POTENTIAL COAL AND COALBED METHANE RESOURCE OF THE TELKWA COALFIELD, CENTRAL BRITISH COLUMBIA (93L/11)

By Barry D. Ryan, British Columbia Geological Survey Branch.

and

Michael F. Dawson, Institute of Sedimentary and Petroleum Geology.

KEYWORDS: Telkwa coalfield, coal resource, coalbed methane, coalbed methane reserve, regional permeability, coal rank.

INTRODUCTION

The British Columbia Geological Survey Branch and the Geological Survey of Canada have initiated a joint project to assess the coalbed methane (CBM) potential of the coalfields of British Columbia. The project includes sampling and desorption testing of fresh coal samples obtained from companies conducting exploration throughout the province. In addition methane adsorption isotherm tests are performed on some samples.

During the summer of 1992 a project was undertaken to test coal seams intersected in the ongoing Manalta Coal Limited drilling program in the Telkwa coalfield. On-site activities consisted of the collection and desorption of five samples. This report presents the desorption results and coal quality data for the five samples and three adsorption isotherms. The coal resource, the potential coalbed methane resource and reserve for the Telkwa coalfield are also discussed.

The Telkwa coalfield in central British Columbia (Figure 1) extends for about 50 kilometres along the Bulkley River from north of the town of Smithers to south of the village of Telkwa (Figure 2). The coalfield

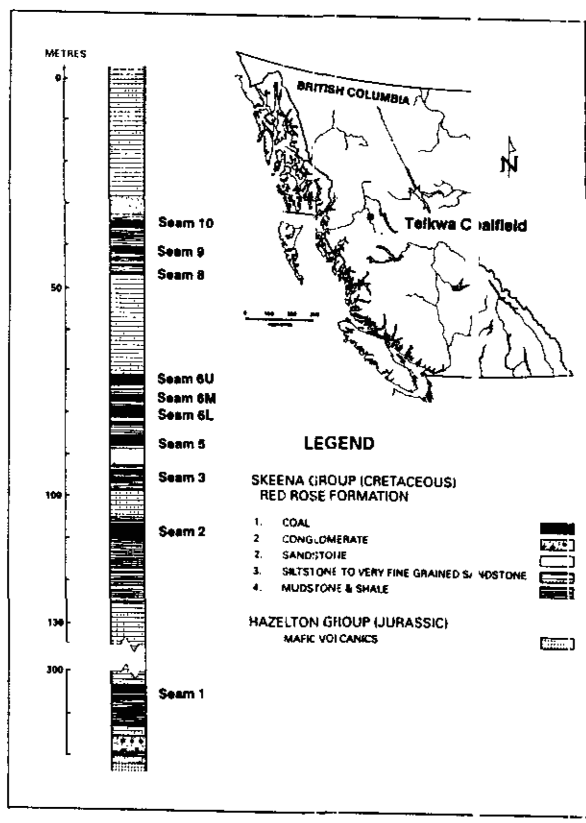

Figure 1: Location map for the Telkwa coalfield and a generalized stratigraphic column for the coalbed methane sampling area.

contains a potential coal resource of approximately 850 million tonnes. South of Telkwa, 20 to 50 million *in situ* tonnes have been identified as potentially surface mineable. The rank of the coal ranges from high-volatile bituminous A to anthracite. Most of the coal is in the range high-volatile to medium-volatile bituminous. The coalfield has historically been explored as a source of thermal coal but the wide range in rank means that there is potential for metallurgical coal.

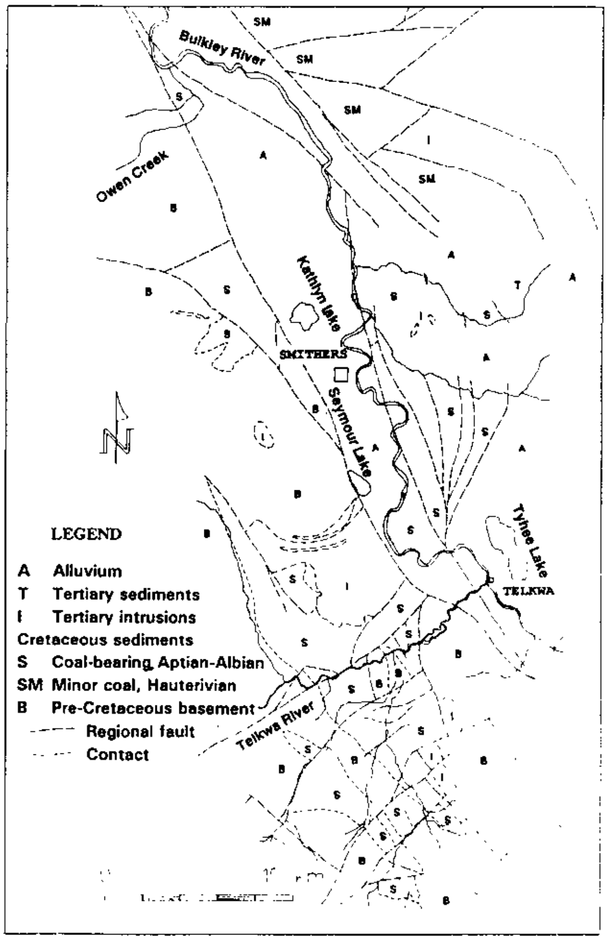

Figure 2: Regional geological map of the Telkwa coalfield.

The geology of the Telkwa coalfield is discussed in a number of papers (e.g. Koo, 1983; Palsgrove and Bustin, 1989) and is covered by regional geology maps, Tipper (1976), MacIntyre *et al.* and Ryan (1993). Coal-bearing rocks in the coalfield belong to the Skeena Group of Early Cretaceous age and are assigned to the Red Rose Formation of late Aptian to Albian age.

Much of the basin is covered by alluvium but coal-bearing rocks outcrop north of Owen Creek, west and south of Smithers near the Bulkley River, north of the Telkwa River in the vicinity of Pine Creek, east and west of Goathorne Creek and at the headwaters of Tenas and Cabinet creeks (Figures 2 and 3). Cretaceous rocks of Hauterivian age outcrop along the northeast edge of the coalfield. These rocks contain traces of coal but no coal seams have been found.

EXPLORATION HISTORY

Thermal coal and small quantities of anthracite were mined in the coalfield in the early part of the century. More recently, near Telkwa, the coalfield has been intensively explored by a number of companies with the intention of developing an open-pit thermal-coal mine. This area, referred to as the Telkwa coal property, is about 100 square kilometres and is centred on the confluence of the Telkwa River and Goathorne Creek (Figure 3). Measured coal resources have been outlined in this area and probable coal resources outlined in the Cabinet Creek area.

The Telkwa coal property was intensively explored in the period 1978 to 1990 by Crowsnest Resources Limited 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 submitted to the B.C. Ministry of Energy, Mines and Petroleum Resources and in Prospectus, Stage 1 and Stage 2 Reports submitted to the Ministry as part of the approval process for mine development. The Ministry drilled six short holes in the Goathorne Creek area in 1989 (Matheson and Van Den Bussche, 1990).

Manalta Coal Limited acquired the property in 1991 and drilled more holes in 1992 and 1993. At the time of writing it plans to continue exploration.

REGIONAL GEOLOGY

The Cretaceous Aptian to Albian sediments on the Telkwa coal property were divided into four units by Palsgrove and Bustin (1989; Figure 3). 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 non-marine coarse clastic unit which contains a single coal zone with of up to six component seams that are together referred to as seam 1. The cumulative vertical coal thickness varies up to 7 metres, based on drill hole information in the Goathorne Creek area (Figure 3).

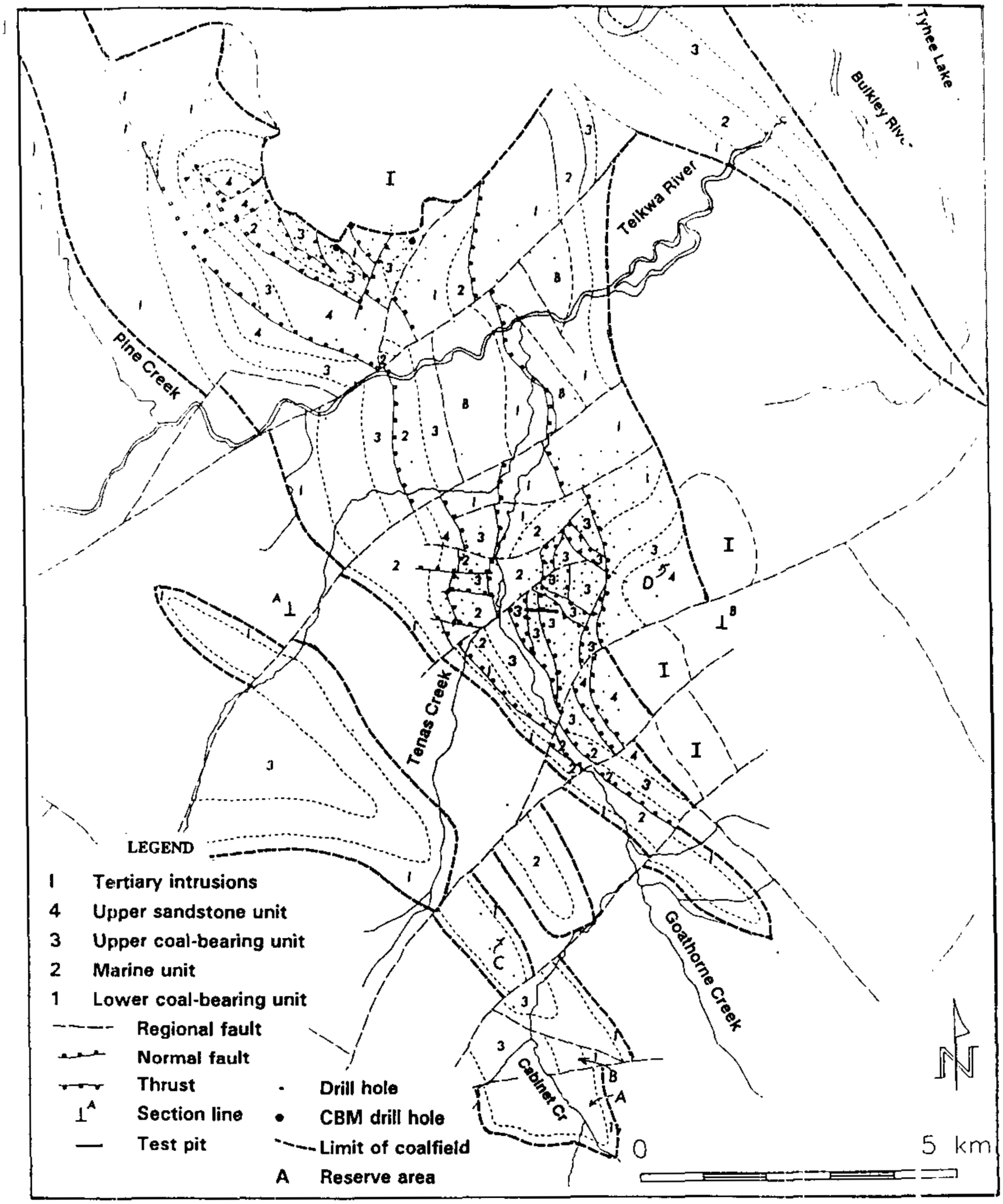

Figure 3: Detailed geology of the Goathorne Creek area in the Southern part of the Telkwa coalfield

Unit 2 is composed of from 60 to 170 metres of shallow-marine mudstones and siltstones and does not contain coal.

The major coal-bearing zone, comprising seams 2 to 10, is within unit 3 which averages 90 metres in thickness. The cumulative coal thickness ranges from 6 to 14 metres in the area covered by Figure 3. Unit 3 is overlain by the sandstone-rich unit 4 of unknown thickness.

Outcrop is sparce on the Telkwa coal property. An understanding of the structural geology has evolved as information from drilling and a number of geophysical surveys has became available. Bedding generally dips gently southeast or east and is disrupted by at least two generations of faulting. Early faults are east-dipping thrusts that, east of Goathorne Creek, offset the effect of the east dip of the sediments. Late steep-dipping faults trend northwest or northeast.

COALBED METHANE DESORPTION TESTS

Two exploration boreholes, drilled in September, 1992, provided five samples for CBM desorption tests. The holes are located on Figure 3 and the coordinates provided in Table 1. Rotary borehole T92R-17 was drilled to a depth of 125 metres and chip samples GSC92-1 (seam 4) and GSC92-2 (seam 2) were collected from depths of 105 to 106 metres and 117.6 to 119.0 metres, respectively. Chip samples were collected off a screen in front of the drill discharge pipe. They were immediately placed into canisters and sealed for desorption measurements. Proximate analyses of the chip samples indicate that some of the sample collected included rock material from elsewhere in the hole.

TABLE 1
DRILL HOLE LOCATION AND SAMPLE IDENTIFICATION DATA
SUMMARY DESORPTION DATA

SAMPLE LOCATIONS METRES

SAMPLE			COLLAR COORDINATES			SAMPLE INTERVAL	
ID	SEAM	HOLE	EAST	NORTH	ELEV	FROM	TO
GSC92-1	S4	T92R-17	617644	6059906	931	105	106
GSC92-2	S2	T92R-17	617644	6059906	931	117 6	119
GSC92-3	S3U	T92D-22	618906	6059980	799	64	64.4
GSC92-4	S2R	T92D-22	618906	6059980	799	83	83 4
GSC92-5	S2L	T92D-22	618906	6059980	799	90 8	91 2
GSB82-6	S1	TW224	620653	6054054	773	231.7	231 8

COALBED METHANE DATA

ID / SEAM	WT adb	DESORB GAS cm^3	LOST GAS cm^3	TOTAL GAS cm^3	GAS CONTENT PER GRAM adb	INSITU	daf	mmfb
1 / S4	629 9	1632 3	60.7	1693	2.69	2.58	3 94	4.45
2 / S2	692.5	223 2	147	370 2	0.53	0.51	0.72	0.79
3 / S3U	724.8	2330.7	170	2500.7	3 45	3.31	3.75	3.82
4 / S2R	671 9	2023.5	38	2061.5	3 07	2.94	4.25	4 69
5 / S2L	758.2	2621	77	2698	3.56	3.41	4 49	4.79

adb = Air-dried basis
INSITU = *In situ* moisture; assumed to be 5 %
daf = Dry ash-free data
mmfb = Corrected for mineral matter using the Parr equation (see text for explanation)

The second borehole (T92D-22), a diamond-drill hole, provided three NQ core samples 4.7 centimetres in diameter and a maximum of 40 centimetres long. Samples were placed in canisters and sealed at the drill site after being described. Sample GSC92-3 (seam 3 upper) is from a depth of 64. to 64.4 metres, sample GSC92-4 (seam 2 rider) is from a depth of 83.0 to 83.4 metres and sample GSC92-5 (seam 2 lower) is from a depth of 90.8 to 91.2 metres. Holes were geophysically logged when completed. Figure 4 illustrates the log response through the coal-bearing interval for boreholes T92R-17 and T92D-22, respectively. A generalized stratigraphic column for the area is presented on Figure 1.

Desorption measurements were undertaken in Smithers, approximately 20 minutes drive from the drill sites. Samples were desorbed at a temperature of approximately 20°C for a period of about 3 days before being transported to Calgary where desorption measurements continued until less than 5 cubic centimetres of gas were evolved over a 24-hour period. Sample weights were estimated by weighing the canisters with and without samples. Dead-space corrections were applied to adjust for variations in barometric pressure and desorption temperature. Lost-gas calculations for each canister were made based upon the U.S. Bureau of Mines method (McCulloch *et al.*, 1975).

After desorption samples were submitted to Core Laboratories, Calgary for laboratory analysis. Based on the results of these analyses two samples were chosen for adsorption isotherms. An additional sample was selected from drill-core samples originally collected by J. Koo in 1982 and stored in Victoria. This provided a sample of seam 1 from a location distant from the intrusions. The sample is from hole TW224 which was collared approximately 100 metres southwest of the western end of the test pit (Figure 3).

DESORPTION RESULTS

Total measured gas volumes, estimated lost-gas volumes and gas contents for the samples are summarized in Table 1. Excluding sample 2, the gas contents range from 3.75 to 4.49 cubic centimetres per gram on a dry ash-free (daf) basis and do not increase with increasing depth. The low desorption value for sample 2 may be due to a failure in the canister seal. The gas contents of the samples are also expressed on an *in situ* basis assuming a 5.0% *in situ* moisture (Ryan 1991).

Before data are corrected to a dry mineral-matter free basis (dmmf) the weight loss experienced by the mineral matter when it is converted to ash must be known. The Parr equation (Rees, 1966) predicts values ranging from 1.1 to 1.25 for the ratio (mineral matter/ash) depending on the sulphur content. Five calculations of the ratio for coals from Telkwa average 1.16 as reported in Ryan (1991 b). These values are derived by plasma ashing the samples and subjecting the mineral matter residue to an ash analysis. An alternative method of estimating the weight loss experienced by ash is to plot volatile content (daf) *versus* ash. As the ash content increases the volatile matter (daf) values increase because of addition of volatiles from the ash. The slope of the plot provides an estimate of the ratio (mineral matter/ash). In the case of the five samples here the ratio is 1.25.

The dmmf gas contents reported in Table 1 are calculated using the Parr equation and are probably low, based on the above discussion. As most measured and theoretical adsorption curves are expressed on an as-

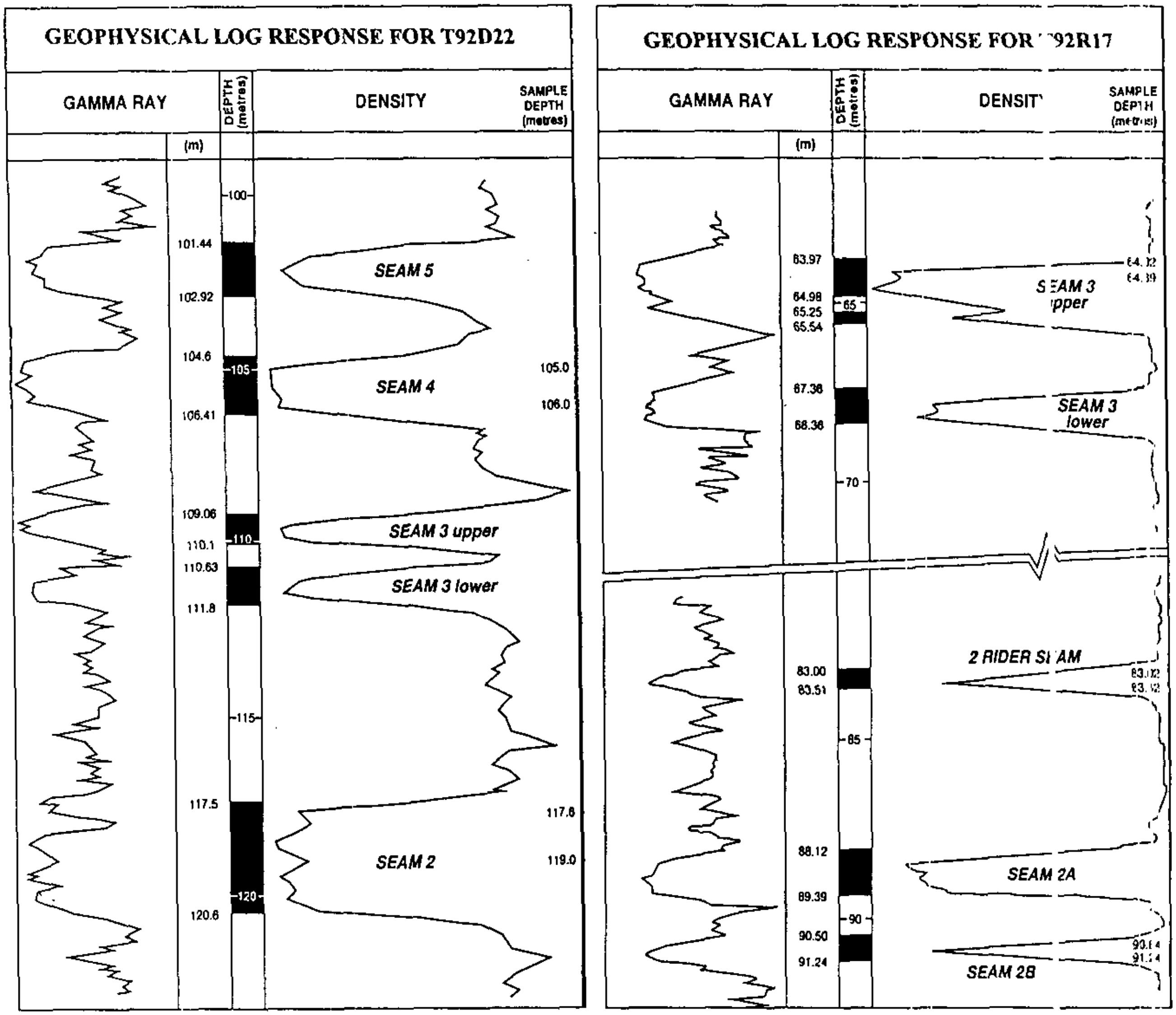

Figure 4: Geophysical log responses over sample intervals in holes T92D22 and T92D17 which provided the CBM desorption samples.

received or daf basis the dmmf calculation is not critical. Normally, for a coal with 20% ash a concentration expressed on a dmmf basis will be less than 10% higher than the same concentration expressed on a daf basis.

COAL QUALITY

Following completion of desorption experiments, the coal samples were analyzed for ash, moisture, volatile, carbon and sulphur contents. Hardgrove Index determinations were made on two samples and equilibrium moisture contents determined on three samples. Analytical data are presented in Table 2.

Samples were sealed in canisters as soon as they reached the surface and there was not always time to pick the most appropriate sample interval for testing. Consequently the ash contents of the samples range from 7.98 to 31.05%. Geophysical logs were not available at the time of sampling. As a result, samples 4 and 5 were collected from thinner seams with ash contents uncharacteristically high for seams at Telkwa. Samples 1 and 2 are chip samples and may contain high-ash contaminants from outside the sample interval.

Sulphur contents vary widely, ranging from 0.53 to 5.87% on an air-dried basis. The intrusion which outcrops less than 150 metres from both holes (Figure 3) may be responsible for the high and variable sulphur contents of samples 4 and 5.

Volatile matter and fixed carbon contents are consistent with coals of high-volatile A bituminous rank.

Mean maximum reflectance measurements (R_{max} values) for samples 3, 4 and 5, are 0.94, 0.99 and 0.92%, respectively, indicating a rank of high-volatile bituminous A . The values are somewhat higher than average R_{max} values north of the Telkwa River calculated by contouring all available data, probably because of the proximity of the drill holes to the intrusion. The values do not correlate with depth and average 0.95%.

ADSORPTION ISOTHERM DATA

Following completion of sample desorption, three samples were selected for testing to provide methane adsorption isotherms. Isotherms were measured on samples at equilibrium moisture and at a temperature of 22° C. Analyses were performed by Core Laboratories Limited, Calgary. Gas adsorption capacity was measured at seven pressures using standard techniques established for this experiment. Adsorption data including Langmuir volumes and pressures, are presented in Table 3 and the curves are plotted on Figure 5.

The adsorption curve for sample 5 is distinctly different from those of samples 3 and 6, even when the data are normalized to a daf basis. The isotherms for samples 3 and 6 project close to the desorption values for samples 1, 3, 4 and 5 (Figure 5). Samples 3 and 6 have R_{max} values 0.94 and 0.90% respectively, and equilibrium moistures of 3.6 and 4.6%.

The isotherm for sample 5 is low, and if real, implies that most of the samples are over saturated. The R_{max} value for sample 5 is 0.92%; this decrease in rank from sample 3 is not large enough to explain the difference in the two isotherms, especially considering that the equilibrium moisture of sample 5 (2.95%) is lower than for sample 3. Adsorption increases as equilibrium moisture decreases.

It is difficult to explain the fact that sample 5 appears to have desorbed more gas than it was capable of adsorbing in a later experiment. If the sample was over saturated with gas at 91 metres then one would expect the lost-gas correction (Table 1) on the desorption test to be noticeably higher than the lost-gas corrections for samples definitely not over saturated (e.g. sample 3). This is not the case. Another possibility is that the sample is slightly oxidized and that the oxidation has increased the desorbed volume of carbon dioxide but decreased the adsorption ability for methane. Whatever the explanation, it appears that the lower isotherm is not representative of Telkwa coal.

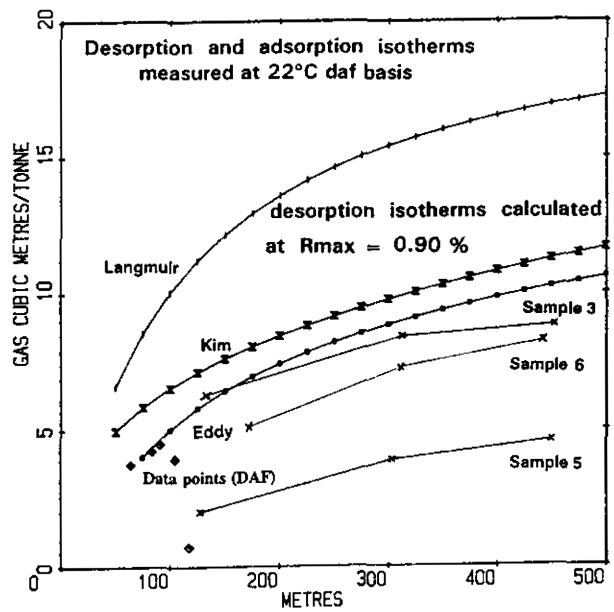

Figure 5: Desorption and adsorption data with theoretical curves from Kim (1977), Langmuir (1918) and Eddy *et al. (1982)*

TABLE 2
COAL QUALITY DATA FOR DESORPTION SAMPLES

ID /SM	BASIS	H_2O%	ASH%	VM %	FC %	S %	R_{max}	HGI
1 / S4	ar	20.24						
	ad	0.75	31.05	24.06	44.14	1.11		
	db	0	31.28					
2 / S2	ar	29.79						
	ad	0.68	25.93	24.58	48.81	0.55		
	db	0	26.11					
3 / S3U	ar	8.6						
	ad	1	6.98	25.12	66.9	0.54	0.94	68
	db	0	7.05					
	eq	3.6						
4 / S2R	ar	21.78						
	ad	0.68	27.13	21.99	50.2	5.87	0.99	
	db	0	27.32					
5 / S2L	ar	10.1						
	ad	0.82	19.92	29.3	49.96	3.69	0.92	69
	db	0	20.08					
	eq	2.95						
6 / S1	eq	4.5	33.83			0.5	0.9	

ar = As-received moisture as measured at laboratory
ad = air-dried moisture
db = dry basis calculated data
eq = equilibrium moisture
HGI = Hardgrove Index

Note Samples 1 and 2 chip samples
Samples 3, 4 and 5 NQ core samples
Sample 6 small core fragment retrieved from archives
Sulphur and R_{max} values estimated from measurements on adjacent core

TABLE 3

ADSORPTION ISOTHERM DATA

SAMPLE GSC92-3					
3.6 % MOISTURE 7.05 % ASH(db)				**DRY ASH-FREE BASIS**	
PRESSURE		**VOLUME**		**VOLUME**	
psia	**H_2O**	**scf/ton**	**cm^3/g**	**scf/ton**	**cm^3/g**
180	127	187.3	5.85	201.5	6.29
442	311	250.9	7.83	270	8.43
638	449	262.8	8.2	282.8	8.83
921	648	281	8.77	302.3	9.44
1317	926	296.2	9.25	318.6	9.94
1543	1085	295	9.21	317.4	9.91
1948	1370	305.9	9.55	329.1	10.27
SAMPLE GSC92-5					
2.95 % MOISTURE 20.1 % ASH(db)				**DRY ASH-FREE BASIS**	
PRESSURE		**VOLUME**		**VOLUME**	
psia	**H_2O**	**scf/ton**	**cm^3/g**	**scf/ton**	**cm^3/g**
180	128	50.5	1.58	63.2	1.97
428	304	100.6	3.14	125.8	3.96
634	450	117.4	3.66	146.8	4.58
1006	713	154.7	4.83	193.6	6.04
1221	806	172.6	5.39	216	6.74
1602	1136	199.6	6.23	249.8	7.8
1971	1398	211.4	6.6	264.5	8.26
SAMPLE GSB82-6					
4.5 % MOISTURE AND 35.43 % ASH (db)				**DRY ASH-FREE BASIS**	
PRESSURE		**VOLUME**		**VOLUME**	
psia	**H_2O**	**scf/ton**	**cm^3/g**	**scf/ton**	**cm^3/g**
240	168.8	106	3.31	164.1	5.12
440	309.4	150.9	4.71	233.7	7.29
626	440.2	170.9	5.33	264.7	8.26
912	641.4	199.4	6.22	308.8	9.64
1210	850.9	225.5	7.04	349.2	10.9
1513	1064	7.33	234.8	363.7	11.35
1984	1395	7.63	244.6	378.8	11.82

	CONSTANTS		
	GSC92-3	**GSC92-5**	**GSB82-6**
Sample depth (metres)	64.0-65.0	91.5-91.9	231.7
Langmuir Volume (cm^3/g) adb	10.38	9.856	9.46
Langmuir Pressure (psia)	171.6	982.7	451.8
Equivalent water column in metres	120.7	691.1	317.7
daf volume (cm^3/g)	11.17	12.331	14.63
Predicted volume adb (cm^3/g) (from adsorption isotherm)	4.8	1.08	3.98
Measured volume adb (cm^3/g) (from desorption data)	3.45	3.56	

Note H_2O is the height in metres of a water column equivalent to psia pressure

DATA SOURCES AND ANALYSIS TECHNIQUES FOR RESOURCE ASSESSMENT

A coalbed methane resource analysis requires information about the thickness, depth and rank of the coal, as well data on its gas content. Data for cumulative coal-seam thicknesses, depth of seams and thicknesses of stratigraphic units are available from geophysical logs of 350 holes drilled in the Telkwa area. This information has been entered into a computer database which makes it possible to grid and contour various parameters.

A number of R_{max} values of Telkwa coal are available (Ryan, 1992a). The R_{max} data are analyzed with help of a number of computer programs. Files of R_{max} data by seam with UTM locations were entered into GEOEAS, a variogram, kriging and contouring computer program distributed in the public domain by the Environmental Protection Agency (1988). This software was used to grid the data. Programs generated in-house were then used to calculated area-weighted averages for the data, construct Autocad DXF files and generate contour files compatible with QUIKMAP; a simple GIS software package (Environmental Sciences Limited, 1990). The series of programs allows for geostatistical analysis, resource evaluation and display of results.

Use was also made of a database of Telkwa coal quality which consists of over 3000 lines, each line representing a set of up to seven different analyses of a single sample. Data are derived from all ten seams sampled from over 350 holes, many of which were cored.

COAL RESOURCE IN THE TELKWA COALFIELD

The intensive exploration from 1978 to 1993 in the area west of Goathorne Creek and north of the Telkwa River has outlined a proven open-pit mineable reserve in the range of 20 to 50 million *in situ* tonnes It is difficult to asses the resource of the whole basin, which extends from Cabinet Creek in the south to north of Owen Creek in the north (Figure 2) because information is scarce or lacking in many areas. The regional geology is compiled on two 20 000-scale map sheets and a set of geological sections (Ryan, 1993). These maps and sections are used extensively to outline coal-bearing areas, as a base to plot the distribution of cumulative coal thickness in units 1 and 3 and as a base to plot the regional distribution of R_{max} values.

There is substantial information available for the area south of the village of Telkwa (sheet 1, Ryan, 1993). North of Telkwa and south of Smithers there is some information (Sheet 2, Ryan, 1993). North of Smithers there is little information except for the Owen Creek area which was sampled by the senior author in 1991.

An attempt is made to apply the informal four-unit stratigraphic classification of Palsgrove and Bustin (1989) to the whole basin and assess the resources in terms of cumulative coal in units 1 and 3. Unit 1 is recognized south of Smithers and possibly near Owen Creek. Unit 3 outcrops extensively south of the Telkwa River, adjacent to the Bulkley River and near Kathlyn Lake.

The coal resources are calculated in ten areas (Figure 6), and assigned to either unit 1 or 3. They are also classified as proven, probable or inferred (Table 4). These terms are used informally; proven refers to areas were there are numerous drill holes; probable refers to areas where there is some outcrop data and/or a few drill holes and inferred refers to areas where unit 1 or 3 are inferred to outcrop and a cumulative coal thickness is assumed.

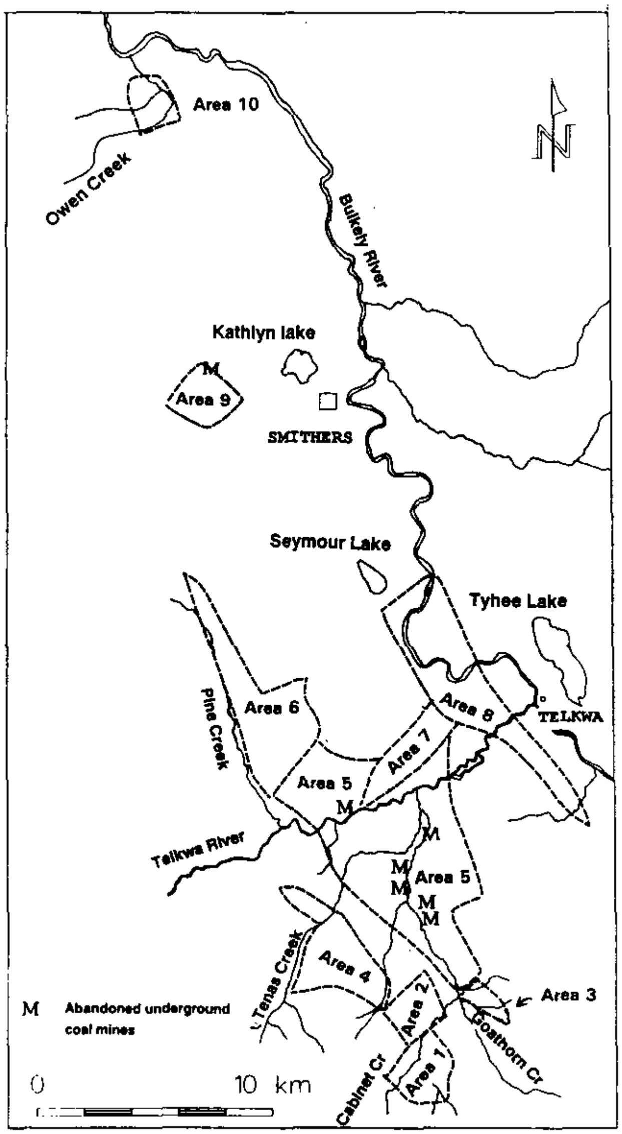

Figure 6: Resource calculation areas; southern Telkwa coalfield.

The average ash content for seams in unit 3 is assumed to be 21% at 1% air-dried moisture. The average ash content of seam 1 (unit 1) is assumed to be 30% at an air-dried moisture of 1%. These values are the average values extracted from the Telkwa Stage 2 report (1984) which covers only area 5. As area 5 contains over 70% of the coal resource in the coalfield, these values are applied to all other areas. The *in situ* moisture for Telkwa coal is estimated to be about 5% (Ryan, 1991a). Based on these data an average specific gravity of 1.26 is used for *in situ* unit 3 coal and 1.45 for *in situ* unit 1 coal.

TABLE 4
COAL RESOURCE IN THE TELKWA COALFIELD

	UNIT 1			UNIT 3			
			million tonnes				
AREA	proven	probable	inferred	proven	probable	inferred	TOTAL
1							
2	0	25	0	0	14.6	0	39.6
3	0	9.7	5.2	0	0	0	14.9
4	0	0	6.6	0	0	0	6.6
5	0	0	49.6	0	0	19	68.6
6	353.7	0	0	316.1	0	0	669.8
7	0	21.6	5.8	0	0.7	0	28.1
8	0		3.1	0	0	2	5.1
9	0		6.5	0	0	13.9	20.4
10	0		0	0	5	0	5
	0	4	0	0	0	0	4
TOTAL	353.7	60.3	76.8	316.1	20.3	34.9	862.1

SUMMARY million tonnes		values used to calculate tonnage in%	Unit 1	Unit 3
PROVEN	669.8			
PROBABLE	80.6	average *in situ* ash	29	20
INFERRED	111.7	average *in situ* moisture	5	5
TOTAL	862.1	average *in situ* S.G.	1.45	1.26

The resources in areas 1, 2, 3 and 4 (Figure 6) are calculated by planimetering the areal extent of units 1 and 3 and multiplying by an average cumulative coal thickness obtained by averaging drill-hole and outcrop data in the area.

The probable resource of area 1, which covers the synclinal remnants of units 1 and 3 in the Cabinet Creek area, is 39.6 million tonnes. There is one drill hole in this area and a number of coal outcrops that were mapped and sampled by the senior author in 1990.

The probable and inferred resource of area 2 is 14.9 million tonnes. This area covers two postulated synclinal remnants of coal-bearing sediments in which there are three drill holes. Area 3 is similar to area 2 and also covers a postulated synclinal remnant of sediments with an inferred resource of 6.6 million tonnes.

There is not much public information available for area 4 which is assigned an inferred resource of 68.6 million tonnes. Manalta Coal Limited drilled here this area in 1992 and 1993 and intersected coal, so that a more confident assessment of the resource will be available in the future.

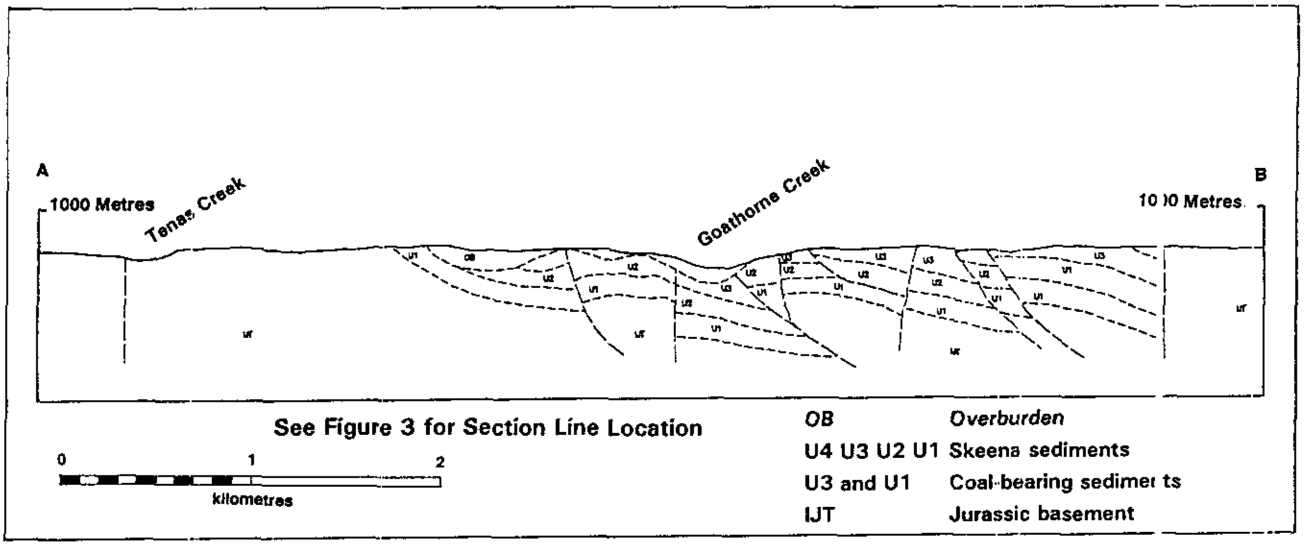

Figure 7: Geological section of the Goathorne Creek area.

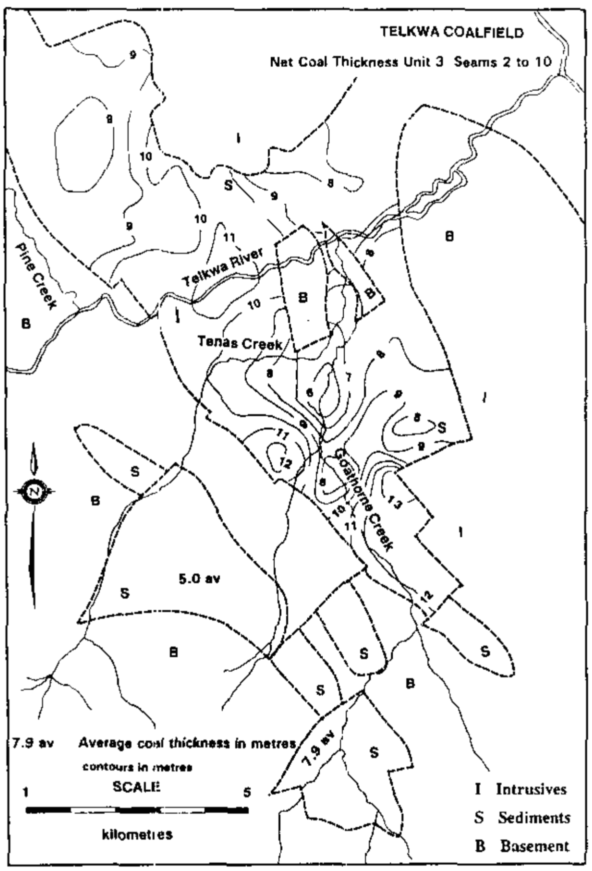

Figure 8: Cumulative coal intersected in unit 3

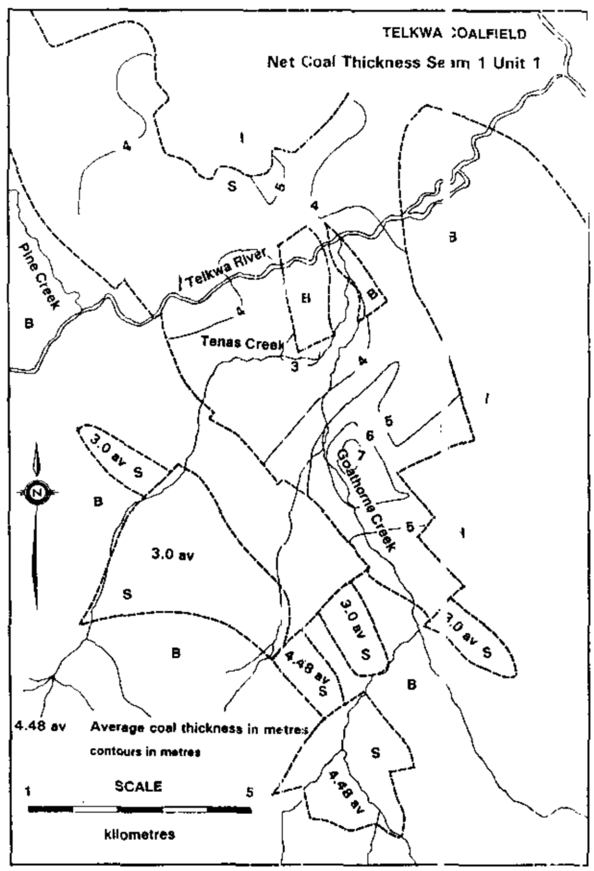

Figure 9: Cumulative coal intersected in unit 1

Much of the exploration in the Telkwa coalfield was in area 5 where most of the 171 holes that intersect unit 3 and the 100 holes that intersect unit 1 were drilled. A test pit in area 5 excavated 5000 tonnes of coal (Figure 3). Five detailed geological sections (Ryan, 1993) outline the distribution of the units in the area. One of these sections (Figure 7) is located on Figure 3.

Cumulative coal data for units 1 and 3 were gridded and the data contoured in Figures 8 and 9. Cumulative coal thicknesses do not indicate the total cumulative coal in the units because few holes penetrated the total thickness of either unit. The grid cells were constructed so that they match the section lines. This allows average coal thicknesses to be located on the sections at 500-metre spacings. Average coal thicknesses were multiplied by the length of coal-bearing unit in each fault block outlined on the sections. Summing the resulting coal area increments provides a volume of coal for each section line. These values were multiplied by an appropriate lateral distance and a specific gravity of 1.26 or 1.45, to provide the appropriate tonnage.

This method of evaluation provides only an estimate of the total resource in area 5. The resource classified as proven is 670 million tonnes. A more complete approach would require constructing isopach and structural contour maps for units 1 and 3 in each fault block. There is sufficient information available to do this in area 5, but it was not considered warranted for this study.

Thirteen holes have been drilled in area 6 but it is not currently included in any mining reserve estimation. A resource of 28.1 million tonnes is outlined. Area 7, to the east, is similar but does not contain any drill holes so the 5.1 million tonne resource is classified as inferred.

In area 8, postulated to contain unit 3 and 1, thin seams outcrop adjacent to the Bulkley River, south of Smithers. Area 8 is assigned an inferred resource of 20.4 million tonnes.

Multiple thin seams outcrop west of Kathlyn Lake (area 9) where there was some mining from 1932 to 1936. All these outcrops are assigned to unit 3 and an inferred resource of 5 million tonnes is estimated.

The Telkwa coalfield extends north of Smithers for about 17 kilometres. The valley floor is covered by alluvium and it is not known if the Skeena Group sediments (unit 1?) which outcrop north of Owen Creek (area 10) are continuous at depth with outcrops at Kathlyn Lake. There are very little data available to assess the potential coal resource in this area. Mapping in 1991 by the senior author located 2.55 metres of cumulative coal in seven thin seams. A probable resource of 4 million tonnes is assigned to the area.

COAL RANK

The rank of coal in the Telkwa coalfield is discussed by Ryan (1992a). Some new analyses are now available for areas in the northern part of the coalfield. This paper presents the new R_{max} data and discusses the lateral and vertical variations of R_{max} values in area 5.

Generally the rank of coal in the Goathorne Creek area of the coalfield (area 5) is high-volatile bituminous A. The rank increases to the south and north away from area 5. In the Cabinet Creek area measurements on outcrop coal provide an average R_{max} value of 2.3%. The coal adjacent to the Bulkley River in area 8 has an average R_{max} value of 1.27% and further to the north a sample has an R_{max} value 1.97%. The Lake Kathlyn deposit is anthracite and R_{max} values of coal north of Owen Creek (area 10) are variable but average 1.6%.

For areas other than area 5 single average R_{max} values are assigned to the area. There are sufficient data in area 5 to produce a contour map of R_{max} values for unit 1 (seam 1) and unit 3 (seam 2). This is done in part using R_{max} measurements and in part using R_{max} values estimated from volatile measurements (Ryan, 1992a). The procedure used is similar to that employed by Stevens *et al.* (1993). 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 R_{max} values (Bustin *et al.*, 1983; Meissener, 1986).

Volatile matter data can be corrected to an ash-free or mineral-matter-free basis by first plotting all VM data against ash data on a seam by seam basis to derive the best-fit linear relationships and then using the slope of the lines to correct individual VM measurements to an equivalent VM ash-free value. The slope of the line will equal the Y intercept (VM af) if the ash acts only as a dilutant. If the mineral matter and any sulphides add inorganic volatile matter to the VM measurement then the slope will be decreased by a component equal to the gassiness of the mineral matter.

Based on the data in Table 5 the mineral matter in seam 2 is gassier than in seam 1. Non-gassy mineral matter is often associated with a reactive rich coal (Slaghuis *et al.*, 1990) and probably also indicates less pyrite.

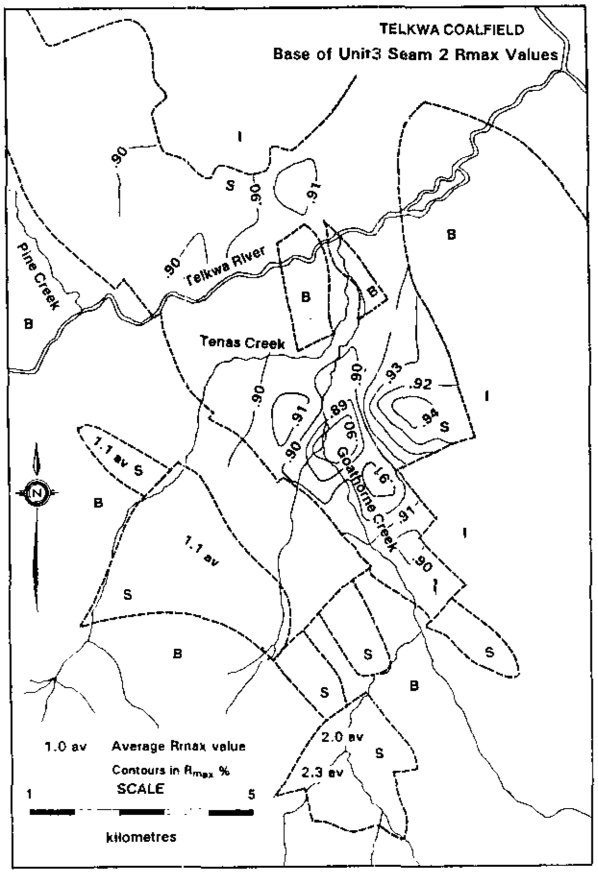

Figure 10: Seam 2 R_{max} contours

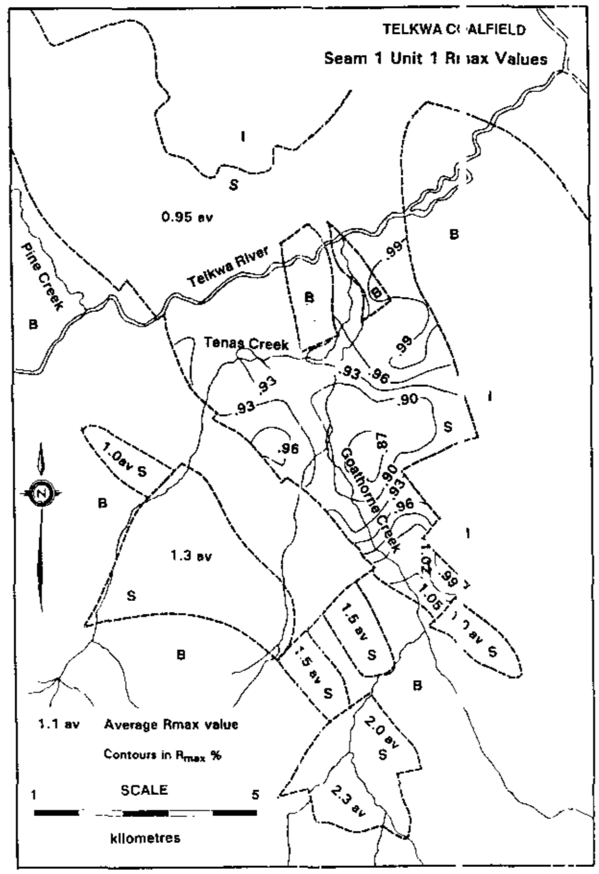

Figure 11: Seam 1 R_{max} contours

Once a method is developed to provide volatile matter ash-free values (VM af%) it is possible to investigate the relationship of VM% (af) *versus* R_{max} values on a seam by seam basis using the existing R_{max} measurements. There are eight VM% (af) *versus* R_{max} pairs for seam 1, and sixteen pairs for seam 2. Lines are fitted through each data suite (Table 5). It is now possible to convert any VM% measurement to an estimated R_{max} value using the VM% *versus* ash% relationships and the VM% (af) *versus* R_{max} value relationships for each seam. Using this technique 128 data points for seam 2 (unit 3) and 56 data points for seam 1 (unit 1) were generated and the data used to generate contour plots (Figures 10 and 11). The calculated R_{max} values were also gridded on grids that matched the geological section base lines. This permitted R_{max} values to be posted onto the sections at 500-metre spacing.

TABLE 5
RELATIONSHIP OF
VOLATILE MATTER ASH-FREE BASIS TO REFLECTANCE (R_{max})

EQUATION	count	R^2
SEAM 6		
VM = 29.6 - 0.176 x ash	134	-0.59
VM af = VM + 0.176 x ash		
R_{max} = 1.53 - 0.022 x VM af	12	-0.82
SEAM 2		
VM = 29.3 - 0.168 x ash	167	-0.54
VM af = VM + 1.68 X ash		
R_{max} = 1.31 - 0.014 x VM af	16	-0.54
SEAM 1		
VM = 30.9 - 0.304 x ash	84	-0.46
VM af = VM + 0.304 x ash		
R_{max} = 2.46 - 0.0479 x VM af	8	-0.88

af = ash-free basis

METHANE CAPACITY OF TELKWA COAL

The best way to calculate the methane resource of an area is to measure the desorbed gas from a number of samples of varying rank and from different depths and to use the results to provide gas content per tonne values for coal tonnages in each sub-area. In the absence of sufficient data there are three alternative approaches.

- Adsorption isotherms provide information on the maximum adsorption gas capacity at increasing pressure and constant temperature (in this case 22°C). The adsorbed gas capacity is not necessarily the actual gas capacity. It does not consider the free-gas component which is probably not measured in the desorption test.

- There are a number of empirical curves that illustrate the actual averaged lost plus desorbed gas contents of coals of different ranks at different depths (Eddy *et al.*, 1982).

- There are equations, derived in part from empirical relationships and in part from theoretical considerations, that predict the maximum adsorption capacity of coal of different ranks and at different depths (Langmuir; 1918; Kim, 1977; Olszewicki and Shraufnagel, 1992).

The five desorption tests performed on Telkwa coal are plotted on an ash-free basis on Figure 5 with the three adsorption isotherms for samples 3, 5 and 6. The adsorption isotherms were measured at a constant temperature of 22°C which may not be the reservoir temperature. Increasing temperature decreases the adsorption capacity of the coal. Most of the coal considered in this study is shallow and at depths ranging up to 500 metres. If the average surface temperature is 11°C and the geothermal gradient is assumed to be 20°C per 1000 metres then a temperature of 22°C corresponds to a depth of 550 metres.

The adsorption isotherms for samples 3 and 6 project close to the plotted positions of samples 1, 3, 4 and 5 (Figure 5). All data are calculated to a dry-ash-free basis. It appears that these samples are saturated and that the isotherms for samples 3 and 6 provide a reasonably accurate method of predicting their gas capacity at increasing pressure and constant temperature.

Eddy *et al.* (1982) provide five curves of lost plus desorbed gas contents for coals of constant rank at varying depths. These are empirical curves based on numerous desorption results. To some extent they provide a static picture, in that the coal rank generally increases with depth.

Ryan (1992b) fitted an empirical equation which contains the additional variable of R_{max} to Eddy's curves. It permits curves to be constructed for intermediate ranks that still conform to the general form of the five original Eddy curves or to illustrate the effect of increasing rank with depth.

A modified Eddy curve for a R_{max} of 0.90% projects close to the desorption data and isotherm for sample 3 (Figure 5). The average R_{max} value of three of the samples (3, 4, and 5) is 0.95%. A similar Eddy curve for R_{max} of 0.95 predicts desorbed gas contents about 16% higher for the depths of 60 to 120 metres than the 0.90%. If this discrepancy is real then it means that Telkwa coal, as represented by samples 3, 4 and 5, even when saturated, contains about 16% less gas than coals of similar rank from the U.S. database used to establish the original Eddy curves.

Kim (1977), using in part desorption data and in part theoretical predictions of the relationships of adsorption *versus* temperature and pressure, produced a set of equations that predict the adsorption capacity of coal. Kim's equations predict a maximum capacity for coals of different ranks at various temperatures and pressures. This maximum capacity is then decreased by an amount based upon the critical moisture content of the coal. This term is rank dependent and is approximated by the equilibrium moisture of the coal and is also dependent on the oxygen content of the coal.

Oxygen data are not always available for coal samples. Because of the partial rank dependency of the oxygen content of coal it is possible to establish a relationship of critical moisture to volatile matter (daf) using data in Kim's paper and a relationship of VM (daf) *versus* R_{max} using relationships in Meissener (1984). Using these relationships it is possible to calculate the critical moisture corresponding to a specific R_{max} value.

There are no oxygen data available for the desorption samples but some averaged data from north of the Telkwa River provide a value of 9.3% and similar data from south of the Telkwa River provide an average of 7.6%. The average R_{max} value of the desorption samples is 0.95% and their average equilibrium moisture is 3.28%.

These data provide four ways of estimating the critical moisture and therefore four different adsorption values at a constant depth. At a depth of 100 metres the four predicted gas contents are 6.73, 5.85, 4.95 and 5.99 grams per cubic centimetre for critical moistures calculated using 1/ an R_{max} value of 0.95%, 2/ an oxygen content of 7.6 3/ an oxygen content of 9.3% and 4/ an equilibrium moisture of 3.28%. This compares to an adsorption content of 5.04 grams per cubic centimetre measured by the adsorption isotherm for sample 3 at a depth of 100 metres.

Kim's equations provide only an estimate of predicted maximum adsorption capacity and no estimate

TABLE 6
PREDICTED GAS CONTENTS OF UNIT 1 AND UNIT 3 COALS WITH INCREASING RANK AND DEPTH OF BURIAL
calculated using Equation A (Ryan ,1992 b)
values adjusted by 16 % (see text)

UNIT 1
***in situ* ash 29 % *in situ* moisture 5 %**

Depth m	R_{max} .86	0.88	0.9	0.92	0.94	0.96	0.98	1
50	1.14	1.3	1.45	1.6	1.74	1.86	2	2.12
100	2.48	2.64	2.79	2.93	3.07	3.2	3.33	3.45
150	3.26	3.41	3.56	3.7	3.85	3.98	4.11	4.23
200	3.81	3.96	4.12	4.26	4.4	4.53	4.66	4.78
250	4.23	4.39	4.54	4.69	4.83	4.96	5.09	5.21
300	4.59	4.75	4.9	5.04	5.17	5.31	5.43	5.56
350	4.88	5.04	5.14	5.33	5.58	5.6	5.74	5.85
400	5.14	5.3	5.45	5.59	5.73	5.86	5.99	6.12

UNIT 3
***in situ* ash 20 % *in situ* moisture 5 %**

Depth m	R_{max} .86	0.88	0.9	0.92	0.94	0.96	0.98	1
50	1.3	1.48	1.66	1.81	1.97	2.13	2.27	2.41
100	2.81	2.99	3.17	3.33	3.49	3.64	3.78	3.92
150	3.7	3.88	4.05	4.22	4.37	4.52	4.67	4.8
200	4.33	4.51	4.68	4.84	5	5.15	5.29	5.44
250	4.81	5	5.17	5.33	5.49	5.64	5.78	5.92
300	5.22	5.39	5.56	5.73	5.88	6.03	6.18	6.32
350	5.55	5.73	5.9	6.07	6.22	6.37	6.52	6.65
400	5.84	6.02	6.19	6.35	6.51	6.66	6.8	6.95

Equation A

$K = 0.98$ $R = R_{max} \times K$ $C = \text{Depth in metres} \times R^{2.5} - 0.2$

$B = (\ln(C)/2.30259 - 1.095)/.003913$ $\text{Gas cm}^3/\text{g} = B \times (100 - M - A)/100/32.037$

M = moisture content A = Ash content

of the free gas component. Based on the data above, Kim's equations provide predictions that range from good agreement with isotherms 3 and 6 to 35% higher than the isotherms. The apparent over estimate of the gas capacity of the samples may be because Kim's equations were developed using coals with a generally higher vitrinite content than Telkwa coals. She used a database of 22 samples collected from Appalachia and the Black Warrior coal basin. Some papers appear to indicate that vitrinite has a higher adsorption capacity than other coal macerals (Lamberson and Bustin, 1992). Work by the present authors may indicate that small amounts of inherent ash can damage the adsorption capacity and confuse the maceral *versus* adsorption capacity relationship. Also Kim's equations use proximate data to estimate coal rank which influences gas adsorption capacity. Because of the lower vitrinite and therefore lower volatile content of Telkwa coals, Kim's equations will over estimate ranks and gas contents for the coal.

Olszewicki and Shraufnagel (1992) used the same database as Kim but used the Langmuir equation (Langmuir, 1918) to produce another model of gas content *versus* depth. Their model has been adapted to allow for construction of gas content *versus* depth tracts that illustrate the effect of increasing rank and temperature with depth. The modified Langmuir curve for a R_{max} of 0.90 and a geothermal gradient of 18°C per 1000 metres (Figure 5) plots much higher than the data. No explanation for the large discrepancy could be found in the data or in the original paper.

The difference in the three methods of predicting desorption curves (Eddy *et al.*, Langmuir, and Kim) indicates the level of uncertainty in trying to predict gas contents. Gas capacities cannot be predicted accurately based only on proximate data, depth and temperature. The various approaches serve mainly to illustrate relative trends as coal quality, rank, depth and temperature change.

The modified Eddy curve appears to provide the best way to model the gas content of Telkwa coal for changing ranks and depths. However predicted gas contents must be decreased by 16% to account for the fact that an Eddy curve of R_{max} = 0.95% is 16% higher than the 4 data points which average a R_{max} of 0.95%.

The desorption samples were collected from within 150 metres of a Tertiary intrusion (Figure 3). The R_{max} values do not appear to have been increased by the intrusion, but intrusions probably cause movement of heated geothermal water outside any identifiable metamorphic halo. This water could easily remove methane from the coal and at the same time deposit finely dispersed mineral matter in the microporosity of the coal which could damage its adsorption ability.

METHANE RESOURCE

Gas contents for different ranks and depths are calculated using modified Eddy curves generated by Ryan, (1992b) and the ranks and depths established for each block or sub-block of the coal resource. The gas contents are all decreased by 16%. This factor could be explained as an adjustment to account for the moderately low vitrinite content of Telkwa coals as compared to the database used to establish the original Eddy curves. Average *in situ* ash and moisture contents are used for all unit 1 coals (29% and 5%) and unit 3 coals (20% and 5%). Table 6 provides a matrix of gas concentrations per tonne calculated using equation A for unit 1 and 3 coals, for varying depth and rank.

In most areas an average depth and rank is assigned to the coal tonnage reported in Table 4. The tonnage is multiplied by the appropriate gas-content value (Table 6). The procedure is not accurate because there is very little coal-depth information in many of the areas. A more accurate assessment of the resource is possible in area 5. Depths are assigned to each block of coal between faults on the sections and individual gas content values used. The methane resource is classified based on an estimate of the degree of assurance (Table 7). Level 1 indicates a high level of assurance and level 3 a low level. The informal level terms were used to avoid using terms such as proven resource which might carry implied definitions from the oil and gas industry that would not be appropriate in this study.

The total coalbed methane resource of the Telkwa coalfield is 3.7 billion cubic metres (Table 7). This is not large when compared to the resources in the major coalfields such as the southeast British Columbia coalfield which has a resource of 565 billion cubic metres (Johnson and Smith, 1991). On the other hand, the Telkwa coalfield is close to the towns of Smithers and Telkwa which may offer ready markets for small quantities of gas.

Any discussion of the potential for recoverable reserves requires an understanding of the regional structure and its influence on regional permeability.

REGIONAL STRUCTURE

Beds in the Telkwa coalfield generally strike northwesterly, dip to the east and are segmented into numerous fault blocks by northwest-striking east-dipping reverse and thrust faults. There are at least two episodes of later normal faulting. Older normal faults trend northerly. A few outcrops of andesite dikes, striking northwest, are apparently associated with these faults. Younger normal faults trend east-west. The regional fault pattern is well documented in the Goathorne Creek area by extensive exploration drilling. In other areas only the major block faults have been identified (MacIntyre *et al.*, 1989).

Mesoscopic faults and folds seen in outcrop support this geometry and sequence. Small-scale thrusts and reverse faults, striking northwest, break the beds and in places are associated with folds which generally are not found elsewhere. In some places early thrusts and reverse faults are broken by younger northwest-striking normal faults. Occasionally easterly striking vertical faults, assumed to be the youngest structures, are seen. They are often associated with brecciation.

Fold trends in some areas are estimated from stereonet plots of poles to bedding. In the Cabinet Creek area folds trend 320 ° and plunge 20 ° To the north, in the Goathorne Creek area the average fold-axis trend is azimuth 135 ° and plunge 25 °. In the Telkwa and Bulkley River areas the fold axes appear to trend 180 ° with a zero plunge. The orientations of minor fold axes, compressional faults and normal faults are plotted on Figure 12. The data are mostly from the area south of Telkwa. The vector average fold-axis orientation is 143 ° trend with a plunge of 13 °.

Some joint and minor fault data have been collected from drill holes and these are discussed in the context of their effect on permeability.

PERMEABILITY

Favourable regional permeability within the coal seams is one of the most important parameters required for an economic CBM well. Permeability measurements were made as part of the Telkwa Stage 2 study (Crowsnest Resources Limited, 1984). The data are included in two geotechnical reports, one by Klohn Leonof Limited and one by Piteau Limited.

The Klohn Leonof study was undertaken to aid pit design in the area east of Goathorne Creek. As part of the study, packer tests were performed over coal intersections in diamond-drill holes. The Piteau study in 1990 was part of an amended Telkwa Stage Two submission and included data on the permeability of interburden rocks north of the Telkwa River.

Permeability data from these two reports are collected in Table 8. Permeabilities of coal seams, numbers 2 to 8 in three drill holes in the east Goathorne area were measured at depths ranging from 29 to 158 metres. Permeabilities do not correlate with depth and values range from 0.5 to 50 millidarcies. Measurements were made as drilling commenced, using packers to isolate individual seams. Data were reported as hydraulic conductivity (metres per second) and an approximate conversion to millidarcies is made by multiplying by 105.

TABLE 7
COALBED METHANE RESOURCE IN THE TELKWA COALFIELD

	UNIT 1			UNIT 3			
	million cubic metres						
AREA	level 1	Level 2	Level 3	Level 1	Level 2	Level 3	TOTAL
1	0	229.1	0	0	131	0	360.1
2	0	75.6	40.9	0	0	0	116.5
3	0	0	3.7	0	0	0	3.7
4	0	0	336	0	0	103.6	439.6
5	1836.9	0	0	735.8	0	0	2572.7
6	0	98.8	0	0	2.9	0	101.7
7	0		13.9	0	0	10.3	24.2
8	0		0	0	0	0	0
9	0		0	0	61.1	0	61.1
10	0	31.4	0	0	0	0	31.4
TOTAL	1836.9	434.9	394.6	735.8	195	113.8	3711

SUMMARY	million m^3
LEVEL 1	2572.8
LEVEL 2	629.8
LEVEL 3	508.4
TOTAL	3711

The CBM content per tonne values were derived using average ash and moisture contents and varying rank and depth values as indicated in Table 6.
Depth and R_{max} data estimated from regional geology as described in text

Levels are informal indications of assurance 1 = high 3 = low.

Permeabilities of 0.5 to 50 millidarcies cover the range from low to excellent for coal, considering the depth of the measurements. In the Black Warrior basin, Alabama, permeabilities range from 0.5 to 14 millidarcies at depths of approximately 350 metres (Ellard and Roark, 1992). Generally a permeability of 5

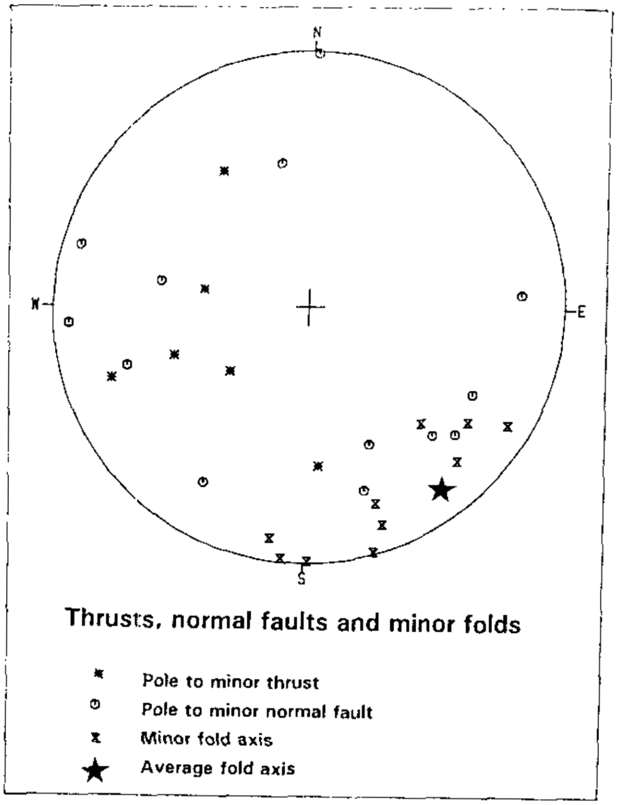

Figure 12: Minor fold axes and minor faults

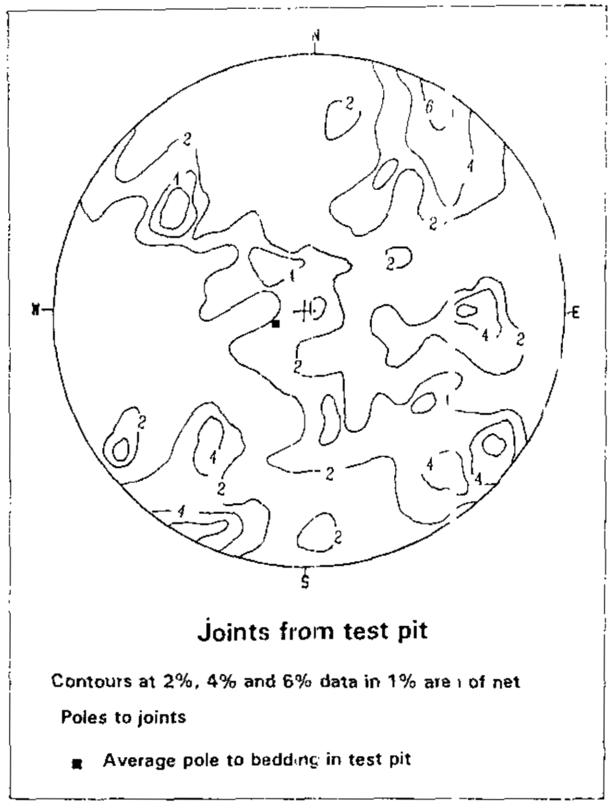

Figure 13: 46 bedding measurements and 198 joints from the test pit east of Goathorne Creek

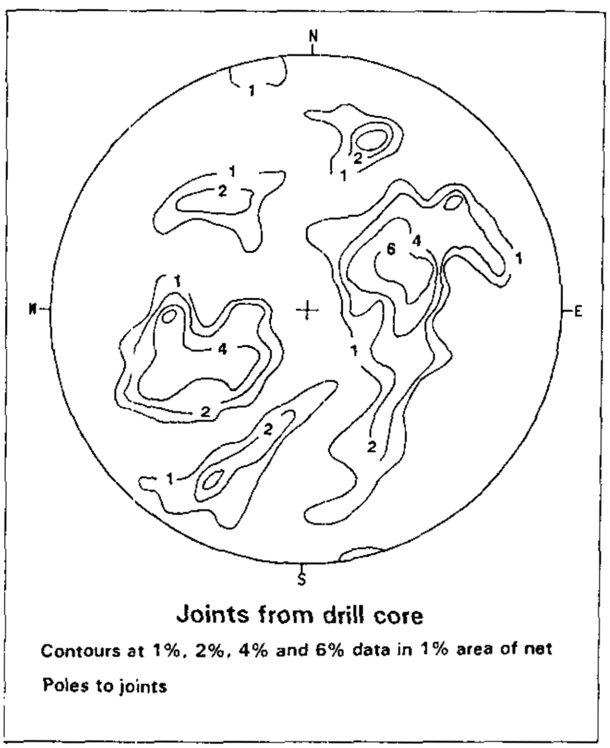

Figure 14: Joint sets from 22 diamond-drill holes

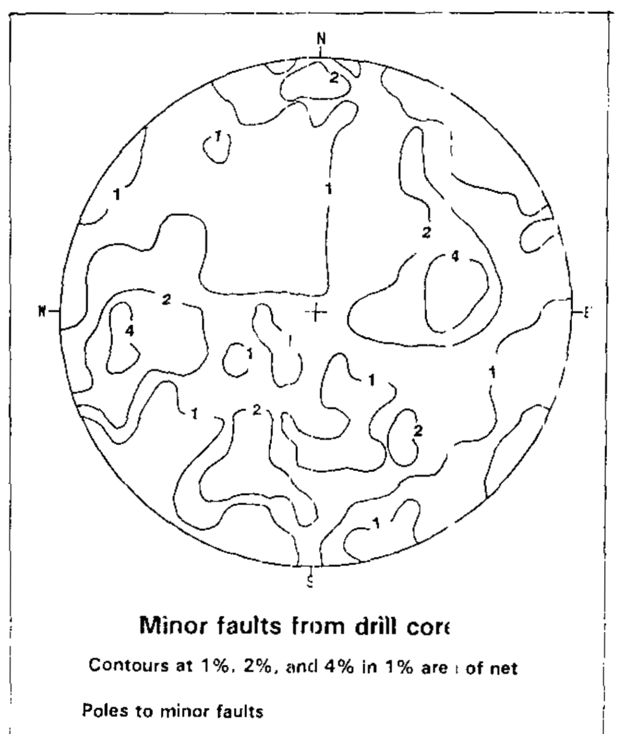

Figure 15: Minor faults from 16 diamond-drill holes

millidarcies is considered to be the minimum required for an economic well (Yee *et al.*, 1992)

The permeability of sections of mudstone, siltstone and sandstone interburden varying in thickness from 14 to 27 metres was measured in drill holes north of the Telkwa River. Permeabilities range from 13 to 35 millidarcies. At the depths of less than 200 metres permeabilities of interburden rock and coal are moderate. The permeability of the interburden is on average greater than that of the coal. In order to be able to drain water from the seams it will be important to have impermeable hangingwall and footwall material. This information is available in the core descriptions and geophysical logs included in the assessment reports submitted to the provincial government.

TABLE 8
PERMEABILITY TEST RESULTS

HOLE	LOCATION	METRES	
	Easting	Northing	Elevation
DR255	6.00E+05	6.00E+06	802
DR256	6.00E+05	6.00E+06	890
DR257	6.00E+05	6.00E+06	729
DR258	6.00E+05	6.00E+06	747
DR604A	6.00E+05	6.00E+06	813
DR905S	6.00E+05	6.00E+06	803
DR905D	6.00E+05	6.00E+06	803
DR906A	6.00E+05	6.00E+06	806
DR913	6.00E+05	6.00E+06	923

HOLE	DRILL SECTION	TEST	HEAD	ROCK OR SM	MILLI DARCIES
DR255	91.7-93.9	PACKER	NA	COAL S8	50
DR255	107.9-110.3	PACKER	NA	SMS8	60
DR255	114.9-121.0	PACKER	NA	SM S6	2
DR255	138.4-139.9	PIEZO	138M	SMS3	3
DR256	157.9-159.4	PIEZO	158M	SL	1
DR257	28.8-31.1	PIEZO	27.6M	SM S2	3
DR258	44.5-46.3	PIEZO	44M	SM S7	1
DR258	45.7-48.0	PACKER	NA	SM S7	6
DR258	50.6-52.9	PACKER	NA	SM S6	1
DR258	64.3-69.2	PACKER	NA	SM S5	2
DR258	114.9-121.0	PACKER	NA	SM S2L	2
DR604A	24.8-32.6	PIEZO	23.4M	MD+CL	24
DR905S	17.9-26.1	PIEZO	25.6M	SL+CL	NA
DR905D	48.9-58.3	PIEZO	24.4M	RK+CL	25
DR906A	55.2-67.7	PIEZO	26.5M	MD+CL	22
DR913	24.9-32.5	PIEZO	14.2M	SL+CL	13

Section = depth range in metres
Test = Packer test or piezeometer
Head = height of water column above test zone in metres
Rock = Rock type or seam number
RK= rock, MD=mudstone, SL=siltstone, ST=sandstone, CL=coal

Permeability is strongly influenced by the regional geometry of folds, faults and cleats or joints. Outcrop is sparse but joints were measured in the test pit in the Goathorne Creek area. The pit which yielded over 5000 tonnes of coal for testing was mapped and 46 bedding and 198 joints measured (Figure 13). Beds dip 13° to the northeast and strike 157°. The joints tend to intersect bedding at large angles along a line of intersection trending northwest (fold-axis trend) or along a line perpendicular to the fold-axis trend. This is a common geometry for tectonic joints.

Subsurface bed orientations are available from dipmeter logs measured during a number of exploration programs. Subsurface joint measurements were made in 1982 during a geotechnical program and the results reported in the Telkwa Stage 2 submission. Joints were measured in core by recording the joint surface to drill-core angle and the clockwise rotation around the circumference of the core of the joint surface dip-line from the bedding surface dip-line. The technique requires good core in which bedding surfaces and joint surfaces are both well developed. Using the dipmeter logs to provide an average true orientation of the bedding for the hole, it is possible to rotate the joints into their "true orientation" using astereonet. The technique is approximate because only a single average bed orientation is used to rotate all the joints in a hole.

Measurements of joints from 22 holes were tabulated and the four best-developed joint concentrations identified for each hole. These concentrations were ranked (1 to 4) based upon degree of development and then plotted separately on astereonet and the distribution analyzed. There was no difference in the plots of the first ranking through to the fourth ranking joint concentrations. All the concentrations are contoured on Figure 14.

TABLE 9
MEAN UNIAXIAL COMPRESSIVE STRENGTHS
FROM POINT LOAD TESTS

LITHOLOGY	FORM/FAILURE	COUNT	STRENGTH (MPa)
COAL	massive	2	14
	joints/bedding	12	2
SILTSTONE	massive	15	50
	bedding or joints	60	7
SILTY	massive	9	16
MUDSTONE	bedded	15	2
TUFFACEOUS	massive	3	35
MUDSTONE	bedded	9	6
COALY	massive	3	7
MUDSTONE	bedded	5	2
SANDSTONE	massive	11	65
	bedded	22	13

MPa = megapascals (1 MPa = 145 psia)

A vertical hole will not intersect a vertical joint and the frequency of intersection of a joint set increases as the dip of the joint set decreases. This means that the data plotted on Figure 14 are not representative of the true joint frequency; despite this, it appears that the joints tend to form a great circle girdle about the northwest-trending fold direction. Eigen vectors provide a pole to the great circle girdle trending 316° with a plunge of 1°. This means that the joints intersect the bedding surface along a line parallel to the northwest-trending foldaxis.

A similarstereonet plot was made for 218 minor faults identified in sixteen drill holes (Figure 15). The pattern is more dispersed but a southwest to northeast girdle is still discernible. The pole to the girdle trends 331° with a plunge of 3°.

Based on the joint data from surface and drill holes and the minor fault data from drill holes, it is probable that the face cleats in the coal seams strike northwest and dip steeply east or west. The surface joint pattern identifies a northeast-trending joint set which is perpendicular to the fold trend. This may be the orientation of butt cleats in the coal.

Permeability will be improved in a direction trending 315° to 360° (face cleats) and probably to a lesser extent in a direction trending 30° to 60° (butt cleats). Generally permeability in the direction of the face cleats is three times better than in the direction of the butt cleats.

Faults mapped in the test pit are generally tight and will block the flow of methane along the seam but probably will also not discharge much water into the coal seam reservoir as it is drained. The area in each coal seam available to be drained will be limited in a northeast to southwest direction, but may extend farther in a northwest-southeast direction because of the improved permeability and the absence of crosscutting faults.

The presence of joints or cleats does not guarantee good permeability. The coal must have sufficient strength to resist overburden stresses and maintain some porosity along the joint surfaces. Generally coal is not as strong as the surrounding rock and it is more difficult to maintain interconnected pathways along the joint surfaces.

The Klohn Leonof report contains data on the uniaxial compressive strength of rock types used in an assessment of ripability of rocks east of Goathorne Creek (Table 9). The coal is as strong as the mudstone and weaker than other rock types. Compared to many coals from other areas in British Columbia, Telkwa coal is strong. This is substantiated by the Hardgrove index of Telkwa coal which ranges from 45 to 65 compared to values on coal from southeast of the province that range from 80 to 110. Hardgrove index is a measure of the friability of coal. It is probably also a measure of coal's ability to resist compaction pressure (overburden pressure minus hydrostatic pressure). A coal with a low HGI is more likely to withstand overburden pressure and maintain joint sets with an interconnected permeability than a friable coal.

Hardgrove index data exist for many seams in the major coalfields in British Columbia. The data may be very useful in provisionally screening coal seams for their potential regional permeability.

GROUNDWATER CHEMISTRY

Coalbed methane wells usually produce formation water before and during methane production. The water can be pumped back into formations or disposed of on the surface, either in evaporation ponds or directly into rivers. The last method of disposal is the cheapest but is permitted only if the formation water meets certain standards.

Water samples were taken from the piezometers in holes 604A, 905S, 905D, 906A and 913 described in Table 8. The samples are from formation intervals that include coal and other rock types. The water is soft with carbonate loadings ranging from 6.4 to 52.3 milligrams per litre (with one exception of 86.8). Total filterable residue concentrations range from 397 to 1045 milligrams per litre. The accepted concentration for drinking water is 500 milligrams per litre. Concentrations of iron, sulphate, chlorine and fluorine are all within drinking water standards. Based on these data it appears that formation water can be disposed of into existing rivers via a series of settling ponds.

POTENTIAL METHANE RESERVES

Two important points must be made before any discussion of potential CBM reserves in the Telkwa coalfield can proceed. Firstly, in a ranking of potential CBM targets in British Columbia Telkwa would not rank high. At present there appear to be much better prospects in the southeast and northeast of the province. Secondly, any plan to develop the CBM potential at Telkwa must come to terms with any ongoing surface coal mining operations.

Cech *et al.* (1992) model the economics of hypothetical wells recovering from 50 to 160 million cubic metres of gas. These wells were projected to depths in excess of 600 metres. Any well at Telkwa would be considerably shallower. To put these numbers in perspective, an area of 1 square kilometre (100 hectars) underlain by 10 metres of coal with a gas content of 5 cubic metres per tonne contains 50 million cubic metres of gas. In the Telkwa coalfield unit 3 contains the most coal, with cumulative thicknesses averaging 9.6 metres, but this unit is generally shallow. The deeper unit 1 contains 4.3 metres of coal on average but is 100 to 200 metres below unit 3. There is a trade-off between 4.3 metres of deeper coal with higher gas contents and 9.6 metres of shallower coal with lower gas contents. Seam 1 in unit 1 generally has higher ash and is more difficult to wash than seams in unit 3. Some data appear to indicate that finely disseminated ash can damage the adsorption ability of coal. Consequently there is some concern that the gas contents of seam 1 in unit 1 may be lower than expected.

Permeability in the coal seams is average. In this case a well has a better chance of being economic if it extracts methane from numerous seams over a small surface area than if it extracts gas from fewer coal seams over a larger surface area. The piezometer data indicate that the coal seams are not under pressured. The water level in the piezometers in most cases was at or close to ground surface. Shallow coal seams are therefore likely to have retained the expected amount of gas based on depth and rank.

A number of potential targets are located on Figure 3 by letter. The synclinal remnants of unit 1 in the south (areas A, B and C) each may contain sufficient gas to support one to three wells. The wells would target a projected 4 to 5 metres of coal with a R_{max} value 2.0% or higher.

The area east of Goathorne Creek is being studied for its open-pit potential. Unit 3 coal may be open-pit mined but wells could still recover methane from unit 1 coal which is 100 to 150 metres below unit 3. Unit 3 dips eastward east of areas presently proposed for open-pit mining and could contain sufficient methane for a single well in area D (Figure 3).

Coal has been mined underground at Telkwa since the 1900s. The mines were small room-and-pillar operations mining down the full dip of the seams. The underground workings located on Figure 6 are probably now flooded but there is some chance that they have been sealed by caving and now act as gas reservoirs.

The potential CBM resource in the Telkwa coalfield is 3.7 billion cubic metres. If only five wells are developed for a total recoverable gas of 0.25 billion cubic metres over 10 years, this is sufficient gas to meet the heating requirements for over 10 000 houses in the area.

The Pacific Northern Gas Limited natural gas pipeline crosses the Telkwa coalfield south of Telkwa. This pipeline connects Prince Rupert and Kitimat with pipelines from northeast and southwest British Columbia. It is unlikely that it would be economic to build the infrastructure to collect and compress Telkwa gas prior to putting it into the provincial pipeline network.

CONCLUSIONS

Five desorption results indicate that coal in the Telkwa coalfield retains methane at shallow depths. Four of the five samples collected over a depth range of 64 to 120 metres have gas contents that range from 3.75 to 4.49 cubic centimetres per gram on a dry ash-free basis. Most of the samples appear to be saturated based on the results of adsorption isotherms. The maximum adsorption capacity of Telkwa coal appears to be less than that predicted by models based on vitrinite-rich U.S. coals by an amount of 16% or more.

The Telkwa coalfield contains a potential coal resource of 862 million tonnes. The rank of this coal varies from high-volatile A bituminous to semi-anthracite.

An assessment of the CBM potential requires information on the coal distribution, coal rank and on gas content. Recent work provides a good database of information on the geology and rank distribution.

In the Goathorne Creek area cumulative coal thicknesses intersected in unit 3 range from 6.4 to 14.3 metres and average 9.6 metres. The coal thickness in unit 1 ranges from 2.8 to 7.7 metres and averages 4.3 metres.

The R_{max} values of seam 2 at the base of unit 3 range from 0.859 to 0.946% and average 0.905%. Values for seam 1 range from 0.855 to 1.11% and average 0.954%.

The CBM resource is estimated at 3.7 billion cubic metres. This is small in comparison to the possible resources elsewhere in the province. Much of the resource may be contained in thin seams, with low gas contents and at shallow depths, making it difficult to recover the gas economically. Despite this, there are areas which appear to be favourable for wells. If there are only five successful wells recovering 250 million cubic metres over 10 years, they could provide sufficient gas to meet the energy requirements for over 10 000 houses.

Drilling wells in the Telkwa coalfield, especially south of the Telkwa River, will be cheap if the proposed open-pit mine is developed, because of the established infrastructure.

ACKNOWLEDGMENTS

Manalta Coal Limited provided the samples for desorption tests. The adsorption isotherms were measured by John Clow of Western Core Laboratories Limited, Calgary.

REFERENCES

Bustin, R.M., Cameron, A.R., Grieve, D.A. and Kalkreuth, W.D.(1983): Coal Petrology; Its Principles, Methods, and Applications; *Geological Association of Canada*, Short Course Notes, Volume 3.

Cech, R., Carlson, J.D. and MacLeod, R.K. (1992): Economics of Coalbed Methane Projects in the Western Canadian Basin; *Canadian Coal and Coalbed Methane Geoscience Forum*, Proceedings, pages 39-55.

Crowsnest Resources Limited (1984): Telkwa Stage 2 Submission; submitted to the *B.C. Ministry of Energy, Mines and Petroleum Resources*.

Eddy, G.E., Rightmire, C.T. and Byren, C.W. (1982): Relationship of Methane Content of Coal Rank and Depth: Theoretical vs. Observed; *Society of Petroleum Engineers, Department of the Interior*, Proceedings of the Unconventional Gas Recovery Symposium, Pittsburg, Pennsylvania, SPE/DOE 10800, pages 117-122.

Ellard, J. and Roark, R. (1992): Coalbed Methane Production from the Pottsville Formation at Cedar Cove Field, Black Warrior Basin, Alabama, U.S.A., *Canadian Coal and Coalbed Methane Geoscience Forum*, Proceedings, pages 73-84.

Environmental Protection Agency (1988): GEOEAS; Geostatistical Environmental Assessment Software; *U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory*, Las Vegas, Nevada.

Environmental Sciences Limited (1990): QUIKMAP; *ESL Environmental Sciences Limited*, Sidney, B.C.

Johnson, D.G.S. and Smith, L.A. (1991): Coalbed Methane in Southeast British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Petroleum Geology, Special Paper 1991-1.

Kim, A.G. (1977): Estimating Methane Content of Bituminous Coalbeds from Adsorption Data; *U.S Bureau of Mines*, Report of Investigations, Number 8245.

Koo, J. (1983): The Telkwa, Red Rose and Klappan Coal Measures in Northwestern British Columbia; *in* Geological Fieldwork 1983, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1984-1 pages 81-90.

Lamberson, M.N. and Bustin, R.M. (1992): Coalbed Methane Characteristics of the Gates Formation Lithotypes, Northeastern British Columbia; *The Canadian Coal and Coalbed Methane Forum*, Proceedings, pages 87-101.

Langmuir, L. (1918): The Adsorption of Gases on Plane Surfaces of Glass, Mica and Platinum; *Journal of the American Chemical Society*, Volume 40, pages 1361-1402.

McCartney, J.T. and Ergun, S. (1967): Optical Properties of Coals and Graphite; *U.S. Bureau of Mines United States Department of the Interior*, Bulletin 641.

MacIntyre, D., Desjardins, P., Tercier, P. and Koo, J. (1989): Geology of the Telkwa River Area NTS 93L/11; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1989-16.

Matheson, A. and Van Den Bussche, B. (1990): Subsurface Coal Sampling Survey; Central British Columbia; *in* Geological Fieldwork 1989, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-1, pages 445-448.

McCulloch, C.M., Levine, J.R., Kissell, F.N. and Duel, M. (1975): Measuring the Methane Content of Bituminous Coalbeds; *U.S. Bureau of Mines*, Report of Investigations 8043.

Meissener, F.F. (1984): Cretaceous and Lower Tertiary Coals as Sources for Gas Accumulations in the Rocky Mountain Area; *in*, Hydrocarbon Source Rocks of the Greater Rocky Mountain Region, Woodward J., Meissener F.F. and Clayton, J.L., Editors, *Rocky Mountain Association of Geologists*, 1984 Symposium, pages 401-431.

Olszewicki, A.J. and Schraufnagel, R.A. (1992): Development of Formation Evaluation Technology for Coalbed Methane Development; *Quarterly Review of Methane from Coal Seams Technology*, Volume 10, No. 2, pages 27-35.

Palsgrove, R.J. and Bustin, R.M. (1989): Stratigraphy and Sedimentology of the Lower Skeena Group, Telkwa Coalfield, Central British Columbia (93I/11); *in* Geological Fieldwork 1989, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1990-1 pages 449-454.

Rees, O.W. (1966): Chemistry, Uses and Limitations of Coal Analyses; *Illinois State Geological Survey*, Report INV 220, page 55.

Ryan, B.D. (1991): Density of Coals from the Telkwa Coal Property, Northwestern British Columbia; (93I/11); *in* Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-1 pages 399-406.

Ryan, B.D. (1992a): Coal Rank Variations in the Telkwa Coalfield, Central British Columbia (93L/11); *in* Geological Fieldwork 1991, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1992-1, pages 451-460.

Ryan, B.D. (1992b): An Equation for Estimation of Maximum Coalbed-Methane Resource Potential; *in* Geological Fieldwork 1991, Grant, B. and Newell, J.M., Editors, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1992-1, pages 393-396.

Ryan, B.D. (1993): Geology of the Telkwa Coalfield, British Columbia; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open File 1993-21.

Slaghuis, J.H., Ferreira, L.C. and Judd, M.R. (1990): Volatile Matter in Coal: Effect of Inherent Mineral Matter; *Fuel*, Volume 70, pages 468-470.

Stevens, S.H., Kelso, B.S., Lombardi, T.E. and Coates, J.M. (1993): Raton Basin, Assessment of Coalbed Methane Resources; *Quarterly Review of Methane from Coal Seams Technology*, Volume 10, No. 3 pages 7-13.

Tipper, H.W. (1976): Smithers Map Area 93/L; *Geological Survey of Canada*, Open File Map 351.

Yee, D., Seidle, J.P. and Hanson, W.B. (1992): Gas Sorption on Coal; Abstract, *American Association of Petroleum Geologists*, Annual Meeting, Calgary, 1992.

NOTES