# POTENTIAL COALBED GAS RESOURCE IN THE HUDSON'S HOPE AREA OF NORTHEAST BRITISH COLUMBIA

**Barry Ryan[1], Randy Karst[2], George Owsiacki[3] and Garry Payie[3]**

## ABSTRACT

The Gething Formation, which underlies an area around Hudson's Hope, east of the disturbed belt in northeast British Columbia, is perspective for coal bed gas (CBG or CBM). The formation has experienced little deformation and contains cumulative coal thicknesses that range up to 17 metres . Coal rank is generally higher than high-volatile A bituminous. North and south of Hudson's Hope the formation dips moderately to the east and it is generally too deep for CBM exploration. However in the vicinity of Hudson's Hope dips are less and a substantial area is prospective for CBM. This study estimates a potential resource of up to 25 tcf in the area and concentrations in places of more than 10 bcf/section.

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## INTRODUCTION

The Gething Formation, which underlies an area around Hudson's Hope in northeast British Columbia, is prospective for coal bed gas (CBG or coalbed methane, CBM) for a number of reasons. The formation in the area contains a number of thin seams, that when thicknesses are cumulated, provide a total thickness that averages about 8 metres with values ranging up to 17 metres in some areas. The area is east of the edge of the disturbed belt and has experienced little deformation. Coal rank varies but in much of the area is higher than high-volatile A bituminous (mean maximum reflectance Rmax values greater than 0.8%). The combination of depth, cumulative coal thickness and rank mean that a substantial coalbed gas resource may exist in the area.

Many regional maps contain a line marking the boundary between the Western Canadian Sedimentary Basin and the "disturbed belt " or "deformation front", which marks the eastward extent of the Rocky Mountain Foothills (Figure 1). In reality the degree of deformation increases gradually towards the west and a single line on a map can be very deceptive in terms of defining areas of increased CBM potential. This is very much the case in the Hudson's Hope-Chetwynd area. However for convenience the area of the Gething Formation discussed here is defined by the edge of the disturbed belt (if some what arbitrarily defined) and in part by the Peace River Arch as outlined by Marchioni and Kalkreuth (1992). The Arch was an area of increased subsidence and deposition in Manville (Lower Cretaceous) times that resulted in a weakly defined thickening of the Gething Formation trending northeast along the trace of the Arch. The Arch is also overlain by thicker deposits of the Upper Manville, which explains a trend towards higher rank in the Gething Formation in the area. The edge of the disturbed belt, which trends northwest from the Alberta border to Chetwynd, deflects more to a northerly trend at about the location where it abuts the Peace River Arch.

In the battle of units it seems that a compromise may be developing in the world of CBM in Canada. Depths and coal thicknesses are usually given in metres; gas contents may be in cc/g or cubic metres/tonne or scf/t, however gas resource numbers are more often given in imperial units of bcf/section and tcf. A tcf =28.32 billion cubic metres and 1 cc/g = 32.037 scf /ton. Converting any resource, in the area discussed here, into a reserve depends on the degree of gas saturation of the coals, the ability to extract gas over intermediate distances through thin seams and on the composition of the gas. A previous resource assessment of the area (Smith *et al.,* 1991) estimated a resource in the Gething Formation of 34.9 tcf to a depth of 1800 metres. The area they studied included part of the disturbed belt, which is not included in this study.

A number of companies have acquired oil and gas exploration rights in the area and Figure 2 illustrates the land position as of August 2004. Companies have drilled at least 8 holes in the area and there has been limited test production from 2 holes.

## COAL RESOURCE DATABASE

The 121 holes utilized in this study are located east of the disturbed belt (Figure 3). Coal intercepts in the Gething Formation were picked using a combination of density, caliper and gamma logs that are available from the Ministry of Energy and Mines in Victoria. The

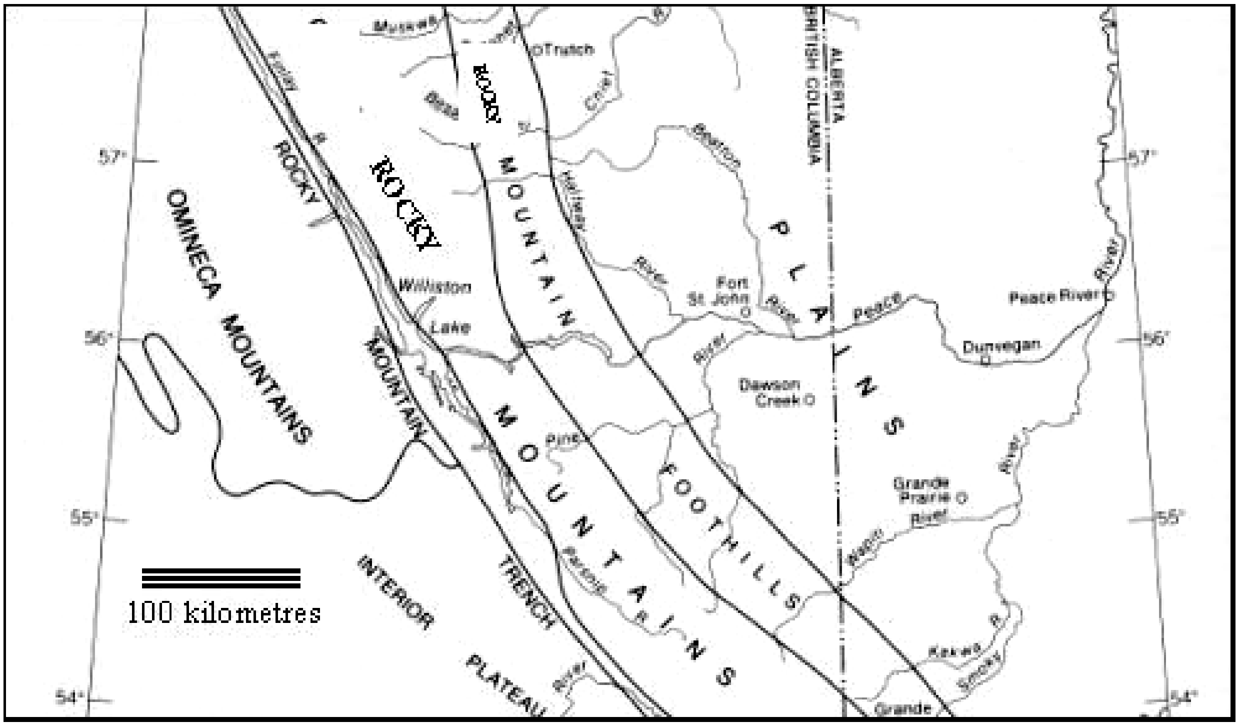



Figure 1. Physiographic divisions NE BC from Stott (1982).

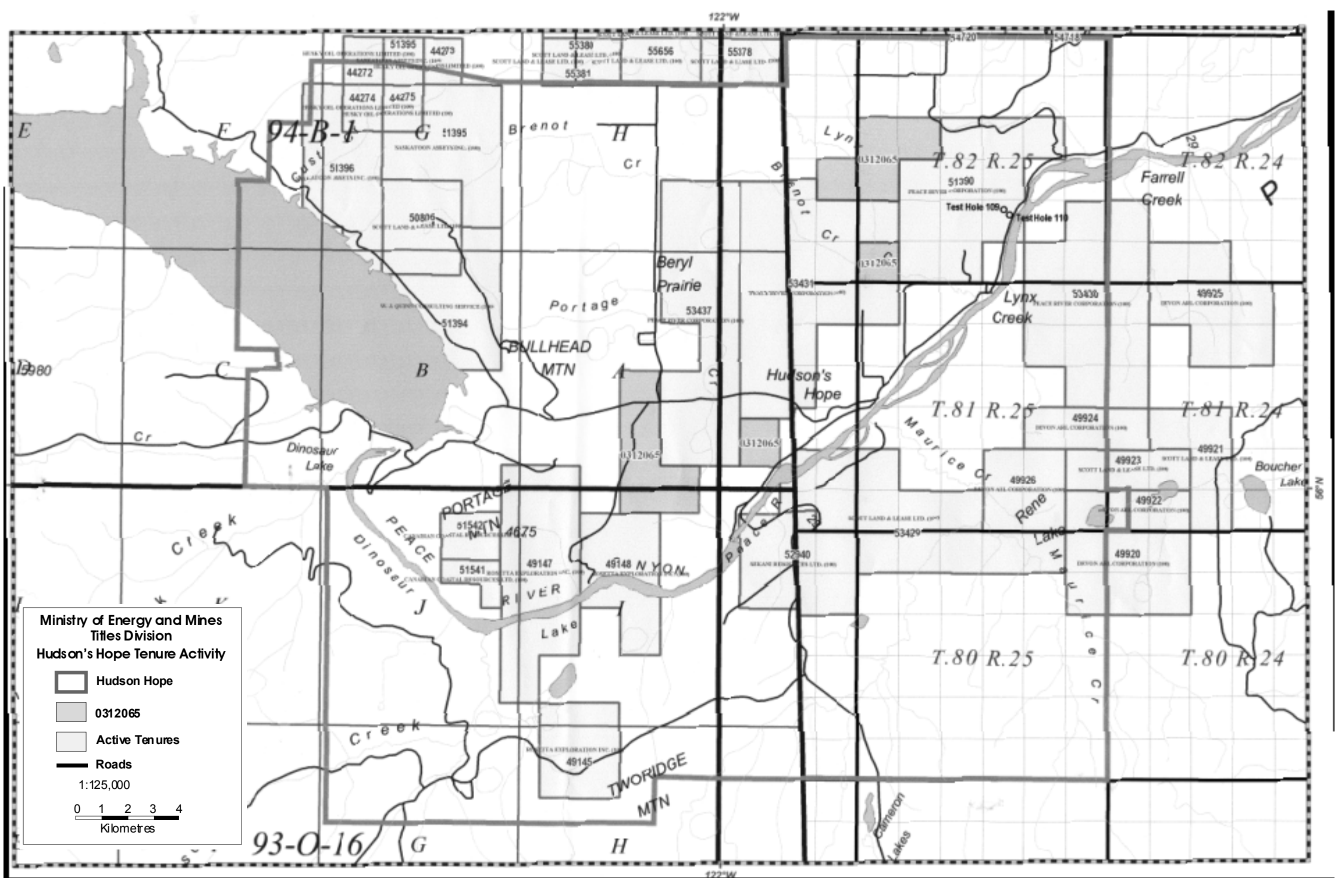



Figure 2. Coalbed gas tenures NE BC as of August 2004.

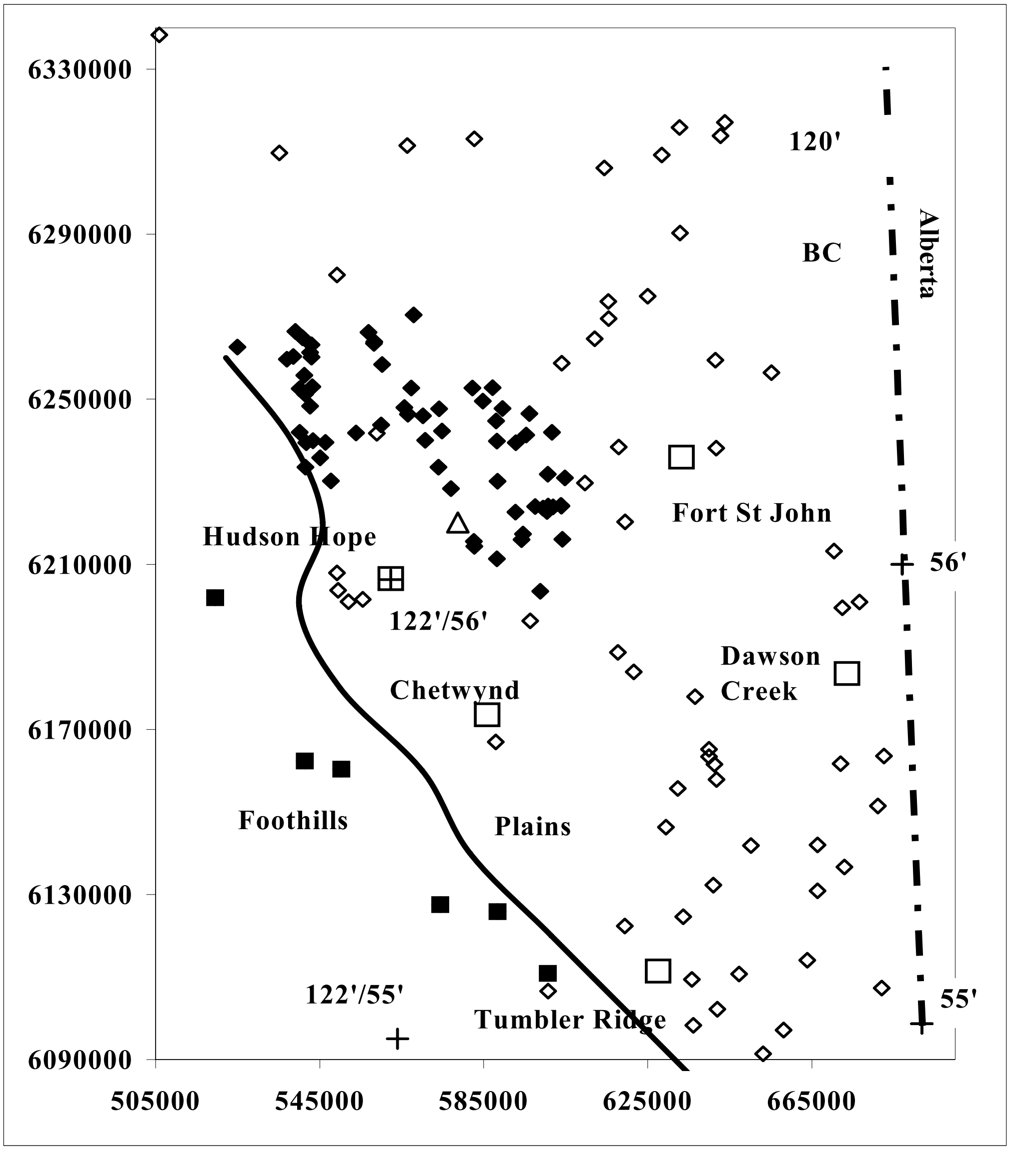



Figure 3. Map of holes used in the study. Black diamonds represent holes for which logs were picked in this study open diamond represent holes for which logs were picked in previous unpublished study. Solid squares are coal properties where coal thicknesses were estimated. The location of Dension hole 80-1 is indicated by a triangle.

resolution of oil and gas logs is marginal for picking thin coal seams because the detector-source spacing and travel rate for the tool do not allow good definition of the thickness or density of thin seams (Figure 4). Longer spaced detector-source spacing tends to result in an over estimation of seam thickness with an over estimation of ash content. There may also be an asymmetrical effect that smears the hanging wall signal based on logging speed (Figure 4). If seam thickness is over estimated and this is accompanied by an over estimate of seam density, then the estimation of the amount of carbon in the section will not be affected as much as might be expected and consequently errors in estimating the CBM resource will be minimized.

The database generated from the 121 holes includes hole location, collar elevation and the depth to formation tops. Data for the Gething Formation includes depth, thickness and ash code (3 low to 1 high) of all seams. All data were krieged and gridded using Surfer software® in such a way that grid nodes overlap and can be manipulated to produce computed node values. At each node the average depth of the coal section and average Mean maximum reflectance (Rmax%) values were used in conjunction with the cumulative coal thickness to calculate a potential gas content using the Ryan Equation (Ryan, 1992). Rmax values were derived from Marchioni, and Kalkrueth (1992) who provide values for the top and bottom of the Gething and their data were re-digitized. Individual ash contents were not incorporated into the calculation and average values were assumed for all seams.

An excel spreadsheet capable of handling up to 5 grid matrixes, each with 5500 nodes, was used to manipulate

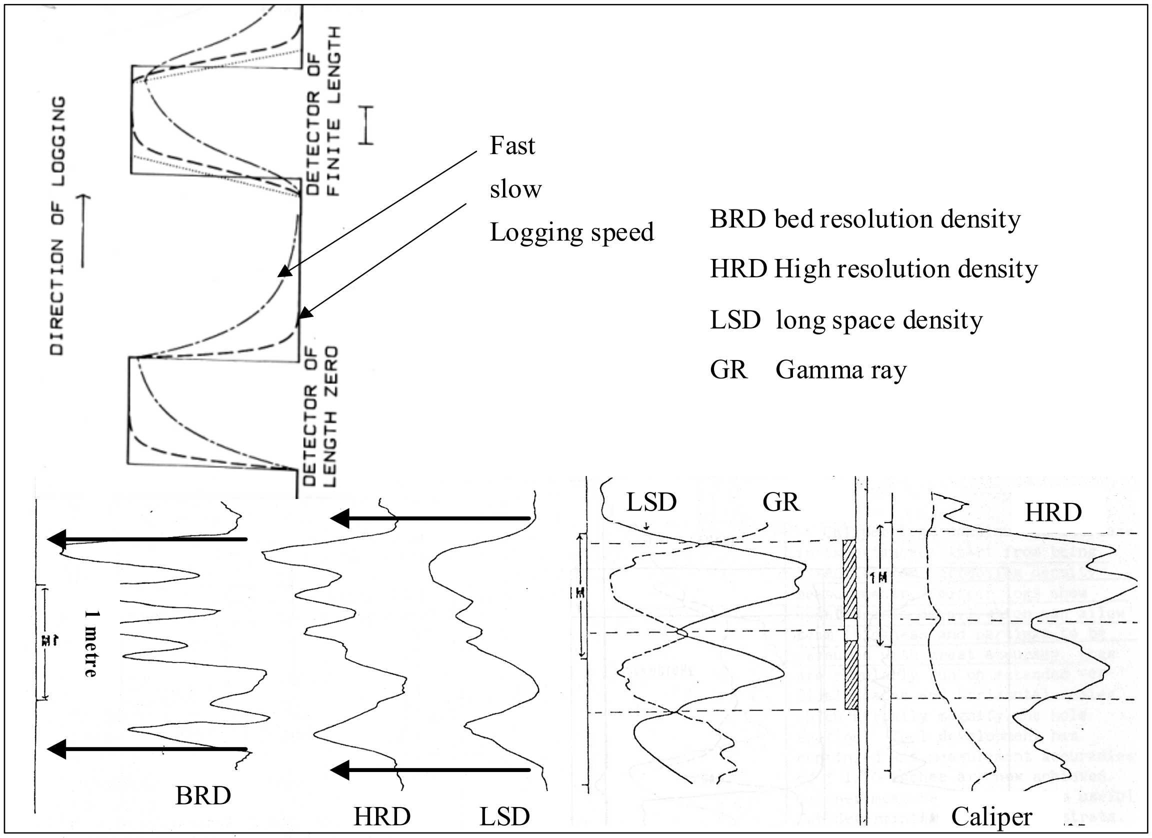



Figure 4. Schematic for log resolution.

the data. The spreadsheet applies conditions to resource calculations and generates derived grid matrixes for contouring in surfer. Grid nodes west of the disturbed belt were blanked and do not add to the resource calculation.

Any calculation of resource is based on an assumption of what seams may be able to hold under depth and rank conditions and must therefore be considered an estimate of maximum potential resource. The Ryan equation provides estimates of maximum potential gas content based on rank, ash content and depth. The equation works for ranks greater than Rmax 0.7% and tends to under predict for ranks above 1.5%. Ranks in the area range from Rmax=0.80% to 1.63% and Figure 5 illustrates the range of gas contents predicted by the Ryan Equation.

A sample of Gething coal from a hole drilled in the Hudson's Hope area was provided for isotherm analysis (Table 1, Figure 6). The sample has an Rmax value of 1.21% and is composed of 50% reactives, 45% inerts and 5% mineral matter by volume (Figure 7). The data (Figure 6) is plotted on an as received basis and for comparison purposes the predicted curve using the Ryan Equation is also plotted. It is apparent that for a rank of 1.21% and the Gething sample, the equation estimates adsorption capacity quite well but tends to over estimate at shallow depths. This may bias the resource estimates discussed below. The sample depth is about 750 metres and the isotherm was run at a temperature of 25ºC. Some geothermal gradient data for the area is available (Ryan and Richardson, 2004) and values for NE BC average about 27ºC /kilometer with a surface temperature of 5ºC; based on a depth of about 750 metres the average temperature should be in the range of 26ºC.

The CBM resource is calculated using the cumulate coal thickness assigned a single depth that is the mid depth of the coal bearing section at that location. The average ash contents used (20% and 30%) are conservative and depth cutoffs are set so that no resource is calculated above a depth of 100 metres (plus depth to mid point of the coal bearing section at that location) and below depths ranging from 800 to 1400 metres (Table 2). A more detailed calculation could apply the Ryan equation to each individual seam with individual estimates of ash content. The process may appear to provide a more precise number but with uncertainties about degree of coal saturation it is unlikely that the result would be any more useful.

There are very limited public desorption data available for coals in the area. However in 1980 Utah Mines explored the Bri-Dowling Property, which is centered on the Dowling and Gething creeks below the Bennet Dam and did some desorption tests on coal core samples (Duncan, 1980). The data indicate that Gething seams may be close to saturated with gas contents that range up to 20 cc/g at 500 metres (Figure 8). It is difficult to determine the calculation basis for the data from the report, but it may be air-dried. The average ash content of seams is 14 % based on analyses in the coal assessment report (Duncan, 1980). This value in conjunction with a

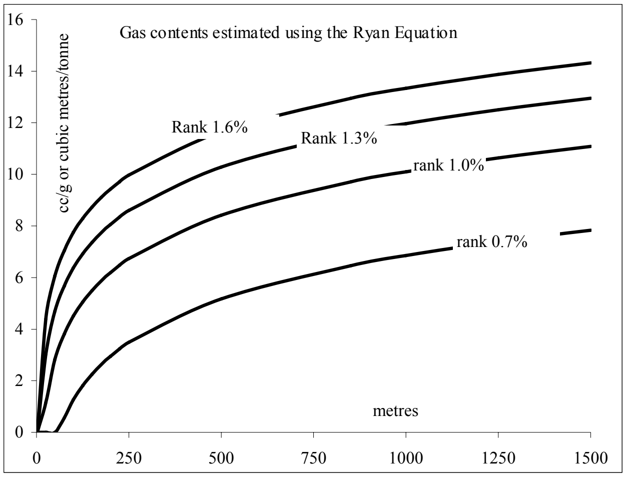



Figure 5. Ryan Equation curves for ranks Rmax=0.7 to 1.6% and 30% ash content.

rank of 1.2% is used to construct the approximated isotherm in Figure 8, which also includes the desorbed gas contents. Samples were probably desorbed at room temperature, which is similar to formation temperature at about 500 metres.

**TABLE 1. ISOTHERM DATA FOR GETHING FORMATION COAL FROM DRILL HOLE HUDSON'S HOPE AREA.**

| | | | |
|---|---|---|---|
| | temperature | | 25ºC |
| | ash% | | 2.9 |
| | Eqmoisture% | | 2.93 |
| | SG | | 1.388 |
| | Rmax% | | 1.21 |
| | Lang Vol AR cc/g | | 38.47 |
| | Lang P Mpa | | 2.09 |
| depth M | MPa | AR | DAF |
| 35 | 0.339 | 1.64 | 1.74 |
| 62 | 0.61 | 3.23 | 3.43 |
| 105 | 1.03 | 5 | 5.3 |
| 158 | 1.549 | 6.59 | 7 |
| 208 | 2.036 | 7.75 | 8.23 |
| 262 | 2.573 | 8.78 | 9.32 |
| 327 | 3.205 | 9.8 | 10.4 |
| 401 | 3.936 | 10.78 | 11.45 |
| 521 | 5.107 | 12.05 | 12.79 |
| 661 | 6.488 | 13.29 | 14.11 |
| 806 | 7.901 | 14.27 | 15.16 |
| 955 | 9.364 | 15.14 | 16.07 |
| 1114 | 10.925 | 15.81 | 16.79 |
| 1349 | 13.234 | 16.15 | 17.15 |

The total desorbed gas contents include estimates of the residual gas contents, which were obtained using the degree of fragmentation of samples (a plot is provided in the report). For "blocky" coals the estimated residual gas content was up to 60% of the lost plus desorbed gas content. The desorption data tabulated in the report for the sample with the highest gas content (hole BC80-19, depth 459.03 metres, Titan seam) is plotted in Figure 9 in conjunction with the total gas reported after addition of the residual gas. Based on the shape of the desorption curve, the estimate of residual gas used in the report is high and this throws into question the validity of the data. When the desorption data is replotted minus the estimated residual gas components, (solid diamonds in Figure 8) the gas contents are reduced but still seem to indicate that at about 400 metres coals were close to saturated. The sorption time constant for the desorption curve is about 25 hours, which indicates moderately fast diffusion from the sample.

## REGIONAL STRATIGRAPHY

The Gething Formation underlies a large area of the Peace River Coalfields in BC and of the Western Canadian Sedimentary Basin east of the disturbed belt (Table 3). The formation is well exposed near Williston Dam and a number of authors have described sections (Stott, 1973, 1982; Legun, 1990; Gibson, 1992). Stott (1973) provides a number of columnar sections, which provide an average thickness for the Gething in the Peace River Canyon of about 500 metres. The formation maintains thicknesses in excess of 500 metres in the area from Williston Dam south to Chetwynd. On the south shore of Williston Lake at Carbon Creek the formation attains a thickness of 1067 metres (Cowely, 1982). The formation gets progressively thinner to the southeast in the Peace River Coalfield and is only 10 metres thick under the Saxon Property near the Alberta border.

As a result of numerous coal exploration programs, the cumulative thickness of coal in the formation is well documented within the Peace River Coalfield. Probably the maximum amount of coal occurs in the Pine River area where cumulative coal thickness is about 20 metres. North of the Pine River the formation thickens, there are numerous seams in the formation and cumulative coal thicknesses are up to 14 metres (Stott, 1973). In the Carbon Creek area there are at least 12 seams more than 1.5 metre thick and over 50 seams have been identified (Northeast Coal Study, 1977). Adjacent to the Bennet Dam on the Bri-Dowling property (Duncan, 1980) the formation is 475 metres thick and contains 4 seams that have mineable thicknesses (greater than 1.5 metres) and many seams thinner than 1.5 metres (Northeast Coal Study, 1977).

## COAL QUALITY AND REFLECTANCE DATA

There are a number of exploration properties in the disturbed belt that extend from Carbon Creek west of the Bennet Dam in the north to Sukunka (near Sukunka

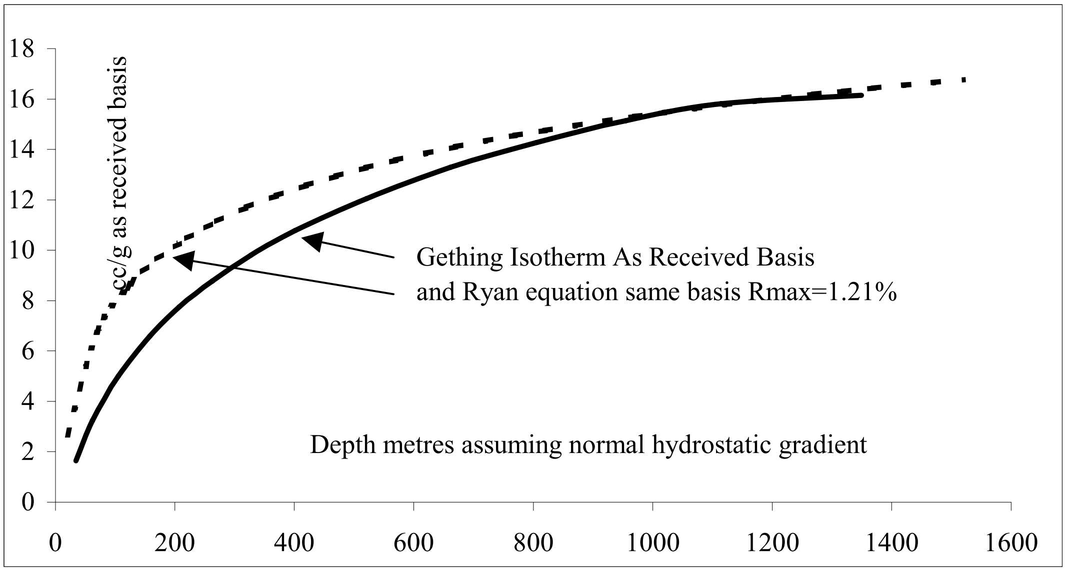
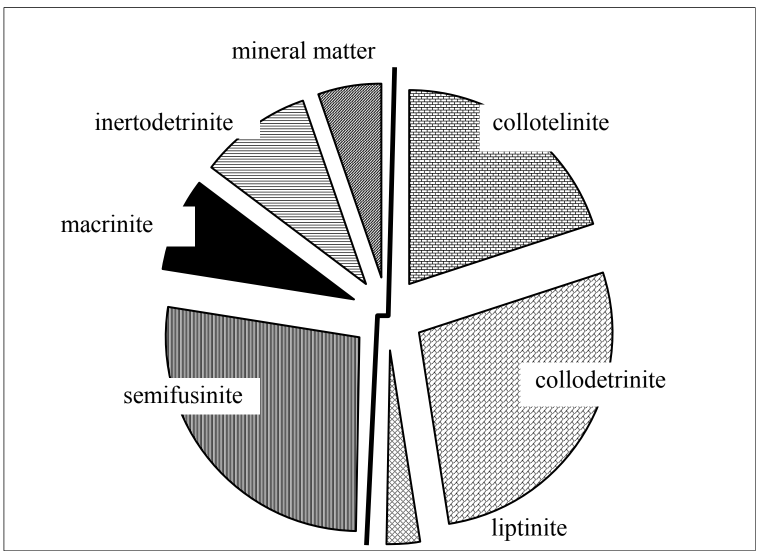



Figure 6. Isotherm Gething Formation coal Hudson's Hope area.




Rrand = 1.145% (SD=0.005). Calculated RmeanMax 1.21%.

Figure 7. Petrography of Gething Formation isotherm sample.

**TABLE 2. ESTIMATED POTENTIAL RESOURCE IN THE GETHING FORMATION EAST OF THE DISTURBED BELT.**

| minimum depth 100 metres | | depth to top Gething Formation metres | | | |
|---|---|---|---|---|---|
| | ash | 800 | 1000 | 1200 | 1400 |
| | % | tcf | tcf | tcf | tcf |
| total area | 30 | 24 | 35.1 | 41.6 | 44 |
| | 20 | 25.9 | 37.9 | 44.9 | 47.4 |
| Hudson Hope | 30 | 16.8 | 25.3 | 28.7 | 28.8 |
| | 20 | 18.1 | 27.4 | 31 | 31.1 |

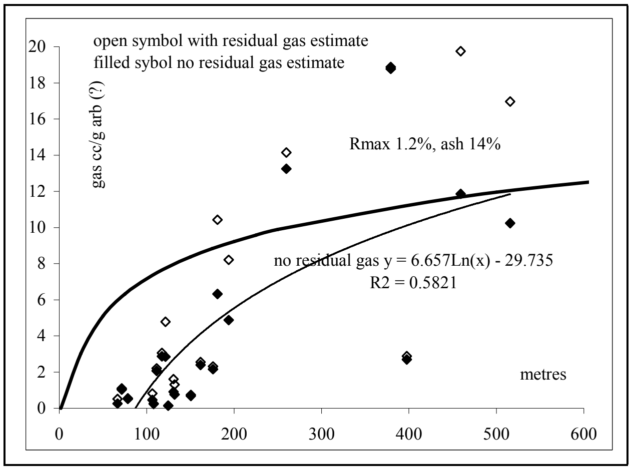



Figure 8. Desorbed gas contents for coals from the Bri-Dowling Property.

River) in the south. These properties provide coal quality information for the western edge of the area of interest. Data from these reports was discussed by Ryan (1997). Coal in the formation is often characterized by low raw ash contents and variable inertinite maceral contents. Other than rank data there is very little quality information on Gething coals at depth to the east.

Data from the Carbon Creek property (Cowley, 1982) indicate that the insitu ash content for thicker seams averages 12.6% and the seams are high-volatile A bituminous in rank. Raw ash contents from exploration holes on the Bri-Dowling property average 13.6% and the rank based on proximate analyses is on the border between high-volatile A bituminous and medium-volatile bituminous. Raw ash contents for 7 seams in the coal section at Willow Creek (Pine Valley Coal Mine) ranges from 7.9 to 14.5 % with no specific trend up section. Rank on the Burnt River property is higher (low-volatile bituminous to semi anthracite) but the average ash contents of the three major seams are still low (7.2% to 10.5%). The Sukunka property was explored extensively as a potential underground coking coal mine. The two major Gething seams in the area are medium-volatile bituminous in rank and average less than 10% raw ash.

Gething Formation seams can contain moderate proportion of inert coal macerals and this can influence the adsorption ability of the coal. Ryan and Lane (2002) discuss the adsorption capacity of Gething coal from the Willow Creek Property where the coal is low-volatile bituminous. Lamberson and Bustin (1993) studied adsorption characteristics of Gates Formation coals with ranks 1.02% to 1.14% in northeast BC (Table 3). The formation overlies the Gething Formation and the rank is similar the rank of the Gething Formation in the Hudson's Hope area. Both papers indicate that adsorption capacity tends to decrease as the inertinite content in coal increases. The effect is greater for low rank coals than high rank coals (Figure 10). In fact based on data from Lamberson and Bustin (1993) the adsorption capacity of high-volatile coals may decrease by 4.3 cc/g as the vitrinite content decreases from 80% to 40% (mmfb) at a depth of about 500 metres. The effect appears to be much less as rank increases and for low- volatile Gething coals the decrease is only 1.4 cc/g for the same change in petrography.

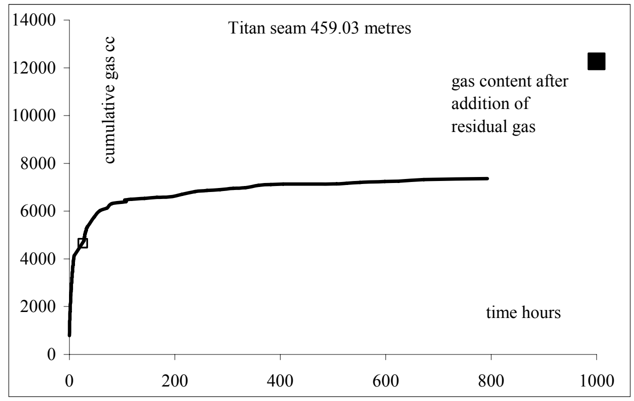



Figure 9. Plot of desorption data from Bri-Dowling hole BC80-19 depth 459 .03; Titan seam.

When coal core or chip samples are recovered there is a tendency to loose the vitrinite component of the coal. Consequently, based on the lower adsorption ability of inertinite macerals the gas content and adsorption capacity of the seam will be underestimated. This will make it difficult to determine the true level of saturation of coal seams at depth. The problem will be exasperated by the difficulty of getting good coal recovery from thin seams.

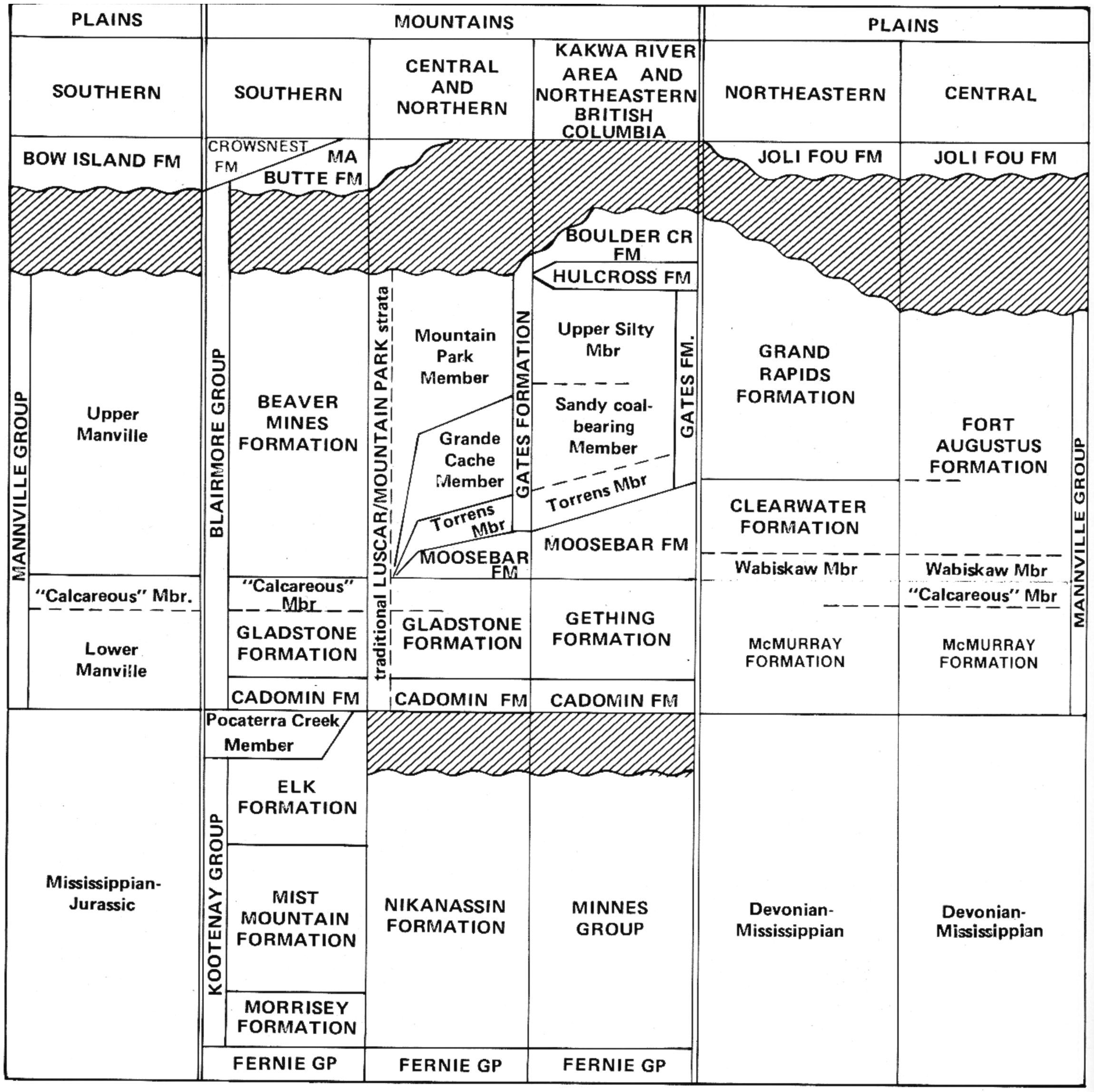
One of the earliest studies of the rank of seams in the Peace River area was by Karst and White (1979). More recent studies (Marchioni and Kalkrueth, 1992) provide mean-maximum reflectance (Rmax%) values for the top and bottom of the Gething Formation (Figure 11). The rank of the Gething is variable with a number of high rank areas within the disturbed belt. East of the disturbed belt the rank decreases but in the Hudson's Hope area is generally above a reflectance of 1.0%.

Samples from a hole drilled in 1980 by Denison (Figure 3, triangle) are analyzed for petrography and rank. The top of the Gething in the hole occurs at a depth of 313 metres and samples were collected from depths ranging from 313 metres to 461 metres. Rmax values range from 0.81% to 1.21% over a depth range of 313 to 461 metres. The depth range is limited and there is a lot of scatter in the data but it appears that the coalification gradient was quite low. Marchioni and Kalkrueth, (1992) indicate that coalification gradients increase to the west where there are areas of increased rank in the Gething Formation.

## OUTCROP OBSERVATIONS

There are good outcrops of the Gething Formation around the Bennet Dam and in the Peace River Canyon below the dam (Photo 1). The lithology and stratigraphy of these outcrops were studied in detail by a number of authors who generally did not record orientations of cleats in seams or of joints in surrounding lithologies. This type of information is critical for a CBM assessment because of its impact on permeability. In this study a number of

**TABLE 3. REGIONAL STRATIGRAPHY FOR CRETACEOUS ROCKS PEACE RIVER COALFIELD.**




***From Horachek, (1985)***

outcrops were studied on the road to the Bennet Dam and in the Peace River Canyon below the dam (Figure 12). There are numerous thin (<1.5 metres thick) seams in the section. Seams are not sheared and there is an absence of conjugate shear joints forming acute angles to bedding.

Cleats are well-developed in seams with two orthogonal sets present in most outcrops. They are perpendicular to seam contacts and surfaces are generally clean and not coated by any cementing minerals. It is possible to differentiate through-going face cleats from butt cleats that are truncated by face cleats. Cleat spacing is dependent in large part on coal petrography. Dull bands presumably rich in inert macerals have wider spaced cleats than bright (vitrinite rich?) bands. In bright bands, cleat spacing on face cleats is about 1 cm and for butt cleats is about 5 cm (Photo 2). Dull bands tend to occur toward the top of seams indicating a regressive depositional environment (Banerjee and Kalkrueth, 2002).

Joints in hanging wall and footwall rocks are generally, but not always, parallel cleats in seams. The joint frequency is always less than cleat frequency in seams and varies based on lithology. Seams are frequently overlain by up to 2 metres of brown mudstone with a few centimetres of material with bedding fissility adjacent to the seam. Joints in this material are widely spaced and often through-going joints are more than 1 meter apart. Sandier units include planar-bedded sandstone, which may have well-developed widely spaced joints. Sandstone channel lithologies are usually not well jointed, probably because cross-bed surfaces provide planes to accommodate any tensional stresses in the rock. Footwall lithologies are more often sandstone or siltstone than mudstone.

Gething Formation Low-volatile bituminous

Gates Formation medium-volatile bituminous

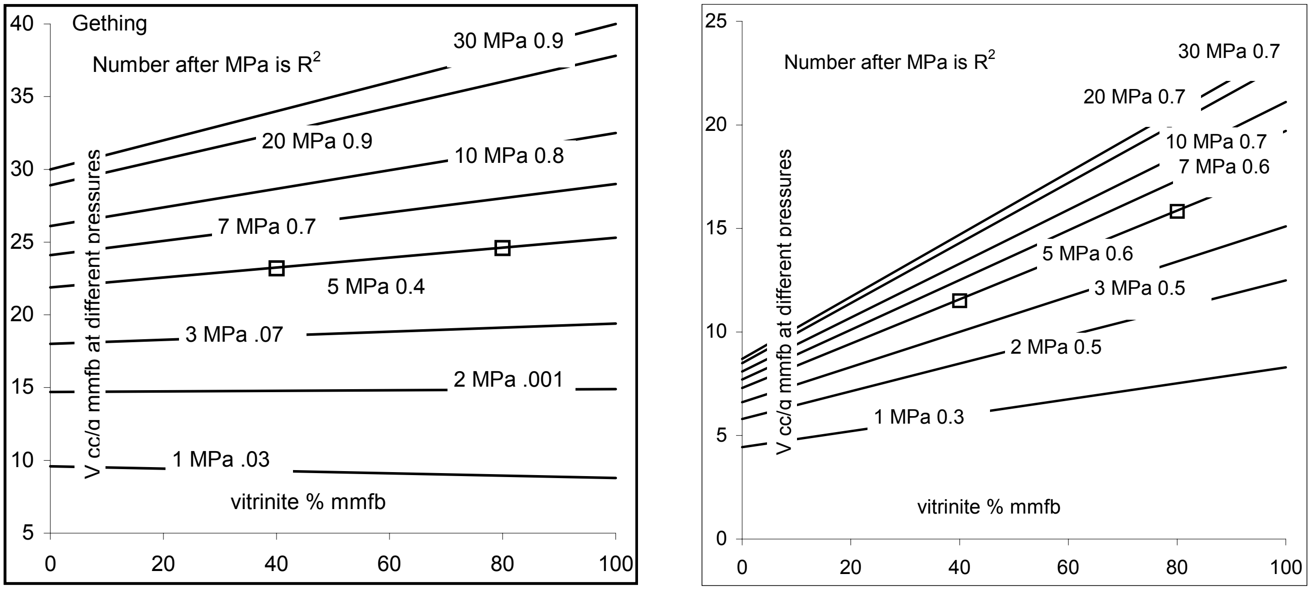



Figure 10. Adsorption capacity *versus* vitrinite content for low-volatile Gething Formation and high–volatile Gates Formation coals. Data from Ryan and Lane (2002) and Lamberson and Bustin (1993).

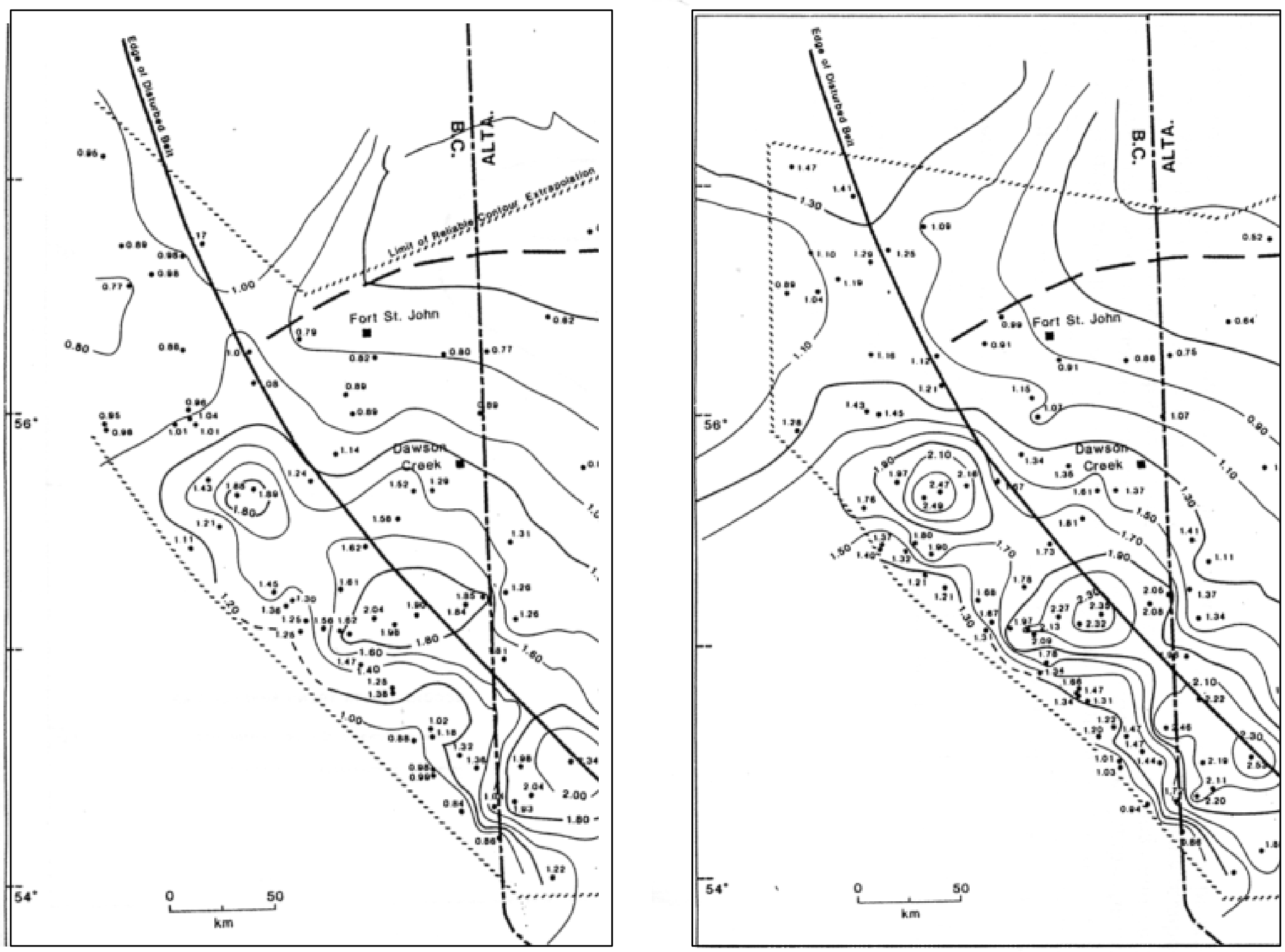



Figure 11. Mean maximum reflectance contours for the top and bottom of the Gething Formation from Marchioni and Kalkrueth (1992)

Photo 1. Outcrop of the Gething Formation below the Bennet Dam

Kilby and Oppelt (1984) examined 16 cores from holes in the Peace River area, mainly below the Bennet Dam. They subjected the lithology descriptions to various numeric analytical techniques including a matrix analysis indicating the probability of what lithologies would overlie each other. They found that coal was frequently overlain by sandstone with mudstone flasers (0.89 correlation) or mudstone with sandstone lenses (0.81). Coal was underlain by sandstone with mudstone, siltstone interbeds (0.71)

## STRUCTURAL INTERPRETATION

On the regional scale the fold trends in the Peace River Coalfield trend at about 42º west of north up to a latitude of about 56°, at which point they deflect to a more northerly trend of 12º to 30º west of north (Legun, 2003). The change in direction occurs in the area where the Peace River Arch intersects the Rocky Mountain Foothills. Face cleats are perpendicular to the fold axis direction characteristic of the southern part of the fold belt. Butt cleats are normal to face cleats and bedding (Figure 13). Langenberg (1990) also found that face cleats in the Rocky Mountain Front Ranges are oriented northeast southwest and are therefore perpendicular to the fold axis trends.

Cleats and fractures were observed in two properties (Willow Creek and Sukunka) in the northern part of the Peace River coalfield within the disturbed belt (Figure 14). At both properties there are low angle conjugate shear fractures in seams and cleats normal to bedding tend to parallel axial planes of the regional folds. Obvious extensional cleats normal to the fold axis trend were not observed.

Areas where fold-trends change orientation are often areas where there is enhanced cleat development and improved permeability (Ayers, 2002). In the area around the Bennet Dam there is no indication of multiple cleat sets. Changes in cleat orientation in the sub surface east of the Bennet dam where outcrop is sparse could be important in terms of permeability. FMI logs are powerful tools in determining fracture geometry but it is difficult to identify spacing and orientation of vertical cleats or fractures. If the technology can be adapted to inclined holes the amount of structural information collected would increase considerably. There are a number of graphic techniques for deciphering structural data from inclined drill holes.

During the Cretaceous, the Peace River Arch was an area of increased deposition, yet at present the Pre Cambrian basement in the area is elevated and depth to the Gething Formation decreases over the Arch (Figure 15). If there was recent uplift of the Arch this could produce extension and open cleats. Bell (2002) studied the present in situ stress regime in the coal-bearing strata of the northeastern plains area of British Columbia. The minimum horizontal stress direction (Shmin) is oriented northwest southeast in the study area (Figure 16 redrafted from Bell, 2002) and is therefore perpendicular to face cleats. Permeability will be enhanced in a direction northeast southwest and fractures with this orientation will have more chance of being open.

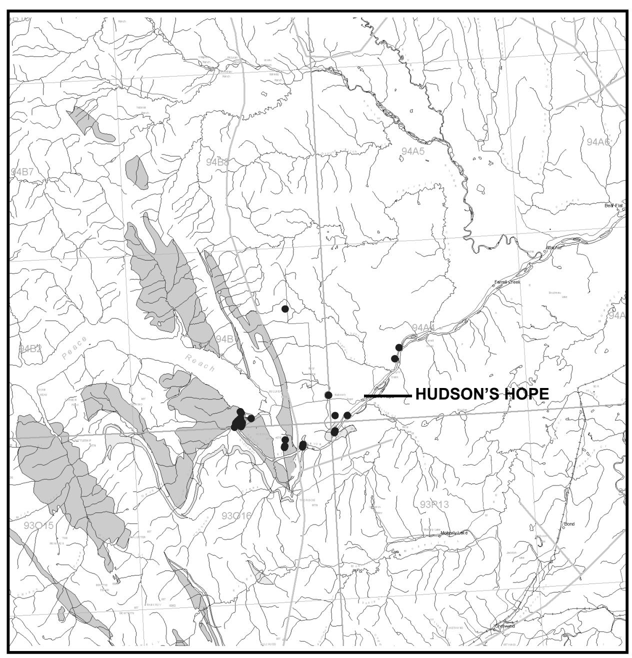



Figure 12. Location of outcrops where cleat measurements were obtained in 2004.

Photo 2. Cleat spacing in vitrain and inertinite rich bands.

The tectonic history of the Cretaceous rocks over the Peace River Arch influences the present stresses in rocks. Increased burial and a thicker sedimentary sequence result in more compaction and a greater vertical stress gradient in Cretaceous rocks. More recent uplift should result in a decrease in magnitude of Shmin over the arch (Figure 16), which appears to be the case, though this is in part related to present depth of burial. There is therefore some evidence that recent uplift along the Arch may have influenced the magnitude though not the direction of the minimum horizontal stress.

Methods of measuring Shmin require opening fractures and measuring closure pressure. Usually measurements will be on pre existing fractures and if cohesion on the fractures is low then at least the local Shmin will be at 90' to orientation of the fractures. As cohesion on the fracture increases the ability of Shmin to rotate away from perpendicular to the fracture increases. In rock with a well-developed system of vertical fractures with low cohesion surfaces present Shmin will be perpendicular to this system. Any other orientation would result in shear movement.

There is a strong log-linear correlation between Shmin and permeability but the relation varies for different coal basins. For example in the Black Warrior Basin a 6 MPa change in Shmin results in a one order of magnitude change in permeability, the same change in permeability in the Bowen Basin (Australia) requires only a 1.5 MPa change in Shmin. (Sparkes *et al*, 1995). Data indicate that Shmin is probably a more important influence on permeability than fracture density (Enever *et al.,* 1994). If vertical stress is constant then closure pressure on a fracture is dependent on Young's Modulus and Poisson's Ratio for the coal. It is obvious that an understanding of the physical properties of the coal in conjunction with values of Shmin may provide some indication of the relative permeability from area to area.

## CBM RESOURCE EAST OF THE DISTURBED BELT IN THE GETHING FORMATION

The potential CBM resource in The Gething Formation is calculated in the area east of the disturbed belt. To the southeast, the margin of the disturbed belt is easily defined by the Gwillum Lake Thrust, east of which the Gething Formation is substantially deeper than to the west above the thrust. To the north in the Hudson's Hope area the transition from un-deformed beds of the Western Canadian Sedimentary Basin to folded beds of the foothills is gradational and not as easily defined.

The area in which the CBM resource is estimated in this paper is confined by the disturbed belt to the west and depth of the Gething to the east. In addition the area is sub divided and the area around Hudson's Hope is analysed in greater detail. The extent of these two areas is indicated in Figure 17 based on a depth to the top of the Gething of greater than 100 metres and less than 1000 metres. The figure indicates the active grid nodes used in the resource evaluation. In the northern area the cell sides are 2 kilometres and in the total area they are 3 kilometres. The areas increase somewhat as the depth cutoff criteria is increased.

A number of parameters were krieged, gridded and contoured for the whole area and for the area around Hudson's Hope**.** They include: depth to the top of the first coal in the Gething; thickness of the coal section in the Gething; cumulative coal in the section; Rmax top of the Gething; Rmax bottom of the Gething. Based on these gridded surfaces a number of values are calculated at each node; average depth of the coal section; average rank; density of the coal based on an ash content of 20% or 30%; potential saturated gas content based on rank and depth; potential resource as bcf/section. Coal density is calculated using an equation (Ryan, 1995) that utilizes estimates of zero-ash coal density, mineral matter density, water content and void porosity volume to determine coal density at varying ash contents.

The formation is at relatively shallow depths in the Hudson's Hope area but is generally deeper to the northwest and southeast (Figure 18). The thickness of the coal section (Figure 19) varies but is generally quite thick when compared to the cumulative coal thickness present (Figure 20). The thickness of the coal section calculated from the 121 logs used in this study compares well with the thickness of the Gething Formation as documented by Gibson (1992) Figure 21. Cumulative coal thickness and thickness of the coal section both tend

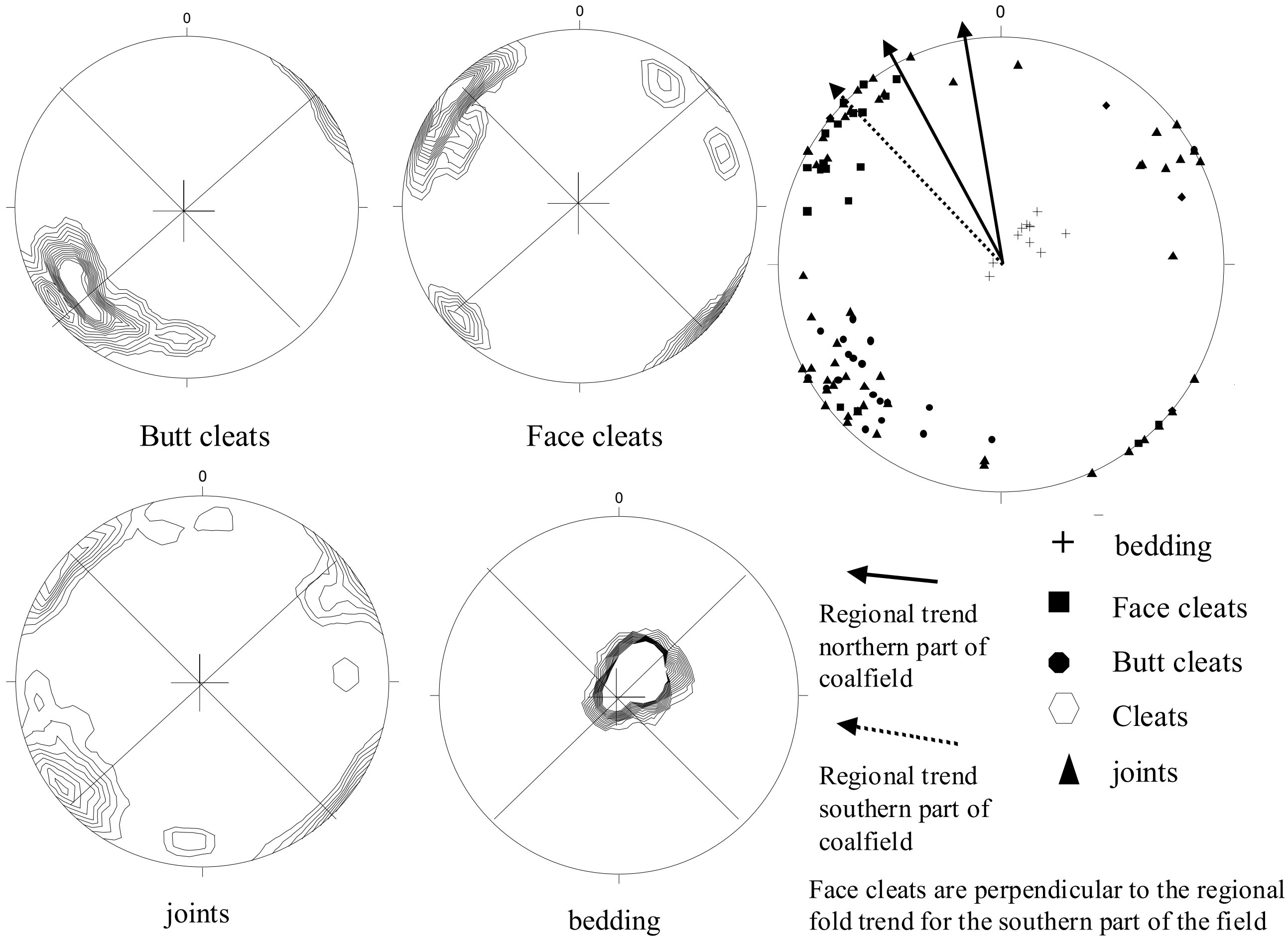



Figure 13. Sterionet plot of poles to bedding, joints and cleats.

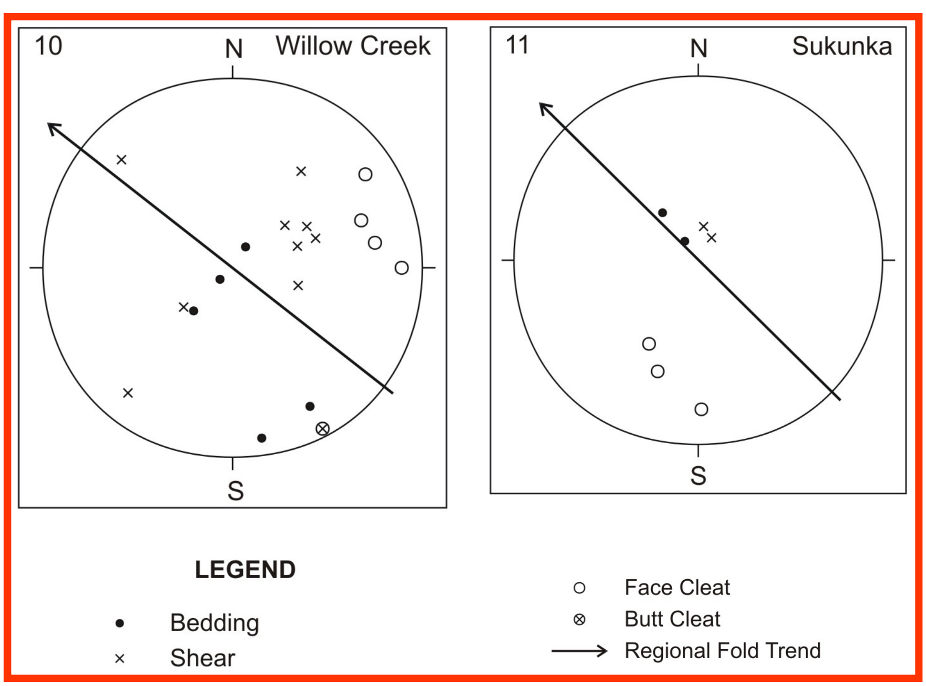



Figure 14. Cleats and fractures in seams at the Willow Creek and Sukunka properties northern Peace River Coal field

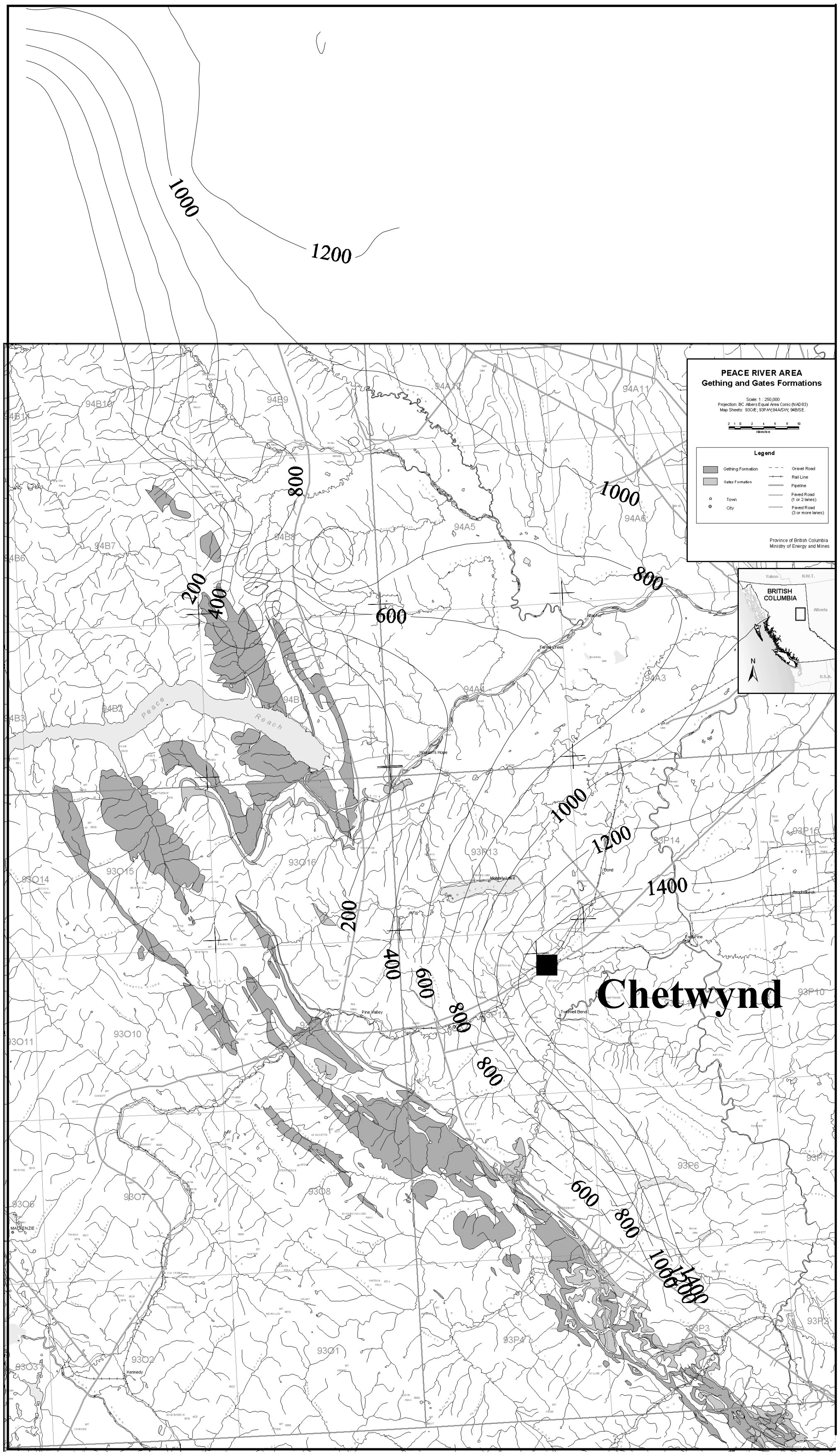


Figure 15. Depth to the top of the coal in the Gething formation.

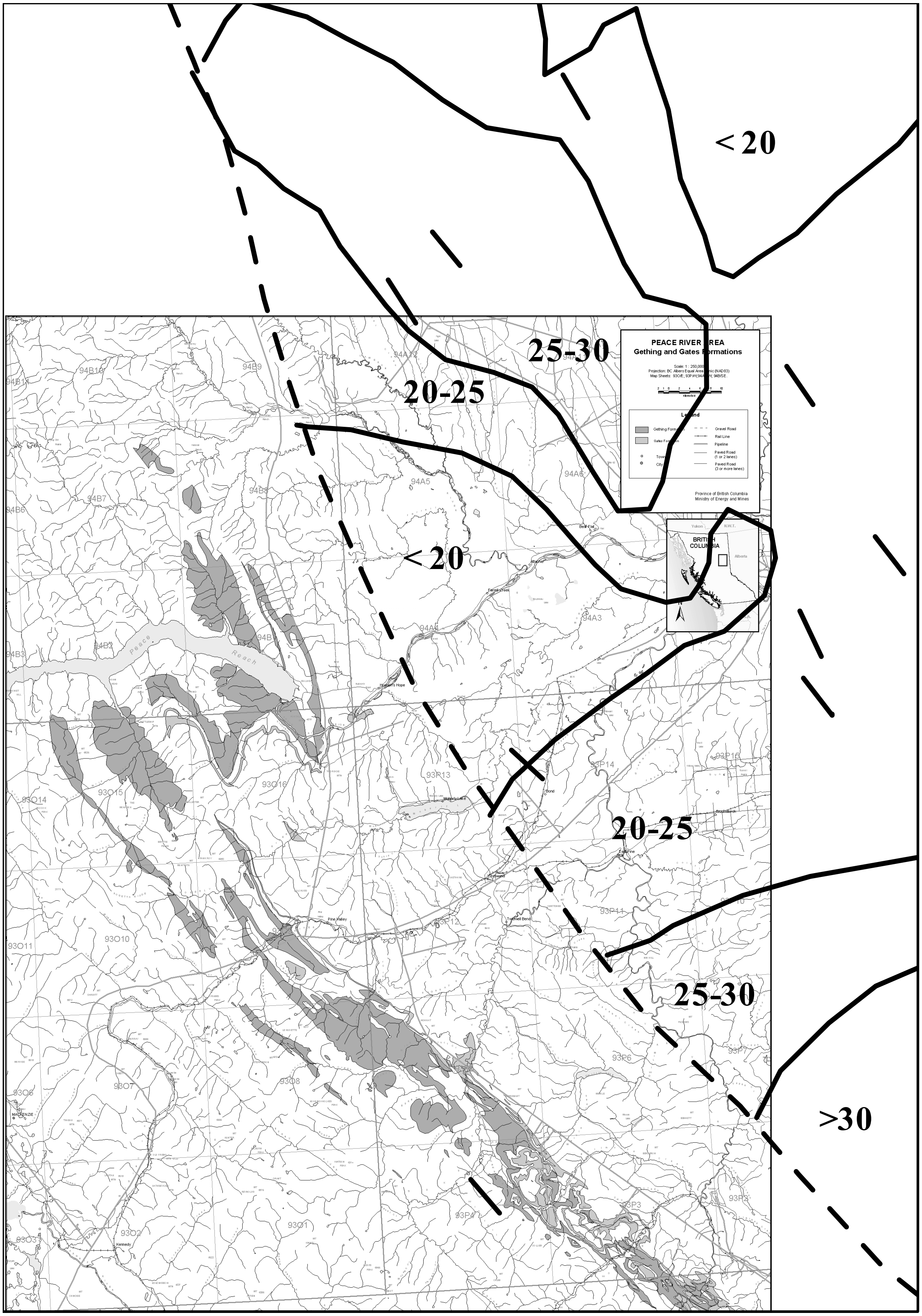



Figure 16. Minimum and maximum horizontal stress directions and magnitude of Shmin (Mpa) at the top of the Bluesky Formation from Bell (2002).

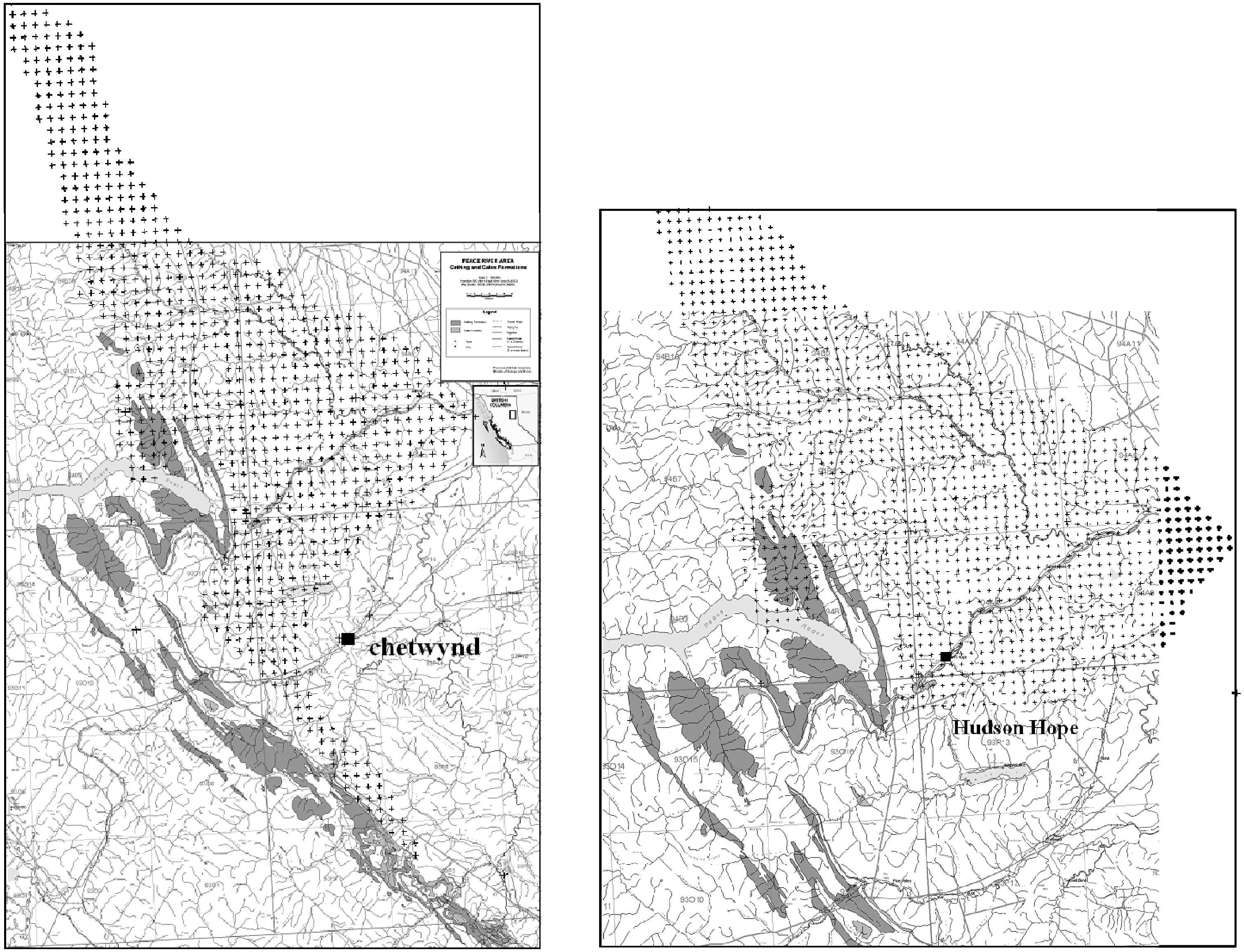



Figure 17. a/ Total resource area defined by deformation front to the west and depth of 1000 metres to the top of the Gething Formation. Area is outlined by active grid nodes on a 3 km by 3 km grid; b/ Sub-area of (a) Hudson Hope area; active grid nodes on a 2 Km by 2 Km grid.

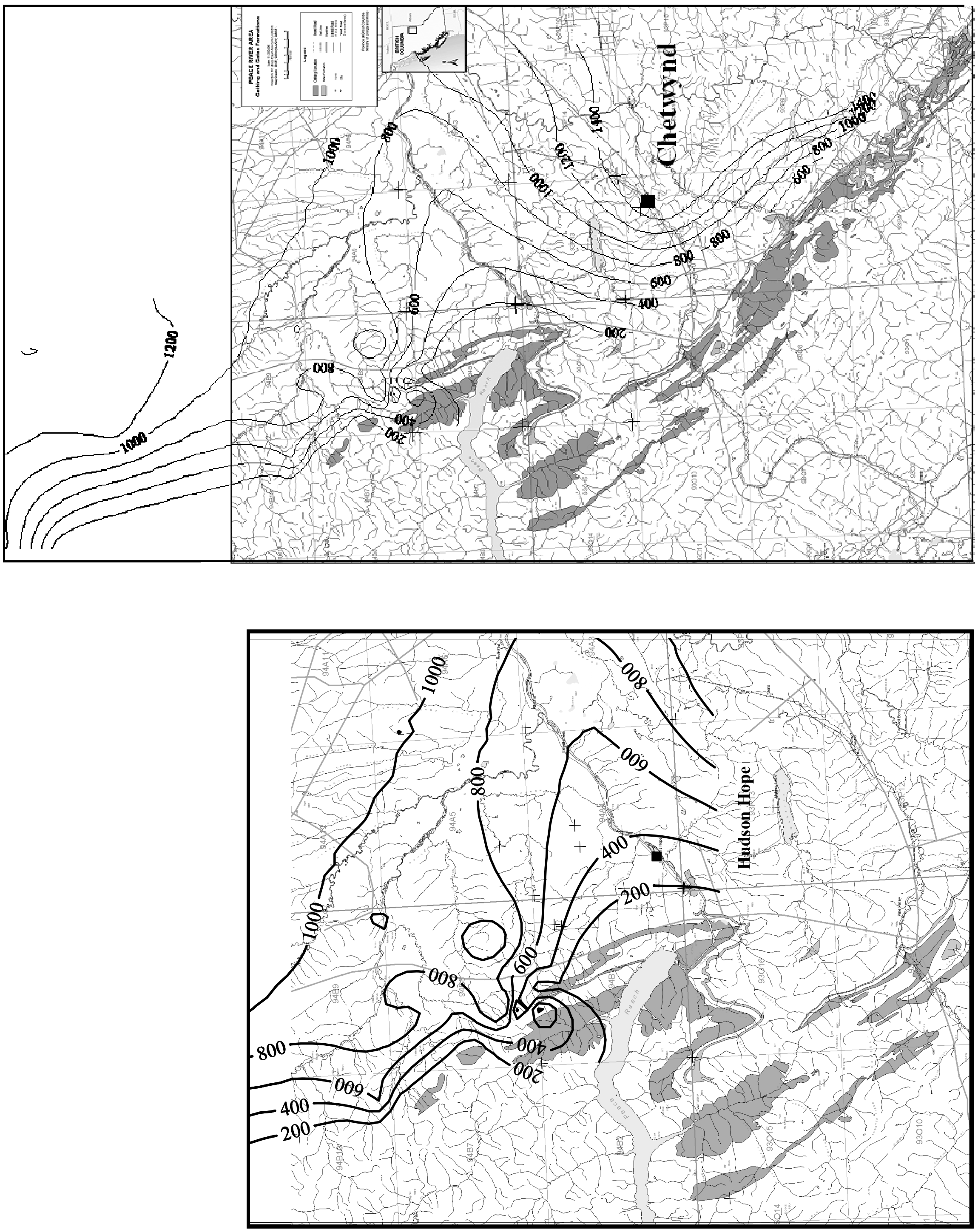



Figure 18. Depth to the first coal in the Gething Formation a/ Hudson Hope area b/ Total area.

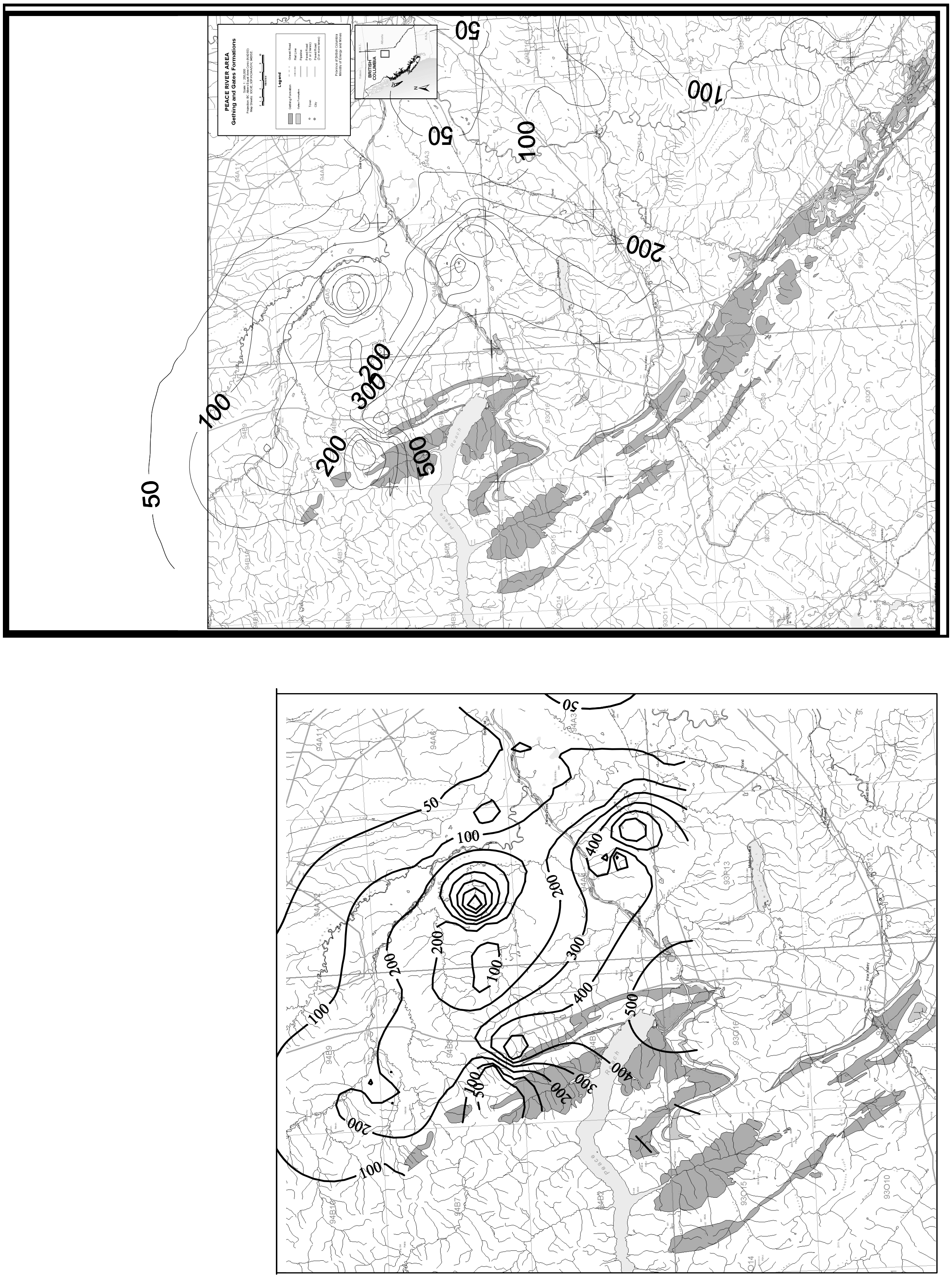



Figure 19. Thickness of coal section in the Gething Formation.

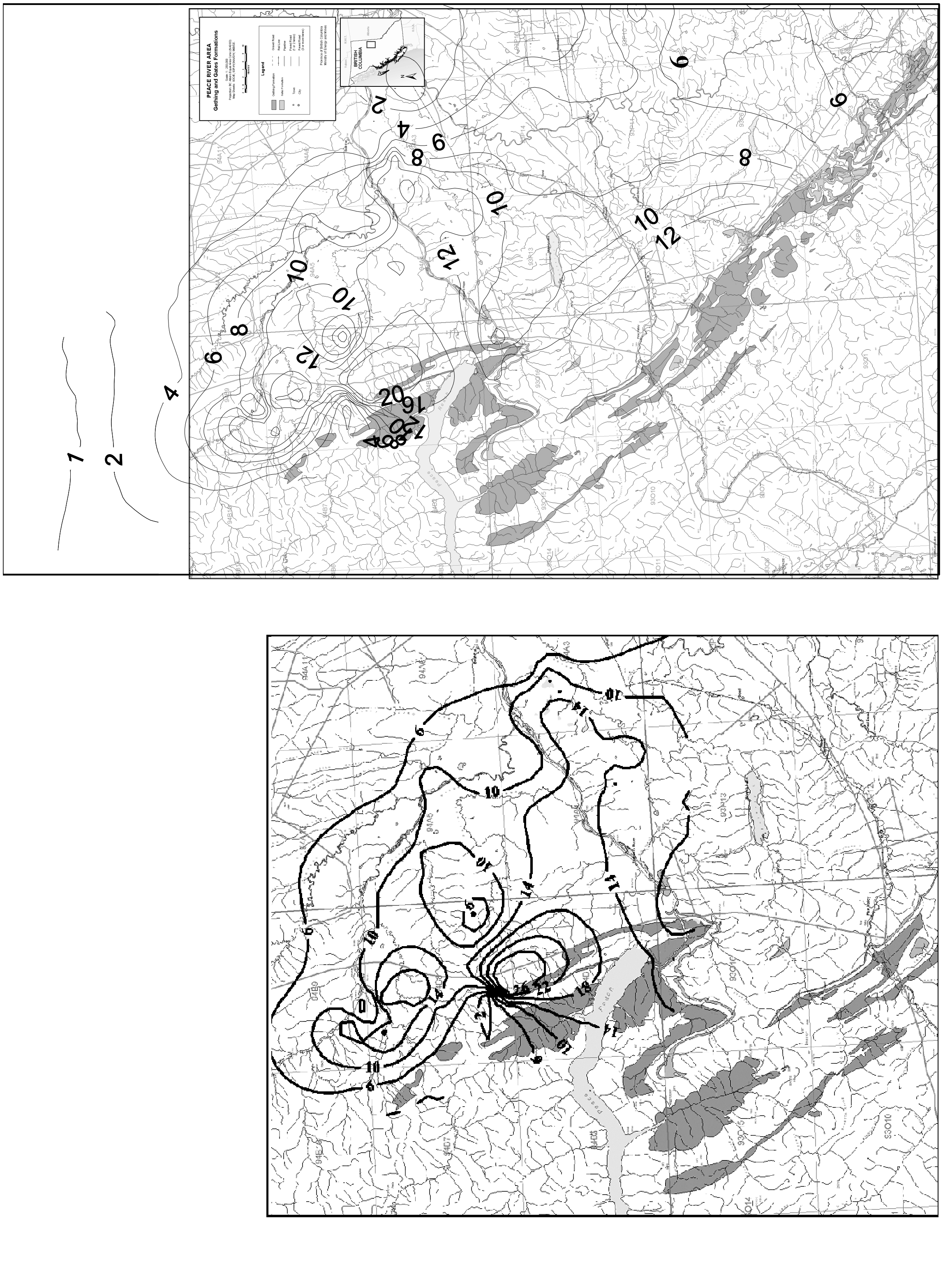


Figure 20. Cumulative coal in the coal section.

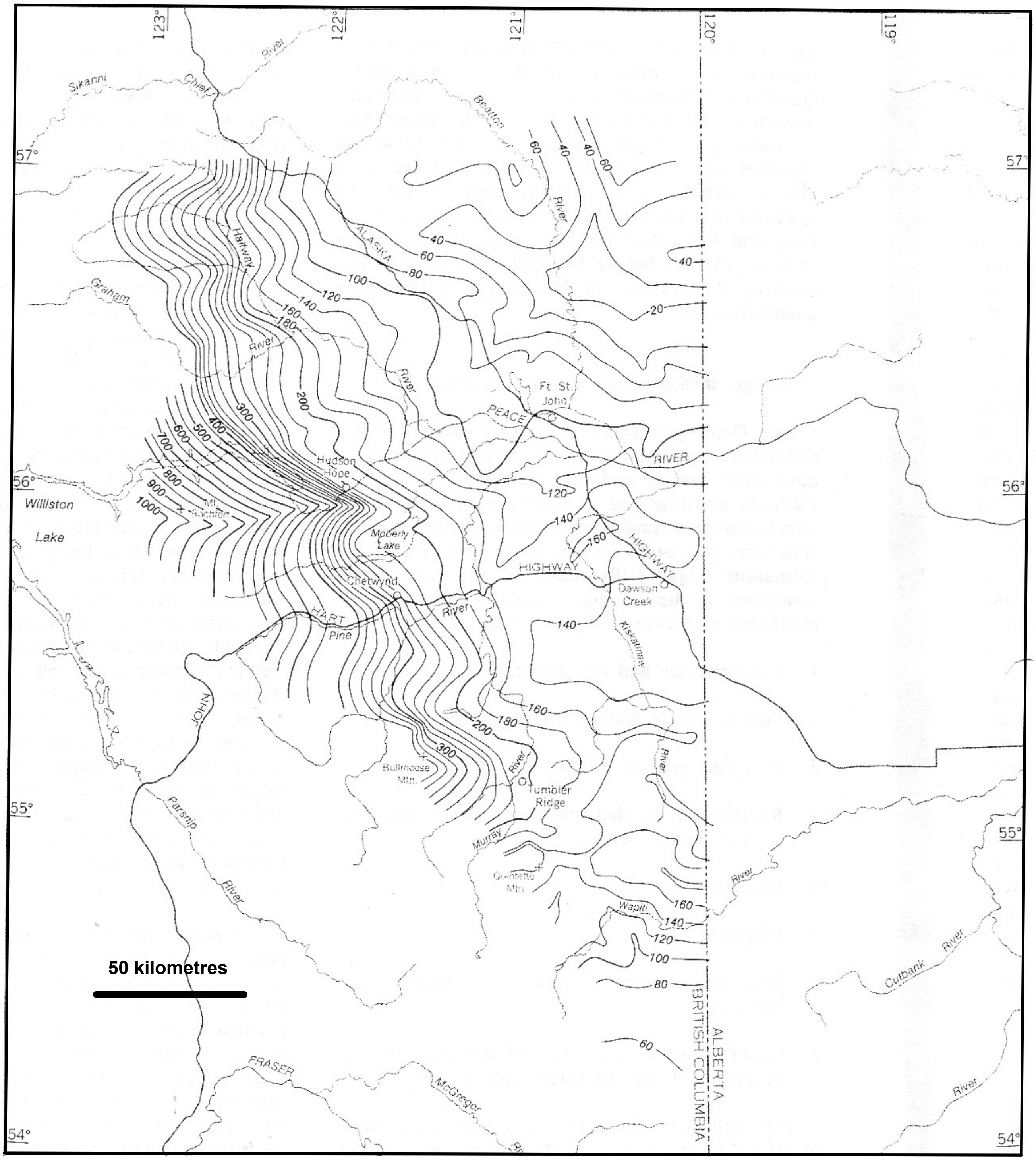



Figure 21. Thickness of the Gething Formation from Gibson (1992).

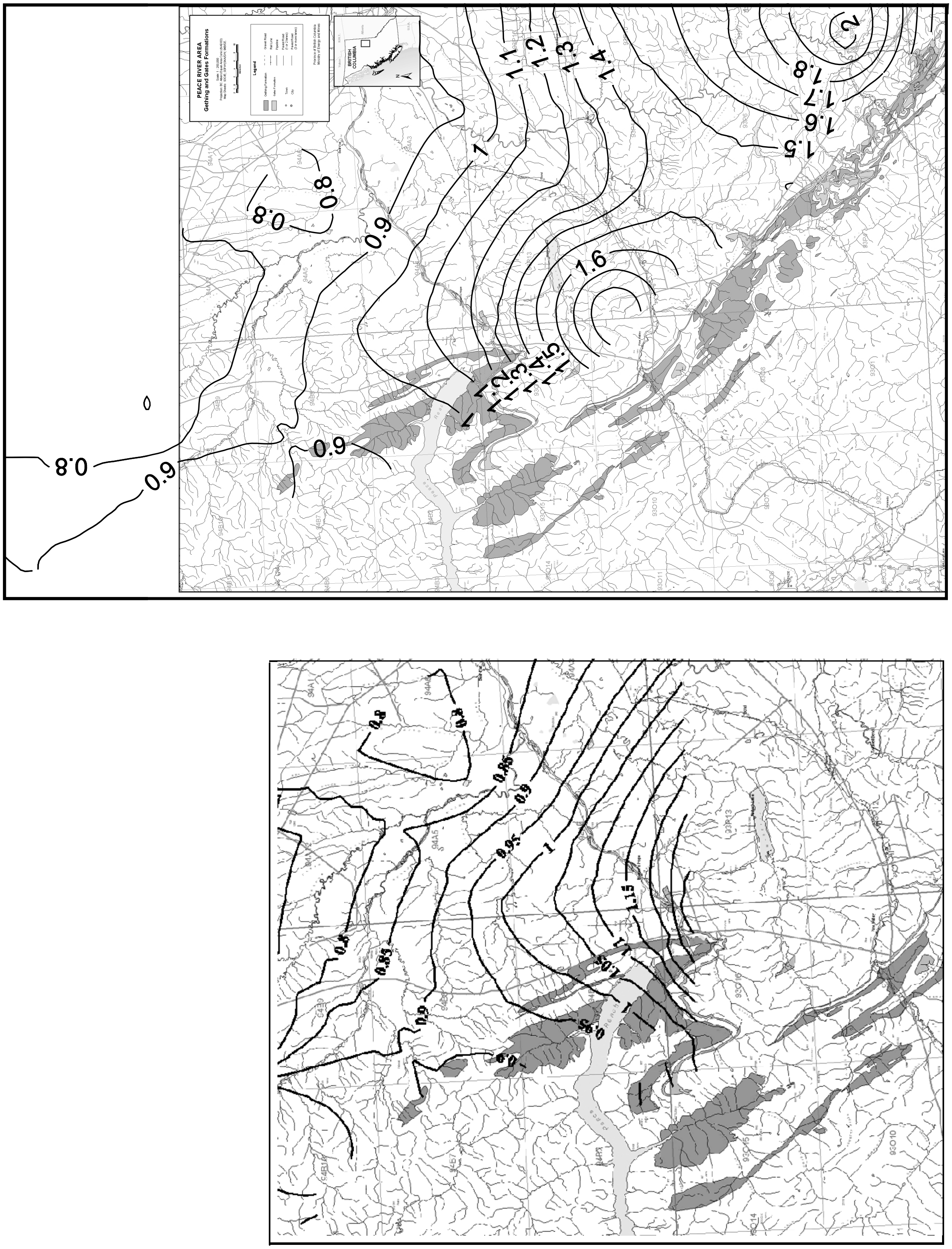
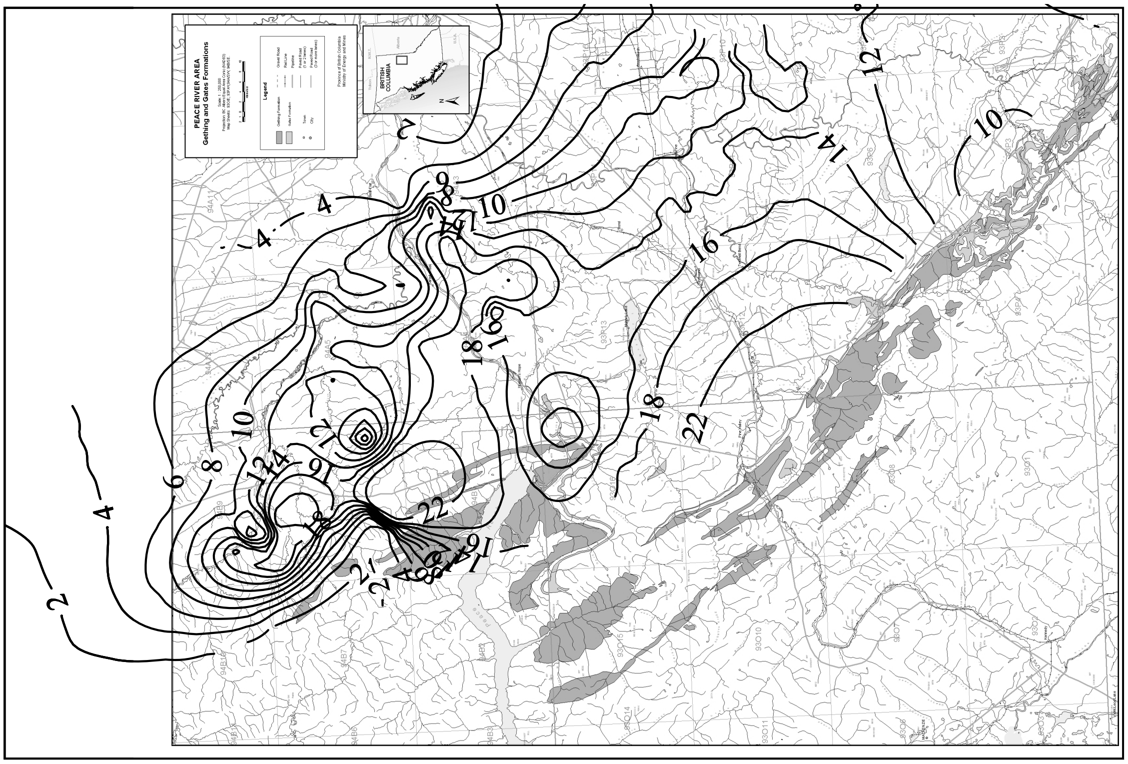


Figure 22. Rmax for the top of the Gething Formation; data derived from Marchioni and Kalkrueth (1992).



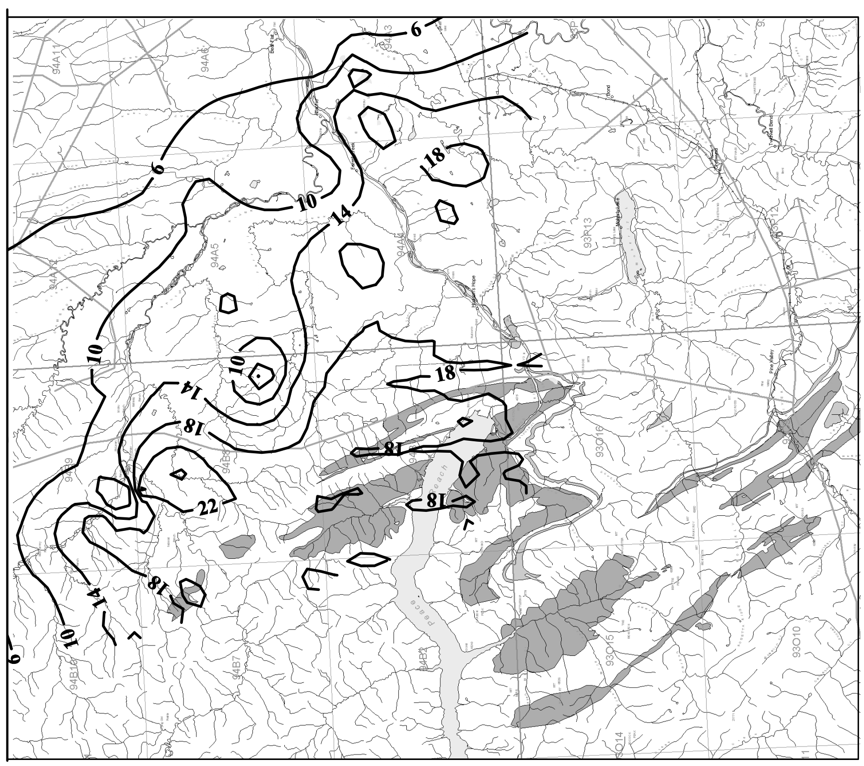


Figure 23. Resource estimate as bcf/section a/ Hudson Hope area and b/ Total area.

to be at a maximum in the Hudson's Hope area decreasing to the northwest and southeast. In the Hudson's Hope area cumulative coal thicknesses are generally over 6 metres and the section thickness over 200 metres. Rank on the top of the Gething Formation is high south of Hudson's Hope but in the area there is little coal in a prospective depth window. Rank decreases to the northeast towards Hudson's Hope but is still in the range of Rmax=1% (Figure 22).

The resource calculated as bcf/section in each cell (cell areas 4 $Km^2$ for Hudson's Hope area and 9 $Km^2$ for total area) (Figures 23) is high south of Hudson's Hope where the rank is high and reaches 22 bcf/section. However the increasing depth of the Gething Formation to the east restricts the total resource available in this area. Most of the area around Hudson's Hope is better than 6 bcf/section and much of it is better than 14 bcf/section.

The potential CBM resource in the Gething Formation in the area east of the disturbed belt from the Alberta Border to north of Hudson's Hope is in the range of 25 to 40 tcf (Table 1). Most of this resource is in the Hudson's Hope area and to the north (17 to 29 tcf). West of the disturbed belt the rank of the formation is variable and high and the potential resource is substantial, however folding limits the area prospective for exploration.

## CONCLUSIONS

There is an enormous volume of coal within the Rocky Mountain fold Belt contained within the Gething and Gates formations and based on rank it probably contains a very large resource of CBM. However initial exploration has indicated that low permeability and deformation may provide challenges to CBM development.

The Gething Formation extends east of the Rocky Mountain Fold Belt. South of the Sukunka River the formation thins and contains less than 10 metres of cumulative coal. In addition the formation is overridden by thrusts and dips steeply into the western Canadian Sedimentary Basin. However to the north the formation is thicker and remains at a shallow depth east of the fold belt. In this area, which is centered on the town of Hudson's Hope, the formation contains from 5 to 20 metres of cumulative coal occurring in a number of thin seams. Rank in the Hudson's Hope area is generally greater than 0.9% decreasing to the north and increasing to the south.

The combination of favourable cumulative coal thickness, depth to coal and rank ensure that there is the potential for good concentrations of gas in the area. In fact most of the Hudson's Hope area has the potential for a resource of greater than 14 bcf per section. Total resource calculations used depth cut offs of 800 1000, 1200 and 1400 metres with average ash contents of 20% and 30%. The potential resource to 1000 metres is estimated to be 27 tcf in the Hudson's Hope area and 38 tcf in the total area, which includes the Hudson's Hope area and extends to the south. It must be emphasized that this is an estimate of the potential resource assuming gas-saturated coals. How much if any of this total will eventually be recovered depends in part on information yet to be obtained by exploration in the area.

Outcrops of Gething coals do not extend east to Hudson's Hope but in the Peace River Canyon below the Bennett dam to the west there are good outcrops of coal seams. Seams are well cleated with the face cleats oriented across the fold trend and at 90° to the minimum horizontal stress direction. In addition the magnitude of the minimum stress tends to be less over the Peace River Arch in the Hudson's Hope area than to the north or south. There are therefore indications that there may be improved permeability in the area and this in conjunction with the high potential resource per section makes the area very prospective.

## REFERENCES


Cowely, P.S. (1982): Geology of the Carbon Creek deposit, Utah Mines Limited; Coal Assessment Report 509 filed with the *Ministry Energy and Mines Victoria*.

Duncan, D.N. (1980): Geology of the Bri-Dowling coal Property, Utah Mines Limited; Coal Assessment Report 469 filed with the *Ministry Energy and Mines Victoria*.

Ayers, B. W. (2002): Coalbed gas systems, resources and production and a review of contrasting cases from the San Juan and Powder River basins; *American Association of Petroleum Geologists*, Volume 86, pages 1853-1890.

Banerje, I. And Kalkreuth, W. (2002): Sedimentology, sequence stratigraphy, organic petrology, geochemistry and palynology of Manville Group coals in south-central Alberta; *Geological Survey of Canada,* Bulletin 571.

Bell, S.J. (2002) In situ stress regime in the coal-bearing strata of the northeastern plains area of British Columbia; Sigma H. Consultants Ltd. Invermere BC. Report for the *Ministry Energy and Mines, British Columbia.*

Enever, J.R., Pattison, C.I., McWatters, R.J. and Clark, I.H. (1994): The relationship between insitu stress and reservoir permeability as a component in developing an exploration strategy for coalbed methane in Australia; In Eurorock, 94, *SPE-ISRM rock Mechanics* in Petroleum Engineering, Balkema, Rotterdam, pages 163-171.

Gibson, D.W. (1992): Stratigraphy, Sedimentology, coal geology and depositional environments of the Lower Cretaceous Gething Formation, northeastern British Columbia and West-central Alberta; *Geological Survey of Canada,* Bulletin 431.

Horachek, Y. (1985): Geology of Alberta coal; *Canadian Institute of Mining and Metallurgy*, Special Volume 31, pages 115-133.

Karst, R..H. and White, G.V. (1979): Coal rank distribution within the Bluesky-Gething stratigraphic horizon of northeastern British Columbia; *Geological survey Branch Ministry of Energy and Mines*, Paper 1980-1 pages 103-107.

Kilby, W.E. and Oppelt, H.P. (1984): Numerical depositional modeling- Gething Formation along the Peace River; *Geological Survey Branch British Columbia Ministry of Energy and Mine* , Paper 1985-1 pages 233-248.

Lamberson, M.N., and Bustin, R.M. (1993): Coalbed methane characteristics of Gates Formation coals, northeastern British Columbia: effect of maceral composition; *American Association of Petroleum Geologists*, Bulletin, V77, pages 2062-2076.

Langenberg, W. (1990): Structural geology and its application to coalbed methane reservoirs*; in* Introduction to coal sampling techniques for petroleum industry; *Coalbed*

*Methane Information Series* 111, *Alberta Research Council*, pages 113-127.

Legun, A. (1990): Stratigraphic trends in the Gething Formation; *Geological Branch, Ministry of Energy and Mines, British Columbia*, Open File 1900-33.

Legun, A. (2003): Geoscience Map 2003-2; *Geological Survey Branch, British Columbia Ministry of Energy and Mines*.

Marchioni, D. and Kalkrueth, W. (1992): Vitrinite reflectance and thermal maturity in Cretaceous strata of the Peace River Arch region: west-central Alberta and adjacent British Columbia; *Geological Survey of Canada,* Open file 2576.

Northeast Coal Study (1977): Report on coal resource evaluation studies; resource sub-committee on northeast development; *Ministry of Energy Mines and Petroleum resources,* British Columbia.

Ryan, B.D. (1991): Density of Coals from the Telkwa Coal Property, Northwestern British Columbia; (93L/11); in Geological Fieldwork 1990, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Paper 1991-1, pages 399-406.

Ryan, B.D. (1992): An Equation for Estimation of Maximum Coalbed-Methane Resource Potential; *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork 1991, Paper 1992-1, pages 393-396.

Ryan, B.D. (1997): Coal Quality Variations in the Gething Formation Northeast British Columbia (93O,J,I); B.C. *Ministry of Employment and Investment*, Paper 1997-1, pages 373-397.

Ryan, B.D. and Lane, R. (2002): Adsorption characteristics of coals from the Gething Formation northeast British Columbia; *B.C. Ministry of Energy and Mines*, Geological Fieldwork, Paper 2002-1.

Ryan, B.D. and Richardson, D. (2004): The potential for $CO_2$ sequestration in British Columbia coal seams; in Summary of Activities 2004, *BC Ministry of Energy and Mines*, pages 137-156.

Smith, L.A., Allen, E.J, Johnson, D.G.S., and Unkauf, J. (1991): Coalbed methane in Northeastern BC; Consultant report by *LAS Energy Associates Ltd*.

Sparkes, D.C., McLendon, T.H., Saulsberry, J.L. and Lambert, S.W. (1995): Effects of stress on coalbed reservoir performance, Black Warrior basin, USA; SPE Paper 30743 in Dallas 95, Proceedings in the *Society of Petroleum Engineers* Annual Technical Conference and Exhibition, pages 339-351.

Stott, D.F. (1973): Lower Cretaceous Bullhead Group Between Bullmoose Mountain and Tetsa River Rocky Mountain Foothills Northeastern British Columbia: *Geological Survey of Canada*, Bulletin 219.

Stott, D.F. (1982): Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the Foothills and Plains of Alberta, British Columbia District of Mackenzie and Yukon Territory; *Geological Survey of Canada*, Bulletin 328.