



Overview of Coalbed Methane Geology in Northeast British Columbia

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KEYWORDS: Coalbed methane, Peace River coalfield, Gething Formation, Chamberlain member, Bullmoose Member, Gaylard Member, Bluesky Formation, Gates Formation, "Fourth coal", exploration model, coal isopachs.

INTRODUCTION

The purpose of this paper is to overview the coalbed methane (CBM) geology of the Peace River District. The CBM potential is examined from regional perspectives relating to coal geology, conventional gas geology, structure and hydrology because there is very limited exploration data. Summary geographic figures are available in several reports and the writer has collated them in a series of overlays. Though some authors have cautioned that each coalbed methane play is unique (Nelson, 2000), a general exploration model for CBM is discussed briefly.

COALBED METHANE

Ryan (2000) provides a good introduction to coalbed methane in British Columbia. How methane is held in coal, reserve estimation and elements of recovery are recapitulated below. These comments draw on Ryan (*ibid*), Davidson *et al.* (1995), Bowden and Ehrlich (1998).

Methane may be adsorbed (held by weak forces to surfaces of microscopic pores in coals), be present as free gas, or be in solution in water associated with the coal. Adsorbed gas is the most important component and the property of adsorption distinguishes coal from conventional reservoirs for gas.

Adsorption capacity can be estimated roughly using basic parameters of depth and rank, but in detail a number of other parameters influence capacity. These include vitrinite content and micropore volume, which increase capacity, and moisture and ash content which decrease capacity.

Coal is not necessarily saturated with methane, particularly at depth. Also not all adsorbed gas is recoverable. Coal, retrieved at depth, must be tested to assess how methane desorbs from the coal. This leads to an estimate of methane content.

Davidson *et al.* (1995) provide a formula for resource assessment:

$$GIP=A *h *G_c *C$$

Where GIP=gas-in-place

A=drainage area

h=coal thickness

G_c=methane content from core studies

C=coal density

The well's drainage area depends on permeability, which is difficult to measure. To assess permeability both macro-permeability (open-space cleats, fractures) and micro-permeability (micro-fractures that release gas from matrix) need to be considered. The removal of formation water is also necessary to provide the pressure gradient to initiate and maintain gas flow from the cleat system to the well.

In practice, commercially successful CBM wells intersect coals with high gas yields at shallow depths (Bowden and Ehrlich, 1998). In some CBM fields secondary methane derived from anaerobic bacterial activity in the coal, and free gas under a compressed state (as in a conventional reservoir) contribute significantly to production.

PREVIOUS WORK

The first exploratory petroleum well, drilled by the B.C. government in 1921 at Farrel Creek, a few km east of the W.A.C. Bennet dam on the Peace River intersected water and gas at shallow depths (243 to 290 m) near the top of the Gething Formation, below a permeable conglomerate (Dresser 1922). The gas, used to heat the drilling camp during the winter of 1921/22, may be an early, unrecognised example of methane gas associated with aquifer flow in coal measures in the Peace District.

Subsequent geologic work in the Peace District focused on mapping specific areas near accessible occurrences of coal such as at Carbon Creek (Matthews, 1947) and Pine River (McKechnie, 1955). The first comprehensive regional work was done by Stott (1974) who measured and correlated a series of sections extending from the town of Cadomin in Alberta to the Peace River canyon in B.C. This provided the stratigraphic context for coal exploration in the foothills of Alberta and B.C. Coal exploration expanded rapidly in the 1970's with licenses stretching from the Graham River to the Alberta border. Duff and Gilchrist (1981) used both coal and petroleum well data to correlate Gething and Gates coal trends along the axis of the coalbelt. Leckie (1983, 1986) in the north and Carmichael (1983, 1988) in the south, conducted field sedimentological studies on major sandstone bodies in the Gates, correlating them and intervening coal intervals to the subsurface of the plains. The sandstones (known as Fahler A to F) are important gas reservoirs in the subsurface of the plains. Karst and White (1980)

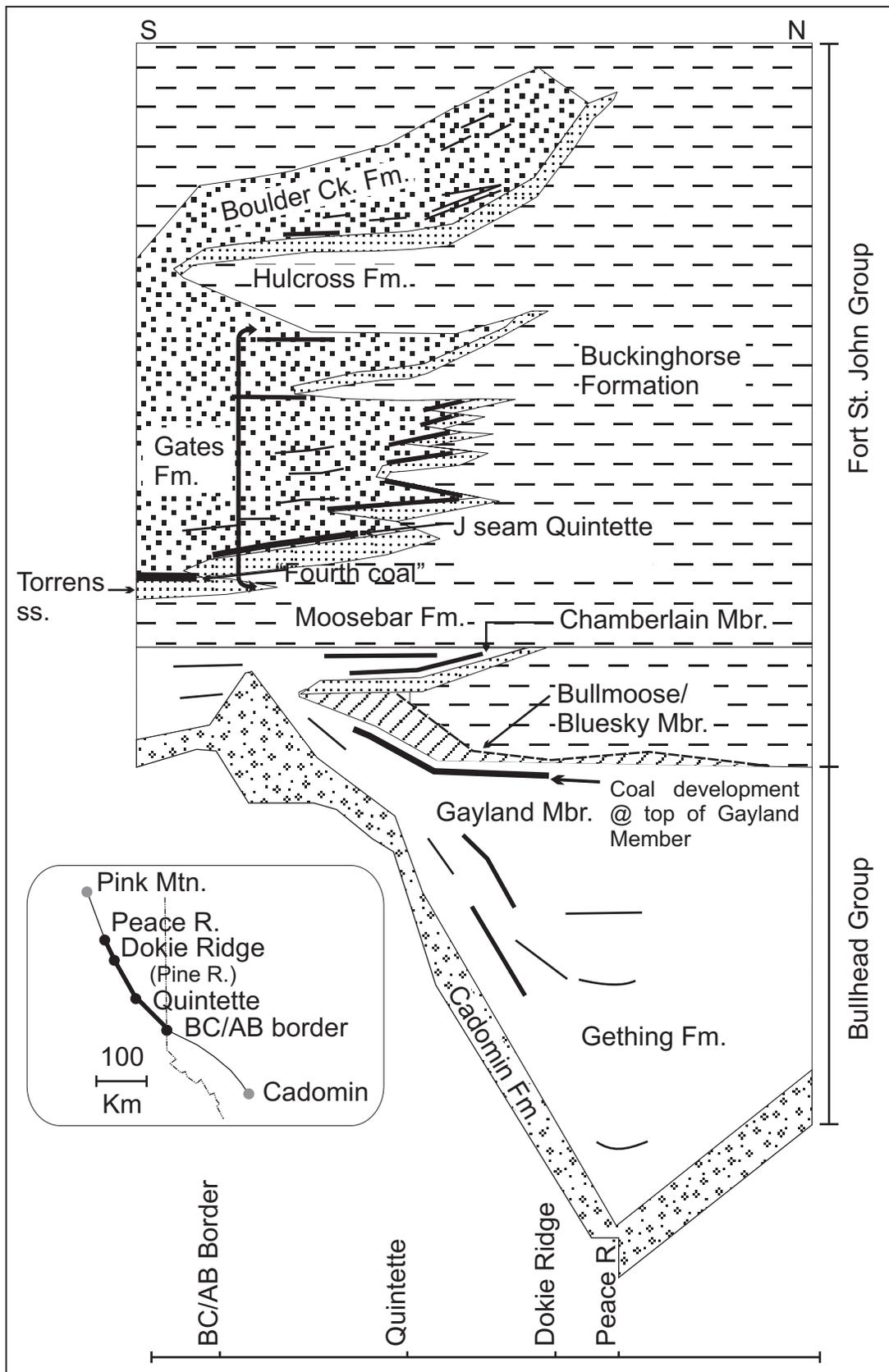


Figure 1. North-south cross section along the foothills of northeastern British Columbia. Modified from Kalkreuth and Leckie (1989).

produced maps showing the distribution of coal reflectance values at the top of the Gething Formation and used the contour plot to discuss the hydrocarbon maturation levels. Kalkreuth *et al.* (1989, 1991) subsequently used reflectance data to interpret the burial and thermal history from the plains to the foothills. Oppelt (1988) showed the Gething marine tongue of Duff and Gilchrist (1981) was a part of the Bluesky Formation, a gas and oil producer in the plains. Broatch (1988) used palynology to identify areas of marine influence in the lower part of the Gething Formation. Legun (1990) researched the extent of upper Gething coals (Chamberlain member) and Gibson (1992) produced a stratigraphic overview of the Gething Formation, formally dividing it into three members. Ryan (1996) compiled coal quality data for the Gething and attempted to gain some understanding of trends in petrography, ash chemistry and rank between coal properties.

Wyman (1984) modeled the coalbed methane potential of the "fourth" coal adjacent to Fahler sandstones in the subsurface of the plains. Lamberson and Bustin (1993) confirmed the high adsorption capacity of Gates coals and studied how maceral composition affected gas content. Ryan (personal communication) made preliminary calculations of CBM resources in the Peace District. Dawson (1995, 2000) formulated CBM exploration models for the foothills and Dawson *et al.* (2000) reviewed the drilling results of an exploratory CBM well (Philips Flatbed) near the Monkman coal property.

REGIONAL STRATIGRAPHY

CBM potential in the area of study is largely restricted to two coal-bearing sequences, the Gething and the Gates of Lower Cretaceous age. The two formations are separated by Moosebar marine shale and part of a much larger sequence of interdigitating marine and continental strata that filled the subsiding foreland basin (*see* Figure 1). Though not reviewed in this paper, there is some potential for CBM in the older Minnes Group, the Boulder Creek Formation above the Gates, and the much younger (Upper Cretaceous) Wapiti Formation.

The general area of interest for potential CBM production is east of the coal license blocks of the coalfield shown in Figure 2. A great portion of the potential corresponds to the Gates and Gething formations in the subsurface of the outer foothills.

The structure of the outer foothills in the Peace District is characterized by low amplitude, long wavelength folds, and widely spaced thrusts. A line of section at Sukunka River (Figure 3 after McMechan, 1994) shows shallow depths to the CBM resource. The presence of the upper Fort St. John Group (Goodrich, Hasler and Cruiser formations) indicates areas where there is 1000 metres or less cover to Gates coal.

REGIONAL COAL RANK

In general methane resources in the outer foothills will be in coals of slightly higher rank than that of the coalfield to

the west. A contour plot of coal rank (Figure 4) for the uppermost seam of the Gaylard member is taken from Kalkreuth and McMechan (1988). It is based on 664 samples taken from outcrop, mine sites, petroleum well cuttings, and coal borehole core. Reflectance values generally decrease in the direction of the inner foothills reflecting decreasing depth of burial. The axis of maximum rank underlies the outer foothills and is parallel to its trend. A significant area of high rank coal underlies an area centered southwest of Chetwynd. This area of low volatile bituminous coal is underlain by an even larger area of semi-anthracite at the stratigraphic level of the Lower Gething. The Burnt River coal deposit lies at the southwestern margin of the node.



Figure 2. Coal licenses, CBM experimental schemes, CBM land sales in relation to the outer and inner foothills of the Peace District.

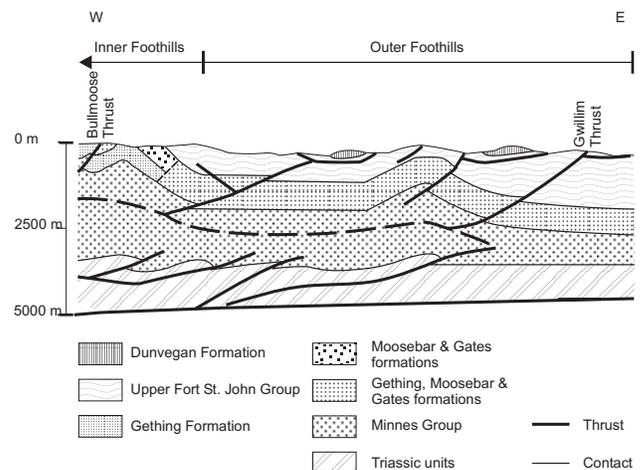


Figure 3. Line of section at Sukunka River from McMechan (1994).

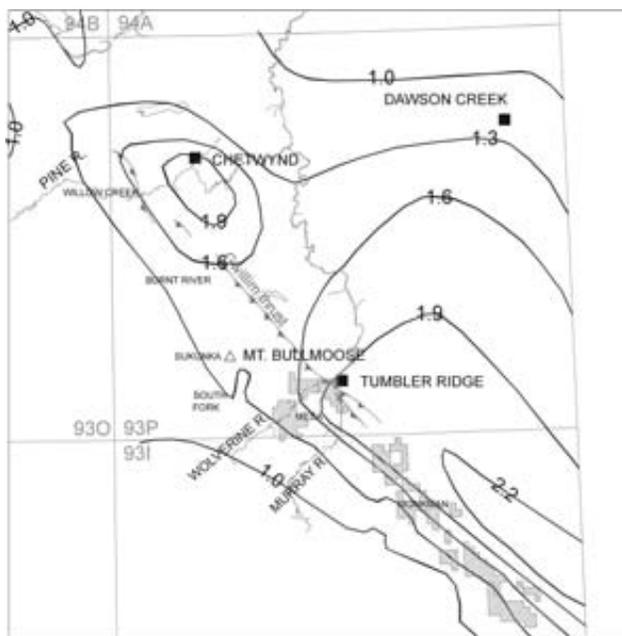


Figure 4. Isorefectance lines for top of Lower Cretaceous Gething Formation after Kalkreuth and McMechan (1988).

The distribution of reflectance values for Gates coal in the Peace District is shown in Kalkreuth and McMechan (1988, 1991) with additional information provided by Kalkreuth and Leckie (1989). The values appear to follow the same trends as the Gething Formation, although they are at a slightly lower rank due to their shallower depth of burial. The rank varies from low volatile to high volatile bituminous, with low volatile bituminous coal restricted to the outer foothills. The reflectance values at some major coal properties are shown in the table below.

DETAILED STRATIGRAPHY

GETHING FORMATION

The Gething Formation reaches its greatest preserved thickness in the northwest part of the Peace River area (Carbon Creek) where the formation is up to 1100 metres thick with 60 thin seams. The formation is 500 m thick between Peace Canyon and the Pine River, declining to 360 m at

TABLE 1
REFLECTANCE VALUES OF GATES FORMATION
COAL AT SOME MAJOR PROPERTIES

Coal Property	Rank	Reference
Quintette	1.2 to 1.26 (mvb)	Kalkreuth and Leckie (1989)
Bullmoose	1.02 to 1.14 (hvb to mvb)	Kalkreuth and Leckie (1989)
Monkman	1.16-1.27 (mvb)	Leckie, Kalkreuth and Snowdon (1988)

Bullmoose Mountain, 200 m at Murray River and less than 100 m at the Alberta border. It also thins eastward, below the outer foothills into the subsurface of the plains.

The Gaylard Member represents the Gething Formation between Peace River and the Sukunka River (Figure 1). South of Sukunka River the Chamberlain member, a progradational deltaic wedge, forms the upper part of the Gething Formation and is separated from the Gaylard by a marine tongue of the Moosevale. The marine tongue, known as the Bullmoose member, thins in the Monkman area-its exact southern limit is unclear. South of Monkman the Gething Formation is not differentiated into members.

Duff and Gilchrist (1981), Kilby and Oppelt (1984), Legun (1990), Gibson (1992) drew stratigraphic sections extending from the foothills into the plains. These give a qualitative impression of coal seam distribution in the Gething Formation.

GAYLARD MEMBER

The Gaylard Member was deposited in a lower delta plain environment. Gibson (1992) noted some distributary channel sands, marine to brackish water bivalves and marine foraminifera in the area of Carbon Creek and West Carbon Creek. In the Sukunka and Wolverine River area Broatch (1988) also identified zones of marine influence based on palynological data. However, most Gaylard Member coals were formed in fresh-water environments, as their sulfur content is low. The seams occur en echelon stratigraphically and they are difficult to correlate laterally, suggestive of migrating delta distributary lobes and back swamps. Gaylard coals are not related to major strandplain sands as in the Gates Formation. Ryan (1996) suggests on the basis of inertinite rich coal at the top of many seams that peat swamps may have developed into raised mires.

The distribution of coal seams in the lower part of the Gaylard Member is poorly known due to limited drilling. A few property reports (East Mt. Gething, Rocky Creek, Burnt River, Carbon Creek) describe seams near the contact with the Cadomin Formation. There is more widespread coal development toward the top of the Member. In the Pine River area Ryan (1996) describes coal seam distribution, coal quality and petrography at the Falling Creek, Pine Pass, Lossan, Moberly and Willow Creek properties. Coals average 2-4 metres thick, with occasional coal intercepts exceeding 5 metres. Kilby (1984) used tonstein markers to show at least one seam in this area has a wide extent. He correlated the no. 1 seam at Willow Creek with the Trojan seam at Peace River canyon and southward to the B seam at Sukunka. Kilby and Oppelt (1984) also correlated the Trojan seam at Peace River Canyon eastward, showing it finally pinches out near Hudson Hope in the subsurface.

The B seam at Sukunka and Burnt River east properties is missing or poorly developed in some adjacent drill holes (Gibson 1992). Near the Wolverine River only thin coal intervals are intercepted in boreholes at this stratigraphic position. However further south on the Hermann Gething licenses near the Quintette mine a 5 metre thick seam lies about 45 metres below the top of the Gaylard Member.

The development of coal toward the top of the Gaylard member in the Pine to Murray River area probably reflects a period of low sediment influx and slow subsidence of the delta plain below sea level.

BULLMOOSE MEMBER

The Gaylard is overlain by the Bullmoose member, an upward coarsening shale to sandstone sequence as evident in the gamma trace on geophysical logs. It is not coal-bearing and contains marine to brackish water macro and microfossils. Isolated upward coarsening bodies at this stratigraphic position are present to the east in the subsurface of the plains and identified as the Bluesky.

CHAMBERLAIN MEMBER

Thick, massive sandstone forms the base of the Chamberlain member, which overlies the Bullmoose member. The Chamberlain coal seam lies directly on this shelf strandplain in a similar fashion to sandstone/coal pairs in the succeeding Gates Formation. Significant traceable seams in the Chamberlain member include the Chamberlain, Skeeter and Bird seams with individual thickness to 3 metres. In the subsurface seam development diminishes eastward toward Gwillim Lake and the disappearance of coal kicks on geophysical logs can be used to define the limit of coal measures. The trace of the zero coal isopach defines a lobe-like projection, probably a delta complex that prograded into the Moosebar sea (Figure 5). A sediment buildup is supported by the convergence of the twin tonsteins in the Moosevale and the Gething Formation in this area (Kilby 1984). A narrower deltaic shelf to the northwest flanks the lobe. The Chamberlain member varies from 60 to 100 metres thickness along the coalbelt. Near the Quintette mine the Cham-

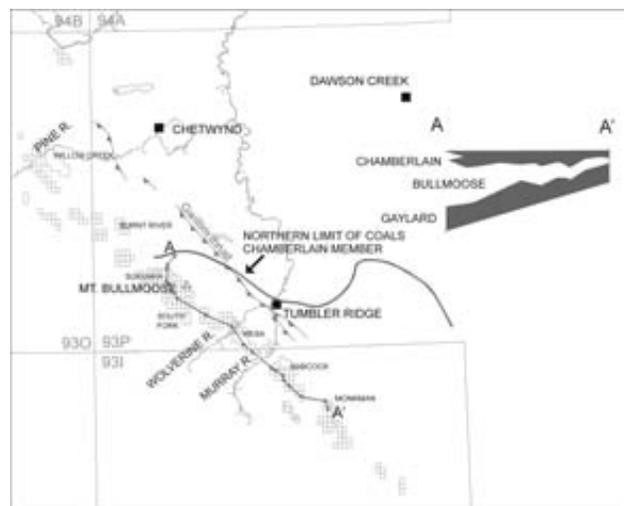


Figure 5. Northern limit of coals in Chamberlain Member with section A-A' illustrating underlying marine Bullmoose Member.

berlain seam is apparently cut out by channel bodies (Legun 1990) but southeast of the Murray River equivalents of the Chamberlain and Bird seams reappear and are well developed (Fig. 5b, Gibson 1992). The Chamberlain delta underlies the outer foothills and is a potentially significant CBM resource due to artesian overpressure potential in continuous seams bounded by shale seals.

GETHING FM. COAL ISOPACHS

The writer is not aware of any regional compilation of total coal thickness for the Gething Formation that incorporates both coalbelt and subsurface plains data. A partial compilation is reported by Ryan (2000a) based on petroleum well data east of the coalbelt, mostly NTS 93P. This data is included in Figure 6; contours should be considered as trends as they omit thicker coal development immediately to the west. The isopach shows a maximum thickness from Pine River to the Murray River at the outcrop belt, and gradual decreasing coal development eastward in the subsurface.

In general the trends from the plains as reported by Ryan (ibid) match trends of thick coal development in the coalfield described above. The thickness in the coalbelt is probably 10-15 metres in a number of properties.

GATES FORMATION FACIES AND COAL ISOPACHS

Coal thickness trends for the Gates Formation are compiled from Carmichael (1983) and Leckie (1986) for the Peace coalfield (Figure 7). Major coals in the Gates tend to be paired with underlying strandline sands. The shoreline oscillated back and forth between Bullmoose Mt. in the north and the Wolverine River to the south. As a result the

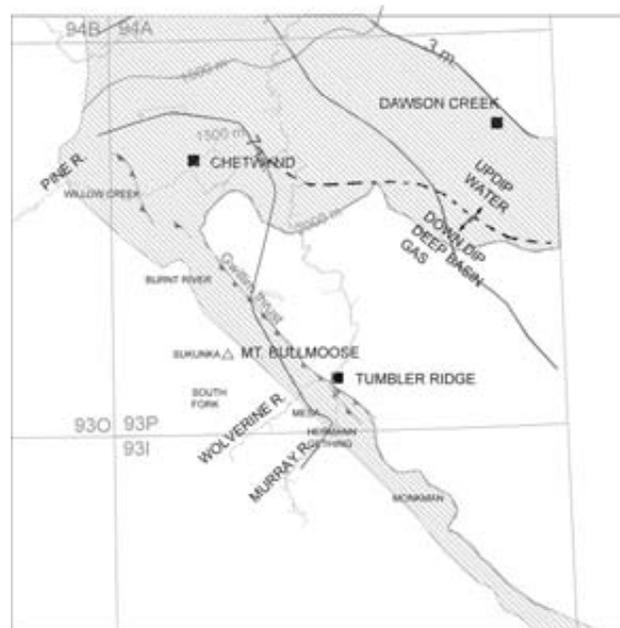


Figure 6. Gething CBM area in outer foothills defined by 2000 metre depth, 3 metre coal isopach and edge of inner foothills. Gething coal isopach after Ryan, (2000a). Note deep basin gas line.

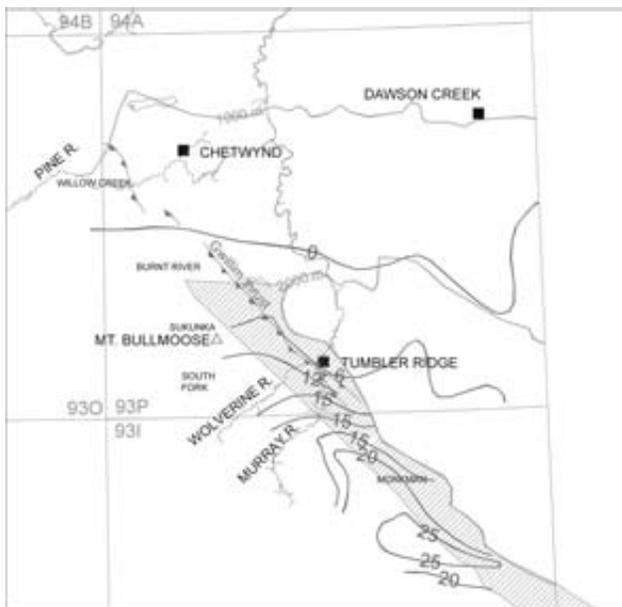


Figure 7. Gates CBM resource area in outer foothills defined by 2000 metre depth, 3 metre coal isopach. Coal thickness data from Carmichael (1983) and Leckie (1986).

coal thickness rapidly increases south of Bullmoose Mt. from 0 to 15 metres. It reaches a maximum of about 25 metres near Monkman and is about 20 metres at the Alberta border. It begins to diminish near Grande Cache in a complicated pattern (Figure 6 in Dawson and Kalkreuth, 1994).

Gates coals are considered to have developed directly on marine strandplains. Longshore drift of sand was an important component in their formation and these strandplains became isolated behind barrier bar delta fronts. Extensive areas were flooded, becoming freshwater lagoons and sites of extensive peat formation. The important strandplains in the Peace District are Fahler F and D. Overlying Fahler F, otherwise known as the Torrens member, is a thick coal that constitutes important coking coal resources at Monkman, Belcourt, Saxon properties in the southern part of the coalfield. Carmichael (1983, 1988) noted that the basal J seam at Quintette sat on sandstone "step" above the Torrens, which he labeled Fahler D. He showed a likely correlation of seams from Alberta northward to the Quintette mine area.

Carmichael (1983, 1988) and Leckie (1986) make apparently different designations of the stratigraphic position of the J seam with Carmichael showing it above Fahler D and Leckie above Fahler F. This makes uncertain the correlation of the "Fourth coal" of the plains region, identified as the coal above Fahler F. The Fourth coal is considered a significant source of methane in the Alberta deep basin and has been isopached to the Peace River coalfield (Figure 8, from Kalkreuth and Leckie 1989).

It is uncertain whether the Fourth coal corresponds to J seam at Quintette and seams A and B at the Bullmoose South Fork deposit or only to a lower coal interval that is identified at the Monkman deposit and further south. If Carmichael is correct, the isopach should not extend so far north.



Figure 8. Isopach of "Fourth Coal" after Kalkreuth and Leckie (1989).

The extent of the "Fourth coal" is economically significant as a potential CBM resource in the subsurface and a marketable coking coal in the coalfield.

COALBED METHANE AREA OF INTEREST

The CBM area of interest in the Peace District has been very broadly defined in Figure 3 of the Ministry's publication Coalbed Methane in B.C. Further definition is obtainable by using isopach data, separating potential according to Formation and utilizing depth to Formation data from oil and gas databases, such as ACCUMAP. The next step might be plots of methane capacity as has been done for Gates coal in the Hinton, Alberta area (Dawson and Kalkreuth, 1994).

The intersection of the 2000 metre contour with coal isopach trends identifies the areas of interest for the Gething and Gates Formation. The 2000 metre line marks depth from surface to the formation top (from ACCUMAP). Two thousand metres is a general depth cutoff for CBM production based on reductions of permeability at these depths. The discontinuity of the Gwillim thrust is used in lieu of the contour in part of the area. Contours near the thrust are suspect, as they appear to include intersections in footwall rocks west of the thrust while in fact the CBM resource is upthrown in the hangingwall.

The area of Gething CBM potential is wide and extensive at the level of the Pine River, narrowing southward (Figure 6). Using the same criteria, the CBM potential in the Gates Formation extends from the vicinity of the Sukunka River near Bullmoose Mt. in a southeast direction along the outer foothills to the Alberta border (Figure 7). There is an area in which good potential for Gates and Gething coalbed methane overlap (Figure 9). This is the area from Bullmoose Mt. to Murray River.

HYDROGEOLOGY

High coalbed methane production is favored by artesian overpressure while hydrocarbon overpressure suggests low permeability. Therefore it is important to distinguish basin areas of artesian and hydrocarbon pressuring (Scott



Figure 9. Area in outer foothills with CBM potential in both Gates and Gething Formation coals.

and Kaiser 1996). Hydrocarbon underpressures prevail at the deformation front in Alberta and they suggest insulation of these areas from recharge by the foothills (Karsten and Bachu (2001).

The gas-producing areas within the Alberta deep basin generally show which areas are subject to hydrocarbon pressures. The gas line, distinguishing up dip water from down dip gas for the Gething Formation, is plotted from Smith, Zorn and Sneider (1984) in Figure 6. This line extends to the

vicinity of Chetwynd and lies within the depth limit of CBM. The gas line probably extends to the Gwillim thrust or its lateral equivalents. To the north there is recharge between the foothills to the subsurface Gething Formation. Subsurface gravity flow of these waters southward into the deeper part of the foreland basin may be impeded by deep basin gas. This is a “no-flow” boundary (see discussion below in the context of an exploration model).

Most of the area identified as a CBM resource area for Gates and Gething coal probably lies within the area of possible artesian overpressures. West of the Gwillim thrust local-scale compartmentalised flow systems are expected in fold structures, with water and gas flow as described by Dawson (2000).

ONE POSSIBLE INTEGRATED MODEL

Tyler *et al.* (2000) developed a general CBM exploration model based on the San Juan, Sand Wash and Piceane basins in the United States. Their model is adapted in Figure 10 and discussed in terms of known data on coal geology, thickness, facies and hydrology in the Peace District.

Tyler *et al.* (ibid) argue favorable conditions for the development of CBM include:

1. Thick laterally continuous coals of high thermal maturity;
2. basinward flow of ground water through coals toward perpendicularly oriented no flow boundaries, such as structural hingelines, faults, facies changes, and discharge areas.
3. generation of secondary biogenic gas; and
4. conventional and hydrodynamic trapping of gas along no-flow boundaries.

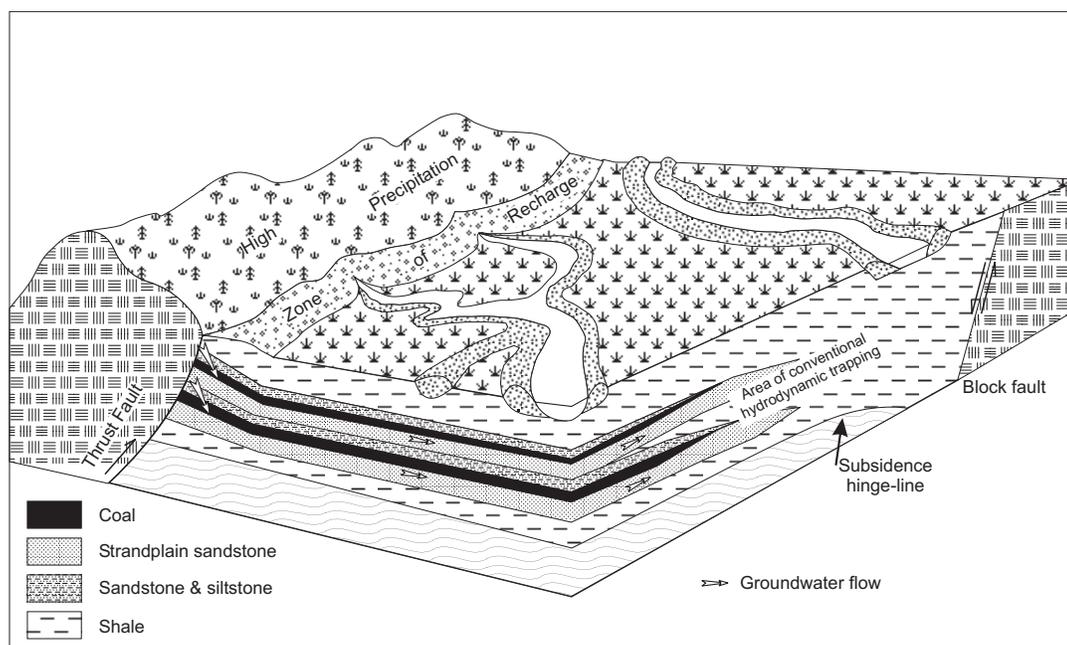


Figure 10. Exploration model showing favorable conditions for the development of CBM in a basin. Adapted from Tyler *et al.* (2000).

The Peace River Coalfield has some of these features:

Condition 1: All coal seams of the Gething and Gates Formation are thermally mature (at least high volatile A) and have moderate to high gas contents of 10-20 cc/g. Coal continuity is very good in the Gates, good in the Chamberlain member of the Gething, and upper part of the Gaylard. The occasional seam in the lower Gaylard is laterally continuous over a coal property.

Condition 2: Basinward flow of groundwater through coal aquifers is uncertain due to very limited data on coal permeability in the Western Canada sedimentary basin. Dawson (2000) suggests permeability averages less than 5 millidarcies and is often less than 0.1 md. Ryan (2000) suggested very low permeability in drilling at Philips Flatbed where Gates Formation coal was intersected in the 1150 to 1550 m depth range. By comparison permeability of the productive San Juan basin is 25md. Finding favorable permeability trends may be the principal challenge in Peace District CBM development.

Wyman (1984) found poor permeability in the “Fourth coal” of the Alberta deep basin, but the sample was derived at an abnormal depth for CBM (>2500 metres). He suggested it might be possible to mitigate poor permeability in coal by tapping an adjacent gas reservoir in permeable conglomerate. His model suggested half the methane content of the coal could be recovered over a period of ten years. In this scenario CBM is produced as an extension to a conventional gas play. Would this model work if there was water or water/gas filled porosity in the permeable sandstone? This is not clear.

Boundaries of “no-flow” perpendicular to presumed regional flow are present in facies changes: shale-outs at the seaward edge of Gates Formation and Chamberlain member “barrier bar” deltas. A structural hinge line at the latitude of Bullmoose Mountain controls the shale-outs. The north-east-trending hinge line marks greater subsidence and marine conditions to the north. However, regional gravity flow in aquifers may be south following the plunge of the major structure, the Alberta syncline. Gravity flow of water from the Sukunka and Murray foothill areas may migrate away from the facies transitions. There are a number of small fold structures west of the Gwillim thrust, some may plunge north and provide for gravity flow to “no-flow” facies traps and seals.

Kalkreuth and McMechan (1988) suggest late north-side up movement on a fault block is responsible for reduced burial and rapid decrease in coal reflectance values north of Chetwynd. The limits of the Alberta deep basin gas near Chetwynd may be related to this structural imprint. As previously mentioned, southward discharge of meteoric waters may be impeded by low permeability deep basin gas. Therefore, this is a “no-flow” boundary of exploration interest.

Condition 3: The writer is not aware of any data indicating generation of biogenic gas in the coals of the Peace District.

Condition 4: Conventional and hydrodynamic trapping of gas along no-flow boundaries may develop in the Chamberlain deltaic wedge. Gibson (1992) notes the Chamberlain sandstones are porous and if the coals have some permeability there may be coalbed methane gas trapped against the Moosevale shale aquitard, which overlies coal seams such as the Bird.

A promising variation on this play occurs where coals are overlain or adjacent to permeable conglomerates. Conglomerates occur at the top of coal measures, in particular the Gaylard (Kilby, 1983), and the upper Gates Formation (Carmichael, 1988). In the latter case Carmichael (1988) has suggested some formed in estuaries where original fluvial deposits were redistributed by marine currents during marine transgression. The association of these conglomerates with coals below shale may facilitate general aquifer permeability and hydrodynamic trapping of gas.

CONCLUSIONS

CBM exploration is at an early stage in northeast British Columbia and requires a further integration of data from coal, petroleum and hydrogeologic datasets. Coal thickness trends, rank and depth to resource suggest the outer foothills between Sukunka and Murray Rivers are particularly prospective due to tiered potential from both Gething and Gates formation coals. It is expected exploration work will develop once the permeability themes relevant to the Peace District are identified.

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