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Production Potential of Coalbed Methane Resources in Alberta

Alberta Energy and Utilities Board
Alberta Geological Survey

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A. Beaton

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Alberta Energy and Utilities Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
Canada T6B 2X3

Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca
Web site: www.ags.gov.ab.ca

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Abstract

Alberta has vast coal resources that may be a potential source of coalbed methane (CBM). Exploration and research are currently underway in the province to quantify gas potential, identify key geological factors that maximize CBM potential, and identify the 'most favourable' areas for CBM production potential.

There are four main coal zones within the Plains and Foothills of Alberta. The Ardley Coal Zone of the Plains and the correlative Coalspur Coal Zone of the Foothills are undergoing limited CBM exploration and production piloting. Much of the effort is centred in the Pembina area of the Plains. Horseshoe Canyon Formation coals of south-central Alberta were initially thought to have gas concentrations too low to be economic CBM producers. It is these coals, however, that host Alberta's first commercial CBM production project. Although similar in both geographic distribution and coal quality to Horseshoe Canyon coals, not much is known regarding the gas potential of underlying coals of the Belly River Group. The deeper Mannville coals have some of the highest gas concentrations of Alberta coals; however, they are also relatively deep and generally have lower permeability than the overlying Belly River, Horseshoe Canyon and Ardley coals.

Maximum gas-in-place for the Plains and Foothills has been estimated to be greater than 1.42 x 10^{13} m^3 (>500 trillion cubic feet [tcf]). Although this number is very large, little is known about the proportion of this vast resource that is actually producible. A key challenge to producibility in Alberta has been the generally low permeability of coals with the highest gas concentrations (Mannville coals), and the moderate to low gas concentrations of higher permeability coals (Horseshoe Canyon, Ardley coals).

Regionally, coal distribution and average gas-in-place concentrations are well established for Alberta. Identifying and explaining local areas with favourable CBM production characteristics within the regional setting is necessary to establish economic CBM plays within Alberta. There are currently several pilots and numerous exploration efforts underway in the province.

This study integrates existing data with new data collected from key areas that show favourable CBM potential. In the Pembina area, increased gas-production potential from stimulated wells in the Ardley Coal Zone is indicated by increasing flow via permeability enhancement (up to 7 mD) to potentially economic levels. A cost-effective, gas-content screening method of using cuttings rather than cores for gas desorption analysis has shown much potential, providing that cuttings results are calibrated and corrected to baseline data derived from core work.

Coal from the Coalspur Formation in the Foothills has been shown to be a potentially attractive CBM exploration target. New data obtained from a shallow exploration hole in the Coal Valley area had saturated gas concentrations averaging 4.3 cc/g, more than double the previously reported gas concentration results from the same area. More detailed studies into geology and reservoir characteristics are warranted in this area.

Coals of the Horseshoe Canyon Formation are currently undergoing CBM production. Seams are typically thin, discontinuous and difficult to correlate. Adjacent wells have significantly different production rates. This study indicates that different seams within a wellbore contribute differently to overall production of that well and, furthermore, that the same (correlatable) seams between adjacent wells have different contributions to well production.

Mannville coals are generally thick, deep and of low permeability. Local areas of the Mannville Coal

Zone are reported to have enhanced permeability, and several of these areas are undergoing production pilots. This study recognized a large region in east-central Alberta with favourable CBM gas-in-place; however, no permeability data were available. Two tests from this area were conducted. Although significant elevated permeability was not encountered, a slight increase over regional values was indicated. Furthermore, differences were encountered in permeability between the two seams tested.

The study indicates great potential for CBM producibility in Alberta. Local areas have enhanced characteristics favourable to production. Ongoing geological investigations are needed to explain these anomalies, and to identify characteristics that will act as an exploration tool for future CBM discoveries.

1 Introduction

The Canadian Gas Potential Committee estimated that the Western Canada Sedimentary Basin contains 4.02 x 10^{12} m^3 (142 trillion cubic feet [tcf])[1] of conventional gas reserves and potential resources (Woronuk, 2001). Alberta's remaining gas resources are estimated to be in the order of 2.78 x 10^{12} m^3 (98 tcf; Alberta Department of Energy, 2002), of which 1.19 x 10^{12} m^3 (42 tcf) are established reserves (Alberta Energy and Utilities Board, 2002). Production of gas in Alberta was 1.47 x 10^{11} m^3 (5.2 tcf) in 2001, and demand is expected to increase in the coming years. This poses a potential supply problem in the near future. The National Energy Board (1999) predicted that unconventional gas reserves would be required to supplement demand for conventional reserves within the next 10 years.

Government and industry are starting to evaluate unconventional gas sources for future supply. A potential resource showing great promise is coalbed methane (CBM). Coal has the potential to generate and retain large quantities of methane, and this gas may be produced if suitable geological and hydrogeological conditions are met. The CBM industry in the United States has grown significantly over the past 20 years, to the point where CBM accounts for approximately 9% of total gas produced, or 3.91 x 10^{10} m^3 (1.38 tcf) in 2000. Coalbed methane accounts for 8.8% (4.45 x 10^{11} m^3, or 15.7 tcf) of total United Sates gas reserves (Ayers, 2002).

Drawing on the earlier American successes in CBM production, Alberta experienced minor exploration activity in the late 1980s and early 1990s, resulting in a limited number of wells being drilled and tested for CBM. Exploration stagnated soon thereafter, in part due to discouraging initial results (which indicated low permeability and low to moderate gas concentrations in many coals investigated) and to the onset of low gas prices.

Predictions of supply shortages and increasing gas prices have again sparked interest in CBM potential. There has been a resurgence in exploration during the past 3 years in Alberta.

Alberta has substantial coal resources in the Plains and Foothills. The potential gas resources held within these coal deposits have been estimated to range from 2.83 x 10^{12} m^3 (100 tcf) to more than 1.56 x 10^{13} m^3 (550 tcf; Woronuk, 2001; Heath, 2001). Studies have been conducted by the Alberta Geological Survey on Upper Cretaceous–Tertiary coal-bearing strata from the Alberta Plains, and all coal-bearing strata from the Mountains-Foothills (Beaton et al., 2002, Langenberg et al., 2002;). Maximum gas-in-place was estimated to be 3.7 x 10^{12} m^3 (130 tcf) for the Foothills-Mountains and 5.28 x 10^{12} m^3 (186 tcf) for the Plains region. Lower Cretaceous Mannville coals were not included in these evaluations; however, previous studies suggest up to 1.13 x 10^{13} m^3 (400 tcf) maximum gas-in-place for the Plains (MacLeod et al., 2000). The wide range in estimates of gas potential stems from the sparse data available on CBM content; even less is known about coal-reservoir characteristics and producibility of the potential resource.

In Alberta, public-domain CBM data are available for approximately 70 wells (Table 1; Dawson et al., 2000), although it is estimated that more than 200 wells have recently been drilled and/or tested (Daily Oil Bulletin, 2003). The majority of the new data are not yet available or still held confidential. Twenty-eight of the wells reported in the public domain are from the Foothills. Of the reported wells from the Plains, the majority target the coals of the Lower Cretaceous Mannville Group. Less than 20 wells are available within the public domain that report adequate data on Upper Cretaceous–Tertiary strata, all from the Ardley Coal Zone. The majority of the wells reported indicate only gas concentrations. Limited permeability data are available and, of those data, it was suggested that some of the tests were flawed and the data may therefore be unreliable (Dawson et al., 2000).

[1] In keeping with current industry paractice, the AGS uses the following non-Si abbreviations for gas volumes: mcf, thousand cubic feet; mmcf, million cubic feet; bcf, billion cubic feet; tcf, trillion cubic feet.

Table 1. Coalbed methane well-test results reported in the public domain (after Dawson et al., 2000).

Well name	Well ID	Depth	Coal seam/zone	Average gas concentration *	Core or cuttings	Additional information	
Plains							
PanCanadian (PCP) Ewing Lake	7-1-37-21w4	1375	Mikwan or Medicine River of Mannville	6.5 cc/g		0.1 - 2mD ?	
PanCanadian Sieu Lake	10-12-24-18w5	1225	Medicine River of Mannville	6.1 cc/g		7 m3/d	
PanCanadian Wintering Hills	11-26-23-17w5	>1600	Medicine River of Mannville				
PanCanadian Westerose	14-7-45-1w5m	1775	Medicine River of Mannville	3.6-6.6 cc/g		26 m3/d	
PanCanadian Westerose East	7-13-45-1w5m	1665	Medicine River of Mannville	10.1 cc/g		17 m3/d	
PanCanadian Westerose South	8-5-45-1w5m	1791	Medicine River of Mannville	3.5 cc/g		low perm, 23 m3/d	
PanCanadian Elnora	6-5-34-23w4	1500	Medicine River of Mannville	7.6 cc/g		5 m3/d	
PanCanadian Homrin	8-4-42-2w5m	1865	Medicine River of Mannville				
Gulf Gough	4-23-36-20w4m	1280	Medicine River of Mannville			0.1-1 mD	78 m3/d
Gulf Fenn West	16-4-36-20w4m	1415	Medicine River of Mannville	8-11 cc/g			
Enron Twining	8-14-32-25w4m	1635	Mikwan or Medicine River of Mannville	2.6 -7.8 cc/g		3 m3/d	
Enron Twining	16-23-33-25w4m	1600	Mikwan or Medicine River of Mannville	6.7-8.6 cc/g		6.5 m3/d	
Lionheart Consortium Attock	5-3-41-25w4m	1544	Medicine River of Mannville	5.6-6.2			
Lionheart Consortium Chigwell	15-36-41-25w4m	1546	Medicine River of Mannville			10-25 mcf/d	
Alberta Energy Jenner	13-23-20-9w4m	921	Medicine River Equivalent	2.2 cc/g			
Alberta Energy Suffield	7-34-19-8w4	>950	Medicine River Equivalent	2.5 cc/g (daf)			
Alberta Energy Suffield	9-35-19-7w4m	?	Medicine River Equivalent				
Alberta Energy Suffield	13-1-20-8w4m	960	Medicine River Equivalent	1.3-6.9 cc/g		1-4 mD test on core in lab	
Gulf Sylvan Lake	14-15-38-3w5m	422	Ardley zone (ScollardFm)	1.25 cc/g	cuttings		
Gulf Gilby	8-13-41-4w5m	2056	Medicine River	4 cc/g	cuttings		
PetroCanada Gilby	6-15-41-3w5m	476	Ardley zone (ScollardFm)	1.95 cc/g			
(2 zones)		2058	Medicine River of Mannville	10-12 cc/g		< 1 mD	
PetroCanada Battle Lake	6-6-46-1w5m	?	Medicine River of Mannville				
PetroCanada Redwater	10-21-57-21w4m	666	Medicine River of Mannville	2.2-5.5 cc/g		1 m3/d, moderate perm (flow test)	
Amoco Blackstone	16-11-44-15w5m	1050	Coalspur Fm	4.3-5.8	cuttings		
Amoco Brazeau River	10-28-45-14w5m	800	Coalspur Fm	1.7-2.9 cc/g			
Norcen Colt	9-22-58-24w5m	2664	Medicine River of Mannville	3.0 cc/g	cuttings		
Norcen Kaybob S	15-21-60-19w5m	2082	Medicine River of Mannville	4.5 cc/g	cuttings		
Norcen Kaybob S	16-24-60-20w5m	2044	Medicine River of Mannville	2.5 cc/g			
Norcen Por Fir	2-14-58-21w5m	2301	Medicine River of Mannville	15.6 cc/g	cuttings		
Norcen Pembina	3-29-47-6w5m	389	Scollard	4.7 cc/g			
Norcen Pembina	3-36-46-2w5m	1673	Medicine River of Mannville	7.8 cc/g			
Norwest Majeau	16-15-57-6w5m	1036	Medicine River of Mannville	1.4 cc/g	cuttings		
Norwest Tomahawk	12-17-52-6w5m	1616	Medicine River of Mannville	10.2 cc/g			
Norcen Seaforth	9-23-57-25w5m	522	Scollard	1 cc/g	cuttings	lost gas not determined	
		2917	Medicine River of Mannville				
Norcen Simonette	9-34-61-26w5m	2532		3.8 cc/g			
Wascana Brazeau	8-5-48-11w5m	560	Coalspur	3.5-4.5 cc/g	cuttings		
		2338	Medicine River of Mannville	12 cc/g	cuttings	<0.1 mD, 100 mcf/d	
BHP Pembina	14-15-46-10w5m	581	Coalspur	3.7 cc/g		4-7 mD (DST) 35 mcf/d	
BHP Brazeau (Peco)	10-16-48-14w5m	820	Coalspur	2.5 cc/g			
BHP Pine Creek	11-06-56-19w5m	825	Coalspur	2 cc/g		<10 mD (between 5-10??)	
BHP Embarras	10-19-50-19w5m	704	Coalspur	1.35 cc/g			
Alberta Energy Columbia 1	1-34-45-15w5	433	Coalspur	4-5 cc/g		<0.1 mD, 7-8 m3/d	
Alberta Energy Columbia 2	8-28-45-15w5	652	Coalspur				
Can Hunter Red Rock	3-16-63-8w6m	3066	Falher/Gates??			<0.1 mD, 23 mcf/d	
Alberta Energy Karr	6-6-66-3w6m	2154	Spirit River	2 cc/g	cuttings		
PCP et al Provost	15-19-41-3w4m	790	Mannville	1.3 cc/g		lost gas not determined	
Barich Penhold	13-02-37-28w4m	265	Scollard	2.59 cc/g		5.8 mD (2 zones 3.3&8.3)	
Foothills							
CanHunter Coleman	4-18-11-3w5m	500	Kootenay			1-2 mD	
CanHunter Coleman	6-14-8-5w5m	1307	Kootenay	9.87 cc/g, daf		1-2 mD	
CanHunter Coleman	7-35-8-4w5m	394	Kootenay	7.92 cc/g, daf		1-2 mD	
Algas Coleman	8-19-9-4w5m	265	Kootenay	12 cc/g, daf		31 mcf/d	
Algas Sullivan	10-34-15-5w5m	121	Kootenay	7.8 cc/g, daf		1 mcf/d	
Saskoil Turner Valley	8-10-19-3w5m	859	Kootenay	10.2 cc/g, daf			
Algas 1 Canmore	8-01-24-10w5m	235	Kootenay	20 cc/g, daf		19 mcf/d	
Algas 2 Canmore	4-06-24-9w5m	191	Kootenay	10 cc/g, daf		9 mcf/d	
Algas 3 Canmore	2-01-24-10w5m	304	Kootenay	20.8 cc/g, daf		36 mcf/d	
Algas R1 Canmore	9-21-24-10w5m	55	Kootenay	10 cc/g, daf		<10 mcf/d	
Algas R2 Canmore	10-21-24-10w5m	124	Kootenay	16 cc/g, daf		48 mcf/d	
Northridge Caroline	6-23-33-7w5m	3016	Gates			2.2 mcf/d	
Shell Ram River	11-11-38-15w5m	582	Gates	7 cc/g, daf			
Mobile Grande Cache	6-14-57-7w6m	592	Gates	13.1 cc/g, daf		0.08 mD	
Mobil/Smoky Grande Cache	8-21-58-8w6m	196	Gates	2.3 cc/g, daf			
Cardinal River Cadomin	7-26-47-24w5m	253	Gates	6.6 cc/g			
Cardinal River Cadomin	7-26-47-24w5m	303	Gates	17.7 cc/g			
Conoco Coal Valley	11-20-47-18w5m	656	Coalspur	1.7 cc/g, daf			
Conoco Coal Valley	11-20-47-18w5m	1114.4	Brazeau	0.3 cc/g, daf			
Luscar-Sterco Coal Valley	12-17-47-19w5m	46.6-300	Coalspur	0.5-3.2 cc/g, daf			
(8 minesite holes)				(average 1.78 cc/g, daf)			

* cc/g = cubic centimetres per gram of coal, as-received basis, unless specified as dry ash-free basis, (daf)

1.1 Purpose of the Project

Alberta's CBM potential is still unclear. Previous studies have indicated that there are potentially large resources of coalbed gas in place; however, there is both a technical and an economic challenge in recovering this gas. Coals in the basin generally have low permeability. Permeability is a critical factor in CBM production because an open reservoir, with a well-established network of interconnected cleats and fractures, is required to allow gas adsorbed onto the coal to desorb and migrate to the wellbore for production. Furthermore, as gas is held onto the coal by pressure, permeability is required to facilitate reservoir depressurizing (e.g., dewatering in water-wet reservoirs), which in turn allows gas to desorb and migrate from the coal matrix for production.

In Alberta, coals typically occur within a 'coal zone', a grouping of individual coal seams that occur in close proximity over a relatively thin (20–50 m) stratigraphic interval. Individual seams from within a given coal zone can have similar reservoir characteristics or they may be very different from one another. Investigations conducted by the Alberta Geological Survey indicate that permeability and gas contents can differ significantly for different seams within a given coal zone. Therefore, their gas production potential will probably be different.

Public-domain data on coal permeability and gas distribution are rare for coals of the Horseshoe Canyon Formation and the Belly River Group. Furthermore, permeability data are minimal, and sometimes questionable for coals of the Scollard Formation (Ardley) and Mannville Group. Test data from Ardley and Mannville Group coals show wide ranges of permeabilities and gas contents over relatively short distances.

Recently, coalbed methane has been successfully produced from Horseshoe Canyon Formation coals in south-central Alberta, and Mannville CBM pilot projects are well established in the north-central Alberta Plains region (New Technology Magazine, 2003; Canadian Discovery Digest, 2002). Foothills CBM exploration is starting to accelerate (Daily Oil Bulletin, 2003). The Ardley Coal Zone is undergoing CBM exploration, and several pilots and/or test wells are underway in different areas of the province.

The goals of this project were to 1) obtain and interpret gas concentration and production data from Ardley and Horseshoe Canyon strata; and 2) gather permeability data from Mannville strata from the Alberta Plains in areas where data are lacking or suspect. The project also investigated gas content data from the Coalspur Formation (Ardley equivalent) in the Foothills, where data are lacking. New data were compared to existing data where available. Permeability has been identified as one of the key technical obstacles for the CBM industry in Alberta (Heath, 2001). Data of this nature are critical in evaluating CBM production potential, and may assist in determining controls on CBM potential across the province. The results obtained will be useful in aiding exploration and production throughout Alberta.

2 Coalbed Methane Review

2.1 Methane Generation in Coal

Coal is an organic-rich rock derived primarily from plant material that underwent burial and compaction, which resulted in progressive physical and chemical changes within the original plant material. With increasing depth of burial, the plant material underwent coalification, progressively losing moisture and volatile matter while increasing its heating value, carbon content and reflectance properties (Levine, 1993). Generation of methane gas is also a result of coalification. Coal rank refers to the degree of physical and chemical alteration to which the plant matter has been subjected. Coal-rank classification identifies the general properties of a given coal, and also indicates the changes and maturation stages that coal has undergone (Figure 1).

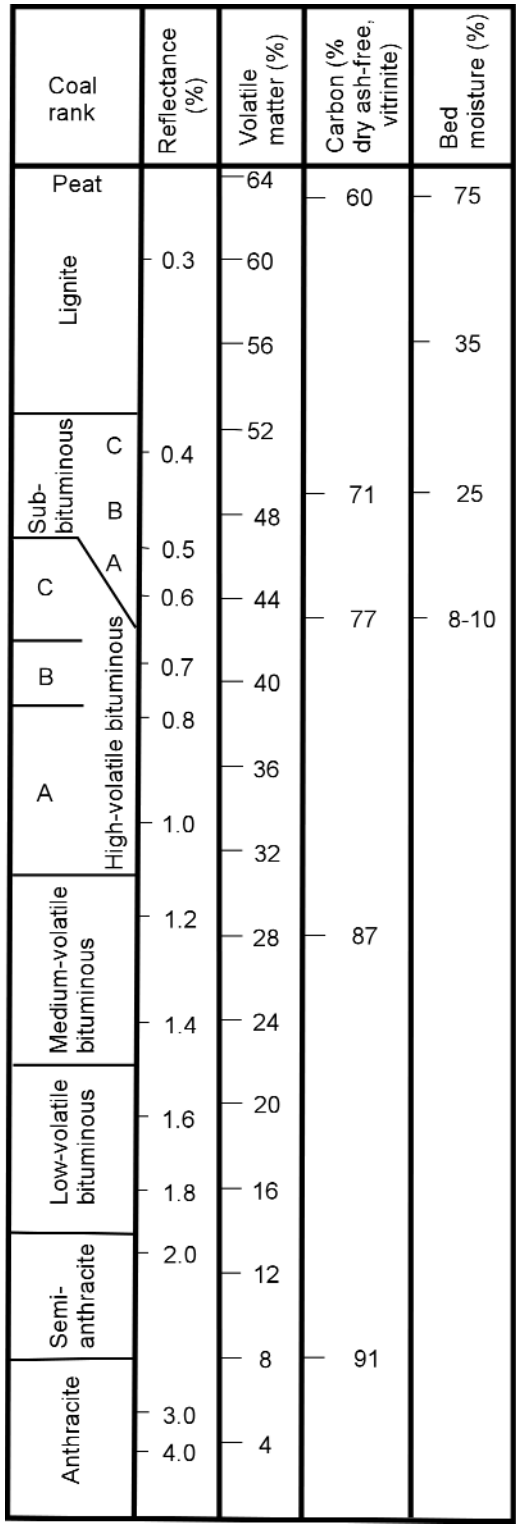


Figure 1. Coal classification based on rank and chemical properties (modified from Stach et al., 1982)

As plant matter (peat) undergoes progressive burial and compaction, it passes through the stages of peatification and dehydration, where the plant material undergoes humification, gelification and loss of volatiles from the organic matrix as the transformation to coal begins. These stages are represented by peat and lignite on Figure 1. With ongoing coalification through the sub-bituminous to bituminous ranks, the material becomes progressively enriched in carbon and continues to expel volatile matter (water, CO_2, CH_4). Generation of methane and hydrocarbon is a result of thermal maturation in coals, and is initiated at a rank of high-volatile bituminous C (reflectance >0.5%); the amounts generated increase significantly throughout the medium- to low-volatile bituminous ranks (Figure 2). Coals may produce anywhere from 100 to 300 cubic centimetres of gas per gram of coal (cc/g) throughout the coalification process.

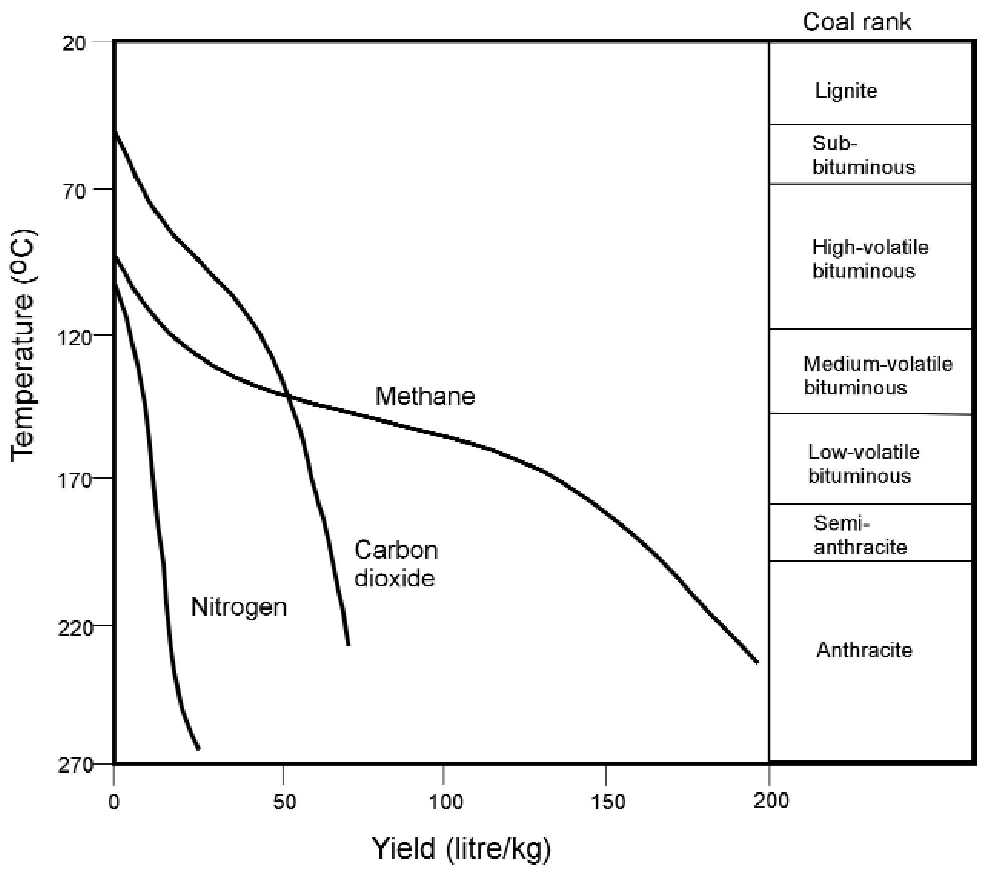


Figure 2. Gas generation potential as a function of coal rank (*modified from* Hunt, 1991).

Biogenic gas may be produced from the early stages of peat through to lignite (Rice, 1993) and be retained in the coal. Late-stage biogenic gas may occur within coals as a secondary product associated with active groundwater systems. Groundwater invasion initially allows aerobic-oxidation microbial processes to occur, the by-products of which provide energy supplies for anaerobic (methanogenic) bacteria (Rice, 1993).

Gas is stored in coal as an adsorbed component on or within the coal matrix, and as a free gas within the micropore structure or cleats within a coal bed. Coal has a large surface area due to its extensive microporous nature, with surface area (determined by CO_2 displacement on Lower Cretaceous Gates coals) being in the range of 160–300 m^2/g coal (Bustin, 2001). The capacity of coal to adsorb gas is dependent on pressure, temperature and coal rank. Increasing reservoir temperature restricts adsorption capacity, whereas increasing pressure increases adsorptive capacity (Bustin, 2001). Medium-volatile bituminous coals have typically generated more gas than they actually have the capacity to store.

2.2 Gas Content and Capacity

Gas content of a coal seam is typically determined by cutting a core of the coal, quickly retrieving it to surface, and placing intervals of the core in sealed canisters (Figure 3). Gas released (desorbed) from the core is determined by measuring cumulative gas bled from the canister over controlled time intervals (Figure 4). Cumulative gas desorption over time is corrected to standard temperature and pressure conditions, and presented on a desorption isotherm plot (Figure 5). Corrections are made for gas lost prior to sealing the sample, pressure-temperature variations and residual gas (Gas Research Institute, 1997). Although core is the preferred sample medium, cuttings and sidewall cores are also used to determine gas content. Because data from these latter sample media may not be as reliable, suitable correction factors must be applied to account for contamination and nonrepresentative samples.

Maximum gas-holding capacity of a coal sample is obtained from adsorption-isotherm analysis. A coal sample (ideally a sample that has previously been desorbed and from which the in-place gas concentration is known) is crushed, brought to equilibrium moisture and placed in a pressure vessel held to reservoir temperature. Gas is introduced into the vessel at specific pressure intervals. The amount of gas the sample adsorbs upon equilibrium is determined. Adsorbed gas volumes with increasing pressure follow Langmuir equations of gas adsorption (Bustin, 2001); from these, Langmuir volume (maximum saturation) and Langmuir pressure (pressure at half the maximum adsorption capacity) can be derived. Langmuir pressure and volume can be used to calculate gas concentrations of similar coals occurring at different depths if the depth-pressure relationship is known for the area of investigation.

The adsorption isotherm provides maximum gas capacity. By comparing maximum gas capacity to results obtained from the desorption analysis, the gas saturation of a sample can be determined.

The adsorption isotherm plot (Figure 6) provides an indication of reservoir potential. Gas concentration derived from desorption analysis (e.g. Figure 5) is plotted against reservoir pressure. A saturated coal will fall on the isotherm curve, whereas an undersaturated sample will plot below the curve. Reservoir pressure increases adsorptive capacity of the coal, so that, in order for a coal to release the adsorbed gas, pressure must be reduced to the point where the sample will fall on the isotherm curve. Pressure is often reduced in CBM wells by pumping water from the seam.

2.3 Challenges to Production: Permeability Constraints

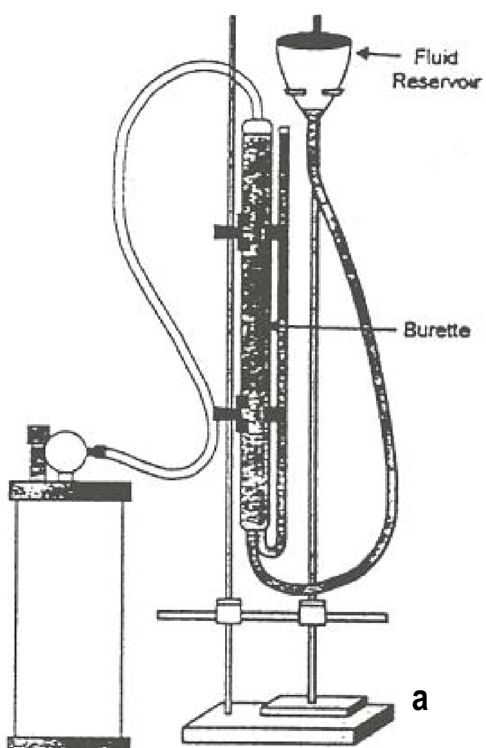
2.3.1 Coal Cleat

The coal matrix, where gas is generated and adsorbed, is commonly too ‘tight’ or impermeable to allow sufficient gas to migrate to a well bore, or to allow dewatering in order to reduce reservoir pressure and establish gas migration. Fluid flow in coals requires a fracture or ‘cleat’ network to reduce reservoir pressure in order to allow gas to desorb from the coal matrix into the fracture network, and facilitate gas movement from the coal matrix toward a wellbore (Ayers, 2002). Permeability in coals is related to the degree of fracturing or cleat within a coal. Coal cleats are a systematic, subparallel network of fractures that are oriented vertically to subvertically to bedding and closely spaced (in the order of millimetres to centimetres). There is commonly a pervasive cleat spacing and direction (face cleat), which may be coupled with an orthogonal subordinate cleat (butt cleat) that often has a wider spacing (Figure 7). These cleats can have various spacings, aperture widths and connectivities (Ayers, 2002; Laubach et al., 1998),

a

b

Figure 3. a) Desorption canisters containing coal core. b) Canister bank in heat box to maintain reservoir temperature



a

(modified from Bustin 2001)

b

Figure 4. Schematic (a) and actual apparatus (b) used to measure desorbed gas from desorption canisters.

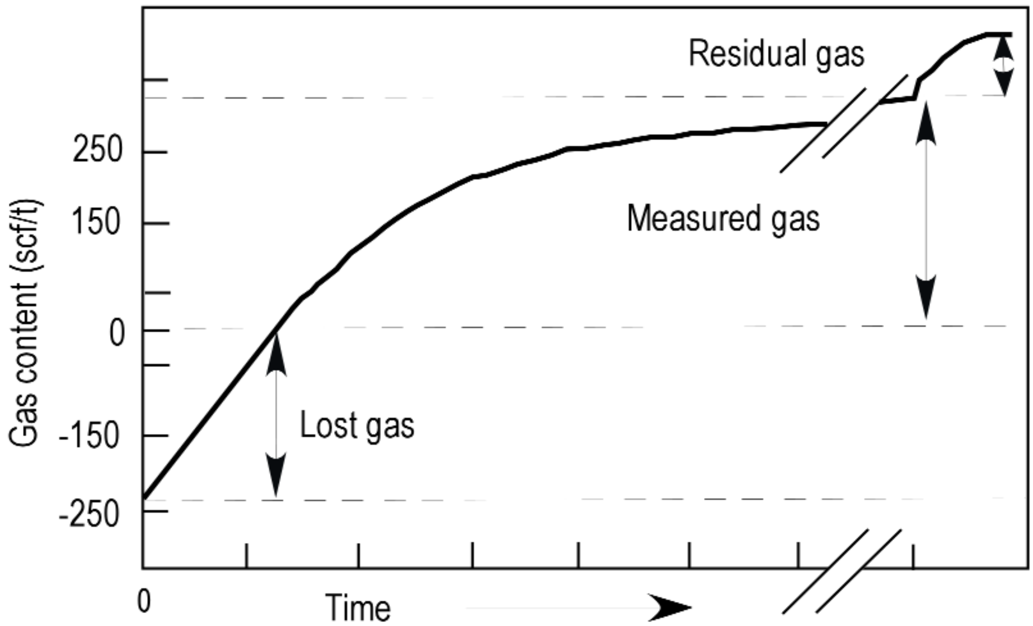


Figure 5. Example of a desorption isotherm plot (modified from McLennan et al., 1995).

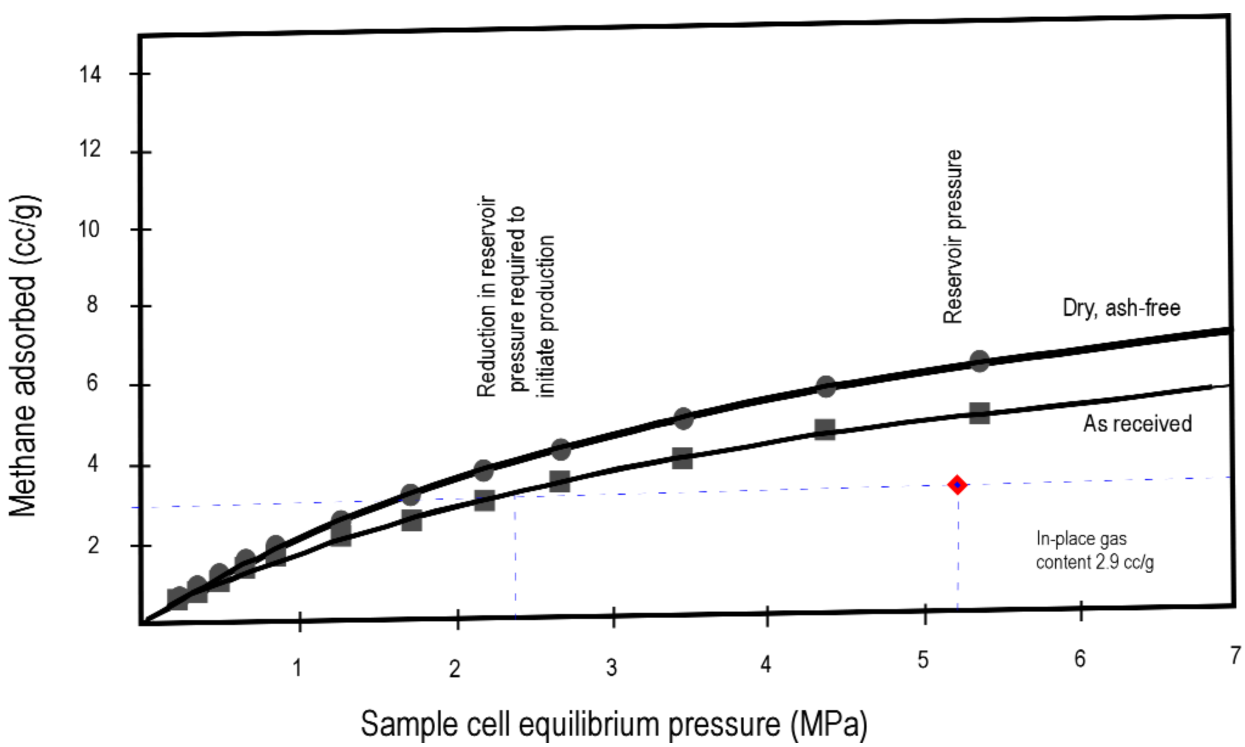


Figure 6. Example of an adsorption isotherm plot.

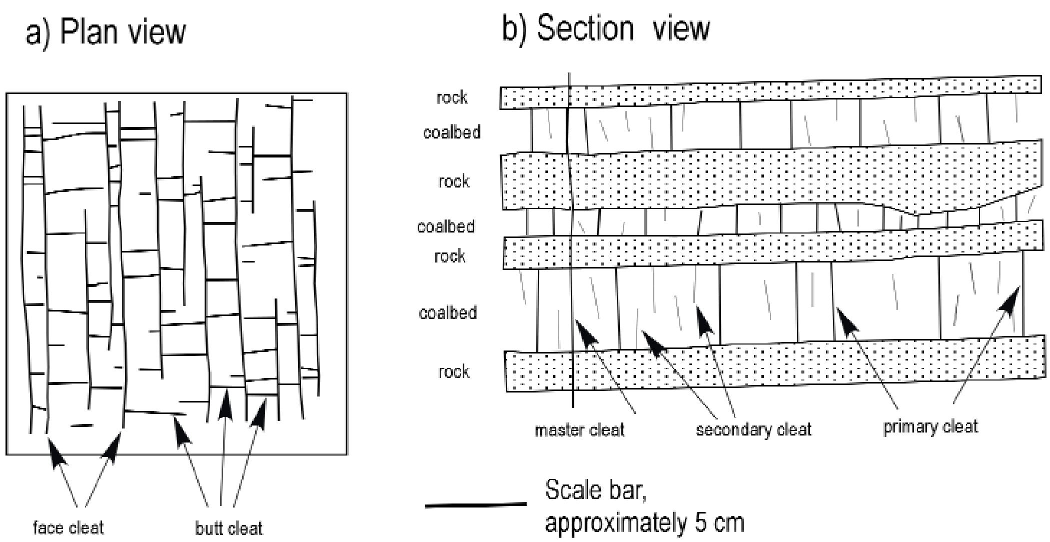


Figure 7. Cleats in coal (modified from Laubach et al., 1998).

which are, in part, related to coal composition, rank and structural history. Cleats can be present in coals of any rank, although cleat spacing typically is greatest in low-rank coals, with spacing distance decreasing in higher coal ranks. Cleats may have formed, in part, as stress fractures resulting from coal devolatilization and shrinkage within an oriented stress regime (Laubach et al., 1998). Cleats act as a conduit for fluid flow, and may also act as sites for biogenic gas production and migration (Ayers, 2002). Permeability generally decreases with depth, as overburden stress compresses the coal and cleat matrix, effectively reducing permeability. Most productive coal seams in the United States occur at depths less than 1200 m (Figure 8).

2.3.2 Permeability and Producibility: United States and Alberta Coals Compared

Permeability is a critical factor controlling CBM production. The highly productive 'Fairway zone' of the Fruitland Formation in the San Juan Basin of Colorado and New Mexico contains individual wells that can produce 1–6 mmcf/day. Permeability within the San Juan Basin ranges from 15–60 millidarcies (mD)[2] in the high productive Fairway zones, and tapers to less than 5 mD in the least productive areas of the basin (Ayers, 2002). A combination of high permeability, favourable coal rank (high- to medium-volatile bituminous) and geology, hydrogeological overpressuring and biogenic methane contributions combine to make the San Juan Basin the largest CBM gas producer in the world. Initially it was hoped that some Alberta coals would match the potential of the San Juan Basin, particularly in the deeper parts of the Plains or in the Foothills, where thermally mature coals and potential hydrogeological and structural conditions may contribute to a 'Fairway' situation. To date, this has not been realized in Alberta.

In recent years, the Powder River Basin of Montana and Wyoming has become a highly productive CBM basin. Initially thought to have coals that were too low in rank (sub-bituminous) and too shallow in depth to produce and retain sufficient methane, the thick, highly permeable coals have limited quantities of thermal methane but large amounts of biogenic methane. Successful gas production in Powder River Basin coalbeds led companies to turn their attention to coals in Alberta that had characteristics similar to those in the Powder River Basin, namely fluvial-deltaic coals of low rank (sub-

[2] Although not an accepted SI unit of measure, the millidarcy has been retained because of it's universal acceptance in the oil and natural gas industries. 1 mD = 9.869223 x 10^{-16} m^2.

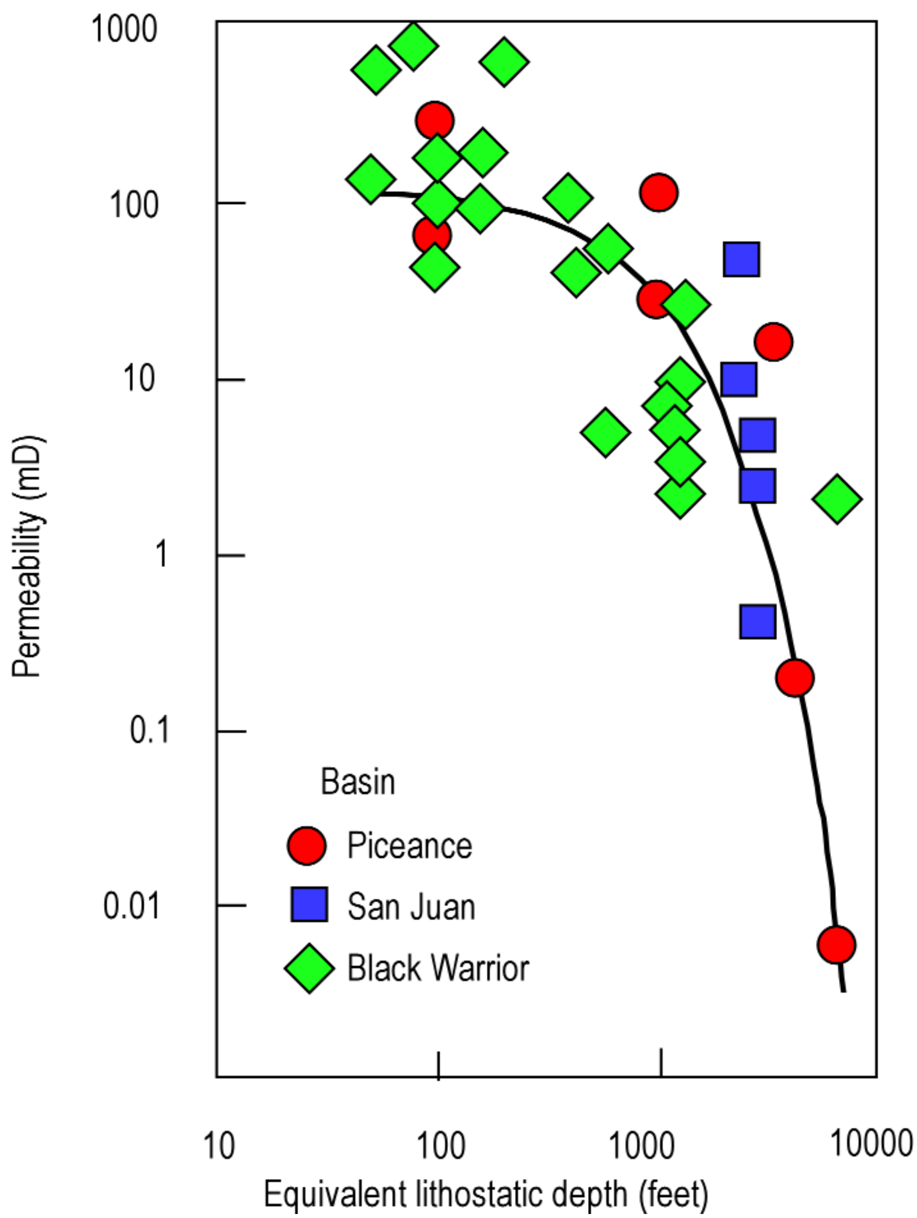


Figure 8. Permeability versus depth (modified from McKee et al., 1988).

bituminous), low gas contents (1–2 cc/g), low reservoir pressures, and possible biogenic gas contributions. Unlike the Powder River Basin, Alberta Plains coals have low permeability (1–3 mD, compared to permeabilities ranging from a few millidarcies to several darcies in the Powder River Basin). Additionally, the coals in the Powder River Basin are thick (net coal can exceed 90 m), whereas net coal of an Alberta coal zone rarely exceeds 20 m, and 6–12 m is typical net coal thickness. The interplay of high permeability and thick coals overcomes the generally low gas contents in the Powder River Basin, whereas Alberta is challenged by thinner, lower permeability coals. Powder River Basin coals are aquifers, and produce large quantities of water during reservoir depressurization (in the order of 200–500 bbl water per day [bbl/d], but some wells exceed 1000 bbl/d). Currently, Alberta Plains shallow coals produce at most a few barrels of water per day during depressurization. Deeper Mannville coals from Alberta may produce in the order of 150 bbl/d during depressurization (New Technology Magazine, 2003).

It has become clear that the Alberta CBM play will have its own set of unique factors that need to be fully examined and understood if Alberta is to become a major CBM producer. The big producers (San Juan and Powder River basins) in the United States that have showcased the potential for CBM production may be unique cases that have no direct analogues in Alberta.

3 Coal-Bearing Formations in the Alberta Plains

Packages of coal occur within distinctive horizons of the Scollard, Horseshoe Canyon, Belly River and Mannville strata in the Alberta Plains, and within the Wapiti, Luscar and Kootenay strata of the Foothills (Figure 9). These coal packages are referred to as 'coal zones', which are laterally continuous intervals of interbedded coal and inorganic partings. There is no defined minimum or maximum thickness of interbedded sediment that defines a coal zone. Nevertheless, the individual zones commonly contain several metres of net coal over a relatively small stratigraphic interval (in the order of several metres), and individual coal zones are separated from one another by several metres (30–50 m) of rock. Coal rank trends in Alberta are presented in Figure 10. Most coals at shallow depths (<1000 m) in the Plains are within the rank range of sub-bituminous to high-volatile bituminous C-B. Coals from the Foothills are generally more mature, with ranks ranging from high-volatile bituminous B to low-volatile bituminous. Stratigraphic relationships of the coal zones in Alberta are presented in Figure 11.

3.1 Paskapoo Formation

The Scollard-Paskapoo contact is defined at the base of the thick massive sandstone above the Ardley Coal Zone. In outcrop, this contact is marked by the thick, buff-coloured sandstone of the Paskapoo lying directly above the coal-bearing strata of the Ardley Coal Zone (Demchuk and Hills, 1991). The Paskapoo-Scollard boundary has been described as abrupt and disconformable (Lerbekmo et al., 1990).

In the Paskapoo Formation, thick (>15 m), tabular, buff-coloured sandstone beds are commonly stacked into successions more than 60 m thick and overlain by interbedded siltstone and mudstone. Laterally, the Paskapoo Formation thickens from east to west. Several thin coal beds occur throughout the Paskapoo Formation (Demchuk and Hills, 1991). In the Alberta Plains, the Paskapoo Formation is commonly covered by Late Tertiary–Quaternary sediments or till.

3.2 Scollard Formation

The Scollard Formation disconformably overlies the Battle Formation and consists of thick, grey- to buff-coloured sandstone and siltstone interbedded with thin shale and coal.

Two units are recognized in the Scollard Formation. The lower (barren interval) and upper (coal-bearing) members are separated by the basin-wide Cretaceous-Tertiary (K-T) boundary (Sweet and Braman, 1992). The K-T boundary is located near the base of the Ardley Coal Zone. Both upper and lower members of the Scollard Formation thicken from east to west.

The lower Scollard is generally barren of coal and comprises primarily thin, fining-upward cycles of fine-grained, buff-coloured sandstone overlain by medium to dark grey mudstone and greenish grey siltstone (Dawson et al., 1994). The upper Scollard contains the thick, widespread Ardley Coal Zone. Based on palynology, the Ardley Coal Zone has been correlated with the Kakwa Coal Zone in the Wapiti area (Dawson et al., 1994).

The Scollard Formation of the central Plains correlates with the Coalspur Formation of the central Foothills and the Willow Creek Formation of the southern Foothills and Plains (Jerzykiewicz, 1997). In Saskatchewan, the lower member is equivalent to the Frenchman Formation and the upper member is correlative with the lower part of the Ravenscrag Formation.

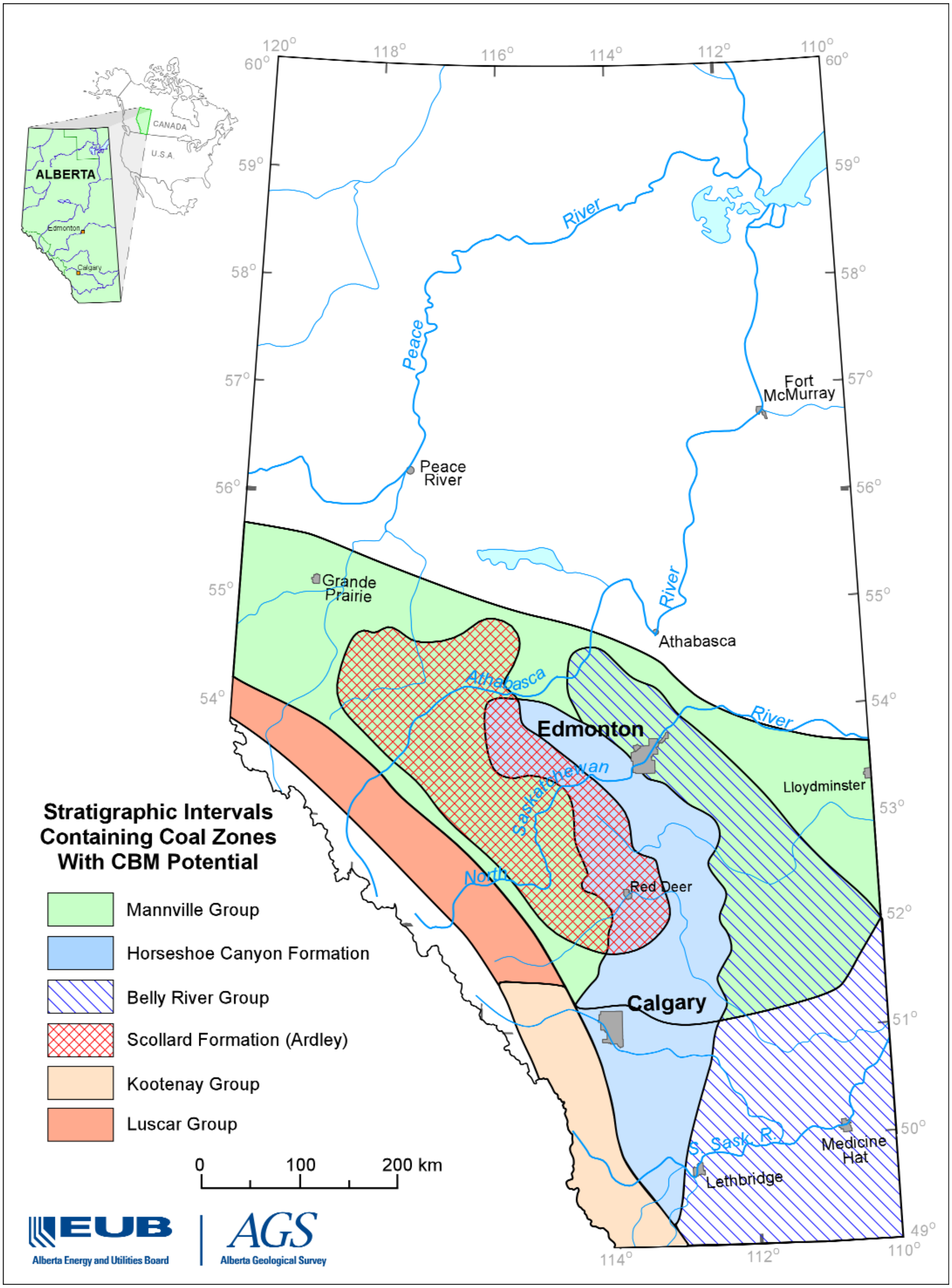


Figure 9. Distribution of major coal-bearing strata with coalbed methane potential, Alberta.

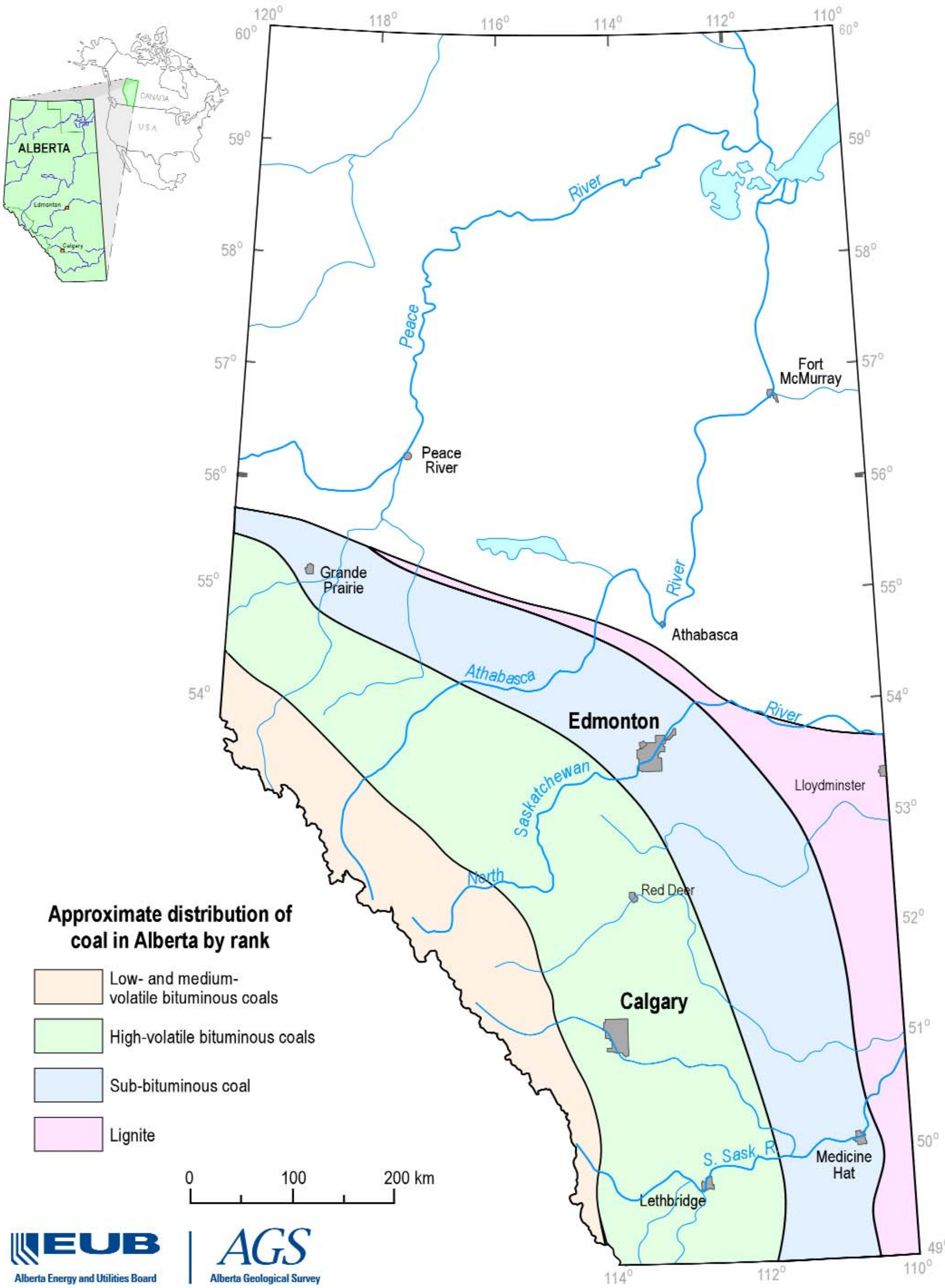


Figure 10. Coal-rank trends across Alberta.

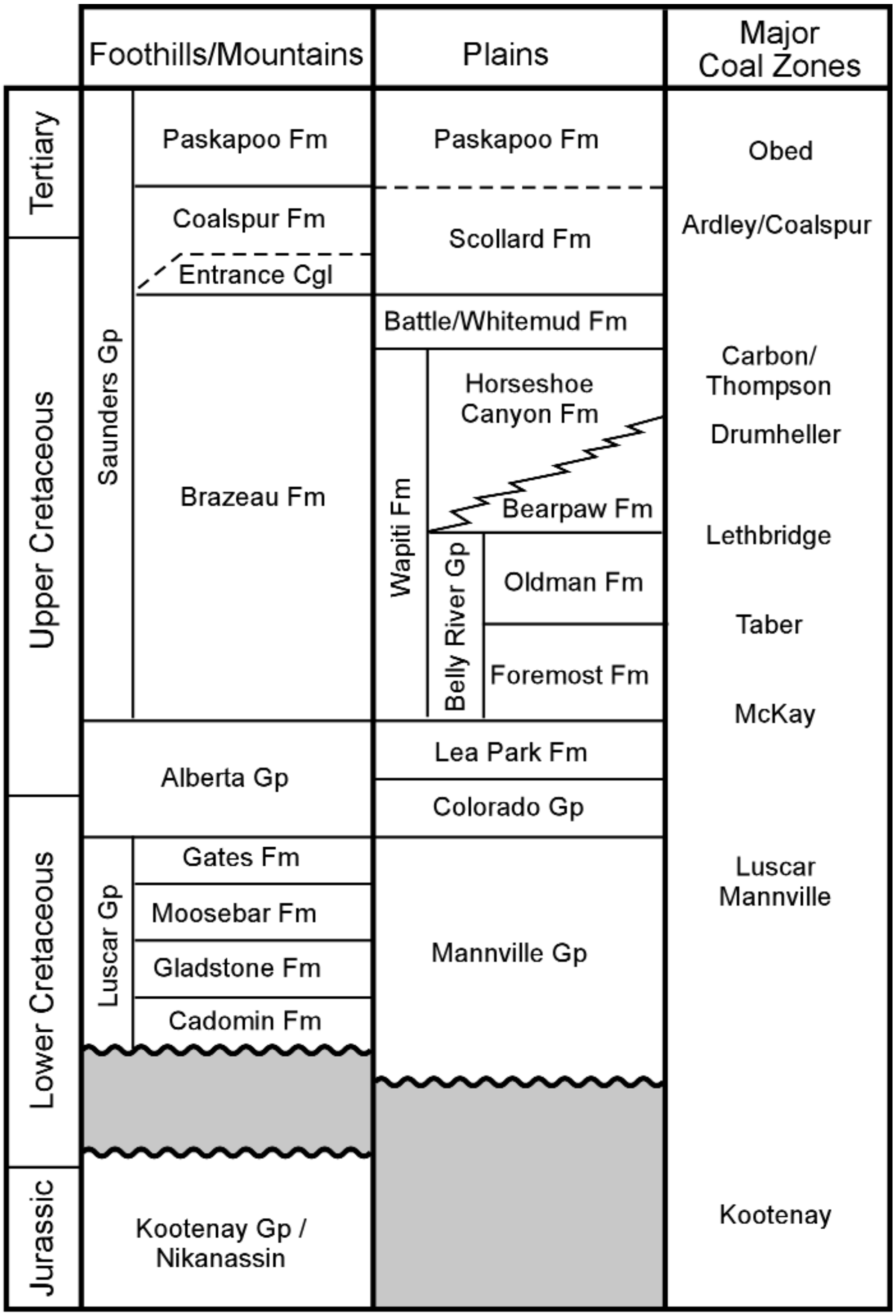


Figure 11. Stratigraphy of coal-bearing strata, Alberta.

3.2.1 Coal Zones of the Scollard Formation

There is one coal zone within the Scollard Formation, the Ardley Coal Zone (Figure 12). This coal zone consists of four individual ‘packages’ of coal seams (essentially distinct coal zones themselves) and related interburden associated with fluvial and lacustrine continental clastic sediments. Coal seams are laterally continuous and thick. Maximum individual seam thickness and number of seams are greatest in the western part of the Plains, where peat accumulation was accentuated by increased subsidence, coupled with protection from clastic input by major river systems running parallel to the mountain front (Richardson et al., 1988). Seam thickness and number of seams decrease eastward in the Plains.

The Coalspur Formation is the Foothills equivalent of the Scollard Formation. The Ardley Coal Zone is continuous across the Coalspur and Scollard formations. Coalspur Formation nomenclature subdivides the coal zone into four coal 'subzones'. These 'subzones' are identified as the Val D'Or, Ardley, Silkstone and Mynheer coal zones. These seams/zones represent up to 18 individual seams that occur as a closely spaced package. All seams/zones are present in the western and central portions of the Plains, although the upper seams are absent toward the east. Proximal to outcrop, Scollard Formation nomenclature identifies only the 'Upper' and 'Lower' Ardley coal zones. Recent compilations by Dawson et al. (2000) have extended Coalspur Formation seam nomenclature eastward toward outcrop. The average thickness of the Ardley Coal Zone ranges from 14 m near outcrop to greater than 200 m at the western margin of the Plains. Furthermore, the number of seams increases from an average of four near outcrop to as many as 18 at depth near the western limit of the Plains. The increased number of seams corresponds to increasing net coal thickness within the Ardley Coal Zone. The Ardley Coal Zone is correlative with the Kakwa Coal Zone of the Wapiti area (Dawson et al., 1994).

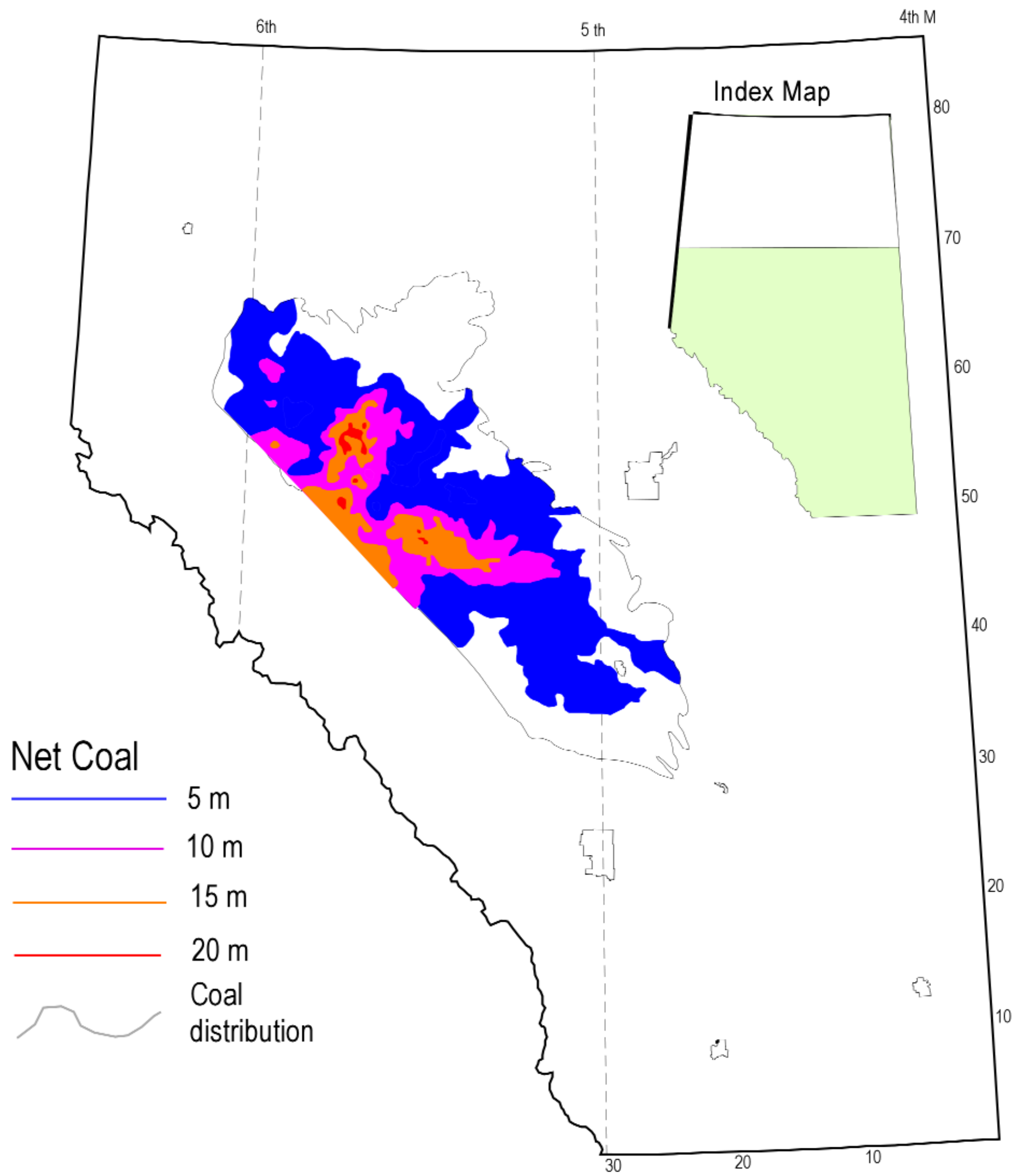


Figure 12. Distribution of net coal greater than 5 m, Ardley Coal Zone, Scollard Formation.

Coal rank within the Ardley ranges from sub-bituminous near outcrop (reflectance <0.5%) to a maximum of high-volatile bituminous B in the western, deepest areas containing Ardley coals. Most of the area underlain by Ardley coal falls within reflectance range 0.5 to 0.65% (high-volatile bituminous C rank), just within the onset of thermogenic-gas generation (Rice, 1993).

3.3 Horseshoe Canyon Formation

During Late Campanian-Maastrichtian time, the Bearpaw Sea retreated from the Alberta Plains. Regression was accompanied by clastic sediments of the Horseshoe Canyon Formation prograding into the basin in an east-southeasterly direction (Nadon, 1988). The Horseshoe Canyon Formation type section at East Coulee consists of a 250 m thick succession of nonmarine sandstone, siltstone, shale and mudstone that contains coal, coaly shale, ironstone concretions and isolated bentonite beds (Gibson, 1977). Up to 10 potentially economic coal seams have been identified in the Horseshoe Canyon Formation.

Beyond the zero edge of the Bearpaw Formation in the northwestern Plains, strata equivalent to the Horseshoe Canyon are included as part of the Wapiti Group (Dawson et al., 1994).

In central Alberta, the thick Drumheller Coal Zone was developed in the lower part of the Horseshoe Canyon Formation. The Red Willow Coal Zone in the Wapiti area is considered equivalent to the Drumheller Coal Zone (Dawson, et al., 1994). The lower part of the Horseshoe Canyon Formation includes alluvial, lacustrine, lagoonal, swamp and beach facies (Rahmani, 1988). Toward the top of the Horseshoe Canyon Formation, clastic sediments were deposited in a fluvial environment. The top of the Horseshoe Canyon occurs just above the Carbon-Thompson Coal Zone.

The base of the Horseshoe Canyon Formation is identified by the contact with the Bearpaw Formation in the southern Plains area; however, the Bearpaw Formation does not extend into the northern Plains and the separation of the Horseshoe Canyon Formation from the underlying Belly River Group becomes difficult. To complicate matters, there are several upper Bearpaw marine tongues that interfinger with Horseshoe Canyon sedimentary units. This results in difficulty in seam correlation and, where the Bearpaw is absent, assignment of coals to appropriate coal zones. Peat accumulation occurred in conjunction with intermittent regressive-transgressive pulses of the Bearpaw sea, where water-table levels allowed peat accumulation for short periods in north-trending, shoreline-parallel mires, commonly 30–50 km inland from the shoreline (Rottenfusser et al., 1991). These peat deposits produced coals that were generally elongate and interfingered with clastic and marine strata; although generally thin, these coals can attain local thicknesses exceeding 4 m. The ‘lower tongue’, capped by the E marker (the second major Bearpaw transgression) of McCabe et al. (1989) and the ‘CU1’ coarsening-upward unit of Langenburg et al. (2001), effectively subdivides the Drumheller Coal Zone into upper and lower coal zones.

3.3.1 Coal Zones of the Horseshoe Canyon Formation

Three coal zones were identified in the Horseshoe Canyon Formation: the Drumheller Coal Zone (divisible into upper and lower intervals), the Daly-Weaver Coal Zone and the Carbon-Thompson Coal Zone.

Thick net coal accumulations are present in the Drumheller Coal Zone, with local accumulations up to 18 m (Figure 13), but the coals are discontinuous. A north-trending zone of thick net coal, which averages 8 m, occurs in the southern region of the Drumheller Coal Zone. Individual seams average 1 to 2 m thick, although seams may be up to 5 m thick in areas of greatest net coal (McCabe et al., 1989; Rottenfusser et al., 1991). The lower Drumheller includes relatively thin coals (commonly <1 m) that are relatively continuous; the upper Drumheller seams, although commonly thicker than those of the lower Drumheller, tend to be less continuous (McCabe et al., 1989). Drumheller coals were developed along coastal plains, commonly associated with coarsening-upward successions, representative of migrating and stacking paleoshorelines.

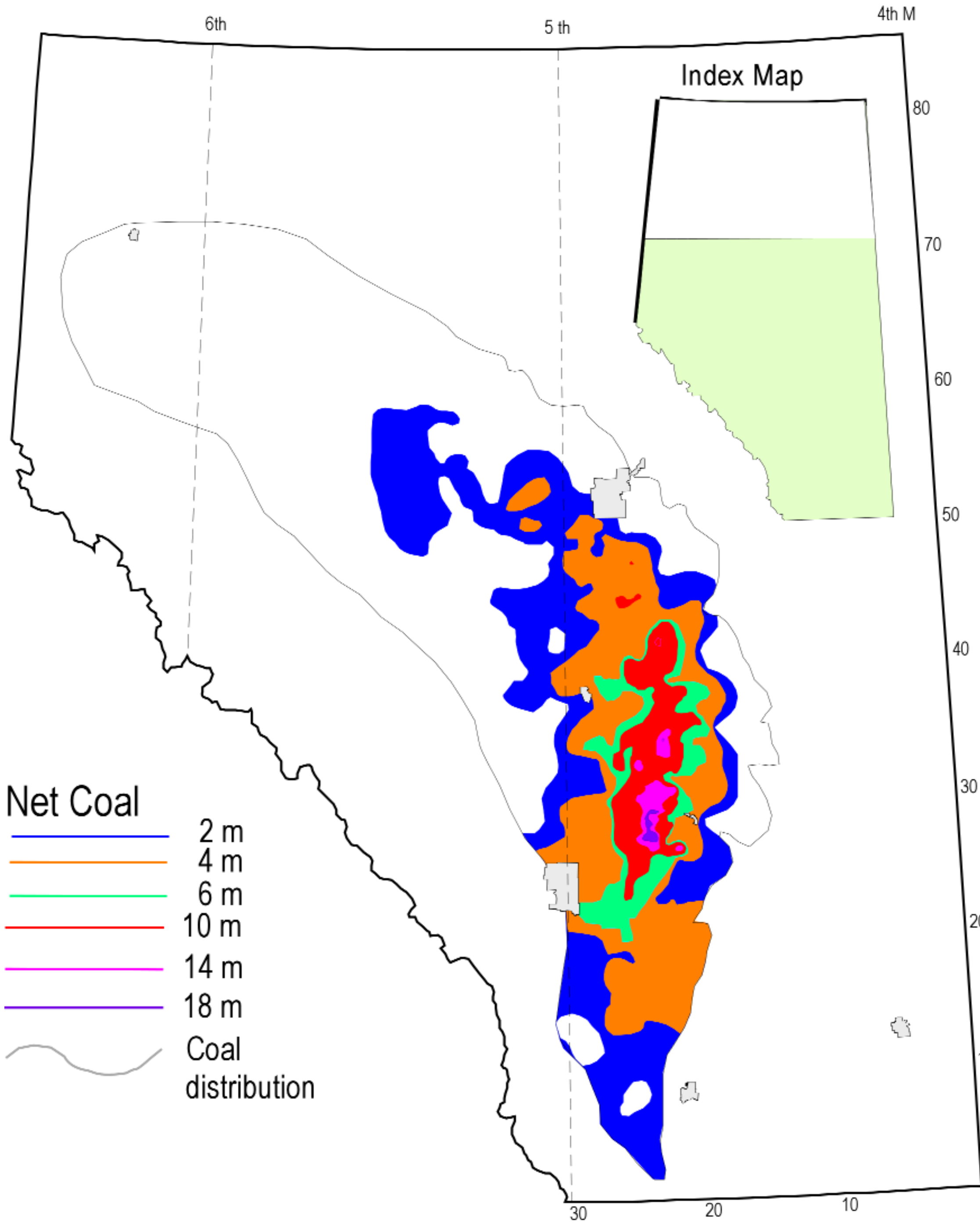


Figure 13. Distribution of net coal greater than 2 m, Drumheller Coal Zone, Horseshoe Canyon Formation.

Discontinuous coal seams, informally referred to as the Daly-Weaver Coal Zone, occur stratigraphically above the Drumheller Coal Zone. McCabe et al. (1989) suggested that the Daly-Weaver Coal Zone formed in an alluvial plain setting, where only thin, discontinuous seams are developed. The distinction between the Daly-Weaver and the Drumheller coal zones is based, in part, on the absence of marine strata in the Daly-Weaver succession, and the fact that fewer coal seams are associated with its coarsening-upward successions.

The upper Horseshoe Canyon Formation contains the discontinuous but laterally persistent Carbon-Thompson Coal Zone (Figure 14). The thickest coals in the Carbon-Thompson Coal Zone occur in northwest-trending 'bands' that coincide with northwest-trending paleochannels associated with fluvial depositional environments. Thickest coals rarely exceed 1–2 m, and net coal for the zone averages 2–3 m. The Carbon-Thompson Coal Zone correlates with the Cutbank Coal Zone of the Wapiti area (Dawson et al., 1994).

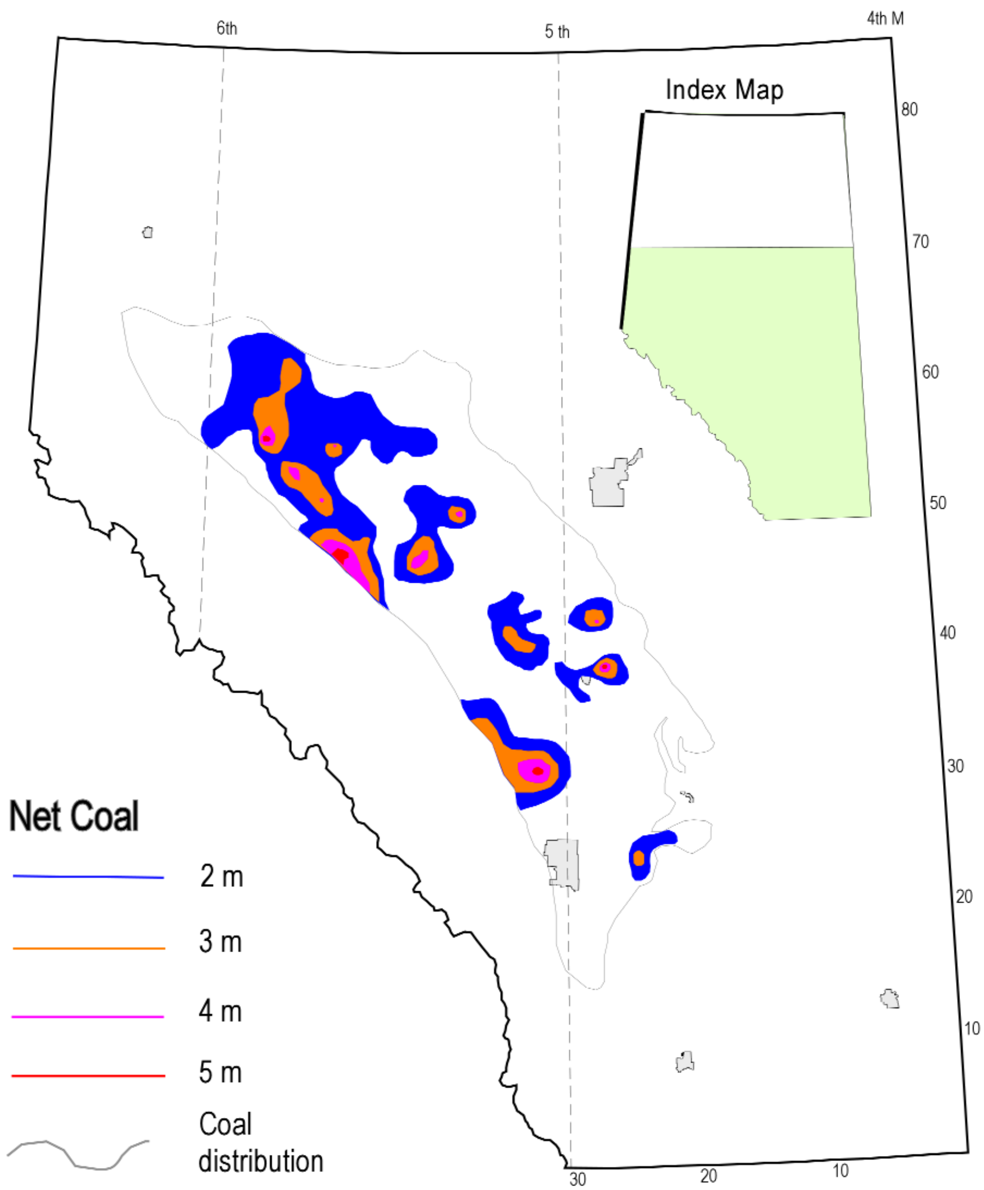


Figure 14. Distribution of net coal greater than 2 m, Carbon-Thompson Coal Zone, Horseshoe Canyon Formation.

Rank of coals in the Horseshoe Canyon Formation ranges from sub-bituminous to high-volatile bituminous. Carbon-Thompson coals are primarily within the ‘upper bounds’ of high-volatile bituminous C rank, with reflectance values typically falling within the 0.5 to 0.65% reflectance range. With increasing depth toward the west, the coal rank increases to high-volatile bituminous B, suggesting increased gas-generation potential in these areas.

Data are sparse for the Daly-Weaver Coal Zone; however, it is expected to follow a rank trend similar to that of the Carbon-Thompson Coal Zone.

The Drumheller Coal Zone includes low-rank coal (sub-bituminous B) at shallow depths, with the majority of coals having a rank of high-volatile bituminous C in the central Plains region. Coal rank increases both westward and northward, where a rank of high-volatile bituminous B is attained.

3.4 Bearpaw Formation

Although not coal-bearing, the Bearpaw Formation is intimately associated with the coal-bearing Horseshoe Canyon Formation and the Wapiti Group. During latest Campanian time, transgression of the Bearpaw Sea commenced in Saskatchewan and southeastern Alberta. Widespread and rapid transgression followed throughout southern and central Alberta (McLean, 1971). Bearpaw strata consist predominantly of laminated shale and siltstone with some sandstone beds and lenses of kaolinitic claystone, deposited in nearshore or marginal-marine environments (Habib, 1981; Macdonald et al., 1987).

The presence of the Bearpaw Formation helps to differentiate the younger Horseshoe Canyon Formation from the older Belly River Group in southern Alberta. Marine shale and silt of the Bearpaw Formation are not present in the central and northern Alberta Plains. Across the southern Plains, the base of the Bearpaw Formation is abrupt and lies just above the Lethbridge Coal Zone. Three major, regionally traceable flooding surfaces are recognized in the Plains (Catuneanu, 2002). These flooding events resulted in an interfingering of marine Bearpaw strata with continental Horseshoe Canyon strata.

3.5 Belly River Group

The Belly River Group is an eastward-thinning sedimentary wedge, composed of clay, silt and sand deposited in a predominantly nonmarine environment. This succession occurs stratigraphically between the overlying Bearpaw Formation and the underlying upper Lea Park Formation.

The Belly River Group has two distinctive lithological units. The lower unit (Foremost Formation) represents a succession from shoreline to alluvial plain deposits, and contains 2 coal zones. The upper unit (Oldman Formation) consists of fine-grained floodplain and lacustrine deposits containing one coal zone near the top. Hamblin and Abrahamson (1996) suggested a more detailed subdivision of the Belly River Group by including the Dinosaur Park Formation in the uppermost part of the succession, above the Oldman Formation.

3.5.1 Coal Zones of the Belly River Group

The McKay Coal Zone represents the first major peat accumulation in continental sediments of the lower Belly River Group (Foremost Formation). The peat accumulated several tens of kilometres westward of the paleoshoreline, in a north-trending belt associated with a coastal-plain depositional environment. The McKay Coal Zone ranges from 30 to 50 m thick. Average net coal thickness ranges from 1 to 3 m; however, in some local areas, up to 4 m net coal may be present (Figure 15). Individual seams typically range between 1 and 3 m thick (Macdonald et al., 1987).

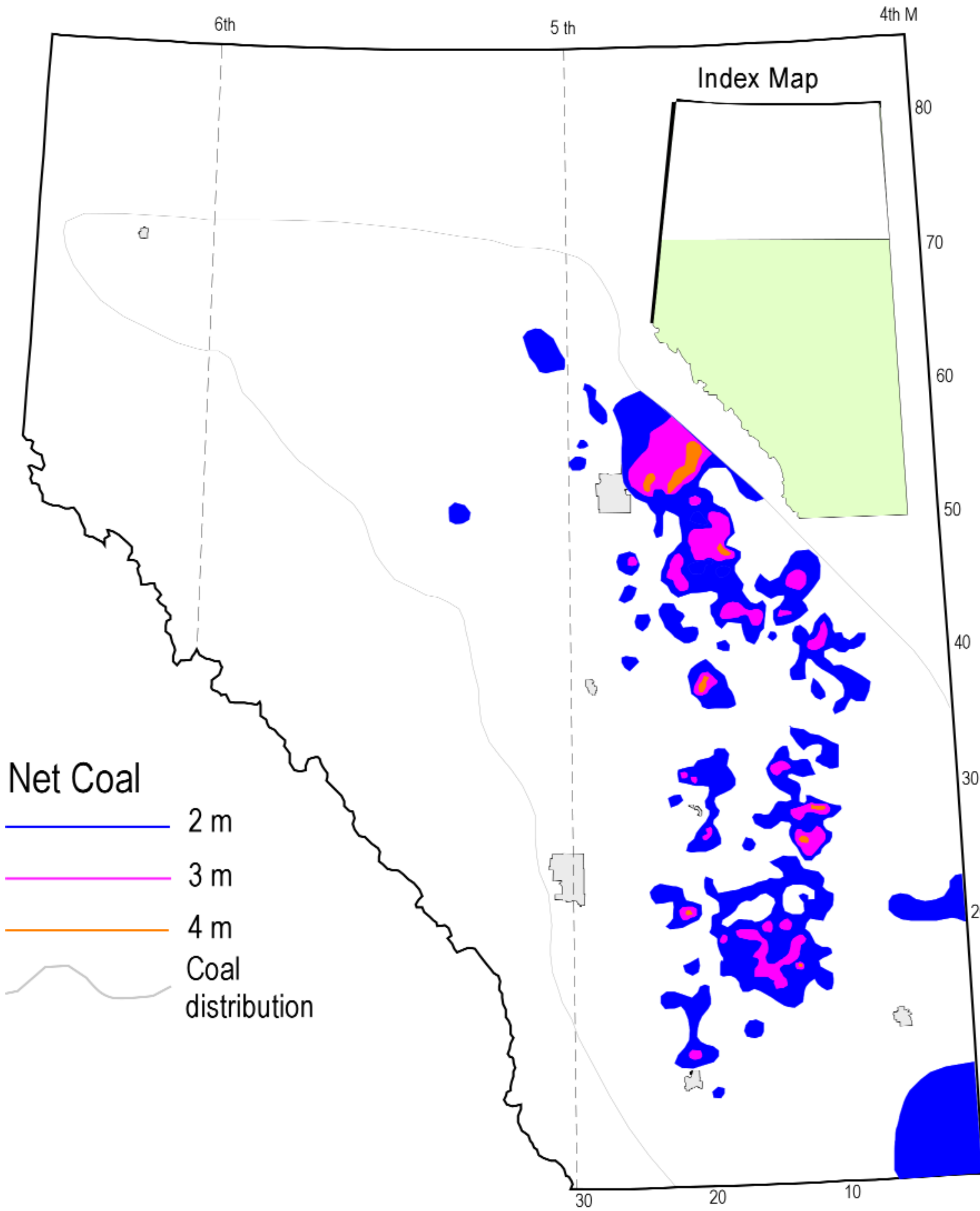


Figure 15. Distribution of net coal greater than 2 m, McKay Coal Zone, Belly River Group.

The Taber Coal Zone, which also which accumulated in a coastal-plain environment, developed eastward of the McKay Coal Zone in response to continued regression of the interior seaway. The Taber Coal Zone occurs near the top of the Foremost Formation, and averages 25 m thick with 1 to 3 m of net coal (Figure 16). Thicker coals occur locally (up to 6 m net coal) in northeast-trending bands. Individual seams range from 1 to 2 m thick.

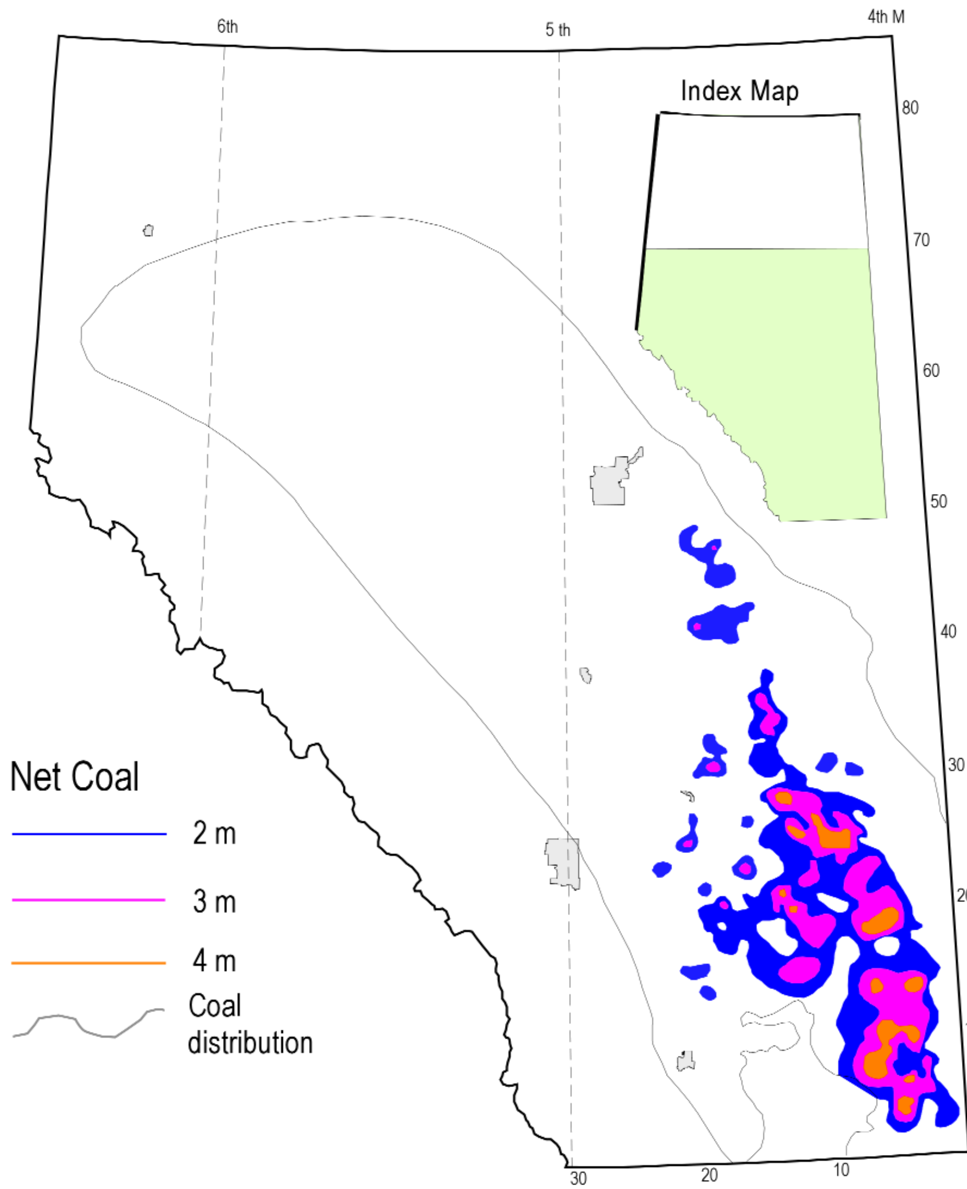


Figure 16. Distribution of net coal greater than 2 m, Taber Coal Zone, Belly River Group.

The Lethbridge Coal Zone developed as a result of rising regional water-table levels associated with the advancing Bearpaw seaway. The coals are laterally continuous, and occur near the top of the Oldman Formation. The Lethbridge Coal Zone averages 10–15 m thick, with an average of 1 to 3 m net coal that commonly occurs in two seams (Figure 17).

The McKay Coal Zone displays a wide range in coal rank. Shallow coals are typically sub-bituminous B to A and, in the central Plains, increase to the high-volatile bituminous C range. The McKay Coal Zone includes an area of variable rank data, centred about Twp. 47, Rge. 3, W 5th Mer. (47-3W5), where reflectance values range from 0.55 to 0.70% (sub-bituminous to high-volatile bituminous B). The majority of data within this area indicate a rank range of high-volatile bituminous C to B, within the range associated with the onset of thermal gas generation (Rice, 1993).

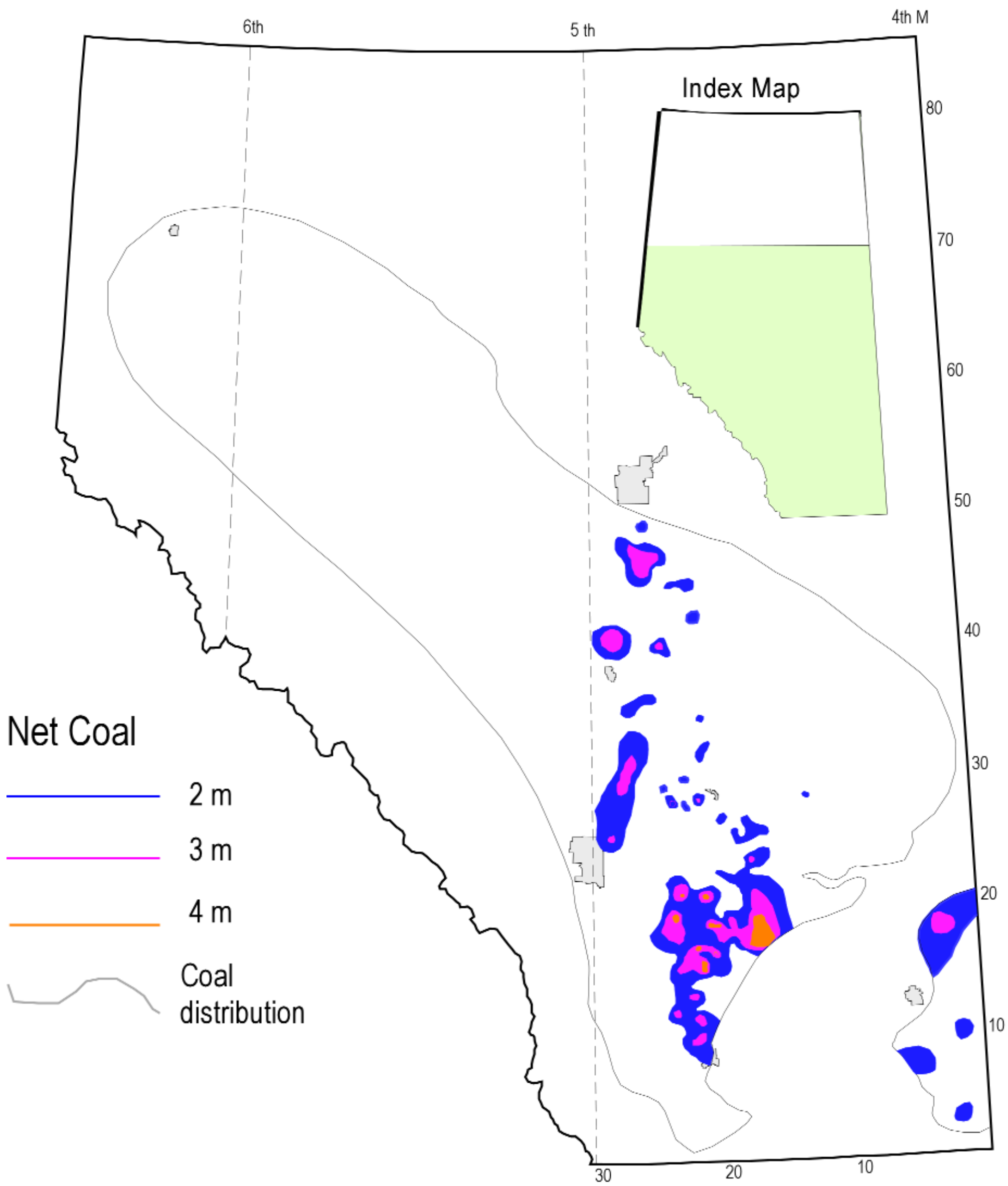


Figure 17. Distribution of net coal greater than 2 m, Lethbridge Coal Zone, Belly River Group.

The Taber Coal Zone is predominantly high-volatile bituminous C in the central Plains, and sub-bituminous C to B in the southeastern Plains. Only in the far western Plains does rank approach high-volatile bituminous B.

The rank of the Lethbridge Coal Zone ranges from sub-bituminous at shallow depths through high-volatile bituminous C and B westward with increasing depth.

3.6 Mannville Group

The Mannville Group overlies a major unconformity that separates Cretaceous from older strata in Alberta. This sub-Cretaceous unconformity represents an eroded land surface that displays considerable paleotopographic relief. The rocks of the lower Mannville typically infill the paleotopography, as alluvial, fluvial, deltaic and estuarine sediments. The lower Mannville shows a progression from fluvial to lacustrine–marginal marine environments, and was terminated by a regional southward transgression of the seaway.

The middle Mannville consists of shoreline and near-shoreline deposits, prograding into estuarine and fluvial deposits. In southern Alberta, coals developed over beach and coastal plain deposits. The upper Mannville represents a prograding clastic wedge that includes several regressive/transgressive cycles. Cycles commonly consist of marine shale overlain by "offshore bars, barrier islands, or deltaic sandstone" (Rottenfusser et al 1991), culminating in coastal plain deposits capped with coals.

Thick, extensive coals occur within the upper Mannville Group (Figure 18). Mannville rocks (and net coal) thicken from east to west in west-central Alberta. They are associated with back barrier and lagoonal depositional environments. In eastern Alberta, the coals are generally thinner. Eastern coals developed within two settings: 1) capping stacked shoreline deposits and overlain, in turn, by marine shale; and 2) within lagoonal, estuarine or tidal flats (but not overlain by marine sequences).

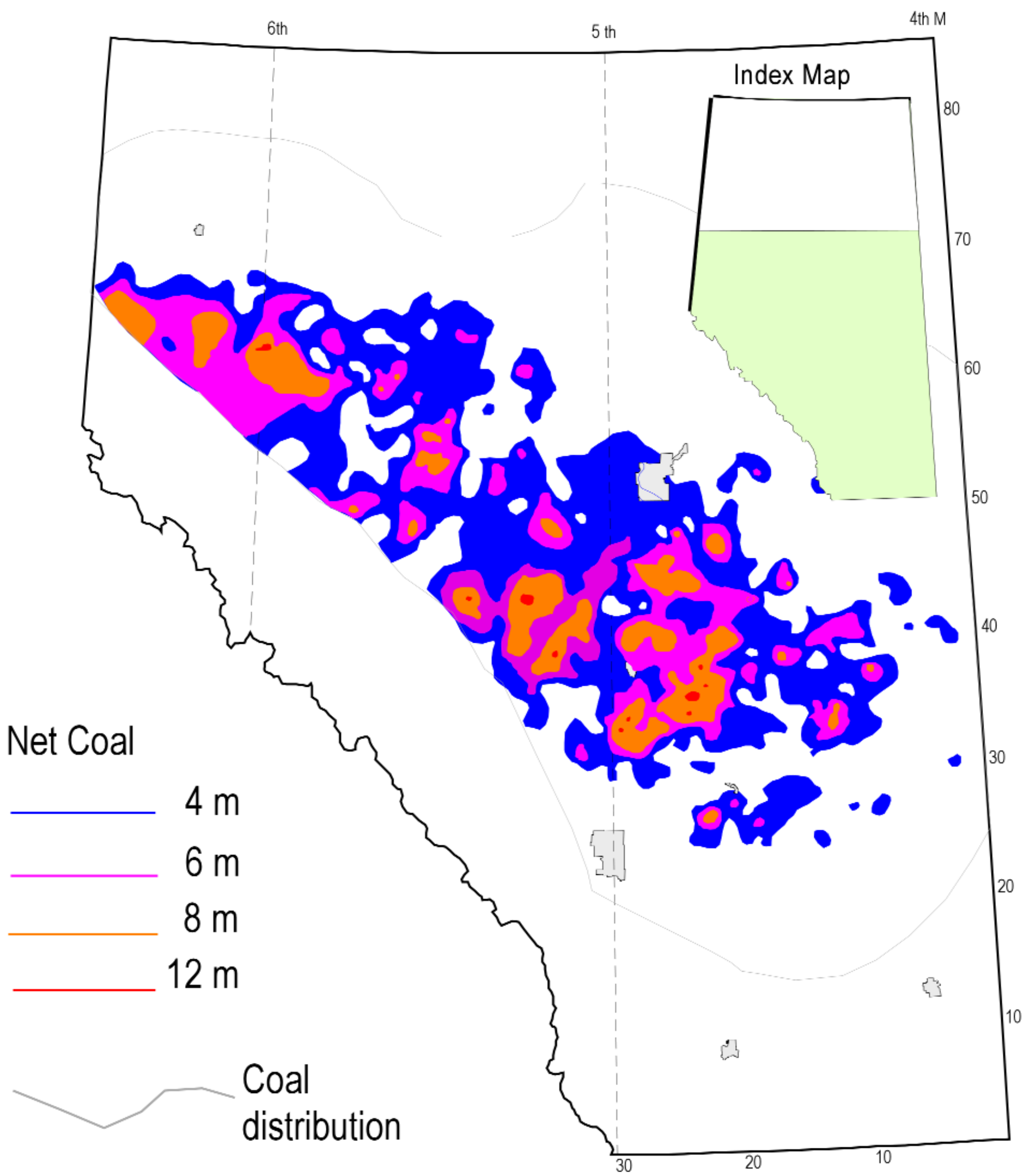


Figure 18. Distribution of net coal greater than 4 m, Mannville Coal Zone.

Thickest Mannville net coal occurs in the Red Deer area, with 6–12 m of net coal. In the deep basin and westward toward the deformed belt, net coal can exceed 12 m; however, net coal is generally in the range of 2–6 m.

Thinner, shallower Mannville coals occur within the Firebag Coal Zone near Fort McMurray. These coals are laterally discontinuous, and thickness is extremely variable. Net coal ranges from less than 1 m to greater than 11 m over short distances.

Gething Formation coal (Mannville equivalent) occurs in west-central Alberta. Numerous thick coals, deposited within an upper to lower deltaic environment, average 2–4 m net coal in western Alberta. Coals are somewhat laterally discontinuous in Alberta, and correlation is difficult among seams.

Gates Formation coals, within the Luscar Group in the central and northern Foothills of Alberta, are nonmarine. Coals occur within two members. The Grande Cache Member, which overlies the shoreface Torrens Member sandstone, has thick, economic coals deposited in a coastal plain setting. The overlying Mountain Park member consists of thinner, less numerous coal seams deposited in a fluvial environment.

Mannville coals from the Alberta Plains typically have a rank of sub-bituminous to high-volatile bituminous in the north and east (Figure 19). Rank increases with depth westward. In the central Plains, rank falls within the high-volatile bituminous C-A rank range, within the thermogenic-gas generation window for coals. Medium- to low-volatile bituminous coals occur along the western margin of the deep basin and the disturbed belt, although they are at greater depths than the Plains coals.

It has been speculated that the rank of Mannville coals in the Plains may be biased low when determined by reflectance analysis. Under microscopic analysis, coals from the Plains commonly show the presence of a fluorescing coal matrix, which is interpreted to be the result of bitumen (oil) impregnation. Bitumen may originate either from in situ hydrocarbon generation in the coals (which can occur at the sub-bituminous to high-volatile bituminous C rank), or from external bitumen migration into the coal seam (Gentzis, 1991).

Firebag coals range in rank from lignite to sub-bituminous C. Gething coals range in rank from high-volatile bituminous to anthracite, suggesting favourable CBM potential from a rank-generation viewpoint. Gething coals show most favourable CBM potential in northwestern Alberta, where favourable thickness and suitable rank (low-volatile bituminous) are present.

3.7 Kootenay Group

The Jurassic-Cretaceous Mist Mountain Formation of the southern Mountains and Foothills consists of a thick nonmarine sequence of shale, siltstone, sandstone and coal, developed in a coastal plain setting. Cumulative coal thicknesses in the order of 12 m are present at depth near Pincher Creek. Generally, coal in the Mist Mountain Formation thins from west to east, and much of the thickest coal occurs in British Columbia. Coal rank ranges from high-volatile bituminous A up to semi-anthracite, within the thermogenic-gas generation window.

4 Coalbed Methane Potential of the Alberta Plains as Related to Coal Distribution

Coal distribution, including net coal thickness, rank and depth to top of the coal zones, has been previously discussed for the Alberta Plains by Rottenfusser et al. (1991) and Beaton et al. (2002), and for the Foothills by Langenberg et al. (2002). From total coal resources (in place), maximum CBM gas-in-place has been calculated to be 5.27 x 10^{12} m^3 (186 tcf) for Upper Cretaceous coals of the Plains

(Beaton et al., 2002), 3.68 x 10^{12} m^3 (130 tcf) for the Foothills (Langenberg et al., 2002) and 1.13 x 10^{13} m^3 (400 tcf) for Mannville coals of the Plains (MacLeod et al., 2000). Recent unpublished studies by the Alberta Geological Survey indicate 9.06 x 10^{12} m^3 (320 tcf) of gas-in-place for Mannville coals.

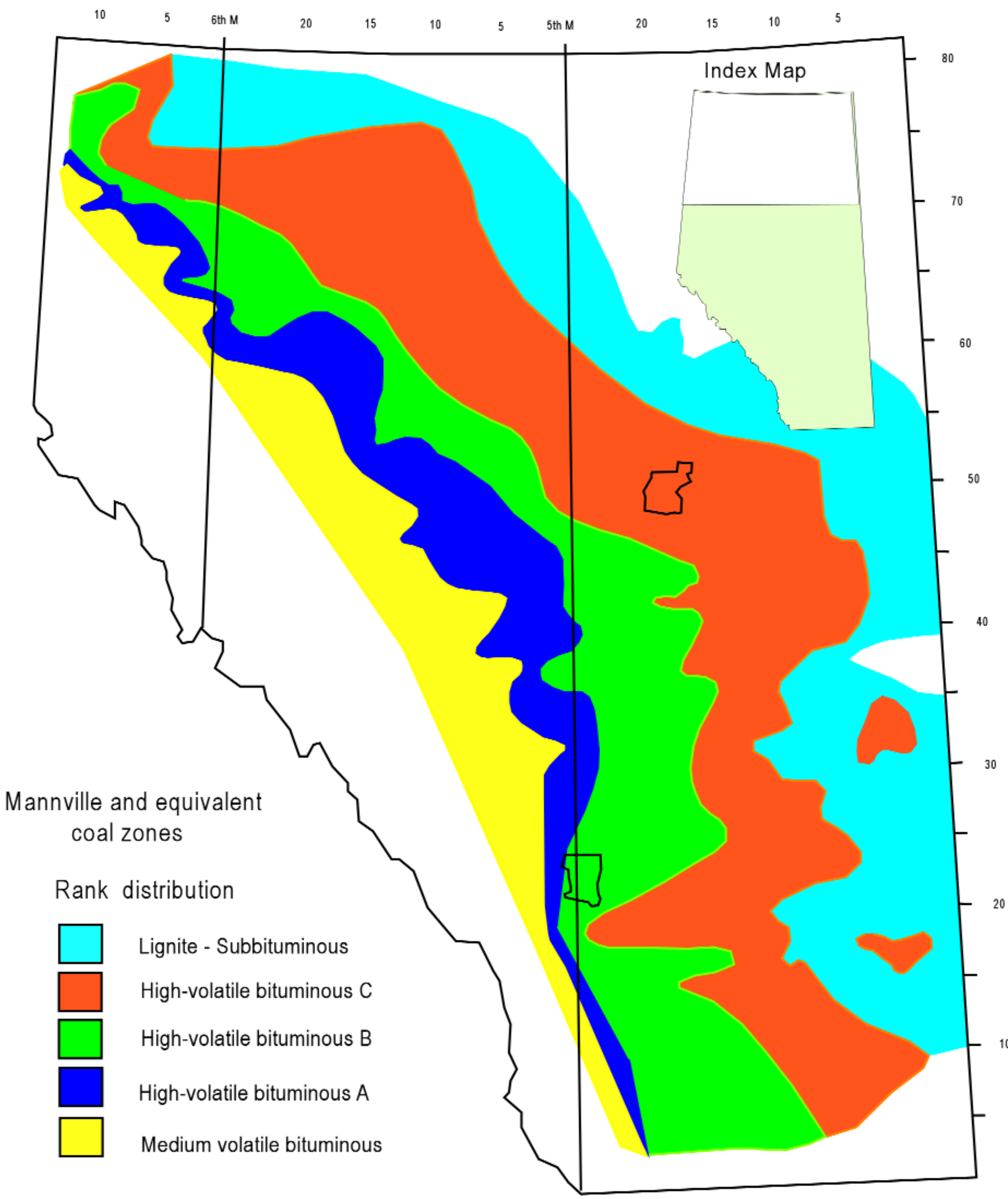


Figure 19. Rank distribution of Mannville coal, Alberta Plains.

Structure and coal thickness are first-line indicators for CBM potential. Exploration efforts are initially focused on finding thick coals to provide favourable gas volumes and structure to enhance permeability. Foothills structure and local thickening of coals are well known but difficult to map in detail (Figure 20). Site access is also more difficult than on the Plains. Within the Plains, coal distribution is well understood, structure is subtle and access to exploration sites is relatively simple. The majority of CBM exploration efforts to date in Alberta have focused on the Plains.

a

b

Figure 20. Sturcture in coals of the Alberta Foothills: a) Coal Valley area, Coalspur Coal Zone, b) Cardinal River Mine, Gates Coal Zone.

Gas concentrations, reported as billion cubic feet/section (bcf/section), are plotted for the main coal zones in the Alberta Plains in Figures 21 to 27. Gas concentrations were determined by using adsorption and desorption isotherm data and depth of coal to calculate gas concentration per unit of coal. This result was multiplied by the total net coal tonnage (determined from coal volume and density), and converted to gas resources as bcf/section (Scott et al., 1995; Beaton et al., 2002)

Figures 12 to 18 show coal distribution for each coal zone in the Plains. The areas of thickest coal typically have the greatest coalbed methane potential, which increases with increasing depth. This is a function of greater ‘source and reservoir’ volumes, and the associations of increasing gas-generation potential with increasing rank (rank increases with depth in the Plains), and of increasing reservoir pressures with increasing lithostatic pressure (higher reservoir pressures favour increased CBM retention or adsorption).

4.1 Calculated Gas-in-Place, Ardley Coal Zone

The Ardley Coal Zone contains the thickest net coal accumulations in the Plains, in some areas exceeding 20 m net coal. Two main trends of thick net coal are present: a northeast-trending zone in the Edson–Pine Creek area and an east-trending zone in the Pembina area. Both of these areas are situated in subregional ‘troughs’ within the Ardley, where depth of strata is slightly greater than surrounding areas. Gas-in-place calculations indicate that the most favourable CBM potential in the Ardley Coal Zone is associated with these two areas (Figure 21). Within these two areas, gas-in-place exceeds 4 bcf/section, with the thickest net coals contributing 6–8 bcf/section. These two areas have so far been the main focus of CBM exploration in the Ardley Coal Zone.

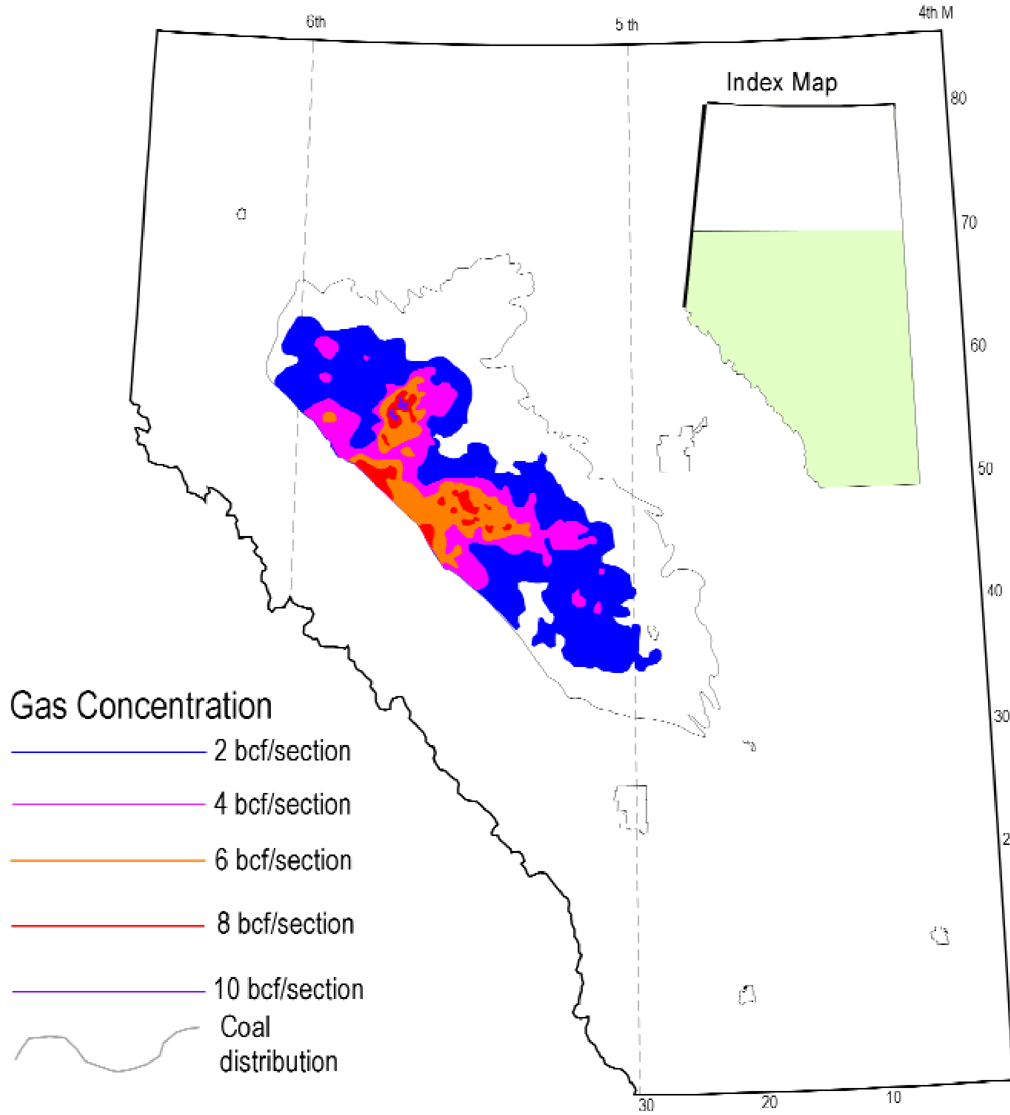


Figure 21. Calculated gas-in-place (in bcf/section), Ardley Coal Zone, Scollard Formation.

4.2 Calculated Gas-in-Place, Horseshoe Canyon Coal Zones

The Horseshoe Canyon Formation contains three coal zones. The uppermost zone, the Carbon-Thompson Coal Zone, is generally thin (<2 m); however, local pods of coal occur with 3–4 m net coal thickness in the Red Deer area and in the northwestern part of the Plains (the equivalent Cutbank Coal Zone). The overall lack of thick continuous coals has negated this coal zone as a CBM target. Gas-in-place has been calculated for the Carbon-Thompson Coal Zone. Most areas have generally low potential (<1 bcf/section), although two areas, one northwest of Calgary and the other west of Edmonton (Figure 22), show elevated gas concentrations, in the order of 1 bcf/section, with thicker coal pods containing up to 1.5 bcf/section.

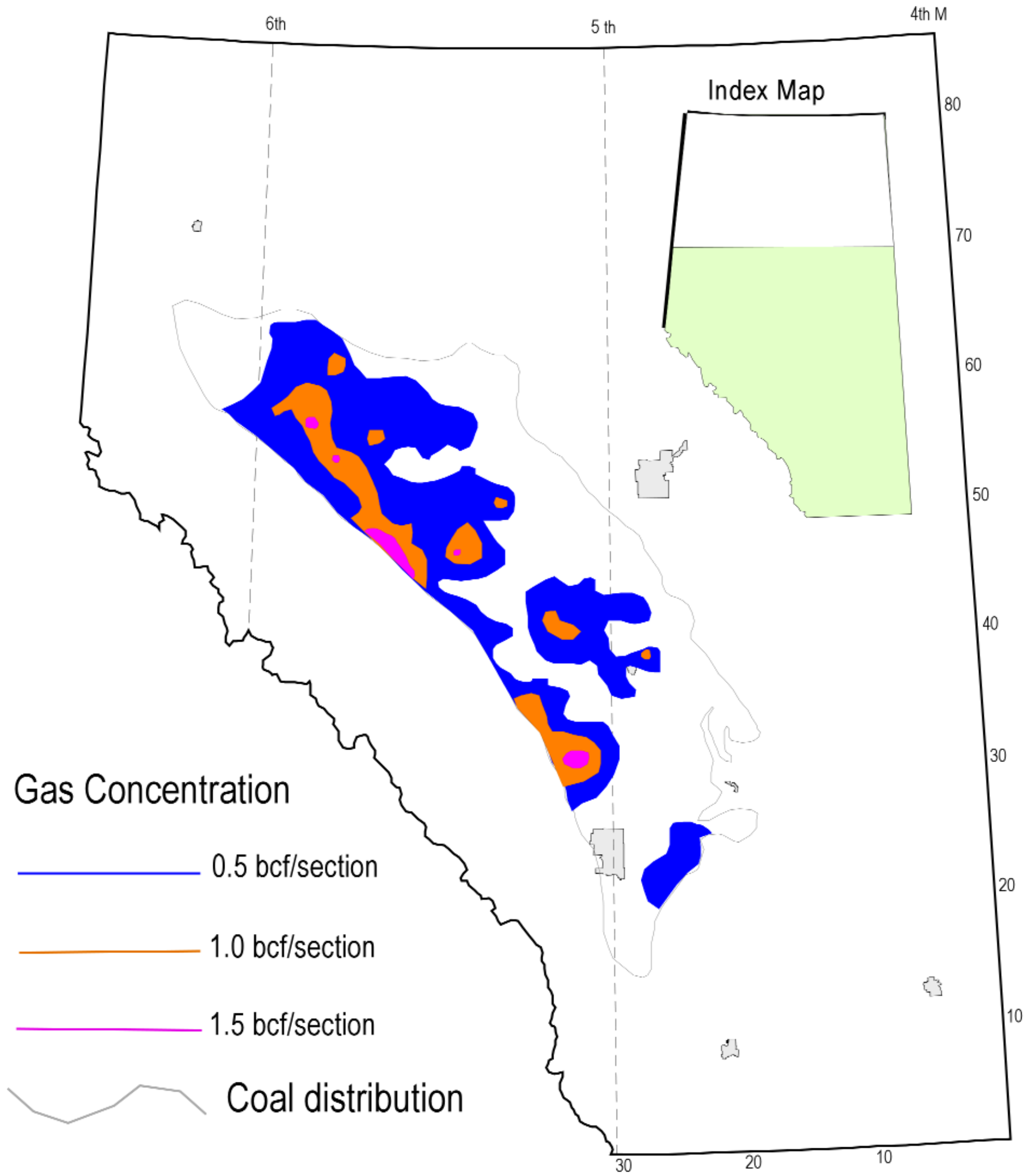


Figure 22. Calculated gas-in-place (in bcf/section), Carbon-Thompson Coal Zone, Horseshoe Canyon Formation.

The Daly-Weaver Coal Zone is very discontinuous and of variable thickness. It has not been a target of CBM exploration to date.

The Drumheller Coal Zone is the main target in the Horseshoe Canyon. Net coal thickness greater than 4 m encompasses a large area, extending from township 12 to 53 and from range 20W4 to the fifth meridian. Within the centre of this distribution, net coal exceeds 10 m, and pods of net coal in excess of 16 m are present. These areas of thick coal are undergoing active CBM exploration, and the first commercial production of CBM in the province is reported from this area (Canadian Discovery Digest, 2002).

Gas-in-place calculations for the Drumheller Coal Zone suggest that a north-trending zone, covering Twp. 20 to 40, Rge. 22 to 28, W 4th Mer., is the most promising area for CBM potential. This trend coincides with thickest coals in the Drumheller Coal Zone. Within this trend, which has minimum gas-in-place concentrations of 2 bcf/section, there are elongate areas where gas-in-place exceeds 3 bcf/section (Figure 23).

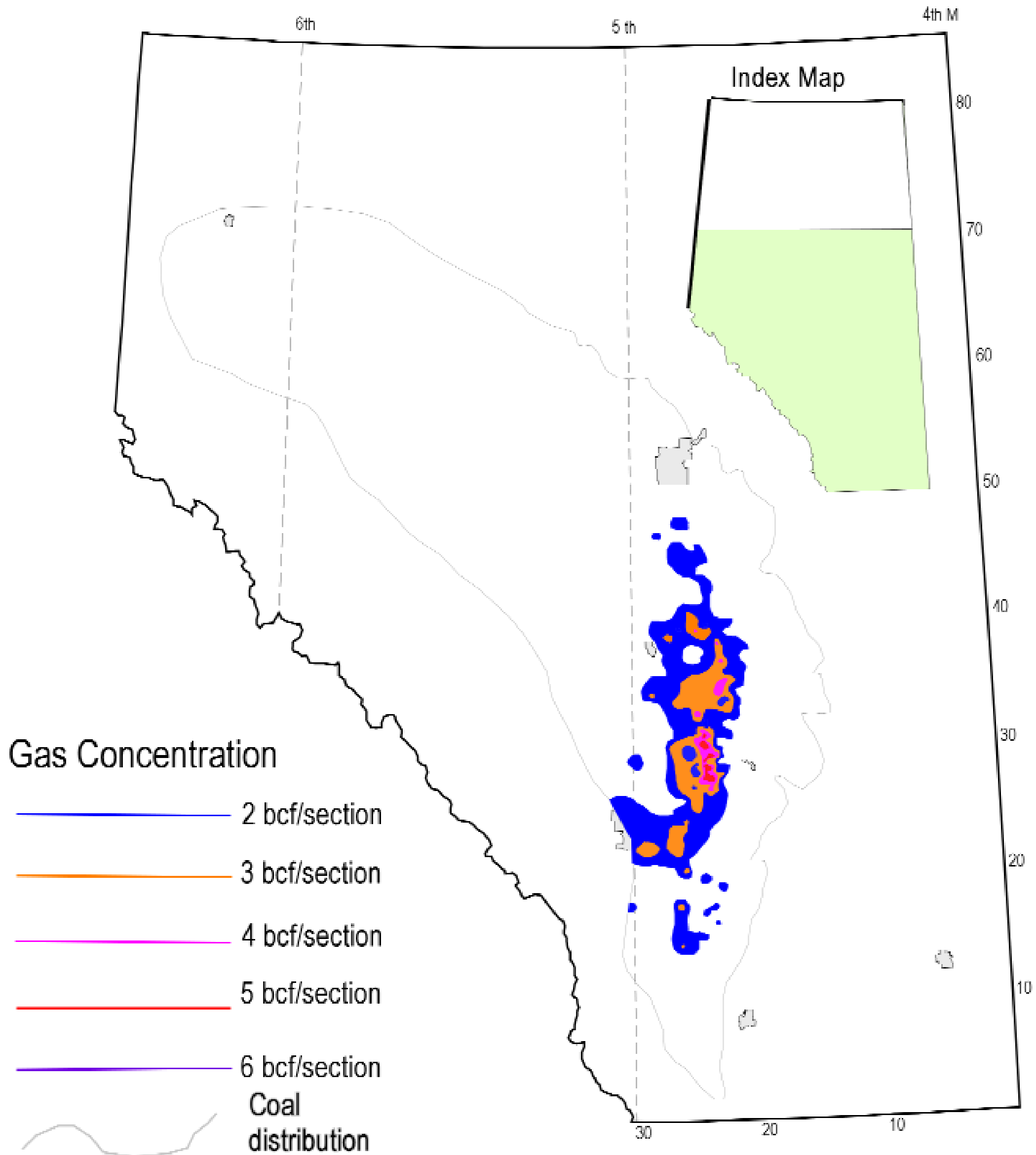


Figure 23. Calculated gas-in-place (in bcf/section), Drumheller Coal Zone, Horseshoe Canyon Formation.

4.3 Calculated Gas-in-Place, Belly River Coal Zones

The generally thin coals of the Belly River Group have undergone very limited explorations. Much of the coal with net thickness greater than 3 m is at relatively shallow depth. Because a shallow depth suggests low reservoir pressures, the gas content of these coals is expected to be low. These factors are reflected in the gas-in-place calculations.

Coal zones of the Belly River Group contain thinner net coal than the overlying Drumheller Coal Zone. Furthermore, areas of net coal greater than 2 m are generally discontinuous. The Lethbridge Coal Zone contains a few areas of interest, the main one being a trend containing net coal thickness of 3–4 m in Twp. 10 to 23, Rge. 15 to 25, W 4th Mer. (north of Lethbridge). These regions, which show most promise for CBM potential, have overall low gas-in-place concentrations, at less than 0.75 bcf/section (Figure 24), although there are some elongate coal pods that may exceed 1 bcf/section. Limited depth of cover and thin net coal have restricted CBM potential in the Lethbridge Coal Zone.

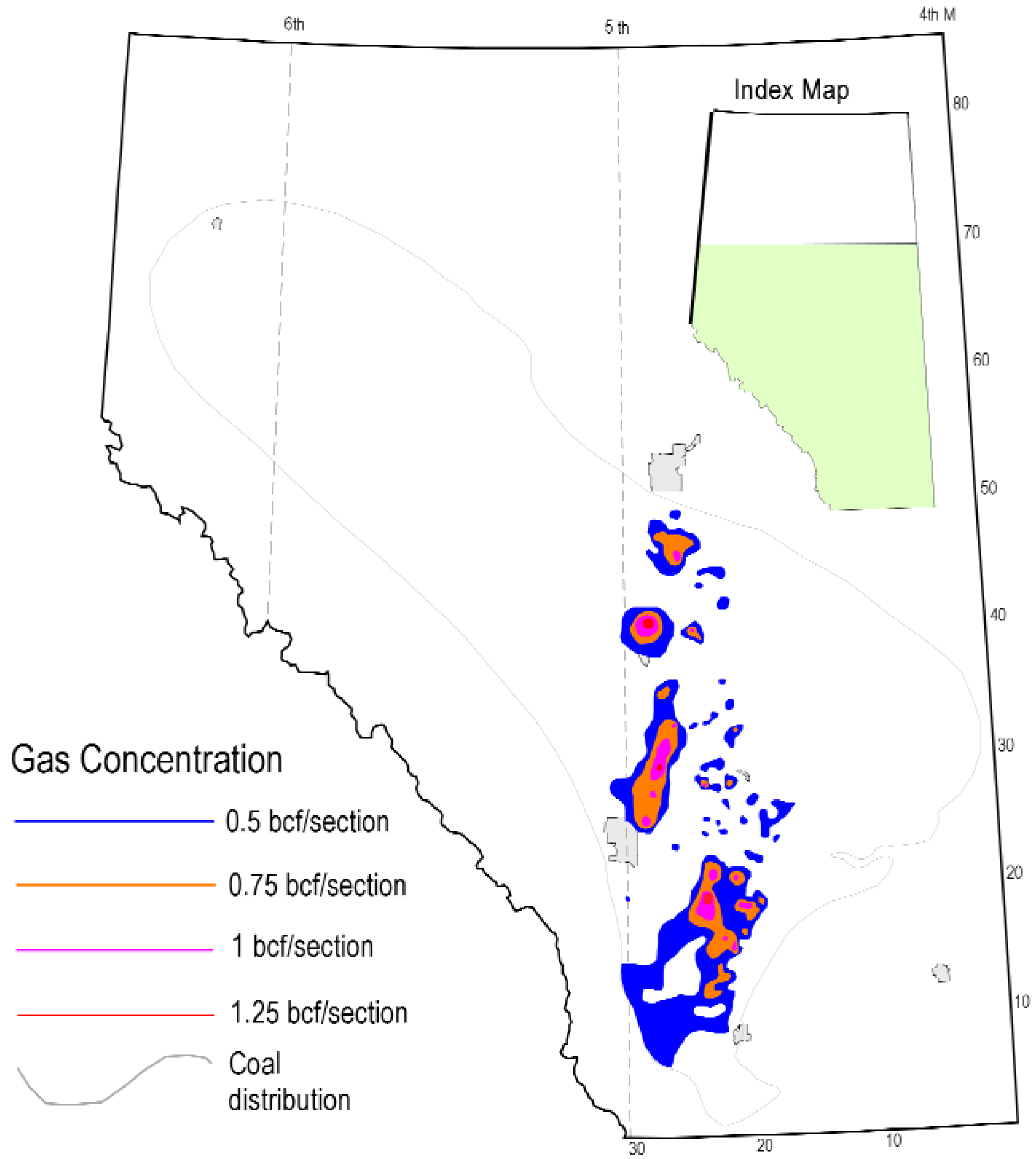


Figure 24. Calculated gas-in-place (in bcf/section), Lethbridge Coal Zone, Belly River Group.

The Taber Coal Zone includes a north-northwest trending zone, extending from Twp. 3, Rge. 5, W 4th Mer. to Twp. 29, Rge. 15, W 4th Mer., that contains 3–4 m net coal. Similar in CBM potential to the Lethbridge Coal Zone, much of the Taber Coal Zone is relatively shallow and/or has thin net coal. Some limited areas of the Taber zone show gas-in-place potential of 0.75–1 bcf/section, but most of the coal zone has 0.5 bcf/section or less gas-in-place (Figure 25).

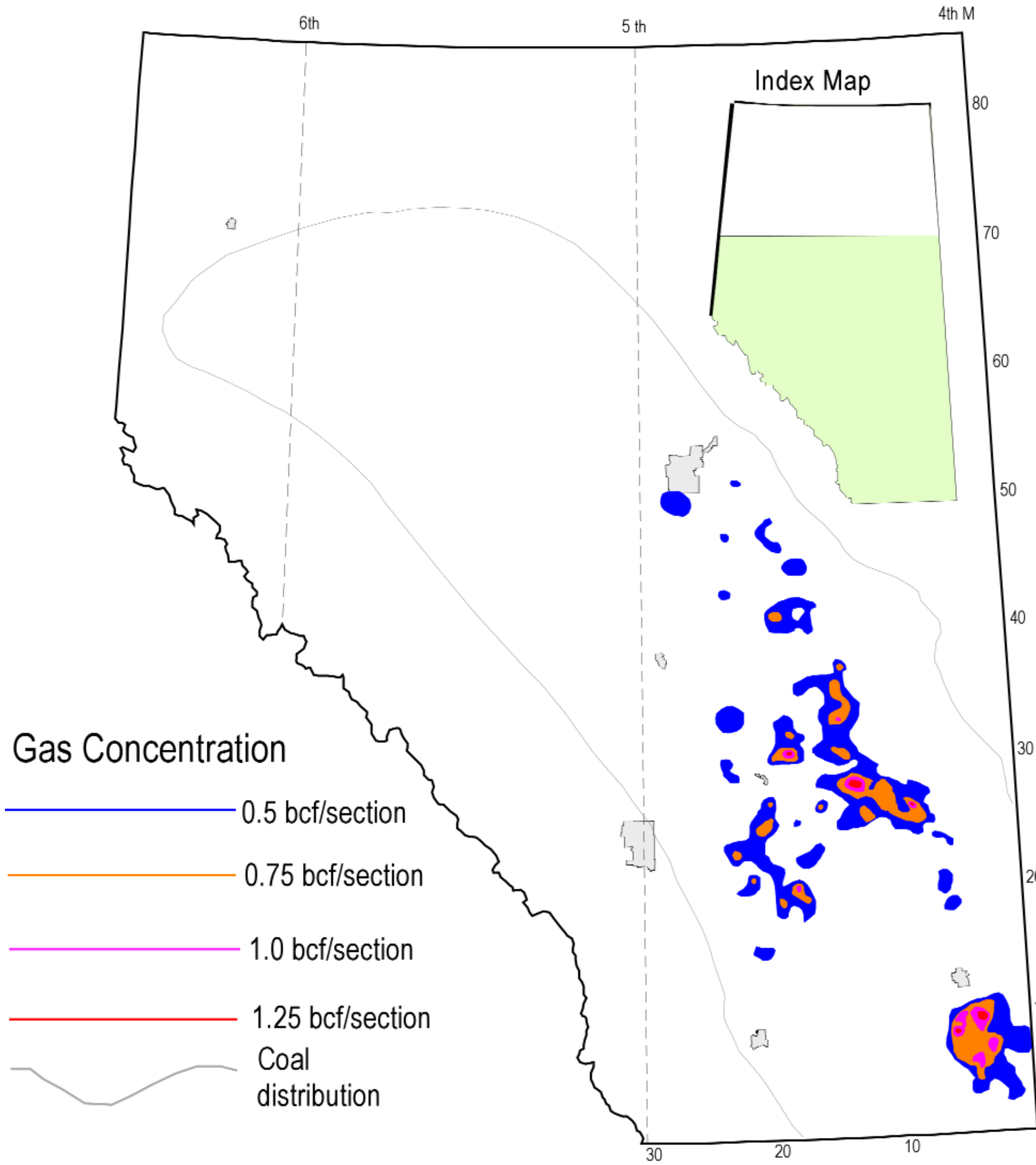


Figure 25. Calculated gas-in-place (in bcf/section), Taber Coal Zone, Belly River Group.

The McKay Coal Zone has a much more discontinuous distribution of coal, with several small areas with net coal greater than 3 m distributed throughout a trend encompassing Twp. 10 to 60, Rge. 11 to 25, W 4th Mer. The discontinuous nature of the coals result in numerous small coal pods, some with gas-in-place concentrations in the 0.75–1 bcf/section range (Figure 26). Most coals in the McKay Coal Zone are thin and have limited gas-in-place potential (0.5 bcf/section and less).

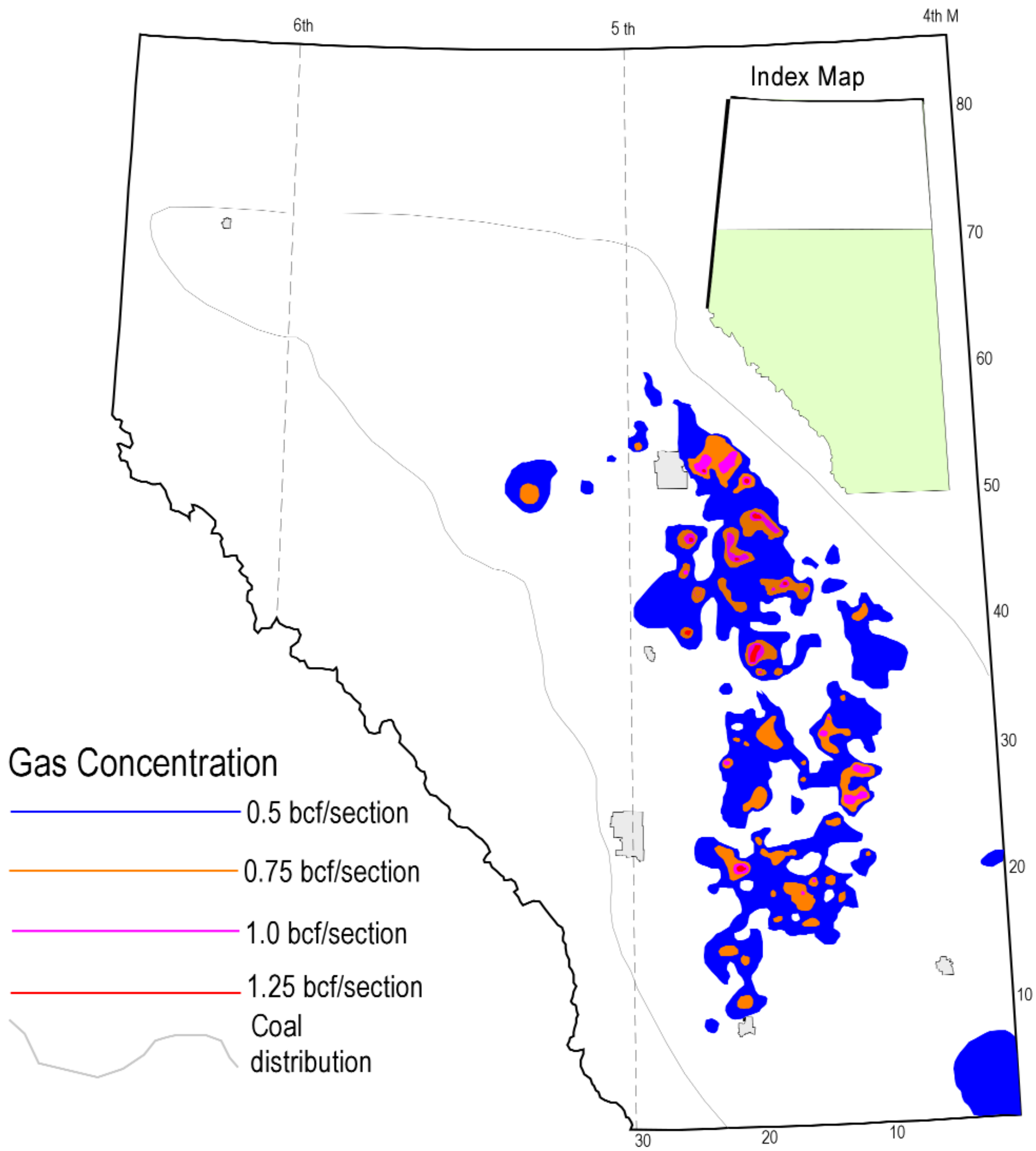


Figure 26. Calculated gas-in-place (in bcf/section), McKay Coal Zone, Belly River Group.

4.4 Calculated Gas-in-Place, Mannville Coal Zone

The Mannville group contains several large areas, where seams are continuous and net coal exceeds 4 m, in a northwest-trending zone extending from the Alberta–British Columbia border, just south of Grande Prairie, to Twp. 10, Rge. 30, W 4th Mer. in east-central Alberta. Within this zone, large areas with net coal greater than 6 m occur, and net thicknesses greater than 8 m are common. Reported high gas contents, thick net coal and the potential for structurally enhanced permeability have made the shallower (<1500 m depth) Mannville coals an attractive CBM target (Allan, 2003).

Gas-in-place calculations for Mannville coals show that most of the zone with greater than 4 m net coal thickness may contain at least 5 bcf/section. (Figure 27). Local areas with 8 m or more net coal may contain up to 10 bcf/section.

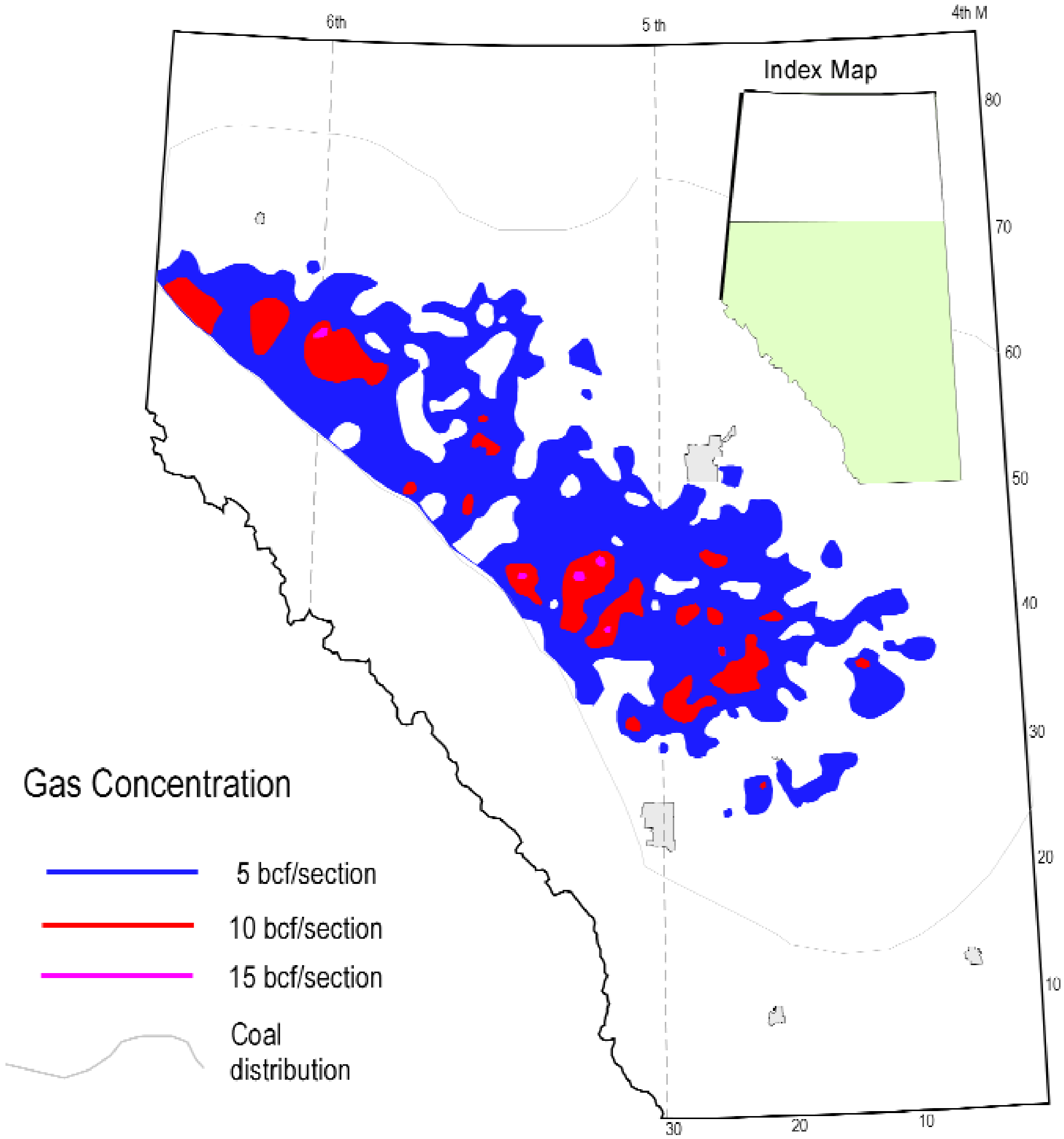


Figure 27. Calculated gas-in-place (in bcf/section), Mannville Coal Zone.

4.5 Summary of Alberta Plains Coalbed Methane Potential

Total coalbed methane potential (maximum gas-in-place) of the Alberta Plains has been calculated at 1.50×10^{12} m^3 (53 tcf) for the Ardley coal zone, 3.97×10^{11} m^3 (14 tcf) for the Carbon-Thompson, 3.97×10^{11} m^3 (14 tcf) for the Daly-Weaver, 1.08×10^{12} m^3 (38 tcf) for the Drumheller, 5.10×10^{11} m^3 (18 tcf) for the Lethbridge, 5.67×10^{11} m^3 (20 tcf) for the Taber and 7.93×10^{11} m^3 (28 tcf) for the McKay (Beaton et al., 2002). Mannville coals may contain up to 1.13×10^{13} m^3 (400 tcf) of gas-in-place (MacLeod et al., 2000). Preliminary estimates by the Alberta Geological Survey indicate a maximum gas-in-place potential for Mannville coals of 9.06×10^{12} m^3 (320 tcf). The above estimates do not take into account minimum seam net thickness or production constraints.

5 Synopsis of Prospective Coalbed Methane Areas in Alberta

The gas-in-place potentials for the main coal zones of the Alberta Plains have been presented above. The thickest Ardley trends in Pine Creek and Pembina are certainly the immediate exploration targets (Figure

12). The Carbon-Thompson and Daly-Weaver coal zones are limited in potential, and probably would not stand alone as a CBM target. The thickest coal trends in the Drumheller Coal Zone present a potential CBM target (Figure 13). Although gas concentrations are low, the relatively shallow depth and numerous seams, as well as potentially greater permeability compared to the Ardley Coal Zone, make the Horseshoe Canyon coals a viable and, to date, a successful CBM target. Limited potential exists for Belly River coals. A few local thick pods of Lethbridge and Taber coals occur, but they present small targets of limited extent and gas potential. There are some areas where the stratigraphic separation between the Drumheller and Lethbridge coals is minimal (a few tens of metres) and the coal zones overlap, so it may be possible to target both coal zones within one CBM well (Figure 17). Limited data suggest that some Belly River coals may have greater gas contents than Horseshoe Canyon coals. McKay coals are thin, discontinuous and have limited CBM potential. Figure 28 indicates potentially favourable areas for CBM exploration in the Alberta Plains, based on coal distribution and calculated gas concentrations.

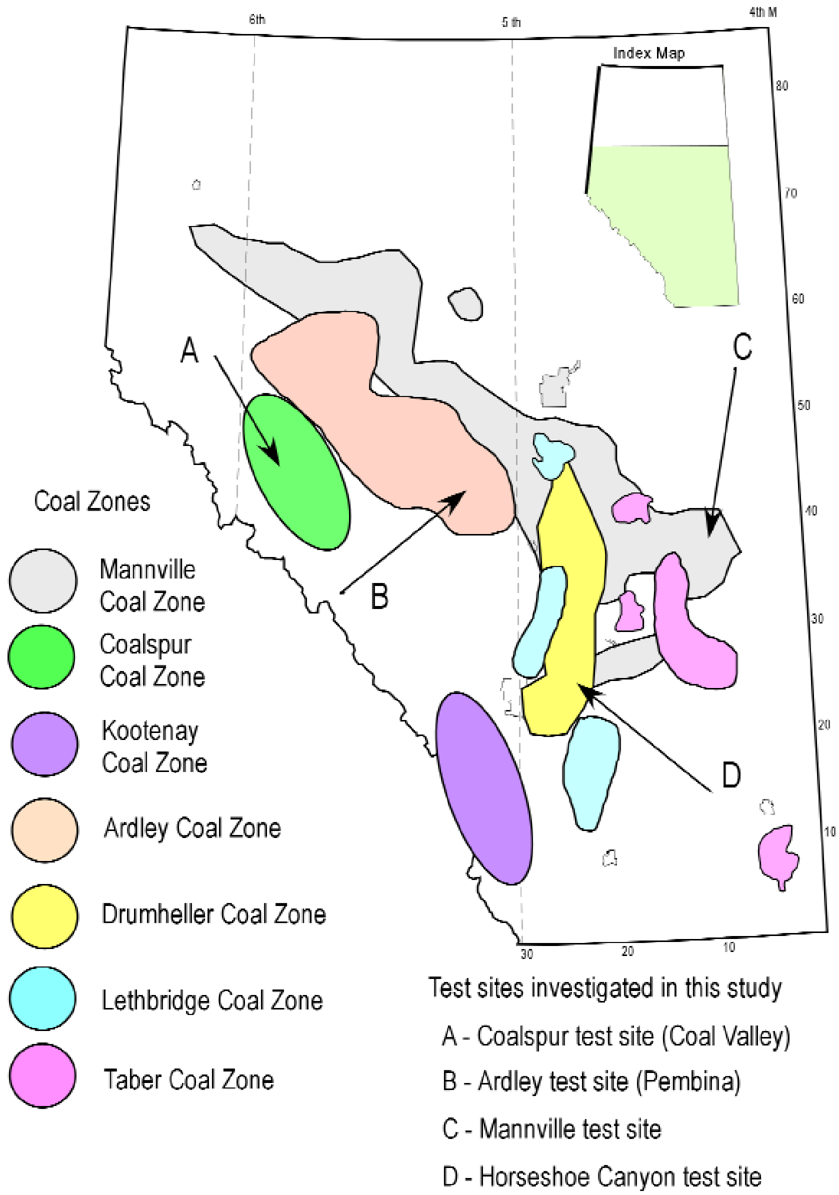


Figure 28. Areas with potentially favourable coalbed methane exploration potential, Alberta Plains, and test site locations investigated in the current study.

Mannville coals have been shown to have favourable gas contents, much higher than most Upper Cretaceous–Tertiary coals of the Alberta Plains. Previous work suggests permeability is low in the Mannville coals (0.1-2 mD), and that much of the Mannville coal occurs at depths greater than 1500 m (Figure 29). Shallower Mannville coals still include thick net coal (>4 m) and therefore present viable exploration targets, particularly where there are thickness anomalies that may be related to underlying structure. It is suggested that these anomalies may also have enhanced permeability (Allan, 2003).

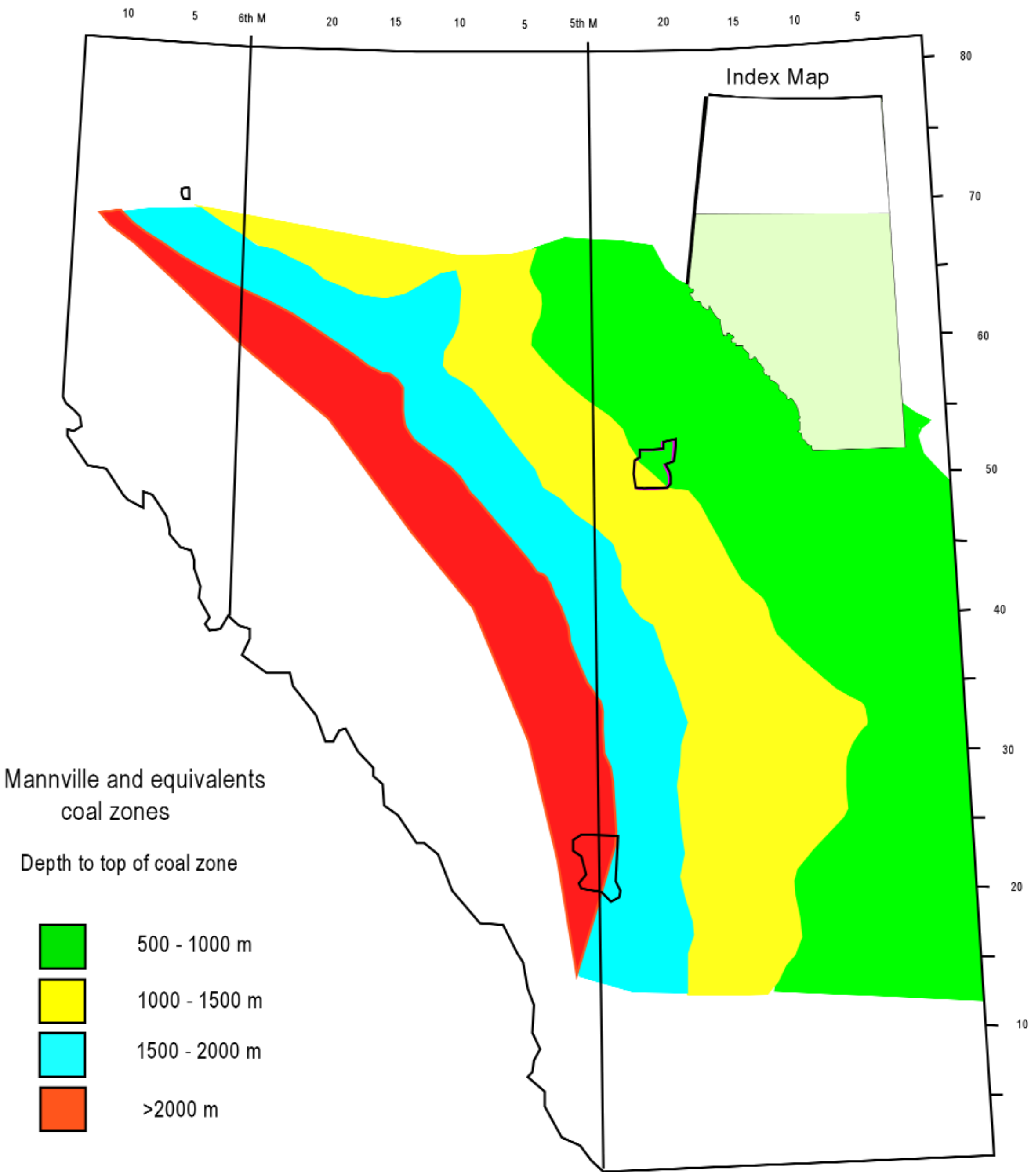


Figure 29. Depth to top of Mannville Coal Zone, Alberta Plains.

The potential for biogenic gas exists within the coal measures, particularly at shallow depths where coals may interact with meteoric water. Coals in the shallow Ardley and Horseshoe Canyon may be most favourable for this potential interaction, owing to the low rank and thicker nature of the seams compared to Belly River coals. Preliminary evidence suggests a possible biogenic contribution to shallow (<100 m) Ardley coals. It must be recognized, however, that these shallow coals may fall within groundwater protection zones and be restricted from development.

6 Producibility Potential of Alberta Coals

6.1 Project Scope and New Data

Coalbed methane exploration companies enjoy a one-year confidentiality period on public release of exploration and production data. To accelerate release of knowledge into the public realm, the Alberta Geological Survey (AGS) partnered with three operators collecting field data on CBM zones of high interest but for which little public data are available. While respecting Alberta Energy and Utilities Board rules on data release, AGS is granted permission to share knowledge and insights from six new CBM wells in this report: three wells in the Ardley Coal Zone, one well in the Horseshoe Canyon Formation, two wells in the Mannville Formation and one well in the Coalspur Formation (Ardley equivalent).

This project obtained gas desorption analytical results from two wells within the Ardley Coal Zone and one from the Coalspur Coal Zone. Four injection-falloff tests were conducted, on two Mannville coal seams in each of two CBM wells. Inline flow-buildup tests were conducted on two wells and were designed to provide specific information in each well:

- A flow (spinner) test in a Horseshoe Canyon Fm. well indicated relative gas production contributions from a series of coal seams in the wellbore
- A flow-buildup test provided information of permeability enhancement in a stimulated (fractured) Ardley CBM well.

Knowledge obtained from the test wells is discussed in conjunction with existing data obtained from well testing and field observations for the Scollard (Ardley), Horseshoe Canyon, Mannville and Coalspur formations.

6.2 Ardley and Coalspur Coal Zones: Coal Characteristics

Mine cuts and outcrop exposures of the Ardley Coal Zone indicate that the coals are moderately cleated, with a pervasive face cleat having a spacing in the order of 2–5 cm. Butt cleat, although not always observed, typically has a spacing in the order of 5–10 cm. (Figure 30). Cleat is better developed in the Coalspur Coal Zone (Ardley equivalent) of the Foothills (Figure 31). Coals from the Coal Valley region south of Hinton commonly have minor amounts of secondary mineralization infilling a portion of the coal cleat network (Figure 32). Mineralization has also been observed in Ardley coal core from the Pine Creek area. The extent of cleat mineralization in the Ardley Coal Zone is uncertain.

Gas concentrations in the Ardley appear to be greater than those of the Horseshoe Canyon and Belly River coals. Gas contents typically range from 2 to 5 cc/g, with the lower concentrations occurring in the west, toward the deformed belt (Figure 33).

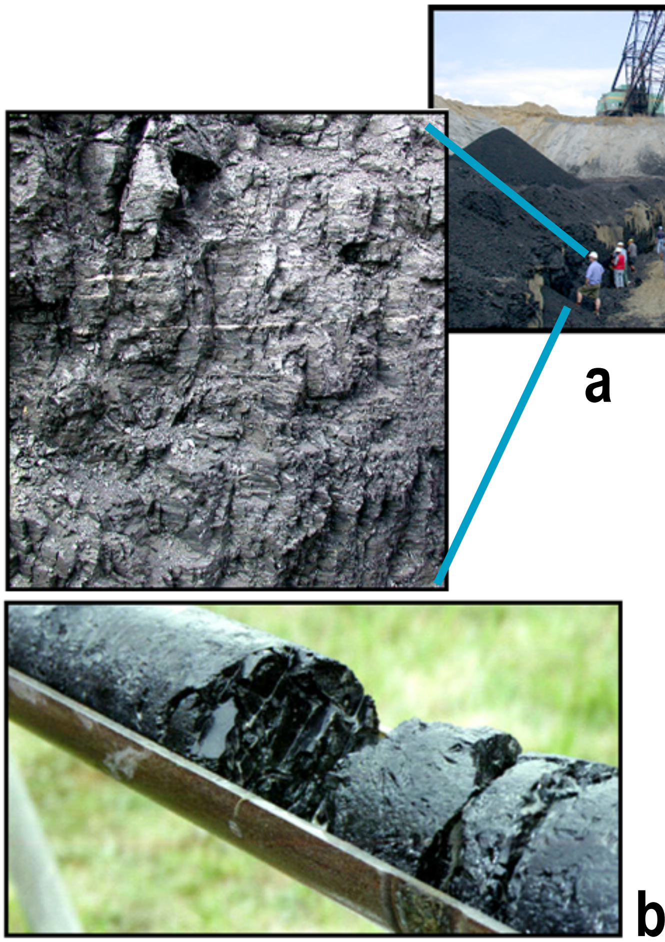


Figure 30. Coal cleat from the Ardley Coal Zone: a) Whitewood Mine, and b) exploration core

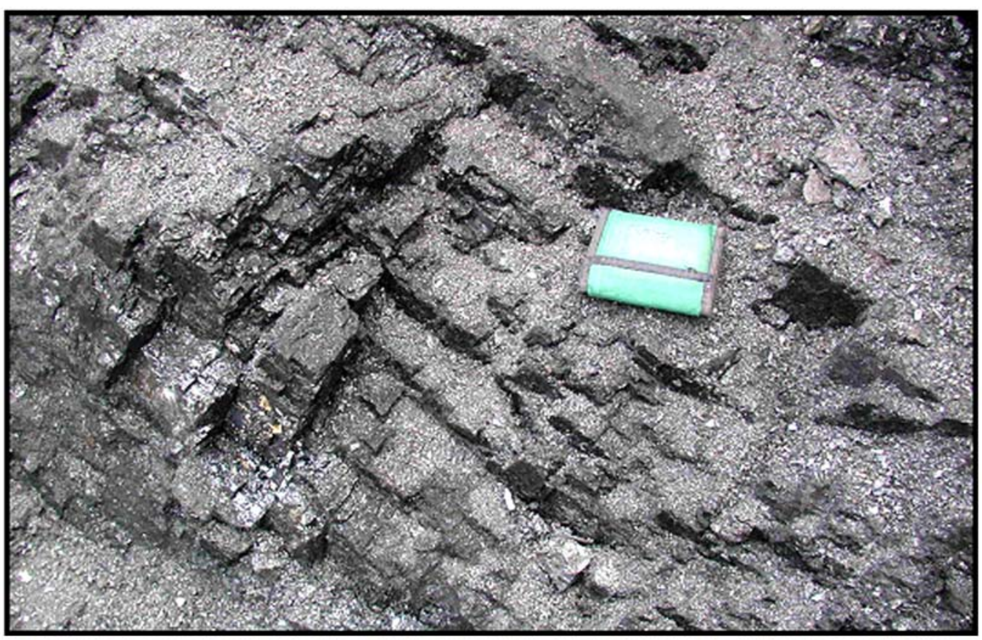
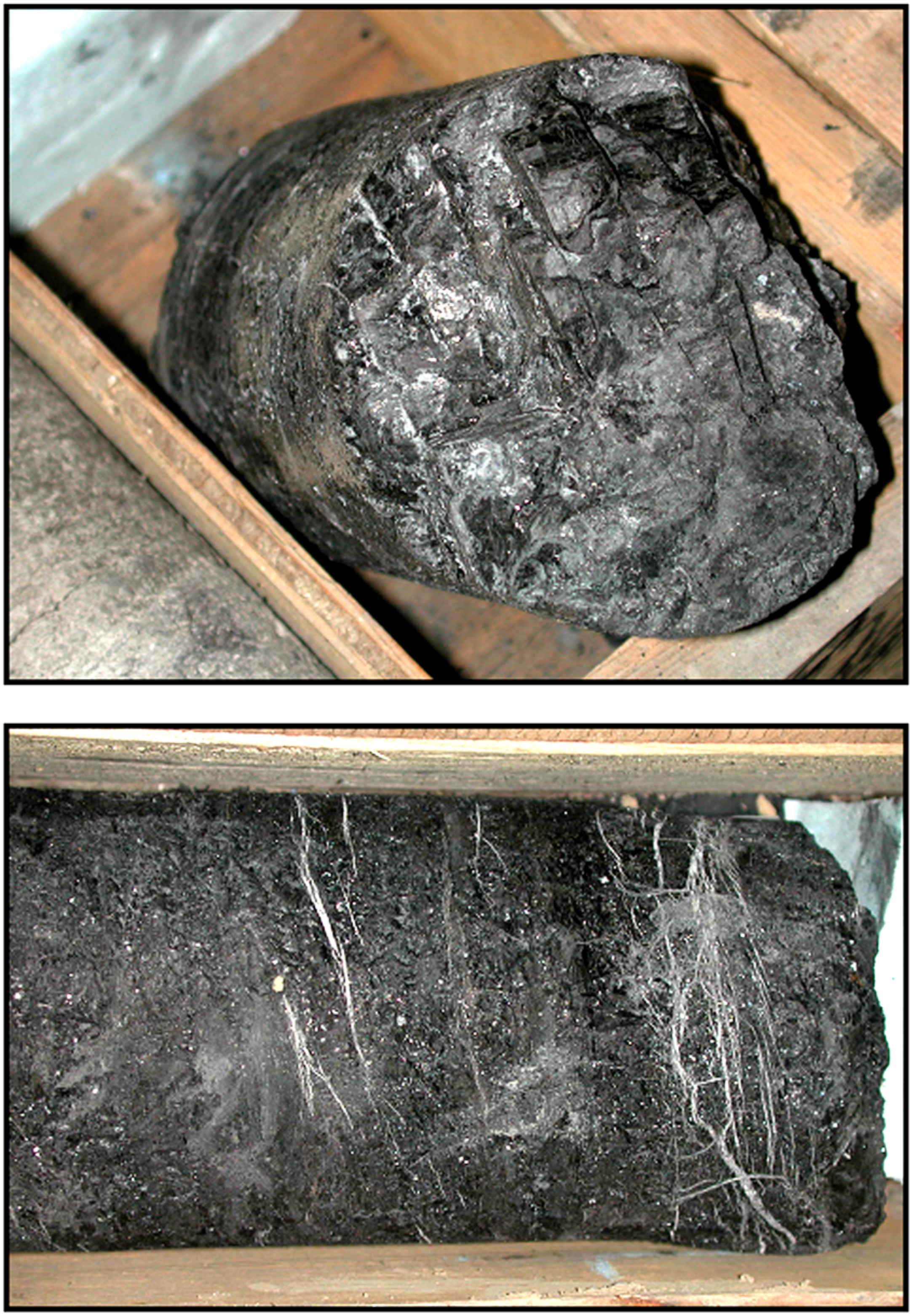


Figure 31. Coal cleat from the Coalspur Coal Zone in the Alberta Foothills (Ardley equivalent).



a

b

Figure 32. a) Coal cleat and b) fractures infilled with mineral matter, Coal Valley.

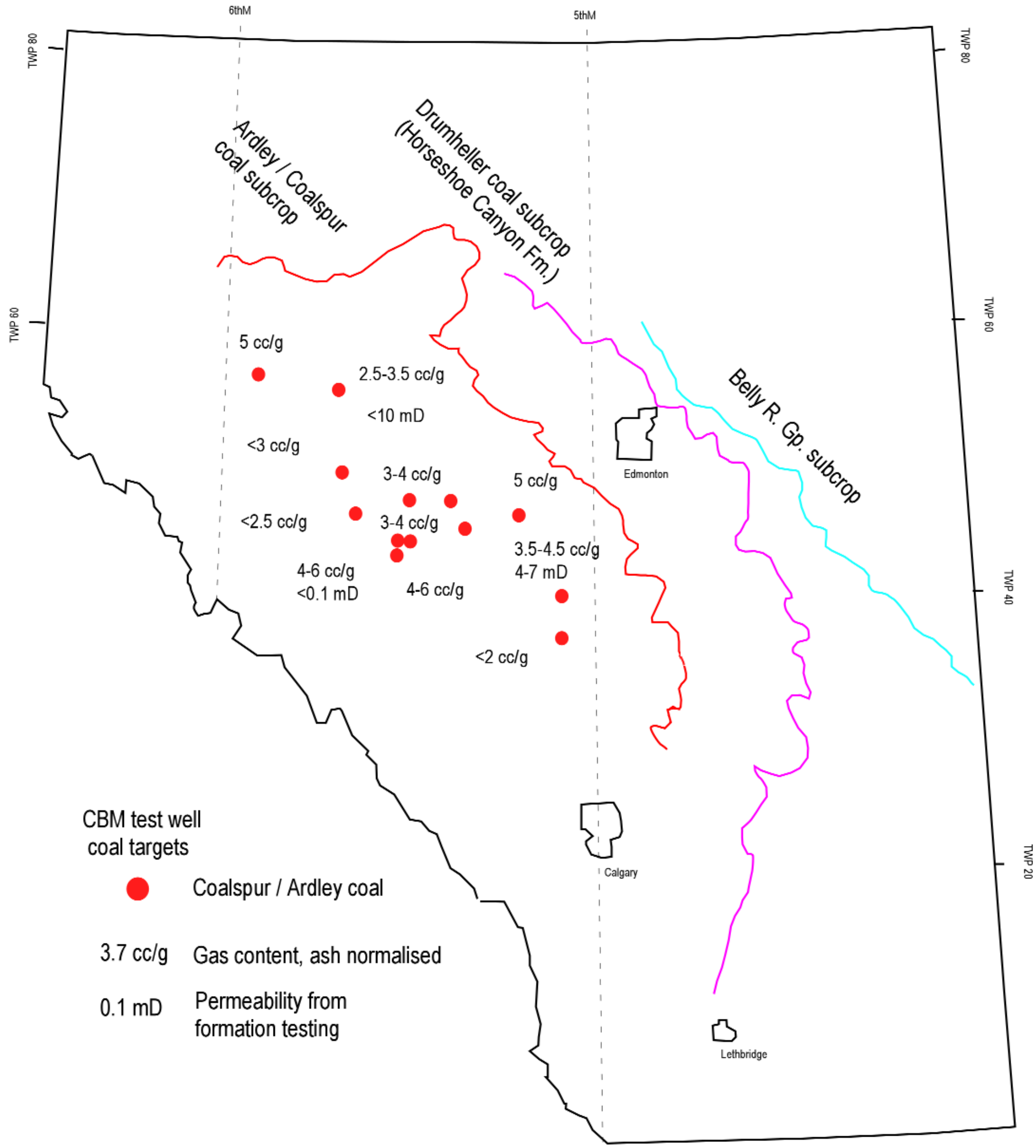


Figure 33. Distribution of coalbed methane wells, gas concentrations and permeability, Ardley and equivalent coal zones.

There are limited permeability data for the Ardley coals. Of the few wells in the Ardley, permeability results have been reported for only three, and those data are variable. In the area northwest of Edmonton (Pine Creek), permeability is vaguely reported as being less than 10 mD. In the western Alberta Plains, permeability is also low, in the order of 1 mD. The only other area for which results have been reported is the central Plains, where permeability is higher, in the range 4–7 mD. The elevated permeability results and the presence of subtle geological structure have led to increased CBM exploration activity in this area.

More recently, Rozak et al. (2002) indicated permeability values greater than previously reported for most Ardley coals. A CBM well drilled near Penhold in the central Alberta Plains was interpreted to have an average permeability of 5.8 mD over a zone with 6 m net coal, at depths of less than 300 m. This elevated permeability agrees with other (limited) data from the area. Gas contents ranged from 1.83–3.48 cc/g and averaged 2.59 cc/g. Adsorption-isotherm analysis indicated that the tested interval was saturated at the reservoir pressure of 2700 kPa.

6.2.1 Controls on Gas Concentrations

Ardley coals from the Pembina area have been reported to have gas concentrations in the order of 3–6 cc/g on a dry, ash-free coal reporting basis. These numbers represent average values obtained from numerous samples taken from different well tests. Within a given seam, different coal-seam intervals can have a wide range of gas-concentration values. Commonly, differences in gas concentration can be related to variations in density of the coal, which is a function of the distribution of noncoaly material, or ash, within the coal seam (Marchioni, 2003). It is noted that, although ash is a major control on gas concentrations within a coal sample, there are often variations in gas concentrations among samples with comparable ash composition and concentrations. Studies comparing organic composition (petrography, Rock-Eval™ analysis) have been initiated at the AGS to investigate organic compositional factors in gas distribution within a coal seam. Different coal components have different capacities for gas generation and storage (Bustin, 2001). Compositional differences may explain why different seams within a closely associated coal zone can have varying gas concentrations. Coal composition is influenced by depositional setting of the original peat swamp, and by facies variations within and across a given seam. The outcome of these investigations may assist exploration efforts by providing an understanding where a seam has maximum CBM potential.

6.2.2 Gas Concentration and Saturation of Ardley Coal: Core Versus Cuttings Analysis

Marchioni (2003) compared gas contents derived from cuttings versus cores from low- and high-rank coals in the Western Canadian Sedimentary Basin. Data are somewhat scattered, but there appears to be a moderate degree of agreement between cuttings and core gas desorption results if appropriate care and normalization techniques are applied to the original data. The possibility of using cuttings rather than core to determine gas concentrations is appealing due to the additional cost of coring during drilling operations. Although cuttings cannot be substituted entirely for core (as core provides samples for coal analysis, reservoir characteristics and good baseline gas-content data), cuttings may be used to supplement core gas-concentration data from an area if results are comparable to (or at least correlatable with) core data.

This study provided the opportunity to evaluate core and cuttings from the same Ardley Coal Zone interval in the Pembina area. Two wells, both within the same township, were subjected to gas-content determination by desorption analysis. One well obtained coal core, and the other coal drill-chips (cuttings), from the same coal seam.

Gas content of Ardley coals obtained from the cored well in the Pembina area ranged from 1.7 to 3.45 cc/g (‘as measured’ basis). This well encompassed two main seam intervals: the upper interval included two seams with net coal of 8.5 m, and the lower interval also contained two seams with 5.2 m net coal. The upper two coals averaged 2.3 cc/g, whereas the two lower coals averaged 1.72 cc/g. (all on an ‘as-measured’ basis). The overall average for all seam samples in the wellbore was 2.03 cc/g (‘as measured’ basis).

Coal cuttings were obtained from the same coal intervals in a second well within the same section of land. Results from desorption analysis on the cuttings were corrected for cavings. Gas concentrations averaged 2.4 cc/g (as measured) for the upper Ardley coal seams, and 2.7 cc/g for the lower Ardley coal seams. Compared to the gas-desorption analysis on the core, the cuttings returned slightly higher gas concentrations. This may be a correct concentration result, as gas concentrations can vary over relatively short distances within a given seam. Close investigation of the data reveals the average lost gas component was less in the core than in the cuttings. The difference was minimal in the upper coal seams (0.21 cc/g lost gas in core and 0.6 cc/g in cuttings), whereas the average lost gas determined for the lower seams was 0.12 cc/g in the core, but 1.0 cc/g in the cuttings. If the lost gas calculation for the lower seam cuttings is brought in line with the lost gas value from the lower seams from the core, then the 'measured' gas concentrations are very similar between the core and cuttings results for the two wells. In this limited dataset, it is difficult to tell if there should be a 'lost gas adjustment' or if the measured data truly reflect in situ gas concentrations. Initial comparison of gas-desorption results from cores and cuttings indicates that analysis of cuttings shows considerable promise as a method of determining gas concentrations quickly and relatively inexpensively compared to cores. That being said, core work is still essential for establishing 'baseline' data upon which cuttings results can be calibrated.

Representative samples of desorbed cuttings were subjected to adsorption-isotherm analysis in order to determine the degree of saturation of the coals. At determined reservoir pressures, a sample from the upper seam showed gas contents on cavings to be 123% of isotherm-determined saturation, and a sample from the lower seam was at 87% saturation of the adsorption isotherm for the measured reservoir pressure. It is possible the two seams have different saturation conditions, although previous studies on Ardley coals suggest that slightly undersaturated conditions are common. Determinations on core would be preferred, as core is not subjected to 'correction factors' and sample separations (density separation of noncoaly material). The possibility for errors in gas content determinations on cuttings is greater than on cores.

New data obtained in this study reveal some information regarding Ardley coal permeability after stimulation. A test well from the Pembina area was completed in the main Ardley coal seam and hydraulically fractured. An in-line flow and buildup test suggested that the completions method had resulted in a permeability of 7 mD. Although initial (prestimulation) permeability was not determined, the high permeability of the stimulated well appears to support the potential for favourable permeability within the Ardley Coal Zone of the Pembina area. Initial flow tests on this well suggested only moderate gas rates, in the order of 12 mcf/d.

6.2.3 Gas Concentrations of the Coalspur Coal Zone

The Coalspur Formation (Ardley equivalent) of the Foothills has been tested in the Coal Valley area of western Alberta. Limited data from relatively shallow depths (<300 m) in the Luscar-Sterco mine site area indicate gas concentrations ranging from less than 1 to 3 cc/g and averaging 1.78 cc/g (Langenberg et al., 2002). A nearby hole intersected the Coalspur at greater depth (886 m) and obtained comparable gas concentrations of 1.7 cc/g.

The Coalspur Formation in the Foothills has been suggested as a good CBM target in the Edson map area, south of Hinton in Coal Valley. The Entrance Syncline and nearby Triangle Zone represent structurally interesting features that have thickened coal measures and may have enhanced permeability. Coal rank is high-volatile bituminous C-B, within the thermogenic-gas generation window. Permeability data are not available for this area, but recent tests of coal from a shallow borehole (300 m) returned saturated gas concentrations averaging 4.37 cc/g. These results indicate significantly greater gas concentrations than previous results from the Coal Valley area.

6.3 Horseshoe Canyon Coals: Producibility Potential

6.3.1 Previous Coalbed Methane Evaluation of Horseshoe Canyon Strata

The Horseshoe Canyon Formation had received relatively little attention in the first round of CBM exploration in the late 1980s and early 1990s in Alberta. The CBM experience in the United States at that time suggested the need for thick continuous coals that had attained a rank of at least high-volatile bituminous B, which falls within the thermogenic-methane generation range for organic matter. Horseshoe Canyon coals are generally thin compared to the Ardley and Mannville coals in Alberta. But, more critically, they are somewhat discontinuous and at a low rank (sub-bituminous to high–volatile bituminous C, which is at the low end of thermogenic-gas generation window). Methane is adsorbed onto coals by pressure, and the geographic area containing Horseshoe Canyon coals is somewhat underpressured relative to hydrostatic pressure gradients (Figure 34). Those factors led earlier investigators to think that gas contents would be low and production potential would be minimal for these coals. The possibility of biogenic gas contributions was not even considered. To date, public domain permeability data are sparse for Horseshoe Canyon Formation coals.

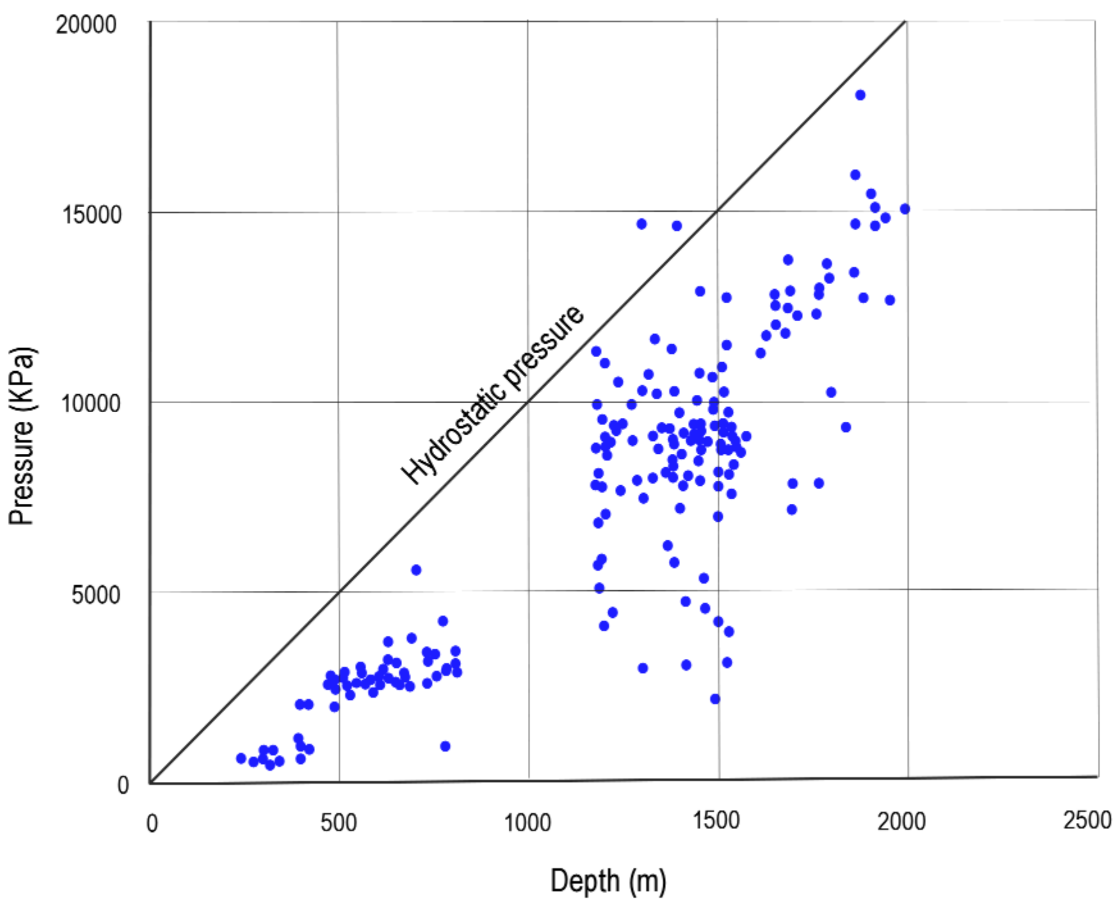


Figure 34. Pressure versus depth, with comparison to hydrostatic gradient, Alberta Plains from oil and gas wells.

6.3.2 Producibility Considerations

Field investigations of Horseshoe Canyon coals indicate that they are of low rank near the surface (sub-bituminous to high-volatile bituminous). The coals are cleated, although cleat is widely spaced. Face-cleat spacing varies with location, from 5 cm near Drumheller up to 25 cm at the Paintearth minesite (Figure 35). Data on gas contents or production potential of the coals are limited. There are a few sand units within the Horseshoe Canyon Formation that are gas producers. Those that do produce are commonly near or in contact with coal seams, and it is speculated that the coal may be a source for some of the gas in the units. The CU1 unit of Langenberg et al. (2000) is one of these gas-producing sand units (Pana and Beaton, 2002; Figure 36).

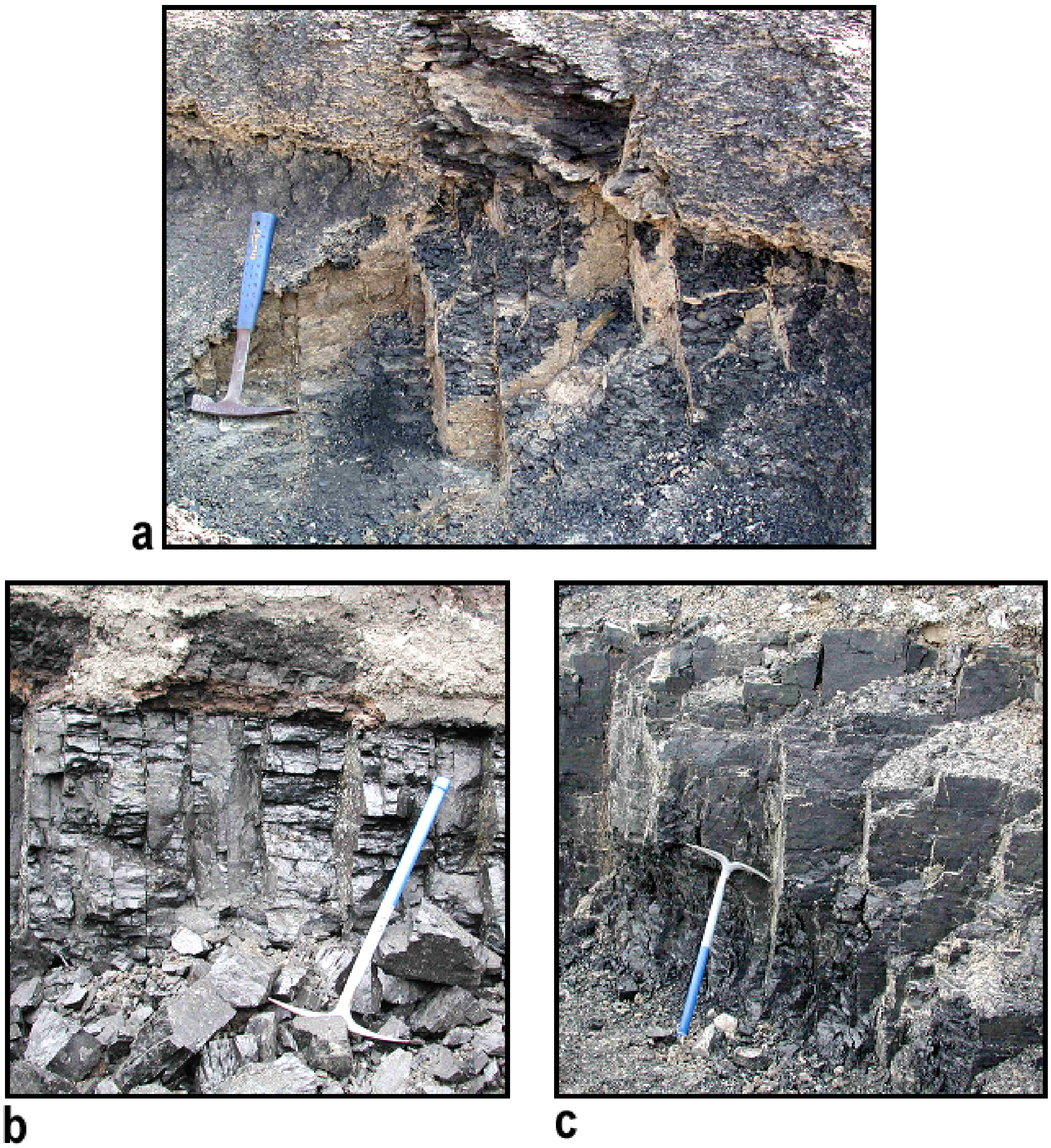


Figure 35. Cleat in Drumheller coals at: a) Willow Creek near Drumheller; b) and c) Paintearth Mine near Forestburg, Alberta.

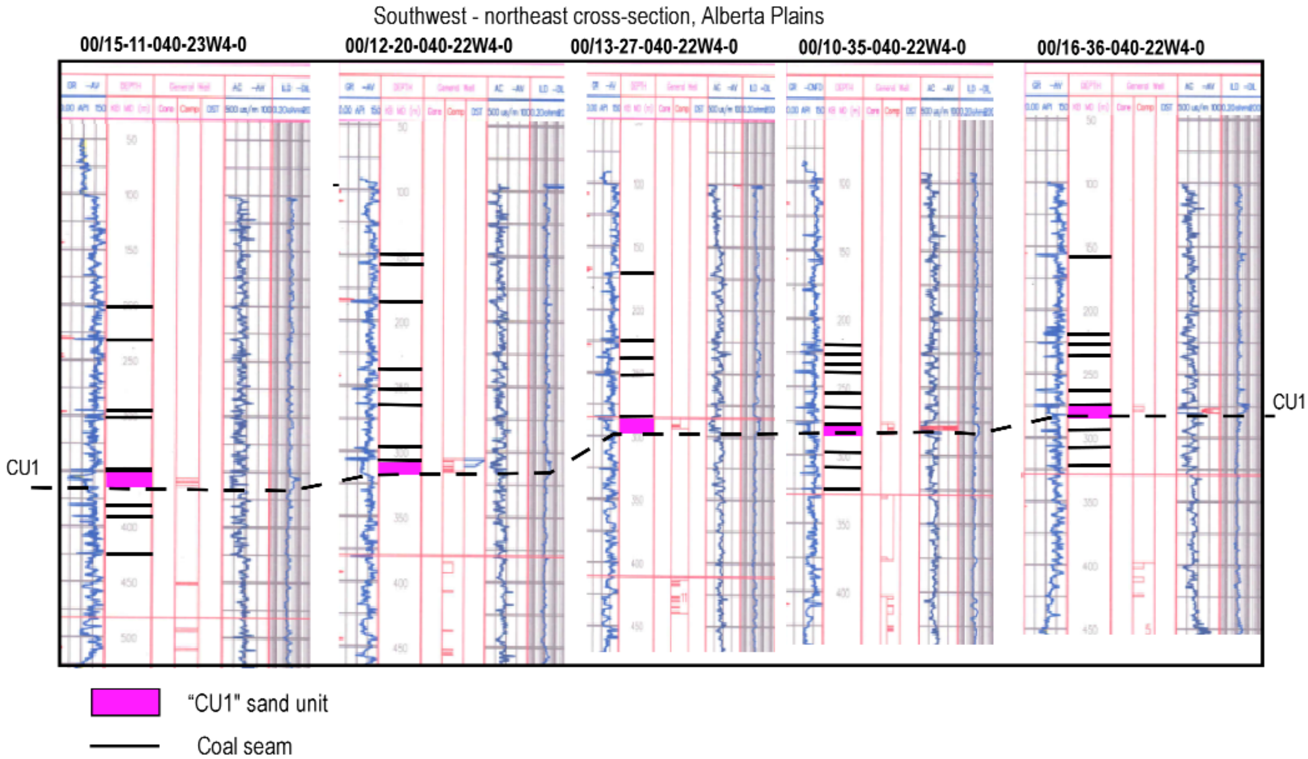


Figure 36. Section showing gas-producing 'CU1' sand in southern Alberta Plains.

Investigations of a still-confidential, shallow, Lower Horseshoe Canyon Formation CBM well as part of this study show a relatively high permeability value (4.9 mD) for the main seam of operator interest, which lies just above the CU1 sand unit. This result, derived from an injection-falloff test, is greater than the reported permeability values for most of the Ardley and Mannville coals.

Shallow strata in southern Alberta are generally of low pressure to underpressured. The above-mentioned well reported underpressured reservoir conditions at a depth of 330 m. Since adsorption of methane to the coal matrix is predominantly a function pressure, the relatively low reservoir pressures encountered would only permit moderate to low gas retention. Desorbed gas contents were typically low, at less than 1 cc/g ('as received' basis). Furthermore, gas contents were significantly different for the six seams tested in the well. Adsorption-isotherm analysis, which indicates the maximum methane holding capacity of the samples, suggested that the coals could adsorb an average of 1 cc/g, and that they were undersaturated by approximately 35% of maximum capacity. Compositional data indicated that the gas was predominantly methane (>96%). Isotopic data suggested a predominance of thermogenic gas in the test samples.

A limited production test on this well indicated low initial production rates that dropped off quickly. The well averaged 19 mcf/day over the 3-month test interval.

Recent commercial coalbed methane production within the Horseshoe Canyon Formation in south-central Alberta has prompted companies to re-evaluate these supposedly 'unfavourable' coals in a new light. Previously thought to have gas contents too low for economic exploitation, these coals may also have low water production, in the order of 1 bbl/day or less (Canadian Discovery Digest, 2002). This, coupled with greater permeability values compared to those of Ardley and Mannville coals, have made the Horseshoe Canyon coals a renewed target for exploration. Although new permeability data are not available in the public sector, the seams are capable of providing some gas movement coupled with very low water production. Horseshoe Canyon CBM wells from the central Alberta Plains show a wide range of production, with typical wells ranging from 30 to 250 mcf/d (Canadian Discovery Digest, 2002). On average, Horseshoe Canyon wells of the Palliser block west of Calgary produce approximately 100–125 mcf/d.

Data from recent exploration by industry confirm the low gas contents in the Horseshoe Canyon strata, as would be expected from the low pressure of the reservoirs. In situ gas contents typically range from 30 to 60 standard cubic feet/ton (scf/t) (0.9–1.9 cc/g), with some subsamples from individual seams indicating gas contents up to 122 scf/t (3.8 cc/g). Gas content varied among seams encountered within a well, and also differed markedly between wells. Marchioni (2003) reported a moderately positive correlation of gas content with depth for Horseshoe Canyon strata.

6.3.3 Seam Production Profiles, Horseshoe Canyon Formation

The current study examined one new Horseshoe Canyon CBM well (well no. 1). Located in south-central Alberta, the well intersected 13 coal seams of interest (seven from the 'middle' Drumheller Coal Zone and six from the lower or 'basal' coal zone). Reservoir pressure was low, ranging from 342.5 kPa at the top of the shallowest seam test (327 m) to 366.8 kPa at the deepest seam (462.5 m).

The seam at the base of the 'middle coal zone' corresponds to the main seam tested in the lower Horseshoe Canyon CBM well discussed previously. The seams were perforated and individual seam pressures were measured. A nitrogen fracture stimulation was conducted on each of the 13 intervals to improve wellbore connectivity with the cleat-fracture network in the coal seams. The wellbore was placed on test production. Gas production after nitrogen recovery was measured from individual perforated zones (flowmeter, or spinner logs) in order to determine relative contributions to total gas flow. Total gas flow of the well was low, averaging 22 mcf/day. Of the middle Horseshoe Canyon coals, only the main seam contributed significantly to cumulative production, averaging 20%. The three lowermost seams of the basal or lower Horseshoe Canyon coals contributed about equally to an average of 72% of the total cumulative production in the wellbore. The remainder of production (8%) was derived from two seams in the Middle coal zone.

Seam thickness did not appear to control gas contribution as much as relative stratigraphic position. Data interpretation at this time is somewhat speculative, but it was noted that the productive coal in the middle coal zone directly overlies a coarsening-upward sand package, which conformably overlies the silt and shale of a 'middle' marine Bearpaw Fm. tongue. This sand package is the 'CU1' sand, which is a gas producer in some parts of southern Alberta. The best gas producers in the lower coal zone are the lower three of six coal seams, all of which are contained within a shale-silt zone, which lies at the base of a silty sand unit and atop the 'lower' Bearpaw Formation tongue. Seam thickness alone did not control gas production.

The results of the production test indicate that not all seams within the test interval contribute equally to the cumulative gas production, and several seams do not contribute to production at all. Furthermore, water production is minimal (a few barrels of water per week).

6.3.4 Comparison of New and Existing Production Data

How do these test results compare with newly reported data from Horseshoe Canyon Formation? MGV Energy Ltd. and Encana Ltd. embarked on a CBM project in the Palliser block, near Rockyford, approximately 50 km east of Calgary. Within a 25-township area, approximately 100 wells were drilled and many were put on production. A strategy of perforating and completing several seams within the wellbore is employed in the area. Although production rates vary across the study area, it is interesting to note that wells close to one another may have very different production rates from essentially the same coal sequences. The new data obtained in this study indicate that different seams have different production potentials. With Encana/MGV testing several to most seams within a wellbore, it is speculated that all seams have some contribution to total well production, and that the seam contribution may vary from location to location (as they did not target selected seams, rather perforated almost all seams in the wellbore). The seams of the Horseshoe Canyon tend to split and are somewhat discontinuous, and seam correlation and characterization will be important in the effort to identify favourable CBM targets.

New production data obtained in this study (well no. 1) were compared to production data from a nearby well (well no. 2) that was one township away. Flowmeter (spinner) data indicated that the seams contributing most to total well flow were different between the two wells. Within the study area, the Drumheller could be subdivided into an upper, middle and lower Coal Zone. In well no. 1, the main ‘upper’ Drumheller Coal Zone seam contributed 20% to total well flow, whereas flow was minimal in well no. 2. The upper seam of the ‘middle’ Drumheller Coal Zone also contributed approximately 20% to total well flow in well no. 1, whereas the lower coal seam was the main producer (20% flow contribution) of the ‘middle’ Drumheller Coal Zone in well no. 2. Within the ‘lower’ Drumheller Coal Zone, all three lower seams contributed to total well flow; however, in well no. 1, the lower seams contributed approximately 34% of total flow, whereas, in well no. 2, they contributed approximately 70% of total flow.

Gas concentration (desorption) data were available to compare with the flowmeter tests for well no. 2. Seams with the greatest desorbed gas concentrations did not always contribute the most to total flow, although there was generally a weak correlation between flow contribution from seams and their gas concentrations.

Comparison of the two wells indicated that gas production potential may be extremely variable within a given seam, even over relatively short distances. Variations in gas production from a given seam may be partly due to subtle pressure variations across the seam, hydrogeological conditions or permeability variations. Furthermore, the flowmeter tests represent the conditions at the time of the test, whereas flow and pressure conditions may be dynamically changing as gas is produced in the wellbore.

6.4 Belly River Group Coals

There are essentially no data on gas-content or CBM-production potential available for coals of the Belly River Group coals. Field investigations of coal outcrop indicate the coals at surface are fairly well cleated, with spacings ranging from 1 to 2 cm on the face cleat, with a lesser developed butt cleat (Figure 37, Figure 38). Coal rank ranges from sub-bituminous to high-volatile bituminous, with much of the coal resources falling within the thermogenic-gas generation boundaries. There are three main coal-bearing zones in the Belly River Group: the Lethbridge, Taber and McKay coal zones. Each zone contains generally thin seams, with net coal thickness averaging less than 3 m, although some localized pods can exceed 4 m net coal thickness within individual coal zones, and may provide a suitable CBM completion interval for employing multiseam completion practices (Figure 39). Recent CBM investigations have included very limited sampling of the Lethbridge Coal Zone (upper Belly River Group), and have indicated gas contents in the 2–4 cc/g range. Promax Energy Ltd. indicated that it has tested Belly River coals from an undisclosed location in the Alberta Plains, and had encountered low gas concentrations (actual values not reported). Flow rates were expected to be correspondingly low, in the order of 30–40 mcf/d (Lemmens, 2003).

Figure 37. Cleat development in the Lethbridge Coal Zone.

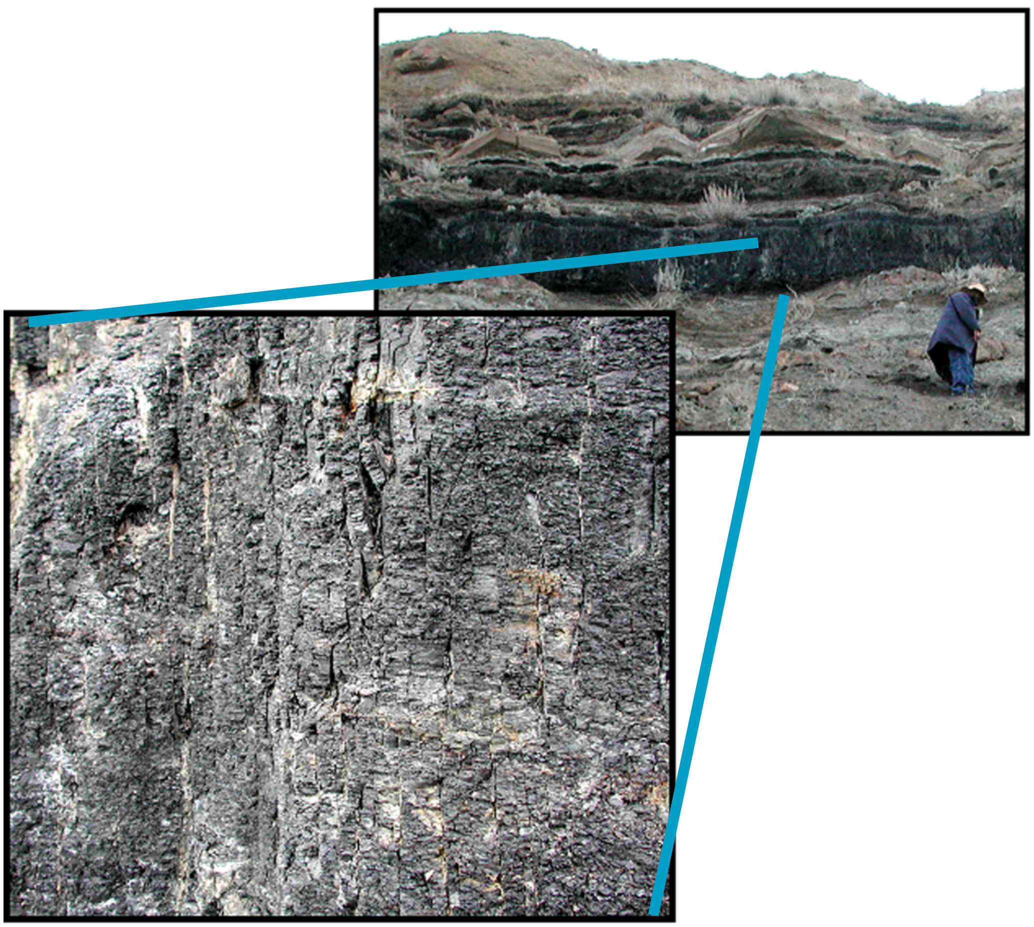


Figure 38. Cleat development in the Taber Coal Zone.

Figure 39. Taber Coal Zone, southern Alberta.

6.5 Mannville and Equivalent Coals

The Lower Cretaceous Mannville Group contains significant coal deposits. In the Alberta Plains, two to four coal zones occur within the Upper Mannville Group (Langenberg et al., 1997). Unlike the coals of the Upper Cretaceous and Tertiary of Alberta, the Mannville coals generally occur at depth in the Plains, only coming near surface in the northeastern area of the province. Coal rank ranges from lignitic–sub-bituminous to high-volatile bituminous A at depths of less than 2000 m in the Plains. The Mannville coals vary in thickness, from <2 m net coal to greater than 12 m net coal. In the northern Foothills, the equivalent coals of the Gates and Gething formations occur at surface, and are of economic (mineable) significance. The Gates and Gething formations can attain a rank of medium-volatile bituminous. In the southern Foothills, the equivalent Kootenay coals of the Mist Mountain Formation average 13 m net coal (Langenberg et al., 2002). Rank ranges from high- to low-volatile bituminous. The occurrence of thick coal within the thermogenic-gas window has made Mannville (and equivalent) coals an attractive target for exploration.

In the late 1980s and early 1990s, Mannville coals were targeted for CBM exploration. Results from this activity indicated that the coals had higher gas contents than the shallower Ardley coals, with gas-in-place ranging from a low of 3 cc/g up to 20 cc/g. The gas concentrations of Mannville coals in the Plains of northwestern Alberta, in the 4–8 cc/g range (although some higher values occur), appear slightly lower than those in the central Plains, which are in the 8–10 cc/g range. This value drops dramatically toward the eastern margin of the province, where coal rank is low (lignite to sub-bituminous) and the coals are shallow. One test well near Provost reported measured gas concentrations of only 1.3 cc/g (Unpublished results, Alberta Research Council, 1993).

It is interesting to note that gas concentrations can vary significantly over a short distance, with both low and high concentrations occurring within the same 'exploration' region, commonly within a township or two of each other. In the southern Foothills, coal gas-in-place values show a tighter range of concentrations, in the 8–10 cc/g range (one instance of gas concentrations up to 20 cc/g was reported). In the northern Foothills, gas concentrations are slightly higher, in the 7–13 cc/g range. In the northern Foothills, permeability is reported to be low (<0.1 mD). Slightly higher permeabilities are reported for the southern Foothills, in the 1–2 mD range (Dawson et al., 2000).

It is established that the Mannville coals generally have high gas concentrations relative to Upper Cretaceous–Tertiary coals. Although reservoir studies are rather limited, the few tests reported indicate that the Mannville has low permeability. In the central Plains, reported permeability is in the 0.1–0.2 mD range. Permeability appears slightly higher in the eastern part of the Plains, where one exploration region reported permeability in the 1–4 mD range. In the northeastern Plains, permeability is even lower than the central Plains, reportedly less than 0.1 mD. The southern Foothills report permeability in the 1–2 mD range (Figure 40).

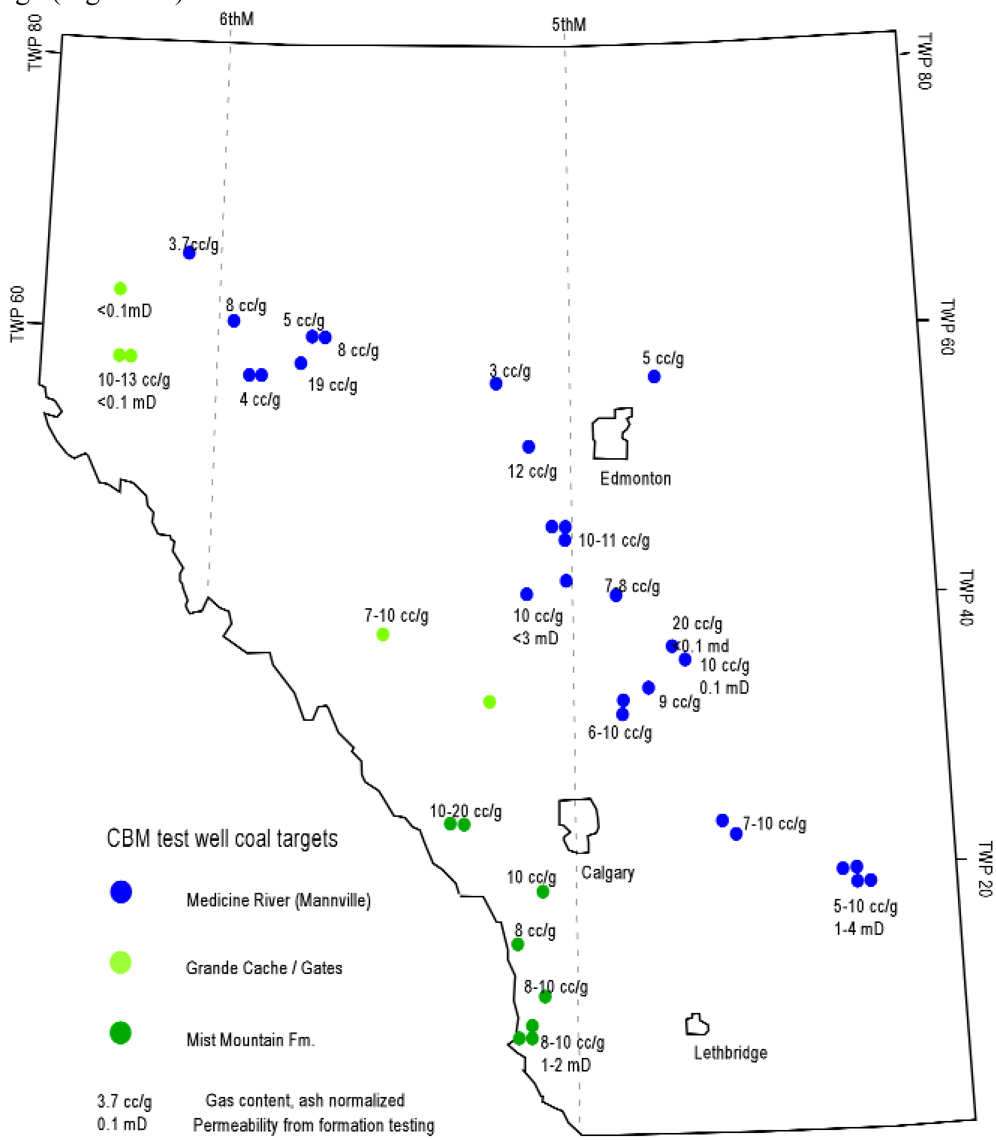


Figure 40. Distribution of CBM wells, gas concentrations and permeability, Mannville and equivalent coal zones.

Permeability is the biggest challenge to CBM producibility in the Mannville coals. Dawson et al. (2000) summarized the permeability tests reported on Mannville coals, and indicated some potentially flawed tests and/or interpretations. Somewhat higher permeability was reported in more recent tests of Mannville coals in the central Alberta Plains, with values of 1 mD (Sloan and McKinstry, 2002) and 3 mD being reported from test sites only 500 m apart**.** The reported data suggest potential for variability in permeability across the province. Recent CBM pilots in the Corbett Creek area of the Plains, northwest of Edmonton, are producing water in an attempt to lower reservoir pressure and initiate CBM production from Mannville coals (New Technology Magazine, 2003). Sloan and McKinstry (2002) suggested that permeability in the order of 3 mD may be present in the area, and that areas along trend may have permeabilities in the 2–5 mD range (based on geophysical log interpretations).

New technology employed by industry in the Alberta Plains may overcome the challenges posed by the low permeabilities of the deep Mannville coals (Payne, 2003). By employing 'pinnate horizontal drilling', where a series of legs are drilled off a horizontal wellbore (all within a coal seam), the maximum number of coal cleats-fractures can be intersected, thereby maximizing conduits from the coal into the wellbore. This technology is expensive, but may allow for development of 'tight' thick coals, with permeabilities <0.1 mD.

6.5.1 Mannville Permeability Test Results

In order to examine the validity of older permeability measurements and obtain new data, this project examined data from two wellbores, a township apart near Stettler, which tested the upper Mannville coals. Two main coal zones were present, between depths of 1000 and 1150 m. In the two wellbores, the lower zone contained 1.5–2 m net coal and the upper coal zone contained 2–3 m net coal. Reservoir pressure was approximately 10,000 kPa. Both coal zones were subjected to injection-falloff analysis. Test data were interpreted to indicate low permeabilities (<0.25 mD) for both zones. In both wells, the lower seam was thinner, but had greater permeability than the upper seam. Furthermore, permeability differed for a given seam between the wellbores. Permeability was interpreted to be 0.17 mD for the lower seam in the shallower well, whereas it was 0.23 mD for the same seam in the deeper well. For the upper seam, permeability was 0.04 mD in the shallow well and 0.17 mD in the deeper well. These data agree with the older data obtained from the south-central Alberta Plains (Dawson et al., 2000), which indicated low permeability (0.1 to 1 mD) within Mannville coals. On the other hand, Sloan and McKinstry (2002) suggest there are areas in the Plains with permeability in the order of 1-3 mD. New results indicate that there is a permeability difference between the upper and lower coals of the Mannville in the area; although the more recent permeability values are low, they are greater than those previously reported (<0.1 mD in older data compared to 0.2 mD in the new test results).

7 Conclusions: What was Learned from the Project?

The investigations presented here indicate that there is a great potential coalbed methane (CBM) resource within the coals of the Plains and Foothills of Alberta. Coal ranks across the province range from low-rank sub-bituminous at shallow depths in the Plains, through high-volatile bituminous at depth, to medium to low-volatile bituminous in the Foothills. The higher rank coals of the Plains and Foothills have been explored as potential CBM targets, but the lower rank, shallow coals of the Plains have also been increasingly targeted for CBM exploration. Experience from American CBM plays has suggested that low permeability and low gas contents combine to make a difficult CBM play. In general, Alberta faces both of these challenges; however, individual coals of interest do not necessarily include both of these unfavourable elements. Mannville coals generally have high gas contents and moderately thick net coals, but low permeability. Ardley coals have somewhat lower gas concentrations, but slightly higher permeability and thick net coals over a narrow stratigraphic range. Limited data suggest that

Horseshoe Canyon (?and Belly River) coals have slightly higher permeabilities than Ardley coals, but lower gas contents. Furthermore, Horseshoe Canyon (?and Belly River) coals appear to be relatively dry, and CBM wells produce very little water. Additionally, the water produced approaches freshwater quality. Mannville coals, on the other hand, produce moderate quantities of saline water, which must be handled properly.

The study identified areas of promising CBM potential within the Plains and Foothills of Alberta on the basis of coal distribution, quality, coal rank and calculated in situ gas concentrations. Four targets of interest and concern were addressed in this study for the purpose of increasing knowledge of CBM potential in Alberta within those areas thought to have the greatest CBM potential (Figure 28):

1) Ardley Coal Zone in the Pembina area: This area is undergoing perhaps the most intensive CBM exploration and testing within the Ardley Coal Zone. Although typical average gas concentrations are known, the current project investigations examined the vertical distribution of gas within a test wellcore of the Ardley Coal Zone. Forthcoming data on coal-seam chemistry, quality and petrology will be compared to the highly variable stratigraphic distribution of gas concentrations in an effort to understand the factors controlling gas distribution.

Coal core, which is used to provide samples from which gas concentrations and coal properties are determined, is expensive to collect. Increasingly, industry is turning to drill cuttings to gather the data traditionally determined from core, for reasons of cost (much less expensive) and as a quick method of collecting data on coal seams as they are encountered during drilling for deeper conventional targets. This study afforded the opportunity to compare data obtained from a core cut for CBM evaluation with data collected from drill cuttings collected from the same strata in an adjacent conventional well.

The Ardley Coal Zone has undergone considerable CBM testing. Permeability data are limited, and there is a wide range in the data being reported, from 1 to 7 mD. This study examined a CBM well that was completed, fracture stimulated, and tested for permeability. The results will shed light on the effectiveness of stimulations in increasing wellbore connectivity to the reservoir and increasing permeability to enhance production potential.

2) Coalspur Coal Zone at Coal Valley: The Coalspur Coal Zone, which is the Foothills equivalent of the Ardley Coal Zone of the Plains, has undergone limited CBM exploration in the past. Results were mixed, with gas concentrations suggesting moderate CBM potential. The Coal Valley area is thought to have favourable CBM potential on the basis of coal rank and potential structural enhancement of permeability (Langenberg et al., 2002). A section of the Coalspur Coal Zone was cored and gas concentrations were determined from a deep coal exploration hole. Results were compared to previous data from the area. The data obtained will provide much-needed information on the CBM potential of this area of interest.

3) Horseshoe Canyon Formation production potential: Coal seams of the Horseshoe Canyon Formation in south-central Alberta host the first commercial CBM project in Alberta. The coals are generally thin, discontinuous, underpressured and of low rank, all factors that would discourage CBM exploration. On the other hand, there are indications of moderate permeability and low water content within the coals. The recent exploration efforts within the Horseshoe Canyon Formation have resulted in numerous wells being completed close to one another. These wells report a wide range of production within a relatively small geographic area. This study investigated production profiles from new CBM wells and compared geology and seam production characteristics from nearby wells in an effort to examine the controls exerted by seam geology on CBM production.

4) **Mannville Coal Zone:** Mannville coals are undergoing exploration, and pilots have been established at various locations in Alberta. Mannville coals have high gas concentrations but typically low permeability. Recent exploration activity has indicated that there are potential areas of elevated permeability within the Mannville coals. This study examined permeability in Mannville coals in the east-central part of the Alberta Plains, where geological studies suggest favourable gas potential but permeability data are lacking.

Key findings from the above study targets were integrated with existing data where available, and are summarized as follows:

1) **The Ardley Coal Zone** in the Pembina area has a moderate range of gas concentrations, from 2.5 to 5 cc/g (on a dry, ash-free reporting basis). In general, the coal zone is slightly undersaturated, but saturated to oversaturated areas may exist, both laterally in the Pembina area and also stratigraphically, between seams and individual samples of a seam within a given wellbore. Permeability data for the Ardley Coal Zone in the Pembina area are sparse, and a wide range of potential permeabilities is reported, from <1 to 7 mD. Although this range sounds promising, there are few public data available to substantiate these values. Results obtained in this study indicate that post-stimulation Ardley coals can have increased wellbore-reservoir connectivity, and near-wellbore permeability can be fairly high (7 mD). These results suggest that some poststimulation Ardley coals may have favourable properties for enhanced CBM production.

Comparisons of gas concentrations of core and cuttings obtained from adjacent CBM test wells in the Ardley Coal Zone generally agree with one another if care is taken to apply proper correction factors to the cuttings data. Proper correction factors are determined by comparing with local core data. If core data are not available, caution must be used if relying on cuttings data alone to assess CBM potential. Cuttings do afford an excellent opportunity to capture coal-gas data from conventional deeper wells (piggyback testing) relatively inexpensively, and as a quick ‘infill’ data-gathering tool in areas where sufficient baseline CBM data exist. Core cannot be eliminated from a proper CBM evaluation program.

2) **Coalspur Formation coals** from the Coal Valley area of the Alberta Foothills present an attractive CBM target. Gas concentrations obtained from a shallow (300 m) exploration hole far exceeded the limited historical data. Historical data (from minesite and conventional exploration holes) averaged 1.8 cc/g, whereas the new test hole averaged 4.4 cc/g. Furthermore, the new data suggested saturated reservoir conditions. Coal rank is well within the gas-generation window. Ongoing exploration and scientific work are needed to ascertain whether the conditions encountered in the current investigations are regional or local, and, if local, what factors govern the favourable conditions encountered. Permeability is still unknown for the study area.

3) **Horseshoe Canyon Formation coals** examined in two nearby wellbores show differences in total well production (flow). Close examination of flowmeter data and in situ gas concentrations indicates that different seams contribute different amounts of gas to the total well flow. Some seams in a given wellbore do not contribute much to total flow, whereas others contribute the ‘lion’s share’. Relative seam contribution to total flow/production does not appear to be strictly dictated by measured in situ gas concentrations (desorption analysis). Furthermore, seams that correlate between nearby wellbores have different contributions to total production. In some cases, the main producing seam in one well may not contribute to production at all in an adjacent well. Coals of the Horseshoe Canyon Formation tend to be unsaturated and underpressured. It is unclear whether 1) the differences in production laterally within a given seam are due to local pressure or saturation differences, or 2) production in one area affects production in another if production contributions are

continually changing. Detailed geological correlation studies, coupled with hydrogeological investigations, may provide insight into coal-production dynamics of the Horseshoe Canyon Formation.

4) Mannville coals have been shown to have high gas content, but reported low permeability had hampered production efforts. Recent reports of local zones of high permeability have again focused interest on the thick Mannville coals. The Mannville underlies much of the Plains. The east-central Plains has favourable in situ gas potential, but there are no permeability results available in the public domain. This study has examined two recent CBM permeability test results from this region. Although the results were low, permeability was marginally higher than previous data obtained elsewhere in the central plains. In addition, permeability was slightly greater in the lower of the two Mannville seams studied. This investigation did not identify areas of increased Mannville permeability, but it does suggest that permeability variations exist laterally and stratigraphically within the coal zone. Further studies on coal composition and regional geology may indicate controls on the variation in permeability, which may prove to be a good exploration tool.

The main conclusion of this study is that the regional permeability and gas-content generalities that have been stated publicly by numerous sources and discussed throughout this report cannot be applied uniformly across the basin.

Ardley coals, which have been targeted mainly because of thickness, depth and gas content, are generally of low permeability, although several areas in the province report elevated permeability. These areas are the focus of exploration in west-central Alberta. Recent testing suggests that stimulating Ardley CBM wells may significantly improve permeability near wellbores and overall well-production performance. Ardley coals are commonly undersaturated with moderate gas content, but areas of saturation and high gas content do exist. Previously reported gas concentrations in the Coalspur Formation (Ardley equivalent) in the west-central Foothills appear lower than the results obtained in this study. New data suggest the presence of high gas concentrations at shallow depth, which implies improved economics due to reduced drilling costs. It is possible that biogenic methane is contributing to the elevated gas concentrations at these shallow depths. Future work should include gas isotopic studies to evaluate potential biogenic activity.

Horseshoe Canyon Formation coals are the big news from the Alberta CBM industry. Previously thought to be unfavourable for CBM production, these coals appear to be at least marginally economic. Low gas contents are being assisted by relatively high permeability and low water production. Multiple seam completions facilitate gas production. Key findings of this study indicate that not all seams in the Horseshoe Canyon produce similar gas volumes, even when seam thickness and variability in coal quality are taken into account. The complex interplay of geology, pressure and hydrogeology that allows gas pockets to develop within the seams of the Horseshoe Canyon warrants further investigation. A question that arises from the Horseshoe Canyon CBM play is what the production profile and history of these wells will be, as they are starting off underpressured with low adsorbed gas concentrations and do not initially produce water. How is flow maintained over time if pressure is not being continually drawn down to facilitate gas desorption? Is this a traditional CBM play with gas adsorbed onto a coal seam, or is it more of a conventional-type play where 'free migrating gas' is being exploited, and it just happens that a cleated coal seam is the reservoir or flow conduit? Is there a biogenic contribution to gas distribution? Detailed geological studies of these plays may reveal the answers.

Data are still lacking for Belly River coals, although preliminary investigations suggest that coals may locally have favourable gas concentrations and permeability. In some areas, Belly River and Horseshoe Canyon coals occur over a small stratigraphic interval and may allow multizone completions within a given wellbore.

Mannville CBM pilots underway in the province suggest local elevated permeability in the northwest-central Plains, and in equivalent strata in the southern Foothills. Low permeability previously reported in the east-central Plains appears consistent with new test data from the current study. Low permeability does not necessarily prohibit development. Conventional vertical holes are suitable for coals with a few mD of permeability. Horizontal wells, although more costly, can access permeability by drilling perpendicular to cleat and fracture, thereby accessing more conduits for fluid flow in low permeability coals.

Recent investigations, as shown by the findings of this study, are challenging the generalities from earlier regional-scale studies regarding gas concentrations, permeability and production potential within all coal zones in the Alberta Foothills and the Plains. It appears that each major coal zone has local areas with characteristics favourable for CBM production. Ongoing geological investigations at a local or 'play' scale will undoubtedly lead to a better understanding of the factors controlling and contributing to local CBM enhancement.

8 Recommendations: Areas for Future Investigations

Interest in coalbed methane is growing in Alberta as industry has already begun to produce and develop this resource. Many questions remain unanswered with respect to CBM potential. With ongoing exploration, some of these questions are closer to being resolved. Areas of interest arising from this study in particular involve permeability estimation, distribution and enhancement, and production from underpressured water-dry plays and reservoir connectivity.

Permeability has been shown to vary considerably within a local area for a given coal seam. The question that arises is whether this variability is real and applicable to the reservoir, or is the variability reflecting wellbore conditions (potential damage) or differences in the testing itself. Stimulation of low permeability coals in some cases dramatically improves permeability, whereas in other coals the enhancement is minimal. Reservoir composition, structure and geological history need to be assessed in conjunction with engineering evaluations at a local (play) scale in order to properly assess permeability results and distribution.

Horseshoe Canyon Formation coal reservoirs have been shown to be of low pressure and water-dry. Wells producing from the same seams may have different production profiles, with different seams in adjacent wells contributing differing amounts to total production. It is unclear if the seams are in communication with interbedded sands and shales, and the extent of lateral communication within a seam is unknown. Furthermore, it is unknown how the reduction of already low reservoir pressure in a CBM field will affect nearby CBM wells (ie. potentially affecting maximizing recovery of the resource). Detailed geological and hydrological studies are needed to address communication and pressure issues.

General issues regarding CBM in Alberta that merit future studies include

1) The role of biogenic methane. Is there a biogenic contribution to the gas produced from coals that are of low rank (low rank coals generally do not produce significant amounts of CBM)? Much of the shallow Plains coals are of low rank, below the thermogenic gas generation window. Isotope compositional studies and hydrogeological investigations may indicate favourable areas of potential biogenic gas enhancements for future exploration.

2) The gas potential of Belly River coals is still not well understood. Limited exploration has been conducted, but more data are required to properly assess Belly River CBM potential.

3) Investigations into gas content and permeability, including the role of coal composition, rank, structure and applications of fracture theory may help to predict areas of enhanced gas concentration and permeability in Alberta.

4) Hydrogeological investigations of potential CBM areas are required in Alberta. From a geological perspective, hydrogeological studies may help to indicate flow pathways and boundaries that may assist in identifying gas “sweeping” and trapping. Understanding pressure regimes is also important in determining CBM potential, from a perspective of suitable exploration locations to potential interference with nearby oil, gas and CBM reservoirs. From an environmental perspective, hydrogeological studies are required to assess potential impacts on local and regional aquifers (volumes, flow rates, chemistry) from CBM production.

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