Coalbed Methane in British Columbia An Update

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INTRODUCTION

The talk will review in a summary fashion the CBM potential of British Columbia. It will include an update of exploration activity and highlight any modifications to the regulatory environment specific for CBM. In addition, some of the aspects of CBM exploration and development that might be somewhat unique to the province will be discussed.

Wholesale natural gas prices per mcf (1000 cubic feet) have risen 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 cUS in 1998 to 0.65 cUS in 2001. These two trends have stimulated interest in exploration for additional supplies of natural gas. Areas of interest include off shore, Mackenzie delta, north shore Alaska and coalbed methane (CBM).

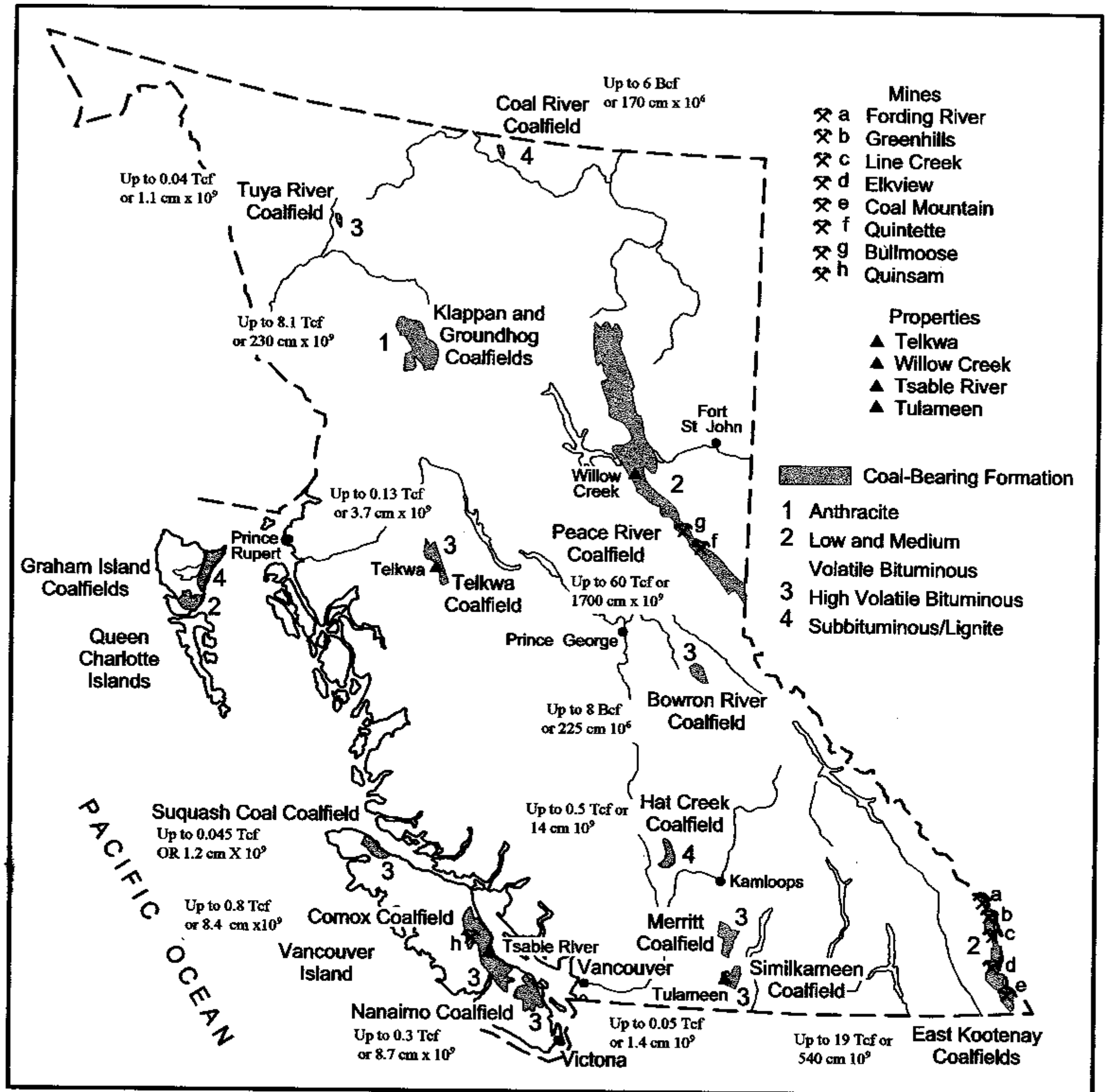
There has been a steady increase in interest in CBM in British Columbia over the last few years. In the last 2 years CBM exploration rights in southeast and northeast BC have been sold for about 20 million dollars. In the last year, Alberta Energy Corporation has permitted 13 test wells in the Elk Valley coal field and at the time of writing has drilled six. In the northeast BP has permitted 4 wells and hopes to begin drilling in the spring of2001. Other companies have expressed interest in permitting CBM test holes in northeast BC 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. It is therefore to some extent an estimate of the coal resource not available for CBM exploration because it is too shallow. The estimated coal resource to a depth of 2000 metres is in the range of 250 billion tonnes and it is this tonnage that is the resource base available for CBM exploration.

SUMMARY OF CBM RESOURCE IN BC

The coal CBM resources of BC (Figure 1) are contained in a number different geological environments. About 75% of the coal resource of British Columbia is contained in a number of Upper Jurassic to Lower Cretaceous coal fields in the foothills of the Rocky Mountains. These coal fields contain structures characteristic of fold and thrust belts. Starting in the south they are the Flathead, Crowsnest, Elk Valley coal fields and in the north the Peace River coal field. The Bowser Basin in northwestern British Columbia is also in a fold/thrust belt. Other Cretaceous coal fields such as those on Vancouver Island and at Telkwa are less deformed and the main structures are vertical faults of various ages. There are some significant Tertiary deposits in the province the largest being Hat Creek. Generally these deposits are fault bounded and have experienced minimal deformation. Coal rank is generally low and their CBM potential will depend in part on the presence or absence of biogenic methane.

In some coal fields coal-bearing formations form basins and therefore the traditional limits of the coal field define the area underlain by coal and with CBM potential. In other coal fields this is not the case. In northeast British Columbia and on Vancouver Island the coal extends at depth



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

CBM 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 cm X 10^9

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

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Figure 1. Estimated CBM resource in British Columbia.

outside areas outlined by existing coal exploration. The extent of some Tertiary coal fields is obscured by unconsolidated material.
The total potential CBM resource of the province is about 90 Tcf. This estimate (hopefully conservative) is heavily influenced by the 60 Tcf estimate for the Peace River coal field which is by far the largest resource in British Columbia. As a comparison the equivalent resource estimate for the USA (lower 48 states) is 703 Tcf of which about 9% is considered proved or economically recoverable. In British Columbia there are published CBM resource estimates available for the southeast coal fields of over 19 Tcf (540 billion cubic metres) (Johnson and Smith, 1991) and the Bowser basin 8 Tcf (230 billion cubic metres) (Ryan and Dawson, 1993). The author estimates a resource of over 60 Tcf (1700 billion cubic metres) for the Peace River coal field 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.

COMMENTS ON CBM IN BRITISH COLUMBIA COALS

In order for a CBM resource to become a recoverable reserve, at least three important conditions must be met. There must be sufficient thickness of coal in the section; the coal must contain sufficient CBM and most importantly there must be adequate permeability. Other considerations are degree of gas saturation, water disposal and gas composition.
Permeability in coal seams is largely dependent on cleats, which probably (but not exclusively) form when the coal is at shallow depth, either during burial or during uplift. In British Columbia where many of the fields have experienced varying degrees of folding and thrusting, it is important to consider the stress *versus* time history of a coal seam in conjunction with its time *versus* maturation history. In some areas the early onset of thrusting may inhibit formation of cleats by ensuring that the coal is in a compressive environment at a time when it would normally forming cleats under tension . This is probably when the maturation increases from a rank of about 0.4% Rmax% to 0.6 Rmax% and the moisture content of the coal decreases by over 30%. Evidence of post folding or thrusting coalification may therefore be accompanied by poor cleat development. Emplacement of thrusts will increase the thickness of the sedimentary package and if coalification post dates thrusting then this will probably produce low geothermal gradients. Alternatively evidence that coalification predates folding, such as steeper coalification gradients, may signal better cleat development. Whatever the pre history of the coal section, it is important that in Tertiary times, there is some extension on structures. This may take the form of normal faulting or normal movement on old thrust surfaces.
Thrusts, where exposed in mines in southeast British Columbia, tend to follow coal seams. Thrust movement was probably accompanied by increased hydrostatic pressure, intense fragmentation of the coal and an increase in seam permeability. Succession of thrusting may be accompanied by decrease in hydrostatic pressure and an increase in water flow throught the seam, which may tend to strip the methane off the coal. De-watering of sheared seams is probably accompanied by movement of fine coal, compression of the seam and a decrease in permeability. Mine geologists in the southeast tend to find that near surface coal seams are impermeable compared to interburden rocks, whereas some sheared seams intersected, at depth in drill holes, were very permeable. Shearing does not appear to effect adsorptive capacity of coal (Vessey and Bustin, 2000) nor does there appear to be heating associated with thrusting (Bustin 1983), which would drive off gas.
Most completion techniques assume that the coal has some skeletal structure that will help support the seam when the hydrostatic pressure is reduced. In cases where coal seams are sheared it may be necessary to develop novel completion techniques. In these situations it may be more realistic to complete in the interburden rock between two seams hoping for a sustainable fracture permeability that will connect with the hanging wall and foot wall of seams defining the interburden. Also in situations where a lower seam has been thrust over an upper seam the interburden is effectively sealed on three sides by impermeable coal seams.
There may be a relationship between gas saturation in coal and folding. Coal migrates into hinge areas of folds in part because of a decrease in hydrostatic pressure. As the coal migrates it will therefore degas to some extent and experience matrix shrinkage, which will further aid migration.

Coal that has migrated along thrusts or into hinge areas of folds may be somewhat under saturated.
Coal rank measures the cumulative effect of temperature, pressure and time. It is possible that the lower adsorption capacities of British Columbia foothills coals compared to Australian coals of similar rank is caused by the fact that the rank of the former was influenced more by pressure and less by temperature than the rank of the latter.

BIOGENIC METHANE

Studies of carbon isotopes indicate that biogenic methane in coal seams is much more important than originally thought. The generation of biogenic methane requires a consortia of bacteria such that the end result is methanogenic bacteria using 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 water penetrates coal seams and introduces bacteria into an anaerobic environment. They are active on the surface of cleats and coal fragments. Sheared coal at depth may exist as a water saturated slurry with a very large particle surface area. Under the right conditions of temperature and nutrient availability there could be major production of biogenic methane. Methanogenic bacteria operate at temperatures 2°C to 110°C, consequently in terms of a geothermal gradient they can survive at depths in excess of 2 kilometres. Because biogenic methane is developed on the surface of coal it is not subject to the constraints of diffusion. It will travel in solution in water or as a gas if the water is removed. Biogasification utilizes oxygen in coal. It decreases as rank increases and concentrate more on the reactive macerals, which have higher oxygen contents than inert macerals. Carbon isotope data on methane leaking from blast holes, surface outcrops and coal outcrops at the Elkview and Quintette mines indicates a major biogenic component (Ryan *et al.,* 1995). There is also some carbon isotope data available (Harrison and Barker, 2000) that indicates that methane from wells and ponds on the east limb of the Alexander Syncline north of the Fording Mine is biogenic.

PEACE RIVER COALFIELD

The Peace River coal field and its down dip extension into the Western Canadian Sedimentary Basin contains 2/3 of the CBM potential resource in British Columbia. The Peace River coal field 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 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 coal field to a depth of 2000 metres is estimated to be over 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 coal field though it thins markedly in the south 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. The rank of the formation is generally medium-volatile bituminous but decreases to the north and northeast and in the Burnt River area is low-volatile bituminous. The formation often has variable inertinite content. This may limit gas content but may aid permeability. Fusinite macerals resist fragmentation and have higher internal permeability than reactive macerals. The Gething Formation extends into the Western Canadian Sedimentary Basin where it produces natural gas. In fact in some places sandstones adjacent to coal seams are gas producers and the production profiles of some holes seem to indicate that gas is bleeding into the sands from the coal seams and recharging them. In a slightly round about way this may actually be the first CBM production in British Columbia.
The Gates Formation contains coal from the Sukunka River south to the Saxon property near the Alberta border, though thicknesses appear to thin to the east at depth in the equivalent formation (Falher). Rank is mainly medium-volatile bituminous but ranks on the western margin of the coal

field are lower. In both formations rank trends are somewhat complicated probably because of post thrusting coalification.
The CBM potential for the Northeast is enormous and has variously been calculated as 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 potential resource. Adsorption data exists for the Gates Formation and a limited amount for the Gething Formation. Desorption data for the Gates Formation indicates that seams are close to saturated at depths of 1100 metres to 1500 metres with contents ranging up to 26 cc/gm on an as received basis. The intensity of deformation is very variable and success of CBM development will probably depend on being able to identify long planar limbs of folds.

SOUTHEAST BC COAL FIELDS

The southeast corner of British Columbia, often referred to as the East Kootenay region, contains the Elk Valley, Crowsnest and Flathead coal fields. Coal in the coal fields 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 and 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 over 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 coal field. Coals at the base of the section in the southwest part of the Crowsnest coal field have vitrinite reflectances (Rmax%) of over 1.6% (Pearson and Grieve, 1978). Generally the coals at the base of the Mist Mountain Formation are medium-volatile with the upper part of the formation containing high-volatile coals.

Elk Valley coal field

The coal resource to a depth of 1500 metres in the Elk Valley coal field is estimated to be 19 billion tonnes (Johnson and Smith, 1991) with an estimated CBM resource of 7.7 Tcf (218 billion cubic metres).
The Elk Valley coal field consists of 2 north trending synclines separated by a major normal fault The west edge of the Elk Valley coal field is defined by the Bourgeau Thrust. To the east, the Greenhills Syncline plunges to the south and its east limb is cut by the north trending Erickson normal fault which has down dropped rocks on the west over 1500 metres. East of the Erickson fault the coal field is folded into the Alexander Creek Syncline which is cut by the Ewin Pass thrust. The three mines in the Elk Valley coal field, provide excellent exposures to study cleating in the coal. Seams in both synclines tend to be fragmented or sheared and cleating is generally not well developed or has not survived the shearing. Thicker coal seams are developed low in the section and tend to host major thrusts, consequently they are generally extensively sheared. Results of the Alberta Energy Corporation drilling are not public, previous CBM exploration by Fording Coal Limited, Norcen and Suncor has tended to encounter seams with gas contents ranging up to about 14 cc/gm and are generally somewhat under saturated.

Crowsnest coal field The Crowsnest coal field 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 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) indicating in part post folding coalification.
Three companies (Mobil/Chevron, Gulf Canada and Saskoil) (Dawson *et al*., 2000) have drilled CBM test holes in the field. Most of the programs found the drilling conditions difficult. Gas contents were very variable with some seams intersected above valley floor apparently de gassed and other seams having gas contents up to 17 cc/gm.

Flathead coal field The Flathead coal field consists of a number of remnants of the Mist Mountain Formation, the largest of which is Sage Creek near the US border. Other smaller remnants 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

The Bowser Basin is a remote region of 50 000 square kilometres of rugged mountainous terrain in northern British Columbia. 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. Coal is found in the northern part of the Bowser Basin in the Currier Formation in the Klappan coal field and in its equivalent, the prudential Formation to the south in the Groundhog coal field. The Currier Formation outcrops on all four sides of the Mt. Biernes Synclinorium the most prominent regional structure in the coal field. 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 an equivalent interval of coal-bearing strata that exceeds 1300 metres contains up to twelve coal zones with a cumulative thickness of 9 metres over an interval of 300 metres.

Fold styles in the basin range from open upright chevron to overturned and stacked recumbent. 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 the east and west limbs of the synclinorium 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 represents the core of the Groundhog and Klappan coal fields and the area with CBM potential.

Coal rank ranges from semi-anthracite to meta-anthracite. Contours for the top of Currier provided an average reflectance of 2.9 % and for the base an average of 4.59%. A coalification gradient for the Currier Formation was calculated as 0.20 % /100 metres. The preservation limit for dry gas in terms of the rank of coal as defined by reflectance is set at between 3.0% and 4.0 % by Dow (1977). 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. CBM resource calculations depend on estimating how much methane was retained by the coal at maximum depth of burial and temperature and how much was scavenged as the coal was uplifted. The adsorption *versus* depth relationship for coal that has attained anthracite rank 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. 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 mentioned until the overburden thickness is reduced to less than 1000 metres. High rank coals whose maximum depth of burial was greater than their present depth of burial may be under saturated with respect to their present depth and rank.

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 at maximum depth and temperature which may be a better measure of its actual gas content at its present shallower depth.

The total potential coal resource in the Klappan and Groundhog coal fields 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 extraction.

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

VANCOUVER ISLAND COAL FIELDS

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. Age ranges from Jurassic to Tertiary though most is found in the Nanaimo Group and is of Upper Cretaceous age. The major Upper Cretaceous coal fields on Vancouver Island are the Nanaimo and Comox fields. Of the other coal fields only the Suquash has any CBM potential. Not much is known about cleat development in Vancouver Island coals but generally they have not suffered the same amount of deformation as coals in southeast and northeast British Columbia.

There are at least three coal bearing formations within the Nanaimo Group. The basal coal bearing Comox Formation is overlain by marine sediments of the Haslam Formation in the Nanaimo coal field or the Trent River Formation in the Comox coal field. The second coal-bearing cyclotherm is marked by the deposition of the Extension and Protection formations, which host the coal seams and mines in the Nanaimo coal field.

A number of holes were drilled on Vancouver Island specifically for CBM. Novacorp drilled 14 holes in 1984/85 and British Petroleum drilled two holes in 1986. Gulf and British Petroleum also drilled deep holes in the early 1980s but not specifically for CBM. In 1996, Quinsam Coal Corporation initiated an exploration project in the Tsable River area south of Courtney. Core was collected from this program and desorbed (Ryan, 1997). In 1994 samples from a two holes near the Quinsam coal mine were desorbed (Ryan and Dawson, 1994). The CBM potential of the Nanaimo coal field and parts of the Comox coal field extend eastward into Georgia Strait beyond the surface expression of the fields. Estimates of resource potential for these coal fields may include under sea CBM, which at the moment cannot be legally recovered.

Published estimates of CBM on Vancouver Island range from 1 Tcf (28million cubic metres) (Energy Market Update, 1992) to 230 Bcf (6.5million cubic metres) Proudlock (1990). 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. (million tonnes) (Cathyl-Bickford, 1991).

Nanaimo coal field The Nanaimo coal field centered on the town of Nanaimo was extensively mined between 1849 to about 1950 when over 50 million tonnes of coal were extracted from seams in the Extension and Protection formations. The coal field covers approximately 777 square kilometres and contains from 10 to 70 mt. of coal (Dolmage Campbell and Associates, 1975). Coal rank is high-volatile A bituminous. Recent work indicates that there is also coal in the Comox Formation in the Nanaimo coal field. Coalbed methane opportunities in the Nanaimo coal field are probably limited because most of the coal in the Pender and Extension formations (Douglas and Wellington seams) has been mined out. Most of the CBM potential will be in the eastward extension of the Douglas and the deeper Comox seam if it is extensive or maybe in mined out areas. The potential CBM resource of the Nanaimo basin is estimated to be in the range of 0.4 Tcf.

Comox coal field The Comox coal field is centered on the Town of Comox and includes the Quinsam mine, which is the only coal mine on the island. Coal in the Comox coal field is contained in the Comox Formation, which forms the base of the Nanaimo Group. The coal field extends from 20 kilometres north of Nanaimo to Campbell River and covers about 1230 square kilometres. It 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 Quinsam sub-Basin has an Rmax% value of 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 form 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 potential CBM resource is 50 Bcf (1.4 billion cubic metres).

The Campbell River sub-Basin extends from Campbell River in the north to Oyster River in the south. The resource of the sub-basin is reported as between 74.5 mt to 400 mt. (Dolmage Campbell and Associates, 1975). The CBM resource is estimated to be about 40 Bcf.

The Anderson Lake Sub-Basin extends 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. A speculative CBM resource potential is 24 Bcf (0. 686 billion cubic metres).

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 of over 200 mt (Dolmage Campbell and Associates, 1975). Four major seams are present with cumulative thickness 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).

The Tsable River sub-basin includes Denman Island and covers 272 square kilometres. The area is at the southern end of the Comox coal field and northern end of the Cowichan fold and thrust belt. Reserve estimates range from 148 mt. to 265 mt. (Dolmage Campbell and Associates, 1975). The total resource to 2000 metres could be over 1 billion tonnes. Cumulative coal in the section is about 8.3 metres contained in about 4 seams. 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. A CBM resource calculation for part of the southern end of the coal field outlines a potential resource 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.

Suquash coal field The basin covers an area of 120 square kilometres. The rank is high-volatile B to A bituminous (Kenyon, 1991). The rocks belong to the Nanaimo group. 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 containing about 4 metres of coal. If the basin is under lain on average by 2 metres of coal then the coal resource is about 300 mt. The coal bearing stratigraphy could extend to the northeast under Malcolm Island. This provides a basin area of 300 square kilometres and a potentially larger coal resource. Using a coal resource of 300 mt the estimated potential CBM resource is 45 Bcf (1.3 billion cubic metres).

TELKWA

The Telkwa coal field 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. A coal resource of approximately 850 million tonnes is outlined at varying levels of assurance in the coal field. 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. During the 1990 exploration program, five samples were collected from 2 rotary drill holes for desorption (Ryan and Dawson, 1994). Gas contents range from 3.75 to 4.49 cc/g on a daf basis and do not increase with increasing depth. Based on comparison to adsorption isotherm data the coal appears to be saturated.

Generally Telkwa coals are hard and well cleated. Permeabilities of coal seams in Unit 3 in three drill holes in the east Goathorne area were measured at depths ranging from 29 to 158 metres. Values do not correlate with depth and range from 0.5 to 50 milli darcies. The permeability of sections of mudstone, siltstone and sandstone interburden varying in thickness from 14 to 27 metres were measured in drill holes. At depths of less than 200 metres, permeabilities of interburden rock and coal range from 13 to 35 milli darcies. Permeability of the interburden is on average greater than that of the coal.

The estimated total CBM resource of the Telkwa coal field is 0.13 Tcf (3.7 billion cubic metres). The Telkwa coal field is close to the towns of Smithers and Telkwa, which may 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 and should have higher gas contents. There is a trade off between less coal with higher 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 coal field south of Telkwa. This pipeline connects Prince Rupert and Kitimat with pipelines from the northeast and southwest B.C.

TERTIARY COAL DEPOSITS

Tertiary sediments survive in many major watersheds in British Columbia. The sediments are generally not well consolidated, poorly exposed and their subcrop extent 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 vary from a few centimetres to many metres. It is important to remove the thickness of Pleistocene till from the coal depths before estimating gas contents.

TUYA RIVER

The Tuya River Basin is located between the communities of Dease Lake and Telegraph Creek in northwestern British Columbia. The basin is potentially quite large, yet it has escaped detailed study. The simplest interpretation based on limited data is that the basin has the form of an open, northerly plunging syncline, complicated by smaller scale faults and folds. Limits of the basin are poorly defined and in places it is overlain by recent volcanic rocks; however, it is estimated that the basin covers approximately 150 square kilometres and contains over 600 million tonnes of coal. A tentative stratigraphic section outlines two units of Eocene age. A lower unit, 200 metres 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 contains from 5 to 30 metres of coal. The lower unit is overlain by an upper unit at least 300 metres thick, which is composed of volcanic-pebble conglomerate, sandstones and volcanics.

In outcrop, 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 contain up to 5 % occurring as blebs ranging up to 5 millimetres, in diameter. Analyses indicate a coal rank of sub-bituminous B to high-volatile bituminous C. Rmax% values from Mansfield Creek and Little Tuya River on the west side of the syncline average 0.76% and samples from Tuya River on the east side of the syncline average 0.68%.

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 if one considers the possibility of biogenic gas in coal porosity.

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. Coal was first reported in the area in 1891 as lignite boulders, at the mouth of Coal River. The source of the lignite (Williams, 1944) is about 6 miles (10 kilometres) as the crow flies up river from the Alaska Highway.

A number of Tertiary lignite outcrops were located along the river. The main outcrop is on the west bank of the river where, for a length of over 100 metres, the hangingwall section of the seam is exposed with 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. Generally 3 to 4 metres of lignite are exposed in the outcrops on the west side. On the east side the topography is flatter and outcrops less well developed. A water well intersected 15 metres of coal at a depth of 15 metres near where the river crosses the Alaska highway. The rank is peat based on Rmax% values of about 0.2%, though the heat value indicates a higher rank. The 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 the 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 consists of two poorly exposed coal deposits located 20 kilometres west of Cache Creek. 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 bounded by north trending normal faults. Displacements on the western faults appear to be more than on the eastern faults causing a rotation and 25° western dip of 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 this means that they can retain moderate amounts of free gas probably of biogenic origin. Because of the large coal tonnages even with gas contents of 1 to 3 cc/gm (30 to 100 scf/ton) there could still be a sizable CBM resource of about 0.5 Tcf (14 billion cubic metres) concentrated in a small area.

SIMILKAMEEN COAL FIELD

Tulameen The Tulameen sub-basin is, with the Princeton sub-basin, considered to be part of the Tertiary Similkameen coal field. The sub-basin is 20 kilometres northwest of Princeton. Underground mining in the area extended along the sub crop for 2500 metres and down dip for 800 metres. Mining activity diminished after a disastrous explosion that killed 45 people in 1930 (Blake, 1988).

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, containing 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 resource of at least 200 mt in the basin. A potential CBM resource of 0.05 Tcf (1.4 billion cubic metres) is possible.

Princeton sub-basin The Princeton sub basin is a northerly elongated basin approximately 4 to 7 kilometres wide and 24 kilometres long, covering 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 up till about 1961. The basin is filled with mid Eocene sediments and is more folded than the Tulameen sub-basin. Coal seam stratigraphy is not well understood compared to 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, however seams are very discontinuous. Rank of the coal varies from lignite to high-volatile B bituminous. Dolmage and Campbell (1975) estimate a potential resource in the southern part of the basin of over 800 mt. The low rank, uncertain coal reserve and discontinuous nature of the coal seams limit the CBM potential.

MERRITT

The Merritt coal field comprises several isolated Eocene sedimentary areas, that outcrop within a radius of 15 kilometres. The main areas are Nicola about 80 square kilometres and Quilchena about 25 square kilometres. In the Quilchena area a single seam 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. There appear to be 7 seams with a cumulative coal thickness of 22 metres in a 250 metres section. Overall the Nicola coal field has not been extensively explored but much of the area underlies the town of Merritt and some of the areas are overlain by recent volcanics. It is difficult to estimate the resource in the area but if a coal thickness of 10 metres extends through the whole Nicola coal field there could be over 800 mt and a moderate CBM resource actually under the town of Merritt.

BOWRON RIVER

The Bowron River graben, which is 50 kilometres east of Prince George, is 2.5 kilometres wide and 15 kilometres long. The lower 85 meters of the Paleocene sedimentary section, which is over 700 metres thick, 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 is high-volatile B bituminous in rank (average Rmax%=0.65%) and is characterized by a high (8%) resin content. Matherson and Sadre (1991) estimate a potential resource of 400 mt down to a depth of 1200 metres considering only the lower seam. Any CBM potential will depend on presence of boigenic 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 lot of coal in the province and the potential CBM resource is similar to that in the San Juan Basin in the US. Much of the coal in the province is in the Rocky Mountains foothills 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 over come 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 will give rise to a large CBM resource.

The gas is in the coal and sooner or later the forceful combination of economic incentive and human ingenuity will get it out. Lets hope sooner than later.

REFERENCES

Blake, D. (1988): Blakeburn, From Dust to Dust; Wayside Press Vernon BC.

Bustin, R.M. (1983): Heating During Thrust Faulting; Friction or Fiction; *Tectonophysics*, Volume 95, pages 309-328.

Bustin, R.M. and Moffat, I. (1989) Semi anthracite, anthracite and meta-anthracite in the central Canadian Cordillera: their geology, characteristics and coalification history. International Journal of Coal Geology, volume 13 pages, 303-326.

Bustin, R.M.(1999): Free Gas Storage in Matrix Porosity: A Potentially Significant Coalbed Resource in Low Rank Coals; Proceedings International Coalbed Methane Symposium 1999, May 3-7th University of Alabama, pages 197-214.

Cathyl-Bickford, C.G. (1991): Coal Geology and Coal bed Methane Potential of Comox and Nanaimo Coal Fields, Vancouver Island, British Columbia; Rocky Mountain association of Geologists pages 155-162.

Church, B.N. (1977): Geology of the Hat Creek coal basin (92I/13E); British Columbia Ministry of Energy, Mines and Petroleum Resources, Geology in British Columbia, 1975, pages 99-118.

Dawson, F.M., Marchioni, D.L., Anderson, T.C. and McDougall, W.J. (2000): An Assessment of Coalbed Methane Exploration Projects in Canada; Geological Survey of Canada Bulletin Number 549.

Dow, W.G. (1977):Kerogen Studies and Geological Interpretations; Journal of Geochemical Exploration, Volume 7, pages 79-99.

Dolmage Campbell and Associates (1975): Coal Resources of British Columbia; Consultant report to British Columbia Hydro and Power Authority.

Energy Marketing Update, (1992) What is Coal bed Methane; British Columbia Ministry of Energy, Mines and Petroleum Resources, Energy Market Update Volume 4, number 1

Goodarzi, F. (1985): Organic Petrology of the Hat Creek Coal Deposit No 1, British Columbia; International Journal of Coal Geology, Volume 5, pages 377-396.

Graham, S.W. (1989): Geology and Coal Potential of Tertiary Sedimentary Basins, Interior of BC; Advances in Western Canadian Coal Geoscience-Forum Proceedings Alberta Research Council Edmonton April 24-25 1989 pages70-89.

Harrison, S. and Barker, J.F. (2000): The Jurassic Cretaceous Mist Mountain Formation Coalseam Gas Origin and Reservoir Rock Characteristics; paper presented at the Canadian International Petroleum Conference, Calgary June 4-8.

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

Matherson, A. and Sadre, M. (1991):Subsurface Coal Sampling Survey Bowron River Coal Deposits Central British Columbia, (93H/13); Ministry of Energy and Mines, Geological Fieldwork 1990, Paper 1991-1, pages 391-397.

Papic, M.M., Warren, I.H. and Woodley, R.M. (1977): Hat Creek Utilization; Canadian Mining and Metallurgical Bulletin, November 1977, pages 99-105.

Pearson, D.E. and Grieve, D.A. (1978): Coal Investigations; Crowsnest Coal field; B.C. Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork 1978 Paper 1979-1, pages 61-65,.

Proudlock (1990): An Overview of Albertan and Canadian Demethanation Experience, Technology Advances and Development Potential; in Coalbed Methane in Alberta- Whats it all about; Alberta Geological Survey, Information Series No 108.

Ryan, B.D. (1991): Geology and Potential Coal and Coalbed Methane resource of the Tuya River Coal basin; *B.C. Ministry of Energy, Mines and Petroleum Resources,* Paper 1991-1, pages 419-427

Ryan, B.D. and Dawson, M.F. (1993): Coal and Coalbed Methane Resource Potential of the Bowser Basin, Northern British Columbia, (104H/104A); *B.C. Ministry of Energy, Mines and Petroleum Resources*, Open file 1993-31.

Ryan, B.D. and Dawson, M.F. (1994a): Coalbed Methane Desorption results from the Quinsam Coal Mine and Coalbed Methane Resource of the Quinsam Coal field, British Columbia; *in* Geological Fieldwork 1993, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 215-224.

Ryan, B.D. and Dawson, F.M. (1994): Potential Coal and Coalbed Methane Resource of the Telkwa Coal field Central British Columbia (93L/11); *in* Geological Fieldwork 1993, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1994-1, pages 225-243.

Ryan, B.D., Dawson, M. and Whiticar, M. (1995): Preliminary Quantification of Methane Released From Two Surface Coal Mines in British Columbia; Report to Environment Canada Industrial Sectors Branch TSD Contract Number K2331-4-0196.

Ryan, B.D. (1997): Coalbed Methane in the Comox Formation Tsable River Area Vancouver Island; Ministry of Energy, Mines and Petroleum Resources, Paper 1997-1, pages 353-363.

Scott, A.R. (1995): Limitations and Benefits of Microbially Enhanced Coalbed Methane; Intergas 95 May 15-19 University of Alabama, pages 423-432.

Vessey, S.J. and Bustin, R.M. (2000): Sedimentology of the Coal-bearing Mist Mountain Formation, Line Creek, Southern Canadian Cordillera, Relationships to Coal Quality; International Journal of Coal Geology, Volume 42, pages 115-128.

Williams, V.E. and Ross, C.A. (1979): Depositional Setting and Coal Petrology of Tulameen Coal field South-Central British Columbia; American Association of Petroleum Geologists Bulletin volume 63,, pages 2058-2069.

Williams, M.Y. (1944): Geological Reconnaissance Along the Alaska Highway from Fort Nelson, British Columbia to Watson Lake, Yukon; *Geological Survey of Canada*, Paper 44-28.