COAL QUALITY VARIATIONS IN THE GETHING FORMATION

NORTHEAST BRITISH COLUMBIA

(93O,J,I)

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INTRODUCTION

There are two major coal-bearing formations in northeast British Columbia, both of which outcrop extensively the length of the Peace River Coalfield (Figure 1). Coal seams of economic interest are generally contained in the younger Gates Formation in the southern part of the coalfield and in the Gething Formation in the northern part of the coalfield. The area where exploration interest switches formations is in the vicinity of Mount Spieker (Figure 2). Coal seams in the two formations have different coal quality characteristics. The quality and rank of coal in the Gates Formation does not reveal major variations either at the two mines or in the southern part of the Peace River coalfield. In contrast, the rank of coal in the Gething Formation ranges from high-volatile bituminous to semi-anthracite and there are significant changes in coal quality characteristics. Similar changes are present in other coal formations, such as the Mist Mountain Formation in

TABLE 1
Jurassic and Cretaceous coal stratigraphy northeast and southeast British Columbia

NORTHEAST				SOUTHEAST	
Age	Group	Formation	Description	Formation	Group
Lower Cretaceous	Fort St. John	Hasler	Marine shale		
		Gates	Non marine sandstone, siltstone and coal.		
		Moosebar	Marine shale.		
	Bullhead	Gething	Siltstone, mudstone and coal.		Blairmo
		Cadomin	Conglomerate.	Cadomin	
Lower Cretaceous and Jurassic	Minnes		Non marine sandstone, siltstone and minor coal.	Elk	Kootenay
			Sltstone, mudstone and coal.	Mist Mountain	
	Fernie		Sandstone, siltstone and shale.	Morrisey	Fernie

southeast British Columbia. However they may be more extensive in the Gething Formation, and they are probably less understood because there are no mines in the formation.

This paper presents coal quality and rank information for the Gething Formation. It has been gathered from existing publications and from the coal assessment reports submitted by industry to the government. There is a lot of information in these reports that has now become public because many of the licenses covered by the reports have lapsed.

There is a long history of coal exploration in the Peace River Coalfield, and numerous informal property names have resulted. Figure 2 locates most of the major properties and identifies whether Gates or Gething coal is of more interest. At present there are two mines (Bullmoose and Quintette) extracting coal from the Gates Formation. In the last few years exploration and land acquisition have increased in areas underlain by the Gething Formation, especially in the area between the Sukunka and Pine rivers.

Resource and reserve calculations exist for most of the properties, usually based on exploration that took place in the late 1970's and early 1980's. No attempt is made here to reinterpret the geology of the various properties or to recalculate their reserves.

The Gething Formation, of Late Jurassic to Early Cretaceous age, overlies the Cadomin Formation (Table 1). Therefore it is slightly younger than the Mist Mountain Formation which underlies the Cadomin Formation in the southeast coalfields. The stratigraphy and sedimentology of the Gething Formation has been studied extensively by Gibson (Gibson, 1992). He describes the type section for the formation in the Peace River Canyon where it is 550 metres thick. It generally thins to the south and at the Saxon property at the southern end of the coalfield is only 7 metres thick. In the area of the Sukunka property (Figure 2) the economic coal seams are found in the upper and lower non-marine sections of the Gething Formation, which are separated by a marine tongue (Duff and Gilchrist, 1981 and Legun, 1987). The extent of the upper Gething coal-bearing zone is limited to the Sukunka River-Mt. Spieker area, but it has been suggested that there are other marine tongues in the Gething that wedge out to the south (Broatch, 1988).

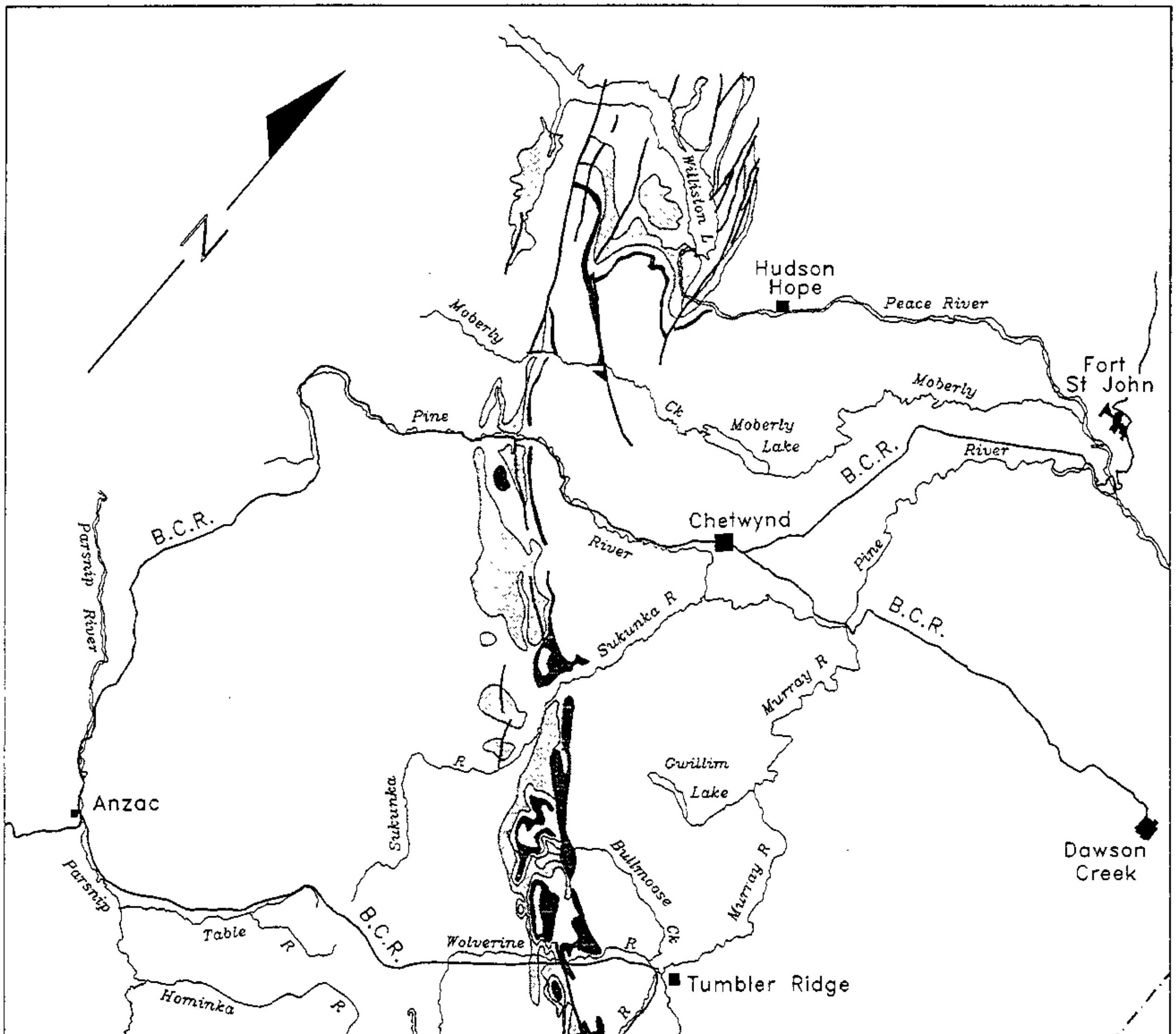


Figure 1: General outcrop pattern of the Gething and Gates formations in northeast British Columbia.

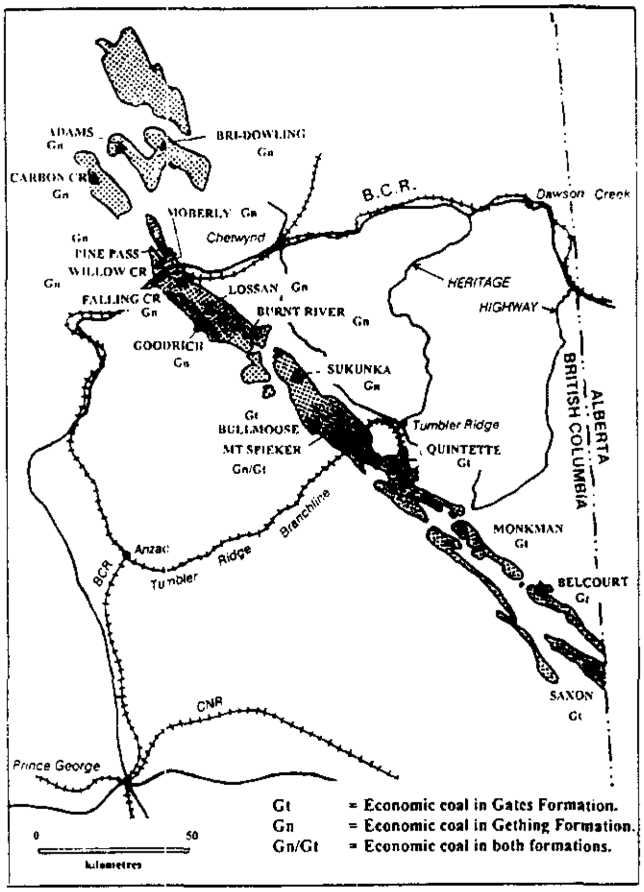


Figure 2: Coal properties in northeast British Columbia identifying them as Gething or Gates formations.

Photo 1: Macrinite in a groundmass of vitrinite B; Gething coal, Pine Pass property. Field of view 0.6 mm

COAL QUALITY AND PETROGRAPHIC CHARACTERISTICS OF THE GETHING FORMATION

One of the most conspicuous characteristics of coal seams from the Gething Formation is the ease with which they wash compared to many seams in the Gates and Mist Mountain formations. Often wash-ash contents of less than 5 percent can be achieved with high yields, as is noted in the discussions of coal quality data from the individual properties described in this paper. Another less welcome characteristic is that the free swelling index (FSI) values often appear to be suppressed and do not increase as much as expected as ash is removed. The explanation for these characteristics is found in the petrography of Gething Formation coal.

There is not a lot of data available on the petrography of the Gething Formation. Kalkreuth (1982) studied the rank and petrographic composition of a number of coals from western Canada but did not provide a lot of petrographic data for the Gething Formation. A number of other studies have concentrated on the Gates Formation (Marchioni and Kalkreuth, 1991 and Lamberson *et al.*, 1991). Some petrographic data are available from coal assessment reports and seven polished samples from the Pine Pass property were examined as part of this study.

Compared to the other major coal-bearing formations in British Columbia (Gates and Mist Mountain), Gething Formation coal has high and variable contents of inert coal macerals (inertinite). Inertinite contents can range from about 20 percent to 60 percent based on data from the Lossan property (Figure 2). This variation explains some of the range of FSI values for washed Gething coals because values will decrease as inertinite contents increase.

The varying concentrations of inertinite do not fully explain the washing characteristics of the coal. Samples from the Pine Pass property contain a lot of fragments composed of more than one maceral. A groundmass of vitrinite B or desmocollinite contains fragments of marcrinite and occasionally semifusinite and fusinite (Photo 1). Generally, compared to coals from the Mist Mountain Formation, there is much less semifusinite and fusinite (Photo 2). These macerals preserve the cell lumen which are the tunnel-shaped cavities in the

Photo 2: Macrinite and semifusinite in a groundmass of vitrinite B, Mist Mountain coal. Field of view 0.6 mm.

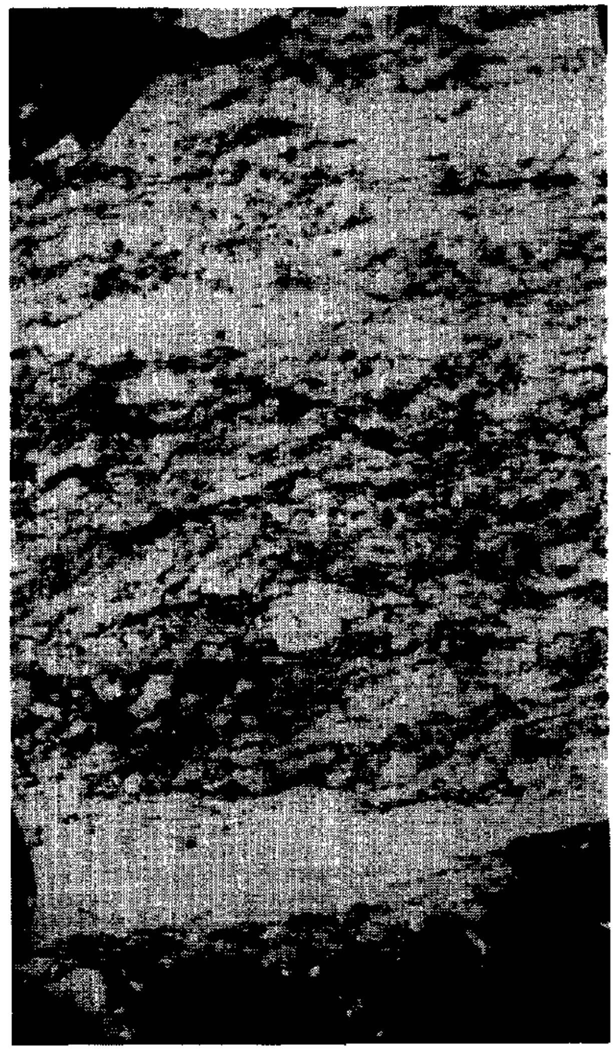


Photo 3: Finely dispersed mineral matter in vitrinite (Gelovitrinite?), Pine Pass property. field of view 0.6 mm.

original vegetation. The lumen provide ideal locations for the precipitation of syngenetic and diagenetic mineral matter, which is very difficult to liberate and remove by washing. Also there are very few dispersed mineral matter grains of extraneous origin dispersed in the vitrinite B, macrinite mixture. These grains will also be difficult to wash-out. Most of the finely dispersed mineral matter which is difficult to wash out is associated with vitrinite A or gelovitrinite (Photo 3).

Depositional Environment

Deissel (1992) describes how various coalification processes lead to the formation of the common macerals and a number of his figures are summarized in Figure 3. The high contents of inertinite found in Gething Formation coal indicate that vegetation experienced a moderate amount of humification in a low pH anaerobic environment, which softened or destroyed most cell structure, followed by periods of oxidation, fungal attack or burning in an aerobic environment. The initial period of humification must have been relatively long as most of the cell structure was destroyed and the inertinite formed was macrinite rather than semifusinite. The vegetal matter was then preserved by being submerged below the water table in an acid anaerobic environment. The term oxidation used to describe one of the processes that form inertinite is a bit misleading. The process is in part oxidation, but also involves removal of volatile constituents, such as hydrogen, with the end result being a decrease in the amount of biomass and an increase in the carbon content.

There does not appear to be much pyro-fusinite or oxy-semifusinite in the Gething coal samples from the Pine Pass property and any degrado-semifusinite that was formed was fragmented and incorporated in desmocollinite without the addition of extraneous mineral matter. A prime way that oxidized vegetation (later to form inertinite) is formed is by fungal alteration in aerobic conditions (Moore *et al.*, 1996). Often the upper part of raised mires, possibly towards the end of their development cycle, are above water and this part of the vegetation mat contains significantly more oxidized vegetation than that lower in the mire (Dehmer, 1993).

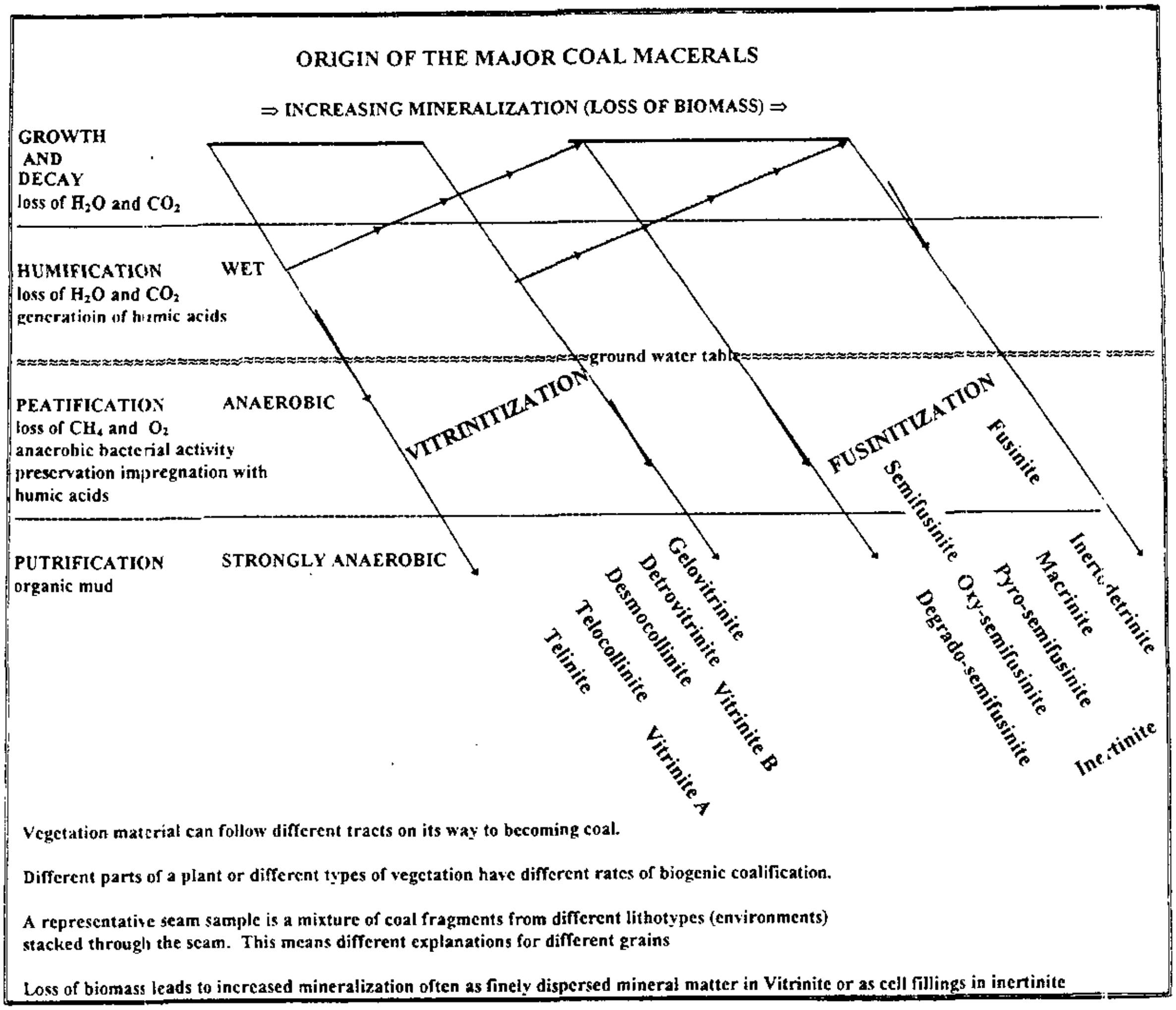


Figure 3: The relationship between various coalification processes and macerals; adapted from Deissel (1992). The vertical axis represents different environments and the horizontal axis the amount of biomass loss or time.

TABLE 2

Mineral Matter in plants and estimation of residual mineral matter in coal

plant	CaO	MgO	K_2O	Na_2O	Al_2O_3	SiO_2	Fe_2O_3	A LTA	Si/Al	B adjusted mm wt	C adjusted mm wt
cedar wood	15	4.2	12	2.8	0.4	3.8	0.3	0.47	9.50	0.03	0.03
cedar bark	22.2	1.7	4	0.7	0.4	2.8	0	10.29	7.00	0.43	0.53
myrtle wood	4.8	7.5	37.4	7.8	0.3	2	0.2	2.1	6.67	0.06	0.08
myrtle bark	10.8	6.5	13.2	3	0.3	2.3	0.1	6	7.67	0.21	0.25
myrle leaves	5.8	13.2	15.6	0.4	0.4	5.4	0.1	6	13.50	0.49	0.59
bay wood	33	8	21	7	3	0	0	2.55	0.00	0.00	0.00
bay leaves	10.1	5.4	13.2	0.3	0.4	2.2	0.1	6.62	5.50	0.22	0.27
grass	1	2.2	5.4	12.5	5.5	23	2.3	18.28	4.18	6.31	7.69
moss	3.5	17.6	1.7	30.3	3.8	15	1.5	12.01	3.95	2.70	3.30
litter	5.4	5.2	1.1	18	0.9	1	0.8	12.3	1.11	0.18	0.23
exc litter	11.8	7.4	13.7	7.2	1.6	6.3	0.51	7.59	3.94	0.72	0.88
AVERAGE	11.22	7.17	12.57	8.18	1.55	5.80	0.54	7.66	5.73	1.03	1.26

A = average mineral matter in plants. Mineral matter in coal is impoverished in Ca, Mg, K, Na with respect to plants

B = adjusted mineral matter calculated assuming a SiO_2/Al_2O_3 ratio of 2 i.e. 40% quartz and 60% kaolinite mixture

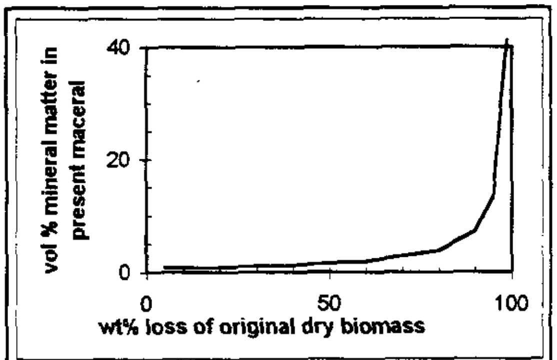
C = adjusted mineral matter calculated assuming only kaolinite survives with SiO_2/Al_2O_3 ratio of 1.2

mm = mineral matter

	B	C
adjusted mm in zero biomass loss sample	1.03	1.26
effective percent after 20% evolatalization	1.29	1.58

99 % of original wt biomass must be removed to increase vol % mm to 43% LTA(low temperature ash) expressed on basis of dry sample

Dry sample devolatilizes by about 20% as rank increases from lignite to bituminuos rank



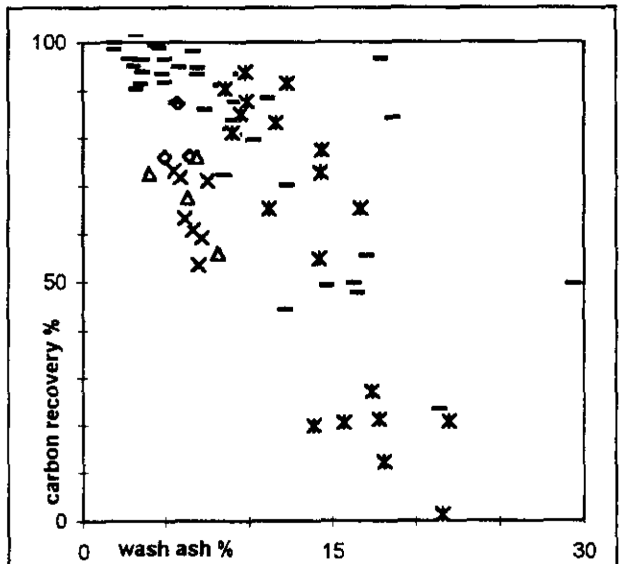
A	B	C	D	E	F
% wt loss bm	cor wt	% wt mm	% wt mm	% vol mm	% vol mm
5	4	2.04	1.67	0.99	0.81
20	16	2.41	1.98	1.18	0.96
40	32	3.19	2.62	1.56	1.28
60	48	4.71	3.88	2.33	1.91
80	64	8.99	7.46	4.54	3.74
90	72	16.49	13.89	8.69	7.21
95	76	28.32	24.39	16.00	13.46
99	79.2	66.39	61.72	48.78	43.74

A= weight loss of biomass
B = weight loss after 20% loss of volatile matter
C = new weight % of mineral matter calculated using B
D = new weight % of mineral matter calculated using A
E = C expressed as a volume percent
F = D expressed as a volume percent

Figure 4: Relationship between loss of biomass and volume percent mineral matter in the remaining coal.

This is probably one of the reasons why the upper parts of some Gething seams are inertinite rich.

The generation of desmocollinite and macrinite generally indicates a prolonged period of humification and destruction of biomass which is accompanied by an increase in the proportion of mineral matter in the remaining biomass. The amount of inherent mineral matter in vegetation varies, but Renton *et al.* (1979) provide an estimate of the average low-temperature ash content of about 8 percent for various plants from the Snuggedy Swamp (Table 2). The ash contains high concentrations of base oxides that are probably lost as the vegetation is dehydrated and coalified to bituminous coal rank. Two estimates of the mineral matter that remains, as an addition to bituminous coal, can be calculated by assuming either sufficient SiO_2 from the analyses is retained to make kaolinite or that sufficient SiO_2 is retained to make a mixture of 40 percent quartz and 60 percent kaolinite. These scenarios provide order of magnitude estimates of 1.6 percent and 2.2 percent weight mineral matter in bituminous coal after a 20 percent devolatalization caused by the increase in rank (Table 2). The relationship of the amount of biomass destroyed to the volume percent mineral matter in the resulting maceral (possibly desmocollinite or gelovitrinite) indicates that very large amounts of biomass must be destroyed to increase the volume of mineral matter (Figure 4). If the inherent ash is about 3 percent, then this implies an overall loss of biomass of about 40 percent. These numbers are only accurate to an order of magnitude because they are based on a small



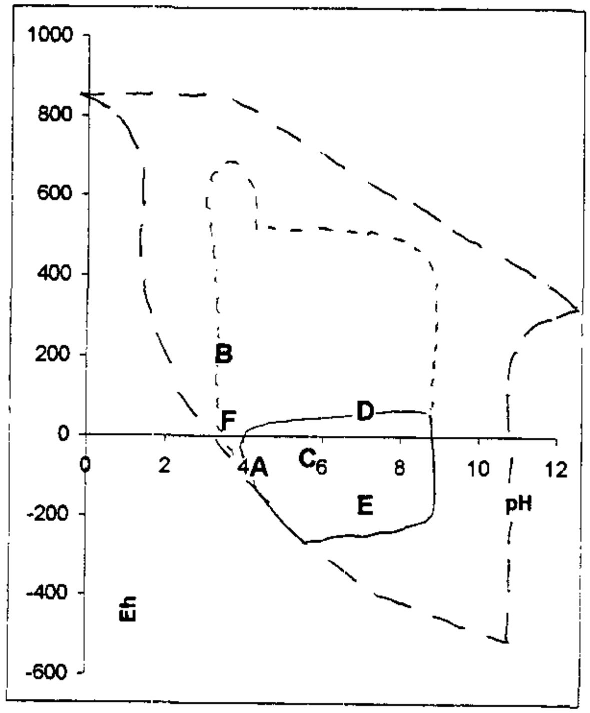
dash = Pine Pass GETHING
Diamond = Quintette GATES
Star = Coal mountain MIST MOUNTAIN
Cross = Elkview MIST MOUNTAIN
Triangle = Fording Coal MIST MOUNTAIN
Carbon recovery = yld x (100- wash min matter)/(100 - raw min matter)

Figure 5: Relative ease of washing of some samples from Gething, Gates and Mist Mountain formations.

database, but they show that the main contribution to the amount of "difficult to remove" ash is probably extraneous mineral matter or syngenetic mineral matter deposited in lumen in semifusinite. It appears that in Gething coal neither of these sources is abundant and therefore the coal exhibits good washability. Gething coal appears to have been isolated from extraneous sources of mineral matter and to have experienced long periods of humification followed by periods of drying during which macrinite was formed.

Leckie and Kalkreuth (1990) have suggested that the Lower Cretaceous coals in northeast British Columbia formed in strandplain environments which were distant and protected from the shoreline and storm-tidal inundations. This does not specifically explain the low contents of extraneous ash or why the wash-ash contents of Gething coals are consistently lower than those of Gates coals. A plot of the relative washing characteristics of coals from the three formations (Figure 5) indicates that the Gething coal from the Pine pass property often washes to a lower wash ash with less loss of carbon than the other formations. Many of the poorer washing samples from the Pine Pass property are hangingwall and footwall samples with high raw ash contents.

Many post Carboniferous coals are enriched in inertinite with respect to Carboniferous coals. One explanation proposed by Taylor *et al.* (1989) is that the high inertinite content of Permian Gondwana coals is caused by cool climates with wet summers and dry cold winters, during which coal swamps dried out and vegetation was oxidized leading to the formation of inertinite. This environment might produce a fine



AREA	pyrite	Ash	REACT	Vit A	Vit B	INERT	Fus	Mac
A	L	L	H	H	L	L	A	A
B	L	A	L	L	H	H	L	H
C	H	A	A	L	H	A	H	L
D	A	H	L	L	H	H	H	L
E	H	L	H	H	L	L	A	A
F	L	L	L	L	H	H	L	H

CONCENTRATIONS DESIGNATED AS L=low H=high A=average
REACT=total reactives INERT= total inertinite
Vit A =vitrinite A Vit B=vitrinite B Fus=fusinites Mac=macrinite

Figure 6: A pH *versus* Eh plot showing the fields for various coal forming environments; derived from. Baas-Becking *et al.* (1960). Long dashes enclose all natural environments, short dashes enclose environments for coal formation and solid line encloses environment for pyrite formation. Gething coals probably formed in environments B and F.

layering of lithotypes similar to varves seen in clays. Possibly the cool climate and lack of ground-covering vegetation also allowed dust to blow into the swamps, which would explain the high contents of dispersed mineral matter found in some Gondwana coals. Hunt and Smyth (1989) suggest that the high inertinite/low ash Permian coals from Australian formed in cratonic basins in fresh water mires with low subsidence rates, allowing for extensive oxidation. Neither of these explanations can be used to explain the variable and sometimes high content of inertinite in Gething coals. However, it appears that conditions in Gething coal swamps were generally drier than those in Gates swamps.

It is possible to characterize Gething coals in terms of their formative swamp environment. To some extent, the contents of ash, pyrite, inerts and reactive macerals are the result of pH and Eh conditions in the swamp and the way these parameters changed over time before the onset of thermogenic coalification. All naturally occurring combinations of pH *versus* Eh are outlined in Figure 6 adapted from Baas-Becking (1960). The depositional pH and Eh conditions for various coals can be plotted and used to draw some conclusions as to their likely contents of ash, pyrite, inertinite and vitrinite. Pyrite is formed by bacterial reduction of sulphate to hydrogen sulphide in a pH environment ranging from slightly alkaline to 4 (Figure 6). The hydrogen sulphide then combines with iron to make pyrite. If this process occurs at higher pH values it will be accompanied by oxidation of biomass leading to a moderate increase in the contents of ash and inertinite. If it occurs at low pH, ash contents will be lower and vitrinite will probably predominate over inertinite. At very low, or high pH conditions pyrite concentrations will be low. High Eh values cause increased oxidation of biomass (increase in ash content) and influence the amount and type of inertinite formed. The exinite macerals are resistant to oxidation and their content may depend on how much biomass is removed, in which case high contents of exinite may be accompanied by high ash contents.

A number of possible pH, Eh environments are identified by letter in Figure 6 and possible characteristics of the coal summarized in the attached table. It is assumed that all environments have already experienced some humification. As in Figure 3, it is possible to use Figure 6 to illustrate that prior to the onset of thermogenic coalification, the biomass moves through a number of possible environments. The three peat environments discussed by Cecil *et al.* (1979) are represented by areas A, B and C in Figure 6. Roberts (1988) discusses the vitrinite and sulphur contents of Permian South African coals in which vitrinite correlates with sulphur content. He suggested that changes in Eh influence formation of inertinite and content of sulphur and the swamp environments he described can probably be represented by areas D and E in Figure 6. Renton *et al.* (1991) found a good correlation between the concentrations of sulphur and exinite in Pittsburgh coals, believed to represent an environment of pH>4.5 (area E, Figure 6). They also suggest that in very low pH environments pyrite does not form and the resultant coal may contain high proportions of bright vitrinite (area A, Figure 6).

Many Gething coals (with the exception of the Bird seam) have low concentrations of pyrite and ash and moderate to high inertinite contents. The inertinite has lost its cell structure and must have formed from biomass that had experienced extensive humification. Based on these characteristics Gething coals should plot within area F in Figure 6. Very low pH values inhibit the formation of pyrite and cause clays to flocculate at the margin of the peat swamp. They would also keep metals in solution and alter clay minerals to kaolinite which would result in coals with kaolinte-rich inherent mineral matter with low base/acid ratios.

The coal rank at the top and bottom of the Gething Formation has been estimated by Karst and White (1980) and Kalkreuth *et al.* (1989). The rank of the Gething coals was established prior to deformation and variations are related to changes in thickness of Gething plus post Gething sediments. The rank decreases to the southeast and northwest away from a central zone where the rank is semi-anthracite. This zone is situated to the east and parallel to the outcrop trend of the Gething Formation. The rank of Gething properties varies from high-volatile bituminous in the northern Peace River Coalfield to semi anthracite north of the Sukunka River.

TECHNIQUES FOR ENHANCING COAL QUALITY DATA INTERPRETATION

Coal quality characteristics of the Gething Formation are discussed below using information from coal assessment reports which are generally over 10 years old. Data available from most of the Gething Formation properties are compiled and attempts made to gain some understanding of overall trends in petrography, ash chemistry and rank. Over time the emphasis on various coal quality parameters has shifted and the challenge is to reinterpret older data in a way that is useful in terms of present day coal quality concerns. A number of approaches are discussed below that attempt to derive additional information from simple coal quality databases. Table 3 provides definitions and formulae for calculating some of the terms used in the following discussion.

Ash Basicity

The base acid ratio of coal is an important parameter used to assess the potential of a coal as a thermal or as a coking coal, yet this type of data are often not available in older coal quality data sets of. Estimates of the amount of non-combustible volatile matter derived from ash, using volatile matter *versus* ash plots and calorific value (CV) *versus* ash plots, provide some information on ash basicity. Ash basicity influences coke strength after reaction (CSR) and the fouling characteristics of ash in boilers. Generally an ash with low basicity is preferred for coking and thermal coals.

Useful information can be obtained from volatile matter (VM) data corrected to zero ash, using either the dry-ash-free calculation (VM daf) or the mineral matter-free basis (VM dmmf) calculation (Table 3). The mineral matter-free calculation attempts to correct for the loss of weight when mineral matter is ashed and when pyrite (FeS_2) in the sample is oxidized to Fe_2O_3 and SO_2. The non-combustible components of the mineral matter that gassify when coal is heated, become part of the volatile matter measurement. If the dmmf correction is applied successfully, then a plot of VM dmmf *versus* ash will be a horizontal line. The daf method corrects only for the dilutant effect of ash and a plot of VM daf *versus* ash will provide a line with positive slope, that intersects the zero ash line at a good estimate of the VM daf at zero ash. The line has a positive slope because of the contribution of non-combustible volatile matter derived mainly from the decomposition of carbonates as the mineral matter is ashed. Magnesium carbonates lose the most weight on oxidation followed by calcium and finally iron carbonates. A simple experiment was conducted to quantify the decomposition of calcite into CaO and CO_2 when heated in an ash analysis. A coal sample was doped with 5 percent calcite and the results indicated that about half the calcite decomposed into CO_2 and CaO when the sample was ashed.

TABLE 3

Formulas used in calculating coal quality parameters.

VOLATILE MATTER (dmmf)
VM dmmf=100-FC dmmf
VM = volatile matter   dmmf = dry mineral matter free
FC dmmf=(FC-.15S)/ {(100-(m+1.08A+.55S)}*100
FC = fixed carbon   m = moisture
A = ash%   S = sulphur%
combine and simplify 1 and 2
VM dmmf=100*(VM-.08*A-0.4*S)/(100-M-1.08*A-0.55*S)
MINERAL MATTER TO ASH
Parr equation mm=1.08*A+0.55*S
mm = mineral matter

A point on a VM daf (y axis) *versus* ash (x axis) plot is moved to the left by an amount equal to the weight difference, mineral matter minus ash, because the X axis is plotted as ash not mineral matter. The point is raised by the same amount because this loss of weight is added to the volatile matter. Consequently the slope of the line is:(mineral matter - ash) / (ash)

This reduces to: (K-1)

where: K = (mineral matter)/ash.

The slope of the line increases as the amount of Ca, Mg and Fe carbonate material in the sample increases. Therefore, for seams low in pyrite it is a rough indication of the basicity of the ash.

The basicity of ash can also be estimated from plots of CV *versus* ash. When coal is combusted for a CV measurement there are various reactions that occur in the ash. These include endothermic break down of Ca, Fe and Mg carbonates to oxides of Ca, Mg and Fe and CO_2, and exothermic oxidation of pyrite to SO_2 and Fe_2O_3. The net amount of heat used when the mineral matter is transformed to ash is approximated by the projected ash concentration at zero CV. If the mineral matter was totally inert the ash value would be 100 percent at zero CV, but as the mineral matter looses weight and uses heat in the process, the ash value at zero CV is reduced to below 100 percent. Figure 7 illustrates the relationship between VM daf slope and ash at zero CV to ash basicity for a number of Gething properties, for which ash-oxide chemistry data are also available. Based on these relationships, if VM daf slope is high and ash at zero CV is low, then the ash base/oxide ratio is probably high.

The use of ash, VM and CV data to estimate ash basicity will not permit a quantitative determination of the ratio but the method discussed above will indicate trends and may be useful in the absence of more detailed information.

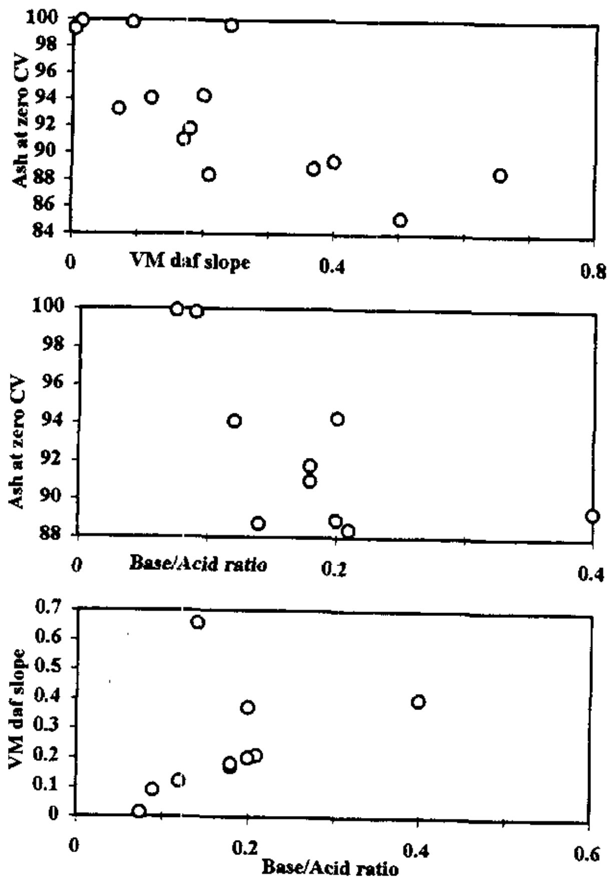
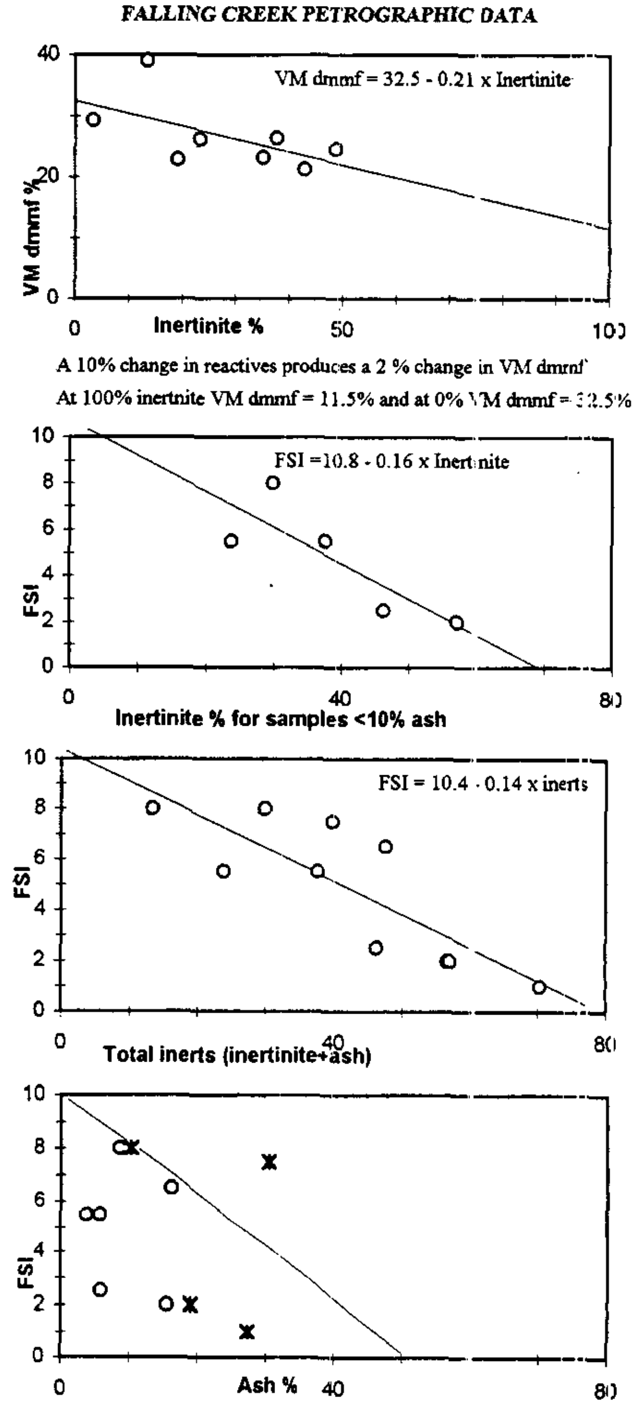


Figure 7: Relationship between slope of a VM daf *versus* ash plot and CV at zero ash to base/acid ratio.

Sulphur and oxide analyses

Plots of sulphur *versus* ash are provided for a number of properties. These are useful because they give a preliminary indication of whether the sulphur is in the coal or ash and how easy it may be to wash out. The same principle can be applied to ash-oxide analyses (Table 4). If oxides have a positive correlation with ash then they will be removed when the coal is washed and if they have a negative correlation then they will concentrate in the coal. A lot of information can be extracted from a correlation matrix of oxides and ash concentrations. For example a negative correlation of CaO and ash implies that there is calcite associated with the coal. A positive correlation of Fe_2O_3 with S indicates the presence of pyrite where as a negative or zero correlation may indicate the presence of organic sulphur and siderite.

A negative correlation of Fe_2O_3 with ash probably indicates the presence of siderite. If base-acid ratios have a negative correlation with ash then there are probably CaO, FeO or MgO carbonates associated with the coal which are difficult to remove.



star = high VM dmmf diamond = low VM dmmf

2 points low FSI and high VM dmmf oxidized and removed from Vm dmmf versus inertinite plots

Figure 8: Relationship between VM dmmf, FSI and inertinite in coals from the Falling Creek property.

Free Swelling Index (FSI)

The free swelling index is a good preliminary measure of the agglomerating potential of a coal. It also has been used as an indicator of oxidation although it reflects more correctly variations in the content of inert

TABLE 4

PART OF A CORRELATION MATRIC FOR OXIDE AND ASH CONCENTRATION DATA FROM SOME GETHING PROPERTIES

		ash	S%	SiO_2	Al_2O_3	Fe_2O_3	TiO	P_2O_5	CaO	MgO	Na_2O	K_2O	SO_3	B/A
Carbon Creek	ash	1.000	0.02	-0.20	0.31	-0.05	-0.22	0.04	-0.15	0.03	-0.59	0.15	-0.01	-0.08
	B/A	-0.08	0.66	-0.90	-0.74	0.99	-0.75	-0.39	0.48	0.90	-0.06	-0.39	0.67	1.00
Falling Creek	ash	1.00	0.58	0.67	-0.96	0.28	1.00	-1.00	-0.94	-0.69	-0.98	0.97	-0.91	-0.42
	B/A	-0.42	-0.98	-0.96	0.67	0.75	-0.38	0.34	0.71	0.95	0.59	-0.62	0.76	1.00
Goodrich	ash	1.00	-0.32	0.23	-0.50	0.21	ND	-0.42	-0.17	-0.08	-0.26	0.03	-0.25	0.06
	B/A	0.06	0.21	-0.84	-0.42	0.90	ND	-0.08	0.51	0.46	-0.05	-0.27	0.61	1.00
Willow Creek	ash	1.00	ND	0.43	-0.54	0.19	-0.51	-0.51	-0.43	-0.18	-0.69	0.14	-0.38	-0.15
	B/A	-0.15	ND	-0.93	-0.55	0.89	-0.33	0.09	0.71	0.97	0.39	-0.52	0.78	1.00
Sukunka	ash	1.00	-0.03	0.56	0.41	-0.18	0.16	0.32	-0.50	-0.67	-0.61	0.46	-0.75	-0.45
	B/A	-0.45	0.56	-0.84	-0.46	0.83	-0.64	-0.29	0.35	0.09	0.28	-0.56	0.41	1.00
Bri-Dowling	ash	1.00	0.12	0.01	0.06	-0.01	0.16	-0.20	-0.02	-0.10	-0.39	-0.03	-0.25	0.02
	B/A	0.02	0.55	-0.12	-0.71	0.88	-0.77	-0.09	0.56	0.69	-0.27	-0.28	0.56	1.00

material in coal, which includes ash, inertinite and oxidized vitrinite. Petrographic data from the Falling Creek property illustrates the relationship between inertinite content and FSI for medium-volatile coal (Figure 8). For samples with low and near constant ash contents the relationship between FSI and inertinite content is:

FSI =10.8 - 0.16 x inertinite

If the same plot is constructed using inertinite plus ash as the X ordinate a similar relationship is derived:

FSI = 10.4 - 0.14 x total inerts

indicating that petrographic inerts and mineral matter have the same effect on FSI. Both relationships indicate that if coal contains approximately 75 percent inert material then the FSI value will be zero and that approximately zero inert material is required to obtain an FSI value of 10. A similar relationship plotted by Price and Gransden (1989):

FSI = 15.9 - 0.29 x total inerts

predicts zero FSI at 55 percent total inerts and an FSI value of 10 at 20 percent total inerts.

A bounding line on the FSI *versus* ash plot (Figure 8) indicates that FSI is zero at 45 percent ash, which implies that the 45 percent ash sample with zero FSI has 75 percent -45 percent = 30 percent inertinite. When the equation of the bounding line on a FSI *versus* ash plot is not the same as that for the FSI *versus* inertinite plot then each FSI/ash point along the bounding line has a different inertinite content in the coal. Inertinite contents decrease to the top left of the latter plot. In fact it is possible to use the inertinite *versus* ash relationship to contour an FSI *versus* ash plot in terms of inertinite content in the coal (Figure 9). Points plotting to the left and below the bounding line are either enriched in inertinite or oxidized vitrinite. The relationship in Figure 9 is extremely schematic but probably gives some indication of the variations in petrography for the Gething Formation. The reactives/inerts ratio for Mist Mountain coals often increases as the ash decreases indicating that much of the finely disseminated ash is in the inertinite material, similar, but weaker relationships exist for the Gething Formation.

Inertinite content can be estimated from VM dmmf values because they increase as the inertinite percent decreases, as illustrated using data from the Falling Creek property (Figure 7) and Price and Gransden (1989,

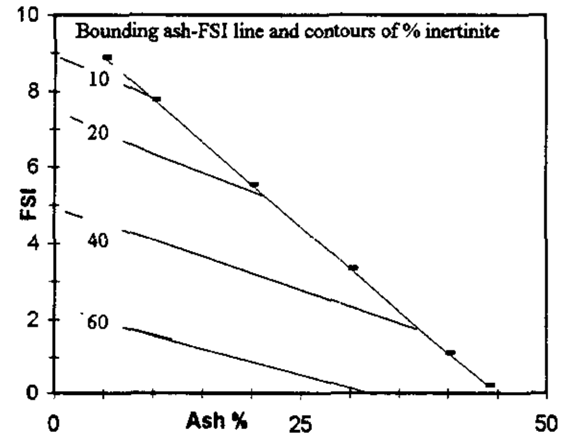


Figure 9: Schematic diagram illustrating variations of inertinite content within a FSI *versus* Ash plot.

Figure 10). Price and Gransden's data are from medium and low-volatile coals and VM dmmf values are 31.3 percent and 27.8 percent at 0 percent inertinite. The Falling Creek data from a medium-volatile coal predict a VM dmmf value of 32.5 percent at 0 percent inertinite. Unoxidized coal in which the FSI is suppressed by an increased inertinite content will have low VM dmmf values. A plot of FSI *versus* ash in which VM dmmf values are posted can be used to illustrate this effect (Figure 10). Data from unoxidized samples which plots in the lower left corner of FSI *versus* ash plots (Figure 10) will have low VM dmmf values (high inertinite contents) and data in the upper left of the plot will have higher VM dmmf values (lower inertinite contents).

Natural oxidation increases the volatile content and VM dmmf values of coals. This means that samples which plot in the lower left corner of an FSI *versus* ash plot and have markedly high VM dmmf values are oxidized, whereas if they have low VM dmmf values then they are enriched in inertinite. Data from Price and Gransden (1989) illustrates this effect (Figure 10) which may be a useful way of identifying oxidized samples using only proximate and FSI data. Oxidized samples are plotted with filled squares in Figure 10 and the VM dmmf values clearly identify 4 of the 5 oxidized samples.

Calorific value is decreased by oxidation but is not as sensitive to it as FSI. This is illustrated in a CV *versus* ash plot (Figure 10), in which the oxidized sample plots

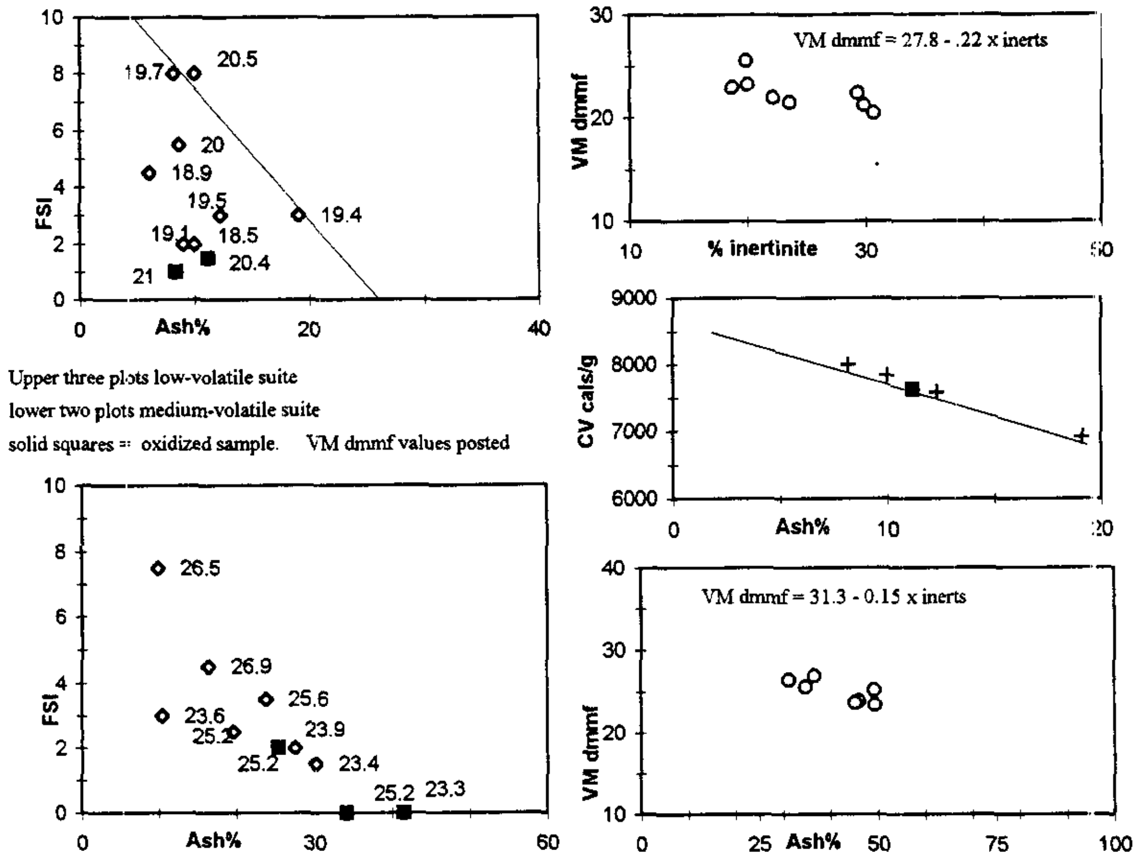


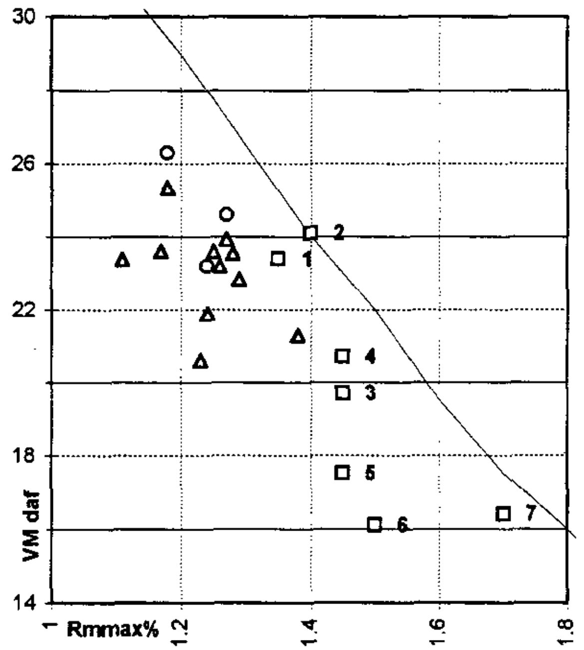
Figure 10: Use of VM dmmf values on an FSI *versus* ash plot to identify oxidation, data from Price and Gransden (1989).

slightly below the line. It is also important to realize that the heat content of pure carbon is about 8160 cals/g whereas that of methane is 12474 cals/g. Therefore, a reactive maceral composed of 32 percent volatile matter (from a medium-volatile bituminous rank coal) has a heat value about 8 percent greater than that of an inert maceral composed of 11 percent volatile matter. As a consequence, a sample with low FSI may plot below the best fit line through data on a CV *versus* ash plot because of high inertinite content. In fact a 20 percent increase in inertinite content can result in about a 150 calorie drop in heat value.

Estimation of Rank

Volatile-matter data (daf at zero ash basis) can be used to predict rank based on the assumption that coal samples are composed mostly of vitrinite. This is a valid assumption for most Carboniferous coals but not for Cretaceous coals. Stach *et al.* (1986, page 45) provides a table of ASTM criteria used to define coal rank. The equivalent mean maximum reflectance of vitrinite values (Rmmax percent) and VM daf values in the table provide a curve that can be used to predict the rank of typical eastern American coals, which contain over 80 percent reactive macerals (Figure 11). The use of VM daf values to predict rank will not work as well for Cretaceous coals because they have higher inertinite contents and lower VM daf values than Carboniferous coals of similar rank. Therefore rank estimates will generally be too high. At any rank, the volatile content of reactive macerals is higher than that of inert macerals and the volatile content of coal is a blend of these two values diluted by any ash present. If Rmmax percent and VM dmmf data are compared to a standard curve provided by Stach *et al.* (1986), then it is possible to estimate the relative degree of inertinite enrichment in the samples based on the distance points plot below the curve (Figure 11). Petrographic data (Falling Creek property, Figure 8) indicate that a 10 percent increase in inertinite content causes a 2 percent decrease in VM dmmf at constant Rmmax percent, which for the property is about 1.2 percent. A VM dmmf value of 32 percent (100 percent reactives) confirms the rank of Falling Creek coal as about 1.2 percent Rmmax, but most of the other data plot below the line implying inertinite enrichments of up to 40 percent. This result is in general agreement with the petrographic data available for the property.

The use of volatile matter to predict rank is complicated by evidence that the volatile content of vitrinite from western Canadian coals is lower than that of vitrinite from Carboniferous coals of the same rank from the eastern United States (Gransden *et al.*, 1991). It



Curve derived from Stach *et al*. (1986) VM daf versus Rmax%
Squares = Willow Creek data with seam number
Triangles = Pine Pass data Circles = Falling Creek data
A 2% change in VM equates to a 10% change in inertinite content

Figure 11: ASTM relationship of VM daf to Rmmax percent and estimation of inertinite content.

appears that vitrinites from British Columbia coals of the same reflectance as vitrinites from Appalachian coals have higher carbon and lower hydrogen contents (Price and Gransden, 1987), indicating that vitrinite reflectance may be in part controlled by the micro porosity of the maceral. In fact there is evidence that the reflectance of vitrinite is positively correlated with the amount of inertinite in a sample (Mastalerz *et al*., 1993 and Kalkreuth, 1982). This is apparent in a summary of petrographic data available for some Gething properties (Figure 12) in which there is a negative correlation of total reactives with Rmmax percent. Kalkreuth (1982) suggests that hydrogen compounds migrate from the liptinite macerals into vitrinite and that this lowers the Rmmax percent value of the vitrinite. He found a negative correlation of liptinite content with vitrinite reflectance. It is also possible that vitrinite in inertinite-rich coal suffers a degree of fusinization, which increases its reflectance and lowers its volatile content. This means that, even if a Cretaceous British Columbia coal sample has a high vitrinite content, the predicted rank may still be too high if it is derived using a VM daf value and data from Stach *et al*. (1986). Care should be taken when interpreting the fine detail of reflectance depth profiles; they may indicate more about petrography and swamp conditions than heat flow during coalification.

COAL QUALITY CHARACTERISTICS OF SOME GETHING FORMATION PROPERTIES

Pink Mountain property

Pink Mountain, which is about 160 kilometres northwest of Fort St. John in the Halfway River map area, is the most northerly property of economic interest. It has been prospected on a number of occasions since 1944 and was drilled in 1971 (Guardia, 1971). The Gething Formation is represented by 310 metres of non-marine sediments containing three coal bearing units. Coal seams up to 6.7 metres thick were found, but. there is evidence of structural thickening of seams. The coal is medium-volatile bituminous in rank based on a VM dmmf calculation of 24.6 percent from a drill core sample (Table 5). The coal has coking potential based on a single FSI measurement of 5.5. However it has high and variable sulphur contents (0.47 percent to 7.1 percent) with very high organic sulphur contents estimated to be up to 6 percent. It has been suggested that the sulphur comes from sour natural-gas leaking from an underlying Mississippian natural-gas reservoir. There is an extensive burn zone in the area which may have been sustained by the leak. It is not clear if sulphur in hydrogen sulphide from natural gas can become organically bound to the coal. However the gas may have increased the sulphur content of the coal after deposition. Coal with high organic sulphur cannot be used for coke making and has a decreased value as thermal coal. High organic sulphur contents have not been found in Gething coal to the south but much of the Gething Formation is underlain by natural-gas fields and the experience of Pink Mountain should be kept in mind.

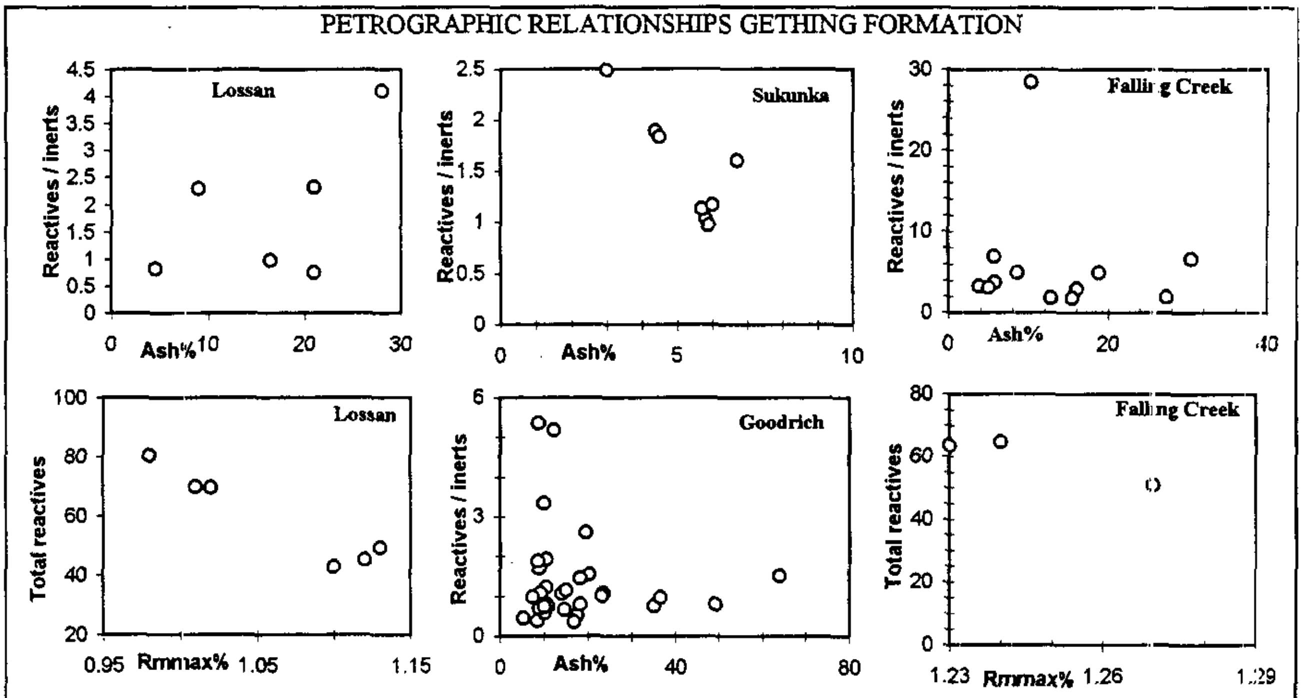
Bri-Dowling property

The Bri-Dowling property was explored extensively by Utah Mining in the 1970's (Duncan, 1980). It is in the Peace River Canyon area, possibly the first area prospected for coal in western Canada. McKenzie (1801) reported coal in the coalfield in 1793 and a number of small mines operated in the area in the early 1900's; though all have since closed.

TABLE 5

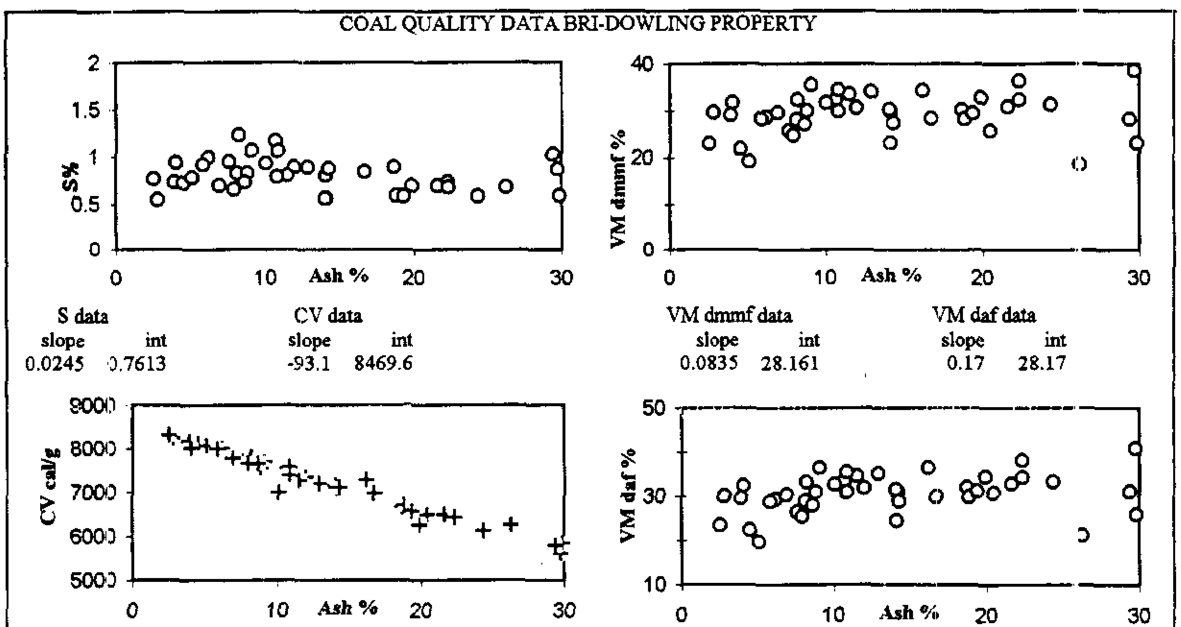
COAL QUALITY DATA PINK MOUNTAIN

				dry basis						VM
hole	seam	thick	H_2O ar	ASH	VM	FC	S	CV	FSI	mmf
trench	p1	6.7	11.02	9.97	34.5	55.5	5.2	5328		29.3
trench	p1		5.62	5.31	33.2	61.5	5.9	6153		28.7
trench	p2	1.07	12.8	11	35.4	53.6	0.8	4611		32.0
trench	p10	3.05	12.67	7.7	33.9	58.4	6.4	6802		28.6
trench	?	3.65	16.12	3.56	27.8	68.6	6	6094		24.0
trench	?	6.1	5.27	1.55	26.6	71.9	6.4	6923		23.0
drill	p1		0.48	5.35	29.4	65.2	7.1	8061	6	24.6



Property	Ash%	S%	Rmmax%	total Vit	Exinite	total semifus	total reactives	macrinite	fusinite	inerto-detrinite	mineral matter	total inerts
Goodrich	17.16	0.30	1.14	51.30	3.62	34.24	61.58	0.58	1.19	1.42	9 53	38.41
Sukunka	5.25	0.76	1.33	58.70	0.00	21.44	65.99	9.16	6.69			34.00
Lossan			1.06	49.85	3.77		59.52	0.35	1.08	2.43	11.67	44.72
Falling Ck	13.39		1.23	63.61	0.05	23.78	78.15		3.19			21.85

Figure 12: Some petrographic relations for the Goodrich, Sukunka, Lossan and Falling Creek properties



Intersection at zero CV =int/slope = 90.96 is less than 100% because of mineral matter/ash ratio and the heat stealing effect of the ash. A smaller value probably means a more basic ash. Predicted mineral matter/ash ratio is 100/90.6 = 1.099

Figure 13: Coal quality data from the Bri-Dowling property; data from Duncan (1980).

The Gething Formation is 425 metres thick and contains over 50 seams, but the majority are less than 1 metre thick. In the upper part of the formation there are four seams of economic interest, named Superior, Trojan, Titan and Falls, that can be correlated across the property. The Superior, Titan and Falls seams are medium-volatile bituminous and the Trojan seam is high-volatile bituminous. Some of the seams have coking properties, but generally the coal is a thermal or weak coking coal. Quality data (Figure 13) indicate that the coal has moderate sulphur. A plot of VM daf *versus* ash provides a line with a 0.175 slope suggesting a moderate base-acid ratio, confirmed by oxide analyses which provide an average base-acid ratio of 0.43.

The seams were tested for methane content to provide information for ventilation design as part of underground mine plans (Duncan, 1980). Gas contents of the Superior seam below 200 metres average 16.5 m^3/tonne and the Titan seam contains 19.5 m^3/tonne at 459 metres, these contents could make the seams interesting targets for CBM exploration. It should be noted that estimates of the residual gas component, which would not be recovered by a CBM well, have been added to these totals. The other two seams contained much less gas.

Adams property

The Adams property, which is located between the Bri-Dowling and Carbon Creek properties, was explored briefly in the 1980's (Ryan, 1982). No reflectance or petrographic data are available, but based on estimates of the VM daf value at zero ash (23.8 percent) a rank of medium-volatile bituminous is predicted for the property (Figure 14). Drilling intersected a number of seams with thicknesses ranging up to 1.6 metres.

The coal has moderate FSI values but one would expect values to be higher based on the rank and low ash concentrations. Based on posting high (star points) and low VM dmmf values (diamond points) into the FSI *versus* ash plot it appears that some of the samples are oxidized but others have high inertinite content. Sulphur is moderately high, averaging about 1 percent, and appears to be concentrated in the ash. No ash-oxide measurements are available for the property but the steep slope of the VM daf *versus* ash line implies a the high base/acid ratio.

Carbon Creek property

The Carbon Creek property was extensively explored for its potential as an underground thermal coal mine by Utah Mining Limited (Janes and Duncan, 1981). There may also be potential for weak coking coal on the property. Nine mineable seams have been identified in the Gething Formation, which is over 1000 metres thick (Gibson, 1985). Coal rank is medium-volatile bituminous with a VM daf value at zero ash of 27.2 percent (Figure 15). Despite favourable rank and low ash contents, seams have only intermediate FSI values, indicating that the coal contains high contents of inertinite. The two seams that average the highest sulphur contents also average the highest FSI values indicating that the sulphur is associated with higher vitrinite contents. Plots of CV *versus* ash and VM daf *versus* ash indicate moderate base/acid ratios.

Twelve Carbon Creek ash-oxide analyses (Figure 16) provide an average base-acid ratio of 0.2, which is acceptable for a thermal coal. No petrography or reflectance data are available but Karst and White (1979) indicate that a Rmmax percent value of 0.9 percent was measured for the top of the Gething. As for most Gething coals, seams wash easily to clean ash contents of less than 5 percent ash.

Falling Creek property

A Gething section of 450 metres, containing seven major seams, is present on the property (Mudry and Horgan, 1983). The thickest seam (Brenda seam) is 50 to 90 metres below the Moosebar and averages 6.5 metres of coal. Other seams range in thickness from 1 to 3.5 metres. Coal rank is medium-volatile bituminous based on Rmmax percent measurements of 1.26 percent to 1.46 percent. Rank calculated from VM daf values is higher and some values are less than 22 percent (Figure 17) predicting a rank of low-volatile bituminous (Stach *et al.*, 1986, page 45). The coal has varying inertinite contents that range up to 50 percent (Figure 8) and some data indicate that the top parts of seams are often inertinite rich. There is a negative correlation of CaO with ash, probably indicating presence of calcite on cleats.

Pine Pass property

There are at least eleven seams in the Gething Formation on the Pine Pass property with thickness varying from 5 metres to less than 1 metre. Seam correlation is difficult because of complex structure. The most recent terminology identifies seams J at the top to A at the bottom of a coal succession that is about 200 metres thick (McKinstry, 1989). Previous reports used a different seam correlation (White and Fietz, 1984). Coal rank ranges from medium-volatile to low-volatile bituminous but resources of coking coal are limited. The coal washes easily and some seams have very low raw-ash concentrations. Sulphur content generally increases up section.

There is no evidence of oxidation in a CV *versus* ash plot. A plot of FSI *versus* ash coded by VM dmmf values (Figure 18) indicates that most of the samples with high VM dmmf values (stars) plot in the upper left and that most of the low FSI samples are characterized by low VM dmmf values (diamonds). This pattern indicates that the low FSI values are caused by high inertinite contents. There are however two samples which come from shallow depths in drill holes that have low FSI values and high VM dmmf values indicating possible oxidation. Organic sulphur is usually associated with reactive macerals so that if FSI values are varying because of changes in reactive content, then there should also be a correlation of FSI with sulphur (Figure 18). There is no evidence of oxidation in polished mounts of samples

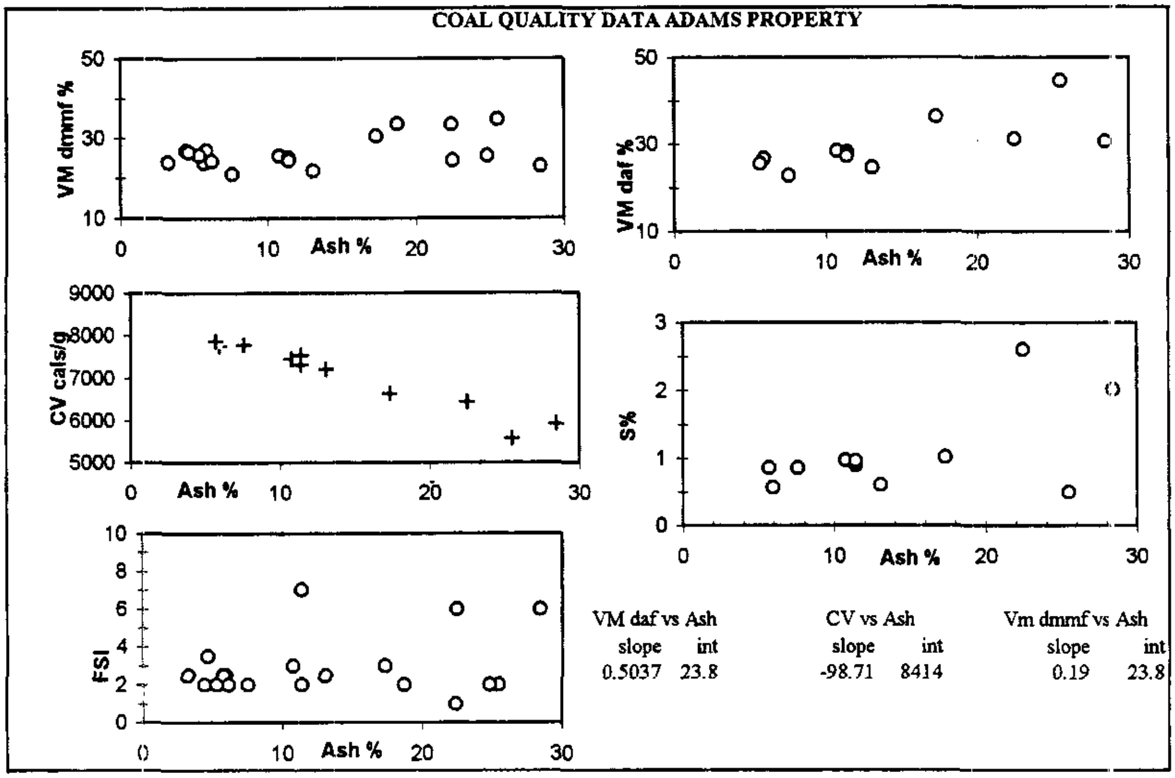


Figure 14: Coal quality data from the Adams property; data from Ryan (1982).

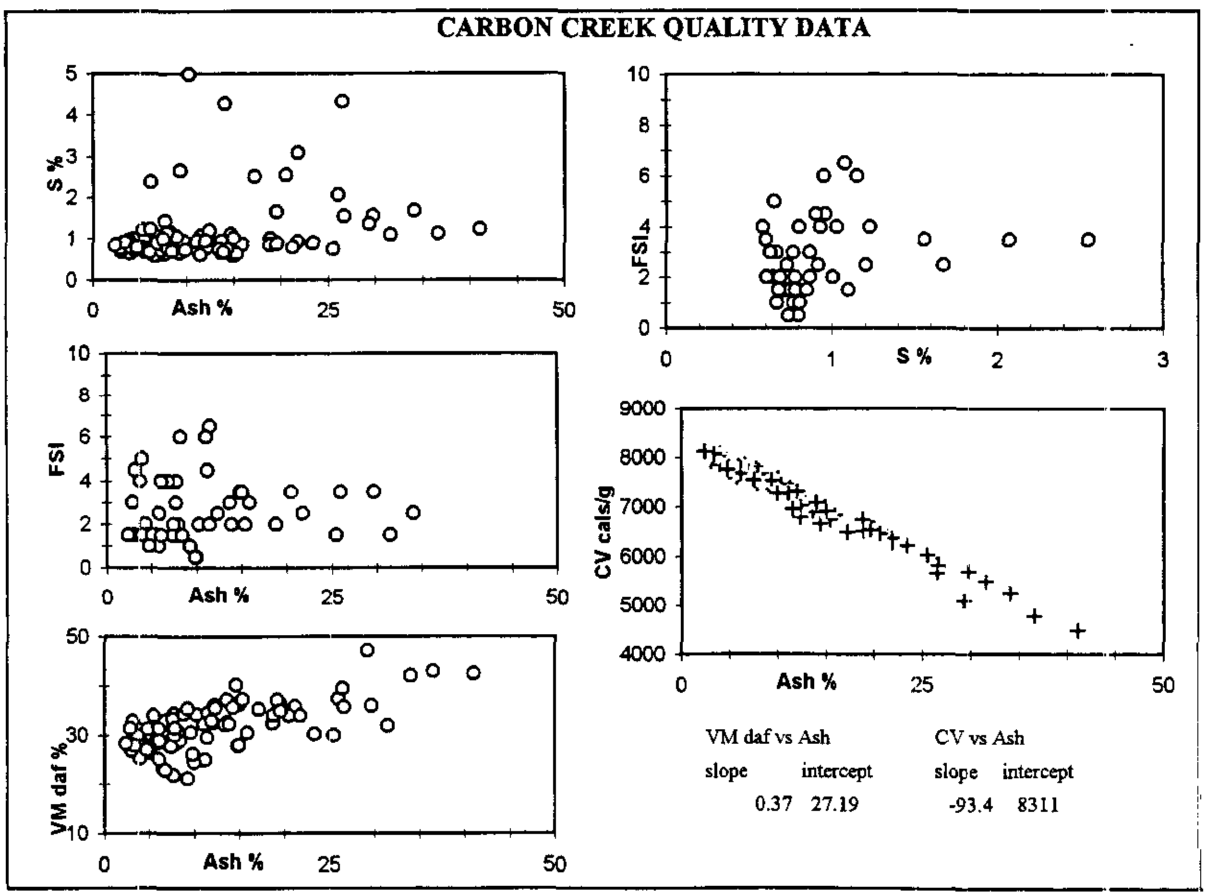


Figure 15: Coal quality data from the Carbon Creek property; data from Janes and Duncan (1981).

studied by the author. In one sample slit-eye vitrinite is present it has been equated with oxidation by some authors); but this is unlikely as the sample has an FSI of 6.5.

Reflectance measurements available for some samples range from 1.1 percent to 1.38 percent. They do not increase consistently with depth and appear to have a negative correlation with VM dmmf (Figure 18) and therefore probably have a positive correlation with inertinite content of the samples. An inverse relationship of vitrinite reflectance with the inert maceral

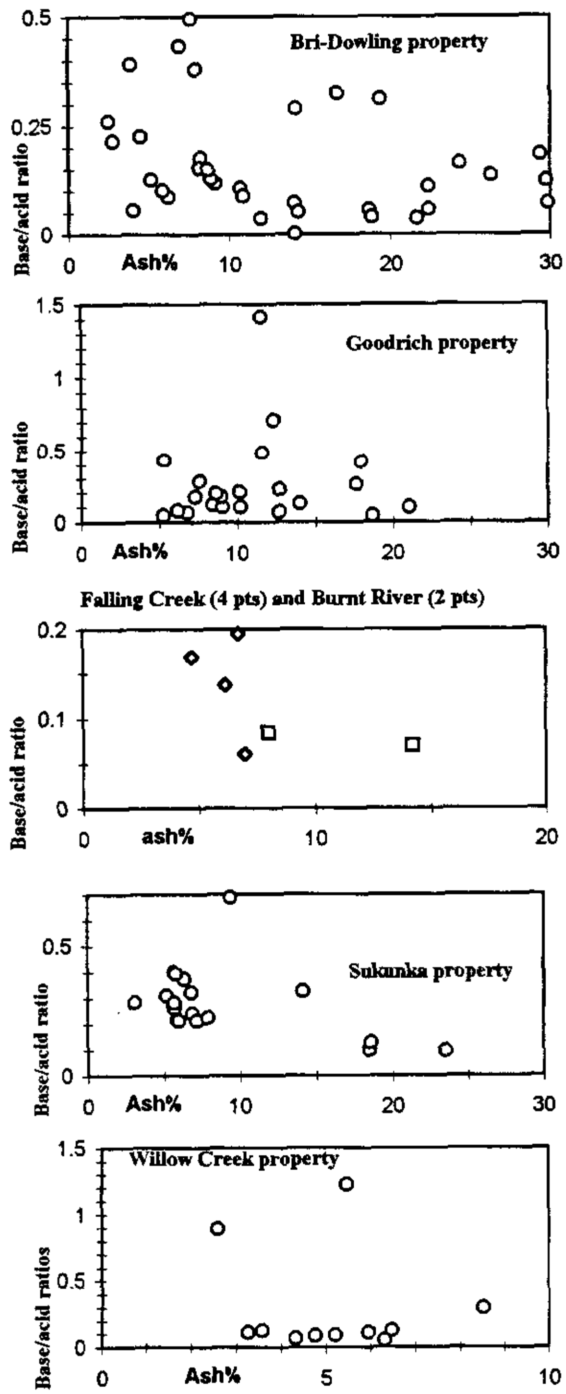
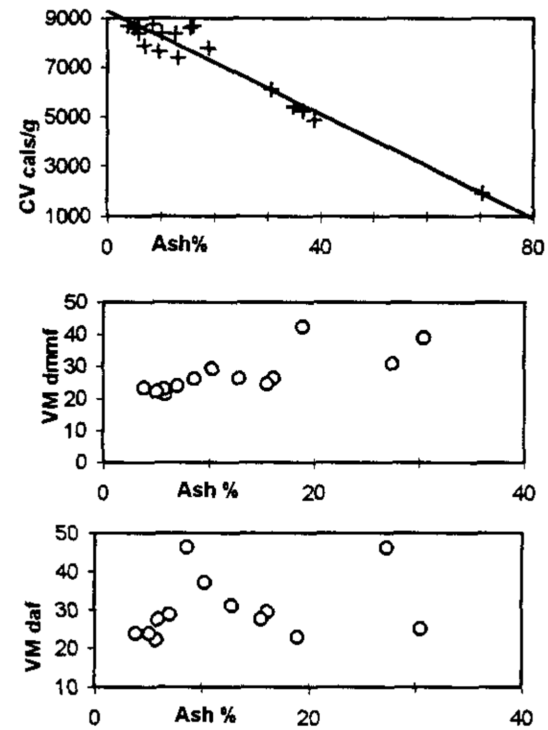


Figure 16: Base acid ratios for some Gething Formation properties.



Cals/g		Vmdaf	
slope	int	slope	int
-105	9312	0.73	23.39

Figure 17: Coal quality data from the Falling Creek property; data from Mudry and Hogan (1983).

content of samples is also apparent in samples from the Lossan and Falling Creek properties (Figure 12).

The Pine Pass samples are characterized by the association of low ash and high inertinite content and therefore have low FSI values which do not indicate oxidation. Finely dispersed mineral matter is associated with gelovitrinite and is probably the residue left after partial loss of biomass during humification. The lack of fusinite and semifusinite means that there are not many cell cavities available to provide sites for difficult to remove ash in the inertinite material, also mixtures of vitrinite B and macrinite are not associated with much finely dispersed extraneous mineral matter.

Moberly property

The Moberly property is west of the Pine Pass property on the north side of the Pine River. The Gething Formation is estimated to be over 350 metres thick and contains at least 7 mineable seams, two in the upper Gething are medium-volatile bituminous and the lower five in the lower part of the formation are low-volatile bituminous (Bienia, 1982). Number five seam contains over 5 metres of coal and is the best mining target. Even at low ash the seam has low FSI values and is therefore a thermal or weak coking coal, probably with a high inertinite content. Sulphur is approximately of 0.5 percent or lower and gross calorific value on an air dried basis ranges from 7000 to 8000 cals/g. A large

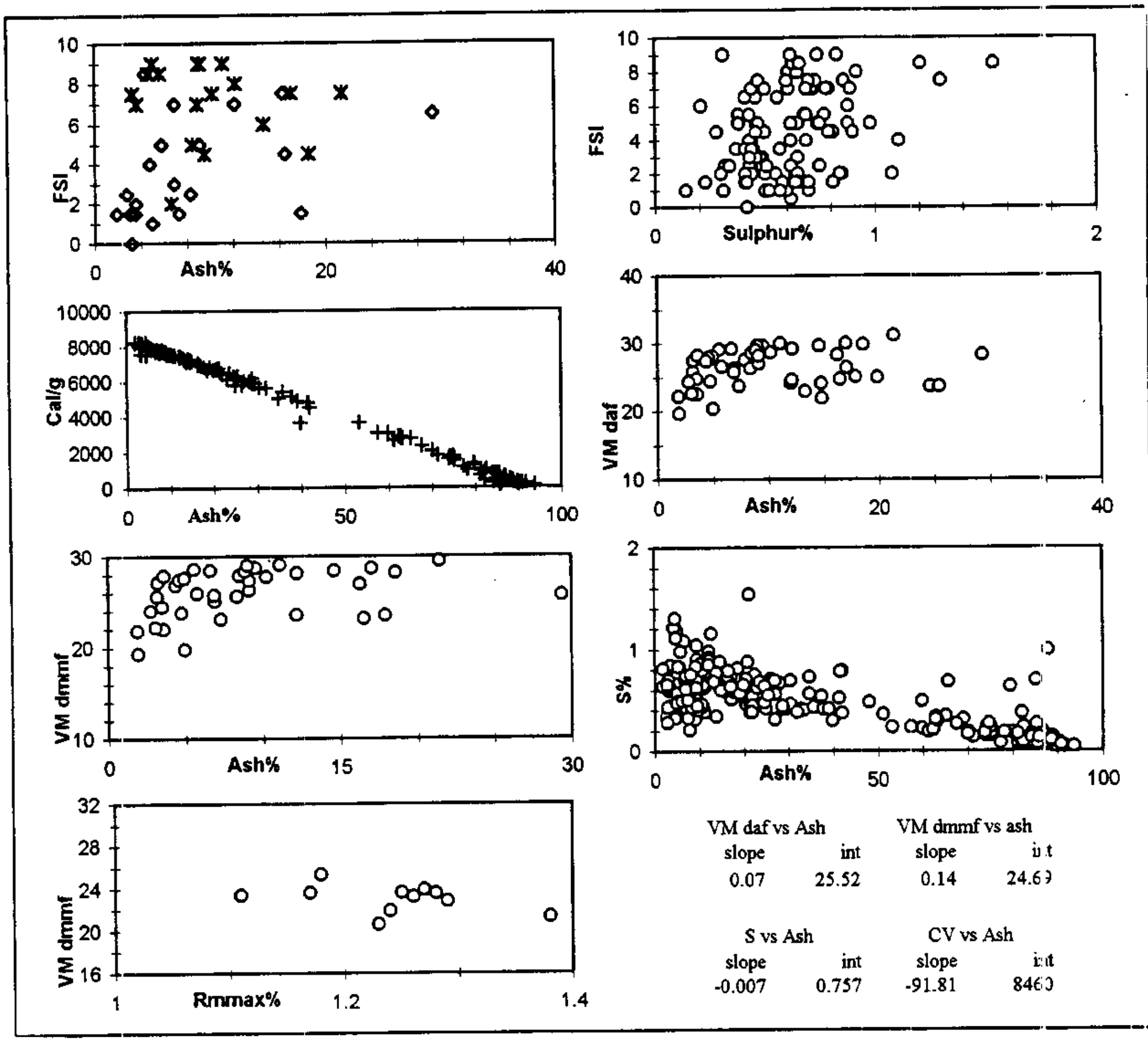


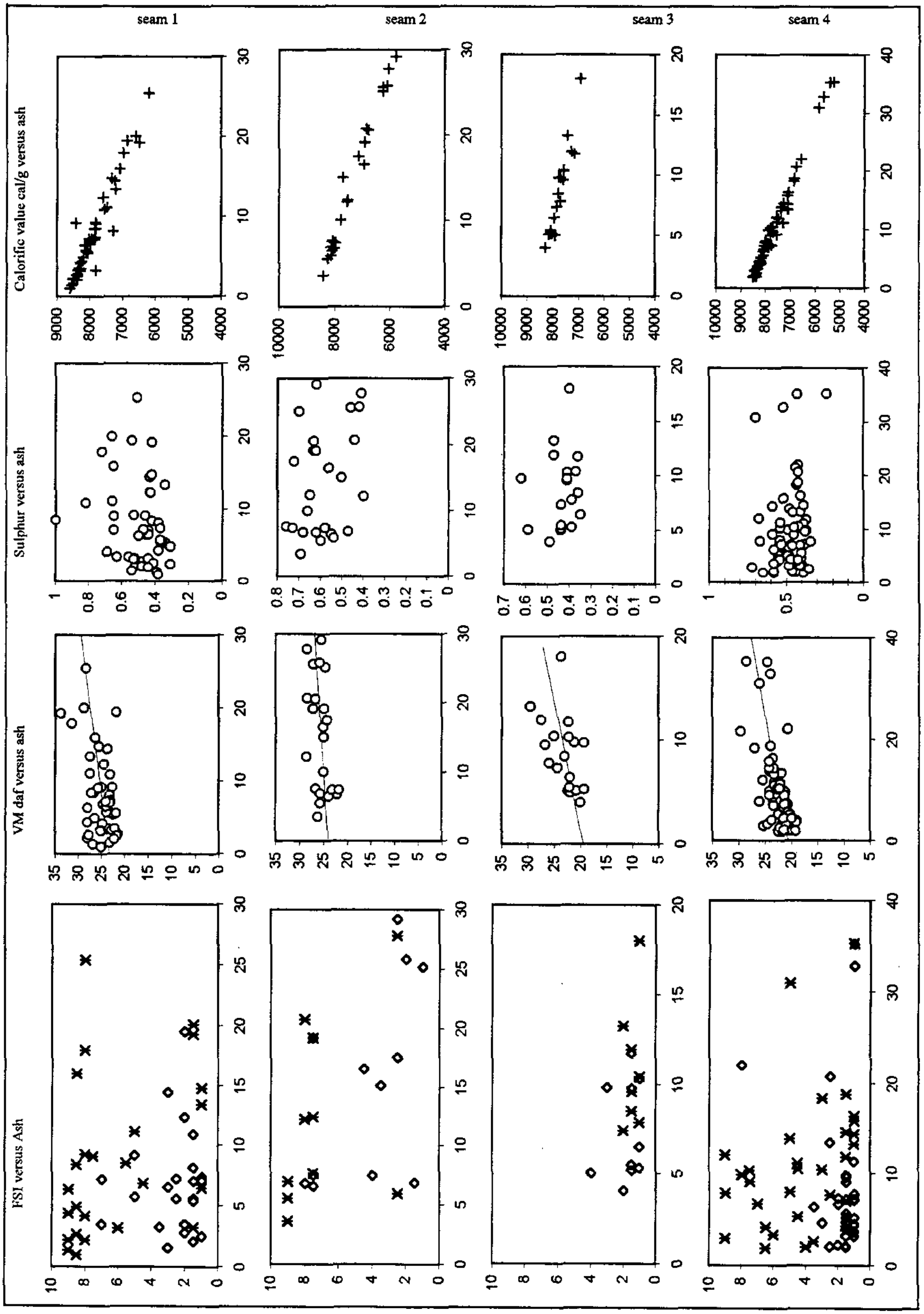
Figure 18: Coal quality data from the Pine Pass property; data from White and Fietz (1984) and McKinstry (1989).

resource has been calculated for the area but no attempt has been made to outline reserves.

Lossan property

Coal is found in the upper part of the Gething on the Lossan property, mostly in the uppermost number 1 seam which averages 8.6 metres in thickness. The total Gething section is 380 to 450 metres thick (Bienia, 1982) and contains five seams in the top 120 metres. Coal rank is medium-volatile bituminous with Rmmax percent values ranging from 0.98 percent to 1.12 percent for 1 seam and higher values up to 1.58 percent for seams lower in the section. Petrography on three samples of 1 seam indicates that the upper two-thirds of the seam is inertinite rich (averaging 54 percent) whereas the lower one-third of the seam averages 26.7 percent inertinite. Ash contents range from 25 percent to 5 percent and are uniform through the seam. The seam's high inertinite content explains the generally poor coking properties despite favorable rank and ash content. A metallurgical coal product with FSI of 4-8 and fluidity of 40-300 ddpm could be mined from the lower third of the seam. The combined seam could be sold as a weak coking or thermal coal.

It is interesting to note that there is a strong positive correlation of Rmmax percent with inertinite content (Figure 12). The higher content of inertinite in the upper part of the seam might indicate long term changes in climate that produced a trend towards drier conditions in the coal swamp prior to burial below the water table. Similar inertinite enrichment in the top of coal seams has been seen by Moore *et al.* (1993). The variable petrography has important implications on the marketability of the seam, as the result is to suppress the coking properties of the coal and to change it from a prime coking coal into a soft (low rank) or weak (higher rank) coking coal. An understanding of the extent of this high inertinite zone within seams is very important because of its implications for coking properties and value of the coal.


seam 1
seam 2
seam 3
seam 4
Calorific value cal/g versus ash
Sulphur versus ash
VM daf versus ash
FSI versus Ash

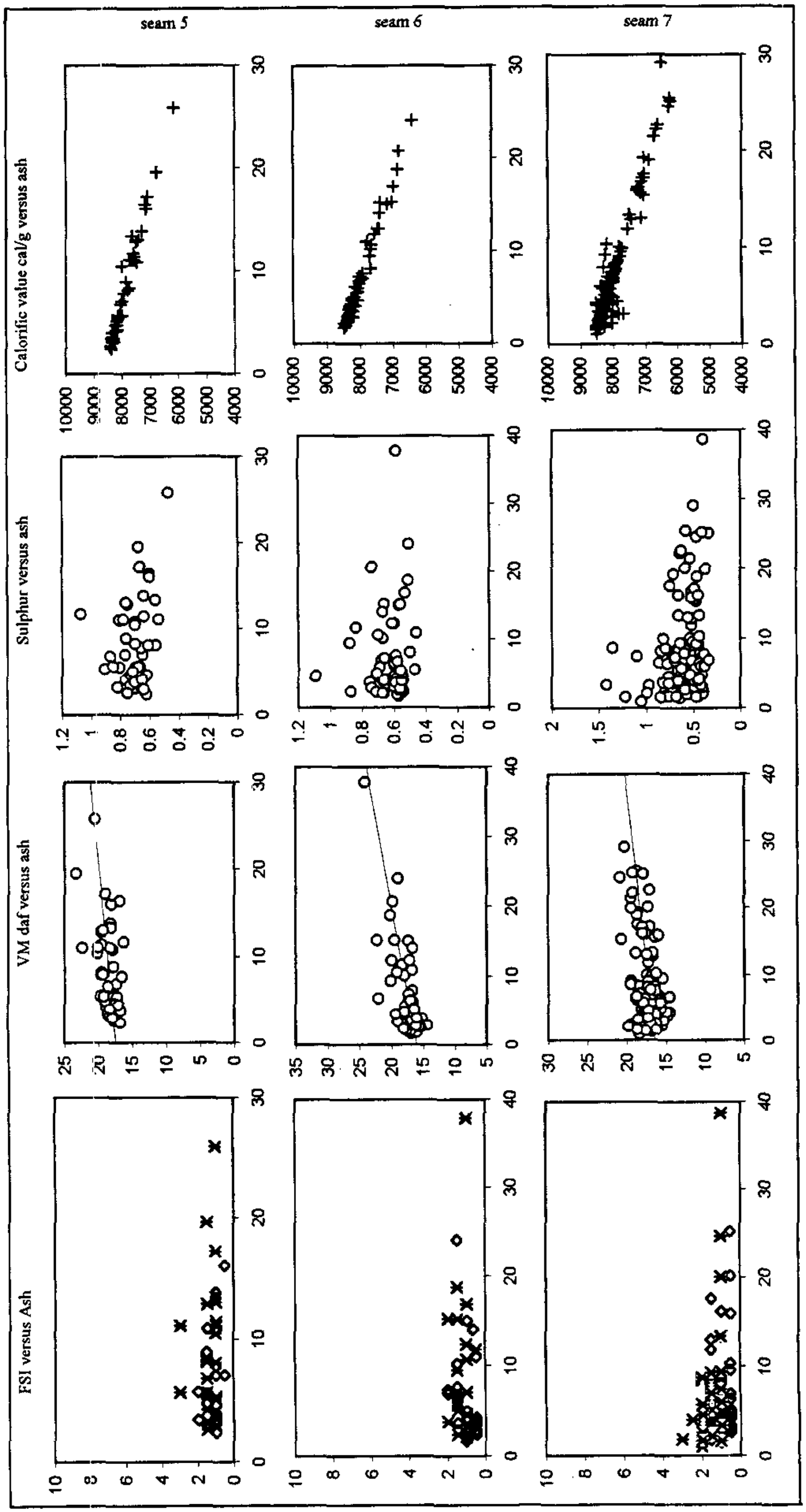
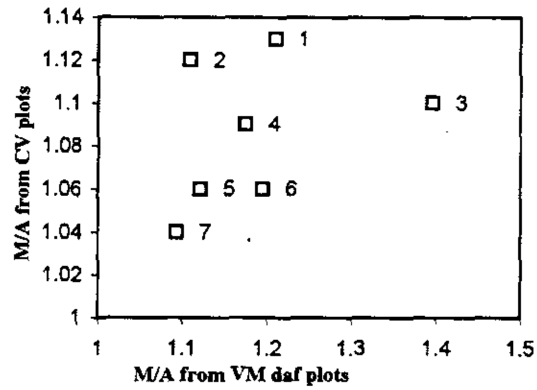


Figure 19: Coal quality data from the Willow Creek property; data from David Minerals (1982).

Willow Creek CV *versus* ash and VM daf *versus* ash data



M/A (mineral matter/ash ratio) can be calculated from VM daf *versus* ash plots and CV *versus* ash plots

seam	M/A (VM)	M/A (CV)
1	1.21	1.13
2	1.11	1.12
3	1.396	1.1
4	1.175	1.09
5	1.122	1.06
6	1.196	1.06
7	1.094	1.04

Figure 20: Estimation of base acid ratio of Willow Creek seams using VM daf and CV data.

Willow Creek property

This property has a long history of exploration and is now being examined for its potential as a surface coal mine. Licenses cover parts of the old Pine Pass and Falling Creek properties as well as the original Willow Creek property. The Gething Formation is a least 300 metres thick and contains four seams in the upper part and 4 (possibly 5) seams in the lower part of the Formation separated by a 100 metre thick barren zone. Seams are numbered from 1 at the top of the formation to 8 at the bottom and 7 seam, which averages over 5 metres of coal, is the thickest. The upper seams are medium-volatile bituminous and may be marketable as coking or weak coking coal. The lower seams are low-volatile bituminous and could be sold as weak coking coal or specialty low-ash thermal coal.

A lot of proximate data are available (David Minerals, 1982) and it is possible to construct a number of plots for each seam (Figure 19). The rank of the seams varies from about 1.25 percent to 1.75 percent and combining these data with VM dmmf data provides estimates of the relative concentration of inertinite in the seams (Figure 11). The vertical distance that data plot below the Rmmax percent *versus* VM daf line in Figure 11 is proportional to the relative enrichment in inertinite in the samples and relative amounts can be estimated using the VM dmmf *versus* inertinite relationship for Falling Creek (Figure 8). Relative estimates of the inert maceral content for the Willow Creek seams agree with the general distribution of FSI values for the seams (Figure 19) and it appears that seams 3, 5, 6 and 7 are enriched in inertinite.

Data in ash *versus* FSI plots (Figure 19) are posted with different symbols depending on whether the VM dmmf values are above (star) or below (diamond) average. The plots indicate that most of the variation in FSI is caused by variation in inertinite content and not the result of oxidation.

The base-acid ratio of each seam is estimated using data from VM daf plots and CV values at zero ash (Figure 20). It appears that seams 1 to 4 in the upper part of the section have higher base-acid ratios than seams 5 to 8 in the lower part of the section. The upper seams have coking potential, therefore it is be important to determine the base-acid ratios because of their effect on coke strength after reaction (CSR) (Ryan and Price, 1993). Higher base-acid ratios lower CSR.

Burnt River property

Over 27 seams of low-volatile bituminous to semi-anthracite rank occur in the Lower Gething on the Burnt River property (McClymont, 1980). Six seams are thick and persistent enough to be considered mineable. The more important seams, which average from 2 to 4 metres in thickness are called the Upper, Lower and 60 seams (Figure 21). Average MV daf values at zero ash range from 18.1 percent to 13.4 percent (Figure 21) confirming a rank of low-volatile bituminous to semi-anthracite. If the seams are enriched in inertinite then the rank may be lower. The slopes of lines through the CV *versus* ash data indicate that the ash has low base-acid ratios, which agrees with two ash oxide analyses that provide an average base/acid ratio of 0.08. Sulphur in the seams is low, averaging 0.3 percent to 0.4 percent and is distributed in the ash and coal. The high rank may preclude the coal being used as a weak coking coal; it may be more suitable for PCI or as a specialty thermal coal.

Sukunka property

Three coal seams (Bird, Skeeter and Chamberlain) occur on the Sukunka property in the upper 60 metres of the Gething Formation, which contains a marine tongue 130 metres thick at this location. There are four thin seams in the lower Gething, below the marine tongue, but they are not considered for development. The uppermost Bird seam contains more sulphur than the Skeeter and Chamberlain seams and is not considered in mining plans, which concentrate on the Chamberlain seam (BP Exploration Canada Limited, 1979). The Chamberlain seam is 1.5 to 2.5 metres thick and has an average Rmmax percent of about 1.3 percent.

Data with above average (stars) and below average (diamonds) VM dmmf values are plotted on Figure 22 which shows that virtually all low FSI samples have below average VM dmmf values and therefore are probably not oxidized. Also there are not many samples with low ash concentrations and low FSI values indicating that there is not a large variation of inertinite content in the seams. This ensures that the coal all be of coking quality. Ash oxide analyses provide an average base/acid ratio of 0.25 (Figure 16) which is one of the

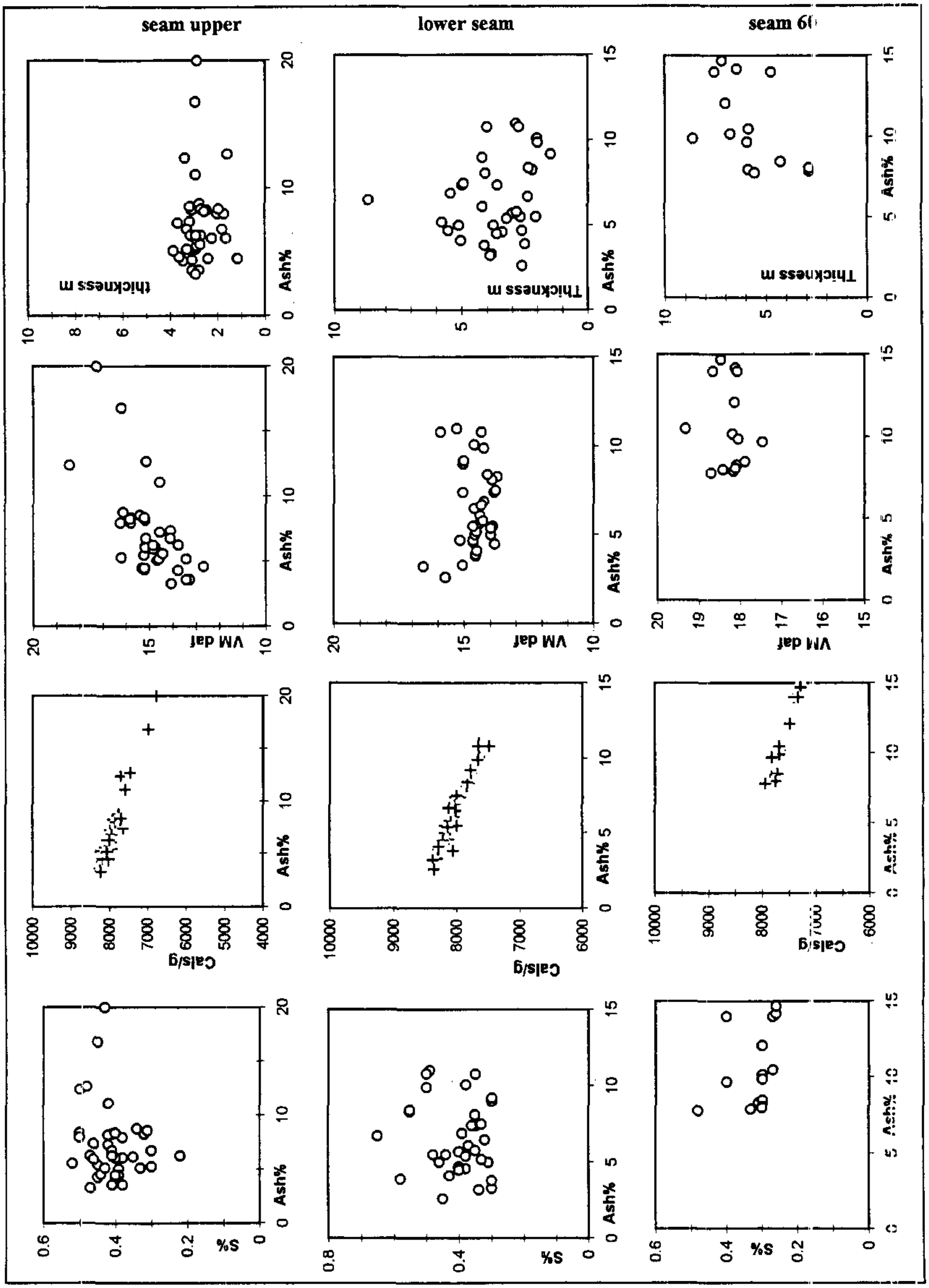


Figure 21: Coal Quality data from the Burnt River Property; data from McClymont (1980).

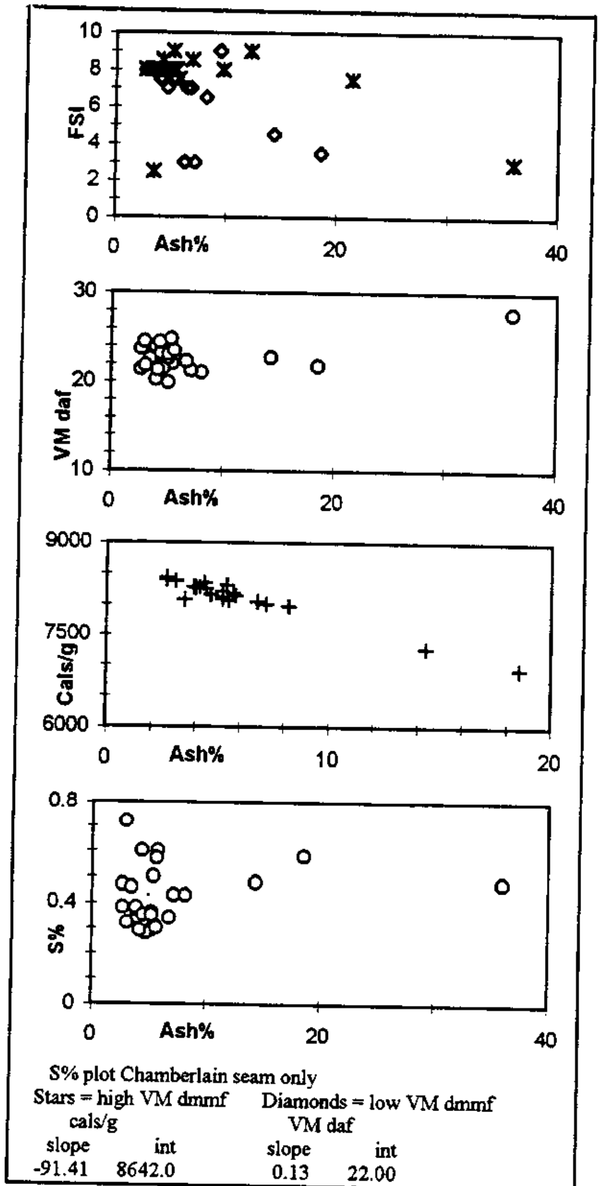


Figure 22: Coal quality data from the Sukunka property; data from British Petroleum Limited Canada (1979)

higher averages obtained for Gething coals and will lower CSR values. The ratio tends to increase as the ash content decreases. This implies that the base oxides effecting the base-acid ratio are associated with the coal part of the sample, probably in carbonates on cleats. It appears that coal above the marine tongue in the Gething may have been infiltrated by solutions that formed carbonate minerals on cleat surfaces. The cleat coating minerals can be removed with difficulty by crushing the coal to a finer size-consist and washing to a lower specific gravity, but if this also increases the base-acid ratio then the improvement in CSR might not be as great as expected.

The Sukunka property has about 190 million tonnes of in place underground mineable reserves. A study conducted in 1977 on nine samples classified three of the samples as highly gassy with methane. A more detailed study of gas content should be undertaken as part of any future mine planning.

Mount Spieker property

The Mount Spieker property is about 4 kilometres east of the Bullmoose wash plant and is the most southerly property in which multiple seams are found in the Gething (Brameda Resources, 1978) . Coal is also present in the overlying Gates Formation in which there are four potentially economic seams. The only important Gething seam is the Bird seam, which is present as a high sulphur 3.5 metres thick upper seam and a 1.75 metres thick lower Bird seam which is lower in sulphur. Other seams in the Upper Gething are not well developed and there has been very little exploration in the lower part of the formation which is 300 metres thick.

The Bird seam is medium to low-volatile bituminous based on a VM daf value of 21.6 percent. It has good FSI values and could be washed to less than 1 percent sulphur. The seam must have a moderate to high percentage of reactive macerals to maintain its rheology at the high rank. The moderate content of pyrite in the samples effects the VM daf *versus* ash relationship by depressing the slope of the line. This is because some of the FeS_2 is oxidized to $FeSO_4$ and SO_2 which effectively increases the weight of the ash. The slope of the line on the CV *versus* ash is decreased because of the exothermic reaction of FeS_2 to SO_2.

Other Gething properties

The Gething Formation is identified as far south as the Saxon property near the Alberta border, but it is thin and usually contains a single seam. While limited there is some coal potential in the Gething Formation in the southern Peace River coalfield. There is a possibility of renewed exploration on the Monkman property and the potential of the Gething coal to provide underground mineable reserves is being considered.

COAL MARKETS FOR SOFT AND WEAK COKING COALS

Coal markets are becoming more diverse and there are now many varieties of thermal and coking coal sold. Over the last few years markets have developed for marginal coking coals called either soft or weak coking coal. Gething coal may make an excellent weak coking coal product.

Soft coking coals are generally low rank and are on the low end of the coking coal window, which encompasses the medium-volatile bituminous coals. The weak coking coals, which are sometimes referred to as semi-soft coking coals, are higher rank and are at the high end of the coking coal range. Soft coking coals are characterized by high fluidity, high positive dilatation and good FSI and they contract in a sole heated oven. If coked on their own, they produce a coke with low stability index (+/- 45 percent) and will produce low pressure and good contraction in the coke oven. However they have a low coke yield because of the high volatile content. They make good bridging coals in a blend because of their high fluidities.

Weak coking coals are so called because high rank is

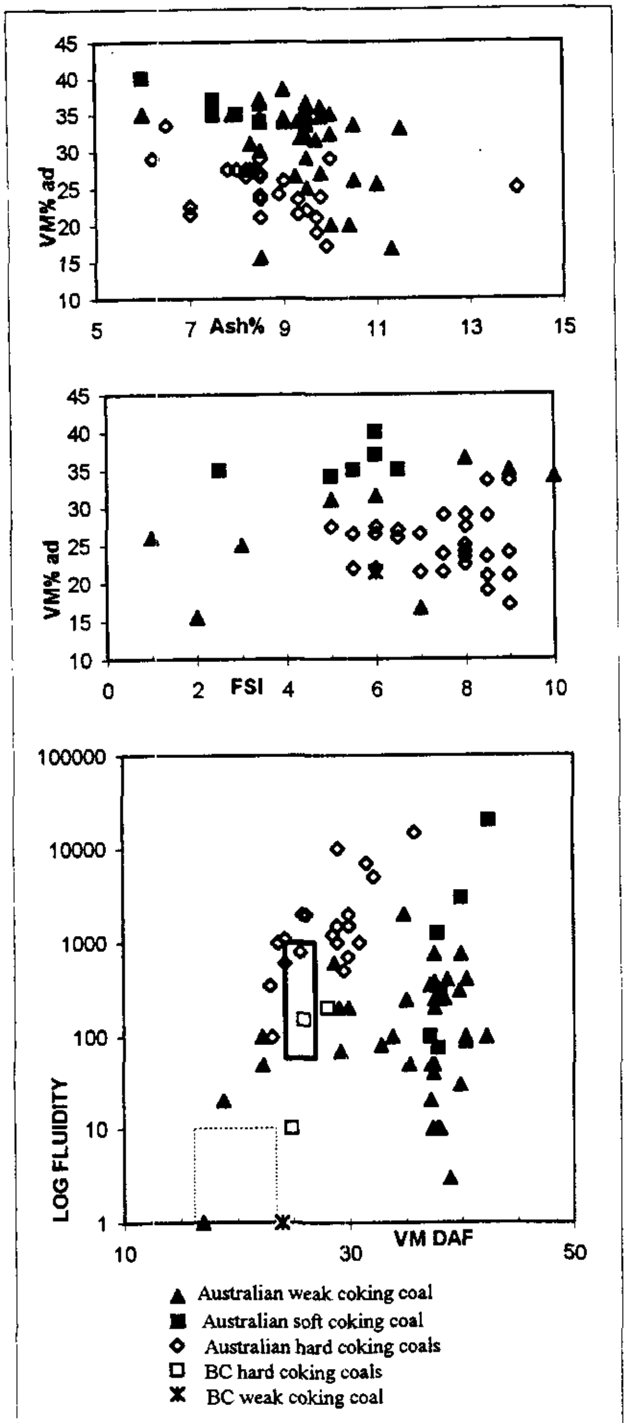


Figure 23: Plot of Australian and British Columbia soft and weak coking coals illustrating blending potential. The two boxes are the optimum blending box (thick line) and the field of some Gething coals (light outline) based on unreleased data.

beginning to destroy the agglomerating properties of the coal, especially if the inertinite content is high (>30 percent). These coals are characterized by low fluidity, low dilatation and moderate FSI. If they have high contents of inertinite, then they will produce cokes with stability indexes in the range of 50 percent. In the coke oven they have approximately zero contraction and produce moderate but acceptable oven pressures. At high rank (Rmmax>1.6 percent) the coal will probably expand in the coke oven and often exert unacceptable oven pressure if coked on its own. Coke stabilities may be in the 55 percent range. Weak coking coals have a higher coke yields than soft coking coals, but produce a lower volume of bi-products.

One of the major insights into coal blending for coke making over the last few years is that low fluidity vitrinites and semifusinite macerals in higher rank coals can soften and flow enough in the coke oven to ensure that a strong and coherent coke is produced. This means that coke oven operators can reduce the amount of low rank, high fluidity soft coking coals in their blends. There are a number of advantages of switching from soft to weak coking coals as long as the blend retains sufficient overall fluidity. Highly fluid coals are usually low rank and therefore produce weak cokes with low coke oven yields. Using less soft coking coal in the blend improves coke yield and makes a stronger coke. However higher rank coals may produce unacceptable coke oven pressures. This is not the case if the coals are high in inertinite which acts to reduce pressure in the coke oven. Therefore, a mixture of weak and hard coking coals produces a stronger coke with better coke oven yield. The mixture does not create much increase in coke oven pressure as long as the weak coking coal has high inertinite content. Ash content in the coke is also a concern. A high volatile coal (35 percent VM) with 10 percent ash will produce a coke with 15 percent ash where as a medium volatile coal (25 percent VM) will produce a coke with 13 percent ash.

Obviously there are advantages gained by switching to a weak coking coal as long as coke oven pressure is kept low and there is sufficient contraction for easy pushing of the coke. Gething coals with moderate to high rank, high inertinite content and low ash contents may be ideal for the expanding weak coking-coal market. A possible problem might be the base-acid ratios of Gething Formation coals, which are variable and sometimes higher than the ratios for other coking coals such as those found in the Gates and Mist Mountain formations.

Coal quality data for a number of Australian export coals are plotted on Figure 23. The data area available at "http://www.dpie.gov.au/resources.energy/coalmin/coalbook/spech.html" on the internet. Also plotted on the lowest plot in Figure 23 is the optimum blending box (heavy line) and a second box (light line) which includes many of the higher rank Gething coals. Individual Gething coals are not plotted, but coals from Willow Creek, Pine Pass and Lossan properties would plot in the box. It is apparent in the plots that the soft coking coals (solid squares) tend to be lower rank (higher VM) and there are not a lot of weak coking coals that are noticeably higher in rank. This has important implications for British Columbian coals, especially Gething coals. As can be seen from the lower plot in Figure 23 weak coking coals provide flexibility to ensure that blends with some Australian hard coking coals plot in the optimum blending box. A majority of the Australian hard coking coals plot to the upper right of the optimum blending box whereas British Columbia weak coking coals plot to the lower left of the box and a mixture of the two will plot in the box.

The shift from soft to weak coking coal and the decrease in the amount of hard coking coal in coke oven blends can be explained by coal and coke quality parameters. The coke maker is maintaining quality, improving yield and saving money. It is important to be aware of the fact that some weak coking coals, such as those from the Gething Formation, may be ideal for the expanding weak coking coal market. High rank, inertinite-rich coals, such as those from the Gething Formation, may not be common. Weak coking coal from the Gething Formation with its low ash, high rank and inertinite content, may be one of the few weak coking coals suitable for blending with Australian hard coking. Weak coking coals presently sell for about $4 to $8 less than hard coking coal. But if availability is limited this price difference might decrease.

CONCLUSIONS

Coal seams in the Gething Formation account for a large coal resource in the Peace River coalfield particularly in the northern part of the field. Smith (1989) estimates that the formation has over 300 million tonnes of measured resource. The raw-ash contents of Gething coal are often low and it washes easily to a low clean ash content. Middling ash seems to be restricted to the reactive macerals and this sometimes causes an enrichment of inertinite in the clean coal. The inverse relationship of ash content *versus* reactive maceral content also causes some low ash samples to have low FSI values. The absence of inherent ash in the inertinite is in part because of the low contents of fusinite and semifusinite macerals which have cell cavities occupied by inherent ash

Not all coal from the Gething Formation is hard coking coal, but much of the remainder is an excellent weak coking coal, which is in demand in today's market.

The maceral composition of seams vary and often the inertinite content of the seam increases towards the hangingwall. Although it might be possible to mine a coking coal product from the lower part of the seam and a thermal or weak coking coal product from the upper part, it is unlikely that this would be economic. Rank in the Gething Formation varies from property to property and because some properties have mineable seams through the full thickness of the formation the rank can vary considerably on a single property.

The existing proximate coal quality data available can be used to provide clues to some of the characteristics of the Gething coal quality in the absence of more detailed tests. It is possible to gain some information about rank, inertinite content, ash chemistry and degree of oxidation from the existing databases that often contain only proximate FSI, CV and sulphur analyses.

There are many aspects of coal quality that all play a part in defining the potential end use and marketability of the coal. Coal properties can only be developed with a clear understanding of the impact of coal quality parameters on the marketability of the clean coal.

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