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BRITISH COLUMBIA COAL QUALITY SURVEY

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ABSTRACT

This report is a compilation of coal quality data from most of the coalfields in British Columbia. Data are from two major sources: 1) analyses of raw coal samples collected at producing mines in northeast and southeast B.C.; and 2) coal assessment reports submitted by industry. Specific analytical parameters discussed include: coal petrography (vitrinite reflectance and maceral composition); ASTM rank; proximate and ultimate analyses; calorific value; mineral matter content; ash chemistry; phosphorus concentrations; trace element concentrations (Sb, As, B, Br, Cd, Cl, Cr, Co, Cu, F, Pb, Hg, Mo, Se, Th, U); and, caking power (FSI, dilation and fluidity). The focus is on raw coals throughout, although in certain cases clean coal data are used.

ASTM rank for coals from both northeast (Peace River) and southeast (East Kootenay) B.C. coalfields ranges from high-volatile A to low-volatile bituminous. Mount Klappan-area coals are anthracitic. High-volatile (hv) bituminous coals are found at Quinsam on Vancouver Island (predominantly hvB), Telkwa (hvA), Tulameen (hvC/B) and Bowron River (hvC/B). Sub-bituminous and lignitic coals are found at Hat Creek. Coals from northeast and southeast B.C. have relatively high concentrations of inertinite macerals (average about 40% mineral matter-free), of which semifusinite is the most common. Liptinite macerals are very scarce. Mean moisture contents (air-dried) of northeast and southeast B.C. coals are generally under 1%. Coals from lower rank basins generally have higher moisture contents. Ash contents of individual seams vary widely; 20% ash (air-dried) is an approximate, representative mean for northeast and southeast B.C. raw coals, as well as for Comox and Telkwa. Generally higher ash contents are found at Mount Klappan, Bowron River, Hat Creek and Tulameen., Volatile matter contents (dry, ash-free) in northeast and southeast coals range from about 22 to 35%. British Columbia coals, for the most part, are classified as having low sulphur contents. The proportion of pyritic sulphur is also low. High-rank (hvA bituminous and higher) coals have mean calorific values in the range 25 to 30 MJ/kg (air dried).

Quartz and kaolinite are the most common minerals in low-temperature ashes of northeast and southeast coals. High temperature ashes of the same coals have low base-acid ratios, which translates into high CSR (coke strength after reaction) characteristics. Mean phosphorus concentrations in the major coking coal-bearing formations (raw coals) are: Mist Mountain - 0.076%; Gething - 0.063%; and Gates - 0.042%. The main factors affecting phosphorus concentrations are the amount of ash, and the proportion of phosphorus-bearing accessory minerals, such as fluorapatite. Most trace elements (for example Sb, As, Cr, Co, Cu, F, Hg, Th and U) are associated primarily with the inorganic fraction of the coal. Concentrations of six important trace elements, namely As, Br, Cl, Co, Pb and Hg, are relatively low when compared with world coal averages, and concentrations of only one element, F, is relatively high.

Mean and modal FSI values in raw coals from northeast and southeast B.C. are on the order of 4.5 (product specifications generally range from 6 to 8). Two-thirds of run-of-mine samples from these regions have no net dilitation; this corresponds with low coke-oven pressures. Modal range in maximum fluidity is 1 to 10 ddpm.

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CHAPTER 1 INTRODUCTION

No two coals are the same. Coal quality represents the characteristics of a coal which determine its suitability for various processes and uses. An economic evaluation of a coal deposit lacking an assessment of coal quality is practically meaningless, because, in addition to asking "where?" and "how much?", we need to ask "what are the properties of the coal?".

The three fundamental geological components of coal quality are grade, rank and type. Most of the variations in coal quality can be related to variations in one or more of these factors. **Grade** refers to the amount of inorganic (non-coal) matter in a coal, and is analagous to ore grade. **Rank** represents the degree of organic maturation, or, in effect, the position of a coal relative to the "metamorphic" gradation from peat to meta-anthracite. **Type** refers to the proportions of the different organic constituents derived from the original vegetation. Some of the commonly measured coal properties provide good indicators of one of the three fundamental components: ash content, for example, is dependent on coal grade; vitrinite reflectance is a sensitive rank indicator; and a maceral count provides good insight to coal type.

The choice of tests to be run on a coal sample depends to a large extent on the intended use of the coal. However, grade, rank and type, in varying combinations and proportions, influence all analytical properties used to characterize coal. For properties which are strongly affected by more than one component, direct comparisons between coals can be problematic. For example, calorific value, a measure of the energy content of a coal, is greatly influenced by both rank and grade. Therefore, in order to characterize a coal's rank using its calorific value, the mineral matter, which has a dilutant effect, is mathematically "removed". This is done by converting the readings to a mineral matter-free basis. This is, in fact, the approach used for lower rank coals by the American Society for Testing and Materials (ASTM) in its classification of coals by rank (ASTM, 1984). Volatile matter content provides another example. It is also used as a rank indicator in the ASTM classification, but for higher rank coals, and is a function of all three components, grade, rank and type. When the effect of grade is removed, there are still two factors, rank and type, which make a significant contribution. To classify higher rank coals by rank using the ASTM method, in other words, one has to be aware of inconsistencies introduced by variations in coal type. For example, an abundance of bright lithotypes and the maceral vitrinite tends to lead to higher volatile matter readings than would be anticipated for a given rank of coal. The implications of the use of various kinds of coal quality data will be discussed in later sections.

Coal is extremely important to the economy of British Columbia; it is the number one mineral commodity in terms of dollar value of production. It is also one of the province's most important overseas exports. The British Columbia coal industry is highly productive, efficient and innovative. The geological processes which formed our coal deposits have produced a very large resource base of high-quality coals. It is hoped that this paper will make some contribution to the general understanding of British Columbia coals.

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It is a pleasure to thank our friends in the coal industry who gave us permission and helped us to sample at British Columbia's coal mines. Brad Van Den Bussche helped with sampling, low-temperature ashing and data manipulation. Joanne Schwemler performed all vitrinite reflectance determinations. Supervisory support of Ward Kilby, Vic Preto and Dave Lefebure, at different stages, is greatly appreciated. Ward Kilby wrote the description of the Peace River coalfield and created Figure 3. Discussions with our colleagues in the British Columbia Geological Survey Branch, Barry Ryan, Alex Matheson, Candace Kenyon and John Cunningham, were very beneficial.

PURPOSE AND SCOPE

This paper is the summation of a multi-year study of the quality characteristics of raw coals found in British Columbia, from a geological perspective. The main focus is on coal seams at the seven producing mines in two mining regions, the northeast and southeast British Columbia. We have also compiled data from the third coal-mining region, Vancouver Island, and other regions in the province.

The main objective of the paper is to document quality parameters, especially their variations and interrelationships, in raw British Columbia coals. We will also compare British Columbia coals with world coals, and comment on factors influencing suitability of the province's coals for various end uses. The aspects of coal quality covered include: basic coal composition (proximate and ultimate analyses); mineralogy and chemical composition of the inorganic components; calorific value; coal petrography; trace element, phosphorus and sulphur concentrations; and caking properties. Another important aspect of the study, coal washability, is covered separately in a companion paper (Holuszko, 1994).

For a general overview of the quality of British Columbia coals from all important basins see Grieve (1992a). Raw coal quality data from various basins with potential for thermal coal production are tabulated in Matheson (1989). Coal quality at the Quinsam, Telkwa, Bowron River and Merritt deposits, based on borehole sampling, is covered by Matheson *et al.* (1994). Ryan and Dawson (1994a) summarize most of the available coal quality data from the Klappan coalfield.

APPROACH

The general approach taken in this study was to sample and analyse raw coals from producing pits in northeast and southeast British Columbia. By studying raw coals we were able to focus on inherent characteristics of the coals on a seam-by-seam basis, and to avoid inconsistencies introduced by the different processing procedures used at mines in the province. This gives us better insight to the fundamental controls on coal quality. Active mine-sites were chosen for sampling to give access to fresh coal, eliminating the influences of oxidation.

Two different types of sampling were used in different phases of this project (see section on sampling). **Channel samples** were used mainly for geochemistry, including trace elements, while **run-of-mine (ROM)** samples were used for most of the other coal quality parameters.

In addition to the data derived from these samples, much further data on raw coals from throughout the province were compiled as part of this project. The main source of these data is the Ministry's library of assessment reports submitted by the coal industry to document exploration results. These compiled data are used mainly for comparisons and to confirm inter-relationships among coal characteristics, and are not used for rigorous characterization of the various coalfields. (One exception is the extensive use of data from assessment reports to describe the distribution of phosphorus in the Gething Formation metallurgical coals from northeast British Columbia.) We have tried to convert data to common bases as much as possible, and, otherwise, to avoid use of, or comparisons between, incompatible data.

As much as possible, the various coal quality parameters are considered in terms of the controlling influences of **grade, rank** and **type**. Correlation and regression analyses of data usually focus on measures of one or more of these three factors. To characterize coal grade we use percent ash content, usually on an air-dried basis. To characterize rank we use vitrinite reflectance, predominantly R_{max}, the mean maximum vitrinite reflectance. To quantify coal type we use the amount of total vitrinite, on a mineral matter-free basis.

Because raw coal data are used almost exclusively, it is important to understand that the quality parameters given in this paper do not represent the characteristics of actual or

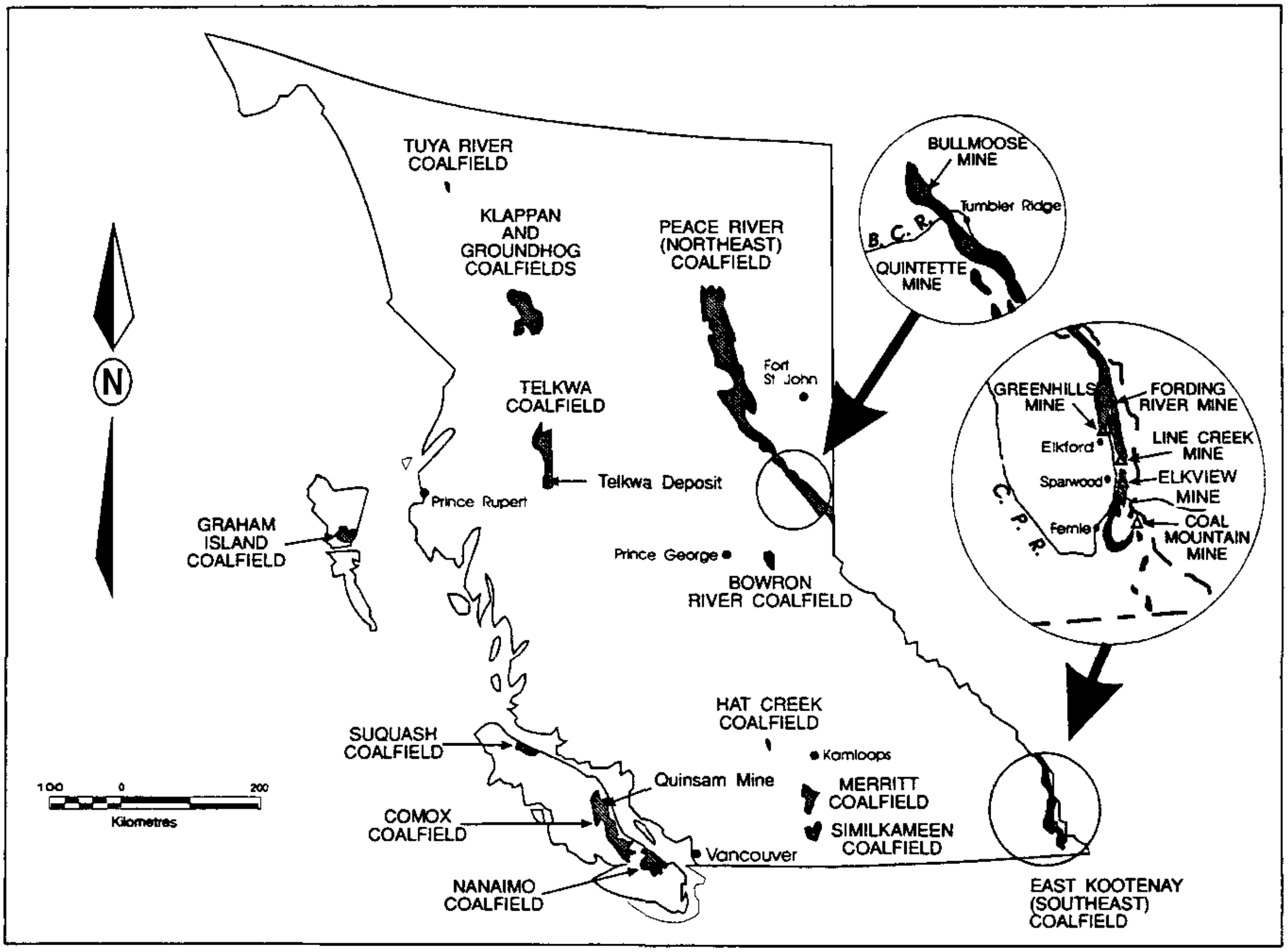

Figure 1. Location of major coal deposits in B.C.

potential clean product coals. This is especially true of the coal geochemistry and proximate ash data, as these properties are influenced greatly (usually enhanced) by coal processing. Basic product specifications from British Columbia coal mines are found in Grieve (1992a), CANMET publications (for example, Price and Gransden, 1987) and in various trade publications.

LOCATION AND SETTING OF B.C. COAL DEPOSITS

The locations of British Columbia coal deposits are shown on Figure 1. The deposits range from Late Jurassic to Tertiary in age, and occur in three of the six major tectonic belts. Starting in the west, the Insular Belt contains the Late Cretaceous Vancouver Island coals, comprising several basins, including the Comox and Nanaimo coalfields. The Intermontane Belt contains Jurassic and Cretaceous coals of northwestern British Columbia (including the Telkwa and Klappan coalfields), and Tertiary coals of south-central British Columbia (including the Hat Creek and Tulameen coalfields). The Foreland Belt includes predominantly Cretaceous coal deposits of northeast British Columbia, known as the Peace River coalfield, and Jurassic-Cretaceous coal deposits of southeast British Columbia, known as the East Kootenay coalfields. Coal mining occurs in the Comox coalfield on Vancouver Island, and in the southeast and northeast regions.

NORTHEAST B.C. COAL REGION

Coal deposit locations in the Peace River coalfield are illustrated on Figure 2. These coals occupy a stratigraphic interval of over 3000 metres and are found in four different

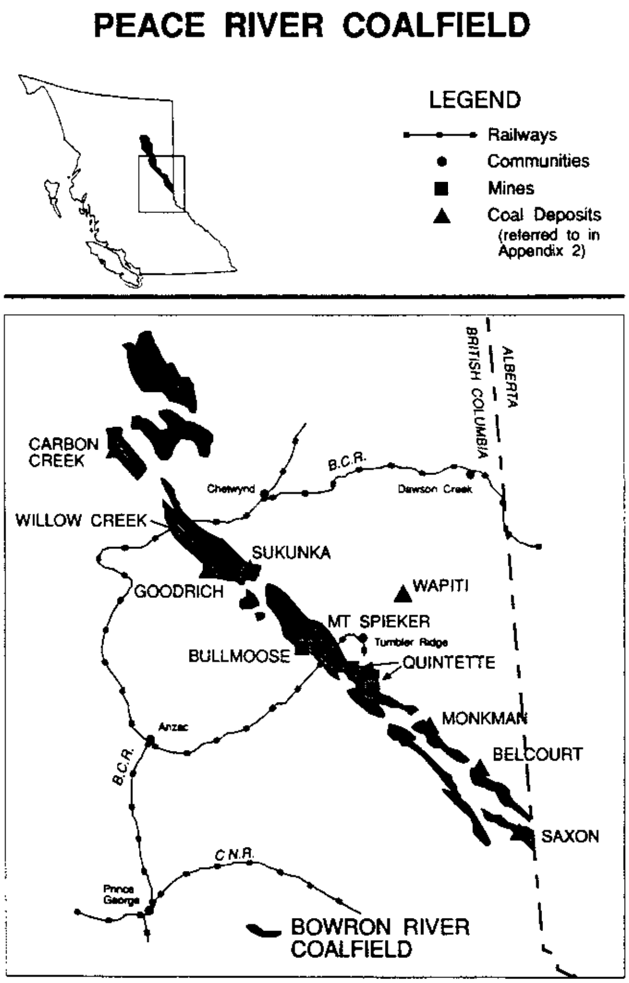

Figure 2. Locations of coal deposits in northeast B.C.

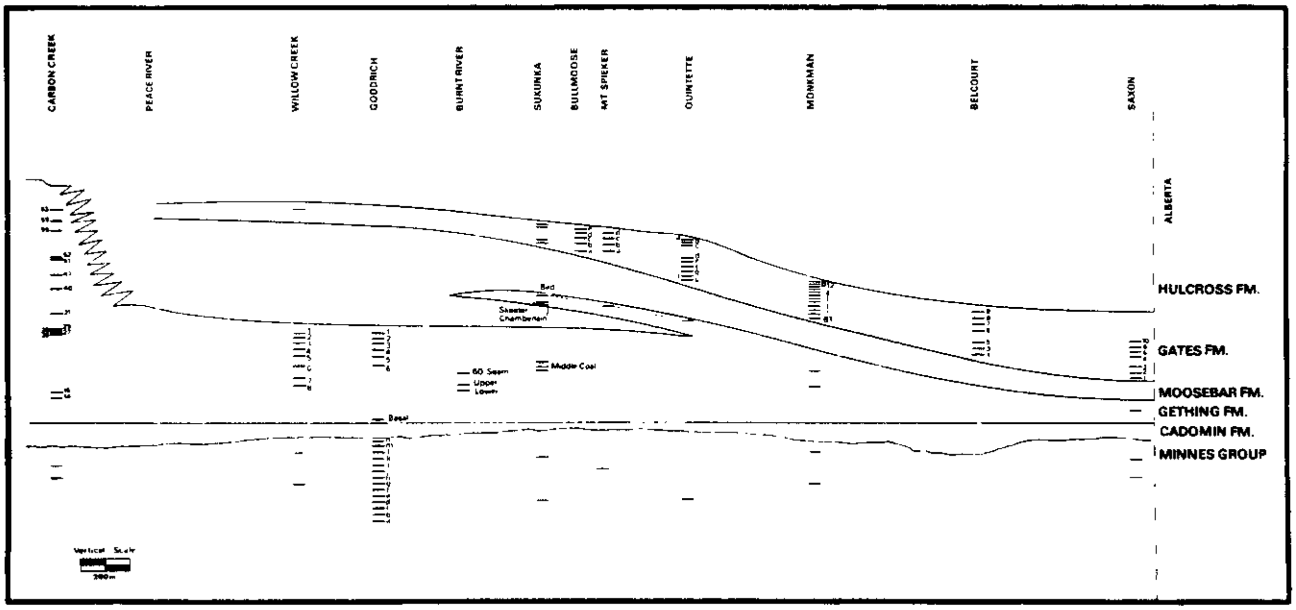

Figure 3. Schematic coal seam stratigraphy of northeast B.C. (compiled by Kilby, 1988).

formations, three of which, the Minnes Group, Gething Formation and Gates Formation, are shown schematically in Figure 3. Minor, thin coal occurrences have been investigated by exploration companies in the Jurassic-Cretaceous **Minnes Group**, but so far nothing has proved to be economic. The Early Cretaceous Gething and Gates formations contain the major coal resources of the region. Within any formation the marine influence on coal seams varies with stratigraphic and lateral position; this influence is best reflected in some elevated sulphur values, most notably in the Gething Formation.

Gething Formation coals are a significant portion of the resource base of the region. However, although there has been minor production from this formation, at present it is not a producer. Formation thickness varies from about 100 metres at the Alberta - British Columbia border in the south to over 1000 metres at Carbon Creek in the north. In the Sukunka to Quintette region an upper member of the Gething Formation contains several major coal seams (Legun, 1990). This member pinches out just north of the Sukunka deposit (Figure 3). North of Sukunka the coals are located in the major body of the Gething Formation only, with the major coal development being near the top of the formation. At Carbon Creek more than 100 coal seams have been identified, but individual seams rarely exceed 3 metres in thickness (Legun, 1988).

All current coal production in the Peace River coalfield is from the **Gates Formation.** Coals of this interval are usually relatively thick and continuous. They form the major coal resource of the coalfield from the Bullmoose area south to the Alberta border. Formation thickness decreases from about 350 metres at the Alberta border to about 60 metres at Peace River (Figure 3). Important coal seams are present in the formation from the southern extremity to just north of the Bullmoose mine, where they become thin and the formation becomes mainly marine and barren.

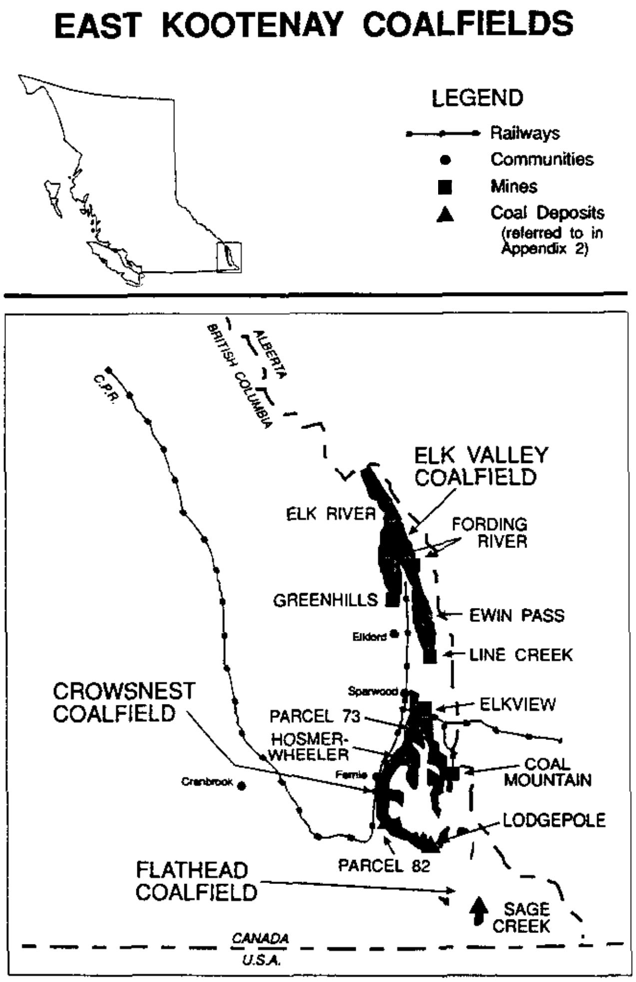

Figure 4. Locations of coal deposits in southeast B.C.

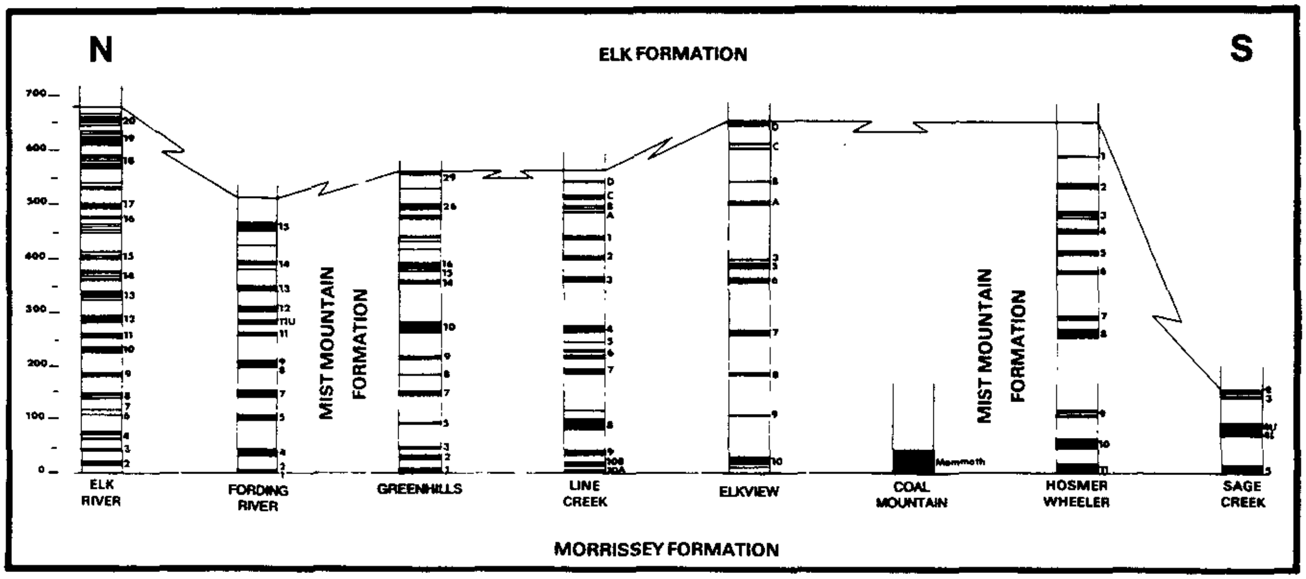

Figure 5. Schematic coal seam stratigraphy of southeast B.C.

The northeast coal region lies mainly in the Inner Foothills of the Rocky Mountains. Folding and thrust faulting are common in the coal deposits of the belt. Structural complications within deposits range from simple to extreme. In some locations multiple fault repeats have substantially increased seam thickness. The geology of the Peace River coalfield, at 1:50 000 scale, is depicted by Kilby and Wrightson (1987a, b), Kilby and Johnston (1988a, b), Hunter and Cunningham (1991), Cunningham and Sprecher (1992) and Jahans (1993).

SOUTHEAST B.C. COAL REGION

The distribution of coal deposits in the East Kootenay coalfields of southeastern British Columbia is shown in Figure 4. Three structurally separate coalfields are recognized: the Elk Valley, Crowsnest and Flathead coalfields. A summary of the geology of the region's coal resources is provided in Grieve (1985), and the Elk Valley coalfield is described in detail by Grieve (1993).

The Mist Mountain Formation of the Jurassic-Cretaceous Kootenay Group, as defined by Gibson (1985), contains essentially all the economic coals in this region. Figure 5 shows generalized sections of the Mist Mountain Formation at selected locations. The formation averages 500 metres in thickness in southeastern British Columbia, with a range from less than 200 to greater than 600 metres. Individual seams range from less than 1 to greater than 15 metres in thickness, and cumulatively they comprise between 8 and 12% of the total stratigraphic thickness of the formation at most locations. The seam numbers and names included in Figure 5 apply only to the sections at the specific locations. As a rule, correlation of individual coal seams on a regional basis is not possible in the East Kootenay coalfields. An exception to this rule is the significant coal zone which occurs at or near the base of the formation at most locations throughout southeast British Columbia. Examples of this include 5-seam at Sage Creek, the Mammoth seam at Coal Mountain, and 10A and 10B seams at Line Creek (Figure 5). Marine influence is generally not evident within the Mist Mountain Formation.

The East Kootenay coalfields are within the Front Ranges of the Rocky Mountains, a structural province characterized by thrust faults and folds. The distribution of the coal deposits is controlled by these features, with large synclines forming the major structures in the Crowsnest and Elk Valley coalfields. Because of the structural setting, most areas contain strata which are moderately to steeply dipping, and which are affected by faulting. These deformational features are important factors in mine planning, but are usually not insurmountable, and are often advantageous, especially in instances where coal seams are tectonically thickened. An example is the Mammoth or Number 1 seam at Coal Mountain, which has been thickened by thrust faulting and folding. The geology of the southeast British Columbia coalfields is depicted at 1:50 000 and smaller scale by Ollerenshaw (in Johnson and Smith, 1991), Price (1962), Price *et al.* (1992a, b), Grieve and Price (1987) and Grieve (1993). More detailed geology has also been published by the B.C. Geological Survey Branch (*e.g.*, Grieve and Fraser, 1985).

VANCOUVER ISLAND

Vancouver Island coals occur in separate basins, including the Comox and Nanaimo coalfields (Figure 6). Only the Comox coalfield is dealt with in this report. All Vancouver Island coals are contained within the Upper Cretaceous Nanaimo Group, with the coals in the Comox basin being older than those of the Nanaimo basin.

The Cumberland and Dunsmuir members of the Comox Formation host the coals of the Comox coalfield (Bickford and Kenyon, 1988). All past and current production is from the Cumberland Member. Its stratigraphy is quite variable, and it generally contains from one to four coal seams or zones, with the thickest individual seam being about 3.5 metres. At the operating Quinsam mine, west of Campbell River (Figure 6), the basal 1-seam, 2.4 to 4.0 metres thick,

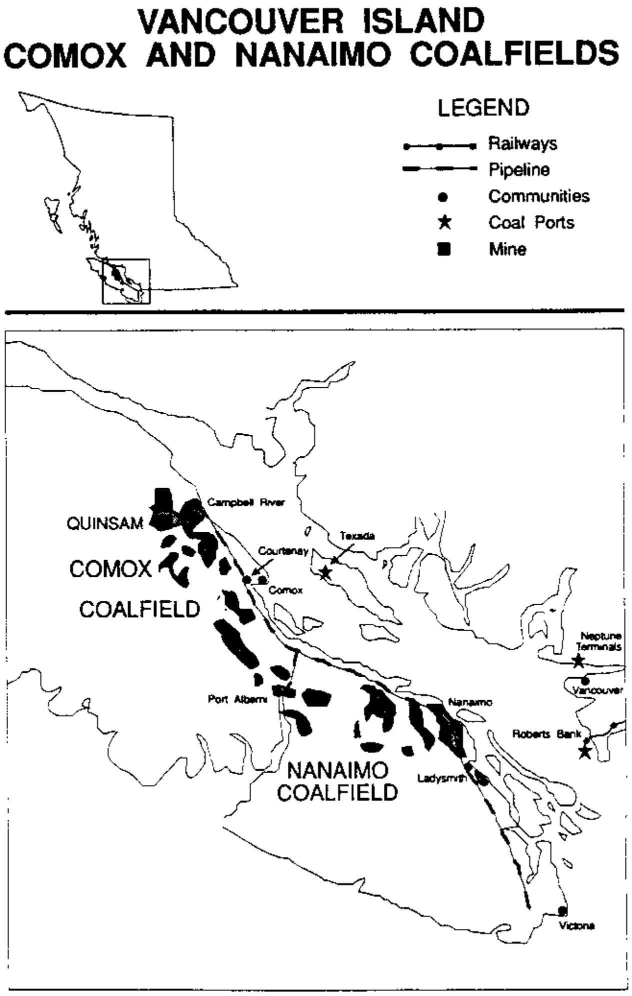

Figure 6. Locations of coal deposits on Vancouver Island, including the Comox coalfield.

is being mined (Kenyon *et al.*, 1992; Matheson *et al.*, 1994). 1-seam is overlain by a thin rider seam. Marine or estuarine influence above the rider seam is evidenced by some higher sulphur values.

The main structures of the Vancouver Island coalfields can be summarized as gently warped and tilted fault blocks (Muller and Atchison, 1971). Most blocks are tilted and downthrown to the northeast along northwest-trending faults. Faults in the Nanaimo coalfield are more closely spaced and have greater displacement than those in the Comox coalfield.

MOUNT KLAPPAN DEPOSIT

The Klappan coalfield, which is contiguous with the Groundhog coalfield, is near the north end of the Bowser Basin of northwestern British Columbia (Figure 7). The host-rocks are the Jurassic-Cretaceous Bowser Lake Group, and major coal seams at Mount Klappan occur in the Upper Jurassic Currier Formation (MacLeod and Hills, 1990). It contains up to 25 coal seams, which range in thickness from 0.5 to 5.0 metres or more. Seams are given letter designations, and are numbered upward from A at the base. Further information concerning coal resources in the Klappan coalfield is found in Dawson and Ryan (1992) and Ryan and Dawson (1994a). The latter reference contains an exhaustive coal quality compilation.

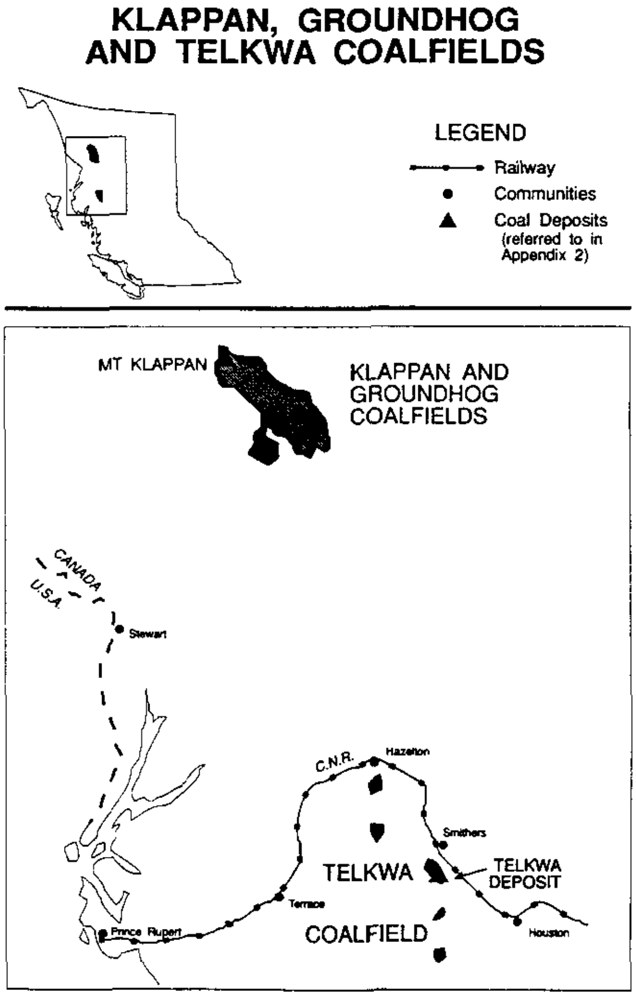

Figure 7. Locations of coal deposits in northwest B.C.

Two phases of deformation have affected the strata of the Mount Klappan area (Moffat and Bustin, 1984). The first phase involved northwest-trending folds and minor thrust faults. These structures were later deformed by broad, open, northeast-trending folds and flat-lying thrust faults.

TELKWA DEPOSIT

The Telkwa deposit is one of a number of coal-bearing sedimentary deposits of different ages in the Smithers-Hazelton area in northwestern British Columbia (Figure 7), referred to collectively as the Telkwa coalfield. It is hosted by the lower part of the Lower Cretaceous Skeena Group. Geology of the Telkwa deposit is described by Palsgrove and Bustin (1991), Ryan (1993) and Ryan and Dawson (1994b).

The 400-metre-thick Telkwa coal measures contain coal in two distinct sequences. The lower sequence includes up to four coal seams with an aggregate thickness of 2 to 12 metres and which individually range from 1 to 6 metres in thickness. Its overall thickness varies from 2 to 40 metres. The upper sequence contains up to 15 coal seams, with individual thicknesses ranging between 1 and 5 metres and having an aggregate thickness of up to 26 metres. Its overall thickness varies from 20 to 170 metres. The two coal-bearing sequences are separated by marine strata.

The Telkwa coal deposit is characterized by high-angle faulting (Schroeter *et al.*, 1986; Ryan, 1993). Faults trend predominantly northwesterly, and are of both normal and reverse types. Telkwa coal measures strata are generally preserved in graben structures formed by these faults, are influenced by broad, open folds, and tend to have shallow northeast or southwest dips.

BOWRON RIVER COALFIELD

The Bowron River coalfield occupies a northwesterly trending elongate basin about 25 kilometres in length which lies 45 kilometres east of Prince George (Figure 2). Coal deposits occur in the lower portion of an unnamed Teritary (late Paleocene or younger) sequence, that may be up to 700 metres thick (Smith, 1989). The coal-bearing zone, which is up to 35 metres thick, contains an aggregate of 12 metres of coal, in lenticular seams which attain thicknesses of 1.5 to 3.5 metres (Matheson *et al.*, 1994).

The structure of the coalfield is an asymmetric graben; strata dip moderately to the northeast (Smith, 1989). Significant folding and faulting of the coal measures occurs within the basin (Matheson *et al.*, 1994).

HAT CREEK COALFIELD

Coal deposits in the Hat Creek coalfield (Figure 8) occur in the Hat Creek Coal Formation of the Eocene Kamloops Group. The best known part of the coalfield is the so-called Number 1 deposit at its northern end, which was extensively explored during the 1970s by B.C. Hydro. The coal measures in the Number 1 deposit are approximately 350 to 560 metres thick, and have been subdivided into four coal zones and two rock zones (Kim, 1985). However, only one of the coal zones, the D-zone, is predominantly coal, and the bulk of the deposit is composed of thinly interbedded coal and rock. This is reflected in the high ash content of Hat Creek coal. Nonetheless, the Hat Creek deposits contain one of the thickest coal sections in the world.

The Hat Creek deposits occupy a north-trending graben (Church, 1977), which is affected by later east-trending normal faults.

TULAMEEN COALFIELD

The Tulameen coalfield is the smaller of two separate basins in the Similkameen coalfield (Figure 8). It is elliptical in shape and covers approximately 29 square kilometres. The coal is contained in the 130-metre-thick middle member of the Allenby Formation of the Eocene Princeton Group. Only two coal seams of significant thickness are found in the basin, and even these are well developed only along the western edge. In this area the lower seam averages about 7 metres in thickness, while the upper or main seam is 15 to 20 metres thick (Williams and Ross, 1979). They are separated by 20 to 25 metres of mudstone.

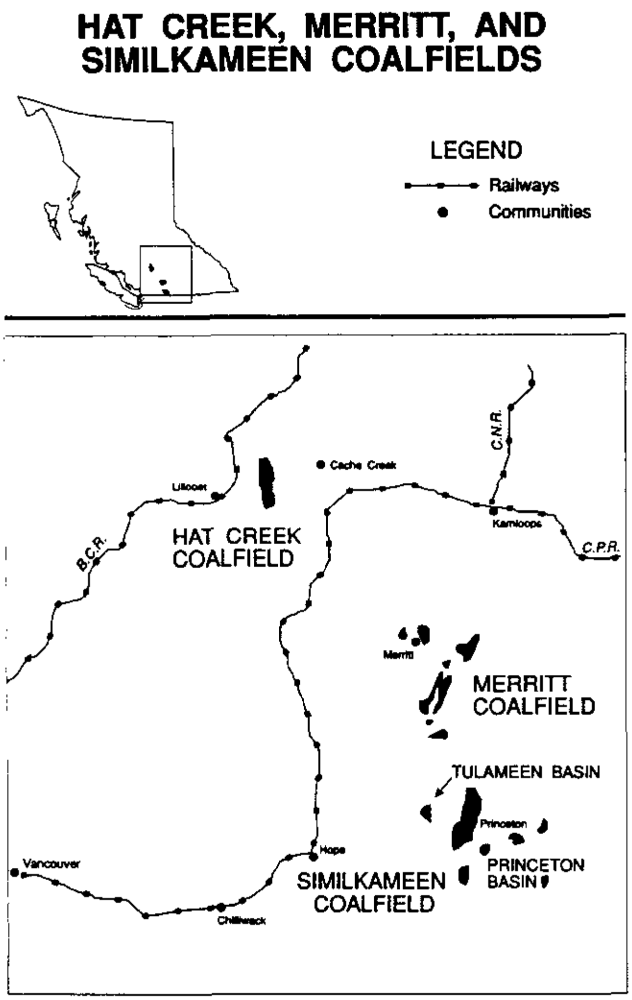

Figure 8. Locations of coal deposits in southwest B.C.

The major structure of the Tulameen basin is a southeast-plunging open syncline. The basin is affected by high-angle normal faults, and in some locations the coal appears to be affected by thrust faulting (Evans, 1985).

COAL MINING IN B.C.

There are currently eight producing coal mines in British Columbia, five in the southeast, two in the northeast and one in the Comox coalfield on Vancouver Island (Figure 1).

The five mines in the southeast (East Kootenay coalfields) are all open-pit operations. The two most northerly sites (Figure 4), Fording River and Greenhills, are operated by Fording Coal Limited. They are both multi-seam operations, and both produce predominantly metallurgical coal, with some thermal coal. The Line Creek mine is operated by a subsidiary of Manalta Coal Ltd. It is also a multi-seam operation, and it markets both metallurgical and thermal coal, with the former contributing the greater tonnage. The Elkview mine (formerly the Balmer mine) at Sparwood is operated by a subsidiary of Teck Corporation. It is a multi-seam operation, but mainly relies on seams from the lower part of the Mist Mountain Formation. Metallurgical coal is the dominant product. The Coal Mountain mine is owned and operated by Fording Coal Limited. It is a single-seam operation, dependent on the structurally thickened Mammoth seam in the basal zone of the Mist Mountain Formation (Figure 5). This mine markets thermal coal and weak coking coal.

The two mines in northeastern British Columbia (Peace River coalfield) are both multi-seam, open-pit operations which produce almost exclusively metallurgical coal from the Gates Formation. The more northerly Bullmoose mine is operated by Teck Corporation and the Quintette mine is operated by a subsidiary of the same company (Figure 2).

The only operating mine on Vancouver Island, the Quinsam mine, is in the Comox coalfield (Figure 6). It is owned and operated by Quinsam Coal Corporation. It is an underground mine which produces thermal coal from a single seam known as 1-seam.

British Columbia coal mines produced 18.3 million tonnes of metallurgical coal and 1.9 million tonnes of thermal coal in 1993. The main market for the metallurgical coal is the Japanese steel industry. Smaller markets for our metallurgical coal include Korea, Brazil, Taiwan, the U.S. and various European and other Asian countries. Korea is the largest single purchaser of the province's thermal coal. Ontario Hydro is also a major buyer and the rest goes to Japan and various other Asian and European countries.

CHAPTER 2 DATA ACQUISITION

Data were acquired by analysing samples collected at mine operation sites, and by compiling information from assessment reports.

SAMPLING

Samples were collected at the five coal mines in southeast British Columbia and the two in the northeast. The larger size of the coal industry in the southeast resulted in a larger number of samples being collected from that region.

Two types of samples, channel and run-of-mine (ROM), were collected (Table 1). The channel samples were mainly used for coal geochemistry (phosphorus, sulphur forms, trace elements and mineral matter), while the ROM samples were used for other applications, including coal petrography and caking tests.

TABLE 1
SAMPLING SUMMARY

Channel samples (1989)	
Elkview:	Whole seams - 8UC, 8UX, 7.S, 7R1, 7RX, 4
Coal Mountain:	Whole seam - Mammoth (No. 1) sampled in three places
Greenhills:	Whole seams - 1, 3, 16, 20, 22, 25
Fording River:	Whole seams - 5, 7, 9, 14-0, 14-2, 14-9, 15
Line Creek:	50 cm plies of seams - 10A, 10B, 9, 8
Bullmoose:	Whole seams - A1, A2, B, C, D, E
Quintette:	Whole seams - J3, G2
Analyses:	Proximate, sulphur, sulphur forms, phosphorus, trace elements, LTA mineralogy
Run-of-mine (ROM) samples (1990)	
Elkview:	Seams - Balmer (No. 10), 8UC, 8UX, 7RC, A
Coal Mountain:	Seam - Mammoth (No. 1) sampled in three places
Greenhills:	Seams - 1, 10, 16, 17, 20
Fording River:	Seams - 4, 5, 9R, 11U,13, 14-2, 15
Line Creek:	Seams - 10A, 10B, 9, 8, 7
Bullmoose:	Seams - A1, B, C, D, E
Quintette:	Seams - J, F, E
Analyses:	Proximate, ultimate, ash analysis, calorific value, vitrinite reflectance, maceral count, FSI, dilatation, fluidity

CHANNEL SAMPLES

Channel samples were collected from fresh coal faces in active mines (Table 1 and Appendix 1). The channels were approximately 10 centimetres wide by 5 centimetres deep. Each sample was intended to be representative of a seam or interval. In the cases of six of the seven mines, whole-seam samples were collected, for a total of thirty samples, twenty-two from southeast British Columbia and eight from the northeast. At the other mine, Line Creek in the East Kootenays, four major seams, 10A, 10B, 9 and 8, were sampled in plies averaging 50 centimetres in thickness, for a total of 37 samples, and an overall total of 67 samples.

RUN-OF-MINE (ROM) SAMPLES

Raw ROM coal samples were collected at all seven of the coal mines in southeast and northeast British Columbia (Table 1). The samples, which were approximately 30 kilograms in weight, were mainly collected from piles of freshly excavated coal in the pits. Each sample represents one seam, with the exception of 16-seam at Greenhills, which was sampled in two segments. Of the total of 34 samples, 26 are from the southeast and 8 are from the northeast.

ANALYTICAL METHODS

SAMPLE PREPARATION

Samples were dried, crushed, split and screened by a commercial laboratory in accordance with ASTM standard procedures. No upgrading was undertaken. Representative splits of -20-mesh and -60-mesh coal were provided to us for petrographic analysis and low-temperature ashing, respectively. Transoptic plastic pellets were made of the minus-20-mesh coal for petrographic analysis. Preparation of pellets included three stages of grinding and two stages of polishing.

LABORATORY PROCEDURES

Standard ASTM laboratory procedures were used for proximate and other routine analyses. Phosphorus in coal was determined by ASTM method D2795, and reported as percent P_2O_5 in coal. Sulphur forms were determined by ASTM method D2492. Dilatation was determined on an Audibert-Arnu dilatometer and fluidity on a Gieseler plastometer.

TRACE ELEMENTS

The following elements were determined by neutron activation: Sb, As, Br, Cr, Co, Mo, Se, Th, U and Zn. Boron concentrations were determined by prompt gamma-ray spectrometry. Concentrations of Cu, Cd, Pb and Hg were determined by atomic absorption, following digestion in $HCl/HNO_3/HF$. Fluorine concentrations were determined by the oxygen bomb digestion method (ASTM, D3761-79), a method known to give low results for various coals (Godbeer and Swaine, 1987; D.J. Swaine, personal communication, 1992). Chlorine was determined by heating a mixture of coal and Eschka mixture in an oxidizing atmosphere (ASTM, D2361-66). The most reliable results were obtained for Sb, As, Br, Cl, Cr, Co, Cu, F, Hg, Th and U. There is more uncertainty in the results for B, Cd, Pb, Mo, Se and Zn, because some concentrations are below detection limits.

PETROGRAPHIC TECHNIQUES

Vitrinite reflectance was determined using the methods of Kilby (1988), as summarized by Grieve (1993). Readings were taken on a total of fifty particles per sample pellet and averaged. Both maximum and random reflectance values, under polarized light, were determined for each sample. The maximum reflectance (R_{max}) of a coal particle is defined as the highest value observed during full rotation of the stage. The random vitrinite reflectance (R_m) of a given coal particle is defined as the square root of the product of the maximum and minimum reflectances (Kilby, 1988). Mean random reflectance was converted to ASTM rank equivalent using boundaries established for western Canadian coals by Cameron (1989, Table 2).

TABLE 2
VITRINITE REFLECTANCE

Coalfield/Formation (Data source) *Sample qualifier*	$R_{max.}$%	$R_{m.}$%	
Northeast B.C./Gates	1.21	1.14	*mean*
(ROM)	1.04-1.39	1.00-1.29	*range*
	(8)	(8)	*(number of samples)*
Northeast B.C./Gates	1.24		*mean*
(AR)	1.01-1.40		*range*
Raw coal samples	(109)		*(number of samples)*
Northeast B.C./Gates	1.32		*mean*
(AR)	1.01-1.62		*range*
Clean coal samples	(187)		*(number of samples)*
Northeast B.C./Gething	1.13		*mean*
(AR)	0.98-1.33		*range*
Raw coal samples	(13)		*(number of samples)*
Northeast B.C./Gething	1.32		*mean*
(AR)	1.06-1.66		*range*
Clean coal samples	(37)		*(number of samples)*
Southeast B.C.	1.25	1.19	*mean*
(ROM)	0.94-1.53	0.92-1.48	*range*
	(26)	(26)	*(number of samples)*
Southeast B.C.	1.17		*mean*
(AR)	0.81-1.45		*range*
Raw coal samples	(135)		*(number of samples)*
Southeast B.C.	1.27		*mean*
(AR)	0.92-1.53		*range*
Clean coal samples	(48)		*(number of samples)*
Klappan	3.63		*mean*
(AR)	3.21-4.22		*range*
Raw coal samples	(20)		*(number of samples)*

ROM: run-of-mine samples

AR: assessment report data

R_{max} *: mean maximum vitrinite reflectance*

R_m *: mean random vitrinite reflectance*

Maceral analyses were done using a Swift point-counting stage using one pellet per sample. Results were determined on a mineral-matter-free basis (coal only), and 300 to 500 points were counted per sample. The following macerals were identified: vitrinite A, vitrinite B, other vitrinite (chiefly vitrodetrinite), sporinite, cutinite, other liptinite (chiefly resinite), semifusinite, fusinite, macrinite, micrinite and inertodetrinite.

LOW-TEMPERATURE ASHING

Representative splits of -60-mesh coal samples provided to us were ready for low-temperature ashing without further treatment. This technique, which uses radio frequency (RF) generated oxygen plasma, is a routine way of producing an ash with the original minerals essentially preserved (see for example, Miller *et al.*, 1979). The Ministry's plasma asher is an LFE Corporation model LTA-504, which uses an RF power supply that operates at 13.56 megahertz. Five to ten grams of coal were placed in a silica sample-boat. One boat was placed in each of the four 10-centimetre diameter reaction chambers, which were then evacuated using a vacuum pump. Ashing was done using 200 watts total RF power (50 watts per chamber), and a total oxygen bleed-rate of about 30 cubic centimetres per minute. Samples were left exposed to the oxygen plasma round-the-clock, for a total of about 72 hours. They were stirred at least twice a day using a glass rod, in order to bring unreacted coal to the surface. At the end of the reaction time a small amount, less than 1% (estimated) by volume, of unreacted organic material was left in the residue. This is assumed to be made up of inertinite. Low-temperature ashes were ground using an agate mortar and pestle, prior to routine x-ray diffraction analysis.

DETERMINATION OF THE MANNER OF ASSOCIATION OF AN ELEMENT IN COAL

A major part of this study was devoted to coal geochemistry, specifically the concentrations of phosphorus and trace elements. Determining the mode of association of an element in coal is as important as knowing its actual concentration (Finkelman, 1980). This is because the mode of association determines the potential for upgrading the coal with respect to the element in question, and the potential for release of the element during utilization.

One generally accepted and simple method of gaining a preliminary impression of this factor is to plot the concentration of the element versus the ash content (Nicholls, 1968). If the concentration increases with increasing ash, it is tentatively concluded that the element is predominantly bonded to the inorganic fraction of the coal. Conversely, a constant or decreasing concentration of the element suggests bonding with the organic fraction. A further refinement is to divide the concentration of the element in each sample by the ash content of the sample, in effect calculating the element's concentration in the ash, and to plot this value against the ash. With this approach, element concentrations which plot on a horizontal line suggest predominantly inorganic bonding, while those which plot on a line with negative slope imply organic bonding. Nicholls (1968) also makes a case for being able to detect a mixed association with this latter type of graph. Figure 32c(ii) is an example of the type of plot which has been interpreted in this way. It shows a high negative slope at low ash contents (supposedly organic bonding), and no slope over higher ash contents (inorganic). This interpretation is suspect, however, as some of the basic assumptions inherent in the use of element/ash graphs (Nicholls, 1968) are unfounded, in particular, the assumption that the element's concentration in ash is consistent in each ash increment.

A second widely used approach for determining an element's affinity in coal is to compare its concentration in specific gravity fractions from sink-and-float testing (Gluskoter *et al.*, 1977). Elements with organic affinity should be concentrated in the light fraction(s), while those with inorganic affinity should be elevated in the heavy fraction(s). This assumes, however, that mineral grains are physically liberated prior to the separation. If they are not liberated, then apparent organic affinity may not necessarily be the result of organic bonding.

The problems with the use of these two approaches will be expanded in a later section.

DATA COLLECTION

An important component of the study was the compilation of coal quality data recorded in exploration assessment reports. As noted above, these data are used mainly to supplement information generated from sampling, most importantly by providing information from formations and regions not sampled. Three separate databases were created, each with a different application: a general regional database, one for phosphorus analyses and a third for vitrinite reflectance measurements.

GENERAL REGIONAL DATABASE

The regional database, shown as Appendix 2 and utilized throughout this paper, provides basic coal quality data for most of the important coal-bearing regions in the province on a seam-by-seam basis. It is identical to Appendix 2 in the B.C. Coal Quality Catalog (Grieve, 1992a), and the ultimate source of most of these data is assessment reports. The bulk of the data is derived from raw drill core samples, although a significant proportion are from raw bulk samples. These data have not been selected randomly and the database is not exhaustive. Consistent with the objectives of the B.C. Coal Quality Catalog, we have tried to optimize coverage (stratigraphic and regional) and sample integrity (expressed as core recovery in the case of core samples), as well as to include petrographic data. The data are therefore not always representative, and so only limited statistical treatment is applied. Most of the vitrinite reflectance data in this database are also part of the reflectance database (below).

PHOSPHORUS DATABASE

Exhaustive phosphorus data collection from assessment reports was undertaken for metallurgical coals in southeast and northeast British Columbia. These data, which are summarized in Tables 13 to 17, allow for comparisons of phosphorus concentrations in raw and clean coals from the Mist Mountain, Gates and Gething Formation coals. Proximate data were also collected, for observing phosphorus variations with ash content. Most of the data represent analyses of drill-core samples. In most cases, data were reported as percent phosphorus in coal, although in some cases the phosphorus values in coal were calculated from the concentration of P_2O_5 in ash. Data not available on an air-dried basis were converted to that basis where possible, or else not included. Data in reports for which the basis of reporting was not explicitly defined were not included.

VITRINITE REFLECTANCE DATABASE

Exhaustive reflectance data collection from assessment reports was undertaken for southeast, northeast British Columbia (Gates and Gething formations) and the Mount Klappan property. These data, which are summarized in Table 2 and Figure 9b, allow for rank characterization of the different regions, together with determination of the relationships between reflectance and other properties. Raw and clean coal data were collected. Most of the data represent analyses of drill-core samples.

CHAPTER 3 COAL PETROGRAPHY

Coal petrographic analyses provide the most fundamental coal quality data. Two tests, vitrinite reflectance and maceral analysis, were applied to the ROM samples. A large volume of vitrinite reflectance data, together with some total vitrinite content data, was also compiled from assessment reports, as noted above. Vitrinite reflectance is a very sensitive and the most widely applicable rank indicator. Coal rank interpretation will be covered below. Maceral analysis is the best indicator of coal type. To users of coal, the proportion of reactive macerals (vitrinite, liptinite and some of the semifusinite) to inert macerals (remainder of semifusinite plus all other inertinite macerals) is critical.

Results of these two tests are also used to investigate controls on variation in other properties, throughout this paper.

VITRINITE REFLECTANCE

Vitrinite reflectance data, determined on the ROM samples, are summarized in Figure 9a and Table 2. As both mean maximum (R_{max}) and mean random (R_m) reflectance are routinely determined in our lab, it is possible to compare these parameters over the range of ranks of productive coal seams in northeast and southeast British Columbia. Figure 10 shows their relationship, and indicates that there is almost perfect correlation between them (r = 0.996). There is some suggestion that the slope of the regression line may be diminishing at the high rank end. The regression equation is:

$R_{max} = -0.0573 + 1.102R_m$.

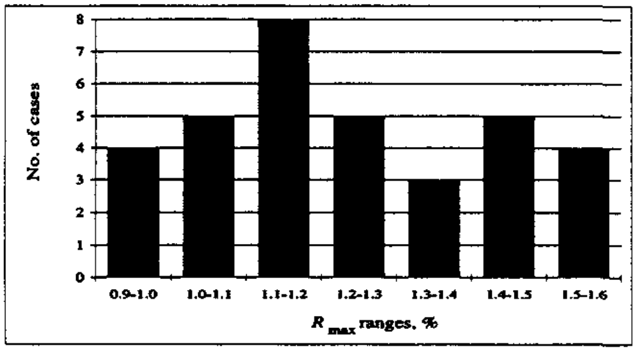

Figure 9a. Vitrinite reflectance data. Frequency histogram of R_{max} data in ROM samples.

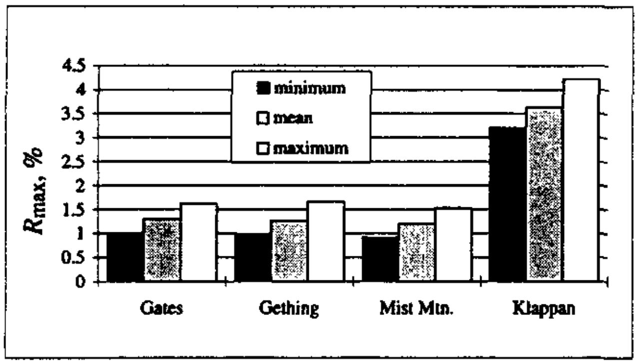

Figure 9b. R_{max} data from various regions, compiled from assessment reports.

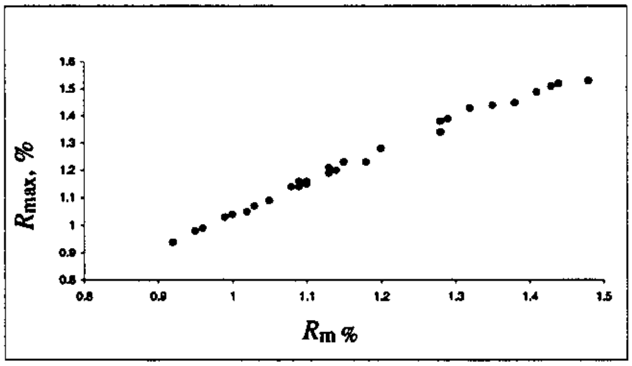

Figure 10. R_{max} vs. R_m in ROM samples.

We will generally refer to the mean maximum reflectance values throughout this study, because that is the parameter used consistently in the assessment reports. However, in the case of rank determinations (next section), we have used the above equation to convert R_{max} values to R_m; given the high correlation coefficient, this is considered to be a reliable conversion.

Vitrinite reflectance (R_{max}) values in the ROM samples range from 0.94 to 1.53%, with a mean of 1.24 (Table 2). The distribution of reflectance data (Figure 9a) is bimodal, with one peak, the larger, of R_{max} values in the range 1.1 to 1.2% and a second peak at 1.4 to 1.5%. The overall range from both regions also applies to the Kootenay region ROM samples, which have a mean of 1.25%. The range in reflectance values for the northeast British Columbia ROM samples, at 1.04 to 1.39%, is much narrower, and the mean, 1.21%, is slightly lower. The smaller range for northeast samples is consistent with the volatile matter data (below), and is an accurate reflection of the narrower range of rank of the seams being mined in the northeast of the province. The vitrinite reflectance database derived from assessment reports (next paragraphs) indicates that a wider range of coal ranks actually occurs throughout the northeast region as a whole than the ROM data would suggest.

The vitrinite reflectance database is summarized in Table 2 and Figure 9b. These data expand the available data to other exploration sites in the two regions, and to the Gething Formation coals of northeast British Columbia and the Klappan coalfield in the northwest. Clean coal reflectance data are also included for the northeast and southeast samples.

The mean for assessment report data (raw coal) from the southeast, 1.17%, is 0.08% lower than the mean for the corresponding ROM data. For Gates coals from northeast B.C., on the other hand, the mean in assessment report data, 1.24, is higher by 0.03%. The mean for the Gething coals is 1.13%. Clean coal mean R_{max} values (Table 2) are higher in all cases and are on the order of 1.30% for all three formations. In the clean coal data, the range in R_{max} values for all three formations is about 0.6%.

Maximum reflectance is one property which should not be influenced greatly by coal cleaning. However, the mean R_{max} values for the clean and raw coal data sets, as already noted, are quite different, the most striking contrast being in the case of the Gething Formation (1.13% for raw coals and 1.32% for clean). These means must therefore be influenced by the proportions of samples utilized from different geographic locations and/or stratigraphic positions. This effect probably also accounts for differences in mean R_{max} values between ROM and assessment report data. Therefore, the means are probably not as useful as the simple ranges of values for characterizing reflectance in the different regions.

Taking all the available data collectively, the R_{max} ranges for both Gething and Gates coals from northeast British Columbia are on the order of 1.0 to 1.6%, while for the southeast the range is from about 0.8 to greater than 1.5%. In studies of rank distributions in southeast B.C. coals, Pearson and Grieve (1985) and Grieve (1993) found that there are localized occurrences of coals with R_{max} values greater than 1.5 or lower than 0.8%. Klappan coalfield coals are much higher in rank, and the mean R_{max} value in raw coals there is 3.63%.

COAL RANK

We have applied the well known North American (ASTM) classification of coals by rank (ASTM, 1984) to raw coals involved in this study. The primary tool in determining rank is vitrinite reflectance, supplemented, where appropriate, by the calorific value and volatile matter contents. Vitrinite reflectance data from Matheson *et al.* (1994) is cited, covering the Quinsam deposit in the Comox coalfield, the Telkwa deposit, and the Bowron River coalfield. Information from the literature has been used for Hat Creek and Tulameen deposits.

The ASTM rank classification system does not actually utilize vitrinite reflectance as a rank criterion. However, Cameron (1989) empirically defined ASTM rank boundaries in terms of random reflectance (R_m) values for western Canadian coals (Table 3), and those boundaries are applied here. Conversions between R_m and R_{max} were made using the regression equation defined in the previous section. Coal ranks for British Columbia coals are summarized in Table 4.

The ASTM classification system utilizes mineral matter rather than ash as the measure of inorganic material content in expressing calorific value (moist, mineral matter-free basis) and volatile matter (dry, mineral-matter-free basis). We have used the more easily determined ash content (*e.g.*, moist ash-free). Nonetheless, the combination of reflectance data with the other parameters provides for good resolution of coal ranks.

TABLE 3
COMPARISON OF REFLECTANCE THRESHOLDS WITH ASTM RANK CLASSES

Rank	Reflectance range %
Lignite	<0.42
Sub-bituminous	0.42-0.50
High vol. B/C bituminous	0.50-0.75
High vol. A bituminous	0.75-0.95
Medium volatile bituminous	0.95-1.45
Low volatile bituminous	1.45-1.90
Semianthracite	1.90-2.40
Anthracite	>2.40

(Note: all reflectances random)
(from Cameron, 1989)

The rank ranges of northeast (Gates and Gething formations) and southeast British Columbia coals are high-volatile A to low-volatile bituminous. Most of the coals in these regions are medium-volatile bituminous in rank. Some high-volatile B bituminous coals are known to occur in the Elk Valley coalfield (Grieve, 1993), but none were in evidence in this study. Klappan coals are anthracitic in rank, based on reflectance data.

Coals of the Quinsam deposit (Comox coalfield) range from high-volatile C to high-volatile A with an average rank in the high-volatile B range (Table 4), based on the drill-core samples from the Quinsam mine area reported on by Matheson *et al.* (1994). The same source of information was used to compile information on the Telkwa and Bowron River coalfields. Telkwa coals were determined to be mainly high-volatile A in rank, while the average rank of Bowron River coals was interpreted to be near the high volatile C/B boundary. Data compiled in this study do not contradict these interpretations.

Rank of the Hat Creek coals, based on R_m data, ranges from lignite to sub-bituminous B (Goodarzi, 1985; Goodarzi and Gentzis, 1987). The calorific value data collected here can not be applied to confirming the Hat Creek rank, because they are all reported on a dry basis. Tulameen coals range in rank from high-volatile C to high-volatile B bituminous, although R_{max} values as high as 0.86 (high-volatile A) have been reported (Williams and Ross, 1979). The Tulameen calorific value data collected in this survey (Table 9) suggest mainly high-volatile C bituminous rank.

MACERAL COMPOSITIONS

Most western Canadian coals are characterized by relatively high inertinite contents, especially when compared

TABLE 4
SUMMARY OF RANKS OF B.C. COALS

Coalfield/Formation (Deposit)	Rank range (Mode)	Data type	Source	Coalfield/Formation (Deposit)	Rank range (Mode)	Data type	Source
Northeast B.C./Gates	high volatile A to low volatile (medium volatile)	R_{max}	this study	Northeast B.C./Gething	high volatile A to low volatile (medium volatile)	R_{max}	this study
Northeast B.C./Minnes	medium to low volatile	volatile matter	this study	Southeast B.C.	high volatile B to low volatile (medium volatile)	R_{max}	this study; Grieve (1993)
Comox (Quinsam)	high volatile C to high volatile A (high volatile B)	R_{max}, calorific value	Matheson *et al*. (1994)	Klappan (Mt. Klappan)	anthracite	R_{max}	this study
Telkwa (Telkwa)	high volatile B to medium volatile (high volatile A)	R_{max}; calorific value; volatile matter	Matheson *et al*. (1994)	Bowron River	high volatile C to high volatile B	R_{max}, calorific value	Matheson *et al*. (1994)
Hat Creek	lignite to sub-bituminous B	R_m	Goodarzi (1985); Goodarzi and Gentzis (1987)	Tulameen	high volatile C to high volatile B	calorific value; R_{max}	Williams and Ross (1979); this study

R_{max}: mean maximum vitrinite reflectance R_m: mean random vitrinite reflectance

TABLE 5
MACERAL ANALYSIS

Coalfield/Formation (Data source) *Sample qualifier*	Vitrinite A %	Vitrinite B %	Vitrodetrinite %	Total vitrinite %	Semifusinite %	Fusinite %	Macrinite %	Micrinite %	Inertodetrinite %	Total inertinite %	Sporinite %	Cutinite %	Other liptinite %	Total liptinite %	
Northeast B.C./Gates (ROM)	37.3 19.5-48.8 (8)	24.7 18.8-31.8 (8)	1.2 0-2.3 (8)	63.2 39.5-79.8 (8)	28.9 13.3-47.0 (8)	1.9 1.0-3.5 (8)	0.9 0.3-1.3 (8)	0.1 0-0.3 (8)	4.8 2.1-9.3 (8)	36.7 20.0-60.3 (8)	0.1 0-0.4 (8)	0 (8)	0 (8)	0.1 0-0.1 (8)	*mean* *range* *(number of samples)*
Northeast B.C./Gates (AR) *Raw coal samples*				54.9 13.6-73.3 (107)											*mean* *range* *(number of samples)*
Northeast B.C./Gates (AR) *Clean coal samples*				54.7 23.6-79.0 (186)											*mean* *range* *(number of samples)*
Northeast B.C./Gething (AR) *Raw coal samples*				47.1 26.1-77.2 (13)											*mean* *range* *(number of samples)*
Northeast B.C./Gething (AR) *Clean coal samples*				49.3 19.2-84.3 (37)											*mean* *range* *(number of samples)*
Southeast B.C. (ROM)	34.4 15.8-55.8 (26)	26.0 15.3-44.0 (26)	1.3 0-4.25 (26)	61.7 41.3-92.0 (26)	31.3 5.25-50.5 (26)	2.1 0.5-3.8 (26)	0.6 0-2.0 (26)	0.0 0-0.3 (26)	3.6 0.7-10.3 (26)	37.5 7.3-58.1 (26)	0.5 0-2.8 (26)	0.2 0-2.0 (26)	0.0 0-1.0 (26)	0.8 0-4.0 (26)	*mean* *range* *(number of samples)*
Southeast B.C. (AR) *Raw coal samples*				60.4 37.1-82.6 (116)											*mean* *range* *(number of samples)*
Southeast B.C. (AR) *Clean coal samples*				58.7 31.0-82.0 (46)											*mean* *range* *(number of samples)*
Klappan (AR) *Raw coal samples*				52.2 38.9-63.0 (4)											*mean* *range* *(number of samples)*

ROM: run-of-mine samples *AR: assessment report data*

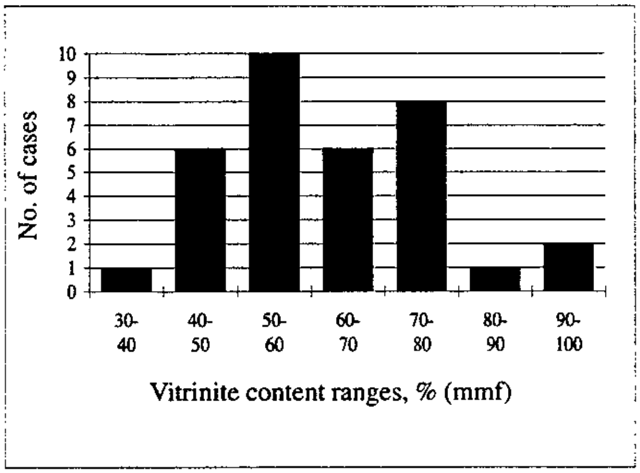

Figure 11a. Maceral composition data. Maceral composition frequency histograms for ROM samples. Total vitrinite in ROM samples.

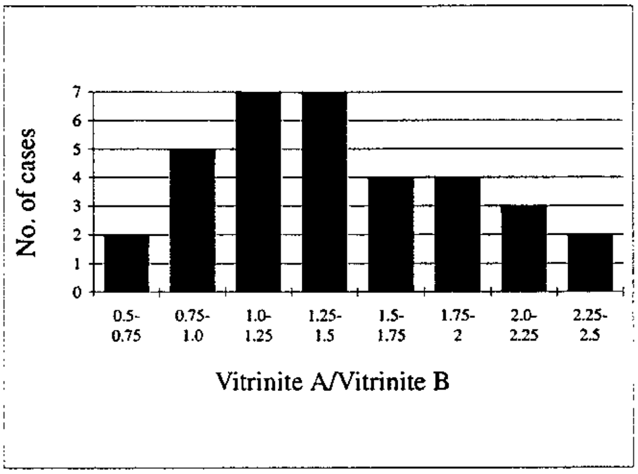

Figure 11b. Maceral composition data. Maceral composition frequency histograms for ROM samples. Vitrinite A/Vitrinite B in ROM samples.

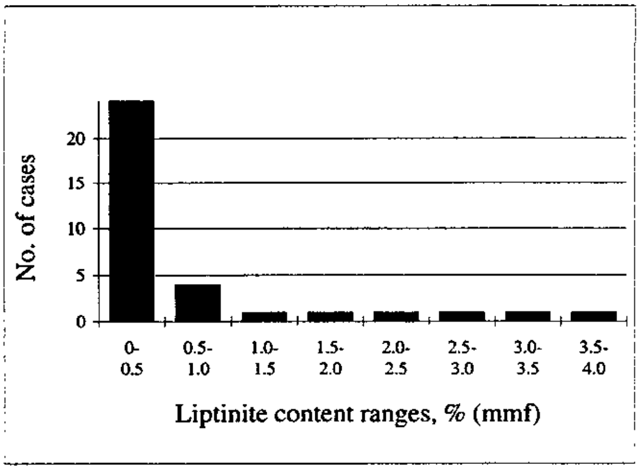

Figure 11c. Maceral composition data. Maceral composition frequency histograms for ROM samples. Total liptinite in ROM samples.

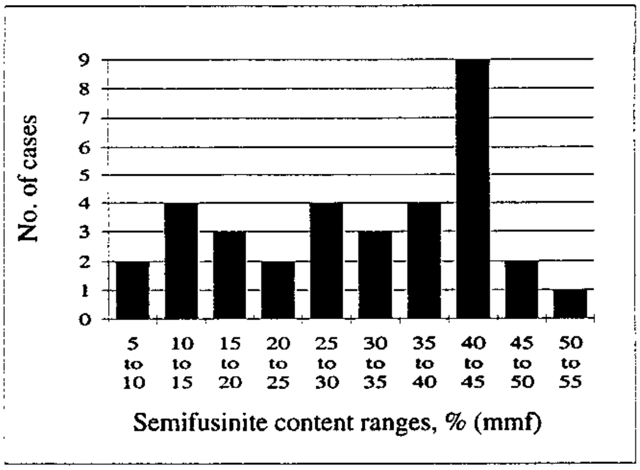

Figure 11d. Maceral composition data. Maceral composition frequency histograms for ROM samples. Semifusinite in ROM samples.

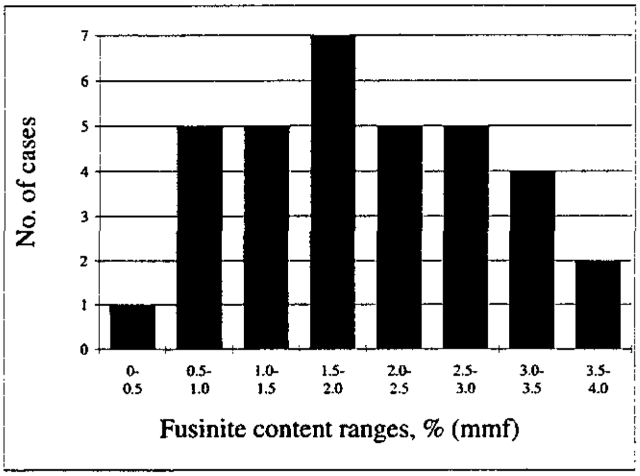

Figure 11e. Maceral composition data. Maceral composition frequency histograms for ROM samples. Fusinite in ROM samples.

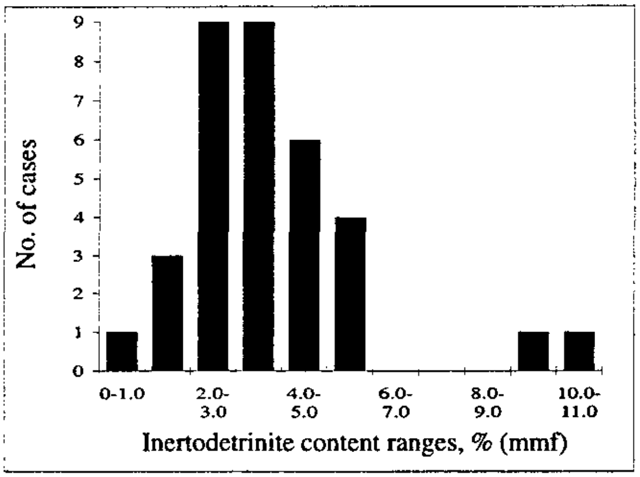

Figure 11f. Maceral composition data. Maceral composition frequency histograms for ROM samples. Inertodetrinite in ROM samples.

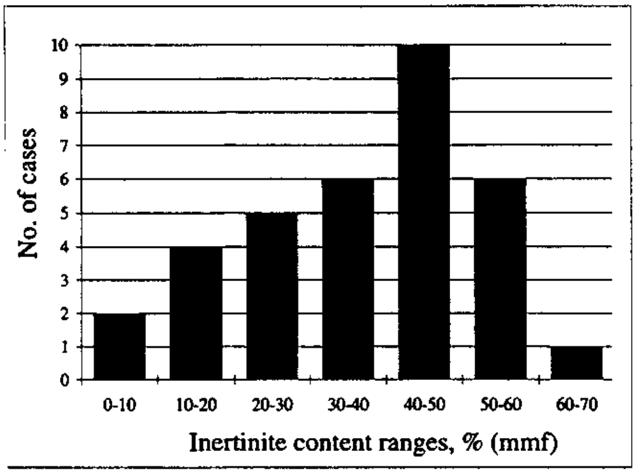

Figure 11g. Maceral composition data. Maceral composition frequency histograms for ROM samples. Total inertinite in ROM samples.

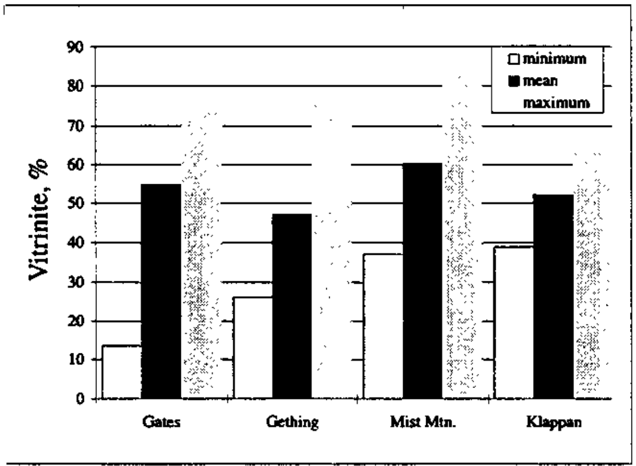

Figure 11h. Maceral composition data. Total vitrinite data from various regions, compiled from assessment reports.

with eastern North American coals (Pearson, 1980). This is especially true of the coking coal belts in the Rocky Mountains. This factor is balanced, however, by the more reactive behaviour of the semifusinite. The data determined and compiled here for northeast and southeast British Columbia, and the Klappan coalfield (Table 5, Figure 11), show that the mean total vitrinite contents of the ROM samples from the northeast and southeast are somewhat higher than the values determined from assessment report data. Overall the Gates Formation and Mist Mountain Formation coals contain an average of about 60% total vitrinite, with maximum values exceeding 80%. Vitrinite A ("structured" vitrinite) is in greater abundance in most samples than vitrinite B ("unstructured" or "degraded" vitrinite). Gething Formation coals, with a mean of about 50%, apparently have, on average, less total vitrinite than either the Gates or Mist Mountain Formation samples, although the number of Gething samples is small. An interesting observation, based on comparison of raw and clean coal data for the Gates, Gething and Mist Mountain formations, is that total vitrinite content changes very little when coal is cleaned.

Liptinite is present in insignificant quantities in these two regions, so that essentially all of the non-vitrinitic material is composed of inertinite. Total inertinite content in ROM samples ranges from 7.3 to 60.3%, with a mean of 37.3%. Semifusinite is by far the most abundant inertinite group maceral in Gates and Mist Mountain coals, with average proportions of about 30% of total organic matter. Inertodetrinite is the next most common inertinite maceral on average, followed by fusinite (average about 2%) and macrinite.

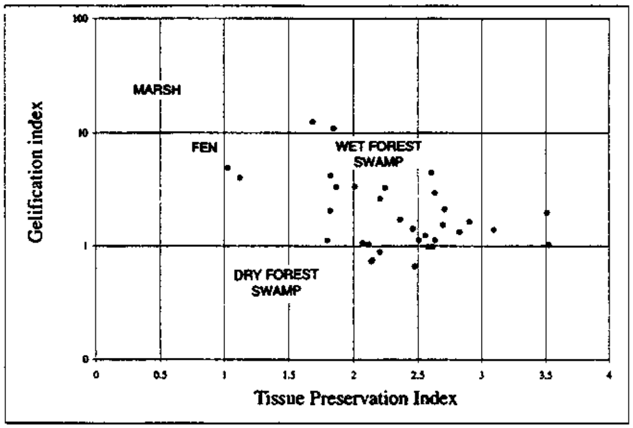

Figure 12a. Gelification index *vs.* tissue preservation index. GI/TPI diagram, with ROM samples plotted.

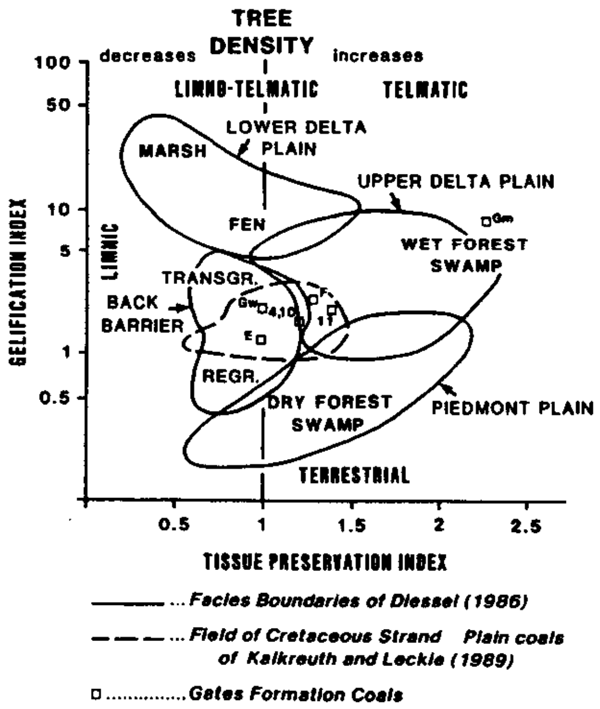

Figure 12b. Gelification index *vs.* tissue preservation index. GI/TPI diagram, with Gates Formation seams plotted (from Marchioni and Kalkreuth, 1991).

For comparison, eastern U.S. coals contain generally in the range of 5 to 20% total inertinite. They also tend to contain an equivalent amount of liptinite, which contributes to higher fluidity (see chapter on caking). Australian coals are similar to our coals, with low liptinite and relatively high inertinite contents (Pearson, 1980).

Vitrinite concentrations in four Klappan area samples are also relatively low, averaging just over 50%. See Matheson *et al.* (1994) for maceral compositions of Quinsam, Telkwa and Bowron River coals.

PETROGRAPHIC INDEXES

Maceral data from the ROM samples were used to derive two parameters, known as the tissue preservation index, or TPI, and the gelification index, or GI. Formulas for these indexes (Diessel, 1986) are as follows:

TPI = (vitrinite A + fusinite + semifusinite)/(vitrinite B + macrinite + inertodetrinite);

GI = (total vitrinite + macrinite)/(semifusinite + fusinite + inertodetrinite).

Various petrographic indexes, including TPI and GI, have been used to characterize coal depositional facies (Diessel, 1982, 1986). A commonly used approach is to plot GI *versus* TPI, and compare the position of a sample with fields of common depositional environments, derived from Australian coals (Figure 12). The gelification index is thought to be a measure of relative wetness, or water table height, with higher GI values representing wetter conditions. The tissue preservation index gives an approximation of tree density (higher values imply higher densities). As can be seen in Figure 12, most of the ROM samples (Figure 12a) lie within, or to the right of, the wet forest swamp field (Figure 12b). This suggests dense arboreal vegetation in an area of high water table as the environment of coal deposition for most ROM samples. This is somewhat inconsistent with the results for the Gates Formation of Kalkreuth and Leckie (1989) and Marchioni and Kalkreuth (1991), who noted that some Quintette coals plot in the field for a back-barrier environment (Figure 12b). It may also be inconsistent with previous depositional models established for the lower part of the Mist Mountain Formation (*e.g.*, Gibson, 1985), in which the lowest seams are believed to have been deposited in a back-barrier environment; (the two samples which plot to the left of the wet forest swamp field in Figure 12a are actually from the uppermost part of the Mist Mountain Formation). This suggests weaknesses in either the published depositional models or more likely this method of facies determination.

CHAPTER 4 PROXIMATE ANALYSIS

Proximate analysis provides "a measure of the relative amount of volatile and non-volatile organic compounds in the coal as well as the percentage of water and non-combustible mineral materials" (Ward, 1984). These four components are referred to, respectively, as volatile matter, fixed carbon, moisture and ash, and their sum is 100%. Results are summarized in Table 6 and Figures 13 through 15.

MOISTURE

Discussion here is concerned with air-dried (ad) moisture, which is also referred to as residual moisture. It is always lower in value than the as-received moisture of a coal sample, and so has less significance to the user. It is also lower than the equilibrium (inherent) moisture content. It is, nonetheless, a useful coal quality parameter and can be used reliably for comparisons.

TABLE 6
PROXIMATE ANALYSIS

Coalfield/Formation *(Data source)*	Moisture, % (ad)	Ash, % (ad)	Vol. matter, % (daf)	
Northeast B.C./Gates	0.92	27.81	29.46	*mean*
(ROM)	0.77-1.13	7.37-47.80	27.03-32.07	*range*
	(8)	(8)	(8)	*(no. of samples)*
Northeast B.C./Gates	0.71	18.81	26.85	*mean*
(AR)	0.17-1.70	4.39-46.16	19.48-35.10	*range*
	(48)	(48)	(48)	*(no. of samples)*
Northeast B.C./Gething	1.63	14.22	25.72	*mean*
(AR)	0.36-3.76	4.47-36.55	13.99-37.26	*range*
	(40)	(40)	(51)	*(no. of samples)*
Northeast B.C./Minnes	0.57	9.87	18.98	*mean*
(AR)	0.46-0.68	3.10-23.45	17.69-22.36	*range*
	(5)	(5)	(5)	*(no. of samples)*
Southeast B.C.	0.86	21.94	28.58	*mean*
(ROM)	0.50-1.51	8.46-37.97	22.43-35.53	*range*
	(26)	(26)	(26)	*(no. of samples)*
Southeast B.C.	1.38	20.42	30.99	*mean*
(AR)	0.60-2.70	6.47-37.40	20.52-37.56	*range*
	(35)	(35)	(35)	*(no. of samples)*
Comox	2.12	19.50	43.67	*mean*
(AR)	0.3-3.53	9.0-36.8	36.3-49.8	*range*
	(34)	(34)	(34)	*(no. of samples)*
Klappan	1.35	29.49	11.19	*mean*
(AR)	0.75-2.89	13.76-42.15	7.65-19.87	*range*
	(34)	(34)	(34)	*(no. of samples)*
Telkwa	1.08	19.71	33.96	*mean*
(AR)	0.84-1.21	16.03-25.14	32.03-37.09	*range*
	(10)	(10)	(10)	*(no. of samples)*
Bowron River	3.37	30.73	47.29	*mean*
(AR)	2.24-4.36	23.65-36.10	40.07-50.26	*range*
	(4)	(4)	(4)	*(no. of samples)*
Hat Creek	0*	36.21*	49.88	*mean*
(Sinclair, 1977)		25.99-57.83	44.47-55.18	*range*
		(7)	(7)	*(no. of samples)*
Tulameen	5.73	39.04	44.35	*mean*
(AR)	4.3-6.6	20.6-49.1	38.48-48.70	*range*
	(11)	(11)	(11)	*(no. of samples)*

ROM : run-of-mine samples
AR: assessment report data

** dry basis*

Essentially all of the ROM samples contain less than 1.5% air-dried moisture (Table 6, Figure 13a), and the ROM means for both regions are under 1%. There is some inconsistency between moisture contents determined on ROM samples and the compiled data from southeast British Columbia. The mean of the latter data set is somewhat higher (1.38%). This may be related to inconsistencies in analytical methods. Minnes Group coals appear to contain less moisture than the ROM samples (mean 0.57%), while Gething Formation and Comox coalfield values are somewhat higher, with means of 1.63% and 1.95%, respectively. Coals in this study with more than 2% average moisture (Figure 13b) are from the lower-rank coal basins, Bowron River

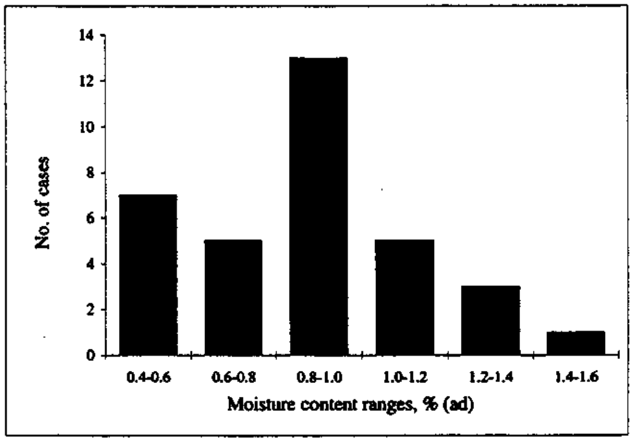

Figure 13a. Moisture data. Frequency histogram of moisture (ad) in ROM samples.

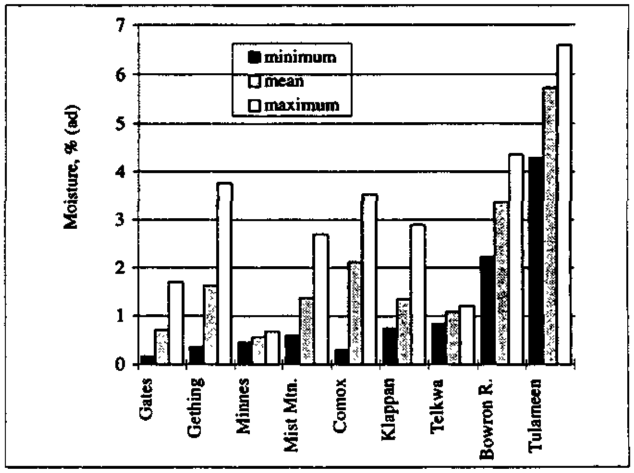

Figure 13b. Moisture data (ad) from various regions, compiled from assessment reports.

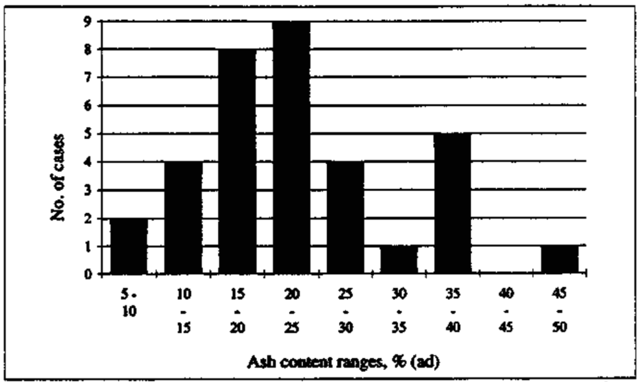

Figure 14a. Ash data. Frequency histogram of ash (ad) in ROM samples.

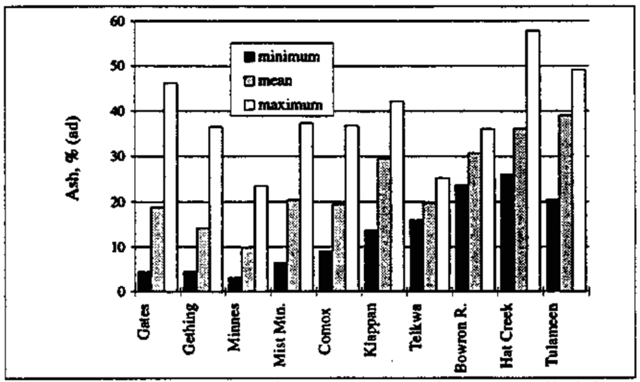

Figure 14b. Ash data (ad) from various regions, compiled from assessment reports. (Hat Creek data reported on a dry basis.)

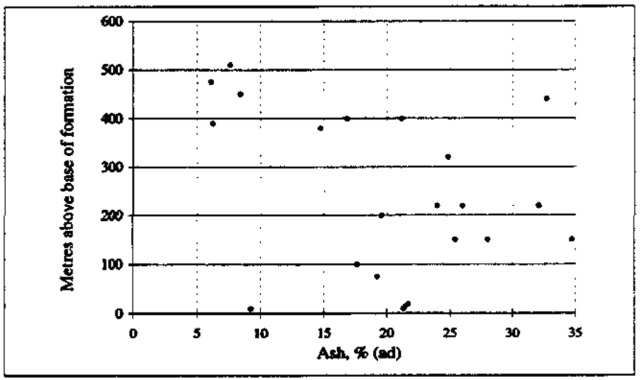

Figure 14c. Variations in ash content with stratigraphic position. Southeast B.C. whole-seam channel samples.

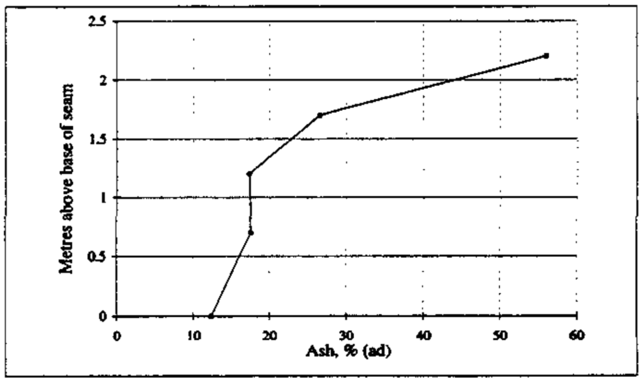

Figure 14d. Variations in ash-content with stratigraphic position. 10A-seam, Line Creek, southeast B.C. channel samples. Air-dried ash.

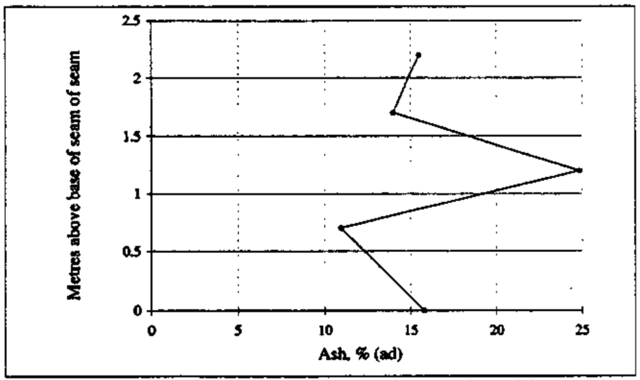

Figure 14e. Variations in ash content with stratigraphic position. 10B-seam, Line Creek, southeast B.C. channel samples.

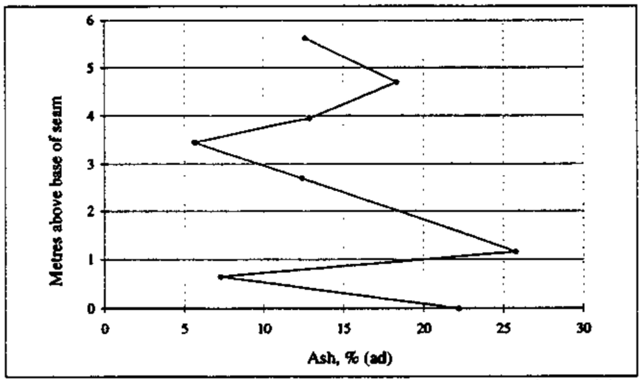

Figure 14f. Variations in ash content with stratigraphic position 9-seam, Line Creek, southeast B.C. channel samples.

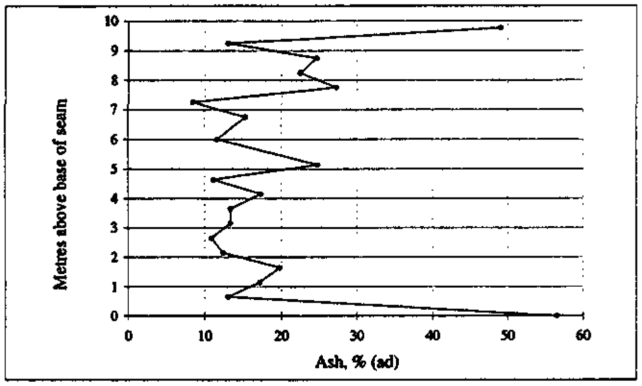

Figure 14g. Variations in ash content with stratigraphic position. 8-seam Line Creek, southeast B.C. channel samples.

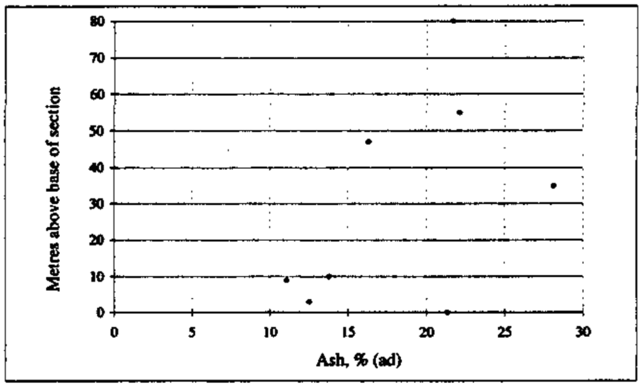

Figure 14h. Variations in ash content with stratigraphic position. Northeast B.C. channel samples.

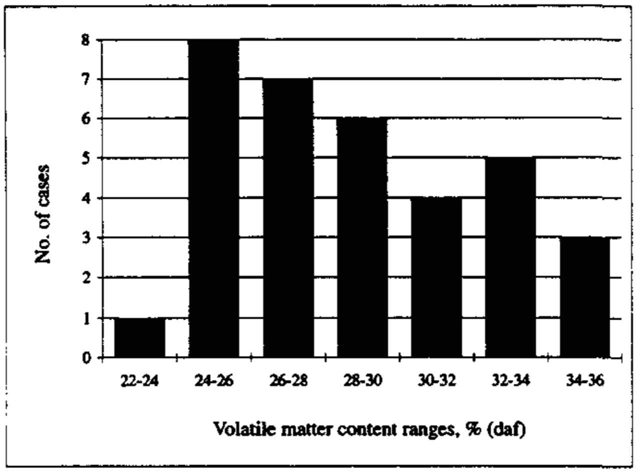

Figure 15a. Volatile matter data. Frequency histogram of volatile matter (daf) in ROM samples.

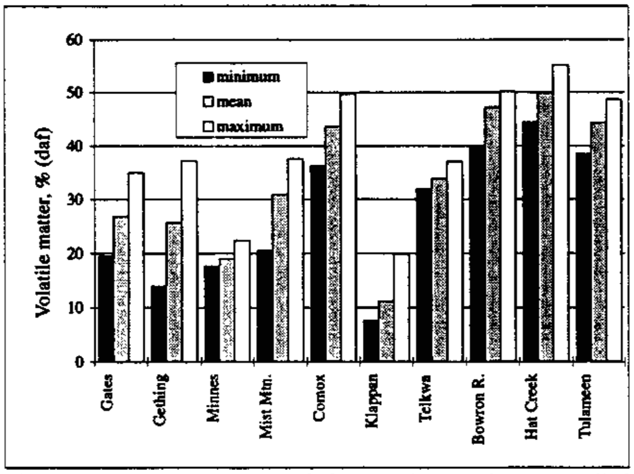

Figure 15b. Volatile matter (daf) from various regions, compiled from assessment reports.

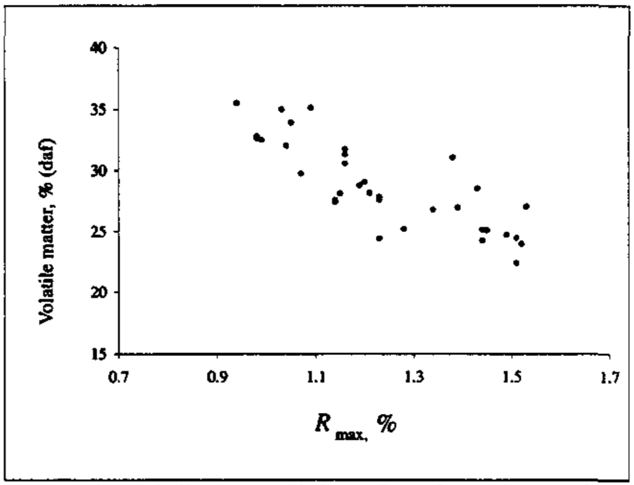

Figure 16a. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. ROM samples.

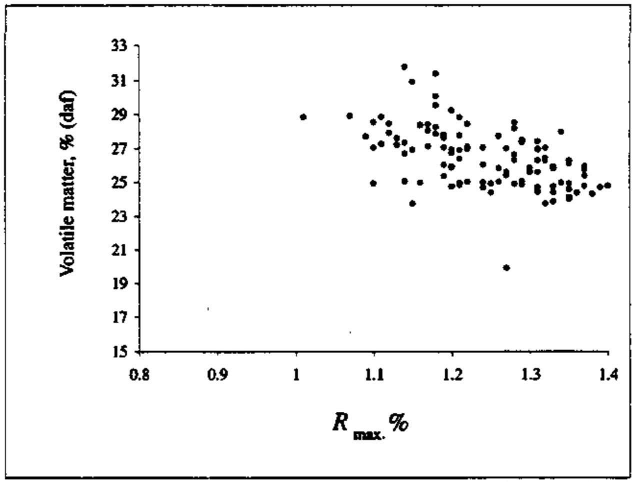

Figure 16b. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Gates Fm. raw samples.

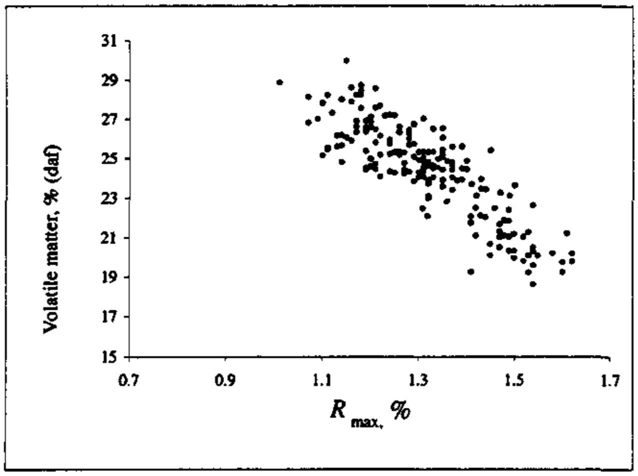

Figure 16c. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Gates Fm. clean samples.

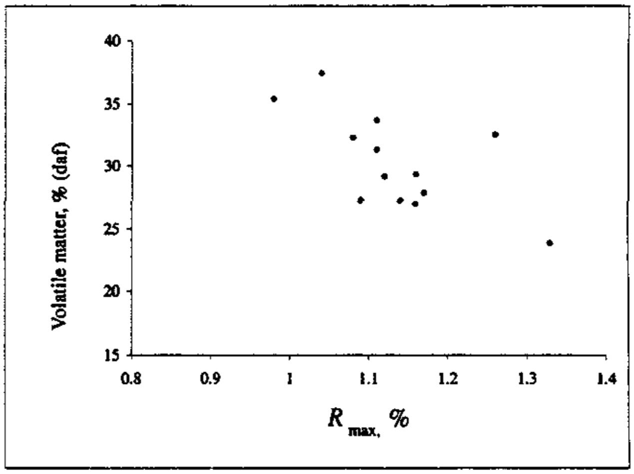

Figure 16d. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Gething Fm. raw samples.

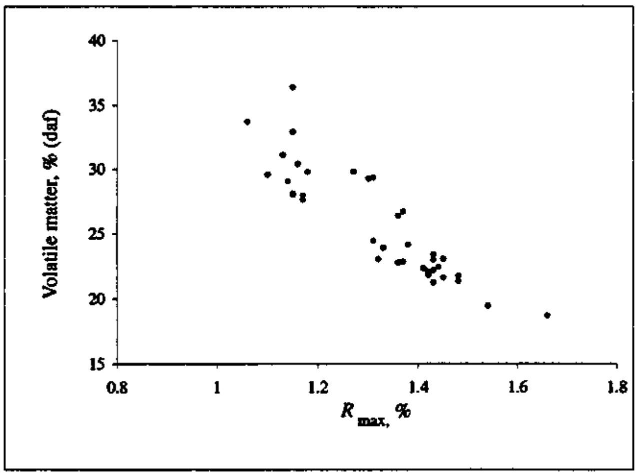

Figure 16e. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Gething Fm. clean samples.

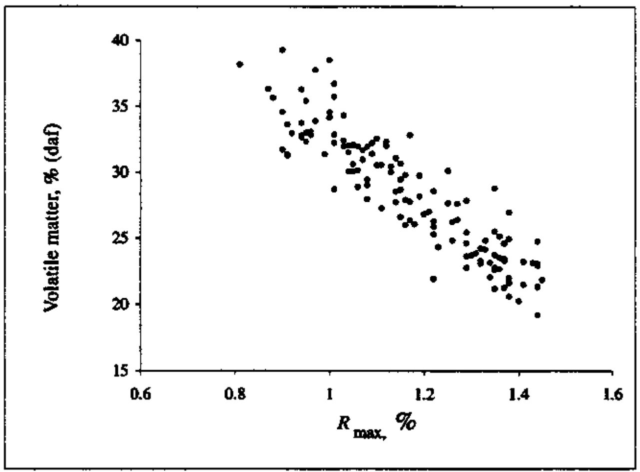

Figure 16f. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Mist Mountain Fm. raw samples.

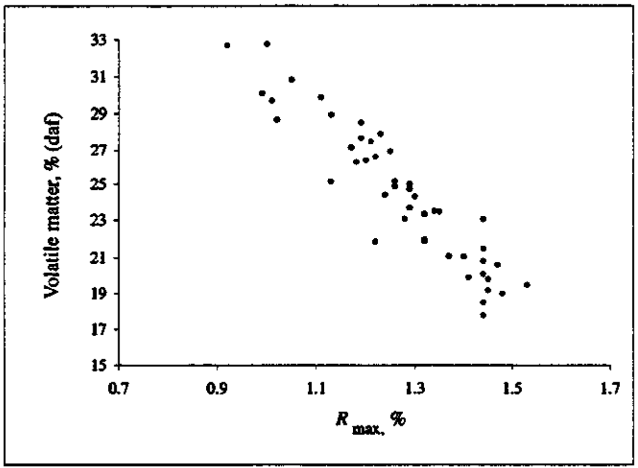

Figure 16g. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Mist Mountain Fm. clean samples.

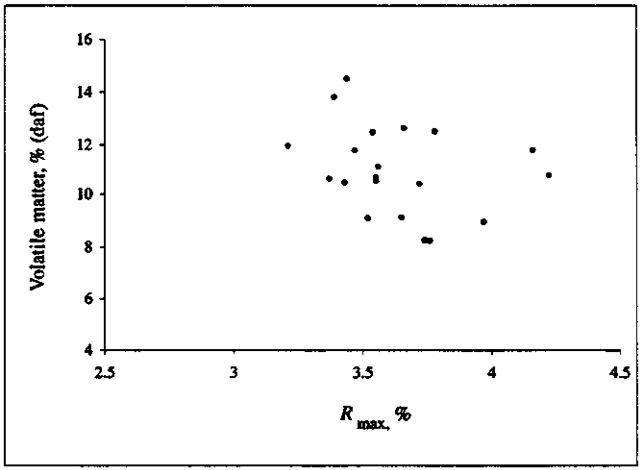

Figure 16h. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Klappan raw samples.

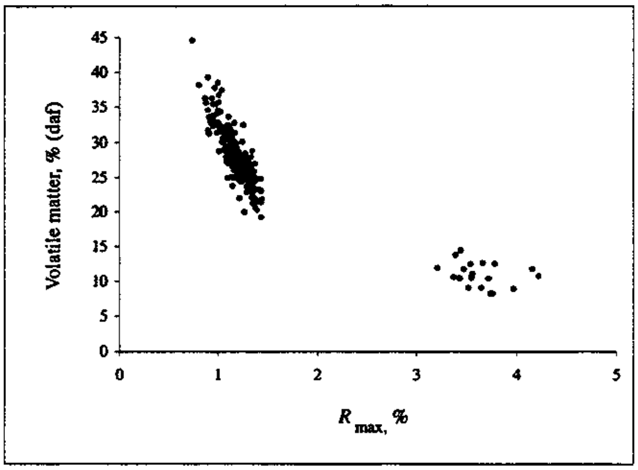

Figure 16i. Volatile matter (daf) *vs.* R_{max} for various regions, compiled from assessment reports. Raw coals from Northeast B.C., Southeast B.C. and Klappan.

(mean 3.37%), Tulameen (5.73%) and Hat Creek (not given, but safely assumed very high). Rank was discussed in an earlier section. Given that moisture is largely rank dependent, the moisture contents here can safely be assumed to conform to values in world coals.

ASH

Ash, the inorganic residue left after coal combustion, is a good indicator of coal grade. Its value is always somewhat lower than the true grade (that is, the mineral matter content) owing to the presence of volatile compounds in some minerals (for example, CO_2 in carbonate minerals), which are lost during heating. Unfortunately, mineral matter content is a very difficult factor to measure, and is seldom determined. It is usually calculated, using empirical relationships such as the Parr formula.

Ash contents are provided on an air-dried basis, with the exception of the Hat Creek data, which are on a dry basis. Ash data on the ROM samples are summarized in Table 6 and Figure 14a. Discussion of these data is brief, because ash content of raw coal samples is strongly dependent on the sampling method. For example, in the case of the channel sampling it was very easy to omit most discernible rock partings, whereas for the ROM samples, not only were partings included in the sample, but in all likelihood roof and floor rock were also sampled. To demonstrate, the mean ash contents in both channel samples and ROM samples have been calculated. The mean ash content in the ROM samples, 23.3% (Table 6), is higher than that in the whole-seam channel samples, 19.5%.

The mean ash content of all ROM samples, 23.3% (Table 6), corresponds almost exactly with the mean for the southeast British Columbia ROM samples. The mean for the northeast British Columbia samples is slightly higher at 27.81%. The data distribution, (Figure 14a) indicates that half of the ROM samples have ash contents between 15 and 25%. The distribution appears to be bimodal, with a second peak (5 samples) representing samples containing between 35 and 40% ash. Compiled Gething and Minnes data (Figure 14b) suggest low ash contents for these formations (means of 14.22 and 9.87%, respectively). Despite the limitations on use of ash data, it is also apparent that among other British Columbia basins four have relatively high (25%) mean ash contents (Figure 14b): Hat Creek, mean 36.21% (dry); Bowron River, 30.73% (ad); Tulameen, 39.04% (ad); and Klappan, 29.49% (ad).

Stratigraphic profiles of ash contents in the channel samples are given in Figures 14c to 14h. They will be discussed later in the context of phosphorus and trace element concentrations in the same samples.

Ash contents in British Columbia product coals are generally below 10% for coking coals, and about 15% for thermal. These values are driven by market specifications, although, to a large extent, inherent characteristics, such as raw ash and ease of washing (amount of near-gravity material, for example) determine clean-coal ash contents (*see* Holuszko, 1994). Eastern U.S. coking coal products, for comparison, with a range of 4.25 to 9.5%, have generally lower ash contents (Pearson, 1980). Australian metallurgical coal products, with a range of 6.8 to 10.3%, are more like our coals.

VOLATILE MATTER CONTENTS

Volatile matter on an air-dried basis was converted to a dry, ash-free (daf) basis (Table 6) to allow comparison between samples and regions and to contribute to rank classifications. In general, volatile matter decreases with increasing rank. The range 24 to 30% contains over 60% of the ROM samples (Figure 15a). The mean values for the Peace River and Kootenay ROM samples are very close and are on the order of 29%. An interesting contrast between the two regions is in the magnitude of the range (highest minus lowest) in volatile matter contents represented by these samples. The range in the southeast is 13%, while for the northeast samples it is only about 5%. This is an accurate reflection of the ranges in rank of the coal seams currently being mined in the two regions, and is substantiated by the vitrinite reflectance data, as pointed out earlier. A much wider range of volatile matter contents is observed in compiled data from northeast British Columbia (Table 6): 15% for the Gates Formation and 23% for the Gething Formation. The range in the data from the southeast (17%) is also higher for the compiled data.

The Gething Formation and Minnes Group coals from the Peace River coalfield, with means of 25.72 and 18.98%, respectively, have somewhat lower volatile matter contents than the Gates Formation coals, based on compiled data (Figure 15b). The Mount Klappan anthracite has the lowest mean daf volatile matter contents (mean about 11%), while coals from the low-rank basins, Tulameen, Comox, Hat Creek and Bowron River, all contain in excess of 40%. The high-volatile A Telkwa deposit has a mean volatiles content of 34%. Coal rank is summarized in the chapter concerned with coal petrography.

Dry, ash-free volatile matter has a negative relationship with vitrinite reflectance. Figure 16 displays this relationship for the ROM samples (r = -0.82), and also for assessment report data. This is, of course, primarily a rank effect, but what is surprising is the amount of scatter in the data. In other words, for any given reflectance a wide range of volatile matter contents can occur, even for the ROM samples, which were treated consistently. This has two main implications, the first being that volatile matter is influenced by more than rank, a fact that was pointed out in the Introduction. In this case coal type is influencing the distribution of volatile matter contents (see next paragraph), and presence of carbonates in the mineral matter may be another factor. The second implication stems from the first, and is that volatile matter is not a particularly good rank indicator for the province's higher rank coals. This is a major drawback of applying the ASTM classification of coals by rank to our coals (and in fact most coals), and is one reason why vitrinite reflectance is a preferred rank index. It is also important to point out what happens to the relationship at very high rank. The data for the Klappan anthracite coalfield in Figures 16h and 16i show no sensitivity of volatile matter to changes in reflectance.

The significant combined effect of coal rank and type on volatile matter is demonstrated for the ROM samples by the regression equation:

$vm_{daf} = 34.44 - 0.56R_{max} + 0.50V$ ($r^2 = 0.854$);

where, vm_{daf} = dry, ash-free volatile matter

V =% vitrinite (mineral matter-free).

CHAPTER 5 ULTIMATE ANALYSIS

Ultimate analysis refers to the determination of the concentrations of the main organic elements in coal, namely carbon, hydrogen, oxygen, nitrogen and sulphur. On a dry, ash-free basis these add up to 100%. Results are summarized in Tables 7 and 8 and Figures 17 to 21.

TABLE 7
CARBON AND HYDROGEN

Coalfield/Formation (Data source)	Carbon, % (daf)	Hydrogen, % (daf)	H/C ratio (atomic)	
Northeast B.C./Gates	88.41	5.32	0.72	*mean*
(ROM)	86.60-90.24	5.00-5.69	0.68-0.75	*range*
	(8)	(8)	(8)	*(no.of samples)*
Northeast B.C./Gething	85.06	5.54	0.78	*mean*
(AR)	82.13-87.82	5.01-5.94	0.70-0.86	*range*
	(15)	(15)	(15)	*(no.of samples)*
Southeast B.C.	87.86	5.06	0.69	*mean*
(ROM)	84.88-91.93	4.61-5.66	0.62-0.78	*range*
	(26)	(26)	(26)	*(no.of samples)*
Klappan	90.59	3.14	0.41	*mean*
(AR)	85.41-93.98	2.66-3.86	0.36-0.51	*range*
	(34)	(34)	(34)	*(no.of samples)*

ROM: run-of-mine samples
AR: assessment report data

CARBON

Ultimate carbon data were converted to a daf basis, to allow comparisons (Table 7). The modal carbon content category in the ROM samples is 87 to 88% (Figure 17a). The mean carbon (daf) contents in northeast and southeast ROM coals, at 87.86 and 88.41%, respectively, are very similar. Compiled Gething Formation carbon values (mean 85.06%) appear to be somewhat lower than those in the Gates Formation, while Klappan anthracites clearly have higher carbon contents (mean 90.59) than either northeast or southeast coals, due to their rank (Figure 17b). The correlation coefficient between C (daf) and $R_{\max}$ in ROM samples is 0.37; this is not a significant correlation. The r^2 value of the regression of carbon on $R_{\max}$ and vitrinite content is only 0.17. Clearly the controlling mechanisms on carbon content are fairly complex.

HYDROGEN

The modal hydrogen (daf) content category in the ROM samples is around 5.0% (Figure 18a). Mean hydrogen contents (daf) are slightly higher in the northeast B.C. ROM samples (5.32%) than in those from the southeast (5.06%, Table 5). Gething Formation compiled values are higher still (mean 5.54%), while Klappan anthracites have the lowest values (mean 3.14%; Figure 18b). The coefficient of the correlation between hydrogen and $R_{\max}$ in ROM samples is -0.61. The combined influence of rank and coal type is demonstrated by the following regression equation:

$$H_{daf} = 4.89 + 0.62V - 0.28R_{\max}\ (r^2 = 0.64).$$

HYDROGEN/CARBON ATOMIC RATIOS

The relative order in hydrogen and carbon contents is emphasized by comparing the atomic ratios of hydrogen to carbon. The modal category in ROM samples is 0.675 to 0.7 (Figure 19), and northeast and southeast British Columbia ROM samples have similar ratios, with the northeast samples (mean 0.72) having slightly higher values than the southeast (mean 0.69). Gething values are higher (mean 0.78) and Klappan ratios are much lower (0.41).

There is a negative relationship between hydrogen/carbon ratio and vitrinite reflectance in the ROM samples (Figure 20), although the correlation coefficient (-0.67) is lower than in the case of volatile matter. Similar factors are probably causing the data scatter as in the case of volatile matter, that is, coal type and perhaps mineralogy. The combined influence of rank and coal type is illustrated by the following equation:

$$H/C_{atomic} = 0.67 + 0.63V - 0.33R_{\max}\ (r^2 = 0.73).$$

SULPHUR

British Columbia is renowned for exporting low-sulphur coals, a feature which makes the coals desirable for steel making, as well as environmentally attractive as thermal coals. Product coals from the northeast and southeast of the province generally contain about 0.5% sulphur; Quinsam product coal contains about 1% sulphur (Grieve, 1992a, Appendix 1). The modal range of contents (air-dried) in the channel samples is 0.4 to 0.5% (Table 8, Figure 21a). These low sulphur values are mainly the result of a lack of marine influence during or after peat deposition.

The coals of the southeast region are characterized by almost uniformly low sulphur contents. Channel samples contain a range of 0.23 to 1.09% sulphur, with a mean of 0.52% (Table 8). Data for the ROM samples are very similar (mean 0.44%).

Coals from the northeast are also mainly low in sulphur, but there are occurrences of higher sulphur coals, especially in the Gething Formation, which are related to marine influence (Table 8, Figure 21b). In the Gates Formation channel samples, sulphur content ranges from 0.18 to 0.65%, with a mean of 0.48%; these values are essentially indistinguishable from those from the Kootenay coalfield channel samples. The mean in ROM Gates Formation samples is very similar at 0.45%. Raw Gething Formation coals, on the other hand, show a range of sulphur (air-dried) from 0.24 to 2.49%, with a mean of 0.79% (Table 8). Minnes

TABLE 8
SULPHUR AND SULPHUR FORMS

Coalfield/Formation (Data source) *Sample qualifier*	Total S, % (ad)	Pyritic S, % (ad)	% Pyritic S of total S	Organic S, % (ad)	% Organic S of total S	
Northeast B.C./Gates	0.48	0.16	25.4	0.41	68.7	*mean*
(Channel samples)	0.18-0.65	0.08-0.28	14.5-42.5	0.37-0.45	56.5-81.6	*range*
	(8)	(4)	(4)	(4)	(4)	*(no. of samples)*
Northeast B.C./Gates	0.45					*mean*
(ROM)	0.25-0.69					*range*
	(8)					*(no. of samples)*
Northeast B.C./Gates	0.45					*mean*
(AR)	0.21-0.78					*range*
	(40)					*(no. of samples)*
Northeast B.C./Gething	0.79					*mean*
(AR)	0.24-2.49					*range*
	(40)					*(no. of samples)*
Northeast B.C./Minnes	0.48					*mean*
(AR)	0.44-0.50					*range*
	(5)					*(no. of samples)*
Southeast B.C.	0.52	0.13	18.3	0.49	77.9	*mean*
(Channel samples)	0.23-1.09	0.01-0.37	1.1-45.9	0.21-0.92	53.3-96.0	*range*
	(22)	(12)	(12)	(12)	(12)	*(no. of samples)*
Southeast B.C.	0.44					*mean*
(ROM)	0.20-1.14					*range*
	(26)					*(no. of samples)*
Southeast B.C.	0.57					*mean*
(AR)	0.40-0.83					*range*
	(6)					*(no. of samples)*
Comox	1.84					*mean*
(AR)	0.19-6.49					*range*
	(34)					*(no. of samples)*
Klappan	0.70					*mean*
(AR)	0.33-3.05					*range*
	(34)					*(no. of samples)*
Telkwa	1.17					*mean*
(AR)	0.65-2.07					*range*
clean samples	(10)					*(no. of samples)*
Bowron River	1.11					*mean*
(AR)	0.97-1.22					*range*
dry basis	(4)					*(no. of samples)*
Hat Creek	0.55					*mean*
(Sinclair)	0.23-0.79					*range*
dry basis	(7)					*(no. of samples)*
Tulameen	0.41					*mean*
(AR)	0.37-0.44					*range*
	(2)					*(no. of samples)*

ROM: run-of-mine samples
AR: assessment report data

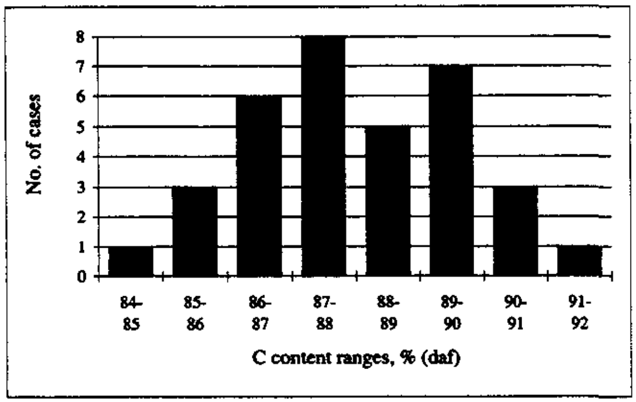

Figure 17a. Carbon data. Frequency histogram of ultimate carbon (ad) in ROM samples.

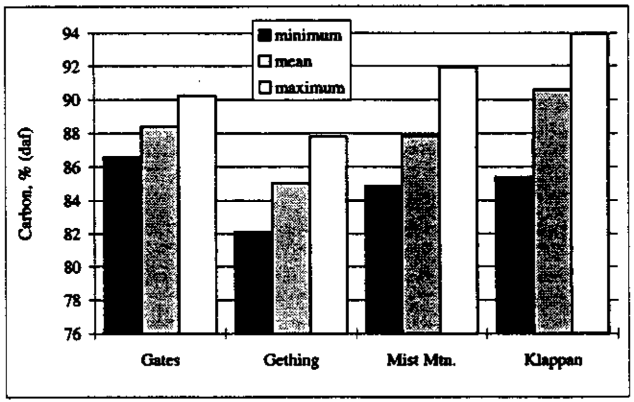

Figure 17b. Carbon data. Ultimate carbon (ad) for various regions, compiled from assessment reports.

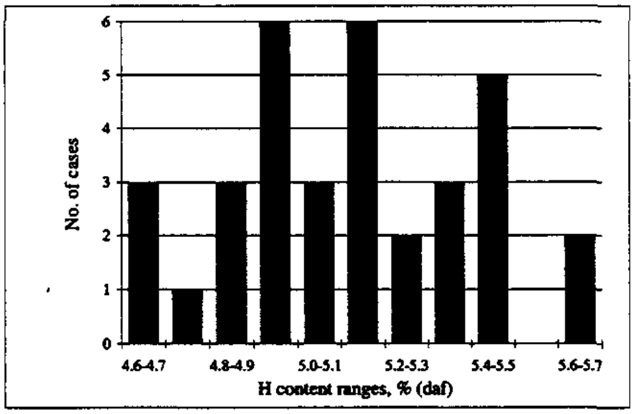

Figure 18a. Hydrogen data. Frequency histogram of hydrogen (ad) in ROM samples.

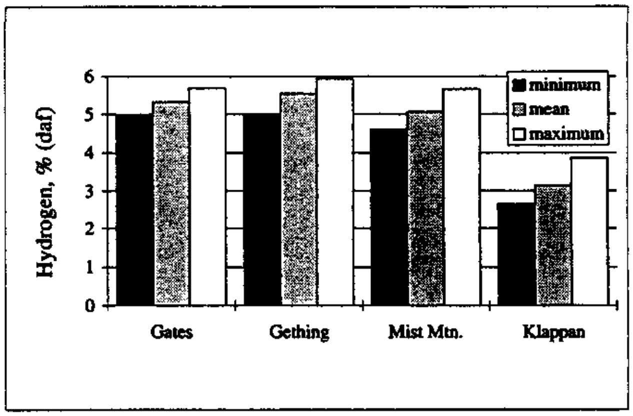

Figure 18b. Hydrogen data. Ultimate hydrogen (ad) for various regions, compiled from assessment reports.

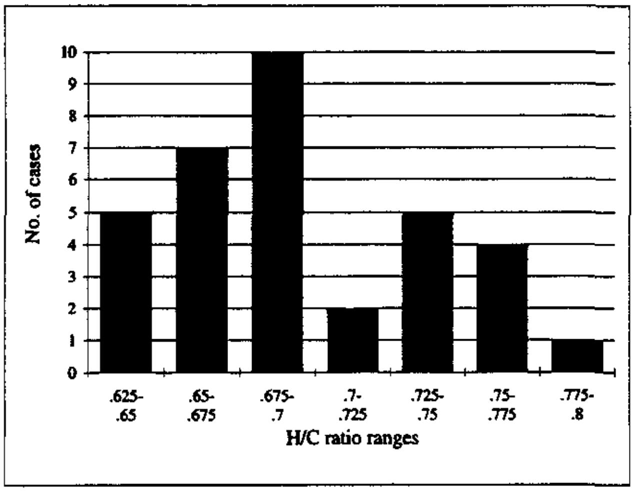

Figure 19a. H/C atomic ratio. Frequency histogram of H/C atomic ratio in ROM samples.

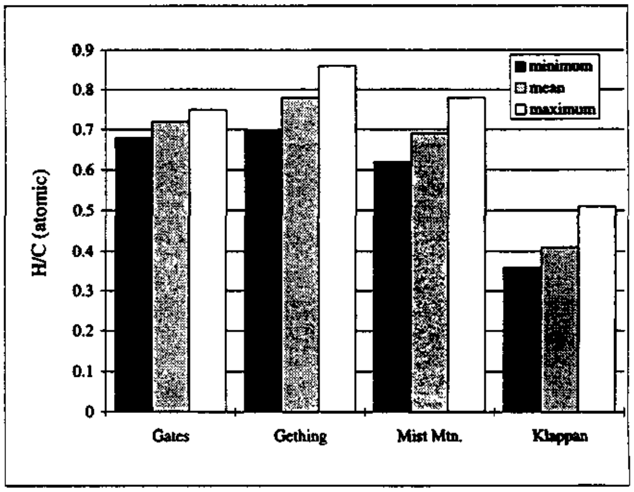

Figure 19b. H/C atomic ratio for various regions, compiled from assessment reports.

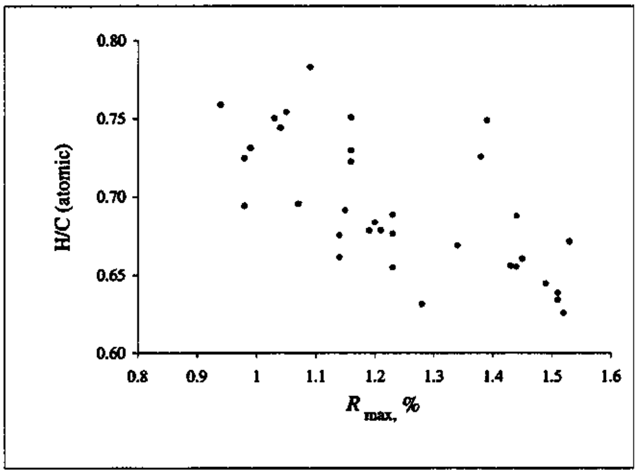

Figure 20. H/C *vs.* R_{max} for ROM samples.

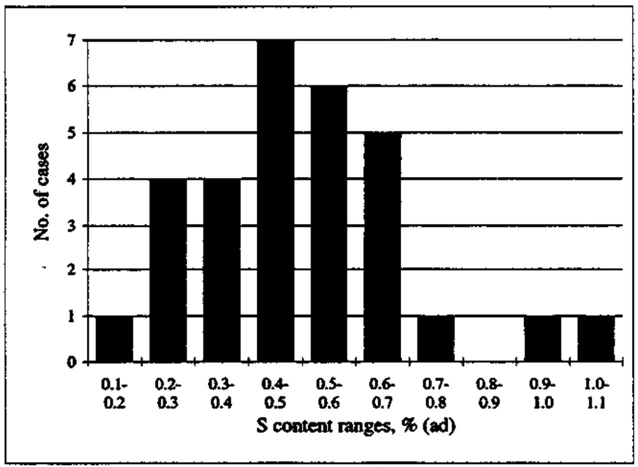

Figure 21a. Sulphur data. Frequency histogram of sulphur (ad) in channel samples.

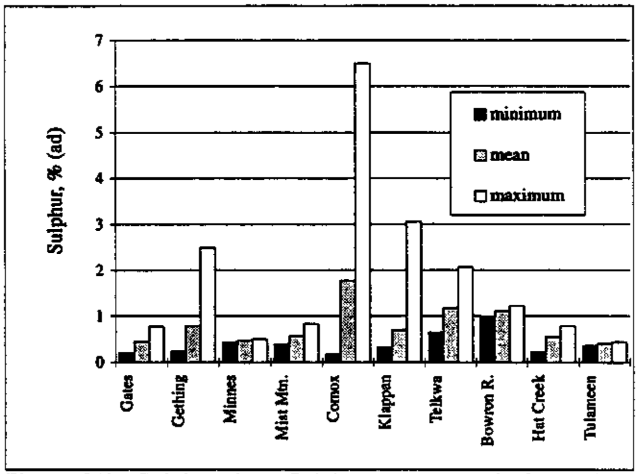

Figure 21b. Sulphur data. Sulphur contents (ad) for various regions, compiled from assessment reports.

Group coals cited in this study are low in sulphur, with a mean of 0.48%.

Coals from the Comox coalfield range from low to high in sulphur. 1-seam at Quinsam, the current source of production at that mine, yields a product with about 1% sulphur, but portions of this seam and the overlying seams (1-rider and 2-seam) are higher in sulphur (Matheson *et al.*, 1994). Over the basin as a whole, based on data in this survey, sulphur values range from 0.19% to 6.49%, with a mean of 1.77% (Table 8, Figure 21b).

Among other British Columbia coal basins, Telkwa and Bowron River coals have mean sulphur concentrations of greater than 1% (Table 8; see also Matheson *et al.*, 1994). Clean Telkwa coal data have a range in sulphur contents on an air-dried basis of from 0.65 to 2.07%, with a mean of 1.16%. Raw Bowron River samples have a mean of 1.11% sulphur. Some basins with low mean raw sulphur contents include Hat Creek (0.55%), Tulameen (0.41%) and Klappan (0.70%).

Australian coking coals cited by Pearson (1980) contain a range from 0.4 to 0.85% sulphur, while eastern U.S. coking coals, with a range of 0.7 to 0.9%, have slightly higher levels. However, marine influence has produced much higher sulphur values in some eastern U.S. thermal coals.

SULPHUR FORMS

A limited number of sulphur forms analyses were run on the channel samples. The generally low total sulphur contents in the samples precluded comprehensive testing. As a rule, low-sulphur British Columbia coals contain a high proportion of organic sulphur, and the ratio of pyritic to organic sulphur increases as the total sulphur content of coal increases (Holuszko *et al.*, 1992, 1993). Thus, as Table 8 shows, pyritic sulphur is a relatively small proportion of total sulphur in these samples, averaging 18.3% in the samples from the southeast and a slightly higher 25.4% in the northeast samples. In no one sample does pyritic sulphur comprise as much as one half of the total sulphur.

Sulphur forms were determined on raw subsurface samples from Quinsam, Telkwa and Bowron River (together with Merritt) by Matheson *et al.* (1994). Pyritic sulphur forms a higher mean proportion of total sulphur in samples from these three basins, which is consistent with their higher total sulphur contents (Holuszko *et al.*, 1992, 1993). Mean proportions of pyritic sulphur are as follows: 49.1% in the case of Quinsam, 33.7% for Telkwa, and 44.6% for Bowron River. Marine influence is at least partly the cause of the higher pyritic sulphur contents in Quinsam and Telkwa coals. Marine-influenced eastern U.S. coals also contain high proportions of pyritic sulphur.

CHAPTER 6 CALORIFIC VALUE

Raw coal calorific values determined on ROM samples and compiled from assessment reports are tabulated in Table 9 on an air-dried (in two cases, dry) basis, dry, ash-free (daf) basis and moist, ash-free (maf) basis. Data converted to the last basis were used to supplement other data for rank classification only, and are not discussed further here (see section on rank).

Air-dried (or dry) calorific values of coal samples are greatly influenced by ash content: ash has a dilutant effect, and, other factors, such as rank, being equal, calorific value is essentially controlled by grade (Cameron, 1989). This relationship has been used in this study to predict calorific values of coals from various basins at 15 and 25% ash contents (Table 9; see subsection below). However, this

TABLE 9
CALORIFIC VALUE

Coalfield/Formation (Data source)	cal. val., MJ/kg (ad)	cal. val., MJ/kg (maf)	cal. val., MJ/kg (daf)	Predicted cal. val. at 15% ash, MJ/kg (ad)		Predicted cal. val. at 25% ash, MJ/kg (ad)	
Northeast B.C./Gates	24.97	34.45	34.9	30.02		26.08	*mean*
(ROM)	16.95-33.30	32.48-35.95	32.96-36.30				*range*
	(8)	(8)	(8)	(8)		(8)	*(no.of samples)*
					r=-0.997		*correlation coefficient*
Northeast B.C./Gates	27.83	35.17	35.51	30.09		26.28	*mean*
(AR)	22.78-31.04	34.47-36.08	34.71-36.38				*range*
	(6)	(6)	(6)	(6)		(6)	*(no.of samples)*
					r=-0.986		*correlation coefficient*
Northeast B.C./Gething	29.12	34.11	34.84	29.01		25.41	*mean*
(AR)	21.23-33.69	31.84-36.23	32.19-36.42				*range*
	(34)	(34)	(51)	(34)		(34)	*(no.of samples)*
					r=-.0.939		*correlation coefficient*
Southeast B.C.	27.17	34.79	35.18	29.73		26.05	*mean*
(ROM)	21.43-32.09	34.02-35.75	34.56-35.97				*range*
	(26)	(26)	(26)	(26)		(26)	*(no.of samples)*
					r=-0.994		*correlation coefficient*
Southeast B.C.	24.58*		34.13	29.23*		25.66*	*mean*
(AR)	20.26-29.12		33.49-34.80				*range*
	(11)		(11)	(11)		(11)	*(no.of samples)*
					r=-0.993		*correlation coefficient*
Comox	25.95	32.19	33.06	27.61		23.92	*mean*
(AR)	18.69-31.01	25.57-35.48	30.54-35.60				*range*
	(34)	(34)	(34)	(34)		(34)	*(no.of samples)*
					r=-0.949		*correlation coefficient*
Klappan	23.41	33.14	33.79	29.09		25.17	*mean*
(AR)	21.23-33.69	31.27-34.64	32.02-35.27				*range*
	(34)	(34)	(34)	(34)		(34)	*(no.of samples)*
					r=-0.991		*correlation coefficient*
Telkwa	26.84	33.42	33.88			24.87	*mean*
(AR)	24.14-28.87	32.23-34.59	32.67-34.98				*range*
	(10)	(10)	(10)			(10)	*(no.of samples)*
					r=-0.916		*correlation coefficient*
Bowron River	20.56	29.68	31.18			22.38	*mean*
(AR)	19.33-23.12	29.04-30.28	30.49-31.92				*range*
	(4)	(4)	(4)			(4)	*(no.of samples)*
					r=-0.966		*correlation coefficient*
Hat Creek	17.34*		26.99			21.56*	*mean*
(Sinclair)	11.45-21.42		23.77-28.94				*range*
	(7)		(7)			(7)	*(no.of samples)*
					r=-0.999		*correlation coefficient*
Tulameen	16.97	27.77	30.67			21.43	*mean*
(AR)	14.05-23.26	26.31-29.29	29.77-31.95				*range*
	(11)	(11)	(11)			(11)	*(no.of samples)*
					r=-0.990		*correlation coefficient*

ROM: run-of-mine samples
AR: assessment report data

* dry basis

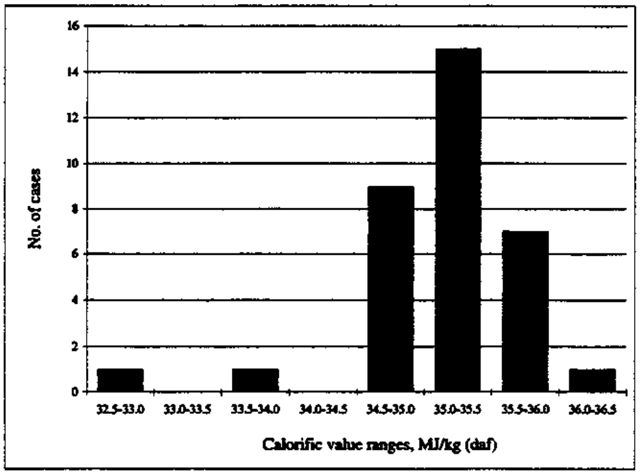

Figure 22a. Calorific value data. Frequency histogram of calorific values (daf) in ROM samples.

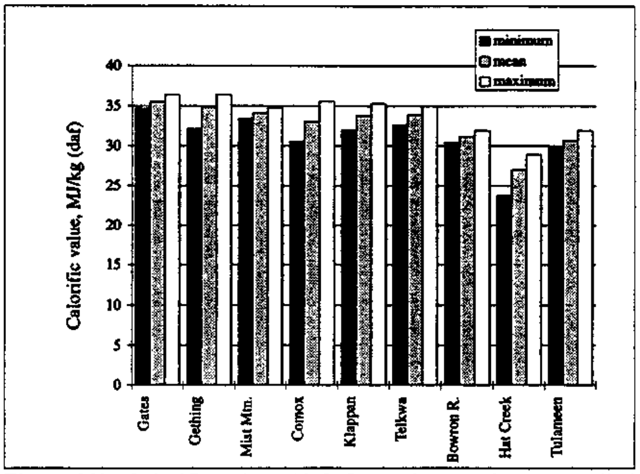

Figure 22b. Calorific values (daf) for various regions, compiled from assessment reports.

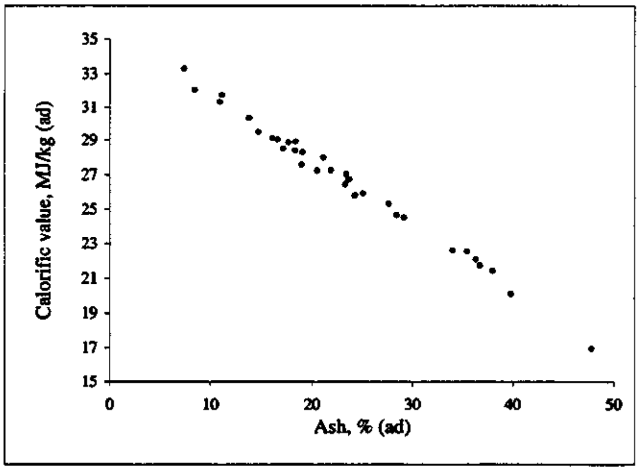

Figure 23a. Calorific value *vs.* ash relationships for ROM samples.

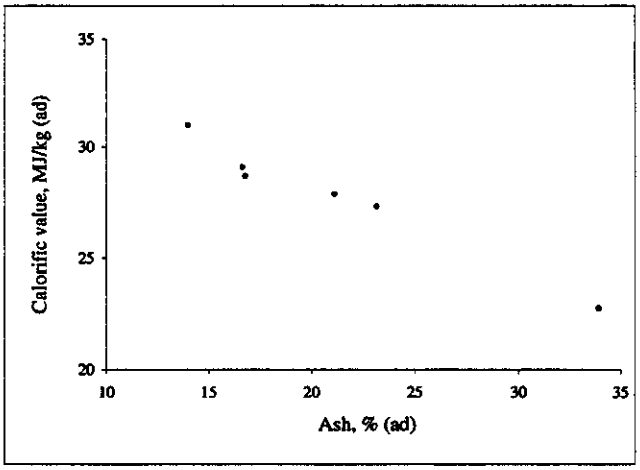

Figure 23b. Calorific value *vs.* ash relationships for Gates Fm. coals (assessment report data).

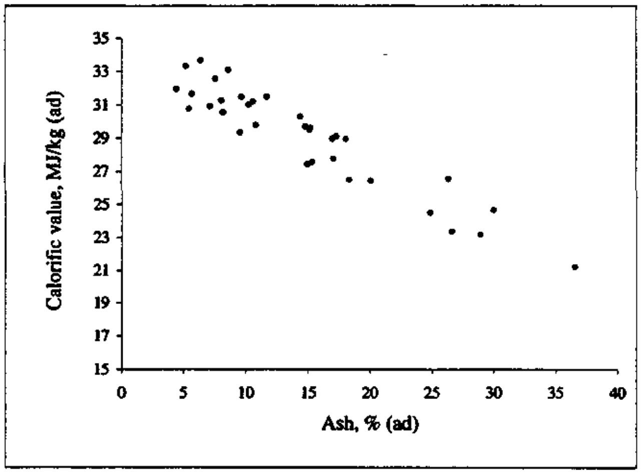

Figure 23c. Calorific value *vs.* ash relationships for Gething Fm. coals (assessment report data).

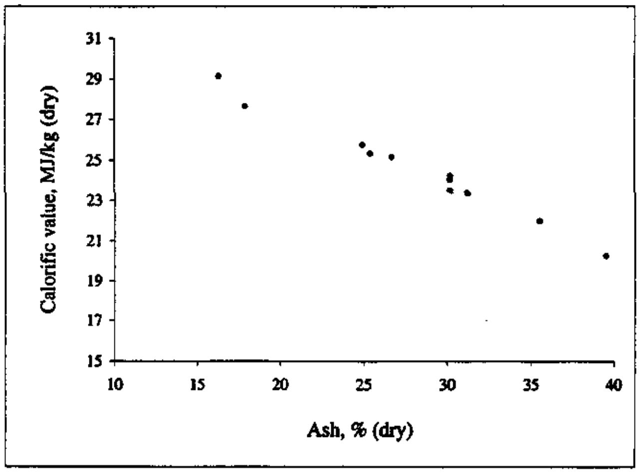

Figure 23d. Calorific value *vs.* ash relationships for Mist Mountain Fm. coals (assessment report data).

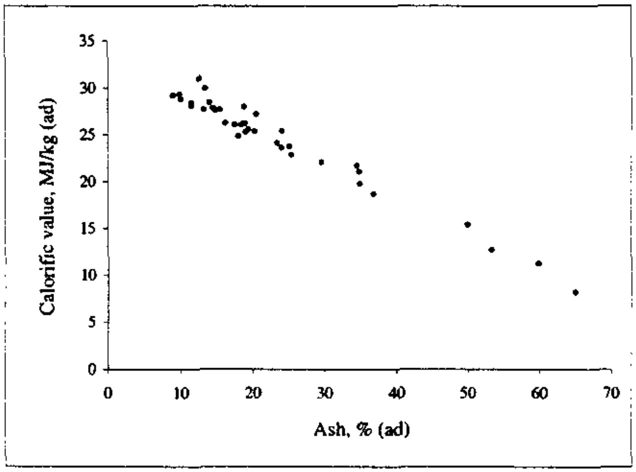

Figure 23e. Calorific value *vs.* ash relationships for Comox coalfield coals (assessment report data).

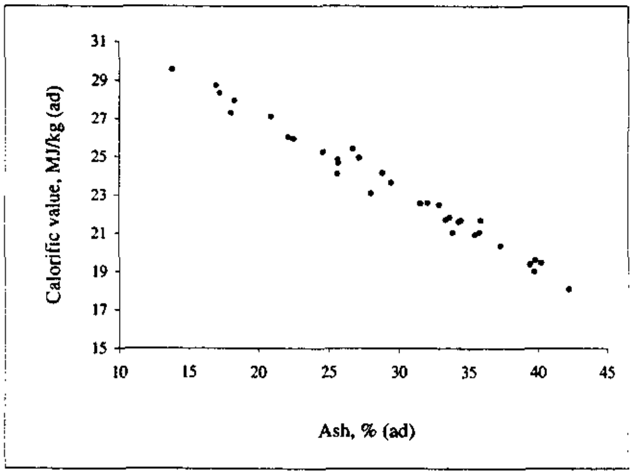

Figure 23f. Calorific value *vs.* ash relationships for Klappan coals (assessment report data).

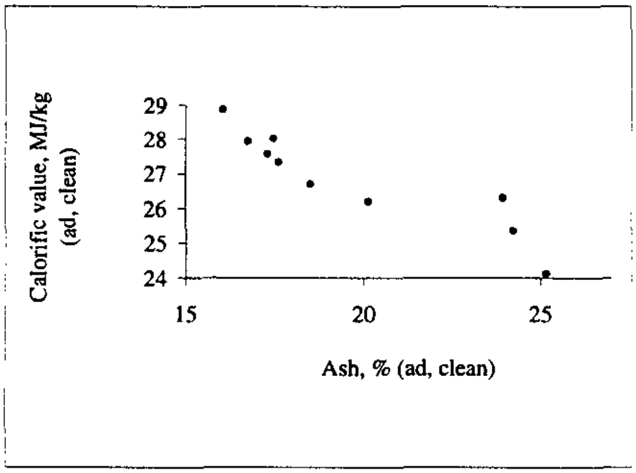

Figure 23g. Calorific value *vs.* ash relationships for Telkwa coals (assessment report data).

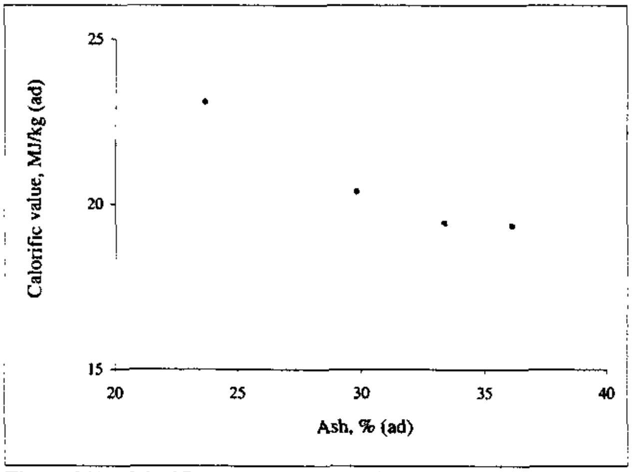

Figure 23h. Calorific value *vs.* ash relationships for Bowron River coals (assessment report data).

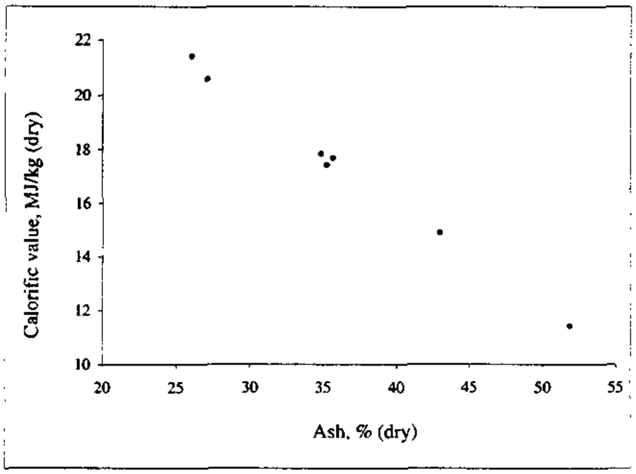

Figure 23i. Calorific value *vs.* ash relationships for Hat Creek coals (assessment report data).

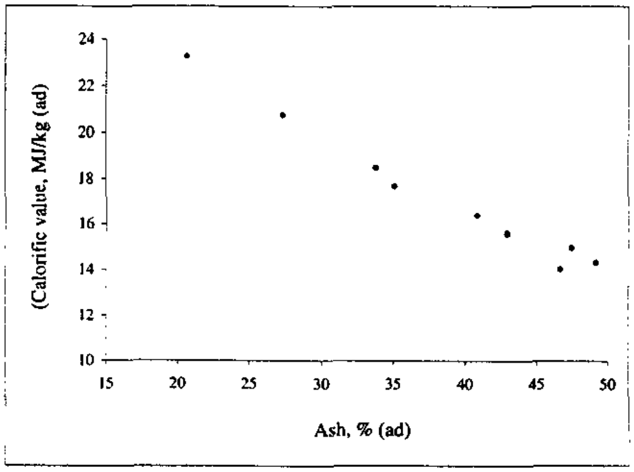

Figure 23j. Calorific value *vs.* ash relationships for Tulameen coals (assessment report data).

dependency on coal grade makes it difficult to compare calorific values on samples from different basins which have not been converted to a zero-ash basis. Nonetheless, the highest mean values, between 25 and 30 megajoules per kilogram, are found in coals from northeast (Gates and Gething) and southeast British Columbia, and the Telkwa deposit. Klappan and Comox coals have slightly lower calorific values. The lowest values (near or below 20 MJ/kg mean) are in the lower rank, lower grade coals, namely, Hat Creek, Bowron River and Tulameen. The mean Hat Creek calorific value, 17.34 megajoules per kilogram, is actually the lowest, because it is based on data determined on a dry basis; the air-dried value can be safely asssumed to be significantly lower.

Dry, ash-free calorific values (Figure 22) are more amenable to comparison, but do not necessarily provide insight to the relative behaviours of coals in a combustion situation. The means for the ROM samples and compiled data for both the southeast and northeast regions are in the neighbourhood of 35 megajoules per kilogram. Means of Klappan and Telkwa compiled data are slightly below 34 megajoules per kilogram. Mean values for the other regions decrease in rank order: Comox (32.5 MJ/kg), Bowron River (31.2 MJ/kg), Tulameen (30.7 MJ/kg) and Hat Creek (27.0 MJ/kg). In ROM samples, calorific values (daf) do not correlate with rank. This is because calorific value reaches a maximum in the rank range of high-volatile A bituminous, and remains fairly constant through the medium-volatile range. In the lower rank coals, however, calorific value (daf) does vary with changes in volatile matter (daf), carbon (daf) and hydrogen/carbon ratio.

The dry, ash-free calorific values for coals in British Columbia are considered typical of coals of similar ranks from throughout the world.

CALORIFIC VALUE/ ASH RELATIONSHIPS

As noted above, the relationship between coal grade (ash) and calorific value (not ash-free) at an individual site, or even across a basin in some cases, is usually linear, other factors being equal, and can be used to predict energy content of coals at specific ash contents (Figure 23). The correlation coefficients between calorific value and ash (ad) for the different basins in this study are all between -0.92 and -1.00, and in several cases, including the ROM samples, are on the order of -0.99 (Table 9). Using these relationships, we have predicted calorific values (air-dried) at 25% ash, and, where possible, at 15% ash. All predicted values are interpolated; in other words we have not extrapolated to outside the actual range of ash contents of the samples. Predictions for Hat Creek and East Kootenay assessment report data should be treated with caution, because the calorific value data are recorded on a dry basis, not air-dried. The impact on Kootenay data is probably not substantial, but could be significant for the low rank Hat Creek deposit, which has considerably more moisture.

The northeast and southeast coalfields (ROM and compiled data), together with the Klappan coalfield, have very similar predicted calorific values (air-dried). These are on the order of 29 to 30 megajoules per kilogram for 15% ash, and 25 to 26 megajoules per kilogram for 25% ash. Based on a predicted value of 24.87 megajoules per kilogram at 25% ash, the Telkwa results are only slightly, if at all, lower. These deposits are followed, in rank order, by Comox (27.64 MJ/kg at 15% ash and 23.89 at 25% ash), Bowron River (22.38 at 25% ash) and Tulameen (21.43 at 25% ash). Hat Creek calorific value on an air-dried basis can safely be assumed to be considerably lower than the 21.56 value in Table 9, which is based on dry sample data.

CHAPTER 7 MINERAL MATTER AND ASH COMPOSITION

Mineralogy of low-temperature ash was determined on the channel samples, and results are listed in Appendix 1. Ash analysis (major oxides) determinations were made on the ROM samples, and results are summarized in Table 10 and Figure 24. Ash chemistry data are used to calculate base/acid ratio, which influences CSR (coke strength after reaction) and two other ash indices which give a preliminary indication of potential for problems during combustion (Tables 11 and 12, Figure 25).

LOW-TEMPERATURE ASH MINERALOGY

Lists of minerals in the low-temperature ashes (Appendix 1) are in decreasing order of abundance. Quartz and kaolinite are ubiquitous and are the most common minerals in almost all cases, with quartz usually being the more abundant. There are two exceptions: a 50-centimetre ply sample from near the base of 8-seam at Line Creek in the Kootenay coalfield contains more siderite than any other mineral, and the B-seam sample from Bullmoose in the Peace River coalfield contains more dolomite. The former instance probably reflects the presence of a band of siderite nodules, although none was observed.

Lesser and trace amounts of illite, illite/mica, calcite, apatite (mainly fluorapatite), siderite, pyrite, dolomite and dolomite/ankerite were also detected frequently. Rarely or tentatively identified minerals, which appear occasionally, and only in trace amounts, include anatase, ilmenite, magnetite, amphibole (species not identified), rhodochrosite and gorceixite.

There are no differences between the mineral suites from the two regions of the province, with a few minor exceptions. For one, apatite is more common in samples from southeast British Columbia. Calcium and magnesium carbonate minerals (dolomite, calcite, dolomite/ankerite) are more common in northeast samples, while iron carbonate (siderite) is more common in the southeast samples. Within each region there are no obvious differences between the mineral suites from the various mine sites, with the exception that the Coal Mountain samples contain more calcium and magnesium carbonate minerals than samples from other locations in the southeast. The various seams at each site also do not appear to be markedly different, with the exception that a number of the 8-seam ply samples from Line Creek contain more kaolinite than quartz. On a whole-seam basis, however, quartz is more abundant than kaolinite. Other trends in variation within the four seams at Line Creek are not apparent.

This mineralogy is typical of nonmarine coals. Kaolinite and quartz are also the dominant minerals in typical Australian coals. Marine-influenced coals, such as some eastern U.S. coals, have mineralogy dominated by calcite, pyrite, illite and quartz (Pearson, 1980).

ASH CHEMISTRY

Results of the standard ash analysis of the ROM samples are summarized in Table 10 and Figure 24. Silica and alumina are by far the most abundant oxides, which is consistent with the preponderance of quartz and kaolinite in low-temperature ash. Silica is also in relatively high abundance in comparison with eastern U.S. and other marine-influenced coals: means here are near 60%, compared with values between 40 and 50% in Appalachian two-coal blends cited by Price and Gransden (1987, Table 6). Relatively low concentrations of Fe_2O_3, MgO and CaO are also evident in the ROM coals when compared with eastern U.S. coals. This is consistent with the contrasts in mineralogy between marine-influenced and nonmarine coals (*see* previous paragraph), and, in conjunction with the silica values, translates into relatively low base-acid ratios in B.C. coking coals (next section).

The most striking contrasts between northeast and southeast British Columbia ROM samples are in their relative abundances of magnesium, calcium and sodium. In all three cases, the mean concentration of each element in the northeast samples is more than double the mean in the southeast samples. This is consistent with the qualitative observation that calcium and magnesium carbonates are more common in the northeast samples. Among the other major elements, silica is in approximately equal abundance in the two regions, iron and potassium are more abundant in northeast samples, while aluminum, titanium and phosphorus are more abundant in southeast samples (*see* also the chapter on phosphorus).

Ash oxide results for Comox, Telkwa, Bowron River and Merritt deposits are given by Matheson *et al.* (1994). There are differences between these thermal coal basins and coals from the northeast and southeast regions. The most striking general contrasts are the higher calcium and iron values in the thermal coal basins. Calcium is in especially high concentration in the case of the Quinsam samples, where it is known to be largely present as calcite on cleats (Kenyon *et al.*, 1992; B.D. Ryan, personal communication, 1993). The higher iron in the thermal coals is probably related to the more common presence of pyrite (Holuszko *et al.*, 1992, 1993).

TABLE 10
ASH ANALYSIS

Coalfield/Formation (Data source)	SiO_2,%	Al_2O_3,%	Fe_2O_3,%	MgO,%	CaO,%	Na_2O,%	K_2O,%	TiO_2,%	P_2O_5,%	MnO,%	BaO,%	SO_3,%	
Northeast B.C./Gates	62.73	20.35	3.39	1.69	3.02	0.36	2.44	1.11	0.50	0.02	0.55	1.72	*mean*
(ROM)	53.06-70.55	16.78-24.46	1.67-5.20	0.94-3.33	0.83-8.85	0.17-0.77	1.20-3.51	0.81-1.64	0.19-1.56	0.01-0.06	0.20-1.10	0.51-3.32	*range*
	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	(8)	*(no. of samples)*
Southeast B.C.	59.90	27.06	2.98	0.74	1.49	0.14	1.68	1.39	0.72	0.02	0.16	0.76	*mean*
(ROM)	48.32-67.79	18.69-35.03	0.98-8.98	0.19-1.94	0.32-6.77	0.05-0.92	0.30-3.63	0.93-2.04	0.22-1.40	0.01-0.15	0.03-0.57	0.11-2.48	*range*
	(26)	(26)	(26)	(26)	(26)	(26)	(26)	(26)	(26)	(26)	(26)	(26)	*(no. of samples)*

ROM: run-of-mine samples

TABLE 11
ASH INDEX FORMULAE

Factor	Formula
Base-acid ratio (B/A) *(slagging propensity in lignitic ash)*	$\frac{\%(Fe_2O_3+CaO+MgO+Na_2O+K_2O)}{\%(SiO_2+Al_2O_3+TiO_2)}$
Total alkali on coal *(fouling propensity in bituminous ash)*	$[\%Na_2O+0.6589(\%K_2O)]\%ash/100$
Fouling factor *(bituminous ash)*	$(B/A)(\%Na_2O)$
Slagging factor *(lignitic ash)*	$(B/A)(\%S)$

(Sources: Skorupska, 1993; Schmidt, 1976)

TABLE 12
BASE/ACID RATIO, SLAGGING INDEX AND FOULING INDEX

Coalfield/Formation (Data source)	Base-acid ratio	Slagging index	Fouling index	
Northeast B.C./Gates	0.13	0.055	0.057	*mean*
(ROM)	0.067-0.26	0.033-0.081	.012-0.20	*range*
	(8)	(8)	(8)	*(no. of samples)*
Southeast B.C.	0.081	0.038	0.013	*mean*
(ROM)	0.024-0.16	0.008-0.18	0.001-0.12	*range*
	(26)	(26)	(26)	*(no. of samples)*

ROM: run-of-mine samples

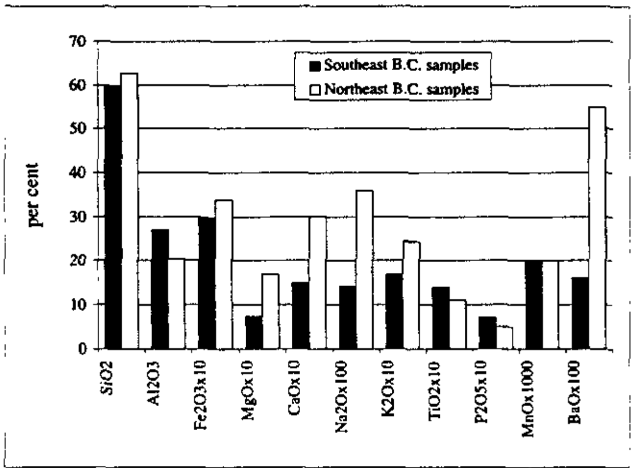

Figure 24a. Ash oxide chemistry. Mean ash oxide values in northeast and southeast B.C. ROM samples.

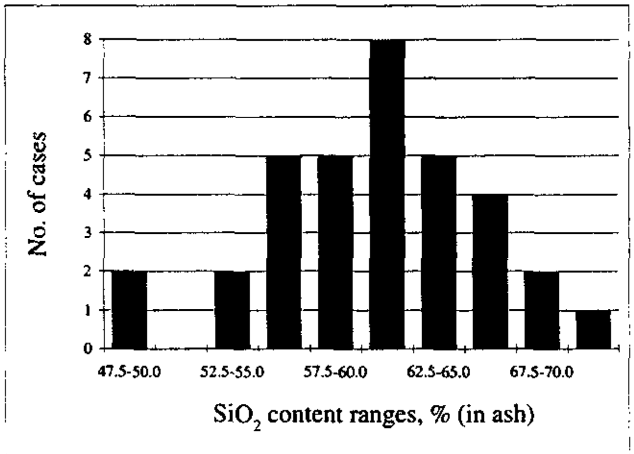

Figure 24b. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. SiO_2 in ash in ROM samples.

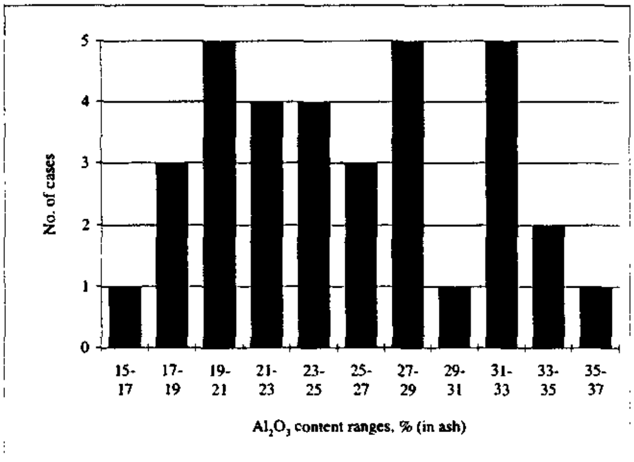

Figure 24c. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. Al_2O_3 in ash in ROM samples.

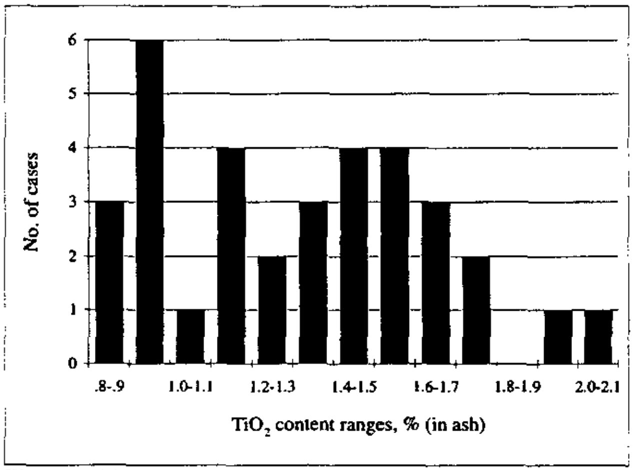

Figure 24d. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. TiO_2 in ash in ROM samples.

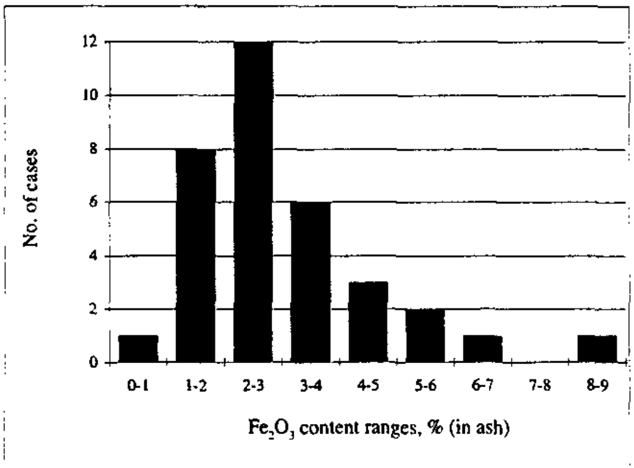

Figure 24e. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. Fe_2O_3 in ash in ROM samples.

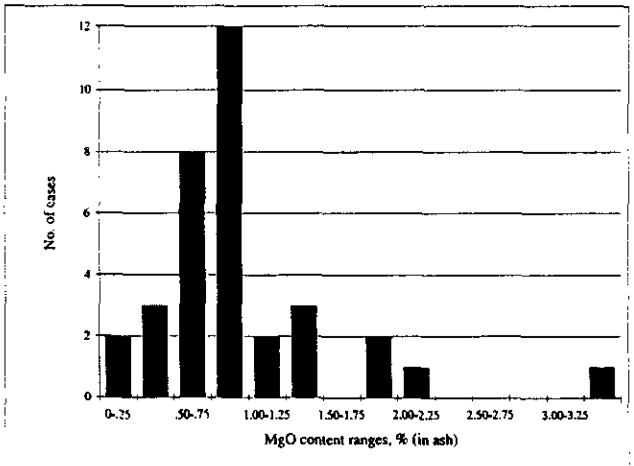

Figure 24f. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. MgO in ash in ROM samples.

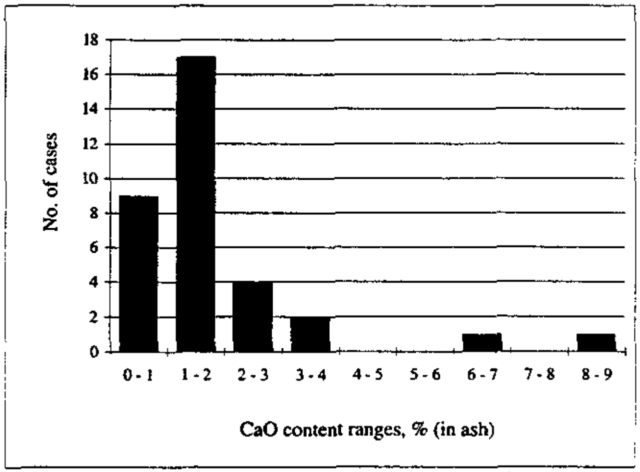

Figure 24g. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. CaO in ash in ROM samples.

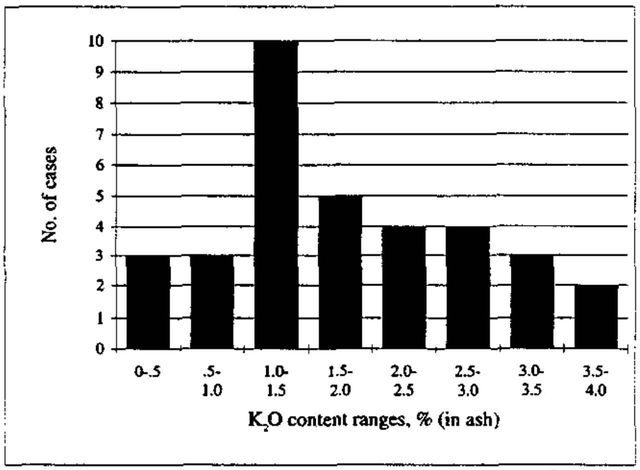

Figure 24i. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. K_2O in ash in ROM samples.

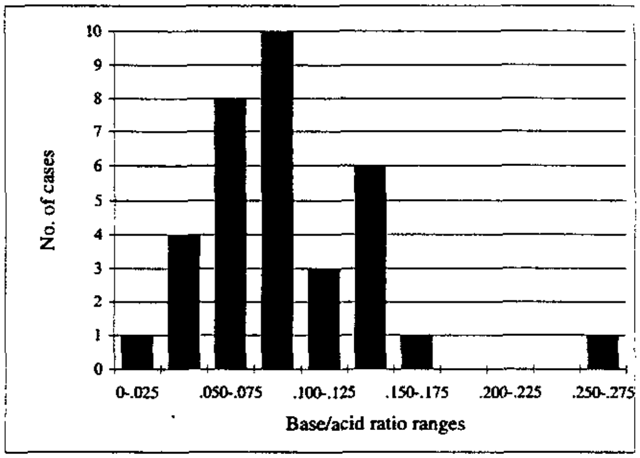

Figure 25. Frequency histogram of base/acid ratio values in ROM samples.

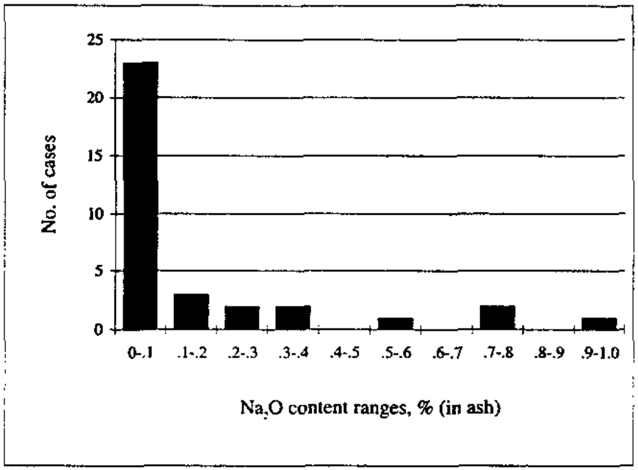

Figure 24h. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. Na_2O in ash in ROM samples.

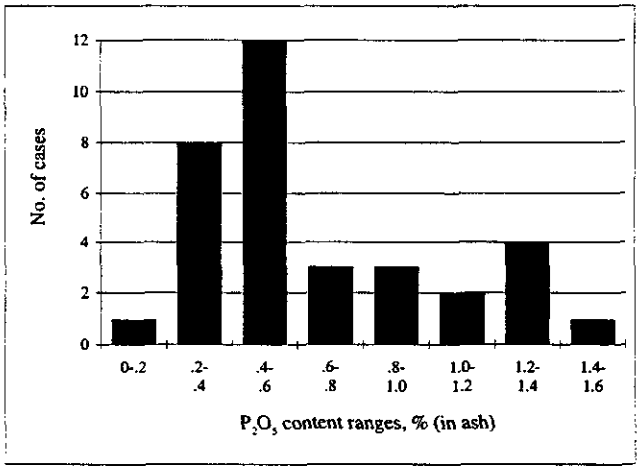

Figure 24j. Ash oxide chemistry. Frequency histograms of selected ash oxides in ROM samples. P_2O_5 in ash in ROM samples.

CALCULATED ASH INDEXES

Ash analysis results can be used in mathematical formulas to calculate various chemical and performance indexes (*see* Schmidt, 1976; Skorupska, 1993). The formulas for the three indexes calculated in this study, base/acid ratio, fouling factor and slagging factor, are listed in Table 11. Base/acid ratio is an important determinant of CSR (coke strength after reaction), with low ratios being desireable (Ryan and Price, 1993). The fouling and slagging factor calculations relate to thermal coal behaviour, but are based on empirical relationships. They are not universally applicable, and they are used here for comparison only. Results of the calculations are listed in Table 12, and base-acid ratios are displayed in Figure 25.

Low base/acid ratios of British Columbia coking coals make them a valuable commodity on the international coking coal market (Ryan and Price, 1993). This is because their low ash basicity leads to low coke reactivity in the blast furnace and thus high CSR. Mean base/acid ratio values are somewhat higher in northeast British Columbia samples (0.13) than in southeast samples (0.081). For comparison, base/acid ratios calculated from ash analysis data for three western Canadian two-coal blends cited by Price and Gransden (1987), are nearly identical to these results, and range from 0.08 to 0.12. The values determined here, therefore, are very favourable because all three blends cited by Price and Gransden have relatively high CSR values compared with those for three Appalachian blends, in which base/acid ratio values range from 0.24 to 0.29. As a further comparison, base/acid ratios for metallurgical coal products from the Elkview and Fording River operations in the Kootenay coalfield range from 0.058 to 0.11 (from data in Grieve, 1992a), very comparable to values determined here. These product values also suggest that cleaning coal does not affect base/acid ratio markedly.

Considerably higher values of base/acid ratio are found in three of the four British Columbia thermal coal basins studied by Matheson *et al.* (1994): Comox, Telkwa and Bowron River. These are certainly related to the higher iron and calcium contents in these coals. In thermal coals, base/acid ratio has been used as an indicator of slagging propensity (Skorupska, 1993), with higher ratios indicating more slagging tendency.

The calculated slagging and fouling factor values are lower in southeast than in northeast British Columbia samples (Table 12), but for both regions the values are favourable (Skorupska, 1993). Values for the four thermal coal basins sampled by Matheson *et al.* (1994) are higher, with one exception: the fouling factor for Telkwa is lower than that for the northeast. This suggests generally better thermal behaviour for the northeast and southeast coals compared with the thermal coal basins, with the exception of Telkwa, but, given the limitations of this type of calculation, it is important not to make too much of this conclusion.

CHAPTER 8

PHOSPHORUS IN B.C. METALLURGICAL COALS

Phosphorus concentrations in coal were determined on the channel samples. In addition, a large database of phosphorus information was assembled from assessment reports (data sources are listed in Table 13). The coals covered in this section are the Kootenay (Mist Mountain Formation) coals, and the Gething Formation and Gates Formation coals from northeast British Columbia. The only source of Gething Formation information was assessment reports, whereas the Mist Mountain and Gates formations are represented by assessment report and channel sample data. Some of the assessment report data represent clean coals. The data cited here are used to make comparisons between phosphorus contents in metallurgical coals in the two regions, and to speculate on the forms of association of phosphorus in the coals.

Phosphorus occurs in all coals in minor or trace amounts. Although it is not generally regarded as a pollutant, the concentration of phosphorus in a coal is an important parameter to coal users, particularly steel mills. Phosphorus in steel, some of which is derived from coke, can be either beneficial or detrimental to its quality. Small additions of phosphorus are sometimes used to increase the strength of low-carbon sheet steel (Bloom *et al.*, 1990). However, under certain conditions, phosphorus addition will cause steel to become brittle. There is no universally accepted tolerance level for phosphorus in coking coal, and in some cases it is not a major concern. Other variables can be equally or more critical, including the phosphorus concentrations in the iron ore, and the actual steel-making process used. Iron formations of sedimentary origin, for example, contain much less phosphorus than iron ores of igneous origin. Phosphorus content is also of interest to operators of some coal-fired boilers, because, under certain conditions, phosphate precipitates (fouling) may form (Burchill *et al.*, 1990).

Data are represented in both tabular (Tables 14 to 17) and graphic form (Figures 26 to 35). Concentrations of phosphorus in channel samples are included in Appendix 1. This subject is also addressed in Grieve (1992b, 1992c).

PHOSPHORUS CONCENTRATIONS IN RAW COALS

Important factors to be considered are the variations in phosphorus in raw coals from the two regions, along with the significance of the mineralogy of the low-temperature ash and the relationships between phosphorus content and other factors, namely ash and fluorine concentrations.

TABLE 13
SOURCES OF PHOSPHORUS DATA

Coalfield	Formation	Deposit name	Sample type	Number of samples	Source of data
Northeast B.C.	Gates	Bullmoose	raw, whole-seam	6	channel sampling program
		Mt. Spieker	clean	36	assessment reports 552, 553, 555, 556, 558
		Quintette	raw and clean	303	assessment reports 603, 611, 615, 619
		Quintette	raw, whole-seam	2	channel sampling program
		Monkman	clean	43	assessment reports 543, 545, 546, 547
		Belcourt	raw and clean	97	assessment reports 463 and 466
		Saxon	raw and clean	86	assessment report 628
Northeast B.C.	Gething	Carbon Ck. & Carbon Ck. W.	raw	56	assessment reports 504, 507, 508
		E. Mt. Gething & S. Mt. Gething	raw	11	assessment reports 520, 639
		Goodrich	raw	21	assessment reports 532, 534
		Sukunka	clean	48	assessment reports 645, 650
		Mt. Spieker	clean	15	assessment reports 552, 553, 555
Southeast B.C.	Mist Mountain	Elk River	raw and clean	51	assessment report 274
		Elk River	clean	194	assessment report 276
		Fording River	raw, whole-seam	7	channel sampling program
		Greenhills	raw, whole-seam	6	channel sampling program
		Line Creek, 10A-seam	raw, ply-by-ply	5	channel sampling program
		Line Creek, 10-B seam	raw, ply-by-ply	5	channel sampling program
		Line Creek, 9-seam	raw, ply-by-ply	8	channel sampling program
		Line Creek, 8-seam	raw, ply-by-ply	19	channel sampling program
		Elkview	raw, whole-seam	6	channel sampling program
		Coal Mountain	raw, whole-seam	3	channel sampling program

TABLE 14
MEAN RAW PHOSPHORUS CONCENTRATIONS

Coalfield/Formation (Data source)	Deposits represented	P, % (ad)	
Northeast B.C. /Gates	Quintette	0.051	*mean*
(AR)		0.001-0.440	*range*
		(303)	*(number of samples)*
Northeast B.C./Gates	Belcourt	0.039	*mean*
(AR)		0.002-0.224	*range*
		(97)	*(number of samples)*
Northeast B.C./Gates	Saxon	0.019	*mean*
(AR)		0.002-0.079	*range*
		(86)	*(number of samples)*
Northeast B.C./Gates	Quintette, Bullmoose	0.043	*mean*
(CS, whole-seam)		0.009-0.114	*range*
		(8)	*(number of samples)*
Northeast B.C./Gething	Carbon Creek and	0.046	*mean*
(AR)	Carbon Creek West	0.003-0.285	*range*
		(56)	*(number of samples)*
Northeast B.C./Gething	East Mount Gething and	0.135	*mean*
	South Mount Gething	0.006-0.626	*range*
		(11)	*(number of samples)*
Northeast B.C./Gething	Goodrich	0.071	*mean*
		0.002-0.271	*range*
		(21)	*(number of samples)*
Southeast B.C.	Elk River	0.076	*mean*
(AR)		0.015-0.181	*range*
		(51)	*(number of samples)*
Southeast B.C.	Fording River, Greenhills, Elkview,	0.096	*mean*
(CS, whole-seam)	Coal Mountain	0.013-0.227	*range*
		(22)	*(number of samples)*
Southeast B.C.	Line Creek 10A, 10B, 9	0.049	*mean*
(CS, ply-by-ply)	and 8-seams	0.009-0.341	*range*
		(37)	*(number of samples)*

AR: assessment report data
CS: channel samples

TABLE 15
PHOSPHORUS IN INDIVIDUAL SEAMS ON THE ELK RIVER PROPERTY, SOUTHEASTERN B.C.

Seam*	No. of samples	Mean P, %	Range in P, %
18	2	0.074	0.073-0.075
17	3	0.094	0.084-0.113
16	6	0.105	0.056-0.151
15	2	0.088	0.079-0.096
14	6	0.059	0.039-0.078
13	10	0.096	0.047-0.152
12	3	0.087	0.072-0.109
10	2	0.059	0.045-0.073
9	2	0.030	0.028-0.031
8	2	0.072	0.056-0.088
7	2	0.062	0.057-0.066
6	1	0.090	
4	4	0.027	0.015-0.039
3	3	0.114	0.049-0.183
2	2	0.021	0.020-0.022

(data from assessment reports)
** Seams listed in descending stratigraphic order*

TABLE 16
PHOSPHORUS IN INDIVIDUAL SEAMS ON THE BELCOURT AND SAXON PROPERTIES, NORTHEASTERN B.C.

Property	Seam*	No. of samples	Mean P, %	Range in P, %
Belcourt	8	16	0.052	0.020-0.124
	7	9	0.042	0.002-0.145
	6	20	0.063	0.004-0.224
	5	11	0.025	0.007-0.047
	4	5	0.014	0.008-0.022
	3	4	0.029	0.018-0.052
	2	14	0.026	0.011-0.084
	1	18	0.026	0.009-0.051
Saxon	10	2	0.043	0.031-0.054
	5	3	0.019	0.010-0.033
	4	25	0.025	0.005-.049
	3	10	0.021	0.006-0.079
	2	18	0.020	0.006-0.035
	1	27	0.043	0.002-0.044

(data from assessment reports)
** Seams listed in descending stratigraphic order*

KOOTENAY COALFIELD

Raw Kootenay (Mist Mountain Formation) coals have mean phosphorus concentrations of 0.076% in the case of assessment report data, and 0.096% in the case of the whole-seam channel samples (air-dried; Table 14).

Variations in phosphorus concentration with stratigraphic position in the Mist Mountain Formation are shown in Table 15 and Figures 26a and 27. An up-section increase in phosphorus contents has been noted at one mine location (B.D. Ryan, personal communication, 1988). However, none of the data shown here suggest that there is any systematic variation in phosphorus values. Data in Figure 26a (channel samples) suggest that phosphorus contents are lowest near the base and top of the formation, and highest in the middle. This pattern, however, is almost identical to that of the ash contents of the same samples (Figure 14c), suggesting that ash content is perhaps a more important determinant of phosphorus content than stratigraphic position. The assessment report data, all from the Elk River property, do not suggest any distinct pattern (Table 15 and Figure 27). However, one obvious conclusion is that there is a great deal of variation in raw phosphorus concentrations between samples of the same seam.

In the cases of the four seams at Line Creek, numbers 9 and 8 have higher average phosphorus contents than the underlying 10A and 10B-seams at the base of the formation, but there are no consistent in-seam variations (Figures 26b to e). In contrast with the whole-seam samples, phosphorus content in the Line Creek ply-by-ply samples do not show a similarity to the ash content profile.

TABLE 17

CORRELATION COEFFICIENTS BETWEEN PHOSPHORUS AND ASH IN RAW COALS

Coalfield/Formation	Properties/deposits represented	Source of data	r	95% confidence	99% confidence	Number of samples
Northeast B.C./Gates	Quintette, Belcourt, Saxon	AR	0.104	yes	no	486
Northeast B.C./Gates	Quintette	AR	0.109	no	no	303
Northeast B.C./Gates	Quintette K-seam	AR	0.666	yes	yes	32
Northeast B.C./Gates	Quintette J-seam	AR	0.116	no	no	69
Northeast B.C./Gates	Quintette I-seam	AR	-0.138	no	no	25
Northeast B.C./Gates	Quintette G-seam	AR	0.117	no	no	31
Northeast B.C./Gates	Quintette F-seam	AR	0.463	yes	yes	52
Northeast B.C./Gates	Quintette E-seam	AR	-0.233	no	no	49
Northeast B.C./Gates	Quintette D-seam	AR	0.107	no	no	40
Northeast B.C./Gates	Belcourt	AR	-0.024	no	no	97
Northeast B.C./Gates	Saxon	AR	0.149	no	no	86
Northeast B.C./Gates	Quintette and Bullmoose	CS	0.730	yes	no	8
Northeast B.C./Gething	East and South Mt. Gething	AR	0.239	yes	no	88
Southeast B.C.	Elk River	AR	0.205	no	no	51
Southeast B.C.	Line Creek 8-seam	CS	-0.268	no	no	19
Southeast B.C.	Fording R., Greenhills, Elkview, Coal Mountain	CS	0.412	yes	no	22

AR: assessment report data
CS: channel sample data

PEACE RIVER COALFIELD

Raw Gething Formation coals have a mean phosphorus concentration (air-dried) of 0.063%; all data are from assessment reports (Table 14). No stratigraphic trends in phosphorus contents are apparent in the Gething.

Raw Gates Formation coals have mean phosphorus concentrations of 0.042% in the case of assessment report data, and an almost identical 0.043% in the case of the whole-seam channel samples (Table 14).

Variations in phosphorus concentration with stratigraphic position for the Gates Formation are shown in Figure 26f (channel samples), and in Table 16 and Figure 28 (assessment report data for the Belcourt and Saxon properties). Assessment report data suggest that mean raw coal phosphorus concentrations tend to be higher in seams in the upper part of the Gates Formation than in the lower, and more so in the case of the Belcourt property than the Saxon property. Again, the amount of variation of phosphorus values within data for some individual seams is very striking. This upwardly increasing trend is basically confirmed by the channel sample data (Figure 26f). As was the case with the Kootenay channel samples, however, the stratigraphic profile of phosphorus concentrations in channel samples matches the profile of ash contents in the same samples fairly closely. There appears to be a regional gradation (increase) in phosphorus contents in Gates Formation raw coals, from southeast to northwest, based on assessment report data (Table 14). For example, the mean phosphorus concentration in raw coals increases from 0.019% at the Saxon property, to 0.039% at the Belcourt property, and to 0.051% at Quintette.

SIGNIFICANCE OF LOW-TEMPERATURE ASH MINERALOGY

The suites of minerals in low-temperature ash derived from the channel samples are listed in Appendix 1 and are discussed in an earlier section. Of interest to this portion of the study is the identification of accessory apatite in many of the samples. Samples in which apatite was positively identified in greater than trace amounts in Line Creek 9 and 8-seams are highlighted in Figures 29c and d. Apatite minerals are more common in Mist Mountain Formation coal samples than in Gates Formation coals; in fact, trace apatite was only tentatively identified in two out of eight Gates Formation samples. The fluorapatite variety of apatite was frequently identified in Mist Mountain coals, but not in the Gates coals. Samples from seams in the basal coal zone of the Mist Mountain Formation, in particular 10A and 10B-seams from Line Creek and the Mammoth seam from Coal Mountain, do not contain detectable apatite.

The phosphate mineral gorceixite, a member of the crandallite series, was tentatively identified in the low-temperature ash of one Fording River sample. This mineral is sometimes associated with tonsteins in southeast British Columbia coals (Grieve, 1984, 1993).

CORRELATIONS OF PHOSPHORUS DATA

PHOSPHORUS-ASH RELATIONSHIPS

In determining the manner of association of phosphorus in these coals, the most important relationship to investigate is that between phosphorus (P) and ash. Correlation coefficients (r) between phosphorus and ash contents in raw

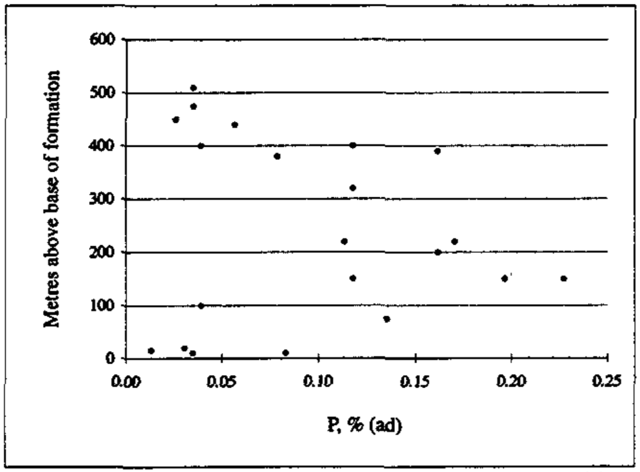

Figure 26a. Variations of phosphorus with stratigraphic position. Southeast B.C. whole-seam channel samples.

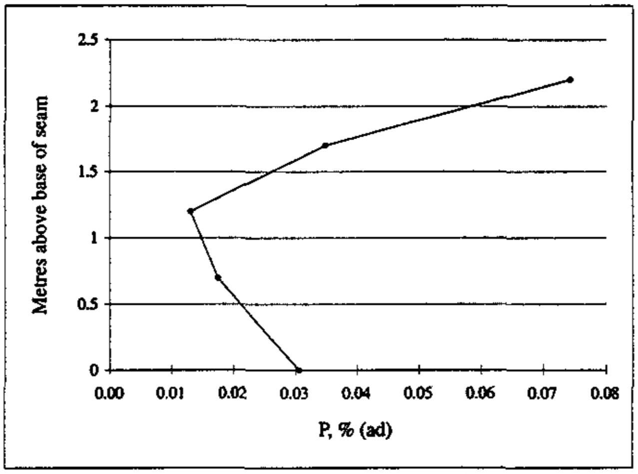

Figure 26b. Variations of phosphorus with stratigraphic position. 10A-seam, Line Creek, southeast B.C. channel samples.

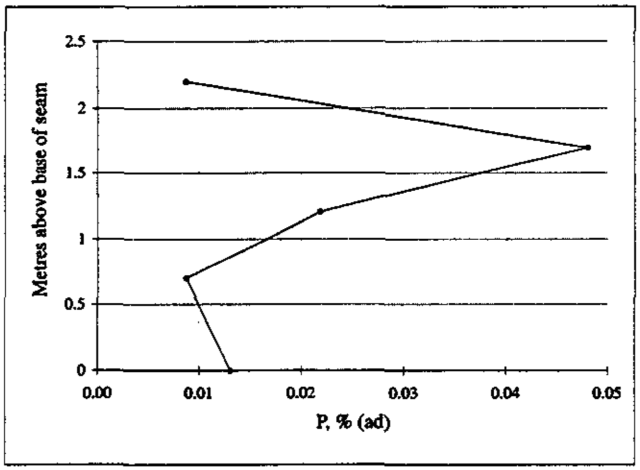

Figure 26c. Variations of phosphorus with stratigraphic position. 10B-seam, Line Creek, southeast B.C. channel samples.

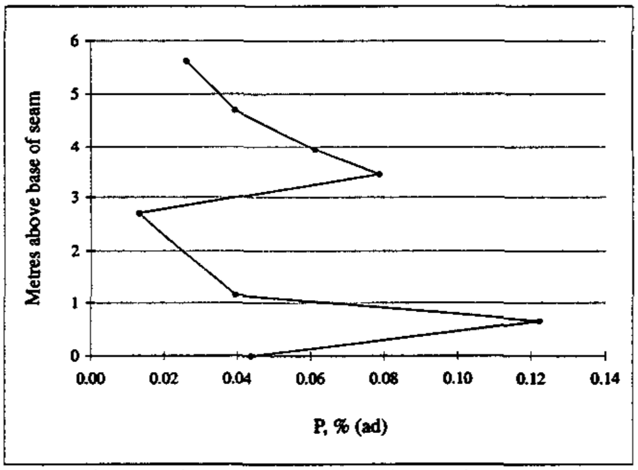

Figure 26d. Variations of phosphorus with stratigraphic position. 9-seam, Line Creek, southeast B.C. channel samples.

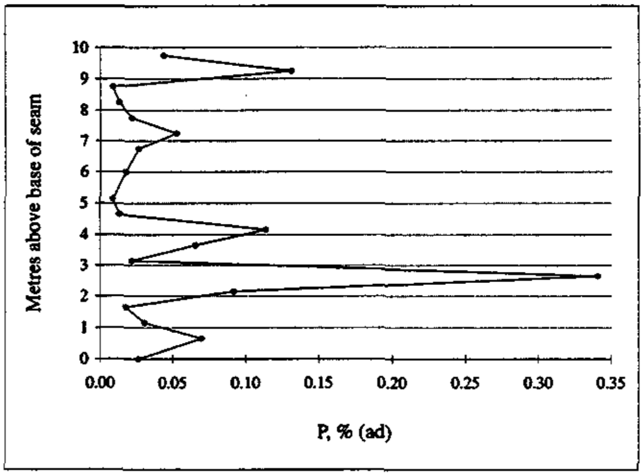

Figure 26e. Variations of phosphorus with stratigraphic position. 8-seam, Line Creek, southeast B.C. channel samples.

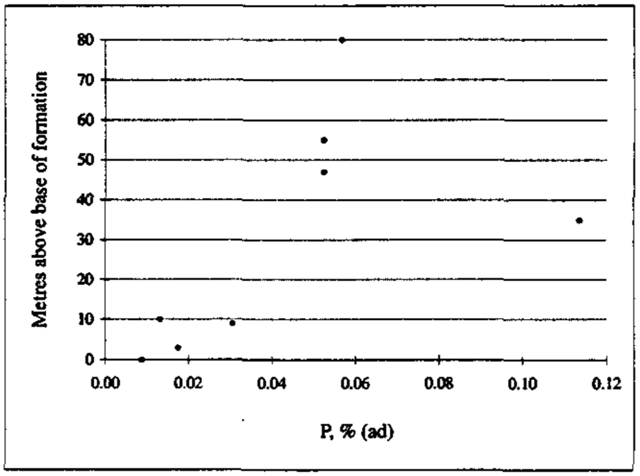

Figure 26f. Variations of phosphorus with stratigraphic position. Northeast B.C. channel samples.

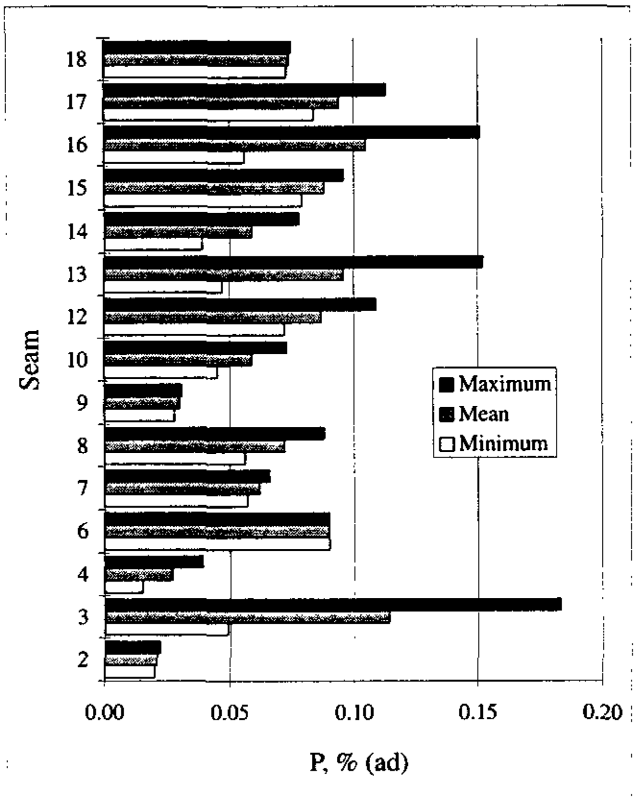

Figure 27. Variations of phosphorus with stratigraphic position on the Elk River property, southeast B.C., compiled from assessment reports.

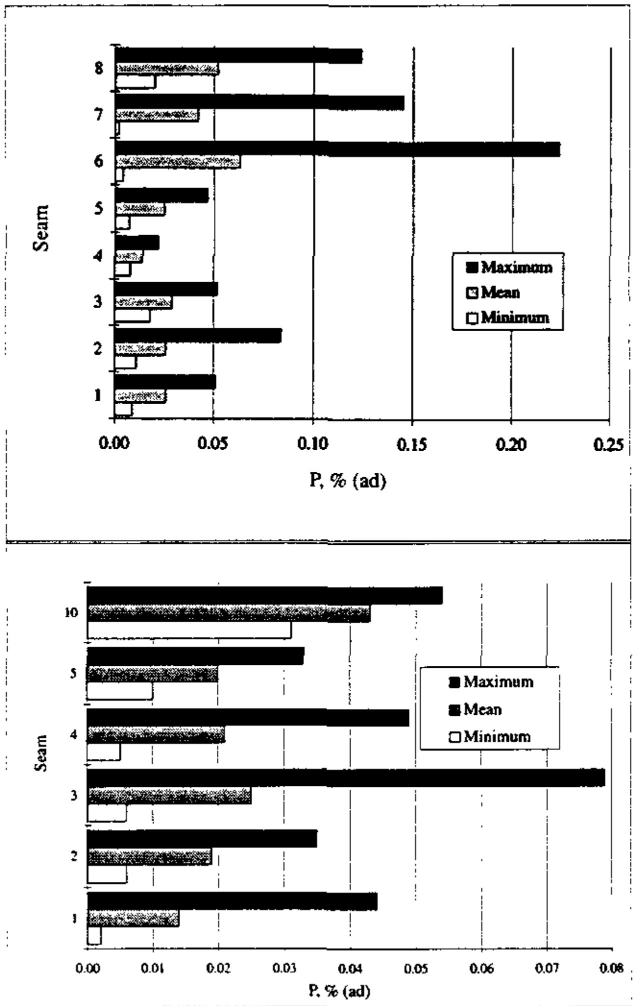

Figure 28. Variations of phosphorus with stratigraphic position on *the Belcourt (28a) and Saxon (28b) properties, northeast B.C.*, compiled from assessment reports.

British Columbia coking coals are listed in Table 17. Graphs illustrating some examples of these relationships, together with corresponding relationships between phosphorus (P_2O_5) in ash *versus* ash, are shown in Figures 29 to 33. In the case of the assessment report data, r-values are low and there are very few instances where there is significant correlation between phosphorus and ash content (Table 17). F and K-seams (Gates Formation) at Quintette, however, do show a significant positive correlation at the 99% confidence level, while the Gates Formation as a whole, and the Gething Formation, show a significant relationship at the 95% level. In the case of the channel sample data, both the Gates and Mist Mountain formations show a significant correlation at the 95% confidence level. This is consistent with the similarity between the stratigraphic profiles of phosphorus and ash in the channel sample data (Figures 26a and f) noted above.

Consistent with the general lack of strong correlations, interpretation of the scatterplots of phosphorus *versus* ash (Figures 29 to 33) is far from straightforward. There is a large amount of data scatter in nearly all cases, and few examples which allow application of Nicholl's (1986) general principles of element affinity, outlined earlier. Even in cases where there is a significant positive correlation between phosphorus and ash (Table 17), the scatterplots are not linear (for example, Qunitette F-seam, Figure 33a). Some of the graphs of phosphorus in ash *versus* ash, however, appear to be similar to the graphs which supposedly demonstrate both organic and inorganic association. These graphs all display a negative slope at low ash concentrations (the "organic" component), and a zero slope at higher ash levels ("inorganic"). For example, *see* Line Creek 8-seam (Figure 29d), Gething Formation in total (Figure 30), Gates Formation in assessment report data (Figure 31a), Quintette, Belcourt and Saxon properties (Figure 32), Quintette F-seam, Belcourt 8-seam, and Saxon 1-seam (Figure 33). Comments concerning the dubious validity of this interpretation are included below.

PHOSPHORUS-FLUORINE RELATIONSHIPS

The relationship between phosphorus and fluorine was also investigated. (The concentrations of trace elements, including fluorine, in the raw channel samples are covered in the next chapter). If a significant fraction of the phosphorus occurs in fluorapatite, a positive correlation between phosphorus and fluorine would be expected. Figure 34 displays phosphorus *versus* fluorine plots; the two elements are positively correlated at the 99% confidence level in all

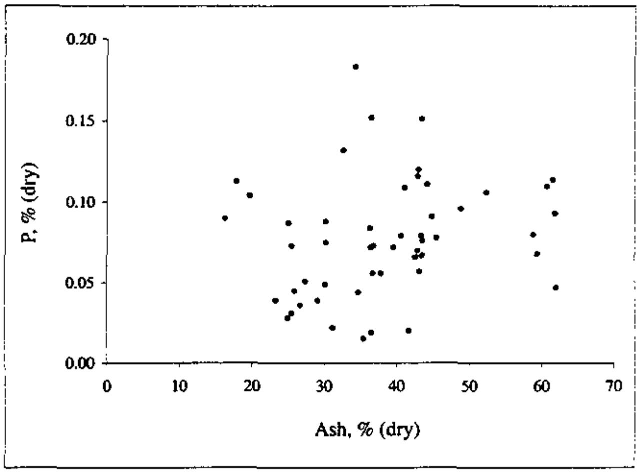

Figure 29a (i). Phosphorus *vs.* ash in raw southeast B.C. coals. Assessment report data.

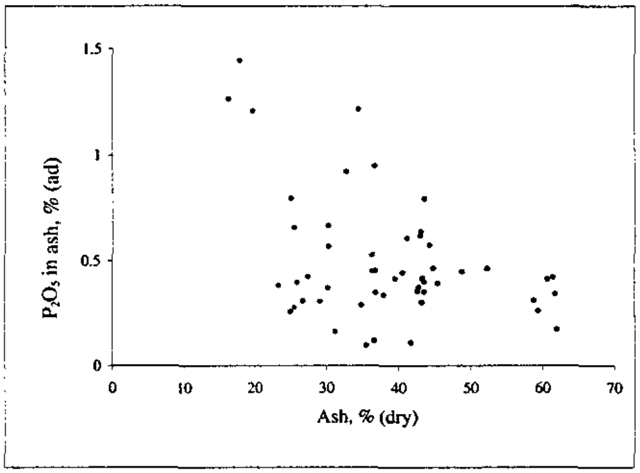

Figure 29a (ii). Phosphorus in ash *vs.* ash in raw southeast B.C. coals. Assessment report data.

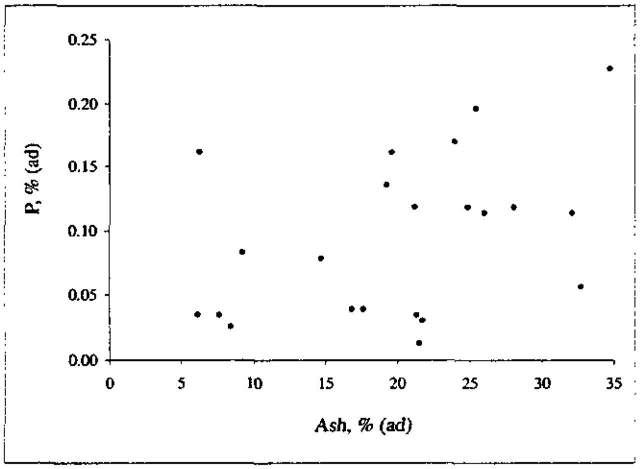

Figure 29b (i). Phosphorus *vs.* ash in raw southeast B.C. coals. Whole-seam channel samples.

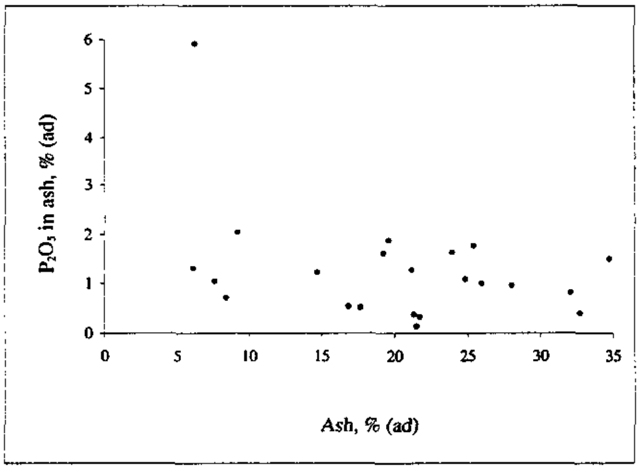

Figure 29b (ii). Phosphorus in ash *vs.* ash in raw southeast B.C. coals. Whole-seam channel samples.

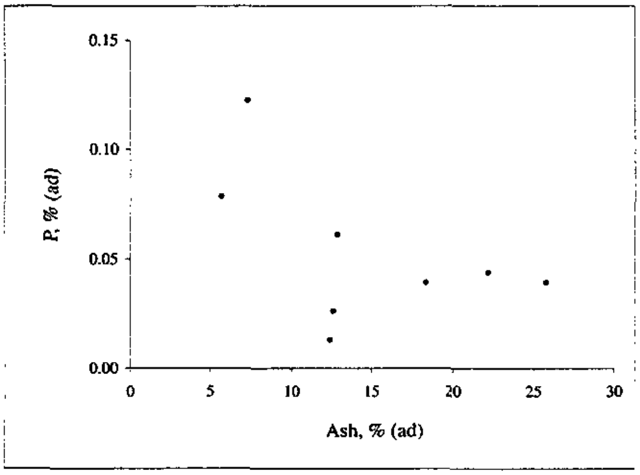

Figure 29c (i). Phosphorus *vs.* ash in raw southeast B.C. coals. Line Creek 9-seam channel samples.

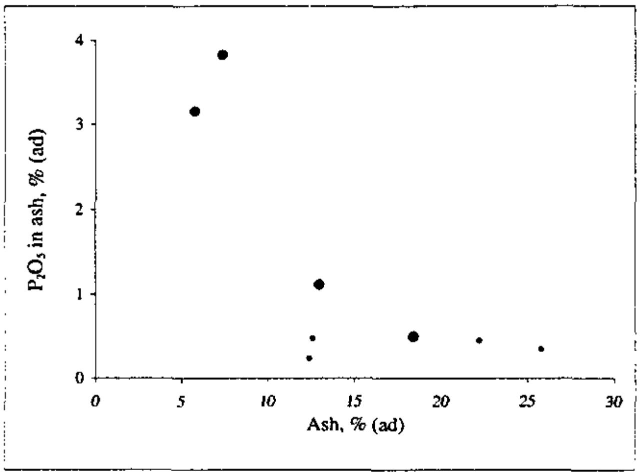

Figure 29c (ii). Phosphorus in ash *vs.* ash in raw southeast B.C. coals. Line Creek 9-seam channel samples.

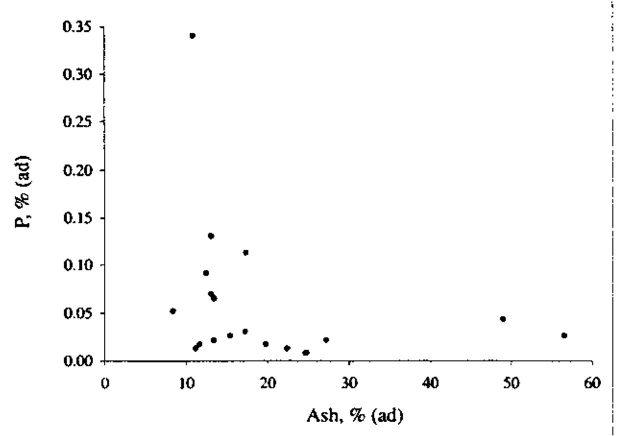

Figure 29d (i). Phosphorus *vs.* ash in raw southeast B.C. coals. Line Creek 8-seam channel samples.

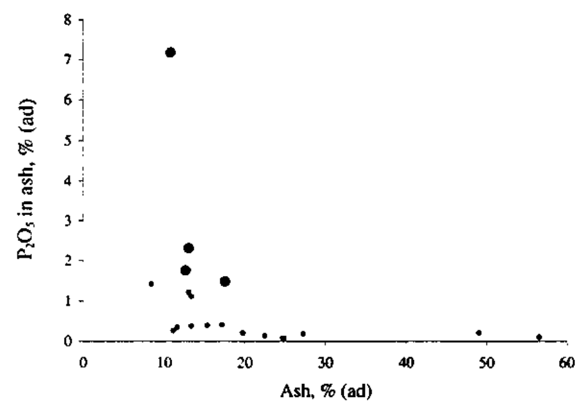

Figure 29d (ii). Phosphorus in ash *vs.* ash in raw southeast B.C. coals. Line Creek 8-seam channel samples.

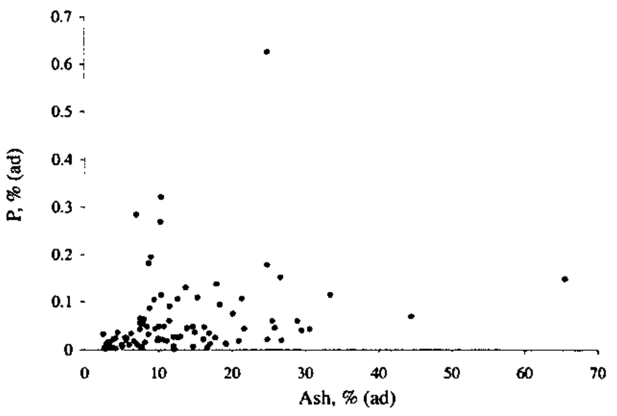

Figure 30 (i). Phosphorus/ash relationships in raw Gething Formation coals, northeast B.C., compiled from assessment reports.

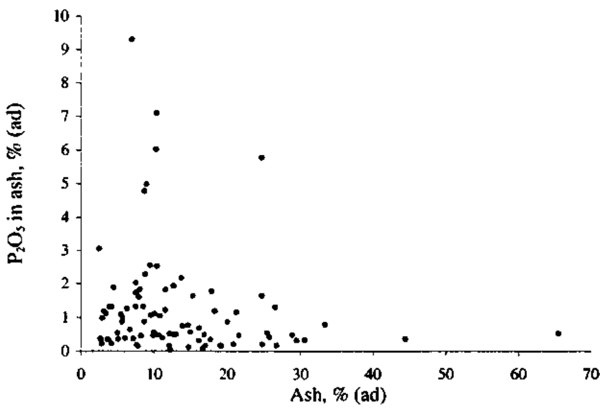

Figure 30 (ii). Phosphorus/ash relationships in raw Gething Formation coals, northeast B.C., compiled from assessment reports.

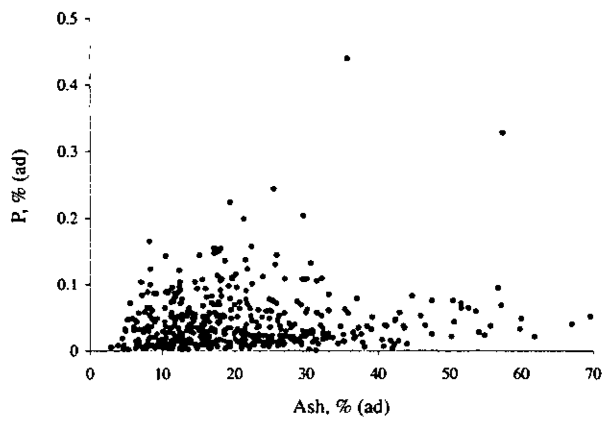

Figure 31a (i). Phosphorus/ash relationships in raw Gates Formation coals, northeast B.C. Assessment report data.

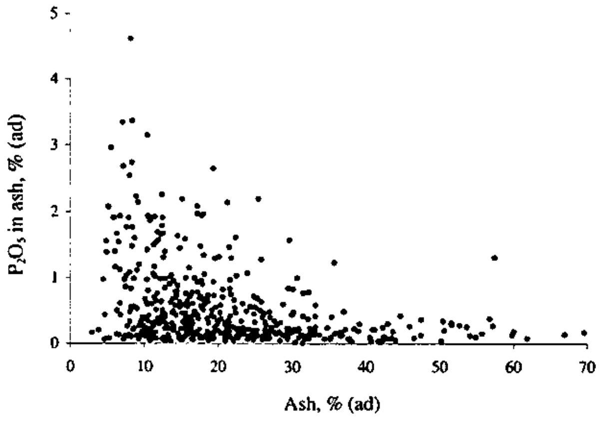

Figure 31a (ii). Phosphorus/ash relationships in raw Gates Formation coals, northeast B.C. Assessment report data.

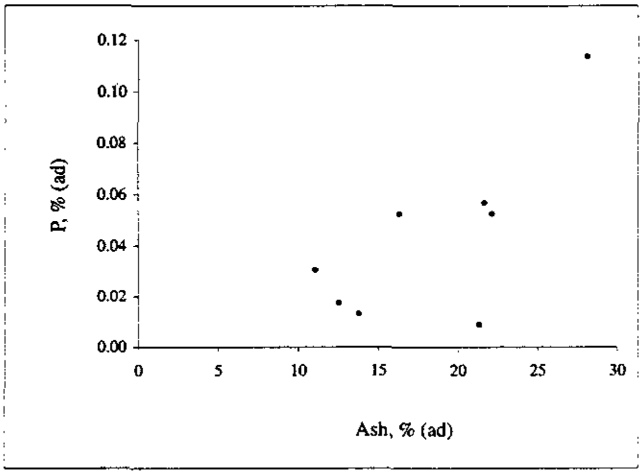

Figure 31b (i). Phosphorus/ash relationships in raw Gates Formation coals, northeast B.C. Channel samples.

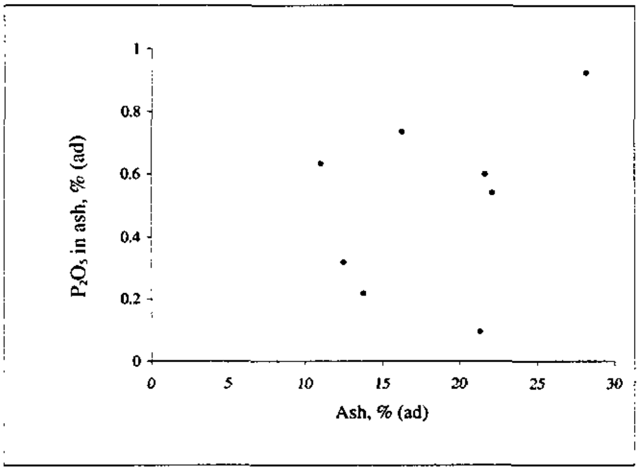

Figure 31b (ii). Phosphorus/ash relationships in raw Gates Formation coals, northeast B.C. Channel samples.

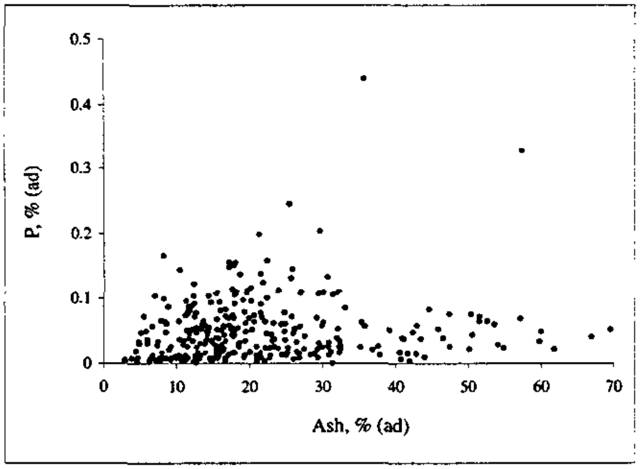

Figure 32a (i). Phosphorus/ash relationships in raw Gates Formation coals from three properties. Quintette.

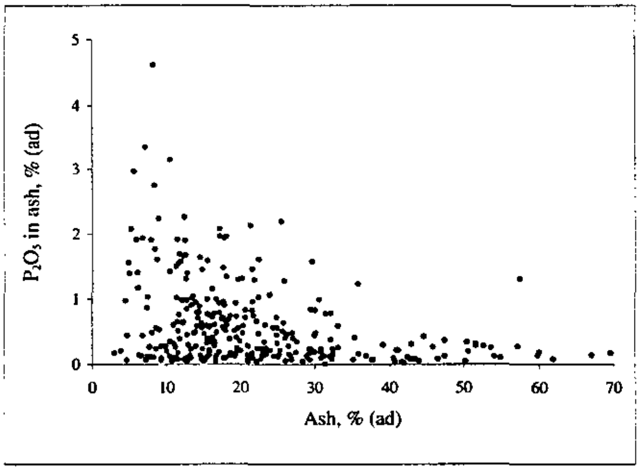

Figure 32a (ii). Phosphorus/ash relationships in raw Gates Formation coals from three properties. Quintette.

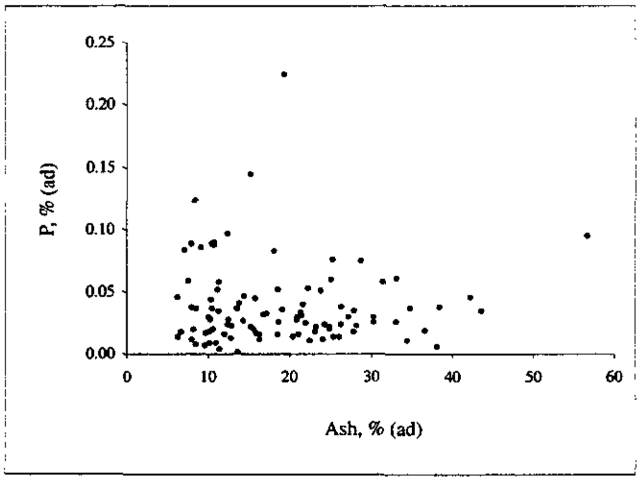

Figure 32b (i). Phosphorus/ash relationships in raw Gates Formation coals from three properties. Belcourt.

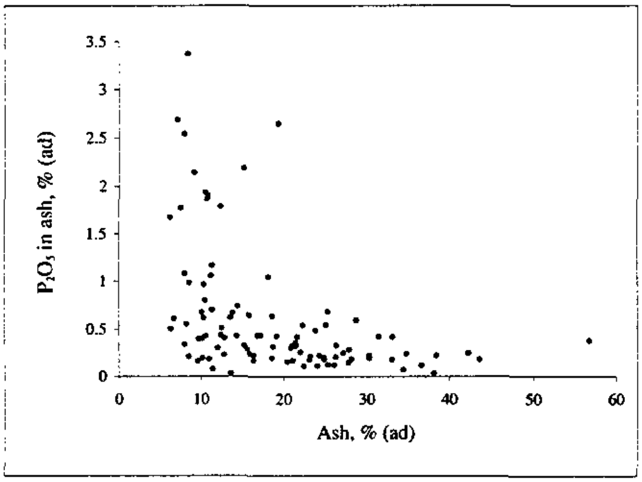

Figure 32b (ii). Phosphorus/ash relationships in raw Gates Formation coals from three properties. Belcourt.

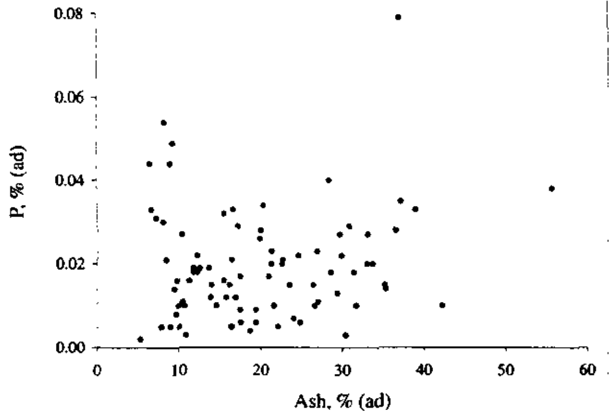

Figure 32c (i). Phosphorus/ash relationships in raw Gates Formation coals from three properties. Saxon.

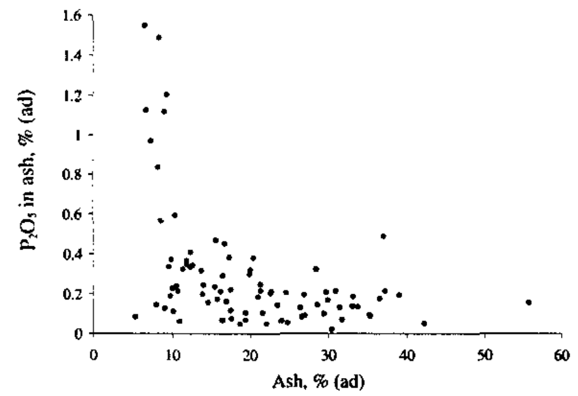

Figure 32c (ii). Phosphorus/ash relationships in raw Gates Formation coals from three properties. Saxon.

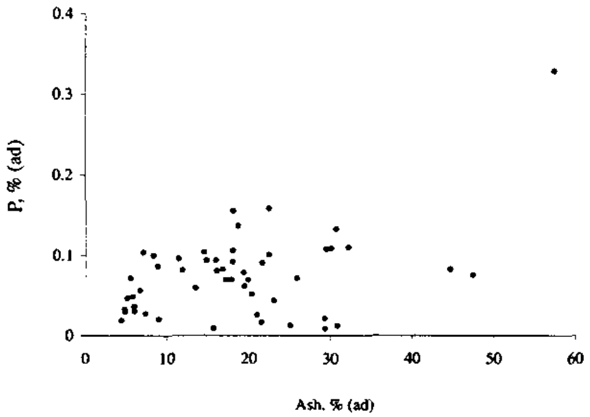

Figure 33a (i). Phosphorus/ash relationships in raw coals from three Gates Formation seams. Quintette F-seam.

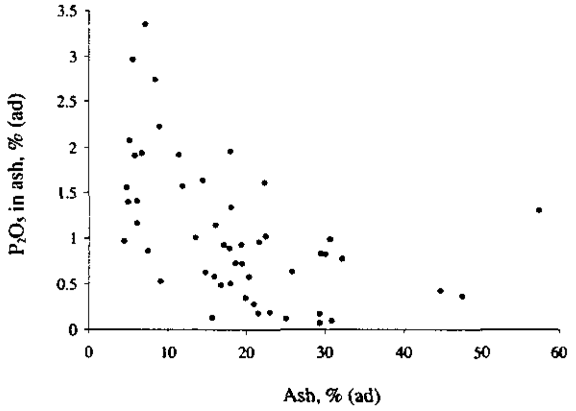

Figure 33a (ii). Phosphorus/ash relationships in raw coals from three Gates Formation seams. Quintette F-seam.

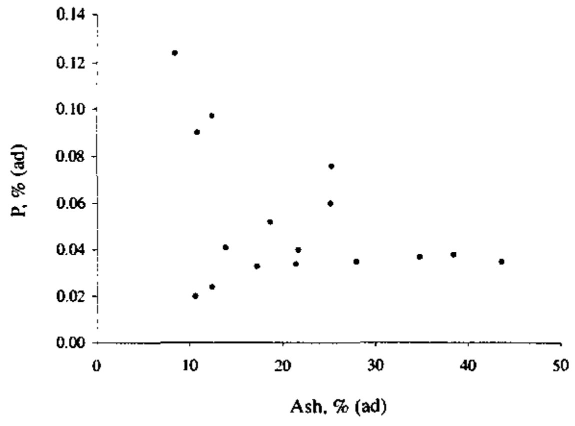

Figure 33b (i). Phosphorus/ash relationships in raw coals from three Gates Formation seams. Belcourt 8-seam.

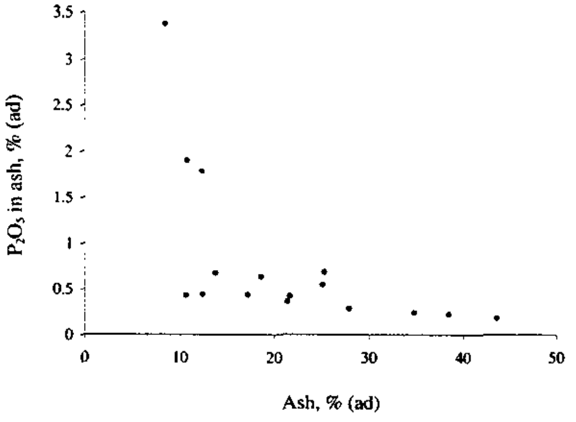

Figure 33b (ii). Phosphorus/ash relationships in raw coals from three Gates Formation seams. Belcourt 8-seam.

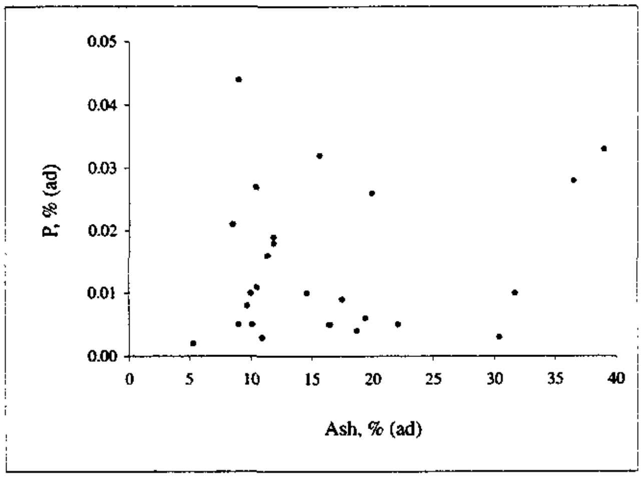

Figure 33c (i). Phosphorus/ash relationships in raw coals from three Gates Formation seams. Saxon 1-seam.

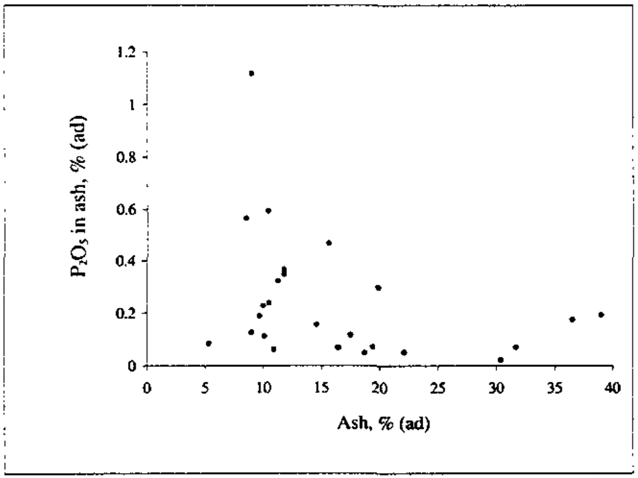

Figure 33c (ii). Phosphorus/ash relationships in raw coals from three Gates Formation seams. Saxon 1-seam.

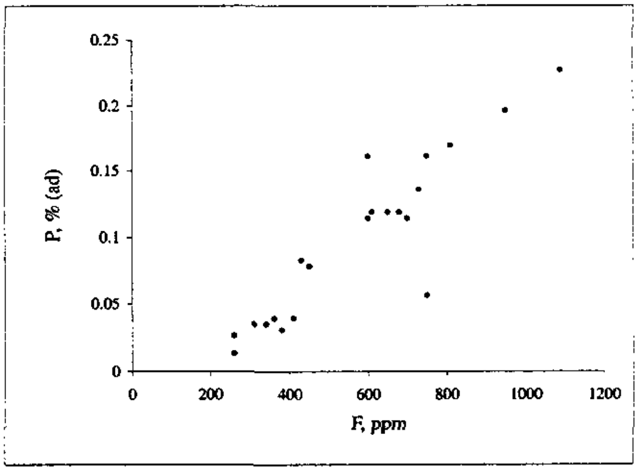

Figure 34a. Phosphorus/fluorine relationships in raw coals. Southeast B.C. whole-seam channel samples.

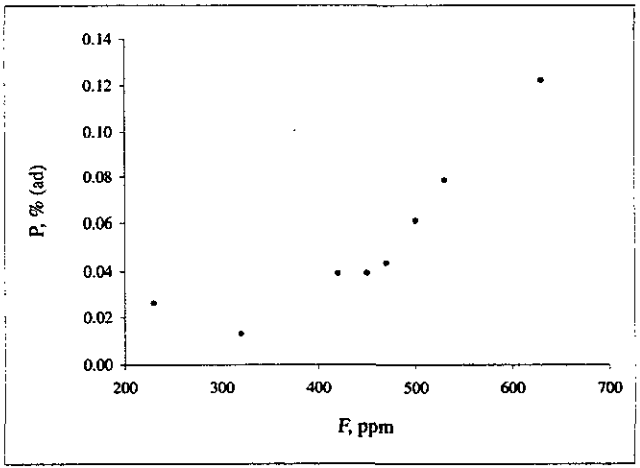

Figure 34b. Phosphorus/fluorine relationships in raw coals. Line Creek 9-seam, southeast B.C. channel samples.

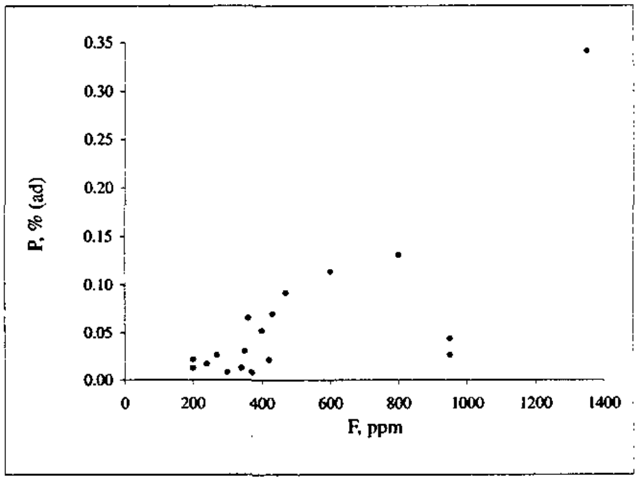

Figure 34c. Phosphorus/fluorine relationships in raw coals. Line Creek 8-seam, southeast B.C. channel samples.

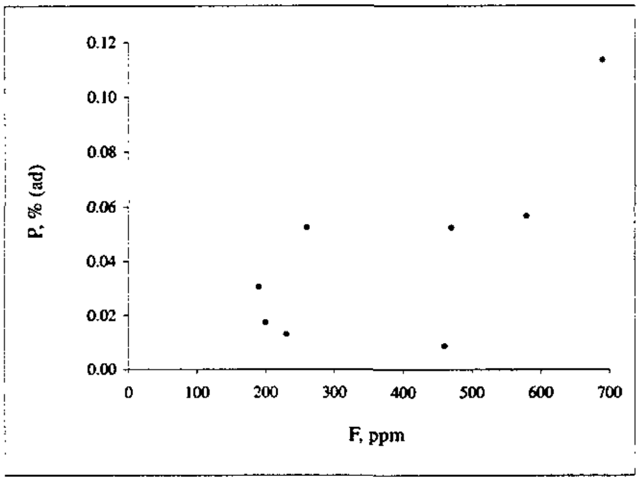

Figure 34d. Phosphorus/fluorine relationships in raw coals. Northeast B.C. channel samples.

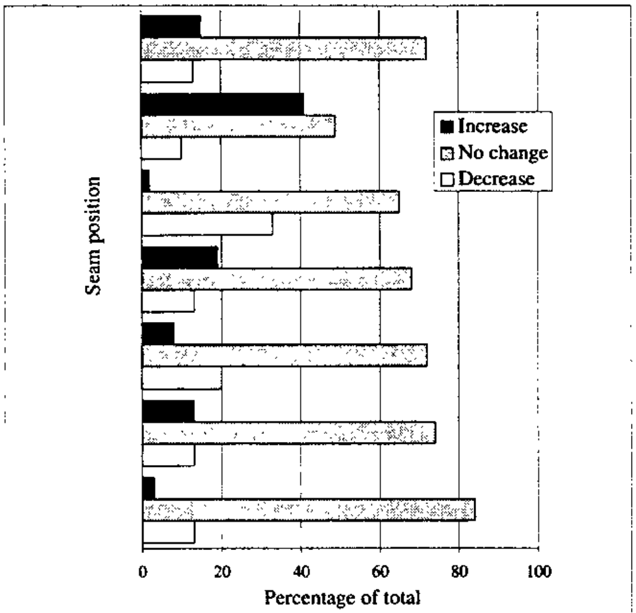

Figure 35. Impact on phosphorus levels of washing coal seams at a Gates Formation property in northeast B.C. Each set of three bars represents one seam, and the seams are arranged in stratigraphic order. *See* text for definitions of "no change" etc.

examples shown, except for the Gates Formation samples (Figure 34d), for which the confidence level is 95%. The correlation coefficients are as follows: Mist Mountain Formation, 0.92; Line Creek 9-seam, 0.88; Line Creek 8-seam, 0.76; Gates Formation, 0.72.

PHOSPHORUS CONCENTRATIONS IN CLEAN COALS

Clean coal data are available in assessment reports. For the Mist Mountain Formation the mean phosphorus concentration in clean coals is 0.033%, while the mean phosphorus concentration in clean Gething Formation coals is 0.030, and in clean Gates Formation coals the value is 0.044%. In the last case, the value is essentially unchanged from the raw coal value, while for the other two the concentration in clean coals represents a significantly lower value than that in raw coals. This comparison is misleading, however, because of differences in analytical procedures between different exploration companies. Most of the Gates samples were not crushed to as fine a size, and were not floated in as low specific gravity medium, as the Mist Mountain coals. This would tend to hinder liberation and separation of mineral matter in the Gates samples relative to the other formations.

In certain cases, clean and raw phosphorus values are available for the same set of samples from the Gates and Mist Mountain formations. Where this occurs a new variable, delta P, was derived for each sample, by subtracting the raw phosphorus concentration from the clean value. Delta P values between -0.01 and +0.01% were interpreted to represent no change, as the error in each reading is assumed to be ±0.005%. For the Mist Mountain Formation, phosphorus concentration decreased (*i.e.*, delta P<-0.01) when the coal was washed in 39 out of 51 samples, and increased in only two cases. For the Gates Formation the situation is somewhat different, with the majority of samples, 285 out of a total of 486, experiencing no change, 79 samples showing a decrease in phosphorus after washing, and 59 exhibiting an increase. However, the contrast between the Mist Mountain and Gates formations is not as important as it first appears, because of the different analytical procedures referred to in the previous paragraph.

The large volume of Gates Formation data also permits some seam-by-seam comparisons of changes in phorphorus concentrations after washing. In Figure 35 data from the coal seams from one Gates Formation deposit are arranged in stratigraphic order. For each seam there are three stacked bars, the top one representing the percentage of samples in which phosphorus increased during washing, the middle one the samples which showed no change, and the bottom bar the samples in which phosphorus increased. In most seams more than 70% of the samples exhibit no change. However, there are two examples in which more samples show an increase (delta P>+0.01) than a decrease (the fourth and sixth seams up from the base). The seam situated between them, in contrast, has the highest proportion of samples showing a decrease. Even in these relatively extreme examples, however, the largest group of samples showed no change.

DISCUSSION

Data indicate that raw Mist Mountain Formation coals have higher mean phosphorus concentrations than the Gething Formation coals, which in turn contain more than the Gates Formation. In all three coking coal bearing formations raw coal data are highly variable on all scales.

There are no consistent systematic variations in raw phosphorus concentrations with stratigraphic position in any of the formations, although in the cases of the Gates Formation coals, seams from the lower half of the formation generally contain, on average, less phosphorus than those from the upper half. Another apparent trend is that the base of the Mist Mountain Formation appears to contain coals relatively low in phosphorus and lacking phosphorous-bearing minerals. In the case of the channel sample data, variations in phosphorus with stratigraphic position are similar to variations in the ash contents of the samples for both the Mist Mountain and Gates formations. This suggests that any effect of stratigraphic position on phosphorus content can be overridden by the influence of variations in the ash content of individual samples, which has implications for the nature of association of the phosphorus.

FORMS OF ASSOCIATION OF PHOSPHORUS

Phosphorus in coals, especially higher rank coals, is generally believed to be associated predominantly with inorganic material (Burchill *et al.*, 1990), although a small but uncertain proportion may be associated with the organic fraction (Swaine, 1990; Finkelman, 1980). The phosphorus-containing mineral phases in coals include: apatite, most commonly fluorapatite (Swaine, 1977); crandallite-series minerals; monazite; and xenotime (Finkelman, 1980). Several recent studies (*e.g.*, Finkelman, 1980; Lyons *et al.*, 1990) have stressed the relative importance of very small (micron and submicron-sized) accessory mineral grains, including phosphorus-bearing minerals, dispersed throughout the organic matrix, as important sites for minor and trace elements in coal.

Four types of evidence have been applied in this study to determine the mode of occurrence of phosphorus in British Columbia coking coals: comparison and correlation with ash content, low-temperature ash mineralogy, correlation with fluorine concentrations, and comparison of phosphorus concentrations in clean and raw coals.

The graphs showing phosphorus in coal *versus* ash and phosphorus in ash *versus* ash (Figures 29 to 33), as mentioned earlier, can not be interpreted with certainty. As noted, however, some of the latter type of graph appear to have two distinct components, a line with a steep negative slope at low ash contents, and a horizontal line at higher ash contents. This type of relationship has been noted elsewhere (Nicholls, 1968; Finkelman, 1980), and has, in some cases, been interpreted to represent two types of association, organic association in the low-ash range, and inorganic in the higher ash range. As pointed out by Nicholls (1968), it is desirable to apply element/ash diagrams to data from one seam and preferably from one location, such as the Line Creek ply-by-ply samples. Based on data for 8 and 9-seams (Figures 29c and 29d), it is apparent that the samples in which accessory apatite was identified in greater than trace amounts (highlighted points), are essentially those low-ash samples which form the segment of the graph with the steep negative slope, that is, the portion which would be ascribed to organic association using Nicholls' approach. If all these samples were removed from Figures 29c and 29d, the remaining data would essentially plot on horizontal lines, the relationship indicative of inorganic association.

These examples demonstrate clearly that another critical variable must be considered in interpreting graphs like those in Figures 29 to 33, and that is the mineralogy of the inorganic fraction. As noted by Finkelman (1980), the presence of a very small amount of an accessory mineral containing a trace element, in this case apatite containing phosphorus, is capable of producing a significant increase in the concentration of that element, with only a negligible increase in ash content. This effect probably has influence not only in the Line Creek 8 and 9-seam samples, but also in other instances where this type of two-component graph occurs (for example, Figure 32c(ii)). This confirms that the main weakness of this approach is that it wrongly assumes that the trace element (phosphorus in this case) concentration in each ash increment remains constant (Nicholls, 1968; Finkelman, 1980).

Our data therefore suggest that phosphorus in British Columbia coking coals is associated with the inorganic fraction, primarily with apatite minerals, including fluorapatite. More support for this conclusion comes from the positive correlations between phosphorus and fluorine (Figure 34), most notably for Mist Mountain Formation samples.

The comparisons between phosphorus contents in raw and clean samples of Mist Mountain coals also tend to confirm an inorganic association. For example, the mean phosphorus concentration in clean coals is substantially lower than the mean in raw coals. Moreover, where phosphorus values are available on both raw and clean coal from the same samples, the majority of clean Mist Mountain coals contain less phosphorus than corresponding raw coals.

In the case of the Gething Formation, it was not possible to compare raw and clean concentrations in the same samples, but the substantially lower mean phosphorus concentration in clean coals suggests an inorganic association.

The situation in the Gates Formation appears at first to be different: the overall mean phosphorus concentration in clean coals is essentially the same as that in raw coals, and there is a higher proportion of samples for which removal of phosphorus was not achieved during washing, or for which phosphorus concentrations actually increased during washing. Despite this outcome, there is no valid basis for concluding that the association of phosphorus in Gates coals is fundamentally different. For example, the relationships between phosphorus and ash, and between phosphorus and fluorine, are similar to those derived from the other formations. Moreover, as mentioned previously, the sample preparation techniques most commonly used for the Gates samples would tend to liberate and separate relatively less fine mineral matter than those used for the coals from the other formations. Alternately, the phosphorus-bearing minerals could be inherently more difficult to liberate in the Gates Formation coals.

Even if a direct comparison between the Mist Mountain and Gates clean samples were valid, there are still conditions which could lead to differences in phosphorus behaviour of the type seen here, without having to invoke a fundamental difference in its manner of association. Finkelman (1980) and Swaine (1990) have summarized the weaknesses in the washability approach to determining an element's affinity in coal, in particular noting that elements associated with mineral grains which are finely dispersed through the organic matrix (macerals) will behave as though they are associated with the organic fraction. The contrasts in the washability behaviour of phosphorus in individual Gates Formation seams (Figure 35), suggest that the influence of the degree of dispersal and grain size of mineral grains may in fact be operating, with the seams which demonstrate more increases than decreases perhaps containing a greater percentage of their phosphorus in finely dispersed grains.

The crandallite-series mineral gorceixite, which was identified in the low-temperature ash of one Mist Mountain Formation sample, occurs in some tonsteins found in the Kootenay coalfields, as does apatite, though less frequently. This suggests a possible volcanic source for some of the phosphorus in British Columbia coking coals, as the tonsteins are believed to have a volcanic origin (Goodarzi *et al.*, 1990).

COMPARISON WITH WORLD COALS

The range in phosphorus values in metallurgical coal products from British Columbia is 0.023 to 0.079%, with an unweighted average of 0.046% (figures derived from ash analysis data in Appendix B of Price and Gransden, 1987). There is essentially no difference between the northeast and southeast producers in terms of phosphorus content of products. The calculated means of clean coal phosphorus data in this study (0.030 to 0.044%) are close to the overall product average, and in the case of the Gates Formation the mean corresponds almost exactly. Overall, a phosphorus concentration on the order of 0.05% is a conservative average for our clean coking coals. With raw coals it is not possible to determine a single average, but mean phosphorus contents in the three metallurgical coal-bearing formations range from about 0.04 to 0.08%.

The estimated range of phosphorus contents in most world coals is on the order of 0.001 to 0.3% (Swaine, 1990), and an estimated world-wide average is 0.05% (Bertine and Goldberg, 1971). The mean concentrations of phosphorus in British Columbia's coking coals, clean and raw, clearly compare favourably with both this range and average. Moreover, phosphorus contents in British Columbia coals do not appear to be anomalous when compared with ranges of values of coals from Australia, South Africa, Europe, U.S.A., U.K. and other regions (*see* Swaine, 1990, Table 5.23). Phosphorus concentrations in 200 samples of Bowen Basin (Queensland) coal, for example, range from 0.001 to 0.35%.

However, when comparing the mean concentrations of phosphorus in our coals with mean values from other countries, some contrasts are apparent. For example, coals from the eastern United States, including Appalachian coals cited by Finkelman (1980), for which the mean in 754 raw(?) samples is 0.018%, tend to contain less phosphorus than our coals. The average phosphorus content in British coals is 0.025% (British Coal Corporation, unpublished data, *in* Burchill *et al.*, 1990), while the average phosphorus concentration in coals from New South Wales and Queensland is 0.031% (Swaine, 1977). British Columbia coals thus appear to contain relatively higher mean concentrations of phosphorus, but by factors much less than an order of magnitude, than coals from some other parts of the world.

PRODUCTION AND MARKETING IMPLICATIONS

Whether phosphorus represents a negative factor in the marketing of coking coals depends on many other variables, as already noted. The large volume of British Columbia coking coal currently being sold on the world market (about 20 million tonnes per year) suggests it is not, in general, a significant problem.

Specific users may have more stringent specification requirements, however, and achieving success in these markets may involve tight production control. The data summarized here suggest that, where limiting phosphorus in raw coal is a concern, there appears to be only limited potential in selectively mining seams from particular parts of the stratigraphy. There is probably more potential in the Peace River coalfield than in the Kootenays. Moreover, careful and repeated sampling, even within a single seam, is necessary to plan for the wide variabilities in phosphorus concentrations within seams.

Phosphorus concentration in a clean coal depends on the concentration in the raw coal, as well as the response of the coal to beneficiation. The positive conclusion here is that the phosphorus in Kootenay and Peace River coking coals appears to be mainly inorganically associated, implying that separation during coal processing should be achievable. However, there appear to be inconsistencies in the responses of individual samples or seams to washing, probably related to the variations in ease of liberation of the apatite mineral grains. Where liberation of mineral grains is not achieved, beneficiation is not possible.

CHAPTER 9

TRACE ELEMENTS IN NORTHEAST AND SOUTHEAST B.C. COALS

This portion of the study is aimed at describing trace element concentrations in raw British Columbia coal samples from the seven producing mines in the northeast and southeast of the province, and interpreting the manner in which trace elements are associated within the coals. Trace element analyses were carried out on the set of channel samples. The list of elements and analytical methods were outlined earlier. Further coverage of this subject is given in Grieve and Goodarzi (1993, 1994).

The main concern with trace elements is environmental contamination related to the use of thermal coal (Swaine, 1989). With growing global emphasis on the use of thermal coal to generate electricity, and with the possibility of coal-burning power-generating facilities being constructed in British Columbia in the future, it is timely to consider the trace element contents of coals currently being produced in the province, and to compare our coals with coals from other parts of the world.

To date, basic statistical analysis has been performed on trace element concentration data. Means for the two regions have been calculated and compared, to determine if there are significant differences in the concentrations of certain elements between them (Table 18, Figure 36). Variations in element concentrations with change in stratigraphic position, both within formations and individual seams, have also been plotted (Figures 37 to 40). Relationships between element concentrations and ash contents have been established (Tables 19 and 20, Figures 41 to 44). These relationships provide a preliminary indication of the mode of association of the elements, that is, whether an element is dominantly associated with the inorganic or organic fraction of the coal. Correlations between different elements were also calculated (Tables 19 and 20), to provide further insight into geochemical controls.

It is important to note that the results given are not **representative of clean coals, that is, those which have undergone coal preparation, and should not be considered typical of current or potential coal products from British Columbia.** For the most part, trace element concentrations in product coals are expected to be lower than in raw coals, as most of the elements are associated with the mineral fraction of coals. However, where trace element bearing minerals are finely disseminated through an organic matrix, physical separation, and thus upgrading, may be difficult (Norton and Markuszewski, 1989).

TABLE 18
TRACE ELEMENT CONCENTRATIONS

	Southeast B.C.				Northeast B.C.				t	Both regions	
Element	Minimum	Maximum	Mean	s.d.	Minimum	Maximum	Mean	s.d.	(2-tailed)	Mean	s.d.
Sb	0.24	2.48	1.13	0.63	0.17	2.17	0.77	0.63	1.37	1.04	0.64
As	0.13	6.50	1.43	1.61	0.39	7.05	2.20	2.20	-1.05	1.64	1.78
Br	0.29	1.75	0.90	0.39	0.41	2.22	1.23	0.62	-1.76	0.99	0.47
B	<18	104	n/a	n/a	<31	56	n/a	n/a	n/a	n/a	n/a
Cd	<0.2	1.4	n/a	n/a	<0.2	0.3	n/a	n/a	n/a	n/a	n/a
Cl	40	220	96	45	150	400	246	94	-5.93	n/a	n/a
Cr	4.16	48.10	21.14	12.61	5.44	34.80	20.70	12.07	0.09	21.03	12.26
Co	0.92	3.70	2.14	0.71	0.72	4.02	2.59	1.17	-1.29	2.26	0.86
Cu	8	33	19	7.20	7	20	14	5.30	1.79	18	6.99
F	260	1090	566	230	190	690	385	191	1.99	518	232
Pb	<2	15	n/a	n/a	<2	12	n/a	n/a	n/a	n/a	n/a
Hg (ppb)	15	116	50	24	20	113	51	30	-0.10	50	25
Mo	<0.33	3.19	n/a	n/a	<0.40	1.10	n/a	n/a	n/a	n/a	n/a
Se	<0.60	3.43	n/a	n/a	<0.60	2.20	n/a	n/a	n/a	n/a	n/a
Th	0.89	5.74	2.86	1.20	1.89	7.24	4.21	2.04	-2.24	n/a	n/a
U	0.57	3.05	1.61	0.67	0.79	4.06	2.28	1.22	-1.92	1.79	0.88
Zn	<10	74	n/a	n/a	<10	53.6	n/a	n/a	n/a	n/a	n/a

n/a: not applicable

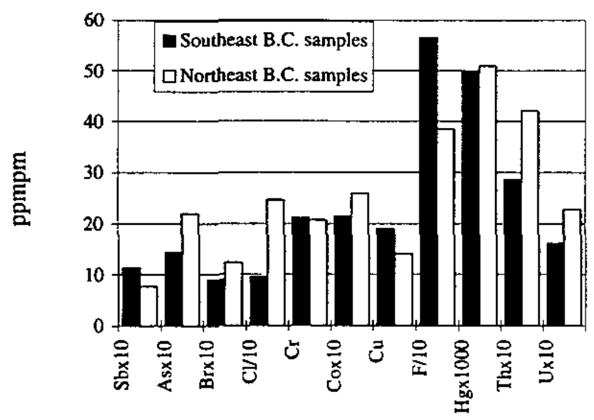

Figure 36a. Trace element concentrations. Mean trace element concentrations in northeast and southeast B.C. channel samples.

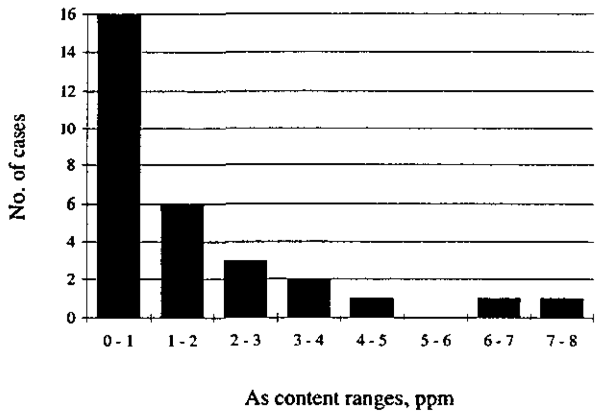

Figure 36c. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Arsenic in channel samples.

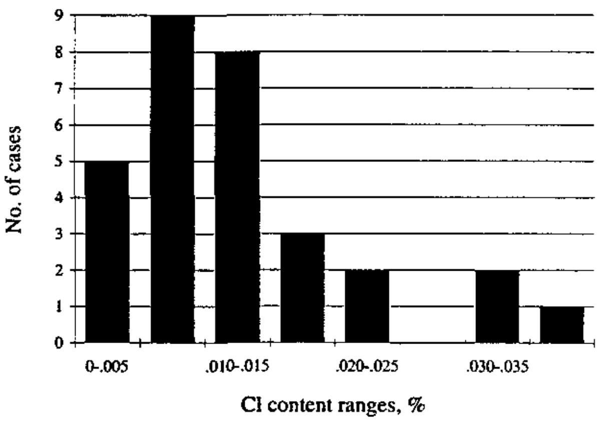

Figure 36e. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Chlorine in channel samples.

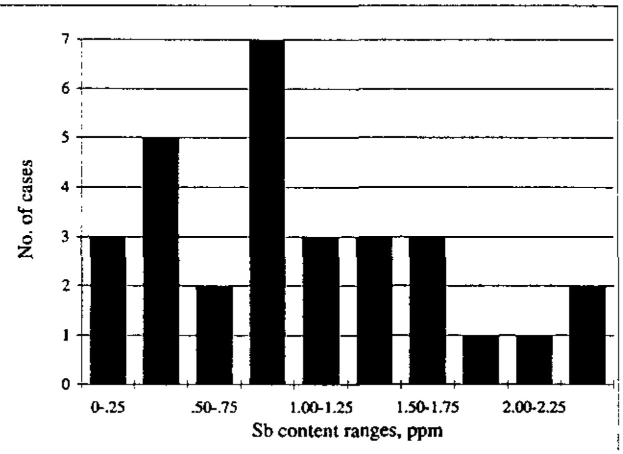

Figure 36b. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Antimony in channel samples.

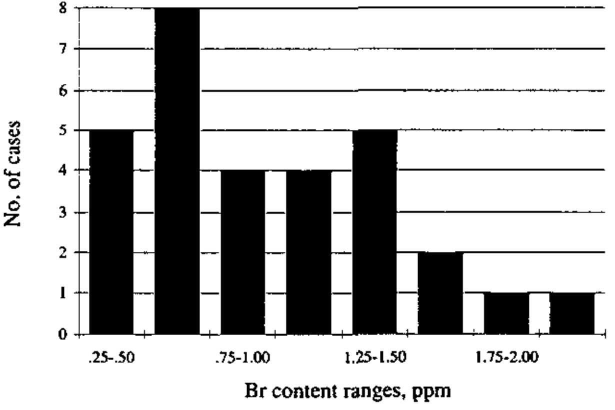

Figure 36d. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Bromine in channel samples.

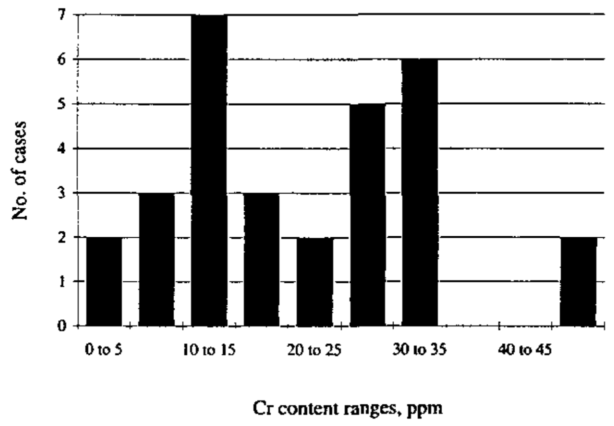

Figure 36f. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Chromium in channel samples.

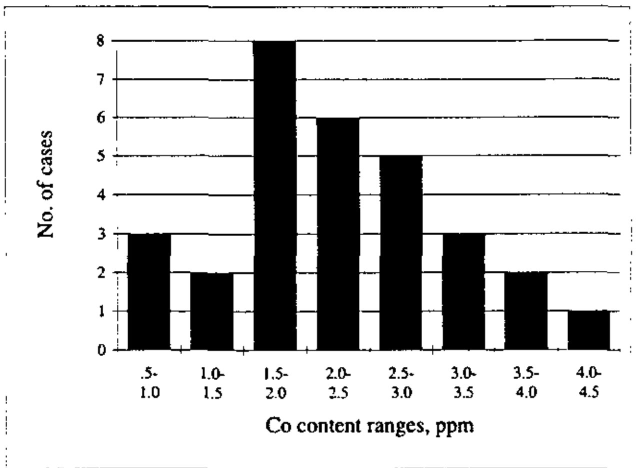

Figure 36g. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Cobalt in channel samples.

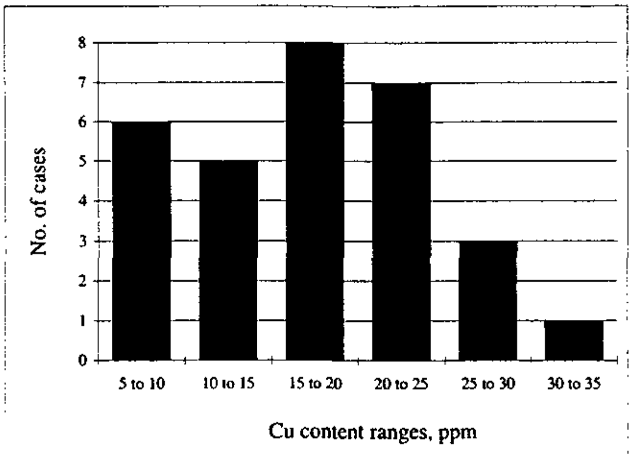

Figure 36h. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Copper in channel samples.

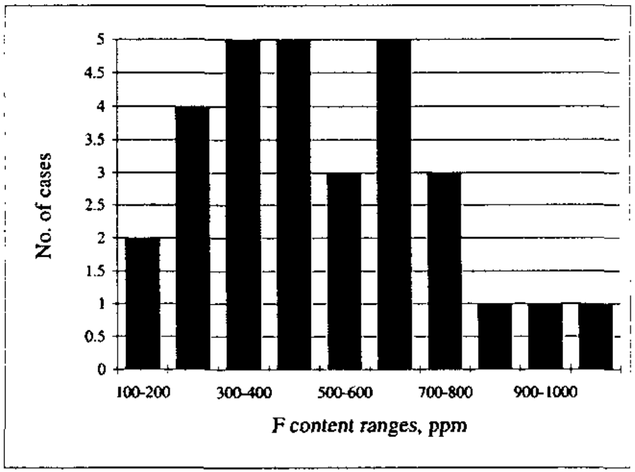

Figure 36i. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Fluorine in channel samples.

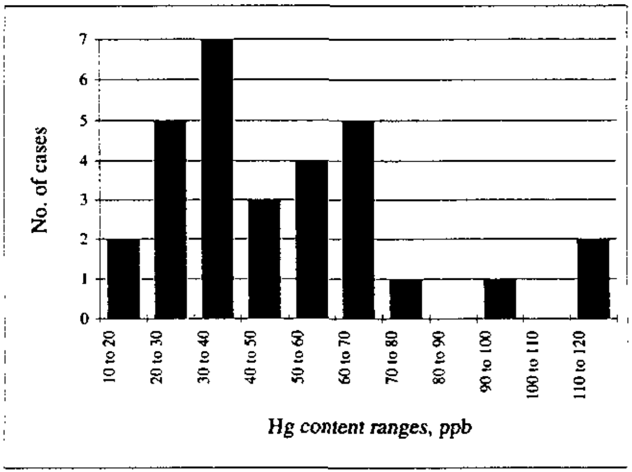

Figure 36j. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Mercury in channel samples.

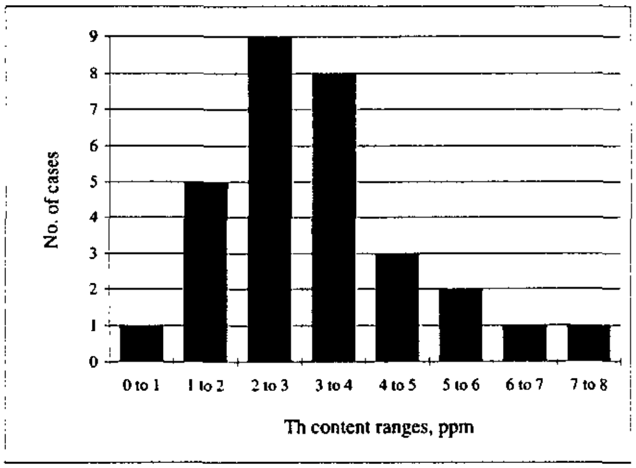

Figure 36k. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Thorium in channel samples.

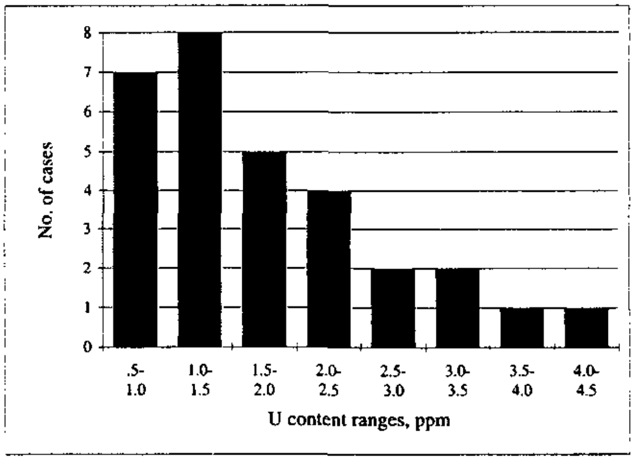

Figure 36l. Trace element concentrations. Frequency histograms of trace elements in samples from northeast and southeast B.C. Uranium in channel samples.

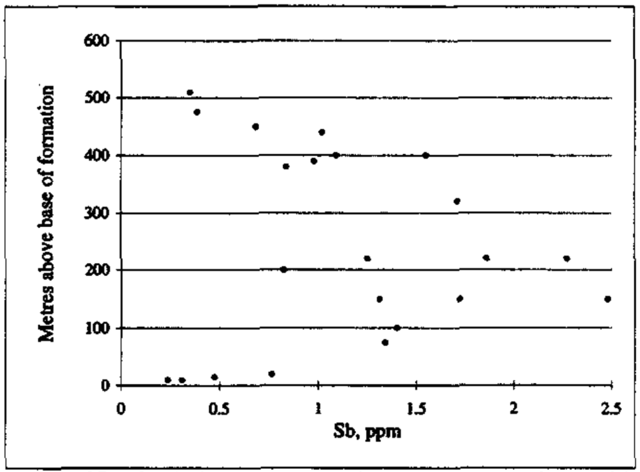

Figure 37a. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of antimony.

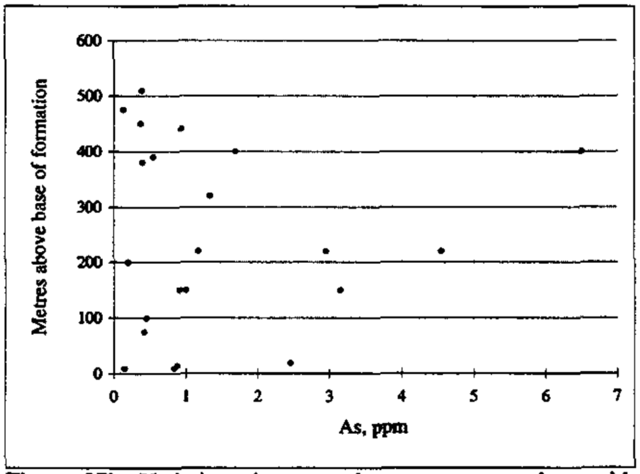

Figure 37b. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of arsenic.

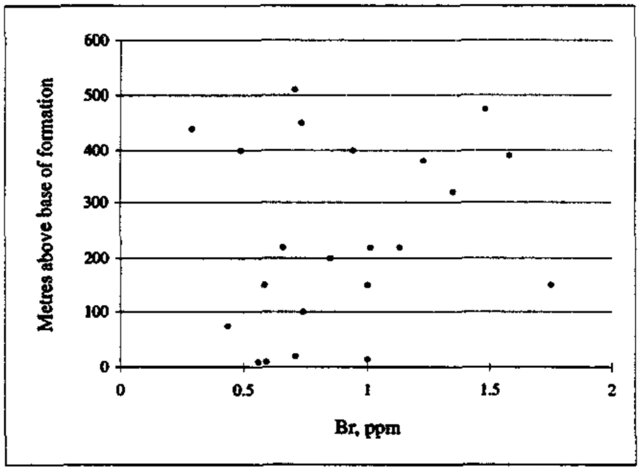

Figure 37c. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of bromine.

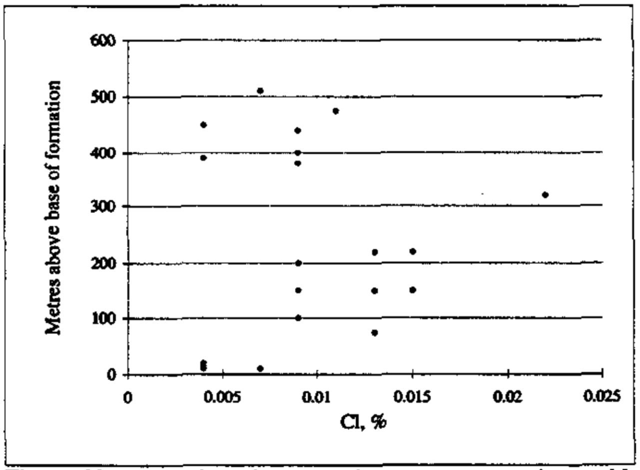

Figure 37d. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of chlorine.

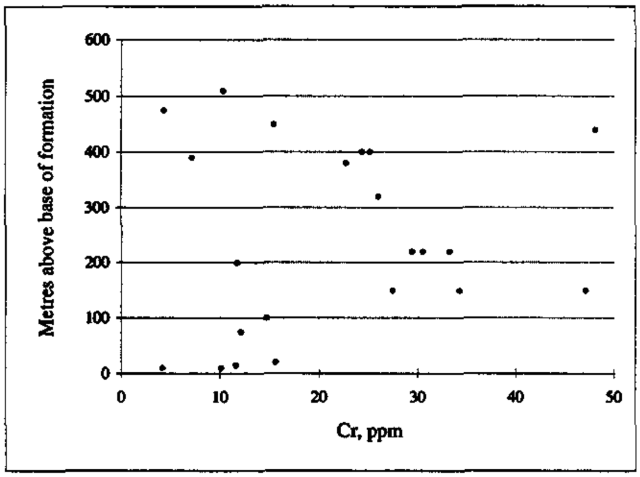

Figure 37e. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of chromium.

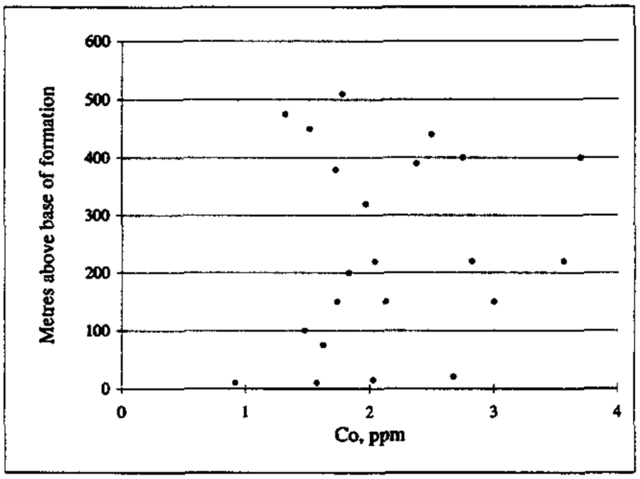

Figure 37f. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of cobalt.

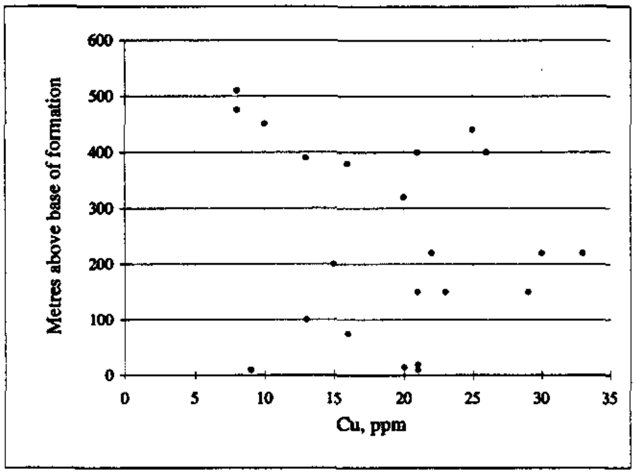

Figure 37g. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of copper.

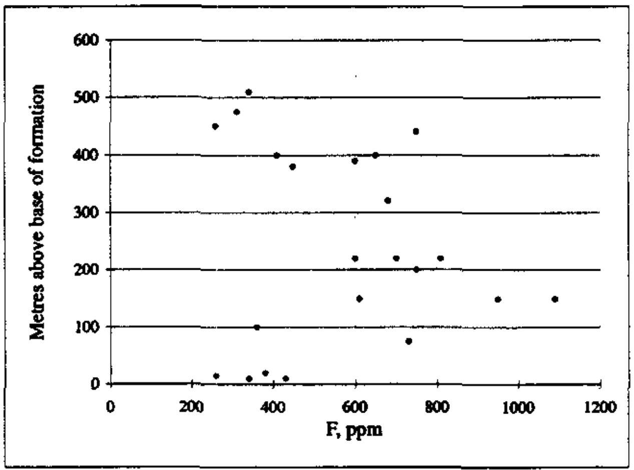

Figure 37h. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of fluorine.

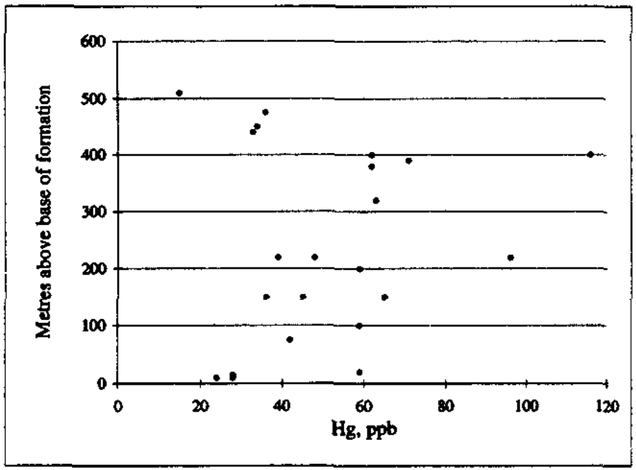

Figure 37i. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of mercury.

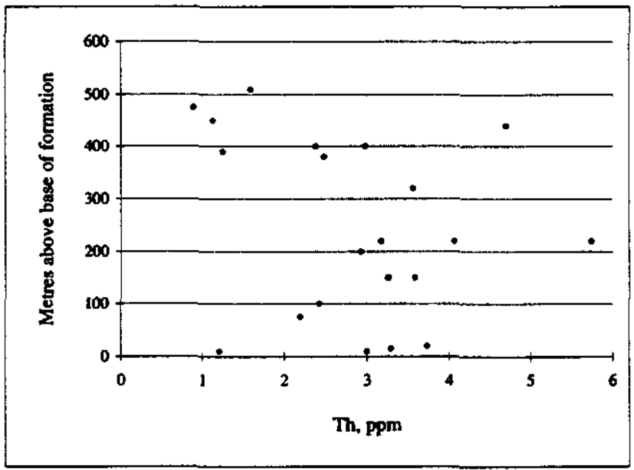

Figure 37j. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of thorium.

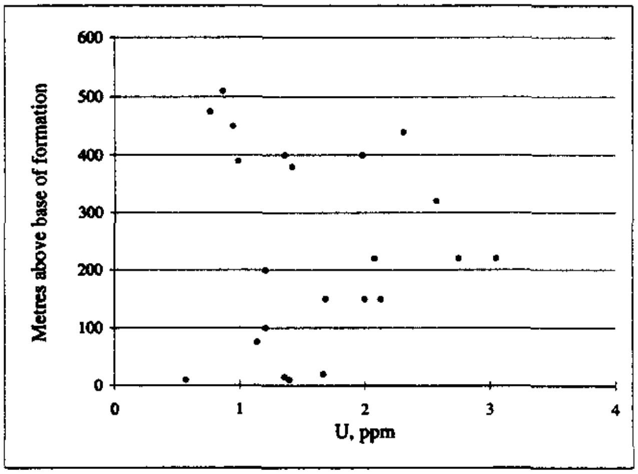

Figure 37k. Variations in trace element concentrations with stratigraphic position, southeast B.C. channel samples. Variation of uranium.

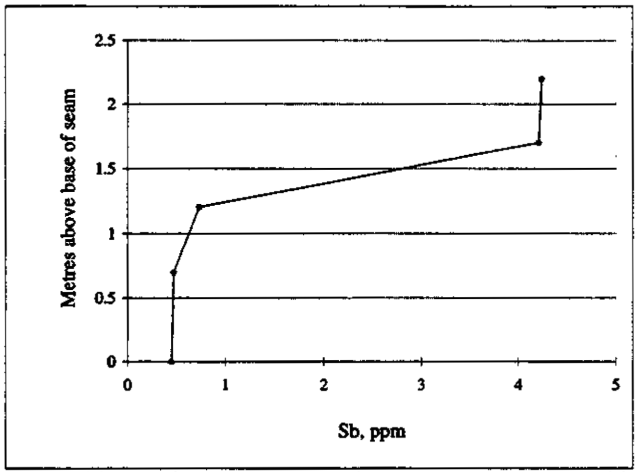

Figure 38a. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of antimony.

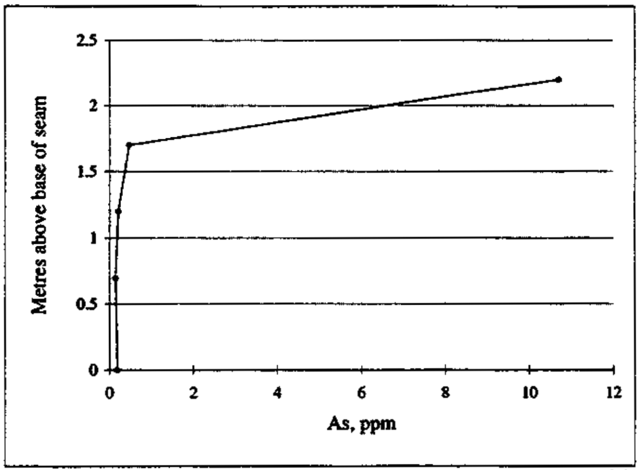

Figure 38b. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of arsenic.

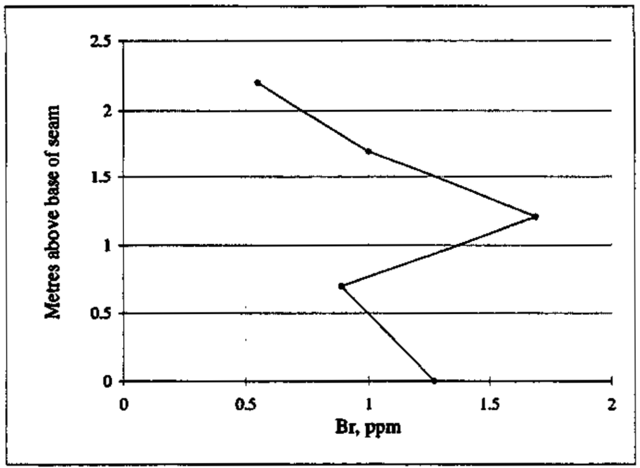

Figure 38c. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of bromine.

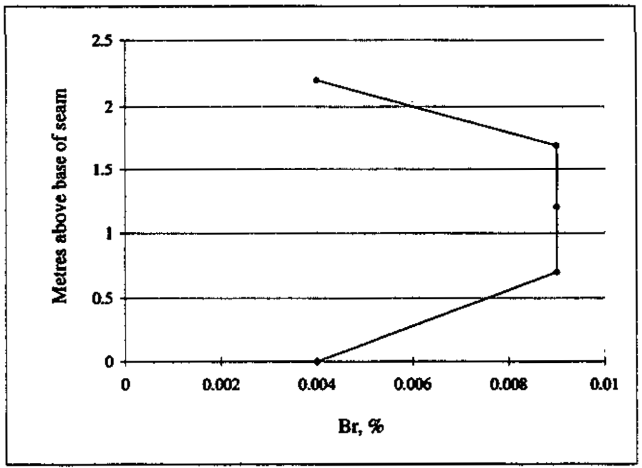

Figure 38d. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of chlorine.

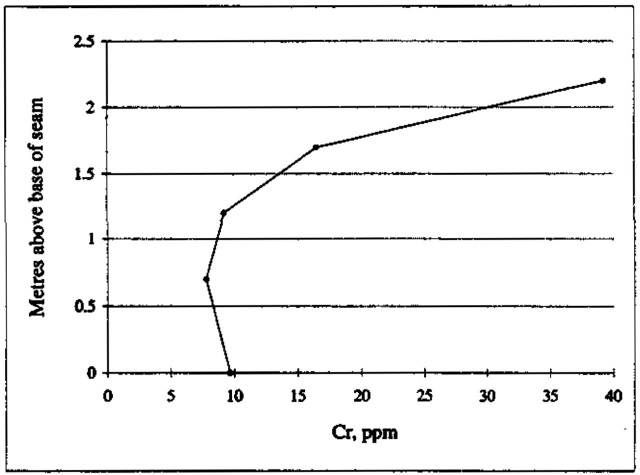

Figure 38e. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of chromium.

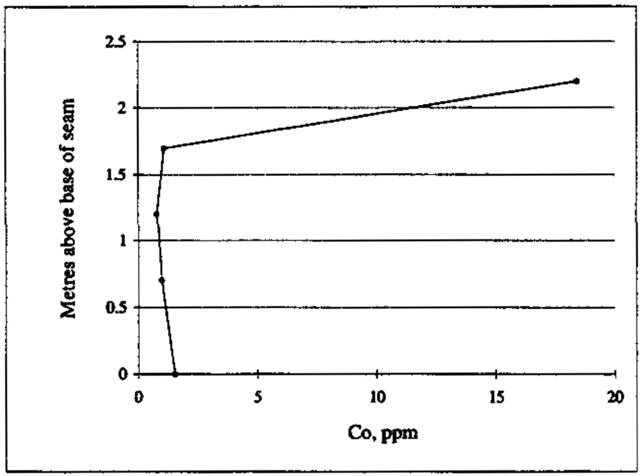

Figure 38f. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of cobalt.

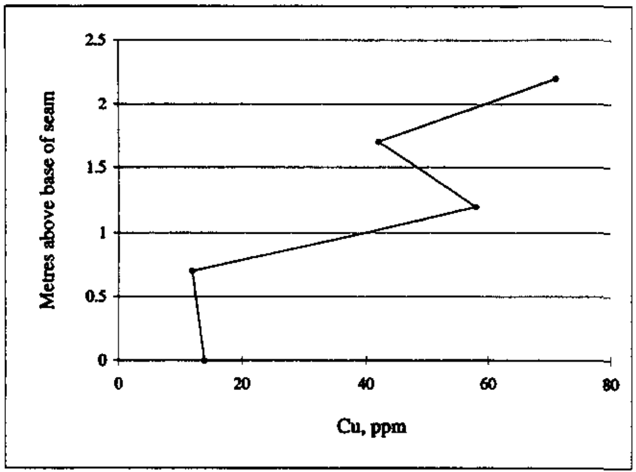

Figure 38g. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of copper.

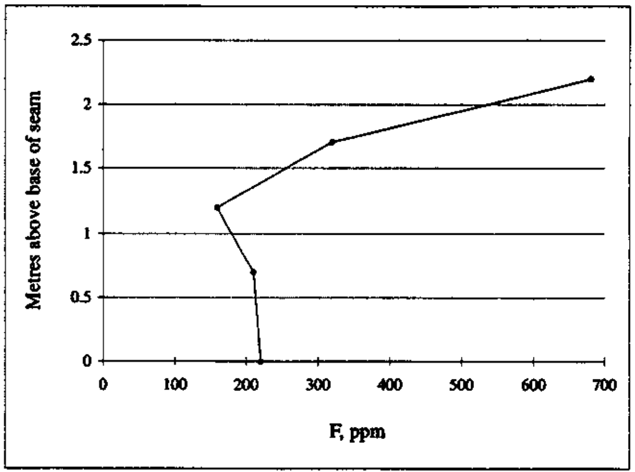

Figure 38h. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of fluorine.

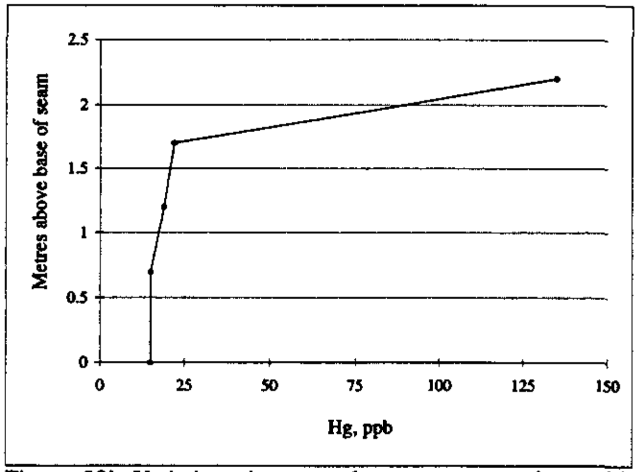

Figure 38i. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of mercury.

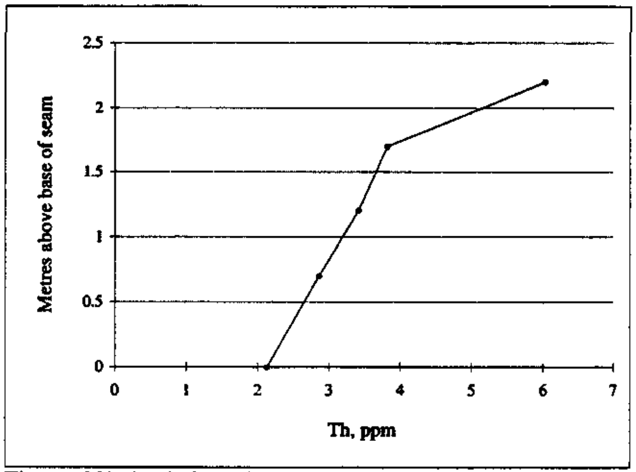

Figure 38j. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of thorium.

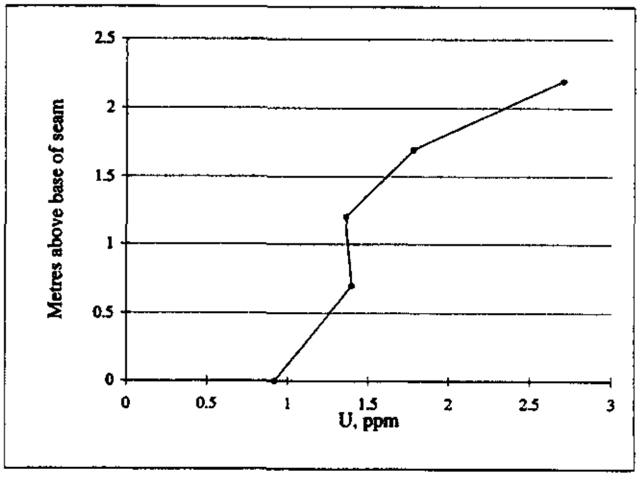

Figure 38k. Variations in trace element concentrations with stratigraphic position, Line Creek 10A-seam, southeast B.C. channel samples. Variation of uranium.

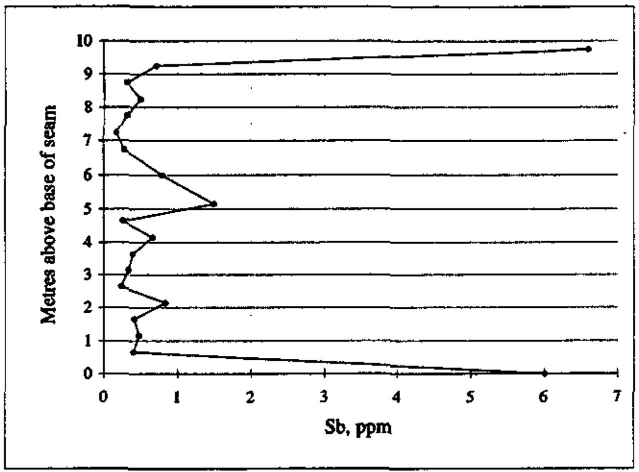

Figure 39a. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of antimony.

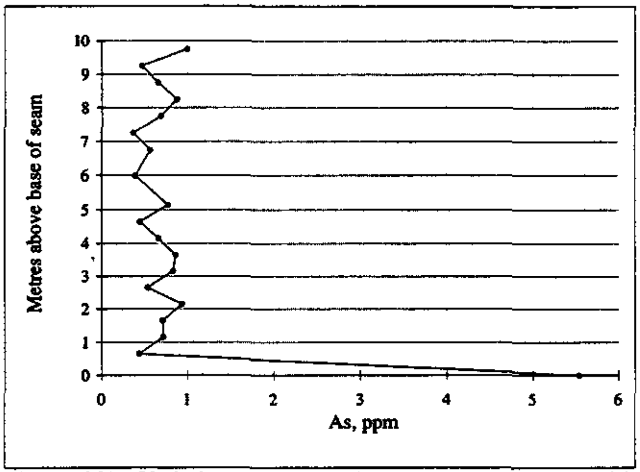

Figure 39b. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of arsenic.

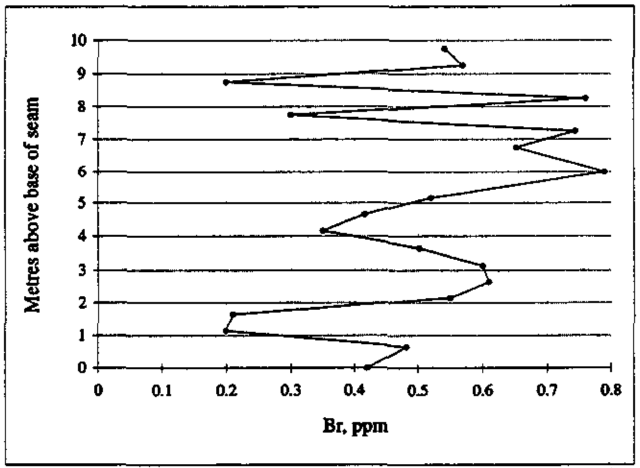

Figure 39c. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of bromine.

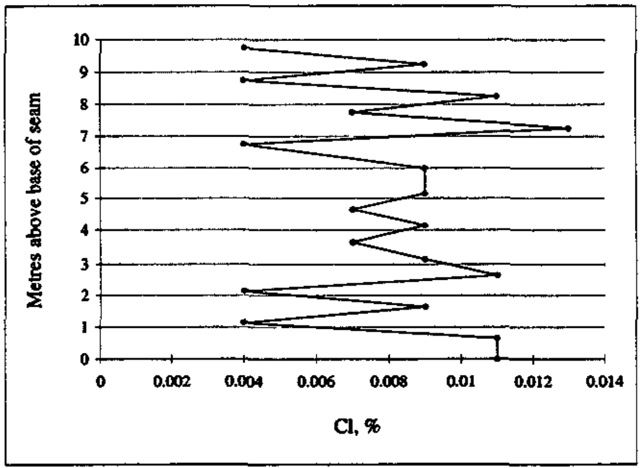

Figure 39d. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of chlorine.

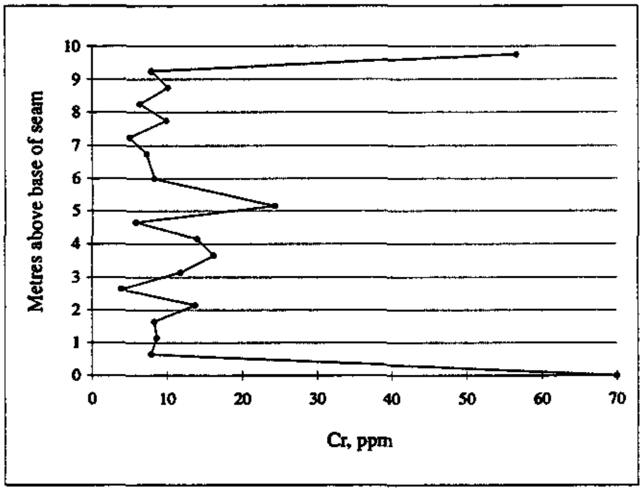

Figure 39e. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of chromium.

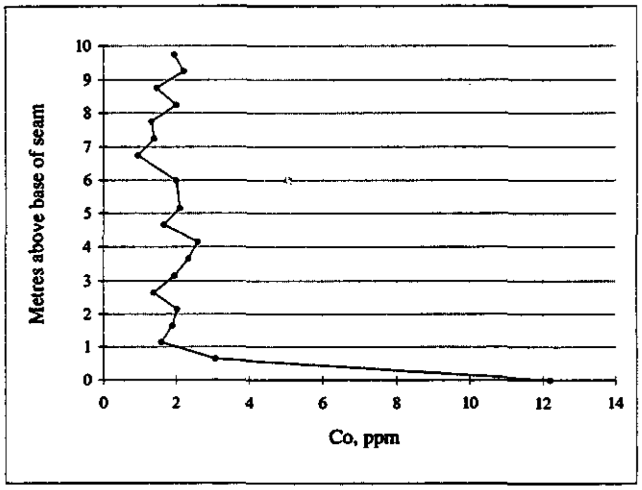

Figure 39f. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of cobalt.

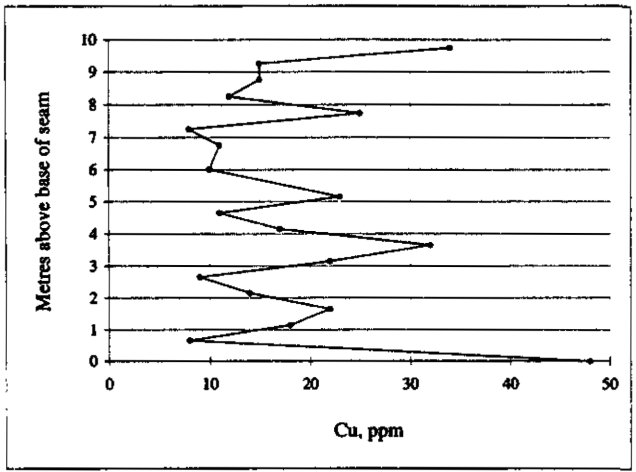

Figure 39g. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of copper.

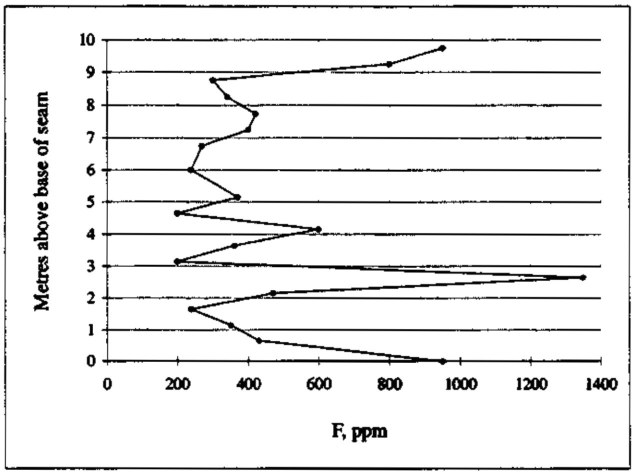

Figure 39h. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of fluorine.

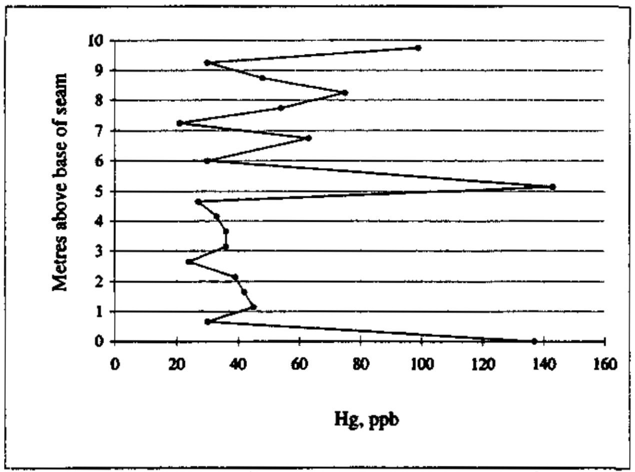

Figure 39i. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of mercury.

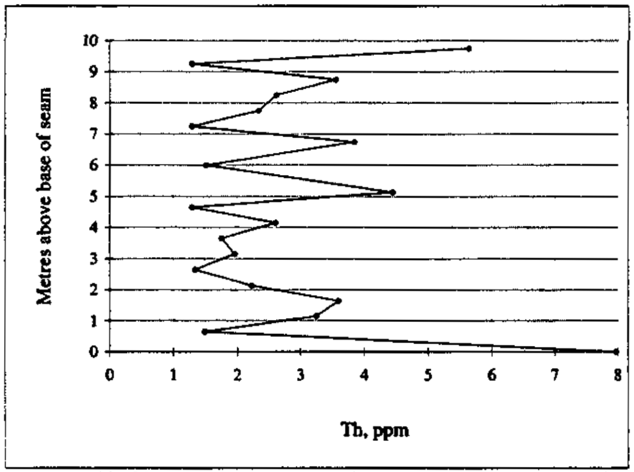

Figure 39j. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of thorium.

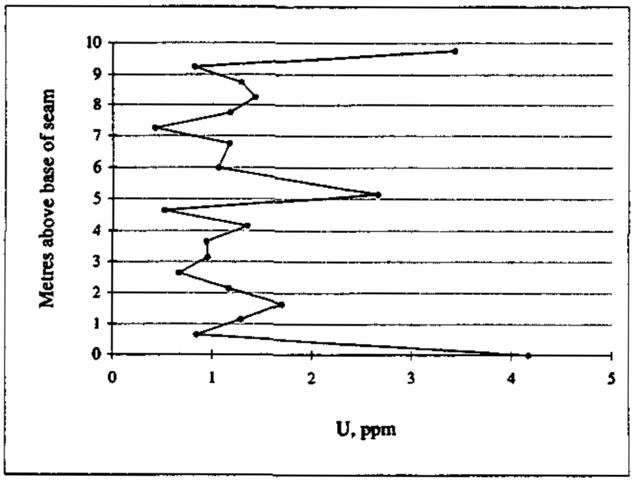

Figure 39k. Variations in trace element concentrations with stratigraphic position, Line Creek 8-seam, southeast B.C. channel samples. Variation of uranium.

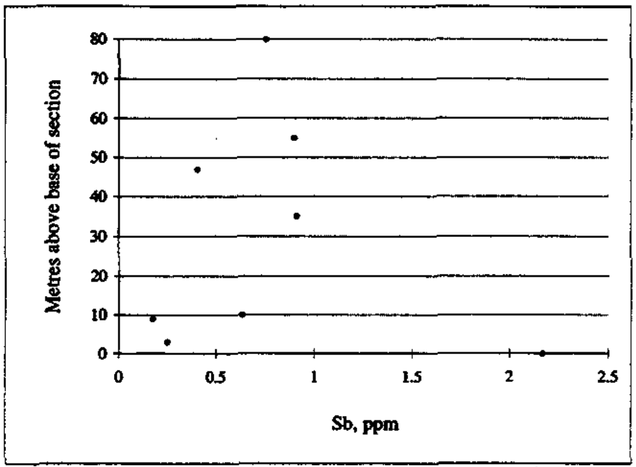

Figure 40a. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of antimony.

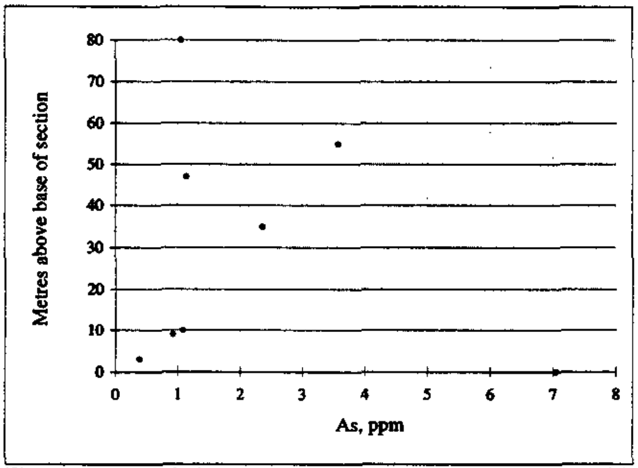

Figure 40b. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of arsenic.

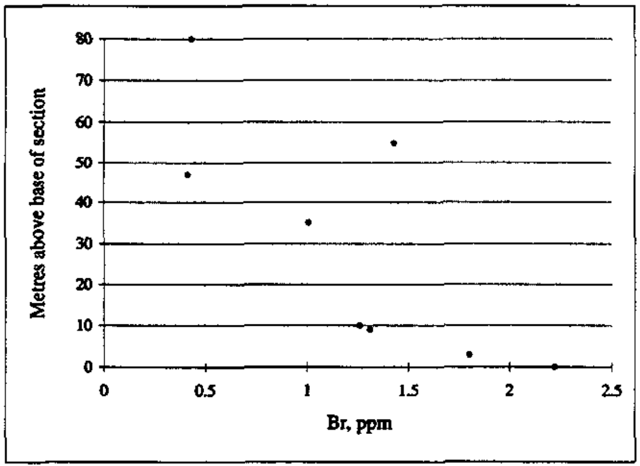

Figure 40c. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of bromine.

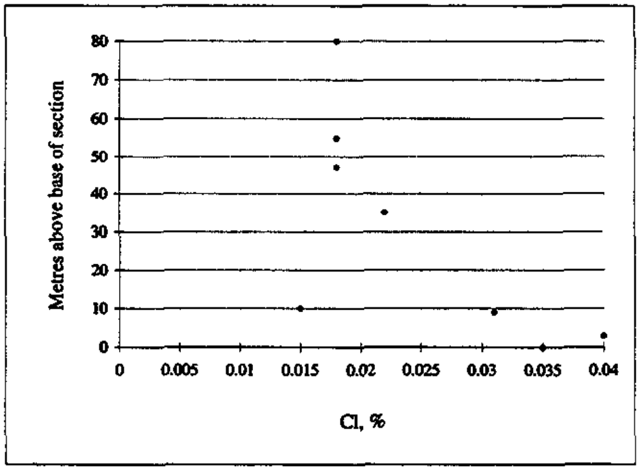

Figure 40d. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of chlorine.

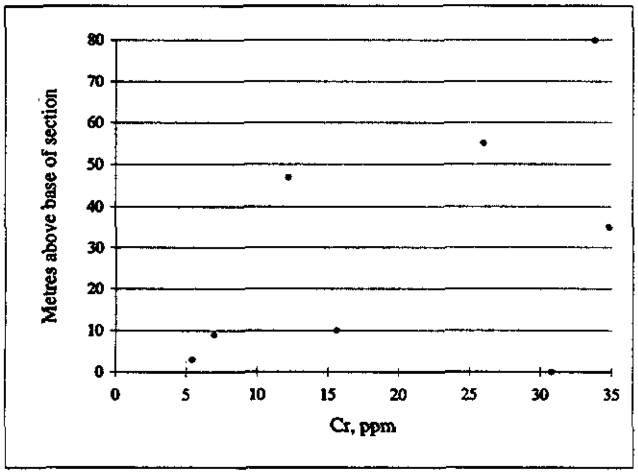

Figure 40e. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of chromium.

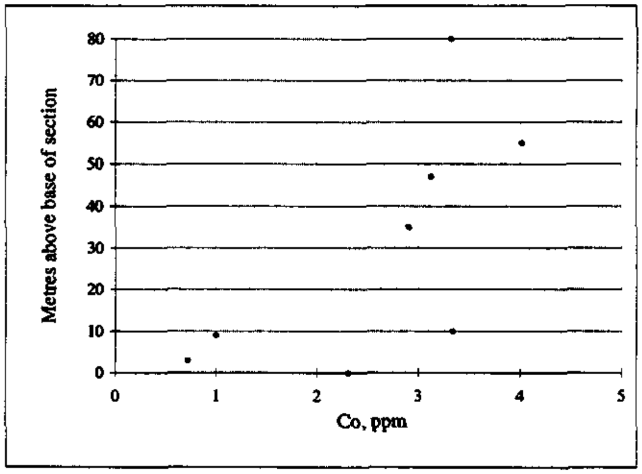

Figure 40f. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of cobalt.

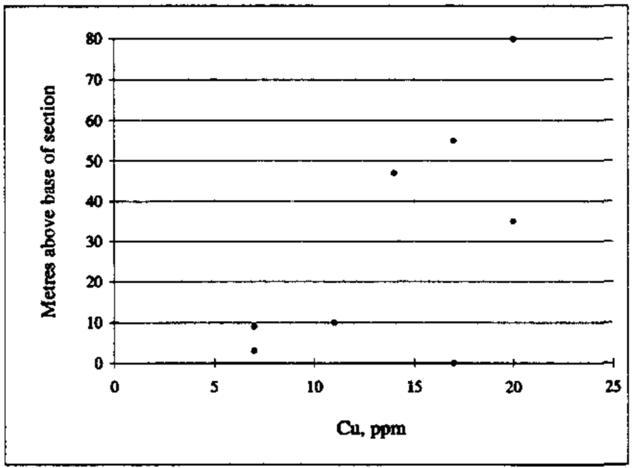

Figure 40g. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of copper.

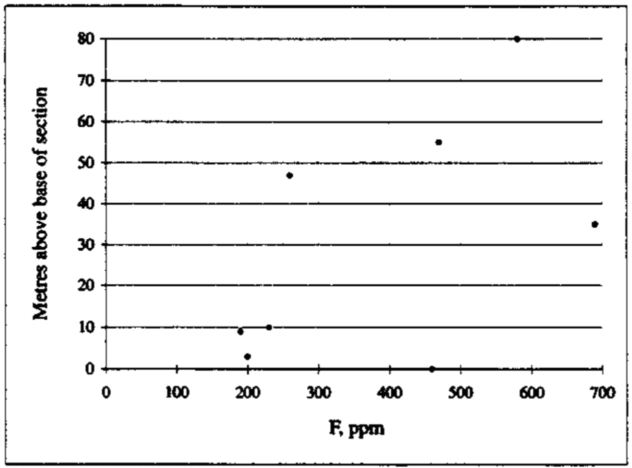

Figure 40h. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of fluorine.

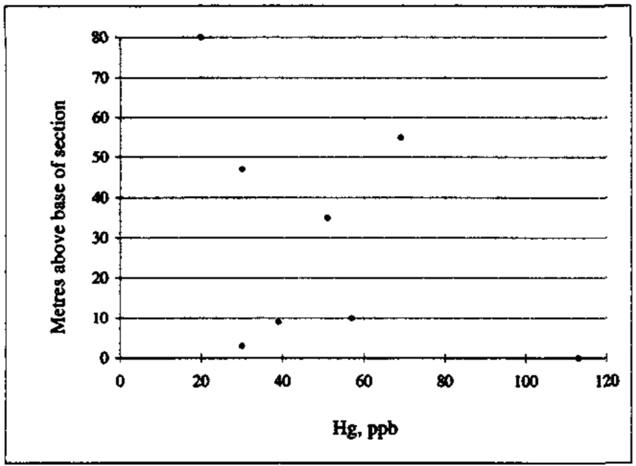

Figure 40i. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of mercury.

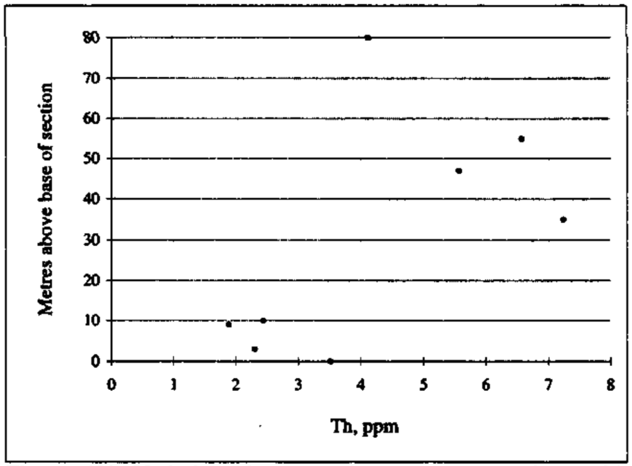

Figure 40j. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of thorium.

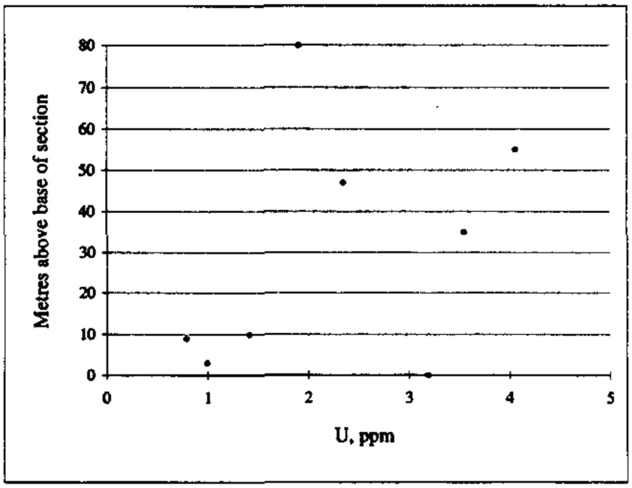

Figure 40k. Variations in trace element concentrations with stratigraphic position, northeast B.C. channel samples. Variation of uranium.

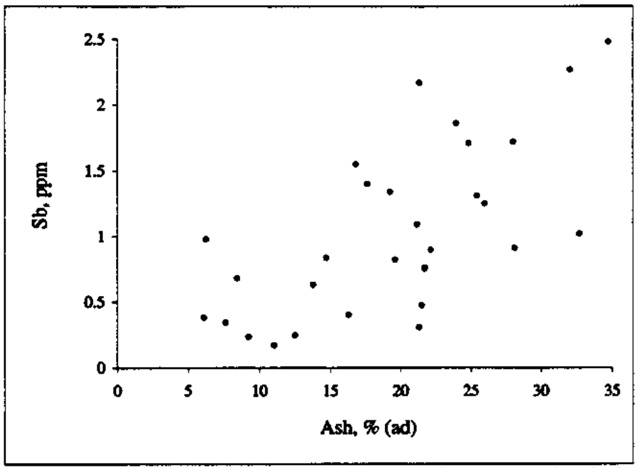

Figure 41a. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. Sb *vs.* Ash.

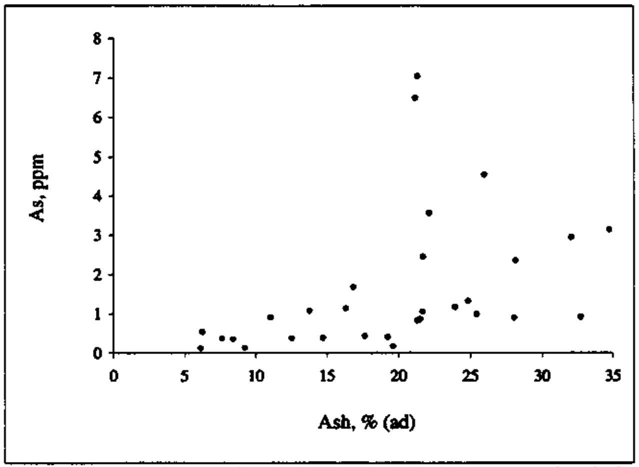

Figure 41b. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. As *vs.* Ash.

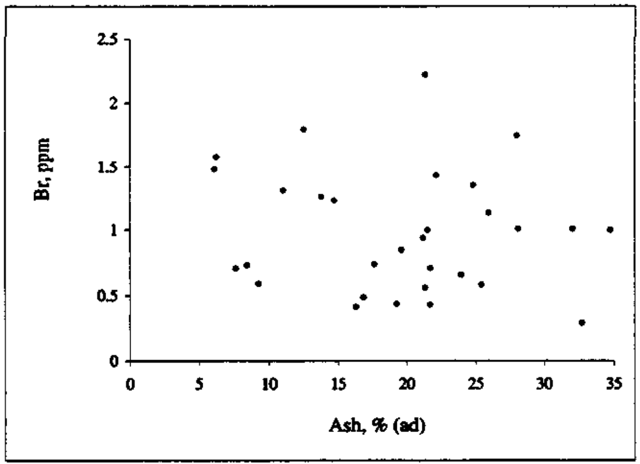

Figure 41c. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. Br *vs.* Ash.

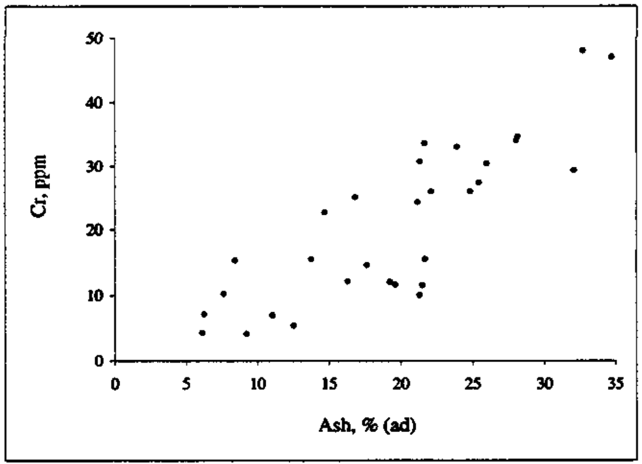

Figure 41d. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. Cr *vs.* Ash.

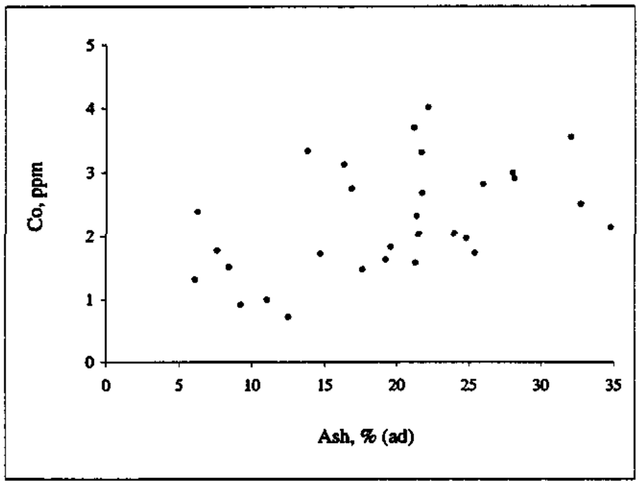

Figure 41e. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. Co *vs.* Ash.

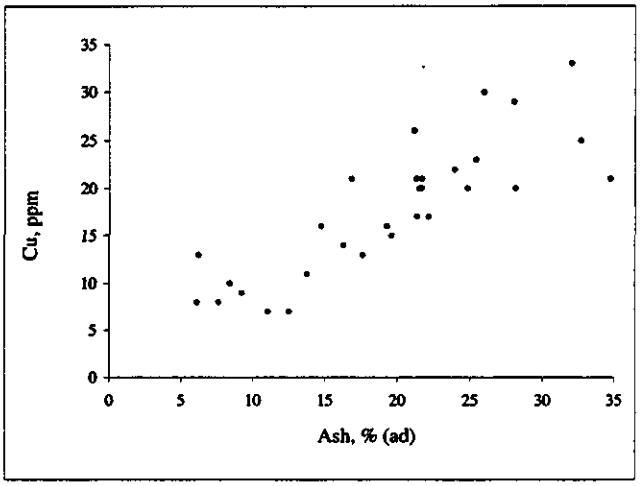

Figure 41f. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. Cu *vs.* Ash.

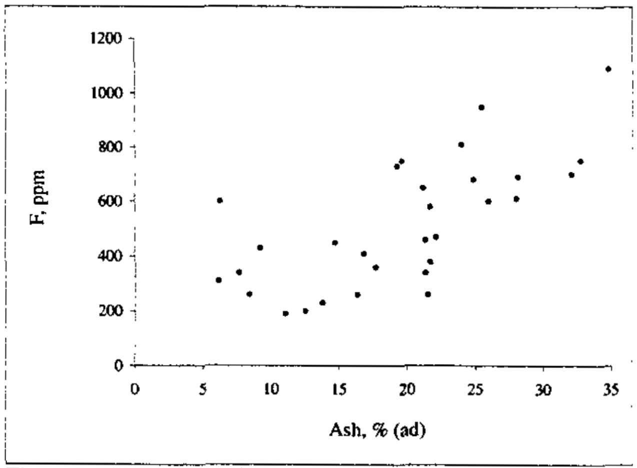

Figure 41g. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. F *vs.* Ash.

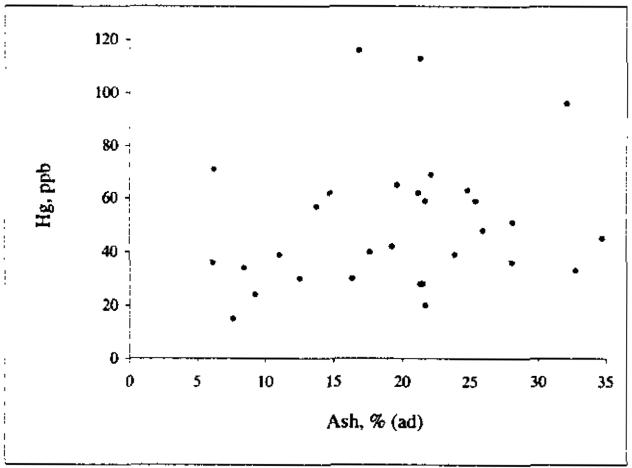

Figure 41h. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. Hg *vs.* Ash.

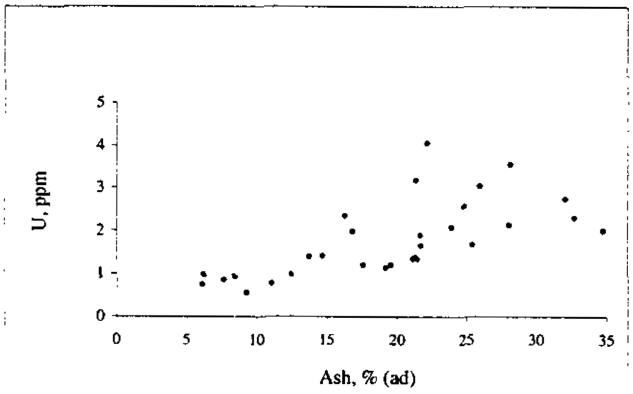

Figure 41i. Relationships between trace elements and ash in whole-seam channel samples from northeast and southeast B.C. U *vs.* Ash.

TABLE 19
CORRELATION COEFFICIENTS BETWEEN TRACE ELEMENTS AND ASH CONTENT IN WHOLE-SEAM SAMPLES FROM NORTHEASTERN AND SOUTHEASTERN B.C.

	Ash	Sb	As	Br	Cl	Cr	Co	Cu	F	Hg	Th
Sb	0.66										
As	0.42	0.48									
Br	-0.13	0.16	0.33								
Cl	0.09	0.09	0.30	0.56							
Cr	0.84	0.70	0.45	-0.07	0.10						
Co	0.46	0.32	0.54	-0.01	-0.06	0.51					
Cu	0.84	0.62	0.47	-0.14	-0.17	0.71	0.60				
F	0.69	0.69	0.23	-0.18	-0.12	0.69	0.21	0.59			
Hg	0.19	0.57	0.54	0.33	0.14	0.24	0.37	0.32	0.19		
Th	0.70	0.28	0.37	-0.07	0.25	0.58	0.66	0.56	0.29	0.22	
U	0.67	0.50	0.59	0.18	0.33	0.67	0.66	0.58	0.34	0.43	0.88

(Note: n=30; r=0.35 is significant at 95% confidence)

TABLE 20
CORRELATION COEFFICIENTS BETWEEN TRACE ELEMENTS AND ASH CONTENT IN LINE CREEK MINE PLY-BY-PLY SAMPLES

	Ash	Sb	As	Br	Cl	Cr	Co	Cu	F	Hg	Th
Sb	0.81										
As	0.74	0.54									
Br	-0.21	-0.04	-0.17								
Cl	-0.18	-0.06	-0.14	0.30							
Cr	0.89	0.87	0.61	-0.22	-0.14						
Co	0.69	0.53	0.97	-0.15	-0.02	0.60					
Cu	0.73	0.63	0.70	0.18	-0.05	0.63	0.64				
F	0.38	0.39	0.34	-0.34	0.02	0.46	0.33	0.12			
Hg	0.78	0.60	0.68	-0.27	-0.08	0.73	0.66	0.51	0.32		
Th	0.91	0.74	0.64	-0.14	-0.17	0.86	0.58	0.70	0.26	0.78	
U	0.89	0.82	0.57	-0.21	-0.11	0.92	0.56	0.63	0.34	0.79	0.93

(Note: n=37; r=0.33 is significant at 95% confidence)

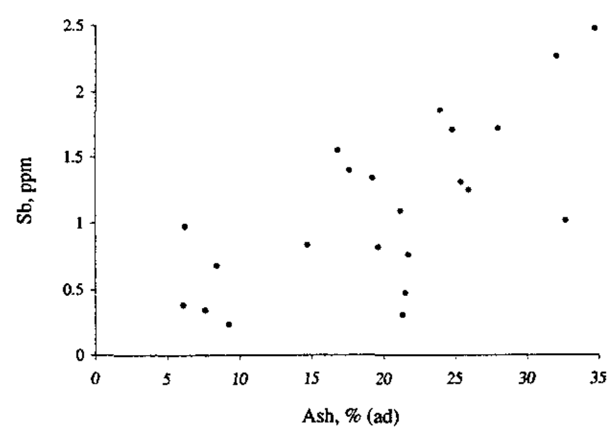

Figure 42a. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Sb *vs.* ash.

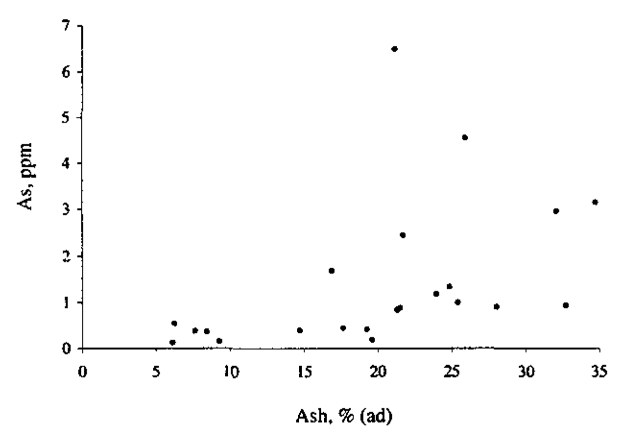

Figure 42b. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. As *vs.* ash.

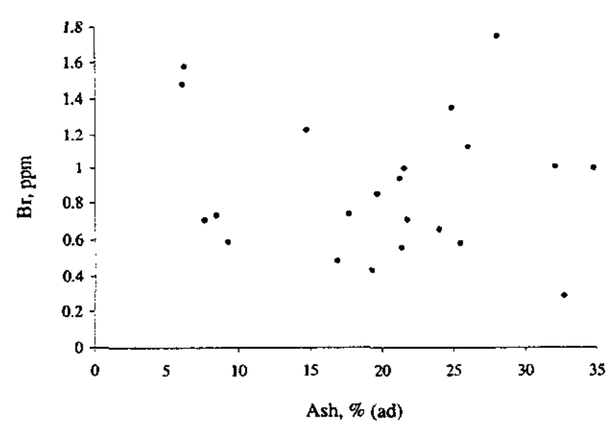

Figure 42c. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Br *vs.* ash.

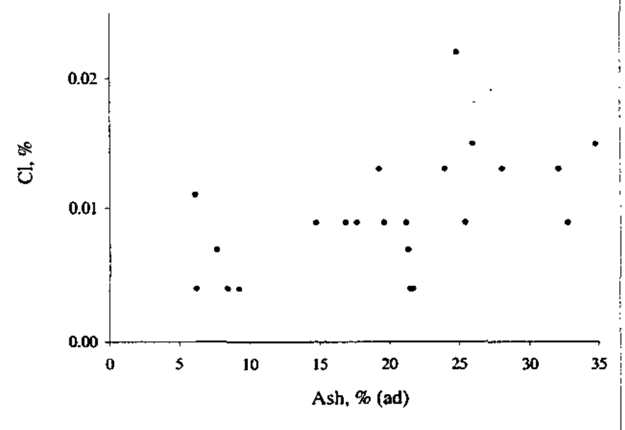

Figure 42d. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Cl *vs.* ash.

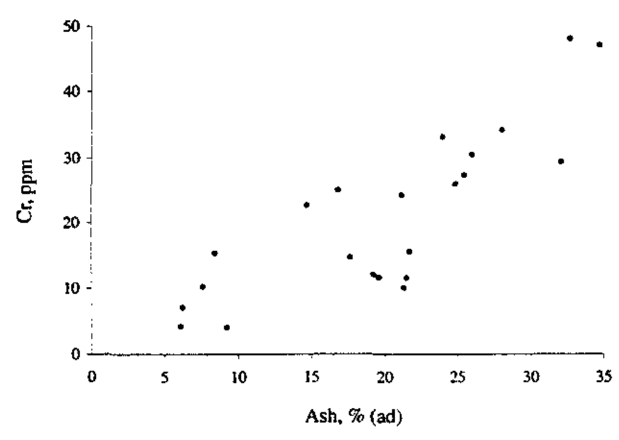

Figure 42e. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Cr *vs.* ash.

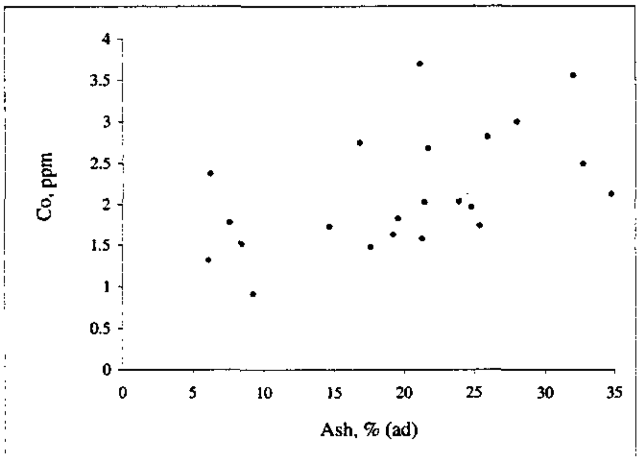

Figure 42f. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Co *vs.* ash.

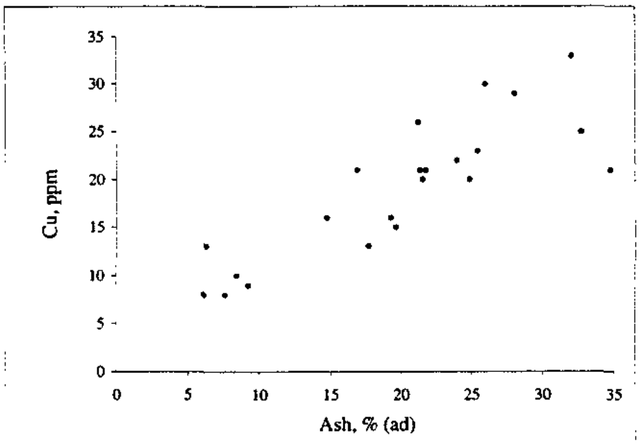

Figure 42g. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Cu *vs.* ash.

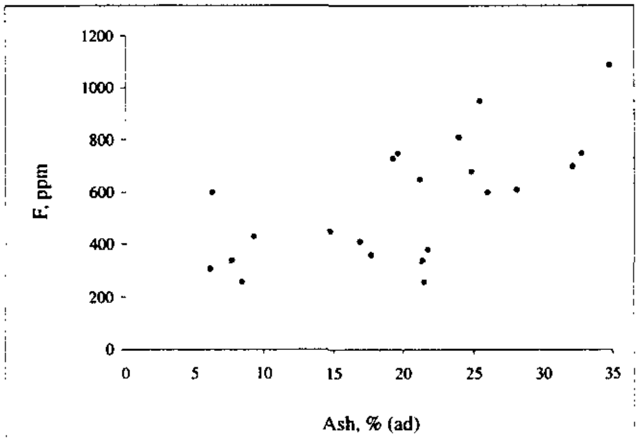

Figure 42h. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. F *vs.* ash.

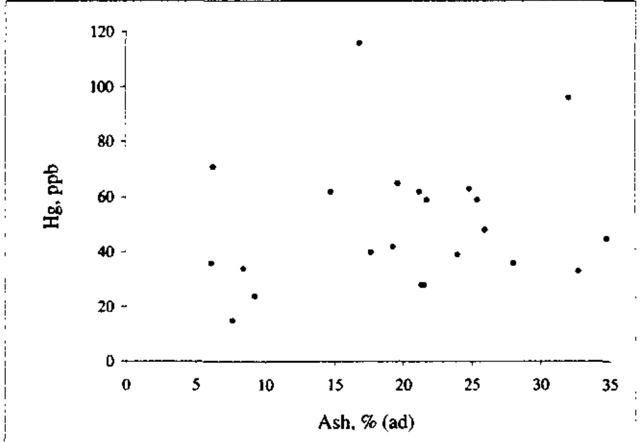

Figure 42i. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Hg *vs.* ash.

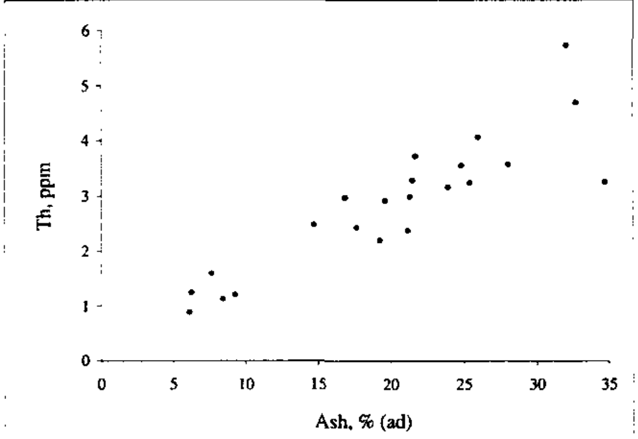

Figure 42j. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. Th *vs.* ash.

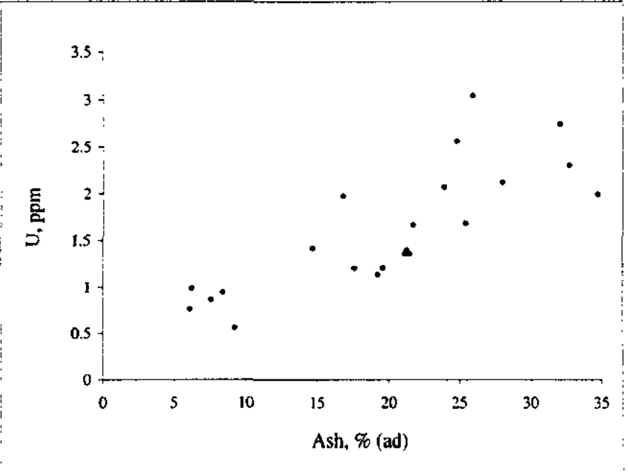

Figure 42k. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. U *vs.* ash.

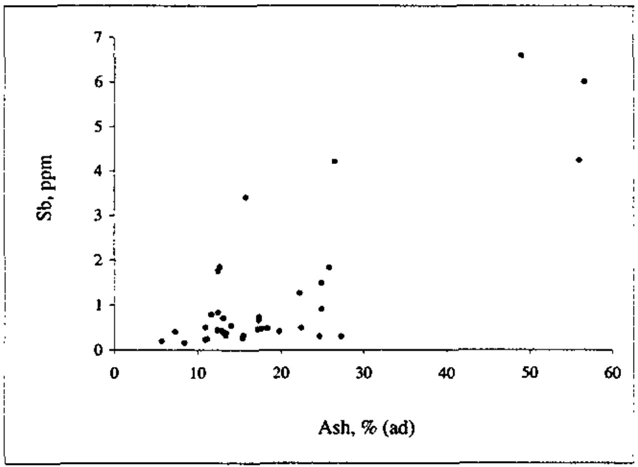

Figure 43a. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Sb *vs.* ash.

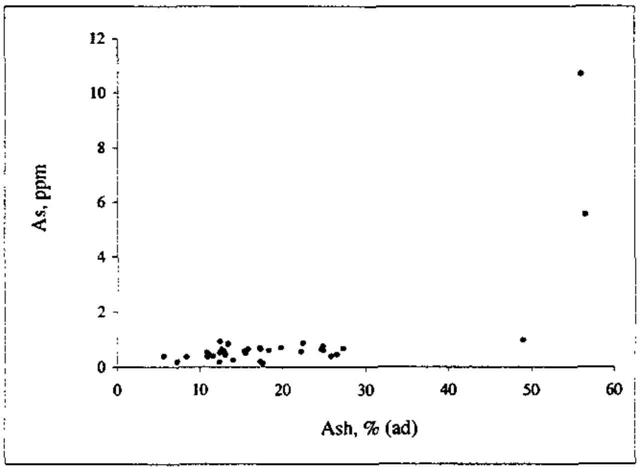

Figure 43b. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. As *vs.* ash.

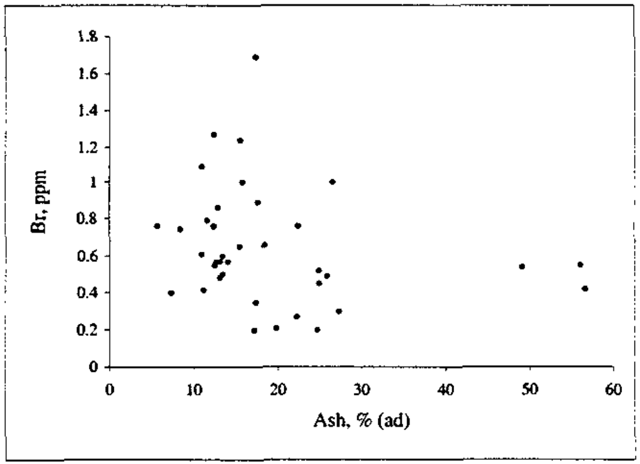

Figure 43c. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Br *vs.* ash.

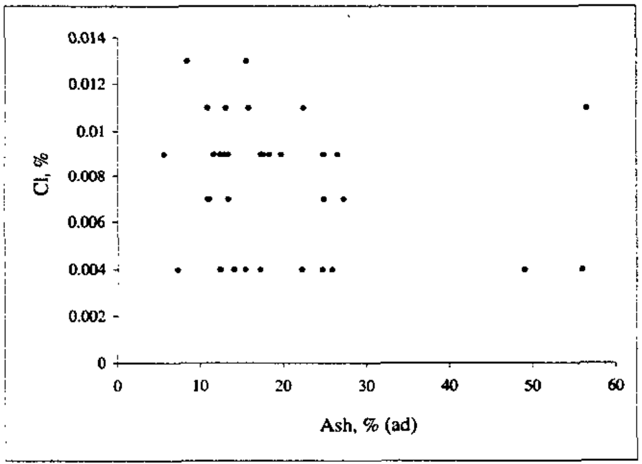

Figure 43d. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Cl *vs.* ash.

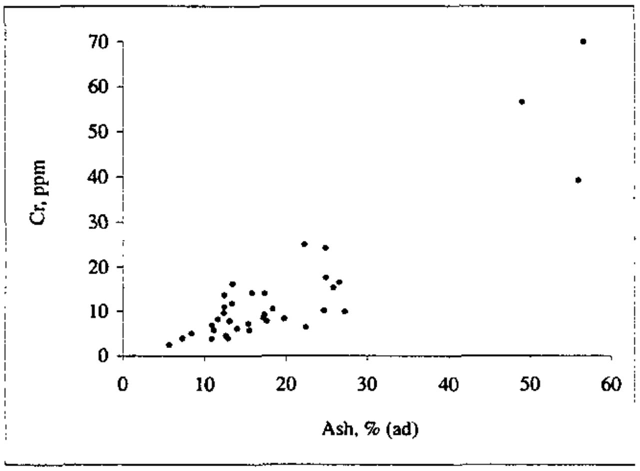

Figure 43e. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Cr *vs.* ash.

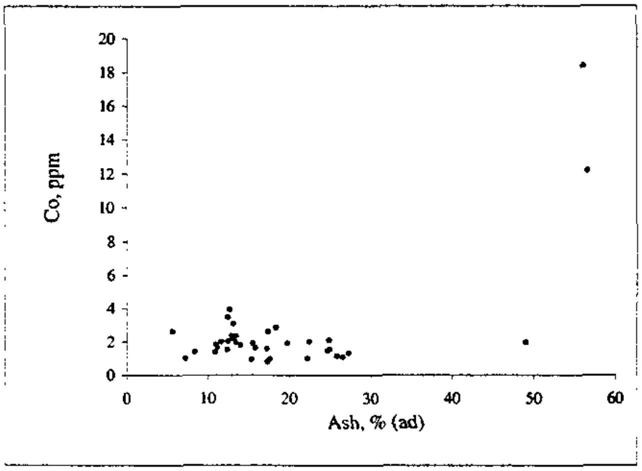

Figure 43f. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Co *vs.* ash.

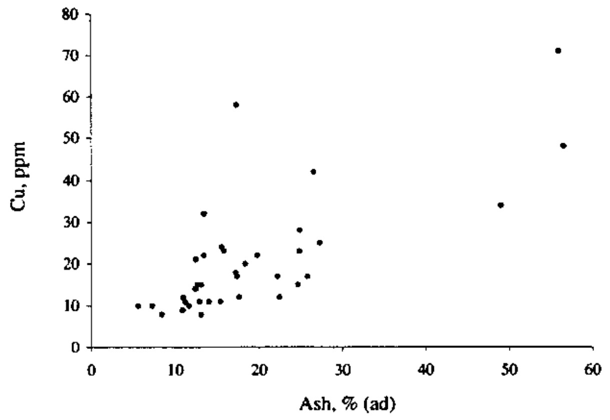

Figure 43g. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Cu *vs.* ash.

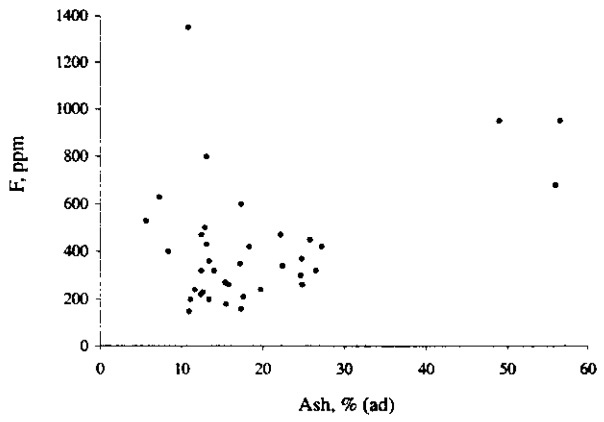

Figure 43h. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. F *vs.* ash.

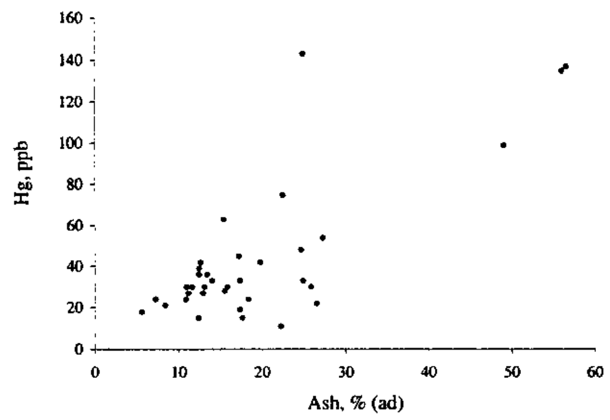

Figure 43i. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Hg *vs.* ash.

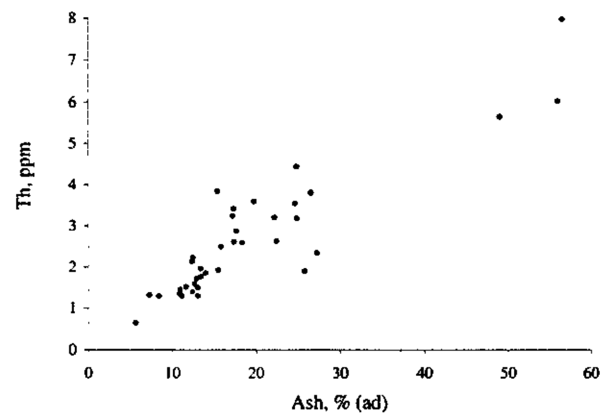

Figure 43j. Relationships between trace elements and ash in ply-by-ply channel samples from Line Creek, southeast B.C. Th *vs.* ash.

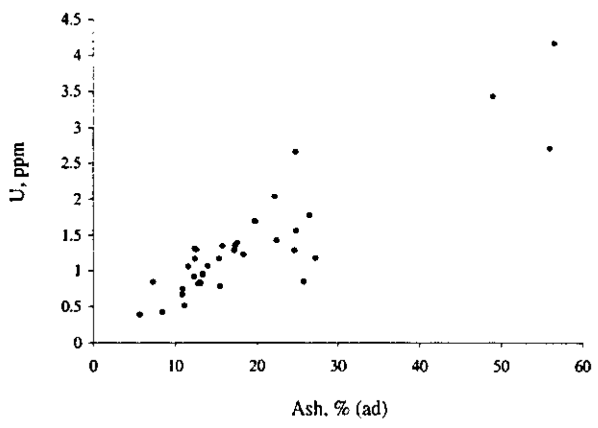

Figure 43k. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. U *vs.* ash.

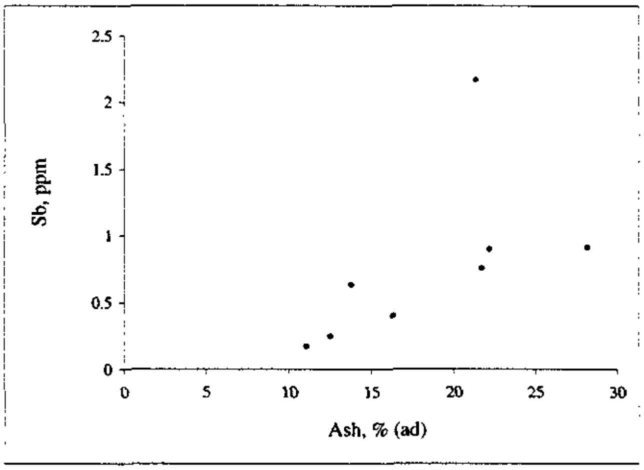

Figure 44a. Relationships between trace elements and ash in channel samples from northeast B.C. Sb *vs*. ash.

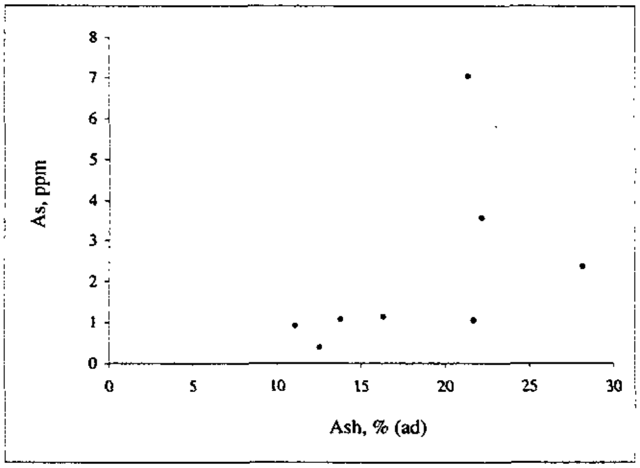

Figure 44b. Relationships between trace elements and ash in channel samples from northeast B.C. As *vs*. ash.

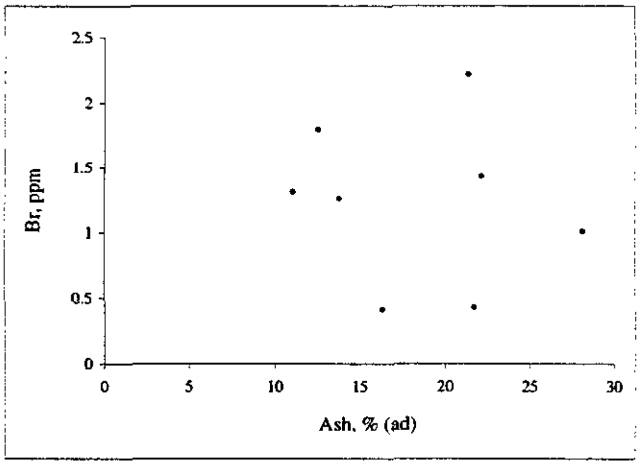

Figure 44c. Relationships between trace elements and ash in channel samples from northeast B.C. Br *vs*. ash.

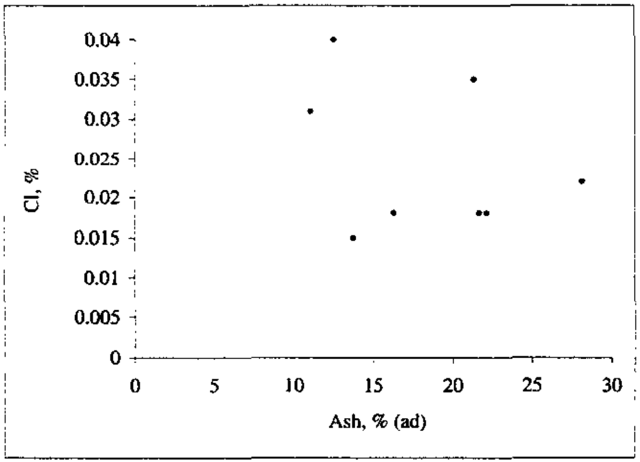

Figure 44d. Relationships between trace elements and ash in channel samples from northeast B.C. Cl *vs*. ash.

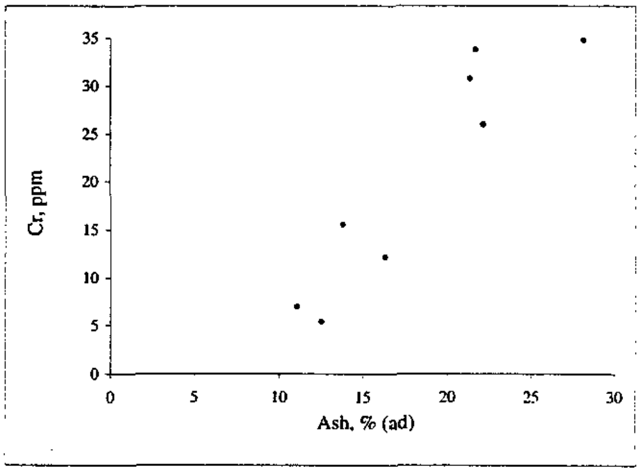

Figure 44e. Relationships between trace elements and ash in channel samples from northeast B.C. Cr *vs*. ash.

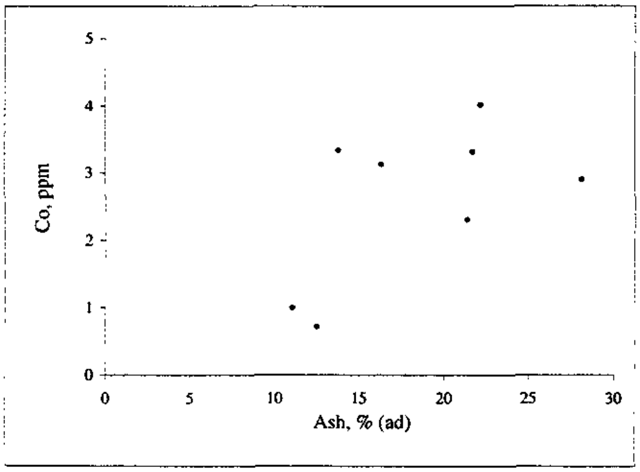

Figure 44f. Relationships between trace elements and ash in channel samples from northeast B.C. Co *vs*. ash.

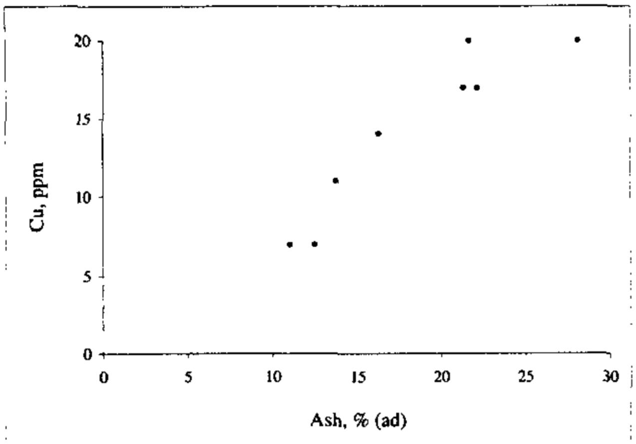

Figure 44g. Relationships between trace elements and ash in channel samples from northeast B.C. Cu *vs.* ash.

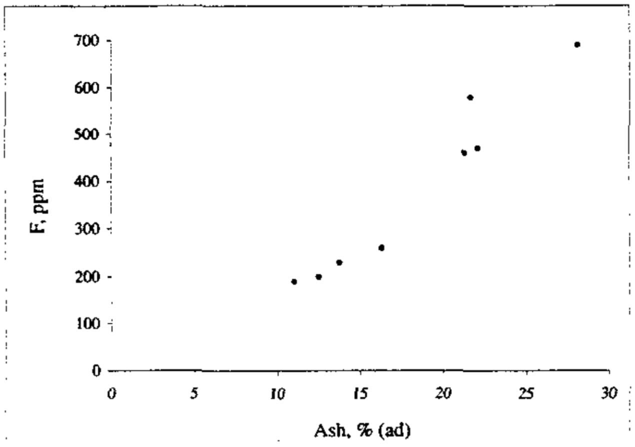

Figure 44h. Relationships between trace elements and ash in channel samples from northeast B.C. F *vs.* ash.

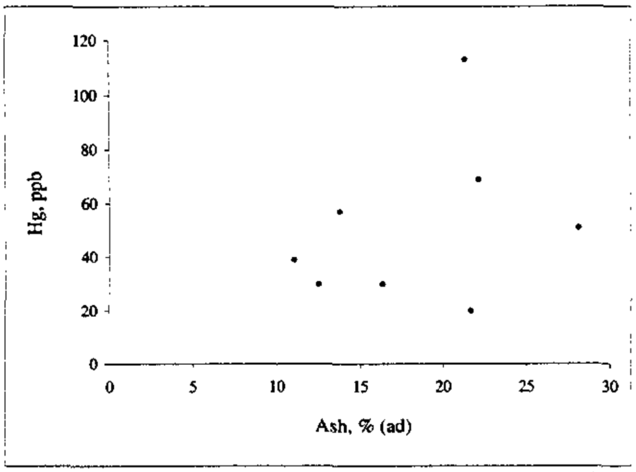

Figure 44i. Relationships between trace elements and ash in channel samples from northeast B.C. Hg *vs.* ash.

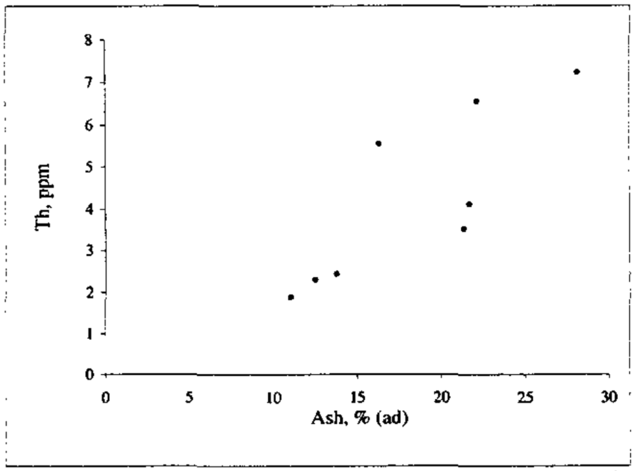

Figure 44j. Relationships between trace elements and ash in channel samples from northeast B.C. Th *vs.* ash.

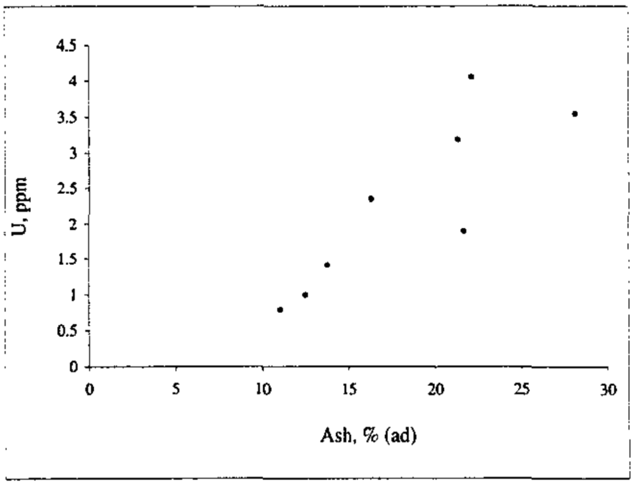

Figure 44k. Relationships between trace elements and ash in whole-seam channel samples from southeast B.C. U *vs.* ash.

TRACE ELEMENT CONCENTRATIONS

Concentrations of elements in the whole-seam samples are displayed in Table 18 and Figure 36, and are listed individually below. For those elements for which all values are greater than the detection level, means and ranges are given, while for those elements for which some values are below detection limits, only ranges are given.

Mean concentrations of only two elements, chlorine and thorium, are significantly different in the two regions; both are higher in northeast coals than in southeast coals (Table 18).

Antimony concentrations in raw whole-seam samples range from 0.13 to 2.48 ppm, with a mean of 1.04. The mean in southeast coals is 1.13 ppm, compared with a mean of 0.77 ppm in northeast coals.

Concentrations of **arsenic** in raw whole-seam samples range from 0.13 to 7.05 ppm, with a mean of 1.64. The mean arsenic concentration in northeast coals is 2.20 ppm, compared with a mean of 1.43 ppm in southeast coals.

Many of the samples contain less than detectable levels of **boron**. The range in boron contents in raw whole-seam Kootenay coals is less than 18 to 104 ppm, while boron values in Peace River coals range from 30 (or <31) to 56 ppm.

Concentrations of **bromine** in raw whole-seam samples range from 0.29 to 2.22 ppm, and the mean is 0.99. The mean in northeast coals is 1.23 ppm, compared with a mean of 0.90 ppm in southeast coals.

The range in **cadmium** contents in raw whole-seam southeast coals is less than 0.2 to 1.4 ppm, while that in northeast coals is less than 0.2 to 0.3 ppm. However, a large proportion of the samples contain levels of cadmium below the detection limit.

Concentrations of **chlorine** in raw whole-seam samples range from 40 to 400 ppm, and the mean is 136 ppm. The mean in northeast coals, 246 ppm, is significantly higher, based on a t-test (Table 18), than the mean in southeast coals, 96 ppm.

Chromium concentrations in raw whole-seam samples range from 4.16 to 48.10 ppm, with a mean of 21.03 ppm. The means in northeast and southeast coals are almost identical, at 20.70 and 21.14 ppm, respectively.

Concentrations of **cobalt** in raw whole-seam samples range from 0.72 to 4.02 ppm, with a mean of 2.26 ppm. The mean concentration in northeast coals is 2.59 ppm, compared with the mean in southeast coals of 2.14 ppm.

Copper contents in raw whole-seam samples range from 7 to 33 ppm, with a mean of 18. The mean value in southeast coals is 19 ppm, while the mean in northeast coals is 14 ppm.

Fluorine concentrations in raw whole-seam samples range from 190 to 1090 ppm, and the mean is 518 ppm. Mean fluorine concentration in Kootenay coals is 566 ppm, compared with a mean of 385 ppm in Peace River coals.

Some of the **lead** readings are below detection limit. Lead contents in raw southeast coals range from less than 2 to 15 ppm. The northeast coals contain from less than 2 to 12 ppm lead.

Mercury concentrations in raw whole-seam samples range from 15 to 116 ppb, with a mean of 50 ppb. In southeast coals the mean mercury concentration is 50 ppb, and the mean in northeast coals, at 51 ppb, is almost identical.

A large proportion of the **molybdenum** concentrations are below detection limit. The range in molybdenum concentrations in raw whole-seam samples from southeast British Columbia is less than 0.33 to 3.19 ppm. In northeast coals the range is less than 0.40 to 1.10 ppm.

A large number of the **selenium** values are below detection limit. In raw whole-seam samples from southeast British Columbia selenium concentrations range from less than 0.60 to 3.43 ppm. In the northeast samples the range is from less than 0.60 to 2.20 ppm.

Mean **thorium** concentration in raw whole-seam samples is 3.22 ppm, and the range is from 0.89 to 7.24. In samples from the southeast the mean is 2.86 ppm, while in the northeast, the mean, at 4.21 ppm, is significantly higher, based on a t-test (Table 18).

Uranium concentrations in raw whole-seam samples range from 0.57 to 4.06 ppm, and the mean is 1.79. The mean in Kootenay coals is 1.61 ppm, and the mean in Peace River coals is 2.28 ppm.

Some of the **zinc** concentrations are below detection limit. The range of zinc contents in raw whole-seam southeast coal samples is less than 10.0 to 74.0 ppm. In northeast samples the range is less than 10.0 to 53.6 ppm.

VARIATIONS WITH STRATIGRAPHIC POSITION

For the elements with concentrations consistently above detection limits, it is possible to display variations in element values with change in stratigraphic position, both for seams throughout the formations (Figures 37 and 40), and for individual ply samples within seams at Line Creek (Figures 38 and 39). These results are summarized below.

KOOTENAY COALFIELD

There are no consistent stratigraphic trends in contents of any of the trace elements in whole-seam samples from the Mist Mountain Formation (Figure 37). However, several of the elements (Sb, Cr, Co, Cu, F, Hg, Th and U) show a distribution shaped like a backward letter "C". In other words, the lowest values are in samples from the base and top of the formation, while the highest values are in samples from roughly the middle one-third. This trend is similar to that in phosphorus concentrations in the same samples (Figure 26a). The amount of variation at any stratigraphic position, especially the middle portion of the section, is high, however. This distribution is very similar to the distribution of the ash values in the samples (Figure 14c), suggesting that, as with phosphorus, stratigraphic position *per se* is not a primary control on trace element concentrations.

INDIVIDUAL SEAMS

The apparent influence of ash content on the stratigraphic variations of certain trace elements is also seen within individual seams. The concentrations of several elements (Sb, Cr, Cu, Hg, Th and U) tend to increase up-section in seam 10A (Figure 38), for example, more or less mirroring the trend in ash contents within that seam. The pattern of ash contents within 8-seam is also reflected in the stratigraphic variations of the same six elements within that seam (Figure 39). The fluorine content profile in 8-seam is also similar to the ash profile, although an anomalous fluorine value occurs in a sample from between 5 and 6 metres above the base. This sample contains fluorapatite. The presence of ply samples with greater than 50% ash at the base of 8-seam and the top of 10A-seam is correlated with anomalously high concentrations of the elements listed above, as well as cobalt and arsenic. Similarities of element profiles in 10B and 9-seam samples (not shown) to ash profiles are not as pronounced, but profiles of three elements, chromium, copper and thorium, appear to mirror the ash profiles in both seams.

In summary, trace elements in the Mist Mountain Formation appear to be separable into two groups, those which tend to follow the ash contents of samples to a greater or lesser degree (Sb, As, Cr, Co, Cu, F, Hg, Th and U), and those with concentrations independent of relative ash contents (Br and Cl).

GATES FORMATION (PEACE RIVER COALFIELD)

As with the Mist Mountain Formation, trace elements in Gates Formation seams do not vary systematically with stratigraphic position (Figure 40). However, the stratigraphic profiles of some of the elements (Cr, Co, Cu, F, Th and U) are roughly parallel to the profile of ash contents of the samples (Figure 14h). This generally results in most of the highest concentrations of these elements being in the upper half of the formation. All these elements display a similar relationship in southeast British Columbia, as shown above.

CORRELATION ANALYSIS

Correlation analysis provides a first impression of the association of an element in coal, as explained earlier. Correlation analysis of data here is somewhat hampered by the small number of samples from the Peace River coalfield, and by large numbers of samples with concentrations below detection limit for certain elements. For these reasons, the analysis is carried out only on the combined whole-seam data from northeast and southeast British Columbia. In other words, comparisons between Peace River and Kootenay data are not attempted. (Trace element concentration *versus* ash graphs for the two regions, however, are included for reference, as Figures 42 and 44). Moreover, correlation analyses of cadmium, boron, lead, molybdenum, selenium and zinc data are not attempted.

ELEMENT-ASH RELATIONSHIPS

Eight elements are positively correlated with ash at the 95% confidence level in the combined southeast and northeast British Columbia whole-seam sample data: Sb, As, Cr, Co, Cu, F, Th and U (Table 19; Figure 41). In the cases of the ply-by-ply samples from Line Creek, all these elements plus mercury are positively correlated to a significant degree with ash (Table 20; Figure 43). Overall the strongest correlations with ash are for Cu, Cr, Th and U. Two elements, bromine and chlorine, are not correlated with ash content.

INTER-ELEMENT RELATIONSHIPS

Not surprisingly, the elements which are positively correlated with ash tend to be positively intercorrelated (Tables 19 and 20). There are more significant positive correlations within the Line Creek data (ply-by-ply samples) than in the whole-seam sample data. This could be related to the larger size of the Line Creek data set, or alternatively to the fact that the Line Creek samples are from one location, perhaps reducing the amount of variation in some of the potential controlling parameters. Some examples of strongly correlated pairs of elements include thorium and uranium, and chromium and antimony. The correlation between arsenic and cobalt is extremely strong ($r = 0.97$) in the Line Creek data. Chlorine and bromine are the least frequently positively correlated with other elements, but are correlated with each other in the whole-seam sample data.

DISCUSSION

In very general terms, elements in this study tend to fall into two groups. One group is comprised of elements which follow ash content stratigraphically, and tend to be positively correlated with ash content and positively intercorrelated (Sb, As, Cr, Co, Cu, F, Hg, Th and U). The other group consists of chlorine and bromine, and represents those elements which are generally not correlated with either the ash contents of samples or with the other elements, but can be positively correlated with each other. It is tentatively concluded that the first group is primarily associated with the inorganic fraction of coals, while the second is ascribed to the organic fraction. Interpretations from the literature are cited below to compare these results and to describe the association of the elements which fall below detection limits in some samples (no statistical analysis).

Elements are discussed separately below. Comparisons between values of elements in British Columbia coals and world coals are included, and British Columbia coals are subjectively classified as being relatively "low", "average" or "high" in each trace element. Data on world coals and the general behaviour of specific elements in coal are taken from Swaine (1990), Finkelman (1980), Clark and Sloss

(1992), and other references, as noted. Estimates of the environmental significance of specific elements in coal are also given. These are taken from two sources: Swaine (1989) classifies elements into one of three levels of environmental significance: "prime," "lesser" and "insignificant"; Clark and Sloss (1992) group trace elements, excepting halogens and radioactive elements, into three categories of environmental concern, "greatest", "moderate" and "minor".

ANTIMONY

Antimony values in British Columbia coals fall well within the range for most world coals (0.05 to 10 ppm according to Swaine, 1990) and the mean corresponds almost exactly with the mean in United States coals, which is 1.1 ppm (Finkelman, 1980). The mean in Australian coals is given as 0.5 ppm (Swaine, 1990), but the concentration of antimony in British Columbia coals in comparison with world coals can be classified as "average". Results here suggest a probable inorganic (mineral) association, which is generally consistent with interpretations in the literature (Finkelman, 1980), although Swaine (1990) ascribes some antimony in coal to an organic association. A positive correlation between antimony and sulphur in Peace River coals may reflect an association in sulphides, which has been noted elsewhere.

Antimony from coal is considered to be environmentally "insignificant" by Swaine (1989, 1990), and of "minor" environmental concern by Clark and Sloss (1992).

ARSENIC

Arsenic concentrations in British Columbia coals fall at the low end of the estimated range for most world coals (0.5 to 80 ppm, Swaine, 1990). The mean corresponds very closely with the mean in Australian coals (1.5 ppm, Swaine, 1990), and is low in comparison with means from some other regions (for example, roughly 15 ppm in United States coals, according to Swaine, 1990, and Finkelman, 1980). Our coals are therefore classified as being "low" in arsenic. The results of this study suggest a probable inorganic association in British Columbia coals, which is consistent with the general interpretation of Swaine (1990). Arsenic concentration is usually low in low-sulphur coals, consistent with a sulphide relationship (Finkelman, 1980; Swaine, 1990).

Arsenic in coal is classified as being of prime environmental significance by Swaine (1989), and of greatest environmental concern by Clark and Sloss (1992). The low mean level of arsenic in British Columbia coals is a favourable characteristic.

BORON

The range in concentrations of boron in British Columbia coals falls well within the estimated range for most world coals (5 to 400 ppm, Swaine, 1990) and these coals are classified as average in a global context. Boron is generally ascribed to organic association in coal (Vickridge *et al.*, 1990; Swaine, 1990), although some argue for a partial inorganic affiliation (Burchill *et al.*, 1990).

Boron in coal is considered to be of prime environmental significance by Swaine (1989) and of greatest concern by Clark and Sloss (1992).

BROMINE

Bromine concentrations in these samples are at the low end of the estimated range for most world coals (0.5 to 90 ppm) and most Australian coals (0.4 to 30 ppm, Swaine, 1990). The mean is also below the means for various regions of the United States (Finkelman, 1980). These coals are thus classified as low in this element. Bromine in the samples studied here is believed to be in predominantly organic association, which is consistent with Swaine's (1990) and Finkelman's (1980) interpretations of the literature.

Bromine, being a halogen, is volatile. However, bromine in coal is considered to be of lesser environmental significance (Swaine, 1989).

CADMIUM

The range in cadmium concentrations in British Columbia coals is within the estimated world coal range (0.1 to 3.0 ppm, Swaine, 1989, 1990), although much of our data are below the detection limit of 0.2 ppm. An estimated range in most Australian coals is given as 0.01 to 0.2 ppm (Swaine, 1990), with a mean of 0.08 ppm, while the mean in United States coals is 1.3 ppm (Finkelman, 1980). Cadmium contents in our coals are tentatively classified here as average, although they may be lower, depending on the nondetectable concentrations. Cadmium in coal is widely believed to be associated with sulphides, including sphalerite, and its concentration is usually low in low-sulphur coals (Swaine, 1990; Finkelman, 1980).

Swaine (1989) classifies cadmium as being of prime environmental significance, and similarly Clark and Sloss (1992) consider it to be of greatest concern. The nature of cadmium occurrence in coal is a good argument for the use of low-sulphur coals in coal-fired power plants.

CHLORINE

Concentrations of chlorine in both the Kootenay and Peace River coalfields are toward the low end of the estimated range for most world coals (50 to 2000 ppm, Swaine, 1990). For example, the mean in United States coals is given as 580 ppm (Finkelman, 1980). Our coals are therefore classified as low in chlorine compared to world coals. Chlorine in the coals studied here is believed to be organically associated, which is consistent with the general view of chlorine in coal (Swaine, 1990).

Swaine (1989) classifies chlorine in coal as being of lesser environmental significance, but it is a very undesirable element because it can cause fouling and corrosion in thermal power plants. Low chlorine content in British Columbia coals makes them attractive as thermal coals.

CHROMIUM

Chromium contents in British Columbia coals are well within the estimated range in most world coals (0.5 to 60 ppm), and the mean corresponds almost exactly with an estimated general world mean of about 20 ppm (Swaine, 1990). It is very reasonable, therefore, to classify our coals as average in their chromium contents. Data here suggest that the mode of occurrence of chromium in our coals is predominantly inorganic, and an inorganic association is generally ascribed to chromium in coals (Swaine, 1990; Finkelman, 1980).

Swaine (1989) considers chromium in coal to be of lesser environmental significance, and Clark and Sloss (1992) rate it as being of moderate concern.

COBALT

Cobalt concentrations in British Columbia coals are toward the low end of the estimated range for most world coals (0.5 to 30 ppm) and the mean is below an estimated mean for most coals (from 4 to 8 ppm, Swaine, 1990). Our coals are therefore classified as being low in cobalt. Data suggest an inorganic association for most of the cobalt, while review of the literature led Finkelman (1980) to conclude that cobalt in coal is dominantly associated with inorganic matter, including sulphides. Swaine (1990), on the other hand, appears to ascribe both an inorganic and organic association to cobalt.

Swaine (1989) classifies cobalt in coal as being environmentally insignificant, and Clark and Sloss (1992) rate it as being of minor concern.

COPPER

Copper concentrations in British Columbia coals fall safely within the estimated range of most world coals (0.5 to 50 ppm), and the mean corresponds closely with a mean for copper in coal of 19 ppm (Finkelman, 1980). Means in Southern Hemisphere coals (8 to 10 ppm) are lower than in American coals (15 ppm, Swaine, 1990). Our coals are therefore classified as average in copper. The data here strongly suggest that copper in British Columbia coals is associated with the inorganic fraction. This is consistent with the well-accepted occurrence of copper in chalcopyrite in coal (Finkelman, 1980; Swaine, 1990).

Swaine (1989) classifies copper as being of lesser environmental significance, and Clark and Sloss (1992) describe it as being of moderate concern.

FLUORINE

Fluorine contents in British Columbia coals appear to exceed the estimated range of fluorine in most world coals (20 to 500 ppm) and the mean is above the estimated world mean of about 150 ppm (Swaine, 1990). The means for United States (74 ppm, Finkelman, 1980) and Australian coals (about 110 ppm, Swaine, 1990) are below the British Columbia mean and the estimated world mean value. Our coals are therefore classified as being relatively high in fluorine. The fluorine is believed to be inorganically associated, probably mainly in fluorapatite, which has been detected in low-temperature ashes derived from these samples (Grieve, 1992b). This is consistent with the thinking of both Swaine and Finkelman.

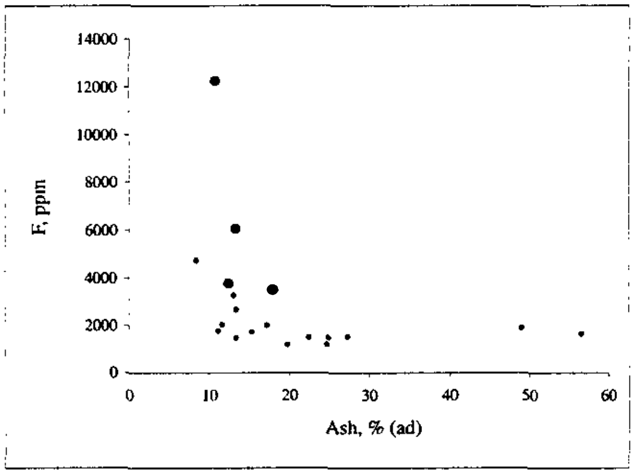

Figure 45. Fluorine in ash *vs.* ash, channel samples from Line Creek 8-seam, southeast B.C.

As noted earlier, fluorine occurrence is closely linked to phosphorus concentrations, mainly through their common occurrence in fluorapatite. The two main factors controlling phosphorus concentrations in raw coals are the amount and mineralogy of the mineral matter. It seems reasonable, therefore, to suggest that fluorine concentrations are also determined to some extent by mineralogy. In order to demonstrate a possible dependence, fluorine/ash *versus* ash for Line Creek 8-seam (southeast B.C.) samples has been plotted (Figure 45), and the samples in which fluorapatite was positively identified by x-ray diffraction in low-temperature ash have been highlighted. The similarity of this diagram to Figure 29d, which represents phosphorus in the same samples, is obvious. Clearly, the presence of fluorapatite has the ability to create anomalous concentrations of fluorine in coals.

Fluorine in coal is volatile, and is classed as being an element of prime environmental significance (Swaine, 1989). The fluorine content of British Columbia coals would appear to be a negative factor. The potential for reduction of fluorine by beneficiation is therefore an important subject for future study. It was noted earlier that the phosphorus content in Kootenay coals tends to be lower in the light fraction of sink-float separates, than in the original sample. This suggests that a significant portion of the fluorapatite can be liberated and removed with relative ease from coals from this region, which would reduce fluorine concentrations.

LEAD

The range of lead values in British Columbia coals is toward the low end of the estimated range for most world coals (2 to 80 ppm, Swaine, 1990). An estimated mean for most Australian, South African and American coals is 10 to 15 ppm, while for European coals it is somewhat higher (Swaine, 1990). British Columbia coals are therefore considered to be relatively low in their lead contents. Lead is thought to be exclusively associated with mineral matter in coal (Swaine, 1990; Finkelman, 1980).

Lead is of prime environmental significance according to Swaine (1989), and of greatest concern according to Clark and Sloss (1992). Low lead concentrations in raw British Columbia coals are therefore a favourable characteristic.

MERCURY

Mercury contents in British Columbia coals are near the low end of the estimated range for most world coals (20 to 1000 ppb, Swaine, 1990), and the mean is below estimated means for Australian (100 ppb, Swaine, 1990) and United States coals (180 ppb, Finkelman, 1980). Our coals are therefore classified as being low in mercury. The mercury is thought to be associated with the inorganic fraction. This is consistent with a generally accepted association of mercury with sulphide minerals (Swaine, 1990; Finkelman, 1989), and the observation that mercury is usually low in low-sulphur coals (Swaine, 1989).

The high toxicity of mercury, in combination with its volatility, make it an element of prime environmental significance (Swaine, 1989) and of greatest concern (Clark and Sloss, 1992). Most mercury emitted by coal-burning power plants is in the vapour state (Clark and Sloss, 1992) and can be carried large distances from its point of discharge. Low mercury contents, as in these British Columbia coals, is an attractive coal quality attribute.

MOLYBDENUM

The range of molybdenum concentrations in British Columbia coals compares favourably with the estimated range in most world coals (0.1 to 10 ppm) and an estimated approximate world mean (1 to 2 ppm, Swaine, 1990). Our coals are therefore classified as low to average in molybdenum, with the Peace River samples being at the lower end of this range. Molybdenum is generally thought to be inorganically associated in coal (Finkelman, 1980).

Molybdenum is classified as having lesser environmental significance by Swaine (1989), but Clark and Sloss (1992) rank it as being of greatest concern.

SELENIUM

The range in selenium concentrations in British Columbia coals places them within the range of most world coals. For example, Swaine (1990) gives an estimated range for several regions of 0.2 to 1.6 ppm, and a mean in Australian coals of 0.9 ppm. Finkelman (1980) cites 4.1 ppm as the mean concentration of selenium in United States coals. Our coals are therefore classified as being of average selenium concentration. Selenium is thought to be both organically and inorganically bound in coal (Swaine, 1990; Finkelman, 1980).

Selenium in coal is classed as being of prime environmental significance by Swaine (1989), and of greatest concern by Clark and Sloss (1992).

THORIUM

Thorium values in British Columbia coals are within the estimated range of most world coals (0.5 to 10 ppm, Swaine, 1990), and their means compare favourably with the mean in United States coals (4.7 ppm, Finkelman, 1980). Thorium is classified as having average abundance in our coals; the evidence concerning its mode of occurrence points to an inorganic association. This is consistent with both Swaine's (1990) and Finkelman's (1980) interpretations of the literature.

Thorium in coal is classed as having lesser environmental significance by Swaine (1989). Most of the concern over thorium is due to its radioactivity, and radioactivity emanating from coal-burning power plants is generally acknowledged not to be significant (Clark and Sloss, 1992).

URANIUM

Uranium concentrations in British Columbia coals are within the estimated range for most world coals (0.5 to 10 ppm), and the mean compares very closely with an estimated world mean of 2 ppm (Swaine, 1990). Our coals are therefore classed as average in terms of their uranium content. The data here strongly suggest that uranium is inorganically associated, although Swaine (1990) and Finkelman (1980) both concluded that there is also an organic association.

As with thorium, Swaine (1989) classes uranium as being of lesser environmental significance. Most of the concern over uranium is related to radioactivity, and comments concerning this issue made with respect to thorium are valid.

ZINC

The range in zinc concentrations in British Columbia coals is classified as average in comparison with other world coals. For example, Swaine (1990) cites 5 to 300 ppm as the estimated range for most world coals, and 25 ppm as an estimated mean for some American and Australian coals. Finkelman (1980) gives 39 ppm as the mean zinc concentration in United States coals. Zinc is generally thought to be associated with the inorganic fraction of coal (Finkelman, 1980; Swaine, 1990), including accessory sphalerite.

Swaine (1989) classifies zinc in coal as being of lesser environmental significance, and Clark and Sloss (1992) classify it as being of moderate concern.

CHAPTER 10 CAKING POWER

Several tests are applied specifically to potential coking coals, the most basic of which measure the tendency of a coal to soften upon heating and the degree to which it becomes plastic and changes size and shape. This tendency of a coal to soften (melt) upon heating and to form a coherent residue on cooling is referred to as caking (Ward, 1984, page 125). We have determined three measures of caking power on the ROM samples: free swelling index (FSI), dilatation and fluidity.

Equally important criteria specific to coke making, though not discussed here, are the strength of the resultant coke, both cold (coke stability) and hot (coke reactivity and coke strength after reaction or CSR). Other critical properties used to characterize coking coals include coal petrography (vitrinite reflectance and amount of reactive macerals), volatile matter and ash content, ash chemistry, and sulphur and phosphorus concentrations. These properties were discussed earlier in this paper.

FREE SWELLING INDEX

Free swelling index (FSI) is a simple test which quantifies the swelling propensity of a powdered coal under pyrolysis and with no physical restriction. Despite its simplicity, it is a very useful indicator of coking potential of western Canadian coals, and in fact provides a more useful

TABLE 21
FREE SWELLING INDEX AND DILATION

Coalfield/Formation (Data cource) *Sample qualifier*	FSI	Dilatation start temp., deg. C	Dilatation max. temp., deg. C	Maximum contraction %	Maximum dilatation %	
Northeast B.C./Gates	3.5+	407		14		*mean*
(ROM)	1.0-7.5	382-447	460-483	3-20	36-67	*range*
	(8)	(8)	(3)	(8)	(3)	*(no. of samples)*
Northeast B.C./Gates	5+					*mean*
(AR)	1.5-8.5					*range*
	(47)					*(no. of samples)*
Northeast B.C./Gething	3.5+					*mean*
(AR)	0.5-8.5					*range*
	(49)					*(no. of samples)*
Northeast B.C./Minnes	3					*mean*
(AR)	1.5-8					*range*
	(5)					*(no. of samples)*
Southeast B.C.	4.5+	407		18		*mean*
(ROM)	1.0-8.5	375-445	460-482	5-25	7-98	*range*
	(26)	(26)	(9)	(26)	(9)	*(no. of samples)*
Southeast B.C.	4+					*mean*
(AR)	1-8.5					*range*
	(27)					*(no. of samples)*
Comox	2+					*mean*
(AR)	1-7.5					*range*
	(26)					*(no. of samples)*
Telkwa	1.5+					*mean*
(AR)	1-3.5					*range*
clean samples	(10)					*(no. of samples)*

ROM: run-of-mine samples
AR: assessment report data

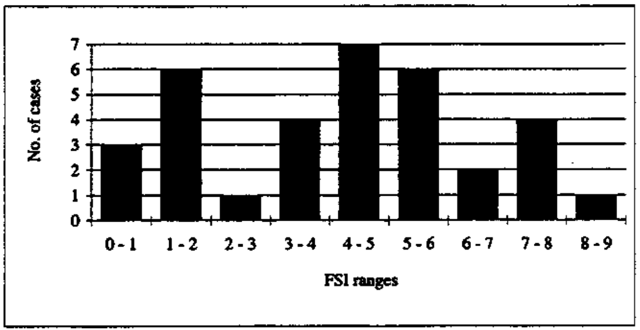

Figure 46a. Free swelling index data. Frequency histogram of FSI in ROM samples.

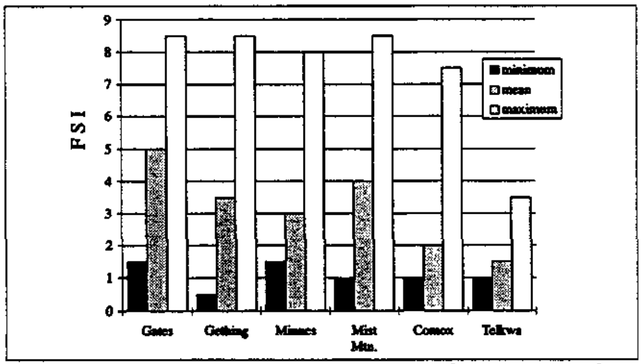

Figure 46b. Free swelling index data. FSI for raw coals from various regions, compiled from assessment reports.

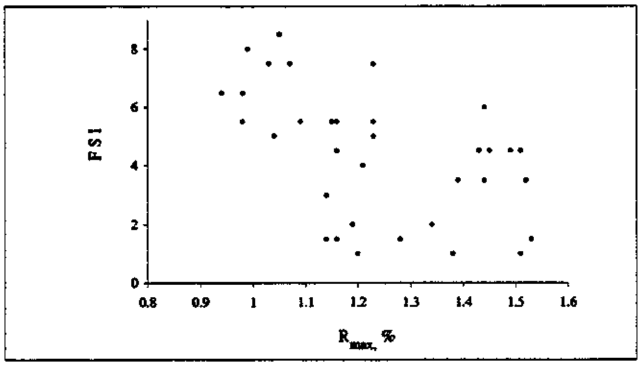

Figure 47. FSI/reflectance relationship in ROM coals.

guide for these coals than the more elaborate tests, such as dilatation and fluidity (Price and Grandsen, 1987). The index is also used routinely as an indicator of oxidation during exploration and production; low FSI correlates with oxidation.

Table 21 and Figure 46a contain the FSI data determined on the ROM samples. Keeping in mind that these data represent raw coals, the average FSI is between 4 and 4.5, and the mode is between 4 and 5. The overall distribution appears to be trimodal, with smaller peaks in the 1 to 2 category and 7 to 8 category. The two regions, northeast and southeast British Columbia, have similar ranges and the southeast samples have a slightly higher average. The same general trend applies to assessment report data, in this case with the northeast coals (Gates Formation) having a slightly higher mean than the southeast coals (Table 21, Figure 46b). Ranges for Gething and Minnes coals are also similar, but the means are slightly lower. Comox and Telkwa thermal coals have mean FSI values of 2 and 1.5, respectively, with the latter value representing clean coals.

For comparison, clean coking coals produced at northeast and southeast mines have FSI values typically in the 6 to 8 range. American metallurgical coal products cited by Pearson (1980) have FSI values in the range of 7 to 9, with 9 being the most common value. The FSI range given for Australian coals is 5 to 8.

The relationship between FSI and R_{max} in run-of-mine coals has a correlation coefficient of -0.50, but the scatterplot (Figure 47) is ambiguous, and suggests only that raw coals with R_{max} <1.1 do not have FSI values less than 4. Stronger caking power for the low rank end (R_{max} between 0.9 and 1.1) of these coals, is therefore suggested. This is of course assuming that all coal samples were free of the effects of oxidation at the time of sampling. There is a slightly stronger correlation of 0.55 between vitrinite content and FSI. If vitrinite content, ash content and R_{max} are combined, a stepwise regression r^2 value of 0.63 is achieved, and R_{max} does not appear as a significant variable. In other words, the combination of total vitrinite and ash contents provides the best predictor of FSI in these samples. The regression equation is:

$$FSI = 0.39 + 0.75V - 0.61Ash_{ad}.$$

DILATATION

Dilatation parameters on ROM samples are summarized in Table 21 and Figure 48. Mean values and ranges for the northeast and southeast regions are strikingly similar to each other. Maximum dilatation values for both regions exceed zero in only one third of the cases and range up to 98. These values are probably suppressed by the fact that the samples are raw, but in general low values are typical of western Canadian coking coals (Price and Gransden, 1987). This stems from the fact that the test was developed using Carboniferous coals and its use with our coals is not entirely appropriate. In other words, low dilatation values do not imply poor coke-making potential (Price and Grandsen, 1987). Moreover, low dilatation values correlate with low coke-oven wall pressures, which translates into less wear and tear on coke ovens. With many of the world's coke-oven batteries nearing the end of their useful life, lower pressure is a very desirable characteristic.

For comparison, U.S. coking coals cited by Pearson (1980, Table 4) have maximum dilatation values ranging from 35 to 215. Australian coals in the same table range from -15 to 87.

Relationships between dilatation parameters and R_{max} are shown in Figure 49, and correlations with R_{max}, total vitrinite and ash content are shown in Table 22. None of the graphs in Figure 49 are unambiguous, even though in one case, dilatation start temperature versus R_{max} (Figure 49a),

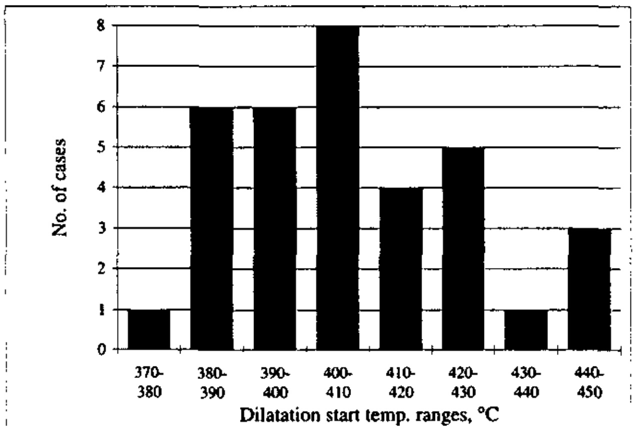

Figure 48a. Frequency histograms for dilation parameters in ROM coals. Dilation start temperature.

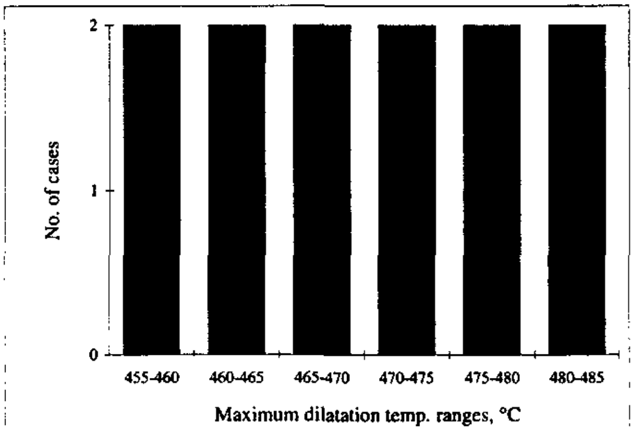

Figure 48b. Frequency histograms for dilation parameters in ROM coals. Temperature of maximum dilation (n=12).

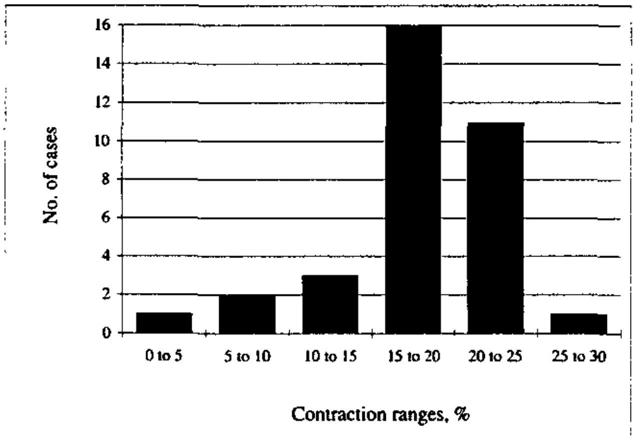

Figure 48c. Frequency histograms for dilation parameters in ROM coals. Maximum contraction.

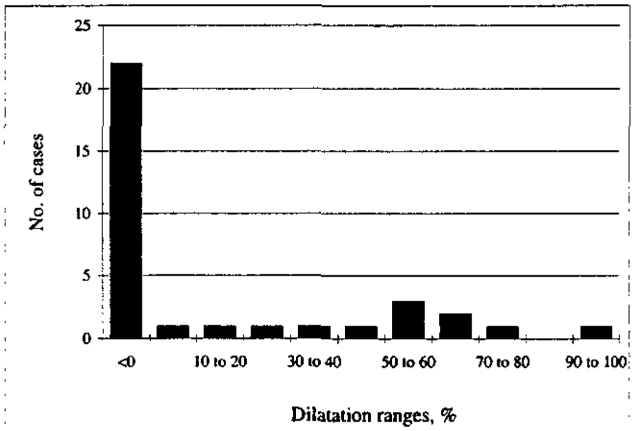

Figure 48d. Frequency histograms for dilation parameters in ROM coals. Maximum dilation (n=12).

TABLE 22
CORRELATION COEFFICIENTS BETWEEN DILATION PARAMETERS, R_{max}, TOTAL VITRINITE AND ASH CONTENT

	R_{max}	% Vitrinite	Ash	Start Temp.	Max. Temp.	Contraction
% Vitrinite	-0.53					
Ash	0.12	0.32				
Start Temp.	0.52	-0.39	0.30			
Max. Temp.	-0.02	0.18	0.31	0.06		
Contraction	0.35	-0.31	0.37	0.73	0.08	
Dilatatation	-0.15	0.48	-0.29	-0.64	-0.04	-0.32

(Note: r=0.41 is significant at 99% confidence, except for Max. Temp. and Dilation, for which r=0.66 is significant)

there is a significant positive correlation coefficient (r) of 0.52. When the variables R_{max}, total vitrinite and ash content are regressed in a stepwise fashion against start temperature, an r^2 value of 0.40 is obtained. The equation is:

$$\text{Dilatation start temperature} = 384 + 0.38Ash_{ad} + 0.27R_{max} - 0.37V.$$

The graph of maximum contraction *versus* R_{max} (Figure 49c) looks like a mirror image of the FSI *versus* R_{max} graph (Figure 47). In this case, no coals with reflectance of less than 1.1 have maximum contraction less than 15%. This perhaps is more evidence for relatively higher caking propensities for coals with R_{max} between 0.9 and 1.1. Although the amount of actual contraction is not correlated with the individual variables R_{max}, total vitrinite or ash content (Table 22), a stepwise multiple regression with an r^2 value of 0.346 is achieved based on these three variables. As was the case with FSI, R_{max} does not make a significant contribution. The equation is:

$$\text{Maximum contraction} = -13.0 + 0.53Ash_{ad} - 0.48V.$$

FLUIDITY

Fluidity parameters on ROM samples are summarized in Table 23 and Figure 50. The mean initial softening temperature is about 16° higher in southeast British Columbia coals than in northeast coals. Mean resolidification temperatures, on the other hand, are identical. This translates into a generally larger fluid range for the northeast coals. Maximum fluidity mean values, in ddpm, are also

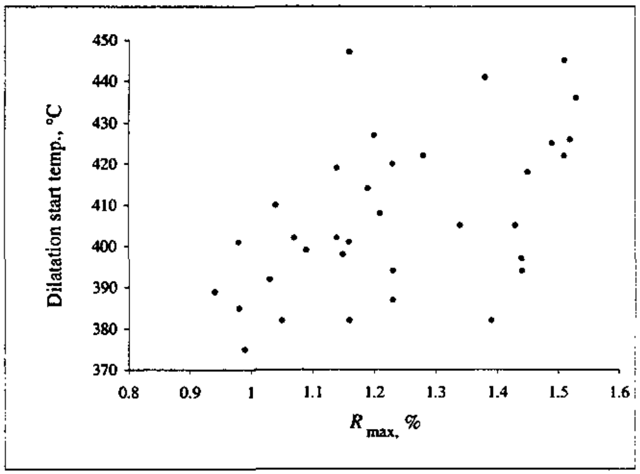

Figure 49a. Dilation/reflectance relationships on ROM coals. Dilation start temperature *vs.* R_{max}.

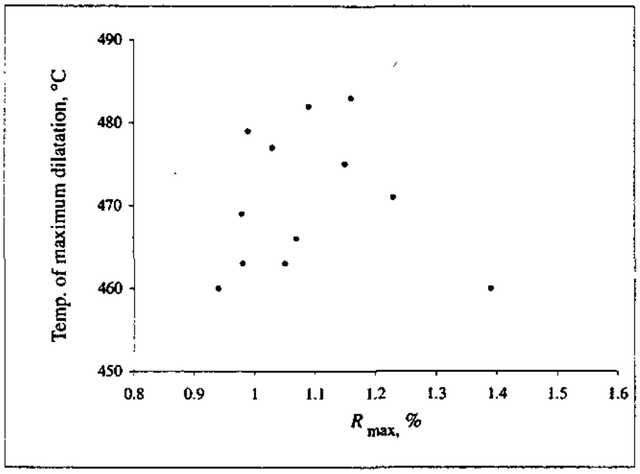

Figure 49b. Dilation/reflectance relationships on ROM coals. Temperature of maximum dialtion *vs.* R_{max}.

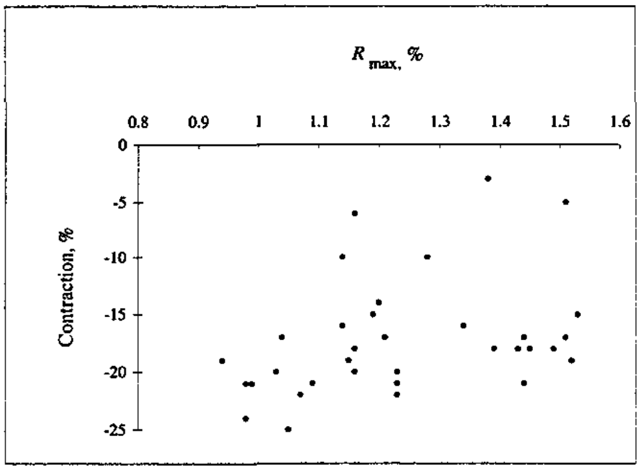

Figure 49c. Dilation/reflectance relationships on ROM coals. Maximum contraction *vs.* R_{max}.

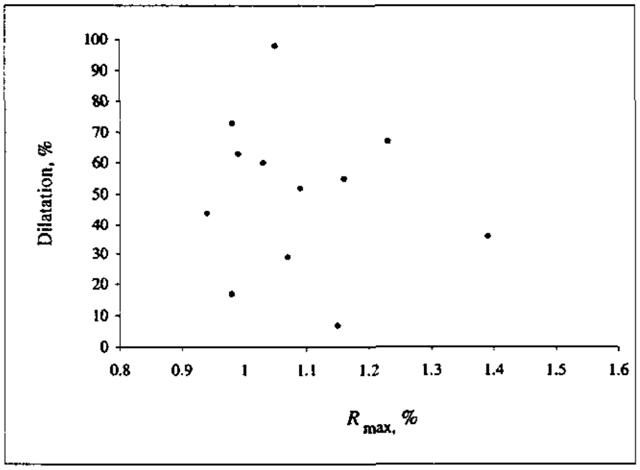

Figure 49d. Dilation/reflectance relationships on ROM coals. Maximum dilation *vs.* R_{max}.

TABLE 23
FLUIDITY

Coalfield/Formation (Data source)	Init. softening temp., °C	Fluidity max. temp., °C	Resolidification temp., °C	Fluidity temp. range, °C	Maximum fluidity, ddpm	
Northeast B.C./Gates	421.5	461	493	71	440.4	*mean*
(ROM)	403-439	448-471.5	485-503	46-95	3.8-1788.2	*range*
	(8)	(8)	(8)	(8)	(8)	*(no. of samples)*
Southeast B.C.	437.5	467	493	55.5	192.8	*mean*
(ROM)	413-472.5	453-489	475-510	2.5-77.5	0.6-853.7	*range*
	(26)	(26)	(26)	(26)	(26)	*(no. of samples)*

(Note: all temperatures to the nearest 0.5°)

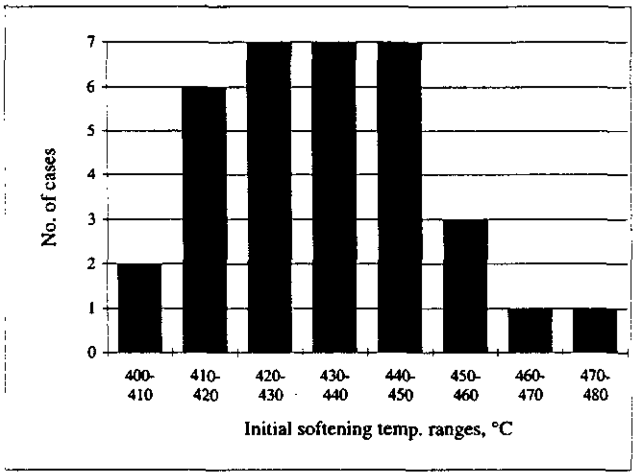

Figure 50a. Frequency histograms for fluidity parameters in ROM coals. Initial softening temperature.

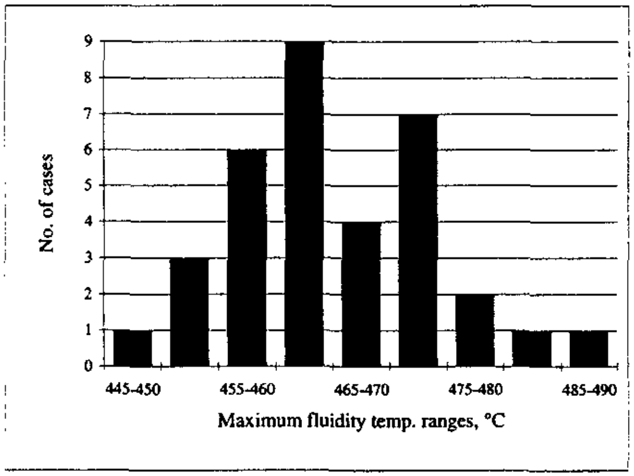

Figure 50b. Frequency histograms for fluidity parameters in ROM coals. Temperature of maximum fluidity.

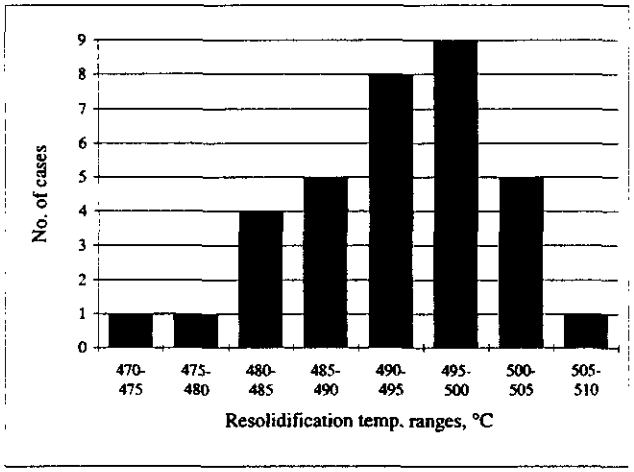

Figure 50c. Frequency histograms for fluidity parameters in ROM coals. Resolidification temperature.

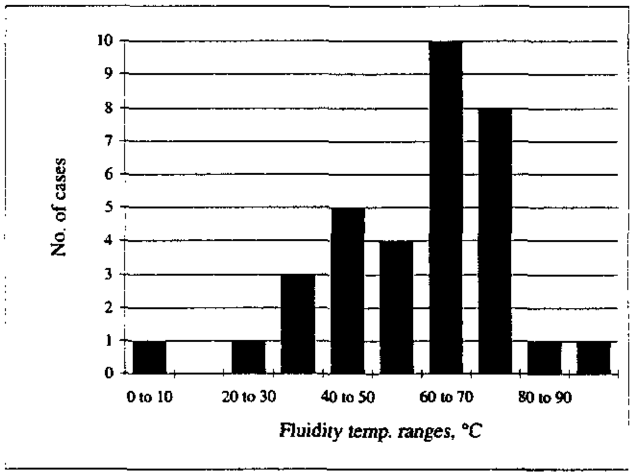

Figure 50d. Frequency histograms for fluidity parameters in ROM coals. Fluid temperature range.

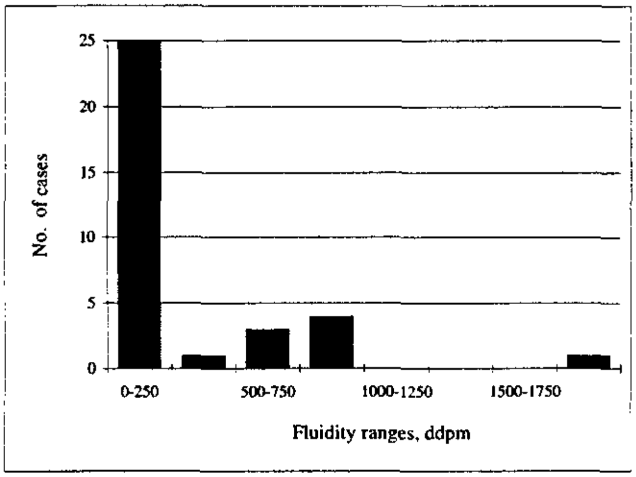

Figure 50e. Frequency histograms for fluidity parameters in ROM coals. Maximum fluidity.

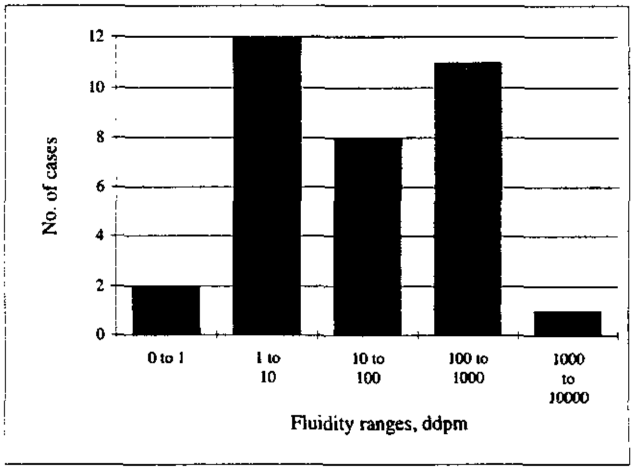

Figure 50f. Frequency histograms for fluidity parameters in ROM coals. Log maximum fluidity.

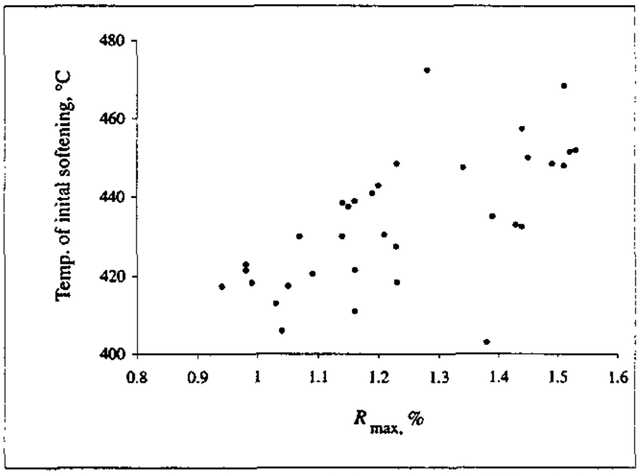

Figure 51a. Fluidity/reflectance relationships in ROM coals. Initial softening temperature *vs.* R_{max}.

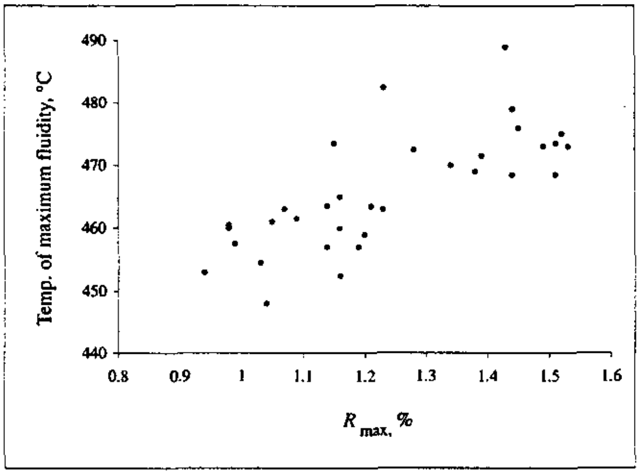

Figure 51b. Fluidity/reflectance relationships in ROM coals. Temperature of maximum fluidity *vs.* R_{max}.

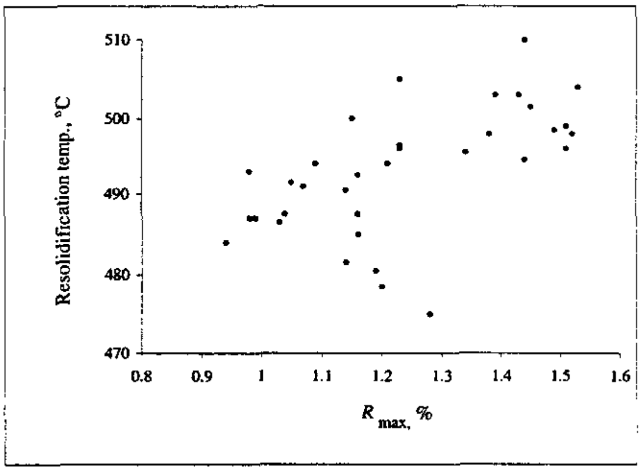

Figure 51c. Fluidity/reflectance relationships in ROM coals. Resolidification temperature *vs.* R_{max}.

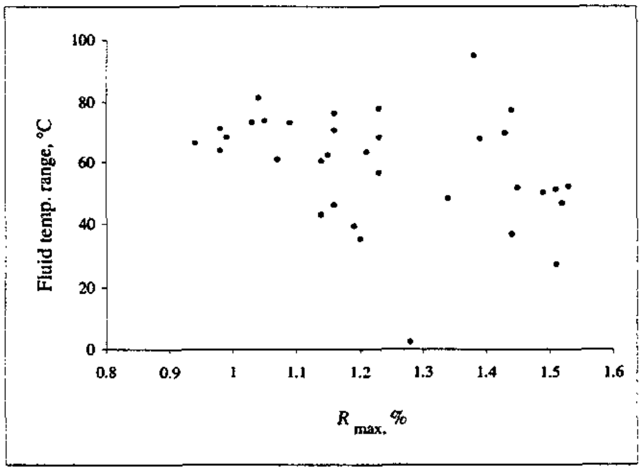

Figure 51d. Fluidity/reflectance relationships in ROM coals. Fluid temperature range *vs.* R_{max}.

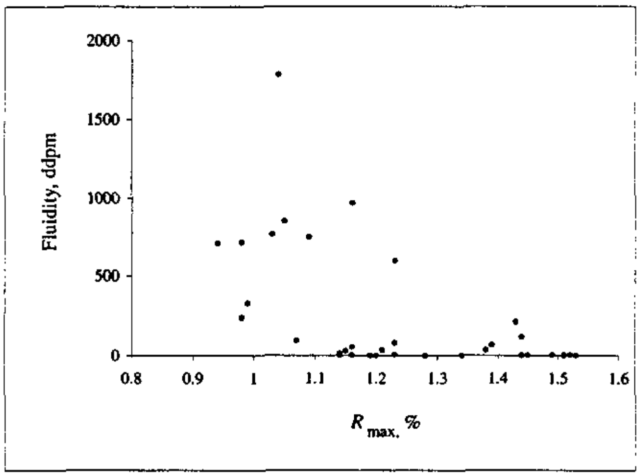

Figure 51e. Fluidity/reflectance relationships in ROM coals. Maximum fluidity *vs.* R_{max}.

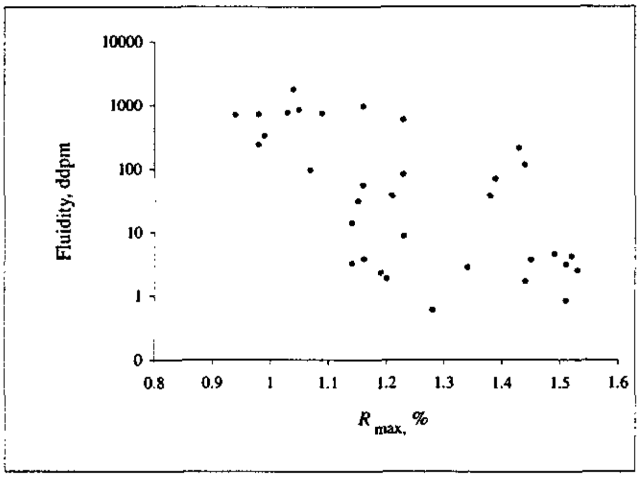

Figure 51f. Fluidity/reflectance relationships in ROM coals. Log maximum fluidity *vs.* R_{max}.

TABLE 24
CORRELATION COEFFICIENTS BETWEEN FLUIDITY PARAMETERS, R_{max}, TOTAL VITRINITE AND ASH CONTENT

	R_{max}	% Vitrinite	Ash	Start Temp.	Max. Temp.	Final temp.	Fluid. Range	Fluidity
% Vitrinite	-0.53							
Ash	0.12	0.32						
Start Temp.	0.64	-0.61	-0.20					
Max. Temp.	0.74	-0.40	0.19	0.55				
Final Temp.	0.59	-0.08	0.21	0.10	0.73			
Fluid Range	-0.33	0.54	0.28	-0.89	-0.19	0.36		
Fluidity	-0.55	0.62	-0.04	-0.66	-0.59	-0.22	0.53	
Log Fluid.	-0.63	0.71	0.04					

(Note: $r = 0.41$ is significant at 99% confidence)

higher in northeast coals, by a factor of about 2. As with the dilatation values, the absolute mean values of fluidity in western Canadian coals are low by world standards (see next paragraph), even when clean coals are analysed rather than raw coals. On a logarithmic scale, for example, the modal range in ROM samples is 1 to 10 ddpm (Figure 50f). This is again a function of the fact that fluidity tests were designed for Carboniferous coals, and the low results in our coals do not translate into poor coke-making potential (Price and Gransden, 1987). A more important parameter is the actual range of temperatures over which the coal is fluid, for this determines the bridging potential of a component in a blend.

For comparison, American coking coals cited by Pearson (1980, Table 4) have maximum fluidity values ranging from 10 to 25 000, and if all the low-volatile coals are removed from Pearson's table, the lower limit of the range rises to 3000. These coals are fundamentally different to our coals, in part because of their higher liptinite contents. Australian coals are more like British Columbia coals; fluidity ranges given in Pearson (1980) range are from 5 to 2300.

Relationships between fluidity parameters and R_{max} are indicated in Figure 51, and correlations between these parameters and R_{max}, total vitrinite and ash content are contained in Table 24. R_{max} is positively correlated with temperatures of initial deformation, maximum fluidity and resolidification, and negatively correlated with maximum fluidity in ddpm. If the last parameter is converted to logarithmic values, the correlation is even stronger. The strongest relationship ($r = 0.74$) is between temperature of maximum fluidity and R_{max} (Figure 51b). Total vitrinite is negatively correlated with temperature of initial deformation and positively correlated with fluid temperature range and maximum fluidity. Ash content does not appear to be significantly correlated with fluidity parameters, although it is reasonable to assume that maximum fluidity values are affected by the fact that these are raw samples. In stepwise multiple regression of fluidity parameters using R_{max}, total vitrinite and ash content, better results are generally obtained. The highest r^2 value (0.60) is achieved for log of maximum fluidity in ddpm. The equation is:

$\text{Log fluidity} = 3.6 + 0.53V - 0.35R_{max}$.

The control on temperature of maximum fluidity by Rmax is not improvedher total vitrinite or ash content. The equation is:

$\text{Temperature of maximum fluidity} = 420 + 0.74R_{max}$.

Temperatures of initial deformation and resolidification regress as follows:

$\text{Temperature of initial deformation} = 404 + 0.51R_{max} - 0.29V - 0.17Ash_{ad}$;

$\text{Temperature of resolidification} = 439 + 0.77R_{max} + 0.33V$.

The r^2 values for these equations are 0.53 and 0.43, respectively.

Another important parameter is the fluid temperature range, as mentioned above. In this case, total vitrinite by itself provides the best predicter. The equation is:

$\text{Fluid temperature range} = 16.4 + 0.54V$.

CHAPTER 11 SUMMARY

A summary of the data is presented here. For discussion of the implications of the data, and comparisons with world coals, see the specific chapters dealing with the various quality parameters.

This study is based on raw coals. Data are derived from two sampling programs (ROM or run-of-mine sampling and channel sampling) at active mines in northeast and southeast British Columbia, and from coal assessment reports representing most coalfields in the province.

Vitrinite reflectance values of run-of-mine (ROM) samples from the southeast range from 0.94 to 1.53%, while for the northeast (Gates Formation only) they range from 1.04 to 1.39%. Incorporating all data in this study, the $R_{\max}$ values for southeast coals range from about 0.8 to over 1.5, and for northeast coals (Gates and Gething), from about 1.0 to 1.6. Klappan area coals have average Rmax values of about 3.5%. The ASTM rank for most southeast and northeast coals ranges from high-volatile A bituminous to low-volatile bituminous. Klappan area coals are anthracitic in rank. High-volatile bituminous coals are found at Quinsam on Vancouver Island (predominantly high-volatile B), Telkwa (high-volatile A), Tulameen (high-volatile C/B) and Bowron River (high volatile C/B). Sub-bituminous and lignitic coals are found at Hat Creek.

Like most western Canadian coking coals, coals from southeast and northeast British Columbia have relatively high concentrations of inertinite. Run-of-mine samples from those regions contain an average of about 60% vitrinite. Semifusinite is the most common inertinite maceral, averaging about 30% content. Liptinite is practically nonexistent in these coals.

Mean moisture contents (air-dried) of ROM samples from both the northeast and southeast coalfields are under 1%. Higher moisture contents are noted in lower rank basins. Mean ash content in ROM samples (23.3%) is higher than in channel samples (19.5%), reflecting the greater selectivity of the latter sampling method. Coals from both regions are washed to specified ash levels for marketing. Volatile matter contents (daf) in ROM samples range from 22 to 35%, consistent with the bituminous rank of these coals. Volatile matter is also controlled to a significant extent by coal type (expressed as percent vitrinite).

British Columbia is well known as a source of low-sulphur coals, a factor related to the lack of marine influence during deposition. Mean sulphur content in ROM samples is 0.44%. Higher sulphur contents occur in some Gething Formation coals, some Comox coalfield coals (excluding current products), and in coals of the Bowron River and Telkwa coalfields. As a rule, low-sulphur coals contain a low proportion of pyritic sulphur, and higher sulphur coals contain a higher proportion.

Highest mean calorific values (25 to 30 MJ/kg, air-dried) correspond with coals from northeast and southeast British Columbia and the Telkwa deposit. Slightly lower values are found in Klappan and Comox coals. Lowest values are found in the lower-rank, lower-grade coals, such as those from Hat Creek, Bowron River and Tulameen. On a dry, ash-free basis, ROM samples have a mean calorific value of about 35 megajoules per kilogram.

Quartz and kaolinite are the most common minerals in low-temperature ash of ROM samples. Other commmon minerals include illite, illite/mica, carbonates (calcite, dolomite, ankerite and siderite), apatite and pyrite. High-temperature ashes of ROM samples have low base-acid ratios; this translates into high CSR (coke strength after reaction) values. Predicted slagging and fouling tendencies of ROM coals are also favourable.

Calculated mean phosphorus concentrations in raw coals of the Mist Mountain, Gething and Gates formations are 0.076%, 0.063% and 0.042%, respectively. There is no consistent stratigraphic trend in mean phosphorus concentrations in the Mist Mountain Formation, but seams in the basal part of the formation are relatively low in phosphorus. In the Gates Formation, seams from the upper part of the section tend to contain higher concentrations of phosphorus. In all examples studied, variations in raw phosphorus concentrations within samples from a single seam can be large. Phosphorus in British Columbia coking coals is predominantly associated with inorganic material, chiefly apatite minerals, including fluorapatite. The two main factors affecting the phosphorus content of a given coal are the amount of ash and the suite of accessory minerals. A representative average phosphorus content in clean coking coals is 0.05%.

Trace elements which are consistently above detection limits in channel samples appear to belong to two groups, based on their apparent mode of association in coal. Elements in the first group (Sb, As, Cr, Co, Cu, F, Hg, Th and U) are primarily inorganically associated, while those in the second group (Br and Cl) are organically bound. Concentrations of trace elements do not vary systematically with stratigraphic position. The ash contents of specific samples appear to exert more control than does stratigraphic position. In the case of the Kootenay coals, this control results in most of the elements in the first group having their highest concentrations in samples from the middle one-third of the formation, and their lowest values from near the base and top. In the Peace River coals, concentrations of a similar set of elements are highest in the upper half of the formation.

Compared with world coals, raw coals from British Columbia tend to have relatively high concentrations of fluorine, average concentrations of ten trace elements (Sb, B, Cd, Cr, Cu, Mo, Se, Th, U and Zn) and relatively low concentrations of six (As, Br, Cl, Co, Pb, and Hg). Among trace elements of prime environmental significance, as defined by Swaine (1989), raw British Columbia coals contain below average mean concentrations of arsenic, lead and mercury, and high concentrations of only one element, fluorine.

Among the tests of caking power, FSI probably provides the most reliable predictor of coking potential for British Columbia coals (Price and Grandsen, 1987). Other common tests, such as dilatation and fluidity were originally developed for Carboniferous coals, and are not appropriate to our coals. Mean and modal FSI values in ROM coals are on the order of 4.5. British Columbia product coals have specified FSI values in the 6 to 8 range. Dilatation of these coals is generally low; for example, two-thirds of the ROM samples have no net dilatation (contraction only). Low dilatation is associated with low coke-oven pressure, a very positive factor in markets at this time. As with dilatation, fluidity values in ROM coals are low by world standards. On a logarithmic scale, the modal range in maximum fluidity is 1 to 10 ddpm.

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APPENDICES

APPENDIX 1

PROXIMATE AND PHOSPHORUS DATA AND ASH MINERALOGY ON CHANNEL SAMPLES

Sample Number	Property	Pit	Seam Name	Ash %	Mois. %	V.M. %	F.C. %	P %	Mineralogy of Low-Temperature Ash (LTA)
						(A.D. BASIS)			
Q8901	FORDING	EAGLE	15	8.43	1.40	31.88	58.29	0.026	Quartz, kaolinite, illite/muscovite, calcite, fluorapatite, trace: – siderite?
Q8902	FORDING	EAGLE	14-9	21.18	1.12	28.76	48.94	0.118	Quartz, kaolinite, siderite, illite, pyrite
Q8903	FORDING	EAGLE	14-0	6.25	1.36	29.07	63.32	0.162	Quartz, kaolinite, gorceixite?, fluorapatite, siderite, trace. – pyrite, amphibole?
Q8904	FORDING	EAGLE	14-2	14.71	1.13	27.49	56.67	0.079	Quartz, kaolinite, dolomite/ankerite, illite, trace: – siderite, apatite, pyrite
Q8905	FORDING	TAYLOR	7	25.42	0.72	20.00	53.86	0.197	Quartz, kaolinite, siderite, illite, trace: – fluorapatite, pyrite?
Q8906	FORDING	TAYLOR	5	17.64	0.77	19.72	61.87	0.039	Quartz, kaolinite, illite, trace: – siderite, pyrite?
Q8907	FORDING	TAYLOR	9	19.61	1.25	21.21	57.93	0.162	Quartz, kaolinite, siderite, trace: – illite, pyrite, apatite?
Q8908	FORDING	POND	TAILINGS	21.35	1.12	20.12	57.41	0.070	Quartz, kaolinite, illite, magnetite, trace: – siderite, dolomite/ ankerite, pyrite
Q8909	BYRON CREEK	12	MAMMOTH	21.71	0.96	21.77	55.56	0.031	Quartz, kaolinite, illite, calcite, dolomite/ankerite, trace: – siderite
Q8910	BYRON CREEK	51	MAMMOTH	21.32	0.87	22.68	55.13	0.035	Quartz, kaolinite, calcite, dolomite/ankerite, illite, trace: – siderite, rhodochrosite?
Q8911	BYRON CREEK	14	MAMMOTH	21.50	1.09	22.17	55.24	0.013	Quartz, kaolinite, dolomite, calcite, illite, trace: – siderite
Q8912	LINE CREEK	MAIN	10A (TOP)	55.97	0.57	13.59	29.87	0.074	Quartz, kaolinite, illite, trace: – pyrite
Q8913	LINE CREEK	MAIN	10A	26.50	0.61	17.58	55.31	0.035	Quartz, kaolinite, illite/mica, trace: – anatase
Q8914	LINE CREEK	MAIN	10A	17.32	0.61	18.08	63.99	0.013	Kaolinite, quartz, trace: – ilmenite?
Q8915	LINE CREEK	MAIN	10A	17.62	0.64	19.13	62.61	0.017	Quartz, kaolinite, trace: – illite, siderite
Q8916	LINE CREEK	MAIN	10A (BASE)	12.36	0.72	19.75	67.17	0.031	Quartz, kaolinite, trace: – siderite
Q8917	LINE CREEK	MAIN	10B (TOP)	15.49	0.82	19.51	64.18	0.009	Quartz, kaolinite, trace: – illite, siderite, calcite
Q8918	LINE CREEK	MAIN	10B	13.99	0.81	19.92	65.28	0.048	Quartz, kaolinite, calcite, trace: – siderite, pyrite, apatite
Q8919	LINE CREEK	MAIN	10B	24.86	0.72	17.28	57.14	0.022	Quartz, kaolinite, illite, trace: – siderite, anatase
Q8920	LINE CREEK	MAIN	10B	10.94	0.72	21.14	67.20	0.009	Quartz, kaolinite, trace: – calcite
Q8921	LINE CREEK	MAIN	10B (BASE)	15.80	1.22	19.79	63.19	0.013	Quartz, kaolinite, illite
Q8922	LINE CREEK	MAIN	9 (TOP)	12.62	0.82	21.12	65.44	0.026	Quartz, kaolinite, trace: – siderite, pyrite
Q8923	LINE CREEK	MAIN	9	18.34	0.88	19.92	60.86	0.039	Quartz, kaolinite, illite, fluorapatite, trace: – pyrite
Q8924	LINE CREEK	MAIN	9	12.88	0.78	19.61	66.73	0.061	Quartz, kaolinite, fluorapatite, trace: – pyrite
Q8925	LINE CREEK	MAIN	9	5.66	0.92	20.90	72.52	0.079	Quartz, kaolinite, fluorapatite, trace: – pyrite?
Q8926	LINE CREEK	MAIN	9	12.41	0.84	21.33	65.42	0.013	Quartz, kaolinite, illite, trace: – siderite
Q8927	LINE CREEK	MAIN	9	25.78	0.70	22.28	51.24	0.039	Quartz, siderite, kaolinite, trace: – illite
Q8928	LINE CREEK	MAIN	9	7.28	0.68	20.22	71.82	0.122	Quartz, kaolinite, fluorapatite, trace: – siderite, pyrite
Q8929	LINE CREEK	MAIN	9 (BASE)	22.20	0.58	18.50	58.72	0.044	Quartz, kaolinite, illite, trace: – anatase?
Q8930	LINE CREEK	MAIN	8 (TOP)	49.02	0.67	14.81	35.50	0.044	Quartz, kaolinite, illite, trace: – anatase?
Q8931	LINE CREEK	MAIN	8	13.07	0.66	20.37	65.90	0.131	Quartz, kaolinite, fluorapatite, trace: – illite, siderite
Q8932	LINE CREEK	MAIN	8	24.64	0.56	19.10	55.70	0.009	Kaolinite, quartz, trace: – illite
Q8933	LINE CREEK	MAIN	8	22.42	0.61	21.40	55.57	0.013	Kaolinite, quartz, trace: – illite
Q8934	LINE CREEK	MAIN	8	27.24	0.56	20.16	52.04	0.022	Kaolinite, quartz, trace: – siderite
Q8935	LINE CREEK	MAIN	8	8.41	0.60	23.73	67.26	0.052	Quartz, kaolinite, trace: – siderite
Q8936	LINE CREEK	MAIN	8	15.37	0.61	19.40	64.62	0.026	Kaolinite, quartz, trace: – siderite, illite
Q8937	LINE CREEK	MAIN	8	11.63	0.69	20.84	66.84	0.017	Quartz, kaolinite, siderite
Q8938	LINE CREEK	MAIN	8	24.81	0.73	19.14	55.32	0.009	Quartz, kaolinite, illite, siderite, trace: – anatase?
Q8939	LINE CREEK	MAIN	8	11.15	0.73	19.96	68.16	0.013	Quartz, kaolinite, siderite, trace: – fluorapatite, anatase?
Q8940	LINE CREEK	MAIN	8	17.34	0.62	20.26	61.78	0.114	Quartz, kaolinite, illite, fluorapatite, trace: – siderite?
Q8941	LINE CREEK	MAIN	8	13.40	0.58	21.88	64.14	0.066	Quartz, kaolinite, trace: – siderite, apatite, pyrite?
Q8942	LINE CREEK	MAIN	8	13.37	0.59	19.66	66.38	0.022	Kaolinite, quartz, trace: – dolomite/ankerite, siderite, anatase?
Q8943	LINE CREEK	MAIN	8	10.88	0.66	19.31	69.15	0.341	Quartz, kaolinite, fluorapatite, trace: – siderite?
Q8944	LINE CREEK	MAIN	8	12.44	0.59	22.62	64.35	0.092	Quartz, kaolinite, fluorapatite, trace: – illite
Q8945	LINE CREEK	MAIN	8	19.77	0.61	19.21	60.41	0.017	Kaolinite, quartz, trace: – illite
Q8946	LINE CREEK	MAIN	8	17.21	0.61	19.76	62.42	0.031	Kaolinite, quartz, trace: – illite, siderite
Q8947	LINE CREEK	MAIN	8	13.07	0.59	25.13	61.21	0.070	Siderite, kaolinite, quartz, trace: – apatite?
Q8948	LINE CREEK	MAIN	8 (BASE)	56.54	0.72	13.73	29.01	0.026	Quartz, kaolinite, illite, trace: – pyrite, anatase?
Q8949	GREENHILLS	BLACKTAIL	25 EAST	7.63	1.49	29.96	60.95	0.035	Quartz, kaolinite, illite, trace: – siderite, pyrite?, apatite?
Q8950	GREENHILLS	BLACKTAIL	16	16.84	0.93	25.71	56.52	0.039	Quartz, kaolinite, illite, trace: – pyrite, apatite
Q8951	GREENHILLS	N COUGAR	22 UPPER	6.12	3.33	28.26	62.29	0.035	Quartz, kaolinite, anatase?, trace: – siderite, apatite?
Q8952	GREENHILLS	BLACKTAIL	20 UPPER	32.72	0.80	22.90	43.58	0.057	Quartz, kaolinite, illite, siderite, trace: – pyrite, apatite, anatase?
Q8953	GREENHILLS	FALCON	1	9.25	0.52	24.79	65.44	0.083	Quartz, kaolinite, siderite, trace: – apatite, pyrite?
Q8954	GREENHILLS	FALCON	3	19.25	0.51	22.92	57.32	0.135	Quartz, kaolinite, siderite, trace: – pyrite, apatite?, illite
Q8955	BALMER	CAMP 8 EX	7R1	23.94	0.43	20.00	55.63	0.170	Quartz, kaolinite, illite, siderite, trace: – apatite, pyrite?
Q8956	BALMER	CAMP 8 EX	7RX	32.06	0.41	18.30	49.23	0.114	Quartz, kaolinite, illite, trace: – siderite, pyrite?
Q8957	BALMER	CAMP 8 EX	7.S	25.96	0.55	21.70	51.79	0.114	Quartz, kaolinite, illite, siderite, trace: – apatite, pyrite
Q8958	BALMER	CAMP 8 EX	8UX	34.74	0.34	18.77	46.15	0.227	Quartz, kaolinite, illite, siderite, trace: – fluorapatite, pyrite, anatase?
Q8959	BALMER	BALDY 3, 4	4	24.83	0.57	19.76	54.84	0.118	Quartz, kaolinite, illite, trace: – fluorapatite, pyrite, siderite?
Q8960	BALMER	ADIT29E	8UC	28.03	0.43	18.47	53.07	0.118	Quartz, kaolinite, illite, siderite, trace: – dolomite?
Q8961	BALMER	POND	TAILINGS	38.28	0.42	18.01	43.29	0.066	Quartz, kaolinite, illite, trace: – dolomite/ankerite, siderite, pyrite?
Q8962	QUINTETTE	WOLVERINE	J3	13.77	0.86	21.24	64.13	0.013	Quartz, kaolinite, siderite, illite, trace: – apatite?
Q8963	QUINTETTE	WOLVERINE	G2	16.31	0.74	21.19	61.76	0.052	Quartz, kaolinite, dolomite/ankerite, trace: – siderite
Q8964	BULLMOOSE		A2	12.51	0.71	24.72	62.06	0.017	Quartz, kaolinite, siderite (manganoan), dolomite/ankerite
Q8965	BULLMOOSE		B	11.05	0.77	24.93	63.25	0.031	Dolomite, quartz, calcite, kaolinite, trace: – pyrite, plagioclase?
Q8966	BULLMOOSE		A1	21.34	0.76	23.63	54.27	0.009	Quartz, kaolinite, illite, dolomite, pyrite
Q8967	BULLMOOSE		C	28.13	1.00	19.90	50.97	0.114	Quartz, illite/muscovite, kaolinite, dolomite/ankerite, trace: – pyrite, magnetite?
Q8968	BULLMOOSE		D	22.14	1.00	23.40	53.46	0.052	Quartz, kaolinite, dolomite, illite, trace: – pyrite, magnetite?
Q8969	BULLMOOSE		E	21.68	1.10	24.42	52.80	0.057	Quartz, kaolinite, illite, trace: – dolomite, pyrite, siderite, apatite?

Note: All results are based on raw coal samples and are not representative of clean, product coals.

APPENDIX 2

B.C. REGIONAL RAW COAL QUALITY DATABASE

LIST OF ABBREVIATIONS

ar	-	As-received basis
ad	-	Air-dried basis
daf	-	Dry, ash-free basis
maf	-	Moist, ash-free basis
mmmf	-	Moist, mineral matter free basis
FSI	-	Free swelling index
R_{max}	-	Mean maximum vitrinite reflectance
Cal. val.	-	Calorific value
A.R.	-	Assessment report
Co. rpt.	-	Company report
DH	-	Drill-hole

Table Item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
1	Nanaimo	*South Wellington*	#10 Mine	Dickson	Nanaimo	Douglas			Mine-run	1	19.3	25.3	54.4	ad	31.7440402		
2	Nanaimo	*Western Fuel Corp.*	#1 Mine	Dickson	Nanaimo	Newcastle			Lump	0.2	10.5	33.5	54	ad	38.2857143		
3	Nanaimo	*Beban Mine*	Extension	Dickson	Nanaimo	Wellington			Mine-run	0.6	15.2	31.9	52.3	ad	37.8859857		
4	Nanaimo	*Northfield Mine*		Dickson	Nanaimo	Little Wellington			Mine-run	0.8	13	34.3	51.9	ad	39.7911833		
5	Nanaimo	*Wolf Mtn.*		A.R. 177	Nanaimo	W1 (Wellington?)	Core, raw	91.9	DH-82-02A	2.25	14.89	36.93	45.93	ad	44.5691528		
6	Comox		#5 Mine	Dickson	Nanaimo	2			Mine-run	1.10	17.60	25.50	55.80	ad	31.37		
7	Comox	*Chute Creek*		A.R. 701	Nanaimo	A (main)	Core, raw	100.0	DH-85-20	3.53	19.02	32.42	45.03	ad	41.86		
8	Comox	*Chute Creek*		A.R. 701	Nanaimo	B	Core, raw	92.9	DH-85-27	2.75	36.80	28.71	31.74	ad	47.49		
9	Comox	*Chute Creek*		A.R. 701	Nanaimo	C	Core, raw	100.0	DH-85-26	2.71	19.42	34.03	43.84	ad	43.70		
10	Comox	*Chute Creek*		A.R. 701	Nanaimo	D	Core, raw	100.0	DH-85-27	3.25	24.00	28.02	44.73	ad	38.52		
11	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	1	Core, raw		Weighted avg.	0.84	23.94	24.73	51.32	ad	32.52	3.5	clean
12	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	2	Core, raw		Weighted avg.	1.09	24.22	25.37	47.56	ad	34.79	1.0	clean
13	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	3	Core, raw		Weighted avg.	0.99	25.14	24.10	46.20	ad	34.28	1.0	clean
14	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	4	Core, raw		Weighted avg.	1.02	17.60	26.80	53.54	ad	33.36	2.0	clean
15	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	5	Core, raw		Weighted avg.	1.16	17.29	25.59	54.34	ad	32.02	1.0	clean
16	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	6	Core, raw		Weighted avg.	1.21	20.13	25.28	51.04	ad	33.12	1.0	clean
17	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	7	Core, raw		Weighted avg.	1.14	18.50	26.24	51.21	ad	33.88	1.5	clean
18	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	8	Core, raw		Weighted avg.	1.21	16.74	26.44	54.43	ad	32.69	1.0	clean
19	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	9	Core, raw		Weighted avg.	1.06	16.03	30.02	50.92	ad	37.09	1.5	clean
20	Telkwa	*Telkwa*	Goathorn East	A.R. 239	Skeena	10	Core, raw		Weighted avg.	1.06	17.46	28.00	50.02	ad	35.89	2.0	clean
21	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	A	Core, raw	100.0	DH-82006	0.75	17.19	8.54	73.52	ad	10.41		
22	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	B	Core, raw	78.0	DH-82006	0.86	28.83	7.39	62.92	ad	10.51		
23	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	C	Core, raw	100.0	DH-82002	1.48	25.67	7.77	65.08	ad	10.67		
24	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	D	Core, raw	89.8	DH-82006	1.57	35.78	7.40	55.25	ad	11.81		
25	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	D	Core, raw	86.8	DH-82002	1.14	25.63	9.22	64.01	ad	12.59		
26	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	E	Core, raw	89.1	?	1.34	27.16	7.94	63.56	ad	11.10		
27	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	G	Core, raw	84.5	DH-82001	1.85	32.05	7.40	58.70	ad	11.20		
28	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	G upper	Core, raw	94.7	?	1.43	25.59	7.75	65.23	ad	10.62		
29	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	H	Core, raw	96.5	DH-82002	1.77	40.16	7.19	50.88	ad	12.38		

Table Item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
30	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	I	Core, raw	79.9	DH-82003	1.50	34.27	7.82	56.41	ad	12.17		
31	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	I lower	Core, raw	85.9	DH-82001	1.63	16.91	6.99	74.47	ad	8.58		
32	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	I upper	Core, raw	91.7	DH-82001	2.04	18.01	7.25	72.70	ad	9.07		
33	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	J	Core, raw	100.0	DH-82001	1.13	22.07	9.05	67.75	ad	11.78		
34	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	K	Core, raw	68.1	DH-82001	1.75	28.02	8.78	61.45	ad	12.50		
35	Klappan		Hobbit-Broach	A.R. 695	Bowser Lake	K	Core, raw	76.4	DH-82003	1.67	35.46	7.80	55.07	ad	12.41		
36	Klappan		Lost-Fox	A.R. 707	Bowser Lake	D	Core, raw	100.0	DH-85016	0.81	33.33	7.56	58.30	ad	11.48		
37	Klappan		Lost-Fox	A.R. 707	Bowser Lake	E	Core, raw	86.3	DH-85004	1.00	13.76	6.68	78.56	ad	7.84		
38	Klappan		Lost-Fox	A.R. 707	Bowser Lake	E	Core, raw	95.3	DH-85016	0.88	18.24	7.32	73.56	ad	9.05		
39	Klappan		Lost-Fox	A.R. 707	Bowser Lake	F	Core, raw	90.8	DH-85004	2.89	42.15	5.87	49.09	ad	10.68		
40	Klappan		Lost-Fox	A.R. 707	Bowser Lake	F	Core, raw	86.9	DH-85014	1.23	35.85	6.59	56.33	ad	10.47		
41	Klappan		Lost-Fox	A.R. 707	Bowser Lake	G	Core, raw	96.8	DH-85001	0.96	39.68	8.05	51.31	ad	13.56		
42	Klappan		Lost-Fox	A.R. 707	Bowser Lake	H	Core, raw	90.6	DH-85001	1.20	29.45	6.66	62.69	ad	9.60		
43	Klappan		Lost-Fox	A.R. 707	Bowser Lake	H	Core, raw	97.9	DH-85013	1.31	33.85	7.89	56.95	ad	12.17		
44	Klappan		Lost-Fox	A.R. 707	Bowser Lake	I	Core, raw	100.0	DH-85001	0.95	20.85	6.35	71.85	ad	8.12		
45	Klappan		Lost-Fox	A.R. 707	Bowser Lake	I	Core, raw	93.6	DH-85016	1.75	24.55	7.12	66.58	ad	9.66		
46	Klappan		Lost-Fox	A.R. 707	Bowser Lake	K	Core, raw	100.0	DH-85005	2.65	22.46	5.73	69.16	ad	7.65		
47	Klappan		Lost-Fox	A.R. 707	Bowser Lake	K	Core, raw	85.7	DH-85009	1.70	31.53	7.65	59.12	ad	11.46		
48	Klappan		Lost-Fox	A.R. 707	Bowser Lake	L	Core, raw	94.8	DH-85027	0.95	39.36	9.48	50.21	ad	15.88		
49	Klappan		Lost-Fox	A.R. 707	Bowser Lake	L	Core, raw	100.0	DH-85005	0.86	34.45	6.05	58.64	ad	9.35		
50	Klappan		Lost-Fox	A.R. 707	Bowser Lake	M	Core, raw	83.6	DH-85009	0.84	33.63	10.03	55.50	ad	15.31		
51	Klappan		Lost-Fox	A.R. 707	Bowser Lake	M upper	Core, raw	100.0	DH-85027	1.10	32.86	6.46	59.58	ad	9.78		
52	Klappan		Lost-Fox	A.R. 707	Bowser Lake	N	Core, raw	90.9	DH-85027	1.09	37.31	7.40	54.20	ad	12.01		
53	Klappan		Lost-Fox	A.R. 707	Bowser Lake	O	Core, raw	91.1	DH-85027	0.99	39.72	5.86	53.43	ad	9.88		
54	Klappan		Lost-Fox	A.R. 707	Bowser Lake	O	Core, raw	75.8	DH-85005	0.76	26.70	5.80	66.74	ad	8.00		
55	E. Kootenay	*Sage Creek*	South Hill	A.R. 365	Mist Mountain	5	Bulk, raw		Adit 73-5A-S	1.00	36.60	19.80	42.10	ad	31.99	2.5	raw
56	E. Kootenay	*Sage Creek*	North Hill	A.R. 365	Mist Mountain	4 lower	Bulk, raw		Adit 72-4-N	1.20	26.90	20.40	51.00	ad	28.57	2.0	raw
57	E. Kootenay	*Sage Creek*	North Hill	A.R. 365	Mist Mountain	4 upper	Bulk, raw		Adit 72-4-N	1.40	19.70	22.80	56.50	ad	28.75	2.5	raw
58	E. Kootenay	*Sage Creek*	North Hill	A.R. 365	Mist Mountain	2	Bulk, raw		Adit 72-2-N	0.90	20.70	21.10	56.50	ad	27.19	5.5	raw
59	E. Kootenay	*Lodgepole*		A.R. 428	Mist Mountain	1	Bulk, raw		Adit LP-1	0.80	37.40	16.20	45.60	ad	26.21	1.0	raw
60	E. Kootenay	*Lodgepole*		A.R. 428	Mist Mountain	2	Bulk? raw		?	0.90	24.90	16.20	58.00	ad	21.83	3.0	raw

Table item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
61	E. Kootenay	*Dominion Coal Block*	Parcel 82, Morrissey Creek	A.R. 292	Mist Mountain	K1	Bulk, clean		Adit K1 lower	1.20	8.50	14.50	75.80	ad	16.06	3.5	clean
62	E. Kootenay	*Dominion Coal Block*	Parcel 82, Morrissey Creek	A.R. 292	Mist Mountain	K5	Bulk, clean		Adit K5 upper	1.00	8.90	16.20	74.00	ad	17.96	4.5	clean
63	E. Kootenay	*Dominion Coal Block*	Parcel 82, Flathead Ridge	A.R. 292	Mist Mountain	A	Bulk, clean		Adit TA-1	1.40	4.60	21.00	73.00	ad	22.34	7.5	clean
64	E. Kootenay	*Dominion Coal Block*	Parcel 82, Flathead Ridge	A.R. 292	Mist Mountain	B	Bulk, clean		Adit TB-6	1.80	6.80	23.20	68.20	ad	25.38	8.5	clean
65	E. Kootenay	*Dominion Coal Block*	Parcel 82, Flathead Ridge	A.R. 292	Mist Mountain	B	Bulk, clean		Adit TB-3	1.30	6.00	20.80	71.90	ad	22.44	7.5	clean
66	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	10	Bulk, raw		Adit 4	1.60	27.50	21.80	49.10	ad	30.75	5.5	raw
67	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	10 upper	Bulk, raw		Adit 4	1.70	19.20	24.20	54.90	ad	30.59	6.5	raw
68	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	9 lower	Bulk, raw		Adit 2	0.90	17.40	26.50	55.20	ad	32.44	4.0	raw
69	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	9 middle	Bulk, raw		Adit 1	1.60	26.50	23.80	48.10	ad	33.10	3.0	raw
70	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	9 upper	Bulk, raw		Adit 3	2.20	13.80	24.50	59.50	ad	29.17	5.0	raw
71	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	8	Bulk, raw		Adit 6	1.40	13.00	25.70	59.90	ad	30.02	3.5	raw
72	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	7	Bulk, raw		Adit 10	1.60	25.20	25.10	48.10	ad	34.29	2.0	raw
73	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	5	Bulk, raw		Adit 13	1.00	15.70	26.70	56.60	ad	32.05	2.5	raw
74	E. Kootenay	*Dominion Coal Block*	Parcel 73	Co. rpt.	Mist Mountain	4	Bulk, raw		Adit 8	2.70	20.60	26.00	50.70	ad	33.90	2.5	raw
75	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	10	Bulk, raw		Adit 21	1.40	15.80	25.90	56.90	ad	31.28	2.5	raw
76	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	9 lower	Bulk, raw		Adit 23	1.50	18.70	26.40	46.60	ad	36.16	5.5	raw
77	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	9	Bulk, raw		Adit 23	1.20	23.60	26.20	49.00	ad	34.84	4.5	raw

Table Item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
78	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	8	Bulk, raw		Adit 19	1.40	14.50	26.00	58.10	ad	30.92	2.0	raw
79	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	7	Bulk, raw		Adit 22	1.20	31.80	23.80	43.20	ad	35.52	2.5	raw
80	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt. Co. rpt.	Mist Mountain	5	Bulk, raw		Adit 17	1.70	22.00	24.80	51.50	ad	32.50	1.5	raw
81	E. Kootenay	*Hosmer-Wheeler*	Hosmer Ridge	Co. rpt.	Mist Mountain	4	Bulk, raw		Adit 25	2.00	23.40	24.60	50.00	ad	32.98	2.5	raw
82	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	3	Bulk, raw		Adit 20	1.80	15.40	28.80	54.00	ad	34.78	6.0	raw
83	E. Kootenay	*Hosmer-Wheeler*	Hosmer Ridge	Co. rpt.	Mist Mountain	3	Bulk, raw		Adit 11	2.00	7.00	31.30	59.70	ad	34.40	7.5	raw
84	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	2	Bulk, raw		Adit 15	2.60	33.50	24.00	39.90	ad	37.56	3.0	raw
85	E. Kootenay	*Hosmer-Wheeler*	Wheeler Ridge	Co. rpt.	Mist Mountain	1	Bulk, raw		Adit 16	2.20	23.30	27.00	47.50	ad	36.24	1.0	raw
86	E. Kootenay	*Ewin Pass*		A.R. 396&397	Mist Mountain	8	Channel, raw		Adit 3	0.86	18.29	28.80	52.05	ad	35.62	5.0	clean
87	E. Kootenay	*Ewin Pass*		A.R. 396	Mist Mountain	7	Channel, raw?		Adit 1	0.62	7.87	27.23	64.28	ad	29.76	7.5	raw?
88	E. Kootenay	*Ewin Pass*		A.R. 398	Mist Mountain	5	Bulk, raw?		Adit 4	1.20	8.70	26.30	63.80	ad	29.19	8.5	raw?
89	E. Kootenay	*Ewin Pass*		A.R. 396&397	Mist Mountain	4	Channel, raw?		Adit 2	0.60	6.47	27.16	65.77	ad	29.23	7.5	raw
90	E. Kootenay	*Elk River*	?	A.R. 274	Morrissey	1	Core, raw	100.0	DH-EB-53	0.60	25.70	18.30	55.40	ad	24.83	9.0	clean
91	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	2	Channel, raw		Adit 2	0.00	31.20	16.00	52.80	dry	23.26	8.0	clean
92	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	3	Channel, raw		Adit 3	0.00	30.20	14.40	55.40	dry	20.63	6.5	clean
93	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	4	Channel, raw		Adit 4	0.00	26.70	14.60	58.70	dry	19.92	1.0	clean
94	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	4A	Channel, raw		Adit 4	0.00	35.50	13.70	50.80	dry	21.24	7.0	clean
95	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	6	Channel, raw		Adit 2?	0.00	16.30	16.60	67.10	dry	19.83	3.5	clean
96	E. Kootenay	*Elk River*	Weary Ridge	A.R. 274	Mist Mountain	7	Core, raw	75.0	DH-EB-31	0.60	21.90	15.90	61.60	ad	20.52	2.5	clean
97	E. Kootenay	*Elk River*	?	A.R. 274	Mist Mountain	8	Channel, raw		Adit 8	0.00	30.19	15.10	54.71	dry	21.63	6.0	clean?
98	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	9	Channel, raw		Adit 9	0.00	24.94	16.00	59.06	dry	21.32	3.0	clean
99	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	10	Channel, raw		Adit 10	0.00	25.40	17.60	57.00	dry	23.59	6.0	clean
100	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	12	Channel, raw		Trench EB-T16	0.00	39.51	16.20	44.29	dry	26.78	8.0	clean

Table Item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
101	E. Kootenay	*Elk River*	Little Weary Ridge	A.R. 274	Mist Mountain	13	Core, raw	98.0	DH-EB-6	1.10	27.40	21.40	50.20	ad	29.89	8.5	clean
102	E. Kootenay	*Elk River*	Little Weary Ridge	A.R. 274	Mist Mountain	14	Core, raw	100.0	DH-EB-14	1.00	27.00	17.40	54.60	ad	24.17	8.5	clean
103	E. Kootenay	*Elk River*	Weary Ridge	A.R. 274	Mist Mountain	15	Core, raw		DH-EB-39	1.00	7.50	26.50	65.00	ad	28.96	9.0	clean
104	E. Kootenay	*Elk River*	?	A.R. 274	Mist Mountain	16	Core, raw	100.0	DH-EB-12	1.50	15.30	24.30	58.90	ad	29.21	8.5	clean
105	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	17	Channel, raw		Trench EB-T17	0.00	17.90	26.30	55.80	dry	32.03	8.0	clean
106	E. Kootenay	*Elk River*	Proposed Elco mine-site	A.R. 274	Mist Mountain	18	Channel, raw		Trench EB-T17	0.00	30.20	25.10	44.70	dry	35.96	8.0	clean
107	Peace River	*Carbon Creek*		A.R. 495	Gething	14	Core, raw		DH-71-1	1.08	14.35	19.71	64.86	ad	23.31	4.0	raw
108	Peace River	*Carbon Creek*		A.R. 496	Gething	14	Core, raw		DH-72-14	1.35	7.58	19.03	72.04	ad	20.90	2.0	raw
109	Peace River	*Carbon Creek*		A.R. 495	Gething	15	Core, raw		DH-71-1	1.28	5.21	20.96	72.55	ad	22.41	2.0	raw
110	Peace River	*Carbon Creek*		A.R. 496	Gething	15	Core, raw		DH-72-14	0.98	9.65	21.36	68.01	ad	23.90	4.5	raw
111	Peace River	*Carbon Creek*		A.R. 495	Gething	31	Core, raw		DH-71-3	1.55	14.76	23.41	60.28	ad	27.97	7.0	raw
112	Peace River	*Carbon Creek*		A.R. 495	Gething	31	Core, raw		DH-71-9	1.72	36.55	18.97	42.76	ad	30.73	4.5	raw
113	Peace River	*Carbon Creek*		A.R. 504	Gething	40	Core, raw	99.0	DH-81-89	2.38	10.81	28.02	58.79	ad	32.28	6.0	raw
114	Peace River	*Carbon Creek*		A.R. 504	Gething	40	Core, raw	100.0	DH-81-90	2.64	8.06	27.45	61.85	ad	30.74	6.0	raw
115	Peace River	*Carbon Creek*		A.R. 504	Gething	46	Core, raw		DH-81-88	2.59	17.04	22.69	57.68	ad	28.23	2.5	raw
116	Peace River	*Carbon Creek*		A.R. 504	Gething	46	Core, raw	100.0	DH-81-90	3.20	5.70	25.98	65.12	ad	28.52	2.5	raw
117	Peace River	*Carbon Creek*		A.R. 504	Gething	47	Core, raw	100.0	DH-81-90	2.81	24.83	21.64	50.72	ad	29.91	1.5	raw
118	Peace River	*Carbon Creek*		A.R. 504	Gething	47	Core, raw	94.0	DH-81-92	3.76	9.54	22.72	63.98	ad	26.21	0.5	raw
119	Peace River	*Carbon Creek*		A.R. 504	Gething	51	Core, raw		DH-81-88	2.95	7.16	25.41	64.48	ad	28.27	1.5	raw
120	Peace River	*Carbon Creek*		A.R. 504	Gething	51	Core, raw	100.0	DH-81-89	3.70	15.33	24.70	56.27	ad	30.51	3.0	raw
121	Peace River	*Carbon Creek*		A.R. 504	Gething	51A	Core, raw	100.0	DH-81-90	3.26	8.19	25.57	62.98	ad	28.88	1.5	raw
122	Peace River	*Carbon Creek*		A.R. 504	Gething	52	Core, raw	98.0	DH-81-89	2.76	28.91	24.57	43.76	ad	35.96	3.5	raw
123	Peace River	*Carbon Creek*		A.R. 504	Gething	52	Core, raw		DH-81-90	2.31	20.07	26.38	51.24	ad	33.99	3.5	raw
124	Peace River	*Carbon Creek*		A.R. 504	Gething	54	Core, raw	88.0	DH-81-88	2.58	4.47	26.99	65.96	ad	29.04	1.5	raw
125	Peace River	*Carbon Creek*		A.R. 504	Gething	55	Core, raw	86.0	DH-81-90	3.50	5.47	28.43	62.60	ad	31.23	1.5	raw
126	Peace River	*Carbon Creek*		A.R. 504	Gething	58	Core, raw	98.0	DH-81-91	2.73	18.32	26.97	51.98	ad	34.16	2.0	raw
127	Peace River	*Carbon Creek*		A.R. 504	Gething	63	Core, raw	91.0	DH-81-91	2.93	14.95	30.60	51.52	ad	37.26	2.0	raw
128	Peace River	*Willow Creek*		A.R. 690	Gething	1	Core, raw	95.0	DH-81-31	0.00	6.85	22.93	70.22	dry	24.62	4.5	raw

Table Item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
129	Peace River	*Willow Creek*		A.R. 690	Gething	2	Core, raw	92.0	DH-81-22	0.00	10.09	22.48	67.43	dry	25.00	8.5	raw
130	Peace River	*Willow Creek*		A.R. 690	Gething	3	Core, raw	100.0	DH-81-15	0.00	11.79	19.70	68.51	dry	22.33	1.5	raw
131	Peace River	*Willow Creek*		A.R. 690	Gething	4	Core, raw	100.0	DH-81-39	0.00	11.34	19.49	69.17	dry	21.98	1.0	raw
132	Peace River	*Willow Creek*		A.R. 690	Gething	5	Core, raw	100.0	DH-81-37	0.00	8.95	16.22	74.83	dry	17.81	1.5	raw
133	Peace River	*Willow Creek*		A.R. 690	Gething	6	Core, raw	99.0	DH-81-10	0.00	7.03	20.54	72.43	dry	22.09	1.0	raw
134	Peace River	*Willow Creek*		A.R. 690	Gething	7	Core, raw	100.0	DH-81-25	0.00	9.04	17.73	73.23	dry	19.49	1.5	raw
135	Peace River	*Willow Creek*		A.R. 690	Gething	A	Core, raw	100.0	DH-81-30	0.00	6.75	19.78	73.47	dry	21.21	4.0	raw
136	Peace River	*Goodrich*		A.R. 533	Gething	6	Core, raw		DH-81005	0.79	26.58	23.62	49.01	ad	32.52	7.0	raw
137	Peace River	*Goodrich*		A.R. 533	Gething	5	Core, raw		DH-81015	0.62	16.93	19.71	62.74	ad	23.91	1.5	raw
138	Peace River	*Goodrich*		A.R. 533	Gething	Lower part #3	Core, raw	54.6	DH-81014	0.36	10.58	25.13	63.93	ad	28.22	4.5	raw
139	Peace River	*Goodrich*		A.R. 533	Gething	Upper part #3	Core, raw	75.0	DH-81014	0.56	18.05	22.66	58.73	ad	27.84	7.0	raw
140	Peace River	*Goodrich*		A.R. 533	Gething	2	Core, raw	96.0	DH-81010	0.44	29.97	21.56	48.03	ad	30.98	5.5	raw
141	Peace River	*Goodrich*		A.R. 533	Gething	Lower part #1	Core, raw	85.3	DH-81005	1.06	15.19	26.24	57.51	ad	31.33	4.0	raw
142	Peace River	*Goodrich*		A.R. 533	Gething	Upper part #1	Core, raw	85.0	DH-81005	1.28	10.24	23.90	64.58	ad	27.01	1.0	raw
143	Peace River	*Burnt River*		A.R. 489	Gething	Lower	Bulk, raw		Adit	0.50	8.60	13.40	77.05	ad	14.81		
144	Peace River	*Burnt River*		A.R. 489	Gething	Upper	Bulk, raw		Adit	0.70	6.40	13.00	79.90	ad	13.99		
145	Peace River	*Burnt River*		A.R. 489	Gething	60	Bulk, raw		Surface	0.70	11.70	16.40	71.20	ad	18.72	1.0	raw
146	Peace River	*Sukunka*	No. 1 mine	A.R. 663	Gething	Chamberlain	Bulk, raw		No. 1 mine	0.80	10.70	20.60	67.90	ad	23.28	7.0	raw
147	Peace River	*Sukunka*	Main mine	A.R. 663	Gething	Chamberlain	Bulk, raw		Main mine	0.60	11.00	20.50	67.90	ad	23.19	7.5	raw
148	Peace River	*Sukunka*	No. 1 mine	A.R. 663	Gething	Skeeter	Bulk, raw		No. 1 mine	1.00	24.50	18.70	55.60	ad	25.17	6.5	raw
149	Peace River	*Sukunka*	Saddle Creek	A.R. 663	Gething	Bird	Bulk, raw		Saddle Ck. adit	0.80	8.50	21.70	69.00	ad	23.93	8.5	raw
150	Peace River	*Sukunka*		A.R. 663	Gates	Gates B	Core, raw		DH-BP-?	0.70	6.10	27.70	65.50	ad	29.72	5.5	raw
151	Peace River	*Sukunka*		A.R. 663	Gates	Gates D	Core, raw		DH-BP-6	0.60	20.10	23.40	55.90	ad	29.51	5.5	raw
152	Peace River	*Sukunka*		A.R. 663	Gates	Gates E	Core, raw		DH-BP-14	0.60	26.70	21.60	51.10	ad	29.71	4.5	raw
153	Peace River	*Mt. Speiker*	Mt. Spieker	A.R. 556	Gething	Lower Bird	Core, raw	85.9	DH-MS-20A	0.70	5.40	19.80	74.10	ad	21.09	7.5	raw
154	Peace River	*Mt. Spieker*	Mt. Spieker	A.R. 556	Gething	Upper Bird	Core, raw	51.7	DH-MS-20A	0.40	8.70	19.80	71.10	ad	21.78	7.5	raw
155	Peace River	*Mt. Spieker*	EB1	A.R. 556	Gates	A	Core, raw	88.5	DH-MS-16	0.70	8.00	22.60	68.70	ad	24.75	6.5	raw

Table Item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
156	Peace River	*Mt. Spieker*	Mt. Spieker	A.R. 556	Gates	B	Core, raw	98.5	DH-MS-20	0.80	11.10	25.00	63.10	ad	28.38	5.5	raw
157	Peace River	*Mt. Spieker*	Underground mining area	A.R. 556	Gates	C2	Core, raw	65.6	DH-MS-33	0.60	10.80	22.00	66.00	ad	25.00	4.0	raw
158	Peace River	*Mt. Spieker*	EB1	A.R. 556	Gates	D	Core, raw	69.0	DH-MS-19	0.80	32.30	20.50	46.40	ad	30.64	1.5	raw
159	Peace River	*Monkman*	Duchess	A.R. 547	Gething	Unnamed	Core, raw	73.0	DH-MUD-81-04	0.56	26.36	16.93	56.15	ad	23.17	1.5	raw
160	Peace River	*Monkman*	Duchess	A.R. 547	Gething	Unnamed	Core, raw	82.0	DH-MUD-81-04	0.59	17.26	17.79	64.36	ad	21.66	1.0	raw
161	Peace River	*Monkman*	Duchess	A.R. 547	Gething	Unnamed	Core, raw	100.0	DH-MUD-81-07	0.70	15.11	19.89	64.30	ad	23.63	6.5	raw
162	Peace River	*Monkman*	Duchess	A.R. 547	Gates	B1-B2	Core, raw	92.0	DH-MUD-81-03	0.72	13.96	21.67	63.65	ad	25.40	7.5	raw
163	Peace River	*Monkman*	Duchess	A.R. 547	Gates	B3	Core, raw	76.0	DH-MUD-81-03	0.78	23.14	20.26	55.82	ad	26.63	7.0	raw
164	Peace River	*Monkman*	Duchess	A.R. 547	Gates	B4	Core, raw	82.0	DH-MUD-81-03	0.74	21.10	21.59	56.57	ad	27.62	6.5	raw
165	Peace River	*Monkman*	Duchess	A.R. 547	Gates	B5	Core, raw	82.0	DH-MUD-81-09	0.78	33.91	21.76	43.55	ad	33.32	5.0	raw
166	Peace River	*Monkman*	Duchess	A.R. 547	Gates	B7	Core, raw	88.0	DH-MUD-81-13	0.45	16.76	22.40	60.39	ad	27.06	7.0	raw
167	Peace River	*Monkman*	Duchess	A.R. 547	Gates	B9	Core, raw	98.0	DH-MUD-81-13	1.05	16.62	22.81	59.52	ad	27.71	2.0	raw
168	Peace River	*Monkman*	Duke	A.R. 546	Minnes	2	Core, raw	70.0	DH-MDD-80-11	0.46	3.10	17.82	78.62	ad	18.48	2.5	raw
169	Peace River	*Monkman*	Duke	A.R. 546	Minnes	6	Core, raw	69.0	DH-MDD-80-11	0.50	4.10	16.88	78.52	ad	17.69	1.5	raw
170	Peace River	*Monkman*	Duke	A.R. 546	Minnes	7	Core, raw	45.0	DH-MDD-80-11	0.68	11.15	16.17	72.00	ad	18.34	1.5	raw
171	Peace River	*Monkman*	Duke	A.R. 546	Minnes	8	Core, raw	64.0	DH-MDD-80-11	0.62	7.57	16.56	75.25	ad	18.04	1.5	raw
172	Peace River	*Monkman*	Duke	A.R. 546	Minnes	10	Core, raw	73.0	DH-MDD-80-11	0.57	23.45	16.99	58.99	ad	22.36	8.0	raw
173	Peace River	*Monkman*	Duke, proposed dump site	A.R. 464	Gething	Lower (low. bench)	Core, raw	100.0	DH-MRC-82-06	0.00	22.26	17.11	60.63	dry	22.01	1.5	raw
174	Peace River	*Monkman*	Duke, proposed dump site	A.R. 464	Gething	Lower (up. bench)	Core, raw	100.0	DH-MRC-82-06	0.00	12.78	18.79	68.43	dry	21.54	2.5	raw
175	Peace River	*Monkman*	Duke, proposed dump site	A.R. 464	Gething	Upper (low. bench)	Core, raw	100.0	DH-MRC-82-06	0.00	17.01	19.22	63.77	dry	23.16	5.0	raw
176	Peace River	*Monkman*	Duke	A.R. 545	Gates	B1	Core, raw	100.0	DH-MDD-79-06	0.25	13.49	23.61	62.65	ad	27.37	8.5	raw
177	Peace River	*Monkman*	Duke	A.R. 545	Gates	B1	Core, raw	100.0	DH-MDD-79-01	0.17	27.82	20.14	51.87	ad	27.97	5.5	raw
178	Peace River	*Monkman*	Duke	A.R. 545	Gates	B3	Core, raw	91.0	DH-MDD-79-03	0.61	21.20	20.68	57.51	ad	26.45	7.0	raw
179	Peace River	*Monkman*	Duke	A.R. 545	Gates	B4	Core, raw	99.0	DH-MDD-79-03	0.58	15.95	22.59	60.88	ad	27.06	7.5	raw
180	Peace River	*Monkman*	Duke	A.R. 546	Gates	B5	Core, raw	74.0	DH-MDD-80-07	1.01	15.27	20.66	63.06	ad	24.68	4.0	raw
181	Peace River	*Monkman*	Duke	A.R. 545	Gates	B7	Core, raw	94.0	DH-MDD-79-03	0.68	30.84	20.57	47.91	ad	30.04	7.0	raw

Table item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
182	Peace River	*Monkman*	Duke	A.R. 545	Gates	B9	Core, raw	100.0	DH-MDD-79-02	0.29	24.39	20.96	54.36	ad	27.83	4.0	raw
183	Peace River	*Monkman*	Honeymoon	A.R. 546	Gates	B1	Core, raw	80.0	DH-MDD-80-01	0.60	4.39	22.84	72.17	ad	24.04	8.5	raw
184	Peace River	*Monkman*	Honeymoon	A.R. 546	Gates	B3	Core, raw	80.0	DH-MDD-80-01	0.64	10.37	22.03	66.96	ad	24.76	7.5	raw
185	Peace River	*Monkman*	Honeymoon	A.R. 546	Gates	B4	Core, raw	79.0	DH-MDD-80-01	0.75	15.88	20.68	62.39	ad	24.89	4.0	raw
186	Peace River	*Monkman*	Honeymoon	A.R. 545	Gates	B5	Core, raw	79.0	DH-MDD-79-10	0.62	20.92	20.24	58.22	ad	25.80	2.5	raw
187	Peace River	*Monkman*	Honeymoon	A.R. 545	Gates	B6	Core, raw	85.0	DH-MDD-79-10	0.25	46.16	18.81	34.78	ad	35.10	3.0	raw
188	Peace River	*Monkman*	Honeymoon	A.R. 545	Gates	B7	Core, raw	100.0	DH-MDD-79-10	0.59	28.06	22.41	48.94	ad	31.41	5.5	raw
189	Peace River	*Monkman*	Honeymoon	A.R. 545	Gates	B9	Core, raw	100.0	DH-MDD-79-08	0.75	11.55	21.93	65.77	ad	25.01	2.5	raw
190	Peace River	*Belcourt*	Omega	A.R. 463	Gates	1	Core, raw	55.6	DH-BD-7806	0.58	10.36	17.35	71.71	ad	19.48	3.0	raw
191	Peace River	*Belcourt*	Holtslander	A.R. 463	Gates	1	Core, raw	58.9	DH-BD-7801	0.88	12.48	23.67	62.97	ad	27.32	6.0	raw
192	Peace River	*Belcourt*	Red Deer	A.R. 463	Gates	1	Core, raw	93.1	DH-BD-7807	0.87	15.60	24.07	59.46	ad	28.82	6.0	raw
193	Peace River	*Belcourt*	Omega	A.R. 463	Gates	2	Core, raw	60.0	DH-BD-7806	0.52	20.88	15.33	63.27	ad	19.50	3.5	raw
194	Peace River	*Belcourt*	Red Deer	A.R. 463	Gates	2	Core, raw	78.0	DH-BD-7812	0.45	7.15	27.60	64.80	ad	29.87	4.0	raw
195	Peace River	*Belcourt*	Omega	A.R. 463	Gates	3	Core, raw	58.8	DH-BD-7806	0.52	23.12	15.44	60.92	ad	20.22	2.5	raw
196	Peace River	*Belcourt*	Omega	A.R. 463	Gates	5	Core, raw	76.0	DH-BD-7806	0.54	10.08	19.22	70.16	ad	21.50	5.5	raw
197	Peace River	*Belcourt*	Holtslander	A.R. 463	Gates	5	Core, raw	53.3	DH-BD-7801	0.94	18.56	22.88	57.62	ad	28.42	5.0	raw
198	Peace River	*Belcourt*	Holtslander	A.R. 463	Gates	6	Core, raw	85.4	DH-BD-7801	1.14	26.35	20.56	51.95	ad	28.35	5.0	raw
199	Peace River	*Belcourt*	Red Deer	A.R. 463	Gates	7	Core, raw	91.1	DH-BD-7802	1.20	22.26	24.24	52.30	ad	31.67	5.5	raw
200	Peace River	*Belcourt*	Red Deer	A.R. 463	Gates	8	Core, raw	77.9	DH-BD-7802	1.05	38.42	19.69	40.84	ad	32.53	4.0	raw
201	Peace River	*Saxon*	Saxon East	A.R. 628	Gates	1	Bulk, raw		Adit 77-1-1	0.80	26.30	16.50	56.40	ad	22.63	4.0	raw
202	Peace River	*Saxon*	Saxon South	A.R. 628	Gates	1	Bulk, raw		Adit 77-1-3	0.60	21.30	19.10	59.00	ad	24.46	4.0	raw
203	Peace River	*Saxon*	Saxon East	A.R. 628	Gates	2	Bulk, raw		Adit 77-2-2	0.80	19.50	17.00	62.70	ad	21.33	4.0	raw
204	Peace River	*Saxon*	Saxon South	A.R. 628	Gates	2	Bulk, raw		Adit 77-2-4	1.70	8.50	22.10	67.70	ad	24.61	7.5	raw
205	Peace River	*Saxon*	Saxon South	A.R. 628	Gates	3	Core, raw	88.0	DH-SD-7720	0.60	17.00	21.80	60.60	ad	26.46	7.5	clean
206	Peace River	*Saxon*	Saxon East	A.R. 628	Gates	4	Bulk, raw		Adit 76-4-1	0.40	18.30	18.40	62.90	ad	22.63	4.0	raw
207	Peace River	*Saxon*	Saxon South	A.R. 628	Gates	4	Bulk, raw		Adit 77-4-5	0.90	23.40	21.60	54.10	ad	28.53	6.0	raw
208	Peace River	*Saxon*	Saxon East	A.R. 628	Gates	5	Core, raw	100.0	DH-SD-7702	0.50	6.70	23.60	69.20	ad	25.43	8.5	raw
209	Peace River	*Saxon*	Saxon South	A.R. 628	Gates	5	Core, raw	100.0	DH-SD-7726	0.80	21.60	21.80	55.80	ad	28.09	8.5	raw
210	Peace River	*Saxon*	Saxon South	A.R. 628	Gates	10	Core, raw	100.0	DH-SD-7724	1.00	8.30	26.50	64.20	ad	29.22	7.5	raw
211	Peace River	*Wapiti*		A.R. 683	Wapiti	1	Core, raw	100.0	DH-W-7943	11.00	22.20	29.00	37.80	ar	43.41		
212	Peace River	*Wapiti*		A.R. 685	Wapiti	1	Cores, raw		Avg. of all DHs	2.42	27.19	29.47	40.92	ad	41.87		

Table Item	Coalfield or basin	Property	Pit or Area	Reference	Unit	Seam	Sample Type	Core Recovery (%)	Sample desc.	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Basis	Vol. mat. (daf) (%)	FSI	Raw/ clean
213	Peace River	*Wapiti*		A.R. 685	Wapiti	1	Bulk, raw		Adit 1	3.70	27.25	27.73	41.31	ad	40.17		
214	Bowron River			A.R. 16		Lower	Bulk, raw			2.24	36.10	30.99	30.67	ad	50.26		
215	Bowron River			A.R. 16		Lower (mn. bench)	Core, raw		DH-77-5	2.95	33.36	31.20	32.49	ad	48.99		
216	Bowron River			A.R. 16		Lower (mn. bench)	Core, raw		DH-77-7	3.93	23.65	36.08	36.34	ad	49.82		
217	Bowron River			A.R. 16		Lower (low. bench)	Core, raw		DH-77-11	4.36	29.81	26.38	39.45	ad	40.07		
218	Hat Creek		No. 1 deposit	Sinclair	Kamloops	D zone	Core, raw		DH-76-135	0.00	25.99	32.91	41.10	dry	44.47		
219	Hat Creek		No. 1 deposit	Sinclair	Kamloops	C zone	Core, raw		DH-76-136	0.00	51.83	26.58	21.59	dry	55.18		
220	Hat Creek		No. 1 deposit	Sinclair	Kamloops	B zone	Core, raw		DH-76-135	0.00	34.84	31.37	33.78	dry	48.15		
221	Hat Creek		No. 1 deposit	Sinclair	Kamloops	A zone	Core, raw		DH-76-135	0.00	42.92	29.63	27.46	dry	51.90		
222	Hat Creek		No. 2 deposit,	A.R. 135	Kamloops		Core, raw		DH-75-100	0.00	35.21	33.64	31.15	dry	51.92		
223	Hat Creek		No. 2 deposit,	A.R. 135	Kamloops		Core, raw		DH-75-080	0.00	27.07	34.35	38.38	dry	47.23		
224	Hat Creek		No. 2 deposit,	A.R. 135	Kamloops		Core, raw		DH-75-077	0.00	35.63	32.39	31.97	dry	50.33		
225	Merritt		Coldwater Hill	A.R. 149	Kamloops	8	Core, clean	87.3	DH-2	4.00	7.30	37.60	51.10	ad	42.39	1.5	clean
226	Merritt		Coldwater Hill	A.R. 149	Kamloops	8	Core, clean	90.9	DH-3	3.30	7.50	38.10	51.10	ad	42.71	2.5	clean
227	Merritt		Coldwater Hill	A.R. 149	Kamloops	No name	Core,	89.9	DH-3	3.20	6.10	38.50	52.20	ad	42.45	2.0	clean
228	Merritt		Coldwater Hill	A.R. 149	Kamloops	4	Core, clean	69.1	DH-3	2.80	6.40	39.50	51.30	ad	43.50	3.0	clean
229	Merritt		Coldwater Hill	A.R. 149	Kamloops	4	Core, clean	72.3	DH-4	2.00	9.00	34.20	54.80	ad	38.43	7.5	clean
230	Merritt		Coldwater Hill	A.R. 149	Kamloops	5	Core, clean	97.0	DH-2	3.60	7.90	38.10	50.40	ad	43.05	3.0	clean
231	Merritt		Coldwater Hill	A.R. 149	Kamloops	5	Core,	81.9	DH-3	2.50	7.70	36.50	53.30	ad	40.65	2.5	clean
232	Merritt		Coldwater Hill	A.R. 149	Kamloops	1 lower	Core, clean	91.6	DH-2	2.90	7.30	37.30	52.50	ad	41.54	3.0	clean
233	Merritt		Coldwater Hill	A.R. 149	Kamloops	1 upper	Core, clean	97.8	DH-2	2.90	8.30	37.70	51.10	ad	42.45	3.5	clean
234	Tulameen			A.R. 200	Princeton	Lower	Core, raw	98.0	DH-T-77-3	4.84	46.72	19.98	28.46	ad	41.25		
235	Tulameen			A.R. 200	Princeton	Main	Core, raw	98.0	DH-T-77-3	5.80	36.54	26.83	30.83	ad	46.53		
236	Tulameen			A.R. 200	Princeton	Main	Bulk, raw		Bulk sample 1	5.99	33.88	27.15	32.98	ad	45.15		
237	Princeton	*Pr.-Tulameen Coal Co.*	No. 1 mine	McMechan	Princeton	Princeton, etc.	Mine run			14.90	8.00	29.50	47.60	?	38.26		
238	Princeton	*Bromley (Granby Coll.)*	No. 1 Mine	Dickson	Princeton	Gem-Bromley Vale	Mine run			13.90	13.70	28.30	44.10	?	39.09		

Note: Table items 227 & 231 Rmax values are expressed as per cent dominant Reflectance expressed in V-class

Table Item	Calorific Value (MJ/kg)	Calorific Value (kcal/kg)	Calorific Value (BTU/lb)	Basis	Cal.val. (maf) (BTU/lb)	HGI	Raw/ clean	Moisture (%)	Ash (%)	Sulphur (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Basis	Rmax (%)	Vitrinite (%)	Exinite (%)	Semi-fusinite (%)	Raw/ clean
1	26.38	6300	11340	ad	14052.045					0.45				ad					
2	27.4	6544	11780	ad	13432.155					1.12				ad					
3	28.01	6689	12040	ad	14198.113					0.51				ad					
4	28.19	6733	12120	ad	13931.034					0.74				ad					
5	28.12	6717	12090	ad	14205.146				14.89	0.42	71.71	5.57	6.08	ad	0.74	73.5	2.2	12.2	raw
6	28.91	6906	12430	ad	15085					2.80				ad					
7	25.27	6035	10860	ad	13411					0.95				ad					
8	18.69	4463	8033	ad	12710					0.73				ad					
9	25.60	6113	11000	ad	13651					2.97				ad					
10	23.58	5630	10130	ad	13329					0.47				ad					
11	26.31	6285	11310	ad	14709					0.85				ad, clean					
12	25.36	6059	10900	ad	14726					0.81				ad, clean					
13	24.13	5764	10380	ad	14560					1.22				ad, clean					
14	27.33	6528	11750	ad	14442					0.96				ad, clean					
15	27.57	6586	11850	ad	14613					0.65				ad, clean					
16	26.20	6258	11260	ad	14523					0.88				ad, clean					
17	26.70	6378	11480	ad	14607					1.32				ad, clean					
18	27.93	6671	12010	ad	14632					1.15				ad, clean					
19	28.87	6896	12410	ad	15134					1.75				ad, clean					
20	28.02	6693	12050	ad	15238					2.07				ad, clean					
21	28.33	6770	12180	ad	14708	59	raw	0.75	17.19	0.48	75.33	2.82	2.62	ad	3.72				
22	24.15	5768	10380	ad	14585	43	raw	0.86	28.83	3.05	63.00	2.26	1.31	ad	3.55				
23	24.66	5890	10600	ad	14261	43	raw	1.48	25.67	0.51	66.07	2.13	3.21	ad	3.55				
24	21.06	5030	9050	ad	14092	43	raw	1.57	35.78	0.42	57.37	2.42	1.75	ad	3.79				
25	24.85	5935	10680	ad	14361	55	raw	1.14	25.63	0.59	66.90	2.58	2.39	ad					
26	24.93	5954	10720	ad	14717	61	raw	1.34	27.16	0.56	65.51	2.23	2.40	ad	3.56				
27	22.61	5400	9720	ad	14305	47	raw	1.85	32.05	0.87	59.71	2.09	2.84	ad	3.65	51.20	0.00	28.10	raw
28	24.09	5754	10360	ad	13923	43	raw	1.43	25.59	0.65	66.32	2.70	2.41	ad	3.37				
29	19.47	4650	8370	ad	13987	46	raw	1.77	40.16	1.26	52.07	1.86	2.27	ad	3.54				

Table Item	Calorific Value			Basis	Cal.val. (maf)	HGI	Raw/ clean	Moisture	Ash	Sulphur	Carbon	Hydrogen	Oxygen	Basis	Rmax	Vitrinite	Exinite	Semi-fusinite	Raw/ clean
	(MJ/kg)	(kcal/kg)	(BTU/lb)		(BTU/lb)			(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	
30	21.60	5159	9290	ad	14134	61	raw	1.50	34.27	1.00	58.06	2.16	2.15	ad	3.27				
31	28.73	6862	12350	ad	14863	40	raw	1.63	16.91	0.47	74.95	2.41	2.71	ad	3.76				
32	27.30	6521	11740	ad	14319	67	raw	2.04	18.01	0.47	73.17	2.26	3.33	ad	3.52	46.10	0.00	40.50	raw
33	26.03	6217	11190	ad	14359			1.13	22.07	0.63	69.33	2.39	3.64	ad	3.47				
34	23.09	5515	9930	ad	13795	45	raw	1.75	28.02	0.54	65.72	2.42	0.69	ad	3.54				
35	20.93	5000	9000	ad	13945	57	raw	1.67	35.46	0.60	57.73	2.16	1.66	ad	3.36				
36	21.71	5185	9330	ad	13994	55	raw	0.81	33.33	0.35	61.44	2.07	1.44	ad					
37	29.56	7060	12710	ad	14738	59	raw	1.00	13.76	0.46	80.11	2.89	0.96	ad					
38	27.95	6676	12020	ad	14702	45	raw	0.88	18.24	0.42	73.43	2.48	3.72	ad					
39	18.09	4321	7780	ad	13449	58	raw	2.89	42.15	1.07	46.94	1.67	4.72	ad					
40	21.66	5173	9310	ad	14513	49	raw	1.23	35.85	0.47	57.55	1.89	2.39	ad					
41	19.01	4540	8170	ad	13544	61	raw	0.96	39.68	0.37	52.82	1.86	3.64	ad					
42	23.65	5645	10170	ad	14415	48	raw	1.20	29.45	0.33	63.26	2.07	3.07	ad					
43	21.04	5025	9050	ad	13681	48	raw	1.31	33.85	0.62	58.47	1.78	3.29	ad					
44	27.12	6478	11660	ad	14732	48	raw	0.95	20.85	0.38	70.66	2.19	4.12	ad					
45	25.23	6026	10850	ad	14380	67	raw	1.75	24.55	0.37	67.62	2.29	2.55	ad					
46	25.93	6193	11150	ad	14380	47	raw	2.65	22.46	0.50	68.08	2.26	3.48	ad					
47	22.57	5391	9700	ad	14167	51	raw	1.70	31.53	0.45	61.75	2.15	1.65	ad					
48	19.38	4629	8330	ad	13737	75	raw	0.95	39.36	0.35	51.95	1.59	5.21	ad					
49	21.67	5176	9320	ad	14218	79	raw	0.86	34.45	1.36	57.42	1.75	3.47	ad					
50	21.82	5212	9380	ad	14133	58	raw	0.84	33.63	0.78	58.15	2.49	3.43	ad					
51	22.50	5374	9670	ad	14403	58	raw	1.10	32.86	0.41	60.71	2.02	2.07	ad					
52	20.35	4861	8750	ad	13958	54	raw	1.09	37.31	1.09	55.64	1.79	2.33	ad					
53	19.61	4684	8430	ad	13985	50	raw	0.99	39.72	1.50	50.70	1.62	4.72	ad					
54	25.39	6064	10920	ad	14898	53	raw	0.76	26.70	0.54	65.27	2.11	3.69	ad					
55										0.53				ad					
56										0.56				ad					
57										0.48				ad					
58										0.83				ad					
59	21.09	5038	9068	ad	14486					0.37				ad					
60	26.20	6257	11262	ad	14996					0.45				ad					

Table Item	Calorific Value (MJ/kg)	Calorific Value (kcal/kg)	Calorific Value (BTU/lb)	Basis	Cal.val. (maf) (BTU/lb)	HGI	Raw/ clean	Moisture (%)	Ash (%)	Sulphur (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Basis	Rmax (%)	Vitrinite (%)	Exinite (%)	Semi-fusinite (%)	Raw/ clean
61	*32.78*	*7830*	*14090*	*ad*	*15399*			*0.00*	*8.50*	*0.60*	*83.10*	*4.00*	*2.50*	*dry*					
62	32.49	7760	13970	ad	15318			0.00	8.90	0.60	82.80	4.00	2.60	dry					
63	34.12	8150	14670	ad	15377			0.00	4.60	0.40	85.50	4.80	3.50	dry		63.00	0.00		clean
64	33.08	7900	14220	ad	15258			0.00	6.80	0.40	79.80	4.90	6.70	dry		86.90	0.00		clean
65	33.75	8060	14510	ad	15436			0.00	6.00	0.50	84.40	4.50	3.40	dry		73.40	0.00		clean
66										*0.69*				*ad, clean*					
67										0.56				ad, clean					
68										0.33				ad, clean					
69										0.39				ad, clean					
70										0.30				ad, clean					
71																			
72																			
73																			
74										0.39				ad, clean					
75										0.32				ad, clean					
76										0.41				ad, clean					
77										0.44				ad, clean					

Table Item	Calorific Value (MJ/kg)	Calorific Value (kcal/kg)	Calorific Value (BTU/lb)	Basis	Cal.val. (maf) (BTU/lb)	HGI	Raw/ clean	Moisture (%)	Ash (%)	Sulphur (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Basis	Rmax (%)	Vitrinite (%)	Exinite (%)	Semi-fusinite (%)	Raw/ clean
78										0.32				ad, clean					
79										0.42				ad, clean					
80										0.37				ad, clean					
81										0.45				ad, clean					
82										0.66				ad, clean					
83										0.38				ad, clean					
84																			
85										0.48				ad, clean					
86										0.56				ad, clean					
87										0.51				ad, clean					
88	33.94	8107	14590	ad, clean						0.63				ad					
89										0.40				ad					
90						89	raw			1.73				dry					
91	23.37	5582	10050	dry		94	raw			0.47				dry	1.47	33.00	0.00		clean
92	24.23	5787	10416	dry		112	raw			0.45				dry	1.53	60.00	0.00		clean
93	25.16	6010	10820	dry		98	raw			0.36				dry	1.44	39.00	0.00		clean
94	22.00	5254	9460	dry		95	raw			0.49				dry	1.45	60.00	1.00		clean
95	29.13	6958	12520	dry		92	raw			0.69				dry	1.44	31.00	0.00		clean
96						101	raw			0.52				dry					
97	24.04	5742	10336	dry		89	raw			0.39				dry	1.45	55.00	0.00		clean
98	25.76	6152	11070	dry		80	raw			0.38				dry	1.41	45.00	0.00		clean
99	25.33	6050	10890	dry		81	raw			0.41				dry	1.32	57.00	0.00		clean
100	20.26	4839	8710	dry		79	raw			0.67				dry	1.31	75.00	1.00		clean

Table Item	Calorific Value			Basis	Cal.val. (maf)	HGI	Raw/ clean	Moisture	Ash	Sulphur	Carbon	Hydrogen	Oxygen	Basis	Rmax	Vitrinite	Exinite	Semi-fusinite	Raw/ clean
	(MJ/kg)	(kcal/kg)	(BTU/lb)		(BTU/lb)			(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	
101						97	raw			0.60				dry					
102						109	raw			0.46				dry					
103						88	raw			0.89				dry					
104						74	raw			0.95				dry					
105	27.65	6604	11890	dry		89	raw			0.79				dry	0.99	74.00	7.00		clean
106	23.50	5613	10100	dry		91	raw			0.66				dry	0.92	77.00	8.00		clean
107	30.31	7240	13032	ad	15215					0.65				ad					
108	32.59	7783	14010	ad	15159					0.58				ad					
109	33.34	7963	14333	ad	15121					0.71				ad					
110	31.50	7523	13541	ad	14987					0.50				ad					
111	29.73	7100	12780	ad	14993					0.70				ad					
112	21.23	5071	9128	ad	14386					0.71				ad					
113	29.79	7116	12809	ad	14361	60	raw	2.38	10.81	0.93	73.21	4.70	6.50	ad					
114	31.30	7477	13458	ad	14638	58	raw	2.64	8.06	1.12	75.74	4.80	6.18	ad					
115	27.79	6638	11949	ad	14403	56	raw	2.59	17.04	0.65	68.65	4.15	5.94	ad					
116	31.68	7566	13619	ad	14442	52	raw	3.20	5.70	0.71	78.63	4.85	5.65	ad					
117	24.52	5857	10542	ad	14024	53	raw	2.81	24.83	0.73	61.30	3.96	5.15	ad					
118	29.36	7013	12623	ad	13954	49	raw	3.76	9.54	0.71	76.14	5.10	3.59	ad					
119	30.93	7388	13298	ad	14324			2.95	7.16	0.71	77.11	4.50	6.64	ad					
120	27.58	6587	11856	ad	14003	58	raw	3.70	15.33	0.84	69.25	4.65	5.16	ad					
121	30.56	7299	13139	ad	14311	50	raw	3.26	8.19	0.69	76.01	4.84	5.79	ad					
122	23.20	5542	9976	ad	14033	55	raw	2.76	28.91	1.52	56.92	3.96	5.06	ad					
123	26.44	6314	11366	ad	14220	52	raw	2.31	20.07	2.49	63.75	4.61	5.55	ad					
124	31.96	7634	13742	ad	14385	51	raw	2.58	4.47	0.71	81.38	5.09	4.61	ad					
125	30.77	7350	13230	ad	13996	47	raw	3.50	5.47	0.66	77.49	5.00	6.60	ad					
126	26.52	6334	11402	ad	13959	53	raw	2.73	18.32	0.85	66.26	4.44	6.23	ad					
127	27.44	6554	11798	ad	13872	50	raw	2.93	14.95	0.63	68.35	4.85	7.18	ad					
128	33.35	7966	14338	dry						0.46				dry					

Table Item	Calorific Value (MJ/kg)	Calorific Value (kcal/kg)	Calorific Value (BTU/lb)	Basis	Cal.val. (maf) (BTU/lb)	HGI	Raw/ clean	Moisture (%)	Ash (%)	Sulphur (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Basis	Rmax (%)	Vitrinite (%)	Exinite (%)	Semi-fusinite (%)	Raw/ clean
129	32.52	7767	13981	dry						0.66				dry					
130	30.03	7173	12912	dry						0.36				dry					
131	31.50	7524	13543	dry						0.54				dry					
132	32.90	7859	14146	dry						0.76				dry					
133	33.08	7902	14224	dry						0.63				dry					
134	32.72	7816	14069	dry						0.85				dry					
135	33.45	7988	14379	dry						0.58				dry					
136	23.38	5584	10052	ad	13691					0.60				ad	1.26	86.50	1.50	10.40	raw
137	28.98	6922	12459	ad	14998					0.31				ad	1.34	28.70	0.20	65.60	raw
138	31.21	7454	13418	ad	15006					0.31				ad					
139	28.96	6917	12451	ad	15193					0.43				ad					
140	24.68	5895	10611	ad	15152					0.31				ad					
141	29.63	7077	12739	ad	15021					0.24				ad	1.10	53.08	5.96	29.80	raw
142	31.02	7409	13336	ad	14857					0.24				ad	1.15	38.80	1.80	42.70	raw
143	33.11	7908	14235	ad	15651	65	raw			0.39				ad					
144	33.69	8047	14486	ad	15476	57	raw			0.38				ad					
145	31.51	7526	13546	ad	15341	79	raw			0.36				ad					
146	34.05	8134	14641	ad, clean		76	clean			0.73				ad	1.36	51.76	0.00	24.90	clean
147	34.19	7609	14697	ad, clean		81	clean			0.58				ad	1.37	52.95	0.00	24.90	clean
148	33.82	8077	14539	ad, clean		86	clean			0.51				ad	1.33	50.26	0.00	26.41	clean
149	33.90	8097	14574	ad, clean		104	clean			2.48				ad	1.32	53.76	0.00	22.94	clean
150										0.78				ad					
151										0.60				ad					
152										0.29				ad					
153						83	raw			0.72				ad					
154						87	raw			2.33				ad					
155						86	raw			0.54				ad	1.20	56.84	0.98	20.19	clean

Table Item	Calorific Value (MJ/kg)	Calorific Value (kcal/kg)	Calorific Value (BTU/lb)	Basis	Cal.val. (maf) (BTU/lb)	HGI	Raw/ clean	Moisture (%)	Ash (%)	Sulphur (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Basis	Rmax (%)	Vitrinite (%)	Exinite (%)	Semi-fusinite (%)	Raw/ clean
156						68	raw			0.53				ad	1.16	49.71	2.35	29.55	clean
157						85	raw			0.41				ad	1.21	39.29	7.23	34.56	clean
158						70	raw			0.33				ad	1.19	53.18	0.56	21.35	clean
159	26.57	6347	11424	ad	15513	74	clean			2.21				ad					
160	29.12	6955	12519	ad	15131	68	clean			0.32				ad					
161	29.54	7056	12700	ad	14961	77	clean			0.38				ad					
162	31.04	7415	13346	ad	15511	93	clean	1.09	5.90	0.46	75.69	4.37	11.87	ad, clean	1.27	61.31	0.00	30.42	clean
163	27.38	6538	11769	ad	15312	90	clean	1.68	6.85	0.66	75.07	4.24	10.84	ad, clean	1.28	62.31	0.00	26.55	clean
164	27.94	6674	12013	ad	15226	82	clean	1.30	8.40	0.28	73.51	4.48	11.10	ad, clean	1.19	58.82	0.24	30.47	clean
165	22.78	5441	9794	ad	14819	81	clean	0.60	11.21	0.57	74.43	3.75	8.61	ad, clean	1.20	65.71	0.00	25.56	clean
166	28.74	6864	12356	ad	14844	77	clean	0.66	10.87	0.63	77.09	4.45	5.47	ad, clean	1.10	62.85	1.41	25.30	clean
167	29.11	6952	12513	ad	15007	74	clean	0.87	8.85	0.31	77.86	4.21	6.98	ad, clean	1.09	40.86	2.05	46.80	clean
168						88	clean			0.49				ad					
169										0.50				ad					
170						79	clean			0.47				ad					
171						79	clean			0.44				ad					
172										0.49				ad					
173	27.60	6593	11867	dry		72	clean			0.46				dry					
174	31.98	7639	13749	dry						0.36				dry					
175	32.68	7806	14051	dry, clean						1.41				dry					
176										0.59				ad	1.29	57.80	0.00	28.90	clean
177										0.64				ad	1.34	60.67	0.00	29.05	clean
178										0.45				ad	1.32	63.67	0.00	26.92	clean
179										0.22				ad	1.24	57.93	0.00	35.12	clean
180										0.38				ad	1.24	55.53	0.00	30.71	clean
181										0.66				ad	1.20	68.06	0.00	19.21	clean

Table Item	Calorific Value (MJ/kg)	Calorific Value (kcal/kg)	Calorific Value (BTU/lb)	Basis	Cal.val. (maf) (BTU/lb)	HGI	Raw/ clean	Moisture (%)	Ash (%)	Sulphur (%)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Basis	Rmax (%)	Vitrinite (%)	Exinite (%)	Semi-fusinite (%)	Raw/ clean
182										0.34				ad	1.19	49.89	1.20	40.08	clean
183										0.56				ad	1.35	62.33	0.00	27.91	clean
184										0.34				ad	1.33	65.75	0.00	25.59	clean
185										0.24				ad	1.28	57.36	0.00	30.78	clean
186										0.50				ad	1.30	50.29	0.00	38.98	clean
187										0.41				ad	1.25	53.96	0.00	34.34	clean
188										0.73				ad	1.18	70.30	0.00	19.55	clean
189										0.39				ad	1.22	32.96	0.00	54.95	clean
190						98	raw			0.31				ad	1.61	59.25	0.19	28.04	clean
191						75	raw			0.28				ad	1.20	57.58	0.96	27.26	clean
192						90	raw			0.21				ad	1.23	66.17	2.55	17.87	clean
193						80	raw			0.49				ad	1.62	61.06	0.00	26.60	clean
194						75	raw			0.30				ad	1.16	58.49	3.21	25.47	clean
195						86	raw			0.37				ad	1.62	61.48	0.00	28.07	clean
196						90	raw			0.33				ad	1.54	68.55	0.00	21.17	clean
197						74	raw			0.33				ad	1.17	58.72	1.83	25.14	clean
198						72	raw			0.39				ad	1.17	63.86	3.01	19.68	clean
199						64	raw			0.67				ad					
200						68	raw			0.41				ad					
201						96	clean	0.00	8.17	0.27	82.77	4.36	3.46	dry, clean	1.38	51.00	0.00		clean
202	32.18	7686	13834	ad, clean						0.39				ad					
203	33.31	7957	14322	ad, clean		119	clean	0.00	7.61	0.46	83.61	4.42	2.92	dry, clean					
204	34.53	8248	14847	ad, clean		85	clean			0.35				ad					
205										0.54				ad					
206						115	clean			0.47				ad	1.35	54.00	0.00		clean
207	33.07	7898	14217	ad, clean		85	clean			0.43				ad					
208						116	clean			0.61				ad					
209										0.73				ad					
210										0.63				ad					
211	18.55	4431	7976	ar	10252	62	raw			0.38				ar					
212	28.27	6753	12156	mmmf		49	raw	0.00	0.00	0.61	78.11	5.49	14.62	daf					

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213	26.59	6352	11433	mmmf		49	raw	0.00	0.00	0.56	75.94	4.38	18.26	daf					
214	19.33	4617	8310	ad	13005	58	raw	0.00	36.10	0.97	48.59	3.75	9.69	dry					
215	19.42	4639	8350	ad	12530					1.11				ad					
216	23.12	5522	9940	ad	13019					1.13				ad					
217	20.38	4868	8763	ad	12485					1.22				ad					
218	21.42	5117	9211	dry						0.23			16.35	dry					
219	11.45	2736	4924	dry						0.40			14.43	dry					
220	17.86	4266	7679	dry						0.79			15.73	dry					
221	14.92	3564	6415	dry						0.68			15.00	dry					
222	17.44	4164	7496	dry						0.56				dry					
223	20.59	4919	8854	dry						0.68				dry					
224	17.71	4230	7614	dry						0.48				dry					
225	30.03	7170	12906	ad	13922					0.64				ad					
226	30.49	7280	13104	ad	14166					0.49				ad					
227	31.11	7430	13374	ad	14243					0.78				ad	68.9%	83.50	11.60	0.40	clean
228	31.41	7500	13500	ad	14423					0.71				ad					
229	30.44	7270	13086	ad	14380					0.64				ad					
230	34.17	8160	14688	ad	15948					0.64				ad					
231	31.11	7430	13374	ad	14490					0.69				ad	36.1%	76.30	18.50	0.00	clean
232	30.86	7370	13266	ad	14311					0.83				ad					
233	30.44	7270	13086	ad	14270					0.57				ad					
234	14.79	3533	6360	ad	11937	49	raw			0.66				ad					
235	17.54	4189	7540	ad	11882	47	raw			0.42				ad					
236	17.98	4299	7730	ad	11691					0.54				ad					
237	22.82	5450	9810	?	10663					0.20				ad					
238	19.91	4756	8560	?	9919					0.63				ad					