The minor proportion of the logged core is from the underlying Morrissey Formation and overlying Elk Formation (the other two formations within the Kootenay Group) and is omitted in this statistical analysis.

The overall depositional environment of the lower Mist Mountain Formation is believed to have been an extensive deltaic-interdeltaic coastal plain and, for the upper Mist Mountain Formation, a fluvial-alluvial plain (Gibson, 1985). It was deposited conformably and abruptly on the subaerial beach ridge – eolian dune lithofacies of the underlying Moose Mountain member of the Morrissey Formation. Fluvial channels within the Mist Mountain Formation were dominantly of the meandering type.

An embedded, first-order Markov chain analysis of the sedimentary sequence was carried out. This method is based on a test of the assumption that the occurrence of a particular sedimentary unit at any given position within the stratigraphic column is dependent on the nature of the immediately underlying unit. Thicknesses of individual units are not taken into account. The frequency of occurrence of upward transitions from one rock type to another is tallied and displayed in matrix form. A second matrix is then generated, containing predicted frequencies of occurrences of upward transitions, based on a theoretical totally random sequence. The difference between these two matrices gives an indication of which upward transitions are occurring more often than at random.

Substitutability analysis was also carried out (Davis, 1973). This analysis examines the tendency for two rock types to occur in a similar stratigraphic setting with respect to overlying and underlying units. Two rock types with high substitutability are usually assumed to have been deposited in similar sedimentary environments (Kilby and Oppelt, 1985).

METHODS OF STUDY

Thicknesses of individual units within core were measured to the nearest centimetre. Intervals representing sampled coal horizons were taken from company lithological and geophysical logs. Units thinner than 5 centimetres were generally not measured separately.

The core logging system of Research Planning Institute, Inc. (RPI) was utilized in this study (Ruby *et al.*, 1981). The RPI system uses three-digit codes to represent rock type, composition/colour, and sedimentary structures; suffixes modify sedimentary structures, and identify penecontemporaneous deformation, cement type, and presence of coal banding or spar. This system is readily applicable to Kootenay Group strata, and offers adequate degrees of detail, speed and consistency.

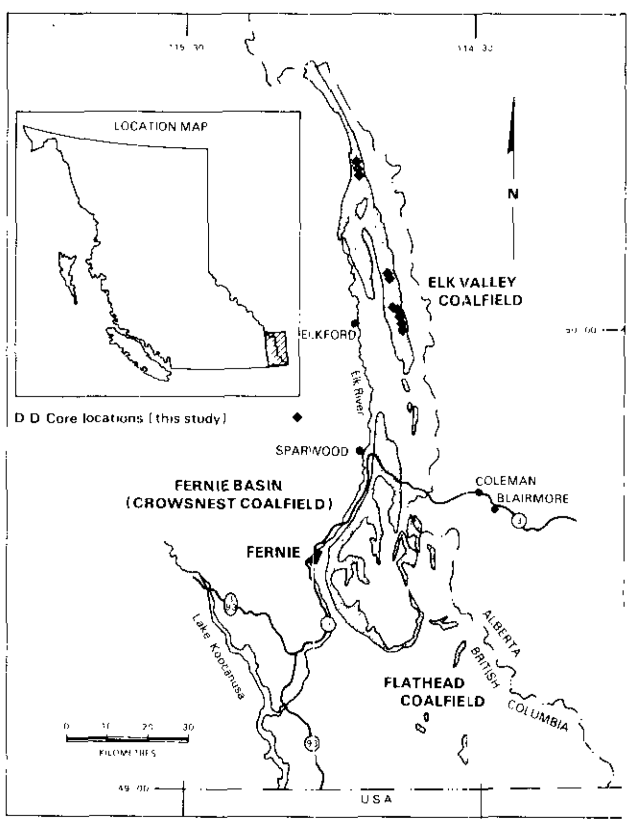

Figure 4-1-1. Locations of the three East Kootenay coalfields and drill cores used in this study.

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1988, Paper 1989- .

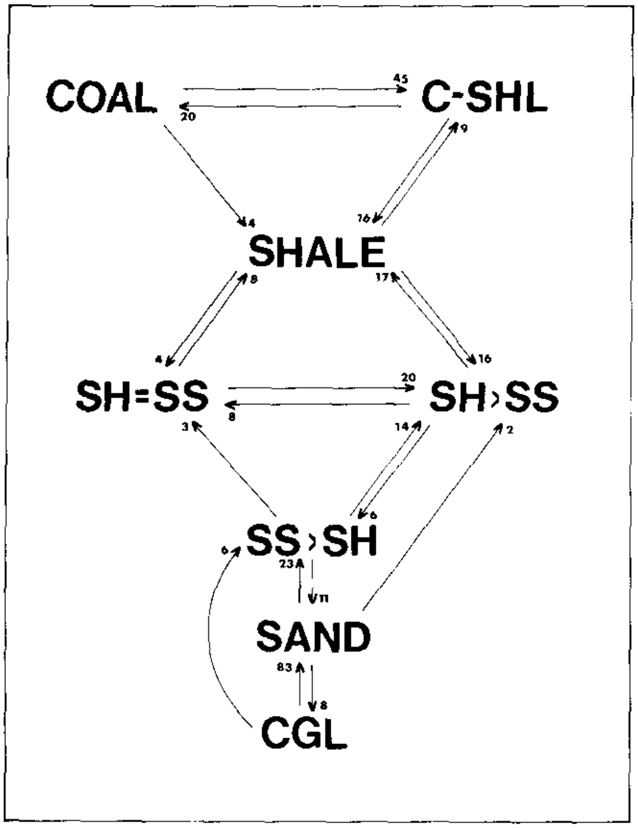

Figure 4-1-2. Transition diagram for the entire Mist Mountain Formation, based on the difference matrix (probabilities). Values less than 1 per cent omitted.

TABLE 4-1-1
ROCK-TYPE CODES USED FOR STATISTICAL ANALYSIS
(Derived from Ruby *et al.*, 1981)

Code	Explanation
CGL	**Conglomerate.** Generally chert-pebble composition.
SAND	**Sandstone.** Generally medium to very coarse grained. May be massive, flat bedded, or crossbedded.
SS>SH	**Intermixed shale and sandstone,** with sandstone in greater abundance than shale. Includes flaser-bedded sandstone, and wavy-bedded sandstone with interbedded shale. Sandstones generally fine grained.
SS=SH	**Intermixed shale and sandstone,** with both in roughly equal amounts. Predominantly lenticular-bedded sandstone with interbedded shale. Sandstone generally fine or very fine grained.
SH>SS	**Intermixed shale and sandstone,** with shale in greater abundance than sandstone. Includes shale with lenticular sandstone streaks, and sandy shales. Sandstone generally fine or very fine grained.
SHALE	**"Shale series".** Generally non-carbonaceous, grey siltstone, silty mudstone or mudstone. May be massive or laminated.
C-SHL	**Carbonaceous shale.** Generally dark grey to black mudstone or shale with coal streaks, bands or spar.
COAL	**Coal series.** Most often missing from core. Where observed it includes banded coal, dull massive coal, and coal with shale interbeds or streaked with shale.
X	**Missing core** (other than coal) and unloggable core.

Logs were entered into a computer database file using the dBASE III PLUS database management software. Fields were created for hole name, base and top of intervals, rock-type code, suffix modifiers, comments, and lastly, a second three-digit generalized rock-type code. This last field was used for the statistical analysis. It was needed because the number of lithological types identified during core logging was too numerous to handle statistically, and some types occur very infrequently. In effect, certain rock types were grouped together to produce a shorter list of lithologies. The list of eight rock-type codes and what they represent is shown in Table 4-1-1. All unloggable and missing core, other than coal removed for sampling, was given an X code and treated as a separate rock type.

The database file was converted to an ASCII file consistent with the Cal Data Ltd. software used in the analysis. Certain modifications to this file were made prior to statistical analysis. Most notably, all transitions from a specific rock type to the same rock type were eliminated simply by deleting one of the records involved. In instances where the same rock type occurs three or more times in succession, all but one of the records were deleted. This was necessary because the type of Markov chain analysis employed (embedded) is based on changes in lithology, irrespective of unit thickness. Another modification was the elimination of all records not belonging to the Mist Mountain Formation.

Subfiles of the overall modified database were defined, each subfile representing one core log. This was necessary to avoid inclusion of the transitions from the end of each core to the beginning of the next.

The modified database, which contains 3707 legitimate transitions, was then subjected to statistical analysis. The statistical computer programs developed and described by Kilby (in Kilby and Oppelt, 1985) were used and these, in turn, were based on techniques described by Siemers (1978) and Davis (1973). The first step in the procedure is generation of a count-transition matrix (Table 4-1-2) which displays the number of occurrences of each possible type of upward transition in the data. Next, an expected matrix is generated, which represents the number of upward transitions of each type which would occur in a totally random sedimentary sequence containing the same quantities of the various rock types. The difference matrix is then generated by subtracting the second matrix from the first (Table 4-1-2).

At this point it is possible to analyse the difference matrix to discover which upward transitions occur more frequently than at random, that is, those which are represented by positive values. Two outstanding examples include transitions from *SHALE* to *SH>SS* and vice versa, with positive difference values of 153 and 145, respectively (Table 4-1-2). Caution must be used in considering these numbers, however, because these two rock types occur most frequently in the database, and hence the number of transitions involving them is automatically high. To provide a more balanced analysis of the difference matrix, it is necessary to convert the positive frequency values in the difference matrix to probabilities based on the total number of transitions each unit is involved in, that is, to divide each positive element in the difference matrix by the sum of all the elements in the

TABLE 4-1-2

Transition, expected, difference and substitutability matrices for the entire Mist Mountain Formation.

Transition Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	15	2	0	1	0	0	0	0
SAND	15	0	58	21	47	32	10	1	0
SS>SH	2	48	0	47	114	76	15	1	7
SS=SH	0	21	34	0	196	159	39	2	3
SH>SS	0	43	125	173	0	377	137	8	9
SHALE	1	40	71	162	383	0	242	64	18
C-SHL	0	17	15	43	105	252	0	158	7
COAL	0	1	2	4	11	73	146	0	5
X	0	0	3	4	12	19	7	4	0

Expected Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	0	1	2	4	4	2	1	0
SAND	0	9	15	22	43	49	29	11	2
SS>SH	1	15	25	37	72	82	49	19	4
SS=SH	2	22	37	55	106	121	73	29	6
SH>SS	4	43	72	106	204	232	140	56	1
SHALE	4	48	82	120	230	261	157	63	12
C-SHL	2	29	49	73	139	159	96	38	7
COAL	1	12	20	29	56	64	38	15	3
X	0	2	4	6	11	13	7	3	0

Difference Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	15	1	-2	-3	-4	-2	-1	0
SAND	15	-9	43	-1	4	-17	-19	-10	-2
SS>SH	1	33	-25	10	42	-6	-34	-18	3
SS=SH	-2	-1	-3	-55	90	-38	-34	-27	-3
SH>SS	-4	0	53	67	-204	145	-3	-48	-2
SHALE	-3	-8	-11	42	153	-261	85	1	6
C-SHL	-2	-12	-34	-30	-34	93	-96	120	0
COAL	-1	-11	-18	-25	-45	9	108	-15	2
X	0	-2	-1	-2	1	6	0	1	0

Difference Matrix (Positive values converted to % probabilities)

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL		83.6	5.6					
SAND	8.2		23.4		2.2			
SS>SH	0.3	10.6		3.2	13.5			
SS=SH					19.8	8.4		
SH>SS			6.1	7.7		16.6		
SHALE				4.3	15.6		8.7	0.1
C-SHL						15.6		20.1
COAL						3.7	44.6	

Upward Substitutability Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL	1.000							
SAND	0.125	1.000						
SS>SH	0.358	0.680	1.000					
SS=SH	0.147	0.751	0.908	1.000				
SH>SS	0.129	0.620	0.584	0.597	1.000			
SHALE	0.150	0.662	0.754	0.690	0.322	1.000		
C-SHL	0.010	0.545	0.697	0.749	0.729	0.376	1.000	
COAL	0.010	0.321	0.368	0.462	0.649	0.501	0.378	1.000

Downward Substitutability Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL	1.000							
SAND	0.109	1.000						
SS>SH	0.389	0.705	1.000					
SS=SH	0.152	0.837	0.891	1.000				
SH>SS	0.188	0.709	0.521	0.644	1.000			
SHALE	0.010	0.681	0.741	0.663	0.303	1.000		
C-SHL	0.010	0.644	0.722	0.824	0.714	0.448	1.000	
COAL	0.010	0.406	0.295	0.442	0.531	0.514	0.308	1.000

Mutual Substitutability Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL	1.000							
SAND	0.010	1.000						
SS>SH	0.139	0.479	1.000					
SS=SH	0.010	0.629	0.809	1.000				
SH>SS	0.010	0.440	0.304	0.384	1.000			
SHALE	0.010	0.452	0.559	0.458	0.010	1.000		
C-SHL	0.010	0.362	0.503	0.618	0.521	0.168	1.000	
COAL	0.010	0.130	0.108	0.204	0.344	0.258	0.116	1.000

corresponding row in the count-transition matrix. (This may also be accomplished by expressing the values in the first two matrices as probabilities, and simply subtracting the second from the first to generate the difference matrix). The difference matrix with positive values expressed as probabilities (percentages) is shown in Table 4-1-2. Examination of this matrix shows that, for example, the 15 transitions from *CGL* to *SAND*, representing an 83.3 per cent probability, are more significant than the seemingly impressive 153 transitions from *SHALE* to *SH>SS*, representing a 15.6 per cent probability, referred to earlier.

All transitions involving missing or unloggable core were ignored.

The probability-difference matrix was converted to graphic form for easier interpretation (Figure 4-1-2). All positive upward transitions, except those below an arbitrary cut-off of 1 per cent, are displayed as an arrow connecting the two lithologies. The positions of the various lithologies on the diagram were selected to simulate a general fining-upward sequence and to show the upward transitions in as simple a manner as possible.

The count-transition matrix is tested for the Markov property by means of a chi-square test, as described by Davis (1973). In this application, rejection of the null hypothesis implies that the transitions observed are dependent to a significant degree (not random) and thus form a Markov chain.

The process was repeated twice, once for each of two subsets of the database. The first represents all strata within 200 metres of the base of the Mist Mountain Formation, and the second strata more than 200 metres above the base. The first contains 2216 transitions and the second 1485 transitions. These were generated to see if there are any sedimentological differences between the lower and upper parts of the formation in the study area.

Three further matrices (Table 4-1-2), known as the substitutability matrices, were generated for the entire formation data following the methods of Davis (1973). Values in the upward-substitutability matrix indicate the tendency of any two lithologic units to be overlain by a similar lithological unit (maximum value 1). The downward-substitutability matrix is the same except that the values indicate the degree of similarity for two lithologic units to be underlain by a similar lithological unit. The mutual-substitutability matrix measures the degree to which two units are overlain and underlain by similar units. The upward-substitutability matrix is calculated from the transition matrix for each pair of lithologies by calculating the cross-product ratio of the respective rows (*see* Davis, 1973). The downward-substitutability matrix is calculated in the same manner but using columns instead of rows. The mutual-substitutability matrix is obtained by multiplying the corresponding values from the upward and downward-substitutability matrices.

RESULTS AND DISCUSSION

Matrices related to the entire Mist Mountain Formation are shown in Table 4-1-2, those related to the lowest 200 metres in Table 4-1-3, and those related to strata more than 200 metres above the base in Table 4-1-4. Corresponding transition diagrams based on the probability-difference matrices are shown in Figures 4-1-2, 3 and 4. Results for the entire Mist Mountain Formation will be discussed first, followed by a comparison of the lower and upper portions of the formation. Rock-type abbreviations will be used throughout. Explanations of the abbreviations are given in Table 4-1-1.

Starting at the base of the transition diagram (Figure 4-1-2), *CGL*, although a rare rock type, shows a very strong trend (83 per cent probability) to be overlain by *SAND*. *SAND* is most likely to be overlain by *SS>SH* (23 per cent). *SS>SH* is most often overlain by *SH>SS* (14 per cent), but is almost as likly to be overlain by *SAND* (11 per cent). *SS = SH* tends to be overlain by finer units, especially *SH>SS* (20 per cent). *SH>SS* is most likely to be overlain by *SHALE* (17 per cent). SHALE shows a stronger trend to be overlain by coarser rock types, especially *SH>SS* (16 per cent), than by *C-SHL* (9 per cent). *C-SHL* shows roughly equal likelihood of being overlain by *SHALE* (16 per cent) or *COAL* (20 per cent). *COAL* is most likely to be overlain by *C-SHL* (45 per cent).

The chi-square test of the transition matrix for the Markov property yielded a value of 452 321. This represents a very strong rejection of the null hypothesis that the observed rock-type transitions are produced by random events.

Fluvial sediments in general can be subdivided into those derived from point-bar deposition and those deposited in the floodplain (Walker and Cant, 1984). In the Mist Mountain Formation the point-bar environment is represented by prominent fining-upward "channel" sandstone bodies, which consist predominantly of medium-grained or coarser sandstone, together with rare conglomerate which forms as basal channel-lag deposits, and fine and very fine-grained sandstone to siltstone, in the upper parts.

The floodplain environment in the Mist Mountain Formation, which is the more common, includes levee, crevasse-splay and flood-basin deposits (Gibson, 1985). As pointed out by Dunlop and Bustin (1987), levee deposits are difficult to recognize in the Mist Mountain Formation, especially in vertical sections, and may be indistinguishable from cre-

TABLE 4-1-3

Transition, expected and difference matrices for the lowest 200 metres of the Mist Mountain Formation.

Transition Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	12	2	0	0	0	0	0	0
SAND	12	0	39	10	34	22	7	1	0
SS>SH	2	34	0	27	80	57	6	0	2
SS=SH	0	9	22	0	118	91	27	0	1
SH>SS	0	33	84	107	0	220	93	7	2
SHALE	0	28	51	92	231	0	132	31	7
C-SHL	0	9	8	29	71	137	0	83	4
COAL	0	0	1	1	5	45	74	0	0
X	0	0	1	1	4	6	3	1	0

Expected Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	0	1	1	3	3	2	0	0
SAND	0	7	11	15	30	32	19	6	0
SS>SH	1	11	19	25	50	54	32	11	1
SS=SH	1	15	25	32	65	69	41	14	1
SH>SS	3	30	51	65	133	142	84	30	3
SHALE	3	32	53	68	140	149	88	31	4
C-SHL	2	19	32	41	83	88	52	18	2
COAL	0	7	11	15	30	32	19	6	0
X	0	0	1	1	3	4	2	0	0

Difference Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	12	1	−1	−3	−3	−2	0	0
SAND	12	−7	28	−5	4	−10	−12	−5	0
SS>SH	1	23	−19	2	30	3	−26	−11	1
SS=SH	1	−6	−3	−32	53	−22	−14	−14	0
SH>SS	−3	3	33	42	−133	78	9	−23	−1
SHALE	−3	−4	−2	24	91	−149	44	0	3
C-SHL	−2	−10	−24	−12	−12	49	−52	65	2
COAL	0	−7	−10	−14	−25	13	55	−6	0
X	0	0	0	0	1	2	1	1	0

Difference Matrix (Positive values converted to % probabilities)

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL		85.7	7.1					
SAND	9.6		22.4		3.2			
SS>SH	0.5	11.1		1.0	14.4	1.4		
SS=SH					19.8	8.2		
SH>SS		0.5	6.0	7.7		14.3	1.6	
SHALE				4.2	15.9		7.7	
C-SHL						14.4		19.1
COAL						10.3	43.7	

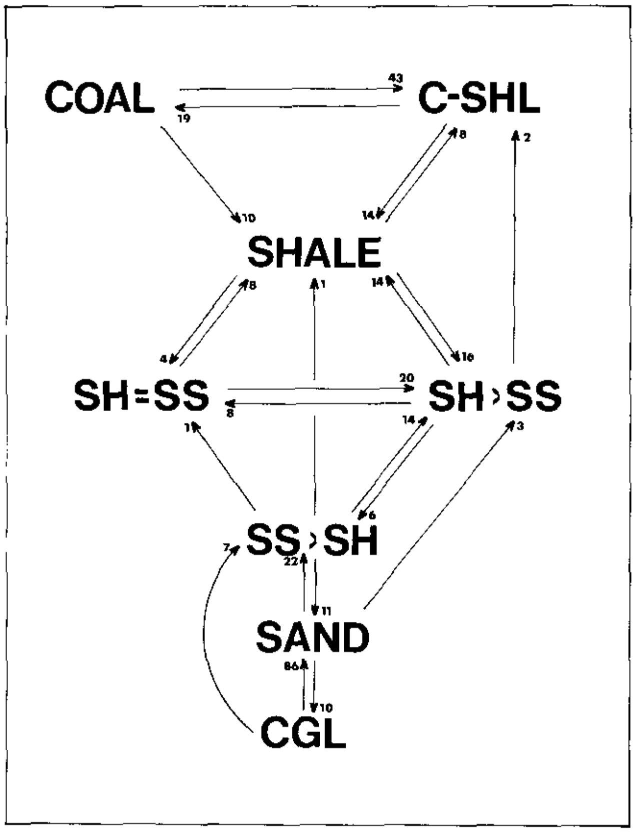

Figure 4-1-3. Transition diagram for the lowest 200 metres of the Mist Mountain Formation, based on the difference matrix (probabilities). Values less than 1 per cent omitted.

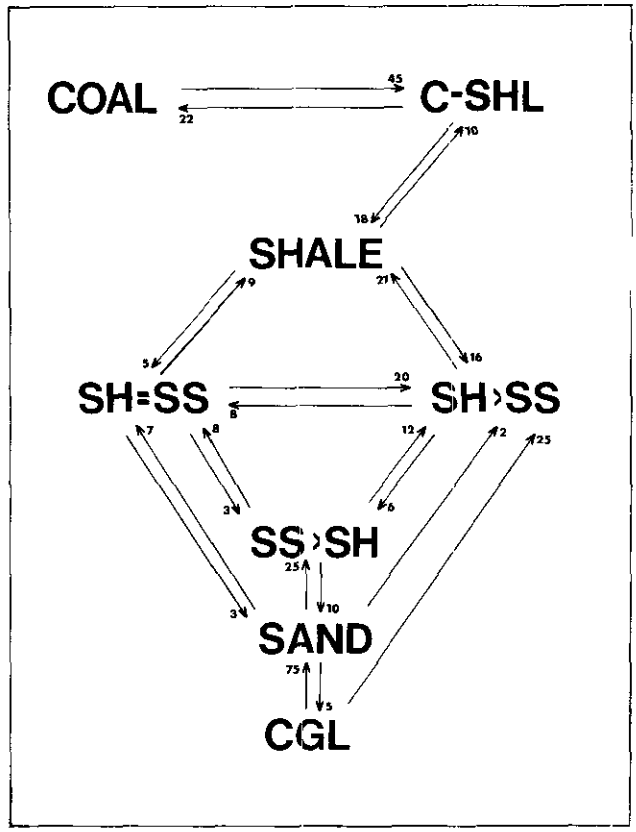

Figure 4-1-4. Transition diagram for strata more than 200 metres above the base of the Mist Mountain Formation, based on the difference matrix (probabilities). Values less than 1 per cent omitted.

TABLE 4-1-4

Transition, expected and difference matrices for strata more than 200 metres above the base of the Mist Mountain Formation.

Transition Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	3	0	0	1	0	0	0	0
SAND	3	0	19	11	13	10	3	0	0
SS>SH	2	14	0	20	34	19	9	1	5
SS=SH	0	12	12	0	78	68	12	2	2
SH>SS	0	10	41	66	0	157	44	1	7
SHALE	1	12	20	70	152	0	107	33	11
C-SHL	0	7	7	14	34	115	0	74	3
COAL	0	1	1	3	6	28	71	0	5
X	0	0	2	3	8	13	4	3	0

Expected Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	0	0	0	0	1	0	0	0
SAND	0	2	4	7	12	16	9	4	1
SS>SH	0	4	7	12	22	28	17	7	2
SS=SH	0	7	12	23	40	51	31	14	4
SH>SS	0	12	22	41	71	90	54	25	7
SHALE	1	16	27	51	89	112	68	31	9
C-SHL	0	10	17	32	55	70	42	19	5
COAL	0	4	7	14	25	31	19	8	2
X	0	1	2	4	7	9	5	2	0

Difference Matrix

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL	X
CGL	0	3	0	0	1	-1	0	0	0
SAND	3	-2	15	4	1	-6	-6	-4	-1
SS>SH	0	10	-7	8	12	-9	-8	-6	3
SS=SH	0	5	0	-23	38	17	-19	-12	-2
SH>SS	0	-2	19	25	-71	67	10	-24	0
SHALE	0	-4	-7	19	63	-112	39	2	2
C-SHL	0	-3	-10	-18	-21	45	-42	55	-2
COAL	0	-3	-6	-11	-19	-3	52	-8	3
X	0	-1	0	-1	1	4	-1	1	0

Difference Matrix (Positive values converted to % probabilities)

	CGL	SAND	SS>SH	SS=SH	SH>SS	SHALE	C-SHL	COAL
CGL		75			25			
SAND	5.1		25.4	6.8	1.7			
SS>SH		9.8		7.8	11.8			
SS=SH		2.7			20.4	9.1		
SH>SS			5.8	7.7		20.6		
SHALE				4.7	15.5		9.6	
C-SHL						17.7		21.7
COAL							45.2	

vasse-splay deposits. All rock types finer than and including fine-grained sandstone are included in the floodplain environment with the finest units deposited in the flood basin.

The results suggest a fining-upward depositional sequence with sandstone (or conglomerate) at the base and coal at the top, with numerous combinations of transitional events possible within the sequence. It must be reiterated here that although the transition diagrams were deliberately drawn to simulate a general fining-upward sequence, the results of the analysis are definitely consistent with this model. For example, *CGL* (channel lag) is nearly always overlain by *SAND*. *SAND* is overlain by an intermixed sandstone and shale unit, usually *SS>SH*. Interestingly, the direct fining-upward transition from *SAND* to *SHALE* is not observed to a significant degree. If *SAND* is assumed to be the characteristic component of a point-bar deposit, and *SHALE* is taken as the major component of the flood-basin deposit, then it is apparently not possible to make the transition from one environment to the other without the intermediate lithologies. This suggests that either the intermixed sandstone and shale rock types are an integral part of the point-bar deposits, or that another floodplain environment must first be "passed through" before reaching the flood basin. The possibilities for the latter suggestion are levees and crevasse splays, which as was pointed out earlier, are difficult to distinguish. The intermixed sandstone and shale rock types are expected to be characteristic of both (Dunlop and Bustin, 1987).

Deposition of distal crevasse-splay deposits on the floodplain is believed to have occurred in the instances where intermixed shale and sandstone units, either *SS = SH* or *SH>SS*, directly overlie *SHALE*. These results suggest that this is more likely to occur than the transition from *SHALE* to the carbonaceous units, *C-SHL* and *COAL*. Interestingly, *COAL* only occurs overlying *C-SHL*, suggesting a gradual transition to the coal-forming environment, and perhaps a relatively isolated environment for coal deposition. *COAL* is most often overlain by fine-grained units, either *C-SHL* or *SHALE*, sugesting that coal deposition is terminated by invasion of flood-basin sediments, perhaps related to increased rate of subsidence in the swamp.

The results are also interesting in that they do not indicate how the depositional sequence described above begins. In other words, there is no evidence of *SAND* or *CGL* overlying units finer than *SS>SH*. It is known from field evidence that channel sandstones frequently overlie fine-grained sequences and in many instances they are observed to directly overlie carbonaceous units, including coal. This transition, in effect, would represent the end of one cycle and the start of the next. The only comment which can be made here is that the transition matrix (Table 4-1-2) does indicate instances where *SAND* overlies either SHALE, *C-SHL* or *COAL*, but the number of occurrences is less than that expected in random situations (expected matrix). This may be partly a function of the high degree of detail in which these cores were logged; the significance of single large-scale events has perhaps been lost in the process of distinguishing such a large number of transitions, most of which represent fairly subtle changes in environment. In effect, the significance of a thick point-bar sandstone body directly overlying a coal-bearing zone depends on whether the latter zone is defined as one unit or as a series of several alternating rock types, as was done here, including *COAL*, *C-SHL* and *SHALE*. It is hoped that similar statistical analysis of sections measured in the field in the same area will yield results which favour large-scale changes.

Analysis of the three substitutability matrices for the entire formation (Table 4-1-2) is both instructive and somewhat confusing. For example, they show that the rock types *SS = SH* and *SS>SH* have a very high degree of substitutability, suggesting their depositional environments were similar. Given the lithological similarity of these two units (Table 4-1-1), and their common presumed association with the upper part of point-bar and/or crevasse-splay depositional environments, this result is not srprising. More unexpected, however, are the relatively high substitutabilities for such pairs of rock types as *C-SHL* and *SS = SH*, *SHALE* and *SS>SH*, and *C-SHL* and *SS>SH*. The depositional model derived from the Markov analysis does not suggest that any of these pairs would be highly substitutable, as their presumed depositional environments are significantly different. Further work will be necessary to explain these results.

The results for the lowest 200 metres of the Mist Mountain Formation and the overlying portion of the formation are presented in Tables 4-1-3 and 4; Figures 4-1-3 and 4. They are in general similar to those for the whole formation, and will not be described in detail. Moreover, the results for the two subsets of data are not markedly different from each other, suggesting the same depositional processes apply to both. This is somewhat surprising given the different depositional settings postulated for the lower and upper parts of the formation (*see* Introduction). There are in fact some subtle differences, such as the fairly weak tendency for *SAND* to overlie and be overlain by *SS = SH* in the upper part of the formation, which did not appear in the lower part or in the formation as a whole. This may suggest a subtle contrast in the deposition of the upper part of point-bar deposits between the upper and lower parts of the formation. Another contrast is in the roof-rock of coal seams. *COAL* in the upper part of the formation is always overlain by *C-SHL* (Figure 4-1-4), in contrast with the lower part of the formation in which *COAL* is overlain by both *C-SHL* and *SHALE*. This may suggest a more gradual "choking out" of coal deposition by shale in the upper part of the formation.

Chi-square tests of the count-transition matrices for the lower and upper parts of the formation also yield high values.

CONCLUSIONS

Statistical analysis of detailed core logs of the Mist Mountain Formation from the Elk Valley coalfield indicates that the sequence has a first-order Markov property. An overall fining-upward sequence is suggested, typical of deposition within a meandering fluvial channel and associated floodplain. Some interesting features of the sequence defined here include:

- *CGL* is closely associated with *SAND*, consistent with a channel-lag deposit.
- *SAND* is generally overlain by intermixed sandstone and shale units, suggesting a gradual transition from a point-bar to a flood-basin environment which is charac-

terized by *SHALE*. These transitional strata may represent an integral part of the point-bar facies or may be part of transitional environments, such as levees or crevasse splays.

- *SHALE* is more likely to be overlain by intermixed sandstone and shale, probably representing distal crevasse-splay deposits, than by carbonaceous units.
- *C-SHL* (carbonaceous shale) is the only rock type which is overlain by *COAL* to a significant degree. This suggests a gradual transition to the coal-forming environment.
- *COAL* is most often overlain by *C-SHL*, and, to a much lesser degree, *SHALE*. This suggests that coal deposition is usually terminated gradually, by invasion of flood-basin sediments.

On the basis of this analysis, the lowest 200 metres of the formation does not differ markedly from the remainder of the formation.

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