COAL RANK VARIATIONS IN THE TELKWA COALFIELD, CENTRAL BRITISH COLUMBIA (93L/11)

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KEYWORDS: Coal rank, coal quality, Telkwa coalfield, medium volatile, bituminous, coking coal, anthracite, thrusts.

INTRODUCTION

The Telkwa coalfield, which is centred on Smithers in central British Columbia, extends for about 50 kilometres along the Bulkley River from north of Smithers to south of Telkwa (Figure 4-8-1). This paper presents 286 mean maximum reflectance measurements of vitrinite from coal samples from outcrop and drill holes in the coalfield. The data are analyzed and the significance of variations in coal rank vertically through the stratigraphy and laterally within single seams is discussed. Analysis of mean maximum reflectance of vitrinite data ($\bar{R}_{max}$) provides some insights into the depositional and post-depositional history of the Telkwa coalfield. It also indicates that there may be resources of metallurgical coal and anthracite in the field.

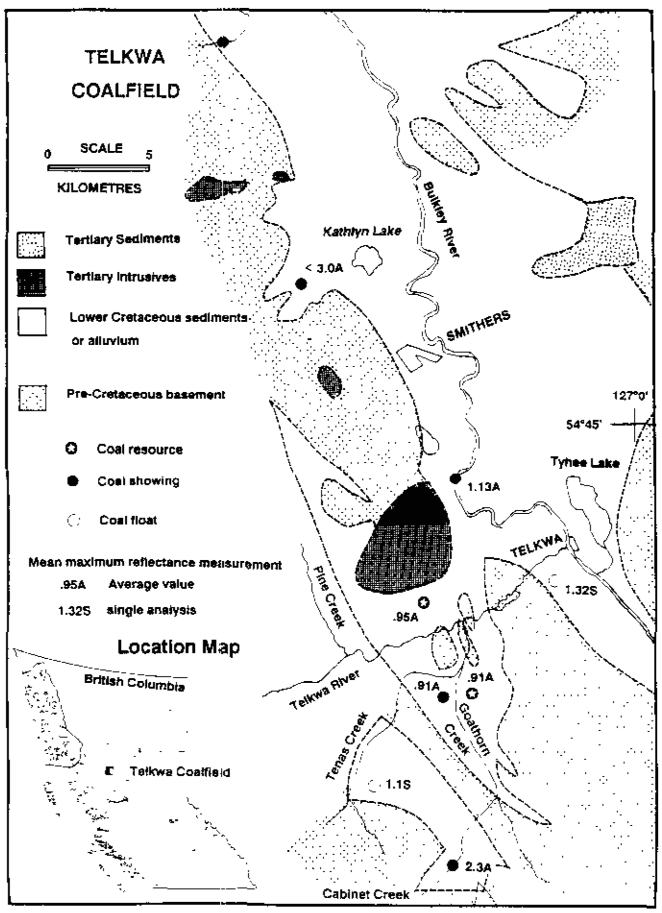

Figure 4-8-1. Regional geological map of the Telkwa coalfield.

Telkwa coalfield geology is discussed in several papers (Koo, 1983; Palsgrove and Bustin, 1989) and is covered by regional geology maps of MacIntyre *et al.* (1989) and Tipper (1976). Coal-bearing rocks in the coalfield belong to the Skeena Group of Lower Cretaceous age and are assigned to the Red Rose Formation of Albian age and possibly also to the older Kitsun Creek Formation of Hauterivian age.

Much of the basin is covered by alluvium. Coal outcrops northwest of Smithers, south of Smithers in the Bulkley River, north of the Telkwa River east of Pine Creek, east and west of Goathorn Creek and at the headwaters of Tenas and Cabinet creeks (Figure 4-8-1). The known coal outcrops are widely separated and restricted to the west side of the Bulkley River, leaving room for additional exploration. Cretaceous rocks east of the Bulkley River are coarser grained, indicating that they are either a different unit within the Skeena Group or that there is a facies change from nonmarine in the west to shallow-marine in the east.

RECENT EXPLORATION HISTORY

The Telkwa coal exploration property, which occupies less than 10 per cent of the whole field, is 15 kilometres south of Smithers and is centred on the confluence of the Telkwa River and Goathorn Creek. Most exploration to date has been on the Telkwa coal property both in the Goathorn Creek area and east of Pine Creek. Measured coal resources for these two areas, and probable coal resources in the Cabinet Creek area, have been estimated at 30 million tonnes. The Telkwa coal property was intensively explored by Crowsnest Resources Limited during the period from 1978 to 1990 when over 350 exploration holes were drilled and a large test-pit excavated. The exploration activity is recorded in a number of geological assessment reports covering the years 1978 to 1989 and in Prospectus, Stage 1 and Stage 2 submissions to the B.C. Ministry of Energy, Mines and Petroleum Resources.

The Cretaceous stratigraphy at the Telkwa coal property was divided into four units by Palsgrove and Bustin (1989). The lowest unit, which is 20 to 100 metres thick, rests unconformably on Lower Jurassic volcanic rocks of the Telkwa Formation, Hazelton Group. It is a nonmarine, coarse clastic unit which contains a single coal zone composed of up to six coal bands together referred to as Seam 1 or Coal Zone 1. Often, one of these bands contains a radioactive marker apparent on downhole geophysical logs and probably represents a layer of volcanic ash. The cumulative coal thickness varies up to 7 metres in the area considered for development (Figure 4-8-2).

Unit 2 is composed of 60 to 170 metres of shallow-marine mudstones and siltstones. It is lithologically monotonous and contains no coal.

Unit 3 consists of mudstones, siltstones, coal and sandstones and averages 90 metres in thickness. It contains the

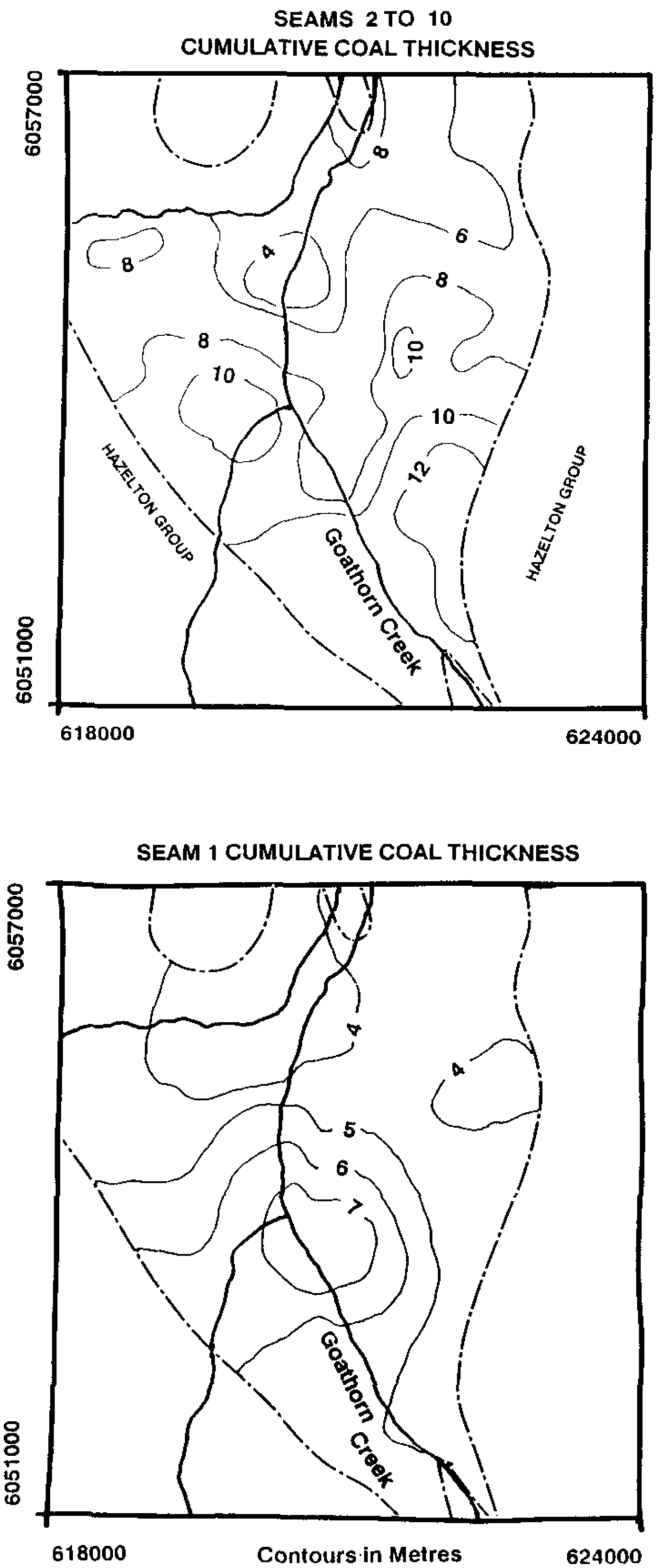

Figure 4-8-2. Cumulative coal thickness for the upper seams (2 to 10) and Seam 1; Goathorn Creek area.

major coal-bearing zone comprising Seams 2 to 10. The cumulative coal thickness ranges from 6 to 14 metres in the area considered for development (Figure 4-8-2). Unit 3 is overlain by the sandstone-rich Unit 4 of unknown thickness.

An understanding of the structural geology of the Telkwa coal property is based largely on information from drilling and geophysical surveys. Bedding generally dips gently southeast or east and is disrupted by at least two generations of faulting. Early faults are east-dipping thrusts; late steep-dipping faults trend northwest or northeast.

DATA SOURCES AND ANALYTICAL TECHNIQUES

Samples used in this study are from:

- Coal outcrop samples collected by the author during the summers of 1990 and 1991 (Table 4-8-1).
- Drill-core samples in the Geological Survey Branch (GSB) rock-sample collection originally collected by J. Koo (Table 4-8-2).
- Drill-core samples from holes drilled, logged and sampled by Matheson and Van Den Bussche (1990) as part of the GSB subsurface coal-sampling program (Table 4-8-2).

All samples were analyzed for mean maximum reflectance by JoAnne Schwemler. Polished pellets of 20-mesh sized coal grains were prepared and the reflectance in oil of at least 50 grains was measured from each pellet.

It is important to understand the component errors in the total reproducibility error for a single sample analysis. The error of the optical procedure is usually considered to be about 0.01 per cent at one standard deviation (Bustin, 1983). The same paper lists a set of duplicate analyses made by different laboratories, the one standard deviation of these inter-laboratory analyses is 0.06 per cent; reproducibility within a single laboratory should be considerably better.

Sampling bias and natural variations within the seam also influence the scatter of values obtained from a suite of related samples. Matheson and Van Den Bussche (1990)

TABLE 4-8-1
TELKWA COALFIELD
OUTCROP COAL SAMPLES

SAMPLE	EAST	NORTH	COMMENTS	SEAM	TYPE	R Max
90-150	620980	6047480	Cabinet Cr	u	oc	2.20
90-150	620980	6047480	Cabinet Cr	u	oc	2.30
90-154	620960	6047240	Cabinet Cr	u	oc	2.33
90-155	620980	6047160	Cabinet Cr	u	oc	2.36
90-155	620980	6047160	Cabinet Cr	u	oc	2.44
90-29	620750	6066250	Bulkley R	u	oc	1.27
90-15	620100	6066100	Bulkley R	u	oc	1.00
90-121	621040	6053280	Goathorn Cr	u	oc	0.94
90-134	616200	6051200	Tenas Cr	?	f	1.10
90-72	625180	6059900	NE Goathorn Cr	?	f	1.32
90-131	619800	6056000	Goathorn Cr	1	oc	0.85
90-133	620500	6055520	Goathorn Cr	1	oc	0.85
90-100	620820	6057280	Goathorn Cr	1	s	0.88
90-97	620760	6057480	Goathorn Cr	1	s	0.81
90-92	620340	6058540	Goathorn Cr	1	s	0.80
90-120	617860	6057560	Telkwa R	1	oc	0.88
90-123	621240	6052740	Goathorn Cr	1	oc	0.90
90-123	621240	6052740	Goathorn Cr	1	oc	0.88
90-88	617940	6057800	Telkwa R	1	oc	0.98

u = seams 2 to 10
oc = outcrop
f = float or bloom
s = coal spar

sampled and analyzed the 1989 drill core on 20-centimetre increments. This suite of analyses is presented in Table 4-8-4. Up to 29 samples from a single seam were analyzed providing a good estimate of the reproducibility of a single sample value. The average standard deviation of a single value from a seam is 0.043 per cent. Consequently in-seam variation and sampling bias must account for something less than 0.043 minus the error in the optical measurement (0.01 per cent).

The analysis technique of the GSB (Kilby, 1988) provides a value of the mean maximum reflectance of vitrinite in oil, classifies the shape of the reflectance-indicating surface (RIS) and quantifies its degree of eccentricity.

The reflectance data are presented in Tables 4-8-1, 3 and 4. Figure 4-8-3 illustrates the shape and type of RIS by seam. The pie diagram is the top triangular segment of a parent triangle diagram in which each corner represents one of the axes of the RIS. Increasing bireflectance is represented by increases in RAM and changes in eccentricity by RST; a negative RST value of 30 indicates a uniaxial negative RIS and positive value of 30 indicates a uniaxial positive RIS, The terms RST and RAM are defined as follows:

$$RST = 30 - \arctan(X/Y)$$
$$RAM = (X\hat{}2 + Y\hat{}2)\hat{}1/2$$
$$R = \bar{R}_{max} + R_{int} + R_{min}$$
$$X = (\tfrac{1}{3} - \tfrac{R_{min}}{R}/\cos(30) - y\tan(30))$$
$$Y = \bar{R}_{max}/R - \tfrac{1}{3}$$

TABLE 4-8-2
TELKWA COALFIELD
LOCATION OF DRILL HOLES PROVIDING SAMPLES USED FOR MEAN MAXIMUM REFLECTANCE MEASUREMENT

HOLE	EASTING	NORTHING	ELEVATION (metre)	DEPTH (metre)
216	618656	6059476	786	138
218	618791	6059835	780	103
224	620653	6054054	773	249
231	619511	6054312	762	330
232	621777	6053797	779	98
236	619821	6054776	733	178
237	619986	6054858	730	151
239	620020	6055035	726	159
243	621396	6053108	829	148
246	621653	6052344	840	164
247	621870	6053110	860	258
248	621840	6052041	852	283
250	622070	6052083	869	173
251	621583	6052867	872	354
252	622346	6052072	887	374
255	621656	6053469	802	200
256	622016	6052584	890	292
259	621075	6054410	747	87
260	621019	6055019	698	155
267	619565	6054091	762	250
268	621643	6054395	745	301
272	621633	6055142	708	121
316	621087	6054904	713	88
318	621012	6055277	715	118
326	621077	6053440	793	84
327	621074	6053287	794	101
337	621527	6054500	733	124
343	621343	6055300	699	173
344	621626	6055420	694	149
345	619642	6053981	764	136
347	619649	6054196	760	136
GSB-89-1	620305	6054860	660	28.5
GSB-89-2	620260	6054970	655	25.0
GSB-89-3	620410	6055285	645	52.0
GSB-89-4	620420	6055320	645	25.0
GSB-89-5	620455	6055705	645	45.6
GSB-89-7	620530	6055720	635	10.3
GSB-89-8	618015	6057665	575	33.4
GSB-89-9	618000	6057700	580	43.3

Much of the scatter of individual maximum reflectance measurements seen in (Figure 4-8-4) is related to the real spread of individual maximum reflectance values within the sample. In fact, in a uniaxial RIS the dispersion of individual maximum reflectance measurements is a direct measure of this spread in the coal and could probably be used to make inferences about coking potential.

At Telkwa, lower rank coal samples from Seams 10 and 6 generally have low bireflectance (RAM) and moderate biaxial eccentricity (RST); higher rank coals have greater bireflectance and more extreme eccentricity, often approaching uniaxial negative RIS patterns. Increasing bireflectance with rank has been described in the literature by a number of authors (*e.g.*, McCartney and Ergun, 1967). Trends in eccentricity with rank are not well developed at Telkwa although some of the high-rank Cabinet Creek coals have uniaxial negative RIS.

Some coal samples do not define a coherent RIS pattern. Coalspar collected from outcrop samples usually has a scattered pattern (Figure 4-8-4). These samples represent coal fragments incorporated in sandstones of Unit 1 (Table

TABLE 4-8-3
TELKWA COALFIELD
CROWSNEST RESOURCES DRILL HOLES, MEAN MAXIMUM REFLECTANCE DATA

HOLE	SEAM 1 R Max/Depth (metre)		SEAM 2 R Max/Depth (metre)		SEAM 6 R Max/Depth (metre)		SEAM 10 R Max/Depth (metre)	
216	-		0.94	48.80	0.90	22.90	-	
218	-		0.95	75.00	0.91	47.20	-	
224	0.90	212.20	-		-		-	
224	0.94	248.30	-		-		-	
231	0.90	306.98	0.98	180.00	-		0.84	106.60
232	-		0.93	79.68	-		-	
236	0.92	153.23	-		-		-	
237	0.89	128.80	-		-		-	
237	1.03	139.34	-		-		-	
239	0.89	40.76	-		-		-	
243	-		0.90	67.70	-		-	
244	-		-		0.84	76.60	-	
246	-		0.89	94.68	-		-	
247	-		0.92	204.78	0.84	154.06	0.81	115.14
248	0.99	267.30	-		-		-	
250	-		-		0.84	74.43	-	
251	-		0.86	131.08	0.94	107.86	0.80	64.96
252	1.24	352.70	1.00	166.60	-		-	
255	-		0.99	179.83	-		-	
256	-		0.90	257.74	0.96	202.58	-	
259	-		-		0.88	18.67	-	
260	0.87	117.02	0.84	22.65	-		-	
267	-		1.02	154.54	0.96	130.80	0.87	81.46
268	-		-		-		0.85	102.95
277	-		0.93	88.08	0.86	53.95	-	
316	-		-		0.82	71.65	-	
318	0.88	91.85	-		-		-	
326	-		0.92	47.92	-		-	
327	-		0.87	76.30	-		-	
337	-		0.90	91.63	-		-	
343	-		1.55	139.55	0.84	104.10	-	
344	-		0.86	123.52	-		-	
345	-		1.51	102.20	0.97	77.00	-	
347	-		1.03	40.62	0.89	25.30	-	

HOLE	SEAM 2		SEAM 3		SEAM 5		SEAM 6	
800c	0.976	?	0.901	?	0.957	?	0.963	?

TABLE 4-8-4
TELKWA COALFIELD
GEOLOGICAL SURVEY BRANCH
DRILL HOLES, COAL INTERSECTIONS AND MEAN MAXIMUM REFLECTANCE DATA

HOLE	TOP (metre)	BOTTOM (metre)	THICKNESS (metre)	AV R Max	COUNT	SD
89-1	*3.05*	*4.88*	*1.83*	*0.899*	*29*	*0.038*
89-1	6.10	6.25	0.15	0.983	1	
89-1	7.62	8.08	0.46	0.908	2	
89-1	9.68	11.28	1.60	0.932	8	0.053
89-1	16.91	17.83	0.92	0.912	4	0.030
89-1	24.46	25.83	1.37	0.922	7	0.029
89-2	2.13	3.51	1.38	0.846	6	0.035
89-2	4.88	5.71	0.83	0.902	4	0.048
89-2	6.55	7.92	1.37	0.955	7	0.048
89-2	13.34	13.66	0.32	0.926	4	0.009
89-2	20.12	20.52	0.40	0.933	2	
89-2	20.73	21.79	1.06	0.946	5	0.040
89-3	4.88	5.18	0.30	0.875	1	
89-3	*29.26*	*29.72*	*0.46*	*0.868*	2	
89-3	30.34	30.48	0.14	0.904	1	
89-3	40.77	40.92	0.15	0.968	1	
89-4	6.43	6.95	0.52	0.871	4	0.02
89-4	12.34	12.95	0.61	0.878	4	0.026
89-5	15.3	15.83	0.53	0.851	2	
89-5	19.6	20.45	0.83	0.916	2	
89-7	3.7	3.9	0.20	0.847	1	
89-7	5.50	5.95	0.45	0.865	2	
89-8	8.30	14.05	5.85	0.956	29	0.061
89-8	14.8	15.67	0.87	0.967	4	0.049
89-8	18.78	21.70	2.92	1.005	11	0.056
89-8	26.82	27.82	1.00	0.989	4	0.051
89-8	*28.9*	*29.9*	*1.00*	*1.004*	5	*0.039*
89-9	13.81	18.12	4.31	0.952	22	0.066
89-9	18.4	19.72	1.32	0.963	7	0.048
89-9	20.85	21.75	0.90	0.976	5	0.054
89-9	*23.35*	*23.47*	*0.12*	*1.00*	1	
89-9	24.3	27.22	2.92	0.986	15	0.04
89-9	32.6	33.55	0.93	1.008	5	0.066
89-9	34.4	35.5	1.10	0.991	6	0.032
89-9	36.9	37.1	0.20	0.932	1	
89-9	42.4	42.97	0.57	0.962	3	
			AVERAGES	0.946	217	0 043

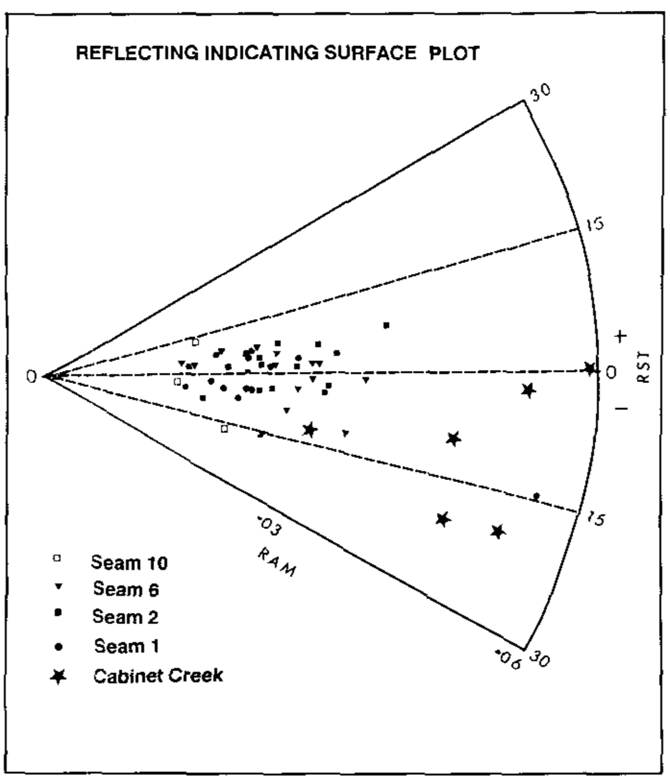

Figure 4-8-3. Plot of the relative shape of the reflectance indicating surface (RIS) for Telkwa coals.

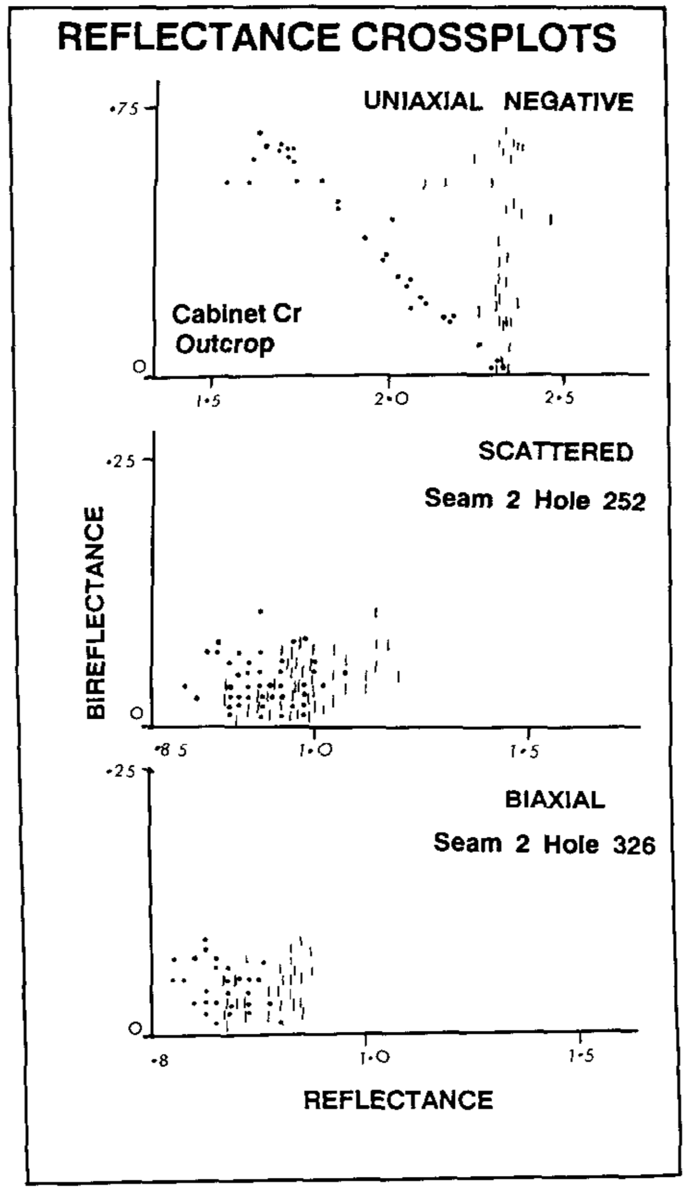

Figure 4-8-4. Examples of reflectance measurement populations for samples, illustrating different RIS.

4-8-1). Based on the angular shape of the fragments, they appear to have been included in the sediment as coal and not pieces of vegetation later compressed and coalified in place. This raises the possibility that coal seams older than Seam 1 were being eroded during deposition of Unit 1. The $\bar{R}_{max}$ values for the coalspar samples are similar to Seam 1 values indicating that the coalspar must be either from Seam 1 or from older coal that was of lower rank than Seam 1 when eroded and deposited in Unit 1. The scatter on the RIS plot probably results from mixing grains of slightly different rank and also the effects of weathering which generally tend to decrease $\bar{R}_{max}$ values (Bustin, 1982).

A few drill-core samples also have scattered RIS patterns. In four out of six cases the $\bar{R}_{max}$ values are higher than would be predicted by the accompanying volatile matter analysis for the seam. One possible explanation for this is that the spot sample used for reflectance measurement was taken from close to an in-seam fault whereas the sample used for quality analysis was a whole-seam composite sample. The high $\bar{R}_{max}$ values may be caused by heating associated with the faulting; an effect which is usually local in extent (Bustin, 1983). Oxidation and lowering of reflectance values is more likely and this probably explains the low values for the other two samples.

The reflectance data were analyzed with the help of a number of computer programs. Files of $\bar{R}_{max}$ coal-seam data with UTM locations were entered into GEOEAS®, a variogram, kriging and contouring computer program distributed in the public domain by the United States Environmental Protection Agency (1988). This software was used to grid the data. Programs generated in-house were then used to calculate area-weighted averages for the data, construct AutoCAD® DXF files and generate contour files compatible with QUIKMap®; a geographical information system (Environmental Sciences Limited, 1990). The series of programs allows for geostatistical analysis resource evaluation and display of results.

To round off discussion of the reflectance data, use was made of a database of Telkwa coal quality. The database consists of over 3000 lines, each line representing a set of analyses of a single sample. Data are derived from all ten seams sampled from over 350 holes, many of which were cored. They are analyzed with the help of a number of in-house programs tailored to the manipulation of coal-quality data.

VERTICAL COALIFICATION GRADIENTS

Change of $\bar{R}_{max}$ with stratigraphic depth can provide information on unconformities or faults in the coalfield. The timing of coalification with respect to folding and faulting can be analyzed using isorank surfaces.

Prior to this study few $\bar{R}_{max}$ data existed for the Telkwa coalfield. Spot analyses established that the coal is high-volatile A bituminous in rank but there were insufficient data to extend the discussion. Additional data required core samples of coal seams. Unfortunately most core samples obtained during the 1978 to 1989 exploration no longer exist so use was made of samples in the GSB collection and samples obtained by GSB drilling. These samples provide reasonable representation of Units 1 and 3 but poor representation of Unit 2. The coalification gradient through Unit 2 can only be estimated from holes that intersect Seam 2, Unit 2 and Seam 1. With the exception of some holes drilled in the early part of the 1982 exploration program, most were targeted to core either Unit 1 or Unit 3 but not the intervening marine Unit 2.

In general, two samples from different seams in the same drill hole were selected to provide $\bar{R}_{max}$ depth pairs. Most of depth pairs are for Unit 3 or Unit 1 and there is only one pair from Hole 231 (Table 4-8-2) which drills through Unit 2 and includes Seams 2 and 1. The $\bar{R}_{max}$ and depth paired data for the drill holes are in Tables 4-8-3 and 4.

Unit 3 is represented by a number of depth pairs for Seams 10, 6 and 2. Most represent depth differences of less than 50 metres and changes of $\bar{R}_{max}$ of less than 0.10 (Table 4-8-3). The average gradient is 0.15 per cent per 100 metres. The reproducibility of a single measurement is about 0.043 as discussed earlier (Table 4-8-4). There is some uncertainty in the exact depths recorded for some of the drill-core samples, consequently a 2.0-metre error is assumed for sample depths. The errors in $\bar{R}_{max}$ and depth make it impossible to calculate meaningful gradients for data pairs usually representing changes in $\bar{R}_{max}$ of less than 0.1 and change in depth of less than 60 metres. Therefore no comments can be made about local gradients at each hole.

It is possible to estimate the regional coalification gradient of Unit 3 by stacking the individual depth pairs in such a way as to allow a consideration of sample error. Table 4-8-5 lists the changes in $\bar{R}_{max}$ and depth for all the data pairs. Each pair can be represented as a two data-point line, one point is the origin and the second point is X = (lower depth−upper depth) and Y = (lower $\bar{R}_{max}$−upper $\bar{R}_{max}$). When ten pairs are overlain on the plot there will be ten overlapping points at the origin and ten other points scattered through the plot. One standard deviation errors of 0.043 for $\bar{R}_{max}$ and 2.0 metres for depth are assigned to the data points. A best-fit least-squares line is fitted through the data using the method of York (1969). Errors in $\bar{R}_{max}$ and depth are considered to be uncorrelated. The resultant best-fit line is a good estimate of the average coalification gradient and the process provides an estimate of the error in the slope (coalification gradient) and intercept (approximately 0.0).

Data from Unit 3 are plotted in Figure 4-8-5. The best-fit line has a gradient of 0.114±0.028 per cent per 100 metres and an intercept of 0.007. The line intersects the one stan-

TABLE 4-8-5
TELKWA COALFIELD
NORMALIZED MEAN MAXIMUM
REFLECTANCE GRADIENTS

HOLE	STARTING POINT X1	STARTING POINT Y1	END POINT X2	END POINT Y2	GRADIENT
SEAM 2					
218	0	0	0.04	27.[illegible]	0.14
224	0	0	0.04	36.[illegible]	0.11
231	0	0	0.14	73.[illegible]	0.19
247	0	0	0.03	38.[illegible]2	0.08
247	0	0	0.11	89.[illegible]4	0.12
251	0	0	0.14	42.[illegible]	0.33
251	0	0	0.06	66.[illegible]2	0.09
260	0	0	0.03	94.[illegible]7	0.03
267	0	0	0.09	49.[illegible]4	0.18
267	0	0	0.15	73.[illegible]8	0.21
272	0	0	0.07	34.[illegible]3	0.21
316	0	0	0.0	59.[illegible]5	0.0
347	0	0	0.14	15.[illegible]2	0.91
SEAM 1					
GSB-89-1	0	0	0.03	21.[illegible]8	0.14
GSB-89-2	0	0	0.1	18.[illegible]4	0.54
GSB-89-3	0	0	0.093	35.[illegible]2	0.26
GSB-89-8	0	0	0.048	18.[illegible]2	0.26

X = R Max difference   Y = Depth difference in metres

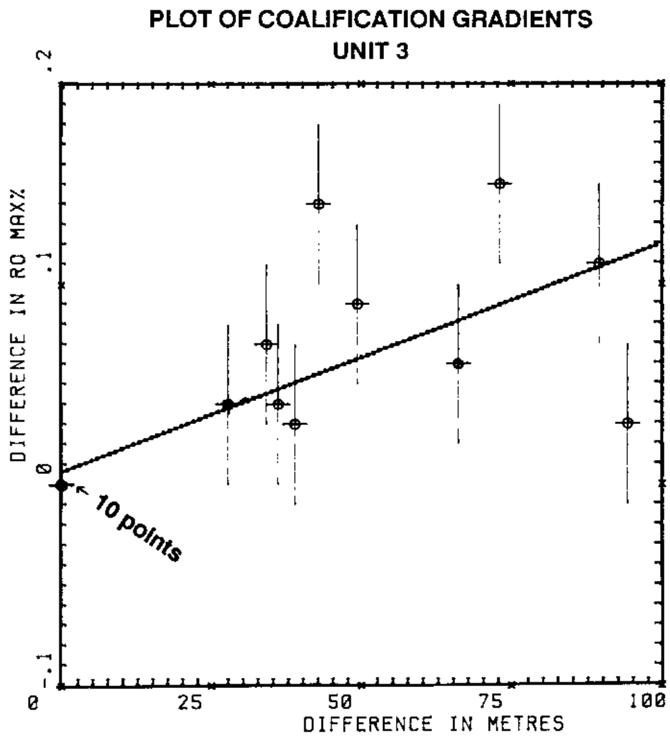

Figure 4-8-5. Stacked coalification gradients for Unit 2.

dard deviation error fields of more than two-thirds of the data. The data scatter can therefore be explained by statistical scatter about the line and any variations in coalification gradient from hole to hole that might exist are masked.

A coalification gradient of 0.114 per cent per 100 metres is similar to gradients calculated for the Lower Cretaceous Mist Mountain Formation in southeast British Columbia (Hacquebard and Cameron, 1989); data in Table 3 in their paper provide an average gradient of 0.114 per cent per 100 metres for sections in the Elk Valley area. The gradient in Unit 3 at Telkwa is somewhat greater than the coalification gradient of 0.06 per cent per 100 metres in the Seaton coal basin north of Smithers (Ryan, 1991).

Most of the short holes appear to penetrate Unit 1. The average coalification gradient for the short holes in Unit 1 is 0.3 per cent per 100 metres (Table 4-8-5). The depth increments used to calculate this gradient are small but the estimate is still reliable because of the large number of $\bar{R}_{max}$ measurements averaged to provide final data points (Table 4-8-4). As for data from Unit 3, data pairs from Unit 1 can be stacked and a best-fit least-squared line fitted through the data. A gradient of 0.27±0.11 per cent per 100 metres and an intercept of 0.002 are calculated. This gradient is significantly higher than that for Unit 3.

ESTIMATE OF THE COALIFICATION GRADIENT FOR UNIT 2

There are no useful $\bar{R}_{max}$ data available to calculate a gradient for Unit 2. It is possible to estimate $\bar{R}_{max}$ values from measurements of volatile matter. If this is done then volatile matter analyses of coal samples from the early 1982 holes which penetrate the total thickness of Unit 2 can be used to estimate Unit 2 coalification gradient. A number of papers discuss the relationship between volatile matter (VM) on a dry ash-free basis (daf) or dry mineral matter free basis (dmmf) and $\bar{R}_{max}$ (Bustin *et al.*, 1983; Meissener, 1984). In the Telkwa area VM analyses exist for the seams also analyzed for reflectance and it is possible to generate correlation plots.

Volatile matter data can be corrected to an ash or mineral matter free basis in a number of ways. One empirical way is to:

1. Regress all VM data against ash data on a seam-by-seam basis to derive the best-fit linear relationships.
2. Use the slope of the lines to correct individual VM measurements to an equivalent individual VM ash-free value.

The slope of the line will equal the Y intercept (VM ash free) if the ash acts only as a dilutant. If the mineral matter and any sulphides add inorganic volatile matter to the VM analysis then the slope will be decreased by a component equal to the gassiness of the mineral matter.

The VM intercept and slope derived from 167 analyses of Seam 2 are 29.3 per cent (or 0.293) and 0.168. The fact that the slope is much less than the intercept indicates that the mineral matter is gassy. Eighty-four samples of Seam 1 data provide an intercept value of 30.9 per cent and slope value of 0.30, indicating a non-gassy mineral matter. Non-gassy mineral matter is often associated with a reactive-rich coal (Slaghuis *et al.*, 1990).

Once a method is developed to provide VM(af) values it is possible to investigate their relationship to $\bar{R}_{max}$ on a

TABLE 4-8-6
TELKWA COALFIELD
CORRELATION BETWEEN MEAN MAXIMUM REFLECTANCE AND VOLATILE MATTER (ASH FREE BASIS)

SEAM 6			SEAM 2			SEAM 1		
HOLE	R Max	VC %	HOLE	R Max	VC %	HOLE	R Max	VC %
216	0.40	29.5	218	0.95	28.0	224	0.92	30.1
218	0.91	29 4	231	0 99	26.6	231	0.90	33 1
247	0.84	29 1	243	0.90	28.5	237	0.96	30 1
250	0.84	26.6	246	0.89	29.3	239	0.89	33 0
251	0.94	29.5	247	0.92	30.7	248	0.99	31 2
256	0.96	25 3	251	0.86	31.0	252	1.24	27 2
259	0.88	29 5	255	0.87	28.7	260	0 87	34 1
267	0.96	25 9	256	0.90	30.3	318	0.88	32.5
272	0.86	30.2	260	0.84	28.9			
316	0.82	31 0	267	1.02	25.5			
343	0 84	30 8	272	0.93	22 3			
345	0.97	26.3	326	0.92	29.1			
347	0 89	27 6	327	0 87	28 0			
			337	0 90	28 5			
			344	0.86	30.1			
			347	1.03	27.2			

SEAM		COUNT	COREL	SL/In
	VM = 29 6 - 0.176 x A	134	-0 41	0.59
6	VC% = VM + 0 176 x A			
	R%c = 1 53 - 0 022 x VC	12	-0.82	
	VM = 29 3 - 0 168	167	-0 54	0 64
2	VC% = VM + 0 168 x A			
	R%c = 1 31 - 0 014 x VC	16	-0 54	
	VM = 30 9 - 0.304 x A	84	-0 46	1
1	VC% = VM + 0 304 x A			
	R%c = 2 46 - 0.0479 x VC	8	-0 88	

VM = Volatile matter % at A = ash percent
Corel = corellation coefficient
SN/In = slope/intercept x 100

R Max = Mean maximum reflectance measured.
VC % = Volatile matter corrected to an ash free basis using the equations below
R%c = calculated mean maximum reflectance

seam-by-seam basis using the existing $\bar{R}_{max}$ measurements. There are eight VM(af), $\bar{R}_{max}$ pairs for Seam 1, sixteen pairs for Seam 2 and thirteen pairs for Seam 6 (Table 4-8-6). Lines were fitted through each data suite (Figure 4-8-6).

It is now possible, using the VM versus ash relationships and the VM(af) versus $\bar{R}_{max}$ relationships for each seam, to convert any Seam 2 or 1 VM measurement to an estimate of $\bar{R}_{max}$. This is done for all the holes that intersect Seams 2 and 1 and the coalification gradients are calculated (Table 4-8-7). An average gradient of 0.04 per cent per 100 metres is determined which is significantly lower than that for either Unit 1 or Unit 3.

The method of deriving the coalification gradient for Unit 2 is fraught with assumptions and errors, in fact a number of other approaches were attempted; all predicted a low to very low coalification gradient through Unit 2. One method of correcting VM to VM(dmmf) uses the Parr Equation (mineral matter = 1.08 × ash % + 0.55 × sulphur %; Ward, 1984). This equation assumes that all mineral matter is equally gassy, although variations are allowed for differences in sulphur dioxide derived from pyritic sulphur. This is not the case at Telkwa for Seams 6, 2 and 1, as indicated by the different ratios of slopes of lines for the VM versus ash plots divided by the intercept value of the line (Table 4-8-6).

Coalification gradients increase exponentially with depth. England and Bustin (1986) indicate that an equation of the type $D = A \times \log((0.938 \times \bar{R}_{max} + 0.001) \times 100)) - B$ describes coalification gradients in deep oil wells in Alberta. If the gradient at Telkwa increase exponentially with depth then the true gradient through Unit 2 should be greater than the Unit 3 gradient of 0.11 per cent per 100 metres. This could be achieved by maintaining the difference in $\bar{R}_{max}$ values between Seams 2 and 1 but dividing by a depth increment of 60 metres instead of 130 metres (the average present separation of Seams 2 and 1). A decrease in thickness of Unit 2 by two-thirds to explain the coalification gradient implies that the thickness of Unit 2 has been increased by post-coalification thrusting from approximately 60 metres to 130 metres.

Thrust faulting does occur in Unit 3 in the area drilled, but no thrusts of sufficient magnitude have been mapped. If Unit 2 is thickened by thrusts there should be areas where the original thickness of about 40 metres is preserved: such areas could have increased exploration potential. The low gradient through Unit 2 may indicate a high thermal conductivity for the unit but this is unlikely.

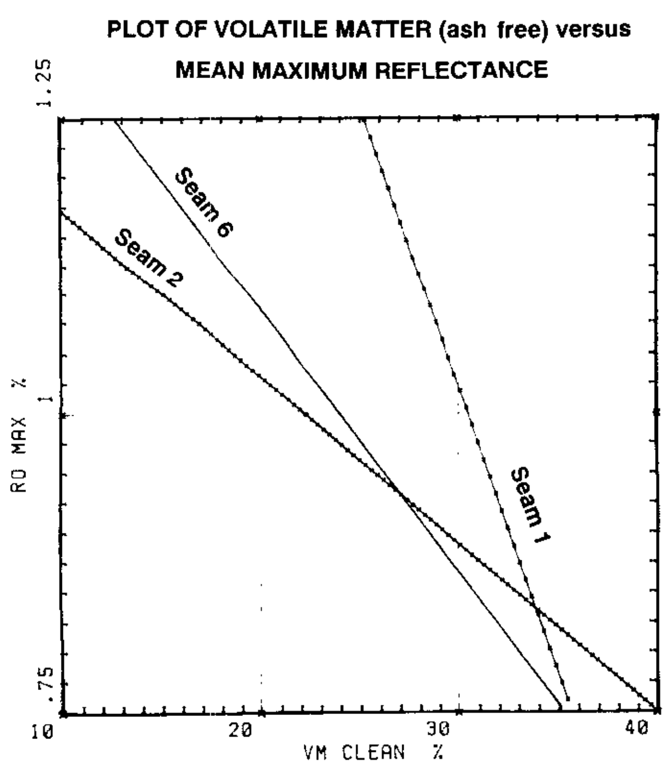

Figure 4-8-6. Mean maximum reflectance versus calculated volatile matter on an ash-free basis, Seams 6, 2 and 1. Contours of $\bar{R}_{max}$% calculated from VM data.

LATERAL VARIATIONS IN THE COALIFICATION GRADIENTS

Most of the $\bar{R}_{max}$ values available for the Telkwa coalfield are from the Goathorn Creek area with a limited amount of data for the rest of the field. The rank of coal in the Lake Kathlyn prospect west of Smithers (Figure 4-8-1) has been increased to meta-anthracite by adjacent intrusions (Dowling, 1915). South of Smithers, along the Bulkley River, two $\bar{R}_{max}$ measurements (Table 4-8-1) indicate a rank of medium-volatile bituminous ($\bar{R}_{max}$ greater than 1.0 per cent). The rank of coal in Unit 3 north of the Telkwa River, in the area drilled by Crowsnest Resources Limited, averages high-volatile A bituminous ($\bar{R}_{max}$ = 0.95, average of four analyses, Table 4-8-1). Locally the rank is increased by a Tertiary intrusion outcropping to the north, but the average rank is not much higher than the rank at Goathorn Creek where the $\bar{R}_{max}$ data range from 0.8 to 1.0 per cent.

TABLE 4-8-7
TELKWA COALFIELD
CALCULATED MEAN MAXIMUM REFLECTANCE (R%c)
FOR SEAMS 2 AND 1
COALIFICATION GRADIENTS THROUGH UNIT 2

HOLE	EASTING	NORTHING	SEAM 2 DEPTH (metre)	SEAM 2 R%c	SEAM 1 DEPTH (metre)	SEAM 1 R%c	GRADIENT
219	621616	6054106	151.2	0.89	275.5	0.94	0.04
220	621378	6053784	82.2	0.90	231.2	0.94	0.02
223	621047	6053853	55.8	0.90	154.9	0.94	0.04
225	621252	6053453	29.6	0.89	190.7	1.00	0.07
227	621386	6053449	61.2	0.86	218.2	0.95	0.06
231	619511	6054312	179.8	0.94	305.8	0.87	-0.06
234	619710	6054451	62.1	0.92	178.2	1.10	0.16
251	621583	6052867	131.1	0.88	267.7	0.96	0.06
260	621019	6055019	56.8	0.91	16.5	0.83	-0.01
265	619687	6054626	98.9	0.92	263.1	1.02	0.06
268	621643	6054395	140.4	0.91	266.4	0.92	0.01
		AVERAGE		0.90		0.95	0.04

Note: average separation of 2 seam to 1 seam = 120 metres.

Gradient = R Max difference per 100 metres
R%c = calculated mean maximum reflectance

Seam1: R%c = 1.31 - 0.014 (VM + 0.168 x A)
Seam 2: R%c = 2.46 - 0.0479 (VM + 0.0309 x A)

VM = Volatile matter percent
A = Ash percent

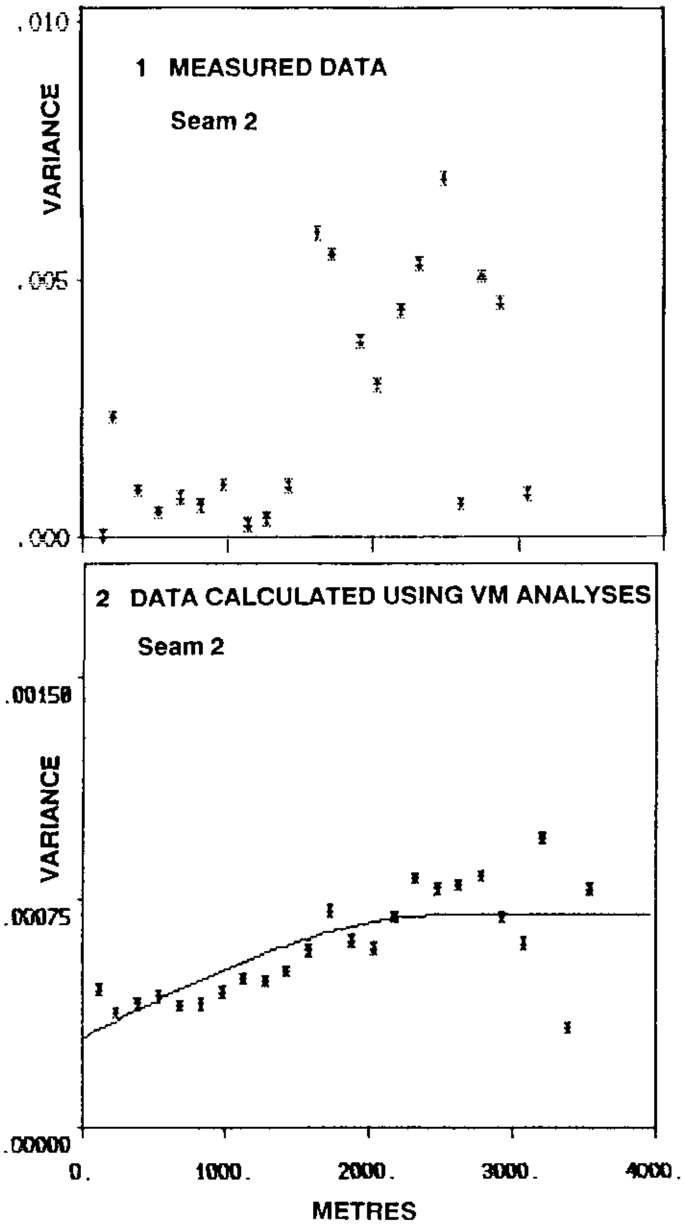

Figure 4-8-7. Variograms for mean maximum reflectance data and calculated mean maximum reflectance data; Seam 2.

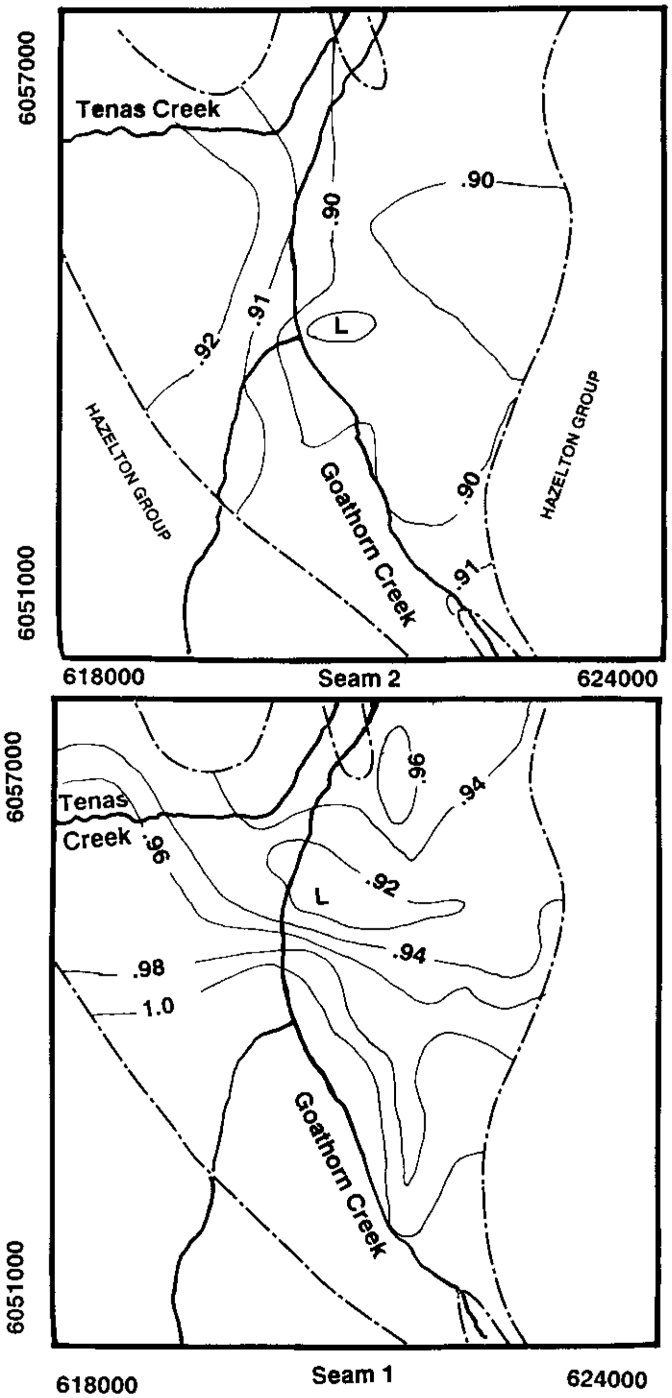

Figure 4-8-8. Contours of calculated mean maximum reflectance data for Seams 2 and 1.

A single $\bar{R}_{max}$ measurement on float collected from northeast of the Goathorn Creek area is 1.32 per cent, indicating the possible presence of coal of medium-volatile rank south of the Telkwa River and northeast of the present Goathorn Creek exploration area. The $\bar{R}_{max}$ value of a sample from a subcrop of coal bloom exposed by logging activity southeast of the headwaters of Tenas Creek is 1.10 per cent, indicating the presence of medium-volatile bituminous coal.

An outlier of the Telkwa coalfield outcrops at Cabinet Creek. A number of seams are exposed in the creek and three drill holes in the area intersect coal assigned to Unit 1. Mean maximum reflectance measurements of outcrop samples indicate a rank of semi-anthracite (Table 4-8-1); in fact Dowling (1915) describes an adit probably located near Cabinet Creek that intersected anthracite. The quality available from the three rotary-drill holes indicates a rank of at least low-volatile bituminous based on ash and VM analyses of chip samples. Two of these holes intersected 6 and 11 metres of fine-grained igneous rock in the sedimentary section. No intrusive rocks were seen in outcrop nor are any Tertiary plutons mapped in the area. The high rank at Cabinet Creek could be caused by: post-Cretaceous heat sources, a deeper stratigraphic section than the Goathorn Creek area, or a higher heat-flux from the pre-Cretaceous basement. The preference of the author is for the third possibility.

The rank of coal through the Telkwa coalfield is obviously more variable than previously thought. The coalfield has the potential to be a source of medium-volatile metallurgical coal as well as an anthracite thermal product.

In-seam lateral variations of coal rank in the Goathorn Creek area were investigated using the GEOEAS software. Variogram diagrams were constructed for Seams 10, 6, 2 and 1. In all cases no variogram models could be fitted through the data and no regional trends contoured. Despite this, the data were gridded to obtain area-weighted average $\bar{R}_{max}$ values for each seam. Values of 0.83, 0.88, 0.91 and 0.91 per cent were obtained for Seams 10, 6, 2 and 1. The similarity of average values for Seams 2 and 1 supports the previous suggestion of a low coalification gradient through Unit 2. It should be noted that in averaging Seam 1 data where there is more than one $\bar{R}_{max}$ value in a hole, the minimum depth value was used.

The beds in the Goathorn Creek area dip gently to the east and it is important to see if present depth has any influence on the coalification gradient. A plot of all Seam 2 reflectance data versus present depth revealed no positive correlation; a line through seventeen points has a slope of 0.01 per cent per 100 metres, an intercept $\bar{R}_{max}$ value of 0.91 per cent and a correlation coefficient of 0.15. It appears that coalification predates folding, thrusting and tilting.

The reflectance data for Seams 2 and 1 cover a limited area; if the method of converting VM measurements into estimated $\bar{R}_{max}$ values is used, then a much larger database covering a larger area is available. Variograms for calculated values of Seams 2 and 1 indicate some regional trends. Figure 4-8-7 illustrates variogram plots measured $\bar{R}_{max}$ data and calculated $\bar{R}_{max}$ data for Seam 2. No variogram model can be fitted to the measured data but a spherical variogram model fits to the larger database of calculated values. The calculated databases for Seams 2 and 1 were kriged, gridded and contoured (Figure 4-8-8).

Figures 4-8-2 and 8 are redrafted printer-output with some distortion in the Y axis. There is considerable random scatter in the data but the two contour diagrams (Figure 4-8-8) show some similarities. Coal rank tends to be high in the southeast and southwest but low in the centre of the map (east of Goathorn Creek and north of the area proposed for development).

Sediments in a small graben in the central part of the basin, away from the fault-bounded margins, might experience less maturation. The area-weighted average for the calculated $\bar{R}_{max}$ values for Seams 2 and 1 are 0.91 per cent and 0.99 per cent which, for an average separation of 130 metres indicates a gradient of 0.06 per cent per 100 metres which is similar to the previously estimated coalification gradient for Unit 2.

ECONOMIC IMPLICATIONS

The Telkwa property has been considered for development as a thermal coal mine for a number of years. Certainly most of the area intensively explored is high-volatile A bituminous in rank. New data indicate that medium-volatile bituminous coal may subcrop near Tenas Creek and in other areas. This leads to the possibility of a metallurgical coal which is a more valuable product. The semi-anthracite in the Cabinet Creek area could be developed as a smokeless high-calorific thermal product for local as well as international markets. Many houses in the area burn wood in stoves for heat; anthracite, a smokeless fuel could be an environmentally acceptable replacement as long as the sulphur content is moderate.

The coalbed-methane potential for Telkwa will be the subject of another study. Gas content increases with rank and the medium-volatile rank at Tenas Creek and semi-anthracite rank at Cabinet Creek should increase the methane resource estimate for the area.

The use of volatile matter to estimate $\bar{R}_{max}$ has an interesting spin-off. Comparison of the VM(af) versus $\bar{R}_{max}$ lines for the different seams provides information about the relative reactivity of the seams and the relative vitrinite contents. Seam 1 has a higher volatile matter content than Seams 6 and 2, at the same rank, indicating that it is the most reactive coal and, at a rank approaching medium-volatile bituminous, may be suitable for coking. Stauss *et al.* (1976) graph the relationship between $\bar{R}_{max}$ vitrinite plus liptinite content and VM (daf). Using the average VM ash-free values derived for Seam 2 (29.3 per cent) and Seam 1 (30.9 per cent) and average $\bar{R}_{max}$ values for Seam 2 (0.91) and Seam 1 (0.99) the diagram predicts vitrinite plus liptinite contents of 30 per cent for Seam 2 and 60 per cent for Seam 1. These predictions are approximate, in part because the VM ash-free values in this study have to be corrected to a dry basis before using the graph.

An $\bar{R}_{max}$ value of 0.99 and 60 per cent reactives for Seam 1 predicts a free swelling index (FSI) value of 4 using the petrographic composition versus $\bar{R}_{max}$ diagram introduced by Pearson (1980). The Telkwa coal-quality database contains some FSI data. Weighted averages of ash and FSI for each seam are as follows:

Seam 6: 10 per cent ash, FSI = 2, count 54 holes;

Seam 2: 13 per cent ash, FSI = 1.5, count 65 holes;

Seam 1: 15 per cent ash, FSI = 3.8, count 36 holes;

The predicted FSI of 4 is in reasonable agreement with the actual average value of 3.8. Based on these inferences Seam 1 classifies as a G4-type coking coal (Pearson, 1980).

Seam 1 generally has the lowest sulphur content of all the seams but maybe difficult to wash. Often vitrinite-rich seams with good metallurgical properties such as fluidity, also have higher ash and are difficult to wash. It should be emphasized that Seam 1, which does not feature in present surface-mining proposals, has potential as a metallurgical coal. The next stage of this study will include petrography to check and extend the above analysis.

CONCLUSIONS

Coal in the Telkwa coalfield varies from high-volatile A bituminous to semi-anthracite. The area most intensively explored is underlain mainly by high-volatile A bituminous coal. Medium-volatile bituminous coal and semi-anthracite are also present and may eventually be developed as reserves. The coalification gradients range from 0.114 per cent per 100 metres for Unit 3 to 0.27 per cent per 100 metres for Unit 1. The gradient in the intervening Unit 2 appears to be low, a possible explanation is the presence of as yet unrecognized thrusts within the unit. Major lateral variations of in-seam rank are not present in the Goathorn area. Apparent minor variations may reflect the local basin structure with higher rank near the margins and lower rank in the centre.

Volatile matter (ash free basis) versus $\bar{R}_{max}$ relationships indicate that the lowest seam in the section is the most reactive and corroborate the correlation between gassiness of mineral matter and reactive content in the coal.

Coalspar material collected from Unit 1 may be derived from coal older than Seam 1 but of equal or lower rank.

ACKNOWLEDGMENTS

The author wishes to thank JoAnne Schwemler for performing the reflectance measurements. David Grieve acted as a sounding board. Anna Peakman and Mike Fournier typed the tables.

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