GAS POTENTIAL OF THE FERNIE SHALE, CROWSNEST COALFIELD, SOUTHEAST BRITISH COLUMBIA

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ABSTRACT

Samples from the Fernie Formation were collected from the Crowsnest Coalfield and analysed for total organic carbon (TOC). It was possible to locate most samples in terms of their stratigraphic position within the formation, however, there were no major variations in TOC with stratigraphic position. TOC values were generally low and Tmax values indicate that the formation is over mature. The formation rides on top of the Lewis thrust and has experienced considerable deformation that may increase its potential as a shale gas resource.

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Keywords: Shale gas, total organic carbon, Fernie Formation, Crowsnest Coalfield

INTRODUCTION

Samples discussed in this report were collected from outcrops of the Jurassic Fernie Formation in the Crowsnest Coalfield (Figure 1). The Crowsnest Coalfield is located between the Elk River and Michel Creek drainages and covers a total area of about 600 square kilometres. The Alberta Natural Gas Company 36 inch pipeline, which connects the Alberta gas fields with the US market, trends north-south through the coalfield (Figure 2).

The most recent geology maps and sections for the area are by Johnson and Smith (1991). Other more recent studies for example Monahan (2002) have used these maps and accompanying sections. One of the earliest regional papers on the Crowsnest Coalfield (Newmarch, 1953) provides a preliminary map of the Coalfield and detailed geology of the Coal Creek area. The map was compiled at a time when the mines in the creek were still operating. Other mapping data includes Pearson and Grieve (1978). These maps provide strike/dip and seam location data not present on the maps in Johnson and Smith (1991). The regional map of Price 1961 covers the Crowsnest Coalfield and also provides strike/dip information.

The Coalfield forms part of the Jurassic and lowest Cretaceous strata of the Rocky Mountains and Foothills (Table 1). This area has been the subject of several in-depth studies, including Poulton (1984, 1989, 1990), and Frebold (1957, 1969). The Coalfield is defined by outcrops of the Jura- Cretaceous Kootenay Group and underlying Fernie Formation and in general terms is a structural basin rimmed by outcrops of the Fernie Formation (Figure 2). The coalfield forms part of the upper plate of the Lewis Thrust and therefore formations in the Coalfield have structural characteristics different from the same formations below the Lewis Thrust and penetrated by numerous oil and gas holes in the Western Canadian Sedimentary Basin to the east.

The coal bearing Mist Mountain Formation, which overlies the Fernie Formation, varies in thickness from 490 to 660 metres (Ryan, 2004). Rank of seams in the Mist Mountain Formation range from 0.82% to 1.64% with ranks increasing with depth and generally being higher in the southwestern part of the Coalfield (Pearson and Grieve, 1985). The formation is the target for conventional coal exploration and since 1990 coalbed gas (CBG also referred to as coalbed methane, CBM) exploration. The most recent CBM exploration program is by Shell in the northern part of the basin where the company has drilled 3 holes.

The marine Fernie Formation, which does not contain coal seams, was designated as the “Fernie Shales” on a map of the Crowsnest Coalfields by McEvoy (1902). Leach (1914) was the first to use the term “Fernie Formation” while the term “Fernie Group” was first used by Henderson and Douglas (1954).

Coalbed methane exploration in the overlying Mist Mountain has resulted in interest in the shale gas potential of the underlying Fernie Formation and this report provides some preliminary data on the subject. The study is composed of two parts. The mapping portion of the study aimed to define the distribution of the various subdivisions of the Fernie Formation and to examine the formation as a potential fractured shale reservoir. Fieldwork included mapping, structural analysis and collection of outcrop, core and cuttings samples within the Fernie Formation (Morris, 2004). The second part of the study, which forms this report includes a discussion of total organic carbon (TOC), analysis of samples.

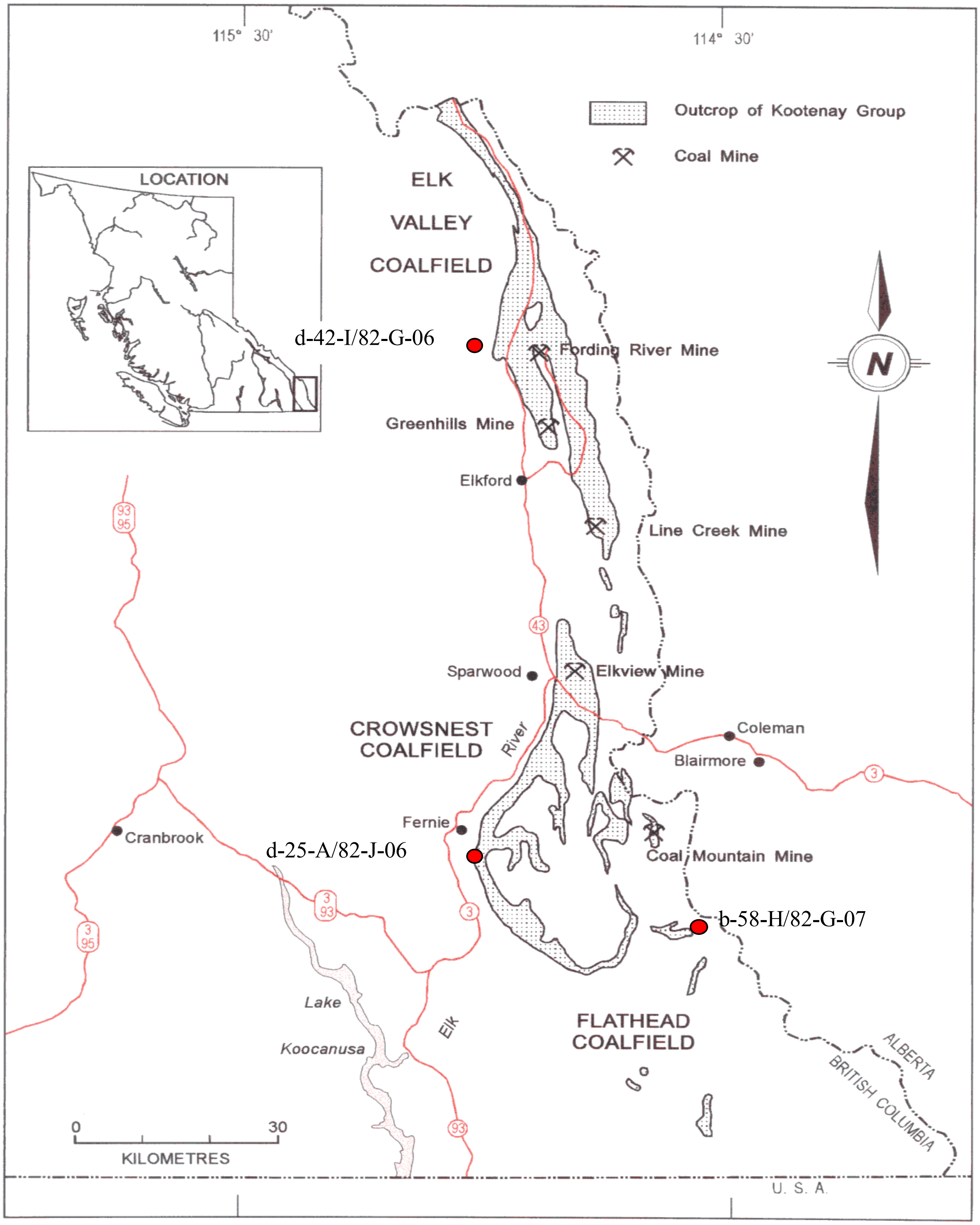


Figure 1. Regional map SE British Columbia.

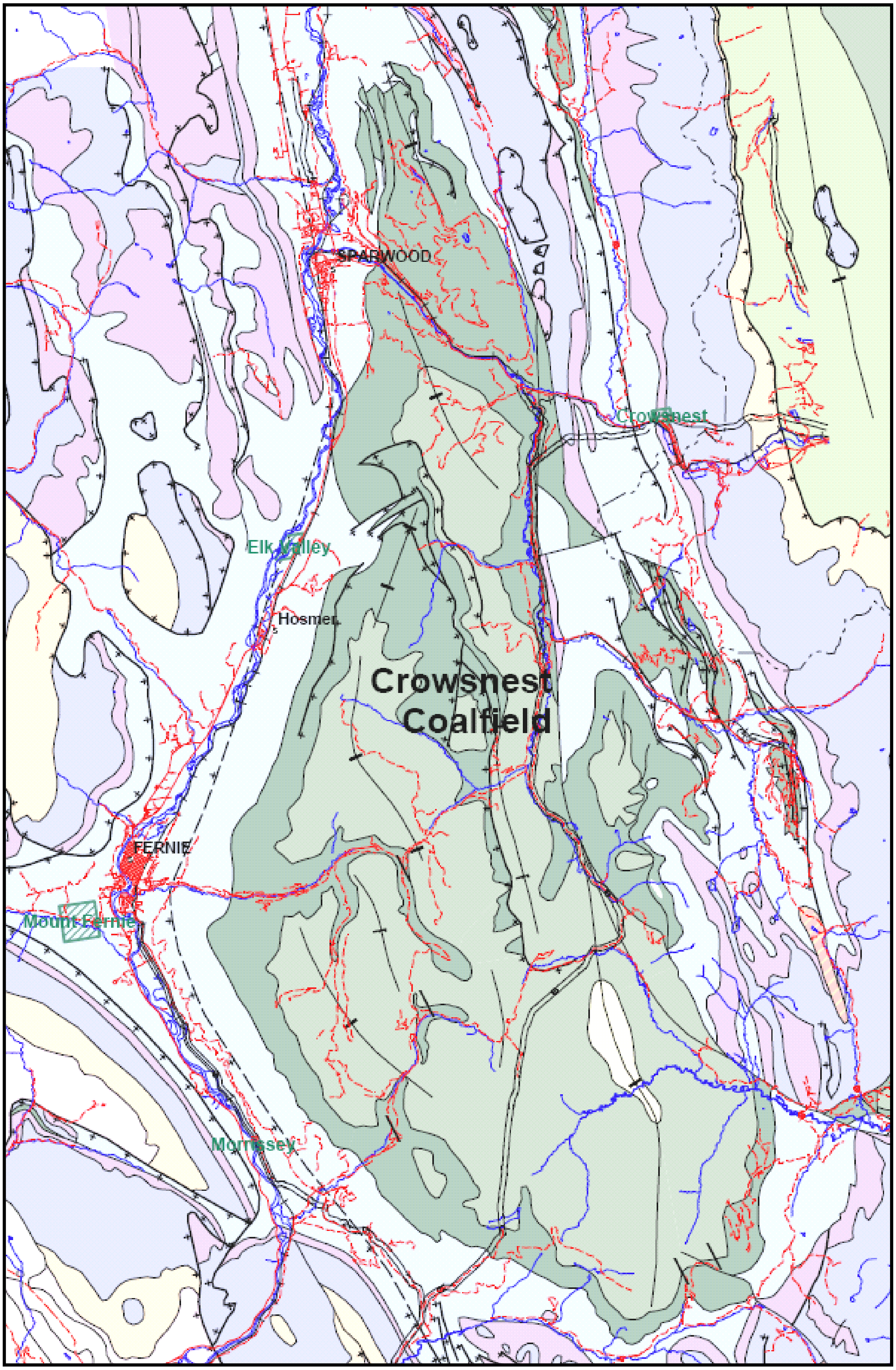


Figure 2. Regional geology Crowsnest Coalfield extracted from Ministry of Energy, Mines and Petroleum Resources MapPlace geology map East Kootenay.

TABLE 1. STRATIGRAPHY OF SOUTHEAST BRITISH COLUMBIA AND FERNIE FORMATION

LOWER CRETACEOUS	CADOMIN FORMATION		
JURASSIC AND CRETACEOUS	KOOTENAY GROUP	ELK FORMATION **minor coal**	
		MIST MOUNTAIN FORMATION **coal seams**	
		MORRISSEY FORMATION	MOOSE MOUNTAIN MEMBER
			WEARY RIDGE MEMBER
JURASSIC	FERNIE FORMATION	PASSAGE BEDS	

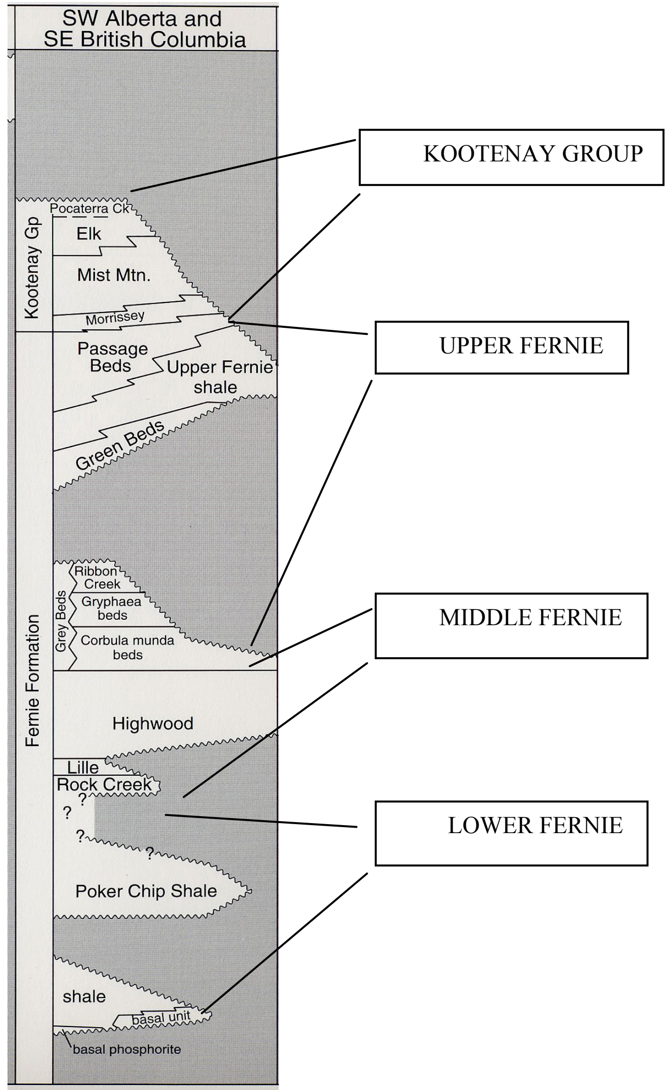


Figure 3. Stratigraphic section of the Fernie Formation adapted from Poulton *et al.* (1994).

STRATIGRAPHY

The Fernie Formation was first described by McEvoy and Leach (1902) who designated the "Fernie Shales" on their map of the Crowsnest Coalfield. There is no type locality designated for the formation, and no known mappable complete section. Price (1961) mapped the area and divided the Fernie Formation into units that from bottom to top are the Dark Grey Shales, Rock Creek, Grey Beds, Green Beds and Passage Beds. The cumulative thickness of these units ranges from 120 to 240 metres. More recently Poulton, *et al.* (1994) provide a section through southeast British Columbia that indicates a thickness of about 200 metres. They also provide a stratigraphic column for southeast British Columbia, a part of which gives a break-down of the Fernie Formation (Figure 3) listing all of the subdivisions that are referred to as Lower, Middle and Upper Members of the formation as well as units and beds.

The Lower Fernie Member contains four units. The lowest unit is the Phosphorite Unit, which is overlain by the Basal unit, the Lower Shale unit and the Poker Chip Shale Unit. All these units are described by Frebold (1957) and Poulton *et al*. (1994). The Poker Chip Shale Unit, also known as the "Paper shale Unit, is described as organic rich (Monahan 2002) and in conjunction with the Phosphatic unit as potential hydrocarbon source rocks. Fossils in this unit are generally restricted to ammonites, which are preserved as imprints or films. Locally, vertebrate remains have been found as well as belemnites.

The Middle Fernie Member is represented by four units. The lowest is the Rock Creek Unit overlain successively by the Lille, Highwood and Grey Beds Unit. Only the Grey Beds Unit was observed during this study. Three main facies are recognized in the Unit; the Corbula munda, Gryphaea beds (a predominantly shaly facies) and a facies characterized by grey shales with sandstone intercalations. The Corbula munda and Gryphaea beds consist of grey shales with brown or green tinges intercalated with bands and lenses of hard grayish calcareous sandstone. Most of these strata are fossiliferous containing abundant pelecypods and less commonly ammonites. The shale facies is characterized by indurated grey, limy, somewhat sandy shales that in places form steep cliffs. Most have a greenish tinge and are easily recognizable from a distance. Belemnites are numerous in the upper part.

The top of the Fernie Formation is marked by the Passage Beds.

STRUCTURE

It is important to recognize that rocks in the Crowsnest Coalfield ride on top of the Lewis Thrust and therefore have structural imprints and present day stress regimes that differ from those in the same formations below the thrust to the east. Coal seams, and often the intervening rock in the overlying Mist Mountain Formation, are highly fractured and this tends to decrease permeability in seams. However fracturing in the underlying shale may be advantageous for shale gas extraction because shale formations often have extremely low permeability measured in micro Darcies. Gas extraction depends on natural fracture intensity. The ultimate amount of gas recovered may be proportional to the ratio "surface area of fracture blocks" divided by their volume. Small blocks or blocks with non-spherical shapes provide a high ratio of surface area to volume which aides diffusion out of shale fragments. The Fernie Shale is a major zone of detachment within the Lewis Thrust sheet and the formation is often structurally thickened (Monahan 2002).

As a part of sample collection a total 129 outcrops were examined and structural data including orientation of bedding and joints collected. Poles to bedding outline a north to north northwest fold trend with shallow plunge to the north (Figure 5) in agreement with regional fold trends outlined by Price (1961), Johnson and Smith (1991) and Monahan (2002). Poles to joints indicate the presence of axial planar joints and a maximum pole concentration at 330°/6° (Figure 6). This set is fold-axis normal based on the fold trend outlined by bedding (Figure 5) and is the most likely to be open. Other joints are axial planar. It is important to identify areas where there may be more complex patterns of joints in the Fernie Formation or areas where joints intersect bedding at oblique angles generating higher surface area to volume ratios for fragments.

SAMPLING

A total of 106 samples were collected from various exposures of the Fernie Formation around the Crowsnest Coalfield (Figure 4). In general the outcrop samples represent grab samples across as much as 6 metres of exposure, though some of the samples represent individual rocks from an outcrop. The UTM grid coordinates and general location were recorded (Table 2). Samples were also designated in terms of stratigraphic position in the Fernie Formation (Table 3) using the stratigraphy described by Poulon *et al*. (1994) (Figure 3). In addition to outcrop samples, a further seven samples of core were obtained from a single well and twelve samples of cuttings from three wells drilled in the area (Table 4).

In the Lower Fernie Member at least twenty outcrops of the Lower Shale Unit were sampled (Table 4). In addition samples were collected from the Poker Chip Shale Unit. The Middle Fernie Member is represented by at least 56 samples of the Grey Beds Unit. The Upper Fernie Member is represented by samples from the Green Beds Unit, which was observed and sampled in at least twelve localities and the Upper Fernie Shale unit, which was sampled at 14 localities. The top of the Fernie Formation is marked by the Passage Beds, which were sampled at one locality.

Fifty outcrop samples and all 19 drillhole samples were analysed using a RockEval 6 (Re6) instrument to provide information on total organic carbon (TOC), organic maturity (Tmax °C) and Kerogen type. Outcrop samples were picked for analysis based on lithology with preference given to shale or black shale samples, as these are more likely to have higher TOC contents.

RESULTS

Rock-Eval analyses provide information on the amount and maturity of the organic matter. A number of parameters are provided and listed in the tables provided. The S1 value is an indication of the amount of free hydrocarbons in the sample and the S2 value an indication of the amount of hydrocarbon material that could be generated if the remaining organic matter is cracked during increased burial and heating. The S3 value indicates the amount of CO_2 generated by destruction of kerogen in the sample during analysis. The production index (PI= S1/(S1+S2)) is a measure of the evolution level of the organic matter. The Tmax °C value is the temperature at which there is a maximum release of hydrocarbon from cracking kerogen in the sample during pyrolysis. The Tmax temperature correlates to vitrinite reflectance and is therefore an important indicator of organic maturity.

Values calculated from measured data include the total organic carbon (TOC), which is calculated by adding the residual organic carbon content to the amount of pyrolyzed organic carbon. The amount of inorganic carbon is calculated using the S3 and S5 peaks. The hydrogen index (HI= 100*S2/TOC) and the oxygen index (OI=100*S3/TOC) are used to represent the sample in a modified Van Krevelen Diagram, which indicates the maturity and type of Kerogen present.

Calculated Tmax values are related to vitrinite reflectance and a number of papers provide data sets of Tmax *versus* vitrinite reflectance (usually random reflectance). The Rock-Eval instrument has evolved over time and this has produced a number of relationships of Tmax measured by the equipment and Ro measured on the organic matter. The Re2 instrument was not capable of differentiating rank above a reflectance of about 2% whereas the Re6 instrument can identify ranks over a reflectance of 4% (Lafargue *et al*., 2000). As a further complication the Tmax *versus* Ro relationship depends on the type of kerogen present in the sample. Type 3 kerogen tends to have a lower temperature Tmax temperature for the same rank than type 2 kerogen (Taylor *et al*., 1998, page 131).

Relationships of Tmax *versus* vitrinite reflectance vary (Figure 7). Lafargue *et al*. (1998) provide a relationship for Tmax *versus* Ro for coal using Re6.

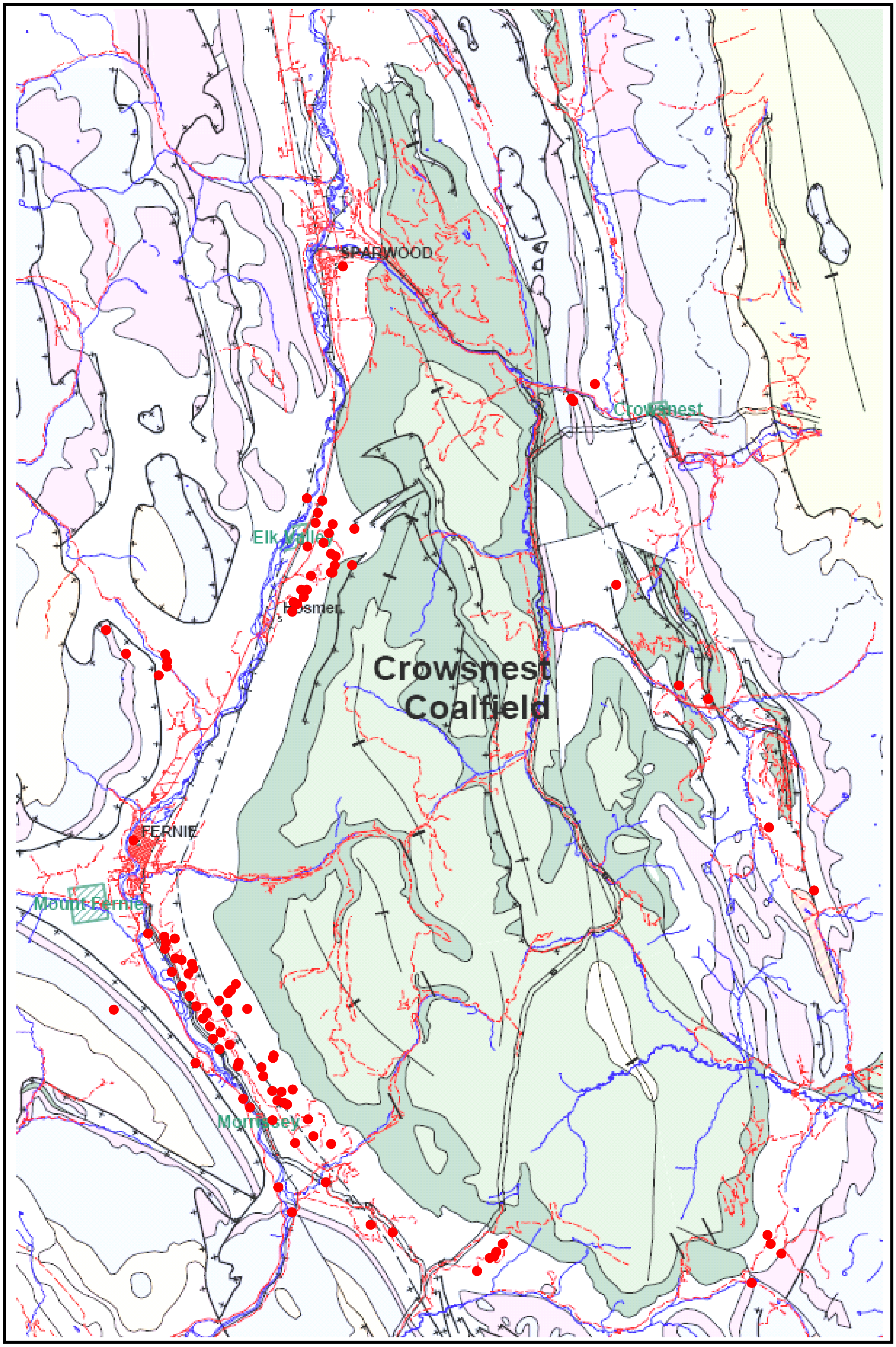
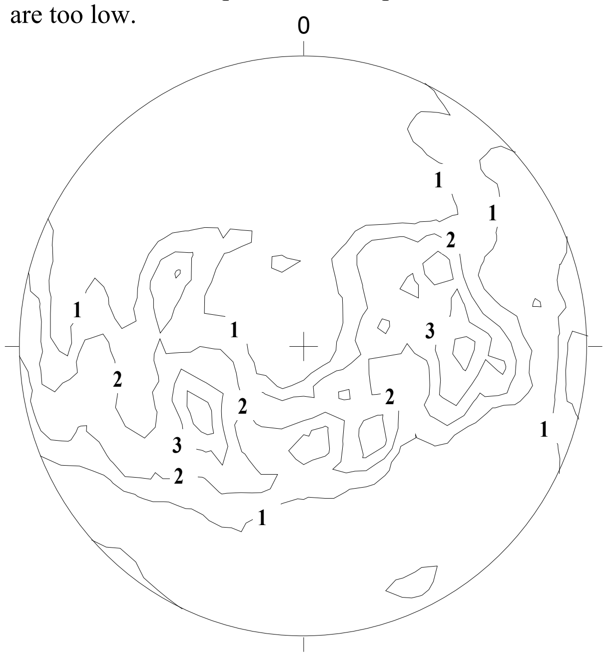


Figure 4. Map of the Crowsnest Coalfield with sample locations.

Krivak (2005) provides a relationship that seems to provided high estimates of Ro. Leachie *et al.* (1988) measured Tmax and Ro values in marine and non marine rocks in northeast BC. Their relationship of Tmax *versus* Ro values for marine rocks seems to provide the best relationship for the Fernie data based on knowledge of the rank of coals in the overlying Mist Mountain Formation. The relations provided by Ibrahimbas and Riediger (2005) for Cretaceous samples seems to provide Ro values that are too low.

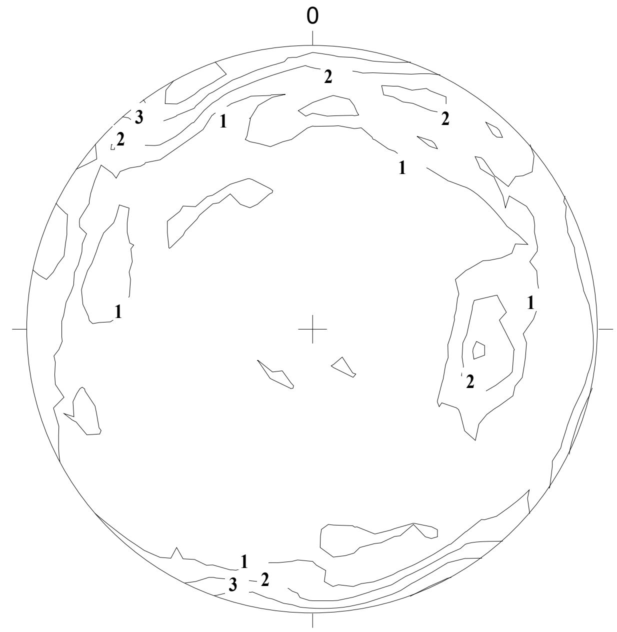


Equal area lower hemisphere projection
contours of poles to bedding at 1 to 4% data density
maximum density at pole 240/54 = 4.59 %

Figure 5. Lower hemisphere equal area projection of poles to bedding.

Tmax temperatures for the outcrop samples range from 449°C to 541°C (Table 5) and place the formation in the dry gas field (Figure 8). Based on these values, Ro values range from 0.9% to 3.1% and average 1.62% using the relationship for marine rocks (Leachie *et al.*, 1998). The data are sorted by unit within the Fernie Formation (Table 6) and plotted into a modified Van Krevelen Diagram (Figure 9). The data is hydrogen poor plotting in the type 3 kerogen field with a high degree of maturity.

Chip samples collected from 3 holes were analysed with most of the samples coming from 2 of the holes (Table 4). Holes ware located: a) to the west of the Elk valley Coalfield, b) below the Bourgeau Thrust, west of the Crowsnest Coalfield in subcrop of Fernie and c) east of the Crowsnest Coalfield intersecting the Fernie below the Lewis Thrust (Figure 1). Hole d-25 intersects the Fernie above and below the Bourgeau Thrust. The Tmax temperatures are low and do not predict realistic ranks indicating the possible presence of contamination (Figure 10). Hole d-42 drilled into Fernie below the Bourgeau Thrust where the formation is steeply dipping. Tmax temperatures increase consistently with depth and do not indicate any major thrusts. The single sample from below the Lewis Thrust (hole b-58 Figure 1) indicates a low rank equivalent to high-volatile A bituminous.



Equal area lower hemisphere projection
contours of poles to joints at 1 to 4 % data density
maximum density at pole 330/6 = 4.68%

Figure 6. Lower hemisphere equal area projection of poles to joints.

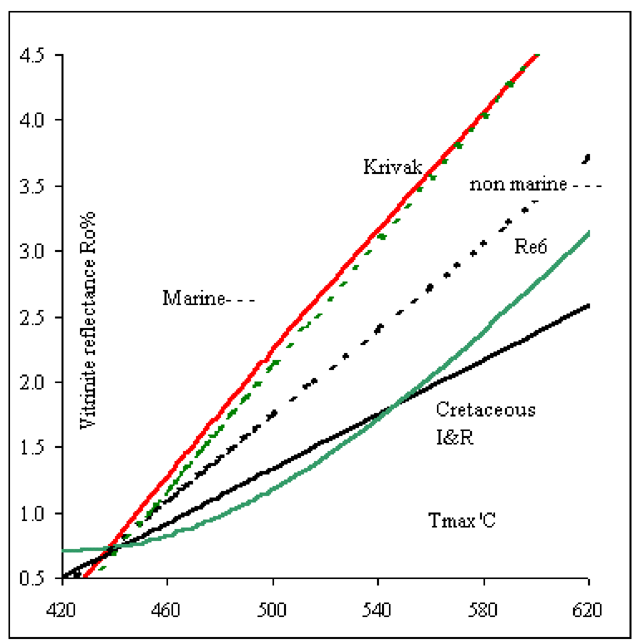


Figure 7. Tmax *versus* Ro relationships derived from Lafargue *et al.* (1998) (Re6), Krivak (2005) Lechie, *et al.* (1988) (marine and non marine) and Ibrahimbas, and Riediger (2005).

TABLE 2. LOCATION OF ALL OUTCROP SAMPLES COLLECTED WITH COORDINATES AND BRIEF DESCRIPTION

	Easting	Northing	Location	analysed		Easting	Northing	Location	analysed
26	645897	5472614	Morrissey Ridge, Branch B		160	641951	5480994	Morrissey Ridge, Branch H	
29	645799	5473399	Morrissey Ridge, Branch B		161	641935	5481219	Morrissey Ridge, Branch H	
33	645036	5472461	Morrissey Ridge, Branch B		164	641239	5481584	Morrissey Ridge, Branch H	164
39	644990	5474228	Morrissey Ridge, Branch C1		165	641503	5481471	Morrissey Ridge, Branch H	
39a	644990	5474228	Morrissey Ridge, Branch C1		166	640974	5481014	Morrissey Ridge, Branch H	166
44	644593	5474478	Morrissey Ridge, Branch C	44	167	640855	5482094	Morrissey Ridge, Branch I	
47	644875	5474317	Morrissey Ridge, Branch C	47	169	640924	5482636	Morrissey Ridge, Branch I	
49	644848	5474834	Morrissey Ridge, Branch C		170	640946	5482365	Morrissey Ridge, Branch I	170
52	645358	5474844	Morrissey Ridge, Branch C	52	171	641377	5482468	Morrissey Ridge, Branch I	
54	644446	5474947	Morrissey Ridge, Branch C	54	172	664072	5462577	Upper Lodgepole	
58a	644170	5475666	Morrissey Ridge, Branch C		174	665621	5463632	McLatchie Pass	174
59	644159	5476076	Morrissey Ridge, Branch C		175	665224	5464147	McLatchie Pass	
64	644750	5476400	Morrissey Ridge, Branch C		176	665157	5464567	McLatchie Pass	176
64a	644750	5476400	Morrissey Ridge, Branch C		180	643328	5474398	Elk River	180
66	644796	5476506	Morrissey Ridge, Branch C		181	643100	5474839	CPR	181
67	644333	5469425	River, tunnel	67	183	641532	5495447	Hartley Lake road	183
68a	643938	5470637	Hwy, road cut	68a	184	640841	5496659	Hartley Lake road	
68b	643938	5470637	Hwy, road cut		191	642797	5494227	Hosmer Mt.	191
69a	641285	5476803	Hwy road cut	69a	193	643232	5494547	Hosmer Mt.	193
69b	641285	5476803	Hwy road cut	69b	195	643291	5494778	Hosmer Mt.	
71	640345	5487143	Fernie bridge, north	71	197	643260	5495103	Hosmer Mt.	197
72	640236	5482907	Cokato road	72	200	650418	5498713	Main road	200
73	642453	5477207	Cokato road		205	651584	5498052	Main road	
74	643117	5476315	Cokato road	74	207	651467	5497661	Main road	207
79	647708	5468237	Lodgepole Pass		212	652239	5497531	Main road, Kootenay shale	
80a	648616	5467722	Lodgepole Pass	80a	215	651311	5497358	Main road, south	215
80b	648616	5467722	Lodgepole Pass	80b	216	651240	5497381	Fernie Ridge, Branch E	216
86	644220	5473651	River Road Ext	86	220	651396	5498206	Fernie Ridge, Branch D	220
90	643193	5476463	River Road Ext		221	651157	5498747	Fernie Ridge, Branch D	
92	642935	5477336	River Road Ext	92	223	651469	5499127	Fernie Ridge, Branch D	
94	643098	5478780	Morrissey Ridge, Branch E		225	651710	5499495	Fernie Ridge, Branch D	
96	643130	5478944	Morrissey Ridge, Branch E	96	230	650785	5500850	Fernie Ridge, Branch A	
102	644006	5478772	Morrissey Ridge, Branch E		252	650969	5499693	Fernie Ridge, Branch B	252
106	641977	5478710	Morrissey Ridge, Branch G		253	651146	5500118	Fernie Ridge, Branch B	
107	642195	5478910	Morrissey Ridge, Branch G		255	651444	5500618	Fernie Ridge, Branch B	
112	642833	5479363	Morrissey Ridge, Branch G		260	650337	5497394	Fernie Ridge, Branch C	260
117	643292	5479624	Morrissey Ridge, Branch G	117	262	649789	5496853	Fernie Ridge, Branch C1	
120	642641	5477943	Morrissey Ridge, Branch E	120	263	649842	5496510	Fernie Ridge, Branch C	
122	646068	5470478	Morrissey road	122	264	649497	5496255	Fernie Ridge, Branch C	
130	646617	5472127	Morrissey ridge, Pine Grove rd		265a	649351	5496370	Fernie Ridge, Branch C	
138	642246	5477731	River Road Ext	138	265b	649351	5496370	Fernie Ridge, Branch C	
139	642213	5478297	River Road Ext	139	266	649213	5495958	Fernie Ridge, Branch C	266
145	652032	5465328	Flathead Ridge, Pipeline		267	650042	5496809	Fernie Ridge, Branch C1	
146	652702	5465804	Flathead Ridge, Pipeline		274	652633	5499115	Fernie Ridge, Branch E	
148	653040	5466019	Flathead Ridge, Pipeline		277	654256	5510803	Michel Creek bridge	277
149	653390	5466319	Flathead Ridge, Pipeline	149	279	665698	5489562	Tent Mtn.	279
151	652917	5465837	Flathead Ridge, Pipeline	151	280	666885	5488725	Tent Mtn.	280
154	643445	5479734	Morrissey Ridge, Branch G		283	668528	5482557	Michel Creek	
155	643703	5479963	Morrissey Ridge, Branch G	155	287	670007	5479409	Flathead Pass	287
156	641778	5479300	River Road Ext		288	663341	5502978	Hwy. road cut	288
157	641558	5479804	River Road Ext	157	290	663270	5503110	Alexander Creek	290
158	641293	5480312	Morrissey Ridge, Branch G	158	296	664433	5503562	Alexander Creek	296
159	641698	5480807	Morrissey Ridge, Branch H	160	308	638104	5479822	Ski hill	308

TABLE 3. ALL SAMPLES COLLECTED DESIGNATED BY UNIT WITHIN THE FERNIE FORMATION

Outcrop Samples by Member	
with analyzed samples high-lighted	
Member	Sample number
	Kootenay Group
Kootenay	212
	Upper Fernie
Passage beds	277
Upper Fernie	49, **52**, **54**, **149, 155**, **176**, **207**, **215, 216**, 263, 264, **266**, 274, **280**
Green beds	29, 39, 39a, **47**, 64, 64a, **117**, 154, 161, 165, 265, 265a
	Middle Fernie
Grey beds	26, 33, **44**, 58a, 59, 66, **71**, **72**, **74**, 79, **80a**, **80b**, **86**, 90, **92**, 94, **96**, 102, 106, 107, 112, **120, 122**, 130, **138, 139**, 145, 146, 148, **151**, 156, **157, 158, 159, 160, 164, 166,** 167, 169, **170**, 171, 172, 175, **200**, 205, **220**, 221, 223, 225, 230, **252**, 253, 255, **260**, 262, 267
Ribbon Creek	No sample
Gryphaea beds	No sample
Corbula Munda beds	No sample
Highwood	No sample
Lille	No sample
Rock Creek	No sample
	Lower Fernie
Poker Chip Shale	73
Lower Shale	**67**, **68a**, 68b, **69b**, **174, 180, 181, 183**, 184, **191, 193**, 195, **197**, **279**, 283, **287, 288, 290, 296, 308**
Basal Unit	No sample
Basal Phosphorite	No sample

TABLE 4. LOCATION, DEPTH AND ROCK-EVAL DATA FOR DRILLHOLE SAMPLES

			from	to
d-42-I/82-G-06	core	Core 1, #1	1548.38	1549.91
d-42-I/82-G-06	core	Core 1, #2	1553.57	1553.57
d-42-I/82-G-06	core	Core 1, #3	1557.53	1557.53
d-42-I/82-G-06	core	Core 2, #1	1921.46	1921.46
d-42-I/82-G-06	core	Core 3, #1	2592.32	2592.32
d-42-I/82-G-06	core	Core 3, #2	2595.52	2595.52
d-42-I/82-G-06	core	Core 3, #3	2600.25	2600.25
d-42-I/82-G-06	chips	WA 1113	350.52	432.82
d-42-I/82-G-06	chips	WA 1113	853.44	935.74
d-25-A/82-J-06	chips	WA 6095	605	610
d-25-A/82-J-06	chips	WA 6095	630	640
d-25-A/82-J-06	chips	WA 6095	2680	2720
d-25-A/82-J-06	chips	WA 6095	2880	2935
d-25-A/82-J-06	chips	WA 6095	2940	2995
d-25-A/82-J-06	chips	WA 6095	3125	3200
d-25-A/82-J-06	chips	WA 6095	3970	4010
d-25-A/82-J-06	chips	WA 6095	4015	4060
d-25-A/82-J-06	chips	WA 6095	4065	4116
b-58-H/82-G-07	chips	WA 6241	3440	3520

TABLE 5. ROCK-EVAL DATA FOR TOTAL ORGANIC CARBON ANALYSES FOR SAMPLES AND RO CALCULATED USING MARINE RELATIONSHIP FROM LEACHIE ET AL. (1988)

Sample No.	Colour	Texture	Rock Type	Notes	MINC%	TOC	HI	OI	Tmax	Ro-1	Ro-2	Av Ro
52	dark grey	fissile	shale	small conc	0.1	1.42	29	66	484	1.01	1.16	1.08
54	dark grey	mod. platy	shale	sericite, concretions	0.1	1.34	25	59	488	1.04	1.21	1.13
68a	dark grey	thin bedded	shale	sericite, belemnite	1.4	0.91	58	51	461	0.82	0.93	0.87
69a	dark grey	thin bedded	shale		1.2	1.23	42	41	474	0.92	1.06	0.99
71	dark grey	fissile	shale		4.3	0.47	23	55	475	0.93	1.07	1.00
72	dark grey	fissile	sh/slst	ca veins	1.7	0.26	12	138	490	1.06	1.23	1.15
74	dark grey	platy	shale	ca veins, clay	2.0	0.33	36	139	472	0.90	1.04	0.97
80a	dark grey	massive	sh/slst		10.7	0.12	0	333	516	1.37	1.50	1.43
80b	dark grey	platy	shale	clay	0.6	0.61	7	118	541	1.73	1.76	1.74
86	dark grey	mod. platy	sh/slst		0.8	0.23	17	178	490	1.06	1.23	1.15
96	dark grey	massive	siltstone	ca veins	1.2	0.21	19	176	490	1.06	1.23	1.15
122	dark grey	massive	siltstone	ca veins	1.1	0.11	18	182	489	1.05	1.22	1.14
138	dark grey	fissile	siltstone	green tint	0.8	0.17	24	212	479	0.96	1.11	1.04
151	dark grey	massive	siltstone		0.3	0.41	20	195	499	1.16	1.32	1.24
155	dark grey	massive	siltstone		0.1	1.51	25	72	478	0.95	1.10	1.03
157	dark grey	mod. platy	shale	clay	0.1	1.40	21	103	477	0.94	1.09	1.02
158	dark grey	massive	shale	mini concretions	1.8	0.25	20	100	466	0.86	0.98	0.92
159	dark grey	platy	shale	ca veins	3.3	0.25	12	216	494	1.11	1.27	1.19
160	dark grey	platy	shale	bivalve	2.7	0.42	14	164	490	1.06	1.23	1.15
164	dark grey	massive	siltstone	mini conc., bivalve?	1.6	0.19	11	168	485	1.01	1.17	1.09
170	dark grey	fissile	siltstone		1.6	0.28	11	139	501	1.18	1.34	1.26
174	dark grey	platy	shale	muddy, dirty, coaly?	0.2	1.18	6	136	513	1.33	1.47	1.40
176	dark grey	mod. platy	siltstone	sericite	0.1	1.43	12	110	493	1.10	1.26	1.18
183	dark grey	platy	siltstone	concretions, sericite	1.3	0.77	34	56	484	1.01	1.16	1.08
191	dark grey	platy	siltstone	rusty	0.2	2.45	17	67	500	1.17	1.33	1.25
197	dark grey	massive	siltstone	ca veins, green tint	0.8	0.27	41	63	472	0.90	1.04	0.97
200	dark grey	massive	shale	belemnite? Rusty	3.8	0.09	11	333	480	0.97	1.12	1.05
260	dark grey	massive	siltstone		0.2	1.19	42	76	474	0.92	1.06	0.99
266	dark grey	fissile	siltstone	very fine sericite	0.1	1.22	34	75	472	0.90	1.04	0.97
277	dark grey	massive	siltstone	slicks	1.3	1.49	34	55	498	1.15	1.31	1.23
280	dark grey	platy	siltstone	sericite, concretions	0.9	0.62	56	71	462	0.83	0.94	0.88
287	gray/brown	fissile	shale	clay, concretions	0.1	0.39	10	259	474	0.92	1.06	0.99
296	dark grey	fissile	shale	sericite	0.2	2.56	36	59	468	0.87	1.00	0.93
308	dark grey	mod. platy	siltstone	sericite	0.1	0.50	42	134	453	0.78	0.84	0.81
47	dark grey	massive	slst/lmst	bivalves, black	1.1	0.33	18	73	453	0.78	0.84	0.81
44	black	massive	siltstone	concretions, dense	2.9	0.14	14	179	463	0.84	0.95	0.89
67	gray/brown	thin bedded	ss/slst	ammonite	4.4	0.37	14	349	483	1.00	1.15	1.07
69b	black	thin bedded	shale	ca veins, plant debris	0.9	0.64	22	45	449	0.76	0.80	0.78
92	dark grey	mod. platy	siltstone		0.1	1.57	31	55	473	0.91	1.05	0.98
117	dark grey	massive	sandstone		3.0	0.16	25	256	493	1.10	1.26	1.18

TABLE 5. CONTINUED

Sample No.	Colour	Texture	Rock Type	Notes	MINC%	TOC	HI	OI	Tmax	Ro-1	Ro-2	Av Ro
139	dark grey	platy	siltstone		0.9	0.18	39	111	480	0.97	1.12	1.05
149	dark grey	platy	siltstone	sericite, carb	0.1	0.92	7	139	500	1.17	1.33	1.25
166	dark grey	mod. platy	siltstone		1.1	0.22	18	195	489	1.05	1.22	1.14
180	black	mod. platy	siltstone	fossils, carb., slicks	0.4	1.35	43	15	452	0.77	0.83	0.80
181	dark grey	mod. platy	siltstone	green tint	1.6	0.25	20	120	459	0.81	0.90	0.86
193	black	mod. platy	shale	carb., slicks	0.7	2.93	20	7	463	0.84	0.95	0.89
207	dark grey	massive	siltstone	rusty, sericite	0.2	1.45	19	110	485	1.01	1.17	1.09
215	very dark grey	massive	siltstone	sericite, ca veins	0.9	1.82	31	70	465	0.85	0.97	0.91
216	very dark grey	massive	siltstone	ca veins	1.1	2.28	58	21	461	0.82	0.93	0.87
220	very dark grey	fissile	siltstone	concretions	0.9	1.64	60	21	463	0.84	0.95	0.89
252	very dark grey	massive	siltstone	very fine sericite	0.6	1.46	60	18	467	0.86	0.99	0.93
279	dark grey	massive	siltstone	concretions	1.1	1.54	42	80	456	0.79	0.87	0.83
288	black	platy	siltstone	carb.	5.0	5.94	58	11	475	0.93	1.07	1.00
290	dark grey	platy	siltstone		2.2	0.88	30	31	455	0.79	0.86	0.83

Ro-1 uses relationship from Lafargue et al (1998)

Ro-2 uses Cretaceous relationship from Ibrahimas and Riediger (2005)

TABLE 6. OUTCROP SAMPLES SORTED BY UNITS WITH TOC, HI AND OI DATA

Unit /No	TOC	Hi	OI	Tmax	Ro
Passage beds					
277	1.49	34.0	55.0	498.0	1.78
Upper Fernie					1.36
52	1.42	29.0	66.0	484.0	1.53
155	1.51	20.0	195.0	499.0	1.42
280	0.62	56.0	71.0	462.0	1.13
54	1.34	25.0	59.0	488.0	1.60
149	0.92	7.0	139.0	500.0	1.81
176	1.43	12.0	110.0	493.0	1.69
207	1.45	19.0	110.0	485.0	1.55
215	1.82	31.0	70.0	465.0	1.19
216	2.28	58.0	21.0	461.0	1.12
266	1.22	34.0	75.0	472.0	1.31
average	1.40	29.1	91.6	480.9	1.43
Green beds Upper Fernie					
47	0.47	18.0	73.0	453.0	1.37
117	0.16	25.0	256.0	493.0	1.69
average	0.32	21.5	164.5	473.0	1.53

Unit /No	TOC	Hi	OI	Tmax	Ro
Grey beds Upper Fernie					
122	0.11	18.0	182.0	489.0	1.62
200	0.09	11.0	333.0	480.0	1.46
80a	0.12	0.0	333.0	516.0	2.10
80b	0.61	7.0	118.0	541.0	2.55
44	0.14	14.0	179.0	463.0	1.15
71	0.47	23.0	55.0	475.0	1.37
72	0.26	12.0	138.0	490.0	1.64
74	0.33	36.0	139.0	472.0	1.31
86	0.23	17.0	178.0	490.0	1.64
92	1.57	31.0	55.0	473.0	1.33
96	0.21	19.0	176.0	490.0	1.64
120	0.23	26.0	235.0	471.0	1.29
122	0.11	18.0	182.0	489.0	1.62
138	0.17	24.0	212.0	479.0	1.44
139	0.18	39.0	111.0	480.0	1.46
151	0.41	20.0	195.0	499.0	1.80
157	1.40	21.0	103.0	477.0	1.40
158	0.25	20.0	100.0	466.0	1.21
159	0.25	12.0	216.0	494.0	1.71
160	0.42	14.0	164.0	490.0	1.64
164	0.19	11.0	168.0	485.0	1.55
166	0.22	18.0	195.0	489.0	1.62
170	0.28	11.0	139.0	501.0	1.83
200	0.09	11.0	333.0	480.0	1.46
220	1.64	60.0	21.0	463.0	1.15
252	1.46	60.0	18.0	467.0	1.22
260	1.19	42.0	76.0	474.0	1.35
average	0.47	22.0	161.3	484.6	1.54

Unit /No	TOC	Hi	OI	Tmax	Ro
Lower Fernie					
67	0.37	14.0	349.0	483.0	1.51
181	0.25	20.0	120.0	459.0	1.08
183	0.77	34.0	56.0	484.0	1.53
197	0.27	41.0	63.0	472.0	1.31
287	0.39	10.0	259.0	474.0	1.35
68a	0.91	58.0	51.0	461.0	1.12
69a	1.23	42.0	41.0	474.0	1.35
69b	0.64	22.0	45.0	449.0	0.90
174	1.18	6.0	136.0	513.0	2.05
180	1.35	43.0	15.0	452.0	0.95
191	2.45	17.0	67.0	500.0	1.81
193	2.93	20.0	7.0	463.0	1.15
279	1.54	42.0	80.0	456.0	1.03
288	5.94	58.0	11.0	475.0	1.37
290	0.88	30.0	31.0	455.0	1.01
296	2.56	36.0	59.0	468.0	1.24
308	0.50	42.0	134.0	453.0	0.97
average	1.42	31.5	89.6	470.1	1.28

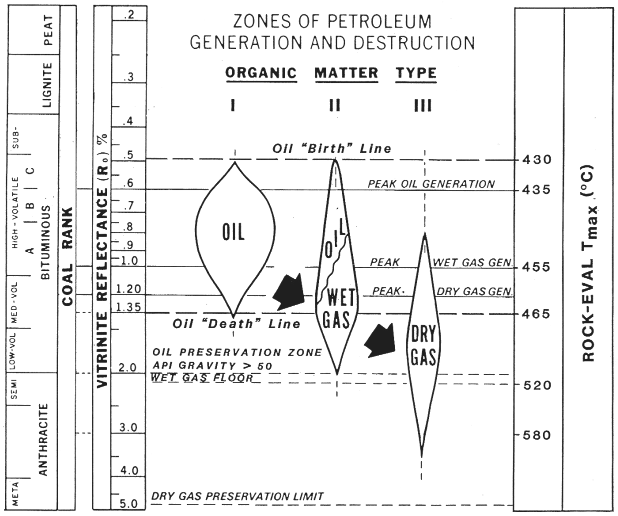


Figure 8. Generation of oil and gas from Kerogen; figure from Dow (1974).

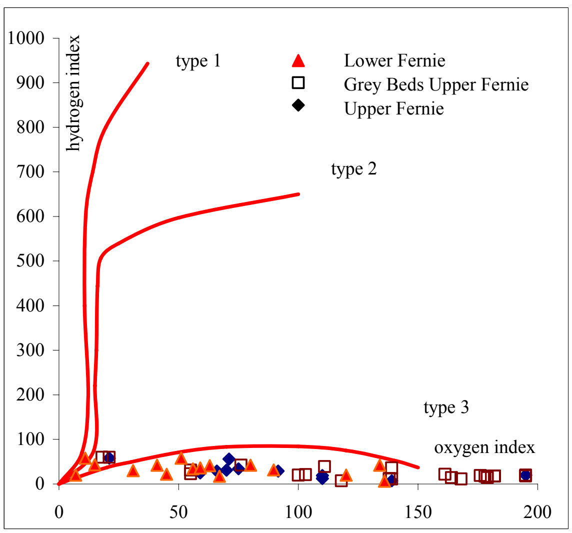


Figure 9. Van Krevelen Diagram for outcrop samples.

DISCUSSION

Organic material that collects in low energy environments, where fine sediments accumulate, is preserved if the environment is anoxic. Shales with moderate contents of preserved organic material have the potential to be a source rocks for oil or gas depending on the kerogen type and its maturity. Shale also has the potential to act as a reservoir for gas, based on the adsorption ability of the organic matter and the ability of the shale to retain gas in the micro porosity.

At depth to the east the Jurassic Fernie Formation is divided from base upwards in part into the Nordegg, Gordondale, Poker Chip, Rock Creek, and Grey Beds. The Nordegg Member underlies part of southeast British Columbia and a large area of southern Alberta. The Gordondale Member underlies southeast and northeast BC and a large area of Alberta. Both members have good source rock potential for oil.

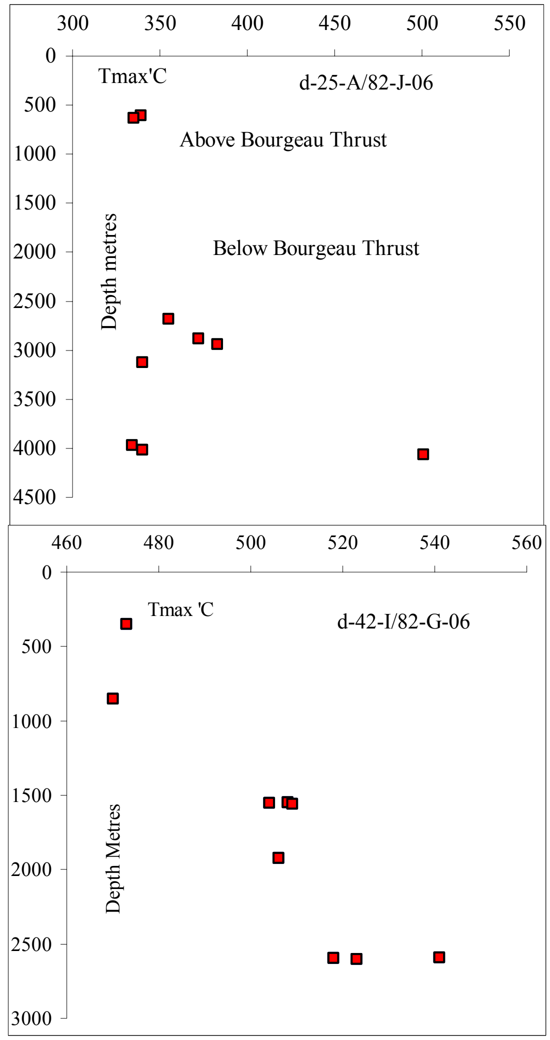


Figure 10. Depth *versus* Tmax plots for holes d-42-I/82-G06 and d-25-A/82-G-07.

In northeast British Columbia the Fernie Formation is overlain by the Nikanassin, Cadomin Gething, and Bluesky formations and on top the lower Cretaceous Moosebar or Wilrich Formation, which is a marine shale with shale gas potential. Ibrahimbas and Riediger (2005) provide an average TOC for the Wilrich of 2.1%. Leckie *et al.* (1988) analysed samples for TOC from the Monkman Pass area. TOC values range from 0.75 to 2.36% and rank ranges from 1.2 to 1.24% Rmax. They derived approximate Tmax versus Ro relationships for marine and non-marine rocks, which are depicted in Figure 7.

Total organic carbon values of samples from the Crowsnest Coalfield and adjoining area, sorted by units (Table 6) provide averages of 1.67 % for the Upper Fernie, 1.41% for the Lower Fernie and 1.75% for the Grey Beds. These reflectances are in the range of what would be expected based on measured reflectance values in the overlying Mist Mountain (Pearson and Grieve 1985). The Tmax values indicate that the formation is in the dry gas field (Figure 8) and values indicate a poor to fair source rock potential especially as the kerogen appears to be type 3 (Figure 9).

Contours of Tmax values indicate higher values to the southwest (Figure 11), which agrees with the general rank trends for the overlying Mist Mountain Formation. Plots of Grey Beds and Lower Fernie data sets separately (Table 6) indicate, with the limited amount of data available, that it is not possible to distinguish any maturity difference between units with in the Fernie Formation.

The TOC contents of producing shale units range from 0.5% to over 20% (Table 7) and in terms of TOC content and rank the Fernie Formation is similar to the Lewis Shale. The Lewis Shale is 300 to 450 metres thick and occurs at a depth of 1000 to 2000 metres in the San Juan Basin. Well productivity correlates with natural fracture spacing (Dart, 1992). Permeability is improved by dissolution of carbonate cement on some fractures. The presence of inorganic carbon is identified by Rock-Eval analyses and contents are generally low in the Fernie shale samples. The shale is considerably under pressured, which decreases gas contents, which are from 0.3 to 0.6 cc/g but probably aids permeability and produceability. There are no data on pressure gradients in the Fernie Formation, though unpublished data probably exists for the overlying Mist Mountain Formation.

Shale gas contents are composed of adsorbed gas on organic material and gas in the non organic rock that is tightly held free gas and possibly some gas adsorbed onto clay surfaces. Adsorption on non organic material is suspected when any isotherm on a sample with low organic content predicts unrealistically high adsorption ability when calculated to the equivalent 100% TOC sample. The effect of clay adsorption or tight free gas is more for lower TOC samples and it can cause a double accounting of gas because it is not part of the gas adsorbed on the organic material. Many isotherms on shale, for which the TOC content is also provided, permit estimation of the adsorption characteristics of the equivalent sample with 100% TOC. As noted previously (Bustin, PC 2005) often calculated langmuir volumes (Vl) at 100% TOC appear to be unrealistically high, indicating double accounting or the possibility that sample preparation may have artificially increased the adsorption ability of the shale component of the sample. The lower the TOC content the more this will affect estimation of Vl at 100%TOC.

Data from the Nordegg (Bustin and Nassichuk, 2002) with a Tmax of 430'C and variable TOC values provides sufficient data to calculate the langmuir volume for 100% TOC samples (Figure 12). As the TOC content decreases, Langmuir Volumes increase to unrealistic values indicating that adsorption values measured on small contents of TOC should be treated with caution.

No isotherms for the TOC from the Fernie Formation are available however it is possible to estimate the adsorption capacity of the rock using isotherms on coal of similar rank and kerogen type. The Gething Formation in northeast British Columbia has similar rank and some samples are inertinite rich (Kerogen type 3 to 4) (Ryan and Lane, 2002). Using Langmuir constants from these samples, a TOC content of 1.5% and a normal hydrostatic gradient, predicts a gas content of about 0.3 cc/gm at 1500 metres. There is no way of estimating the amount of free gas that might be held in the micro porosity.

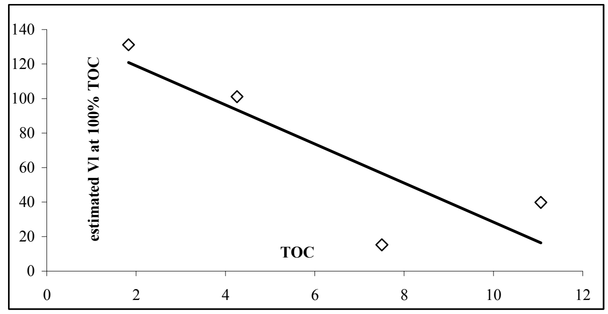


Figure 12. Langmuir volume calculated for 100% TOC sample *versus* actual TOC content Nordegg samples Tmax 430, data from Ramos (2002).

It is not proven that finely dispersed organic matter in shales has the same adsorption characteristics as various coal macerals in coal seams of the same maturity. Some indication is available from studies of adsorption on samples with different maceral composition. It appears that as kerogen type changes from type 2 to type 3 or 4, adsorption ability (Langmuir Volume) decreases but Langmuir pressure remains constant (Ryan and Lane, 2002). Estimated Langmuir pressures for shales appear to be higher than for coals with similar rank and kerogen type. The reason for this is not clear but may in part be related to increased solubility of methane in water as pressure increases and in shales the ratio water/organic matter is much higher than in coals.

In the literature there are plots of adsorption ability for samples with different Tmax values at a single fixed pressure and with varying TOC contents (Bustin and Nassichuk, 2002, Figure 8-10). Best-fit lines through data sets (Figure 13a) with more than 4 points (data for Tmax>470 and Tmax=460 combined) provide relationships of TOC to adsorption for kerogen type 3? for different ranks. Slope of lines generally increase as Tmax increases indicating that adsorption ability increases with rank of kerogen; also lines generally have positive Y intercepts that increase with rank and indicate that at TOC=0 (i.e. 100% shale) samples still have the ability to adsorb gas and that the adsorption ability of clays may be rank dependent. The equation of the lines indicate that at 5 Mpa and 100% TOC, adsorption varies from 6 cc/g to 10 cc/g. A study Bustin (2005) provides data similar to that from Bustin and Nassichuk (2002) (Figure 13b) except that adsorption is calculated at 11 Mpa and represents kerogen that has high Tmax values. Using the Exshaw data (Figure 13b) and data with Tmax values of 460 or greater (Figure 13a) provides 2 lines of adsorption *versus* TOC; one for a pressure of 5 Mpa and another for a pressure of 11Mpa. These two lines provide pairs of points on isotherms for increasing TOC contents. Calculation of Langmuir Volumes and Langmuir Pressures for increasing TOC indicate that at 100% TOC Langmuir Volume increases to about 30 cc/g and pressure remains fairly constant as TOC increases as would be expected (Figure 14). The approach is interesting but is in danger of over-working the data. However, it appears that adsorption ability increases as kerogen maturity increases. Langmuir Volume may be high or at least similar to

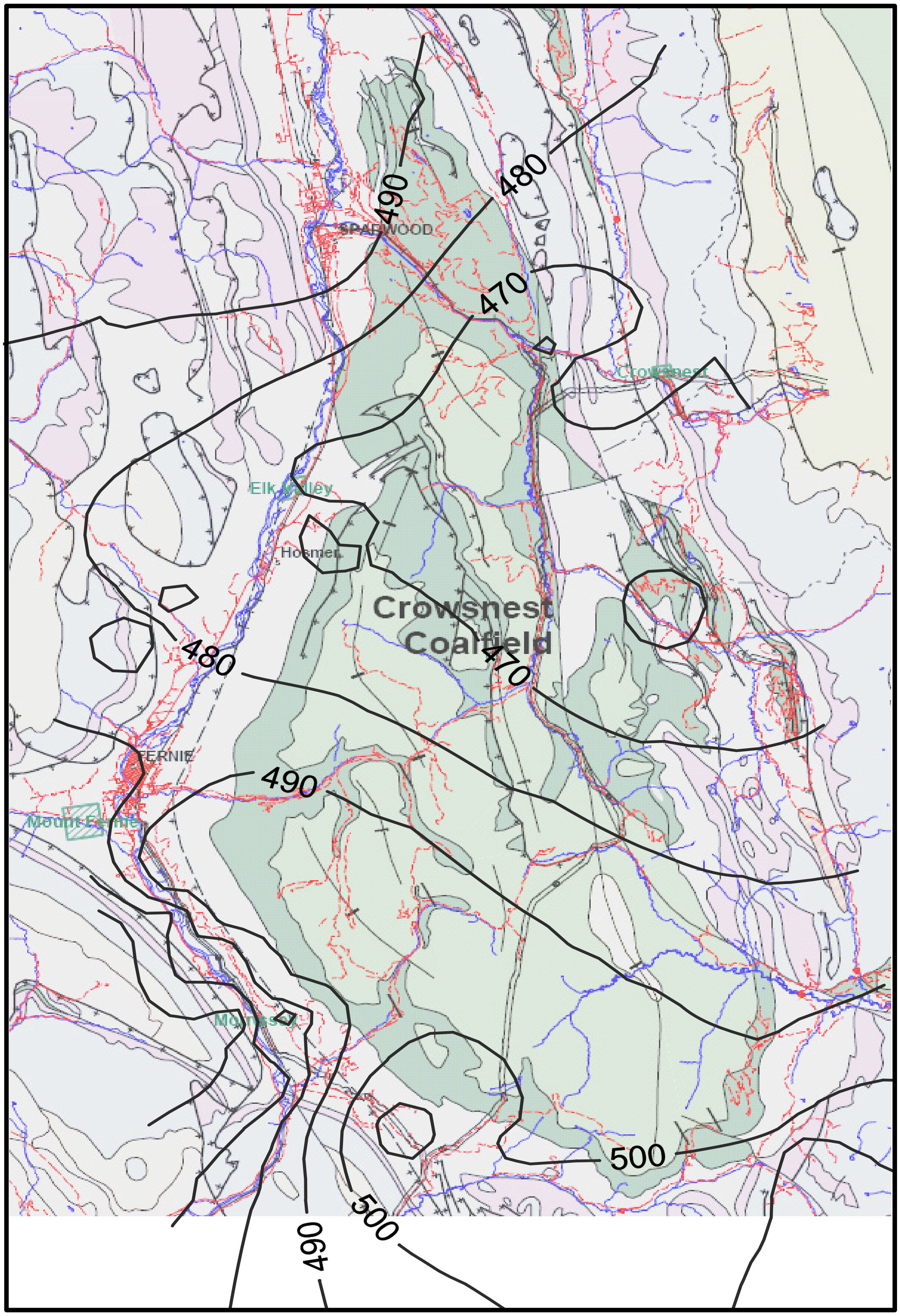


Figure 11. Contours of Tmax for all samples, Crowsnest Coalfield.

TABLE 7. SUMMARY OF DATA ON SHALE GAS SYSTEMS; DATA COLLECTED FROM BUSTIN (2004)

Formation	location	Age	Pressure gradient	rank Ro %	total porosity	TOC	gas content scf/t	Av gas in porosity	Av % gas adsorbed	GIP bcf/sect	gross thickness ft	total resource tcf
Lewis	San Juan Basin	Late Cretaceous	0.2-0.25	1.6-1.88	0.5--5	0.5-2.5	15-45	75-85	15-25	8--50	500-1900	100
Barnett	ft Worth Basin	Mississippian	0.43-0.44	1.1-1.4	1--6	1.0-4.5	60-250	35-75	25-65	30-40	200-300	26.2
Antrim	Michigan basin	Late Devonian	0.35	0.4-1.6	2--10	0.5-20	40-100	15-25	75-85	6--15	160	12--20
New Albany	Illinois Basin	Late Devonian	0.43	0.63-1.3	5--15	1.0-20	40-80	25-35	65-75	7--10	180	2--20
White Speckled	Alberta	Lower Cretaceous				3--5		55-75	25-45		20--90	
Ohio	Appalachian	Late Devonian	0.15-0.4	1.0-1.3	2--5	0.5-23	60-100	50	50	5--10	300-1000	225---250

macerals in coal seams and Langmuir Pressure is high and higher than for coals of similar rank. There is no indication that higher kerogen maturity is accompanied by low Langmuir Pressures, which is the case for high rank coal.

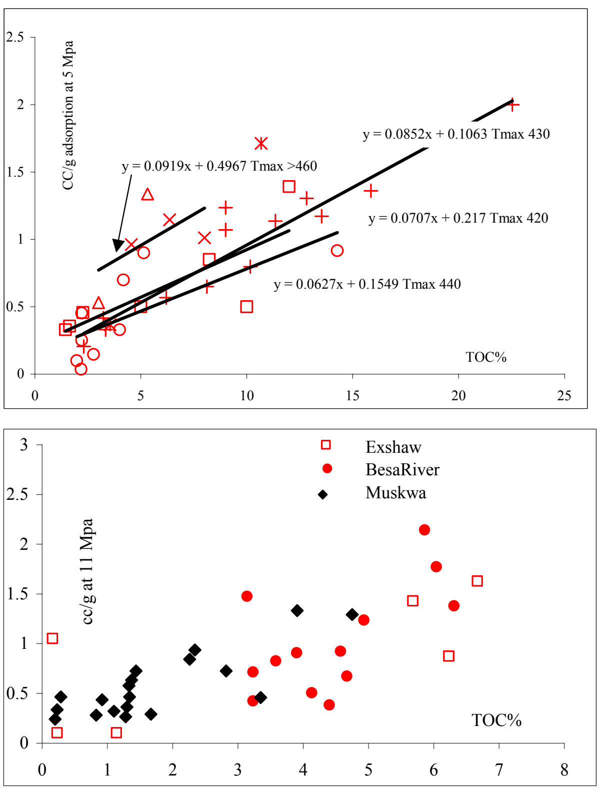


Figure 13. Plots of adsorption (a) from Bustin and Nassichuk (2002) at 5 Mpa for samples with varying TOC and Tmax values and (b); data from Bustin (2005) at 11 Mpa for samples with varying TOC and Tmax values.

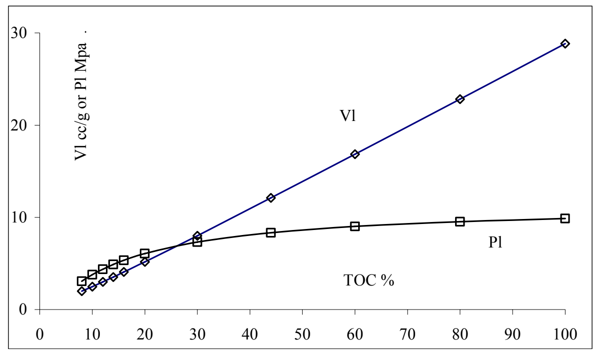


Figure 14. Estimated trend of Langmuir Volume and Pressures for high Tmax samples with increasing TOC contents.

CONCLUSIONS

The Fernie shale that underlies the Crowsnest Coalfield and is contained in the upper Lewis Thrust sheet generally contains moderate to low concentrations of TOC with high maturity. Rank is well constrained by data on coal seams in the overlying Mist Mountain Formation and Tmax values indicate similar trends of increasing rank to the south.

The regional structure of the Coalfield is well documented by a number of papers. Joint measurements indicate a normal relationship of joints to fold geometry. Field observations and CBM exploration experience in the overlying Mist Mountain Formation indicate that the Fernie Formation is moderately to highly fractured.

The lithology of the formation is variable on the regional scale as indicated by the number of members of varying lithology that form the formation. More local variations in lithology are documented by numerous descriptions and these all help to enhance permeability.

In many aspects the Fernie Formation in the Crowsnest Coalfield area is similar to the Lewis Shale in the San Juan Basin (Table 7). Based on a very rough estimate of the volume of the upper and lower members of the formation that underlie the Crowsnest Coalfield, the total resource in the area could be in the range of 1 to

5 tcf. At this time there are no isotherm or adsorption data to permit a reasonable estimate of the resource.

REFERENCES

Bustin, R.M. and Nassichuk, B. (2002): Gas shale geology, engineering application to exploration and development; Short course notes Course Calgary October 10th and 11th 2002.

Bustin R.M. (2005): Gas shale potential of Devonian strata northeastern British Columbia; British Columbia Ministry of Energy, Mines and Petroleum Resources, Petroleum Geology Special Paper 2005-1.

Dart, Jr. S.W. (1992): Evaluation of San Juan Basin fractured reservoirs from surface data; Rocky Mountain Association of Geologists, page 95-114.

Dow, W. (1974): Kerogen studies and geological interpretations; Journal of Geochemical Exploration, Volume 7, pages 79-99.

Frebold, H. (1957): The Jurassic Fernie Group in the Canadian Rocky Mountains and foothills; Geological Survey of Canada, Memoir 287, 197 p.

Frebold, H. (1969): Subdivision and facies of Lower Jurassic rocks in the southern Canadian Rocky Mountains and foothills. Proceedings of the Geological Association of Canada, v. 20, pages 76-89.

Henderson, G.G.L. and Douglas R.J.W. (1954): Southern Rocky Mountains of Canada, tectonic compilation Map; Alberta Society Petroleum Geology Guide Book.

Ibrahimbas, A. and Riediger, C. (2005): Thermal maturity and implications for shale gas potential in northeastern British Columbia and northeastern Alberta; paper presented Canadian Society of Unconventional Gas, Conference, November 2005, Calgary.

Krivak, D. (2005): Progressive analysis in the development of tight gas shale plays; Canadian Institute Shale Gas Short curse Calgary, January 31.

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.

Lechie, D.A., Kalkrueth, W.D. and Snowdon, L.R. (1988): Source rock potential and thermal maturity of Lower Cretaceous Strata: Monkman Pass area, British Columbia; American Association of Petroleum Geology, Bulletin, Volume 72, pages 820-838.

Leach, W.W. (1914): Blairmore map area, Alberta; Geological Survey of Canada, Summary Report 1912, page 234.

Lafargue, E., Espitalie, J., Marquis, F. and Pillot, D. (2000): Rock-Eval 6 applications in hydrocarbon exploration, production and soil contamination studies; Revuede l'institut Francais du Petrole, volume 53, number 4, pages 421-437.

McEvoy J. (1902): Geological and topographical map of Crowsnest Coal Fields; Geological Survey of Canada Map Number 767.

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

Morris, B. (2004): Geochemistry, Fracture Analysis, and Hydrocarbon Potential of the Jurassic Fernie Formation, Crowsnest Coalfield, Southeast British Columbia; Report submitted to Resources Development and Geosciences Branch, British Columbia Ministry of Energy, Mines and Petroleum Resources.

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

Pearson, D.E. and Grieve, D.A. (1978): Preliminary geological map of the Crowsnest Coalfield, west part; British Columbia Ministry of Energy, Mines and Petroleum Resources, Preliminary map 27.

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.

Poulton, T.P., Christopher, J.E., Hayes, B.J.R., Losert, J., Tittemore, J. and Gilchrist, R.D. (1994): Jurassic and lowermost Cretaceous strata of the Western Canada Sedimentary Basin; Chapter 18 Geological Atlas of the Western Canada Sedimentary Basin.

Poulton, T.P. (1984): Jurassic of the Canadian Western Interior, from 49°N Latitude to Beaufort Sea, In: The Mesozoic of Middle North America, D. F. Stott and D. Glass (eds.); Calgary, Canadian Society of Petroleum Geologists, Memoir 9, pages 15-41.

Poulton, T.P. and Aitken, J.D. (1989): The Lower Jurassic phosphorites of southeastern British Columbia and terrane accretion to western North America; Canadian Journal of Earth Sciences, v. 26, pages 1612-1616.

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.

Ramos, S.(2002): The effect of shale composition on the gas adsorption potential of organic rich mudrocks in the Western Sedimentary Basin; University of British Columbia, Department of Earth and Ocean Sciences; Masters of Science Thesis.

Ryan, B.D. and Lane, R. (2002): Adsorption characteristics of coals from the Gething Formation northeast British Columbia; British Columbia Ministry of Energy and Mines, Geological Fieldwork, Paper 2002-1.

Ryan, B.D. (2004): Coalbed gas Resource of prospective areas of the Crowsnest Coalfield; Report of activities 2003, Resources Development Branch, Oil and Gas Division, British Columbia Ministry of Energy, Mines and Petroleum Resources.

Taylor, G.H, Teichmuller, M., Davis, A., Diessel, C.F.K., Littke, R. and Robert, P. (1998): Organic Petrography; Geruder Borntraeger, Berlin-Stuttgard.