COALBED METHANE POTENTIAL OF THE BONNET PLUME BASIN YUKON TERRITORY

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Introduction

The Bonnet Plume Basin is a physiographic and structural depression, located near the eastern margin of the Frontal Belt of the Cordilleran Orogen, in northern Yukon (Figure 1, from Hannigan, 2001). The basin formed in the Late Cretaceous and is filled with late Cretaceous (Albian) and Early Tertiary (Paleocene) sediments of the Bonnet Plume Formation. A major unconformity separates the non-marine Bonnet Plume Formation from underlying Paleozoic rocks (Figure 2, from Hannigan, 2001). The area is bordered by the Richardson Mountains on the east, the Knorr Ranges on the west and the Wernecke Mountains to the south.

The Bonnet Plume Basin is about 240 kilometres northeast of Dawson City. Access to the area is by air or by a 165 kilometres winter road from Elsa, which provides access to the south-western corner of the basin.

The basin is an area of low relief, generally less than 200 metres, with elevations that range from 300 to 600 metres. The terrain is swampy and covered by stunted timber. The basin is traversed by two north flowing rivers, the Bonnet Plume to the east and the Wind River to the west, both of which flow into the Peel River to the north. The Wind River has three major tributaries, which are from south to north, the Little Wind River, Illtyd Creek and Hungary Creek (Figure 3). Most coal outcrops are found along the Wind River and its tributaries; there is little outcrop in the rest of the basin.

The basin covers about 3000 square kilometres (Cameron and Beaton, 2000). The present extent of the basin is defined by the north-trending Knorr Fault to the east and the Deslauriers Fault on the west. Between these faults a number of other north trending faults disrupt the basin. The southern end of the basin is marked by a number of east-west trending north-directed thrusts; the main one being the Wernecke Fault (Figure 4). Norris and Hopkins, (1977) estimate the extent of the basin to be 1800 square kilometres, based on their mapping.

Folds within the basin trend southeast to east and are cut-off by the major north-south trending faults that define the edges of the basin.

Regional Geology

Coal was first reported in the area by the explorer De Sainville in 1893 (referenced in Norris and Hopkins) and the first detailed geological map of the area was made by Stelck (1944) who coined the name Bonnet Plume Basin. Since then the area has been mapped by Norris *et. al*. (1963) and Norris (1975). The geology and coal potential were described by Mountjoy (1967), Norris and Hopkins, (1977) and Long (1983, 1986).

The Bonnet Plume Formation was defined by Mountjoy (1967), who estimated it to be over 1500 metres thick. He measured two sections one over 1500 metres and the other over 1200 metres. However Norris and Hopkins (1977) considered these measurements to represent apparent thicknesses and the true thickness to be considerably less. Norris and Hopkins (1977) describe the formation as deposited in a non-marine alluvial and fluvial environment. They do not provide a thickness but appear to assume it to be about 500-1000 metres thick, based on a section in their paper.

Long (1978) divided the Bonnet Plume Formation into upper and lower members. The lower member is estimated to be over 1000 metres thick (McKinney, 1978) and outcrops mainly in the southern part of the basin. Long (1983) assigned a total thickness of 1960 metres to the formation. This is broken down into 804 metres Maastrictia (lower member), 770 metres Cenomanian to Campanian (lower member) for a total thickness of 1574 metres for the lower member. The lower member is dated by palynology as mid to late Albian (Rouse and Srivastava, 1972) and there therefore appears to be a 35 million year hiatus between the lower and upper member, which is Late Cretaceous to Eocene. Sweet (1979) indicates that the hiatus may be somewhat less than 35 million years. The lower member contains conglomerates, sandstones, siltstones, shales and bituminous-rank coal seams that occur in a number of repeating cycles.

The upper member, which is Late Cretaceous to Eocene (Paleocene, Long, 1978) contains sandstones, shales and lignite. Long (1983) indicates that the upper member accounts for 386 metres of the 1960 metres he assigned to the formation.

Coal Geology

Coal was first described in detail in the area by MacKay (1947) who records seeing lignite along the Peel River and estimates a resource of 1.7 billion tonnes. Lignite was also reported by Mountjoy (1967) and Norris and Hopkins, (1977) who estimated the lignite resource to be 1.4 billion tonnes. This estimate is for the upper member over an area of 90 square kilometres in the northern part of the basin and assumes a cumulative thickness of 12 metres of lignite. The Arial extent of the upper member is much larger than 90 square kilometres.

In 1977 Pan Ocean Oil discovered coal in the lower member of the Bonnet Plume Formation and acquired 24 coal exploration licenses covering an area of 387308 hectares. The company no longer exists and the licenses have changed ownership. However in order to reference the geology discussed in the Pan Ocean Oil reports the licenses with the company numbers are overlain on simplified geology of Norris and Hopkins (1977) (Figure 5). The company conducted a number of exploration programs in the period 1978 to 1980. During that period the company drilled 53 holes for a cumulative length of 10700 metres and mapped the area. A total of seven areas with surface mineable potential were identified that together contain an in-place reserve of 121 million tonnes and a resource in excess of 650 million tonnes (Cullingham *et. al.,* 1981).

There have been a number of more recent estimates of the total amount of coal in the basin. Long (1986) estimates that the lower Cretaceous lower member could contain a coal resource of 1.4 billion tonnes. Cameron (1993) assigns an estimated resource of 200 million tonnes to the whole basin. Cameron and Beaton (2000) describe the basin as having an inferred coal resource of 2.8 billion tonnes. There is obviously a confusion of numbers because of a lack of data. Some authors are estimating resources for the formation and others for one or other of the two members. Also some quoted tonnages include estimates of inferred resources and others do not.

It is useful to consider the coal resource of the basin as three components for the purpose of estimating the CBM resource:

- The ill defined lignite resource in the upper Bonnet Plume Member
- The coal resource in the lower Bonnet Plume Member under part or all of the 1800 square kilometres of subcrop of the upper Bonnet Plume member (Norris and Hopkins, 1977). There are no data on the lower member in the area where it is overlain by the upper member, yet the resource, which would probably be within 1500 metres of surface, could be enormous.
- The better-defined high-volatile B bituminous resources in the lower Bonnet Plume Member where it outcrops in the southern part of the basin.

Norris and Hopkins, (1977) estimate the lignite resource in the upper Bonnet Plume member in the northern part of the basin to be 1.4 billion tonnes based on assuming a cumulative lignite thickness of 12 metres, derived from seams greater than 1.5 metres thick extending over an area of 90 square kilometres (Figure 2 in Norris and Hopkins, 1977). Lignite seams 4-11 metres thick were mapped in the upper member by Long (1978) who also reported seeing coal seams 4.5 to 9 metres thick in the lower member in a small creek between Illtyd Creek and Wind River. The area of the upper member, using the map of Norris and Hopkins, was calculated to be 1832 square kilometres which is in agreement with their quoted value of 1800 square kilometres. If lignite extends into the southern part of this area, then the 1.4 billion tonnes resource estimate could increase substantially. In fact the tonnage could range from the conservative estimate of 1.4 billion tonnes to 28 billion tonnes (1800/90*1.4).

Outcrops of the lower member cover about 630 square kilometres in the southern part of the basin based on Figure 2 in Norris and Hopkins, (1977). Pan Ocean Oil (McKinney, 1978 and 1979, Cullingham *et. al.,* 1981) explored extensively in the southern Bonnet Plume Basin in areas underlain by the lower member and divided the member into three informal units. The lowest unit contains thin coal seams and is about 200 metres thick. The middle unit contains 5 coal zones, that were the focus of Pan Ocean Oil exploration. These coal zones cover the lower 130 metres of the middle unit, which is 220 metres thick. The upper unit, which is at least 300 metres thick, contains rhythmic cycles of coarse to fine sediments capped with carbonaceous shale and occasionally poorly developed coal seams.

It is critically important to determine the thickness of sediments above the 5 coal zones in the middle unit of the lower member because this thickness will determine whether there is any reasonable chance of recovering CBM from most of the basin. This thickness is composed of the upper member , the upper unit of the lower member and 90 metres of the upper part of the middle unit in the lower member. The generalized stratigraphic section (Cullingham, *et al.,* 1981) indicates that the lower member is at least 720 metres thick. Long (1983) estimates the lower member to be at least 1574 metres thick. It is possible that the thickness of the formation is less than 1960 metres and that the thickness of the lower member is greater than 720 metres. Norris and Hopkins (1977) estimated the formation to be less than 1200 metres so it is possible that the lower member is about 800 metres. If this is the case it would be necessary to drill through about 400 metres of the upper member and 600 metres of the lower member to be ensured of testing the 5 coal zones. This means that the coal in the lower member could be accessed by holes less than about 1000 metres deep, which is within prospective depth for CBM and therefore most of the 1800 square kilometres of the Bonnet Plume Basin may be prospective for CBM.

Cullingham, *et al.* (1981) describe the 5 coal zones in 630 square kilometres of the southern part of the basin which were explored by Pan Ocean Oil and they provide average coal quality and thickness data.

The uppermost number 1 coal zone occurs through out the southern end of the basin and contains from 2 to 8 metres of coal. The zone is generally capped by a thick conglomerate sometimes separated from the coal by a shale bed. The average raw ash of the zone is 36.5%.

The Number 2 coal zone is 10 to 40 metres below the number 1 zone and varies in thickness from 2 to a maximum of 10 metres of coal. The roof is usually composed of coarse sediments and the floor is mudstone. The average raw ash of the zone is 24%.

The number 3 coal zone is not well developed and is not recognized in all drill holes. Where developed, it is 10 to 50 metres below the number 2 coal zone. It is often present as two seams with cumulative thickness of about 5 metres. It is less than 3 metres thick when present as a single seam.

The presence of a number 4 coal zone is uncertain and where recognized it has a maximum thickness of 5.45 metres of coal.

The number 5 coal zone is well developed in most areas and ranges in thickness from 2.3 to a maximum of 9 metres of coal. The roof varies from siltstone to conglomerate and the floor is siltstone or sandstone.

The coal quality data presented in Cullingham, *et al.* (1981) are summarized in Table 1 by area and by coal zone (seam). Cumulative coal and the raw and clean coal quality in each zone are presented. Clean coal refers to samples ¼ inch to 28 mesh size floated at 1.9 SG. These samples provide data for estimating rank using volatile matter calculated on a dry ash free basis starting with low ash samples.

CBM Methodology

Cullingham *et. al*. (1981) divide the subcrop of the lower member in the southern part of the Bonnet Plume Basin into seven surface mineable areas, based on minimal outcrop and drill hole data. These areas were enlarged to cover areas where the coal probably occurs at depth and then the coal and CBM resource potential of each area estimated. Cullingham *et. al*. (1981) list average cumulative coal thicknesses for the 5 zones in each of the seven surface mineable areas (Table 1) as well as average coal quality. An empirical equation was developed by the author to estimate mean-maximum vitrinite reflectances (Rmax%) from calculations of volatile matter on a dry ash free basis (VM daf) using clean coal quality and percentage of reactive macerals on a mineral matter free basis. Once Rmax values are established, it is possible to estimate potential CBM content in the coals using the Ryan Equation (Ryan, 1992). When values of VM daf are calculated from samples of varying ash composition and plotted against the ash %, the data do not plot on a horizontal line because of contributions of volatile matter from the ash to the VM daf value. This means that the data have to be projected to a zero ash content to provide the real VM daf value that is used to predict rank.

Ranks of coal in the five zones in each of the seven areas (Table 1) are calculated using VM daf data calculated from the average clean coal quality of the seven mining areas and an assumed reactives content of the coal. The data indicate that the rank of the seams increases with depth but does not appear to vary from area to area. Cullingham *et. al*. (1981) indicate that the average rank of the coal is high-volatile C bituminous. Assuming 100% reactives on an ash free basis the rank for the 5 seams ranges from 0.66% to 0.8% Rmax or if a 90% reactives content is assumed rank varies from 0.59% to 0.72%. The first range covers high-volatile B bituminous and the second high-volatile C bituminous. Late Cretaceous coals are typically rich in vitrinite so there is some indication that the rank might be a little higher than that assumed by Cullingham *et. al*. (1981). For the purposes of this study a 95% reactives content is assumed which provides ranks of seam 1 =0.64% seam 2=0.66% seam 3=0.68%, seam 4=0.70% and seam 5=0.77% (Table 2). These ranks are in the range of high volatile bituminous B and they were then used to predict potential gas contents at varying depths for each seam (Table 3, Figure 6)

The seven surface mineable areas identified by Cullingham *et. al*. (1981) were combined to make four CBM resource areas (Figures 8 and 9). Figures 8 and 9 are located with reference to the regional map (Figure 5) by license numbers, which occur on all Figures. Resource areas are delineated by inward pointing arrows. On Figure 8 the Wernecke+Airstrip area is defined by the 5 zone. The Illtyd west and Spaceship area to the north is also delineated by the 5 zone. It is arbitrarily separated from the Garlic Ring area to the north by an east-west line. The Garlic Ring area is divided into a west portion containing only zones 3, 4 and 5 and an east portion containing zones 1 and 2. On Figure 9 the Wind River area is delineated by the 5 zone. The names of the areas are taken from the report by Cullingham *et. al*. (1981)., The area underlain by each seam was calculated within each resource area. This area multiplied by an average seam thickness to provide an estimate of the tonnage available for the CBM resource calculation. Obviously any folding would increase the surface area of the seam and the estimate of tonnage. In the absence of detailed subsurface geology it was not possible to construct sections illustrating the depth distribution of the tonnages attributed to each seam. Instead an estimate was made of the deepest occurrence of the seam and the tonnage distributed equally in 50 metre depth slices. Gas contents were assigned to each depth slice based on rank, with the exception of the top 25 metre slice that was assigned a zero gas content. The CBM resource of each area was then derived by summing the CBM resources of each slice for all the seams present. The process was made easier with the help of an interactive excel spread sheet that permitted a good deal of trial and error.

A rigorous attempt interpret the geology in each area was not undertaken. In the absence of any CBM data, it was felt that the time involved would not add much to the accuracy of the interpretation. When CBM data are available it should be possible to construct a better interpretation of the geology and a better estimate of the CBM resource.

Coal and Coalbed Methane Potential

The potential CBM resource of the four areas of the lower Bonnet Plume member is 0.43 tcf (Table 4). Tonnages are distributed over depths ranging from surface to 475 metres for the 5 zone and shallower depths for the overlying zones. The resources in the four combined areas are documented in Tables 5 to 8. The CBM resource for combined Wernecke and Airstrip area (Table 5) is 125.8 bcf. The CBM resource for Illtyd west, Illtyd and spaceship areas 40.7 (Table 6). The CBM resource for Garlic Ring area and area north of west Illtyd is 52.5 bcf (Table 7). The CBM resource for Wind River and area to east is 215.4 bcf (Table 8). Based on the tonnage estimate the average gas content is a bit over 100 scf/t, which is probably conservative but takes into account the average raw ash and insitu moisture of the coal. It may be possible to obtain better estimates of the depth distribution of the coal in each area and if depths are increased the CBM resource estimate will also increase.

There is potentially an enormous resource of lignite in the Bonnet Plume upper member. Norris and Hopkins, (1977) estimate a 12 metres thickness of lignite over 90 square kilometres based on the work of Mountjoy (1967) and calculate a lignite resource of 1.4 billion tonnes. The area of the upper member is 1832 square kilometres so that the potential could increase to 28 billion tonnes if the 12 metres cumulative thickness of lignite extends over the whole area. This is a large resource but there may not be enough gas per well spacing to make extraction economic. Adsorbed gas contents in Powder River Basin coals are in the range 25 to 45 scf/t. Production data indicates that there is also a lot of free gas present, which may increase the gas content per tonne of coal to over 100 scf. If an adsorbed plus free gas content of 50 scf/t is assumed for the Bonnet Plume lignite, then a billion tonnes provides a resource of about 0.05 tcf and 10 billion tonnes 0.5 tcf. There is no logic for assuming 10 billion tonnes of lignite other than it increases the 90 square kilometers resource area used by Norris and Hopkins, (1977) to about 1/3 of the area of upper Bonnet Plume member.

The largest CBM resource may exist in the lower Bonnet Plume member where it is overlain by the upper member. This area is up to 1832 square kilometres. It may be considerably less if the upper member overlaps the pre Tertiary basement, which is possible because there is a major hiatus between the upper and lower members. If it is assumed that 1000 square kilometres of the upper member is underlain by the lower member then this is 5 times the area of lower Bonnet Plume member that accounted for a CBM resource of 0.43 tcf. (201 square kilometres, Table 4). Obviously where ever the lower member is overlain by the upper member all the 5 coal zones may be present. A possible stratigraphic section (Figure 7) indicates that one might have to drill from 880 metres to 1010 metres to intersect all five coal zones. If this is the case, then gas contents should be assigned to each zone based on these depths (Table 9). This would indicate a possible resource of 7.6 tcf.

The total estimated potential CBM resource of the basin is 0.43 tcf lower member subcrop, 0.5 tcf upper member and 7.6 tcf lower member where it underlies the under upper member. The total resource is therefore approximately 8.6 tcf. This value is obtained by making some completely unsupported assumptions about the distribution of lignite in the upper member and the extent of coal in the lower member where it is overlain by the upper member. Depending on more conservative or more optimistic assumptions the resource estimate can range from 1 tcf to15.5 tcf. All these estimates are of potential resource. There has been no discussion of feasibility of economic recovery and consequently they are not reserve estimates.

One of the most important parameters for reserve assessment is the concentration of the resource, in this case measured as bcf/section (Table 4) spacing where a section is 1 square mile or 640 acres. CBM drill spacings range from 320 acres per site to 40 acres per site. Closer spacing is required in coals with low permeability but obviously as the drill spacing decreases there is less reserve to pay for drilling the hole. For the areas of the lower member subcrop the resource per drill site (160 acre spacing) ranges from 0.8 to 1.7 bcf/160 acres. Gas prices at the moment range from 3 to 3.5 $US per million BTU. This represents an in-ground value of 7.8 to 9.2 million dollars Canadian based on a 65 cent dollar and it appears that a resource of better than 1 bcf/160 acre or 4 bcf/section has a chance of being economic. In areas where lignite in the upper member overlies areas of the lower member, there is a potential for about 5.5 bcf/160 acre spacing. The high potential value of each 160 acre unit is offset by the fact that one is assuming that CBM can be recovered from all the seams. Also holes will have to be drilled to depths in the range of 1000 metres.

Summary

The Bonnet Plume basin covers over 3000 square kilometres of which 1800 square kilometres is overlain by subcrop of the upper Bonnet Plume member and an additional 600 square kilometres by subcrop of the lower member. There has been a moderate amount of exploration in the 600 square kilometres of the subcrop of the lower member and 200 square kilometres of this area is probably underlain by coal zones. There has been very little exploration aimed at outlining the potential lignite resource in the upper member and there has been no exploration for coal in the lower member, where it is overlain by the upper member.

There are no CBM desorption data for the Bonnet Plume Basin. All the values discussed in this paper are derived by estimating rank and then using estimated rank values to estimate saturated gas capacity for the coal considering also moisture and ash contents. The Ryan equation used to make gas content estimates was derived by curve fitting to a published database of desorption results (Ryan, 1992). Experience has shown that there is considerable variation in desorption results from coals of similar ranks and sampled at similar depths.

Keeping in mind the limitations discussed above, there appears to be a potential CBM resource in the range of 8.6 tcf in the basin. There is sufficient coal in the section to make possible reasonable resource concentrations expressed as bcf/drill spacing. The potential resource is large but the basin is very isolated and no attempt is made here to discuss development strategies or the cost of infrastructure. Until there is a plausible plan for getting the CBM to market the potential CBM in the Bonnet Plume basin remains a potential resource.

Initial exploration should concentrate on areas which are accessible, and where a drill hole has a good chance of intersecting the maximum amount of coal at a prospective depth. Based on drill hole coal intersection data in the report by Cullingham *et. al*. (1981) (Table 10) hole SC 80-25 in the West Illtyd, Illtyd and Spaceship resource area offers the best compromise.

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Figures

Tables

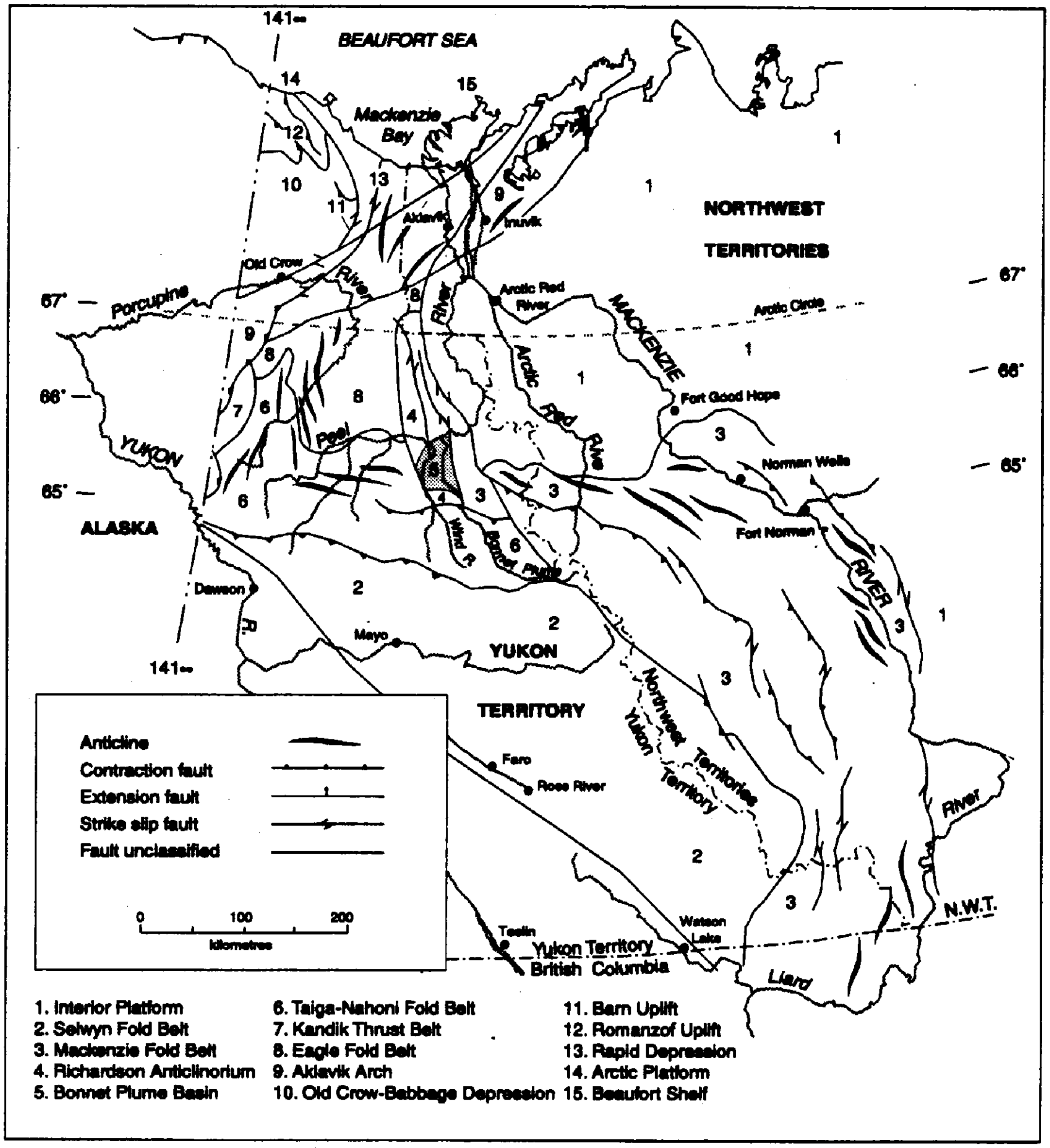

Figure 1: Location of the Bonnet Plume Basin with reference to the tectonic units of northern Canada after Hannagan (2001).

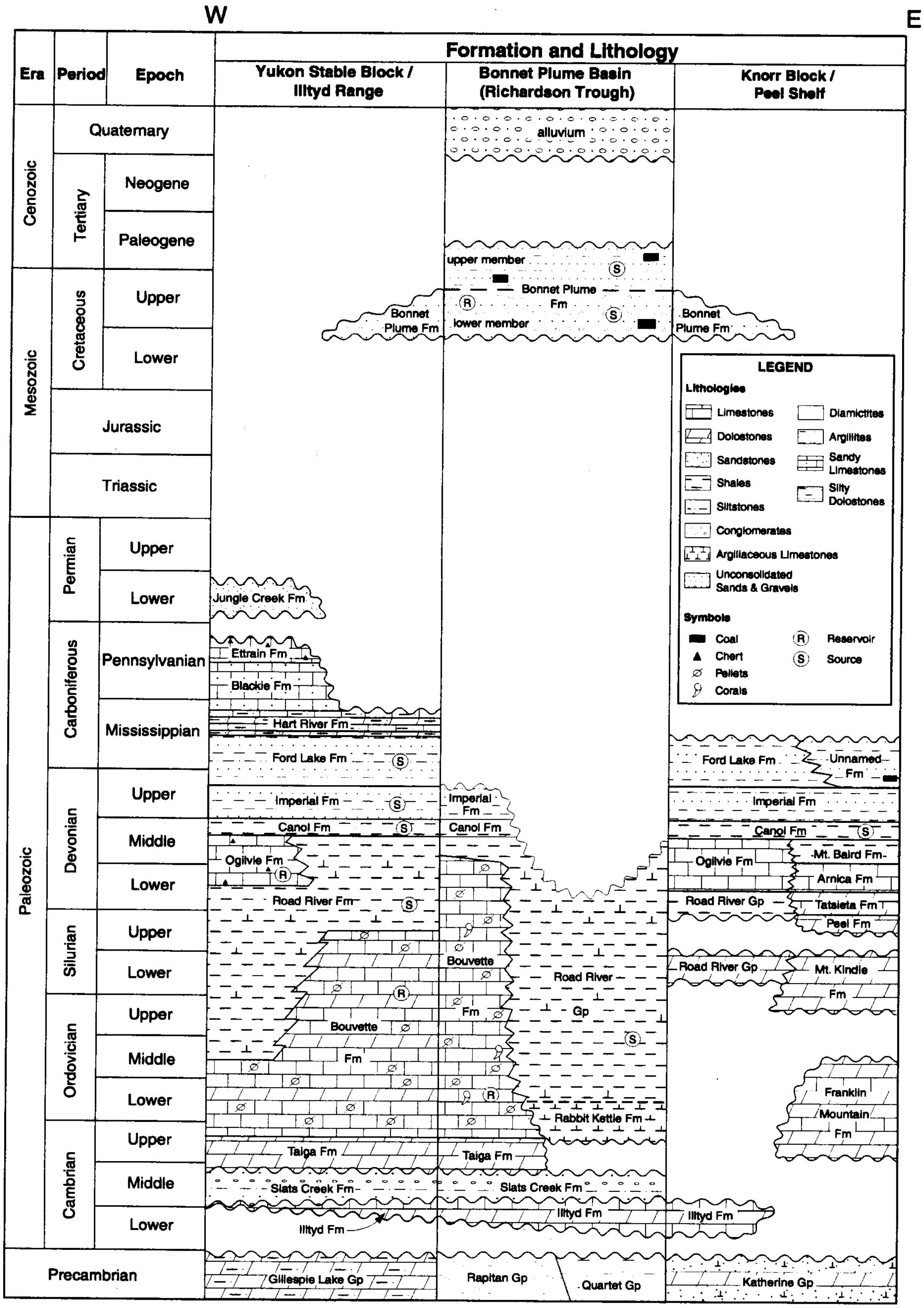

Figure 2: Stratigraphic setting of the Bonnet Plume Basin after Hannigan (2001).

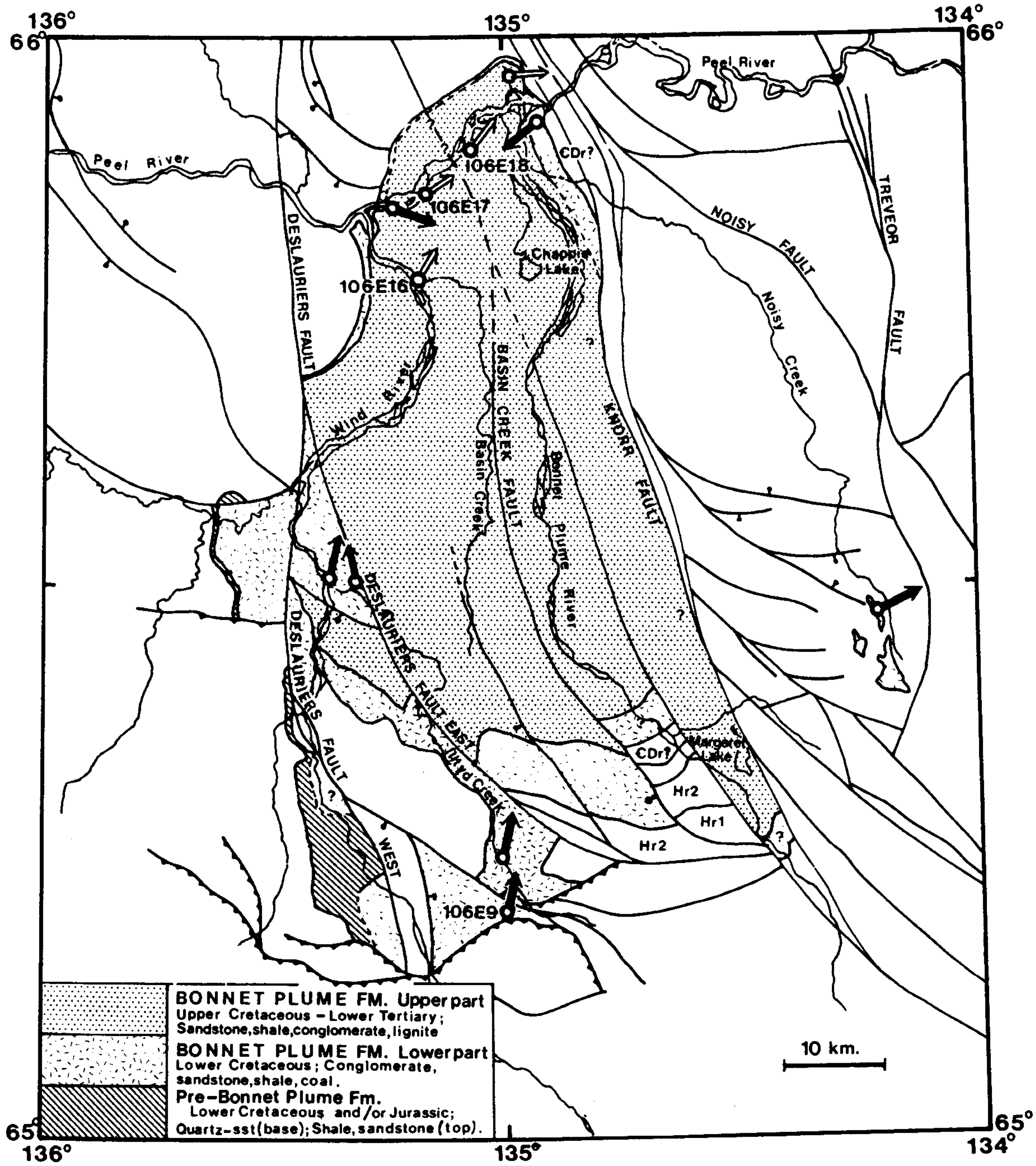

Figure 3: Major rivers and faults in the Bonnet Plume basin (after Long, 1978).

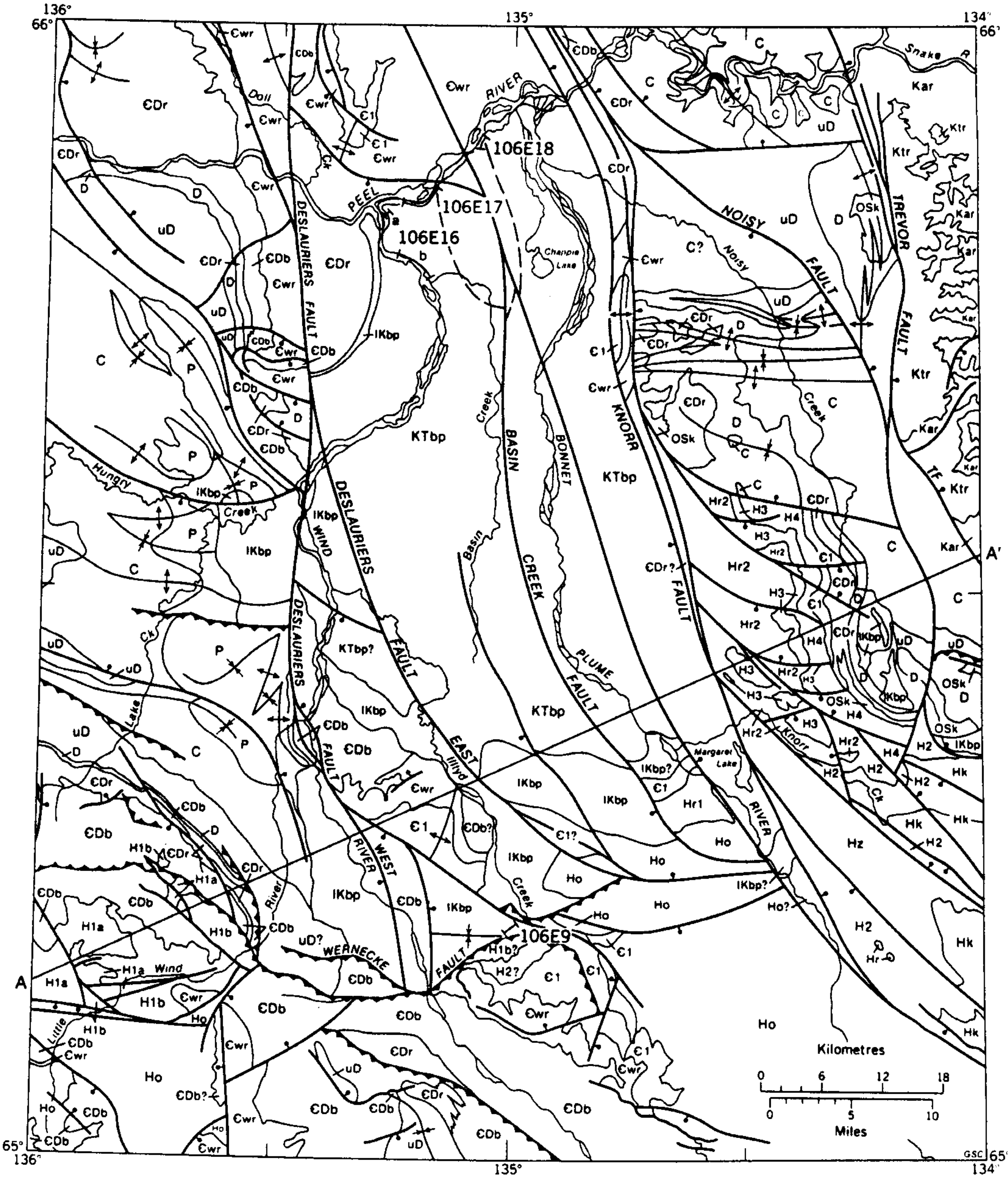

Figure 4: Major faults within and bounding the Bonnet Plume Basin (after Norris and Hopkins, 1977).

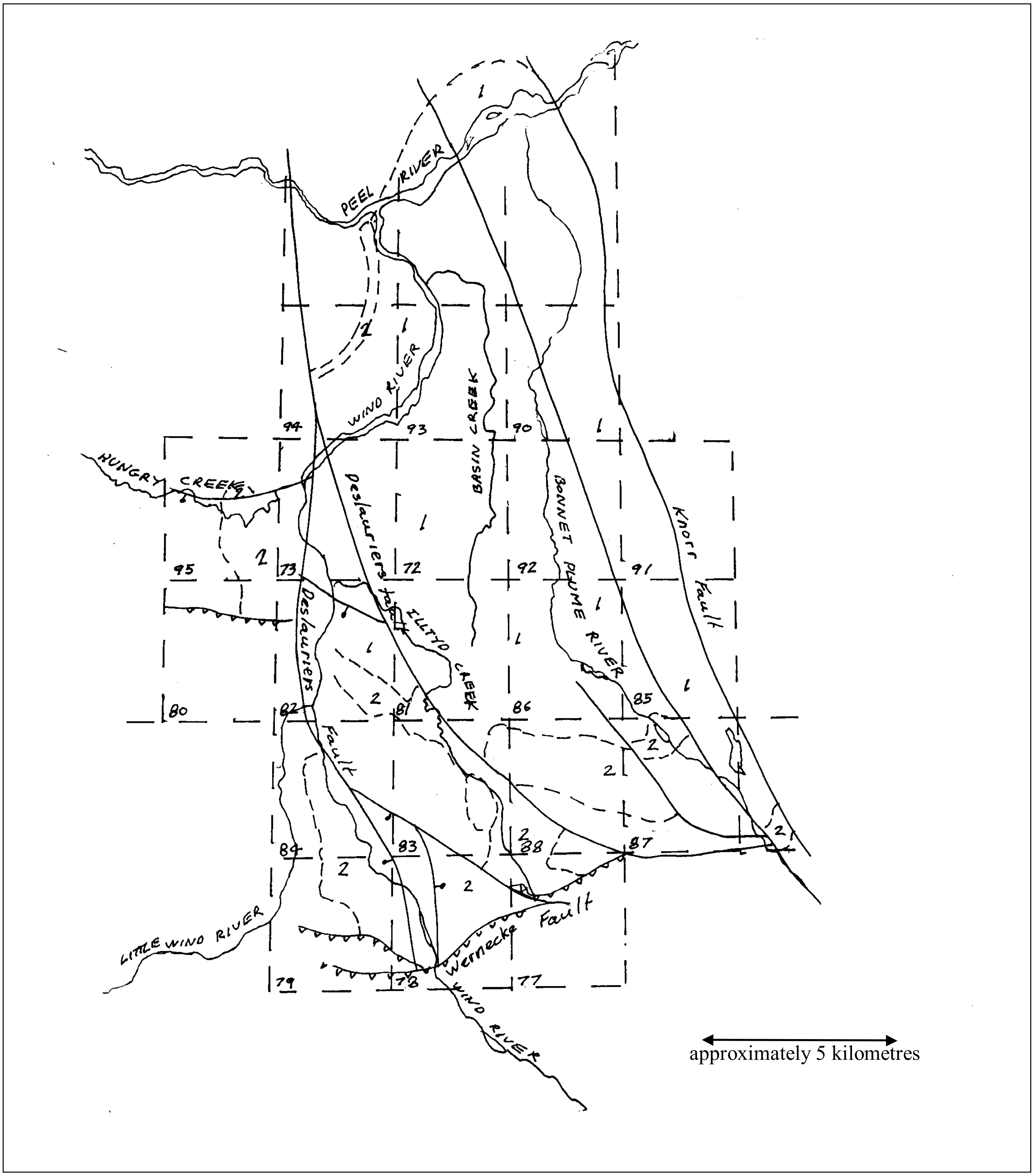

Figure 5: Simplified geology from Norris and Hopkins (1977) with Pan Ocean licenses for reference. Unit 1 is upper Bonnet Member and Unit 2 is lower Bonnet Plume Member.

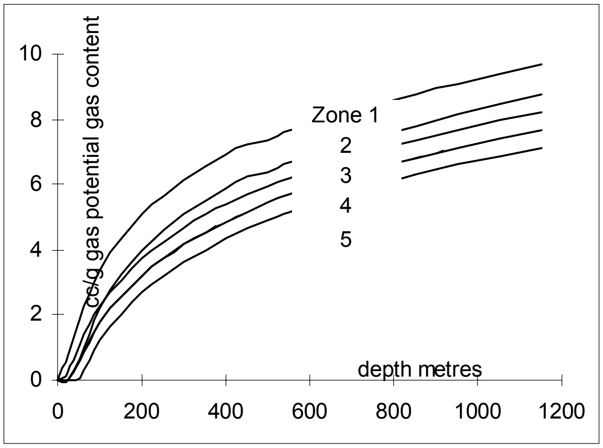

Figure 6: potential gas contents of each seam based on calculated Rmax% values.

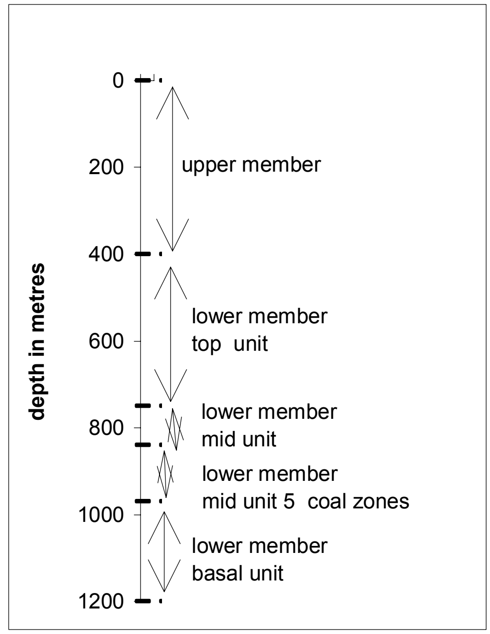

Figure 7: Possible thicknesses of the upper and lower members of the Bonnet Plume Fm and location of the 5 coal zones.

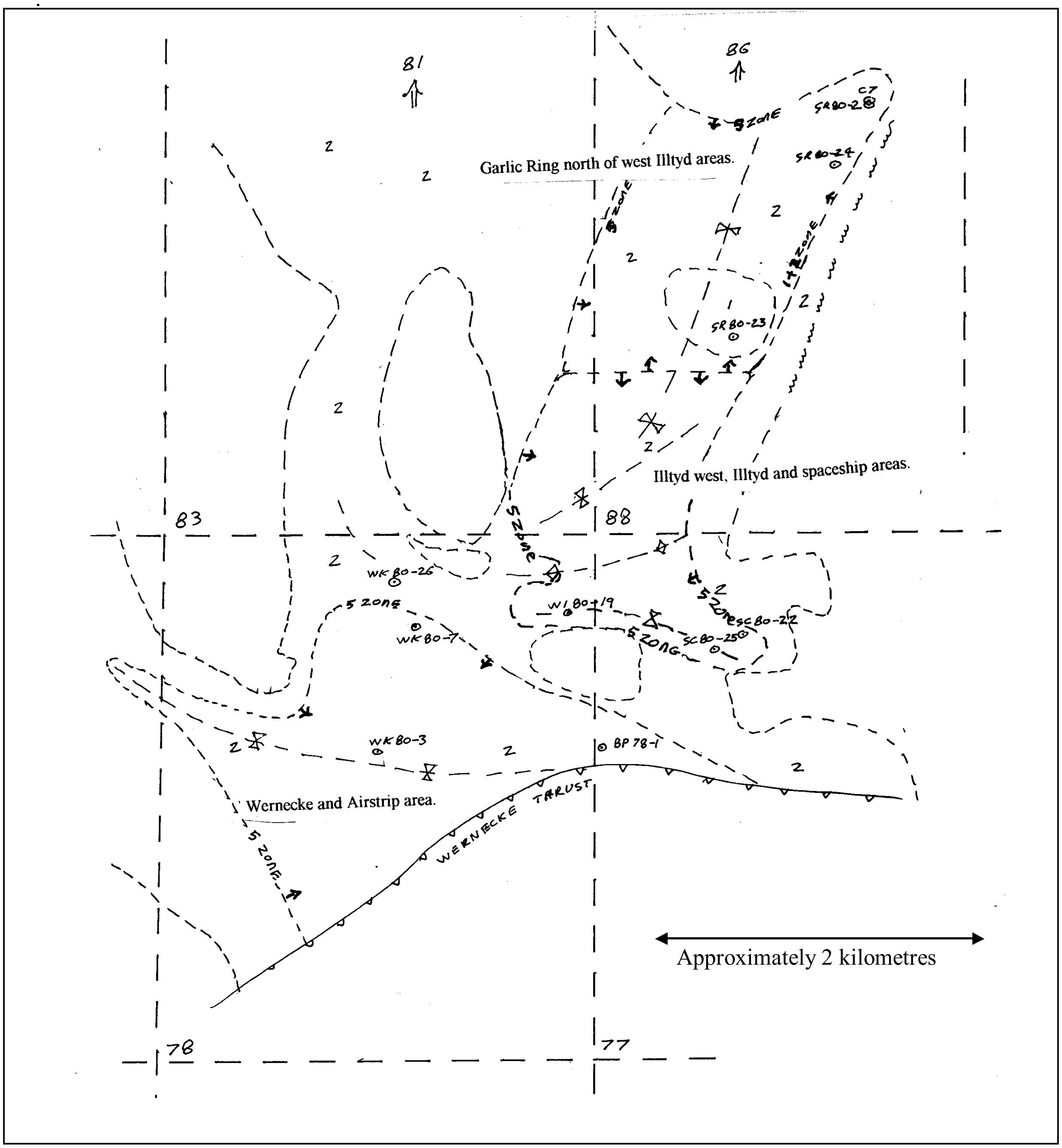

Figure 8: Simplified geology for the Wernecke plus Airstrip; Illtyd west plus Illtyd plus Spaceship and Garlic Ring plus Illtyd north CBM resource areas.

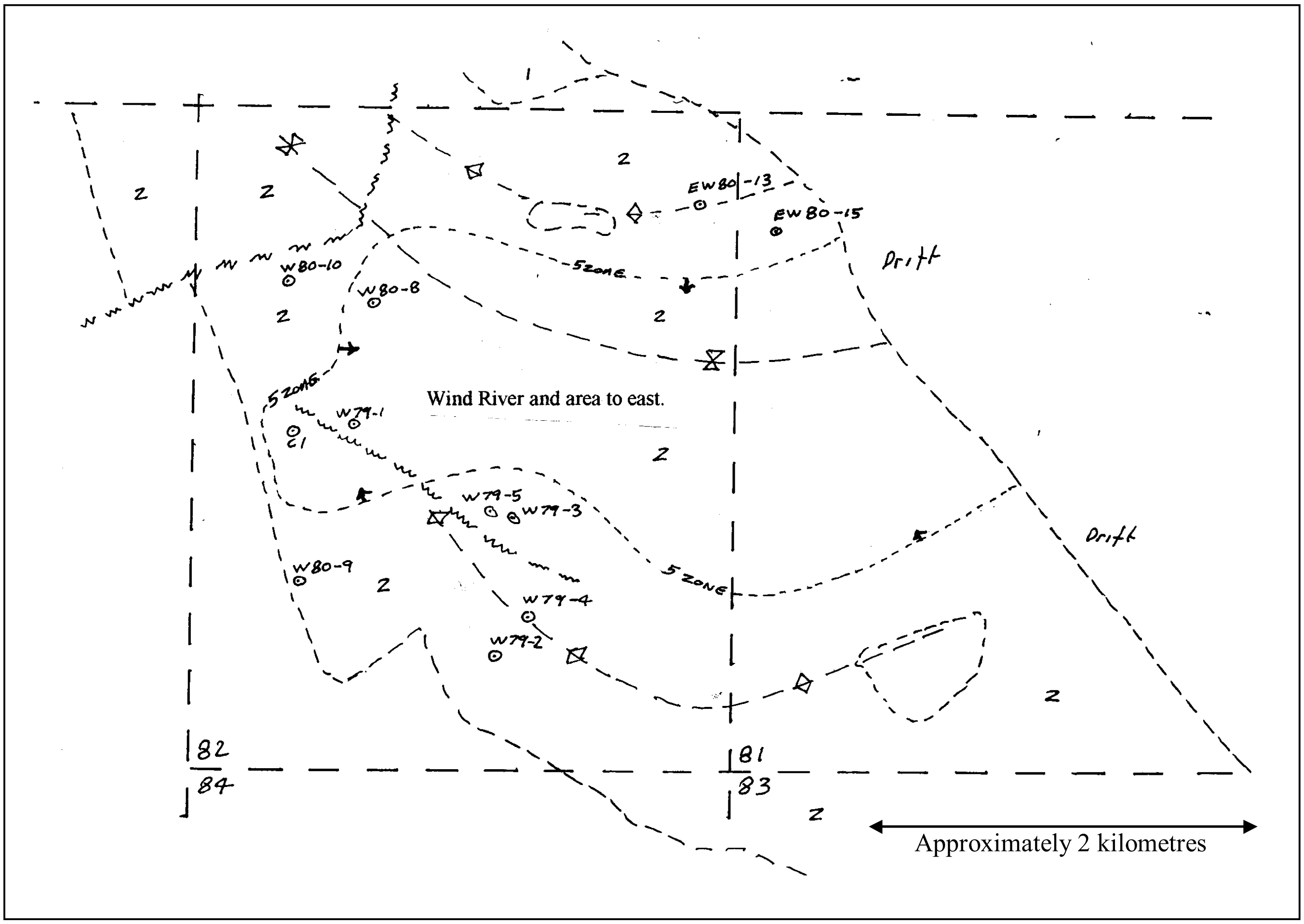

Figure 9: Simplified geology for the Wind River and area to east CBM resource area.

Table 1

Coal thicknesses and coal quality for the 7 surface mineable areas

			RAW			CLEAN						
area name	seam No	thick metres	RM %	ash %	VM %	ad %	ash ad %	VM ad %	FC	VM daf %	VM daf adjust	Rmax %
Spaceship	1	6.42	7	27.8	29.8	4.5	14.9	34.4	46.2	42.7	38.2	0.65
A	2	8.99	7.4	20.9	32	5.2	12.4	34.5	48.2	41.9	38.1	0.68
	3	7.12	7.9	19.3	31.6	4.7	13.3	33.3	48.7	40.6	36.6	0.71
	4	5.45	7.3	16.3	32.5	4.7	12.6	32.8	49.6	39.7	35.9	0.74
	5	1.93	7.5	15.8	30.6	4.9	11.8	30.5	52.8	36.6	33.1	0.84
West Illtyd	1											
B	2											
	3	3.91	7.6	13.1	33.1	6.4	10.5	33	50.2	39.7	36.6	0.74
	4	2.76	7.6	14.1	32.6	6.4	10.3	33.2	50.1	39.9	36.8	0.74
	5	4.1	5.7	34.8	25.4	5.9	16.2	30.2	47.7	38.8	33.9	0.77
Illtyd	1	6.85	6.1	40.2	25.9	5	20.4	32.6	41.9	43.7	37.6	0.62
C	2	3.66	7.1	33.9	31	5.3	13.9	34.3	46.2	42.5	38.3	0.66
	3	2.4	5.1	40.7	25.9	4.9	19.7	32.5	42.7	43.1	37.2	0.64
	4	3.25	7.9	13.6	33.6	4.2	11.2	35.6	48.5	42.1	38.7	0.67
	5	2.28										
Wernecke	1	3.21	4.1	34.3	30.5	5.3	13.5	35.3	46	43.5	39.4	0.63
D	2	8.52	5.4	25.4	32.2	6	13	34.5	46.5	42.6	38.7	0.66
	3	3.43	6.2	25.9	30.1	6.7	16.2	32.2	45.1	41.8	36.9	0.68
	4	2.92	7.3	12.3	34.3	7.3	9.6	33.9	49.3	40.8	37.9	0.71
	5	2.72	6.4	25.6	27	6.5	16.5	29.5	48.5	38.3	33.4	0.78
Airstrip	1											
E	2											
	3	3.04	7.6	20.5	31.3	4.6	14.3	33.5	47.4	41.3	37.0	0.69
	4	4.89	5.7	32.6	25.9	5.1	18.8	30.1	45.6	39.6	33.9	0.75
	5											
Wind River	1											
F	2											
	3	8	6.1	39	25.7	4.4	18.1	31	45.6	40.0	34.6	0.73
	4	4.75	6	30.8	27.5	4.7	14.3	32.6	48.3	40.2	36.0	0.72
	5	9.19	5.1	29.6	26.8	4.5	11.6	31.9	51.9	38.0	34.5	0.79
Garlic Ring	1	2.56	6.3	27.8	28.8	4.3	20.2	31.2	44.2	41.3	35.3	0.69
G	2	3.28	5.6	36.7	27.2	4.4	27.3	28.3	40.2	41.4	33.2	0.69
	3											
	4											
	5											

Combination of areas for CBM evaluation

A+B+C	thickness				ash				RM			
	A	B	C	average	A	B	C	average	A	B	C	average
1	6.42		6.85	6.65	27.8		40.2	34.5	7		6.1	6.5
2	8.99		3.66	6.12	20.9		33.9	27.9	7.4		7.1	7.2
3	7.12	3.91	2.4	4.50	19.3	13.1	40.7	28.6	7.9	7.6	5.1	6.5
4	5.45	2.76	3.25	4.08	16.3	14.1	13.6	14.8	7.3	7.6	7.9	7.6
5	1.93	4.1	2.28	2.36	15.8	34.8		20.2	7.5	5.7		7.1
tonnes	157.95	47.56	183.64									
total tonnes A+B+C	389.15											

D+E	thickness metres			ash%			moisture%		
	D	E	average	D	E	average	D	E	average
1	3.21		3.21	34.3		34.3	4.1		4.1
2	8.52		8.52	25.4		25.4	5.4		5.4
3	3.43	3.04	3.34	25.9	20.5	24.65	6.2	7.6	6.52
4	2.92	4.89	3.38	12.3	32.6	17.00	7.3	5.7	6.93
5	2.72		2.72	25.6		25.6	6.4		6.4
tonnes	157.95	47.56							
total tonnes D+E	205.51								

Note mean maximum reflectance (Rmax%) is estimated from volatile matter on a dry-ash-free basis VM daf

VM daf is calculated from volatile matter with an additional correction

ie VM daf at zero ash= VM daf -0.3* ash%

Rmax% is calculated from VM daf zero ash and reactives percent mineral matter free

Table 2

Calculation of average rank for each seam assuming 95% reactives and correcting VM daf for ash effect

Rmax=-1.2124*ln(Vmdaf)+0.0073*R%+4.4851 Rmax% = -1.2124Ln(VMdaf-0.3*ash) + 5.2045 95

seam 1				seam 2				seam 3				seam 4				seam 5			
	ash	VM daf			ash	VM daf			ash	VM daf			ash	VM daf			ash	VM daf	
A	14.9	42.7		A	12.4	41.87		A	13.3	40.61		A	12.6	39.66		A	11.8	36.61	
C	20.4	43.7		C	13.9	42.45		B	10.5	39.71		B	10.3	39.86		B	16.2	38.77	
D	13.5	43.5		D	13	42.59		C	19.7	43.1		C	11.2	42.08		D	16.5	38.31	
G	20.2	41.6		G	27.3	41.43		D	16.2	41.76		D	9.6	40.79					
								E	14.3	41.31		E	18.8	39.55					
								F	18.1	40		F	14.3	40.25					
averages			Rmax				Rmax				Rmax				Rmax				Rmax
	18.0	**42.9**	**0.636**		**18.07**	**42.16**	**0.658**		**17.08**	**41.54**	**0.675**		**13.48**	**40.67**	**0.70**		**16.5**	**38.31**	**0.77**

rank does not seem to vary within one seam but increases down section from about 0.65% to about 8.0% over about 220 metres

Table 3

Predicted gas contents for the 5 seams at various depths.

seam 1		seam 2		seam 3		seam 4		seam 5	
Rmax%	0.6	Rmax%	0.7	Rmax%	0.68	Rmax%	0.70	Rmax%	0.77
ash	18.0	ash	18.1	ash	17.1	ash	13.5	ash	16.5
metres	cc/gm	metres	cc/gm	metres	cc/gm	metres	cc/gm	metres	cc/gm
0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
25	0.0	25	0.0	25	0.3	25	0.0	25	0.7
50	0.1	50	0.6	50	1.1	50	0.7	50	1.9
75	0.7	75	1.2	75	1.7	75	1.6	75	2.7
100	1.2	100	1.8	100	2.2	100	2.2	100	3.4
125	1.7	125	2.2	125	2.7	125	2.8	125	3.9
150	2.0	150	2.6	150	3.1	150	3.2	150	4.4
175	2.4	175	2.9	175	3.4	175	3.6	175	4.7
200	2.7	200	3.2	200	3.7	200	4.0	200	5.1
225	2.9	225	3.5	225	4.0	225	4.3	225	5.4
250	3.2	250	3.7	250	4.2	250	4.6	250	5.7
275	3.4	275	3.9	275	4.5	275	4.9	275	5.9
300	3.6	300	4.2	300	4.7	300	5.1	300	6.1
325	3.8	325	4.4	325	4.9	325	5.3	325	6.4
350	4.0	350	4.5	350	5.1	350	5.5	350	6.6
375	4.2	375	4.7	375	5.2	375	5.7	375	6.7
400	4.3	400	4.9	400	5.4	400	5.9	400	6.9
425	4.5	425	5.0	425	5.6	425	6.1	425	7.1
450	4.6	450	5.2	450	5.7	450	6.2	450	7.2
500	4.9	500	5.4	500	6.0	475	6.4	475	7.4
550	5.2	550	5.7	550	6.2	525	6.7	525	7.7
650	5.6	650	6.1	650	6.7	575	6.9	575	7.9
750	6.0	750	6.5	750	7.1	675	7.4	675	8.4
850	6.3	830	6.8	830	7.3	775	7.8	775	8.7
950	6.3	860	6.9	860	7.4	855	8.1	855	9.0
1050	6.4	890	7.0	890	7.5	885	8.2	885	9.1
1150	6.5	920	7.0	920	7.6	915	8.3	915	9.2
		950	7.1	950	7.7	945	8.4	945	9.3
						975	8.5	975	9.4
						1005	8.6	1005	9.5
						1035	8.6	1035	9.6
						1075	8.8	1075	9.7

Table 4

Coal and CBM resources of Lower Bonnet Plume subcrop area

COAL RESOURCES SURFACE MINEABLE COAL

	measured	indicated	inferred	total
A Spaceship			157.95	157.95
B West Illtyd		0	47.56	47.56
C Illtyd	120.93	29.21	33.5	183.64
D wernecke		104.65	28.93	133.58
E Airstrip			18.4	18.4
F Wind		60.83	43.8	104.63
G Garlic Ring		8.6	5.55	14.15
			TOTAL	454.4

COAL RESOURCES FOR CBM — 1 acre =4840 sq ft=450 m^2 . 1 section = 640 acres

		area Km^2	coal bt	CBM bcf	bcf/section
Wernecke+Airstrip (D+E)	area 1	58.30	1464	126	5.59
Illtyd west, Illtyd and Spaceship (A+B+C)	area 2	19.70	481	41	5.35
Garlic Ring north and part of west Illtyd (G+B)	area 3	42.44	535	53	3.21
Wind River and area to east (F)	area 4	80.61	1523	215	6.92
Totals lower member outcrop area		201	4003	434	
Average bcf/section lower member outcrop area					5.60
average coal thickness metres lower member outcrop area					17

Total Upper member scf/t=	50	600	10000	500	2.16
Total where lower member under upper member 1000 Km^2 (Table 9)		1000	32.10	7642.0	19.79
Total Bonnet Plume Formation as tcf				8.6	

bt billion tonnes bcf billion cubic feet tcf trillion cubic feet

Table 5

CBM resource for combined Wernecke and Airstrip area

1km^2 on planimetre = 0.0238 seam separatior 0.118125

Sm	plan	Km^2	av thick	ash	RM	SG	mt	maxdpth
1	0.915	38.45	3.21	34.3	4.1	1.6145	199.245	230
2	1.033	43.41	8.52	25.4	5.4	1.481	547.735	275
3	1.151	48.37	3.339745	24.65	6.524	1.469755	237.438	305
4	1.269	53.34	3.375906	16.998	6.93	1.354969	243.968	410
5	1.3875	58.30	2.72	25.6	6.4	1.484	235.32	450
cumthick			**21.17**		**total**		**1463.71**	

SG=1.1+.015*ash

const	slope
1.1	0.015

estimated CBM cc/g — **cc/g to scf** **32.037**

	depth									
Sm	0	50	100	150	200	250	300	350	400	450
1	0	0.1	1.2	2.0	2.7	3.2	3.6	4.0	4.3	4.6
2	0	0.6	1.8	2.6	3.2	3.7	4.2	4.5	4.9	5.2
3	0	1.1	2.2	3.1	3.7	4.2	4.7	5.1	5.4	5.7
4	0	0.7	2.2	3.2	4.0	4.6	5.1	5.5	5.9	6.2
5	0	1.9	3.4	4.4	5.1	5.7	6.1	6.6	6.9	7.2

	S1			S2			S3			S4			S5		
	thick	3.21	gas	thick	8.52	gas	thick	3.34	gas	thick	3.38	gas	thick	2.72	
depth	area	cc/g	mmcf	area	cc/g	mmcf	area	cc/g	mmcf	area	cc/g	mmcf	area	cc/g	gas
0-25	7.69	0.00	0.0	7.23	0.00	0.0	6.91	0.00	0	5.93	0.00	0	5.83	0.00	0
25-75	7.69	0.07	92.9	7.23	0.60	1761.5	6.91	1.08	1174.3	5.93	0.71	612.45	5.83	1.90	1434
75-125	7.69	1.22	1563.4	7.23	1.75	5126.1	6.91	2.25	2439.7	5.93	2.24	1941.8	5.83	3.38	2548
125-175	7.69	2.04	2606.7	7.23	2.57	7513.3	6.91	3.07	3337.5	5.93	3.24	2817.5	5.83	4.35	3281.8
175-225	7.69	2.68	3415.9	7.23	3.20	9365.0	6.91	3.71	4034	5.93	4.00	3471.5	5.83	5.08	3829.9
225-275				7.23	3.72	10877.9	6.91	4.24	4603	5.93	4.60	3993.8	5.83	5.66	4267.5
275-325							6.91	4.68	5084.1	5.93	5.10	4428.5	5.83	6.14	4631.8
325-375										5.93	5.53	4800.9	5.83	6.56	4943.9
375-425										5.93	5.90	5126.6	5.83	6.92	5216.9
seam													5.83	7.24	5459.4
totals	**mmcf**		**7678.88**			**34643.68**			**20672**			**27193**			**35613**
total bcf		**125.801**													

Table 6

CBM resource for Illtyd West, Illtyd and Spaceship areas

1km^2 on planimetre = 0.365 seam separation 0.8888 tonnes

	planimetre	km2	av thick	av ash	av RM	SG	10^6	maxdpth	
seam 1	3.635	9.96	6.7	34.0	6.6	1.61	106.64	230	SG=1.15+.015*ash
2	4.524	12.39	6.1	27.4	7.3	1.51	114.70	275	const slope
3	5.413	14.83	4.5	24.4	6.9	1.47	97.80	305	1.1 0.015
4	6.301	17.26	4.1	14.7	7.6	1.32	93.05	410	
seam 5	7.190	19.70	2.4	25.3	6.6	1.48	68.79	450	
		cumthick	**23.72**			total mt	**480.97**		

estimated CBM cc/g **cc/g to scf** **32.037**

	depth									
seam	0	50	100	150	200	250	300	350	400	450
1	0	0.1	1.2	2.0	2.7	3.2	3.6	4.0	4.3	4.6
2	0	0.6	1.8	2.6	3.2	3.7	4.2	4.5	4.9	5.2
3	0	1.1	2.2	3.1	3.7	4.2	4.7	5.1	5.4	5.7
4	0	0.7	2.2	3.2	4.0	4.6	5.1	5.5	5.9	6.2
5	0	1.9	3.4	4.4	5.1	5.7	6.1	6.6	6.9	7.2

	S1			S2			S3			S4			S5		
	thick	6.7	gas	thick	6.1	gas	thick	4.5	gas	thick	4.1	gas	thick	2.4	
depth	area	cc/g	mmcf	area	cc/g	mmcf	area	cc/g	mmcf	area	cc/g	mmcf	area	cc/g	gas
0-25	1.99	0.00	0	2.07	0.00	0	2.12	0.00	0	1.92	0.00	0	1.97	0.00	0
25-75	1.99	0.07	50	2.07	0.60	369	2.12	1.08	484	1.92	0.71	234	1.97	1.90	419
75-125	1.99	1.22	837	2.07	1.75	1073	2.12	2.25	1005	1.92	2.24	741	1.97	3.38	745
125-175	1.99	2.04	1395	2.07	2.57	1573	2.12	3.07	1375	1.92	3.24	1075	1.97	4.35	959
175-225	1.99	2.68	1828	2.07	3.20	1961	2.12	3.71	1662	1.92	4.00	1324	1.97	5.08	1120
225-275				2.07	3.72	2278	2.12	4.24	1896	1.92	4.60	1523	1.97	5.66	1248
275-325							2.12	4.68	2094	1.92	5.10	1689	1.97	6.14	1354
325-375										1.92	5.53	1831	1.97	6.56	1445
375-425										1.92	5.90	1955	1.97	6.92	1525
425-475													1.97	7.24	1596
seam total	9.96	**mmcf**	**4110**	12.39	**mmcf**	**7254**	14.83	**mmcf**	**8515**	17.26	**mmcf**	**10371**	19.70	**mmcf**	**10411**
total bcf			**40.7**												

Table 7

CBM resource for Garlic Ring North of West Illtyd areas

NOTES planimeter 1 and 2 seams on east side of syncline to axis
and seams 3,4,5 from west from west north projection of west Illtyd to syncline axis

1km2 on planimetre 0.02427 seam separation 0.025

	seam	plan	areaKm2	av thick	ash	RM	SG	mt	maxdpth	
garlic	1	0.465	19.16	2.56	27.8	6.3	1.517	74.412	230	SG=1.15+.015*ash
Garlic	2	0.465	19.16	3.28	36.7	5.6	1.6505	103.73	275	const slope
W Il	3	0.565	23.28	3.91	13.1	7.6	1.2965	118.02	305	1.1 0.015
W Il	4	0.565	23.28	2.76	14.1	7.6	1.3115	84.274	410	
W Il	5	0.565	23.28	4.1	34.8	5.7	1.622	154.83	450	
		cum coal		**16.61**			**total**	**535.27**		

estimated CBM cc/g **cc/g to scf** **32.037**

	depth									
seam	0	50	100	150	200	250	300	350	400	450
1	0	0.1	1.2	2.0	2.7	3.2	3.6	4.0	4.3	4.6
2	0	0.6	1.8	2.6	3.2	3.7	4.2	4.5	4.9	5.2
3	0	1.1	2.2	3.1	3.7	4.2	4.7	5.1	5.4	5.7
4	0	0.7	2.2	3.2	4.0	4.6	5.1	5.5	5.9	6.2
5	0	1.9	3.4	4.4	5.1	5.7	6.1	6.6	6.9	7.2

	seam1	thick	2.56	seam2	thick	3.28	seam3	thick	3.91	seam4	thick	2.76	seam5	thick	4.1
depth	area	cc/g	gas	area	cc/g	gas	area	cc/g	gas	area	cc/g	gas	area	cc/g	gas
0-25	3.8322	0	0	3.193506	0	0	3.326	0	0	2.5869	0	0	2.3282	0	0
25-75	3.8322	0.072756	34.6893	3.193506	0.6023	333.59	3.326	1.0806	583.6967	2.5869	0.7052	211.56	2.3282	1.9021	943.51
75-125	3.8322	1.22459	583.871	3.193506	1.7527	970.78	3.326	2.2451	1212.693	2.5869	2.236	670.77	2.3282	3.3798	1676.5
125-175	3.8322	2.04183	973.522	3.193506	2.569	1422.9	3.326	3.0713	1658.973	2.5869	3.2443	973.24	2.3282	4.3532	2159.3
175-225	3.8322	2.67573	1275.76	3.193506	3.2021	1773.5	3.326	3.7122	2005.135	2.5869	3.9974	1199.2	2.3282	5.0801	2519.9
225-275				3.193506	3.7194	2060.1	3.326	4.2358	2287.97	2.5869	4.5987	1379.6	2.3282	5.6606	2807.8
275-325							3.326	4.6785	2527.103	2.5869	5.0993	1529.7	2.3282	6.1439	3047.5
325-375										2.5869	5.5282	1658.4	2.3282	6.5578	3252.8
375-425										2.5869	5.9032	1770.9	2.3282	6.9199	3432.4
425-475													2.3282	7.2416	3592
seam totals		**mmcf**	**2867.84**			**6560.9**		mmcf	**10275.57**		mmcf	**9393.3**		mmcf	**23432**
total bcf			**52.5292**												

Table 8

CBM resource for Wind River and area to east

NOTES planimeter 5 and 4 seams

1km^2 on planimeter 0.024252 seam separation 0.4888

	seam	plan	areaKm2	av thick	ash	RM	SG	mt	maxdpth		
Wind	1	0	0.00	0			1.1	0	230	SG=1.15+.015*ash	
River	2	0	0.00	0			1.1	0	275	const	slope
	3	0	0.00	8	39	6.1	1.685	0	305	1.1	0.015
	4	1.240	51.13	4.75	30.8	6	1.562	379.36	410		
	5	1.955	80.61	9.19	29.6	5.1	1.544	1143.8	450		
		cum coal		**21.94**		total mt		**1523.2**			

estimated CBM cc/g **cc/g to scf** **32.037**

seam	depth 0	50	100	150	200	250	300	350	400	450
1	0	0.1	1.2	2.0	2.7	3.2	3.6	4.0	4.3	4.6
2	0	0.6	1.8	2.6	3.2	3.7	4.2	4.5	4.9	5.2
3	0	1.1	2.2	3.1	3.7	4.2	4.7	5.1	5.4	5.7
4	0	0.7	2.2	3.2	4.0	4.6	5.1	5.5	5.9	6.2
5	0	1.9	3.4	4.4	5.1	5.7	6.1	6.6	6.9	7.2

	seam1	thick	0	seam2	thick	0	seam3	thick	8	seam4	thick	4.75	seam5	thick	9.19
depth	area	cc/g	gas	area	cc/g	gas	area	cc/g	gas	area	cc/g	gas	area	cc/g	gas
0-25	0	0	0	0	0	0	0	0	0	5.6811	0	0	8.0612	0	0
25-75	0	0.072756	0	0	0.6023	0	0	1.0806	0	5.6811	0.7052	952.32	8.0612	1.9021	6970.401
75-125	0	1.22459	0	0	1.7527	0	0	2.2451	0	5.6811	2.236	3019.5	8.0612	3.3798	12385.37
125-175	0	2.04183	0	0	2.569	0	0	3.0713	0	5.6811	3.2443	4381.1	8.0612	4.3532	15952.11
175-225	0	2.67573	0	0	3.2021	0	0	3.7122	0	5.6811	3.9974	5398	8.0612	5.0801	18616.15
225-275				0	3.7194	0	0	4.2358	0	5.6811	4.5987	6210.1	8.0612	5.6606	20743.34
275-325							0	4.6785	0	5.6811	5.0993	6886.1	8.0612	6.1439	22514.19
325-375										5.6811	5.5282	7465.2	8.0612	6.5578	24031.11
375-425										5.6811	5.9032	7971.7	8.0612	6.9199	25357.9
425-475													8.0612	7.2416	26536.93
seam totals		**mmcf**	**0**			**0**		mmcf	**0**		mmcf	**42284**		mmcf	**173107.5**
total bcf			**215.391**												

Table 9: CBM in lower member where overlain by upper member

assumed area overlain by upper member 1000 km

seam	depth	thick	coal bt	gas cc/g	area Km^2	ash	SG	bcf
1	880	6.65	9.11	6.3	1000	18	1.37	1838.8
2	910	6.12	8.39	7	1000	18.1	1.37	1882.336
3	940	4.5	6.10	7.7	1000	17.1	1.36	1505.826
4	970	4.08	5.31	8.5	1000	13.5	1.30	1447.134
5	1000	2.36	3.18	9.5	1000	16.5	1.35	967.8682
totals		**23.71**	**32.10**				**tcf**	**7.6**

Table 10: Coal thicknesses intersected in drillholes (Cullingham et. al. 1981)

	seam 1		seam 2		seam 3		seam 4		seam 5		total coal
hole	depth	thick	depth	thick	depth	thick	depth	thick	depth	thick	by hole
BP-78-1	63.97	5.65	103.68	3.3							13.69
			108.45	4.74							
W-79-1					11.4	8	61.29	4.53			12.53
W-79-6/6A							7.12	5.28	87.48	8.84	16.22
							22.06	2.1			
W-79-3											
W-79-5							69.42	3.15			3.15
W-79-23					28.7	3.11	92	4.89			8
WK-80-1	27.13	1.38	63.49	3.95	149.01	1.29	241.82	2.15			15.51
			70.19	3.54	151.95	2.15	266.57	1.05			
WK-80-7	66.25	0.57	100.3	4.08	167..86	3.41	245.67	2.12	325.4	2.72	20.01
	68.27	2.88	105.07	4.23							
W-80-8							8.72	4.69	83.2	9.6	14.29
WI-80-16							40.35	2.12	128.05	2.38	5.32
							57.4	0.82			
WI-80-19					43.2	1.51	107.46	3.04	153.4	3.8	12.89
					48.2	2			172	2.54	
GR-80-27											
GR-80-26	156.05	2.4	196.22	2.57							4.97
SC-80-22			39.76	6.07	97.35	4.81	193.83	7.37	255.42	3.17	29.88
			47.77	5.56	107.17	1.63					
					129.81	1.27					
SC-80-25	153.1	6.42	196.11	4.13	233.5	3.38	321.87	3.83	374.15	2.99	26.6
			203.88	2.62	243.67	1.68					
					262.56	1.55					
TOTALS		19.3		44.79		35.79		47.14		36.04	183.06