PART B

COALBED METHANE

MOUNT FLEET ALKALINE COMPLEX

PROSPECTORS ASSISTANCE PROGRAM

AN INTRODUCTION TO COALBED METHANE POTENTIAL IN BRITISH COLUMBIA

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INTRODUCTION

Recently, there has been much interest in coalbed methane (CBM) potential from coal seams. Background information about CBM will be presented, then a brief description of the potential CBM resource of the province and information about CBM exploration activity to date.

The geological process that forms coal also generates a major amount of volatile matter. In fact production of a tonne of anthracite generates over 200 cubic metres of methane (CH_4). Most of this gas escapes into the surrounding rocks but some is retained in the coal as coalbed methane (CBM). Methane is held in coal in three ways:

adsorbed onto the surfaces of microscopic pores where it exists in a quasi liquid state,

as a free gas in the micro porosity in the coal,

in solution in water associated with the coal.

Adsorption is by far the most important way that coal holds methane. Coal is unique among geological strata with regards to its ability to adsorb gases. Adsorbed gas forms a single molecule thick layer coating the surfaces that create the micro porosity in the coal. It therefore has the density of a liquid and this, in conjunction with the very large cumulative surface area of the pores that make up the micro porosity, accounts for the surprisingly large volume of methane that coal can adsorb. In fact a medium rank coal buried at a depth of 500 metres could hold 15 cubic metres of methane per tonne. A conventional natural gas sandstone reservoir holds much less at similar depths (2.5 to 5 m^3). The amount of methane that can be adsorbed by coal is dependent on its rank and depth of burial, which incorporates the effects of temperature and pressure. Coal rank, which is a measure of coal maturity is usually documented by measuring the amount of light reflected back from the vitrinite coal maceral (Rmax%). Sub-bituminous coals have values in the range 0.3% to 0.7% and high rank anthracites have values over 2%. The amount of ash included in the coal also affects the amount of CBM; ash does not adsorb CBM.

Wholesale natural gas prices per mcf (1000 cubic feet) rose from about 2.2 $US in 1998 to about 5.3 $US in 2001. At the same time the Canadian dollar has fallen from 0.68¢US in 1998 to 0.65¢US in 2001. These two trends have stimulated interest in exploration for additional supplies of natural gas, which is composed mainly of methane (CH_4). Areas of interest include the offshore, Mackenzie delta and north shore Alaska for natural gas, and coalfields for coalbed methane (CBM). This note addresses the interest in CBM in British Columbia and gives an overview of the potential resource in the province.

Interest in CBM in B.C. has risen steadily over the last few years. In the last 2 years CBM exploration rights in southeast and northeast B.C. have been sold for about 20 million dollars. In the last year Alberta Energy Corporation has permitted 13 test wells in the Elk Valley coalfield and to date has drilled six. In the northeast BP has plans to begin drilling 4 wells in the spring 2001. Other companies have expressed interest in drilling test holes in northeast B.C. and other parts of the province.

British Columbia has a measured coal resource of over 3 billion tonnes. This is really an estimate of coal available for surface and underground mining. Therefore to some extent it is an estimate of the coal resource that is not favorable for CBM exploration because it is too shallow. The estimated coal resource to a depth of 2000 metres, which is available for CBM exploration is in the range of 250 billion tonnes.

SUMMARY OF CBM RESOURCE POTENTIAL IN B.C.

Coal in B.C. occurs in a number of different geological environments. Each has different implications for CBM development.

About 80% of the coal resource in the province is contained in a number of upper Jurassic to lower Cretaceous coalfields in the foothills of the Rocky

Mountains. These coalfields are within fold and thrust belts and are defined by continuous outcrop or subcrop of coal bearing formations. In the south are the Flathead, Crowsnest, Elk Valley coalfields (Figure 1) and in the north the Peace River coalfield. The Bowser Basin in northwestern B.C. is also in a fold and thrust belt. Other Cretaceous coalfields, such as those on Vancouver Island and at Telkwa, are less deformed and the main structures are vertical faults of various ages. There are also some significant Tertiary deposits in the province, the largest being Hat Creek. Generally these deposits are fault bounded and internally faulted but folding is minimal. Coal rank is generally low and their CBM potential depends in part on the presence or absence of biogenic methane.

In some coalfields, the coal-bearing formations form basins, therefore the traditional limits of the coalfield define the area underlain by coal, hence the area with CBM potential. In other coalfields the coal bearing formations dip to increasing depths and historical limits of the coalfield include only areas where surface mineable coal may exist. In these cases the traditional coalfield limits do not outline the area of CBM potential.

Published CBM resource assessments for southeast British Columbia indicate potential for more than 19 Tcf (540 billion cubic metres, Johnson and Smith, 1991) and for northwest British Columbia 8 Tcf (230 billion cubic metres, Ryan and Dawson, 1993). The author estimates a resource of over 60 Tcf (1700 billion cubic metres) for northeast B.C. and on Vancouver Island the resource is estimated to be 0.3 to 1.6 Tcf (14 - 42 billion cubic metres). To put these numbers in perspective, at present, about 0.8 Tcf (22 billion cubic metres) of natural gas are produced in British Columbia each year.

A large CBM resource does not necessarily mean there will be a large reserve. A number of practical constraints must be met. The methane content per tonne must be high enough to permit easy extraction, that is the coal seam should be close to saturated with CH_4 based on depth and rank so that pressure will not have to be reduced to much before gas desorption starts, and regional permeability must allow extraction of sufficient reserve to make a single well economic.

Permeability is of overriding importance for a CBM exploration program to succeed. Permeability in coal seams is largely dependent on cleats, which are tensional fractures characteristic of coal. Consequently they probably (but not exclusively) form when the coal is at relatively shallow depth, either during burial or during uplift.

In British Columbia where many of the coal basins have experienced varying degrees of deformation, it is important to consider the stress time history of a coal seam in conjunction with its time *versus* maturation history. In some areas early onset of deformation hindered formation of cleats or destroyed existing ones by shearing.

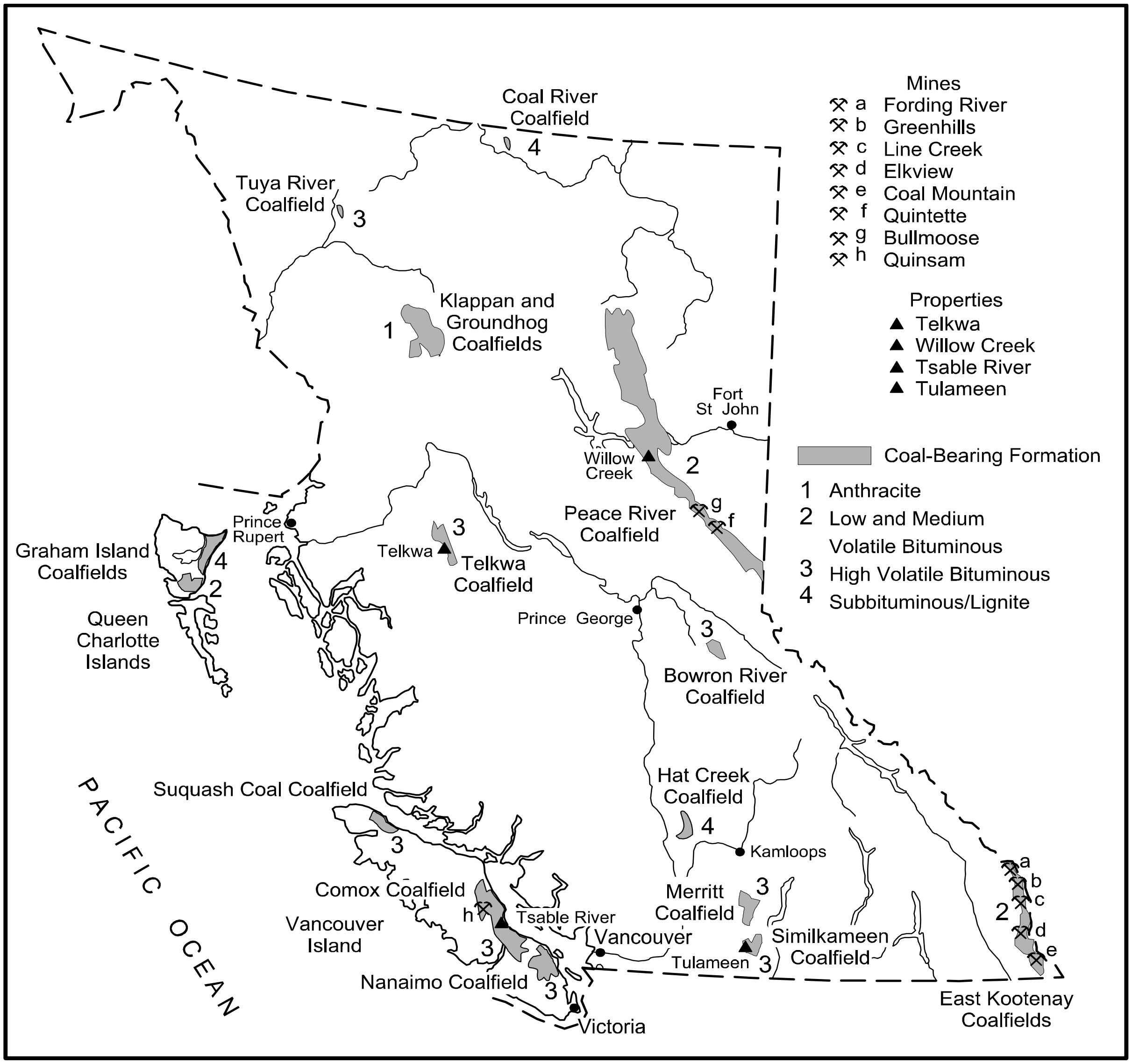
Methane formed during coalification is referred to as thermogenic. However, bacteria also can generate biogenic CH_4 from coal under the right conditions. Carbon isotopes indicate that biogenic methane in coal seams is much more important than originally thought (Scott, 1995). Generation of biogenic methane requires consortia of bacteria that use hydrogen and CO_2 to produce methane. Depending on conditions, more or less CO_2 can remain in the gas (Scott, 1995). Biogenic methane generation is usually initiated when meteoric waters penetrate coal seams and introduce bacteria into this anaerobic environment. The bacteria are active on the surface of cleats.

PEACE RIVER COALFIELD

The Peace River coalfield contains a number of coal bearing units that regionally dip to the east into the western Canadian Sedimentary Basin. In order of decreasing age these are the Minnes Group, Gething Formation and Gates Formation. Younger formations also contain thin seams but are unlikely to be economic for CBM production. Upper Cretaceous and Tertiary formations with sufficient coal for CBM exploration outcrop in Alberta.

The coal resource in the Peace River coalfield to a depth of 2000 metres is estimated to be more than 160 billion tonnes. This is divided between the Gates (+10 billion tonnes) and Gething Formations (+130 billion tonnes). The Gething Formation underlies a large area of the Peace River coalfield though it thins markedly at the south end of the field. The best coal development in the formation is between Williston Lake and Sukunka River to the south. It contains coal at depth to the east towards Dawson Creek. South of Sukunka River the formation is thin and contains only a few seams. Data on coal in the formation there are sparse because it was not extensively explored. The Gates Formation contains coal from the Sukunka River south to the Saxon property near the Alberta border, although thicknesses appear

Figure 1. Coalbed Methane in BC.



Tcf = trillion cubic feet **cm = cubic metres** **bt = billion tonnes** **cm = cubic metres**

Coalbed methane resources are calculated using estimated coal resource, rank and depth data and an appropriate gas content. Very little measured desorption data are available to confirm the gas contents used in the calculations. With the exception of the Kootenay coal fields data, which comes from Johnson and Smith (Petroleum Geology Special paper 1991-1) all other calculations are by Barry Ryan (GSB) and are either from GSB publications or internal studies.

	bt	Tcf		bt	Tcf
Peace River	160	60	Telkwa	0.8	0.13
Kootenay	50	19	Tulameen	0.2	0.05
Bowser Basin	37	8.1	Suquash	0.3	0.045
Hat Creek	2	0.5	Tuya River	0.7	0.04
Comox	3	0.8	Coal River	0.1	0.006
Nanaimo	1	0.3	Bowron River	0.4	0.008

TOTAL POTENTIAL CBM RESOURCE = 90 Tcf OR 2500 X 10^9 cm

NOTE: RECOVERABLE RESERVE WILL BE MUCH LESS THAN THIS ESTIMATE OF POTENTIAL RESOURCE

to thin to the east at depth in the equivalent formation (Falher).

Coal rank varies in both formations. In the Gething, rank is generally medium-volatile bituminous but decreases to the north and northeast toward Williston Lake and in the Burnt River area is low-volatile bituminous. The Gates is mainly medium-volatile bituminous but ranks on the western margin of the coalfield are lower. In both formations rank trends are somewhat complicated probably because of post thrusting coalification.

The CBM potential for the Northeast coalfield is enormous and has variously been calculated to be between 60 and 200 Tcf (1700 to 5664 billion cubic metres). In that there is no CBM production, one can only have moderate confidence in any estimate of the coal and CBM resource potential and should treat all estimates with extreme caution.

There has been some previous CBM exploration in the Peace River coalfield. This falls into 3 categories. First were estimates of desorbed gas contents of samples collected from shallow holes. These data were collected as part of the appraisal of the underground coal mining potential of a number of properties. The data generally indicate low gas contents, but the data are old and were collected at shallow depths; they have little relevance to CBM resource evaluation. Second, adsorption work done on samples from Gates coals (Lamberson and Bustin, 1992) confirmed the high adsorption capacity of Gates Formation samples with varying maceral compositions. Third, there are limited CBM data for the Gething Formation (Dawson *et al.*, 2000). Phillips Petroleum carried out one CBM exploration program (Dawson *et al.,* 2000). In 1995/96 Phillips drilled 4 holes into the Gates Formation in an area 30 kilometres southeast of Tumbler Ridge. The holes intersected cumulative thicknesses of coal averaging 20 metres at depths ranging from 1200 to 1550 metres. Gas contents ranged from 6 to 26 cc/g on an as received basis. Comparisons of desorption and adsorption data indicate that the seams are close to saturated; apparently, low permeabilities were encountered. This is not surprising considering the structure and depth.

SOUTHEAST B.C. COALFIELDS

The southeast corner of British Columbia, often referred to as the East Kootenay region, contains the Elk Valley, Crowsnest and Flathead coalfields. Coal is contained in the Mist Mountain Formation of the Jurassic - Cretaceous Kootenay Group. The formation consists of a sequence of interbedded clastic sediments, ranging from mudstone to conglomerate, and coal. The formation averages 500 to 600 metres in thickness of which 8% to 12% is coal. The total resource in the three fields is estimated to be in excess of 50 billion tonnes.

Coal seams range in rank from low to high-volatile bituminous with the highest rank coals being exposed in parts of the Crowsnest coalfield. Coals at the base of the section in the southwest part of the coalfield have vitrinite reflectances (Rmax%) of over 1.6% (Pearson and Grieve, 1978). Generally coals at the base of the Mist Mountain Formation are medium-volatile while those in the upper part of the formation are high-volatile.

ELK VALLEY COALFIELD

The coal resource to a depth of 1500 metres in the Elk coalfield is estimated to be 19 billion tonnes (Johnson and Smith, 1991) with an estimated CBM resource potential of 7.7 Tcf (218 billion cubic metres).

The Elk Valley coalfield contains 2 north trending synclines separated by a major normal fault. The Bourgeau Thrust defines the west edge of the Elk Valley coalfield. To the east, the east limb of the Greenhills Syncline, which plunges to the south, is cut by the north trending Erickson normal fault, which has down dropped rocks on the west by over 1500 metres. East of the Erickson fault the coalfield is folded into the Alexander Creek syncline, which is cut by the Ewin Pass thrust. In the three mines of the Elk Valley coalfield, coal seams in both synclines tend to be fragmented or sheared. Generally, either cleating is not well developed or has not survived the shearing. Thicker coal seams are developed low in the section but they tend to host major thrusts, consequently most are extensively sheared.

There is a history of CBM exploration in the field. In 1981 CANMET desorbed samples from 3 holes over a depth range of 0 to 400 metres (Feng *et al.,* 1981). They found that seams above 200 metres contained less than 2 cc/g of gas but below 200 metres gas contents ranged from 5 to 11 cc/g.

Fording drilled a single hole into the core of the Greenhills Syncline in 1993. The hole, drilled to 533 metres depth, intersected 44 cumulative metres of coal between 300 to 520 metres depth. Gas contents ranged from about 3cc/g to 12.6 cc/g on an air-dried basis (arb), ash varied from 4% to 60%. Seams appear to be undersaturated and gas contents do not increase with depth. The apparent degree of undersaturation indicates that a considerable reduction in hydrostatic pressure would be needed to obtain a sustained gas flow. Generally measurements indicated low permeability for the coal seams; they ranged from 1 to 6 mD (Dawson *et al.,* 2000)

Norcen drilled 4 stratigraphic holes in the northern part of the Elk Valley coalfield in 1991 then drilled a limited production test well in 1992. The holes were located on the east Limb of the Alexander Creek syncline. In this area the Mist Mountain Formation is 650 metres thick and contains 19 seams with a cumulative thickness of 54 meters. Gas contents averaged 13.25 cc/g for coals deeper than 250 metres. There were indications of moderate CO_2 contents in the gas desorbed from some samples. Gas contents did not increase systematically with depth and this may in part be because lower seams are rich in inert macerals and therefore have lower gas storage capacities than coals rich in vitrinite macerals.

Suncor drilled a single hole in the core of the Alexander Creek syncline south of the Greenhills coal mine in 1998. Data are not public but the company did not follow up on the exploration.

CROWSNEST COALFIELD

The Crowsnest coalfield has a coal resource of over 25 billion tonnes and a potential CBM resource of 12 Tcf (340 billion cubic metres) (Johnson and Smith, 1991). The field includes the Elkview mine in the north and extends from Sparwood to 20 kilometres south of Fernie. The structure is that of a large basin that is cored by the younger Elk Formation and almost completely rimmed by outcrops of the older Mist Mountain Formation. Coal rank varies around the perimeter and down dip (Pearson and Grieve, 1985).

Three companies drilled stratigraphic holes in the field. Mobil/Chevron drilled 2 holes. One, in Morrissey Creek, penetrated 491 metres of Mist Mountain and intersected 7 major coal zones with a cumulative coal thickness of 54.16 metres. The hole encountered numerous problems because of fines, squeezing and strata instability (Dawson *et al.,* 2000). Dawson *et al* reported that the coal is fragmented or sheared. Gas contents ranged from 1.36 to 16.56 cc/g. Based on comparison of measured gas contents on a dry ash free (daf) basis to adsorption isotherm results samples, samples were saturated to between 25% and 63% of maximum gas capacity. Permeability appeared to be low to moderate.

In 1990, Gulf Canada drilled 2 stratigraphic holes in Coal and Lodgepole creeks. Core was collected for desorption but no other testing was done. One hole (Lodgepole Creek) was drilled to 295 metres; 15 desorption tests indicated very low gas contents (averaging less than 1 cc/g). This may be because the hole was spudded above the valley floor and the effective long-term water table was much lower than the collar. The second hole (Morrissey Creek) was drilled to 600 metres and intersected a cumulative coal thickness of 24.41 metres. Coal from this hole had an average gas content of 7 cc/g arb, but appeared to be undersaturated.

Saskoil drilled holes close to the location of the 2 Gulf holes. Two holes were near Morrissey Creek and, combined, they intersected about 500 metres of the Mist Mountain Formation with about 63 metres of coal. The coal was moderately gassy with gas contents ranging from 0.4 cc/g to 11.9 cc/g . The third hole was drilled in the Lodgepole Creek area near the Gulf hole and, like the Gulf hole, had very low gas contents. Permeability tests were performed in the holes near Morrissey Creek, results were ambiguous or indicated low permeability.

In most wells the gas content (daf basis) decreased for the lowest seams. This can be explained by changes in petrography because the lower seams are richer in inert macerals, which adsorb less gas. It can also be explained by assuming that all the seams were initially undersaturated and those closer to surface were later recharged with biogenic methane. There are indications that biogenic methane is present in the Elk Valley coalfield.

FLATHEAD COALFIELD

Coal in the Flathead coalfield occurs in a number of outliers of the Mist Mountain Formation, the largest of which is Sage Creek near the United States border. Other smaller ones are Lillyburt, Harvey Creek and Cabin Creek. The coal resource available for CBM exploration is about 1 billion tonnes (Johnson and Smith, 1991) with a potential CBM resource of 0.4 Tcf (11 billion cubic metres).

BOWSER BASIN

INTRODUCTION

The Bowser Basin is a remote region of rugged mountainous terrain in northern British Columbia. The area encompasses approximately 50 000 square kilometres and is bounded on the east by the Omineca and Cassiar mountains and on the west by the Coast Mountains. The Basin is defined by the outcrop extent of the Bowser Lake Group of Middle Jurassic to Lower Cretaceous age. The group contains a thick assemblage of at least 3500 metres of sediments that generally lack good stratigraphic markers or fossils and are moderately to intensely folded. It is a successor basin filled with a regressional sequence of marine to non-marine sediments that were deposited conformably on volcanics of the Hazelton Group. The Stikine Arch borders it to the north and the Skeena Arch to the south.

Coal in the northern part of the Bowser Basin is found in the Jurassic Currier Formation in the Klappan coalfield and in its equivalent in the south the Prudential Formation in the Groundhog coalfield. The Currier Formation crops out on all four sides of the Mt. Biernes Synclinorium, the most prominent regional structure in the coalfield. Potentially economic coal seams up to 7 metres thick are present in the lower third of the Currier Formation. In the Mt Klappan area the formation is 900 to 950 metres thick and contains a cumulative coal thickness that ranges up to 53.62 metres. At Panorama Mountain to the south the stratigraphically equivalent interval of coal-bearing strata exceeds 1300 metres and contains up to twelve coal zones with a cumulative thickness of 9 metres over an interval of 300 metres.

STRUCTURE

Fold styles in the basin range from open upright chevron to overturned and stacked recumbent. Folds often resemble asymmetric mega-kink bands with shallow and steep dipping limbs. The doubly plunging Mt. Biernes Synclinorium, which trends southwest for 85 kilometres, dominates the area between the Nass and Skeena rivers. The coal-bearing Currier Formation is exposed on its east and west limbs in the Nass and Skeena valleys and wraps around both ends of the trace. The depth to the Currier Formation below the axial trace of the synclinorium is probably between 1000 to 2000 metres. Coal-bearing rocks therefore underlie approximately 2000 square kilometres around the synclinorium. This comprises the area with CBM potential.

COAL RANK

Coal rank ranges from semi-anthracite to meta-anthracite. Reflectance values are higher to the east and lower in the central part of the coalfield. The average Rmax% over an area of 6600 square kilometres is 3.88% but within it there are 2100 square kilometres in which the reflectance is less than 3.5%. Values for the top of the Currier average 2.9 %, and those for the base 4.59%. However, the high value for the base of the Currier Formation is biased by some very high values in the extreme southeast of the area. A coalification gradient for the Currier Formation was calculated as 0.20 % /100 metres.

At high temperatures CBM is either destroyed or expelled from coal. Dow (1977) determined that the preservation limit for dry gas in terms of the rank of coal as defined by reflectance is between 3.0% and 4.0 %. Wolfgang and McMechan (1988) use a dry gas preservation limit defined by a reflectance of 4.8%. Coal that has been heated to this rank has the ability to adsorb methane once the temperature falls but the possibility exists that all the methane has been destroyed or flushed from the rocks. Bustin and Moffat (1989) suggest that the maximum temperature experienced by coal at the base of the Currier Formation was between 180°C and 230°C. CBM resource calculations depend on estimating how much methane the coal retained at the maximum depth of burial and highest temperature reached, and how much was scavenged as the coal was uplifted.

The adsorption versus depth relationship for coal as it is progressively buried and heated indicates an adsorption capacity of 6.8 cm/tonne (245 scf/ton) at the maximum depth of 5000 metres for the coal zone (Ryan and Dawson, 1993). At this depth adsorptive capacities are decreasing as depth and temperature increase. The adsorption capacity initially increases with depth and increasing rank but eventually the influence of temperature predominates and the capacity decreases with increasing depth. This means that at maximum depth of burial, coal higher in the coal zone will have a higher adsorption capacity than coal lower in the coal zone and may be able to scavenge gas from deeper seams. This inversion is maintained until the cover depth is reduced to less than 1000 metres. Isotherms that indicate high gas contents for anthracites are misleading. It is unlikely that one will find a saturated anthracite seam and it becomes important to know the depth, temperature and rank history of the anthracite in order to predict its adsorption capacity. High rank coals whose maximum depth of burial was greater than their present depth may be undersaturated in methane.

COAL RESOURCE

The total potential coal resource in the Klappan and Groundhog coalfields is 37 billion tonnes and much of this is in the Currier Formation within the Biernes Synclinorium. This is a speculative number and should be used only as an indication of the order of magnitude of the coal resource available for CBM exploration.

POTENTIAL METHANE RESOURCE

The estimated potential CBM resource of the Groundhog and Klappan coalfields is up to 8 Tcf (or 214 billion cubic metres). The resource assessment is restricted to the area of Currier Formation outcrop within the coalfields. Coal outcrops outside this area but usually in thin and widely scattered seams. The Biernes Synclinorium area of the Groundhog and Klappan coalfields could be a major source of CBM.

Sustut Basin

The upper Cretaceous to Tertiary Sustut Group unconformably overlies the Bowser Lake Group along its eastern margin. although coal is found in strata of the deformed Bowser Lake Group and in the overlying less deformed Sustut Group. the area appears to have limited CBM potential.

VANCOUVER ISLAND COALFIELDS

INTRODUCTION

Coal resources of the coastal area of British Columbia are restricted to Vancouver Island, the Queen Charlotte Islands and some of the Gulf Islands. Coal rank ranges from anthracite to lignite, with most being high-volatile bituminous. Ages range from Jurassic to Tertiary though most is found in the Nanaimo Group, which is of Upper Cretaceous age. The major Upper Cretaceous coalfields on Vancouver Island are the Nanaimo and Comox fields. Smaller coalfields of the same age are the Suquash, Cowichan and Alberni. The Quatsino coalfield on Vancouver Island is Lower Cretaceous. Not much is known about cleat development in Vancouver Island coals but generally they are less deformed than coals in southeast and northeast British Columbia.

There are at least three coal bearing formations within the Nanaimo Group. The first is the basal Comox Formation, which is overlain by marine sediments of the Haslam Formation in the Nanaimo coalfield or the Trent River Formation in the Comox coalfield. The others are in the Extension and Protection formations, and these host the coal seams that provided coal for former mines of the Nanaimo coalfield. This coalfield is centered on the town of Nanaimo and from 1849 to about 1950 over 50 million tonnes of coal were extracted from seams in the Extension and Protection formations. The Comox coalfield is centered on the Town of Comox and includes the Quinsam mine, which is the only operating coal mine on the island. Coal seams in the Comox coalfield are in the Comox Formation. This coalfield is considered to have good CBM potential.

A number of holes were drilled on Vancouver Island specifically to assess CBM potential. Novacorp drilled 14 holes between 1984 and 1985 and British Petroleum drilled two holes in 1986. Gulf and British Petroleum also drilled deep holes in the early 1980's but not specifically for CBM. In 1996 Quinsam Coal Corporation initiated an exploration project in the Tsable River area south of Courtenay. Core was collected from this program and desorbed (Ryan, 1997). In 1994, samples from two holes drilled near the Quinsam coal mine were desorbed (Ryan and Dawson, 1994).

The CBM potential of the Nanaimo coalfield and parts of the Comox coalfield extend eastward under Georgia Strait beyond the surface expression of the fields. Estimates of resource potential for these coalfields may include undersea CBM, which at the moment cannot be legally recovered.

Published estimates of the CBM resource potential for Vancouver Island range from 230 bcf (6.5 million cubic metres) Proudlock (1990) to 1 Tcf (28 million cubic metres) (Energy Market Update, 1992). The first number is not broken down in terms of the different coal basins, gas contents or coal tonnages. Proudlock (1990) used an average gas content of 9cc/g (288 scf/ton) to calculate his value. Estimates of the coal resources on Vancouver Island range from a low of 800 mt to a high of 6920 mt and average 3850 mt.

NANAIMO COALFIELD

Estimates of the size of the Nanaimo coalfield range from 259 square kilometres (McKay, 1947) to 777 square kilometres (Dolmage Campbell and Associates, 1975). Previous independent estimates of coal resource remaining in the Nanaimo coalfield are 60.5 mt (McKay, 1947), 10 mt (Smith, 1989) and between 10 and 70 mt (Dolmage Campbell and Associates, 1975). Coal rank is high-volatile A bituminous. Recent work indicates that there is also coal in the Comox Formation within the Nanaimo coalfield. Coalbed methane opportunities in the Nanaimo coalfield are probably limited because most of the coal in the Pender and Extension formations (Douglas and Wellington seams) has been mined. There may be some potential to retrieve CBM from the underground mine workings, but these often now underlie residential areas of Nanaimo. There may be potential in the deeper Comox Formation. Most of the CBM potential will be in the eastward extension of the Douglas seam and the deeper Comox seam if it is extensive. Generally it becomes uneconomic to extract CBM below about 2000 metres depth because of problems completing drill holes? and decreased permeability.

The Douglas seam subcrop and the outer coastline of the Gulf Islands to the east and the generally defined bounds of the Nanaimo coalfield to the north and south apparently outline the area of Nanaimo group strata that are favorable for CBM exploration. This provides a tract area of 400 square kilometres. Cumulative coal thickness in the Douglas coal zone ranges from 3 to 10 metres (Cathyl-Bickford, 1992). A single intersection of the Comox seam was 3.0 metres thick. The potential CBM resource of the Nanaimo basin is estimated to be in the range of 0.4 Tcf.

COMOX COALFIELD

The Comox coalfield extends from 20 kilometres north of Nanaimo to Campbell River and covers about 1230 square kilometres. The coalfield is subdivided into six sub-basins: Quinsam, Campbell River, Anderson Lake, Cumberland, Tsable River and Qualicum. Generally the rank in all the sub-basins ranges from high-volatile B bituminous to high-volatile A bituminous. There is a tendency for rank to increase to the south (Kenyon and Bickford, 1989). Coal in the Comox coalfield is restricted to the Comox Formation.

Quinsam Sub-Basin

The Quinsam mine is in this sub-basin where two seams occur in the Cumberland Member and two seams in the Dunsmuir Member of the Comox Formation. Away from the mine area information about this sub-basin is sparse. The average Rmax% value is 0.70% +/- 0.07% indicating a rank of high-volatile B bituminous and cumulative coal thickness is about 7.5 metres. Some desorption data (Ryan and Dawson, 1994) were collected from 2 shallow holes near the Quinsam coal mine. Gas content of seven samples collected from depths ranging from 100 to 150 metres ranged from 0.44 cc/g to 1.632 cc/g on a dry ash free (daf) basis. The sub-basin covers an area of 155.4 square kilometres (Dolmage Campbell and Associates, 1975) and is generally fault bounded. The total coal resource in the sub-basin is about 200 mt Dolmage Campbell and Associates (1975). After removing near surface, the tonnage reduces to about 100 mt of coal available for CBM exploration.

The CBM resource associated with the mine, based on an average gas content of 1.6 cc/g is 1.7 Bcf (0.05 billion cubic metres). Kenyon *et. al.* (1991) estimated a resource of 90 Bcf (2.55 billion cubic metres) for the whole field using an average methane content of about 4.7 cc/g. This estimate is high based on present data. Using an area of 155 square kilometres, assuming that a cumulative coal thickness of 7.5 metres (Bickford and Kenyon, 1988) is present over half the field, and that the gas content is 1.6 cc/g, the resource would be 50 Bcf (1.4 billion cubic metres).

Campbell River Sub-Basin

The Campbell River coalfield extends from Campbell River in the north to Oyster River in the south. Nanaimo Group rocks do not extend under Quadra Island so that the approximate extent of coal-bearing rocks is 138 square kilometres. Separate estimates of the resource of the sub-basin range from 74.5 mt to 400 mt. (Dolmage Campbell and Associates, 1975). With an area of 138 square kilometres, if the coal resource is 400 mt, then the average coal thickness through out the whole basin is 2.4 metres. The CBM resource is estimated to be about 40 Bcf.

Anderson Lake Sub-Basin

The Anderson Lake area extends from south of Oyster River to Brown River. Coal resources are estimated to be 21.9 mt. The area of the sub-basin is approximately 450 square kilometres. There is little information on seam thicknesses or quality. Seams range up to 2 metres, are very ashy and were intersected at depths ranging up to 160 metres. A speculative CBM resource potential is 24 Bcf (0. 686 billion cubic metres).

Cumberland Sub-Basin

The Cumberland sub-basin extends from Brown River in the north to south of Cumberland and east of Comox; the approximate area is 266 square kilometres. The area has a possible resource ranging from 228 mt to 240 mt (Dolmage Campbell and Associates, 1975). Four major seams are present with cumulative thickness ranging from 2 to 8 metres. There are some CBM emission data from mines in the area, and average gas contents range from 7.8 to 11.7 cc/g at depths that average 250 metres. Two samples were tested for CBM in the field; one had 4.12 cc/g (132 scf/ton) at 122 metres and the other 2.4 cc/g (77 scf/ton) at 124 metres. The CBM potential is moderate to good considering the number of seams and amount of coal in the section and the CBM resource estimate is 160 Bcf (4.5 billion cubic metres).

Tsable River Sub-Basin

Including Denman Island, the area of this sub-basin is 272 square kilometres. The area is at the southern end of the Comox coalfield and northern end of the Cowichan fold and thrust belt. Reserve estimates range from 148 mt. to 265 mt. (Dolmage Campbell and Associates, 1975). Both these numbers are reserve not total resource estimates. The total resource to 2000 metres could be over 1 billion tonnes. Cumulative coal in the section is about 8.3 metres contained in up to 4 seams. Some CBM has been extracted from holes in the area that are about 500 metres deep (Bickford *et al*., 1990). Gas has been reported in a few deep holes in the Tsable River area (Cathyl-Bickford, 1991). In 1996 (Ryan, 1997) desorbed a total of 13 samples covering depths from 126 to 376 metres. Gas contents on an as-received basis range from 1.6 to 5.5 cc/g. The gas contents increase consistently with depth but appear to be undersaturated. Based on a linear extrapolation, data indicate that gas contents at 600 and 1000 metres may be 6.2 and 8.4 cc/g for 20% ash coal. These concentrations are high enough to make the area attractive for its potential CBM resource. Resource calculations for part of the southern end of the Comox basin indicate a potential of about 0.45 Tcf (12.6 billion cubic metres). The Tsable River coal has a rank of high-volatile A bituminous based on four Rmax% values that average 0.83%. The area has attractive CBM potential and is well located in terms of markets.

Qualicum Sub-Basin

South of Tsable River in the Qualicum area there is little information on coal distribution. Dolmage Campbell and Associated, (1975) could find no record of coal occurrences south of Tsable River in the Comox Basin and considered the coal potential of the sub-basin to be very low. Bickford and Hoffman (1991) report two coal occurrences with seams that are 3.26 and 1.99 metres thick (including rock splits) at Cowie and Wilfred creeks. The CBM potential for the Qualicum sub-Basin is considered to be low and no estimate is made.

ALBERNI COALFIELD

The coalfield, which contains rocks of the Upper Cretaceous Nanaimo Group, covers about 190 square kilometres in the Alberni valley centered on the town of Alberni. Prospecting over the years has found only a few outcrops of coal. It is unlikely that there is any significant CBM potential.

COWICHAN COALFIELD

The Cowichan coalfield, which includes Upper Cretaceous Nanaimo group rocks, extends from Sidney in the south to Chemainus in the north. The coalfield includes the area around Cowichan Lake and extends to the east to encompass many of the southern gulf islands with the exception of most of Saltspring Island. The CBM potential is very low and no CBM resource is assigned to the Cowichan coalfield.

QUATSINO SOUND COALFIELDS

Nine fault-defined basins of Lower Cretaceous rocks cover a cumulative area of 260 square kilometres in the Quatsino Sound area. The four major basins are Coal Harbour, Quatsino, Winter Harbour and Standby River. Thin coal seams, generally 1 metre or less in thickness, have been explored in a number of places without success. There is little to no CBM potential.

SUQUASH COALFIELD

The basin covers an area of 120 square kilometres. Coal seams in Nanaimo Group strata are of high-volatile B to A bituminous rank (Kenyon, 1991). Beds dip at 5 to 10° to the northeast. The coal bearing section is at least 360 metres thick. Coal is in the upper 200 metres of the section in approximately 9 zones that contain about 4 metres of coal in total. If the basin is underlain on average by 2 metres of coal then the coal resource would be about 300 mt. If the coal bearing stratigraphy extends to the northeast under Malcolm Island, it provides a basin area of 300 square kilometres and a potentially larger coal resource. Assuming a coal resource of 300 mt the estimated potential CBM resource is 45 Bcf (1.3 billion cubic metres).

QUEEN CHARLOTTE ISLANDS

JURA-CRETACEOUS PROSPECTS

Jura-Cretaceous Queen Charlotte Island coals occur in the Yakoun, Queen Charlotte and Haida formations, all of which are folded and faulted. The CBM potential is low.

TERTIARY COAL

Lignite occurs in the lower member of the Skonun Formation that underlies the northeastern portion of Graham Island. A number of seams of lignite and coal of higher rank have been intersected in oil wells but no reserve calculations exist. Smith (1989) estimated a resource of 50 mt (inferred) whereas McKay (1947) estimated a resource of 739 mt (probable plus possible). Three coal quality analyses indicate a rank of lignite to sub-bituminous. The CBM potential is low and no CBM resource is assigned to the Skonum Point area.

TELKWA

INTRODUCTION

The Telkwa coalfield in central British Columbia extends for about 50 kilometres along the Bulkley River from north of the town of Smithers to south of the village of Telkwa. Two coal bearing units separated by a marine mudstone unit are contained in the Lower Cretaceous Skeena Group. The upper unit (Unit 3) contains at least 8 seams with cumulative coal thickness up to 14 metres. The lower unit (Unit 1) contains a single coal zone with cumulative coal thickness up to 7 metres. South of Telkwa, these two units contain 20 to 50 million *in situ* tonnes which are potentially open pit mineable. In the whole field a coal resource of approximately 850 million tonnes is outlined at varying levels of assurance. Coal rank ranges from high-volatile bituminous A to anthracite, though most of the coal is in the range high-volatile A to medium-volatile bituminous. Rmax% values at the base of unit 3 range from 0.86% to 0.95% and average 0.91% . The Rmax% values for Unit 1 range from 0.86% to 1.1% and average 0.95 %. Rank increases to the south and north away from the centre of the field. In the south, measurements on outcrop coal provide an average Rmax% value of 2.3 % . The coal adjacent to the Bulkley River has an average Rmax% value of 1.27 % and further to the north a sample has an Rmax% value 1.97 %.

During the 1990 exploration program, five samples were collected from 2 rotary drill holes for desorption studies (Ryan and Dawson, 1994). Excluding one sample, gas contents range from 3.75 to 4.49 cc/g on a daf basis and did not increase with increasing depth. The single low desorption value may have been due to a failure in the canister seal. Based on comparison to adsorption isotherm data the coal appears to be saturated.

PERMEABILITY

Much information on the coalfield is contained in coal assessment and Stage 1 and Stage 2 reports submitted to the B.C. government. These reports include geotechnical studies that formed part of mine feasibility studies and they provide information on permeability and joint patterns. Generally Telkwa coals are hard and well cleated. Seams have moderate permeability and regional joints trend northwest or southwest. Permeabilities of coal seams in Unit 3 were measured in three drill holes in the east Goathorne area at depths ranging from 29 to 158 metres. Values do not correlate with depth and range from 0.5 to 50 milliDarcies. These values cover the range from low to excellent for both coal and CBM recovery, considering the depth of the measurements. The permeability of sections of mudstone, siltstone and sandstone interburden varying in thickness from 14 to 27 metres also were measured in the drill holes. At depths of less than 200 metres, permeabilities of interburden rock and coal range from 13 to 35 milliDarcies. Interburden permeability is on average greater than that of the coal.

POTENTIAL CBM RESERVES

The estimated total CBM resource of the Telkwa coalfield is 0.13 Tcf (3.7 billion cubic metres). This is not large when compared to the resources in major coalfields such as the Elk Valley coalfield, which has a resource of 7.7 Tcf (218 billion cubic metres).

On the other hand the Telkwa coalfield is close to the towns of Smithers and Telkwa, which could offer ready markets for small quantities of gas. Unit 3 contains the most coal in the field, but is generally shallow. The deeper unit 1 contains less coal but is 100 to 200 metres below unit 3. There is a trade off between less coal with higher unit gas contents in Unit 1 and more coal with lower gas contents in Unit 3. The Pacific Northern Gas Limited natural gas pipeline crosses the Telkwa coalfield south of Telkwa. This pipeline connects Prince Rupert and Kitimat with pipelines from northeast and southwest B.C. However, the potential resource in the Telkwa coalfield is probably too small for it to be economic to build the infrastructure needed to collect and compress Telkwa gas to put it into the provincial pipeline network. Much of the resource may be contained in thin seams, with low gas contents and at shallow depths.

TERTIARY COAL DEPOSITS

Tertiary sediments survive in many major watersheds in British Columbia. The sediments, which are generally not well consolidated, are poorly exposed and their subcrop extent is arbitrarily delineated by adjacent high ground underlain by pre-Tertiary rocks. Many of these Tertiary basins contain coal, varying in rank from lignite to medium-volatile bituminous and seam thicknesses that vary from a few centimetres to many metres.

TUYA RIVER

The Tuya River Basin is located between the communities of Dease Lake and Telegraph Creek in northwestern British Columbia (Figure 1). The basin is potentially quite large, yet it has escaped detailed study. The simplest interpretation of the basin, based on limited data, is that it has the form of an open, northerly plunging syncline that is complicated by smaller scale faults and folds. Limits of the basin are poorly defined and in places recent volcanic rocks overlie basin rocks; however, it is estimated that it covers approximately 150 square kilometres and contains nearly 700 million tonnes of coal. About 400 million tonnes are within 1600 metres of surface.

A tentative stratigraphic succession has been established. The section contains two units of Eocene age. The lower unit, 200 to 300 metres thick, is composed of mudstones and sandstones in the west and sandstones and chert-pebble conglomerates in the east; it contains a single coal zone. The coal zone is about 100 metres thick and includes from 5 to 30 metres of coal. The upper unit, which is at least 300 metres thick, is composed of volcanic-pebble conglomerate, sandstones, and volcanic rocks.

In outcrop the coal is blocky, well banded and usually clean with well developed cleats. It is often harder than the enclosing poorly consolidated sandstones. Seams vary in thickness up to 20 metres. Mudstone and bentonite bands are common in the seams. The coal is vitrain rich and contains an unusually high percentage of resin; some bands have up to 5 % as blebs ranging up to 5 millimetres in diameter. Analyses indicate a coal rank of subbituminous B to high-volatile bituminous C. Seventeen samples were analyzed for Rmax% values. Samples from Mansfield Creek and Little Tuya River on the west side of the syncline average 0.76% (7 values) and samples from Tuya River on the east side of the syncline average 0.68% (9 values).

A moderate CBM resource of up to 50 Bcf (1.4 billion cubic metres) may exist in the basin (Ryan, 1991). The resource could be larger because biogenic gas is a possibility in coal of this rank. The CBM resource is estimated by multiplying the incremental tonnages from 200 metres to 1600 metres by CBM concentration values derived using the Ryan equation (Ryan, 1992). Predicted CBM concentrations range from 2.99 cc/g at 300 metres to 7.65 cc/g at 1500 metres.

COAL RIVER

Coal River flows south joining the Liard River approximately 150 kilometres east of Watson Lake and 40 kilometres south of the Yukon border (Figure 1). Coal was first reported in the area in 1891 when lignite boulders were found at the mouth of Coal River. The source of the lignite was located by Williams and DeLeen prior to 1944 (Williams, 1944) about 6 miles (10 kilometres) as the crow flies up river from the Alaska Highway. Generally Tertiary outcrops are restricted to the riverbanks and trees, swamp and a burn zone cover the rest of the area. The area around the river is marked by large crescent shaped slumps, presumably where younger sediments have slid on the clay layer, which overlies the coal.

A number of lignite outcrops were found along the river. The main exposure is on the west bank of the river where, for a length of over 100 metres, the hangingwall section of the seam has a shallow apparent dip to the south. The full thickness of the seam was not observed in any of the outcrops and the thickness exposed ranges up to over 8 metres at one outcrop. The lignite is cleated with two sets generally developed. Typically, 3 to 4 metres of lignite are exposed in the outcrops on the west side of the river. On the east side the topography is flatter and there are fewer outcrops. A water well near where the river crosses the Alaska Highway intersected 15 metres of coal at a depth of 15 metres.

Samples of the lignite were analyzed by Williams in 1944 and by Ryan (1996). Rmax% measurements are difficult to make because of the very low rank. In fact the average of five Rmax% measurements is 0.2%, which classifies the material as a peat and not lignite. This is supported by the average volatile matter on a dry ash free basis which is 75%, but is not supported by the heat value or the as-received moisture measurements, both of which are characteristic of a coal with higher rank.

The Tertiary basin has a possible area of about 35 square kilometres. If the lignite seam is on average 5 metres thick then the preliminary resource estimate is about 100 million tonnes of peat/lignite.

The rank is too low for the lignite to have generated thermogenic methane. However based on experience in the Powder River Basin it is possible that the lignite does contain reasonable quantities of biogenic methane. A lignite resource of about 100 mt could contain a CBM resource of about 0.7 Bcf (0.2 billion cubic metres) depending on its ability to retain free gas and adsorb gas.

HAT CREEK

The Hat Creek Basin located 20 kilometres west of Cache Creek contains of two poorly exposed coal deposits (**Figure 1**). The northern, Number 1, deposit covers 3.5 square kilometres and the larger, Number 2, deposit, 3 kilometres to the south, covers 25 square kilometres. The Tertiary section in the area is 1500 metres thick and is divided into 3 units. The lowest Coldwater unit is 375 metres thick and contains no coal. The overlying Hat Creek Formation is about 500 metres thick of which about 65% is coal (Church, 1977). The upper Medicine Creek Formation is 600 metres thick and contains no coal.

The Hat Creek Basin contains an enormous amount of low rank coal concentrated in a small area. The number 1 deposit has been explored as a potential open pit mine. Reserves in this deposit to a depth of 200 metres are over 500 mt of lignite A to sub-bituminous C coal (Rmax% 0.38% to 0.50%, Goodarzi, 1985). The No 1 deposit comprises two south plunging half synclines truncated on the southeast end by northeast trending gravity faults (Graham, 1989). Dips average about 25°.

The No 2 deposit occurs within a graben that is bounded by north trending normal faults. Displacements on the western faults appear to be more than on the eastern faults causing rotation and a resultant 25° western dip in the sediments. The resource of the No 2 deposit to a depth of 460 metres is estimated to be over 2 billion tonnes (Papic *et. al.,* 1977).

The low rank of the coal means that generation of thermogenic methane will be small to nil and the ability of the coal to adsorb methane will also be low. However low rank coals can have high meso porosities compared to higher rank coals (Bustin, 1999) and can retain moderate amounts of free gas, much of which would likely be of biogenic origin. Even if gas contents are only of 1 to 3 cc/g (30 to 100 scf/ton) because of the large coal tonnages there could still be a sizable CBM resource of about 0.5 Tcf (14 billion cubic metres) concentrated in this small area.

SIMILKAMEEN COALFIELD

Tulameen sub-basin

The Tulameen and Princeton sub-basins comprise the Tertiary Similkameen coalfield (Figure 1). The Tulameen sub-basin is 20 kilometres northwest of Princeton. Underground mining carried out in the area began in 1919. Workings extended along the sub crop for 2500 metres and down dip for 800 metres. Underground mining activity diminished after a disastrous explosion that killed 45 people in 1930 (Blake, 1988) and ended in 1940. The mines extracted about 2 million tonnes from the Tulameen sub-basin. Renewed interest in the 1950's led to surface mining that extracted a further 150 000 tonnes of coal.

The sub-basin consists of an asymmetric syncline, which plunges gently to the southeast. Beds on the northwest limb dip at 40° to 65° and on the southwest limb at 25° to 49°. An area of 5 kilometres by 3 kilometres is underlain by coal-bearing Eocene sediments overlying Eocene volcanics all of the Princeton Group. The Eocene sediments are divided into 3 members with a total thickness of 780 metres.

The middle member, which is 140 metres thick, contains coal in its lower 80 metres. Coal rank is high-volatile B bituminous with Rmax% values ranging from 0.62% to 0.86% (William and Ross, 1979). Rank increases to the south.

The coal bearing section contains 2 coal seams though they tend to be very dirty with partings of shale and bentonite. The lower seam is 7 to 8 metres thick and the upper seam 15 to 21 meters thick. The seams are thought to underlie the whole basin. Based on the synclinal form of the coal horizon there is a potential coal resource of at least 200 mt And a potential CBM resource of 0.05 Tcf (1.4 billion cubic metres) in the basin.

Princeton sub-basin

The Princeton sub-basin is elongated northerly and approximately 24 kilometres long and 4 to 7 kilometres wide; it covers a total area of about 170 square kilometres. There were 13 small underground and one surface mine that operated in the central part of the basin until about 1961. The basin, which is filled with mid Eocene sediments, is more folded than the Tulameen sub-basin. Consequently, coal seam stratigraphy is not as well understood as that in the Tulameen sub-basin. In the southern part of the sub-basin 4 main coal zones were identified in a 500 metre sedimentary section. The cumulative coal thickness for the 4 seams is 17 metres, but seams are very discontinuous. Rank of the coal varies from lignite to high-volatile B bituminous.

Surface mineable reserves of about 10 mt have been quoted by a number of authors although it is difficult to estimate a resource through the southern part of the sub-basin Where Dolmage and Campbell (1975) estimate a potential resource of more than 800 mt. The low rank, uncertain coal reserve, and discontinuous nature of the coal seams limit CBM potential.

MERRITT COALFIELD

Several isolated Eocene sedimentary areas within a 15-kilometre strip between the city of Merritt and Quilchena, at the eastern end of Nicola Lake comprise the Merritt coalfield (Figure 1). The main areas are near Nicola, which underlies about 80 square kilometres, and near Quilchena, where it is about 25 square kilometres in size. In the Quilchena area a single 1.5 metre seam was explored and no significant reserves outlined. The Nicola area, which contains high-volatile C to A bituminous coal, was explored in 1945 and 1960 and about 10 mt of underground mineable reserves were outlined. There appear to be 7 seams with a cumulative coal thickness of 22 metres in a 250-metre section. Overall the Nicola coalfield has not been extensively explored but much of the area underlies the town of Merritt and some of the areas are overlain by relatively recent (500 000 years based on K/Ar dates) volcanic flows. It is difficult to estimate the resource in the area but if a coal thickness of 10 metres extends through the whole Nicola coalfield there could be over 800 mt and have a moderate CBM resource under the town of Merritt.

BOWRON RIVER

The Bowron River graben (Figure 1), which is 50 kilometres east of Prince George, is 2.5 kilometres wide and 15 kilometres long. The lower 85 meters of the more than 700 metre thick Paleocene sedimentary section is coal bearing. The coal section dips at 20° to 60° to the northeast and contains at least 3 seams with a cumulative thickness of 8.5 metres. The coal, which is high-volatile B bituminous in rank (average Rmax%=0.65%), is characterized by a high resin content (8%). Considering only the lower seam, Matherson and Sadre (1991) estimated a potential resource of 400 mt down to a depth of 1200 metres. Any CBM potential will depend on the presence of biogenic methane though the presence of amber may help initiate generation of thermogenic methane at a lower rank.

SUMMARY

There is in British Columbia, at the time of writing, a dramatic increase in interest in and exploration for CBM. There is a large coal resource in the province and the potential CBM resource is similar to that of the San Juan Basin in the United States, which is the largest CBM producer in the world. Much of the coal in the province is in the foothills of the Rocky Mountains where it has experienced a moderate amount of deformation. In this environment careful selection of drill targets and possibly novel completion techniques may be required to overcome low permeability and shearing of coal seams. The structural history is less complicated in coal areas such as at Telkwa and on Vancouver Island. Many Tertiary deposits offer the possibility of small CBM plays in part dependent on the generation of biogenic methane in the coal. The Hat Creek deposit is so large that even small concentrations of gas could give rise to a large CBM resource.

Across B.C., there is significant potential for the development of coalbed methane. The gas is in the coal and sooner or later the forceful combination of economic incentive and human ingenuity will get it out.

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ABBREVIATIONS AND CONSTANTS

mt = million tonnes
scf = standard cubic foot
cm = cubic metres
cc = cubic centimetres
Rmax% = mean maximum vitrinite reflectance
psi = pounds per square inch

Volumes
1 scf = .028317 cm
1 Tcf =28.32 billion cubic metres
mcf = 1000 scf
mmcf = 1 million scf
Tcf = 1 x 10 ^12 scf
Bcf = 1 billion scf
1 scf/ton = 0.031217 cc/g or meter^3/tonne
1 m^3/tonne = 32.034 scf/ton (1 ton=2000 lb)
100 scf/ton = 3.1 cc/g

Pressures
150 scf/ton = 4.8 cc/g
1atmos =14.69 psi
200 scf/ton = 6.2 cc/g =10.33 metres water
250 scf/ton = 7.8 cc/g =101.29 kPa
300 scf/ton = 9.4 cc/g
1 psi =6.895 kPa