



TRACE ELEMENTS, MINERAL MATTER AND PHOSPHORUS IN BRITISH COLUMBIA COALS

By D.A. Grieve and M.E. Holuszko

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INTRODUCTION

The objectives of the British Columbia Geological Survey Branch's Coal Quality Project are to collect, compile and interpret data concerning the intrinsic characteristics of the province's coal resources. Current studies fall into five categories, all of which are inter-related:

- Washability of coals — This study is concerned with the washability characteristics of coals from different seams, sites, geological formations, coalfields and regions.
- Trace elements and mineral matter in coals — This study addresses the nature of the inorganic constituents of coals, with emphasis on the trace element concentrations and mineralogy.
- Phosphorus content in coking coals — This study stems from the second, and focuses on the quantities and forms of association of this element in British Columbia coals.
- Coal petrography — Petrographic analyses to determine reflectance (rank) and maceral composition (type) of coal samples form a component of all other studies listed here. Separate petrographic studies are also underway or planned.
- Utilization potential of coals — The combination of various coal quality parameters determines the suitability of a coal for various end uses. This new study, in effect, combines and extends the data from the other studies. We are endeavouring to determine potential uses for coals from different parts of the province. The implications of the new "Alpern Classification System" (Alpern *et al.*, 1989) to our coals will also be addressed.

One planned study will be concerned with sulphur content and forms in British Columbia coals.

The current status and early results of the trace elements and phosphorus studies are outlined below. Preliminary results of the washability study are described in Holuszko and Grieve (1991, this volume).

Coals referred to in this paper are from two regions of British Columbia: the northeast or Peace River area, and the southeast or East Kootenay area (Figures 5-1-1 and 5-1-2). Peace River coals described here belong to the Gates Formation of the Lower Cretaceous Fort St. John Group. Kootenay coals belong to the Mist Mountain Formation of the Jurassic-Cretaceous Kootenay Group.

TRACE ELEMENTS AND MINERAL MATTER IN BRITISH COLUMBIA COALS

OBJECTIVES

Knowledge of the mineral matter and trace elements in coals is important for both technological and environmental reasons. For example, problems during combustion, such as slagging and fouling, are affected by the mineralogy and chemistry of the inorganic material. Determining the forms of association of minerals and elements in coal is also important. Washability of coal, for example, is affected by the forms of mineral matter association (*see* Holuszko and Grieve, 1991, this volume). Potential for improving a coal's quality with respect to concentrations of undesirable minerals or elements is also dependent on their affinity in the coal.

The aims of this study are to delineate both the amounts and forms of association of mineral matter and trace elements in British Columbia coals. These components are related, in the sense that it is impossible to discuss a trace element's associations in coals without knowing the minerals, particularly accessory minerals, present. This is because the accessory minerals usually contain a disproportionately large fraction of the trace elements in coal (Finkelman, 1980). Micron and submicron-sized inclusions of certain minerals also contain significant amounts of trace elements (Lyons *et al.*, 1990; Swaine, 1990).

To date, we have results of X-ray diffraction analysis of low-temperature ash (LTA) and analyses for the trace elements chlorine, fluorine and mercury in coal samples collected at operating coal mines in 1989 (*see* Van Den Busche and Grieve, 1990). These data have so far been evaluated with respect to the stratigraphic positions of samples. Determining the forms of association of the minerals and trace elements will be carried out at a later date.

The results of analysis of a large suite of trace elements determined by neutron activation on the same samples have yet to be received. This latter work is being carried out in conjunction with F. Goodarzi of the Geological Survey of Canada. The concentrations of phosphorus in the same samples are described in a subsequent section of this paper.

METHODS

SAMPLING

Channel samples were collected in July, 1989 at newly exposed coal faces at the following mines: Westar Mining Limited's Balmer and Greenhills operations, Esso Resources Canada Limited's Byron Creek Collieries, Crows Nest Resources Limited's Line Creek mine and Fording Coal Limited's Fording River operations in southeast Brit-

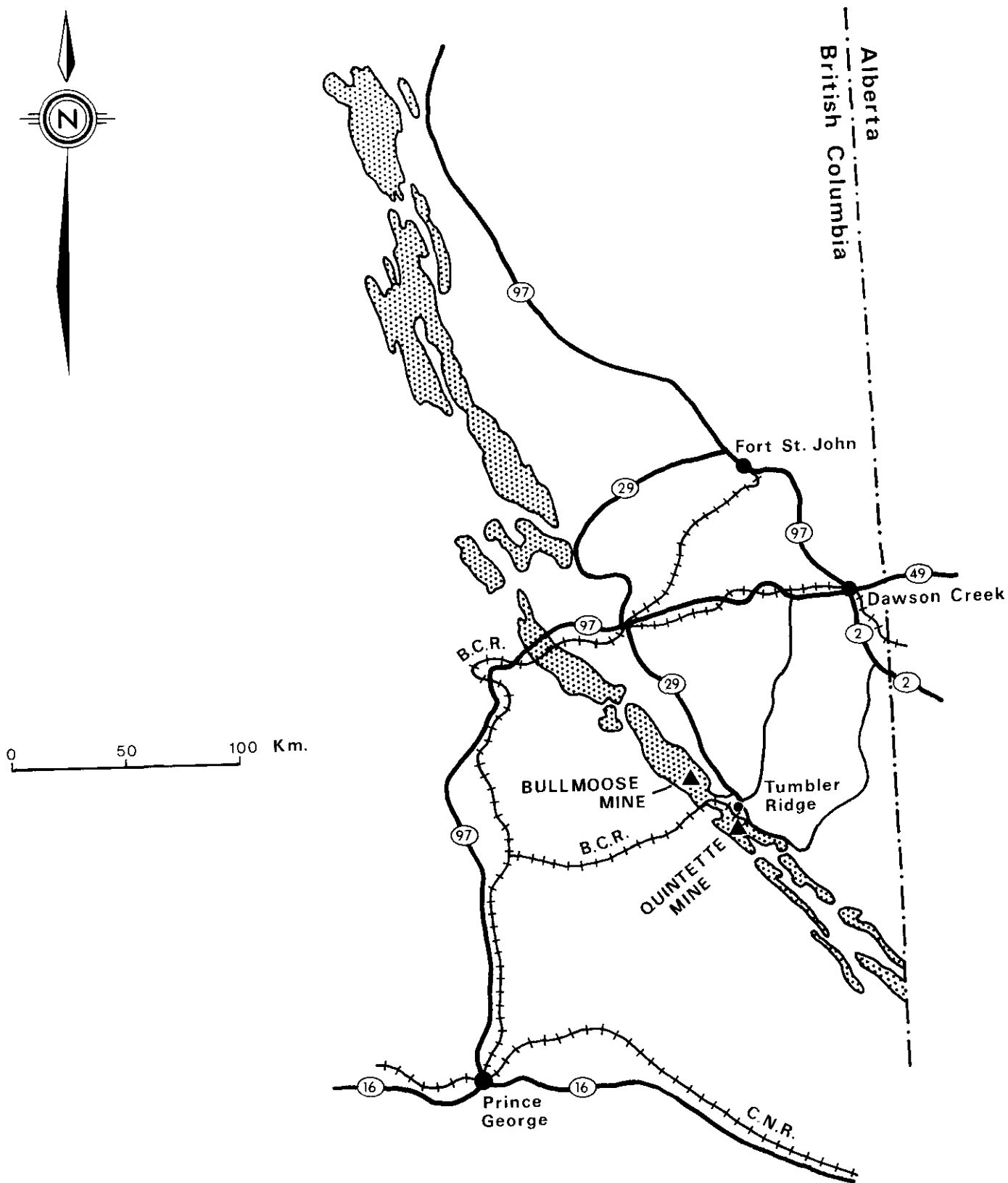


Figure 5-1-1. Distribution of coal deposits and locations of mines in the Peace River coalfield of northeastern British Columbia.

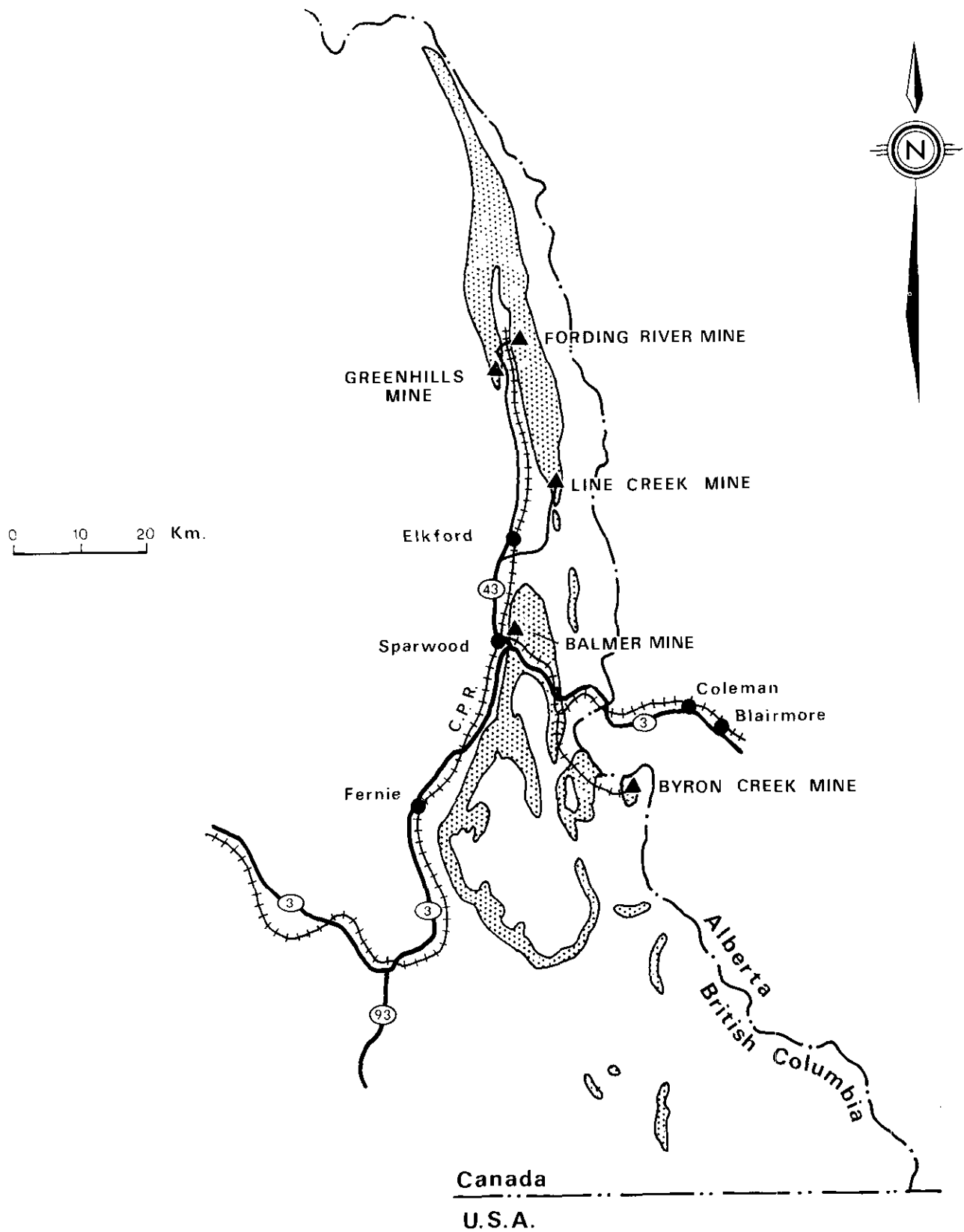


Figure 5-1-2. Distribution of coal deposits and locations of mines in the East Kootenay coalfields of southeastern British Columbia.

**TABLE 5-1-1
ASH, TRACE ELEMENTS AND PHOSPHORUS
BRITISH COLUMBIA COALS**

Sample Number	Property	Pit	Seam Name	Ash %	Cl %	F ppm (A.D. BASIS)	Hg ppb	P ₂ O ₅ %	Mineralogy of Low-Temperature Ash (LTA)
Q8901	FORDING	EAGLE	15	8.43	0.004	260	50	0.06	Quartz, kaolinite, illite/muscovite, calcite, fluorapatite, trace: - siderite?
Q8902	FORDING	EAGLE	14-9	21.18	0.009	650	130	0.27	Quartz, kaolinite, siderite, illite, pyrite
Q8903	FORDING	EAGLE	14-0	6.25	0.004	600	70	0.37	Quartz, kaolinite, goethite?, fluorapatite, siderite, trace: - pyrite, amphibole?
Q8904	FORDING	EAGLE	14-2	14.71	0.009	450	130	0.18	Quartz, kaolinite, dolomite/ankerite, illite, trace: - siderite, apatite, pyrite
Q8905	FORDING	TAYLOR	7	25.42	0.009	950	130	0.45	Quartz, kaolinite, siderite, illite, trace: - fluorapatite, pyrite?
Q8906	FORDING	TAYLOR	5	17.64	0.009	360	110	0.09	Quartz, kaolinite, illite, trace: - siderite, pyrite?
Q8907	FORDING	TAYLOR	9	19.61	0.009	750	100	0.37	Quartz, kaolinite, siderite, trace: - illite, pyrite, apatite?
Q8908	FORDING	POND	TAILINGS	21.35	0.004	470	60	0.16	Quartz, kaolinite, illite, magnetite, trace: - siderite, dolomite/ankerite, pyrite
Q8909	BYRON CREEK	12	MAMMOTH	21.71	0.004	380	80	0.07	Quartz, kaolinite, illite, calcite, dolomite/ankerite, trace: - siderite
Q8910	BYRON CREEK	51	MAMMOTH	21.32	0.007	340	50	0.08	Quartz, kaolinite, calcite, dolomite/ankerite, illite, trace: - siderite, rhodochrosite?
Q8911	BYRON CREEK	14	MAMMOTH	21.50	0.004	260	40	0.03	Quartz, kaolinite, dolomite, calcite, illite, trace: - siderite
Q8912	LINE CREEK	MAIN	10A (TOP)	55.97	0.004	680	130	0.17	Quartz, kaolinite, illite, trace: - pyrite
Q8913	LINE CREEK	MAIN	10A	26.50	0.009	320	40	0.08	Quartz, kaolinite, illite/mica, trace: - anatase
Q8914	LINE CREEK	MAIN	10A	17.32	0.009	160	30	0.03	Kaolinite, quartz, trace: - ilmenite?
Q8915	LINE CREEK	MAIN	10A	17.62	0.009	210	40	0.04	Quartz, kaolinite, trace: - illite, siderite
Q8916	LINE CREEK	MAIN	10A (BASE)	12.36	0.004	220	30	0.07	Quartz, kaolinite, trace: - siderite
Q8917	LINE CREEK	MAIN	10B (TOP)	15.49	0.013	180	30	0.02	Quartz, kaolinite, trace: - illite, siderite, calcite
Q8918	LINE CREEK	MAIN	10B	13.99	0.004	320	40	0.11	Quartz, kaolinite, calcite, trace: - siderite, pyrite, apatite
Q8919	LINE CREEK	MAIN	10B	24.86	0.007	260	30	0.05	Quartz, kaolinite, illite, trace: - siderite, anatase
Q8920	LINE CREEK	MAIN	10B	10.94	0.007	150	30	0.02	Quartz, kaolinite, trace: - calcite
Q8921	LINE CREEK	MAIN	10B (BASE)	15.80	0.011	260	40	0.03	Quartz, kaolinite, illite
Q8922	LINE CREEK	MAIN	9 (TOP)	12.62	0.009	230	50	0.06	Quartz, kaolinite, trace: - siderite, pyrite
Q8923	LINE CREEK	MAIN	9	18.34	0.009	420	30	0.09	Quartz, kaolinite, illite, fluorapatite, trace: - pyrite
Q8924	LINE CREEK	MAIN	9	12.88	0.009	500	40	0.14	Quartz, kaolinite, fluorapatite, trace: - pyrite
Q8925	LINE CREEK	MAIN	9	5.66	0.009	530	20	0.18	Quartz, kaolinite, fluorapatite, trace: - pyrite?
Q8926	LINE CREEK	MAIN	9	12.41	0.009	320	40	0.03	Quartz, kaolinite, illite, trace: - siderite
Q8927	LINE CREEK	MAIN	9	25.78	0.004	450	30	0.09	Quartz, siderite, kaolinite, trace: - illite
Q8928	LINE CREEK	MAIN	9	7.28	0.004	630	30	0.28	Quartz, kaolinite, fluorapatite, trace: - siderite, pyrite
Q8929	LINE CREEK	MAIN	9 (BASE)	22.20	0.004	470	70	0.10	Quartz, kaolinite, illite, trace: - anatase?
Q8930	LINE CREEK	MAIN	8 (TOP)	49.02	0.004	950	110	0.10	Quartz, kaolinite, illite, trace: - anatase?
Q8931	LINE CREEK	MAIN	8	13.07	0.009	800	50	0.30	Quartz, kaolinite, fluorapatite, trace: - illite, siderite
Q8932	LINE CREEK	MAIN	8	24.64	0.004	300	90	0.02	Kaolinite, quartz, trace: - illite
Q8933	LINE CREEK	MAIN	8	22.42	0.011	340	140	0.03	Kaolinite, quartz, trace: - illite
Q8934	LINE CREEK	MAIN	8	27.24	0.007	420	140	0.05	Kaolinite, quartz, trace: - siderite
Q8935	LINE CREEK	MAIN	8	8.41	0.013	400	100	0.12	Quartz, kaolinite, trace: - siderite
Q8936	LINE CREEK	MAIN	8	15.37	0.004	270	50	0.06	Kaolinite, quartz, trace: - siderite, illite
Q8937	LINE CREEK	MAIN	8	11.63	0.009	240	100	0.04	Quartz, kaolinite, siderite
Q8938	LINE CREEK	MAIN	8	24.81	0.009	370	40	0.02	Quartz, kaolinite, illite, siderite, trace: - anatase?
Q8939	LINE CREEK	MAIN	8	11.15	0.007	200	180	0.03	Quartz, kaolinite, siderite, trace: - fluorapatite, anatase?
Q8940	LINE CREEK	MAIN	8	17.34	0.009	600	40	0.26	Quartz, kaolinite, illite, fluorapatite, trace: - siderite?
Q8941	LINE CREEK	MAIN	8	13.40	0.007	360	70	0.15	Quartz, kaolinite, trace: - siderite, apatite, pyrite?
Q8942	LINE CREEK	MAIN	8	13.37	0.009	200	60	0.05	Kaolinite, quartz, trace: - dolomite/ankerite, siderite, anatase?
Q8943	LINE CREEK	MAIN	8	10.88	0.011	1350	70	0.78	Quartz, kaolinite, fluorapatite, trace: - siderite?
Q8944	LINE CREEK	MAIN	8	12.44	0.004	470	30	0.21	Quartz, kaolinite, fluorapatite, trace: - illite
Q8945	LINE CREEK	MAIN	8	19.77	0.009	240	50	0.04	Kaolinite, quartz, trace: - illite
Q8946	LINE CREEK	MAIN	8	17.21	0.004	350	80	0.07	Kaolinite, quartz, trace: - illite, siderite
Q8947	LINE CREEK	MAIN	8	13.07	0.011	430	50	0.16	Siderite, kaolinite, quartz, trace: - apatite?
Q8948	LINE CREEK	MAIN	8 (BASE)	56.54	0.011	950	140	0.06	Quartz, kaolinite, illite, trace: - pyrite, anatase?
Q8949	GREENHILLS	BLACKTAIL	25 EAST	7.63	0.007	340	10	0.08	Quartz, kaolinite, illite, trace: - Siderite, pyrite?, apatite?
Q8950	GREENHILLS	BLACKTAIL	16	16.84	0.009	410	90	0.09	Quartz, kaolinite, illite, trace: - pyrite, apatite
Q8951	GREENHILLS	N COUGAR	22 UPPER	6.12	0.011	310	40	0.08	Quartz, kaolinite, anatase?, trace: - siderite, apatite?
Q8952	GREENHILLS	BLACKTAIL	20 UPPER	32.72	0.009	750	50	0.13	Quartz, kaolinite, illite, siderite, trace: - pyrite, apatite, anatase?
Q8953	GREENHILLS	FALCON	1	9.25	0.004	430	40	0.19	Quartz, kaolinite, siderite, trace: - apatite, pyrite?
Q8954	GREENHILLS	FALCON	3	19.25	0.013	730	70	0.31	Quartz, kaolinite, siderite, trace: - pyrite, apatite?, illite
Q8955	BALMER	CAMP 8 EX	7R1	23.94	0.013	810	80	0.39	Quartz, kaolinite, illite, siderite, trace: - apatite, pyrite?
Q8956	BALMER	CAMP 8 EX	7RX	32.06	0.013	700	150	0.26	Quartz, kaolinite, illite, trace: - siderite, pyrite

TABLE 5-1-1
ASH, TRACE ELEMENTS AND PHOSPHORUS
BRITISH COLUMBIA COALS — *Continued*

Sample Number	Property	Pit	Seam Name	Ash %	Cl %	F ppm (A.D. BASIS)	Hg ppb	P ₂ O ₅ %	Mineralogy of Low-Temperature Ash (LTA)
Q8957	BALMER	CAMP 8 EX	7S	25.96	0.015	600	70	0.26	Quartz, kaolinite, illite, siderite, trace: - apatite, pyrite
Q8958	BALMER	CAMP 8 EX	8UX	34.74	0.015	1090	90	0.52	Quartz, kaolinite, illite, siderite, trace: - fluorapatite, pyrite, anatase?
Q8959	BALMER	BALDY 3, 4	4	24.83	0.022	680	110	0.27	Quartz, kaolinite, illite, trace: - fluorapatite, pyrite, siderite?
Q8960	BALMER	ADIT29E	8UC	28.03	0.013	610	80	0.27	Quartz, kaolinite, illite, siderite, trace: - dolomite?
Q8961	BALMER	POND	TAILINGS	38.28	0.018	660	100	0.15	Quartz, kaolinite, illite, trace: - dolomite/ankerite, siderite, pyrite?
Q8962	QUINTETTE	WOLVERINE	J3	13.77	0.015	230	40	0.03	Quartz, kaolinite, siderite, illite, trace: - apatite?
Q8963	QUINTETTE	WOLVERINE	G2	16.31	0.018	260	40	0.12	Quartz, kaolinite, dolomite/ankerite, trace: - siderite
Q8964	BULLMOOSE		A2	12.51	0.040	200	60	0.04	Quartz, kaolinite, siderite (manganous), dolomite/ankerite
Q8965	BULLMOOSE		B	11.05	0.031	190	180	0.07	Dolomite, quartz, calcite, kaolinite, trace: - pyrite, plagioclase?
Q8966	BULLMOOSE		A1	21.34	0.035	460	80	0.02	Quartz, kaolinite, illite, dolomite, pyrite
Q8967	BULLMOOSE		C	28.13	0.022	690	150	0.26	Quartz, illite/muscovite, kaolinite, dolomite/ankerite, trace: - pyrite, magnetite?
Q8968	BULLMOOSE		D	22.14	0.018	470	60	0.12	Quartz, kaolinite, dolomite, illite, trace: - pyrite, magnetite?
Q8969	BULLMOOSE		E	21.68	0.018	580	50	0.13	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.

ish Columbia; and Denison Mines Limited's Quintette mine and Teck Corporation's Bullmoose mine in northeast British Columbia (Figures 5-1-1 and 5-1-2; Table 5-1-1; see also Van Den Bussche and Grieve, 1990). The actual sample sites were chosen on the basis of availability on the day of sampling; consequently we were not able to acquire equal representation of the entire coal-bearing formation at all locations.

An attempt was made to make each sample as representative as possible, although at some locations, most notably at Byron Creek with its thick Mammoth seam, this was difficult. Of the total of 69 samples, 30 represent entire seams and were collected at all locations except Line Creek. At this last location, each of four seams was sampled on a ply-by-ply basis, in average intervals 0.50 metre thick, for a total of 37 samples (Table 5-1-1). In addition, one grab sample of tailings material (fine plant rejects) was taken at each of the Balmer and Fording mine sites.

SAMPLE PROCESSING

Sample drying, crushing, riffing and screening were carried out at a commercial laboratory in accordance with ASTM procedures (see Van Den Bussche and Grieve, 1990). A representative split of minus-60 mesh material was supplied to the authors for low-temperature ashing.

TRACE ELEMENT (Cl, F, Hg) DETERMINATIONS

Concentrations of chlorine, fluorine and mercury in whole coal were carried out by a commercial laboratory in accordance with the following standard procedures:

- Chlorine determinations were done by burning with Eschka mixture (ASTM D2361). The detection limit is 0.001 per cent by weight.

- Fluorine determinations were carried out using the oxygen-bomb digest method (ASTM D3761). The detection limit is 20 ppm.
- Mercury determinations were also carried out using the oxygen-bomb digest method (ASTM D3761). The detection limit is 1.0 ppb.

LOW-TEMPERATURE ASHING

Low-temperature ashing of coal using radio-frequency-generated (RF) oxygen plasma is a routine method of producing an ash with the original minerals essentially preserved (see for example, Miller *et al.*, 1979). The Branch'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 minus 60 mesh coal is placed in a silica sample boat. One boat is placed in each of the four 10-centimetre-diameter reaction chambers, which are then evacuated using a vacuum pump. Ashing is 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 are left exposed to the oxygen plasma round-the-clock, for a total of about 72 hours. They are stirred twice a day using a glass rod, in order to bring unreacted coal to the surface. At the end of the reaction process a small amount, less than 1 per cent (estimated) per volume, of unreacted organic material is left in the residue. This is assumed to be made up of inertinite. Low-temperature ashes are ground using an agate mortar and pestle, prior to X-ray diffraction analysis.

RESULTS

All results are reported on raw coals, and are not considered representative of product coals.

MINERAL MATTER

Lists of minerals in the low-temperature ashes (in relative order of abundance detected) are given in Table 5-1-1. Quartz and kaolinite are ubiquitous and are the most abundant minerals in almost all cases. Lesser and trace amounts of illite, illite/mica, calcite, apatite (mainly fluorapatite), siderite, pyrite and dolomite/ankerite were also detected. Tentatively or rarely identified minerals, which appear mainly in trace amounts, include anatase, ilmenite, magnetite, amphibole (species not identified), rhodochrosite and goseixite.

There are no obvious differences between the mineral suites from the two regions of the province, with one possible exception. It appears that apatite is more commonly recognized in samples from southeast British Columbia. Within each region there are no obvious differences between the mineral suites from the various mine sites. The various seams at each site also do not appear, at first inspection, to be markedly different, and trends in variation within the seams at Line Creek are not apparent. Closer analysis may reveal systematic variations on some scale. The suites of minerals from the two tailings samples (Samples 8 and 61) are indistinguishable from those in the raw coals.

CHLORINE

Chlorine contents, on an air-dried basis, in the coal samples from southeast British Columbia (excluding the two tailings samples) range from 0.004 to 0.022 per cent, with a mean of 0.0084 (Table 5-1-1). There are no consistent trends in chlorine variation throughout either the Mist Mountain Formation (Figure 5-1-3A), or within individual coal seams at Line Creek (Figure 5-1-3B).

Chlorine values in samples from northeast British Columbia, with a range of 0.015 to 0.035 and a mean of 0.025 per cent, are somewhat higher than those from the southeast. There does not appear to be a trend in chlorine values throughout the coal-bearing section of the Gates Formation (Figure 5-1-3C).

FLUORINE

Values of fluorine concentrations, on an air-dried basis, in samples of coal from southeast British Columbia (excluding the two tailings samples) range from 150 to 1350 ppm and have a mean value of 475 ppm (Table 5-1-1). Lowest fluorine values appear to be associated with the base and top of the Mist Mountain Formation (Figure 5-1-4A). There are no consistent trends in fluorine values within individual coal seams at Line Creek (Figure 5-1-4B).

Values in samples from northeast British Columbia are very similar to those in samples from the southeast region. The range of concentrations is from 190 to 690 ppm, and the mean is 385 ppm. No systematic variation in fluorine contents with stratigraphic position is apparent within the Gates Formation coals (Figure 5-1-4C).

A cursory inspection of Table 5-1-1 suggests that some of the samples containing the highest fluorine values also contain relatively high amounts of phosphorus, and are likely to contain fluorapatite in their low-temperature ashes.

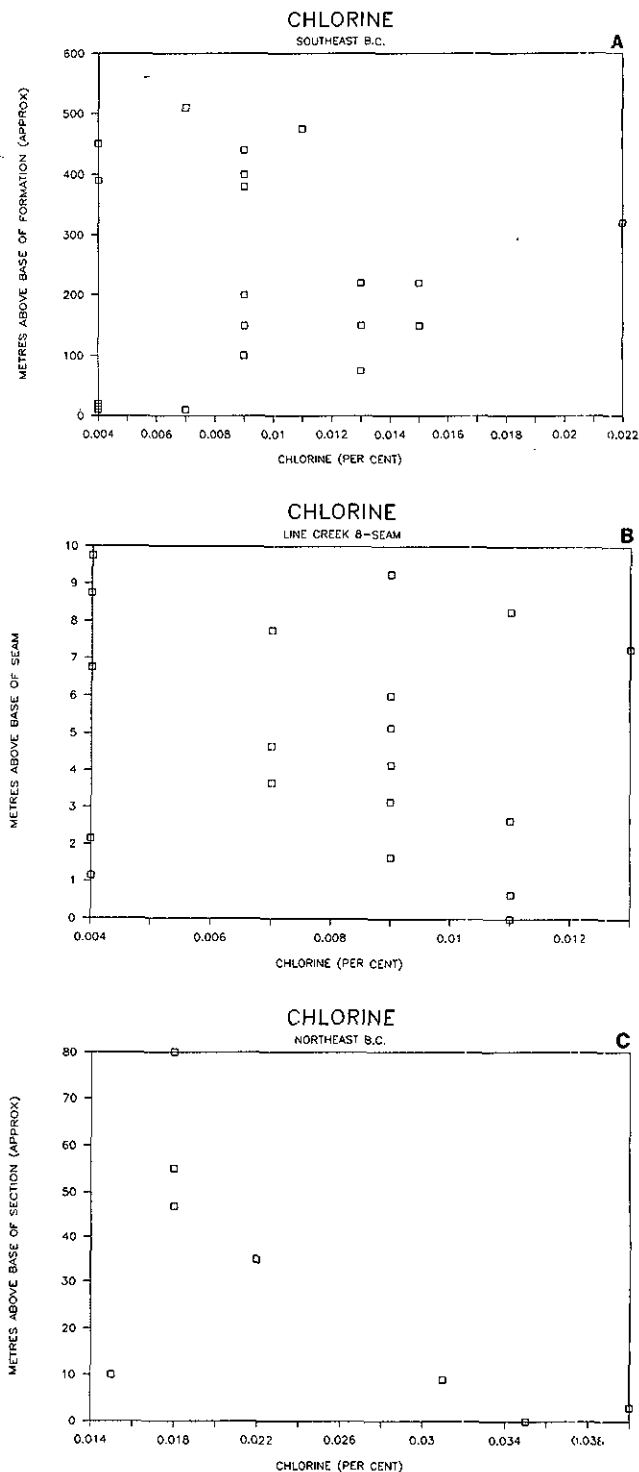


Figure 5-1-3. Variations in concentrations of chlorine in coal with stratigraphic position in southeast and northeast British Columbia. All results are based on raw coal samples and are not representative of clean, product coals.

Samples 43 and 58 from the southeast are good examples. This may be significant, but we cannot be sure until correlation analysis is carried out.

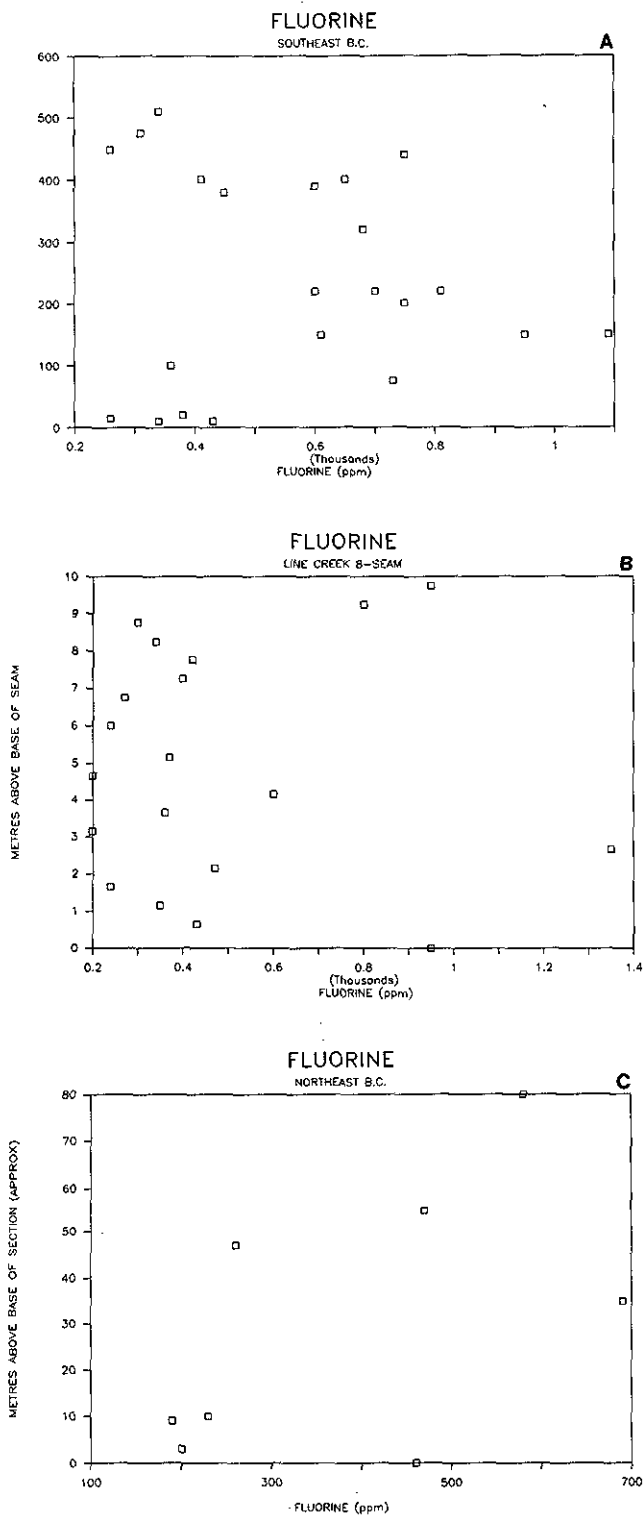


Figure 5-1-4. Variations in concentrations of fluorine in coal with stratigraphic position in southeast and northeast British Columbia. All results are based on raw coal samples are not representative of clean, product coals.

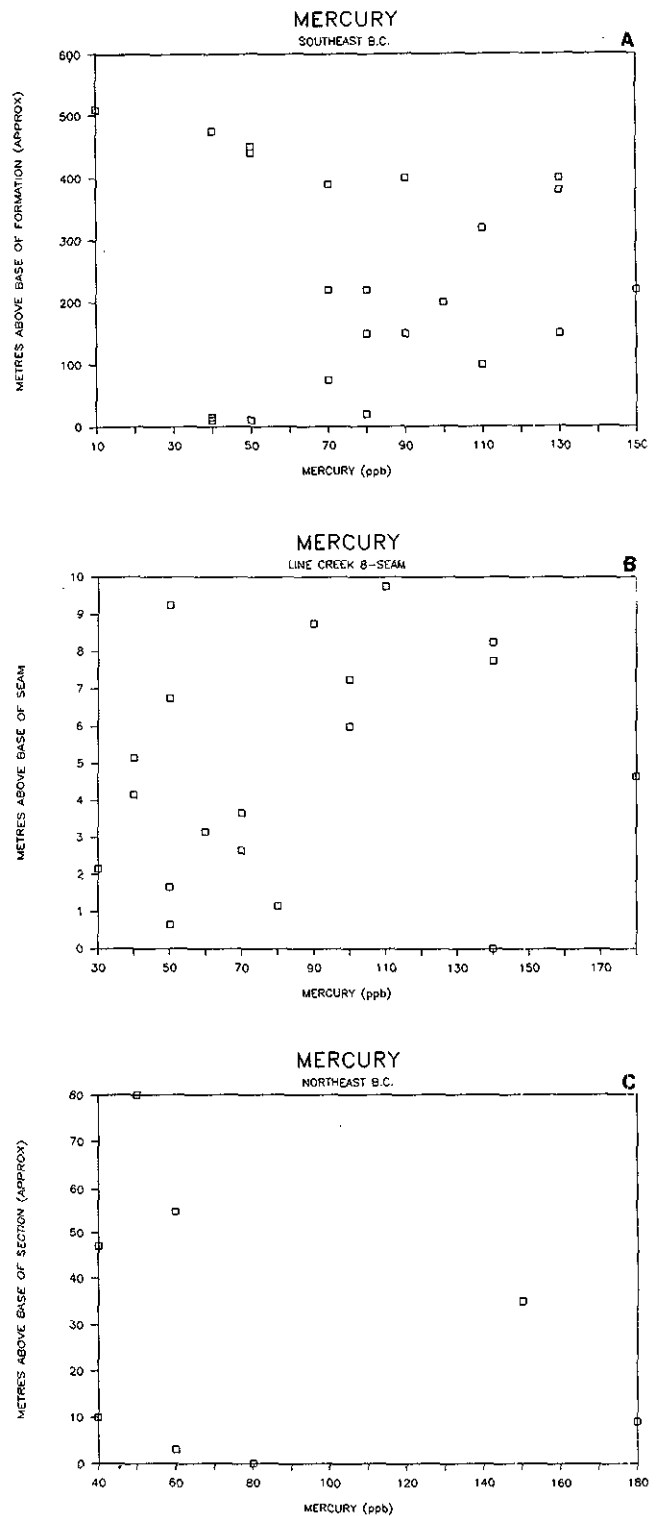


Figure 5-1-5. Variations in concentrations of mercury in coal with stratigraphic position in southeast and northeast British Columbia. All results are based on raw coal samples are not representative of clean, product coals.

MERCURY

Mercury concentrations, on an air-dried basis, in the samples from southeast British Columbia (excluding the two tailings samples) range from 10 to 180 ppb, with an average of 70 (Table 5-1-1). As was the case with fluorine, mercury values in the Mist Mountain Formation appear to be lowest at the base and top of the formation (Figure 5-1-5A). No trends within coal seams at Line Creek are observed (Figure 5-1-5B).

Values of mercury in samples from northeast British Columbia are very similar, with a range of 40 to 180 ppb, and a mean of 83 ppb. Again, no stratigraphic trends are observed in Gates Formation coals (Figure 5-1-5C).

DISCUSSION

The predominance of quartz and kaolinite in the low-temperature ashes of samples from southeast and northeast British Columbia in this study is consistent with nonmarine depositional conditions (see Pearson, 1980). This is also consistent with the generally low sulphur content of coals of the Gates and Mist Mountain formations (see British Columbia Geological Survey Branch Information Circulars 1989-22, *British Columbia Coal Quality Catalog*, and 1990-5, *British Columbia Coal Specifications*).

The origins of the various mineral species identified in these coals will not be delineated until forms of association are determined. Minerals in coal are both syngenetic and epigenetic.

Overall, chlorine values in the samples from both regions are relatively low. Finkelman, for example, cites 0.0629 per cent as the average of over 600 coal samples from the Appalachian region of the United States. Swaine (1990, page 101) suggests the probable range in chlorine values in most world coals is 0.005 to 0.2 per cent.

The causes of the difference between chlorine contents in samples from the two regions is not known at this time. Chlorine in coal can be an indicator of marine influence (Finkelman, 1980). A subtle marine influence (*i.e.* a slight brackishness) may be indicated for the Gates Formation coals of northeast British Columbia. Lamberson *et al.* (1990) state that although predominantly nonmarine conditions prevailed during deposition of the Gates Formation coal sequence, the paleoshoreline was situated just north of the Bullmoose mine site. Goodarzi (unpublished data) has inferred a slightly brackish depositional environment for coals of the Gates Formation in northeastern British Columbia, on the basis of geochemical data.

On the other hand, chlorine in coal has also been found to be sensitive to current groundwater chemistry (Gluskoter and Ruch, 1971), in which case the data do not reflect solely the depositional conditions.

No chloride minerals were found in the low-temperature ashes of samples used in this study. Minerals in coal which may contain chlorine include some clays and apatites (Finkelman, 1980). Finkelman (page 144) concluded, however, that it is possible that much of the chlorine in coals is associated with organic matter. Further study of these samples will be needed to discern its mode of occurrence.

Average values of fluorine in these British Columbia coals fall within the probable range of most world coals (20 to 500 ppm, Swaine, 1990, page 113). Some of the fluorine in these samples must reside in fluorapatite, which was detected in many of the low-temperature ashes, including some of those with the highest phosphorus contents, as noted above. This association, together with corresponding high phosphorus values, has been noted in other parts of the world (Gluskoter *et al.*, 1977; Finkelman, 1980). Finkelman notes that fluorine may have a very complex association in coals, although a strong organic affinity is not likely. Future work will delineate the forms of association of fluorine in these samples.

These coals appear to contain relatively low average mercury values when compared with the probable range of most world coals (20 to 1000 ppb, Swaine, 1990, page 133), and the mean of American coals (180 ppb, Swanson *et al.*, 1976, in Finkelman, 1980). It is not possible, at this stage, to speculate on the modes of occurrence of mercury in these samples. Finkelman (1980, page 177) notes that there is good evidence that a "significant proportion" of the mercury in coal is associated with pyrite. The scarcity of pyrite in these samples may then account for the relatively low mercury levels.

FUTURE PLANS

Coal petrographic analysis will be applied to these samples to determine both maceral compositions and forms of association of the minerals visible at standard magnification.

Results yet to be received include further trace element analyses carried out by neutron activation. This work is being done in conjunction with F. Goodarzi of the Geological Survey of Canada. When these data are available they will be treated in the same way as described here for chlorine, fluorine and mercury.

Further interpretation of all trace element data will focus on the forms of association of each element within the coals. This will involve, at the first stage, looking for correlations between each element and other fundamental parameters, especially the amount of ash, low-temperature ash mineralogy and maceral composition, and also between the various elements. At a later stage, samples will be subjected to scanning electron microscopy to refine the understanding of the modes of occurrence of both elements and minerals.

PHOSPHORUS IN BRITISH COLUMBIA COKING COALS

OBJECTIVES

Phosphorus can be an undesirable element in coking coals because of its potential to impart a brittle quality to steel. Other variables in this phenomenon include the phosphorus content of the iron ore, and the actual steel-making process used. Generally, eastern North American steel producers are more concerned about the amount of phosphorus in coals than are Asian producers, our traditional coking coal purchasers. Thermal coal users may also be concerned about phosphorus content in feedstocks.

The aims of this study are essentially identical to those of the previous study concerned with trace elements. We intend to determine the amount of phosphorus in British Columbia coals, and the nature of its association. To date we have the results of P_2O_5 analyses on the same coal samples referred to in the previous section. These have been evaluated with respect to variations in stratigraphic position.

In addition, the Branch's coal exploration assessment report files contain phosphorus concentration data determined by exploration companies. These data will be used, where not confidential, to complement phosphorus data described here.

METHODS

This study utilizes the same samples as the previous study on trace elements. Sampling and processing procedures were identical. Phosphorus contents were determined as P_2O_5 in coal in per cent by ASTM method D2795. The detection limit is 0.01 per cent.

RESULTS

All results are reported on raw coals, and are not considered representative of product coals.

Phosphorus contents, on an air-dried basis, in the coal samples from southeast British Columbia (excluding the two tailings samples) range from 0.02 to 0.78 per cent P_2O_5 , with a mean of 0.156 (Table 5-1-1). Phosphorus values are lowest at the base and top of the Mist Mountain Formation (Figure 5-1-6A). There are no clear trends within any of the four seams sampled at Line Creek (Figure 5-1-6B).

Phosphorus values from northeast British Columbia samples are in general lower than those from the southeast. The range is from 0.02 to 0.26 per cent P_2O_5 , and the mean is 0.099. There is a general increase in P_2O_5 concentrations up-section in the Gates Formation coal-bearing section, although the highest value occurs in a sample from the middle part of the section (Figure 5-1-6C).

As noted earlier, data in Table 5-1-1 suggest that some of the samples containing the highest P_2O_5 values also contain relatively high amounts of fluorine, and are likely to contain fluoroapatite in their low-temperature ashes.

DISCUSSION

Average phosphorus contents in raw British Columbia coking coals from both the Northeast and Southeast fall well within the probable range for most world coals (0.0023 to 0.69 per cent P_2O_5 , Swaine, 1990, page 140). The reason for the contrast between phosphorus contents from the two regions of the province is not known, although it is probably related to the more common occurrence of apatite in the southeast coals.

There is considerable disagreement in the literature concerning the modes of association of phosphorus in coal. Finkelman (1980, page 191) concludes that "substantial amounts of the phosphorus in many coals occur in rare-earth phosphates and/or apatite. The proportion of organically bound P is still to be determined." Certainly the common

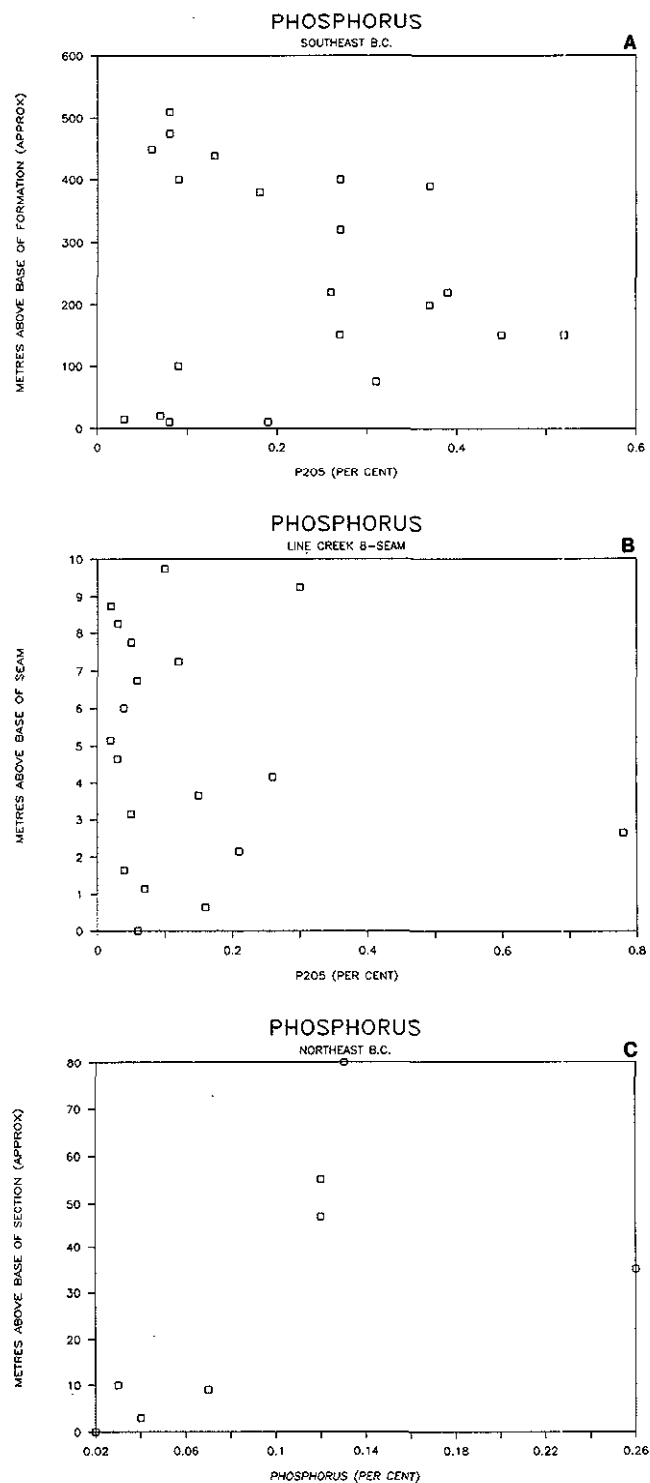


Figure 5-1-6. Variations in concentration of P_2O_5 in coal with stratigraphic position in southeast and northeast British Columbia. All results are based on raw coal samples and are not representative of clean, product coals.

occurrence of apatite and fluoroapatite in these coals, together with the observed correlation of phosphorus and fluorine in certain samples, argues for an inorganic association for a significant portion of the phosphorus. The tenta-

tive identification of gorceixite $(\text{Ba,Ca})\text{Al}_3(\text{PO}_4)_2(\text{OH})_5 \cdot \text{H}_2\text{O}$ in the low-temperature ash of one sample is further proof.

Studies of tonsteins in the southeast British Columbia coalfields (Grieve, 1984 and in preparation; Goodarzi *et al.*, 1990) have indicated that high phosphorus contents of many tonsteins are related to the presence of gorceixite and apatite. It is conceivable that some of the phosphorus observed in coal samples has a similar source to that contained in tonsteins. One of the likely sources of the tonsteins (Grieve, in preparation) is volcanic ash or reworked volcanic ash.

FUTURE PLANS

As in the case of the trace element study, future work will focus on the forms of association of phosphorus in coals. Correlations between phosphorus and ash content, maceral composition, and other elements of known affinity (for example, sulphur) will be determined, on both the data derived from these samples, and those compiled from the coal assessment reports. At a later stage, scanning electron microscopy will be used.

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