THE CBM RESOURCE OF SOME PROSPECTIVE AREAS OF THE CROWSNEST COALFIELD

By Barry Ryan[1]

*KEYWORDS: C*oal rank, gas contents, coal thicknesses, Mist Mountain Formation

INTRODUCTION

The title refers to coalbed methane. The predominance of literature refers to the extraction of coalbed methane (CBM) from coal. This is not scientifically correct as the gas extracted from coal is a mixture of methane carbon dioxide and other gases. The British Columbia government is adopting the term coalbed gas (CBG). The abbreviations CBM and CBG both refer to the commercial gas extracted from coal at depth. To avoid confusion with existing scientific literature this paper uses the term CBM.

The Crowsnest Coalfield is located between the Elk River and Michel Creek drainages and covers a total area of about 600 square kilometres. A major pipeline, which, trends north south through the coalfield (Figure 1), connects the Alberta gas fields with the US market. This pipeline has been expanded from the original 36-inches Trans Canada pipeline and is now twinned with a 48-inch Foothills pipeline following the same right-of-way. An 8-inch pipeline, which branches off the main line in the northeast corner of the coalfield, serves the towns of Sparwood, Elkford and some of the mines. A second 8-inch pipe line branches off at Morrissey and serves the town of Fernie. Title to the gas rights in the coalfield is in part with the crown and in part un assigned at this time. This paper summarizes existing mapping data, coal quality and coal resource data. It also attempts to delineate the resource potential of areas where the crown has clear title. This means disregarding areas where various companies have at least freehold coal rights.

The Crowsnest Coalfield has been mapped by a number of geologists. One of the earliest was Newmarch (1953) who provided a preliminary map of the coalfield and detailed geology of the Coal Creek area, which was compiled at a time when the mines in the creek were still operating. Price (1961) produced a regional map of the Crowsnest Coalfield, which also provides strike/dip information. The area was mapped in the period 1977 to 1981 using orthophotos by a number of personnel from the British Columbia Ministry of Mines (Pearson *et al.*, 1977; Pearson and Grieve, 1978; Pearson and Grieve, 1980). These maps outline seam trends and provide structural information. A recently a compilation of the mapping and construction of geological sections was completed by Johnson and Smith (1991). Other recent studies such as Dawson *et al.*, (1998) have used these maps and accompanying sections. Monahan (2002), as part of an assessment of the oil and gas potential of the area, produced a revised map using existing mapping and well data.

The map from Johnson and Smith is reproduced here (Figure 1) with addition information, which includes, approximate delineation of various land blocks, areas in which the Mist Mountain Formation is at least in part at a depth of less than 1000 metre and fold axial plunge data transferred from Price (1961). In addition geological sections from Johnson and Smith (1991) are reproduced with some additional sections to give a spacing of 5 kilometres for sections through the coalfield (Figure 2). The 1000 metre depth line is shown on the sections.

There are a number of publications that deal with coal quality and surface and underground coal resources of the coalfield. A summary paper (Pearson and Grieve, 1985) discusses coal quality. Coal rank in the coalfield varies from high-volatile bituminous to low-volatile bituminous, with higher rank coals in the southwest part of the basin. There is also evidence that rank increases down dip into the core of the major syncline that crosses Morrissey Creek

Johnson and Smith (1991) were the first to estimate the CBM resource of the coalfield and they calculated a value of 12 Tcf. They used an average gas *versus* depth curve derived from data from the San Juan basin. In 1990 a number of companies drilled stratigraphic test holes in the southern part of the coalfield (Dawson *et al.*, 2000) (Figure 3). A best curve fit to all desorption data (Figure 4) resulting from this drilling in the coalfield indicates a lower total resource for the coalfield of 6.7 Tcf.

To date the only assessment that covers parts of the coalfield is that by Dawson *et al.* (1998) who assessed the CBM resource potential of the two Dominion Blocks (block 73 in the north and block 82 in the south) (Figure 1). These blocks have a total area of 202 square kilometres (block 73 = 20.2 and block 82 = 182.1 square kilometres). Dawson *et al.*, (1998) considered gas contents to vary from 10.9 to 20.1 cc/gm (350 – 650 scf/t). They estimated a total resource for the two blocks of 6.57 Tcf to a depth of 1000 metres. The northern block

[1] *Resource Development and Geosciences Branch, BC Ministry of Energy and Mines, barry.ryan@gems4.gov.bc.ca*

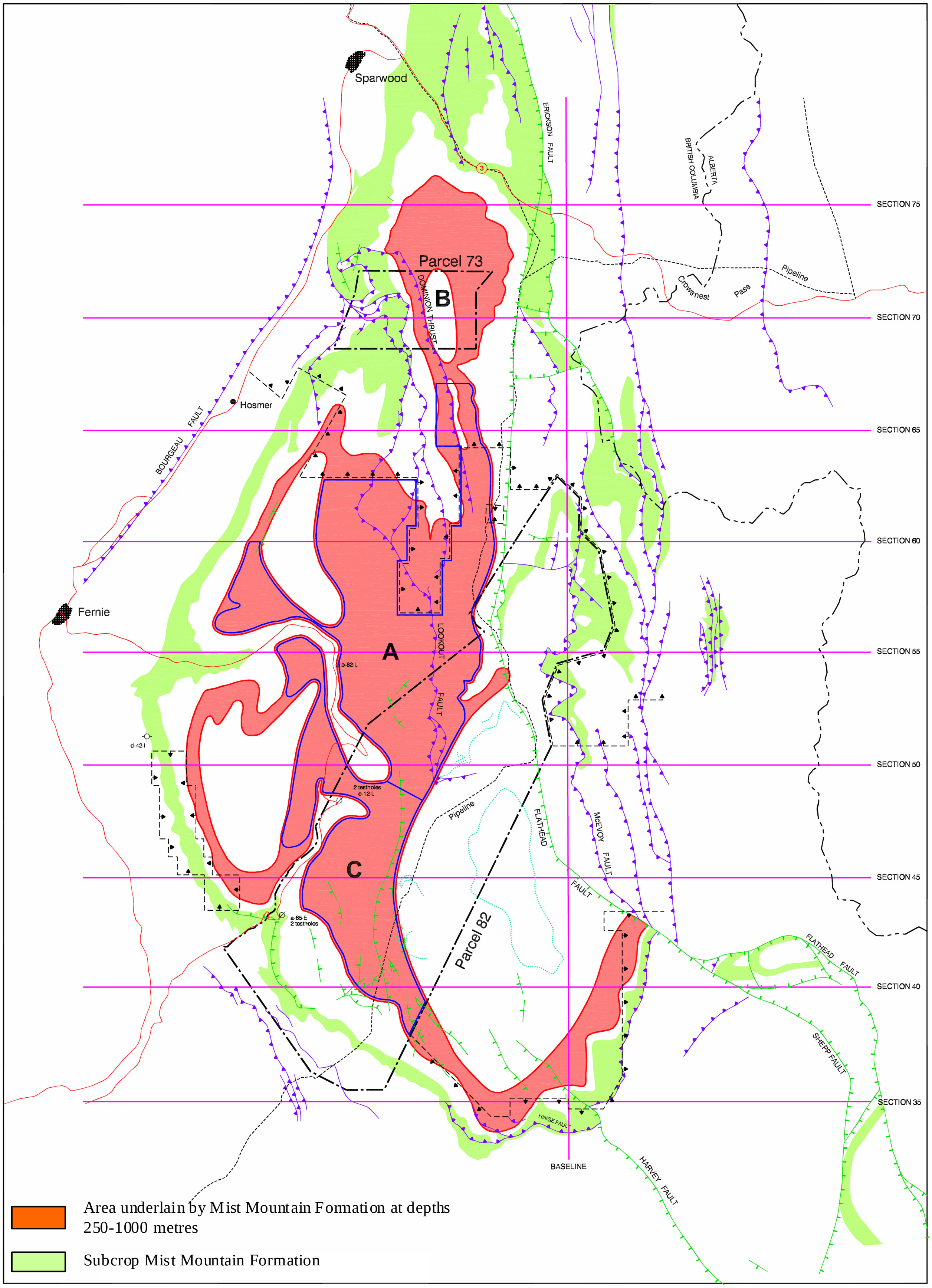


Figure 1. Outline of the Crowsnest Coalfield. CBM Resources of areas A, B and C discussed in text.

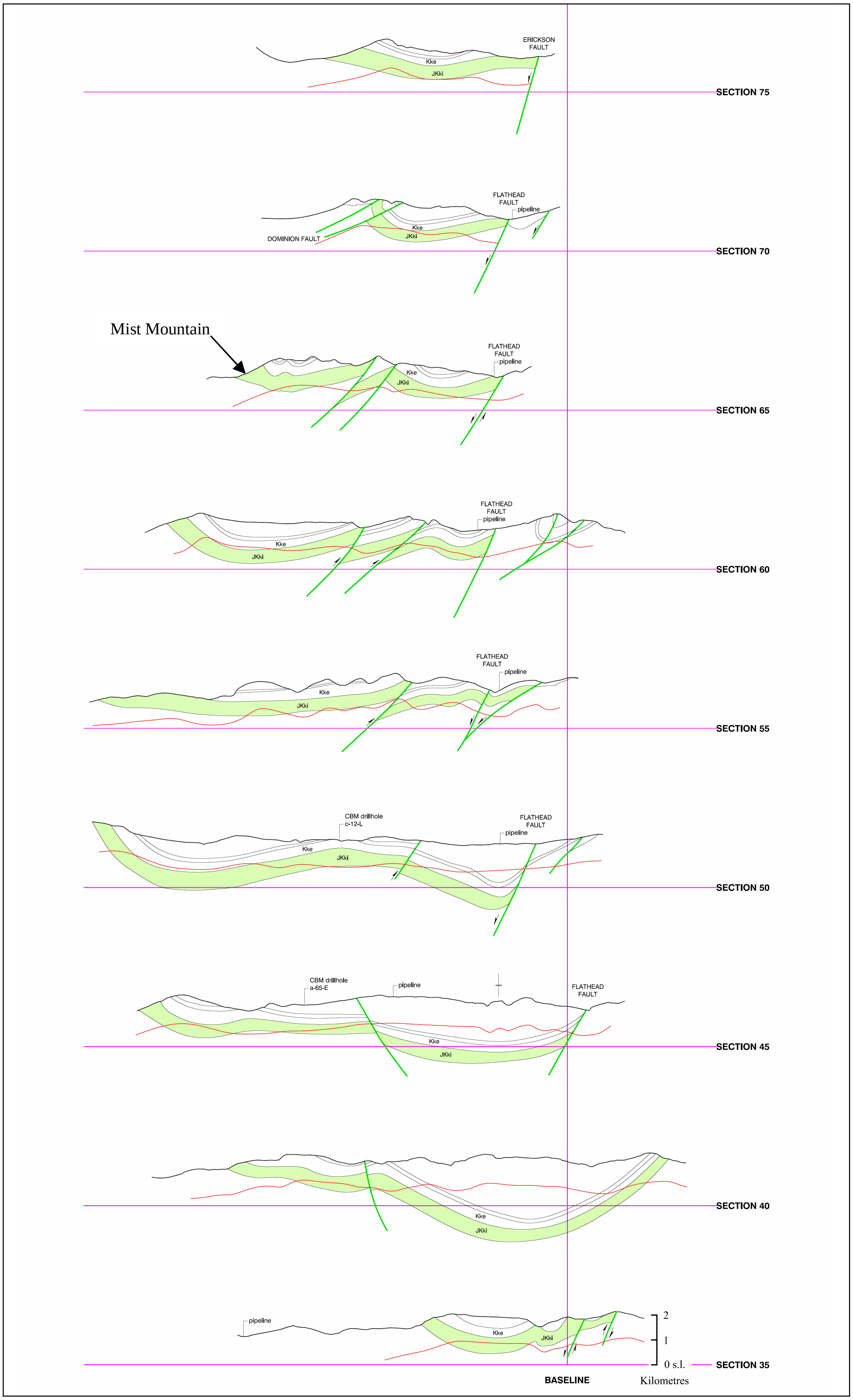


Figure 2. Schematic sections of Crowsnest Coalfield

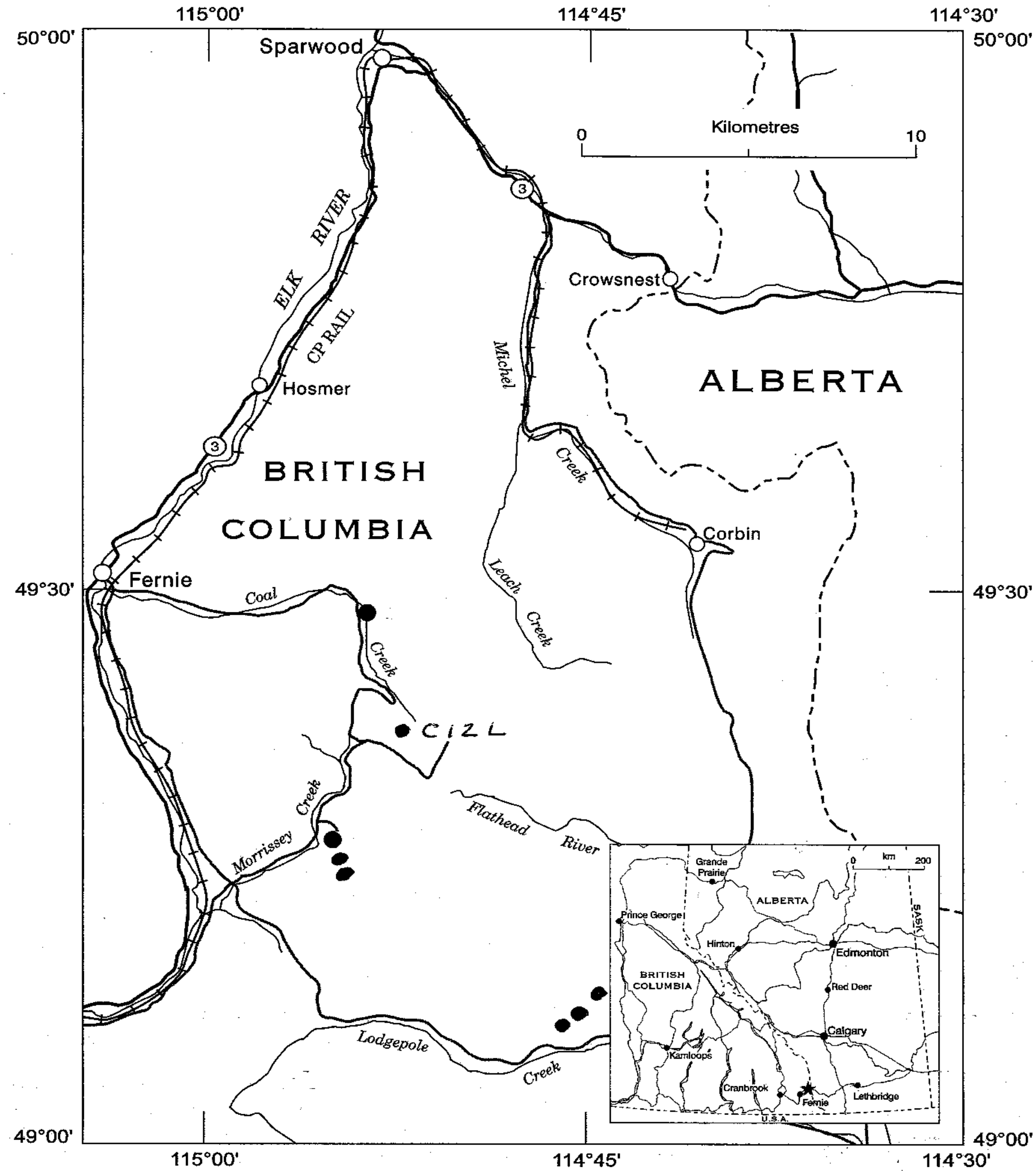


Figure 3. Location of Stratigraphic test holes drilled in 1990, data from Dawson *et al.,* (2000).

73 having 0.65 Tcf (93% shallower than 1000 metres) and block 82 having 5.92 Tcf (62% shallower than 1000 metres) providing a resource shallower than 1000 metres of 4.28 Tcf. They used estimated gas contents of 16 and 18 cc/g applied to all seams (Table 1). The specific seam thickness and gas content values used by Dawson *et al.,* (1998) seem to be high, based on available desorption data (Figure 4) and on cumulative coal thickness data for the Crowsnest Coalfield as a whole (Table 2).

Dawson *et al.,* (1998) used the seam designation applied to the northern part of the Crowsnest Coalfield where the basal seam is number 10. Some papers (for example Newmarch, 1953) designate the basal seam in the Crowsnest Coalfield as 1 Seam and count up section. People checking literature on coal in southeast BC should make sure they know the specific seam designation being used in each paper.

STRATIGRAPHY

Any estimation of the depth to the Mist Mountain Formation requires at least some knowledge of the thickness of overlying formations and of the regional dips. In the Crowsnest Coalfield formations above the Mist Mountain include the Elk Formation and Blairmore Group (Figure 5), which includes the basal Cadomin

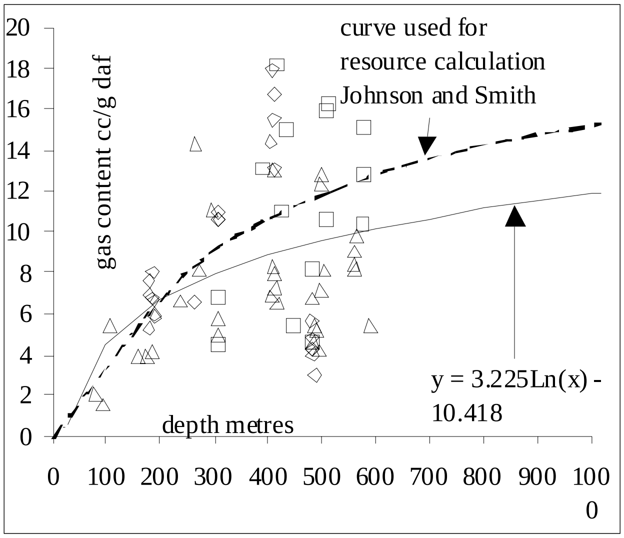


Figure 4. Desorption data Crowsnest Coalfield. Squares are for hole C12L, diamonds from Mobile Chevron holes and triangles from Saskoil holes.

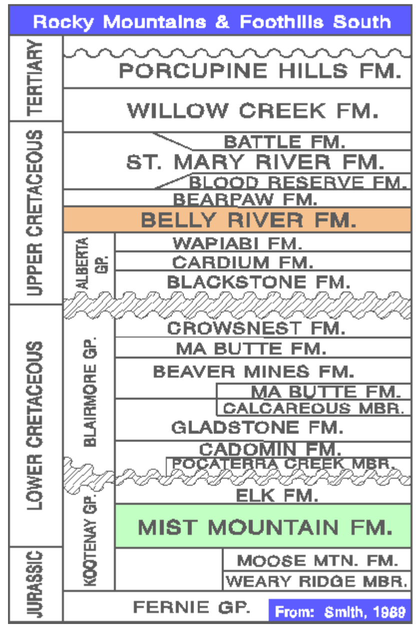


Figure 5: Statigraphic Table from Smith, (1989).

Formation and overlying lower and middle Blairmore rocks. Most authors indicate that the Elk and Mist Mountain formations thin to the east. Table 3 summarizes some of the thickness information available in a number of papers.

Newmarch (1953) indicates that Kootenay Group, which includes the Elk and Mist Mountain formations, varies in thickness along the western margin of the coalfield from 1097 metres at Michel to 686 metres at Hosmer and 625 metres at Fernie. The Kootenay Group is described as 305 to 777 metres thick (Crabb, 1957). It thins to the east in the Lewis thrust block (Price 1964) and is 1076 metres at Coal Creek; 488 metres at Mt Taylor and 396 metres 12.1 km northeast from the mouth of Lodgepole Creek (Price, 1961).

The Mist Mountain Formation at Coal Creek is described as 645 metres thick (Gibsons, 1985) or 629 metres thick (Newmarch, 1953). Gibsons (1985) states that it is up to 625 metres thick in southeast British Columbia. Pearson and Grieve (1978) provide a number of Mist Mountain sections for the western and southern margins of the coalfield (Table 3) that range from 657 to 490 metres in thickness. The overlying Elk Formation varies in thickness up to 488 metres (Gibson, 1977), (Jansa, 1972).

The Cadomin Formation forms the base of the Blairmore Group and ranges up to 170 metres thick (White and Leckie, 2000). The formation is 137 to168 meters thick on the east side of the McEvoy Syncline and 184 metres thick at Coal Creek. The Blairmore group thins to the east and Crabb (1957) provides thicknesses of 700 metres on the west and 300 metes on the east. Price (1961) quotes thicknesses of 365 to 2000 metres.

The Blairmore Group is overlain by the upper Cretaceous Crowsnest Formation (mainly alkaline volcanics), which is 40-100 metres thick below the Lewis Thrust, but does not occur within the thrust sheet. Outcrops of the Upper Cretaceous Alberta Group only survive in the Crowsnest Coalfield in the core of the McEvoy Syncline where it is up to 229 metres thick.

Stratigraphic thickness data is essential for estimating depth to the prospective seams in the Mist Mountain Formation. However thicknesses need to be adjusted to take account of bed dips. As mentioned strike and dip data is available on a number of published maps and is not reproduced in Figure 1. A simple nomograph (Figure 6), in conjunction with Table 3, provides estimates of drill depth to seams in the Mist Mountain Formation.

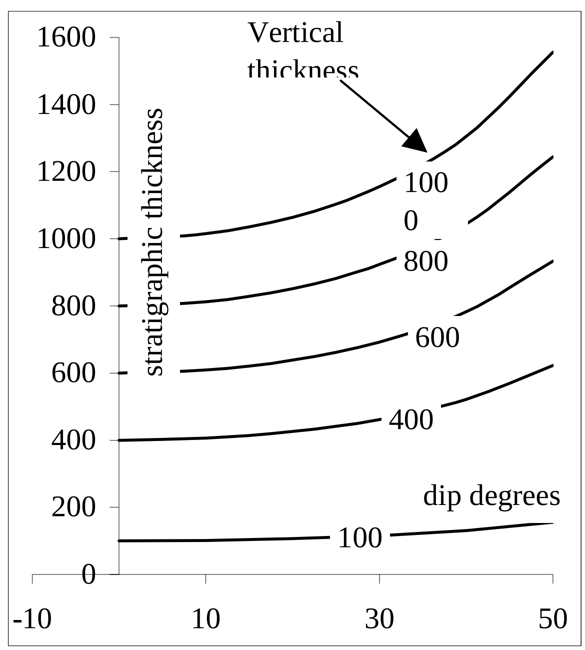


Figure 6. Nomograph of vertical thickness from dip and stratigraphic thickness.

TABLE 1
DOMINION BLOCKS CBM RESOURCE SUMMARY*

block 73

section	A-A	500-1000	metres	A-A	1000-1500		A-A	>1500	
	thick	gas	bcf	thick	gas	bcf	thick	gas	bcf
Elk	1.37	18	9.87	1.37	18	5.17			
1	2.07	18	16.09	2.07	18	7.1			
2U	2.44	18	15.82	2.44	18	7.37	2.44	18	3.84
2L	5.64	18	34.25	5.64	18	16.5	5.64	18	12.95
3	13.71	18	54.79	13.71	18	32.35	13.71	18	72.91
5U	7.32	18	28.79	7.32	18	15.89	7.32	18	41.23
5L	1.52	18	5.88	1.52	18	2.97	1.52	18	9.04
7U	3.66	18	13.13	3.66	18	3.45	3.66	18	27.29
7L	1.52	18	5.5	1.52	18	1.24	1.52	18	13.88
8U	3.5	18	14.87				3.5		27.64
8L	7.32	18	29.71				7.32		58.96
9	20.09	18	60.69				20.09		194.7
10U	3.05	18	8.83				3.05		30.23
10L	6.1	18	17.27				6.1		61.23
totals	79.31		315.49	39.25		92.04	75.87		553.9

Block 83

	Mt Taylor		A-A						
seam		250-500			500-1000			1000-1500	
	thick	gas	bcf	thick	gas	bcf	thick	gas	bcf
1	2.86	16.6	0	2.86	18	6.14	2.86	18	3.61
2	2.13	16.6	0	2.13	18	5.66	2.13	18	1.62
3	7.68	16.6	0	7.68	18	21.84	7.68	18	4.1
4	1	16.6	0.27	1	18	3.18			
5	10.61	16.6	6.19	10.61	18	30.63			
6	1.16	16.6	0.7	1.16	18	3			
7	5.39	16.6	3.11	5.39	18	12.13			
8	13.23	16.6	9.56	13.23	18	23.87			
9	5.79	16.6	4.37	5.79	18	7.66			
10	1.31	16.6	1.16	1.31	18	1.2			
B	2.47	16.6	2.32	2.47	18	1.74			
totals	53.63		27.68	53.63		117.05			9.33

	Mt Taylor		B-B						
seam		500-1000			1000-1500			>1500	
	thick	gas	bcf	thick	gas	bcf	thick	gas	bcf
1	2.86	18	23.47	2.86	18	13.75	2.86	18	6.34
2	2.13	18	16.31	2.13	18	9.34	2.13	18	3.29
3	7.68	18	25.83	7.68	18	33.28	7.68	18	7.48
4	1	18	5.25	1	18	4.26			
5	10.61	18	60.11	10.61	18	42.66			
6	1.16	18	8.57	1.16	18	3.51			
7	5.39	18	45.79	5.39	18	8.56			
8	13.23	18	121.93						
9	5.79	18	49.5						
10	1.31	18	10.24						
B	2.47	18	15.85						
totals	53.63		382.85	30.83		115.36	12.67		17.11

*from Dawson *et al.,* (1998).

TABLE 1. CONTINUED

Block 83

	Lookout		C-C						
seam	250-500			500-1000			1000-1500		
	thick	gas	bcf	thick	gas	bcf	thick	gas	bcf
1				33.8	18	116.67	33.8	18	63.37
2				5.2	18	27.67	5.2	18	3.41
3				12.2	18	72.98			
5	9	16	20.07	9	18	39.79			
6	4.8	16	14.17	4.8	18	18			
9	2.5	16	6.82	2.5	18	6.14			
10	1.8	16	4.97	1.8	18	3.63			
totals	18.1		46.03	69.3		284.88	39		66.78

		Lookout	D-D			
seam	1000-1500			>1500		
	thick	gas	bcf	thick	gas	bcf
1				12.11	18	161.36
2				14.4	18	191.87
3	3.55	18	10.72	3.55	18	35.51
4	11.04	18	55.58	11.04	18	91.89
5	13.07	18	156.16	13.07	18	23.69
7	1	18	13.32			
9	1.7	18	22.65			
10	1	18	13.32			
totals	31.36		271.75			504.32
south extension	54.17	18	612.83	54.17	18	573.65
totals		total	884.58	54.17		1077.97

		Pipeline	C-C
seam	500-1000		
	thick	gas	bcf
1	33.8	18	1410.14
2	5.2	18	216.94
3	12.2	18	508.98
5	9	18	375.48
6	4.8	18	200.26
9	2.5	18	104.3
10	1.8	18	75.1
totals	69.3		2891.2

total <1000 metres 3.42 tcf
total 5.77 tcf

TABLE 2
CUMULATIVE COAL THICKNESSES FOR SECTIONS IN THE CROWSNEST COALFIELD

seam	Fernie Ridge	Morrissey Ridge	Coal Creek	Hosmer Ridge	West Lodgepole	North Lodgepole	Mclatchie Creek	martin Ridge	Parcel 73
11	4.48	0.00	2.44						
10	2.44	2.32	2.44						
9	3.23	3.38	3.20						
8	6.22	2.19	1.37	1.52					
7	2.99	5.09	0.30	5.79	5.94			1.52	
6	2.77	2.41	0.76	10.67	2.65			6.00	6.10
5	7.25	3.72	5.49	1.83	8.08	6.40		5.43	1.50
4	3.41	4.15	3.81	2.13	6.89	5.79	7.62	2.20	
3	4.02	9.57	2.44	11.58	9.33	7.92	7.47	8.35	11.30
2	6.71	5.49	7.62	5.79				8.02	18.89
1	4.30	7.22	6.10	6.10	14.02	12.19	6.64		
			3.05						
			3.66						
total coal	**47.82**	**45.54**	**42.68**	**45.42**	**46.91**	**32.31**	**21.73**	**31.53**	**37.79**

note seam 11=B seam

TABLE 3
SUMMARY OF STRATIGRAPHIC THICKNESSES FOR JURA-CRETACEOUS UNITS

location	thickness metres	
		Blairmore Group
Coal Creek	610	Lower Blairmore Price, R.A. (1961)
McEvoy Syncline	365-2000	Blairmore Price, R.A. (1961)
west	700	Blairmore Crabb, J. (1957)
east	305	Blairmore Crabb, J. (1957)
		Cadomin Formation
Coal Creek	185	Jansa, L. (1972)
Michel	731	Jansa, L. (1972)
Coal Creek	32	McLean, J. R. (1977)
		Kootenay Group
lodgepole	549	Price, R.A. (1961)
Mt Taylor	465	Price, R.A. (1964)
West	700	Crabb, J. (1957)
East	305	Crabb, J. (1957)
		Elk Formation
SE BC	up to 488	Gibson, D.W. (1977)
Michel	483	Jansa, L. (1972)
Coal Creek	519	Jansa, L. (1972)
		Mist Mountian Fomraion
Lodgepole	490	Pearson, D.E. and Grieve, D.A. (1978)
Flathead	604	Pearson, D.E. and Grieve, D.A. (1978)
Morrissey Creek	663	Pearson, D.E. and Grieve, D.A. (1978)
Morrissey Ridge	460	Pearson, D.E. and Grieve, D.A. (1978)
Coal Creek	616	Pearson, D.E. and Grieve, D.A. (1978)
Coal Creek	645	Gibson, D.W. (1985)
Coal Creek	617	Jansa, L. (1972)
Coal Creek	629	Newmarch, C.B. (1953)
Fernie Ridge	634	Pearson, D.E. and Grieve, D.A. (1978)
Hosmer	657	Pearson, D.E. and Grieve, D.A. (1978)
Sparwood Ridge	628	Pearson, D.E. and Grieve, D.A. (1978)
Michel	645	Jansa, L. (1972)

COAL SECTIONS

There has been very limited exploration in the center of the coalfield where the Mist Mountain Formation does not outcrop, consequently most of the information on seam thickness and cumulative coal thickness in the Mist Mountain Formation comes from mapping, exploration and mining along the western and southern margin of the coalfield. There are a number of partial coal sections described for the purpose of estimating mineable reserves. It is probable that in many cases these sections do not document all coal in the formation, so that cumulative coal thicknesses probably represent minimum values. Data (Table 2 and Figure 7) indicate that cumulative coal thicknesses range from 40 to 50 metres on the west and between 30 and 40 metres on the east. Seams generally decrease in thickness up section and the third or second seam from the base is usually the thickest.

COAL RANK AND MACERAL DATA

Coal rank varies from high-volatile bituminous to low-volatile bituminous increasing down dip to the east and along strike to the south (Pearson and Grieve, 1985). . There is also evidence that rank increases down dip into the core of the major syncline that crosses Morrissey Creek. If rank increases down dip into major synclines, then upward migration of biogenic methane may saturate up dip lower rank coal within a seam leaving the deeper higher rank parts of a seam under saturated. Obviously production from a shallow saturated seam, with lower gas content, is more economic than production from a deeper under saturated seam with higher gas content. Rank gradients range from 0.01 to 0.12 (delta Rmax/100 metres) (Figure 8).

Adsorption characteristics of seams are controlled by environmental factors (depth and temperature) and physical properties such as rank and maceral content. Jura-Cretaceous coals in southeast British Columbia differ from many coals now producing CBM in that they have high and variable contents of organic inert macerals on a mineral matter free basis (mmfb). These are grouped under the name inerts and include in part the macerals, fusinite, semi fusinite, inertodetrinite and macrinite. Various sub varieties of the vitrinite maceral make up the rest of the seam on an mmfb. The inert macerals when compared to the vitrinite macerals are characterized by lower adsorption ability, higher diffusivity and greater strength. The inert maceral content of seams (mmfb) varies and tends to increase down section with rank (Figure 9); though it is usually the second or third seam above the base of the section that contains the highest inert maceral content. There is also a tendency for the upper parts of seams to be vitrinite rich. The lower parts of seams with higher inertinite content will have better diffusivity and may be less sheared.

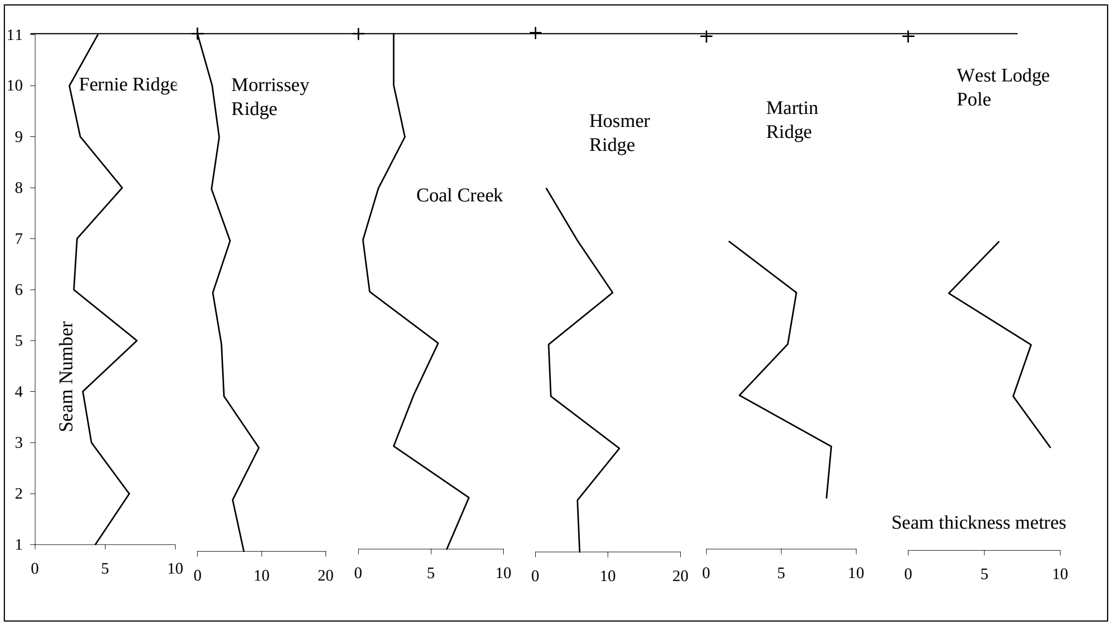
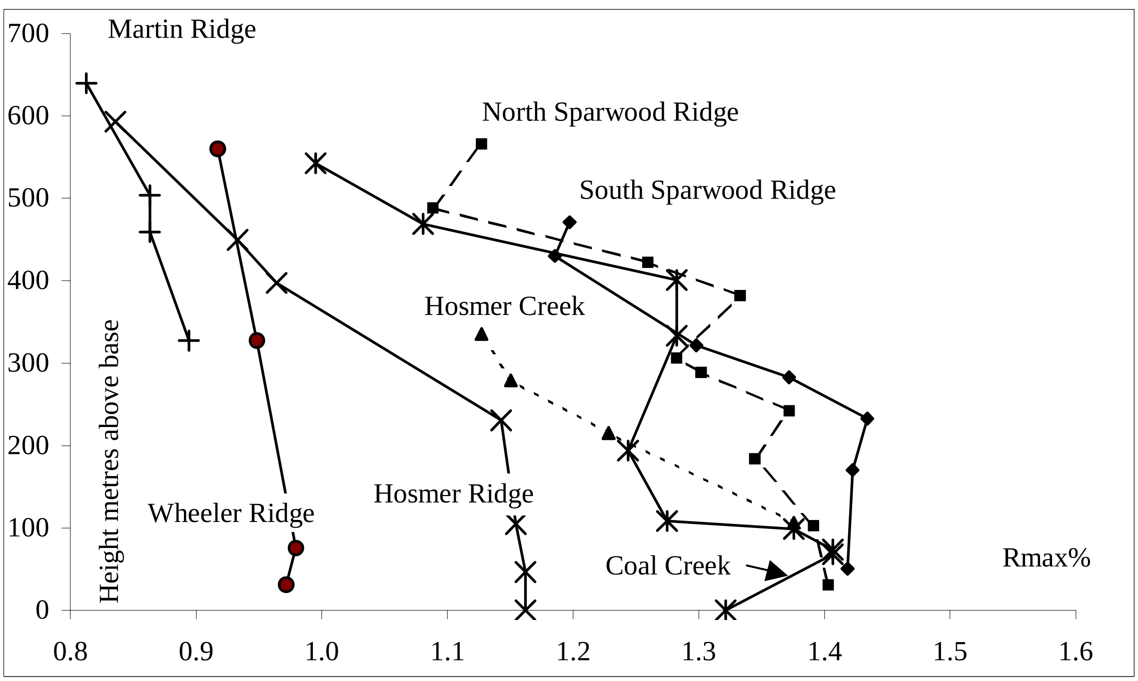


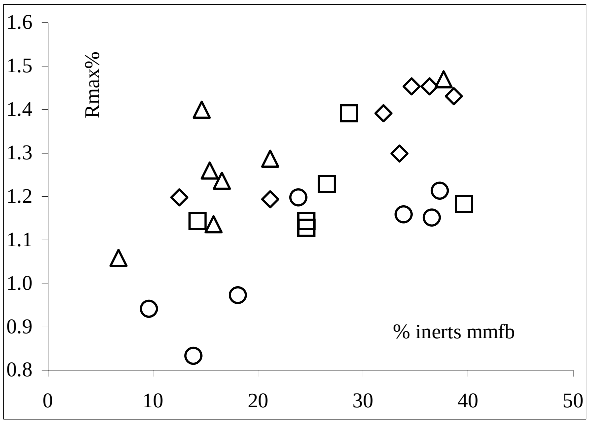
Figure 7. Plot of seam thicknesses by seam number



gradient Rmax/100 metres

Wheeler Ridge	0.01	Hosmer Creek	0.12	North Sparwood	0.08
Martin Ridge	0.03	Coal Creek	0.07	South Sparwood	0.08
Hosmer ridge	0.06				

Figure 8. Rank gradients in the Crowsnest Coalfield.



circle=Hosmer Ridge triangle =Sparwood North
square=Hosmer Creek diamonds=Sparwwod South

Figure 9. Variation in inerts content (mmfb) with rank.

CBM RESOURCE AREA

Experience in moderately deformed coals indicates that, except in unusual structural environments, reasonable permeability (>2mD) does not extend below about 1000 metres. Areas where at least the top of the Mist Mountain Formation is less than 1000 metres from surface are outlined on the map derived from Johnson and Smith (Figure 1) and in the accompanying sections (Figure 2).

The eastern margin of the Crowsnest Coalfield is in part defined by the Erickson/Flathead normal fault system, which by down dropping the Kootenay Group on the west by 1000 to 3000 metres has preserved the coalfield. A simplified structural model of the coalfield is represented by two thrust blocks each containing a north trending syncline. The Sparwood Syncline (Dawson *et al.*, 1998) in the north and the McEvoy Syncline in the south (Price 1961) are the dominant structures in the block below the Lookout/Dominion thrust and above the Erickson/Flathead normal fault. Above the Lookout/Dominion thrust, the tight Hosmer Syncline (Dawson *et al.*, 1998) is cut off by a thrust north of Hosmer. To the south the syncline opens up, has very flat limbs and merges with the flat limb of the McEvoy syncline.

Within these two synclinal trends there are obviously areas where seams are too shallow to contain gas. This depth depends on topography and groundwater flow patterns. Ideally groundwater flow should be down dip and away from seam outcrop. Generally seams below 200 metres and not intersected close to valley walls or above valley floor should contain gas and consequently areas where Mist Mountain Formation seams are between 200-1000 metres of surface are most perspective for CBM. There is insufficient structural control to accurately delineate the 200-metre depth to the Mist Mountain Formation. As a conservative approximation, the formation is assumed to be at a depth greater than 200 metres where ever it was overlain by the full thickness of the Elk Formation, which varies in thickness up to 488 metres (Gibson, 1977). This line is easy to mark on Figure 1 and with data from the sections (Figure 2) helps delineates the area prospective for CBM. Figure 1 also locates the two dominion blocks (73 and 82) and areas where companies have freehold coal rights. Data are derived from standard 1 to 50 000 topographic maps and Grieve and Kilby (1989).

It appears that potential exists in three areas where the crown has gas rights. These areas are:

A/ Headwaters of Bray and Martin creeks.

B/ Dominion block 73.

C/ West of Dominion Block 82 and the south west part of the block.

Area A

The main area where the BC government has the gas rights covers the head-waters of Bray and Martin Creeks, north of Coal Creek (Figure 1). The area includes parts of Block 82 and skirts the freehold blocks in the center of the coalfield. The area is about 93 square kilometres. The area overlies the west limb of the Coal Creek Syncline, which is traced north from the headwaters of Coal Creek. In the north it plunges to the southwest at 10 to 30 degrees (Armstrong *et al.*, 1976) with dips on the limbs increasing to the north. In the south the syncline plunges to the north (Price 1961). The Dominion Thrust progressively cuts off the east limb of the syncline and it is not present in Dominion Block 73.

The west limb of the syncline is steep an over ridden by a number of thrusts. There are probably more thrusts than are mapped and they will tend to seal seams so that up dip migration of gas to the west will be limited and water movement in seams will probably be along the up plunge direction of the syncline either to the north or south. Steeply dipping seams below thrusts probably initially developed west dipping shear surfaces that as the seam is rotated become near horizontal. A vertical hole drilled into these seams will intersect an extended apparent thickness of coal with near horizontal fractures. Fracing of these seams at shallow depth will open up the fractures in directions extending along strike to the north and south. Drainage areas may extend along strike and not up and down dip. Holes may access structural traps below west dipping thrusts. Also as hydrostatic pressure is decreased the effective lithostatic pressure will be somewhat reduced because the increased amount of low density coal in the vertical column.

Mining occurred from 1908 to 1914 west of an area near Hosmer Creek. Portals were driven through the Fernie Formation into the Mist Mountain Formation, which contains at least 10 seams and the basal Number 1 seam was mined for a time. The Mist Mountain

Formation is described as 762 metres thick with 79 metres of coal (Armstrong, *et. al.*, 1976) however these may be apparent not true thicknesses based on thicknesses quoted elsewhere (Table 2, 3), which indicate true cumulative coal thicknesses ranging from 45 metres at Hosmer to 31 metres on Martin Ridge. The rank at Hosmer Creek ranges from 0.95% to 1.19% with a gradient of 0.12 delta Rmax per 100 metres and to the east on Martin Ridge from 0.83% to 0.91% (gradient 0.03 delta Rmax per 100 metres). To the north in Dominion Block 73, rank of the basal seam is 1.16% (Grieve and Kilby, 1989). In the past, there was a lot of exploration and mining to the south in the Coal and Morrissey Creeks and adjacent areas. In these areas the Mist Mountain section contains between 45 and 48 metres of coal dispersed in about 11 seams.

Gulf Canada drilled a 590 metre stratigraphic test hole (hole C12L, Dawson *et al*., 2000) (Figure 3) south of the area at the head waters of Martin and Coal creeks. The hole intersected 24.4 metres of coal in the top 280 metres of the Mist Mountain Formation. It was drilled west of a major thrust into an area where the Mist Mountain Formation is flat dipping. Gas contents indicate that coals are under saturated, but gas contents were higher than in holes drilled by other companies further to the south. Data for coals near the bottom of the hole indicate that coals are close to saturated. These seams are in the mid part of the Mist Mountain Formation section. The lowermost coal was the thickest and this may correspond to seam 5 in the Morrissey and Fernie Ridge sections, in which case the coal remaining lower in the section would be between 18 and 24 metres cumulative thickness providing a possible total cumulative thickness ranging of between 42 to 48 metres.

No detailed estimates of the coal resources in Area A delineated in Figure 1 exist. However mining studies estimate a coal resource on Hosmer Ridge of about 700 million tonnes to 760 metres. Alternatively the resource can be estimated by utilizing the area of 93 square kilometers and a cumulative coal thickness of 45 metres and this provides an estimated coal resource of 5200 million tonnes.

The average gas content of the Gulf Canada hole is about 10 cc/g on an as received basis. This is probably a low average value to use for resource estimates however the value of 18 cc/g used by Dawson *et al.*, (1998) may be high. Using the lower gas content of 10 cc/g, provides an estimated in place resource of about 1.6 Tcf.

Area B

The Dominion block 73 covers an area of 20.23 square kilometres. Dawson *et al.*, (1998) calculated a CBM potential resource of 0.32 Tcf to 1000 metres (Table 1). They provide a 750 metre thick stratigraphic section of Mist Mountain that appears to contain over 70 metres of cumulative coal. Grieve and Kilby (1989) identified a section of 480 metres, which excludes seams number 1 and 2, and contains 37.8 metres of coal up to and including 3 Seam. The basal seam has a rank of 1.16% but ranks appear to increase down dip and definitely increase to the south.

Structurally most of block 73 is in a thrust block below the Dominion/Lookout Thrust and east of area A. The structural style is similar to that of area A, being a syncline with steep dipping west limb and shallow east limb Opportunities for thrust generated traps in the steep dipping west limb exist. The syncline is along the trend of the McEvoy syncline to the south and Sparwood Syncline to the north. The Sparwood Syncline trends across Michel Creek to the north where it becomes the Elk Syncline in the Elkview Coal mine north of Highway 3 at the north end of the Crowsnest Coalfield.

The coal potential was analyzed by Grieve and Kilby (1989) who used seams with a cumulative thickness of 37.8 metres in their study. The thickness of coal available for CBM resource calculations is probably between this thickness and the thickness used by Dawson *et al.*(1998). They provide a total coal resource in the block of about 1 billion tonnes, which agrees with the estimate provided by Latour (1970). The tonnage estimated to be shallower than 1000 metres is 550 million tonnes. Dawson *et al.*, (1998) used an average gas content of 18 cc/g for all coal deeper than 250 metres and calculated a gas resource of 0.32 Tcf. Using a lower gas content of 10 cc/g (320 scf/t) this resource decreases to 0.18 Tcf.

Area C

In the south, the southern extension of the Hosmer Syncline is ill defined and dips west of Morrissey ridge are flat. There is an extensive area where the Mist Mountain Formation is flat dipping and at least in part shallower than 1000 metres. There are also some areas where the formation on the west limb of the McEvoy Syncline is shallower than 1000 metres. In this area the offset on the Lookout/Dominion Thrust reverses and it is shown on sections in the south as a normal fault (Figures 1 and 2). If this interpretation is correct, then the southern area west of the fault should have experienced extension at the time of faulting and may still have better permeability on cleats.

Most of Area C is within Block 82 with some of the area on the southwestern margin of the block. The total area is about 51 square kilometers. Block 82 has a CBM resource potential of 3.42 Tcf to 1000 metres (Dawson *et al,* 1998) and most of this is in the Pipeline area (Table 1) in the southwest where the pipeline crosses the area trending north through the coal field. The centre and northern part of the block is underlain by the McEvoy Syncline, which is cored by the Blairmore Formation and younger rocks. Based on the presence of these formations and their thicknesses the Mist Mountain Formation is over 1000 meters deep in the core of the syncline.

In the southwest of Block 82 there is an area where the east limb of the southern extension of Coal Creek syncline is flat and partially within the 1000 metre depth window. Small changes in the structural interpretation could change the resource assessment significantly.

Saskoil (Dawson *et al*, 2000) drilled two holes in 1991 in the Lodgepole Creek area. The holes were drilled near the subcrop in different parts of the Mist Mountain Formation. By combining the data from the holes, it appears that in the area, the full Mist Mountain Section is 500 metres thick and contains a cumulative coal thickness of 63 metres. To the west the cumulative coal in the section at Coal Creek is 42.7 metres and at Morrissey Ridge 45.5 metres.

The rank of coal to the west under Fernie and Morrissey Ridges ranges from low-volatile bituminous to high-volatile bituminous in rank (Figure 8). The vitrinite reflectance values are 1.45% for the basal seam at Morrissey Creek decreasing to 1.38% at Coal Creek. However rank appears to increase down dip to the east into the syncline (Pearson and Grieve, 1978).

Gas contents of samples from the holes drilled by Saskoil were low but are probably not representative of contents further to the northeast. For the purposes of calculation an assumed gas content of 10 cc/g (320 scf/t) is used. This is considerably lower than the value used by Dawson *et al.*, (1998) but is approximately the average gas content for samples from hole C12 L drilled by Gulf (Figure 3).

Based on an area of 51 square kilometers, 50 metres cumulative coal and a gas content of 10 cc/g the CBM resource is 1 Tcf.

ESTIMATED RESOURCE AVAILABLE ON CROWN LANDS

The total resource estimated in the three areas is 2.78 Tcf (Table 4). This is an estimate of the gas resource available in all the coal in the section to a depth of 1000 metres. It is derived using a conservative gas content value but assumes that all the area outlined is underlain by the full coal section and this is probably an optimistic assumption. Other than the order of magnitude size of the 2.78 Tcf resource and the general areas to which it is assigned, not too much significance should attached to its value. Companies interested in fine-tuning estimates of the resource potential in the coalfield should use the process and references outlined in this paper as a guide and complete their own assessment. In terms of the available reserve this will depend on the presence of permeability and on the number of seams in the section that can be economically drained of gas.

COAL QUALITY AND IMPLICATIONS FOR CBM PRODUCTION

If higher rank coals are to achieve gas saturation or near gas saturation at present depths then it is probable that a large component of the gas will be biogenic. One should therefore consider the conditions that favour generation and retention of biogenic gas, which is generated on coal surfaces and then penetrates the micro porosity to be adsorbed. Excessive water movement will limit the ability of biogenic gas to migrate into coal micro porosity and be adsorbed. Some seams in the Crowsnest Coalfield are sheared, which increases surface area available for bacteria but limits the ability of a seam to maintain permeability when hydrostatic pressure is decreased. In situations where biogenic gas is generated down dip within a syncline limb, introduction of hot CO_2 could initiate up dip movement of water, CO_2 in solution and methane, without any decrease in hydrostatic pressure. Hot CO_2 would be readily available from a coal fired power plant.

Coal petrography varies and seams lower in the section contain more inertinite on a mineral matter free basis. However it is often the 3rd seam above the Moose Mountain Member that contains the most inertinite (Pearson and Grieve, 1978). The inertinite content of seams varies from hanging wall to footwall with the lower parts of seams having consistently higher inertinite contents (Pearson and Grieve, 1985). As a maceral group inertinite is stronger than vitrinite and resists shearing better. It has lower adsorption abilities and higher diffusivities. These properties may be advantageous for CBM recovery. In thick seams that are initially under saturated, but in which biogenic methane is being generated in the micro fractures of the coal, inert macerals will reach re saturation sooner because of lower demands and better diffusivity of methane from micro fractures into the micro pores. A seam may therefore be partitioned with the lower inertinite rich part being saturated at a moderate gas content and the upper vitrinite rich part being under saturated possibly with the same gas content. Completion in the whole seam may resul t in no gas

TABLE 4. CBM RESOURCES WHERE THE CROWN HAS GAS RIGHTS

	Reference	gas content cc/g	tonnage billion tonnes	total gas tcf
Area A	south of Dominion Block 73	10	2.2	0.7
Area B	Dominion Block 73	10	560	0.18
Area C	part of Dominion Block 82 and area to west	10	6.55	2.1
		total	**568.75**	**2.98**

reaching surface because gas released from one part of the seam may be adsorbed by another part. Completion in the inertinite rich lower part of the seam may result in immediate gas production. The higher diffusivity and strength of the inertinite should help it maintain fracture opening and permeability despite the fact that there is probably less matrix shrinkage to aid permeability.

In the Elk Formation, there are some thin coal seams, which are generally less than 1 metre thick and are characterized by high liptinite contents. They are often referred to as needle coals because of their structure, which derives from a high algae content. They tend to be better developed near the Mist Mountain contact. Coals of this type generate large quantities of thermogenic methane at ranks of 0.6 to 1.0%. The liptinite maceral is not very micro porous so that they have lower adsorption abilities than other macerals. However the maceral is less brittle than vitrinite and tends to withstand deformation better. In areas where the Mist Mountain is below prospective depths the overlying Elk Formation, which contains a higher sand content than the Mist Mountain Formation, may well contain free gas in sandstones and adsorbed gas in thin coal seams.

HISTORICAL DATA

In 1939 the Minister of Mines Report states that in the Coal Creek Number 1 Colliery " a considerable amount of methane is given off this amounting to an average of 1250,000 cubic feet in 24 hours". Elsewhere in the report it states that ventilation was 74300 cubic feet per minute. The numbers suggest that the methane content in the mine air was upwards of 1%. McCulloch *et al.*, (1975) indicate that there is an approximate empirical relationship between the amount of methane per ton released for a mature mine and the in-place gas content of the coal (Figure 10). The relation predicts that the in place gas content (cc/g) is $1/7^{th}$ the gas emission/tonne of mined coal. In 1939 coal production in the East Kootenays was about 500 000 tonnes and production from the Number 1 East Colliery, Coal Creek was 124616 tons (Newmarch, 1953). If this tonnage is assigned to the Number 1 mine and it operated for 300 days in the year then the predicted gas content is over 13 cc/g. The Number 1 seam (lowest in the section) was reported to be the gassiest seam mined. There are a number of reports indicating that the coal from the Coal Creek Collieries was gassy and dusty.

The Carbonado Colliery (6.5 Km up Morrissey Creek from the Elk River), which opened in 1902, is described as being very gassy and prone to outbursts. It was closed in 1909 after a number of serve gas outbursts. Other reports indicate that seams low in the section were very fractured and produce a lot of fine coal.

There is very limited public data on CO_2 concentrations in coals in the Crowsnest Coalfield. A report (Rice, 1918) provides some analyses. In 1916, five

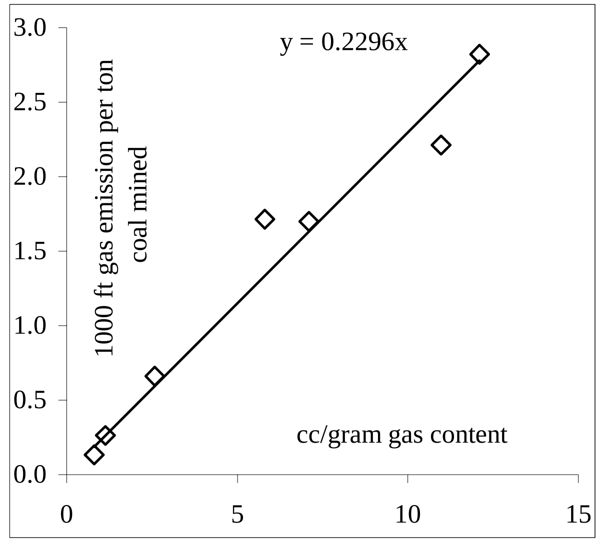


Figure 10. Relationship of gas released in underground mine and adsorbed gas content plot; derived from McCulloch et al., (1975).

samples were collected from the working face in the underground Coal Creek Colliery and placed into sealed jars (Table 5). When the gas was analyzed it was apparent that all had leaked, however the CO_2 content may be estimated from the $CO_2/(CH_4+CO_2)$ ratio and it appears that except for one sample CO_2 contents were probably less than 5% (data are reported as cc per 100 grams equivalent to mole fractions). Based on the trace of the Bourgeau Thrust relative to the outcrop of the basin (Monahan, 2002), it appears that seams in the Mist Mountain Formation in the Crowsnest may not have been as close to carbonates in the overlying Bourgeau Thrust plate as seams in the Elk Valley Coalfield and may therefore have lower CO_2 concentrations.

TABLE 5
ESTIMATED GAS COMPOSITION

sample	CH_4	CO_2	O_2	N_2	$\frac{CO_2}{(CO_2+CH_4)}$
17	64.1	1.4	1	33.5	2.1
18	24.6	0.9	4.4	70.1	3.5
19	27	1.2	3.2	68.6	4.3
20	15.8	0.4	1.2	82.6	2.5
21	0.3	1.6	20	78.1	84.2

Data from Rice (1918). Composition of gas in coal samples volume per cent. Samples from working faces of Coal Creek Colliery (1916), Coal Creek, Crowsnest coalfield.

COAL DEFORMATION AND IMPLICATIONS FOR CBM PRODUCTION

The Crowsnest Coalfield is folded into a series of north trending anticlines and synclines, which generally have steep dipping west limbs and shallower dipping east limbs. Folds open to the south indicating less east west compression of the coalfield in that direction. They are contained in a number of north trending blocks defined by thrusts and normal faults. On the east, the major fault system is composed of the Erickson and Flathead normal faults and on the west it is the Lookout/Dominion thrust system. The folds reverse plunge through the basin, with the McEvoy Syncline in the south forming a distinct basin and the Coal Creek Syncline forming a basin under Fernie Ridge. The map of Price (1961) indicates a number of plunge reversals for folds. It is not clear if these are related to a later phase of cross folding or controlled by changes in statigraphic thickness. Obviously if they are related to a later stage of cross folding then this could cause extension and improved permeability in areas where the cores of synclines or anticlines form culminations.

The Crowsnest Coalfield forms part of the Lewis thrust sheet, which in southeastern BC was transported between 140 and 200 kilometres at a rate of about 1.5 centimetres per year (Osadetz *et al*., 2003). Movement took place in the period from 74 to 59 million years as is indicated by profound cooling in the thrust block at about 75 million years (Osadetz *et al*., 2003). This movement is documented by analyzing the displacement on the thrust plane however there was also probably bedding plane slip within the thrust sheet that would over the estimated 7 kilometres thickness of the sheet (Osadetz *et al.*, (2003) account for more displacement.

Some of this additional displacement is hidden in the Fernie Formation in that rocks below the Fernie Formation are more folded than the overlying Kootenay Group and fold geometries are offset (Price 1961). Additional displacement almost certainly occurred along coal seams. Bedding plane movement along seams will increase coal fragmentation and its amount will not be related to the degree of any subsequent folding. If the coal was maturing through high-volatile bituminous rank at the time of thrust displacement it would be very susceptible to bedding plane slip.

In-seam shearing related to Lewis thrust movement and not to folding produces fine coal and inhibits the formation of cleats or destroys those that have formed. It plays a key role in limiting permeability and causing production problems. It is therefore important to consider what factors might limit the amount of shearing in seams. Some examples of seams that may resist shearing are:

- Thinner seams
- Seams rich in inert macerals or liptinite
- Seams that attain high rank before thrusting started
- Seams with higher ash content
- Seams with non clay rich hanging wall and footwalls.

There have been a number of studies of coal seam deformation in the northern part of the Crowsnest Coalfield. Norris (1965) studied A seam in underground A-North Mine at the north end of the coalfield. This seam is approximately 420 metres above the basal Balmer or 10 Seam in the Mist Mountain Formation. He describes the seam as being highly sheared with abundant shear surfaces and intrastratal folds. Joints tended to strike north or northwest with evidence of early minor extension faults cut off by renewed bedding plane slip. He does not directly discuss cleats or the degree of shearing in the seam but the impression is left that the seam is highly sheared and fragmented.

Bustin (1982) studied the lowest seam in the Mist Mountain Formation in a number of underground coalmines (Balmer North, Five Panel and Six Panel) at the north end of the Crowsnest Coalfield. In the Balmer North Mine, the best-developed cleats formed acute angles to bedding, striking northwest and dipping shallowly to the southeast. Cleat surfaces were polished and striated. Other cleat sets were measured but did not have a consistent orientation through the mine. Cleats in the Five and Six Panel mines are more consistent with a set striking north to northwest with a steep dip to the west. These cleats are sub perpendicular to bedding and trend parallel to the regional fold axis. All fractures and most cleats in the seam appear to have a tectonic influence, with surfaces polished and often showing evidence of shearing. However their orientations are not easily related to a regional stress field. Thrusting probably started with differential movement between the roof and floor (Norris, 1965) that disrupted earlier extension faults. As seam thickening and thrusting progressed exogenetic fractures with fold axis parallel trends and variable dips to the west developed in the coal.

SUMMARY

The Crowsnest Coalfield is an area of 600 square kilometers underlain by the Jura-Cretaceous Mist Mountain Formation, which contains from 30 to 60 cumulative metres of high-volatile to low-volatile bituminous coal. The combination of area and cumulative coal guarantees a large resource of coalbed methane, which has been estimated at 12 Tcf. However outlining a resource is a far cry from defining a reserve. The coalfield forms part of the Lewis thrust sheet and has therefore had a protracted deformational history, which started with thrusting followed by folding in the late Cretaceous and continued with extension on north trending major faults in the Tertiary. The thrusting caused shearing within some seams that is unrelated to the amount to subsequent folding. This has probably limited permeability and generated fine coal that will make production more difficult.

Successful production will probably rely on understanding the interplay between deformation coal quality and location in specific structures. With these caveats in mind the more perspective area is where the Mist Mountain Formation is in the depth window of approximately 200 to 1000 metres. The Crown has clear title to the CBM in part of this area (Figure 1) and it is within this sub area that a more detailed assessment of the CBM resources has been made. The value of about 3 Tcf defines the size of a box within which hopefully reserves can be located.

A number of ideas relating structure coal quality and CBM are proposed that may help explorationists zero in on areas where reserves are located.

ACKNOWLEDGEMENTS

Bob Morris was kind enough to read the manuscript and correct some of the more obvious errors in the original draft.

REFERENCES

Armstrong, W.M., Fyles, J.T., Guelke, C.B., MacGregor, E.R., Peel, A.L., Thompson, A.R. and Warren, L.H. (1976) Coal in British Columbia, A technical Appraisal*; Coal task Force,* Report of the Technical Committee.

Bustin, R.M. (1982): Geological factors affecting roof conditions in some underground coal mines in the southeastern Canadian Rocky Mountains; *Geological Survey of Canada,* Paper 80-34.

Crabb, J. (1957): a summary of the geology of the Crowsnest coalfields and adjacent areas; *Alberta Society of Petroleum Geology* 7th annual field conference Guide book

Dawson, F.M. Marchioni, D.L. Anderson, T.C. and McDougall, W.J. (2000): An assessment of coalbed methane exploration projects in Canada; *Geological Survey of Canada,* Bulletin 549.

Dawson, F.M., Lawrence, G.F. and Anderson, T.C. (1998): Coalbed methane resource assessment of the Dominion coal blocks southeast British Columbia; *Geological Survey of Canada,* Open File 3549.

Gibson, D.W. (1977): Sedimentary facies in the Jura-Cretaceous Kootenay Formation, Crowsnest Pass area southwestern Alberta and southeastern British Columbia, Bulletin of the *Canadian Petroleum Geology,* Volume 25, pages 767-789.

Grieve, D.A. and Kilby, W.E. (1989): Geology and coal resources of the Dominion coal block southeastern *British Columbia; Ministry of Energy and Mines,* paper 1989-4.

Jansa, L. (1972): Depositional history of the coal-bearing Upper Jurassic-Lower Cretaceous Kootenay Formation Southern Rocky Mountains, Canada*; Geological Society of America,* Bulletin, Volume 83, pages 3199-3222.

Johnson, D.G.S. and Smith, L.A. (1991): Coalbed Methane in southeastern British Columbia; *British Columbia Ministry of Energy and Mines, Petroleum Geology Branch,* Special paper 1991-1.

Latour, B.A. (1970): Coal deposits of the dominion government coal block Fernie area British Columbia*; Department of Energy Mines and Resource, Geological Survey of Canada,* Report.

McLean, J,R. (1977): The Cadomin Formation Stratigraphy, sedimentology and tectonic implications; Bulletin of the *Canadian Petroleum Geology,* Volume 25, pages 792-827.

McCulloch, C.M., Levine, J.R. Kissell, F.N., and Deul, M. (1975): Measuring the methane content of bituminous coals; United States department of the *Interior Bureau of Mines* report 8043.

Monahan, P. (2002): The Geology and oil and gas potential of the Fernie-Elk Valley Area, southeastern *British Columbia, Ministry of Energy and Mines.*

Newmarch, C.B. (1953): Geology of the Crowsnest Coal Basin; *British Columbia Department of Mines*, Bulletin Number 33.

Norris, D.K. (1965): Structural analysis of part of the north A-North Coal Mine Michel, British Columbia; Geological Survey of Canada, Paper 64-24.

Osadetz, K.G., Kohn, B.P. Kohn, Feinstein, S. and R. A. Price (2003): Aspects of foreland belt thermal and geological history in southern Canadian Cordillera from fission-track data, *Petroleum Geology Special Paper 2002-2*

Pearson, D.E. and Grieve, D.A. (1977): Coal Investigations, Crowsnest coalfield; *BC Ministry of Energy and Mines* pages 47-54.

Pearson, D.E. and Grieve, D.A. (1978): Petrographic evaluation of the Crowsnest Coalfield; *Canadian Institute of Mining and Metallurgy,* Annual General meeting Vancouver 1978.

Pearson, D.E. and Grieve, D.A. (1978): Preliminary geological map of the Crowsnest Coalfield, west part*; BC Ministry of Energy and Mines*, Preliminary Map 27.

Pearson, D.E., Gigliotti, F.B. Ollerenshaw, N.C., and Grieve, D.A. (1977): Preliminary map of the Crowsnest coalfield northwest part; *BC Ministry of Energy and Mines*, Preliminary Map 24.

Pearson, D.E. and Grieve, D.A (1980): Coal measures of the Crowsnest coalfield; *BC Ministry of Energy and Mines*, Preliminary Map 42.

Pearson, D.E. and Grieve, D.A (1985): Rank variation, coalification pattern and coal quality in the Crowsnest Coalfield, British Columbia; *Canadian Institute of Mining and Metallurgy* Bulletin, Volume 78, pages 39-46.

Price, R.A. (1961): Fernie map area east half Alberta and British Columbia 82G E1/2; *Geological Survey of Canada,* Paper 61-24.

Price, R.A. (1964): Flathead map area British Columbia and Alberta; Memoir 336.

Rice, G.S. (1918): Bumps and outbursts of gas in the mines of the Crowsnest Pass Coalfield, British Columbia Department of Mines, Bulletin Number 2.

Smith, G.G. (1989): Coal resources of Canada; *Geological Survey of Canada*, Paper 89-4.

White, J.M. and Leckie, D.A. (2000): the Cadomin and Dalhousie formations of SW Alberta and SE British Columbia; age sedimentology and tectonic implications; *Canadian Society of Exploration Geologists* Conference 2000, abstract.