CONTROLS ON COAL WASHING DIFFICULTY

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INTRODUCTION

Coal seams are a mixture of pure coal and rock. The coal scientist may be interested in the relationship between the coal-rock mixture and the environment in which the coal formed. The mining engineer is more interested in how easy it will be to separate the coal from the rock and how much coal will be lost in the process. A number of papers (Sanders and Brookes, 1986; Sarkar and Das, 1974) have attempted to bridge the gap between the interests of the scientist and the engineer by looking at the linkage between environmental controls on coal formation and washing difficulty. These papers may be of some interest to the engineer, but he or she is more interested in predicting the washing characteristics of a particular coal seam than in finding a genetic explanation for the characteristics.

The first part of this paper looks at some possible environmental controls of washing difficulty of British Columbia coals. Lithotype and maceral evidence are obtained from a number of published papers and the relationship between these data and the amount of dispersed mineral matter is discussed. It is generally considered that it is the amount and distribution of the finely dispersed mineral matter that most effects washing difficulty. If the coal contains a higher than normal amount of finely dispersed mineral matter then it will be difficult to wash. There is no universal definition of this material. It is probably present in the coal as fine particles associated with the different coal macerals, as fillings in the coal macerals and as chemically bound components in the coal molecular structure. Changes in washability are caused by changes in the amount and distribution of this material.

The dispersed mineral matter has a number of origins:

- wind blown;
- water transport;
- original component of the vegetation;
- introduced subsequent to the start of coalification (syngenetic or epigenetic emplacement)

The source and amount of the dispersed mineral matter and the environment in which the coal formed are related and therefore there will be some relationship between washing difficulty of the coal and the depositional environment in the coal swamp.

The second part of the paper examines a way of estimating washing difficulty, using small samples. New data from the Elkview and Quintette mines are introduced and data from the Corbin, Quinsam and Telkwa properties are re-interpreted.

Washing difficulty is not the same as plant recovery, which is the main concern of the plant engineer. Plant recovery is dependent on:

- the type of wash plant used;
- the size-consist of the run-of-mine coal (ROM coal);
- the amount of rock mixed into the coal by the mining process (in-seam and out-of-seam dilution);
- the washing difficulty of the coal.

The first three elements are largely under the control of the operator the last is largely an inherent property of the coal seam.

The difficulty of washing coal is related to the degree of liberation of rock from coal in the size-consist (range of particle sizes) that enters the plant. If there is incomplete liberation of rock from coal then whatever the washing process in the plant, some rock will be misplaced in the clean product and some coal will escape with the reject material. Rock splits are generally easy to liberate from the coal and an increase in their amount in the ROM coal decreases plant recovery but does not make the coal more difficult to wash. It is the amount of dispersed mineral matter that most influences washing difficulty.

A wash plant can respond to changing washing characteristics of ROM coal by making process adjustments or by blending different seams with different washing difficulty. The key is foreknowledge of changes in the washing characteristics of the seams to be mined. The method of predicting washing difficulty proposed in this paper helps in this respect.

PART 1 ENVIRONMENTAL CONTROLS ON WASHING DIFFICUILTY

RELATIONSHIP BETWEEN LITHOTYPES AND DISPERSED MINERAL MATTER

Coal seams can be subdivided into lithotypes which are, outcrop mappable zones of coal within the seam, distinguished by brightness, banding and general appearance. Terms such as bright, banded or banded dull are used. Lithotype mapping is a somewhat tedious and subjective process, however the results may correlate with washing difficulty if there is a relationship between lithotypes and dispersed mineral matter. There may also be an underlying relationship between macerals, that make up the lithotypes, and the dispersed mineral matter.

A number of studies provide information on the maceral composition of various lithotypes and the amount of mineral matter associated with each. The mineral matter that is reported as part of a lithotype analysis is finely dispersed because the lithotype mapping excludes obvious rock bands. This will be the mineral matter that controls washing difficulty.

It is apparent from the maceral composition of lithotypes that there is some correlation of vitrinite content with lithotype brightness (Lamberson and Bustin, 1993; Holuszko, 1993) but in other studies there is little correlation (Cathyl-Bickford, 1993). Cathyl-Bickford concluded that the main control on lithotype appearance is the amount of finely dispersed mineral matter. Dull or banded lithotypes contain more finely dispersed mineral matter than the brighter lithotypes.

Kalkreuth *et al.* (1991) found that there are two types of dull lithotypes, one formed in a dry environment and is inertinite rich, whereas the other formed in a wetter, tidally influenced environment, is inertodetrinite rich and contains more dispersed mineral matter. Similar conclusions were reached by Davis (1992). These two dull lithotypes will probably have different washing difficulties because they contain different concentrations of dispersed mineral matter.

It appears that lithotype appearance may give some indication of washing difficulty but there will be exceptions. A seam with a lot of dull lithotypes may not always be difficult to wash. Seams with a high proportion of the bright lithotypes are more likely to be easy to wash. Only if lithotype appearance is a good indicator of the amount of dispersed mineral matter will lithotype mapping provide useful information on washing difficulty.

Holuszko (1993) studied the washing characteristics by lithotype of seam 16 (Greenhills mine, Figure 1) from the Mist Mountain Formation. She used the optimum washability number introduced by Sarkar and Das (1974) as a measure of washing difficulty and found that, on average, the brighter lithotypes contained less mineral matter and are easier to wash. The optimum washability number correlated with the amount of mineral matter in the lithotypes.

RELATIONSHIP BETWEEN MACERALS AND DISPERSED MINERAL MATTER

If lithotype mapping is not a useful indicator of washing difficulty, then it might be worth looking on a more detailed scale to investigate the relationship between macerals and washing difficulty. This may lead to an understanding of conditions in the original peat swamp that effect washing difficulty. Two studies of coal from the Gates Formation in northeast British Columbia and two studies of coal from the Mist Mountain Formation in southeast British Columbia are discussed.

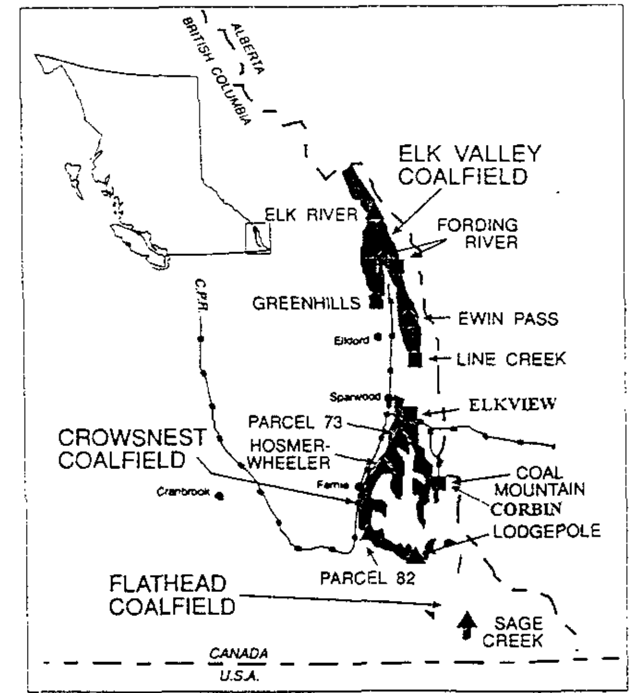

Figure 1. Location of mines in southeast British Columbia.

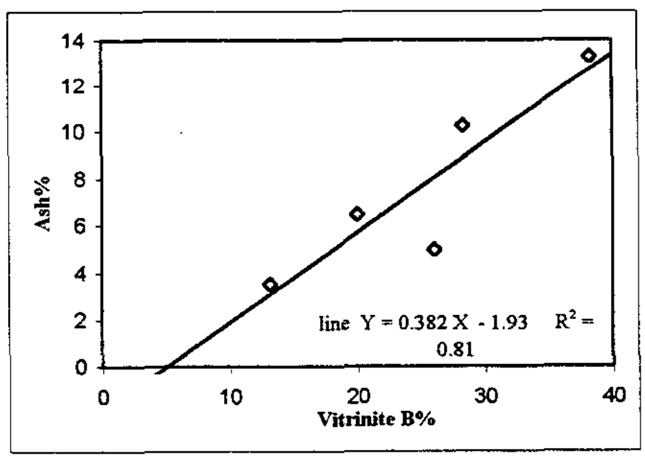

Figure 2. Vitrinite B *versus* ash in lithotypes from the Mist Mountain Formation (data from Holuszko, 1993)

Data from Holuszko (1993) indicate a good correlation of vitrinite B with the amount of mineral matter (Figure 2). Above a threshold of 5%, there is about 0.4% mineral matter for each 1% of vitrinite B. This could be interpreted as meaning that vitrinite B is associated with a potential 40% porosity in the coal seam.

Vitrinite B (equivalent to desmocollinite) is structureless vitrinite of lower reflectance than vitrinite A.. It is formed from the gel components of the degraded vegetation and, based on its present form, may in part have a detritial origin (Stach *et al.*, 1975). When vitrinite is subdivided into vitrinite A and B it is

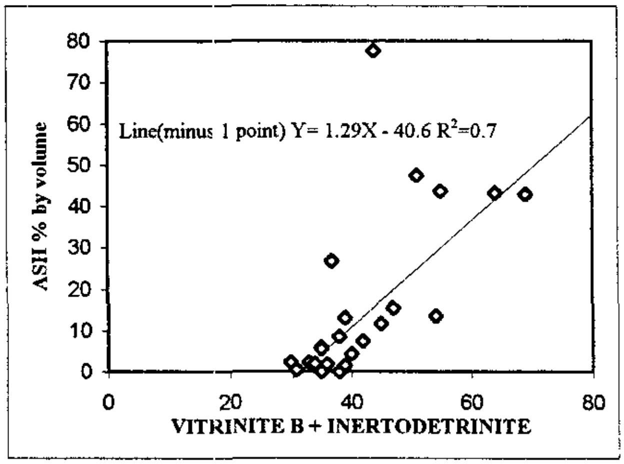

Figure 3. Vitrinite B plus inertodetrinite *versus* ash, southeast British Columbia samples (data from Dawson *et al.*,1994)

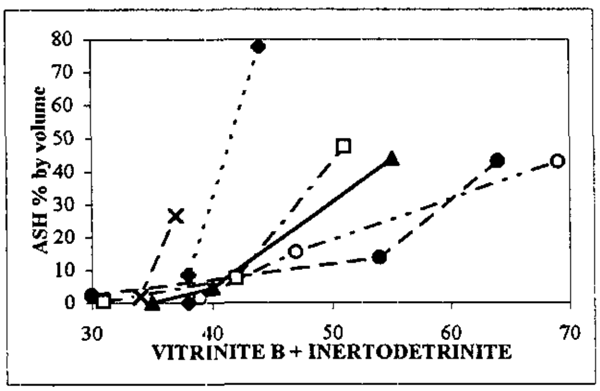

Figure 4. Vitrinite B plus inertodetrinite *versus* ash for samples at different specific gravity (data from Dawson *et al.*, 1994). Lines represent different SG splits of the same sample.

probable that the true detrital vitrinite (vitrodetrinite) is counted with the vitrinite B. Vitrodetrinite is composed of vitrinite fragments produced either by turbulence in the peat swamp or because the swamp was dry and contained a high proportion of reeds easily broken into small fragments.

Detailed petrography for a number of Mist Mountain seams is contained in Dawson *et al.* (1994). Mineral matter was correlated with all individual maceral types and with the sum of vitrinite B plus inertodetrinite. Inertodetrinite is composed of detrital fragments of fusinite and therefore represents the inert maceral contribution to the detrital macerals in the coal. The best correlation was between mineral matter and the sum of detrital macerals, which has an R^2 value of 0.70, excluding one high-ash point (Figure 3). It appears that below about 30% detrital maceral content there is no relationship of mineral matter with detrital maceral content. It is possible that a minimum amount of detrital maceral material is required before water movement through the vegetation mat can introduce finely dispersed mineral matter. The data suite plotted in Figure 3 includes samples that were split into three density fractions (1-1.3 specific gravity (SG), 1.3 -1.6 SG and 1.6 - 2.5 SG). These data also clearly indicate a correlation of vitrinite B plus inertodetrinite with mineral matter, both of which are concentrated in the denser fractions (Figure 4). The three density fractions of each sample are joined by lines in Figure 4; as the ash increases, the remaining organic material contains a higher proportion of the detrital macerals. The slope of the bestfit lines in Figures 3 and 4 indicates that more than 0.5% ash is added to the coal for each 1% increase in the content of detrital macerals. This could imply a porosity of greater than 50%.

General data from Line Creek mine (southeast British Columbia, Figure 1) tend to indicate that variations in washability are not related to over-all maceral content. Seam 8, which has a higher inert maceral content than 10 seam, washes better than 10 seam yet, within 10 seam, the sub-seam with higher vitrinite content washes better than the rest of the seam.

Lamberson and Bustin (1993) report petrography for a number of coals from the Gates Formation in northeast British Columbia. Their data also indicate a correlation of vitrinite B plus inertodetrinite with mineral matter (Figure 5). Data from Kalkreuth and Leckie (1989) appear to indicate that as mineral matter increases, the ratio of fusinite+semifusinite to inertodetrinite+macrinite+micrinite decreases. This may be because of an increase in inertodetrinite in the sample which would indicate a correlation between dispersed mineral matter and inertodetrinite.

The positive correlation of vitrinite B plus inertodetrinite with mineral matter indicates that it may be intermixed with these macerals in Mist Mountain and Gates coals. It has also been suggested that mineral matter is negatively correlated with total vitrinite content (Renton and Cecil, 1979). They proposed that some seams are thinner because the vegetation experienced more biological degradation, leaving a coal seam with a higher ash residue and a greater content of inert macerals. This may imply that an increase in inertinite is accompanied by an increase in dispersed mineral matter, or that there is just an increase in the total mineral matter, much of it occurring as discrete bands.

Gamson *et al.* (1993) suggest that mineral matter may fill in the cell (phyteral) porosity in fusinite and semifusinite. This would imply a correlation of dispersed mineral matter with inertinite content. It is probable that the cell porosity available from the inert macerals is more limited than the coarser porosity made available by the presence of detrital maceral fragments. It is also possible that the cell porosity will not always be filled with finely dispersed mineral matter. Syngenetic mineral matter may well concentrate in the cell structure in the inert macerals, but other, possibly more abundant, types of dispersed mineral matter will be intermixed with the detrital macerals.

In general, there does not appear to be a consensus on the relationship between dispersed mineral matter and coal macerals. However, in the Mist Mountain and Gates formations there is evidence to suggest a

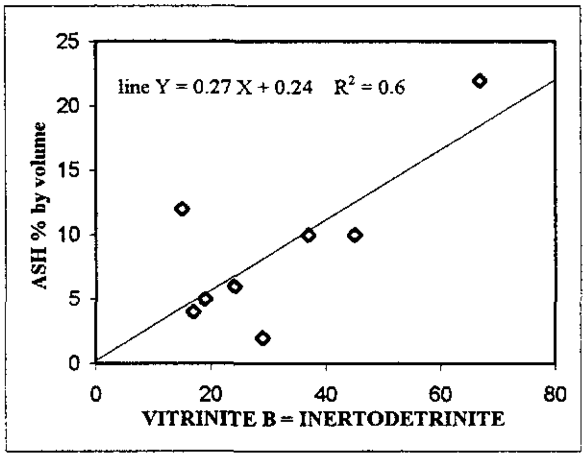

Figure 5. Plot of vitrinite + inertodetrinite *versus* ash for samples from Gates Formation (data from Lamberson and Bustin, 1993).

correlation of dispersed mineral matter with the detrital coal macerals from both the vitrinite and the inertinite groups. This permits some discussion of the connection between coal swamp environment and washing difficulty.

RELATIONSHIP BETWEEN ENVIRONMENT AND WASHING DIFFICULTY

Regional variations in washing difficulty of seams in the Mist Mountain and Gates formations are probably related to changes in the amount of the detrital coal macerals, inertodetrinite and vitrinite B, generated in the coal swamp. A dry environment favours a decrease in the amount of vitrinite and an increase in the ratio of vitrinite B to vitrinite A. Tidal influence, and more agitation and transportation of organic material in the swamp, favours the formation of inertodetrinite and also vitrinite B. The association of inertodetrinite with vitrinite B has been interpreted to represent a reed-type raised bog environment (Diessel, 1982). An increase in the amount of detrital macerals not only indicates drier conditions, but also more degradation and transportation of organic material in the peat swamp. This provides the opportunity for the inclusion of small mineral particles in the organic debris.

Kalkreuth and Leckie (1989) suggest that high contents of inertodetrinite and vitrinite B in the Gates Formation are caused by flooding and turbulence in the swamp, related to off-shore storms. This would explain why there is generally more consistency in washing characteristics laterally within seams than from seam to seam. Seams higher in the Mist Mountain Formation formed in a delta environment, removed from the shore line, and based on this model, should therefore generally have better washing characteristics.

In general, Lower Cretaceous coals of North America are characterized by high contents of inert and detrital macerals (Kalkreuth and Leckie, 1989) and this is considered to be characteristic of coals formed in a strandplain environment. Despite different climate and vegetation types, Permian coals from India, Australia and South Africa, which are often difficult to wash, probably formed in similar environments and are also characterized by high levels of inert and detrital macerals.

Coal seams at the Telkwa property and Quinsam mine (Figure 6) formed in estuarine conditions that were probably fairly tranquil compared to the strandplain environment represented by seams in the lower parts of the Mist Mountain and Gates formations. Petrography for both these properties is presented in Matheson *et al.* (1994).

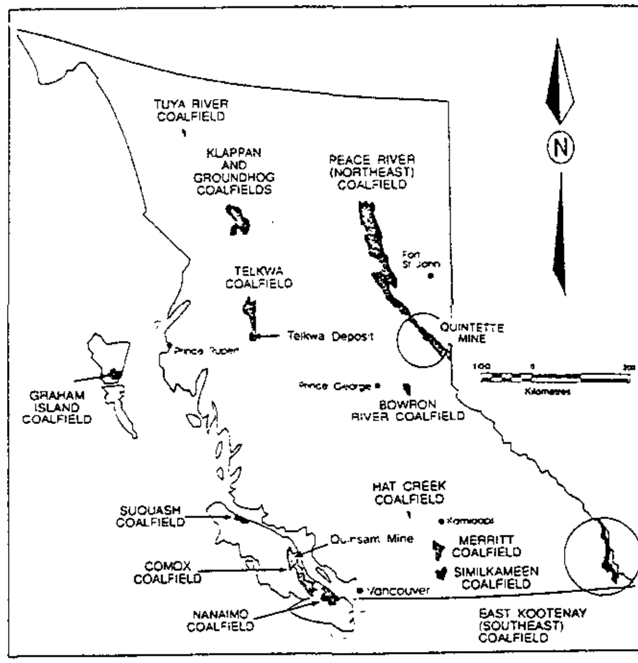

Figure 6. Location map for coal properties in British Columbia.

Data for the number 1 seam at Quinsam reveal a negative correlation of mineral matter with vitrinite B plus inertodetrinite and a positive correlation with vitrinite A (Figure 7). Much of the dispersed mineral matter was possibly introduced after coalification and therefore its location was controlled by cleating developed most extensively in bands rich in vitrinite A. Quinsam coal is characterized by calcite that occurs on cleats, predominately in the brighter vitrinite-rich lithotypes (Ryan, 1994). The data are from samples collected in the 2-north area where the first underground mine was developed. The seam has poorer washing characteristics to the south of this development.

At Telkwa, samples were collected from the upper and lower coal units. The mineral matter contents of the samples are generally high, which indicates the presence of rock splits. There is no correlation of mineral matter with any of the macerals, which implies that it will be difficult to find any relationship between peat swamp environment and washing difficulty. The lower seam (seam 1), which is more difficult to wash (Ryan, 1992), contains more total vitrinite and less vitrinite B plus inertodetrinite than the upper seams. This implies that washing difficulty may increase as the amount of vitrinite A increases, which is similar to the situation at Quinsam. It appears that seams formed in an estuarine environment wash easily, except for seams formed around the margins of the basin or over uneven basement surfaces.

The difficulty of washing can be related, in broad terms, to depositional environment. The Lower Cretaceous coals of eastern British Columbia have more dispersed mineral matter than Appalachian coals, probably because of a more turbulent environment in the swamps. It is probable that younger coals, such as Telkwa, Quinsam and some of the Tertiary coals, formed in more quiescent estuarine or lacustrine environments. They generally have less dispersed mineral matter and are easier to wash. Any variations in ease of washing for these coals may correlate with the vitrinite A content and derive from the fact that this maceral is brittle, cleats easily, and is therefore a host for minerals deposited on cleat surfaces and micro-fractures.

This discussion provides some insight into possible relationships between coal-forming environments and washing difficulty. It is obvious that neither lithoptype mapping nor maceral analysis will provide a reliable way of predicting washing difficulty.

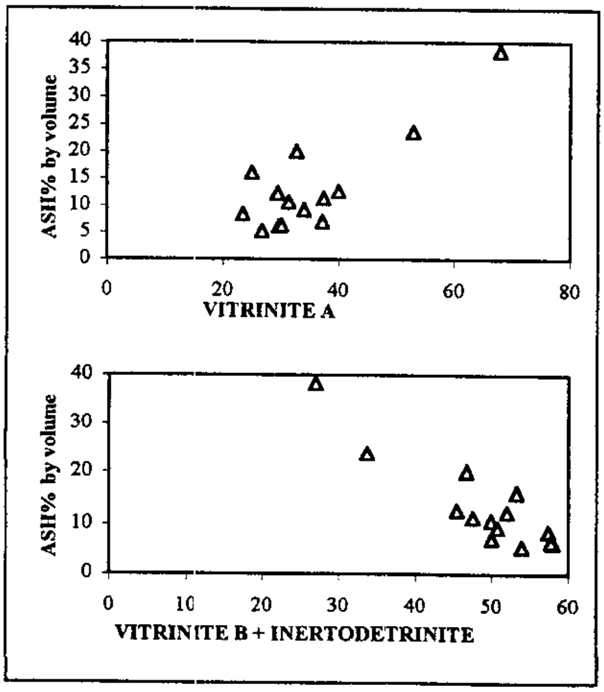

Figure 7. Vitrinite A and vitrinite B *versus* ash for Quinsam samples (data from Matheson *et al.*, 1994).

PART 2 METHODS OF PREDICTING WASHING DIFFICULTY

COAL QUALITY PARAMETERS USED FOR ESTIMATING WASHING DIFFICULTY

Plant engineers need to have some information on the washing difficulty of coal being delivered to the plant. Plant recovery cannot be predicted accurately without knowing details of the equipment in the plant, but it is possible, without knowing plant details, to rank coals in terms of washing difficulty. This is often done using results from pilot plant runs or washability tests on bulk samples.

Changes in washing difficulty can be illustrated using washability data in a number of ways; all attempt to reduce the large amount of data acquired in a full washability analysis to a single number. This number purports to represent washing difficulty. It should be treated with caution because it will, in part, represent inherent properties of the coal and, in part, the degree of crushing and liberation resulting from sample preparation.

Sanders and Brookes (1986) discuss the use of the degree of washing number and the optimum washability number first introduced by Sarkar and Das (1974). The degree of washing number is defined as:

$$N = yld \times (Ra-Wa)/Ra$$

where yld = yield, Ra = raw ash, Wa = wash ash and the optimum washability number is defined as:

$$Wn = 10 \times (Nopt/Wa)$$

where Nopt = maximum value for N determined by calculating all possible N values for a range of specific gravities and Wa is corresponding wash ash.

The optimum washability number varies depending on the size-consist of the samples. A smaller size-consist improves mineral-matter liberation and results in a higher optimum washability number. Because of this, washability numbers from different seams or areas should not be compared with each other, unless the size-consists of the samples used in the washability analyses are the same.

The addition of rock dilution to a seam should not effect washing difficulty. The effect of adding rock to a seam on the degree of washing number and optimum washability numbers was checked by mathematically adding nearly pure rock to a pre-existing washability curve (Figure 8). The dotted line represents the coal and the solid line coal plus 20% rock. The degree of washing number is changed by the addition of the rock, but the calculated optimum washability number is similar. The specific gravity at which the maximum degree of washing number occurs decreases with the addition of the rock.

It is possible to calculate a washability number at each specific gravity using the appropriate degree of washing number. If this is done, the optimum washability number derived is different from that calculated by taking the maximum degree of washing

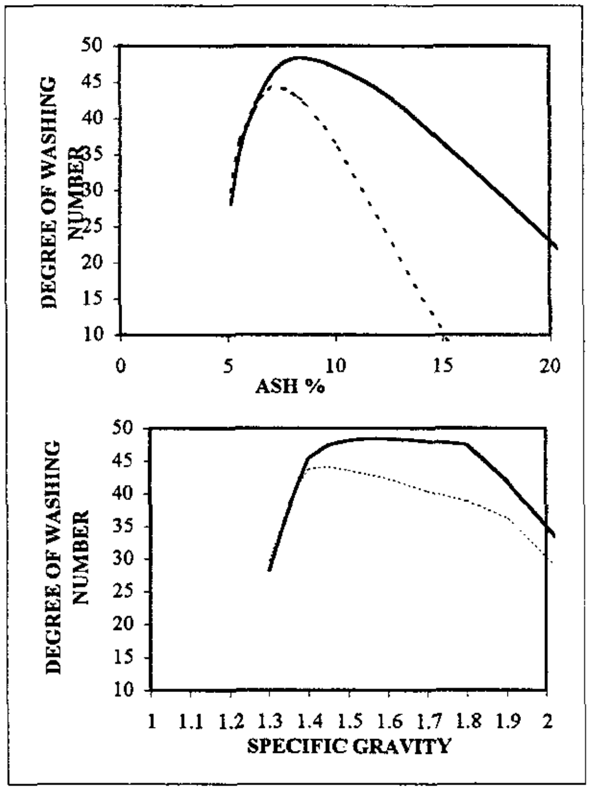

Figure 8. Effect on degree of washing number of adding 20% rock dilution to a sample.

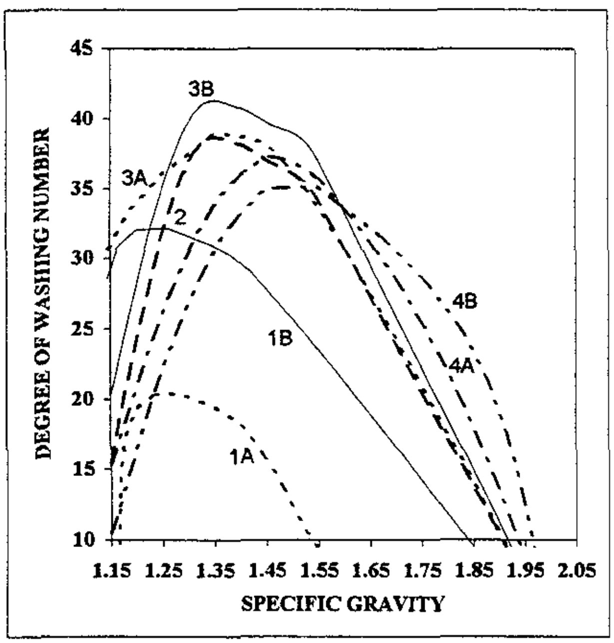

Figure 9. Degree of washing numbers *versus* specific gravity for seams from Line Creek mine (data from Ryan, 1992).

number and its corresponding wash ash. The maximum degree of washing number, divided by its corresponding ash, does not necessarily provide the highest value for the optimum washability number.

When looked at in detail, there are some inconsistencies in optimum washability numbers. They are a useful way of reducing a lot of washability data to a single number which is a relative indication of washing difficulty. However, they are not an absolute measure of washing difficulty. They are sensitive to the size-consist of the samples and the amount of out-of-seam dilution included in them.

Washability data, obtained for a number of seams in the lower part of the Mist Mountain Formation (Ryan, 1992), illustrate the changes in degree of washing numbers with SG for each seam (Figure 9). The seams are numbered from 1 at the bottom of the section. The maximum degree of washing occurs at specific gravities ranging from 1.26 to 1.5. Sanders and Brookes found that seams more difficult to wash had optimum washability numbers occurring at higher specific gravities, with higher clean ash concentrations. In a wash plant, seams may be washed as blends at a fixed SG to achieve a constant wash ash. This means that comparing optimum washability numbers may be deceptive. Degree of washing numbers should be compared at either a fixed wash ash or a fixed SG. The specific gravities at optimum washabilities for the Mist Mountain data do not correlate with the optimum washability number, illustrating the extreme variability of the washing characteristics of these seams.

Other methods of predicting washing difficulty from full washability data (Ryan (1992) involve calculation of the amount of near-gravity material. The amount of material in the SG range from about 1.4 to 1.6 is compared to the amount of material with an SG less than 2.1. This technique is a fairly accurate way of calculating directly the amount of dispersed mineral matter.

All these methods require a complete washability analysis, which is time consuming and expensive. In situations where multiple seams, from numerous locations, are being mined, it is not always possible to have sufficient bulk sample results and it is therefore useful to be able to predict changes in washability using, quicker, less expensive tests on small samples

DATA FROM THE ELKVIEW AND QUINTETTE MINES

Seven samples from Elkview mine and three samples from the Quintette mine were collected for this study, with the intention of extending the conclusions reached in Ryan (1992).

The Quintette mine (Figure 6) is located in the Peace River coalfield in northeast British Columbia and mines coal from the Gates Formation. At this mine, seams E and G generally wash well, whereas the J seam is more difficult to wash. Two samples of J seam were collected from the Shikano North and P1 Mesa pits and a single sample of G2 seam from the Wolverine pit. The Elkview mine (Figure 1) is located in the Elk River coalfield in southeast British Columbia and mines coal from the Mist Mountain Formation. Hangingwall and footwall samples were collected from the basal Number 10 seam (Elk 2 pit). Two duplicate samples were collected from the overlying 8UX seam (Baldy pit) and an additional sample from 8LG seam in the Elk 2 pit.

TABLE 1

QUALITY AND SCREEN DATA FOR WASHABILITY SAMPLES

		SCREEN DATA		RAW DATA >0.5 mm				1.4 SG FLOAT > 0.5 mm			
SAMPLE	PIT	10-0.5 mm	< 0.5 mm	H_2O ad	ASH%	VM%	FC%	yield	H_2O ad	ASH%	carb rec
ELKVIEW											
7R1/A	Baldy East	78.42	21.58	0.55	35.20	16.41	47.84	50.35	0.45	7.51	70.99
7R1/B	Baldy West	83.00	17.00	0.64	32.25	17.22	49.89	43.75	0.38	7.21	59.22
8LG	Elk 2	80.59	19.41	0.65	21.14	19.00	59.21	61.62	0.61	5.52	73.18
8UX/A	Baldy	67.65	32.35	0.58	20.29	21.11	58.02	52.51	0.58	6.64	60.85
8UX/B	Baldy	78.14	21.86	0.59	32.97	16.97	49.47	38.98	0.30	6.96	53.50
10FW	Elk 2	62.30	37.70	0.70	17.56	18.47	63.27	56.14	0.86	6.16	63.27
10HW	Elk 2	53.66	46.34	0.65	10.89	19.52	68.94	68.53	0.62	5.88	71.70
QUINTETTE											
J	Shikano North	75.60	24.40	0.62	18.27	17.03	64.08	67.26	0.51	6.46	76.18
J	Mesa P1	80.92	19.08	0.66	10.16	22.99	66.19	83.94	0.57	5.73	87.28
G2	Wolverine	79.68	20.32	0.73	12.01	21.17	66.09	70.90	0.39	4.95	75.99

carb rec = carbon recovery ad = air dried

TABLE 2

WASHABILITY DATA FOR SAMPLES FROM QUINTETTE AND ELKVIEW

7R1A ELKVIEW

SG	INC W	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	10.55	10.55	2.75	2.75
1.3 - 1.35	10.06	20.61	6.23	4.45
1.35 - 1.4	20.14	40.75	10.36	7.37
1.4 - 1.45	6.96	47.71	15.78	8.60
1.45 - 1.5	3.51	51.22	21.59	9.49
1.5 - 1.6	2.98	54.20	29.03	10.56
1.6 - 1.7	2.55	56.75	39.84	11.88
1.7 SINK	43.26	100.01	81.71	42.08

7R1B ELKVIEW

SG	INC W	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	8.81	8.81	2.66	2.66
1.3 - 1.35	11.62	20.43	6.28	4.72
1.35 - 1.4	18.33	38.76	10.07	7.25
1.4 - 1.45	7.14	45.90	15.16	8.48
1.45 - 1.5	5.70	51.60	19.79	9.73
1.5 - 1.6	5.17	56.77	28.19	11.41
1.6 - 1.7	5.63	62.40	37.31	13.75
1.7 SINK	37.62	100.02	73.94	36.39

8LG ELKVIEW

SG	INC W	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	22.06	22.06	3.26	3.26
1.3 - 1.35	25.92	47.98	6.58	5.05
1.35 - 1.4	11.70	59.68	11.00	6.22
1.4 - 1.45	4.17	63.85	16.06	6.86
1.45 - 1.5	3.16	67.01	20.43	7.50
1.5 - 1.6	3.45	70.46	27.54	8.48
1.6 - 1.7	4.40	74.86	37.21	10.17
1.7 SINK	25.14	100.00	60.13	22.73

10 FW ELKVIEW

SG	INC W	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	7.93	7.93	2.05	2.05
1.3-1.35	13.36	21.29	5.29	4.08
1.35-1.4	13.78	35.07	7.71	5.51
1.4-1.45	11.34	46.41	10.61	6.75
1.45-1.5	10.30	56.71	14.45	8.15
1.5-1.6	10.41	67.12	21.57	10.23
1.6-1.7	10.89	78.01	32.47	13.34
1.7 SINK	21.99	100.00	51.04	21.63

8UXA ELKVIEW

SG	INC W	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	20.06	20.06	2.75	2.75
1.3-1.35	13.02	33.08	7.87	4.77
1.35-1.4	15.96	49.04	13.07	7.47
1.4-1.45	5.33	54.37	21.76	8.87
1.45-1.5	11.02	65.39	26.09	11.77
1.5-1.6	15.90	81.29	32.42	15.81
1.6-1.7	6.14	87.43	40.83	17.57
1.7 SINK	12.55	99.98	61.27	23.05

J SHIKANO NORTH PIT QUINTETTE

SG	INC WT	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	8.73	8.73	2.91	2.05
1.3-1.35	17.04	25.77	5.18	4.12
1.35-1.4	36.36	62.13	9.36	7.19
1.4-1.45	8.54	70.67	15.21	8.16
1.45-1.5	4.87	75.54	20.02	8.92
1.5-1.6	2.98	78.52	24.58	9.52
1.6-1.7	2.48	81.00	28.44	10.09
1.7 SINK	18.99	99.99	77.51	22.90

J MESA PIT QUINTETTE

SG	INC WT	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	19.71	19.71	2.50	2.05
1.3-1.35	33.09	52.80	5.92	4.48
1.35-1.4	30.32	83.12	9.42	6.28
1.4-1.45	4.72	87.84	14.75	6.7[illegible]
1.45-1.5	2.76	90.60	18.35	7.0[illegible]
1.5-1.6	2.58	93.18	21.83	7.50
1.6-1.7	1.65	94.83	29.46	7.8[illegible]
1.7 SINK	5.18	100.01	59.76	10.5[illegible]

G2 WOLVERINE PIT QUINTETTE

SG	INC WT	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	18.41	18.41	2.69	2.0[illegible]
1.3-1.35	33.46	51.87	4.37	3.5[illegible]
1.35-1.4	18.99	70.86	8.55	4.89
1.4-1.45	6.34	77.20	15.00	5.7[illegible]
1.45-1.5	6.33	83.53	19.89	6.79
1.5-1.6	6.89	90.42	27.37	8.36
1.6-1.7	3.58	94.00	36.34	9.43
1.7 SINK	6.00	100.00	66.28	12.84

10 HW ELKVIEW

SG	INC WT	CUM WT	INC ASH	CUM ASH
1-1.3	12.82	12.82	1.82	2.05
1.3-1.35	17.37	30.19	5.56	4.07
1.35-1.4	26.79	56.98	9.60	6.67
1.4-1.45	20.56	77.54	13.90	8.59
1.45-1.5	10.50	88.04	18.65	9.79
1.5-1.6	6.93	94.97	24.87	10.89
1.6-1.7	2.23	97.20	34.49	11.43
1.7-2.5	2.81	100.01	63.52	12.89

8UXB ELKVIEW

SG	INC WT	CUM WT	INC ASH	CUM ASH
1.3 FLOAT	7.46	7.46	3.26	2.75
1.3-1.35	10.91	18.37	6.72	5.11
1.35-1.4	15.37	33.74	11.03	7.81
1.4-1.45	7.29	41.03	16.61	9.[illegible]7
1.45-1.5	7.20	48.23	21.94	11.[illegible]5
1.5-1.6	5.71	53.94	29.44	13.17
1.6-1.7	4.90	58.84	39.71	15.[illegible]8
1.7 SINK	41.16	100.00	77.48	40.94

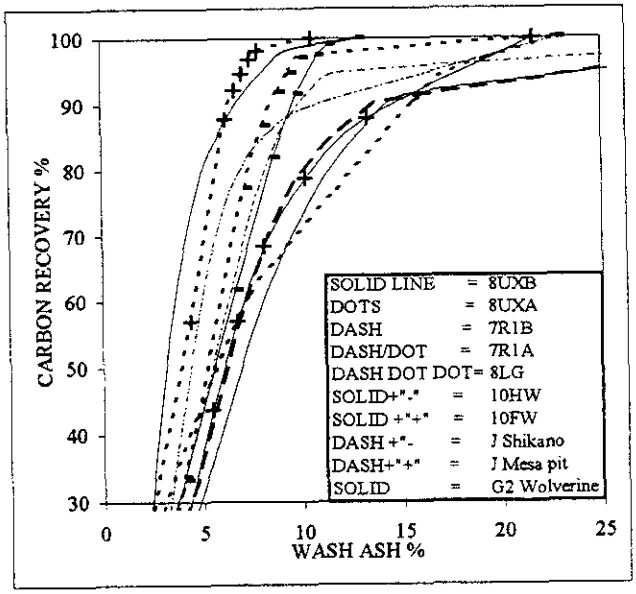

Figure 10. Plot of carbon recovery *versus* wash ash for data from this study.

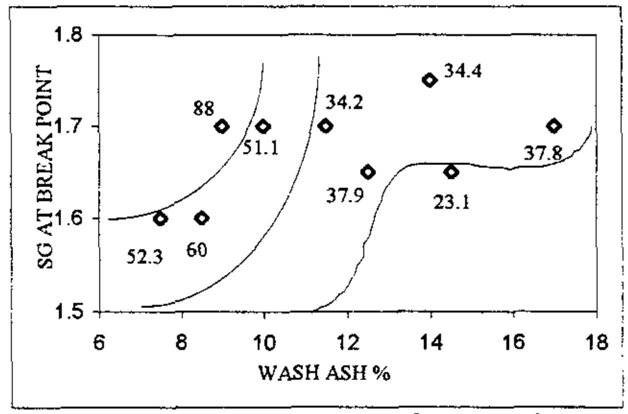

Figure 11. Plot of wash ash *versus* SG_b for samples from this study.

Two samples of 7R1 seam were collected from different areas in the Baldy pit. Samples were subjected to proximate analysis and screened in sizes 10 to 0.5-millimetres and less than 0.5 millimetres.(Table 1). A full washability analysis was performed on the 10 to 0.5-millimetre fraction (Table 2).

THE WASH ASH VS CARBON RECOVERY PLOT AND WASHING DIFFICULTY

The optimum washability number of Sarker and Das (1974), derived from full washability data, can also be predicted with moderate accuracy from a single float-sink analysis using the wash ash and carbon recovery (Ryan, 1992). This means that calculated optimum washability numbers, or estimates of washing difficulty, can be derived from small samples and useful initial estimates made of changes in washing difficulty. Often small drill-core or channel samples are subjected to a standardized float-sink analysis. in which the samples are crushed to minus 9.5 millimetres and all floated at the same specific gravity This provides a good database for illustrating changes in washability

The amount of dispersed mineral matter in a sample is proportional to the wash ash. At any specific gravity, the ash of the float sample may vary from zero to the value corresponding to the ash of a rock-plus-coal mixture with the same density as that of the separating liquid. Higher concentrations of wash ash indicate higher concentrations of dispersed mineral matter. It is also possible to calculate the amount of coal lost in the sink material, providing another estimate of the efficiency of liberation. This term is referred to here as the carbon recovery and is calculated as follows:

$$CR = yld \times (100 - Wa \times K)/(100 - Ra \times K)$$

where K = (weight of mineral matter)/(weight of resultant ash)

Carbon recovery is therefore the ratio of coal in the wash sample to coal in the original sample. The calculation is insensitive to changes in the amount of rock dilution, but sensitive to the amount of dispersed mineral matter which will tend to reduce the carbon recovery. Samples with low contents of dispersed mineral matter will have low wash ash and high carbon recovery values.

Using the full washability data from Table 2, it is possible to construct plots of carbon recovery *versus* wash ash (Figure 10). The curves for individual seams tend to have break points above which carbon recovery is insensitive to increases in wash ash. These break points occur at slightly different ash values, and if carbon recovery is plotted against specific gravity, similar break points are apparent at specific gravities ranging from 1.6 to 1.75. Obviously the concentration of dispersed mineral matter in individual coal particles does not exceed a value fixed by the specific gravity of the break point (SG_b). The value SG_b is the optimum SG at which to wash the coal for best carbon recovery and low ash content; unfortunately this does not necessarily mean that the wash ash will meet market specifications. The wash ash values on the x-axis tend to indicate the number of particles contaminated with mineral matter and the value of SG_b tends to indicate the concentration of ash in these particles. Difficult to wash coals will plot in the lower right of the diagram and easy to wash samples in the top left. The data from Elkview and Quintette are presented on this type of plot (Figure 11) which may be useful in demonstrating relative washing difficulty. The plot, however, is still derived using full washability analyses.

The SG_b values are not sensitive to increases in the amount of rock dilution and correspond to the point where particles composed mainly of rock are first incorporated in the wash product. This specific gravity is higher than that corresponding to the optimum washability number. Above the SG_b value, carbon recovery *versus* specific gravity plots for different seams tend to converge; below this value, which varies from about 1.6 to 1.75 SG, the curves tend to follow parallel but different trends. Obviously carbon recovery values for a particular coal seam are more distinct if measured on a sample floated at an SG less than 1.6.

A plot that combines wash ash and carbon recovery measured at a specific gravity of less than 1.6 should provide a good way of separating coals of the same rank based on their washing difficulty. Both parameters are independent of rock dilution and, because they are obtained from a standard proximate analysis, samples have been prepared to a standard size-consist.

This approach was used by Ryan (1992) with moderate success, based upon comparing the carbon recovery *versus* ash plot to previously calculated optimum washability numbers. There was a distinct trend for samples with high washability numbers to plot in the top left of the diagram and those with low values to plot in the bottom right. These samples were analyzed at an SG of 1.5. In the present study, the wash ash *versus* carbon recovery diagram was constructed for data at 1.5, 1.45 1.4 and 1.35 SG. On each diagram the optimum washability numbers were posted next to the appropriate data points. It was found that the best relationship between position of point and optimum washability number was obtained for data plotted at 1.4 SG.

INTERPRETATION OF ELKVIEW AND QUINTETTE DATA

The carbon recovery *versus* wash ash data for the Elkview and Quintette mines measured at a 1.4 SG are plotted on Figure 12. The optimum washability numbers derived from the full washability, are posted next to the points. The positions of the points correspond well with the values of the optimum washability numbers. Contours for optimum

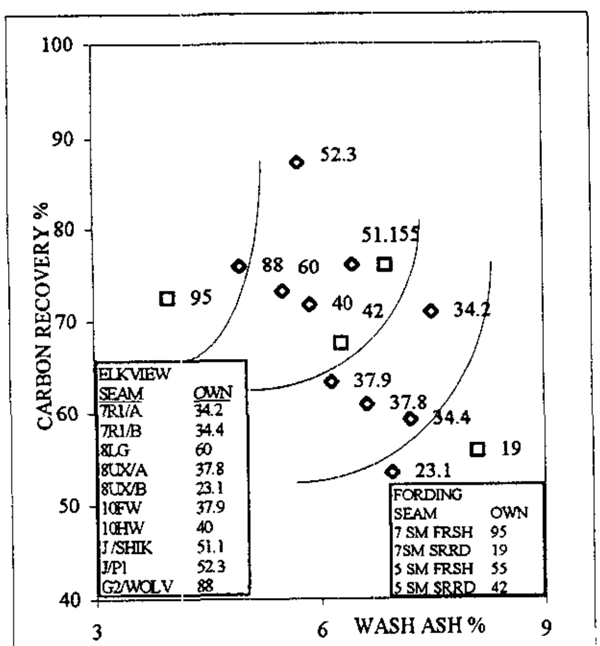

Figure 12. Wash ash *versus* carbon recovery at 1.4 SG for samples from Quintette, Elkview and Fording mines.

washability numbers are sketched onto the figure to illustrate the general trend of increasing optimum washability numbers to the top left of the diagram

There is no reason to assume a perfect correspondence between the position of a point in the figure and the optimum washability number. The two may not correspond exactly and the diagram may be giving a better estimate of washing difficulty than the optimum washability number. For the Quintette data, the diagram separates the more easily washed G seam from the two J-seam samples which plot some distance apart. The Elkview data scatters widely. The seam-10 footwall sample, which is reported to wash better than the hangingwall coal, plots some distance from the 10-seam hangingwall sample. The two duplicate 8UX samples plot quite close to each other, despite the fact that the calculated washability numbers differ. The sample of 8LG collected from the Elk 2 pit washes better than the 8UX samples from Baldy pit. The two samples of 7 seam from the Baldy pit do not appear to have very different washing difficulties and the increase in ash to the west must result mainly from the addition of rock splits which will effect the plant recovery, but not the washing difficulty.

EXAMPLES OF VARYING WASHING DIFFICULTY

Bustin (1982) provides washability data for seams from the Fording mine (Figure 1). The data are used to calculate washability numbers, carbon recovery and wash ash values at 1.4 SG. The data are plotted in Figure 12. The four samples are from two seams, and represent sheared and unsheared coal from each seam. The 7-seam samples, which have optimum washability numbers of 95 and 19, illustrate a significant increase in washing difficulty with shearing. On the other hand ,the washing difficulty of 5 seam (optimum washability numbers 55 and 42) is not much increased by shearing.

Development on the Telkwa property, in northwest British Columbia, has reached an advanced stage and in 1986 Crowsnest Resources Limited submitted a

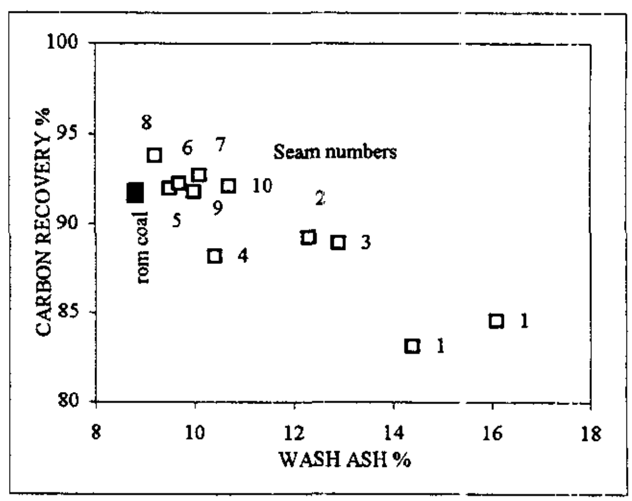

Figure 13. Carbon recovery *versus* wash ash, average data for seams from the Telkwa property, northwest British Columbia.

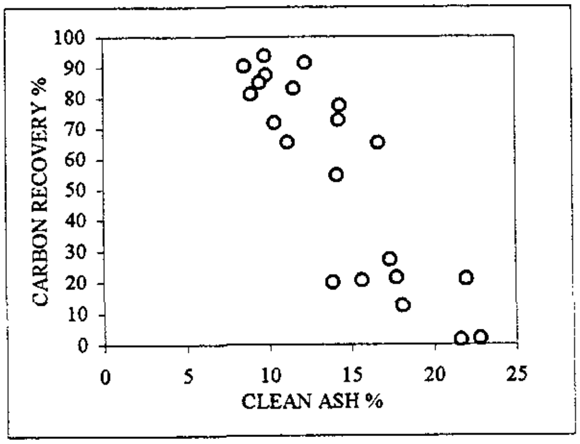

Figure 14. Carbon recovery *versus* wash ash for samples from the Corbin property, southeast British Columbia.

Stage Two Application document describing the geology and proposed mining activities for the area south of the Telkwa River. Averaged raw and wash proximate data for the ten seams in this area were included in the report. A plot of carbon recovery *versus* wash ash indicates that the seams probably have a wide range of washing difficulties (Figure 13). The data plot into clusters with increasing washing difficulty; (cluster 1 = seams 5,6,7,8, 9, 10; cluster 2 = seams 2, 3, 4; and cluster 3 = seam 1). This information should be considered when blending seams for ROM coal.

Data from the Corbin property, adjacent to and south of the Coal Mountain mine in southeast British Columbia (Figure 1), indicate that the coal has a wide range of washing difficulty with high-ash coal being very difficult to wash (Figure 14).

The Quinsam coal mine is located in the Comox coal basin on Vancouver island. Data for the number 1 seam in the 2-north area (Gardner, 1992) can be used to construct a carbon recovery *versus* wash ash plot at 1.4 SG (Figure 15) which has the same axes as Figure 14 for comparison purposes. The number 1 seam in this area washes very easily in comparison to coal from Quintette or Elkview. In the area to the south, the number 1 seam does not wash as well (S.L. Gardner, personnel communication 1995). No comparison can be made with the Telkwa or Corbin data because they were analysed at 1.5 SG in contrast to Quinsam, Quintette, Fording and Elkview data which were analysed at 1.4 SG.

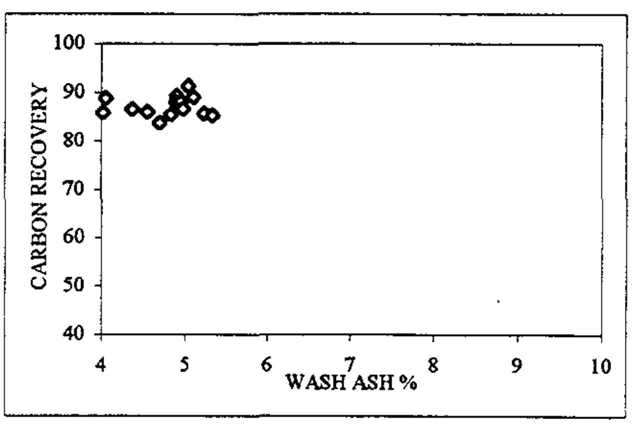

Figure 15. Carbon recovery *versus* wash ash for samples of number 1 seam, Quinsam mine; same scales as Figure 14 for comparison.

SUMMARY

Washing difficulty is related to the amount of dispersed mineral matter in the coal. There appears to be a correlation between detrital maceral content and the amount of dispersed mineral matter in Cretaceous coals from southeast and northeast British Columbia. Increases in both dispersed mineral matter and detrital mineral abundance may be caused by increased turbulence in coal swamps as a result of off-shore storms. Alternatively increase in detrital vitrinite may result from a change to more reedy vegetation in a dryer swamp. This also may provide a porosity into which dispersed mineral matter can be deposited.

Based upon these observations, there is some correlation between washing difficulty and swamp environment; but this will not be of use to a coal wash plant engineer seeking an easy way to obtain information on the probable washing difficulty of coal from new areas in a mine. This type of information is available from full washability analysis of bulk samples; for convenience, the data may be expressed as a single number such as the optimum washability number of Sarkar and Das (1974). There are some concerns with the optimum washability number and, if a full washability analysis is available, then it might be more useful to calculate the amount of near-gravity material.

In the absence of a full washability analysis, a plot of carbon recovery *versus* wash ash provides reasonable estimates of relative washing difficulty. This information can be cheaply obtained using small samples analysed at a single specific gravity. A more detailed examination of the relationship between carbon recovery and wash ash over a range of specific gravities indicates that data obtained at an SG of 1.4 provide the most accurate assessment of washing difficulty.

The plot is used to illustrate the wide variation in washing difficulty of some Lower Cretaceous coals from British Columbia. Washing difficulty varies on all scales, from mine to mine or within a single seam.

Cretaceous coals, such as those at Telkwa and Quinsam, formed, in an estuarine environment generally wash better. There appears to be more variation of washing difficulty in Telkwa coals than Quinsam coals. The washing difficulty for these coals correlates with the amount of vitrinite A. Possibly mineral matter is post-depositional and is deposited on cleats and microfractures in the vitrinite.

Maximum recovery is achieved when a plant operates under constant conditions and the run of mine coal maintains a constant quality. Frequent adjustments to the operating density in the plant will result in a decrease in recovery. The washing difficulty of seams can vary widely and this information is essential if consistent run of mine blends are to be maintained and plant recovery maximized.

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