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Regional Evaluation of the Coal-Bed Methane Potential of the Foothills/Mountains of Alberta

Alberta Energy and Utilities Board

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We also thank Society of Petroleum Engineers/Department of Energy for permission to reproduce the graph in Figure 3. Please note that permission is required from the original publisher or holder of copyright for further use.

Executive Summary

Coal is present in the Alberta Foothills/Mountains in five zones: the Kootenay, Gething, Gates, Brazeau and Coalspur coal zones. For coal-bed methane (CBM) evaluation purposes, they can be divided into shallow (200 to 2500 m depth) and deep (over 2500 m depth) coal zones. The gas content of all shallow coal areas totals about **1.5 x 10^{12} m^3** (about **53 Tcf**) of in-place CBM, which is considered the best CBM resource estimate for the region at the present time.

The gas content of all deep coal areas totals **2.5 x 10^{12} m^3** (about **90 Tcf**) of in-place CBM. The deep coal zones could be considered an ultimate resource. Consequently, the total ultimate CBM resource could be **4 x 10^{12} m^3** (about **143 Tcf**).

The shallow Gates coal in the central and northern Foothills is very prospective for CBM production and needs to be better tested. The best potential for coalbed methane in the Coalspur Coal Zone is in the Edson area (Entrance Syncline and Triangle Zone).

The size of coal areas, continuity of coal zones and cumulative coal thickness may have been overestimated in this report, as a result of inadequate compilation mapping. For this reason, it is recommended that existing 1:250 000 scale geological maps be updated and additional cross-sections displaying coal zones be constructed.

1 Introduction

Conventional gas reserves in Alberta are predicted to decline in the next decade and, consequently, the Alberta Government and the oil industry are showing a renewed interest in exploring for coalbed methane (CBM). Coalbed methane was neglected in the past in Alberta because it is cheaper to produce conventional gas. However, with the forecasted decline in gas reserves and increased demand and prices, industry's interest in Alberta's CBM potential is rising (Dawson et al., 2000). In addition, the government also has an interest in more accurately estimating Alberta's potential and recoverable reserves to assist in development of its economic and fiscal policy.

A previous regional evaluation of the CBM potential of Alberta Foothills/Mountains coal zones was included in the report by Rottenfusser et al. (1991). The present study re-evaluates the CBM potential of these coals. A best estimate of their total gas content is given, based on limited data. The gas content and related data are presented by dividing the area into nine map sheets (Figure 1). Recommendations are made on how to obtain more reliable resource numbers and some ideas about producibility are presented.

2 Geology of Foothills/Mountains Coal Zones

The various coal zones of the Alberta Foothills/Mountains are shown in Figure 2 and are discussed here from oldest to youngest.

2.1 Kootenay Coal Zone

Alberta's oldest coal-bearing strata belong to the Kootenay Group, found in the southern Rocky Mountains and Foothills. The northern boundary of the Kootenay Group roughly follows latitude 52°N, which is the northern boundary of the Calgary map sheet (NTS 82O; Figure 1). The Kootenay Coal Zone has been described extensively by Gibson (1985). Macdonald et al. (1989) described some coal-quality aspects of the Kootenay.

The Kootenay Coal Zone forms part of the Mist Mountain Formation of the Kootenay Group. The Mist Mountain Formation thins from west to east to a zero erosional edge along the eastern margin of the Foothills (Gibson, 1985). Near the Clearwater River, this formation is no longer coal bearing and grades into the Nikanassin Formation.

The Mist Mountain is composed of a thick, interstratified sequence of predominantly nonmarine siltstone, sandstone, shale and coal seams. The coal seams are thickest and most numerous in the western part of the region. Up to 12.6 m of cumulative coal was encountered in a well in the Pincher Creek area, typical of the thickness that can be expected in the western part of the region.

The coal-bearing lower Mist Mountain Formation was deposited in a coastal plain setting and passes transitionally up-section into an alluvial plain setting, represented by the upper Mist Mountain Formation (Gibson, 1985). Some of the peat swamps therefore developed in some kind of marine coastal environment.

2.2 Gething Coal Zone

The Gething Formation (type section along the Peace River) is mainly restricted to British Columbia, but extends into the northern Alberta Foothills and northern Interior Plains of the Wapiti area (NTS 83L;

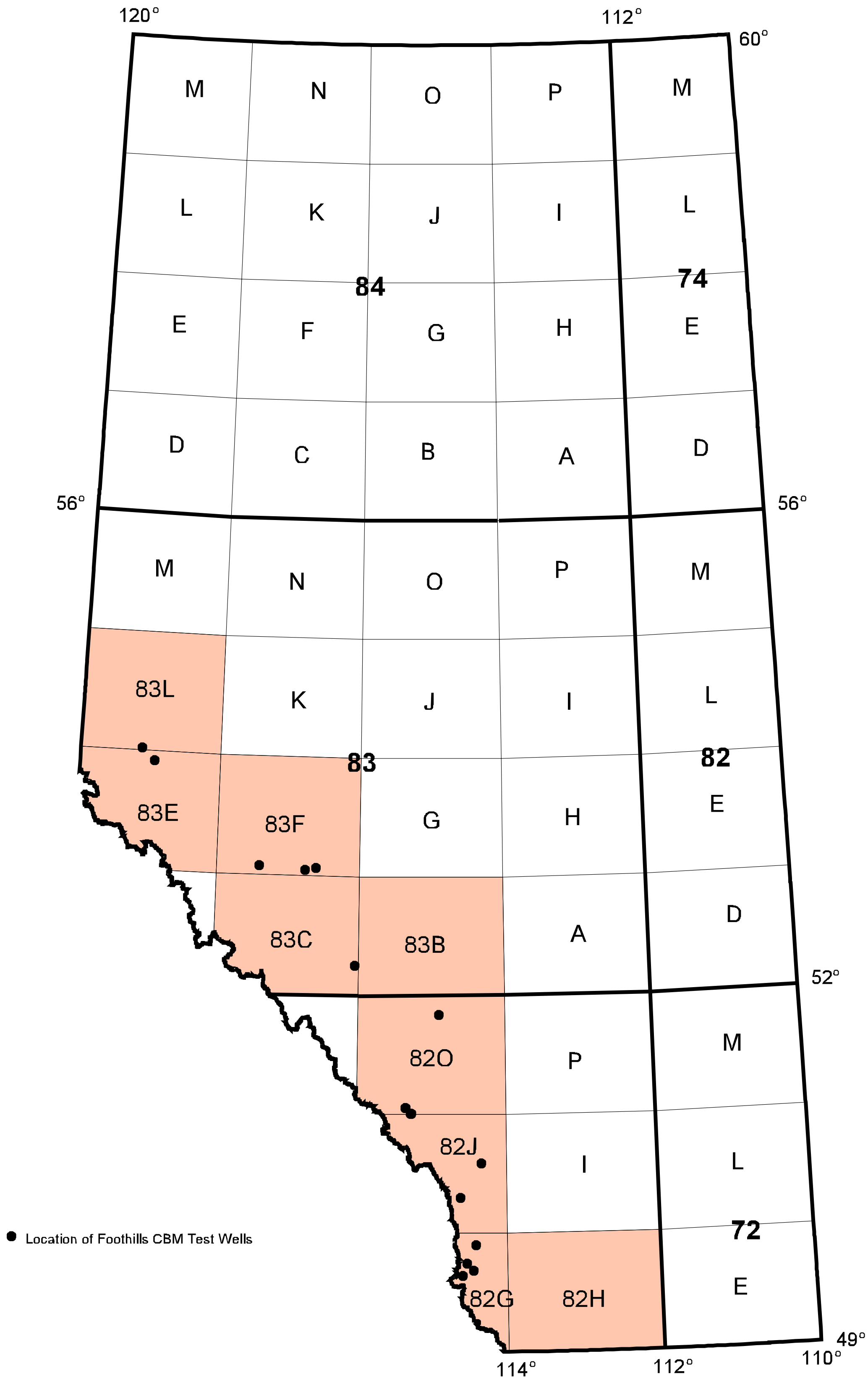


Figure 1. Location of NTS map areas and CBM test wells

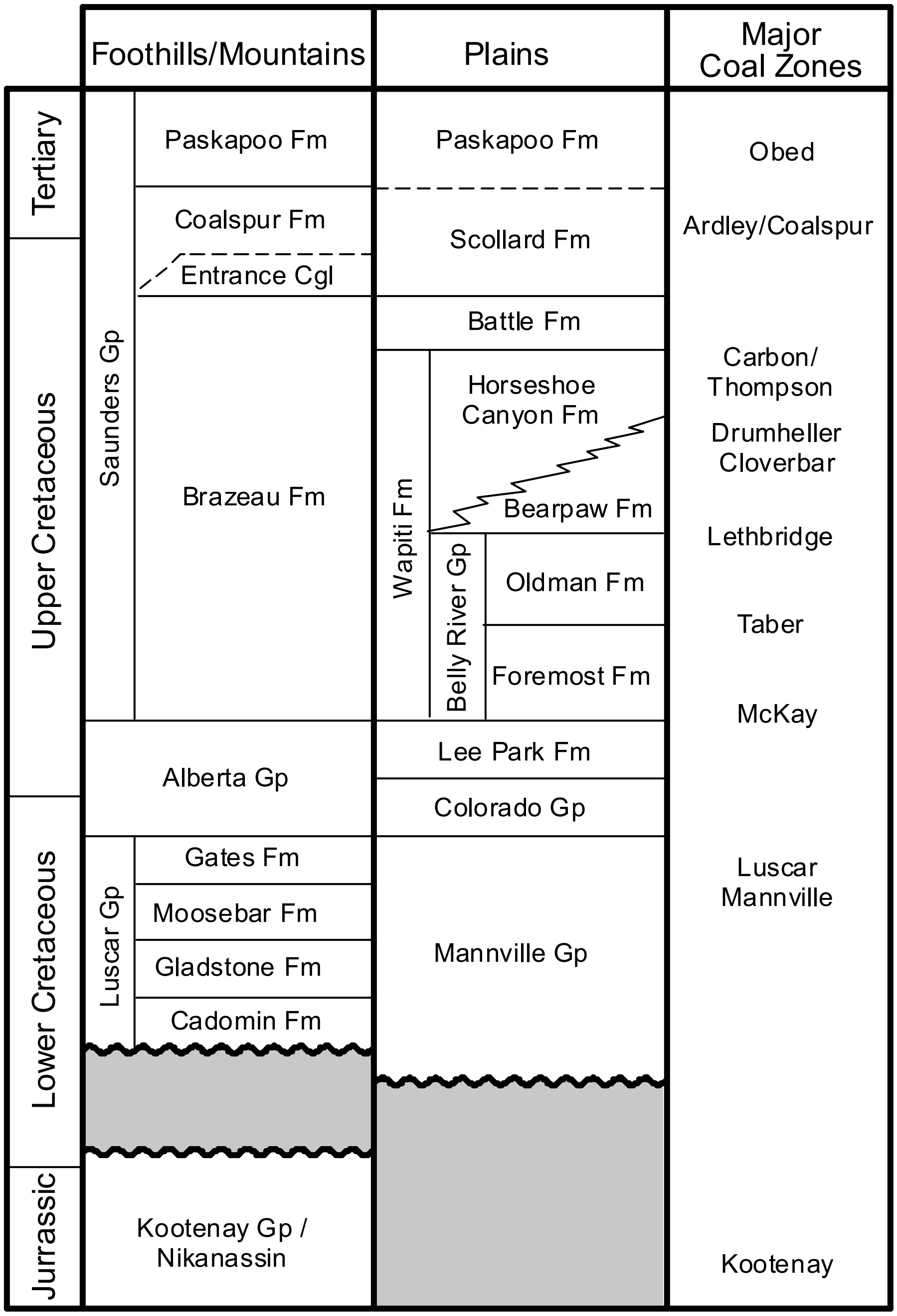


Figure 2. Table of coal-bearing rock units and coal zones in Alberta.

Figure 1). South of the Kakwa River, this stratigraphic interval has only minor coal seams and the interval is called the Gladstone Formation. Coals of the Gething Formation have been described by Kalkreuth (1982) and Kalkreuth and McMechan (1984, 1988, 1996).

2.3 Gates Coal Zone

The Gates Formation of the central and northern Foothills (equivalent to the Spirit River Formation of the plains region) is an important coal-bearing unit. South of the Clearwater River (at latitude 52°N; Figure 1), it grades into the non–coal-bearing Blairmore Group. Its coal quality was discussed by Macdonald et al. (1989). The Gates Formation is the main source for Alberta's metallurgical export coal. The equivalent Spirit River Formation is important as a gas reservoir in the Deep Basin. Various data on Gates coal are presented by Kalkreuth and McMechan (1984, 1988, 1996) and Dawson and Kalkreuth (1994a, b).

The Gates Formation forms part of the Luscar Group of the central and northern Foothills of western Alberta. Outcrop of the Luscar Group is largely confined to the Inner Foothills, which consist largely of folded and faulted Lower Cretaceous rocks and are topographically higher than the Outer Foothills. In the Outer Foothills and in the Interior Plains, the Luscar Group is at depth.

The largely nonmarine Gates Formation can be divided into three members, in ascending order: the Torrens, Grande Cache and Mountain Park members (Langenberg and McMechan, 1985). The age of the Gates Formation ranges from Early to Middle Albian. The basal Torrens Member, which is thin (about 30 m) compared with the other members, consists of sandstone deposited in a shoreface environment. The Grande Cache Member is characterized by coastal plain sandstone, shale and major economic coal seams. It grades into the Mountain Park Member, which consists of fluvial, fining-upward sandstone, shale and minor coal seams.

Macdonald et al. (1988) have shown several transgressive-regressive cycles in an overall prograding shoreline sequence for the Moosebar to Gates transition. Four marine cycles are recognized in outcrop in the Cadomin area, the lower three associated with possible wave-dominated prograding deltas and strandlines, the upper one having a more brackish (lagoonal, tidal channels, etc.) association.

Sedimentological examination of the lower three cycles in the Cadomin area shows a progression of offshore to shoreface to foreshore environments (strand plains), culminating in the deposition of peat units such as the one found in the Jewel Seam. The marine strata of the Moosebar–Gates transition at Cadomin are likely correlative with the more regional Wilrich and Falher cycles. These marine strata are divided into the first, second and third regional cycles, forming a series of prograding shorelines, coastal plain deposits and possibly tidal deposits. Seaward stepping of coastal shoreline sediments was the most common stratigraphic architectural style.

Sedimentary structures in sandstone of the Torrens Member at the base of the Gates Formation indicate shallow marine conditions. Peat swamps likely developed, initially some distance landward on this coastal plain and eventually prograding northward with the shoreline. Subsequent marine transgressive periods reached as far south as Grande Cache. One of these reached the Cadomin area, as indicated by marine microfossils above the lower coal seams (Macdonald et al., 1988). Most of the coals of the lower Gates Formation are coastal plain coals. Coals higher in the succession were deposited on alluvial plains (Kalkreuth and Leckie, 1989).

2.4 Brazeau–St. Mary River Coal Zone

The Brazeau Formation of the central Alberta Foothills contains coals that are equivalent to those from the Belly River and Horseshoe Canyon formations. Jerzykiewicz (1985) redefined the usage of the term Brazeau for this specific stratigraphic interval.

The upper Brazeau Coal Zone is roughly equivalent to the Carbon–Thompson Coal Zone (Figure 2). The St. Mary River Coal Zone, which is stratigraphically below the Carbon–Thompson Coal Zone, could be recognized in southern Alberta south of latitude 51°N (Figure 1) and is equivalent to the Drumheller Coal Zone.

2.5 Coalspur Coal Zone

The Coalspur Formation of the central and northern Foothills (Jerzykiewicz, 1997) contains a 600 m thick continental succession of interbedded sandstone, mudstone and thick economic coal seams. The base of the Coalspur Formation is the so-called Entrance Conglomerate. Thick coal seams, interbedded with coaly shale and numerous bentonite layers, occur in the upper part of the formation. This interval is known as the Coalspur Coal Zone. The Val d'Or coal seam is at the top of the interval and the Mynheer coal seam is at the bottom. These seams (plus other coal seams) are recognizable throughout the area between Hinton and Coal Valley, and can also be recognized extending into the Ardley Coal Zone of the Interior Plains (Dawson et al., 2000). The Cretaceous–Tertiary boundary is at the base of the Mynheer coal seam. The Coalspur Formation represents a nonmarine, fluvially dominated environment of deposition.

The Coalspur Coal Zone of the Coalspur Formation in the Foothills is equivalent to the Ardley Coal Zone of the Scollard Formation in the Interior Plains. Some aspects of this coal zone have been discussed in Macdonald et al. (1989). The Coalspur Coal Zone is between 200 and 300 m thick, with many different coal seams. Its cumulative thickness ranges up to 26 m; in places, it is over 50 m thick due to tectonic thickening. The Coalspur Formation (and Coalspur Coal Zone) represents a sedimentary environment similar to that of the Ardley Coal Zone.

South of Calgary, the Coalspur Formation grades into the Willow Creek Formation, which is the non–coal-bearing equivalent of the Coalspur (and Scollard) Formation.

3 Methodology

Estimates of coal area (area underlain by a particular coal zone) and gas content (based on coal rank) provided the means for calculating possible gas content.

3.1 Coal Areas

Coal areas were defined for nine 1:250 000 scale map sheets in the Foothills/Mountains (Figure 1). Three of these map sheets are available as GSC geological map compilations: Wapiti (NTS 83L; McMechan and Dawson, 1995), Mt. Robson (NTS 83E; Mountjoy, 1978) and Calgary (NTS 82O; Ollerenshaw, 1977). For the other six map sheets, the geology from in-house map compilations (Holter and McLaws, unpublished data, 1972) was used. On these maps, coal areas were defined based on the geological formations present in the subsurface. The subsurface is known from seven regional structural cross-sections through the Foothills/Mountains, published in Rottenfusser et. al. (1991). Two additional cross-sections were produced by TEK Consulting for this project (Kubli and Langenberg, AGS publication in preparation.): the Copton Creek section, located between the Narraway River and Grande Cache sections, and the Moberly Creek section, located between the Grande Cache and Cadomin sections.

The coal-bearing Coalspur Formation was not mapped separately from the Brazeau and Paskapoo formations in the 1972 compilation. For that reason, the geology from the *Geological Map of Alberta* (Hamilton et al., 1999) was transferred to the 1:250 000 scale map sheets. Coal areas were defined based on these two (slightly different) map compilations, in the following manner.

All areas where Triassic and older rocks outcrop were excluded as coal areas because no coal older than Jurassic is known in Alberta. Some younger coal is, in places, overlain by Triassic and older rocks as a result of faulting (e.g., the Lewis and McConnell thrust blocks), but these occurrences are generally situated below high mountain ranges, which would prevent drilling for CBM.

The area of a coal zone was defined as that area where the coal zone is exposed, together with all younger rocks. A certain percentage of the area must be excluded because the coal will be within 200 m of the surface and will be degassed to varying degrees. Some of the map compilations include Triassic and Jurassic rocks with the lower Cretaceous coal-bearing rocks, so it was necessary to estimate, from the cross-sections, what percentage should be excluded. In addition, shortening by deformation (folding and faulting), which would result in a larger coal volume, had to be taken into account. Based on these three considerations, an area correction factor ranging from 0.5 to 1.5 was introduced.

This correction factor is somewhat arbitrary, because it is based on the judgement and experience of the geologist. For example, the shortening can be measured from the cross-sections, but will vary somewhat over the map sheet. More cross-sections must be obtained to get a better estimate of the shortening. More cross-sections will result in better resource estimates, although it must be emphasized that reliable regional resource estimates are extremely hard to obtain in these types of deformed rocks. Nevertheless, the two new cross-sections resulted in 18 new wells with coal picks, in addition to the 42 wells from the previous study (Rottenfusser et al., 1991).

From the cross-sections, shallow (roughly from 200 to 2500 m depth) and deep (over 2500 m depth) coal zones can be distinguished. Coal zones between 200 and 1000 m in depth are optimal for CBM exploitation. A large percentage of the shallow coal zones will fall in this depth range and should be considered as exploration targets. The gas content of the shallow coal zones can be considered a best resource estimate, based on limited data. The deep coal zones could be considered an ultimate resource.

The thickness of the various coal zones was estimated from the coal picks in the 42 wells presented by Rottenfusser et al. (1991), together with the new picks obtained from the additional 18 wells identified during this study (Appendix 1). The volume of the various coal zones can be calculated based on areal extent and thickness of the coal.

3.2 Gas Content

Total gas in place (GIP) equals the product of coal tonnage and gas content per unit weight of coal. Because density is expressed in g/cm^3 and gas content in cm^3/g, the formula for the GIP calculation can be simplified. For each coal type, the density and gas content are considered constant and the GIP estimate therefore reduces to multiplying the coal volume by a constant. The constant is different for each type of coal and is calculated as the product of the density (in g/cm^3) and the gas content (in cm^3/g). For example, for a coal with density of 1.4 g/cm^3 and gas content of 10 cm^3/g, this constant is 14.

Consequently, the formula used is:

GIP (Gas In Place) = Constant x Coal Volume
where the Constant = Density (in g/cm^3) x Gas Content (in cm^3/g)
and Coal Volume is generally in cubic metres (m^3)

Density is estimated from bulk density logs. The density logs from Foothills wells show that the density of good coals varies between 1.3 and 1.6 g/cm^3, so a good conservative estimate of density for all Foothills coal is 1.4 g/cm^3.

Gas content per unit weight can be estimated from coal rank data and depth, based on measured gas content from United States coal (Eddy et al., 1982; Ryan, 1992). Most resource studies relate gas content to rank and depth (Scott et al., 1995); however, factors other than coal rank and pressure can influence gas sorption capacity (Levine, 1993). For this reason, the validity of the numbers was evaluated against measured gas content of desorbed core (*see* next section). From the previous work (Table 1), a conservative typical gas content of 10 cm^3/g for medium-volatile bituminous and higher rank coals, and 5 cm^3/g for high-volatile bituminous coal can be assumed (*see also* Langenberg et al., 1997). Gas resources will be estimated for each coal zone based on these data. It is important to realize that these are conservative values, which are based on the measured gas-content data of Table 1.

In addition, a calculation using the higher (less conservative) gas-content values implied by the measured gas values from United States coals reported by Eddy et al. (1982) was done (*see* Figure 3). This calculation provides a maximum gas content value. However, this value is unrealistic because the actual measured gas content in Alberta is lower than those of equivalent coals from the United States (Dawson et al., 2000).

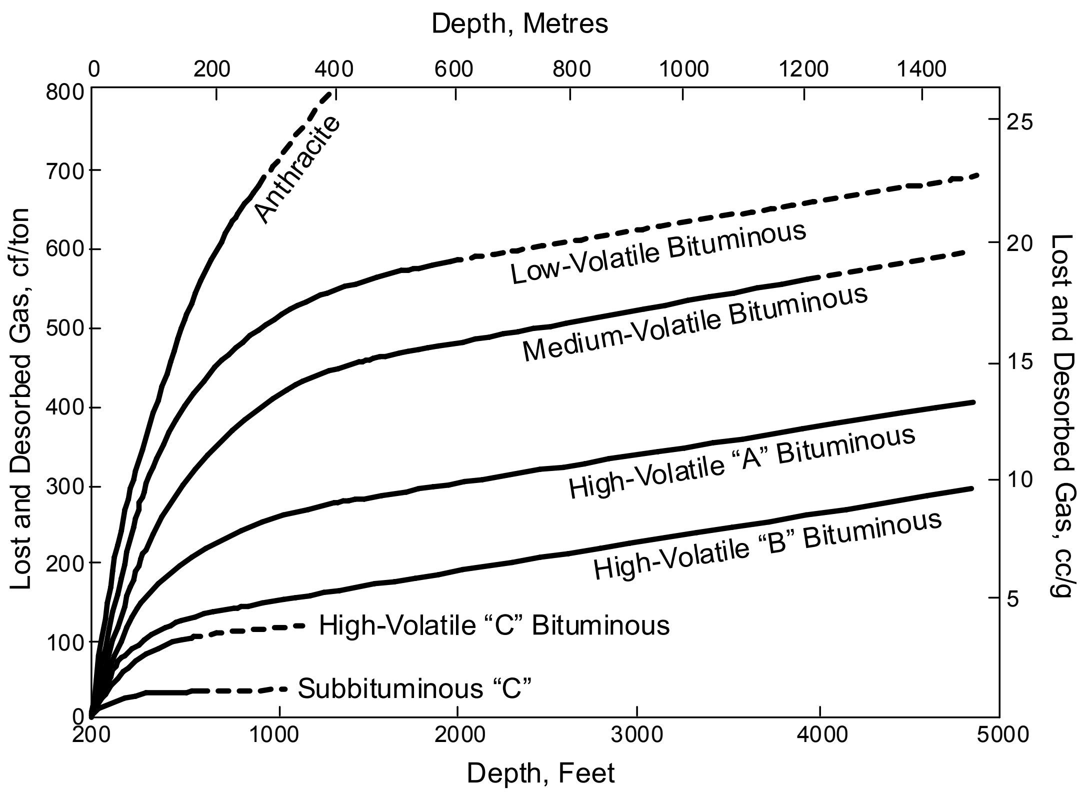


Figure 3. Estimated maximum producible methane content with rank and depth (from Eddy *et al.*, 1982).

Table 1. Summary of measured gas contents and formation-test data

Well I.D.	Company	Area	Coal formation	Top of interval (m)	Bottom of interval (m)	Desorption gas content (ash-normalized; cm3/g)	Number of tests	Formation tests
4-18-11-3W5	CanHunter	Coleman	Kootenay	500	525	na	na	1-2 mD
6-14-8-5W5	CanHunter	Coleman	Kootenay	1307	1399	9.87	20	1-2 mD
7-35-8-4W5	CanHunter	Coleman	Kootenay	394	485	7.92	35	1-2 mD
8-19-9-4W5	Algas	Coleman	Kootenay	265	354	12	6	31 Mcf/d
10-34-15-5W5	Algas	Sullivan	Kootenay	121	228	7.8	1	1 Mcf/d
8-10-19-3W5	SaskOil	Turner Valley	Kootenay	859	940	10.2	6	na
8-01-24-10W5	Algas 1	Canmore	Kootenay	235	288	20	?	19 Mcf/d
4-06-24-9W5	Algas 2	Canmore	Kootenay	191	240	10	?	9 Mcf/d
2-01-24-10W5	Algas 3	Canmore	Kootenay	304	305	20.8	?	36 Mcf/d
9-21-24-10W5	Algas R1	Canmore	Kootenay	55	58	10	4	<10 Mcf/d
10-21-24-10W5	Algas R2	Canmore	Kootenay	124	126	16	3	48 Mcf/d
6-23-33-7W5	Northridge	Caroline	Gates	3016	3121	na	na	2.2 Mcf/d
11-11-38-15W5	Shell	Ram River	Gates	582	740	7	3	na
6-14-57-7W6	Mobil	Grande Cache	Gates	592	692	13.1	2	0.08 mD
8-21-58-8W6	Mobil/Smoky	Grande Cache	Gates	196	280	2.3	4	na
7-26-47-24W5 (#3046)	Cardinal River	Cadomin	Gates	253.9	260.2	6.6 (arb)	7	na
7-26-47-24W5 (#3072)	Cardinal River	Cadomin	Gates	303.3	413.6	17.7 (arb)	6	na
11-20-47-18W5	Conoco	Coal Valley	Coalspur	656.1	886.5	1.7	21	na
11-20-47-18W5	Conoco	Coal Valley	Brazeau	1114.3	1116.3	0.3	2	na
12-17-47-19W5	Luscar-Sterco	Coal Valley	Coalspur	46.6	300.8	0.05-3.22	30	na
8 minesite holes						(av. 1.78)		

na, not available

arb, as received basis

Data compiled from Dawson et al. (2000), Feng and Augsten (1980) and Das et al. (1982).

4 Previous Coal-Bed Methane Exploration in the Alberta Foothills/Mountains

Many studies of Alberta coal have reported theoretical gas content based on the gas generation and storage curves of Eddy et al. (1982) and Ryan (1992). However, there have been few wellsite analyses of desorption, formation testing and adsorption to substantiate the gas-content predictions for coals in the Foothills/Mountains (Table 1). Coal-bed methane test wells in the region have targeted Kootenay Group coal in the Crowsnest and Canmore areas, and Gates Formation coal in the central to northern areas of the Foothills. A few tests targeted the Coalspur and Brazeau Formations in the Coal Valley area. Relevant data for the present study, taken largely from Dawson et al. (2000), are summarized below.

4.1 Kootenay Group Coal

Dawson (1995) and Dawson et al. (2000) evaluated theoretical gas content of coal from the Foothills/Mountains, and reviewed coal-bed methane test-well data from the Alberta Foothills/Mountains. The Crowsnest Pass coal district in southwestern Alberta contains thick coals belonging to the Mist Mountain Formation (Kootenay Group). Coal rank ranges from high- to low-volatile bituminous, and net coal thickness locally exceeds 20 m. Gas content was estimated to be similar to that of the Elk Valley coalfield in British Columbia, ranging from 16 to 24 cm^3/g.

Four wells were drilled in the Coleman area (NTS 82G), by Canadian Hunter and Algas Resources, to Kootenay Group coals ranging in depth from 265 to 1399 m. Gas content determined by desorption ranged from 7.8 to 12 cm^3/g (ash normalized). These gas content ranges are lower than gas volumes calculated using adsorption (Langmuir) isotherms, suggesting that these coals may be undersaturated. Formation tests indicated that coal permeability was low, in the range 9.9 to 19.8 x 10^{-16} m^2 (1 to 2 mD). One well, Algas Coleman, was put on test-production and averaged 31 Mcf/d.

Algas drilled another coal-bed methane test well west of Longview, at Sullivan Creek (NTS 82J). This well targeted low-volatile bituminous coal of the Mist Mountain Formation (Kootenay), intersecting 14 m of coal between 121 and 227 m depth. One desorbed gas content was reported (7.8 cm^3/g), and formation testing indicated low reservoir pressures, low flow rates and low permeability.

SaskOil/Mobil drilled a coal-bed methane test well close to Turner Valley (NTS 82J), targeting Mist Mountain coal in the depth range 859 to 938 m. Coal rank was determined to be high-volatile bituminous A, which is lower than the low-volatile bituminous rank measured in the Algas Sullivan well. A net coal thickness exceeding 20 m was encountered. Desorbed gas content was determined from cuttings rather than core, and ranged from 5 to 11 cm^3/g as determined (6 to 14 cm^3/g on an ash-normalized basis).

The Canmore coalfield (NTS 82O) includes high-rank coal of the Mist Mountain Formation (Kootenay Group). Net coal thickness exceeds 15 m in this area. Historically, these low-volatile bituminous to semi-anthracite coals were reported to be gassy in underground workings (2 Mmcf/d of methane were ventilated from the Riverside Mine according to Dawson et al., 2000, p. 79) and have therefore been a target of coal-bed methane exploration.

Dawson (1995) reported typical theoretical gas capacity (derived from predictions by Eddy et al., 1982) in the range 12 to 15 cm^3/g. Coal-bed methane test wells were drilled by Algas in this area and small-scale production was attempted over a three-year period. Desorbed gas content ranged from 4 to 25 cm^3/g (ash-normalized), from stratigraphic depths ranging from 55 to 288 m. Deeper intersections had the greater gas concentrations. Formation testing indicated permeability ranging from 4.9 to 19.8 x 10^{-16} m^2 (0.5 to 2 mD), with borehole flow rates up to 5.2 m^3/d. Upon stimulation and completion, the gas flow rates ranged from 0.5 to 48 Mcf/d.

4.2 Gates Formation Coal

The Grande Cache member of the Gates Formation contains several thick seams, and can attain a net coal thickness of up to 13 m (although local structural thickening is common). Coal from the Gates Formation in the central Alberta Foothills was evaluated for coal-bed methane potential by Dawson and Kalkreuth (1994a). Based on a Langmuir adsorption isotherm from a Nordegg minesite trench (NTS 83C) and Ryan's (1992) gas-capacity curves for varying rank, ash and depth, maximum gas capacity was calculated for the medium- to low-volatile bituminous coals. Gas content ranged from 10.9 to 18.3 cm^3/g for different areas, with depths ranging from 500 to 2400 m. No coal desorption measurements were available at the time of their report to allow comparison of theoretical capacity with actual gas contents.

Northridge Exploration tested gas flow from 8.5 m net thickness Grande Cache Member coals intersected at 3052 to 3072 m while drilling a deeper hydrocarbon target in their Caroline 6-23-55-7W5 well (NTS 82O). A flow rate of 2.2 Mcf/d was recorded, but no other tests were performed on the coal.

Coal from the Grande Cache Member in the Ram River area (20 km south of Nordegg in NTS 83C) was tested by Shell Canada Resources. Two cores containing high- to medium-volatile bituminous coal were recovered from depth intervals 697.6 to 706.6 m and 711.8 to 716.2 m. The cores missed the intended 4 m thick target (Jewel seam equivalent), only catching thinner coal horizons. Desorbed gas contents of the sampled coal ranged from 6.11 to 7.93 cm^3/g. Gas capacity calculated from Langmuir isotherms derived from the samples indicated maximum capacity of 11.4 cm^3/g.

Two desorbed gas concentrations were reported for the Jewel seam from within the Cardinal River mine area (NTS 83F; Feng and Augsten, 1980). Two core samples from the Gates Formation Jewel seam were collected and desorbed. An average gas content of 6.6 cm^3/g was obtained at a depth of 256 m in borehole #3046, whereas borehole # 3072 yielded an average gas content of 17.7 cm^3/g at a depth of 408 m.

Two wells were evaluated for coal-bed methane potential in the Grande Cache area. Mobil Oil and Chevron Canada drilled a joint well near Susa Creek (NTS 83E), targeting the Grande Cache Member at depths of 600 to 700 m. The intended thick coals were missed and thinner, deeper Gladstone coals intersected. Sidewall cores were subsequently cut from the lower Grande Cache coal (the 0.5 m thick No. 3 seam) and one seam in the Gething Formation. Gas contents were 16.8 and 9.4 cm^3/g (ash-normalized basis), respectively. Langmuir isotherm-derived gas capacities were in the 18 cm^3/g range for these medium-volatile coals.

Limited formation testing was done on the No. 4 and No. 10 seams in the Grande Cache Member. Low permeabilities were indicated, and flow rates of 10 m^3/d and 145 m^3/d were obtained from seam No. 4 and No. 10, respectively.

Mobil Oil also tested a well in collaboration with Smoky River Coal Ltd. near their No. 3 mine area, 25 km north of Grande Cache (NTS 83L). The interval containing No. 11 and No. 11A seams of the Grande Cache Member were cored at a depth of 244.7 to 233.5 m. The well did not reach deep enough to penetrate the No. 4 seam, the thickest seam in the area. A net thickness of 8.6 m of medium-volatile bituminous coal averaged only 1.8 to 2.8 cm^3/g gas (ash-normalized). The high ash content of the samples and shallow intersection depths may account for the low gas content, as the ash-normalized adsorption isotherm suggested a much higher gas capacity of 19.1 cm^3/g.

4.3 Coalspur and Brazeau Formation Coal

The Coal Valley area of the Foothills contains significant quantities of coal. Although Tertiary Coalspur coals are currently being surface-mined in the area, structural deformation has taken them to depths that may make them suitable for coal-bed methane production.

Early desorption tests were conducted on drillcore samples collected from the Luscar–Sterco mine area at Coal Valley (NTS 83F) as part of an underground mine-feasibility study (Das et al., 1982). High-volatile bituminous coal from the Silkstone and Mynheer seams of the Coalspur Formation were tested. The Silkstone seam consists of two parts, an upper and a lower, separated by a 10 m parting. The upper 'seam' ranges in thickness from 2.4 to 5.8 m, whereas the lower 'seam' ranges from 0.6 to 1.6 m. The Mynheer seam lies 80 to 90 m below the Silkstone and averages 4 m in thickness. Sample depths ranged from 46 to 301 m, with gas content ranging from 0.05 to 3.22 cm^3/g and averaging 1.78 cm^3/g. Gas concentrations were presented on an 'as received coal' basis and ash content was not reported. Gas content showed a general increase with increasing depth, the Mynheer seam tending toward slightly greater gas contents than the Silkstone seam.

Conoco Canada evaluated the Val D'Or, and Mynheer coal zones of the Coalspur Formation, and the Upper Brazeau Coal Zone in a coal-bed methane test well near Coal Valley (NTS 83F). The Val D'Or samples averaged 1.40 cm^3/g at a depth of 656.1 to 662.6 m, with 5.7 m net coal thickness. The Mynheer samples averaged 0.9 cm^3/g at a depth of 879.8 to 886.5 m, with 4.9 m net coal thickness. The underlying Brazeau samples represented a thinner coal interval, with a net coal thickness of 0.59 m. The Brazeau sample gas content averaged 0.24 cm^3/g at a depth of 1114.3 to 1116.3 m (all on an 'as received' basis). All samples were high-volatile bituminous "B" in rank. The gas content is lower than expected for this type of coal at this depth. The reason for this anomaly is not fully understood, although high average ash content of 30% for these Coalspur coals is certainly a contributing factor (Dawson et al., 2000, p.93).

5 Areal Extent and Gas Content of Coal Zones

Areal extent of coal zones for the nine map sheets are discussed from north to south. Coal volume and gas content of the various coal zones in these areas are summarized in Tables 2 and 3.

5.1 Map Sheet NTS 83L (Wapiti)

Major coal zones are present in the Brazeau, Gates and Gething formations (Figure 4). The Coalspur Formation is present near the surface but is too shallow to be a CBM source and is therefore not included in the resource calculations.

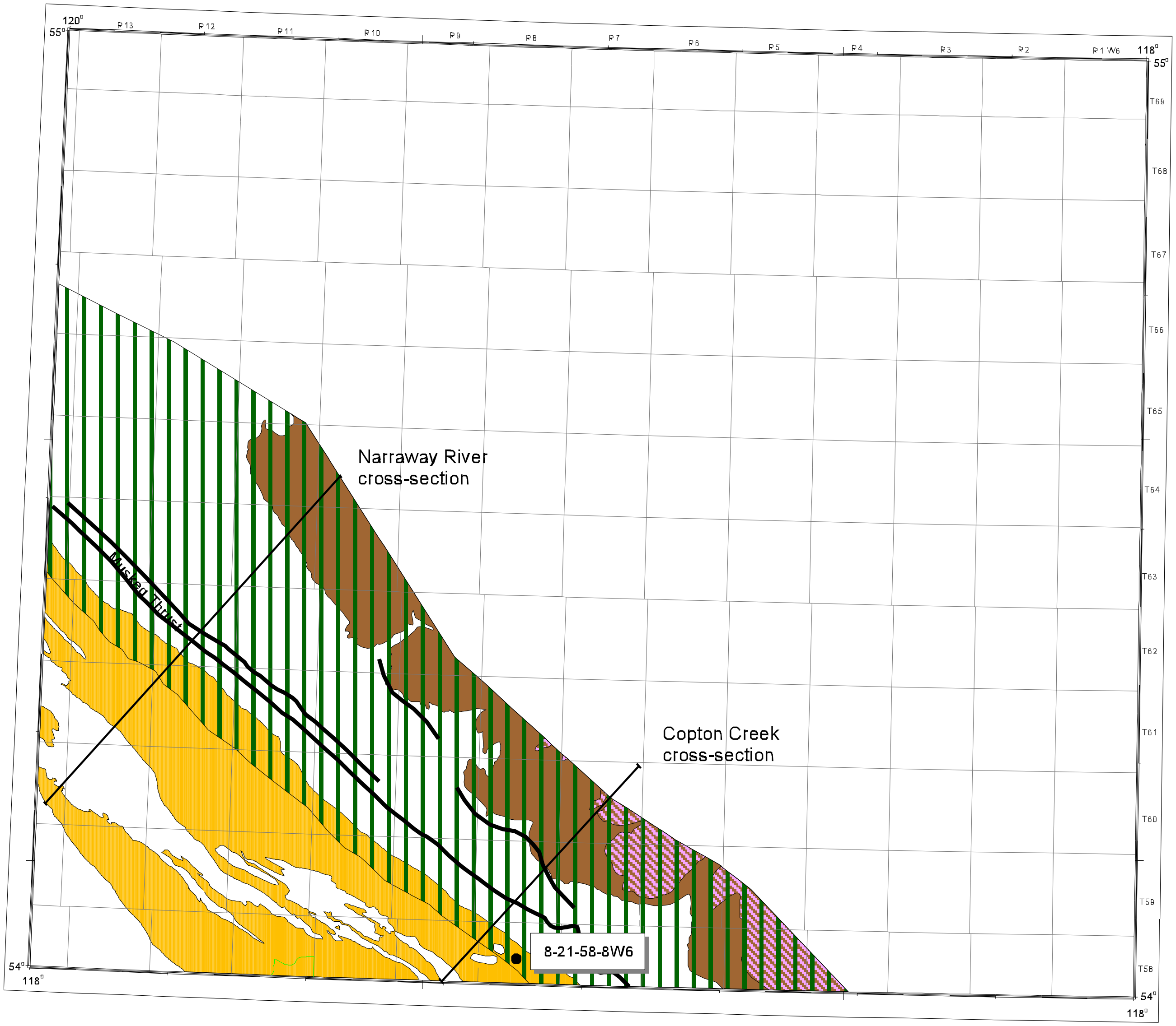
The subsurface geology can be visualized from two cross-sections. The western cross-section (*see* line of section on Figure 4) is presented in Rottenfusser et al. (1991) and is based on a cross-section now published in McMechan (1994). Coal zones were drawn on this section based on the coal picks. The Cutbank and Red Willow coal zones were drawn based on outcrop and coal-drilling information (Dawson et al., 1994). The Triangle Zone has a low-angle taper and is similar to structures found further to the northwest (McMechan, 1985; *see also* McMechan, 1999).

The eastern cross-section (Kubli and Langenberg, AGS publication in preparation), one of those prepared for this study, is through the Copton Creek area (*see* line of section on Figure 2). A more classical triangle zone is observed in this area, with emergent, west-verging back thrusts (*see also* a nearby cross-

Table 2. Gas content of shallow coal zones										
Coal zone	Area (km^3)	Area correction factor	Average thickness (m)	Coal volume (m^3)	Average density (g/cm^3)	Reflectance (% max)	Typical gas content (cm^3/g)	Expected gas content (m^3)	Maximum gas content (cm^3/g; Eddy, 1982)	Maximum gas potential, based on Eddy Curves (m^3)
Wapiti (NTS 83L):										
Shallow Brazeau	794	0.5	3.9	1.55E+09	1.4	0.76	5	1.08E+10	8	1.63E+10
Shallow Gates	1070	1.25	8.5	1.14E+10	1.4	1.84	10	1.59E+11	20	3.18E+11
Shallow Gething	1070	1.25	2.3	3.08E+09	1.4	1.9	10	4.31E+10	20	8.61E+10
Mt. Robson (NTS 83E):										
Shallow Coalspur	651	0.7	3.6	1.64E+09	1.4	0.75	5	1.15E+10	9	2.01E+10
Shallow Brazeau	651	0.8	4	2.08E+09	1.4	0.78	5	1.46E+10	12	3.50E+10
Shallow Gates	1415	0.8	10.9	1.23E+10	1.4	1.35	10	1.73E+11	18	3.02E+11
Edson (NTS 83F):										
Shallow Coalspur	2656	0.7	15.3	2.84E+10	1.4	0.66	5	1.99E+11	8	2.99E+11
Shallow Brazeau	2656	0.8	2.9	6.16E+09	1.4	0.68	5	4.31E+10	10	8.63E+10
Shallow Gates	425	0.8	7.1	2.41E+09	1.4	1.3	10	3.38E+10	19	6.34E+10
Brazeau (NTS 83C):										
Shallow Coalspur	970	0.7	10	6.79E+09	1.4	0.66	5	4.75E+10	8	7.13E+10
Shallow Brazeau	970	0.8	2.9	2.25E+09	1.4	0.68	5	1.58E+10	10	3.15E+10
Shallow Gates	3015	0.8	7.1	1.71E+10	1.4	1.3	10	2.40E+11	19	4.50E+11
Rocky Mtn. House (NTS 83B):										
Shallow Coalspur	3094	0.7	5.3	1.15E+10	1.4	0.71	5	8.04E+10	9	1.41E+11
Shallow Brazeau	3094	0.8	2.5	6.19E+09	1.4	0.75	5	4.33E+10	9	7.58E+10
Shallow Gates	1536	0.8	7.1	8.72E+09	1.4	1.3	10	1.22E+11	19	2.29E+11
Calgary (NTS 82O):										
Shallow Brazeau	754	1	3.1	2.34E+09	1.4	0.78	5	1.64E+10	10	3.27E+10
Shallow Kootenay	105	1.5	20	3.15E+09	1.4	2.08	10	4.41E+10	20	8.82E+10
Kananaskis (NTS 82J):										
Shallow St. Mary River	330	1	4.6	1.52E+09	1.4	0.75	5	1.06E+10	13	2.66E+10
Shallow Kootenay	1542	1	3.1	4.78E+09	1.4	1.1-1.7	10	6.69E+10	20	1.34E+11
Fernie (NTS 82G):										
Shallow Kootenay	1501	1.25	4	7.51E+09	1.4	1.25	10	1.05E+11	20	2.10E+11
Lethbridge (NTS 82H):										
Shallow Kootenay	808	1.5	3	3.64E+09	1.4	1	5	2.55E+10	12	5.85E+10
TOTAL GAS POTENTIAL								1.51E+12		2.77E+12

Table 3. Gas content of deep coal zones

	Area (km3)	Area correction factor	Average thickness (m)	Coal volume (m3)	Average density (g/cm3)	Reflectance (% max)	Typical gas content (cm3/g)	Expected gas content (m3)	Maximum gas content (cm3/g; Eddy, 1982)	Maximum gas potential, based on Eddy Curves (m3)
Wapiti (NTS 83L):										
Deep Gates	2835	1.1	10	3.12E+10	1.4	1.8	10	4.37E+11	20	8.73E+11
Deep Gething	2835	1.1	4.6	1.43E+10	1.4	2.1	10	2.01E+11	20	4.02E+11
Mt.Robson (NTS 83E):										
Deep Gates	1387	1.25	8.5	1.47E+10	1.4	1.4-1.8	10	2.06E+11	20	4.13E+11
Edson (NTS 83F):										
Deep Gates	4157	1.25	8.3	4.31E+10	1.4	1.7	10	6.04E+11	20	1.21E+12
Brazeau (NTS 83C):										
Deep Gates	1580	1.05	8.3	1.38E+10	1.4	1.7	10	1.93E+11	20	3.86E+11
Rocky Mtn. House (NTS 83B):										
Deep Gates	3614	1.05	7.9	3.00E+10	1.4	1.48	10	4.20E+11	20	8.39E+11
Calgary (NTS 82O):										
Deep Kootenay	5339	1.25	4	2.67E+10	1.4	1.6	10	3.74E+11	20	7.47E+11
Kananaskis (NTS 82J):										
Deep Kootenay	3266	1.2	2	7.84E+09	1.4	0.94	5	5.49E+10	14	1.54E+11
Fernie (NTS 82G):										
Deep Kootenay	1056	1.25	2.5	3.30E+09	1.4	1.05	5	2.31E+10	15	6.93E+10
Lethbridge (NTS 82H):										
Deep Kootenay	1049	1.25	3	3.93E+09	1.4	1.11	5	2.75E+10	15	8.26E+10
TOTAL GAS POTENTIAL								2.54E+12		5.17E+12



Coal Area	Area in (km^2)
Shallow Coalspur	167
Shallow Brazeau	794
Deep Gates	2835
Shallow Gates	1071

Figure 4. Areal extent of coal areas in NTS map sheet 83L (Wapiti) and location of cross-sections.

section by McMechan, 1996). The three major coal zones are represented by the coal picks in the wells evaluated along this cross-section.

From these cross-sections, five major coal zones can be distinguished: shallow Brazeau, deep Gates, shallow Gates, deep Gething and shallow Gething.

5.1.1 Shallow Brazeau Coal Zone

Coals in this succession are exposed on Nose Mountain and Morley Hill. They are fairly close to the surface and were not logged in wells (the interval is often cased). From mapping, two coal zones can be distinguished in the upper Brazeau: the Cutbank and Red Willow (Dawson et al., 1994). They measure 794 km^2 (or 7.9 x 10^8 m^2; *see* Figure 4) in area and the coal has an average cumulative thickness of 4 m. Some of this coal is shallower than 200 m, so only 50% of the volume is considered, giving a corrected total volume of 1.6 x 10^9 m^3.

The vitrinite reflectance of 0.76% (Table 2) indicates a gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Brazeau coals is estimated to be **1.1 x 10^{10} m^3**.

5.1.2 Shallow Gates Coal Zone

These coals have been targets for coal exploration in the western part of the area and are being mined at the Smoky River coal mine. The shallow Gates coals cover an area of 1070 km^2 (or 1.07 x 10^9 m^2; *see* Figure 4) and have an average thickness of 8.5 m. The shortening is estimated at 20%, so the correction factor is 1.25 and the corrected volume is 1.1 x 10^{10} m^3.

The rank of the coal is low-volatile bituminous (1.84% maximum vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Gates coals is estimated to be **1.6 x 10^{11} m^3**.

5.1.3 Deep Gates Coal Zone

The Deep Gates Coal Zone can be easily mapped in all wells east of the Muskeg Thrust. Because of overthrusting, it likely extends about 5 km southwest of the Muskeg Thrust. It underlies an area of 2835 km^2 (or 2.835 x 10^9 m^2; *see* Figure 4) and the coal has an average cumulative thickness of 10 m. Shortening does not appear to be significant and is estimated at about 10%, so the correction factor 1.1 and the corrected coal volume is about 3.1 x 10^{10} m^3.

The rank of the coal is medium-volatile bituminous (1.8% average vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Gates coals is estimated to be **4.4 x 10^{11} m^3**.

5.1.4 Shallow Gething Coal Zone

This is the only area in the Foothills where this stratigraphic interval contains coals of significant thickness. Elsewhere, this interval is known as the Gladstone Formation, which has only minor coal. The shallow Gething coals cover the same area as the shallow Gates, 1070 km^2 (or 1.07 x 10^9 m^2; *see* Figure 4), and have an average thickness of 2.3 m. The shortening is estimated at 20%, so the corrected coal volume is 3.1 x 10^9 m^3.

The rank of the coal is medium-volatile bituminous (1.9% average vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy *et al.*, 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Gething coals is estimated to be **4.3 x 10^{10} m^3**.

5.1.5 Deep Gething Coal Zone

The Gething Coal Zone underlies the same area as the deep Gates Coal Zone (2835 km^2 or 2.835 x 10^9 m^2; *see* Figure 4) and has an average cumulative thickness of 4.6 m. The shortening is estimated at 10%, so the corrected coal volume is 1.4 x 10^{10} m^3.

Based on similar gas content and coal density, the total methane content of the deep Gething coals is estimated to be **2 x 10^{11} m^3**.

5.2 Map Sheet NTS 83E (Mount Robson)

Major coal zones are present in the Coalspur, Brazeau and Gates formations. The Gladstone Formation contains minor coals. Three cross-sections are used in this map sheet (*see* lines of section on Figure 5). The central cross-section is after Mountjoy (1978) and was updated with coal zones in Rottenfusser et al. (1991). No drilling for oil and gas took place west of the Mason Thrust and the interpretation is based only on outcrops and seismic data. Isolated outcrops of lower Gates coals allow the Gates Coal Zone to be drawn on the section in this area. The depth of the Paleozoic can be inferred from seismic and stratigraphic thicknesses. The Findley Triangle Zone is underlain by an anticlinal stack of duplexes involving Paleozoic to Lower Cretaceous rocks. The upper and lower detachment surfaces come together in the Shaftesbury Formation. The Copton Creek and Moberly Creek cross-sections (Kubli and Langenberg, AGS publication in preparation) display the depth and thickness of the various coal zones.

Thrusts appear to have more displacement in the Paleozoic than in the Mesozoic part of the stratigraphic succession. However, the Mesozoic shows more folding than the Paleozoic. Considerable shortening by thrusting of the Paleozoic is balanced by folding in the Mesozoic. Most of the folds in the Mesozoic are detachment folds and the folds in front of the thrusts are fault-propagation folds.

5.2.1 Shallow Coalspur Coal Zone

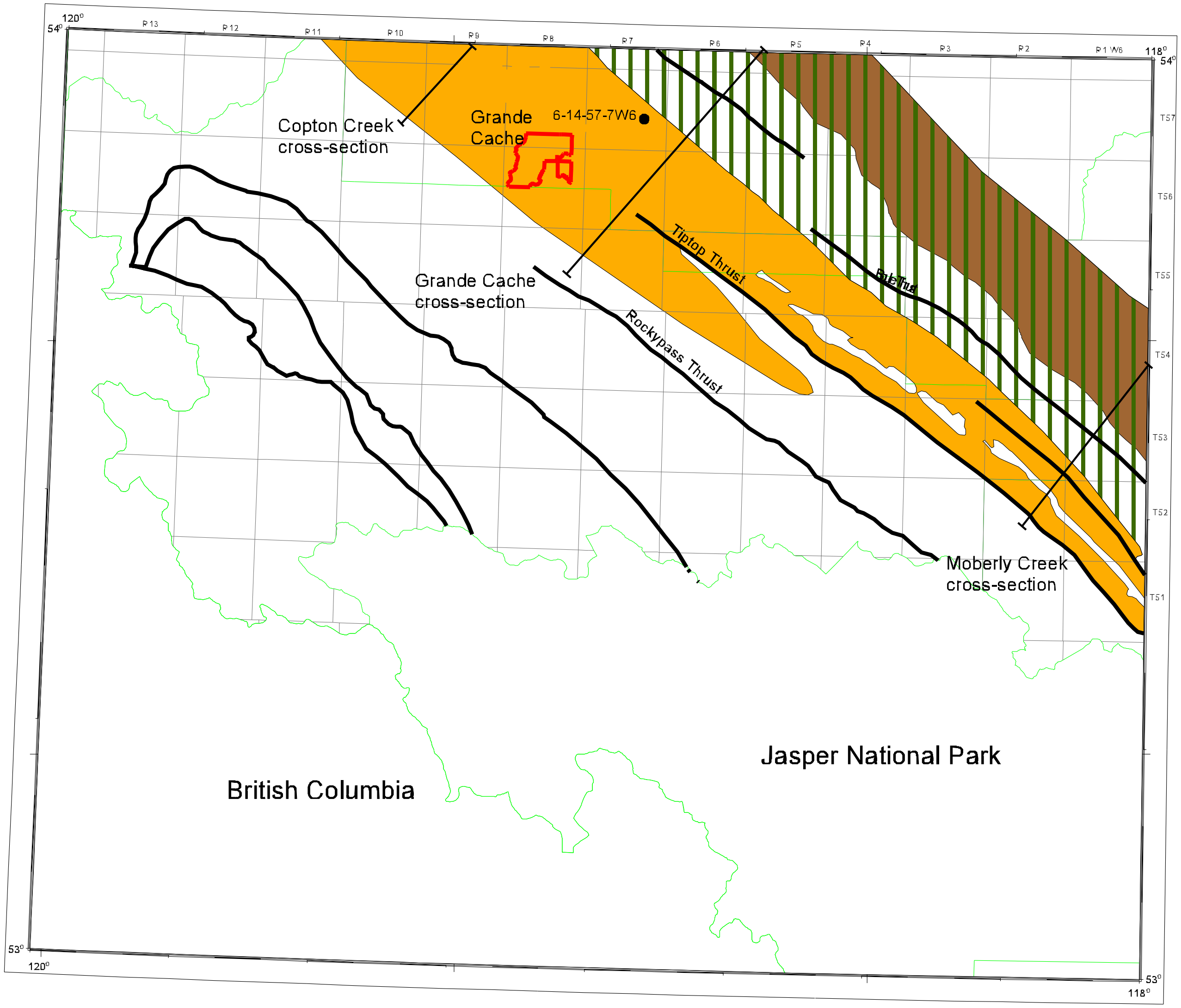
The Coalspur Coal Zone is well developed on the east limb of the Triangle Zone, covers an area of 651 km^2 (or 6.5 x 10^8 m^2; *see* Figure 5) and has an average thickness of 3.6 m. About 30% of the zone might be closer to the surface than 200 m and is therefore excluded. Consequently, the volume of coal is estimated at 1.6 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.75% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Coalspur coals is estimated to be **1.2 x 10^{10} m^3**.

5.2.2 Shallow Brazeau Coal Zone

The Brazeau Coal Zone is developed on the east limb of the Triangle Zone, covers an area of 651 km^2 (or 6.5 x 10^8 m^2; *see* Figure 5) and has an average thickness of 4 m. About 20% might be closer to the surface than 200 m and is therefore excluded. Consequently, the volume of coal is estimated at 2.1 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.78% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Brazeau coals is estimated to be **1.5 x 10^{10} m^3**.



Coal Area	Area in (km^2)
Shallow Coalspur / Brazeau	651
Deep Gates	1387
Shallow Gates	1415

Figure 5. Areal extent of coal areas of NTS map sheet 83E (Mount Robson) and location of cross-sections.

5.2.3 Shallow Gates Coal Zone

These shallow coals have been targets for coal exploration in the southwestern part of the area and are being mined at the Smoky River Coal Mine. The shallow Gates coals cover an area of 1415 km^2 (or 1.4 x 10^9 m^2; *see* Figure 5) and have an average thickness of 10.9 m. Some of the older Triassic and Jurassic rocks were not separated from younger rocks in the geological compilation, so some areas may not be underlain by Gates coal. In addition, some of the coal might be closer to the surface than 200 m. For these reasons, an area correction factor of 0.8 is used. Consequently the volume of coal is estimated at 1.2 x 10^{10} m^3.

The rank of the coal is medium-volatile bituminous (1.35% vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Gates coals is estimated to be **1.7 x 10^{11} m^3.**

5.2.4 Deep Gates Coal Zone

The Deep Gates Coal Zone can be easily mapped in all wells east of the Mason Thrust. It underlies an area of 1387 km^2 (or 1.4 x 10^9 m^2; *see* Figure 5) and the coal has an average cumulative thickness of 8.5 m. Shortening is substantial in the Findley structure and is estimated at about 20%, so the volume needs to be multiplied by 1.25. Consequently, the coal volume is about 1.5 x 10^{10} m^3.

The rank of the coal is low-volatile bituminous (1.9% average maximum vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Gates coals is estimated to be **2.1 x 10^{11} m^3**.

5.3 Map Sheet NTS 83F (Edson)

Major coal zones are present in the Coalspur, Brazeau and Gates formations. The Gates zones can be divided in deep and shallow (Figure 6). The Cadomin cross-section from Rottenfusser et al. (1991) was used (*see* line of section on Figure 6). The eastern part is well constrained by a seismic line (*see also* Lebel et al., 1996), whereas the western part is based mainly on surface information. The cross-section clearly shows the interaction between east-verging structures in the west and west-verging structures (Mercoal and Pedley thrusts) in the east. The Brazeau Syncline and the syncline in the Cadomin East Coal Field show some of the overturned structures, which are characteristic for this part of the Foothills.

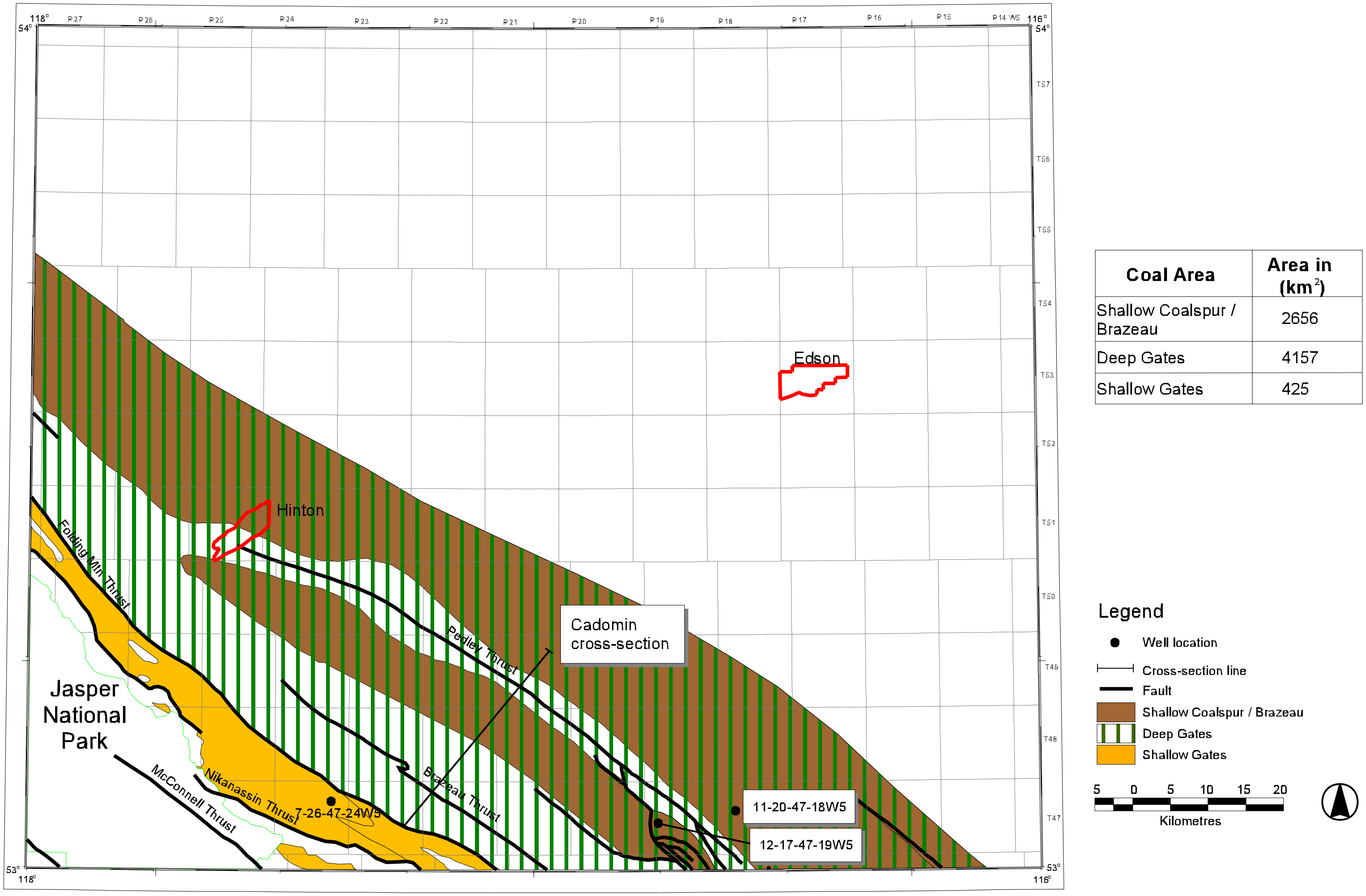
5.3.1 Shallow Coalspur Coal Zone

The Coalspur Coal Zone comes close to the surface and outcrops in the Triangle Zone near the Pedley Thrust and in the Entrance Syncline. It has been extensively mined in the past and is presently mined at Coal Valley (Luscar–Sterco Mine). It covers an area of 2656 km^2 (or 2.7 x 10^9 m^2; *see* Figure 6) and has an average thickness of 15.3 m. About 30% might be closer to the surface than 200 m and is therefore excluded. Consequently, the volume of coal is estimated at 2.8 x 10^{10} m^3.

The rank of the coal is high-volatile bituminous (0.66% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Coalspur coals is estimated to be 2.0 x 10^{11} m^3.

5.3.2 Shallow Brazeau Coal Zone

The Brazeau Coal Zone is developed on the east limb of the Triangle Zone and in the Entrance Syncline near the top of the formation, covers an area of 2656 km^2 (or 2.7 x 10^9 m^2; *see* Figure 6) and has an aver-



Coal Area	Area in (km^2)
Shallow Coalspur / Brazeau	2656
Deep Gates	4157
Shallow Gates	425

Figure 6. Areal extent of coal areas of NTS map sheet 83F (Edson) and location of cross-section.

age thickness of 2.9 m. About 20% might be closer to the surface than 200 m and is therefore excluded. Consequently, the volume of coal is estimated at 6.2 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.68% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Brazeau coals is estimated to be **4.3 x 10^{10} m^3**.

5.3.3 Shallow Gates Coal Zone

These shallow coals have been targets for coal exploration in the southwestern part of the area and are being mined at the Cardinal River Coal Mine. The shallow Gates coals cover an area of 425 km^2 (or 4.3 x 10^8 m^2; *see* Figure 6) and have an average thickness of 10 m. Some of the older Triassic and Jurassic rocks were not separated from younger rocks in the geological compilation, so some areas may not be underlain by Gates coal. In addition, some of the coal might be closer to the surface than 200 m. For these reasons, an area correction factor of 0.8 is used. Consequently, the volume of coal is estimated at 2.4 x 10^9 m^3.

The rank of the coal is medium-volatile bituminous (1.3% vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Gates coals is estimated to be **3.4 x 10^{10} m^3**.

5.3.4 Deep Gates Coal Zone

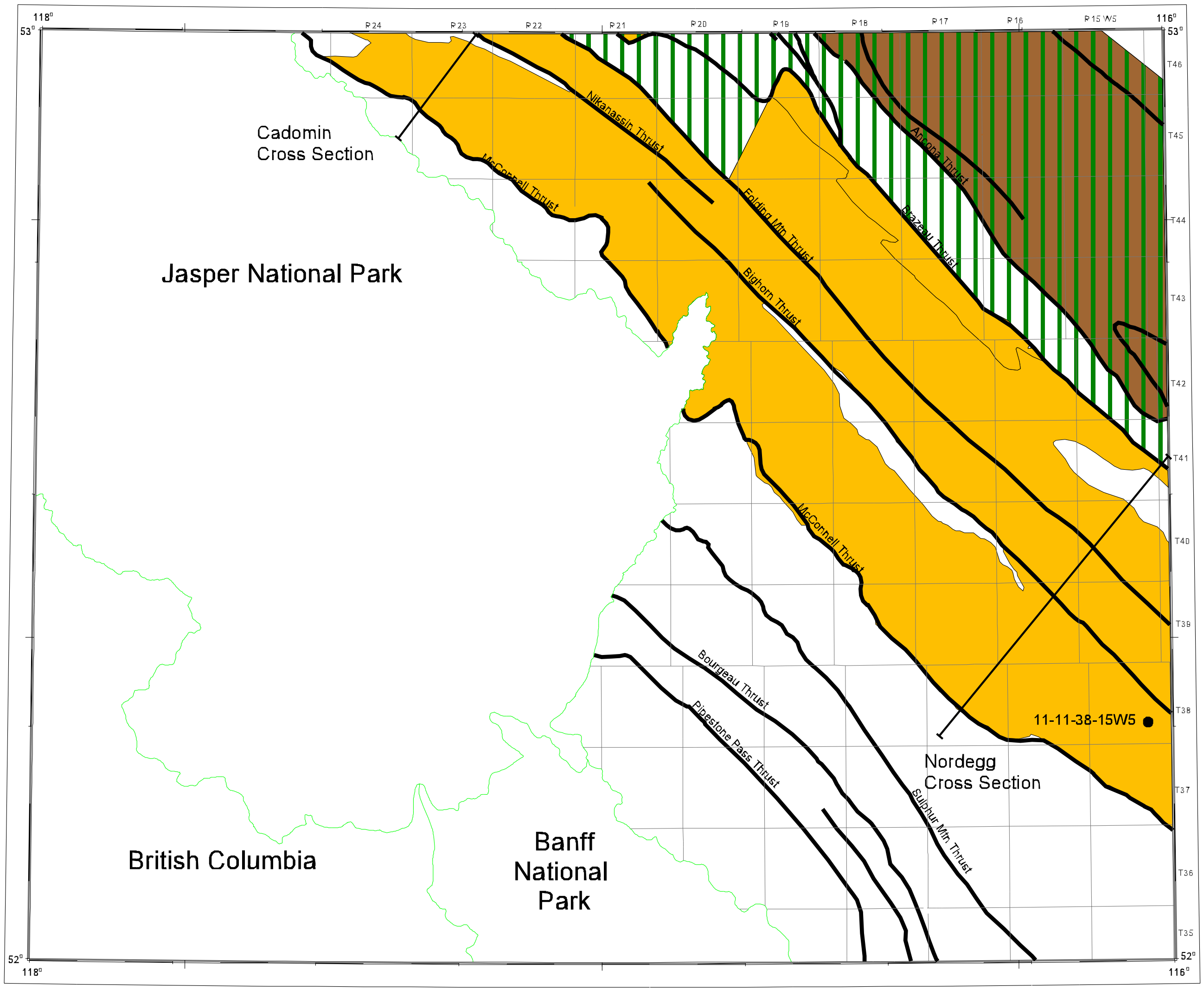
The Deep Gates Coal Zone can be easily mapped in all wells east of the Folding Mountain Thrust. It underlies an area of 4157 km^2 (or 4.2 x 10^9 m^2; *see* Figure 6) and the coal has an average cumulative thickness of 8.3 m. Shortening is present in the Triangle Zone and Mercoal structures and is estimated at about 20%, so the volume needs to be multiplied by 1.25. Consequently, the coal volume is about 4.3 x 10^{10} m^3.

The rank of the coal is low-volatile bituminous (1.7% average vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total gas content of the deep Gates coals is estimated to be 6.0 x 10^{11} m^3.

5.4 Map Sheet NTS 83C (Brazeau)

Major coal zones are present in the Coalspur, Brazeau, and Gates formations. The Gates zones can be divided in deep and shallow (Figure 7). Two cross-sections from Rottenfusser et al. (1991) can be used for the present evaluation (*see* lines of sections in Figure 7). The northern one is the western part of the Cadomin section, which is based on Mountjoy et al. (1992), and the southern one is part of the Nordegg section, which is based on a seismic line through the Nordegg townsite (Perkins et al., 1984). The main structures of importance are the McConnell Thrust, the Folding Mountain Thrust and the Brazeau Thrust. Displacements along the Brazeau Thrust decrease to the North, and the boundary between deep and shallow Gates zones steps from the Brazeau to the Folding Mountain (locally called Grave Flats Thrust) in the northern part of the map sheet.

Repeats of the Cardium Formation and faulting in the Luscar Group are shown by the east-verging structure below the Stolberg Gas Field. The Ancona Thrust is generally shown as a folded thrust over the Ancona Anticline, following the interpretation of Jones and Workum (1978). They excluded the Stolberg structure from being a Triangle Zone, because of the folded fault theory for the Ancona Thrust. However, we believe that west-verging faults may be present on the east limb of the Ancona Anticline,



Coal Area	Area in (km²)
Shallow Coalspur / Brazeau	970
Deep Gates	1580
Shallow Gates	3015

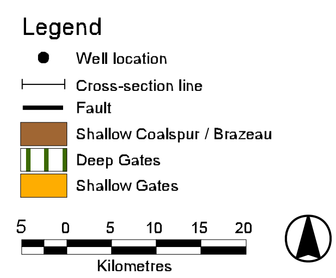


Figure 7. Areal extent of coal areas of NTS map sheet 83C (Brazeau) and location of cross-sections.

making it a typical Triangle Zone. The Ancona Thrust could connect with the east-verging faults in the core of the Ancona Anticline.

The western part of the cross-section is somewhat problematic, because the section crosses the Bighorn lateral ramp and tear faults (Douglas, 1956). The cross-section will not balance in this area, because some of the displacement is out of the section on this lateral ramp. The cross-section is a cartoon of how the subsurface could look.

5.4.1 Shallow Coalspur Coal Zone

The Coalspur Coal Zone was encountered in several wells near the Stolberg Gas Field and outcrops along the North Saskatchewan River near Saunders, where it used to be mined. However, no vitrinite reflectance measurements from this site are in the AGS database.

The zone underlies an area of 970 km^2 (or 9.7 x 10^8 m^2; *see* Figure 7) and has an average thickness of 10 m. About 30% might be closer to the surface than 200 m and is therefore excluded. Consequently the volume of coal is estimated at 6.8 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.66% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Coalspur coals is estimated to be **4.8 x 10^{10} m^3**.

5.4.2 Shallow Brazeau Coal Zone

Some coal is present in the upper part of the Brazeau Formation. However, the coal seems to be discontinuous and the coal zone is not well developed. The coal zone might outcrop along the North Saskatchewan River (Erdman, 1950). It underlies an area of 970 km^2 (or 9.7 x 10^8 m^2; *see* Figure 7) and has an average thickness of 2.9 m. About 20% might be closer to the surface than 200 m and is therefore excluded. Consequently, the volume of coal is estimated at 2.3 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.68% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Brazeau coals is estimated to be **1.6 x 10^{10} m^3**.

5.4.3 Shallow Gates Coal Zone

The shallow Gates coals were mined in the Nordegg area and the old mine workings are currently one of the main tourist attractions for this area. These coals have been documented by Dawson and Kalkreuth (1994a), underlie an area of 3015 km^2 (or 3 x 10^9 m^2; *see* Figure 7) and have an average thickness of 7.1 m. It is estimated that 80% of this area is underlain by coal. Consequently, the volume of coal is estimated at 1.7 x 10^{10} m^3.

The rank of the coal is medium-volatile bituminous (1.3% vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Gates coals is estimated to be **2.4 x 10^{11} m^3**.

5.4.4 Deep Gates Coal Zone

The deep Gates coals can be easily recognized in many wells (Dawson and Kalkreuth, 1994a). They underlie an area of 1580 km^2 (or 1.6 x 10^9 m^2; *see* Figure 7) and the coal has an average cumulative thickness of 8.3 m. Some shortening is present in the Triangle Zone structures, so the volume needs to be multiplied by 1.05. Consequently, the coal volume is about 1.4 x 10^{10} m^3.

The rank of the coal is low-volatile bituminous (1.7% average vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Gates coals is estimated to be **1.9 x 10^{11} m^3**.

5.5 Map Sheet NTS 83B (Rocky Mountain House)

Major coal zones are present in the Coalspur, Brazeau and Gates formations. The Gates coal zones can be divided in deep and shallow (Figure 8). The Nordegg cross-section from Rottenfusser et al. (1991) can be used for the present evaluation (*see* line of section on Figure 8). The main structures of importance are the McConnell and Brazeau thrusts. The Brazeau Thrust separates the shallow and deep Gates coals.

5.5.1 Shallow Coalspur Coal Zone

The Coalspur Coal Zone was encountered in several wells near the Stolberg Gas Field in the northwestern part of the map sheet. It underlies an area of 3094 km^2 (or 3.1 x 10^9 m^2; *see* Figure 8) and has an average thickness of 5.3 m. About 30% might be closer to the surface than 200 m and is therefore excluded. Consequently, the volume of coal is estimated at 1.2 x 10^{10} m^3.

The rank of the coal is high-volatile bituminous (0.71% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Coalspur coals is estimated to be **8 x 10^{10} m^3**.

5.5.2 Shallow Brazeau Coal Zone

Coal is present in the upper part of the Brazeau Formation, underlies an area of 3094 km^2 (or 3.1 x 10^9 m^2; *see* Figure 8) and has an average thickness of 2.5 m. About 20% might be closer to the surface than 200 m and is therefore excluded. Consequently, the volume of coal is estimated at 6.2 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.75% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Brazeau coals is estimated to be **4.3 x 10^{10} m^3**.

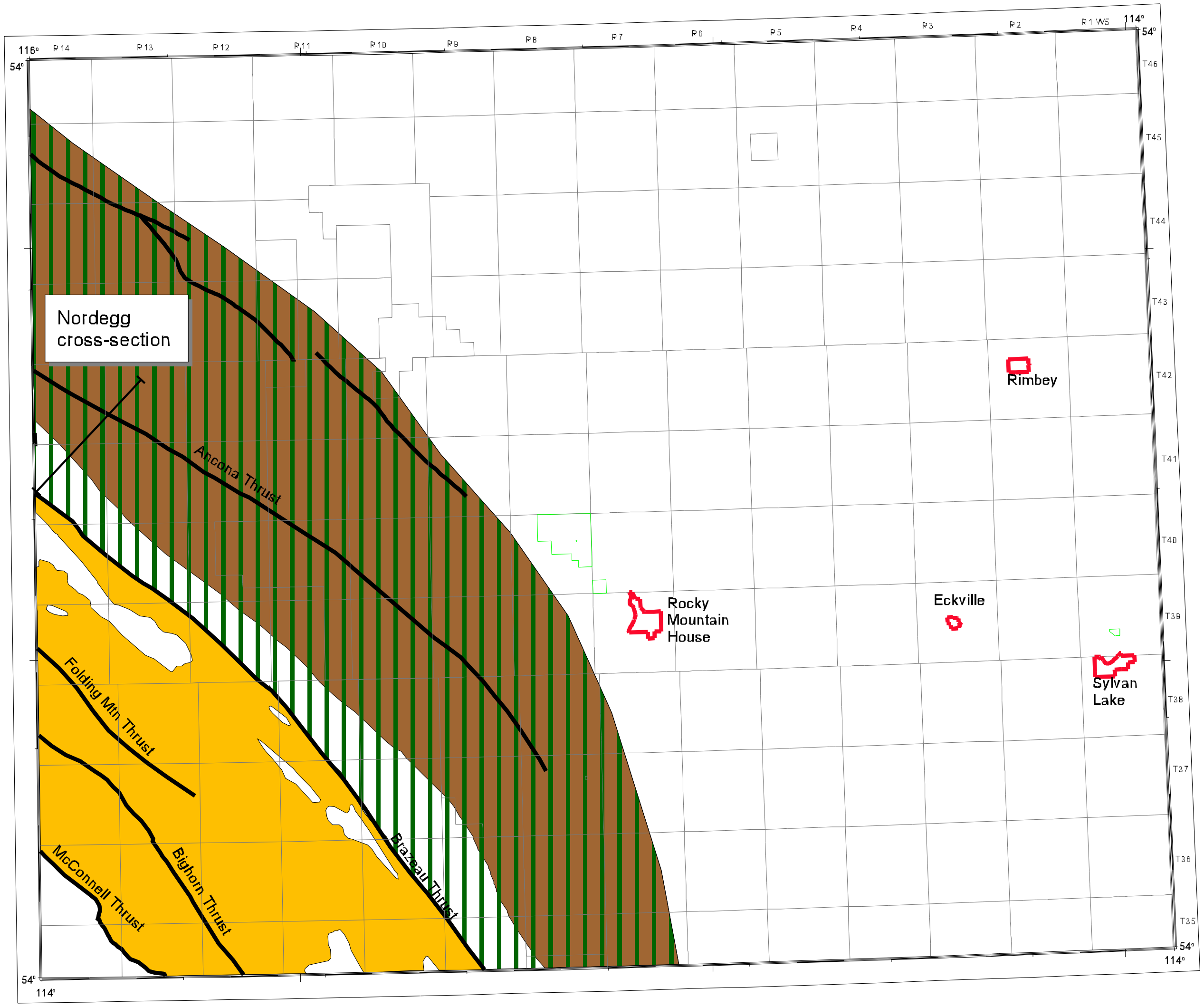
5.5.3 Shallow Gates Coal Zone

The shallow Gates coals of this map sheet have been documented by Dawson and Kalkreuth (1994a). The coals underlie an area of 1536 km^2 (or 1.5 x 10^9 m^2; *see* Figure 8) and have an average thickness of 7.1 m. It is estimated that about 80% of this area is underlain by coal, so the volume of coal is estimated at 8.7 x 10^9 m^3.

The rank of the coal is medium-volatile bituminous (1.3% vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Gates coals is estimated to be **1.2 x 10^{11} m^3**.

5.5.4 Deep Gates Coal Zone

The deep Gates coals can be easily recognized in all wells and have been documented by Dawson and Kalkreuth (1994a). They underlie an area of 3614 km^2 (or 3.6 x 10^9 m^2; *see* Figure 8) and the coal has an average cumulative thickness of 7.9 m. Some shortening is present in the Triangle Zone structures, so



Coal Area	Area in (km^2)
Shallow Coalspur / Brazeau	3094
Deep Gates	3614
Shallow Gates	1536

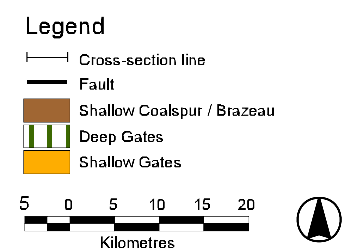


Figure 8. Areal extent of coal areas of NTS map sheet 83B (Rocky Mountain House) and location of cross-section.

the volume needs to be multiplied by 1.05. Consequently, the coal volume is about 3 x 10^{10} m^3.

The rank of the coal is low-volatile bituminous (1.5% average vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Gates coals is estimated to be **4.2 x 10^{11} m^3**.

5.6 Map Sheet NTS 82O (Calgary)

The major coal zones are in the Brazeau Formation and Kootenay Group, the Kootenay zone being divided into deep and shallow (Figure 9). Minor coal is present in the Blairmore Group and Coalspur Formation, but these seams are too thin for CBM production. The structural Canmore cross-section (Rottenfusser et al., 1991; *see* line of section on Figure 9) displays the subsurface geology of the area and is based on Price and Fermor (1985). The most important thrusts are the McConnell and Brazeau thrusts. The McConnell Thrust separates the shallow and deep Kootenay coals.

5.6.1 Shallow Brazeau Coal Zone

The Upper Brazeau Coal Zone may be equivalent to the Carbon/Thompson Coal Zone. Coal lower down in the succession may be equivalent to the Lethbridge Coal Zone. However, accurate correlations are difficult because the Bearpaw Formation cannot be mapped. The coal underlies an area of 754 km^2 (or 7.5 x 10^8 m^2; *see* Figure 9) and has an average thickness of 3.1 m. Consequently, the volume of coal is estimated at 2.3 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.78% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Brazeau coals is estimated to be **1.6 x 10^{10} m^3**.

5.6.2 Shallow Kootenay Coal Zone

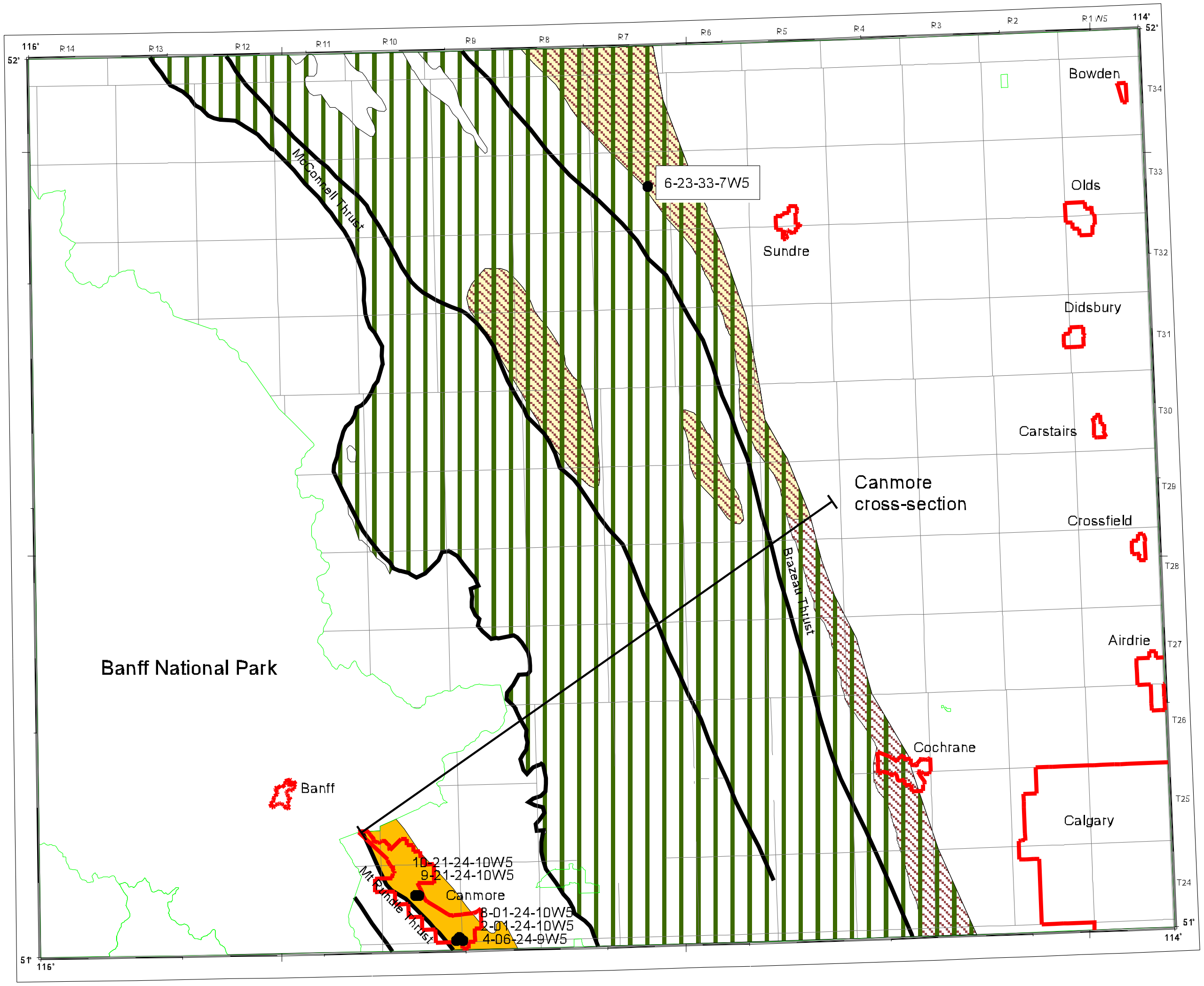
The coals underlie an area of 105 km^2 (or 1.5 x 10^9 m^2; *see* Figure 9) in the Canmore area and have an average cumulative thickness of 20 m. Shortening by folding indicates that the areal extent of the coal must be multiplied by 1.5. Consequently, the volume of coal is estimated at 3.1 x 10^9 m^3.

The rank of the coal is semi-anthracite (2.1% vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Kootenay coals is estimated to be **4.4 x 10^{10} m^3.**

5.6.3 Deep Kootenay Coal Zone

The deep Kootenay Coal Zone can be mapped in all wells west of the erosional edge. The coal tends to be thinner than the shallow Kootenay and is often sheared. The coal underlies an area of 5339 km^2 (or 5.3 x 10^9 m^2; *see* Figure 9) and has an average cumulative thickness of 4 m. Some shortening is present in the Triangle Zone structures and the volume needs to be multiplied by 1.25. Consequently, the coal volume is about 2.7 x 10^{10} m^3.

The rank of the coal is low-volatile bituminous (1.6% average vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Kootenay coals is estimated to be **3.7 x 10^{11} m^3**.



Coal Area	Area in (km^2)
Shallow Coalspur	547
Shallow Brazeau	754
Deep Kootenay	5339
Shallow Kootenay	105

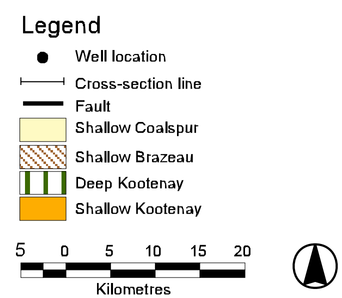


Figure 9. Areal extent of coal areas of NTS map sheet 82O (Calgary) and location of cross-section.

5.7 Map Sheet NTS 82J (Kananaskis Lakes)

The major coal-bearing units are the St. Mary River Formation and the Kootenay Group (Figure 10). The Highwood River cross-section from Rottenfusser et al. (1991) shows the subsurface geology of the area (*see* line of section on Figure 10). The interpretation is based on a cross-section, published in a guidebook by Gordy et al. (1975), which was previously published by Bally et al. (1966).

5.7.1 Shallow St. Mary River Formation

The St. Mary River Coal Zone can be mapped into the Triangle Zone from the plains. Some St. Mary River coals are exposed beneath the Longview Bridge. In the Foothills, the Bearpaw Formation generally cannot be mapped and the entire Belly River to St. Mary River interval is mapped as Brazeau Formation. No significant coals were seen in the Brazeau interval west of the Triangle Zone. The St. Mary River coals, considered to have the same areal extent as the Brazeau interval (including the Belly River, Bearpaw and St. Mary River formations), underlie an area of 330 km^2 (or 3.3 x 10^8 m^2; see Figure 10) and have an average thickness of 4.6 m. Consequently, the volume of coal is estimated at 1.5 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.75% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow St. Mary River coals is estimated to be **1.1 x 10^{10} m^3**.

5.7.2 Shallow Kootenay Coal Zone

Shallow Kootenay coals are present in the area between the Lewis and McConnell thrusts and around the Moose Mountain culmination. The coals underlie an area of 1542 km^2 (or 1.5 x 10^9 m^2; *see* Figure 10) and have an average cumulative thickness of 3.1 m. Shortening by folding and thrusting is considered to be equalized by areas where the coal is too shallow or not present, so the area correction factor is 1. Consequently, the volume of coal is estimated at 4.8 x 10^9 m^3.

The rank of the coal is medium- to low-volatile bituminous (1.1–1.7% vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Kootenay coals is estimated to be **6.7 x 10^{10} m^3**.

5.7.3 Deep Kootenay Coal Zone

The deep Kootenay Coal zone can be mapped in all wells west of the erosional edge. The coals underlie an area of 3266 km^2 (or 3.3 x 10^9 m^2; *see* Figure 10) and have an average cumulative thickness of 2 m. Some shortening is present in the Triangle Zone structures, so the volume needs to be multiplied by 1.2. Consequently, the coal volume is about 7.8 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (0.94% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Kootenay coals is estimated to be **5.5 x 10^{10} m^3**.

5.8 Map Sheet NTS 82G (Fernie)

The major coal-bearing units present in the Fernie map sheet are the St. Mary River Formation and the Kootenay Group. The St. Mary River coals are too shallow and are excluded from the present calculations (Figure 11). The cross-section for the Pincher Creek area from Rottenfusser et al. (1991) depicts the subsurface geology of the area (*see* line of section on Figure 11). The cross-section shows that the

Coal Area	Area in (km^2)
Shallow St. Mary River	330
Deep Kootenay	3266
Shallow Kootenay	1542

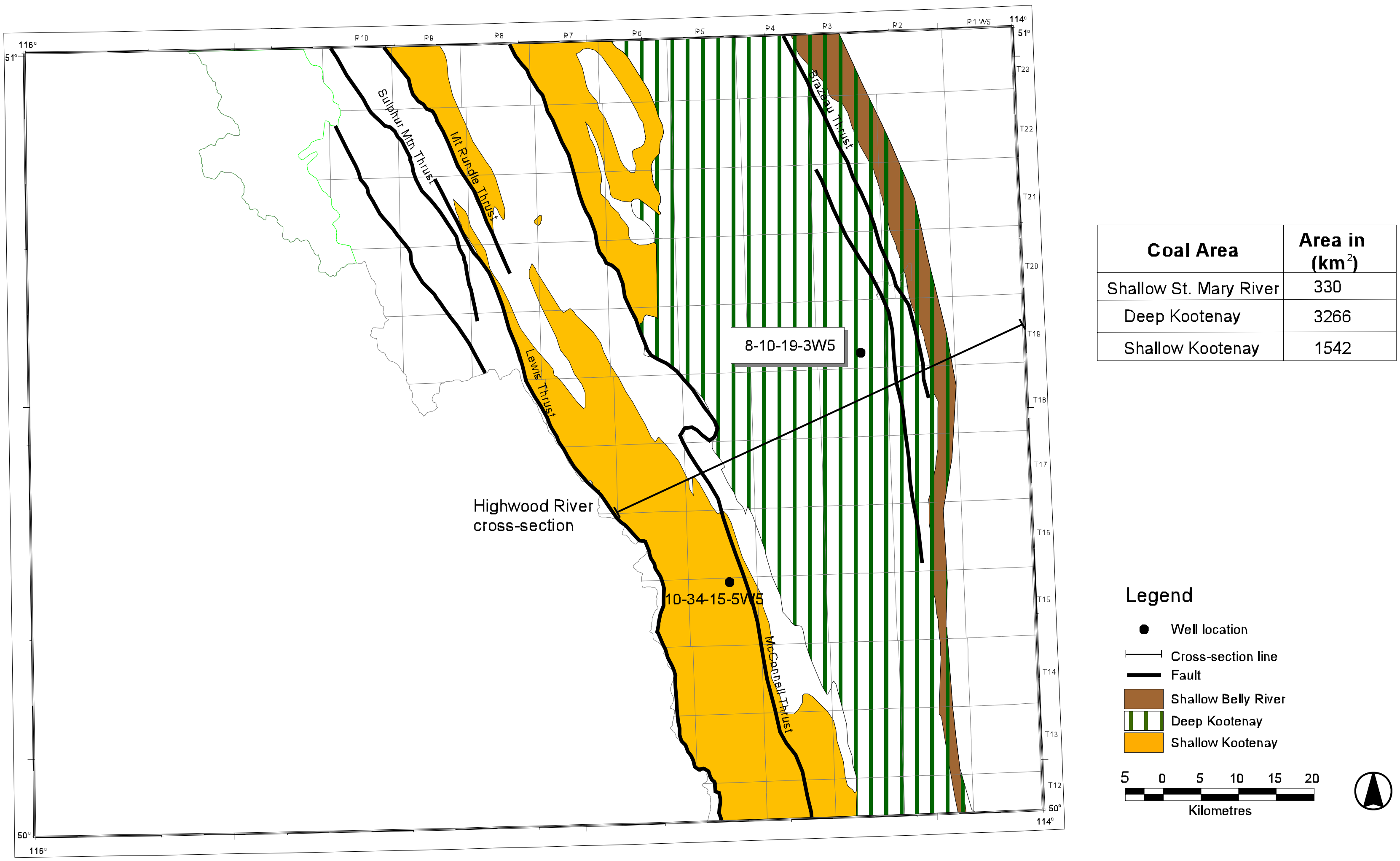
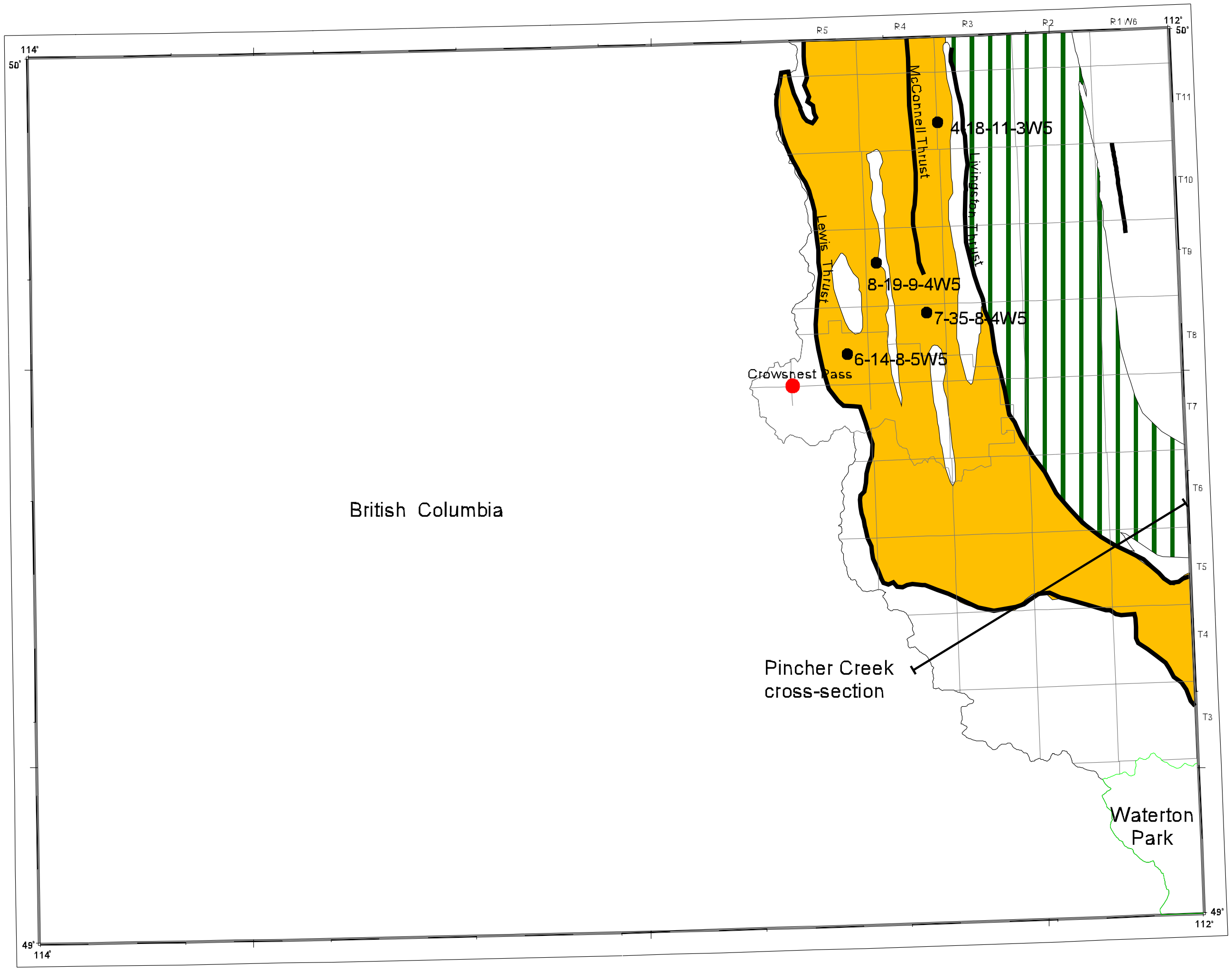


Figure 10. Areal extent of coal areas of NTS map sheet 82J (Kananaskis Lakes) and location of cross-section.



Coal Area	Area in (km^2)
Deep Kootenay	1056
Shallow Kootenay	1501

Figure 11. Areal extent of coal areas of NTS map sheet 82G (Fernie) and location of cross-section.

Livingston Thrust brings Kootenay coals to the surface and this thrust separates the deep and shallow Kootenay coals. The McConnell Thrust has lost displacement compared to the area to the north and is no longer the dividing line.

5.8.1 Shallow Kootenay Coal Zone

Shallow Kootenay coals have been mined in the Crowsnest Pass in the past. The major coal-bearing unit of the Kootenay Group is the Mist Mountain Formation. Shallow Kootenay coals are present in the area between the Lewis and Livingston thrusts. The coals underlie an area of 1501 km^2 (or 1.5 x 10^9 m^2; *see* Figure 11) and have an average cumulative thickness of 4 m. Shortening by folding and thrusting is considerable, so an area correction factor of 1.25 is used. The volume of coal is estimated to be 4.8 x 10^9 m^3.

The rank of the coal is medium-volatile bituminous (1.25% vitrinite reflectance), which implies a conservative gas content of 10 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Kootenay coals is estimated to be **1 x 10^{11} m^3.**

5.8.2 Deep Kootenay Coal Zone

The deep Kootenay Coal zone can be mapped in all wells west of the erosional edge. The coals underlie an area of 1056 km^2 (or 1.1 x 10^9 m^2; *see* Figure 11) and have an average cumulative thickness of 2.5 m. Some shortening is present, so the volume needs to be multiplied by 1.25. Consequently, the coal volume is about 3.3 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (1.05% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Kootenay coals is estimated to be **2.3 x 10^{10} m^3**.

5.9 Map Sheet NTS 82H (Lethbridge)

The major coal-bearing units present in the Lethbridge map sheet are the St. Mary River Formation and the Kootenay Group. The St. Mary River coals are too shallow and are excluded from the present calculations (Figure 12). The cross-section for the Pincher Creek area from Rottenfusser et al. (1991) is partly in this map sheet and depicts the general subsurface geology of the area (*see* line of section on Figure 12). It shows the extension of the Livingston Thrust, which brings Kootenay coals to the surface and delineates deep and shallow Kootenay coal zones.

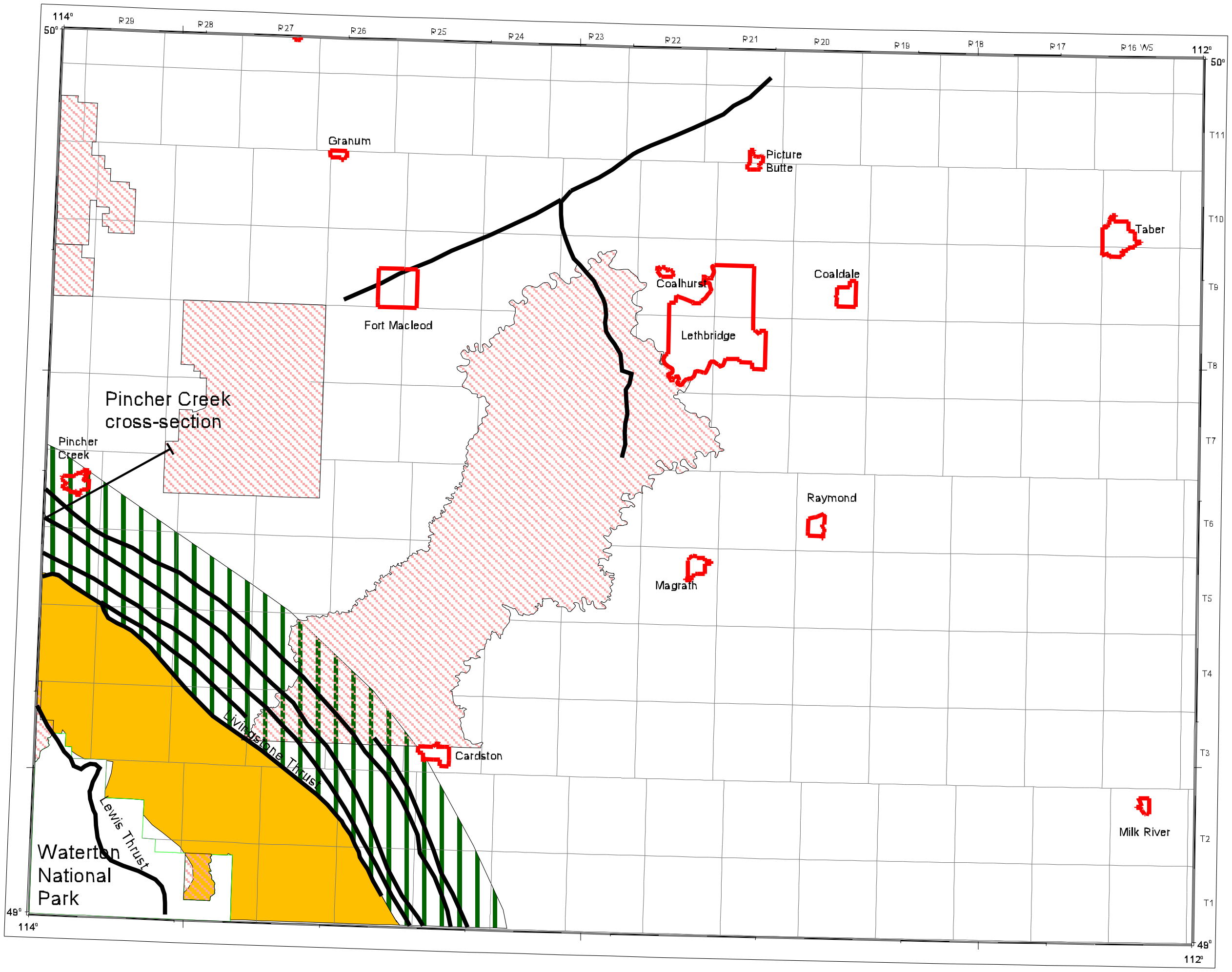
5.9.1 Shallow Kootenay Coal Zone

Shallow Kootenay coals are present in the area between the Lewis and Livingston thrusts. The coals underlie an area of 808 km^2 (or 8.1 x 10^8 m^2; *see* Figure 12) and have an average cumulative thickness of 3 m. Shortening by folding and thrusting is considerable, so an area correction factor of 1.5 is used. The volume of coal is estimated to be 4.8 x 10^9 m^3.

The rank of the coal is high-volatile bituminous (1% vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the shallow Kootenay coals is estimated to be **2.6 x 10^{10} m^3**.

5.9.2 Deep Kootenay Coal Zone

The deep Kootenay Coal Zone can be mapped in all wells west of the erosional edge. The coals underlie



Coal Area	Area in (km^2)
Deep Kootenay	1049
Shallow Kootenay	808

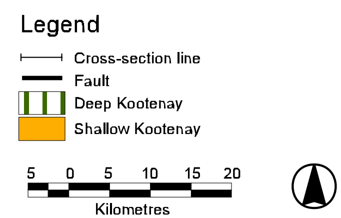


Figure 12. Areal extent of coal areas of NTS map sheet 82H (Lethbridge) and location of cross-section.

an area of 1049 km^2 (or 1.0 x 10^9 m^2; *see* Figure 12) and have an average cumulative thickness of 2.5 m. Some shortening is present, so the volume needs to be multiplied by 1.25. Consequently, the coal volume is about 3.9 x 10^9 m^3.

The rank of the coal is high- to medium-volatile bituminous (1.11% average vitrinite reflectance), which implies a conservative gas content of 5 cm^3/g (Eddy et al., 1982) and a density of 1.4 g/cm^3. Consequently, the total methane content of the deep Kootenay coals is estimated to be **2.7 x 10^{10} m^3**.

6 Estimated Volumes of In-Place Coalbed Methane

Coal-bed methane recovery from deep coals is generally not attempted because of the high cost of drilling and the low permeability that results from high overburden load and stress. The gas content of all shallow coal areas can be totalled to give a volume of **1.5 x 10^{12} m^3** (about **53 Tcf**) of in-place CBM, which is considered a best CBM resource estimate based on limited data. It is interesting to note that this number is close to the 60 Tcf that has been mentioned by the Canadian Potential Gas Committee as a maximum in-place gas estimate for the Alberta Foothills/Mountains (D. Hughes, pers. comm., 2000).

The gas content of all deep coal areas totals **2.5 x 10^{12} m^3** (about **90 Tcf**) of in-place CBM gas. Consequently, the total ultimate CBM resource could be **4 x 10^{12} m^3** (about **143 Tcf**).

Using the higher (less conservative) gas content numbers (Tables 2, 3), which are based on measured amounts from United States coals reported by Eddy et al. (1982), the maximum gas content of all shallow coal zones totals **2.8 x 10^{12} m^3** (about **99 Tcf**) of in-place CBM. The gas content of the deep coal zones would total **5.2 x 10^{12} m^3** (about **183 Tcf**) of in-place CBM. Therefore, the total ultimate CBM resource would be **8 x 10^{12} m^3** (about **281 Tcf**). These numbers are unrealistic, however, because the actual measured gas content in Alberta is lower than that of equivalent coals from the United States (Dawson et al., 2000) and the deep coals are presently uneconomical for CBM development.

7 Producibility of Foothills/Mountains Coalbed Methane

It should be noted that the producibility of this gas is completely unknown. The few production tests on these coals indicate low permeability, possibly resulting from the pervasive shearing observed in many places in these coals.

Because of the high CBM potential of the Coalspur coals of the Triangle Zone, a specialized coal log analysis (termed LogFAC) was performed on four wells in the Hanlan area (twp 47, rge 17-18, W 5th mer; *see* summary of consultant report in Appendix 2). LogFAC analysis is a coal-log analysis procedure designed to estimate the abundance and openness of fractures (cleat) in coal, which is widely regarded as the primary control on permeability in coal. LogFAC is a software package that calculates invading mud filtrate volumes and generates a metric termed the LogFAC Permeability Factor (LPF), which is a dimensionless factor that is not convertible to an accurate permeability (millidarcy) value at this stage of research. The four wells are located on the Alberta Syncline, just east of the Triangle Zone. An anomalous trend indicating enhanced openness of fractures and possible elevated permeability (indicated by LogFAC Permeability Factors of 1.6 in the Val d'Or B seam) is noted in an area in the syncline. These results indicate a possible link between the elevated permeability factors and structural features.

Data from the nearby Conoco Hanlan 11-20-47-18W5 CBM well (Dawson et al., 2000) show that gas content is lower than expected for these coal ranks (about 2.1 cm^3/g). The reason for this anomaly is not understood, because nearby shallow coal in the Coal Valley mine has gas contents of up to 3.2 cm^3/g (Table 1). High average ash content of 30 % for this coal is certainly a contributing factor (Dawson et al., 2000, p.93). Nevertheless, these data indicate that this is an area of reasonable permeability and gas content, where cautious CBM exploration could proceed.

8 Areas of Greatest CBM Potential in Alberta's Foothills/Mountains

The shallow Kootenay coals have optimal rank and gas content. This information, combined with the observed cumulative thicknesses of up to 20 m (in the Canmore area), indicates favourable areas for coal-bed methane exploration. The shallow Kootenay coal is the only Foothills/Mountains coal that has produced any CBM gas (Table 1). It should be noted that most published formation tests were performed in shallow Kootenay coal, whereas only one test was completed in shallow Gates coal.

The thickness and rank distribution (largely medium volatile and higher ranks) of the shallow Gates Coal Zone indicates optimal coal-bed methane potential for these coals. In the inner Foothills of the Wapiti (NTS 83L), Mount Robson (NTS 83E), Edson (NTS 83F), Brazeau (NTS 83C) and Rocky Mountain House (NTS 83B) map sheets, the coals are at reasonable depth and would therefore be the main prospects. In the Wapiti map sheet, wells could be completed in both the Gates and Gething coal zones, which would make drilling cost effective. The shallow Gates Coal Zone needs to be better tested in all these areas.

From the combination of thickness, rank and permeability factors, the best potential for coal-bed methane in the Coalspur Coal Zone appears to be in the Edson (NTS 83F) map sheet, in the structure known as the Entrance Syncline and the nearby Triangle Zone (southeast of Hinton; *see* Figure 6).

9 Recommendations

Most of the surface-geology compilation maps (1:250 000 scale) need updating. Because of the lack of up-to-date maps, the size of coal areas might have been overestimated in this report. On several maps, the Gates Formation or the Luscar Group (which includes other formations) was not separated from other formations, thus making the calculations of areal extent inaccurate. The Gates Formation (or Luscar Group) and the Coalspur Formation need to be located accurately on these maps by transferring contacts from existing 1:50 000 scale maps. Without adequate mapping of the coal-bearing formations, accurate resource numbers for the coals involved cannot be obtained.

More cross-sections, which show the subsurface location of coal zones, need to be constructed. The present availability of only nine cross-sections is inadequate to properly evaluate this large and structurally complex area. At mine sites, resources are generally estimated from drilling with a spacing of less than 50 m. The spacing in the present analysis, between 20 and 100 km, is inadequate for a proper resource assessment. As a result, the continuity of coal zones and cumulative coal thickness might have been overestimated in this report.

The coverage of reliable coal picks from Foothills oil and gas wells is very sparse. Many more coal picks from wells need to be added to the AGS coal database. These wells should preferably be located along the new cross-section lines.

Not all available coal outcrop in the Foothills/Mountains has been sampled. Data on coal thickness and rank need to be collected for outcrops in southern Alberta. Coal data from these outcrops need to be added to the AGS coal database. It will be useful to add coal-rank data to the existing database. Rank data could be collected from chip samples in the intervals indicated by coal picking.

Appendix 1 - Coal Picks in Wells Used for this Study

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
PINCHER CREEK AREA - Coal picks:				
00/05-07-004-03W5	3095	3096	1	Kootenay
	3102.5	3104.8	2.3	Kootenay
	3105.8	3106.5	0.7	Kootenay
	3127.3	3129.7	2.4	Kootenay
00/02-16-005-02W5	1677.8	1678.7	0.9	Kootenay
	1678.7	1679.3	0.6	Kootenay
	1679.3	1680.3	1	Kootenay
	1680.3	1681	0.7	Kootenay
	1681	1681.7	0.7	Kootenay
	2782	2783.3	1.3	Kootenay
	2784.5	2785.1	0.6	Kootenay
	2793.3	2794.1	0.8	Kootenay
	2794.5	2795.1	0.6	Kootenay
	2798.5	2801.5	3	Kootenay
	2809	2810.4	1.4	Kootenay
	2813.8	2818	4.2	Kootenay
	2935.3	2936.3	1	Kootenay
	2937.1	2939.6	2.5	Kootenay
00/11-04-006-01W5	4212.5	4214	1.5	Kootenay
	4220	4221	1	Kootenay
HIGHWOOD RIVER AREA - Coal picks:				
00/10-25-017-05W5	317.9	319.2	1.3	Kootenay
	330.5	332.1	1.6	Kootenay
	1285.7	1287.8	2.1	Kootenay
			0	
00/11-32-018-01W5	1192.5	1194.8	2.3	St. Mary River
	1252.6	1254.1	1.5	St. Mary River
	1278.4	1279.5	1.1	St. Mary River
	1305.5	1306.6	1.1	St. Mary River
	1311	1316.7	5.7	St. Mary River
	1325.8	1327	1.2	St. Mary River
	1507.4	1508.2	0.8	Lethbridge
	1515.1	1515.8	0.7	Lethbridge
00/16-14-018-02W5	1446	1449	3	St. Mary River
	1458.2	1458.8	0.6	St. Mary River
	1562	1563	1	St. Mary River
00/08-30-018-03W5	1500	1500.4	0.4	Kootenay
	1559.8	1560.2	0.4	Kootenay
	1564.2	1565	0.8	Kootenay
	1570.6	1571.2	0.6	Kootenay
	1853.8	1855.1	1.3	Kootenay
	1889.4	1890.6	1.2	Kootenay

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
	1932.5	1933.5	1	Kootenay
	1982.9	1984	1.1	Kootenay
	3326	3326.5	0.5	Kootenay
	3533.2	3535.2	2	Kootenay
	3539.4	3540	0.6	Kootenay
00/06-11-019-03W5	886.1	887.6	1.5	Kootenay
	889.7	891.8	2.1	Kootenay
	910.7	911.8	1.1	Kootenay
	934	935.3	1.3	Kootenay
	3165	3165.8	0.8	Kootenay
	3179.8	3180.7	0.9	Kootenay
CANMORE AREA - Coal picks:				
00/15-24-0260-8W5	2381.3	2382.3	1	Kootenay
	2421.8	2422.6	0.8	Kootenay
00/11-14-027-07W5	3314.2	3315	0.8	Kootenay
	3321.4	3322.5	1.1	Kootenay
	3332.5	3335.4	2.9	Kootenay
00/02-18-027-07W5	2948.2	2949.8	1.6	Kootenay
	2954.1	2955	0.9	Kootenay
	2956.8	2958.5	1.7	Kootenay
	3358.8	3359.8	1	Kootenay
00/11-22-028-05W5	1029.5	1030.3	0.8	Brazeau
	1652.6	1653.5	0.9	Brazeau
	1750.4	1751.2	0.8	Brazeau
00/15-32-028-05W5	487	487.5	0.5	Brazeau
	520	521.5	1.5	Brazeau
	699.5	700	0.5	Brazeau
	983	983.4	0.4	Brazeau
	1053	1053.3	0.3	Brazeau
	1354	1354.5	0.5	Brazeau
00/05-05-028-06W5	2406.1	2406.7	0.6	Kootenay
	2802.9	2804.3	1.4	Kootenay
	3261	3262	1	Kootenay
00/09-08-028-07W5	2296	2296.5	0.5	Lethbridge
00/06-03-033-06W5	706	707.5	1.5	Coalspur
(2001 - Picks)	898	899	1	Coalspur
	962	963	1	Brazeau
	972.5	973.5	1	Brazeau
	992.5	993.5	1	Brazeau
	1000	1001	1	Brazeau
	1014.5	1015.5	1	Brazeau
	1154	1156	2	Brazeau
	1179	1180	1	Brazeau

Well location	**Top (m)**	**Bottom (m)**	**Thickness (m)**	**Coal group**
00/08-14-026-04W5	1099	1101	2	Brazeau
(2001 - Picks)	1210	1211.5	1.5	Brazeau
	1492	1493	1	Brazeau
	1505	1506	1	Brazeau
	1531	1532	1	Brazeau
	1569	1570.5	1.5	Brazeau
	1600	1601	1	Brazeau
NORDEGG AREA - Coal picks:				
00/16-33-038-16W5	1055.4	1058.1	2.7	Gates
	1773	1775	2	Nikanassin
	1783	1785	2	Nikanassin
00/10-15-040-15W5	181	183.1	2.1	Gates
	225.4	226.3	0.9	Gates
	227.6	228.1	0.5	Gates
	249.9	255	5.1	Gates
	287.4	289.9	2.5	Gates
00/03-23-041-13W5	897.3	898.2	0.9	Coalspur
	917.4	919.1	1.7	Coalspur
	958.7	960.4	1.7	Coalspur
	968.5	970.3	1.8	Coalspur
	980.3	981.2	0.9	Coalspur
	997.5	998.3	0.8	Coalspur
	1344.2	1345.2	1	Brazeau
	3367.7	3369.3	1.6	Gates
	3443	3446	3	Gates
	3446.7	3447.5	0.8	Gates
	3460.7	3462.1	1.4	Gates
	3471.3	3472.3	1	Gates
00/10-16-041-14W5	484.1	484.9	0.8	Coalspur
	535.1	535.9	0.8	Coalspur
	3169.6	3170.7	1.1	Gates
	3314.3	3318.6	4.3	Gates
	3365.3	3367.2	1.9	Gates
	3369	3371.6	2.6	Gates
	3422.2	3423.1	0.9	Gates
00/06-12-042-13W5	922.8	924.6	1.8	Coalspur
	943.6	945.3	1.7	Coalspur
	954.6	955.3	0.7	Coalspur
	1003.9	1005.4	1.5	Coalspur
	1062.3	1063	0.7	Coalspur
	1300	1300.9	0.9	Brazeau
	1314.2	1315.3	1.1	Brazeau
	1328.9	1331.5	2.6	Brazeau
	3141.3	3142.3	1	Gates
	3217.1	3221.1	4	Gates
	3233.5	3234.2	0.7	Gates
00/10-26-041-15w5	496.5	498	1.5	Coalspur/Brazeau

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
(2001 - Picks)	538.5	539.5	1	Coalspur/Brazeau
	634	635	1	Coalspur/Brazeau
	653	654	1	Coalspur/Brazeau
	655	655.5	0.5	Coalspur/Brazeau
	714	715.5	1.5	Coalspur/Brazeau
	1102	1104	2	Coalspur/Brazeau
	3620	3623	3	Gates
	3663	3663.5	0.5	Gates
	3708	3711	3	Gates
00/16-33-038-16W5	1054	1055.5	1.5	Gates
(2001 - Picks)	1731	1732	1	Gates
	1777	1778	1	Gates
CADOMIN AREA - Coal picks:				
00/11-15-047-22W5	3378.3	3379.3	1	Gates
00/10-20-047-21W5	2586.4	2589.2	2.8	Gates
	2682.9	2684.1	1.2	Gates
	2706.4	2709.4	3	Gates(Jewel Seam)
00/14-08-048-21W5	1019	1020	1	Brazeau
	3804.8	3806	1.2	Gates
	3842.4	3843.3	0.9	Gates
	3869.2	3870.5	1.3	Gates
	3898	3899.4	1.4	Gates(Jewel Seam)
	3901.7	3903.6	1.9	Gates(Jewel Seam)
	4038.8	4039.8	1	Gething
00/06-09-048-22W5	2541	2542.2	1.2	Gates
	2576.7	2577.8	1.1	Gates
	2602.1	2603.1	1	Gates
	2613.8	2614.8	1	Gates
	2634.2	2636.3	2.1	Gates(Jewel Seam)
	2637.2	2638.5	1.3	Gates(Jewel Seam)
00/06-05-049-21W5	319.1	320.1	1	St. Mary River
	328	330.7	2.7	St. Mary River
	436.3	438	1.7	Coalspur (Mynheer seam)
	438.7	439.7	1	Coalspur (Mynheer seam)
	922.9	923.8	0.9	Brazeau
	945.3	945.9	0.6	Brazeau
	991.6	992.7	1.1	Brazeau
	996.8	998	1.2	Brazeau
	3284.7	3287.7	3	Gates
	3330	3331	1	Gates
	3332.2	3333.6	1.4	Gates
	3431.6	3432.2	0.6	Jewel seam (Gates)
00/09-12-049-22W5	871	872.3	1.3	Brazeau
	875.9	876.8	0.9	Brazeau
	893.9	894.8	0.9	Brazeau
	950.6	951.2	0.6	Brazeau

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
	1202.4	1203.3	0.9	Brazeau
	3335.4	3338.4	3	Gates
	3354.9	3355.8	0.9	Gates
	3368	3371	3	Gates
	3405.5	3406.4	0.9	Gates
	3444.5	3445.4	0.9	Gates
	3478	3481.7	3.7	Jewel seam (Gates)
00/11-33-049-21W5	645	645.8	0.8	Coalspur (Val d'Or seam)
	646.2	649	2.8	Coalspur (Val d'Or seam)
	649.5	655.2	5.7	Coalspur (Val d'Or seam)
	656	657	1	Coalspur (Val d'Or seam)
	657.6	659.1	1.5	Coalspur (Val d'Or seam)
	660.2	662	1.8	Coalspur (Val d'Or seam)
	662.4	663.1	0.7	Coalspur (Val d'Or seam)
	677.6	678.5	0.9	Coalspur (McLeod seam)
	711.5	712.5	1	Coalspur (McPherson seam)
	713.2	715	1.8	Coalspur (McPherson seam)
	715.9	718	2.1	Coalspur (McPherson seam)
	797.8	799.1	1.3	St. Mary River
	825.8	829.4	3.6	Coalspur (Mynheer seam)
	831	832	1	Coalspur (Mynheer seam)
	1183	1185	2	Brazeau
	3351.2	3353.8	2.6	Gates
	3382.4	3383.3	0.9	Gates
	3383.8	3384.7	0.9	Gates
	3411.2	3412.3	1.1	Gates
	3415	3416.7	1.7	Jewel seam (Gates)
	3436	3437.5	1.5	Jewel seam (Gates)
	3558.5	3559.2	0.7	Gething
00/15-03-046-21W5	2295.7	2297.6	1.9	Gates
	2415.7	2417.2	1.5	Gates
	2434.3	2436.1	1.8	Gates
	2450.3	2452.5	2.2	Jewel seam (Gates)
00/11-15-047-22W5	1523	1524	1	Brazeau
(2001 - Picks)	3377	3378	1	Gates
GRANDE CACHE AREA - Coal picks:				
00/06-23-056-06W6	889.9	891.2	1.3	Gates
	932.9	934.8	1.9	Gates
	949.1	950.3	1.2	Gates
	951.2	952.1	0.9	Gates
	996	997	1	Gates
	997.9	999.7	1.8	Gates
	1021	1023.8	2.8	Gates
	1170.7	1171.3	0.6	Gething
00/10-32-057-06W6	2218.4	2220	1.6	Gates
	2228.5	2229.3	0.8	Gates
	2247.5	2249.8	2.3	Gates
	2264.1	2265	0.9	Gates

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
00/11-20-058-04W6	927	928	1	Coalspur
	1024	1025	1	Coalspur
	3654	3655	1	Gates
	3656	3657	1	Gates
	3695	3696	1	Gates
	3710.5	3712	1.5	Gates
	3751.5	3753	1.5	Gates
	3776.5	3777	0.5	Gates
	3894.5	3896	1.5	Gething
00/15-11-0580-5W6	943	944	1	Coalspur
	952.8	953.5	0.7	Coalspur
	1092.5	1093.5	1	Coalspur
	3809.5	3810	0.5	Gates
	3823	3824	1	Gates
	3861	3864.2	3.2	Gates
	3885.5	3886.5	1	Gates
	3888	3889.9	1.9	Gates
	3890.1	3890.6	0.5	Gates
	3913.5	3915	1.5	Gates
	3915.2	3915.6	0.4	Gates
	4033.5	4034.5	1	Gething
00/10-29-058-05W6	745.5	746.3	0.8	Coalspur
	806.7	807.5	0.8	Coalspur
	851.9	852.5	0.6	Coalspur
	853.7	854.6	0.9	Coalspur
	915	916	1	Coalspur
00/10-07-058-05W6	535	537.1	2.1	Coalspur
	541.8	542.7	0.9	Coalspur
	668	669.2	1.2	Coalspur
00/06-22-059-05W6	814.9	815.6	0.7	Coalspur
	903.7	904.3	0.6	Coalspur
	3557.7	3558.5	0.8	Gates
	3559.3	3560.4	1.1	Gates
	3568.3	3569.9	1.6	Gates
	3590.9	3593.2	2.3	Gates
	3608.5	3610	1.5	Gates
	3634.4	3636.4	2	Gates
	3648.1	3650.4	2.3	Gates
	3676.5	3677.5	1	Gates
	3849.9	3850.6	0.7	Gething
	3850.8	3851.4	0.6	Gething
00/11-23-053-02W6	10388'	10392'	1.2	Gates
(2001 - Picks)	10936'	10938'	0.6	Gates
	10941'	10944'	0.9	Gates
	11214'	11216'	0.6	Gates
	11218'	11220'	0.6	Gates
	11224'	11230'	1.8	Gates

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
00/01-35-056-01W6	2870'	2872'	0.6	Coalspur
(2001 - Picks)	2879'	2881'	0.6	Coalspur
	2888'	2890'	0.6	Coalspur
	3089'	3090'	0.3	Coalspur
	3140'	3142'	0.6	Coalspur
	4650'	4652'	0.6	Brazeau
	6319'	6321'	0.6	Brazeau
	11004'	11012'	2.4	Gates
	11018'	11022'	1.2	Gates
	11026'	11028'	0.6	Gates
	11072'	11076'	1.2	Gates
	11215'	11222'	2.1	Gates
	11228'	11230'	0.6	Gates
	11753'	11755'	0.6	Gething
00/04-09-055-03W6	2813	2816	3	Gates
(2001 - Picks)	3039	3040.5	1.5	Gates
	3042	3043	1	Gates
	3057	3058.5	1.5	Gates
	3059	3060	1	Gates
00/05-16-056-04W6	3165	3166	1.0	Gates
(2001 - Picks)				
00/07-26-054-01W6/00	513.5	514.5	1	Coalspur
(2001 - Picks)	515	516	1	Coalspur
aka 08-26-54-01W6/02	566.5	567.5	1	Coalspur
	1011	1012	1	Brazeau
	1048	1048.5	0.5	Brazeau
	1049	1049.5	0.5	Brazeau
	3679	3681	2	Gates
	3715	3716	1	Gates
	3731.8	3733	1.2	Gates
00/08-26-054-01W6/02	3873	3874.5	1.5	Gething
(2001 - Picks)				
aka 07-26-54-01W6/02				
00/11-21-059-08W6	2810	2812	2	Gates
(2001 - Picks)	2846.5	2848.5	2	Gates
	2884	2886	2	Gates
	2895	2895.5	0.5	Gates
	3012.6	3013.3	0.7	Gething
	3055	3056	1	Gething
	3063	3063.8	0.8	Gething
	3127.5	3128.5	1	Gething
	3200.8	3201.8	1	Nikanasin
00/11-25-059-09W6	2500	2501	1	Gates (Spirit River)
(2001 - Picks)	2594.5	2595.5	1	Gates (Spirit River)
	2601	2603	2	Gates (Spirit River)
	2653	2654	1	Gates (Spirit River)
	2686	2688	2	Gates (Spirit River)
	2700.5	2701.5	1	Gates (Spirit River)

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
	2705.5	2706.5	1	Gates (Spirit River)
	3071.5	3072.5	1	Nikanasin
00/15-23-059-09W6	7918	7920	0.6	Gates
(2001 - Picks)	8308	8314	1.8	Gates
	8322	8324	0.6	Gates
	8339	8341	0.6	Gates
	8460	8463	0.9	Gates
	8465	8470	1.5	Gates
	8590	8600	3.0	Gates
	8627	8630	0.9	Gates
	8643	8648	1.5	Gates
	9458	9460	0.6	Gates
	9542	9546	1.2	Gates
NARRAWAY RIVER - Coal picks:				
00/06-19-063-10W6	801.5	801.8	0.3	Brazeau
	3262.3	3263.5	1.2	Gates
	3280.6	3282	1.4	Gates
	3285	3286	1	Gates
	3302	3302.7	0.7	Gates
	3310	3311	1	Gates
	3318	3319.1	1.1	Gates
	3332.7	3333.2	0.5	Gates
	3334	3335	1	Gates
	3359	3360	1	Gates
	3558.8	3559.9	1.1	Gething
	3614	3616	2	Gething
	3664.5	3665.2	0.7	Gething
00/05-03-063-11W6	2683.3	2684.2	0.9	Gates
	2704.7	2705.5	0.8	Gates
	2732.7	2734	1.3	Gates
	2752.8	2754.2	1.4	Gates
	2802.8	2807	4.2	Gates
	3028.4	3030	1.6	Gething
	3049	3050	1	Gething
	3151.5	3152.8	1.3	Gething
	3172	3172.4	0.4	Gething
00/06-24-062-11W6	3196.8	3198	1.2	Gates
	3225	3225.7	0.7	Gates
	3260.7	3261.7	1	Gates
	3294.3	3295	0.7	Gates
	3336.4	3340.5	4.1	Gates
	3341.5	3343.4	1.9	Gates
	3374.5	3375.1	0.6	Gates
	3385.4	3386.2	0.8	Gates
	3524.9	3525.7	0.8	Gething
	3537.5	3539	1.5	Gething
	3547.4	3548.3	0.9	Gething
	3553.2	3554.2	1	Gething
	3571.8	3572.2	0.4	Gething

Well location	Top (m)	Bottom (m)	Thickness (m)	Coal group
	3592.2	3592.8	0.6	Gething
00/11-03-062-12W6	2528.8	2529.7	0.9	Gates
	2545.5	2546.8	1.3	Gates
	2610.1	2611.9	1.8	Gates
	2696.4	2704.8	8.4	Gates
	2760	2761.3	1.3	Gates
	2772.1	2773.8	1.7	Gates
	2916.8	2917.8	1	Gething
	2927	2927.7	0.7	Gething
	2956.4	2957	0.6	Gething
	2980	2980.9	0.9	Gething
00/01-18-062-12W6	2103.6	2105.1	1.5	Gates
	2182.5	2184	1.5	Gates
	2235	2241.5	6.5	Gates
	2437.8	2438.2	0.4	Gething
	2455.7	2456.5	0.8	Gething
00/15-26-061-13W6	889.3	890.5	1.2	Gates
	904.9	905.5	0.6	Gates
	982	983.5	1.5	Gates
	992.7	993.9	1.2	Gates
	1048.5	1049.7	1.2	Gates
	1050.6	1055.2	4.6	Gates
	1076.2	1077.7	1.5	Gates
	1090.8	1092.4	1.6	Gates
	1117.7	1119.8	2.1	Gates
	1228.7	1229.6	0.9	Gething
	1237.8	1238.7	0.9	Gething
	1256.1	1256.7	0.6	Gething
	1261.9	1262.8	0.9	Gething
00/09-11-065-13W6	2901	2902	1	Gates
	2963	2969	6	Gates
	3010.5	3012	1.5	Gates
	3192.5	3194	1.5	Gething
	3208.5	3209	0.5	Gething

Appendix 2 – LogFAC Analysis, Hanlan Area

Log analysis was performed by Tom Rozak in the Hanlan area (twp 47, rge 17–18, W 3rd mer.) in west-central Alberta. The goal of the study was to examine a foothills geological setting for coal-bed methane potential by performing LogFAC analysis on wells drilled in the Hanlan area and comparing the data to structural or other features. The Conoco Hanlan well, located at 11-20-47-18W5, serves as the key well for this examination because it was tested for CBM potential in 1994.

LogFAC analysis is used to determine permeability variability in coal. LogFAC is an experimental volume-based log-analysis technique that uses conventional well-log data to define a predetermined volume of coal and the effective volume of moveable fluid occupying that coal. Higher permeability factors are indicated by greater volumes of moveable fluid within the coal.

The primary targets of investigation were the Val D'Or, Arbour, Silkstone and Mynheer seams within the Edmonton Formation. Other minor coal seams are present, but are thin and discontinuous. Net coal thickness varies from less than 13.5 m on the eastern edge of the study area to greater than 17.0 m on the western edge. No significant deposition centres were noted at the scale of this investigation.

Well control in the area is moderate to poor. Although sufficient wells exist for reasonable conventional analyses of coal-seam thickness, depth and structure, there are few wells with the combination of mud chemistry factors required for LogFAC analysis. Most conventional wells drilled in Foothills environments are drilled with invert (diesel- or oil-based) mud or with saltwater-based mud. Neither of these muds can be used in LogFAC analysis. Several potential Foothills areas were examined, with the Hanlan area being selected due to the combination of data suitability and previous CBM exploration history.

The main structural feature present is a synclinal trough trending north-south through the central portion of the Hanlan area. The trough is more pronounced in the northern part of the area, and opens and flattens to the south. The shape of this feature is not well defined due to the lack of well control.

An anomalous trend indicating elevated permeability is noted in the north-central portion of the study area. The anomalous trend coincides with the north-trending synclinal trough. The highest permeability factors coincide with the area exhibiting the most pronounced synclinal features. Elevated permeability factors are noted in three of the five coal seams in this anomaly, although significantly elevated values exist only in the Val D'Or 'B' seam. The results indicate a possible link between the elevated permeability factors and structural features.

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