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A Regional Evaluation of Coal Quality in the Foothills/Mountains Region of Alberta

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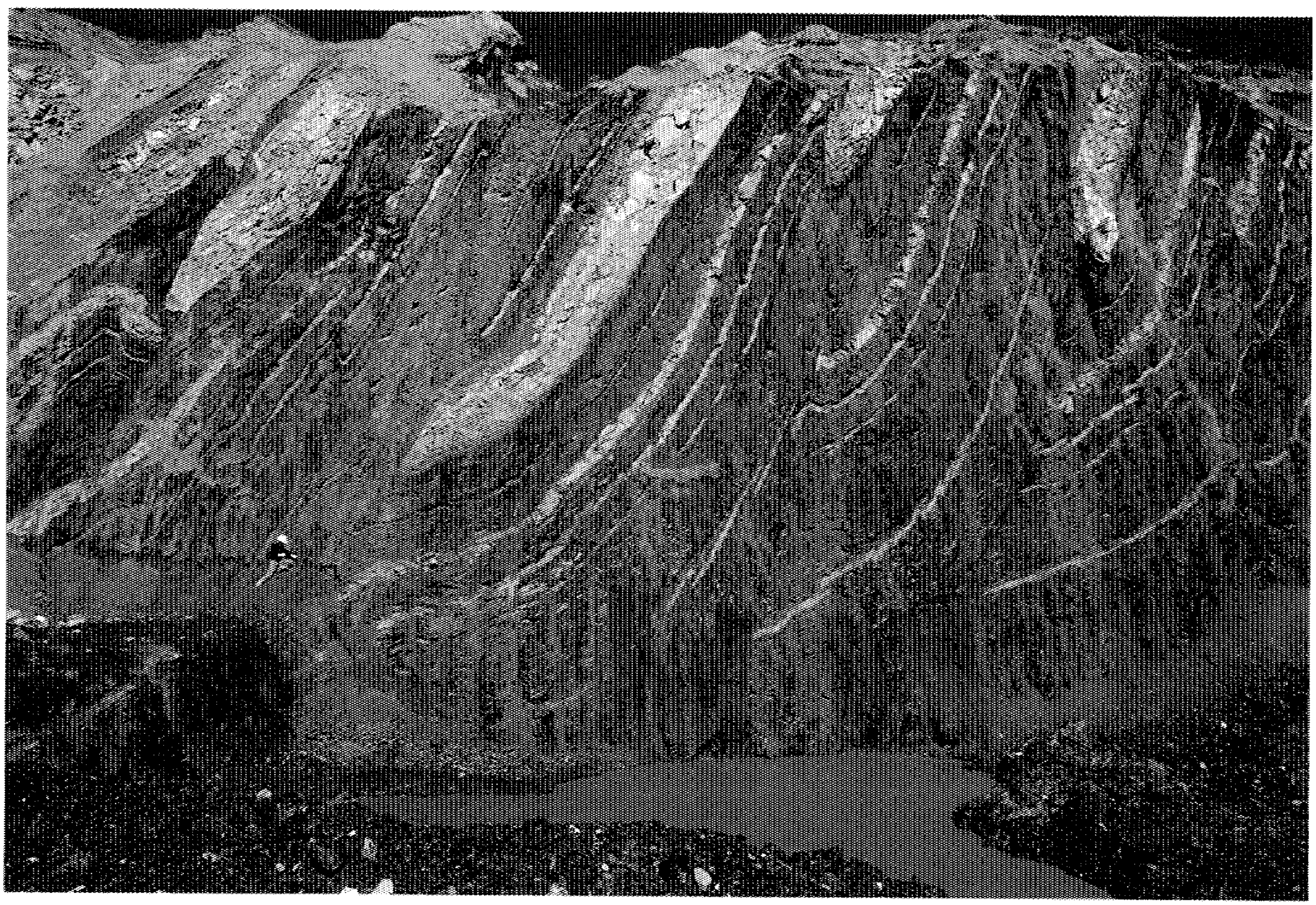

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Preface

The amount of publicly available knowledge regarding coal quality in the foothills/mountains region of Alberta is very small (Langenberg et al. 1986). The coal industry provides the Energy Resources Conservation Board (ERCB) with coal quality data on a regular basis. All data received by the ERCB is added to the existing ERCB coal database. The ERCB supplies mean values for coal quality parameters within designated mine permits (ERCB 1987). No regional synthesis of available coal quality and geological data has thus far been completed for all of the foothill/mountain coals.

This report is the last in a three-part series of publications that attempts to document and provide a geological understanding of coal quality variations in the foothill and mountain regions of Alberta. The first in the series dealt with coals in the central and southern foothills/mountains region (Macdonald et al. 1987), while the second focused on the northern foothills/mountains reference region (Macdonald et al. 1989). This publication summarizes the coal quality findings of the first two reports, i.e. for the entire region.

Abstract

This report is the conclusion of a three-part series that describes and attempts to explain regional coal quality variations within the foothills/mountains region of Alberta. Proximate and ultimate analysis variables, plus some vitrinite reflectance and maceral analyses, are examined for the Jurassic-Lower Cretaceous Kootenay Group, Lower Cretaceous Luscar Group, the Lower Paleocene Coalspur Formation, and the Upper Paleocene Obed-Marsh coal-bearing units.

The study has two major components: 1) a statistical analysis and mapping of coal quality data provided by the Energy Resources Conservation Board, and 2) a "geologic models" section, in which regional and local in-seam coal quality variations are examined from a geological perspective. The first component is designed to describe, characterize, and set limits for the coal quality variables, while the second component should provide from a geological perspective, insight as to why and how these quality parameters vary as they do.

The statistical analyses and maps of coal-rank related variables (e.g. volatile matter, fixed carbon, calorific value, and vitrinite reflectance) show that coals in this region range from semianthracite to subbituminous "A" and that the present suite of data is sufficient to describe the regional rank variations within the four coal-bearing units. Coal quality variables related to the original depositional environment (e.g. ash and sulfur) show highly variable regional and statistical distributions. These variables must be examined on a local, individual seam and in-seam basis. On a regional scale, there is insufficient data set to accurately describe these variables.

The "geologic models" section shows that coal rank for the base of the Gates Formation parallels, the disturbed belt, and in general, decreases toward the disturbed belt. This distribution is explained by a combination of original depth of burial in the foreland basin and a minor syndeformational coalification component. Coals at the base of the Kootenay Group increase in rank from south to north. Coalification of the Kootenay coals is thought to be related to a combination of depth of burial, geothermal gradient, and deformational history. The coalification pattern of the Coalspur Formation and Obed-Marsh coals is largely predeformational.

Ash content of these coals is generally separable into three components: inherent ash derived from original plant mineral matter, water-derived clastic partings, and air-deposited volcanic ash horizons. Water-derived clastic partings are usually thick enough, from a mining perspective, to be easily be removed from the coal. Inherent ash contents tend to vary vertically and laterally within a seam, often being lowest near the middle of the seam. Thin, airborne volcanic ash partings are usually impossible to separate during mining; they also tend to be high in montmorillonitic minerals and sometimes double the overall "as mined" ash content from that expected with inherent ash only.

Sulfur values for all coals examined are very low (0.2-0.5%, db) by international coal standards. However, elevated values commonly occur at the base, top and immediately below major waterborne clastic partings or overlying fluvial or tidal deposits. These elevated values are typically only in the 0.5-0.7% (db) range, though values as high as 3.0% (db) have been recorded for some seams.

Introduction

Objectives

The objective of this study is to provide a geological understanding and document the variation in coal quality parameters in the foothill/mountain regions of Alberta. The major aspects of coal quality are determined by original depositional environment, diagenesis, depth of burial, length of coalification, geothermal gradient, and structural deformation. This study will document regional coal quality variations and an attempt to explain the variations will be made.

Incentive

Alberta must continue to find new markets for both its metallurgical and thermal coals. The metallurgical coal market, in particular, has suffered considerably in the past five years. Well-documented descriptions of coal quality variations should prove useful for marketing of and contract negotiations for foothill/mountain coals.

A comprehensive review of available coal quality information from the foothills/mountains region will be valuable for government planners involved in making land use decisions. The information may be particularly useful for the integrated resource planning projects undertaken by Alberta Forestry, Lands and Wildlife. The Energy Resources Conservation Board may find it valuable for its coal resource estimations.

Finally,. "any scientific hypothesis, however absurd, may be useful in science if it enables a discoverer to conceive things in a new way; but that, when it has served this purpose by luck, it is likely to become an obstacle to further advance" (Russell 1985). A better understanding of the geological factors that control coal quality and resulting models will prove beneficial to both industry and government.

Scope of present study

The first phase of the study concentrated on the central and southern foothills/mountains region (Tp 1-45, Macdonald et al. 1987). The second phase concentrated on the northern foothills/mountains region (Tp 46 to the British Columbia border, Macdonald et al. 1989, figure 1).

The four major coal-bearing units evaluated included the Lower Cretaceous-Jurassic Kootenay Group, the Lower Cretaceous Luscar Group, the Paleocene Coalspur Formation, and the Upper Paleocene Paskapoo Formation (Obed-Marsh coal zone, figure 2). The Obed-Marsh coal zone in this area lies in the plains geological domain; however, it is classed as a foothills deposit by the Energy Resources Conservation Board (ERCB 1986). It is included in this report for comparison with the Coalspur Formation coals and because of its importance in providing export thermal coal.

Coal quality data was obtained from the ERCB files, existing published works, and fieldwork during the 1987 and 1988 field seasons. The types of coal quality parameters addressed were mainly those from proximate, ultimate, and calorific analyses value.

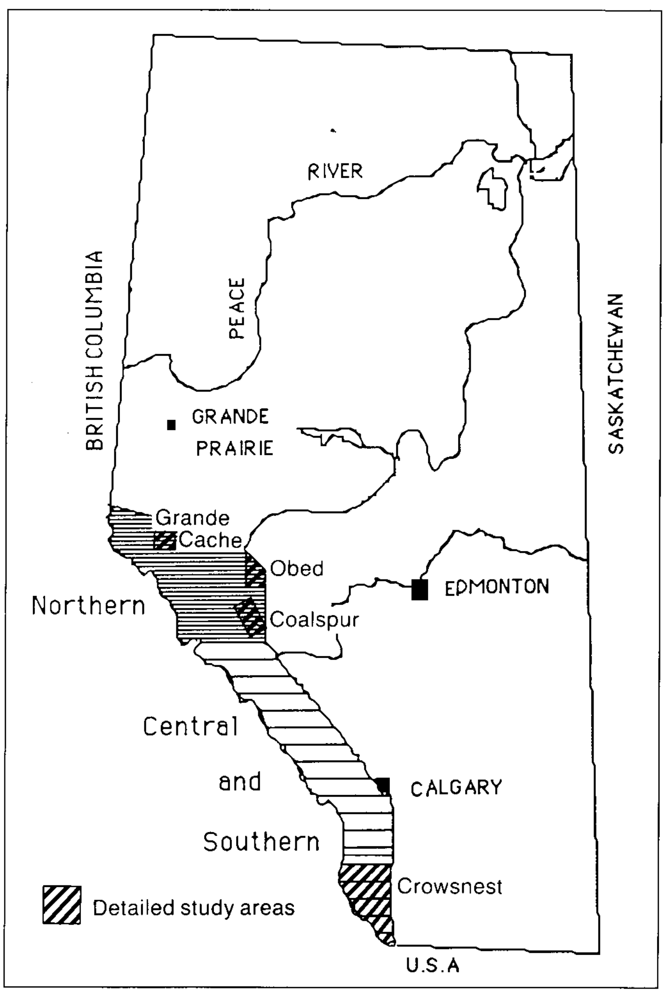

Figure 1. Study areas.

This study was carried out by a team of geologists, statisticians, computing specialists, coal chemists, and technologists over a two-year period.

Previous work

Regional coal quality variations in the foothills/mountains region have been addressed by Steiner et al. (1972) in a study dealing primarily with plains coals. Prior to this, the work by Stansfield and Lang (1944) was the most comprehensive. More recent works have focused on coal rank variations (Kalkreuth and Langenberg 1986; Kalkreuth and McMechan 1988; Hughes and Cameron 1985; Bustin 1982), with the ex-

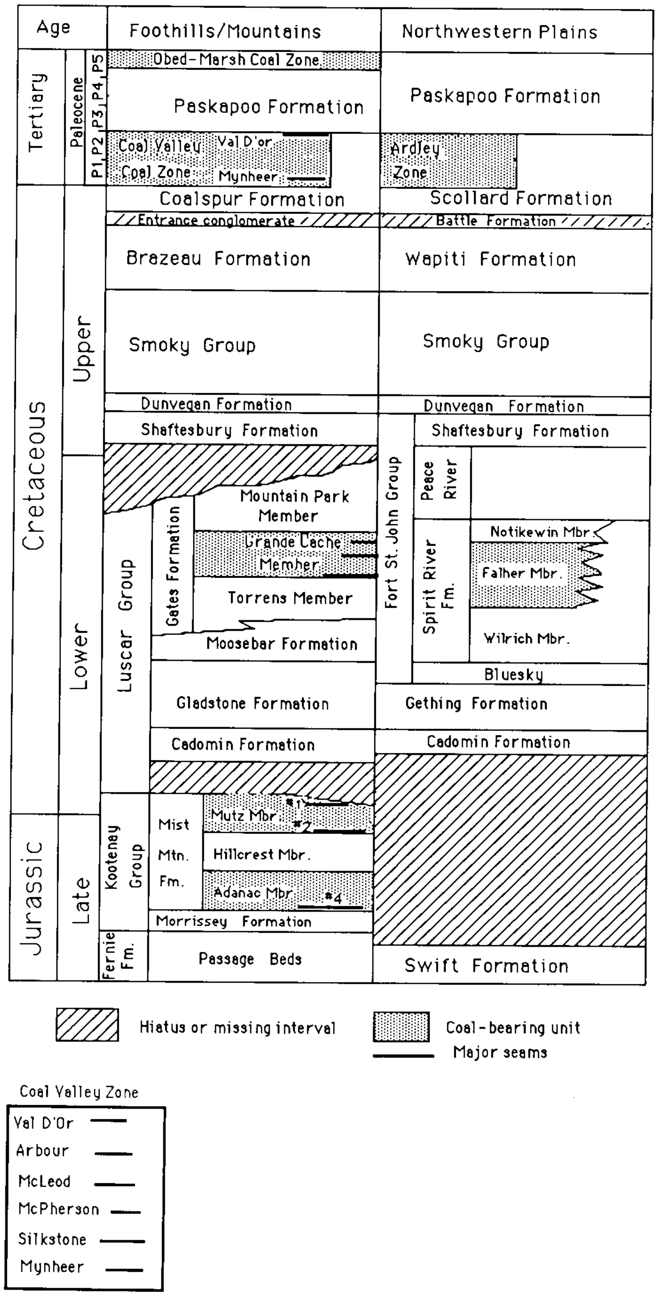

Figure 2. Stratigraphic nomenclature adopted.

ception of the reports issued in the present series of publications (Macdonald et al 1987, 1989).

To date, little has been published, except data from local minesites, about regional calorific values; volatile matter; fixed carbon; sulfur, ash, and moisture contents; petrographic composition; and trace element distributions of coal within the foothill/mountain coal zones in Alberta. The most recent comprehensive coal quality study in this area is the work by Langenberg et al. (1989) which deals with the Cadomin-Luscar coalfield. In-seam variations with respect to most coal quality parameters have only begun to be documented, and again, mostly at minesites (Macdonald 1989). To compound the coal quality problem, regional coal seam stratigraphic correlations are poorly understood throughout the region, except for local areas.

Data sources and processing

Sources

Coal quality data for this study came from three sources: the July 1987 and March 1988 versions of the ERCB electronic data file, the authors after the 1987 and 1988 field seasons, and the coal companies in the area. The ERCB data was used primarily to document coal quality variations with respect to ash, sulfur, volatile matter, fixed carbon, calorific value and moisture parameters in a statistical and geographic sense. The data collected in the field was used to provide a geological understanding of coal quality variations.

The ERCB data file contains coal quality determinations from several different coal sample types, including raw, washed, screened, washed and screened, and float-sink. From this, a smaller subset based only on the raw sample types, was selected for analysis and will hereafter be referred to as the "raw data set." The raw data set contains over 2000 proximate analyses from more than 470 locations and over 1260 ultimate analyses from over 370 locations. The raw data may be found in Macdonald et al. 1987 (southern area) and Macdonald et al. 1989 (northern area). It contains only those analyses with less than or equal to 50% ash present.

The new coal quality data collected (137 samples from 23 locations) by the authors were analyzed at the Alberta Research Council's coal laboratory in Devon and at the GSC laboratory in Calgary. These data were used for two purposes: 1) in-seam channel samples were collected across individual seams to relate coal quality parameters to depositional environments, and 2) grab samples were collected to show regional rank variations. In general, in-seam channel samples were collected so as to exclude visible partings. These data appear as appendices 1-4.

Processing

The ERCB provided the Alberta Geological Survey with a magnetic tape in mixed-data format; an inhouse computer program was written to reformat the data into a more readable, standard ASCII format. As the ERCB data has no publicly available geological or stratigraphic identifiers attached to the coal quality data, another program was written to select and transfer to separate files, the locations of coal holes (and all associated quality data) which penetrated either the Kootenay Group, Luscar Group, Coalspur Formation, or Obed-Marsh coal zone.

The coal quality data sets of the geological formations were further refined to include only the coal holes with analyses based upon raw coal. This refined data set was used in the statistical analyses of the data. From this smaller data set, thickness weighted averages of ash, sulfur, volatile matter, fixed carbon, calorific value, and residual moisture were calculated for each coal hole. These values are plotted as a series of regional coal quality maps (figures 3-14, in pocket).

Most of the statistical analyses were performed using STATGRAPHICS on a microcomputer and SAS (SAS Institute Inc.) on a VAX 8600 computer. Postings of coal quality variables were produced using the in-house GEOPLOTTER software and a VAX minimainframe computer.

Reporting Bases

Coal quality can be reported on at least five different bases depending upon the intended use, and to some extent, the laboratory performing the analyses. The most common bases include "as analysed," "as received," "dry," "dry-ash-free" (daf), "moist mineral matter-free" (mmmf), and "dry mineral matter free" (dmmf) (Ward 1985). One of the biggest problems in compilation studies and comparing coal quality data is the lack of uniformity in reporting the bases, or worse yet, not reporting the bases at all.

Regional geology

Geological divisions

Geologists have traditionally divided the Canadian Rocky Mountains into the Foothills and Mountains based on geological and physiographic criteria. The ERCB division deviates somewhat from this convention. The traditional subdivisions are used in this report.

Changes in structural style have traditionally provided the basis for distinguishing a series of diverse subparallel geological regions in the southeastern Rocky Mountains. Each is characterized by unique features of topography, stratigraphy, and structure and they are called the Foothills, Front Ranges, and Main Ranges. Because no commercial coal is present in the Main Ranges, only the foothill and front range divisions are dealt with here. Mountains will be considered equivalent to Front Ranges in this report and the general term foothills/mountains will be used for the combination of Foothills and Front Ranges taken together.

The boundary between plains and foothills is defined by an abrupt change from relatively flat bedding to steeply dipping bedding. In the Foothills, where the main level of exposure is of Cretaceous rocks, the structure at the surface is characterized by folding and thrusting in central and northern Alberta.

The McConnell Thrust defines the boundary between the Foothills and Front Ranges in the northern part of the south-central study area. South of the Highwood Range, the boundary skips to the Lewis Thrust. As a consequence, the only coalfields in the mountains region of the south-central area are the Costigan, Bankhead, Canmore, Pocaterra, and Tent Mountain coalfields. Throughout the northern study area, the boundary between the Foothills and Front Ranges is defined by the McConnell Thrust in the south, the Boule and Tip Top Thrusts in the central region, and the Rocky Pass Thrust in the north. Consequently, the coal deposits of the Pocahontas and Rock Lake area are the only deposits in the northern Front Ranges proper.

Coal-bearing units

Kootenay Group

In Alberta, the Kootenay Group is present in the Rocky Mountain Foothills and Front Ranges, and extends from the Crowsnest Pass area in the south to the North Saskatchewan River in the north (figure 9, in pocket). The Kootenay Group occupies the stratigraphic interval between the Jurassic Fernie Formation and the overlying Lower Cretaceous Blairmore Group. The Kootenay Group consists of the Morrissey, Mist Mountain, and Elk Formations. The Mist Mountain Formation contains the economically significant coal deposits throughout the region. A complete stratigraphic sequence of the Kootenay Group is absent in the eastern Foothills and the Crowsnest Pass area. In these areas, the Mist Mountain Formation is unconformably overlain by the Cadomin Formation.

Mist Mountain Formation

The geological distribution of the coal-bearing Mist Mountain Formation is well known, as interest in the formation's coal has been great for several decades. The Mist Mountain Formation thins from west to east to a zero erosional edge along the eastern edge of the foothills (Gibson 1985). Near the North Saskatchewan River, this formation is no longer coal-bearing and grades laterally into the Nikanassin Formation.

The Mist Mountain Formation is composed of a thick, interstratified sequence of predominantly nonmarine siltstone, sandstone, mudstone, shale, and thin to thick coal seams (Gibson 1985). The predominant rock type is siltstone ranging to fine-grained sandstone. The coal seams are thickest and most numerous in the Sparwood Ridge Elk Valley region of British Columbia.

Luscar Group

The Luscar Group, as recently defined by Langenberg and McMechan (1985), is the northern coal-bearing equivalent of the Blairmore Group in the southern Rocky Mountains (Mellon 1967), and is also equivalent to the subsurface Mannville Group of the plains region. The Luscar Group consists of the Cadomin, Gladstone, Moosebar, and Gates Formations (figure 2), with the Gates Formation (Grande Cache Member) containing the economically important coal deposits.

In general, the Luscar/Mannville Group was deposited as the second major continental clastic wedge sequence to prograde into the western interior Cretaceous seaway as a result of Cordilleran orogenic activity. During this time (Aptian to Albian), the area that is now central Alberta was undergoing large-scale transgressive and regressive events. The Moosebar Formation represents a major marine transgression that divides the Luscar Group into the two major continental units, i.e. Cadomin/ Gladstone Formations and the Gates Formation. (McLean and Wall 1981).

Gates Formation

The Gates Formation is divided into the Torrens, Grande Cache, and Mountain Park Members. The coal-bearing Grande Cache Member conformably overlies the Torrens Member and is more finely grained and recessive in comparison. In some places, a coal seam directly overlies the Torrens Member. The Grande Cache Member consists of an alluvial plain succession of coal seams interbedded with mudstone, siltstone, and very fine-grained sandstones (McLean 1982). The sequence also contains brackish deposits that become thicker and more numerous from south to north (Macdonald et al. 1988a).

Throughout this area, the coal seam correlations for the Grande Cache Member are not well understood Macdonald et al. (1988) suggest possible correlations between the seams at Cadomin and those at Grande Cache and the subsurface Elmworth Deep Basin. Earlier, McLean (1982) showed how the coal zone from Grande Cache to the Nordegg area was thought to be ideally correlated, based on outcrop exposures only.

Coalspur Formation

Coals lying above the Entrance conglomerate and below the Paskapoo Formation have been termed the Coalspur Formation by Jerzykiewicz (1985). The coal-bearing portion of the Coalspur Formation has been informally named the Coal Valley coal zone (ERCB 1987). The Coalspur Formation is stratigraphically correlative with the Ardley coal zone found in the plains region; it is simply the upthrust expression of the Ardley coal zone. Engler (1986) has shown how the informally named coal seams in the Coal Valley area are correlated throughout the foothills region, and Rogan (1983) provides a detailed description of these seams in the same area. Industry drilling in this zone has shown that the zone extends from the southern end of the present study area to north of the Athabasca River (figure 3). This compares favorably with the subsurface extent of the Ardley coal zone (Richardson et al. 1988).

The Cretaceous-Tertiary boundary lies near the base of the coal-bearing portion of the Coalspur Formation (Sweet and Jerzykiewicz 1985). Demchuk (1987) provides an initial palynological zonation of the Paleocene in Alberta and places these coals in the Lower Paleocene (his P1 and P2).

Obed-Marsh Coal Zone

The Obed-Marsh coal zone lies at the top of the Paleocene Paskapoo Formation and has a very limited regional extent. The coal zone is transitionally subbituminous "A" to high-volatile bituminous "C" in rank and has coal reserves in the order of 226 million tonnes. The coal zone is best expressed north of Obed summit (northeast of Hinton) as an erosional upland remnant. Here, the coal zone lies immediately east of the axial trace of the Alberta syncline, with the beds dipping very gently (0.5°) to the northeast (Demchuk 1986). Over 135 m of stratigraphic section, five high-volatile bituminous "C" coal seams have been identified from two mining blocks. At present, only the lower Nos. 1 and 2 seams are being mined.

The Obed-Marsh coal zone has been palynologically zoned to be Upper Paleocene in age (Demchuk 1986). Demchuk (1987) also reports Upper Paleocene carbonaceous shales and thin coals in an Alberta Research Council corehole near Lacombe.

Coal quality variations

Introduction

It has been shown in other coal basins that major coal quality parameters are determined by original depositional environment, diagenesis, depth of burial, duration of coalification, geothermal gradient, and structural deformation (table 1).

The original depositional environment of coals determines or influences, the quality of the coal. For example, the relationship between marine depositional environments and sulfur content of coals is well known (Davies and Raymond 1983). The paleobotanical assemblage and paleoclimate are also known to have influenced coal quality (Demchuk and Strobl 1989).

Diagenesis has been shown to influence some coal quality parameters, e.g. the forms of sulfur present in a coal (Wiese and Fyfe 1986). Ash composition may also change through time with varying diagenetic conditions. Clay minerals undergo alterations during diagenesis that change their chemical and mineralogical compositions.

The moisture and volatile matter contents of coal progressively decreases with increasing rank. Rank is determined by temperature and length of heating time during burial. In most stratigraphic sequences, the deeper the coal has been buried, the higher the temperature it has been exposed to, and usually, the greater its rank.

Proximate, ultimate, and calorific analyses

Statistical analyses

Statistical analyses were performed on proximate and ultimate analysis data for the four major coal-bearing units. Analyses were performed separately for each geological formation using the raw data sets.

Data analyses resulted in descriptive statistics (tables 2 and 3), histograms describing data distribution, normality tests, and box-and-whisker plots. Histograms and normality testing details can be found in the previous publications in this series (Macdonald et al. 1987, 1989). This report will summarize the statistical analyses using descriptive tables and box-and-whisker plots. Box-and-whisker plots show details of the maximum, minimum, median, and the 25th and 75th percentiles for each variable (see Wong et al. 1988 for details). The variables examined were ash, moisture, volatile matter, fixed carbon, and sulfur contents, and calorific value. Some regression analyses and scatter plots were used to explore relationships between variables.

Table 1. Coal quality parameters and controlling factors.

Controlling factors	Coal quality parameters
Original depositional environment, including original plant communities	- ash content and composition - sulfur content - trace elements
Diagenesis	- sulfur content and form - rank
Depth of burial Duration of burial Geothermal gradient	- calorific value, rank, fixed carbon, moisture, volatile matter, ash
Structural setting	- ash, particle size

Moisture

Residual moisture contents from the raw coal data set were used to calculate weighted average values for each sampling location. Figures 8 and 10 show these distributions for the Kootenay, Luscar, Coalspur and Obed-Marsh coals. There is no discernible regional pattern. The maps (figures 8 and 10) are best used to gain a general impression of residual moisture values for the smaller areas.

Kootenay Group coals have a mean moisture value of 0.70% (residual, table 2). Horachek (1985) indicates that typical moisture contents for Kootenay Group coals are in the 1.5-4.0% range (basis not given). Box-and-whisker plots of "as received" (figure 15) and "as determined" (figure 16) moisture for the Kootenay Group coals show them to have the lowest median values of all the foothill/mountain coals.

The Luscar Group coals have the widest range of "as received" moisture contents (figure 15) and, similar

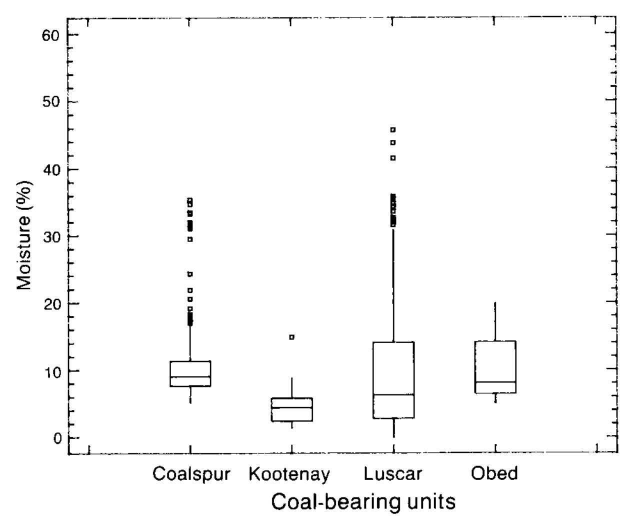

Figure 15. Moisture contents (as received) for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals.

to the Kootenay Group, relatively low "as determined" moisture values (figure 16).

Mean, mode, and range of values for the Coalspur Formation coals appear in table 2, and the multiple box-and-whisker plot (figure 15) shows the Coalspur Formation coals to have the greatest number of outlier values on an "as received" basis. On an "as determined" basis, they have moisture values comparable to the Obed-Marsh coals.

The moisture content values of the Obed-Marsh coals have medians of 4.4% (as determined) and 8.5% (as received, table 2). The box-and-whisker plots show the Obed-Marsh coals to have the highest "as determined" moisture contents of all the coals evaluated (figure 16). Equilibrium moisture values for the Obed-Marsh coals, while not present in the current ERCB data set, are reported by Bonnell and Janke (1986) to be in the 12.66-13.61% range for the Nos. 1 and 2 seams within the Obed-Marsh zone (channel samples from the mine face).

Ash

Mineral matter in coals is derived almost exclusively from the original sedimentary environment and falls into two main groups: finely disseminated mineral matter in the coal itself, and discreet clastic partings. Reported ash contents of coals depends on the original sedimentary environment, the field sampling procedure, and the reporting basis chosen. These factors are discussed in a later section of this report.

Thickness weighted average values were calculated for ash and plotted on the regional maps (figures 3 and 11). No information on the number of seams averaged or the sampling procedure undertaken is available. The maps should therefore be used with caution and considered to be only an approximate

Table 2. Descriptive statistics of proximate analyses for the Kootenay, Luscar, Coalspur and Obed-Marsh coals.

Variable/Analysis	N	Av.	Med.	Mode	Var.	Sd.	Min.	Max.	Range	Skew	Kurt
Kootenay Group											
Moisture, AR	35	4.7	4.4	2.0	7.3	2.7	1.4	14.9	13.5	1.7	4.8
Moisture, AD	156	1.2	0.8	0.8	2.3	1.5	0.3	10.1	9.8	4.1	17.4
Ash, db	173	26.4	25.8	28.5	100.5	10.0	4.8	49.8	45.0	0.2	-0.5
Fixed Carbon, db	173	52.4	52.5	51.0	107.7	10.4	31.3	86.6	55.3	0.5	0.6
Fixed Carbon, daf	173	70.9	70.6	65.3	40.7	6.4	55.9	91.0	35.1	0.8	0.9
Vol. Mat., db	173	21.1	21.8	21.5	19.0	4.4	8.6	32.6	24.0	-0.7	0.6
Vol. Mat., daf	173	29.1	29.4	31.0	40.6	6.4	9.0	44.1	35.1	-0.8	0.9
Cal. Val., db	157	25.0	25.3	25.2	13.7	3.7	15.3	32.7	17.4	-0.2	-0.4
Cal. Val. daf	157	34.1	34.3	35.3	2.2	1.5	27.7	37.0	9.3	2.1	6.3
Luscar Group											
Moisture, AR	345	10.1	6.3	2.2	91.7	9.6	0.0	45.7	45.7	1.3	0.9
Moisture, AD	320	1.0	1.0	1.0	0.3	0.03	0.0	4.0	3.9	0.7	4.1
Ash, db	590	22.1	19.4	10.9	135.7	11.7	3.6	50.0	46.4	0.6	-0.7
Fixed C., db	513	59.6	61.4	58.8	131.0	11.4	30.8	76.4	43.2	-1.5	0.8
Fixed C., daf	513	75.0	77.0	80.4	39.1	6.3	55.7	83.7	28.0	-0.5	-1.1
Vol.Mat, db	513	19.4	17.4	15.6	21.4	4.6	11.7	32.4	20.7	0.9	-0.3
Vol.Mat., daf	513	24.9	22.9	19.6	38.3	6.2	16.3	44.2	27.9	-0.5	-1.2
Cal.Val., db*	424	27.8	29.1	32.5	20.8	4.6	16.4	34.8	18.4	-0.7	-0.6
Cal.Val., daf*	424	35.3	35.5	35.9	0.8	0.9	31.4	37.0	5.6	-1.2	1.8
Coalspur Formation											
Moisture, AR	220	10.7	9.0	9.5	33.5	5.8	5.2	35.4	30.2	2.6	7.0
Moisture, AD	1416	5.3	5.4	5.9	3.1	1.8	0.6	12.1	11.5	0.1	-0.5
Ash,db	1448	26.1	25.1	14.3	120.4	11.0	5.0	49.8	44.7	0.3	-1.0
Fixed C., db	734	43.4	43.8	48.8	54.5	7.4	19.4	58.9	39.5	-0.2	-0.8
Fixed C., daf	734	58.9	59.3	59.5	8.8	3.0	38.1	65.5	27.4	-1.6	5.9
Vol. Mat., db	734	29.9	30.0	33.8	17.6	4.2	19.6	40.2	20.6	-0.1	-0.8
Vol. Mat., daf	734	40.7	40.5	40.5	6.0	2.5	29.5	55.1	25.6	0.5	2.6
Cal. Val., db*	1155	22.6	22.9	26.5	13.8	3.7	10.0	35.3	19.6	-0.3	-0.8
Cal. Val., daf*	1155	30.6	30.7	31.1	1.2	1.1	19.7	38.9	19.2	-l.8	17.7
Obed-Marsh coal zone											
Moisture, AR	88	10.2	8.1	8.1	19.5	4.4	5.1	19.9	14.8	0.7	-1.8
Moisture, AD	142	5.2	4.4	2.0	9.4	3.1	1.8	23.6	21.8	2.2	10.0
Ash, db	151	28.6	28.7	17.1	107.4	10.4	9.0	49.7	40.7	0.1	-0.8
Fixed C., db	149	38.2	39.9	49.2	104.0	10.2	2.6	54.4	51.8	-1.1	1.4
Fixed C., daf	149	52.9	56.8	52.0	113.2	10.6	4.4	64.9	60.5	-2.4	6.7
Vol. Mat., db	149	33.3	32.6	29.0	48.2	6.9	21.3	57.9	36.6	1.2	2.1
Vol. Mat., daf	149	47.1	43.2	48.0	112.8	10.6	35.1	95.6	60.5	2.4	6.8
Cal. Val., db*	151	22.0	21.8	25.2	13.7	3.7	14.5	29.7	15.2	-0.1	-0.9
Cal. Val., daf*	151	30.7	30.9	31.2	2.1	1.4	19.1	32.8	13.7	-3.8	27.7

*Mj/Kg

guide to the ash values that might be expected in a given area. Langenberg et al. (1988) and Macdonald (1989) have shown that ash content in coal can vary quite dramatically within a very small coal field and within a single coal seam. Regional evaluations of ash should ideally be done with much more geological and coal quality information (e.g. stratigraphic position of seams and presence of partings).

Kootenay Group

The mean ash value for the Kootenay Group coals is 26.4% (table 2). In part, this mean value is a mathematical product affected by the 50% cutoff used for defining a coal. It is important to point out that economic coals within the Kootenay Group frequently have much lower ash values.

Horachek (1985) states that typical ash values for the Kootenay Group coals are in the 8-14% range (no basis given). The apparent discrepancy with the ERCB data is probably related to the fact that the Horachek data were derived solely from economic coal seams, while the ERCB data includes exploration holes. Steiner et al. (1972) found the average ash content for the Kootenay Group coals to be 15% (no basis given).

Table 3. Descriptive statistics of ultimate analyses for the Kootenay, Luscar, Coalspur and Obed-Marsh coals.

Variable/Analysis	N	Av.	Med.	Mode	Var.	Sd.	Min.	Max.	Range	Skew	Kurt
Kootenay Group											
Carbon, db	8	78.6	79.5	64.7	65.6	8.1	64.7	88.7	24.0	-0.5	-0.4
Carbon, daf	8	91.0	91.8	84.7	7.2	2.7	84.7	93.3	8.6	-2.3	5.8
Sulfur, db	437	0.5	0.4	0.3	0.2	0.4	0.1	6.5	6.4	8.0	96.7
Sulfur, daf	437	0.7	0.6	0.4	0.3	0.5	0.1	7.7	7.6	7.2	81.1
Hydrogen, db	8	3.7	3.6	3.6	0.1	0.2	3.3	4.0	0.7	0.03	-0.4
Hydrogen, daf	8	4.3	4.1	4.1	0.2	0.4	3.9	5.2	1.3	2.3	5.9
Nitrogen, db	8	1.1	1.1	1.1	0.03	0.2	0.8	1.4	0.6	0	2.0
Nitrogen, db	8	1.3	1.3	1.3	0.03	0.2	1.0	1.5	0.5	-0.5	-0.6
Oxygen, db	8	2.3	1.8	0.8	3.5	1.9	0.8	6.7	5.9	2.3	5.8
Oxygen, daf	8	2.8	2.1	2.1	6.4	2.5	0.8	8.8	8.0	2.4	6.0
Luscar Group											
Carbon, db											
Carbon, daf											
Sulfur, db	565	0.5	0.4	0.3	0.08	0.3	0.1	3.0	2.9	3.7	22.0
Sulfur, daf	565	0.7	0.6	0.4	0.2	0.4	0.1	4.5	4.4	3.6	19.8
Hydrogen, db											
Hydrogen, daf											
Nitrogen, db											
Nitrogen, daf											
Oxygen, db											
Oxygen, daf											
Coalspur Formation											
Carbon, db	49	68.7	69.4	71.4	64.0	8.0	44.0	78.7	34.7	-1.5	2.3
Carbon, daf	49	77.4	77.2	77.2	2.7	1.6	73.4	81.4	8.0	0.2	0.4
Sulfur, db	686	0.3	0.3	0.2	0.1	0.3	0.1	2.8	2.7	4.7	27.9
Sulfur, daf	686	0.4	0.4	0.3	0.2	0.4	0.1	5.0	4.9	5.7	45.2
Hydrogen, db	49	4.5	4.6	4.2	0.3	0.5	3.1	5.4	2.3	-0.8	0.5
Hydrogen, daf	49	5.1	5.1	5.1	0.04	0.2	4.7	5.6	0.9	0.1	-0.7
Nitrogen, db	50	0.9	0.9	0.9	0.04	0.2	0.3	1.3	1.0	-0.2	0.1
Nitrogen, daf	50	1.0	1.0	1.0	0.04	0.2	0.4	1.3	0.9	-0.9	1.0
Oxygen, db	49	14.3	14.9	14.9	6.0	2.4	7.4	17.6	10.2	-1.0	0.6
Oxygen, daf	49	16.0	16.3	16.2	3.1	1.8	11.4	20.0	8.6	-0.4	.1
Obed-Marsh coal zone											
Carbon, db											
Carbon, daf											
Sulfur, db	152	0.4	0.3	0.3	0.08	0.3	0.1	2.7	2.6	4.4	30.4
Sulfur, daf	152	0.6	0.5	0.4	0.2	0.4	0.2	4.2	4.0	4.8	35.3
Hydrogen, db											
Hydrogen, daf											
Nitrogen, db											
Nitrogen, daf											
Oxygen, db											
Oxygen, daf											

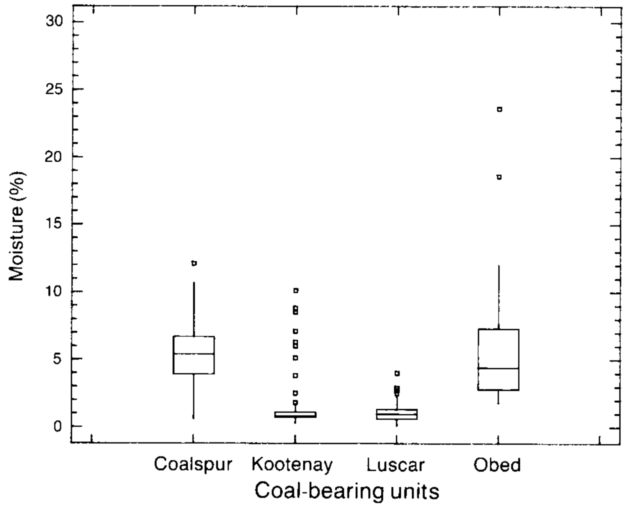

Figure 16. Moisture contents (as determined) for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals.

Luscar Group

The raw data set for the Luscar Group coals shows a positively skewed histogram (Macdonald et al. 1989) with 75% of the sample population containing less than 30% ash (figure 13). The median ash value (19.4%) is the lowest of all of the foothill/mountain coals (figure 17); the mode is 10.9% (table 2).

With this statistical distribution, the mode may be more meaningful than the median as it represents the most frequently occurring value. It may also be more meaningful from a geological/economic sense in that it suggests that any economic coal seam within the Luscar Group will likely to have an ash value near 10%. Samples collected during the course of this study at the Smoky River mine support this conclusion, as few values exceeded 15% (appendix 2). Langenberg et al. (1988) reports a median ash value of 13.6% (db) for the Luscar Group-Jewel Seam in the Cadomin-Luscar coalfield. This is consistent with the median value obtained in this study. The mean and median may not be the best predictors of ash content in Luscar Group coals. The mean and median also indicates that the ERCB data set probably includes information from several uneconomical seams with many partings.

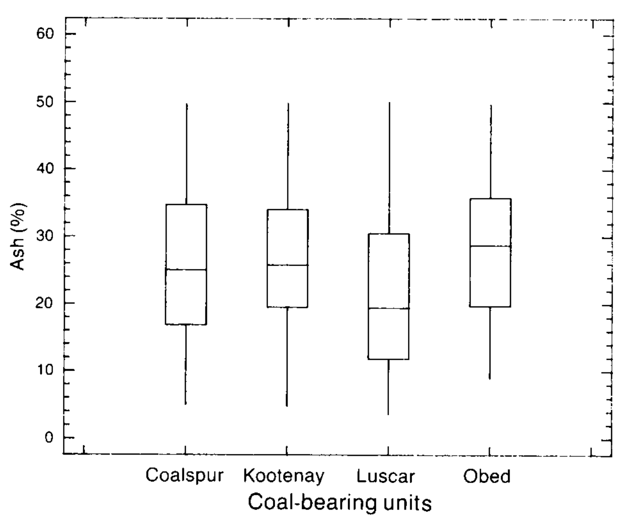

Figure 17. Ash contents (dry basis) for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals.

Coalspur Formation

The box-and-whisker plot for content ash in the Coalspur Formation shows that 75% of the sample population has values less than 35% (figure 17). In this distribution, the mean and median are about the same (25-26%, table 2) and the mode is somewhat lower (14.3%). The mode value alone, the use of which was suggested for the Luscar Group coals, would probably not be a reliable predictor of ash in the Coalspur coals.

Bonnell and Janke (1985) report ash values from channel mineface samples from the Coal Valley mine ranging between 13.6 and 18.4% (db). This suggests that a 14% ash estimate based on the mode would represent the lowest ash coals from this mine. Analysis of samples collected during this study (appendix 3) support this conclusion, with very few samples containing less than 15% ash.

Obed-Marsh Coal Zone

The data set for the Obed-Marsh coal zone shows a bimodal or perhaps trimodal distribution (Macdonald et al. 1989); 75% of the sample population has ash values less than 36% (figure 17). Like the Coalspur Formation coals, the Obed-Marsh coals have similar mean and median values (28% db, table 2), and a slightly lower mode value (17.1%, (db). Bonnell and Janke (1986) report channel samples from the mineface with ash values between 19 and 20% (db) and clean coal ash values near 12% (db). The ash values of samples taken from the Obed Mountain mine during this study (visible partings excluded, appendix 4) vary from 9 to 42%. This is consistent with the distribution seen in the ERCB raw data set (figure 17).

When compared to the Kootenay, Coalspur, and Obed-Marsh coals, the Luscar Group coals stand out as having the lowest median ash value and the single lowest ash value (figure 17). The Kootenay, Coalspur, and Obed- Marsh coals show very similar distributions and median values with respect to ash.

Volatile Matter/Fixed Carbon

Thickness weighted averages from the raw coal data set were calculated for volatile matter; these values appear on the two regional maps (figures 5 and 9). Fixed carbon distributions appear on two other maps (figures 6 and 12). As for ash, information on the number of seams averaged or the samplingused procedure is unavailable. The implications of the the information included in these maps are discussed in detail in a later section of this report.

Kootenay Group

The volatile matter mean value within the Kootenay Group coals is 29.13% (9.03-44.08% (daf), table 2); however, 75% of the sample population has volatile matter contents less than 33% (daf, figure 18).

There is a discernible decrease from south to north in the regional distribution of volatile matter (daf, figure 9). For the Kootenay Group coals, this is a reflection of increasing rank to the north. A more detailed discussion of regional volatile matter distribution and rank implications is given in a later section of this report.

Figure 18 shows the lower volatile matter values of the Kootenay and Luscar coals – a reflection of the higher rank of these coals relative to those of the Coalspur and Obed-Marsh zones (both of which contain lower rank coals). The narrower range and higher rank of the Coalspur versus the Obed-Marsh coals are also apparent.

Luscar Group

The data set for the Luscar Group coals shows volatile matter values (daf) to be positively skewed (Macdonald et al. 1989), and the box-and-whisker plot shows that 75% of the sample population has values less than 32% (daf, figure 18). For this data set, the mean, mode, and median are all similar (19-21%, table 2), and any one of these values can be used to describe volatile mater in the Luscar Grup coals.

The relatively wide range of values for this variable is related to the Luscar Group coals having a rank variation from high volatile bituminous "A" to low-volatile bituminous (see later section for details). The mode indicates that most of the Luscar Group coals in this data set are low-volatile bituminous in rank.

Coalspur Formation

The Coalspur Formation coals show a near normal distribution of volatile matter values, and the box-and-whisker plot shows that 75% of the sample population lies in the 35-42% range (daf, figure 18). The mean, median, and mode values for volatile matter for this data set are 40.7, 40.5, and 40.5, respectively (table 2). These results indicate that the Coalspur Formation coals are most commonly High Volatile Bituminous "B" in rank, but do contain some high volatile bituminous "A" ranks. Bonnell and Janke (1986) report volatile matter contents of 37.38-39.21% (daf) for Coalspur coals from the Coal Valley mine.

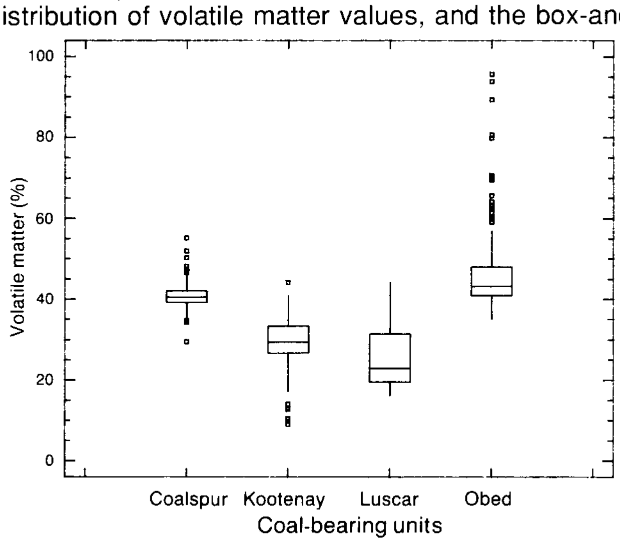

Figure 18. Volatile matter contents (dry, ash-free basis) for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals.

Obed-Marsh Coal Zone

Volatile matter values obtained from the Obed-Marsh coals show a near normal distribution, with the exception of some outliers greater than 52% (figure 18). The box-and-whisker plot shows that 75% of the sample population lies in the 35-58% range (daf, figure 18). The mean, median, and mode are 47.0, 43.2, and 48.0, respectively (table 2). The mode value comes very close to predicting the "clean coal" volatile matter contents from the Obed mine as reported by Bonnell and Janke (1986).

These values and ranges are generally consistent with those reported by Bonnell and Janke (1986) for channel samples from the Nos. 1 and 2 seams (38.93-41.77%, db and 48.80-51.82%, daf. Volatile matter content of samples collected during this study from the Obed mine varied between 42.7 and 47.5% (daf, appendix 4), with these values being very close to the mean, median, and mode described previously.

Calorific Value

Thickness weighted averages were calculated for calorific value and plotted on two regional maps (figures 7 and 13). As with the other variables, no information on the number of seams averaged or the sampling procedure used is available. The paucity of data for the Luscar Group coals is a reflection of their primary utilization as metallurgical coking coals for which calorific values are seldom determined.

Kootenay Group

Calorific values for the Kootenay Group coals range from 27.7 to 37.0 MJ/kg (daf). Horachek (1985) reports average coal calorific values for the Kootenay Group in the 29.0-32.0 MJ/kg range (no basis given).

The regional geographic distribution of calorific values (figures 7 and 13) shows that many of the mean values are in the 33-37 MJ/kg range (daf). Calorific value does not vary much with coal rank in this area (figure 19). Coals that are higher than medium-volatile bituminous in rank show very little increase in calorific value (Teichmuller and Teichmuller 1968). This explains the calorific value distribution in this study.

Luscar Group
Figure 19 shows a near normal distribution of calorific values for the Luscar Group coals. This figure also shows that 75% of the sample population lies between 34.3 and 36.0 MJ/kg (daf). The mean, median, and mode are all around 35.5 MJ/kg (daf, table 2). These results are consistent with the general observation that coals in this rank range (i.e. low- to medium-volatile bituminous) do not vary greatly in calorific value. However, these coals have the widest range of calorific values of all the coals evaluated.

Coalspur Formation
If the outliers at both ends of the diagram are ignored, the box-and-whisker plot of calorific values for Coalspur Formation coals shows a normal distribution (figure 19). Figure 19 also shows that 75% of thesample population lies in the 28.8-31.0 MJ/kg (daf) range. The mean, median, and mode values are 30.5, 30.7, and 31.1 MJ/kg, respectively (daf, table 2).

Bonnell and Janke (1986) report calorific values of 30.62-30.72 MJ/kg for Coalspur Formation coals at the Coal Valley mine. Within these high-volatile bituminous coals, calorific value is sensitive to change in rank and is therefore used in assigning ASTM rank.

Obed-Marsh Coal Zone
The box-and-whisker plot of calorific values for the Obed-Marsh coal zone shows a near normal distribution with 75% of the sample population lying between 28.5 and 32.8 MJ/kg (daf, figure 19). The median, mean, and mode values may be found in table 2.

These findings are consistent with the sub-bituminous "A" classification of this coal and compare well with the findings of Bonnell and Janke (1986) who report values of 30.45 and 30.28 MJ/kg for channel samples taken from the mine face in the Nos. 1 and 2 seams.

Ultimate Analysis
Kootenay Group
Only seven complete ultimate analyses are present in the ERCB data set for the Kootenay Group coals, making assessment of carbon, nitrogen, oxygen, and hydrogen values difficult. Descriptive statistics for these data appear in table 3. New ultimate analyses data were collected in the field by the Alberta Geological Survey in 1987 (appendix 1).

Luscar Group
Less than two complete ultimate analyses determinations are present in this data set, making statistical analysis impossible (table 3). Sixteen ultimate analyses of the Luscar Group coals from the Smoky River mine, sampled during the course of this study, appear in appendix 2. In a detailed coal quality study by Langenberg et al. (1988), 104 ultimate analyses

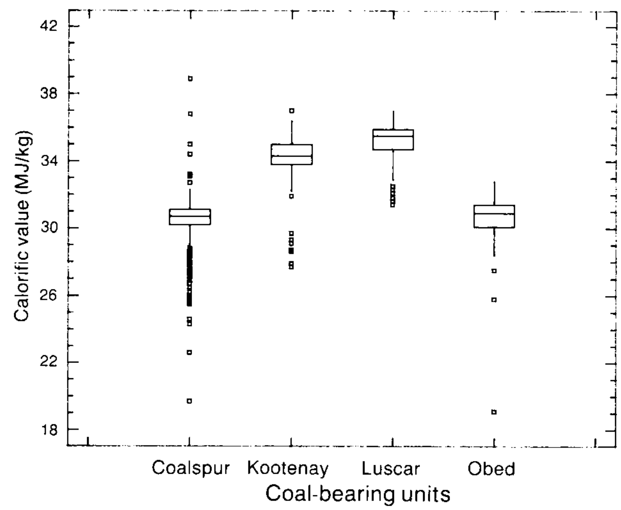

Figure 19. Calorific value (dry, ash-free basis) for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals.

from the Jewel coal seam in the Cadomin-Luscar coalfield were used to statistically characterize this seam.

Coalspur Formation
The raw data set contains 49 complete ultimate analyses determinations for coals from the Coalspur Formation. Histograms and box-and-whisker plots for C, H, N, and O all show non-normal distributions (Macdonald et al. 1989). Descriptive statistics appear in table 3. Eight complete ultimate analyses from samples collected in the Coal Valley-Robb area are indicative of the Arbour, Val D'Or, Mynheer, Silkstone, and McPherson seams within the Coalspur Formation coal zone (appendix 3).

Obed-Marsh Coal Zone
No ultimate analyses data from the Obed-Marsh coal zone are present in the data set used. Two complete ultimate analyses data sets that were collected from the Obed mine during the course of this study are indicative of the Nos. 1 and 2 seams within the Obed-Marsh coal zone (appendix 4).

Sulfur
Thickness weighted averages for sulfur appear on two regional maps (figures 4 and 14). Information on the number of seams averaged and the sampling procedure used is unavailable. These maps, as with these for ash content, should be used only as an approximate guide to expected sulfur values for a given area. Langenberg et al. (1988) have shown that sulfur values, over three to four seams within the Luscar Group, can vary between 0.1 and 2.9% (db) in the Cadomin-Luscar coalfield. As with ash, regional evaluations of sulfur should ideally be performed using a much larger data set than is presently available.

Kootenay Group

The regional geographic distribution of sulfur shows that, within the Kootenay Group, the sulfur content of coals is consistently below 0.50% throughout the region south of the Bow River (figure 14). No strongly discernible pattern is obvious in the distribution of the Kootenay Group sulfur values, with the possible exception of a slight tendency for sulfur content to be higher in the Highwood versus the Crowsnest Pass area. No data are present for the Kootenay Group coals north of the Bow River.

Steiner et al. (1972) suggest that the central and southern Rockies are characterized by moderately low sulfur coals (i.e. >0.5%). With respect to the Luscar Group coals in the central portion of the study area, this study supports their findings. However, no evidence to support this claim was found for the Kootenay Group coals in the area south of the Bow River; here, exactly the opposite situation is evident. Extreme caution should be exercised in making generalizations about geographic distributions of sulfur where data are scarce.

Luscar Group

The sulfur distribution for Luscar Group coals is positively skewed; the box-and-whisker plot shows that 75% of the sample population falls between 0.1 and 0.7% (db, figure 20). The mean, median, and mode for sulfur in the Luscar Group coals are 0.5, 0.4, and 0.3% respectively (n = 565, table 3).

Bonnell and Janke (1986) report sulfur values from the Cardinal River, Gregg River, and Smoky River mines to be in the 0.15-0.58% range (db, channel samples, raw coal). Organic sulfur predominates except when total sulfur exceeds about 0.5% (db); at this point, the excess sulfur is pyritic sulfur and proportions are roughly equal. Langenberg et al. (1988) report sulfur values for the Cadomin-Luscar coalfield Jewel Seam to be in the 0.1-0.6% (db) range with both the median and average being 0.3% (db).

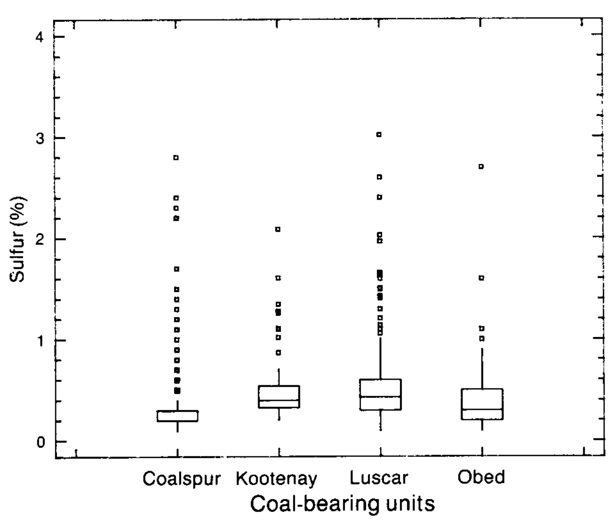

Figure 20. Sulfur contents (dry basis) for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals.

Coalspur Formation

The sulfur histogram for the Coalspur coal zone is positively skewed; the box-and-whisker plot shows that 75% of the sample population has sulfur contents between 0.1 and 0.4% (db, figure 20). The mean, median, and mode are 0.3, 0.3, and 0.2%, respectively (db, n = 686, table 3). The Coalspur Formation coals stand out as having the lowest median ash values compared to those from any of the other coal zones (figure 20).

Bonnell and Janke (1986) report that the total sulfur values for the Coalspur coals from the Coal Valley mine range between 0.17 and 0.33% (db, channel samples raw coal). In addition, they note that the sulfur is usually divided evenly between pyritic and organic varieties, with the exception of the Silkstone Seam in which the pyritic form predominates. Vertical in-seam sulfur profiles and data collected during the course of this study appear in a later section of this report and in appendix 3.

Obed-Marsh Coal Zone

The sulfur data distribution for the Obed-Marsh coal zone is positively skewed, with the box-and-whisker plot showing that 75% of the sample population has sulfur values between 0.1 and 0.5% (db, figure 20). The median and mode are both 0.3% (db) and the mean is 0.39% (db, table 3).

Bonnell and Janke (1986) report that surface channel samples from the Obed Mountain mine contain between 0.33 and 0.91% (db) sulfur. This is consistent with the results from this study. They form also reveal that the sulfur is mainly in organic and pyritic form, with organic sulfur composing a little more than half the total (e.g. pyritic = 0.13%, organic = 0.20%, db). This relationship also seems to hold true at higher total sulfur contents, with pyritic sulfur content increasing as organic sulfur content increases (e.g. pyritic = 0.35%, organic = 0.47% db). In the field, pyrite has been observed on cleats within the No. 2 seam.

Rank/vitrinite reflectance

Coal can be classified according to rank, i.e., according to degree of metamorphism, or progressive alteration from lignite to anthracite. The ASTM classification is based on fixed carbon a dry, mineral-matter-free basis for coals of anthracite, semianthracite, low-volatile bituminous, and medium-volatile bituminous ranks. The coals of the Kootenay and Luscar groups of southern Alberta fall largely into these classes.

ASTM rank can also be determined by measuring the maximum reflectance of vitrinite. Bustin et al. 1983 report that a good correlation exists between ASTM rank determined according to the standard method and the rank determined from maximum vitrinite reflectance.

Kootenay Group

The ERCB database contains information on volatile matter (VM) that can be expressed on a dry, ash-free basis. Weighted values are plotted in figure 9. The data, represented by 32 different drill hole locations, are from three areas: 1) around the Adanac Mine in the Coleman-Blairmore coalfields, 2) at Grassy Mountain in the Blairmore coalfield, and 3) at the Flat Creek deposit. The coal in these areas shows a gradual increase in rank, expressed as decreasing VM percentages, from 32% VM at Adanac Mine to 20% at the Flat Creek deposit. On a regional basis, the VM content of Mist Mountain Formation coals gradually decreases from south to north, as has been previously documented by Norris (1971).

Petrological techniques for measuring the reflectance, of vitrinite are commonly used to establish rank. Because of the good correlation between percent volatile matter and maximum vitrinite reflectance, an estimate of volatile matter (on a dry, ash-free basis) can be obtained from vitrinite reflectance values (Bustin et al. 1983, section 8.1).

For the present study, reflectance data were obtained from Hacquebard and Donaldson (1974), Gibson (1985), and Hughes and Cameron (1985). The data is from 12 different locations where relatively complete sections through the Mist Mountain Formation are present. These locations are labelled GSC-1 to GSC-12 (table 4). Because the sections are rela-

Table 4. Volatile matter content (daf) of selected coals. Estimated from maximum percentage vitrinite reflectance for samples GSC-1 to 12 and ARC-1 to 14. Volatile matter (daf) for sections CNP-2 and CNP-4 to 9 obtained by averaging values from VM proximate analyses. Samples labelled base are generally from within 50 m of the top of the Morrissey Formation; those labelled top are generally from within 50 m of the base of the Cadomin Formation.

Section	Location	Location (UTM coordinates) Eastings (m)	Northings (m)	VM (%, daf) Mist Mountain Fm. Base	Top
GSC					
GSC-1	Mt. Allan	626750	5649300	9.0	13.0
GSC-2	Bragg Ck.	654000	5646500	13.0	16.3
GSC-3	Barrier Mtn.	597900	5728700	9.8	14.4
GSC-4	Mist Mtn.	645900	5602000	15.0	26.5
GSC-5	H. Ranger Stn.	666500	5586200	18.5	20.5
GSC-6	Wilkinson	670700	5565400	22.5	28.9
GSC-7	Cabin Ridge	678200	5547700	25.4	24.7
GSC-8	Ridge Ck.	688500	5554100	–	31.6
GSC-9	Oldman River	692700	5527200	29.9	26.8
GSC-10	Grassy Mtn.	686800	5506100	25.0	27.0
GSC-11	Canmore	613000	5659700	8.0	16.0
GSC-12	Beaver Mines	703850	5481000	–	32.0
ARC					
CNP-2 to 9					
CNP-2	York Ck.	681000	5496400	–	28.6
CNP-4	Vicary Ck.	678600	5515200	–	29.4
CNP-5	Vicary Ck.	685600	5514350	–	25.8
CNP-6	Tent Mtn.	666300	5492500	27.3	31.1
CNP-7	Grassy Mtn.	685900	5506100	–	27.0
CNP-8	Grassy Mtn.	685700	5504900	25.0	–
CNP-9	Adanac Mine	687500	5484200	–	32.2
ARC-1	Tent Mtn.	666560	5491150	–	29.0
ARC-2	Cat Mtn.	687900	5522600	24.3	–
ARC-3	Oldman River	683300	5535900	26.5	–
ARC-4	Trap Ck.	670050	5596850	–	18.4
ARC-5	Fir Ck.	673450	5585450	17.5	19.8
ARC-6	Cat Ck.	662450	5587000	20.2	–
ARC-7	Trap Ck.Mine	670460	5593880	17.2	–
ARC-8	Wilkinson Ck.	673100	5563000	–	18.8
ARC-9	Hailstone Butte	683100	5565250	–	26.2
ARC-10	Sheep River	671450	5613910	–	18.4
ARC-11	Sheep Falls	661550	5609860	–	16.4
ARC-12	Burn's Mine	650630	5607500	10.0	–
ARC-13	Storm Ck.	648000	5598200	–	25.8
ARC-14	Gladstone Ck.	706250	5476820	–	32.6

tively complete, the stratigraphic position of the sampled coal seam is known. The volatile matter content of coalsnear the base and top of the Mist Mountain Formation are listed in table 4, if information was available. The samples from near the base were generally within 50 m of the top of the Morrissey Formation, and the samples from near the top were usually within 50 m of the base of the Cadomin Formation (figure 2). These sections generally show a gradual increase in VM from base to top; this indicates a decrease in rank (Hacquebard and Donaldson 1974). The two sections that deviate from this pattern, Cabin Ridge and Oldman River, suggest that either postdeformational coalification has played a role or that the section has internal faults.

Additional coal samples were collected during the 1987 field season from nine stratigraphic sections in open pits of the Crowsnest Pass area. Coal seams were sampled so as to exclude visible partings. From the proximate analyses (appendix 1), an average percentage of volatile matter (daf) was calculated. Because the sampled intervals were generally 1 m thick, no weighting factor was applied. These values are shown in table 4 (CNP-2 to CNP-9) and plotted in figure 9.

Grab samples from natural exposures throughout the outcrop area of the Kootenay Group were collected for petrographic analysis (ARC-1 to ARC-14, table 4). Maximum vitrinite reflectance determinations were performed by Dr. A. Cameron (Geological Survey of Canada) and converted to volatile matter contents (table 5) in the manner explained earlier. These values are also plotted in figure 9, and for these cases in which information on the base and top of the section is available, the value for the base is given. Regional variations in rank will be discussed further in the section on regional coalification.

Luscar Group

The Geological Survey of Canada and the Alberta Geological Survey have been collecting coal samples from the northern study area for petrographic analysis since 1981. Results have been published by Kalkreuth and McMechan (1984, 1988), Kalkreuth and Langenberg (1986), and Langenberg et al. (1987, 1988). During the summers of 1986, 1987, and 1988, addi-

Table 5. Vitrinite reflectance data (Rmax) for the Mist Mountain Formation coals in the Crowsnest Pass and Kananaskis areas.

Sample	Location	Part/section of Fm from which samples were taken	Maximum Reflectance (%)	SD
CNP-2-5	York Creek	Top	1.10	0.05
CNP-5-4	Vicary Creek	Top	1.24	0.05
CNP-6-8	Tent Mountain	Middle	1.14	0.04
-6-17	Tent Mountain	Middle	1.04	0.04
-6-27	Tent Mountain	Top	1.02	0.05
ARC-1	Tent Mountain	Middle	1.09	0.04
ARC-2	Cat Mountain	Base	1.33	0.05
"	Cat Mountain	Base	1.30	0.05
"	Cat Mountain	Base	1.27	0.06
ARC-3	Oldman River	Base	1.22	0.05
ARC-4	Trap Creek	Top	1.58	0.08
ARC-5	Fir Creek	Middle	1.62	0.05
"	Fir Creek	Top	1.51	0.05
ARC-6	Cat Creek	Base	1.50	0.07
ARC-7	Trap Creek Mine	Base	1.64	0.05
ARC-8	Wilkinson Creek	Top	1.59	0.07
"	Wilkinson Creek	Top	1.54	0.07
"	Wilkinson Creek	Top	1.59	0.06
ARC-9	Hailstone Butte	Top	1.23	0.05
"	Hailstone Butte	Top	1.12	0.05
ARC-10	Sheep River	Top	1.58	0.06
"	Sheep River	Top	1.61	0.07
"	Sheep River	Top	1.51	0.06
ARC-11	Sheep Falls	Top	1.69	0.05
ARC-12	Burn's Mine	Top	2.18	0.08
ARC-13	Storm Creek	Top	1.25	0.05
"	Storm Creek	Top	1.22	0.03
"	Storm Creek	Top	1.25	0.05
ARC-14	Gladstone Creek	Top	1.00	0.07
"	Gladstone Creek	Top	0.86	0.06
"	Gladstone Creek	Top	0.96	0.10

tional channel and grab samples were collected throughout the area. Maximum vitrinite reflectances were measured at the Institute of Sedimentary and Petroleum Geology by Dr. W. Kalkreuth.

Most analyses are for the Luscar Group, but some additional results for the Coalspur Formation and Obed-Marsh coals are included (table 6). Most of the analyses selected are from samples collected near the base of the Gates Formation of the Luscar Group. They include coal from the Jewel Seam of the Cadomin area, the Kennedy Seam of the Mountain Park area, the Nos. 3 and 4 seams of the Grande Cache area, and equivalent seams in adjacent areas (table 6).

The maximum vitrinite reflectance for the base of the Gates Formation ranges from 0.86% (Willmore Park) to 1.97% (from 2779 m in the CS ET AL. SHERMAN 11-3-62-12-W6 oil and gas well). This indicates rank ranging from high- to low-volatile bituminous. For these coals, the conversion from maximum vitrinite reflectance to volatile matter content (dry and ash-free) is not linear (Bustin et al. 1983), but for restricted rank ranges it can be approached by a linear curve. The relation for the Cadomin-Luscar coalfield was VM (daf) = 58-27*Rmax for the range 0.9-1.4% Rmax (Langenberg et al. 1988). For the range 1.4-1.8% Rmax, the relation is VM (daf) = 38-11*Rmax as (estimated from unpublished GSC data from the Grande Cache area, courtesy of Dr. W. Kalkreuth).

These relationships can only be established from samples on which both proximate analysis and reflectance determinations have been performed (in other words, the analyses have to be done on splits from the same sample). The estimated volatile matter contents are shown in table 5 and plotted on the map in figure 5. There is a systematic variation in vitrinite reflectance and rank for samples from the base of the Gates Formation. This will be discussed in the section on regional coalification.

Table 6. Coal rank data for the base of the Gates Formation.

Map	Zone	Loc. UTM Coord.	Area	Fm.	Seam	Meters	Pellet	Sample	Rmax	SD	VM (daf)
Base of Gates Formation											
83F/3	11	478090 5873850	CADN E	GA	JL		942/87	6/87	1.02	0.03	30
83F/3	11	479920 5873100	CADN E	GA	JL	3.8+	1067/87	81/87	0.99	0.04	31
83F/3	11	477141 5874629	CADN W	GA	JL		2100/87	203/87	1.07	0.05	29
83F/3	11	475722 5875457	CADN W	GA	JL	646/88		162/88	1.02	0.03	30
83F/3	11	473417 5879500	CRIV 50B5	GA	JL		2007/87	195/87	1.40	0.04	20
83F/3	11	469345 5884294	CRIV 51C5	GA	JL	12.10	64/88	COMP 8	1.27	0.05	24
83F/3	11	471228 5877873	CRIV 50A3	GA	JL	10.00	67/88	COMP 11	1.10	0.04	29
83F/3	11	472221 5877288	CRIV 50A5	GA	JL		627/88	179/88	1.02	0.04	30
83F/3	11	473050 5881198	CRIV 51B3	GA	JL		993/87	57/87	1.34	0.06	22
83F/4	11	465420 5885031	GREGG	GA	JL		111/88	WL87128	1.29	0.06	23
83F/4	11	463968 5885433	GREGG	GA	JL		107/88	WL87124	1.34	0.07	22
83F/4	11	465763 5882582	GREGG	GA	JL		104/88	WL87121	1.08	0.05	29
83F/3	11	467552 5883581	GREGG	GA	JL		101/88	WL87117	1.40	0.06	20
83F/4	11	466110 5883409	GREGG	GA	JL		102/88	WL87118	1.41	0.04	20
83F/3	11	469254 5879780	GREGG PQ	GA	JL	10.05	56/88	COMP 1	1.15	0.05	28
83F/3	11	469583 5882035	GREGG CD	GA	JL		951/86	122/86	1.40	0.04	20
83C/4	11	474760 5864160	MT. PARK	GA	KE		915/86	28/86	1.01		31
83C/4	11	479380 5864400	MT. PARK	GA	KE		925/86	56/86	1.08		29
83C/4	11	482700 5863700	MT. PARK	GA	KE		129/86		0.94		33
83F/4	11	456540 5890880	FLD. MTN.	GA			770/88	198/88	1.45	0.06	20
83F/4	11	455640 5891040	FLD. MTN.	GA			773/88	200A/88	1.53	0.04	19
83F/5	11	441800 5907920	BRULE	GA			1976/87	122/87	1.57	0.05	19
83F/4	11	437840 5895040	POCA	GA			1004/87	67B/87	1.62	0.04	19
83E/10		377200 5944675	WILLMORE	GA			759/88	187/88	0.98	0.03	31
83E/10		390050 5933800	WILLMORE	GA			761/88	189/88	0.86	0.04	35
83E/9	11	398980 5933600	THOREAU	GA			765/88	193/88	1.02	0.03	30
83E/9	11	400760 5930700	THOREAU	GA			767/88	195/88	1.01	0.03	31
83E/9	11	402000 5931360	THOREAU	GA			769/88	197/88	0.97	0.04	32
83E/9	11	402580 5929280	THOREAU	GA		10.0	2113/87	216/87	0.94	0.04	33
83E/9	11	406300 5946625	MOON CK.	GA		5.0		COMP	1.84		18

Table 6. (continued)

Map	Zone	Loc. UTM Coord.	Area	Fm.	Seam	Meters	Pellet	Sample	Rmax	SD	VM (daf)
83E/14		357600 5967850	SULFUR R.	GA	3	2.6	826/88	250/88	1.29	0.04	25
83E/14		356689 5981777	GR. CACHE	GA	4	3.5	810/88	235/88	1.72	0.04	19
83E/14		363175 5973236	GR. CACHE	GA	3	1.25+	466/83	WL1003	1.41	0.05	22
83E/14		362779 5977553	GR. CACHE	GA	3		548/83	WL1011	1.52	0.04	21
83E/14		363692 5983918	GR. CACHE	GA	4		528/83	WL235	1.55	0.06	22
83E/14		357200 5978620	GR. CACHE	GA	4		968/82		1.66	0.07	20
83E/14		345650 5984800	GR. CACHE	GA			1025/81		1.76	0.07	29
83E/13		329550 5983100	RIM RIDGE	GA			978/82		1.16	0.05	27
83L/3	11	364178 5986249	SMOKY	GA	4	5.5	COMP	WL63	1.54		21
83L/3	11	362210 5987370	SMOKY	GA	4	1.0+	480/83	WL662	1.59	0.05	20
83L/3	11	359434 5986959	SMOKY	GA	4		504/83	WL736	1.65	0.04	20
83L/3	11	354127 5990164	SMOKY	GA	4		698/83	WL1012	1.65	0.05	20
83L/3	11	354386 5986969	SMOKY	GA	4	8.0	1068/88	GC3-1	1.61	0.06	20
83L/3	11	351146 5987030	SMOKY	GA	4	0.5+	830/88	254/88	1.62	0.04	20
83L/3	11	346600 5991329	COPTON	GA	4		787/88	DH-256	1.69	0.05	19
83L/3	11	345082 5992116	COPTON	GA	4	5.0	793/88	219/88	1.67	0.05	20
83L/3	11	345066 5992269	COPTON	GA	3	1.1	796/88	221/88	1.73	0.06	19
83L/3	11	343250 5995250	COPTON	GA			974/82		1.62	0.04	20
83L/3	11	347100 5986300	COPTON	GA			982/82		1.54	0.06	21
83L/3	11	344250 5992600	COPTON	GA				CAW CK	1.78		18
83L/4	11	309340 6012350	KAKWA	GA			998/81		1.66	0.05	20
83L/4	11	329650 6001650	KAKWA	GA			1020/81		1.66	0.07	20
83L/4	11	312670 6005320	KAKWA	GA			1009/81		1.37	0.06	22
83L/5	11	305750 6019150	TORRENS	GA			1005/81		1.59	0.07	20
83L/5	11	323500 6023550	TORRENS	GA				SHERMAN	1.97		16
Coalspur and Obed-Marsh coals											
83E/16		408640 5958640	BERLAND	CS		0.5	785/88	212/88	0.59	0.05	40
83E/16		411460 5957200	BERLAND	CS		1.0	786/88	213/88	0.63	0.02	39
83F/3	11	499080 5892550	COALSPUR	CS			936/86	69/86	0.67		39
83F/3	11	498550 5899500	ROBB	CS			935/86	68/86	0.58	0.03	41
83F/2	11	502100 5897000	ROBB	CS			934/86	67/86	0.59	0.03	40
*83F/11		469000 5936600	OBED	OB						0.50	44

*Mean values, n = 40, based on random reflectance and converted to Rmax.

Coal quality relationships

A number of different linear relationships have been documented through bivariate analysis of coal quality parameters (Teichmuller and Teichmuller 1968; Berkowitz 1979; Nurkowski 1985). Negative linear relationships between calorific value and equilibrium moisture, calorific value and ash, and volatile matter/fixed carbon and calorific value have been documented (Renton and Hidalgo 1975).

Correlation coefficients dealing with variables, such as those derived from proximate analyses, have an inherent problem that can lead to erroneous results. This problem involves the way in which a proximate analysis is performed. The four components of a proximate analysis (ash, fixed carbon, volatile matter, and moisture) must add up to 100%. Statistically, this means that the four proximate analysis variables are not independent variables. If the value of one variable decreases, the values of the other three will increase. This can lead to strongly negative correlations: for example, there is a strong negative correlation (near -1) between volatile matter and fixed carbon on a dry, ash-free basis. Geologically it is known that these two variables do in fact have a strong negative correlation. However, because of the reporting basis (daf) two of the four components have been set to zero; therefore, fixed carbon and volatile matter must show a perfect negative correlation (i.e. -1).

Calorific value and ash

Regression analyses and scatter plots of calorific value vs. ash for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals show nearly perfect, negative linear relationships, with correlation coefficients between -0.92 and -0.99 (figures 21-24). This relationship has been confirmed worldwide, and therefore applies to Alberta foothill/mountain coals as well.

Calorific value is particularly important for evaluating coals from the Coalspur Formation and Obed-Marsh zone as these are presently being mined for the thermal coal export market. Most Luscar Group coals are mined as metallurgical coals; however, in some of the lower quality coals are also used as thermal coals (e.g. Alberta Power uses these at the Smoky River mine near Grande Cache).

For the Kootenay Group coals, the correlation coefficient for the linear relationship between % ash content (%) and calorific value is -0.96 (i.e. a higher ash content results in a lower heat of combustion). The r^2 value is 0.92 which means that 92% of the variation in calorific value can be explained by ash content. Figure 21 shows the wide spread of coal ranks present in the Kootenay Group coals and also shows that not all of the variation in calorific value variation is explained by ash.

The formula for predicting calorific value based solely on ash content are nearly identical for the Coalspur and Obed-Marsh coals (figures 23 and 24). The large data set for the Coalspur Formation coals necessitated considering only those coals with ash contents less than 30%. Geologically, these two coal zones have much in common that may help to explain this relationship, e.g. both coal zones were formed in an alluvial plain setting, both are Paleocene in age, and both have similar maturation/burial histories (see later section).

The Luscar Group coals have the highest correlation coefficient for ash and calorific value of all four of the coal-bearing units (r = -0.99, figure 22). This is

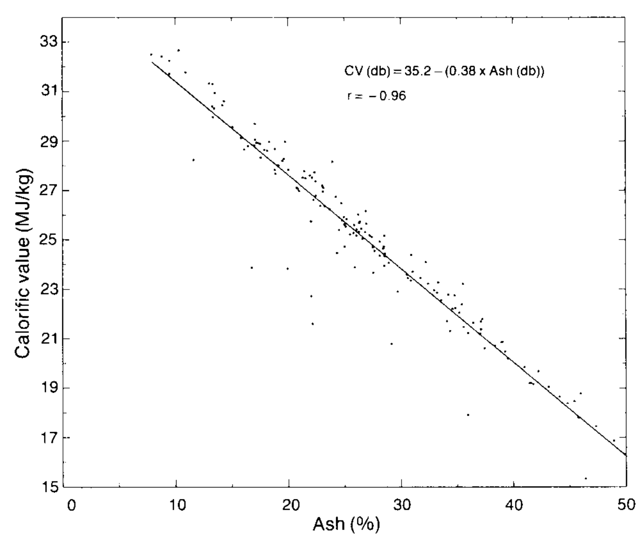

Figure 21. Relationship between calorific value and ash (dry basis) for the Kootenay Group coals. Best-fit linear regression.

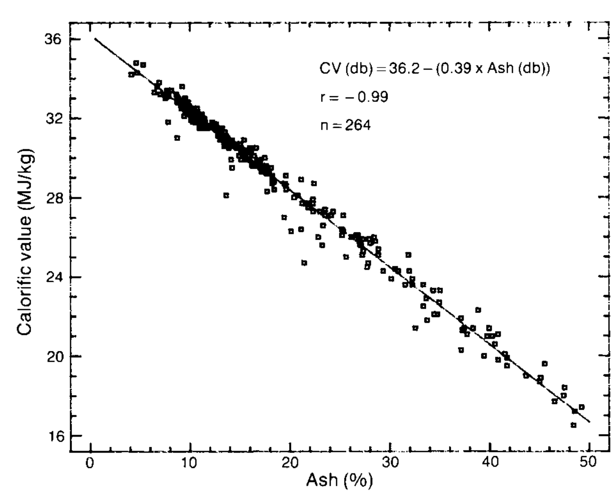

Figure 22. Relationship between calorific value and ash (dry basis) for the Luscar Group coals. Best-fit linear regression.

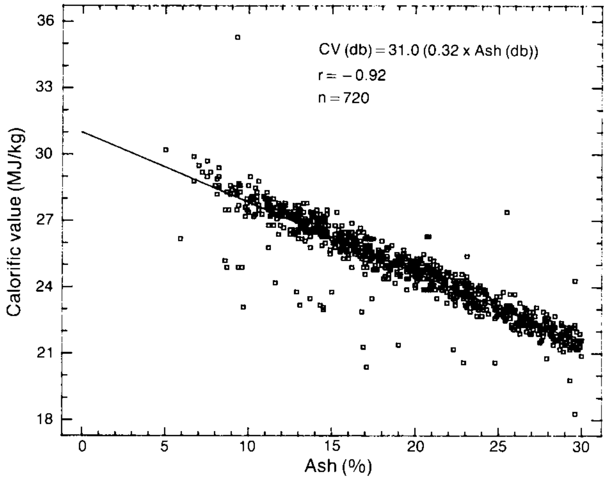

Figure 23. Relationship between calorific value and ash (dry basis) for the Coalspur Formation coals. Best-fit linear regression.

related to the rank of these coals, which are known not to vary significantly in calorific value (Bustin et al. 1983). This suggests that the calorific value of Luscar Group coals can be predicted, almost perfectly, knowing only the ash content.

Volatile matter and ash

Volatile matter and fixed carbon are related primarily to coal rank; however, it was found that for some coals, volatile matter content is sometimes affected by ash content. Nurkowski (1985) reports erroneous volatile matter values, the error increasing with increasing ash content in cases where chemically bonded water is released during analysis.

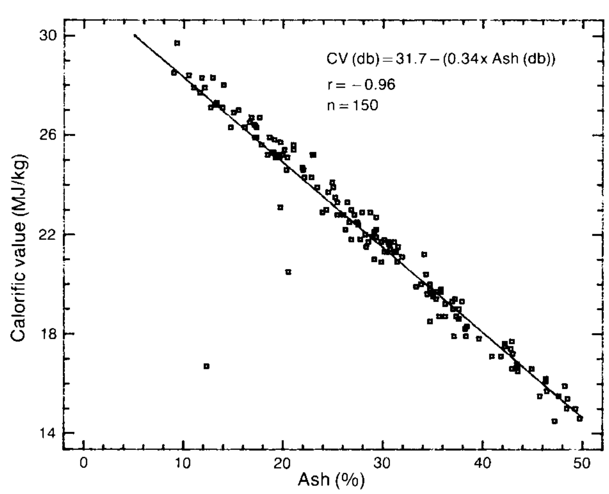

Figure 24. Relationship between calorific value and ash (dry basis) for the Obed-Marsh coals. Best-fit linear regression.

Volatile matter content is a direct measure of coal rank for bituminous coals (usually expressed as fixed carbon) if the analysis is reported on a dry, mineral-matter-free basis (dmmf). This basis was not available for the ERCB data set used in this study; however, volatile matter values on a dry, ash-free (daf) basis were calculated using the Parr formulae (Ward 1984). Volatile matter content on a "daf basis" is a close approximation to rank on a "dmmf" basis.

Approximately 11% of the volatile matter content (daf) variation reported in the Obed-Marsh coals can be explained by the ash content (db, Macdonald et al. 1989). However, within all Luscar Group coals of varying ash contents, up to 25% of the variation in volatile matter content can be explained by the ash content (i.e. r^2). Where the Luscar coals contain <25% ash, r^2 = 16.8% for ash contents in the 25-50% (db) range. Langenberg et al. (1988) report r^2 of 9.6% for the volatile matter/ash relationship (<50% ash) for the Luscar Group coals in the Cadomin-Luscar coalfield.

The fact that volatile matter content seems to be partial affected by ash content in the Luscar Group coals may be related to the large amounts of clay minerals in these coals. High clay mineral contents are suggested by the ash analysis results of Bonnell and Janke (1986). They observed that the Luscar Group coals tended to have Al_2O_3 contents greater than 20%, whereas the Obed-Marsh and Coalspur Formation coals usually contained to be less than 20% Al_2O_3.

In theory, large amounts of calcite may also result in erroneously high volatile matter values. Abundant calcite was observed on cleats at the Coal Valley mine and in thin beds within the Val D'Or and Mynheer seams during the field program for this study. Bonnell and Janke (1986) report CaO values in the 7-12% range for the Coalspur Formation coals at the Coal Valley mine and values in the 1-6% range for the Obed-Marsh and Luscar Group coals. Therefore, one would expect the Coalspur coals to have a higher r^2 values than they do (table 6). This does not seem to be the case and suggests that calcite has a minimal affect on volatile matter values.

Ash and sulfur

Regression analyses comparing sulfur and ash content to all of the other coal quality variables failed to reveal any strong statistical relationships for ash or sulfur. Further, sulfur does not seem to depend on ash, nor ash on sulfur. Ash and sulfur content are controlled by the original sedimentary environment (table 1). These relationships are discussed in a later section.

Coal quality and utilization

Carbonization properties

Most coals in the foothills/mountains region are of bituminous rank, through some deposits of semi-anthracite and subbituminous "A" coals are present. The ERCB estimates reserves of 4.42 gigatonnes of bituminous coal in the foothills/mountains region (ERCB 1986).

Bituminous coals are the main coking coals; however, coal rank is but one important parameter used for determining whether or not a coal will make a good coke. Four mains groups of factors influence the coking capacity of a coal: rank, maceral distribution, chemical properties, and physico-chemical properties (Mackowsky 1982). The conditions of coke utilization also determine the overall coking capacity. Price and Gransden (1987) provide a thorough treatment of all of these factors.

Rank

Coal rank is one of the most important factors in carbonization. The best coking coals are generally from the medium-volatile bituminous group; however, low- and high-volatile bituminous coals will also form coke. Low- and medium-volatile coals are usually blended with varying amounts of high-volatile bituminous coals to produce a suitable coke product (Bustin et al. 1985).

Coal rank within the bituminous coals is commonly measured using vitrinite reflectance, as discussed earlier. Volatile matter content values (one of the four carbonization factors) are available from the ERCB.

Chemical properties

The chemical properties that determine a good coke include volatile matter, ash, sulfur, calorific value, and phosphorous content. In contrast, the chemical properties present of a coal suitable for producing a good coke are less well-defined and depend, to some extent on the specifications of the "target" coke. In practice, volatile matter, ash, sulfur, percent alkalies in the ash, and ash analysis are the most critical factors considered for the coals. These analyses are performed on clean, marketable coals. Metallurgical coal companies will commonly report the results of complete proximate, ultimate, and ash analyses, calorific value, and chlorine and mercury contnet. Some typical analyses of cleaned coal from five Western Canadian coal mines may be found in Price and Gransden (1987).

The data set used in this study is based on raw coals and is therefore of limited use in assessing the chemical properties suitable for good coking coals. The data tape provided by the ERCB has clean coal proximate analysis data on it, suitable for assessing coking properties. However,this analysis was outside the scope of this study.

Physico-chemical properties

Physico-chemical properties generally relate to a coal's potential to produce a strong coke (Ignasiuk 1974). Fluidity, free-swelling index (FSI), grindability, dilation, size composition, density, and porosity are some of the more common ones. Price and Grandsden (1987) provide some typical analytical results for Western Canadian coals, and Bonnell and Janke (1986) supply analytical data from mines across Canada. In addition, Ward (1984) provides an exhaustive treatment of the subject.

Data pertaining to some of these parameters were also collected by the ERCB (e.g. FSI.). However, it appears that this information is confined to the two active metallurgical coal mining areas in the province (i.e. the Grande Cache and Cadomin-Luscar coalfields).

Maceral analysis

Petrographic analysis is becoming a very important tool for predicting many of the previously discussed coking coal parameters (e.g. rank, strength, fluidity, FSI, and volatile matter). The relative proportions of reactive versus inert macerals provide some of this predictive capability (Bustin et al. 1985).

No coal maceral analysis data is present in the ERCB data set.

To date, petrographic work on metallurgical coals, mostly through the Geological Survey of Canada, has concentrated on vitrinite reflectance as a rank determiner. Some generalized maceral analysis distributions for the Kootenay and Luscar Group coals have been completed (Cameron and Kalkreuth 1982; Kalkreuth and Leckie 1989), but detailed maceral analyses are at a very early stage of development in Alberta (Langenberg etal. 1986).

Combustion properties

At the present time, there are two active thermal coal mines in the foothills/mountains region (Coal Valley and Obed Mountain). Several of the metallurgical mines have at times produced thermal coal: Smoky River Coal Ltd. provides an Alberta Power generating station with a continuous supply of thermal quality coal. The potential for export thermal coals throughout the area is very good.

The coal quality parameters related to combustion include calorific value, ash, fixed carbon, volatile matter, moisture, Cl, N, and S contents, macerals, grindability, combustibility, and ash properties (Mitchell 1974).

Understanding quality variations – models

In-seam variations and depositional models

Introduction

This section addresses coal quality variations and controls on coal quality. As described in an earlier section, coal quality variables can be loosely classified into two groups: those variables that are primarily controlled by the original depositional environment, and those variables that owe their variation to later burial history (table 1). This section deals mainly with the first group of variables and addresses several questions. Having established a regional understanding of coal quality variation, what is the variability on a local, in-seam scale? Does this local variability change how we view our regional coal quality understanding? Where do coal quality variations occur in a seam and to what factors are they related? Are variations systematic enough that we can predict them? In a study of Paleocene Ardley coals in the plains, Strobl et al. (1989) stressed the importance of conducting regional coal quality studies with a firm understanding of local scale variations.

The approach taken in this study involved measuring stratigraphic sections and collecting in-seam coal samples from the Crowsnest Pass area, the Smoky River mine at Grande Cache, the Coal Valley mine and surrounding Robb area, and the Obed Mountain mine near Hinton. This strategy was designed to address these questions for the Kootenay Group, Luscar Group, Coalspur Formation, and Obed-Marsh coals, respectively.

Kootenay Group

The coal-bearing Mist Mountain Formation of the Kootenay Group was the focus of the work in the Crowsnest Pass area. Recent and abandoned open-pits and large roadcuts were sampled, Natural outcroppings were avoided, as weathered coals would make speculations on coal quality variations of dubious value (figure 25). Channel coal samples were collected at regular intervals excluding visible partings. The samples were analyzed for proximate and ultimate variables(including amounts of C, H, N, and S present). The results of this analytical work have been plotted as a series of bar graphs alongside the sampled coal seam so that the overall lithostratigraphic setting can be compared to the coal quality (see appendix 5 for legend)

Coal seam stratigraphy

Stratigraphic correlations within the Mist Mountain Formation are believed to be well-established in the Crowsnest Pass area. Norris (1959b) described four members (figure 2) within the "Kootenay Formation" (now called the Mist Mountain Formation) and outlined how major coal seams were thought to be correlated. Gibson (1985) suggests that these members can only be correlated within the Crowsnest Pass area.

Excluding the Tent Mountain section, the Mist Mountain coal seams in this area are all situated on splay faults off the main Livingstone Thrust. Displacements on these splays (e.g. the Coleman and Turtle Mountain faults) are believed to be less than 10 km. The Tent Mountain section (CNP-6, figure 26) is on the Lewis Thrust sheet and has probably been transported more than 35 km from its original depositional site. Also, the Mist Mountain Formation at Tent Mountain is 10 times thicker stratigraphically, than at the Adanac minesite (figure 27, estimate from Gibson 1985).

Norris (1959b) correlates the thick coal seam at Grassy Mountain, at the base of the Mutz Member (No. 2 seam, Gibson and Hughes 1981), with the uppermost seams at York Creek and Adanac mine. Coals within the Mist Mountain Formation at Tent Mountain have not been correlated with any in the eastern Crowsnest Pass area. The seam numbering used at Tent Mountain (figures 26) was done by

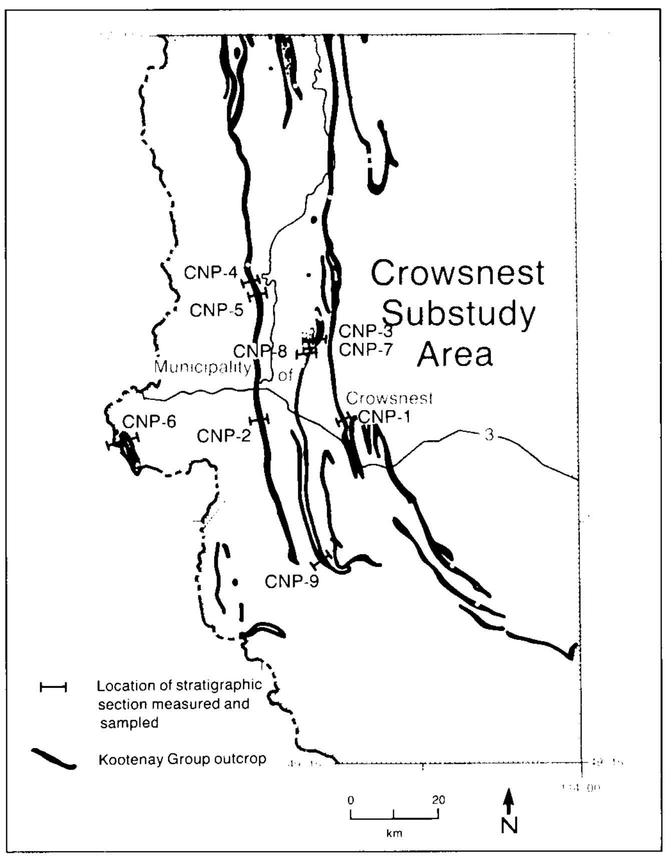

Figure 25. Location map of measured stratigraphic sections in the Crowsnest Pass area.

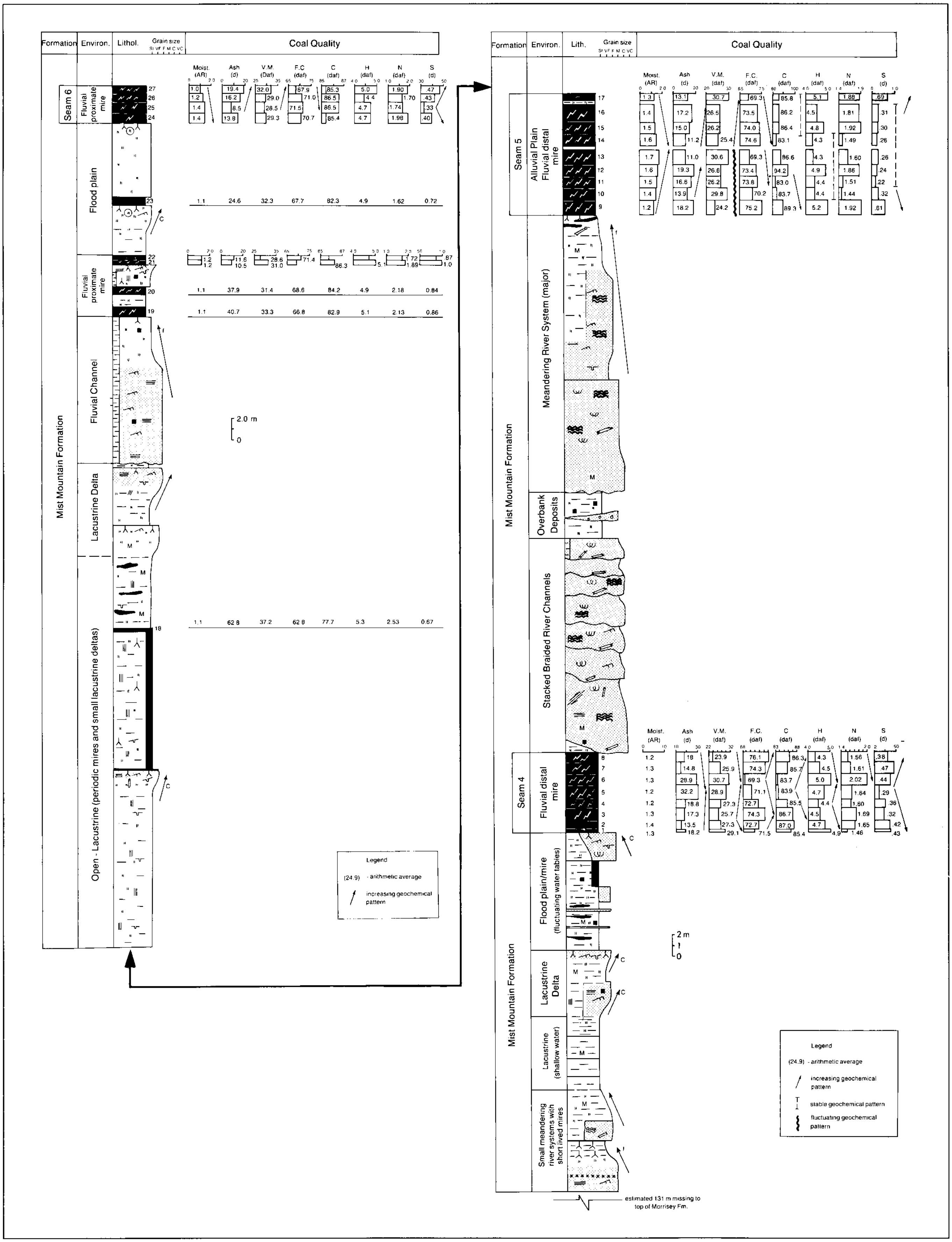

Figure 26. Stratigraphic section and depositional environments as they relate to coal quality – Tent Mountain, north pit (CNP-6).

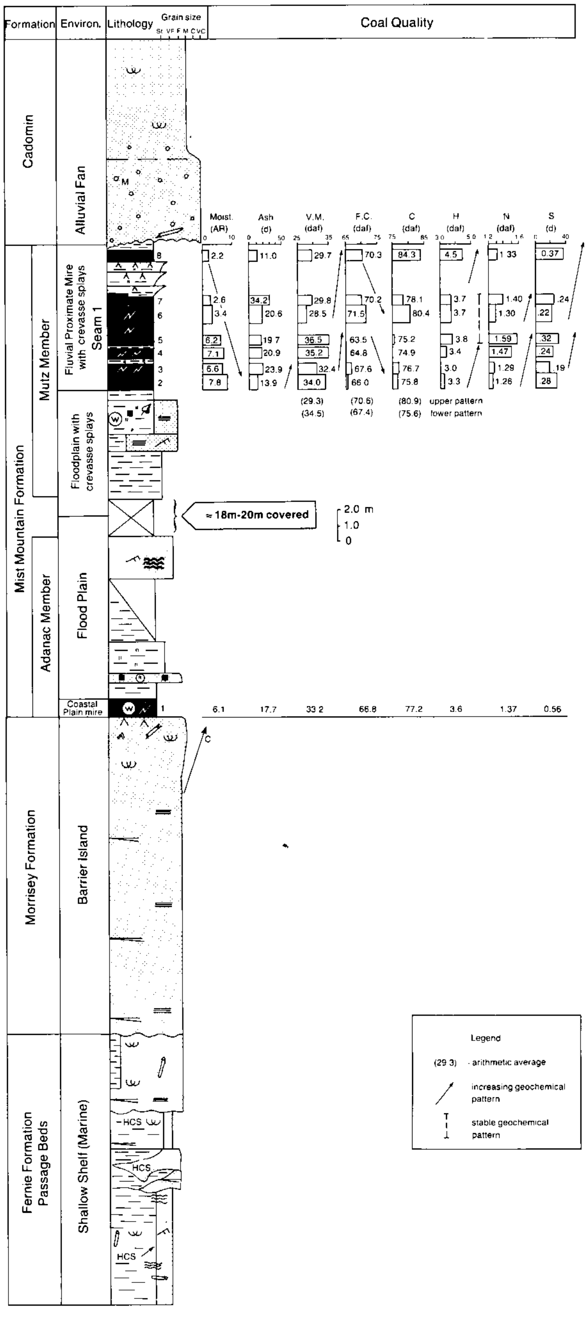

Figure 27. Stratigraphic section and depositional environments as they relate to coal quality – Adanac mine, south pit (CNP-9).

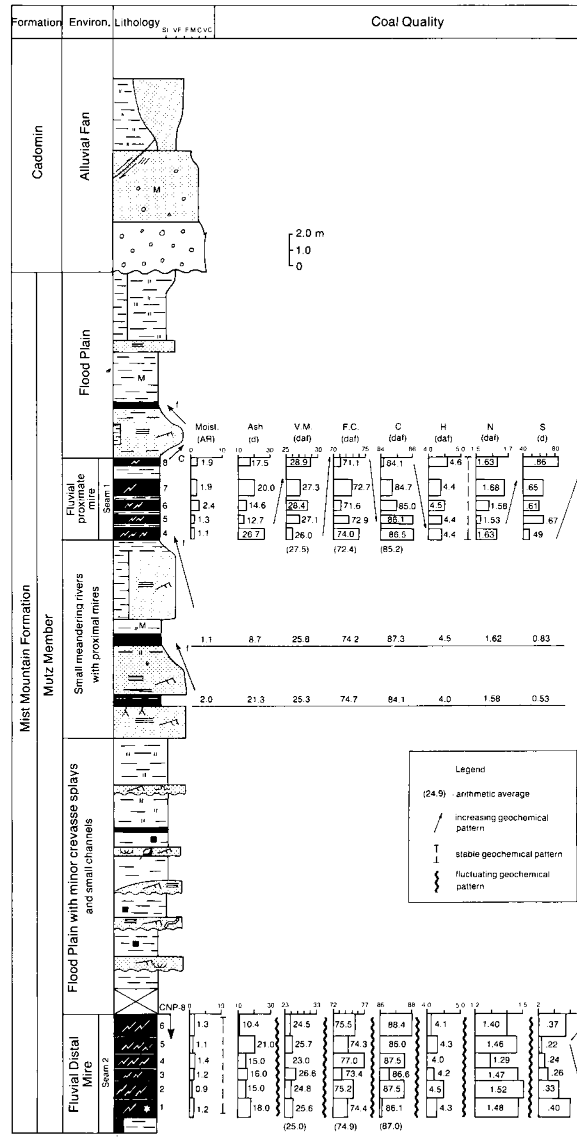

Figure 28. Stratigraphic section and depositional environments as they relate to coal quality – West Grassy Mountain (CNP-7, CNP-8).

Manalta Coal Ltd. These seam numbers do not correspond to those from the eastern Crowsnest Pass area. Jansa (1972) correlated the coals at Grassy Mountain to the lowermost coals in the Fernie Basin region, using the top of the Morrissey Formation as a reference datum.

The coal seam correlations established in this study (figures 27-30) are based on stratigraphic characteristics and supported by coal quality evidence. Assuming that depth and length of burial were reasonably uniform throughout the Crowsnest Pass area, the coal rank, as expressed by volatile matter (daf), fixed carbon (daf), and carbon (daf), can be used to support coal seam correlations. This assumption is reasonable over relatively short north-south distances. However, as previously discussed, coal rank does increase from south to north.

Figure 28 shows that the mean VM, fixed carbon (FC), and C values for the coals in the uppermost seam (No.1) at West Grassy Mountain (CNP-7, 8) are very close to those from the upper seam at York Creek (figure 29), laying some 20 km to the south-

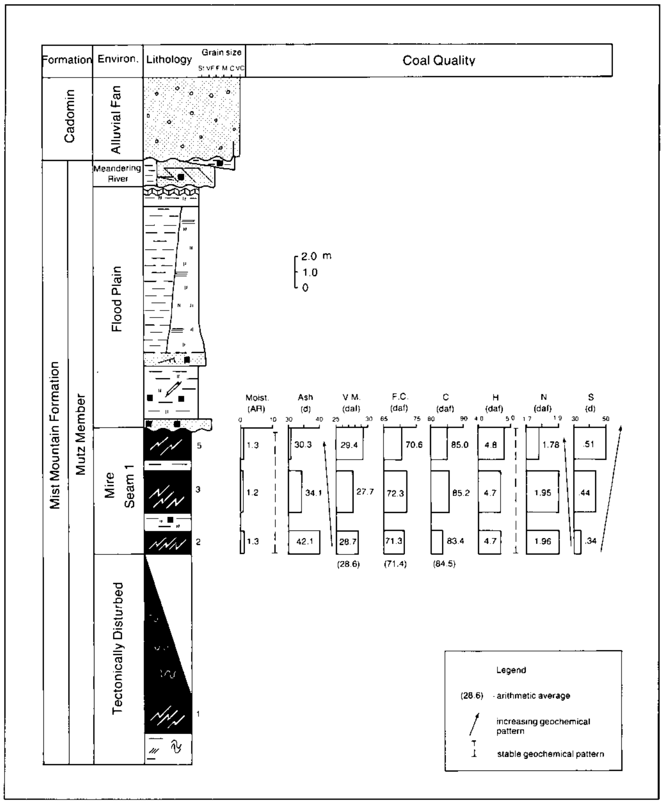

Figure 29. Stratigraphic section and depositional environments as they relate to coal quality – York Creek open pits (CNP-2).

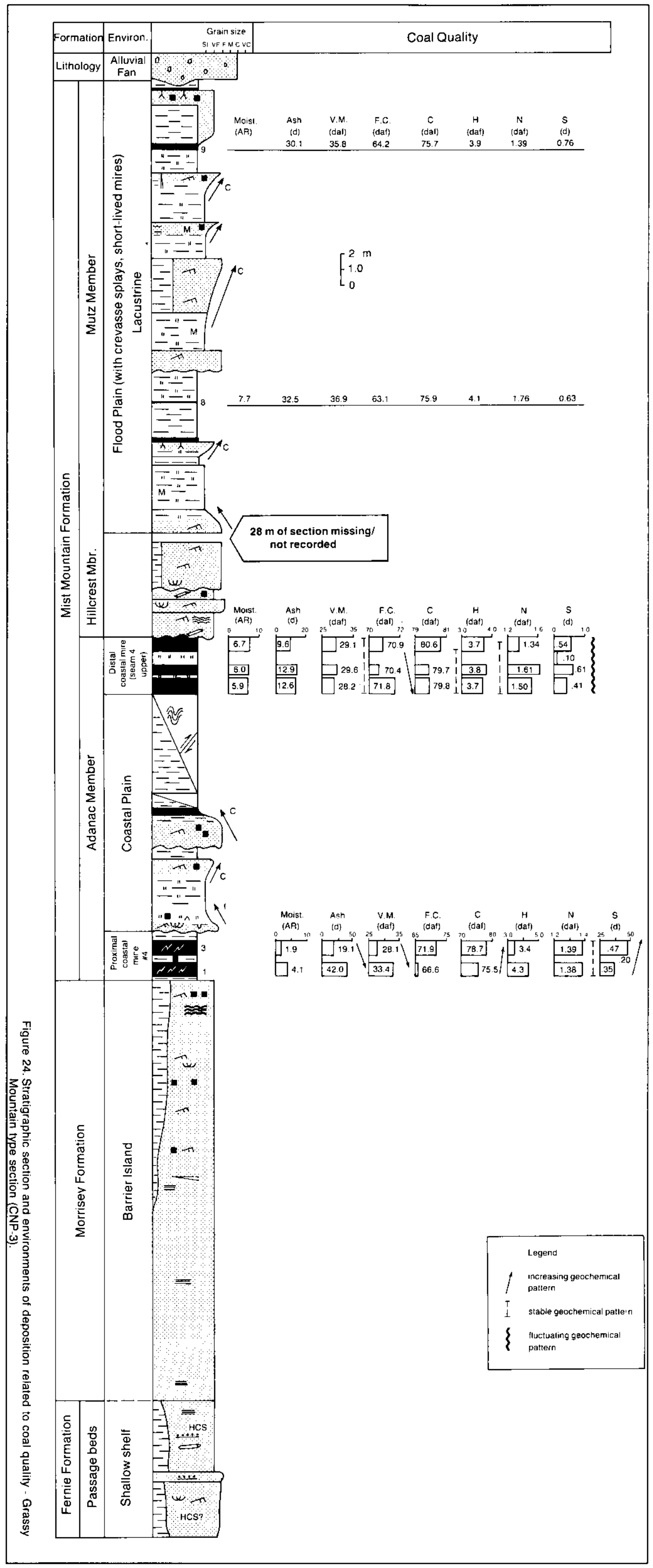

Figure 30. Stratigraphic section and depositional environments as they relate to coal quality – Grassy Mountain type section (CNP-3).

west. Both seams at both locations contain a large number of partings and show a tendency for sulfur content to increase upward in the seam. The No. 1 seam at the York Creek pits is structurally thickened; however, the upper portion of the seam appears less disturbed (figure 29). By correlating the two seams in this way, the Mutz Member strata amounts to approximately the same thickness between the top of the No. 1 seam and the Cadomin Formation in both of these areas.

The No. 1 seam at the Adanac mine (this study, figure 27) has a somewhat problematic geochemistry. There appear to be two distinct geochemical regimes with respect to many of the coal quality parameters examined. The upper part of the seam has mean VM, FC, and C values very close to those for the uppermost seams at West Grassy Mountain and York Creek. As seen at West Grassy Mountain and York Creek, the sulfur content in the upper part of the No. 1 seam at the Adanac mine also shows a slight tendency to increase upward in the seam. However, the VM, FC, and C values for the lower part of the seam (samples 2-5, figure 27), suggest a lower rank coal. The apparent increase in volatile matter in the lower part of the seam may be related to higher ash contents or to the presence of carbonate or clay minerals in the ash, resulting in an anomalously high VM content. Though the presence of carbonate minerals should indicate a relative increase in C content, it does not seem to, nor does the total ash content increase. A bedding plane fault may exist within this seam, as the Adanac mine stratigraphic section is noted to be anomalously thin (Norris 1959a). Surface oxidation of part of the seam may be an alternate explanation for this phenomenon.

From a geochemical approach, a seam can be characterized or "fingerprinted" using a number of different chemical parameters. This seam correlation technique cannot be applied as easily to the Tent Mountain coals because the thickness of the Mist Mountain Formation is greater at this locality than in the eastern Crowsnest Pass area. This implies a different maturation history.

Depositional Environments

The Kootenay Group and portions of the Fernie Formation (Passage Beds) represent the first western-sourced clastic wedge shed off the rising Cordillera. Throughout Jurassic time, a large seaway covered much of Alberta, into which the Kootenay Group prograded from west to east. The entire package of sediments, from Upper Fernie to the Cadomin Formation, represents a transition from shelf environments (Passage Beds) to alluvial fan deposits (Cadomin Formation, Gibson, 1985). Gibson (1985) claims that no convincing evidence for the existence of brackish or marine sediments above the Morrissey Formation has ever been presented.

The coal-bearing lower Mist Mountain Formation was deposited in a coastal plains setting and passes transitionally upsection into an alluvial plains setting represented by the upper Mist Mountain Formation. In the following discussion, the focus of the interpretations will be on the depositional environment as it relates to coal and coal quality. General Kootenay Group depositional models appear in Gibson (1985), Hughes and Cameron (1985), and Jansa (1972).

Coals in the eastern Crowsnest Pass area are found in three stratigraphic horizons in the Mist Mountain Formation: the No. 4 seam and equivalents at the base, the No. 2 seam on top of the Hillcrest Member, and the No. 1 seam near the top of the formation. These three coal zones have unique depositional environment associations (both clastic and mire) and possibe unique geochemical patterns. They can be grouped into three generalized depositional/geochemical facies: coastal plain mires, fluvial-distal mires, and fluvial-proximate mires.

Coastal plain coals originated in peat swamps (mires) that developed in some kind of marine coastal environment. High sulfur contents are expected if the peat was covered by marine sediments. McCabe (1984) notes that in order for thick, clean coals to form in coastal settings, a considerable time and/or geographic distance must have existed between shelf sedimentation and mire development. Raised mires, or low-lying mires that developed some distance landward of active shorelines (or at a much later date than active clastic sedimentation), provide alternative explanations. These swamps can be expected to produce low ash, low sulfur coals.

The No. 4 coal seam in the Crowsnest Pass area is part of the coastal-mire facies. The Morrissey Formation is thought to be a shallow shelf deposit (figures 27 and 30), and the lower No. 4 coal seam immediately overlies it. The lower No. 4 seam at Grassy Mountain (figure 30) is 2 m thick, contains several clastic partings, and the inherent ash content (i.e. excluding partings) tends to be high (19-42%, db). The equivalent seam at the Adanac mine site (figure 27) is less than 1 m thick and has a moderately high inherent ash content (18%, db). At Grassy Mountain, there is a tendency for sulfur content to be slightly high and to increase upward in both the upper and lower No. 4 seams. An inverse relationship with ash is also sometimes apparent.

The inverse relationship between ash and sulfur was noted by Hackney (1983) for British coals. He attributes this to sulfur-concentrating bacteria in the original mire, thriving in an anaerobic environment. High ash content of coals signifies depositional events that introduced oxygenated waters, causing bacterial action to cease or be suppressed. The major split in the lower No. 4 seam has a very low sulfur content (0.20%, this study), lending support to Hackney's (1983) hypothesis. The form that sulfur takes in these coals is unknown, making the distinction between the three possible stages of sulfur emplacement, as described by Davies and Raymond (1983), difficult to discern.

The lower and upper No. 4 seams probably developed as coastal mires, reasonably close to the active shorelines. The relatively high ash content and existence of multiple partings do not support a raised mire theory. However, the seam thickness is sufficient to preclude a proximal shoreline environment such as a back-barrier or lower delta plains setting. The No. 4 seam(s) likely formed in a low-lying mire on the sand platform deposited by the Morrissey Formation. The mire was periodically subjected to active clastic deposition. Rooting is fairly common below the seam, tending to support an autochthonous origin.

Thick coastal plain coals are known to occur in the Fernie Basin region of B.C.; they immediately overlie the Morrissey Formation (e.g. Balmer seam, Gibson and Hughes, 1981). These coastal plain coals developed in a more westward and landward position, and therefore attained greater thicknesses. The Crowsnest Pass coals (upper and lower No. 4 seams) represent the less developed, more proximal mires.

Fluvial-distal facies coals formed in an overall alluvial plains setting, well-removed from both marine and major fluvial systems. Richardson et al. (1987) describe the plains Ardley coal zone as containing alluvial plain coals that were protected from major fluvial activities during early Paleocene time. Strata above and below these coals are typically fluvial, lacustrine, or floodplain in origin. Coals in this facies tend to be very thick (>4.0 m, depositionally), have very few partings, and are often tectonically thickened.

The No. 2 seam at west Grassy Mountain (figure 28), and the No. 4 and 5 seams at Tent Mountain (figure 26) are characteristic fluvial-distal facies. The No. 2 seam at Grassy Mountain is underlain by fluvial channel deposits (Hillcrest Member) and overlain by interbedded sandstone/claystones of floodplain origin. This sequence suggests the occurrence of a major fluvial event followed by river avulsion and abandonment, mire development, and finally, destruction of the mire by resumption of fine-grained floodplain sedimentation. The No. 5 seam at Tent Mountain shows a probable sequence of events involving a major meandering river system, fining upward and gradual abandonment, in situ mire development, and a fairly abrupt return to high water levels resulting in the formation of an extensive lacustrine environment (figure 26). The No. 4 seam at Tent Mountain shows almost exactly the opposite depositional sequence (figure 26). An initial alternating, shallow lacustrine/mire environment was followed by progradation of a small lacustrine delta and a lowering of the water table, in situ mire formation, and finally, the formation of a major braided river system in the area, halting swamp formation.

The fluvial-distal coals possess certain characteristic coal quality parameters. Sulfur content tends to increase as one moves away from the center of the seam and reaches a maximum at the top and base of the seam. This pattern has long been recognized by coal geology researchers (Chandra et al. 1983; Gluskotr and Simon 1968). Gluskoter and Simon (op. cit.) attribute this pattern, for Illinois coals, to the very early diagenetic environment in which the contacts between the top and base of the seam and the under- and overlying strata represented a boundary in which geochemical conditions might be expected to change. This would make the upper and lower parts of the seam ideal locations for iron sulfide precipitation. It is important to note, however, that the Illinois coals are associated with overlying marine sediments and that sulfur contents may be as high as 8.0%, compared to the relatively "high" sulfur content values in this study of 0.69%. This process may still explain the relative increase in sulfur at the top and base of the seams in this study. More recently, Donaldson et al. (1980) have suggested that this sulfur pattern is related to changing geochemical conditions, mostly acidity, during swamp formation.

The inherent ash content of coals from the fluvial-distal facies is relatively low and usually shows fluctuating, vertical, in-seam variations. As suggested by Hackney (1983), some inverse relationships with sulfur do occur (West Grassy Mountain, figure 28). The No. 5 seam at Tent Mountain (figure 26) characterized by high ash-high sulfur (base of the seam), high ash-low sulfur (samples 12 and 16), and low ash-low sulfur (samples 13 and 14, center of seam) relationships. Three different processes may have been operating to form these relationships. The high ash-low sulfur relationship may be explained by Hackney's (1983) hypothesis; both of the regions in Seam 5 that show this relationship are associated with "upward-ashing" versus "stable" sulfur geochemical patterns (figure 26). The hypothesis put forth by Donaldson et al. (1980) involving a period of maximum mire development (and hence acidity) that kept the activities of sulfate-reducing bacterial to a minimum may explain the low sulfur-low ash regions. The high ash-high sulfur relationship occurs at the base of the No. 5 seam and is probably a result of early peats forming in an alkaline environment during the final stages of fluvial abandonment, as suggested by Donaldson et al. (1980).

The fluvial-proximate mire facies characterizes coals that formed in a depositional setting close to fluvial systems. The No. 1 seam in the eastern Crowsnest Pass area (figure 28) and the No.6 seam at Tent Mountain (figure 26) are characteristic of this facies. Seams may be up to 5 m thick; however, much of this consists of partings and interbedded clastics. These partings are typically crevasse splays and thin claystone overbank deposits. This facies should pass gradationally into the fluvial-distal mire facies.

The sequence of depositional environments preceding and following the fluvial-proximate mire facies typically involves: floodplain deposits with numerous crevasse splay or small channel deposits fining upward and passing gradationally upward into mire environments, mire development with frequent crevasse splays or overbank deposits, and the termination of mire formation by resumption of floodplain sedimentation or the development of larger fluvial systems.

The geochemical pattern of coals in the fluvial-proximate mire facies frequently involves an in-seam upsection increase in sulfur (figures 26 and 28), with possible values up to 1.0% (section CNP-6, figure 26). This pattern has also been recognized by other workers (Chandra et al. 1983; Crelling et al. 1983). These authors attribute this pattern to an association with overlying marine strata. The coals examined in this facies do not seem to have been influenced by any coastal or marine factors; therefore, the pattern observed may reflect an overall increasing supply of sulfur and/or iron as the mire developed. Inherent ash content is generally in the 10-20% range, with values up to 40% not uncommon. Poor quality coals are the result of mires formed in this type of environment.

Luscar Group Coals

Introduction

The Smoky River minesite at Grande Cache was chosen for examination of in-seam coal quality variations within the Luscar Group to better address earlier

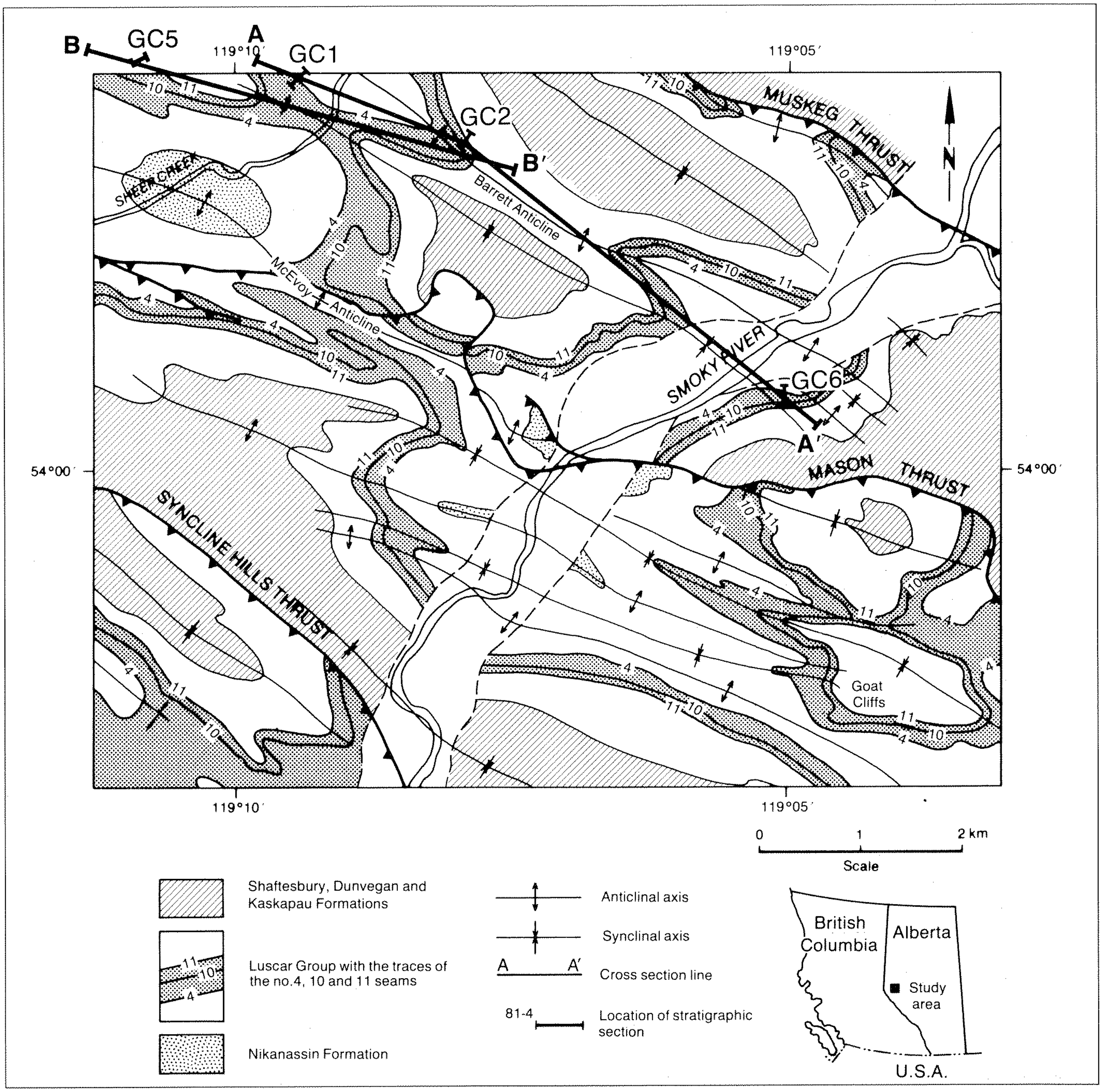

Figure 31. Geologic map and locations of measured stratigraphic sections for the Luscar Group coals at the Smoky River mine. (Modified from: Kalkreith and Langenberg, 1986).

questions and to better understand regional coal quality variations. Several pits were sampled on the property in order to construct vertical profiles and in-seam cross sections (figure 31). Several continuous stratigraphic sections through the coal-bearing portion of the Luscar Group were also measured. Langenberg et al. (1988) have also examined coal quality variations within the Luscar Group coals in the Cadomin-Luscar coalfield.

Clastic depositional environments

Langenberg et al. (1987) suggest a low-energy, coastal or delta plain environment behind shorelines as a likely depositional setting for the coal-bearing portion of the Luscar Group (i.e. Gates Formation). The overall stratigraphic architecture and inferred depositional setting for the Moosebar/Gates Formations has more recently been described by Macdonald et al. (1988; this study, figure 32). Macdonald et al. (1988) recognize six marine cycles of sedimentation within the Luscar (or Mannville) Group in the Grande Cache area,

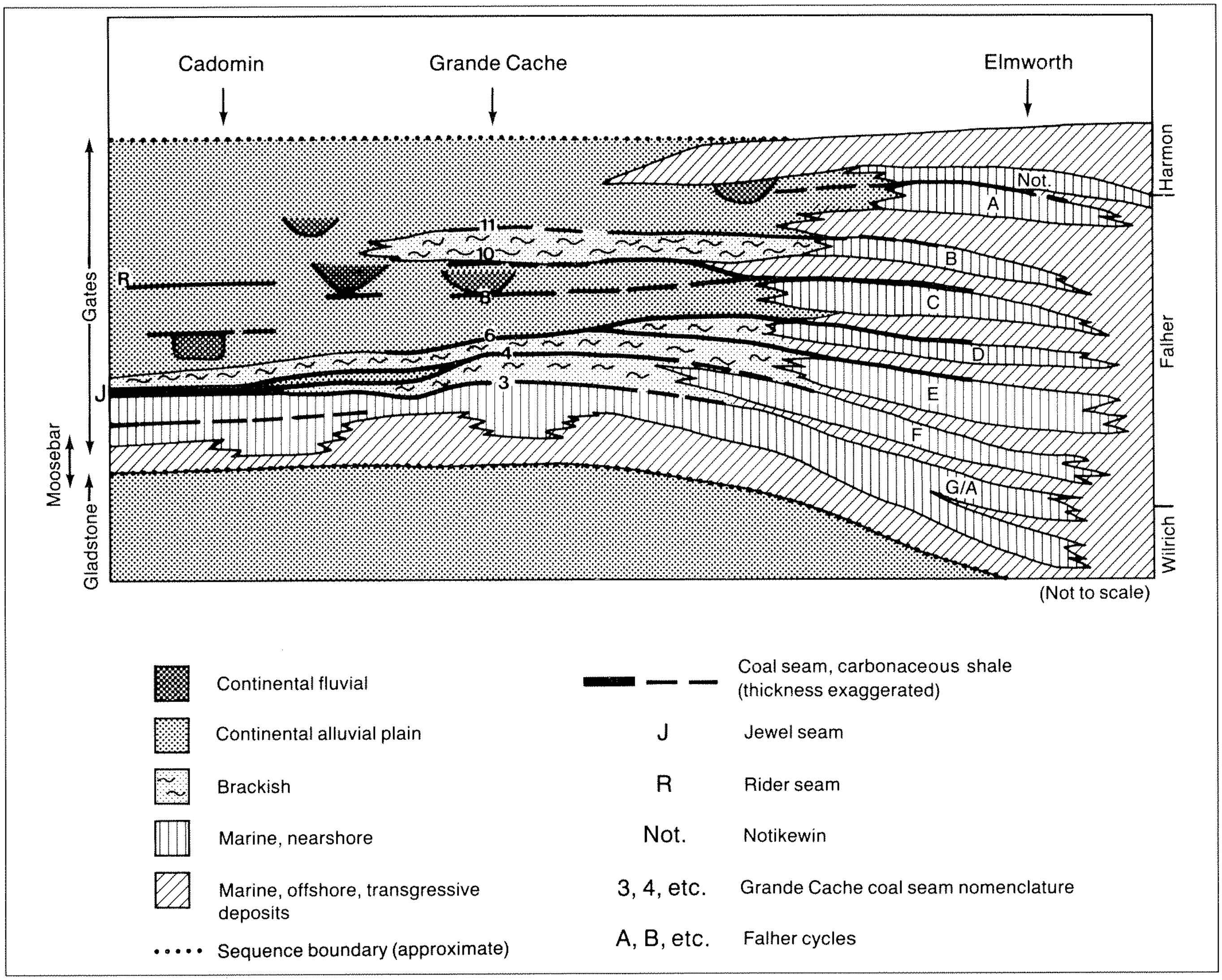

Figure 32. Schematic diagram of the Luscar/Spirit River clastic wedge between the Moosebar and Harmon transgressions in the Cadomin to Grande Prairie region (modified from Smith et al. 1984; Stott 1984).

which correlate to several of the Falher Members in the Peace River arch/Deep Basin area (figure 32).

Ash variations

In-seam ash variations were examined within the Nos. 4 and 10 coal seams at the Smoky River mine. To better understand inherent ash variations, sampling was undertaken so as to exclude visible partings (not including for composite channnel samples). Macdonald et al. (1988) believe that the No. 4 seam is approximately stratigraphically equivalent, though not necessarily time equivalent, to the Jewel Seam in the Cadomin area. In-seam ash variations within the Jewel Seam at Cadomin have been documented by Langenberg et al. (1988) and show variations on pit, intra-pit, and coalfield scales.

The No. 4 seam at Grande Cache shows very few partings north of the Smoky River and shows a marked argillaceous facies change south of the river between sections GC2 and GC6 (figure 33). Throughout most of cross-section A-A' (figure 33), the base of the seam is characteristically very low in inherent ash (<6%, db). The central part of the seam consists of alternating very low-ash (<10%) and low-ash (11-20%) zones. The upper portion of the seam is consistently very low in ash content, except for the uppermost 0.5 m which becomes characteristically high in ash as a result of interbedding with clastics.

The No. 10 seam is much higher, stratigraphically, in the Gates Formation (figure 32) and was sampled in two locations (sections GC5 and GC2, figure 30). Cross section B-B' (figure 34) shows that this seam is characterized by a very low-ash basal zone, a central low-ash zone, an upper very low-ash zone, and it becomes interbedded with clastics in the upper half of the coal-bearing section. The proportion of clastic material within the No. 10 seam increases toward section GC2.

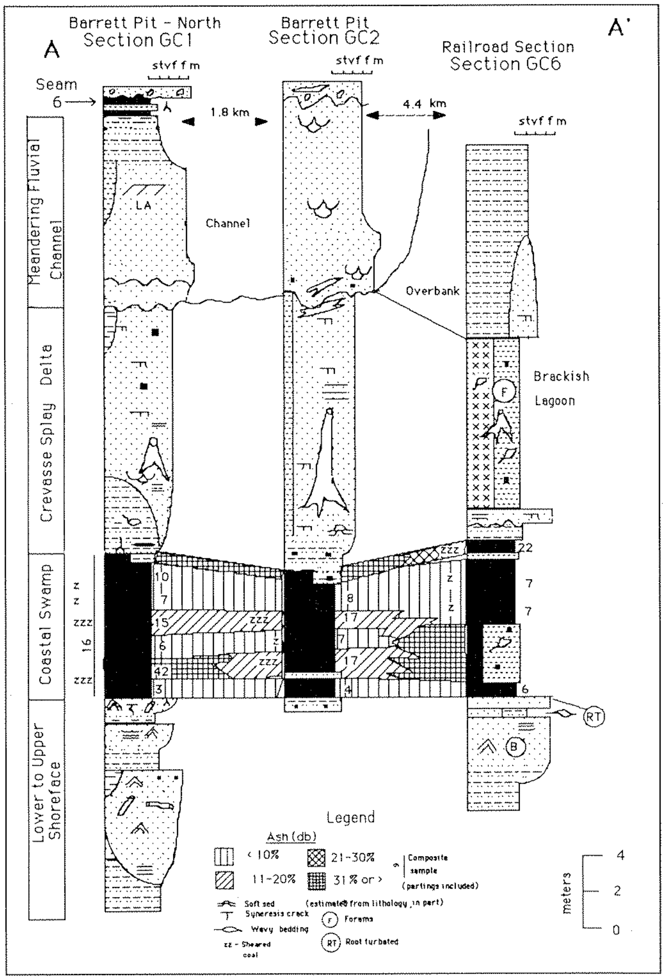

Figure 33. Stratigraphic cross section A-A' (Luscar Group coals) showing in-seam ash variations within the No. 4 seam and associated clastic depositional facies at the Smoky River mine.

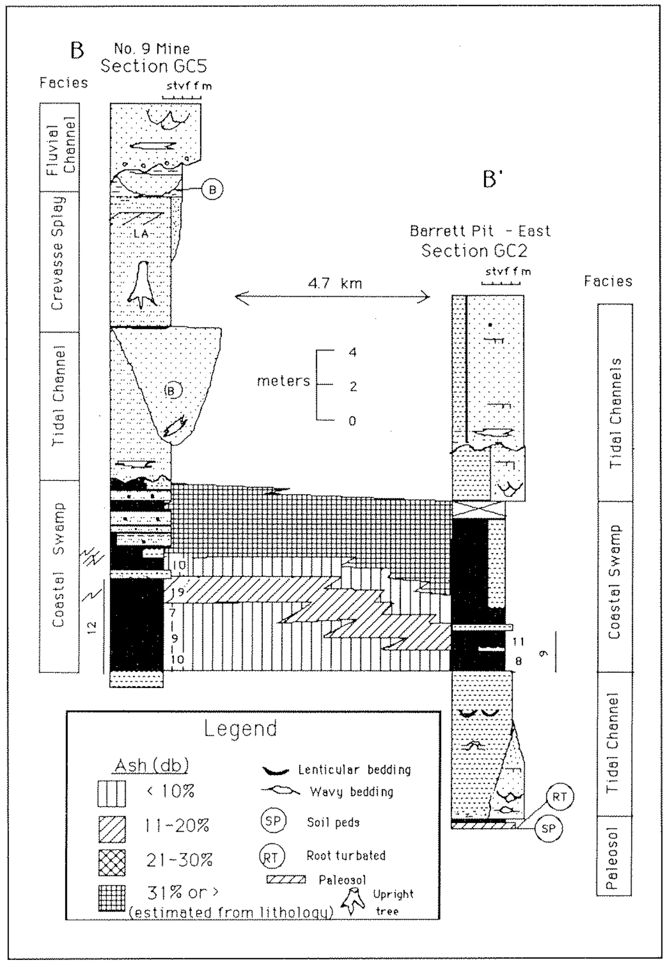

Figure 34. Stratigraphic cross section B-B' (Luscar Group coals) showing in-seam ash variations within the No. 10 seam and associated clastic depositional facies at the Smoky River mine.

From a mining perspective, it is interesting to note that, for example, the mineable portion of the No. 4 seam at section GC1 has an average 16% ash content (db, partings included), whereas the in-seam inherent ash content varies between 3 and 42% (db). Similarly, the mineable portion of the No. 10 seam at section GC5 has an average 12% ash content (db), yet the in-seam inherent ash content varies between 7 and 19% (db). Being aware of these in-seam ash variations has helped present mine operators to exploit these differences through selective mining and/or blending of coals at preparation plants.

From these two examples, it can be seen that the mean, median and weighted ash values reported in the previous regional maps and tables must be used with extreme caution. There is still an insufficient amount of precise geological data to truly characterize regional ash variations within the Luscar Group.

Sulfur variations

The in-seam sulfur variations within the No. 4 seam are very slight (figure 35). Values are consistently around 0.3% (db) throughout the central portion of the seam. Slightly higher values (0.4-0.6%, db) are consistently found at the top and base of the seam. A channel sample through the entire mineable portion of the seam at section GC1 shows, however, that these slightly elevated basal and upper sulfur content values tend to increase the overall "as mined" sulfur content to around 0.5% (figure 35).

The sulfur content values for the No. 10 seam are consistently around 0.3% (db). Again, slightly elevated sulfur contents values are sometimes present near the top of the seam, though not apparently so at the base. For this seam, the "as mined" channel sample shows a consistent sulfur content value of 0.3% (db).

The findings for these two seams agree well with the statistical distribution and regionally mapped values outlined earlier in this report for the Luscar Group coals in general.

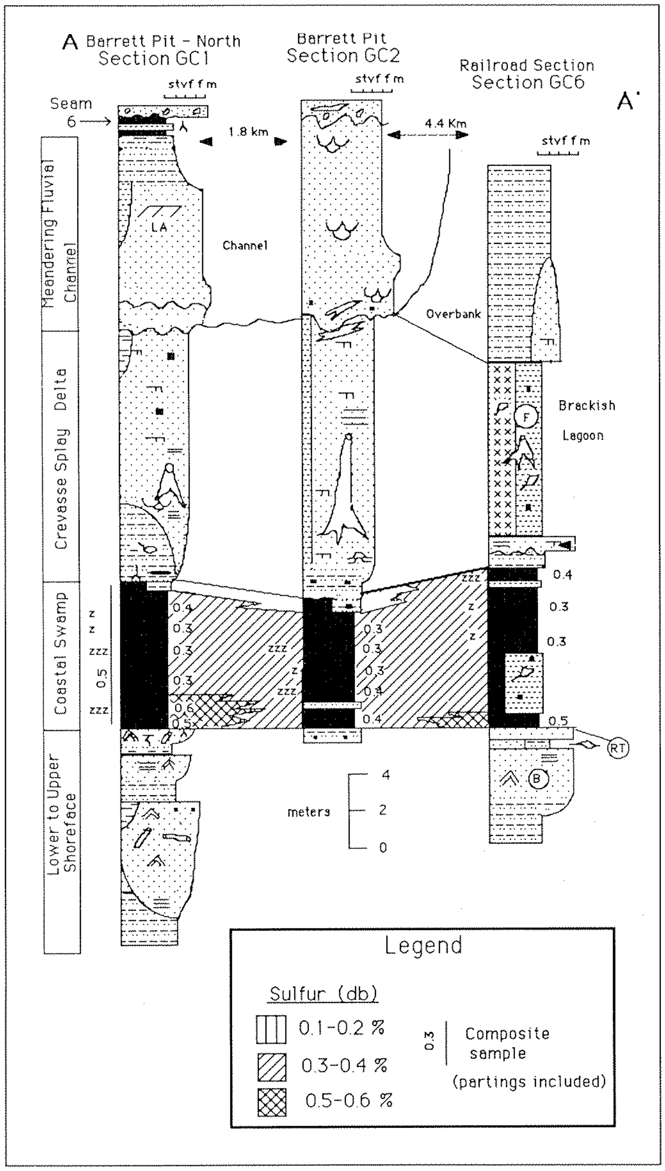

Figure 35. Stratigraphic cross section A-A' (Luscar Group coals) showing in-seam sulfur variations within the No. 4 seam and associated clastic depositional facies at the Smoky River mine.

Coal-forming environments

Kalkreuth and Leckie (1989) have suggested that Gates Formation coals formed behind active, wave-dominated shorelines in areas undergoing subsidence related to shale compaction and dewatering. Macdonald et al. (1988), however, argue that in order for thick, relatively low-ash, low-sulfur seams to have accumulated, they must have done so several tens to hundreds of kilometers away from the active shoreline. They further reason that the overall stratigraphic architecture of the Gates Formation (figure 32) supports this conclusion because the active shorelines were confined to the Peace River Arch/Elmworth Deep Basin area. Therefore, the thick coal-forming environments of the Cadomin and Grande Cache areas must have accumulated some distance landward. All of the Gates Formation coal seams, according to this interpretation, are thought to have formed in association with a series of wave-dominated deltas or strandplains, some distance removed (perhaps in time also) from the active shoreline progradation.

Based on maceral and geochemical evidence, Langenberg et al. (1988) have suggested that the Jewel Seam in the Cadomin area was deposited under relatively dry, planar, low-lying forest/swamp conditions. This supports the contention of Macdonald et al. (1988) that the swamps formed some distance from the active shoreline.

The in-seam chemical profiles from this study suggest that the Grande Cache coals developed in planar, low-lying swamps in a more seaward proximal position than did the Cadomin coals. A more pronounced and abrupt facies change to waterlain clastics in both seams at Grande Cache supports this hypothesis. Based on the general geochemical models of Cecil et al. (1980) and Donaldson et al. (1980), coal-forming periods must have been relatively acidic, which produced low-sulfur, low-ash zones. The presence of overlying brackish units (figure 32) may have contributed to the minor elevated sulfur content values for the tops of the seams; overall, however, the effect is remarkably negligible.

Coalspur Formation coals

Introduction

The Coalspur-Robb area was selected for study of in-seam ash and sulfur variations within the Coalspur Formation coal zone (figure 36). Several sections within the Luscar-Sterco Coal Valley mine and from roadcuts and abandoned pits in the Robb area were examined. Several coal seams occur within these areas and informal names regional stratigraphic correlations have been established (Engler 1986).

The sampling strategy used attempting to provide at least one vertical in-seam profile showing ash and sulfur distributions for each of the main seams within the coal zone. In addition, several sections of the Val D'Or Seam were sampled so as to provide information on vertical and lateral in-seam variations (figures 37 and 38). The sections that were sampled were generally undeformed.

Ash variations

Within the Val D'Or Seam, ash variations that can be attributed to the original sedimentary environment, are associated with mineral matter derived from at least three principal sources: water-transported clastic partings, wind-deposited volcanic ash beds, and inherent mineral matter derived from the original plant material (figure 37).

The majority of the discreet partings within the Val D'Or Seam are bentonitic, being derived from volcanic

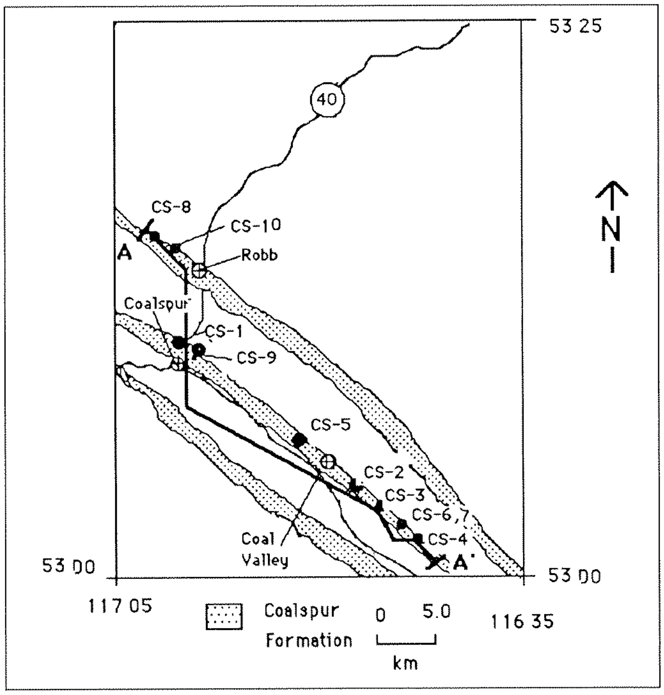

Figure 36. Location map of measured stratigraphic sections for the Coalspur Formation coals in the Coalspur-Robb area.

ash beds. The volcanic ash interpretation is supported by X-ray diffraction analysis that was performed on three of these beds and shows that they are composed of montmorillonite, quartz, and cristobalite. The clay-size fraction of these samples is between 95 and 100% montmorillonite and <5% illite and/or kaolinite. These partings are generally thin (<10 cm) and impossible to remove during mining operations.

There are relatively few water-deposited clastic partings, and from a mining standpoint they are generally thick enough to selectively mine out. These partings are related to crevasse splay facies associated with intermittent fluvial systems.

The in-seam lateral ash variations shown in figure 37 are believed to be largely a result of inherent, plant-derived mineral matter, as partings were generally excluded during sampling. This ash occurs in moderate amounts (11-34%, db) throughout much of the seam below the major crevasse splay deposit. Above this splay unit, inherent ash contents are low to very low (<10%, db).

From a mining perspective, channel samples taken through the seam that included the thin volcanic ash horizons but excluded the thicker splay deposits show it to be higher in content "as mined" ash than the inherent ash content. This is well illustrated at section CS-4 in which inclusion of the six volcanic ash beds nearly doubles the ash content, resulting in a relatively high "as mined" ash content (28%, db, figure 37).

Vertical in-seam ash distributions within the Upper Mynheer Seam show two cycles of upward, decreasing inherent ash values, with the top of the seam very high in ash (figure 39). This seam contains five volcanic ash partings, each usually less than 10 cm thick. The overall "as mined" section contains 23.1% ash, based on a channel sample through the entire seam (partings included).

The Arbour Seam, sampled along the Robb highway roadcut, contains up to seven thin volcanic ash horizons (each generally less than 5 cm thick). When all of these partings are combined to form a composite "as mined" channel sample, the seam has an ash content of 24.7% (db, figure 39). The vertical, in-seam, inherent ash content varies considerably, with a very high-ash zone present near the middle of the seam and a moderately low-ash zone near the base (figure 39).

The Silkstone or Wee Seam shows a characteristic reduction in inherent ash upward toward the center of the seam and an increase near the top (figure 40). All of the inherent ash content values are less than 20% (db), and even when the two volcanic ash partings are included to form an "as mined" channel sample, the ash content is only 15.7% (db, figure 40).

The McPherson Seam was sampled at an abandoned pit above the town of Coalspur (section CS-9, figure 36). This seam contains one major clastic crevasse splay parting and six thin volcanic ash partings (each less than 5 cm thick, figure 40). The splay deposit divides the seam into an upper and a lower unit, both having low inherent ash content values (%, db). The upper seam has a composite "as mined" ash content (partings included) of 13%, while the lower has a composite content of 22% (db, figure 31). The higher composite values for the lower seam are related to the slightly more numerous and thicker volcanic and clastic partings present here.

Sulfur variations

Sulfur contents within the Val D'Or Seam show a complex pattern of vertical and lateral in-seam variations (figure 38). Overall, this seam contains some of the lowest sulfur values obtained in this study, with most of the seam containing 0.1-0.2% (db) sulfur. "Higher" values (i.e. >0.3%, db) are commonly found at the top and base of the seam, and below the major crevasse splay parting. Several exceptions to these generalizations can be found. The lateral continuity of in-seam sulfur variations is highly variable. Between sections CS-8 and CS-10, sulfur values vary quite dramatically over a distance of less than 500 m, while in the south, between sections CS-3 and CS-4 (a similar distance), the sulfur values vary very little from one section to the other.

In-seam sulfur variations within the Upper Mynheer Seam are small, with no values above 0.3% (db). To some degree, sulfur content seems to be related to ash content; an increase in sulfur is associated with an increase in ash. An "as mined" composite sample that included partings had a sulfur content value of

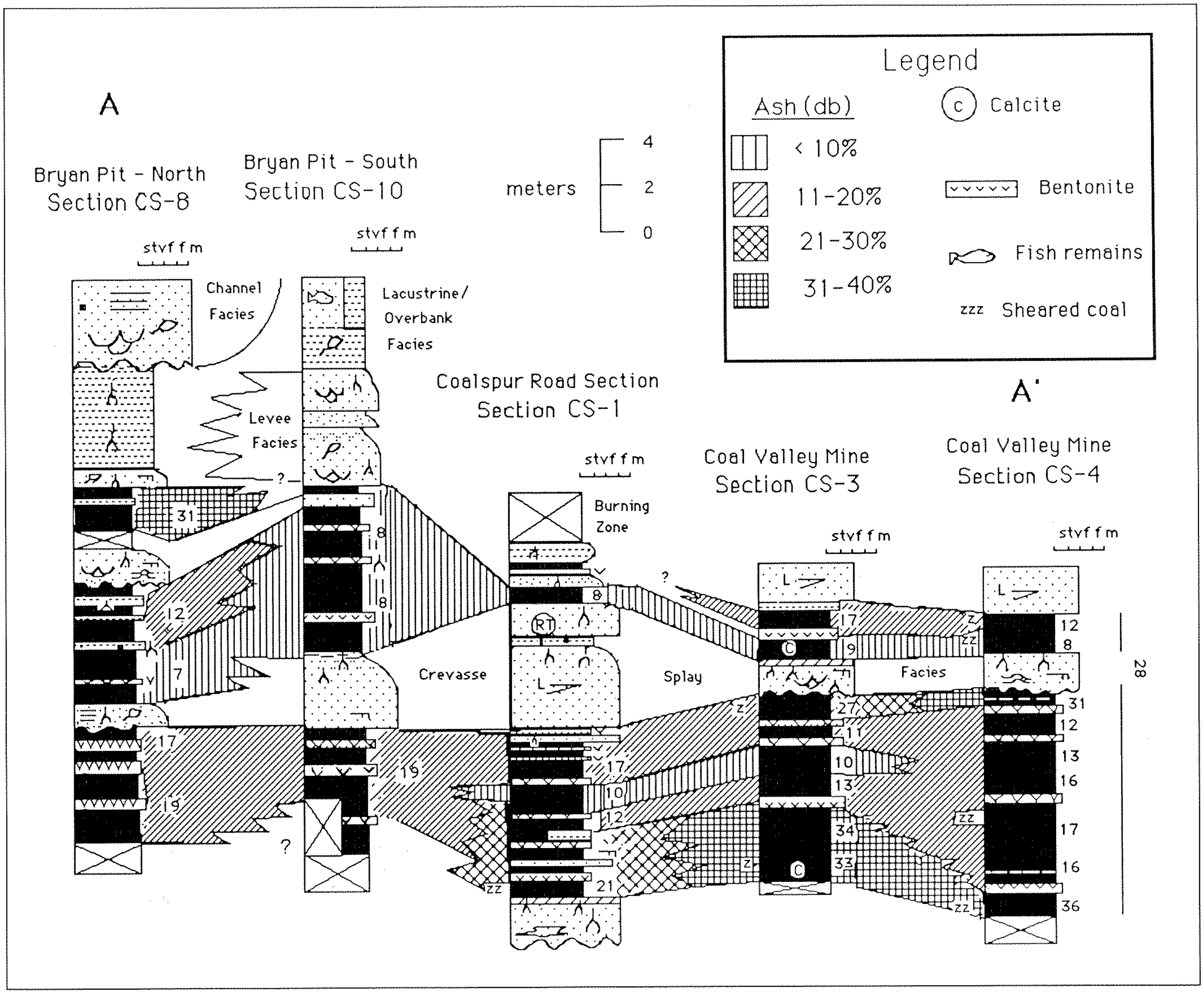

Figure 37. Stratigraphic cross section A-A' (Coalspur Formation coals) showing in-seam ash variations within the Val D'Or Seam and associated clastic depositional facies.

0.2% (db, figure 39). The Arbour Seam also shows very slight in-seam sulfur variations; however, sulfur seems to have an inverse relationship with ash (figure 39). The "as mined" composite sample contained 0.2% (db) sulfur. The lowest sulfur values within the Silkstone Seam are found in the middle of the seam, with slightly higher values present at the top and base (figure 40). The "as mined" composite sulfur content value was 0.2% (db) for the Silkstone Seam. Bonnell and Janke (1986) report that most of the sulfur in the Silkstone Seam is of the pyritic variety. The McPherson Seam has the same "as mined" sulfur content value as the Silkstone Seam (0.2%, db, figure 40). Vertical in-seam sulfur variations are predictable within the lower and upper seam splits; they are low at the base and increase upward (figure 40). Except in a few cases, no relationship with ash is apparent.

Volatile matter

Variation in vertical, in-seam volatile matter content was examined within the Upper Mynheer, Arbour, Silkstone, and McPherson seams (figures 39 and 40). Volatile matter values seem to vary consistently within a 6% (daf) range. This in-seam variation helps to explain the statistical variation for the regional volatile matter contents within the Coalspur Formation, as described in an earlier section of this report.

Depositional environments

Richardson et al. (1988) recognized that the Ardley coal zone thickens from <30 m in the east to over 150 m in the west. They believe that this zone formed in a rapidly subsiding foreland basin during late Cretaceous to Paleocene time. In addition, they suggest that rapid subsidence near the basin axis (i.e. somewhere west of the present-day Coalspur Forma-

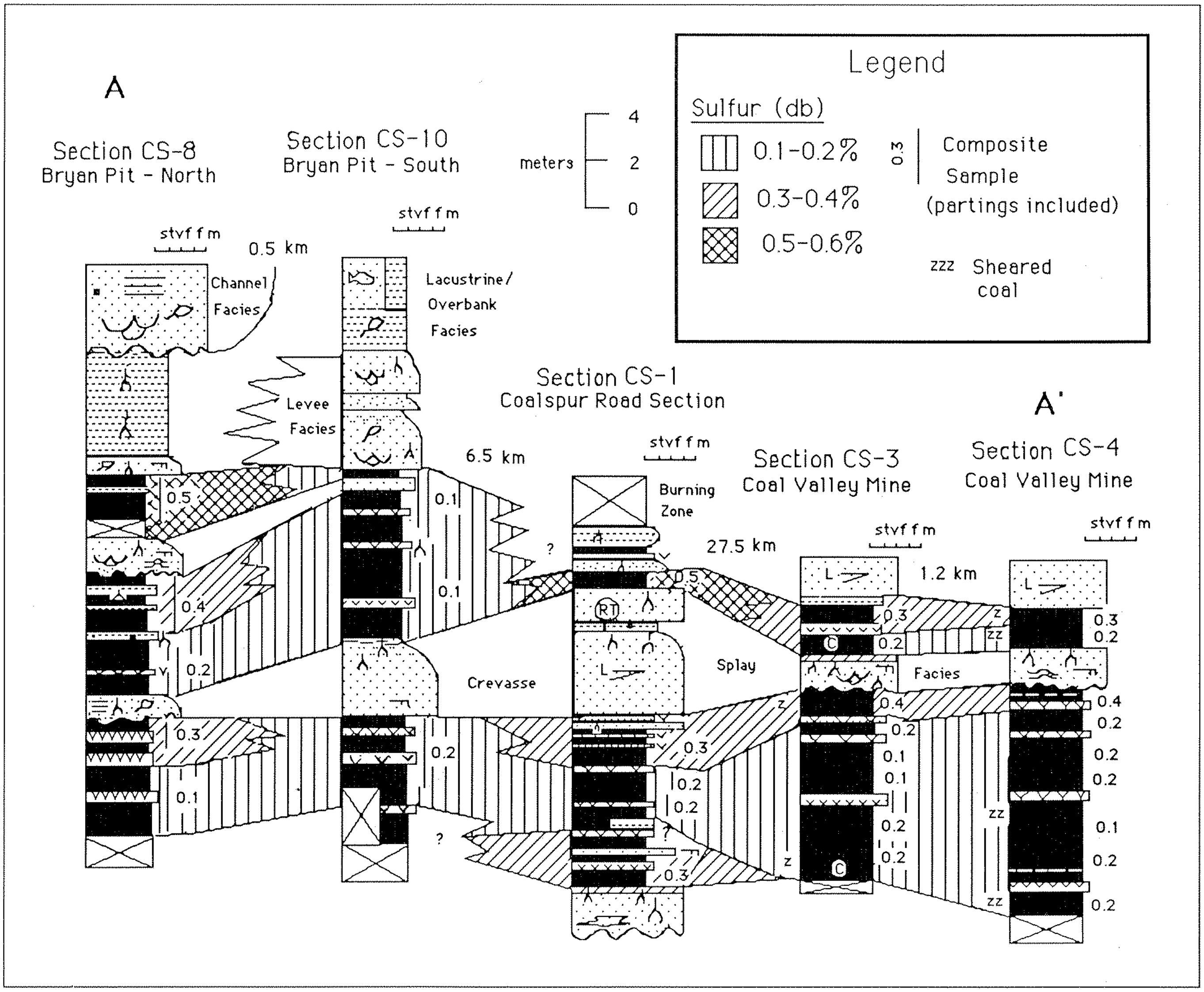

Figure 38. Stratigraphic cross section A-A' (Coalspur Formation coals) showing in-seam sulfur variations within the Val D'Or Seam and associated clastic depositional facies.

tion outcrop) may have caused river systems to flow either north or south along the mountains. This would have left a relatively sheltered area to the east, where coal swamps could develop in a relatively quiet alluvial plains environment. Jerzykiewicz and McLean (1980) agree with this interpretation for coal formation in the Coalspur Formation and further suggest the following three sub-environments: 1) abandoned channels 2) the overbank area of active channels, and 3) the floodplain, isolated from fluvial channels.

The in-seam chemical profiles suggest that for most of the Coalspur coals, coal-forming swamps were probably widespread, acidic (and consequently very low in sulfur), and developed unhindered by frequent water-derived clastic influxes. Most of the partings were derived from volcanic ash falls. The relatively minor amounts of water-derived clastics tends to support the hypothesis of Richardson et al. (1988) suggesting that the Ardley/Coalspur swamps developed in a relatively sheltered alluvial plains environment.

Obed-Marsh coal zone

Introduction

The Obed-Marsh coal deposit is located approximately 24 km northeast of Hinton, Alberta at the boundary between the Alberta plains and the foothills (figure 41). Although there are five major coal seams in the Obed and Marsh blocks, this section will concentrate only on the organic petrology and coal quality variations within Seams 1 and 2. The thickness of these seams ranges between 3.5 and 4.3 m. Seams 1 through 5 are present in the Obed Block, but due to erosion, only Seams 1 and 2 have been preserved in the Marsh Block (figure 41).

Two profiles of the No. 1 Seam (sections OM1 and OM6) and one of the No. 2 Seam (section OM5) were

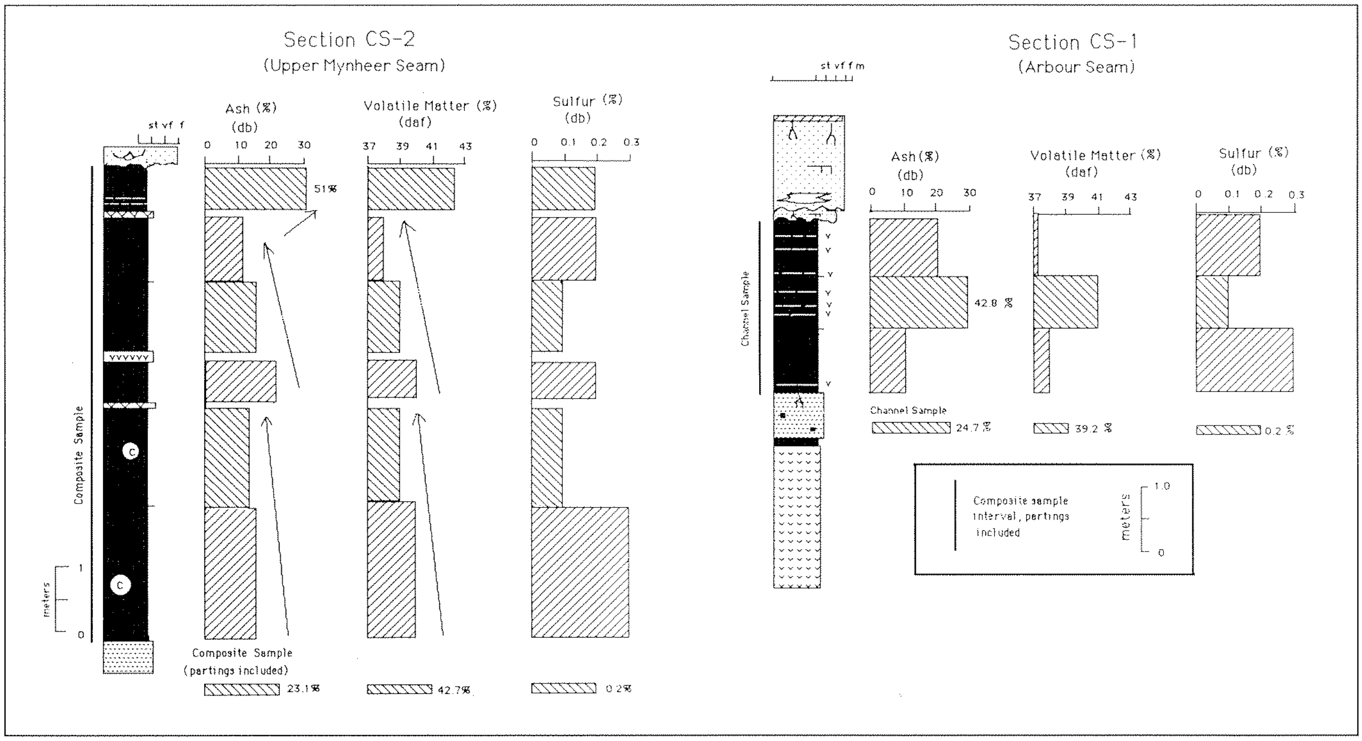

Figure 39. Vertical in-seam ash and sulfur profiles of the Coalspur Formation coals in the Upper Mynheer and Arbour seams.

measured and sampled. A vertical, in-seam profile of No.1 seam, provided by Obed Mountain Coal Ltd., is also included (section OM10). The coal and interbedded sediment samples were prepared, polished, and analyzed for maceral composition according to the International Committee of Coal Petrology (1971) procedures and classification. Some compositing of samples for coal quality determinations was done based on sampling for the maceral analysis.

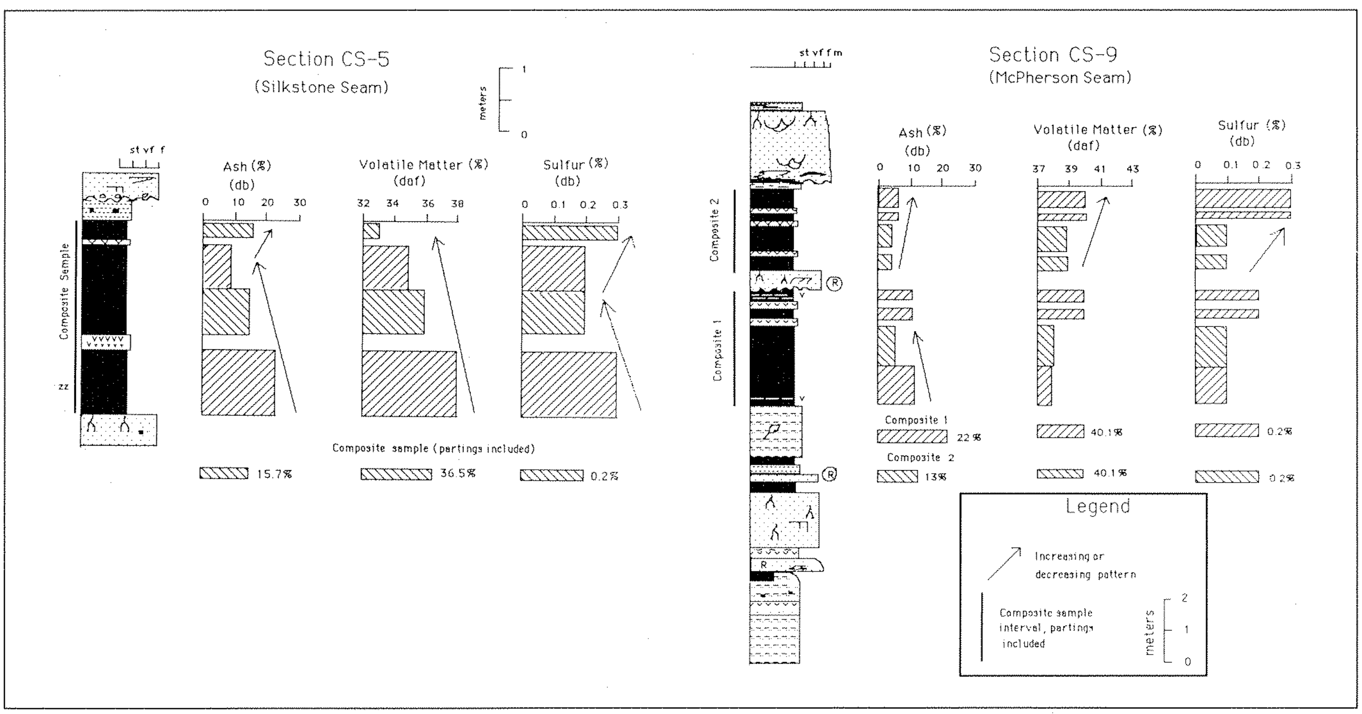

Figure 40. Vertical in-seam ash and sulfur profiles of the Coalspur Formation coals in the Silkstone and McPherson seams.

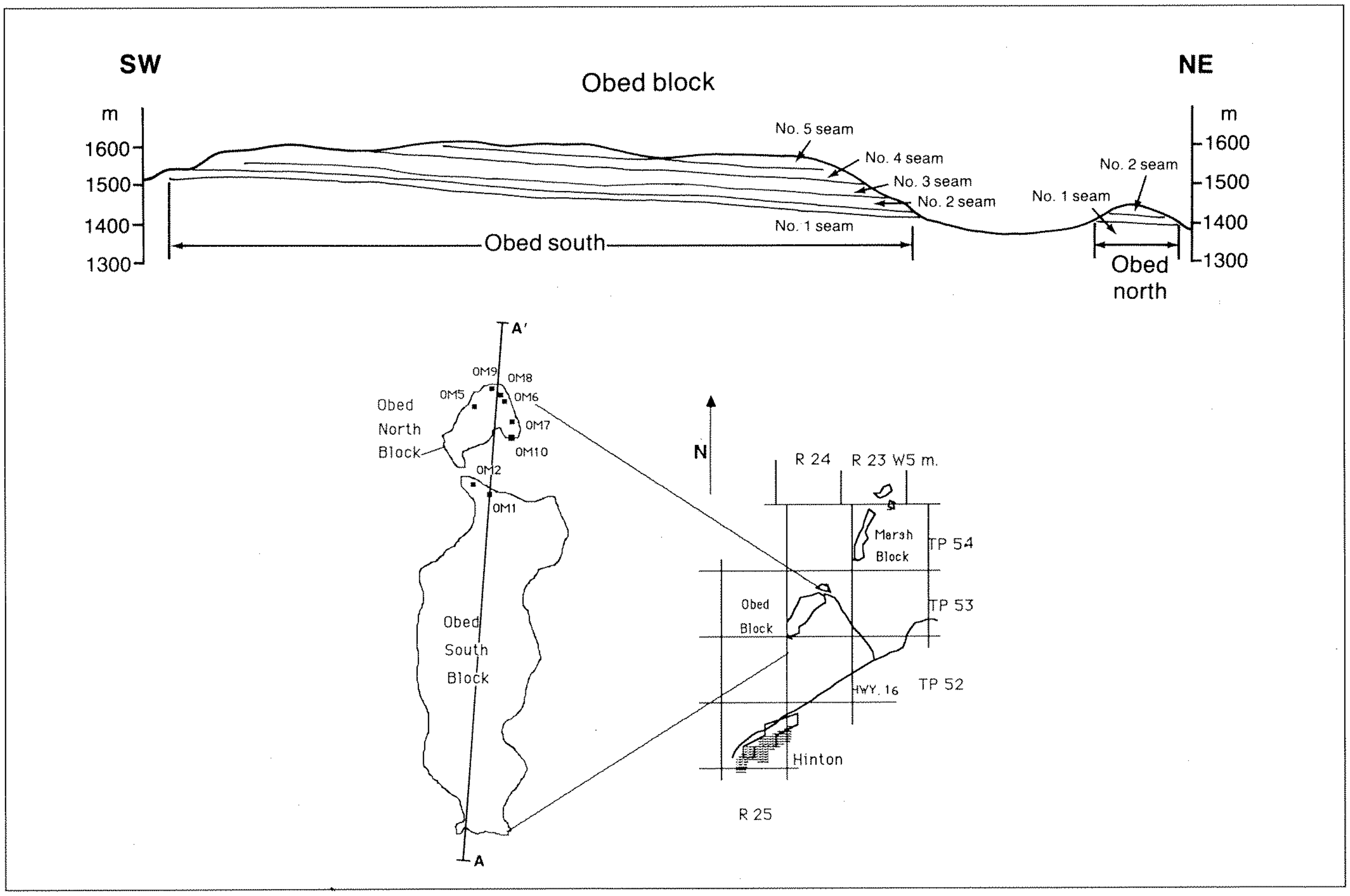

Figure 41. Location map, sections examined, and generalized stratigraphic cross section of the Obed Mountain deposit and mine (from Dawson et al. 1986).

Depositional environments

The prerequisites for accumulation of thick peat deposits are: 1) an adequate supply of plant matter, 2) a balance between the groundwater level and peat surface, and 3) the absence or limited presence of detrital clastic sediments (Teichmuller 1982). Peat accumulation can occur adjacent to river systems with well-developed floodplains (Jerzykiewicz and McLean 1980). However, McCabe (1984) points out that it is unlikely that thick, low-ash peats will accumulate adjacent to such an environment because of the almost continuous flooding events typical of such systems. However, coals found in an alluvial setting may have formed in swamps that were protected in time and/or space from such clastic flooding events. Several authors have recently suggested that raised swamps, with their upward domed shape and very low ash and sulfur contents may explain how swamps could be spatially protected.

The depositional environments surrounding the Obed-Marsh coals are separable into three time/lithostratigraphic units: 1) clastics which immediately preceded the coal-forming time, 2) interburden clastics, and 3) the coal zone itself.

The clastics that were deposited immediately prior to coal formation are part of the largely non-coal-bearing Paskapoo Formation. Several excellent roadcut exposures of this unit can be found along the road to the Obed Mountain mine (section OM3, figure 42). Such exposures show typically fine- to medium-grained sandstones and several channel features such as lateral accretion bedding; large-scale, trough-cross stratification; scoured and pebble-based channels; stacked channels; peat mats at the base of channels; and upward fining sequences (figure 42). Regionally, the Paskapoo Formation is largely composed of sandstone and extends over a very wide area (Green 1972). The previous existence of a river system involving braidplains or slightly meandering sands is a resonable depositional setting for the Paskapoo. Jerzykiewicz (1985) associates the sequence with an anastomosing river system and attributes the coal zone and interbedded clastic sediments to the fine-grained coaly termination of a major depositional cycle.

The sedimentological interpretation for the interbedding of clastics with the Nos. 1 and 2 seams is illustrated on a representative section from the mine (section OM1, figure 42). The sequence from the upper part of the No. 1 seam to the base of the No. 2 seam records an initial rise in the water table, which drowned the peat-forming environment, followed by the introduction of a crevasse splay unit. Small meandering fluvial river systems, interrupted by low water tables and the development of paleosols, characterize the remainder of the sequence.

The coal-forming environment interpretation must then be consistent with the braidplain interpretation for the underlying strata and the small fluvial interpretation for the interburden sediments. Coal petrographic techniques were used to help establish an interpretation for the coal-forming environments of the Nos. 1 and 2 seams. A more complete description of the coal petrology can be found in Gentzis et al. (1989).

Seam 1 petrology

Humotelinite and humocollinite, followed by humodetrinite, are by far the dominant macerals in most samples. The cell structure of humotelinite is visible and the cell lumens are often impregnated with porigelinite, resinite, and mineral matter. Humocollinite content ranges between 3.0 and 63.0% in most samples. Humodetrinite abundance ranges in quantity from 2.0 to 13.0%. This maceral is present in the form of densinite and forms the groundmass for the intimate mixing of humic detritus with other liptinite and inertinite macerals. Phlobaphinite is almost exclusively associated with suberinite or corkified cell walls and is never present in quantities exceeding 1.0%. Humocollinite is the only maceral in the huminite group that shows any consistent variation in quantity within the seam; it is found in increasingly smaller amounts as one moves upsection (figure 43).

Inertinite macerals are present in minor quantities, and most often in the form of inertodetrinite. No increase in inertinite content is observed in the partings, but various forms of fungal remains or sclerotinite are consistently present in the huminitic groundmass. Finally, small amounts of anisotropic inertinite occur throughout the coal seam. Pyrolytic carbon is intimately associated with seemingly unaltered humocollinite. Inertinite content generally increases from the base of the seam to the middle, then remains fairly constant to the top (section OM6, figure 43).

Primary liptinitic macerals include sporinite (occasionally sporangia), cutinite, resinite, fluorinite, and suberinite. Exsudatinite or secondary resinite is generally associated with primary resinite and amorphous fluorescing matrices. Total liptinite content ranges from 1.0 to 12.0%. Sporinite is most abundant, followed by cutinite, resinite, fluorinite, and suberinite. Chitin has been informally, but suitably placed, with the liptinites, and is very rare. Liptinite content remains relatively constant throughout the seam at section OM6 (figure 43). Gentzis et al. (1989), however, have documented two cycles of decreasing liptinite contents upward in this seam from more southern locations within the deposit.

Mineral matter consists mainly of clays and minor amounts of pyrite. There is a positive linear correlation between mineral matter and ash content as well as mineral matter and inertinite content at section OM6 (figure 43).

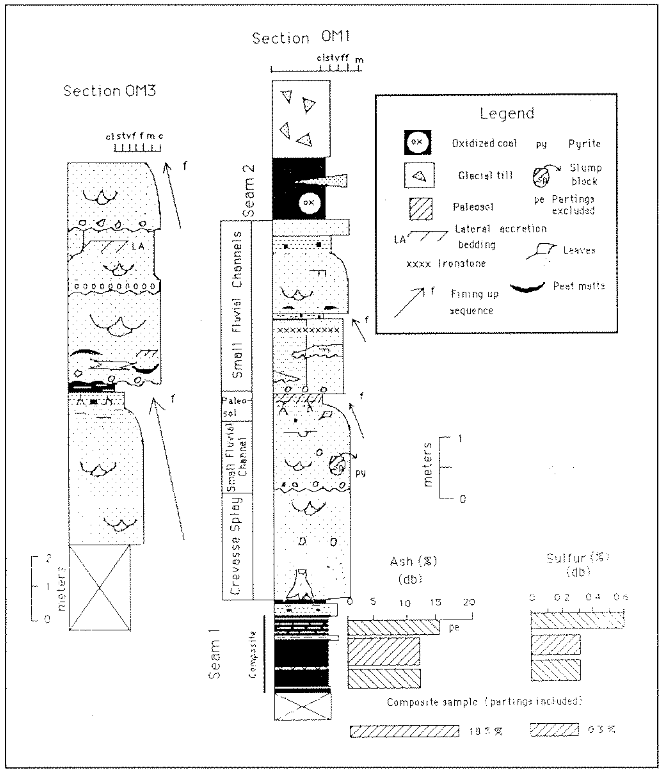

Figure 42. Stratigraphic sections OM3 and OM1 showing vertical, in-seam ash and sulfur profiles through the No. 1 seam and the sedimentology of the over and underlying strata within the Obed-Marsh coal zone.

Seam 2 petrology

In the No. 2 seam, humocollinite is the most abundant maceral (44-93%), followed by humodetrinite (4-35%) and humotelinite (%). The relative proportions of these three macerals remain constant throughout most of the seam, except near the top and base (figure 44). Liptinite and inertinite contents are usually less than 10%. Quantities of liptinite increase upward to a maximum near the top of the economic portion of the seam. The inertinite content is relatively constant throughout the seam (figure 44).

Ash variations

The No. 1 seam contains four to six clastic and volcanic partings. When composited together to form an “as mined” sample show 18.5% (db) ash (figure 42). The vertical, in-seam, inherent ash content varies from approximately 12 to 35% (figures 42, 43, and 45), with high values typically occurring at the top and/or base of the seam. The maceral profile (figure 43) shows that the high inherent ash zones are associated with high mineral matter and high inertinite content portions of the seam.

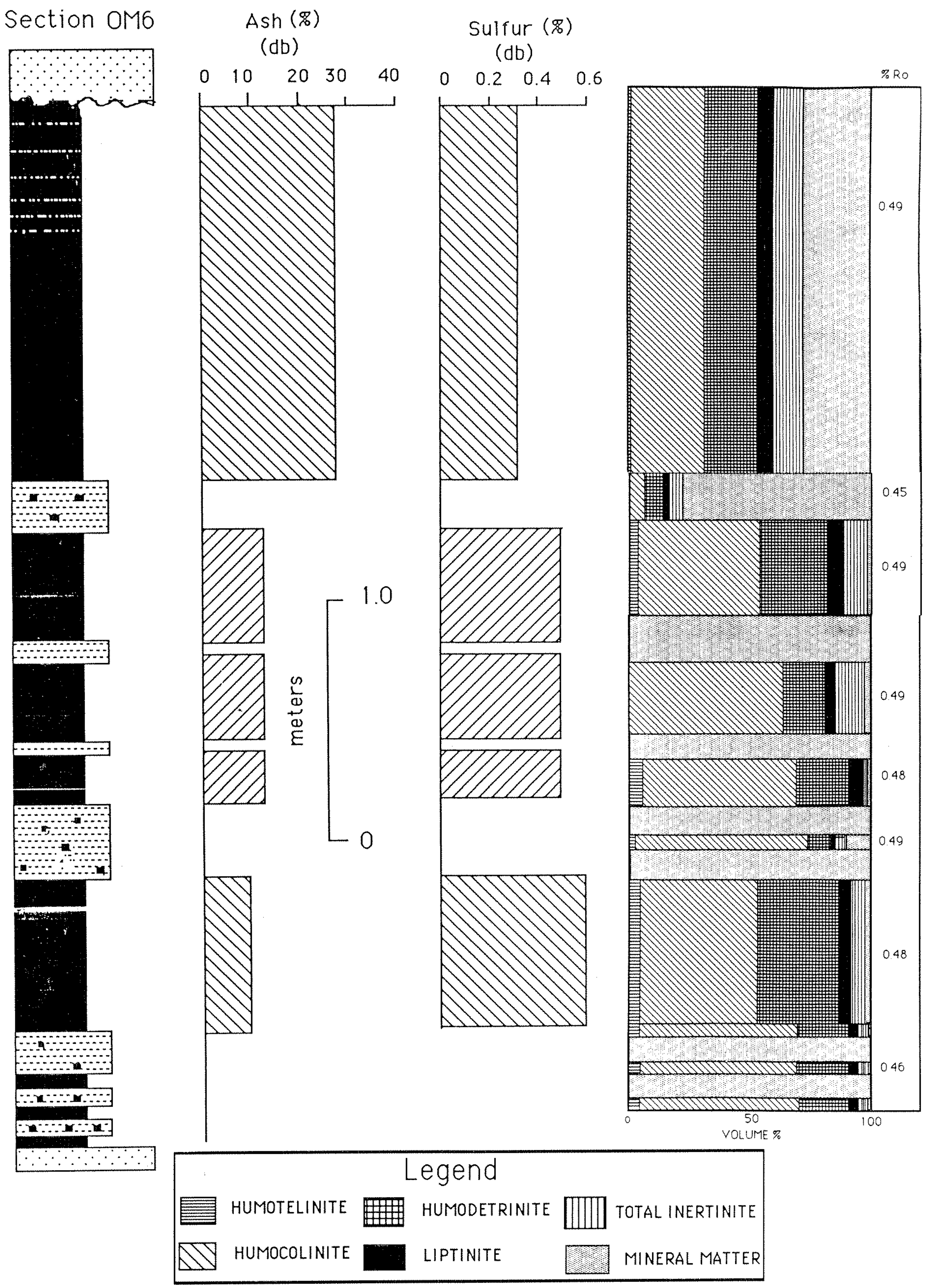

Figure 43. Vertical, in-seam coal profile showing chemical and petrographic maceral distributions within the No. 1 seam in the Obed-Marsh coal zone.

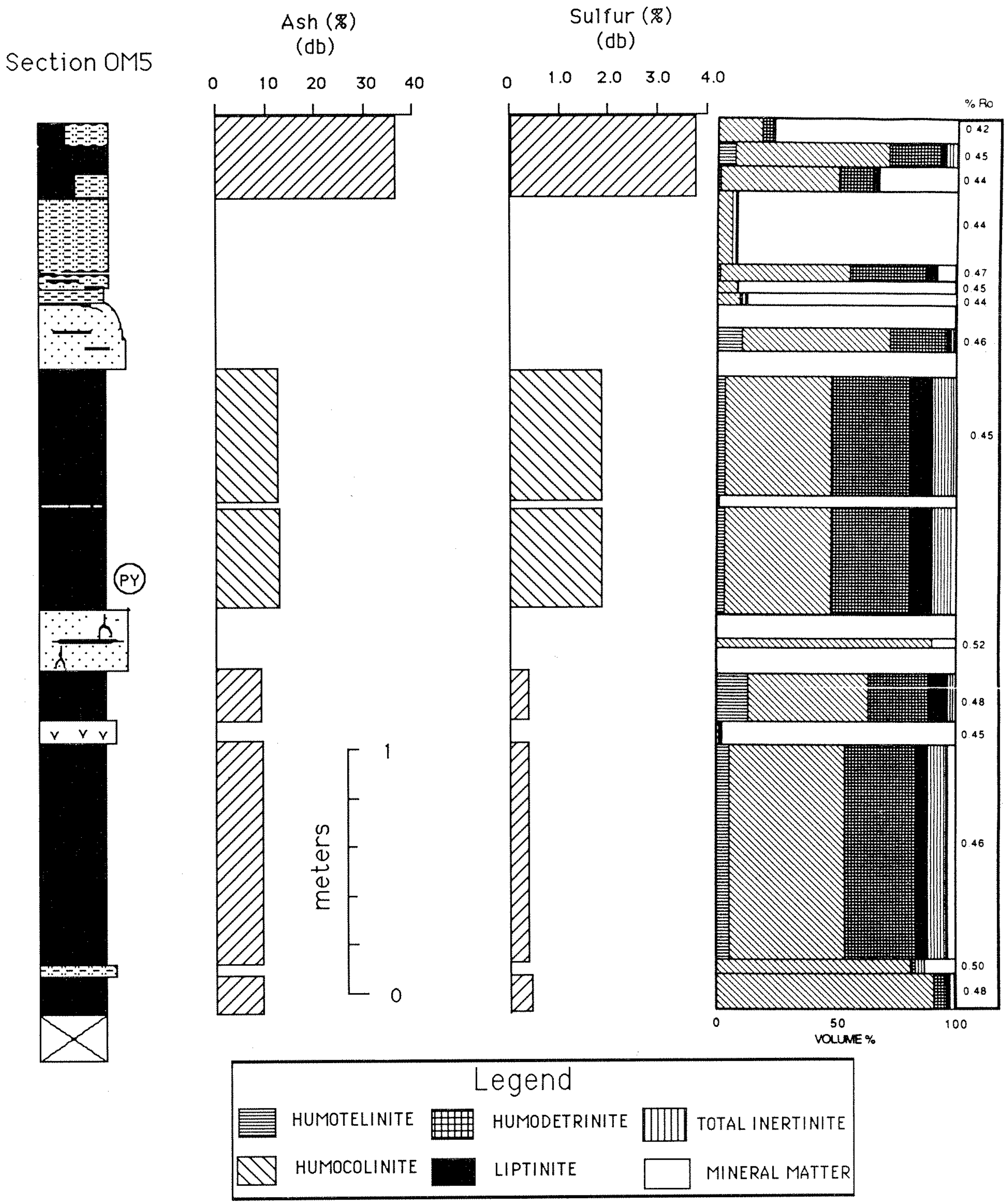

Figure 44. Vertical, in-seam coal profile showing chemical and petrographic maceral distributions within the No. 2 seam in the Obed-Marsh coal zone.

At present in the minesite, the No. 2 seam is not well exposed and therefore only one section was available for study (figure 44). The seam contains only three partings of any significance. Vertical, in-seam, inherent ash contents are generally less than 12% (db), except for the uppermost portions of the seam whichthe ash content rises to 38% (db). An overall increase in inherent ash upward in the seam is observed. The accompanying maceral profile (figure 44) shows that the very high ash contents in the uppermost portion of the seam are a result of both an increase in clastic partings and inherent, plant-derived mineral matter.

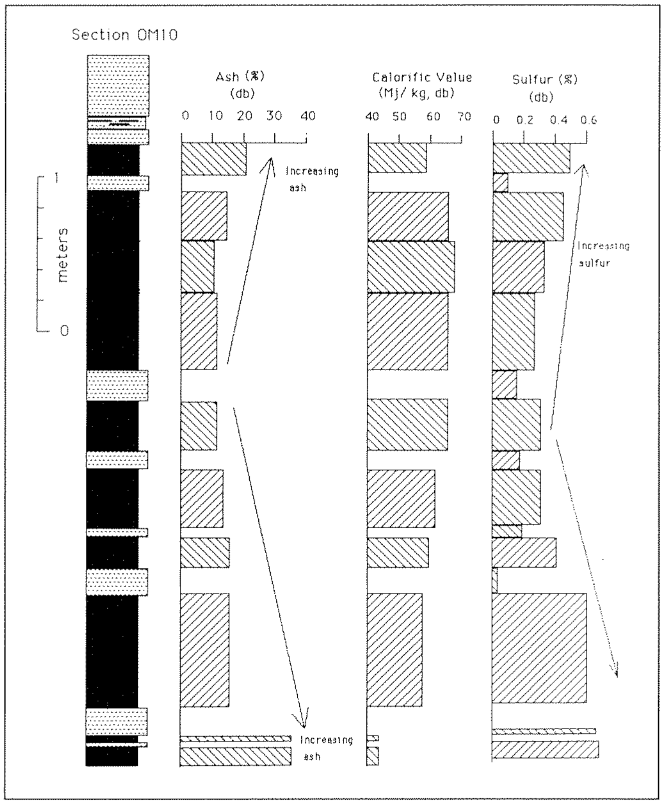

Figure 45. Vertical, in-seam coal profile showing ash, calorific value, and sulfur distributions within the No. 1 seam in the Obed-Marsh coal zone (courtesy Obed Mountain Coal Ltd.).

Sulfur variations

Variations in sulfur content within the No. 1 seam range from 0.2 to 0.6% (db), with higher values almost always occurring at the top and/or base of the seam (figures 42, 43, and 45). Sulfur content also tends to increase with increasing ash content. The partings sampled generally have very low sulfur content values (<0.2%, db, figure 45). Bonnell and Janke (1986) report that organic and pyritic varieties of sulfur are in roughly equal proportions within the No. 1 seam.

The No. 2 seam was only sampled at one location and therefore may not be representative of all sulfur values (section OM5, figure 44). The in-seam sulfur profile shows a fairly typical increase in sulfur from the base to the top of the seam; this corresponds to an increase in ash in the same direction. Bonnell and Janke (1986) report approximately equal proportions of organic and pyritic sulfur in the No. 2 seam, even when sulfur content increases. Field studies, however, show that large amounts of visible pyrite exist on cleat faces within this seam, which suggests pyrite may locally be more prevalent in some parts of the seam.

Coal-forming environments

Humotelinite and humocollinite both form from the lignin and cellulose of plant cell walls. They are present in coal that has formed from peat accumulated at a time when conditions in the peat-forming swamp were favorable for the preservation of woody tissue. Anaerobic conditions, generally regarded as a prerequisite for huminite and vitrinite formation and preservation, probably involved swamp water of a low enough pH (<4.5) to suppress bacterial degradation, and a high enough water table to prevent extensive oxidation (Renton and Cecil 1980).

Inertinite macerals are derived from the same plant components that form huminite; however, they do not undergo humification and gelification but are rather subjected to the process of fusinitization. Fusinitization may be caused by oxidation, charring, mouldering, and/or fungal attack either prior to or during peat accumulation. As a result, fusinite forms in peat layers that have been subjected to either swamp fires or strong oxidation. The high inertinite content of some intervals in the No. 1 and 2 seams indicates that severe oxidation has taken place, and the overall predominance of fusinite over semifusinite is indicative of the strong oxidation that completely fusinitized the plant cell walls.

The persistently high ratio of huminite macerals to liptinite and inertinite macerals indicates that a relatively constant reducing environment existed, a feature expressed also by the relatively low inertinite content of the coal. The macroscopic, bright and brittle bands probably formed under stable preservation conditions that did not allow rafting, mixing, and oxidation. These features suggest that the Obed peat swamp was at least partially covered by stagnant water, probably derived from a locally high water table. In addition, the well-preserved cell lumens in huminite, the phlobaphinite-suberinite association that indicates corkified tissues (Teichmuller 1982), and the resinite bodies in particular, attest to the presence of localized areas rich in tree-like vegetation. The presence of limited amounts of inertinite indicates that some of the plants experienced drier conditions, possibly in areas of slightly higher elevation.

Humotelinite is thought to have formed in situ (autochthonously) in treed areas, whereas humodetrinite and the intervals rich in sporinite and cutinite (associated with densinite) attest to the presence of a reed-marsh type of depositional environment. The profiles in this study and in that done by Macdonald et al. (1989), mainly from the northern part of the north block (figure 41), show that for this area the proportions of humodetrinite are greater than humotelinite. In contrast, Gentzis et al. (1989) report a predominance of humotelinite over humodetrinite in the southern half of the north block. These findings suggest a more tree-like environment in the south and a reed-marsh setting in the north. This relationship also applies to the No. 2 seam throughout the area.

The chemical/stratigraphic evidence for the No. 1 seam suggests the following evolutionary sequence: 1) base – initially restricted, alkaline swamp conditions resulting in high-ash, low-sulfur coals; 2) central portions – maximum extent of the swamp, producing low-ash, very low-sulfur coals; and 3) top – encroachment of the small fluvial and crevasse splay systems, once again creating alkaline conditions and resulting in high-ash, low-sulfur coals. The moderately high inherent ash contents, coupled with the presence of water-derived clastic partings, preclude a raised swamp in favor of a low-lying swamp model for the No. 1 seam. The excellent preservation of cell structure, distinct floor and roof boundaries, presence of seat earth, and thickness and continuity of the seam all tend to support an autochthonous origin. (Teichmuller, 1982; Goodarzi and Gentzis 1987). Most of the thin partings are believed to have originated from volcanic ash, and their low sulfur contents suggest that a strongly acidic environment produced shortly after the ash fall.

The No. 2 seam probably developed as a low-lying, planar swamp that was intermittently flooded with clastic material. Strongly oxidizing peat swamp conditions toward the end of the period in which the Number 2 seam developed would lead to a high inherent ash, high-sulfur peat as suggested in the geochemical model proposed by Donaldson et al. (1980).

For both seams, the combined evidence points to a coal-forming depositional environment involving a distal floodplain that was generally isolated from large active channels except during deposition of the interburden. The high-energy, large channels of the underlying Paskapoo Formation gave way to lower energy, fluvial systems. The petrographic and chemical evidence for the Nos. 1 and 2 seams suggest periods of relative quiescence that permitted the establishment of forested peat lands in the south and reed-marsh environments in the north; these were punctuated with brief periods of minor fluvial activity. Swamp conditions evolved from being initially alkaline (base of seam) to being highly acidic (mid-seam) and becoming alkaline again (top of seam).

Regional coalification

Kootenay Group

Figure 9 provides information about regional rank variation. However, it should be realized that this area has been structurally shortened since deposition of the coal-bearing strata. Consequently, in order to reconstruct the burial history, all features must be palinspastically restored to their original geographic positions (Gibson 1985). The additional ERCB and ARC volatile matter data points have been interpolated between Gibson's sections (Gibson's data listed as GSC-1 to 12, table 4). Because the ERCB data are for three specific areas, only those points within the existing range of volatile matter were plotted and contoured (figure 46). The contours shown include the

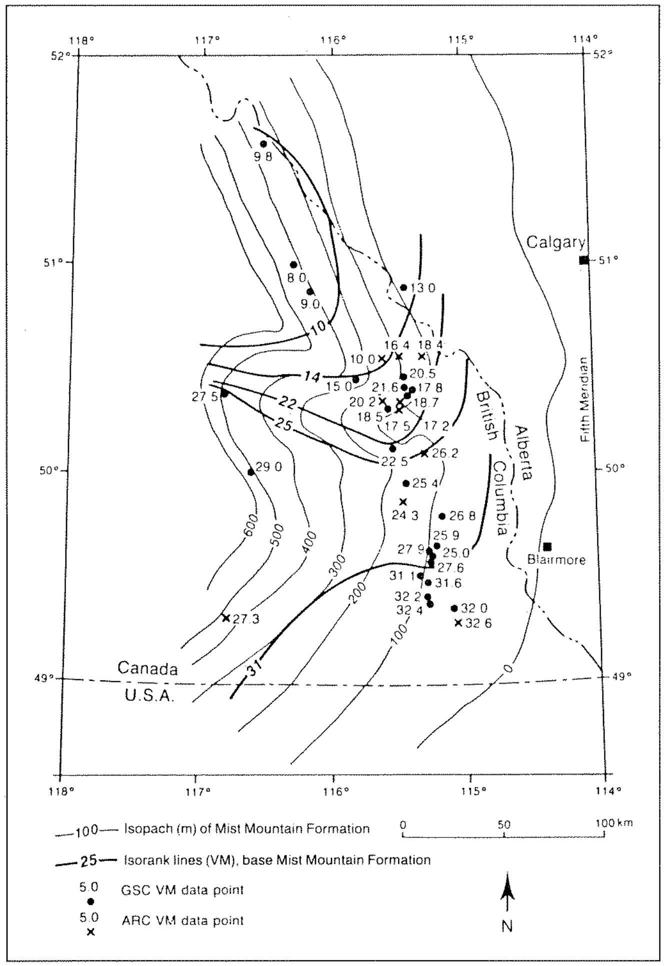

Figure 46. Palinspastic map showing isorank lines and isopachs of the Mist Mountain Formation (modified from Gibson 1985).

limits of the following ASTM rank classes: 31, 22, and 14% volatile matter. This indicates that the rank at the base of the Mist Mountain Formation increases from high-volatile bituminous in southern Alberta to medium-volatile bituminous in the Crowsnest Pass area to low-volatile bituminous in the Highwood River area and to semianthracite in the Canmore area.

It was first noted by Norris (1971) that the isorank lines cut across the isopachs (figure 46, this study). He explained this by suggesting that the geothermal gradient may have been higher in the Canmore area than in southern Alberta, assuming that all coalification resulted from pre-Laramide sedimentary loading. However, Hughes and Cameron (1985) propose that the high coal ranks in the Canmore area are a result of postdeformational coalification caused by loading by the Rundle Thrust sheet and partly by a high geothermal gradient. Postdeformational coalification in deep oil and gas wells is also documented by England and Bustin (1986). However, as noted by these authors, relatively low rank coals occur south of the Crowsnest Pass area below the Lewis Thrust sheet, indicating that not all large thrust sheets cause increased levels of coalification. The increase in coalification from south to north in the disturbed belt can be explained by variations in depth of burial, geothermal gradient and deformational history.

Depth of burial

The depth of burial of the Kootenay Group coals can be inferred from published data but the estimate may not be very accurate because of erosion in the mountains and foothills. Depth of burial in the plains gradually increases from east to west. This is indicated by the isopachs for the Mist Mountain Formation (figure 46). The overlying Elk Formation and Blairmore/Alberta groups show a similar pattern. Hughes and Cameron (1985) suggest a 3800 m depth of burial for the base of the Mist Mountain Formation in the Canmore area.

In the western part of the Alberta plains, the top of the Jurassic is generally at 3 km depth. Nurkowski (1985) estimates that in this area about 2 km of overburden has been removed by erosion, bringing the estimate for burial of the base of the Mist Mountain Formation to 5 km. Based on isopachs of the Kootenay (Gibson 1985) and Blairmore groups (Norris 1964) it is reasonable to assume that burial of the base of the Mist Mountain Formation increases from 5 km in the eastern part to approximately 7 km in the western part of the area. The length of time and depth of burial has subsequently been affected by the Laramide deformation. Undoubtedly varying geothermal gradients also played a role. These factors combined explain the regional coalification pattern (figure 46).

Luscar Group

The information from the ERCB proximate analyses focuses on five designated coalfields: from southeast to northwest of the Ram River, and the Cadomin-Luscar, Moberly, Smoky River, and Kakwa River coalfields. The data are from proximate and petrographic analyses of samples from freshly exposed seams in open pits, as well as petrographic analyses of samples from naturally exposed seams. These data were supplemented with vitrinite reflectance measurements from samples collected in areas between these coalfields (figure 5). Information about the Cadomin-Luscar coalfield has been documented in detail by Langenberg et al. (1988).

Although no stratigraphic information is available in the ERCB coal quality data files, it is safe to assume that most of the samples are from the basal part of the Gates Formation (base of Grande Cache Member, figure 2) because most of the commercial coal is from that section (i.e. Jewel Seam – Cadomin area and the No. 4 seam – Grande Cache area). Stratigraphically higher seams, such as the Nos. 10 and 11 seams in the Grande Cache area and higher seams in the Gates Formation, Kakwa area, were probably also sampled. Consequently, the volatile matter content (estimated from drill holes) for the base of the Gates Formation in the Kakwa and Grande Cache areas may be somewhat lower than the true values. However, the consistency of volatile matter content values, as determined by vitrinite reflectance of outcrop samples that have good stratigraphic control, indicates that these deviations are small. The contour map (figure 47) shows a very consistent rank pattern, where the highest rank (low-volatile bituminous) is along the northeastern side and the lowest rank (high-volatile bituminous "A") is along the southwestern part of the area. It should be noted that no sudden changes in rank are observed across major thrust faults.

For the Gates Formation, a pattern of westward decreasing rank was observed by Kalkreuth and McMechan (1984) in the area northwest of Grande Cache. This decrease in coalification was attributed to a westward decrease in duration and depth of burial as a result of the timing of Laramide deformation across the area. In a subsequent publication (Kalkreuth and McMechan 1988), it was shown that, in the plains area, the level of coalification also decreases eastward from a maximum near the eastern limit of the foothills. Within the smaller Grande Cache area, rank data from laterally continuous coal seams were used to illustrate relationships between timing of coalification and deformation (Kalkreuth and Langenberg 1986). This study showed that coalification on a local scale was largely predeformational.

In the Cadomin-Luscar coalfield, the intersections of isorank surfaces and the Jewel Seam indicate components of syndeformational coalification (Langenberg et al. 1988). The highest rank for the Jewel Seam was found in the central part of the coalfield, with decreases in rank to the southwest and the northeast. This pattern may be compared with the westward and eastward decreases in maturation of the Lower Cretaceous from a maximum near the edge of the deformed belt (Kalkreuth and McMechan 1988). It is interesting to note that the area of maximum rank is exposed at the surface in the foothills of the Cadomin area, while in the Grande Cache area the highest ranking area is present in the subsurface of the interior plains. Oil well information needs to be collected to verify whether or not the decrease in rank eastward continues in the subsurface area northeast of Cadomin.

The rank variation at the base of the Grande Cache Member (figure 47) can be explained by possible variation of three parameters: 1) paleogeothermal gradients, 2) depth and duration of stratigraphic burial, and 3) tectonic burial history or a combination of the three parameters. Unfortunately, no detailed information on paleogeothermal gradients for the study area is available (some suggestions may be found in Hitchon 1984). Kalkreuth and McMechan (1984) as-

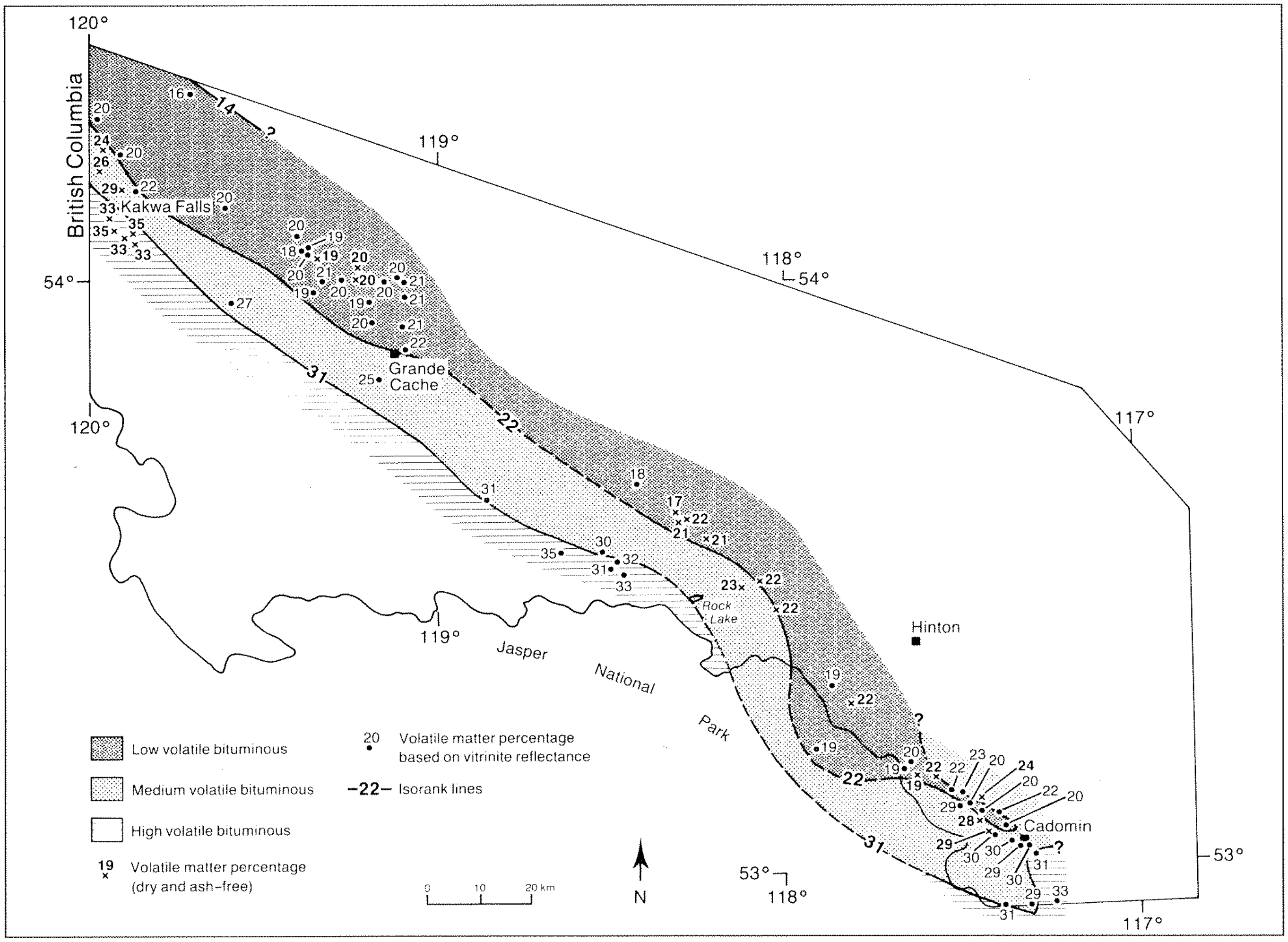

Figure 47. Volatile matter variations at the base of the Grande Cache Member.

sumed a paleogeothermal gradient similar to the present-day geothermal gradient of 27°C/km for the area northwest of Grande Cache. This may also apply to the present study area, and consequently, the rank variation cannot be explained by variation in geothermal gradients. However, the deflection of the isorank lines southwest of Hinton may be a result of a 'hot spot' related to a high geothermal gradient (Jones et al. 1985).

Little information on variation in depth of stratigraphic burial because of extensive erosion is available. It seems reasonable to assume a 5500 m depth of burial in this area for the base of the Gates Formation, based on Kalkreuth and McMechan (1984) work north of Grande Cache. There are insufficient numbered exposed sections or drill holes to construct isopachs for the Luscar Group as done for the Kootenay Group (see also McLean 1982). The isorank lines run largely parallel to the trend of the foothills. This indicates that rank may be related to burial in a linear foreland basin during late Cretaceous and Paleocene that was formed by thrust loading (Beaumont 1981; Kalkreuth and McMechan 1984). The broad areas of equal rank in the Kakwa, Grande Cache, and Rock Lake areas could support this interpretation. However, the rank changes over short distances in the Cadomin area are more difficult to explain using this basin model. The rank distribution is probably a result of components of syndeformational coalification (Langenberg et al. 1988). It is believed that the rank variation (figure 47) is largely controlled by stratigraphic burial, with tectonic burial playing a lesser role. The amount of tectonic burial may have increased from northwest to southeast resulting in syndeformational coalification in the Cadomin area.

Coalspur Formation

Coalspur coals were collected from a roadcut exposure near Coalspur and from two abandoned open pits near Robb (table 6). Rank determinations based on vitrinite reflectance indicate slightly higher coalification in the Coalspur trend (through the town of Coalspur) compared to the Robb trend (0.67 and 0.54-0.57% Rmax, respectively). Calorific values (daf) are very similar for the coals from the two locations. This suggests that vitrinite reflectance may be better suited to indicating slight changes in coalification levels at this rank. Based on these data, the coal is classified as high-volatile bituminous "C".

Obed-Marsh coal zone

Petrographic analysis of about 40 samples shows an average random vitrinite reflectance of 0.47% and a range of 0.43-0.52%. These reflectance measurements were performed on the maceral, eu-ulminite B. Using random reflectance, the average maximum vitrinite reflectance is 0.50% (table 6), using the formula Rmax = 1.066*Rm (Bustin et al. 1983, p. 109). Based on reflectance, the Obed-Marsh coals are classified as high-volatile bituminous "C"/subbituminous "A". The average volatile matter content (daf) is 47% for the Obed coals and 41% for the Coalspur coals. These data indicate a lower rank for the Obed coals. This is substantiated by Bonnell and Janke (1986) who show differences in equilibrium moisture between Obed (the mean of four samples is 13.3%) and Coalspur coals (the mean of six samples is 9.2%), indicating a slightly lower rank for the Obed coals.

Effects of structural deformation

Kootenay Group

The effects of deformation on the quality of the Kootenay coals has further been investigated by Bustin (1982, 1983) and Pearson and Grieve (1985). Extensive deposits of sheared coal are present in the study area, and even in areas of mild deformation the coal may be locally sheared.

At Tent Mountain (figure 26), the ash content of Seam 4 increases toward the center of the seam, while the sulfur content decreases. The qualitative degree of tectonic shearing of the coal, as observed in the field, also increases toward the center of the seam. Other variables such as VM, FC, C, and H contents all show tendencies to either increase or decrease away from the center of the seam. Bustin (1982) has shown the correlation between sheared coals and fine grain size, which results in increased susceptibility to surface oxidation. He also noted that within oxidized, near-surface coal zones, the C and H content values tend to increase, then level off with increasing depth, i.e. away from the zone of oxidation. In comparison, oxygen contents tend to decrease away from the near-surface weathered zone. Some of the variables measured within the vertical seam profile of this study show similar trends relative to the most intensely sheared coal. This suggests that shear zones within the No. 4 seam at Tent Mountain can act as oxidation conduits at great depths below the surface (section CNP-6, figure 26, was measured on a mine bench approximately 40 m below the ground surface). The increase in ash content of sheared coal may reflect both the greater susceptibility to shearing when there are abundant rock partings present and the dissemination of formerly discrete rock partings (Bustin 1982).

Bustin (1983) studied the rank of coals close to thrust faults in the area, noting only minor effects on rank close to the faults. Pearson and Grieve (1985) documented syndeformational coalification in the Fernie area (B.C.).

The thickening of coal seams in the hinges of folds has been documented by Bustin (1985) at Grassy Mountain and Tent Mountain. He also describes thickening by imbricate faulting at Vicary Creek and Tent Mountain. Fieldwork in July 1987 showed that similar thickening has occurred in the York Creek open pits. Drilling in this area confirms that the seam pinches and swells parallel to the regional strike resulting in minable coal pods (P. Graham, Manalta Coal Ltd., pers. comm.). The exact nature of this thickening is still poorly understood and warrants further investigation.

Luscar Group

Structural shearing and thrusting of coals into duplex and similar structures are believed to contribute to unpredictability in estimating ash contents. This structural influence on ash content involves two mechanisms: 1) physical thrust repeating of partings in the coal, and 2) increased susceptibility of crushed and sheared coal to surface groundwater oxidation processes that reduce carbon content, resulting in a relative enrichment in mineral matter (Bustin 1982).

This structural influence has been documented for the Luscar Group coals in the Cadomin - Luscar coalfield by Langenberg, et al. (1988). These authors suggest that structurally thickened limbs and/or the cores of fold structures are expected to have highly unpredictable ash contents as a result of structural ash augmentation.

The process of ash augmentation is very apparent in the No. 4 seam in the Grande Cache area. Here, most of the inherent ash is present in quantities less than 8% (db), except in those zones described as highly sheared (multiple "zzz"'s, figure 33. A 3 m composite sample taken from a highly sheared, tectonically thickened 15 m portion of the No. 4 seam showed ash values above the inherent norm (14%, db). Another channel sample collected from an 8 m section of a less deformed duplex structure in the No. 4 seam revealed only slightly elevated ash values (11%, db). The exact effect that structural deformation has on coal quality is not simple and must always be compared with the depositionally derived inherent and partings-related ash. More work needs to be done in this area.

Coalspur Formation

The effects of structural deformation on the Coalspur Formation coals were not specifically investigated during the course of this study; however, there are several areas in the Coal Valley region in which the coals have been thrust into complex duplex structures. Field observations suggest that there may be differences in ash content among the different structural settings.

Simple thrusts that stack entire sections of a seam on top of other portions of the same seam would probably not significantly increase the overall "as mined" ash content. However, en echelon thrusts that slice a seam into smaller packages and restack them may increase ash content in a given mine area. In this case, depositionally thin partings that have a minor or predictable ash content in undisturbed sections may be thrust repeated several times, increasing ash content and making it more difficult to predict.

One of the most pressing problems facing all producers of foothill/ mountain coals that have undergone structural deformation is the amount of fine coal produced by this mechanism (G.Johnston, Luscar-Sterco Ltd., pers. comm.). Excess fine coal tends to decrease the efficiency of preparation plants and lower overall plant production.

Obed-Marsh coal zone

The Obed-Marsh coal zone is essentially undeformed, as it lies outside of the foothills region proper. Field observations suggest, however, that some glacially induced deformation and near-surface creep processes have both been operative at this location. Their influence on coal quality, if any, is as yet undetermined.

Conclusions

From this study, a number of conclusions were drawn and are organized by topic in the following section.

Coal quality data set

The publicly available Energy Resources Conservation Board raw coal data set contains sufficient information, when combined with recently collected Alberta Geological Survey data, to describe the regional coal rank trends throughout the foothills/mountains area. This data set adequately describes calorific value for the Coalspur and Obed-Marsh coals but not the Luscar Group coals. The paucity of data for the Luscar Group coals is directly related to the present use of these coals (i.e. as metallurgical coals), and their future potential as possible thermal coals has largely been ignored (except at Smoky River). Ash content for all three coal zones cannot be meaningfully described on a regional scale using the present data set because of the small number of measurements and a lack of information on stratigraphic position and in-seam variation. Sulfur content variations are generally small and the present data set is adequate for characterizing the coals in a statistical and regional sense, but not in a stratigraphic or mine-scale sense. Ultimate analysis data is almost nonexistent for all coal zones.

The data available for the foothills/mountains coals also tends to be within existing mines and established coalfields. This problem is more pronounced in the central and southern regions. In addition, there is often a lack of important geological information such as coal zone, structural setting, and seam stratigraphic identification. In seam coal quality data and trace element data is also very scarce.

Statistical analysis

Classical statistics can be used for initially describing coal quality on a regional basis. The data distribution and type of distribution must first be established. However, coal quality values can be very different depending on how the coal is sampled, the scale of investigations, representativeness, and on what basis it is reported. Local variations in coal quality within a given economic coal seam can also be very high; however, the sulfur and inherent ash content values for the localized mine sites are almost always less than the mean values of the more regional statistics. This is probably a result of the derivation of regional coal quality data from mixed exploration and mine site sources, while localized data is from economic seams only. The regional values are probably reasonable first estimates for exploration level investigations. A firm geological understanding of coal quality must accompany any statistical evaluation.

Calorific value

Calorific values are highest for the Luscar Group coals (mean = 35.5 MJ/kg), slightly lower for the Kootenay Group (mean = 34.5 MJ/kg), and lowest for the Coalspur and Obed-Marsh coals (mean = 30.0-31.0 MJ/kg). Within a given seam of fixed rank, calorific value is almost directly related to ash content. Vertical in-seam profiles show how this variation occurs from the bottom to the top of seams. Linear regressions show these relationships to be: CV (db) = 35.2 - 0.38*Ash (db) for the Kootenay Group coals; CV (db) = 36.2 - 0.39*Ash (db) for the Luscar Group coals; CV (db) = 31.0 - 0.32*Ash (db) for the Coalspur Formation coals containing <30% ash; and CV (db) = 31.7 - 0.34*Ash (db) for the Obed-Marsh coals. Correlation coefficients for the four zones are -0.96, -0.99, -0.92, and -0.96, respectively.

Ash

Reported ash contents for coals can pose complex problems. Ash content of these coals is generally separable into three components: inherent ash derived from original plant mineral matter, waterlain clastic partings, and air-deposited volcanic ash horizons. Only inherent ash should be used to describe the original chemical conditions of the coal precursor, i.e. peat. However, total ash or "as mined" ash (which would include all nonremovable partings) should be examined if the coal is being evaluated from a mining perspective. For this reason, it is difficult to report average, mean, or median ash values that have any meaning. In spite of this, the reported ash content values are similar for all four coal-bearing units, with the Luscar Group coals having the lowest median value. In-seam inherent ash variations for all coal zones range from 5 to 20% (db), reflecting the original geochemical swamp conditions. The lowest inherent ash content values tend to be found at the center of seams; this is related to the original maximum extent of the coal swamp. This range of inherent ash content values is the basis for total or "as mined" ash. As-mined ash content is then governed by the thickness and number of nonremovable partings present and the inherent ash. Partings in the Luscar Group coals at Smoky River tend to be water-derived clastics, those in the Coalspur Formation near Robb are normally volcanic ash in origin, and those in the Obed-Marsh area are usually of mixed origin. Ash has also been correlated to calorific value, and to a minor extent, to volatile matter.

Sulfur

Sulfur values reported in this study support the widely held belief that Western Canadian coals are low in sulfur. Statistically, 75% of the sample populations from all coal zones have sulfur content values less than 0.5% (db). For all four coal zones, however, there are outliers (i.e. the other 25% of the samples) whose values can range up to nearly 3.0% (db). The distinction of having the largest percentage of its sample population with the lowest sulfur values (i.e. 75% of the samples contained less than 0.4% sulfur (db)) belongs to the Coalspur Formation coals. In-seam sulfur content studies of the three coal-bearing units, at four small areas, showed that elevated values commonly occur at the base, top, and immediately below major waterborne clastic partings or underlying fluvial or tidal channel deposits. These elevated values are typically in the 0.5-0.7% (db) range; however, knowing where such coals exist stratigraphically within a seam may be important if very low-sulfur export coals are being sought. At least one mine operator in this area has been selectively mining for this type of coal. With growing concern for the environment and increasing interest in low-sulfur emissions from thermal coals, in the near future it may not be sufficient to say Western Canada has .."low-sulfur coals."

Coal rank

Standardized volatile matter values for the base of the Kootenay Group show a gradation from high-volatile bituminous coals in the area south of Crowsnest Pass to semianthracite in the Canmore area. The increase in coalification from south to north can be explained by a combination of the following factors: varying depths of burial; geothermal gradients; and locally, additional loading by thrust sheets. The presumed depth of burial for coals at the base of the Kootenay Group varies from 5 km in eastern regions to about 7 km in the western region.

Using volatile matter and vitrinite reflectance measurements, the rank of the Luscar Group coals is defined as being in the low-volatile to high-volatile bituminous "A" range. Coal rank at the base of the Luscar Group decreases from southwest to northeast and is believed to be related to the original depth of stratigraphic burial within the foreland basin and minor effects associated with tectonic burial.

The rank of the Coalspur Formation coals is generally high-volatile bituminous "C". A slightly higher degree of coalification occurs in the southwest versus the northeast (at least in the Coalspur-Robb area). This coalification pattern is believed be predeformational, maximum coal rank being determined by depth of burial in the Paleocene foreland basin.

The Obed-Marsh coals lie on the high-volatile bituminous "C"/subbituminous "A" boundary. The coalification pattern here is entirely predeformational and is related to post-Paleocene infilling of the basin.

Coal-forming environments

Three distinct depositional environment/coal quality facies are recognizable in the Crowsnest Pass area: 1) proximal-coastal plain mire facies that, overall, tend to have poor coal quality parameters; 2) fluvial-distal (alluvial plain) mire facies that contain thick, high-quality economic coals; and 3) fluvial-proximate (alluvial plain) mire facies that often contain thick coal seams but also possess very high ash contents. In-seam coal quality chemistry profiles show increasing, decreasing, stable, and fluctuating geochemical patterns. Sulfur increases at the top and base of the seam are in most cases related to the early diagenetic environment rather than the overlying marine strata. Ash content is inversely related (depositionally) to sulfur at some locations.

The Luscar Group coals generally formed as low-lying swamps on a broad, wave-dominated coastal plain that was prograding northward. The Nos. 4 and 10 seams at Grande Cache probably formed closer to the paleocoastline than did the more removed Jewel Seam in the Grande Cache area. Most of the thick coal seams are found in close association with under and overlying marine or brackish deposits, yet this seems to have had only a minor effect on sulfur content, commonly raising it to 0.5-0.6% (db). In-seam ash profiles for Grande Cache show relatively low inherent ash contents except where the seam has been structurally sheared or waterlain clastics introduced.

The Coalspur Formation and Obed-Marsh coals both developed on broad, low-energy, alluvial plains in the rapidly subsiding Alberta foreland basin. Swamps were largely protected from frequent fluvial clastic activity; however, there were occasional splay deposits. Many partings in both zones are volcanic ash in origin. Inherent ash content tends to be in the 10-20% (db) range, and high regional ash means are probably a result of the inclusion during sampling, of the volcanic ash partings. Sulfur content was found to be generally low in the mid-seam position; this is primarily related to the original geochemical swamp conditions. Former low-lying swamp environments are hypothesized for both coal zones. Coal petrographic techniques suggest a mixed reed swamp/treed setting for the Obed-Marsh coals.

Regional coal quality maps

The regional coal quality maps presented in this report must be used with some caution. As has been shown, ash and sulfur contents are largely determined by the original depositional environment. They vary considerably both vertically and laterally within a given coal seam and even more so in a coal zone. For these variables, the regional maps should only be used as guidelines for predicting ash or sulfur contents in local areas.

The rank-related variables, volatile matter, vitrinite reflectance, and fixed carbon, show regional trends and can be used to predict coal rank throughout this area. The data for these variables show south to north trends for the Kootenay Group and east to west trends for the Luscar Group coals. The distribution of calorific values is remarkably constant throughout the area, within each coal zone. Calorific value is a function of both rank and ash content and should therefore be compared on a regional basis only within a given coal rank.

Structural deformation effects

Local tectonism causes shearing of coal which makes it more susceptible to oxidation and causes local increases in ash content, above those that might be expected from the original depositional environment. Ash content of the Kootenay Group coals increases when there is a higher degree of tectonic shearing at the center of coal seams, while C values are decreased by shearing. Rank does not seem to be enhanced by proximity to major thrust faults. Structural thickening of coals occurs in anticlinal and synclinal axes and by imbricate thrusting.

Other

Stratigraphic sections of the Kootenay Group coals and coal seams in the Crowsnest Pass area that were sampled for proximate and ultimate analysis suggest that mean in-seam values of ash, sulfur, C, FC, and VM contents can be used to assist in determining local coal seam correlations.

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Appendix 1. Raw coal quality data collected by the Alberta Geological Survey; Kootenay Group coals, Crowsnest Pass area.

Field	UTM Location		Depth (m)		H_2O	Dry Basis							Dry Ash Free					
Number	North	East	Lower	Upper	AD	Ash	VM	FC	C	H	N	S	VM	FC	C	H	N	S
Unnamed Seam																		
CNP2-2	5496400	681000	0.0	1.5	1.3	42.1	16.6	41.3	48.3	2.7	1.14	0.34	28.7	71.3	83.4	4.7	1.96	0.59
CNP2-3	5496400	681000	2.5	5.0	1.2	34.1	18.3	47.6	56.2	3.1	1.28	0.44	27.7	72.3	85.2	4.7	1.95	0.66
CNP2-5	5496400	681000	5.6	7.5	1.3	30.3	20.5	49.2	59.2	3.3	1.24	0.51	29.4	70.6	85.0	4.8	1.78	0.73
Seam Number 4																		
CNP3-1	5506100	685900	0.0	0.9	4.1	42.0	19.4	38.6	43.8	2.5	0.80	0.35	33.4	66.6	75.5	4.3	1.38	0.60
CNP3-3	5506100	685900	1.4	2.3	5.6	19.3	22.7	58.0	63.5	2.8	1.12	0.47	28.1	71.9	78.7	3.4	1.39	0.58
CNP3-4	5506100	685900	0.0	1.0	5.9	12.6	24.6	62.7	69.7	3.3	1.31	0.41	28.2	71.8	79.8	3.7	1.50	0.47
CNP3-5	5506100	685900	1.2	1.8	6.0	12.9	25.8	61.3	69.4	3.4	1.40	0.61	29.6	70.4	79.7	3.8	1.61	0.70
CNP3-7	5506100	685900	2.7	3.4	6.7	9.6	26.3	64.1	72.9	3.3	1.21	0.54	29.1	70.9	80.6	3.7	1.34	0.60
Unnamed Seam																		
CNP3-8	5506100	685900	0.0	0.2	7.7	32.5	24.9	42.6	51.2	2.7	1.19	0.63	36.9	63.1	75.9	4.1	1.76	0.94
Seam Number 1																		
CNP3-9	5506100	685900	0.0	0.3	7.1	30.1	25.0	44.9	53.0	2.7	0.97	0.53	35.8	64.2	75.7	3.9	1.39	0.76
CNP4-1	5515200	678600	0.0	0.7	6.8	10.8	26.7	62.5	71.1	3.3	1.34	0.46	29.9	70.1	79.7	3.7	1.50	0.51
CNP4-2	5515200	678600	0.7	1.4	6.1	11.5	25.1	63.4	71.1	3.2	1.38	0.40	28.4	71.6	80.3	3.6	1.56	0.45
CNP4-3	5515200	678600	1.4	4.4	5.2	7.6	24.6	67.8	75.7	3.4	1.48	0.38	26.6	73.4	81.9	3.7	1.60	0.41
CNP4-4	5515200	678600	4.4	5.2	9.0	12.3	28.6	59.1	67.8	3.0	1.40	0.36	32.6	67.4	77.3	3.5	1.59	0.41
Seam Number 4 (Tent Mountain)																		
CNP6-1	5492500	666300	0.0	0.2	1.3	18.2	23.8	58.3	69.9	4.0	1.20	0.43	29.1	71.2	85.4	4.9	1.46	0.52
CNP6-2	5492500	666300	0.2	1.2	1.4	13.5	23.6	62.9	75.3	4.1	1.43	0.42	27.3	72.7	87.0	4.7	1.65	0.49
CNP6-3	5492500	666300	1.2	2.4	1.3	17.3	21.3	61.2	71.7	3.7	1.40	0.32	25.7	74.3	86.7	4.5	1.69	0.38
CNP6-4	5492500	666300	2.4	3.4	1.2	18.8	22.2	59.0	69.4	3.6	1.30	0.36	27.3	72.7	85.5	4.4	1.60	0.44
CNP6-5	5492500	666300	3.4	4.4	1.2	32.2	19.6	48.2	56.9	3.2	1.11	0.03	28.9	71.1	83.9	4.7	1.64	0.43
CNP6-6	5492500	666300	4.4	5.4	1.3	28.9	21.8	49.3	59.5	3.5	1.44	0.44	30.7	69.3	83.7	5.0	2.02	0.62
CNP6-7	5492500	666300	5.4	6.4	1.3	14.8	22.1	63.1	73.0	3.8	1.37	0.47	25.9	74.1	85.7	4.5	1.61	0.55
CNP6-8	5492500	666300	6.4	7.3	1.2	18.0	19.6	62.4	70.7	3.5	1.28	0.38	23.9	76.1	86.3	4.3	1.56	0.46
Seam Number 5 (Tent Mountain)																		
CNP6-9	5492500	666300	0.0	1.0	1.2	18.2	19.8	61.5	73.0	4.3	1.57	0.61	24.2	75.2	89.3	5.2	1.92	0.75
CNP6-10	5492500	666300	1.0	2.0	1.4	13.9	25.6	60.4	72.0	3.8	1.24	0.32	29.8	70.2	83.7	4.4	1.44	0.37
CNP6-11	5492500	666300	2.0	3.0	1.5	16.6	21.9	61.6	69.3	3.7	1.26	0.22	26.2	73.8	83.0	4.4	1.51	0.26
CNP6-12	5492500	666300	3.0	4.0	1.6	19.3	21.5	59.2	76.0	4.0	1.05	0.24	26.6	73.4	94.2	4.9	1.86	0.29
CNP6-13	5492500	666300	4.0	5.3	1.7	11.0	27.3	61.7	77.0	3.8	1.42	0.26	25.4	74.6	83.1	4.3	1.49	0.30
CNP6-14	5492500	666300	5.6	6.6	1.6	11.2	22.6	66.2	73.8	3.8	1.32	0.26	25.4	74.6	83.1	4.3	1.49	0.30
CNP6-15	5492500	666300	6.9	7.9	1.5	15.0	22.2	62.8	73.4	4.1	1.63	0.30	26.2	74.0	86.4	4.8	1.92	0.35
CNP6-16	5492500	666300	7.9	9.5	1.4	17.2	22.0	60.8	71.3	3.7	1.50	0.31	26.5	73.5	86.2	4.5	1.81	0.38
CNP6-17	5492500	666300	9.9	10.5	1.3	13.1	26.6	60.2	74.5	4.4	1.63	0.69	30.7	69.3	85.8	5.1	1.88	0.79
Unnamed Seam (Tent Mountain)																		
CNP6-18	5492500	666300	0.0	0.3	1.1	62.8	13.8	23.4	28.9	2.0	0.94	0.67	37.2	62.8	77.7	5.3	2.53	1.79
CNP6-19	5492500	666300	0.0	1.0	1.1	40.7	19.7	39.6	49.1	3.0	1.26	0.51	33.3	66.8	82.9	5.1	2.13	0.86
CNP6-20	5492500	666300	2.1	2.8	1.1	37.9	19.5	42.6	52.2	3.0	1.36	0.52	31.4	68.6	84.2	4.9	2.18	0.84
CNP6-21	5492500	666300	4.8	5.3	1.2	10.5	27.8	61.8	77.2	4.6	1.69	1.00	31.0	69.0	86.3	5.1	1.89	1.11
CNP6-22	5492500	666300	5.3	5.7	1.2	11.6	25.3	63.1	75.8	4.1	1.52	0.87	28.6	71.4	85.8	4.7	1.72	0.98
CNP6-23	5492500	666300	10.3	11.0	1.1	24.6	24.4	51.1	62.1	3.7	1.22	0.72	32.3	67.7	82.3	4.9	1.62	0.96
Seam Number 6 (Tent Mountain)																		
CNP6-24	5492500	666300	0.0	1.0	1.4	13.8	25.3	60.9	73.6	4.1	1.70	0.40	29.3	70.7	85.4	4.7	1.98	0.46
CNP6-25	5492500	666300	1.0	2.0	1.4	8.5	26.1	65.5	79.1	4.3	1.59	0.33	28.5	71.5	86.5	4.7	1.74	0.36
CNP6-26	5492500	666300	2.3	3.1	1.2	16.2	24.3	59.5	72.6	3.7	1.43	0.43	29.0	71.0	86.5	4.4	1.70	0.52
CNP6-27	5492500	666300	3.1	3.9	1.0	19.4	25.9	54.8	68.7	4.1	1.54	0.47	32.1	67.9	85.3	5.0	1.90	0.59

Appendix 1. (continued)

Field Number	UTM Location North	East	Depth (m) Lower	Upper	H_2O AD	Dry Basis Ash	VM	FC	C	H	N	S	Dry Ash Free VM	FC	C	H	N	S
Unnamed Seam																		
CNP7-1	5506100	685900	0.0	0.8	2.0	21.3	19.9	58.8	66.2	3.2	1.24	0.53	25.3	74.7	84.1	4.0	1.58	0.68
CNP7-2	5506100	685900	3.9	4.5	1.1	8.7	23.5	67.8	79.7	4.1	1.48	0.76	25.8	74.2	87.3	4.5	1.62	0.83
Seam Number 1																		
CNP7-4	5506100	685900	0.0	0.7	1.1	26.7	19.0	54.3	63.4	3.2	1.19	0.49	26.0	74.0	86.5	4.4	1.63	0.66
CNP7-5	5506100	685900	1.0	1.4	1.3	12.7	23.6	63.7	75.2	3.9	1.34	0.67	27.1	72.9	86.1	4.4	1.53	0.77
CNP7-6	5506100	685900	1.7	2.2	2.4	14.6	24.2	61.2	72.6	3.9	1.35	0.61	28.4	71.6	85.0	4.5	1.58	0.71
CNP7-7	5506100	685900	2.6	3.6	1.9	20.0	21.8	58.2	67.8	3.5	1.35	0.65	27.3	72.7	84.7	4.4	1.68	0.81
CNP7-8	5506100	685900	6.8	7.3	1.9	17.5	23.9	58.7	67.8	3.5	1.35	0.65	28.9	71.1	84.7	4.4	1.68	0.81
Seam Number 2																		
CNP8-1	5504900	685700	0.0	1.0	1.2	18.0	21.0	61.0	70.7	3.5	1.21	0.40	25.6	74.4	86.1	4.3	1.48	0.49
CNP8-2	5504900	685700	1.0	2.0	0.9	15.1	21.0	63.8	74.3	3.8	1.29	0.23	24.8	75.2	87.5	4.5	1.52	0.28
CNP8-3	5504900	685700	2.0	3.0	1.2	16.0	22.3	61.6	74.3	3.8	1.29	0.33	26.6	73.4	87.5	4.5	1.52	0.38
CNP8-4	5504900	685700	3.0	4.0	1.3	15.0	19.6	65.4	74.3	3.4	1.09	0.24	23.0	77.0	87.5	4.0	1.29	0.28
CNP8-5	5504900	685700	4.0	5.0	1.1	21.0	20.3	58.7	67.9	3.4	1.15	0.22	25.7	74.3	86.0	4.3	1.46	0.28
CNP8-6	5504900	685700	5.0	6.4	1.3	10.4	21.9	67.7	79.3	3.7	1.26	0.37	24.5	75.5	88.4	4.1	1.40	0.41
Seam Number 4																		
CNP9-1	5484200	687500	0.0	1.0	6.1	17.7	27.4	55.0	63.6	3.0	1.13	0.46	33.2	66.8	77.2	3.6	1.37	0.56
Seam Number 1																		
CNP9-2	5484200	687500	0.0	1.0	7.8	13.9	29.3	56.8	65.2	2.8	1.08	0.28	34.0	66.0	75.8	3.3	1.26	0.32
CNP9-3	5484200	687500	1.0	1.7	6.6	23.9	24.7	51.4	58.3	2.3	0.99	0.19	32.4	67.6	76.7	3.0	1.29	0.25
CNP9-4	5484200	687500	2.0	2.8	7.1	20.9	27.9	51.3	59.3	2.7	1.16	0.24	35.2	64.8	74.9	3.4	1.47	0.30
CNP9-5	5484200	687500	2.9	3.4	6.2	19.7	29.3	51.0	60.4	3.0	1.28	0.32	36.5	63.5	75.2	3.8	1.59	0.39
CNP9-6	5484200	687500	4.2	5.2	3.4	20.6	22.6	56.7	63.8	2.9	1.03	0.22	28.5	71.5	80.4	3.7	1.30	0.28
CNP9-7	5484200	687500	5.2	5.8	2.6	34.2	19.6	46.2	51.4	2.5	0.92	0.24	29.8	70.2	78.1	3.7	1.40	0.36
CNP9-8	5484200	687500	8.1	8.8	2.2	11.0	26.4	62.6	75.0	4.0	1.19	0.37	29.7	70.3	84.3	4.5	1.33	0.42

Appendix 2. Raw coal quality data collected by the Alberta Geological Survey; Luscar Group coals, Grande Cache area.

Field Number	UTM Location Easting	UTM Location Northing	Depth (m) Lower	Depth (m) Upper	H_2O AD	Dry Basis Ash	VM	FC	C	H	N	S	O	Dry, Ash-Free VM	FC	C	H	N	S	O	CV
Seam Number 4																					
P2-GC1-1	358680	5989560	0.0	0.5	0.6	2.7	18.0	79.3				0.5		18.5	81.5				0.5		
P2-GC1-2	358680	5989560	0.5	2.1	0.8	42.3	12.9	44.8				0.6		22.4	77.6				1.0		
P2-GC1-3	358680	5989560	0.5	2.1		30.7															
P2-GC1-4	358680	5989560	2.1	3.6		18.7															
P2-GC1-5	358680	5989560	2.1	3.6	0.5	5.7	17.8	76.6				0.3		18.9	81.2				0.3		
P2-GC1-6	358680	5989560	3.6	4.3	0.4	14.5	16.3	69.3				0.3		19.0	81.0				0.4		
P2-GC1-7	358680	5989560	4.3	5.5	0.4	7.2	17.6	75.1				0.3		18.9	81.0				0.3		
P2-GC1-8	358680	5989560	5.5	6.6	0.4	10.1	17.1	72.8				0.4		19.0	81.0				0.4		
P2-GC1-9	358680	5989560	0.0	6.6	0.5	15.7	16.2	68.1	75.4	3.8	1.2	0.5	3.4	19.2	80.8	89.4	4.5	1.4	0.6	4.1	
Seam Number 4																					
P2-GC2-1	360110	5989030	0.0	0.7	0.5	3.7	18.6	77.6	87.4	4.4	1.5	0.4	2.5	19.3	80.6	90.8	4.6	1.6	0.4	2.6	
P2-GC2-2	360110	5989030	0.9	1.4	0.7	17.3	16.9	65.8	74.3	3.8	1.4	0.4	2.7	20.5	79.5	89.9	4.6	1.7	0.5	3.3	
P2-GC2-3	360110	5989030	1.4	2.7	0.5	7.1	18.0	75.0	84.5	4.2	1.6	0.3	2.2	19.4	80.7	91.0	4.5	1.7	0.3	2.4	
P2-GC2-4	360110	5989030	2.7	3.2	0.8	16.6	15.7	66.5	75.0	3.6	1.3	0.3	3.1	18.9	79.8	90.0	4.4	1.6	0.4	3.7	
P2-GC2-5	360110	5989030	3.2	5.6	0.7	8.3	18.8	72.9	83.5	4.1	1.4	0.3	2.4	20.5	79.5	91.0	4.5	1.5	0.3	2.6	
P2-GC2-6A	360110	5989030	0.0	5.6	0.6	7.4	18.3	74.2	83.2	4.2	1.4	0.3	3.4	19.8	80.2	89.9	4.6	1.5	0.3	3.7	
Seam Number 10																					
P2-GC2-7	360110	5989030	0.0	1.3	4.3	7.5	22.5	70.0	78.9	3.7	1.1	0.2	8.6	24.3	75.7	85.3	4.0	1.2	0.2	9.3	
P2-GC2-8	360110	5989030	1.6	2.6	5.4	10.6	23.4	66.1	74.7	3.4	1.3	0.3	9.7	26.1	73.9	83.6	3.8	1.4	0.4	10.9	
P2-GC2-9	360110	5989030	0.0	2.6	4.6	8.9	22.3	68.7	75.7	3.6	1.0	0.3	10.5	24.5	75.4	83.1	3.9	1.2	0.3	11.5	
Seam Number 4																					
P2-GC3-1	354386	5986969				10.6															
P2-GC3-2	354386	5986969				4.6															
P2-GC3-3	354386	5986969				12.0															
Seam Number 6																					
P2-GC3-4	354423	5986967				3.2															
Seam Number 4																					
P2-GC4-1	353904	5987316				13.8															
Seam Number 3																					
P2-GC4-2	353784	5987367				12.2															

Appendix 2. (continued)

Field Number	UTM Location Easting	UTM Location Northing	Depth (m) Lower	Depth (m) Upper	H_2O AD	Dry Basis Ash	VM	FC	C	H	N	S	O	Dry, Ash-Free VM	FC	C	H	N	S	O	CV
Seam Number 10																					
P2-GC5-1	355640	5989840	0.0	0.9	0.6	9.5	17.5	72.9	82.5	4.1	1.2	0.3	2.4	19.3	80.6	91.1	4.6	1.3	0.3	2.7	
P2-GC5-2	355640	5989840	0.9	1.7	0.7	8.6	18.5	72.9	82.9	4.1	1.2	0.3	2.9	20.3	79.7	90.6	4.5	1.3	0.3	3.2	
P2-GC5-3	355640	5989840	1.7	2.4	0.7	7.0	17.7	75.2	85.3	4.2	1.2	0.3	1.9	19.1	80.9	91.8	4.6	1.3	0.3	2.1	
P2-GC5-4	355640	5989840	2.4	3.2	0.8	18.5	16.7	64.8	72.7	3.7	1.0	0.3	3.7	20.5	79.6	89.2	4.6	1.2	0.4	4.6	
P2-GC5-5	355640	5989840	0.0	3.9	0.8	12.3	17.5	71.0	79.8	3.9	1.1	0.3	2.5	20.0	80.9	91.0	4.5	1.3	0.3	2.9	
P2-GC5-6	355640	5989840	3.4	3.9	0.5	9.7	18.7	71.7	80.7	4.1	1.1	0.4	3.9	20.7	79.4	89.4	4.6	1.2	0.4	4.3	
Seam Number 11																					
P2-GC5-8	355640	5989840	0.0	1.0	1.6	8.8	18.9	72.3		0.4				20.7	79.3				0.4		
P2-GC5-9	355640	5989840	1.2	1.7	1.6	21.1	17.7	61.2	70.1	3.7	1.2	0.4	3.5	22.4	77.6	88.9	4.6	1.5	0.5	4.4	
Seam Number 4																					
P2-GC6-1	363560	5985990	0.0	0.8	1.2	6.1	18.0	75.9		0.5				19.2	80.8				0.5		
P2-GC6-2	363560	5985990	4.0	5.9	0.7	6.5	19.2	74.3		0.3				20.6	79.5				0.3		
P2-GC6-3	363560	5985990	5.9	7.5	1.0	7.1	17.6	75.4		0.3				18.9	81.1				0.3		
P2-GC6-4	363560	5985990	7.6	8.5	0.7	22.3	15.1	62.7		0.4				19.4	80.7				0.5		

Appendix 3. Raw coal quality data collected by the Alberta Geological Survey, Coalspur Formation coals, Coal Valley–Robb area.

Field	UTM Location		Depth (m)		H_2O	Dry Basis								Dry, Ash-Free							
Number	Easting	Northing	Lower	Upper	AD	Ash	VM	FC	C	H	N	S	O	VM	FC	C	H	N	S	O	CV
Arbour Seam																					
P2-CS-1-1	499075	5892585	0.0	1.0	5.9	11.1	33.7	55.4				0.3		37.9	62.2				0.4		
P2-CS-1-2	499075	5892585	1.0	1.8	6.4	42.8	23.4	33.8				0.1		40.9	59.1				0.2		
P2-CS-1-3	499075	5892585	1.8	2.7	6.0	20.5	29.6	49.9				0.2		37.2	62.8				0.3		
P2-CS-1-4	499075	5892585	0.0	2.7	5.4	24.7	29.5	45.9	57.9	3.6	1.1	0.2	12.5	39.2	61.0	77.0	4.8	1.4	0.3	16.6	31.1
Val D'Or (lower) Seam																					
P-CS-1-20	499075	5892585	4.4	5.1		21.1						0.3							0.4		
P2-CS-1-21	499075	5892585	6.5	7.5		11.7						0.2							0.2		
P2-CS-1-22	499075	5892585	7.5	8.1		10.1						0.2							0.2		
P2-CS-1-23	499075	5892585	8.4	9.8		17.4						0.3							0.4		
P2-CS-1-24	499075	5892585	6.5	9.8	5.3	33.5	27.0	39.5	50.7	3.3	0.8	0.2	11.5	40.6	59.4	76.2	4.9	1.3	0.3	17.3	31.1
Val D'Or (incomplete upper) Seam																					
P2-CS-1-25	499075	5892585	15.3	15.9		8.3						0.5							0.5		
Unnamed Seam (38.9 m above base of Arbour)																					
P2-CS-1-26	499075	5892585	38.9	39.2		14.1						1.4							1.6		
P2-CS-1-27	499075	5892585	40.3	41.3		18.0						1.8							2.2		
Unnamed Seam (95.3 m above base of Arbour)																					
P2-CS-1-28	499075	5892585	95.3	95.7		11.7						1.0							1.1		
Upper Mynheer Seam																					
P2-CS-2-1	518180	5878250	0.0	2.0	7.0	15.8	33.8	50.4				0.3		40.1	59.9				0.4		
P2-CS-2-2	518180	5878250	2.0	3.5	7.4	13.8	33.9	52.4				0.1		39.3	60.8				0.1		
P2-CS-2-3	518180	5878250	3.6	4.2	7.1	21.7	31.6	46.6				0.2		40.4	59.6				0.3		
P2-CS-2-4	518180	5878250	4.4	5.4	7.3	16.2	32.9	50.9				0.1		39.3	60.7				0.1		
P2-CS-2-5	518180	5878250	5.4	6.4	7.9	11.8	33.2	54.9				0.2		37.7	62.3				0.2		
P2-CS-2-6	518180	5878250	6.5	7.2	8.7	50.9	20.8	28.1				0.2		42.4	57.4				0.4		
P2-CS-2-7	518180	5878250	0.0	7.2	7.0	23.1	32.8	44.1	58.0	3.8	1.0	0.2	14.0	42.7	57.3	75.4	4.9	1.3	0.3	18.2	30.1
Val D'Or Seam																					
P2-CS-3-1	520525	5874750	0.0	1.5	5.3	32.7	27.5	39.8				0.2		40.8	59.2				0.3		
P2-CS-3-2	520525	5874750	1.5	3.0	5.2	34.3	26.8	38.9				0.2		40.8	59.2				0.3		
P2-CS-3-3	520525	5874750	3.4	4.4	6.0	12.9	32.4	54.8				0.1		37.2	62.9				0.1		
P2-CS-3-4	520525	5874750	4.4	5.4	6.4	10.3	33.8	56.0				0.1		37.6	62.4				0.1		
P2-CS-3-5	520525	5874750	5.7	6.3	6.7	10.9	34.6	54.4				0.2		38.9	61.1				0.2		
P2-CS-3-6	520525	5874750	6.5	7.1	6.5	26.6	29.5	43.9				0.4		40.2	59.8				0.6		
P2-CS-3-7	520525	5874750	8.7	9.5	6.6	9.2	35.4	55.4				0.2		39.0	61.0				0.2		
P2-CS-3-8	520525	5874750	9.8	10.9	6.4	17.1	33.3	49.6				0.3		40.2	59.8				0.4		
P2-CS-3-9	520525	5874750	0.0	10.9	6.7	20.5	31.8	47.6	60.5	3.9	1.0	0.2	14.0	40.0	59.8	76.0	4.9	1.2	0.3	17.7	29.9

Appendix 3. (continued)

Field Number	UTM Location Easting	UTM Location Northing	Depth (m) Lower	Depth (m) Upper	H_2O AD	Dry Basis Ash	Dry Basis VM	Dry Basis FC	Dry Basis C	Dry Basis H	Dry Basis N	Dry Basis S	Dry Basis O	Dry, Ash-Free VM	Dry, Ash-Free FC	Dry, Ash-Free C	Dry, Ash-Free H	Dry, Ash-Free N	Dry, Ash-Free S	Dry, Ash-Free O	Dry, Ash-Free CV
Val D'Or Seam																					
P2-CS-4-1	520900	5874450	0.0	1.0	5.0	36.4	26.3	37.6				0.2		41.4	59.1				0.3		
P2-CS-4-2	520900	5874450	1.1	2.6	6.1	16.3	32.3	51.4				0.2		38.5	61.5				0.3		
P2-CS-4-3	520900	5874450	2.6	4.2	6.5	16.5	30.9	52.7				0.1		37.0	63.1				0.1		
P2-CS-4-4	520900	5874450	4.4	5.4	6.0	16.2	32.7	51.2				0.2		39.0	61.0				0.3		
P2-CS-4-5	520900	5874450	5.4	6.4	6.6	13.2	33.6	53.3				0.2		38.7	61.4				0.2		
P2-CS-4-6	520900	5874450	6.6	7.4	6.7	12.2	35.4	52.3				0.2		40.3	59.6				0.2		
P2-CS-4-7	520900	5874450	7.6	8.3	6.6	31.4	27.6	41.0				0.4		40.2	59.8				0.6		
P2-CS-4-8	520900	5874450	0.0	11.5	6.3	28.0	29.2	42.8	55.1	3.4	0.9	0.1	12.6	40.6	59.4	76.4	4.7	1.2	0.1	17.5	30.7
P2-CS-4-9	520900	5874450	9.7	10.7	6.9	8.2	35.8	56.1				0.2		38.9	61.1				0.2		
P2-CS-4-10	520900	5874450	10.7	11.5	6.6	11.9	35.2	52.9				0.3		40.0	60.0				0.4		
Wee or Silkstone Seam																					
P2-CS-5-1	512350	5882300	0.0	1.0	8.8	22.7	29.4	48.0				0.3		38.0	62.1				0.4		
P2-CS-5-2	512350	5882300	1.3	1.9	8.8	15.2	30.4	54.4				0.2		35.8	64.2				0.3		
P2-CS-5-3	512350	5882300	1.9	2.6	8.8	9.0	31.8	59.3				0.2		34.9	65.2				0.2		
P2-CS-5-4	512350	5882300	2.7	3.0	8.41	6.3	27.6	53.6				0.3		33.0	64.0				0.4		
P2-CS-5-5	512350	5882300	0.0	3.0	8.3	15.7	30.8	53.5	65.6	4.0	1.1	0.2	13.3	36.5	63.5	77.9	4.8	1.3	0.3	15.8	31.6
Val D'Or Seam																					
P2-CS-8-1	498575	5899675	0.0	2.9		19.1						0.1							0.1		
P2-CS-8-2	498575	5899675	2.9	5.1		17.4						0.3							0.4		
P2-CS-8-3	498575	5899675	5.9	8.1		6.9						0.2							0.2		
P2-CS-8-4	498575	5899675	8.3	10.0		11.6						0.4							0.5		
P2-CS-8-5	498575	5899675	12.4	13.6		30.5						0.5							0.7		
McPherson Seam																					
P2-CS-9-1	499700	5892350	0.0	2.5	6.8	12.2	33.3	54.6				0.1		37.9	62.2				0.1		
P2-CS-9-2	499700	5892350	2.5	5.0	6.9	6.1	35.8	58.1				0.1		38.1	61.9				0.1		
P2-CS-9-3	499700	5892350	5.3	7.3	5.8	10.8	36.4	52.8				0.2		40.8	59.2				0.2		
P2-CS-9-4	499700	5892350	0.0	7.3	6.1	22.2	31.2	46.6	59.3	3.7	0.9	0.2	13.7	40.1	59.9	76.2	4.8	1.1	0.3	17.6	30.3
P2-CS-9-5	499700	5892350	8.7	11.2	6.4	4.9	37.2	58.0				0.1		39.1	61.0				0.1		
P2-CS-9-6	499700	5892350	11.4	13.4	6.2	7.4	37.1	55.5				0.3		40.0	60.0				0.3		
P2-CS-9-7	499700	5892350	8.7	13.4	6.6	13.4	34.8	51.8	66.1	4.3	1.0	0.2	15.1	40.2	59.8	76.3	4.9	1.1	0.2	17.4	30.8
Val D'Or Seam																					
P2-CS-10-1	499025	5899375	2.0	4.7		19.1						0.2							0.2		
P2-CS-10-2	499025	5899375	7.3	10.0		8.0						0.1							0.1		
P2-CS-10-3	499025	5899375	10.0	12.6	9.6	8.0						0.2							0.2		

Appendix 4. Raw coal quality data collected by the Alberta Geological Survey; Obed-Marsh coal zone, Obed Mountain mine.

Field Number	UTM Location Easting	UTM Location Northing	Depth (m) Lower	Depth (m) Upper	H_2O AD	Dry Basis Ash	VM	FC	C	H	N	S	O	Dry, Ash-Free VM	FC	C	H	N	S	O	CV
Seam 1																					
P2OM1-COMP1	468700	5938050	0.0	1.5	10.8	11.9						0.3							0.4		31.2
P2OM1-4	468700	5938050	1.6	2.2	10.2	15.3						0.6							0.7		31.1
P2OM1-8	468700	5938050	0.0	2.2	10.8	18.5	35.1	46.5				0.3		43.1	57.1				0.4		30.4
Seam 1																					
P2OM2-1	468600	5938200	0.0	0.8	10.7	21.4						0.7							0.9		30.4
P2OM2-COMP	468600	5938200	0.9	1.6	9.9	13.3						0.3							0.4		31.2
P2OM2-6	468600	5938200	1.8	2.1	10.6	9.1						0.3							0.4		31.1
P2OM2-8	468600	5938200	2.3	3.0	9.4	11.9						0.3							0.4		31.3
P2OM2-9	468600	5938200	0.0	3.0	11.1	18.6	34.8	46.8				0.3		42.7	57.5				0.4		30.5
Seam 2																					
P2OM5-COMP	469650	5940200	0.0	1.4	10.6	10.0						0.4							0.5		30.8
P2OM5-7	469650	5940200	1.7	2.7	9.6	12.7						1.9							2.2		31.3
P2OM5-COMP	469650	5940200	3.4	3.7	9.4	37.3						3.8							6.0		29.6
P2OM5-16	469650	5940200	0.0	3.7	11.4	41.3	27.9	30.7	42.6	3.0	1.0	1.2	10.8	47.5	52.3	72.5	5.2	1.7	2.1	18.5	28.2
Seam 1																					
P2OM6-2	470000	5940000	0.5	1.1	11.7	9.9						0.6							0.6		30.5
P2OM6-COMP	470000	5940000	1.4	2.4	11.4	12.1						0.5							0.5		30.6
P2OM6-8	470000	5940000	2.6	4.2	10.8	27.5						0.3							0.5		31.2
P2OM6-9	470000	5940000	0.0	4.2	12.3	34.1	29.8	36.1	48.5	3.4	1.3	0.3	12.4	45.2	54.8	73.5	5.2	1.9	0.5	18.9	29.0
Seam 1																					
P2OM7-1	470150	5939600	0.0	0.6	10.0	15.0						0.6							0.7		31.3
P2OM7-COMP	470150	5939600	0.8	1.8	10.5	14.6						0.3							0.4		30.7
P2OM7-9	470150	5939600	2.1	3.5	11.7	42.4						0.3							0.6		29.8
P2OM7-10	470150	5939600	0.0	3.5	12.4	38.1	27.3	34.6				0.3		44.1	55.9				0.6		29.4

Appendix 4. (continued)

Field Number	UTM Location Easting	UTM Location Northing	Depth (m) Lower	Depth (m) Upper	H_2O AD	Dry Basis Ash	Dry Basis VM	Dry Basis FC	Dry Basis C	Dry Basis H	Dry Basis N	Dry Basis S	Dry Basis O	Dry, Ash-Free VM	Dry, Ash-Free FC	Dry, Ash-Free C	Dry, Ash-Free H	Dry, Ash-Free N	Dry, Ash-Free S	Dry, Ash-Free O	CV
Seam 1 (Obed Mountain Coal Co. Ltd.)																					
N.B. Calorific value on a dry basis - this section only.																					(db)
1	469950	5939150	0.0	0.12		37.0						0.82									40.9
2	469950	5939150	0.12	0.14		73.8						0.40									
3	469950	5939150	0.14	0.19		36.0						0.98									41.9
4	469950	5939150	0.19	0.36		88.5						0.11									
5	469950	5939150	0.36	1.02		13.5						0.66									58.4
6	469950	5939150	1.02	1.20		89.9						0.02									
7	469950	5939150	1.20	1.39		14.4						0.45									60.2
8	469950	5939150	1.39	1.43		74.4						0.16									
9	469950	5939150	1.43	1.77		13.4						0.31									62.0
10	469950	5939150	1.77	1.85		66.7						0.15									
11	469950	5939150	1.85	2.18		11.7						0.31									66.4
12	469950	5939150	2.18	2.36		64.2						0.14									
13	469950	5939150	2.36	2.84		11.6						0.27									66.4
14	469950	5939150	2.84	3.13		11.0						0.36									67.5
15	469950	5939150	3.13	3.43		12.8						0.43									65.7
16	469950	5939150	3.43	3.49		78.2						0.10									
17	469950	5939150	3.49	3.67		20.5						0.50									59.6
18	469950	5939150	3.67	3.77		88.2						0.05									
19	469950	5939150	3.77	3.85		38.4						0.48									44.4
20	469950	5939150	3.85	4.25		81.1						0.18									
21	469950	5939150	1.02	3.67								0.38									
22	469950	5939150	0.0	3.67								0.49									

Appendix 5. Symbols used in stratigraphic sections.

Legend:

- Sandstone
- Conglomerate
- Interbedded mudstone/coal (<25% coal)
- Clay-shale Claystone
- Siltstone Siltshale
- Interbedded claystone Mudstone (<25% claystone)
- Mudstone Mudshale
- Interbedded sandstone Claystone (>50% sandstone)
- Interbedded sandstone Claystone (>75% sandstone)
- Paleosol
- Coal
- Low-angle x-strata
- Hummocky cross stratification
- Very fine interlaminated
- Carbonaceous matter - particles
- Shells (marine)
- Fining-upward cycle
- Coarsening-upward cycle
- Carbonaceous matter - finely disseminated
- Carbonaceous matter in thin laminae
- Scour and fill
- Sheared coal
- Large scale x-bedding
- Trough x-strata
- Ripples
- Soft sediment deformation
- Roots
- Leaf imprints
- Logs or stems
- Basal lag
- Parallel stratification
- Intraclasts
- Graded bedding
- Slickensides
- Folding
- Fault
- G Glauconitic
- Pyrite
- Bioturbated
- Forams
- Gradational contact
- Sharp contact
- Burrows (vertical horizontal, with spriten, branching)
- Ironstone band
- Erosional contact
- Dinosaur track
- Heavily rooted
- Soil mottled
- Symmetrical ripples
- Wavy bedding

Figure 14.

Regional Sulfur Variations (dry basis) Luscar and Kootenay Group coals, Alberta

Southern and Central Rocky Mountains

D.E. Macdonald, N. Chidambaram, C.W. Langenberg, G.B. Mandryk, C.E. Sterenberg, A. Cameron

Published 1987

Any revisions or additional geological information would be welcomed by the Alberta Research Council.

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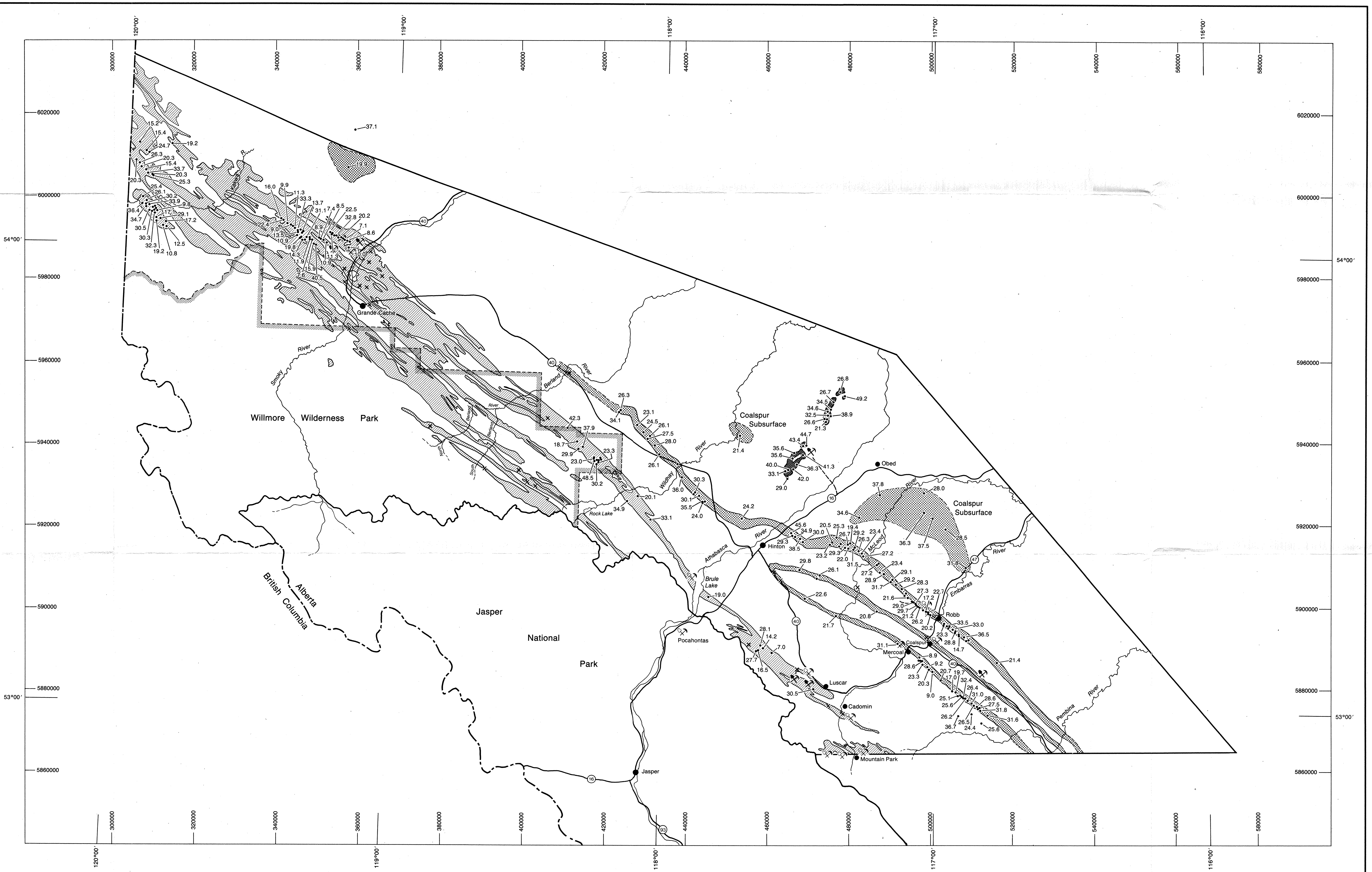
Natural Resources Division
Alberta Geological Survey

Geology based on Geological Survey of Canada maps.
Cartography by Alberta Research Council, Graphic Services.



Legend

- Obed-Marsh coal zone (Paskapoo Formation) — Tertiary
- Coalspur Formation — Tertiary
- Luscar Group — Lower Cretaceous
- × Coal outcrop (1987 or 1988)
- Coal mine - active
- Coal mine - abandoned
- • Sample location

Sample locations and values from Energy Resources Conservation Board coal hole data file, March 1988 version

N

5 0 5 10 15 20 Miles
5 0 10 20 30 Kilometres

Scale 1:500 000

Figure 3

Regional Ash Variations (dry basis) Luscar, Coalspur and Obed-Marsh coals, Alberta

Northern Rocky Mountains

D.E. Macdonald, C.W. Langenberg, T. Gentzis, W. Kalkreuth

Published 1988

Any revisions or additional geological information would be welcomed by the Alberta Research Council.

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Natural Resources Division
Alberta Geological Survey

Geology based on Geological Survey of Canada maps.
Cartography by Alberta Research Council, Publishing and Graphics

Figure 13.

Regional Calorific Value Variations in MJ/kg (dry ash-free basis) Luscar and Kootenay Group coals, Alberta

Southern and Central Rocky Mountains

D.E. Macdonald, N. Chidambaram, C.W. Langenberg, G.B. Mandryk, C.E. Sterenberg, A. Cameron

Published 1987

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Geology based on Geological Survey of Canada maps.
Cartography by Alberta Research Council, Graphic Services.

Figure 12.

Regional Fixed Carbon Variations (dry ash-free basis)
Luscar and Kootenay Group coals, Alberta

Southern and Central Rocky Mountains

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Figure 11.

Regional Ash Variations (dry basis)
Luscar and Kootenay Group coals, Alberta

Southern and Central Rocky Mountains

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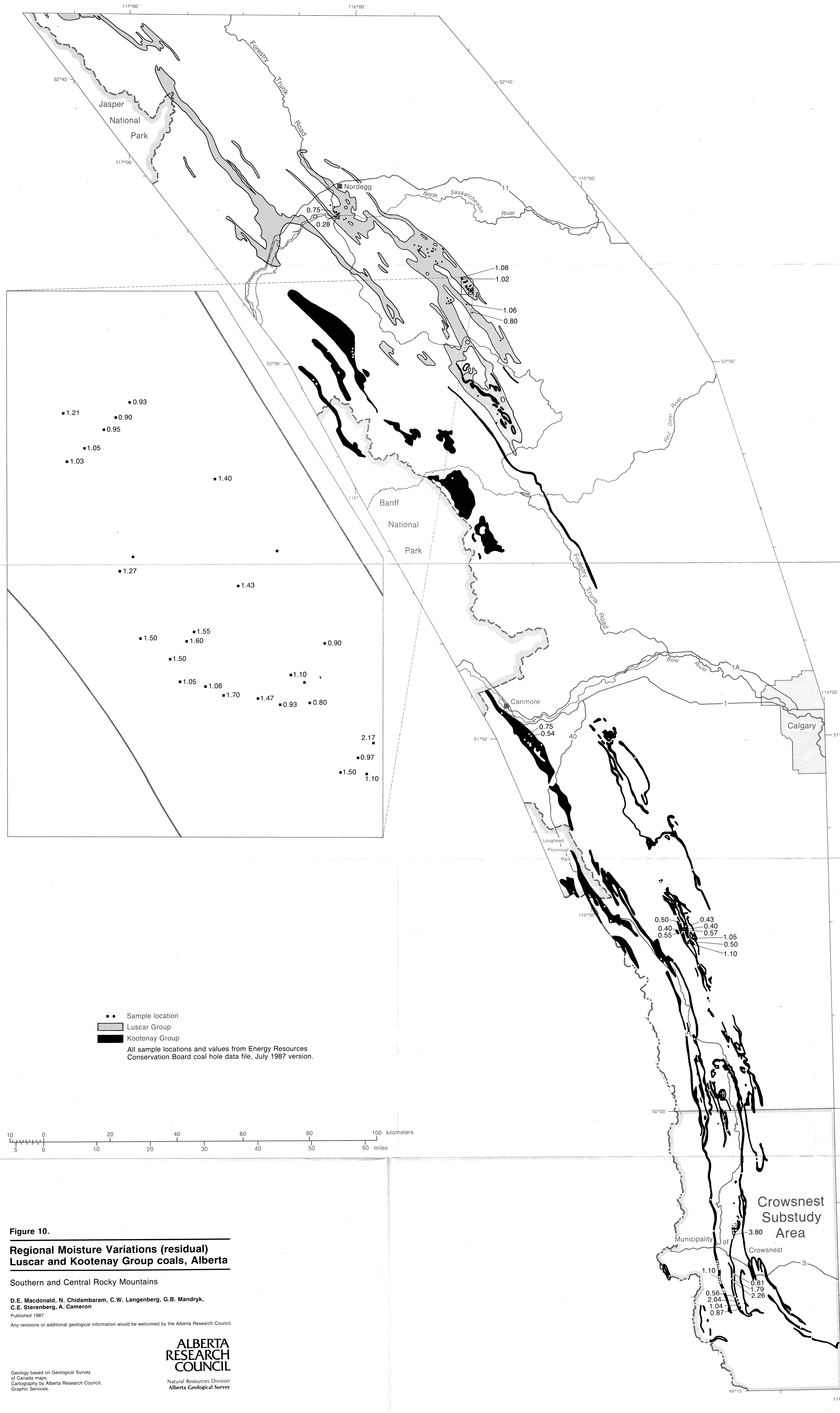

Figure 10.

Regional Moisture Variations (residual) Luscar and Kootenay Group coals, Alberta

Southern and Central Rocky Mountains

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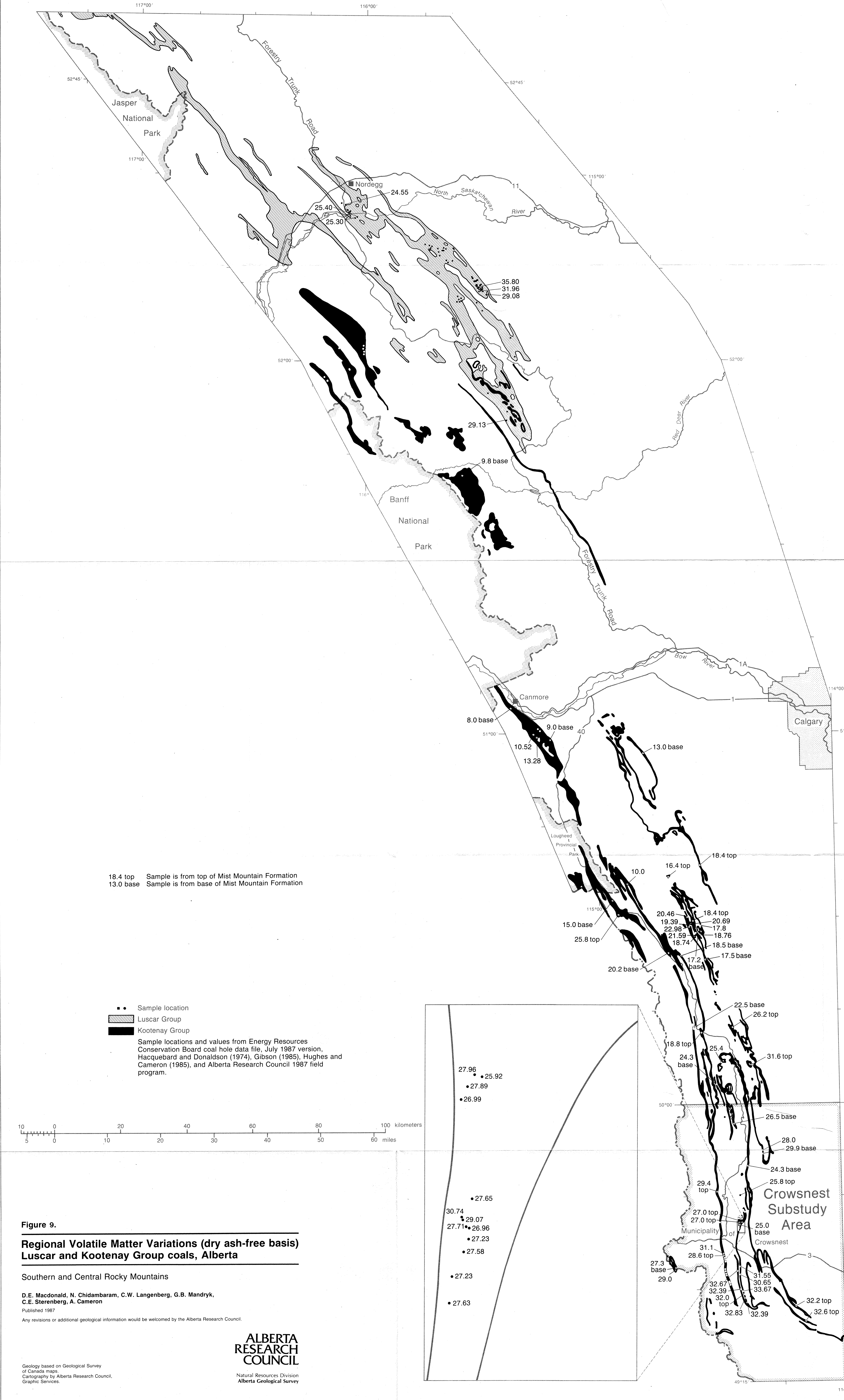

Figure 9.

Regional Volatile Matter Variations (dry ash-free basis) Luscar and Kootenay Group coals, Alberta

Southern and Central Rocky Mountains

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Legend

- Obed-Marsh coal zone (Paskapoo Formation) — Tertiary
- Coalspur Formation — Tertiary
- Luscar Group — Lower Cretaceous
- × Coal outcrop (1987 or 1988)
- Coal mine - active
- Coal mine - abandoned
- • Sample location

Sample locations and values from Energy Resources Conservation Board coal hole data file, March 1988 version

N

5 0 5 10 15 20 Miles
5 0 10 20 30 Kilometres

Scale 1:500 000

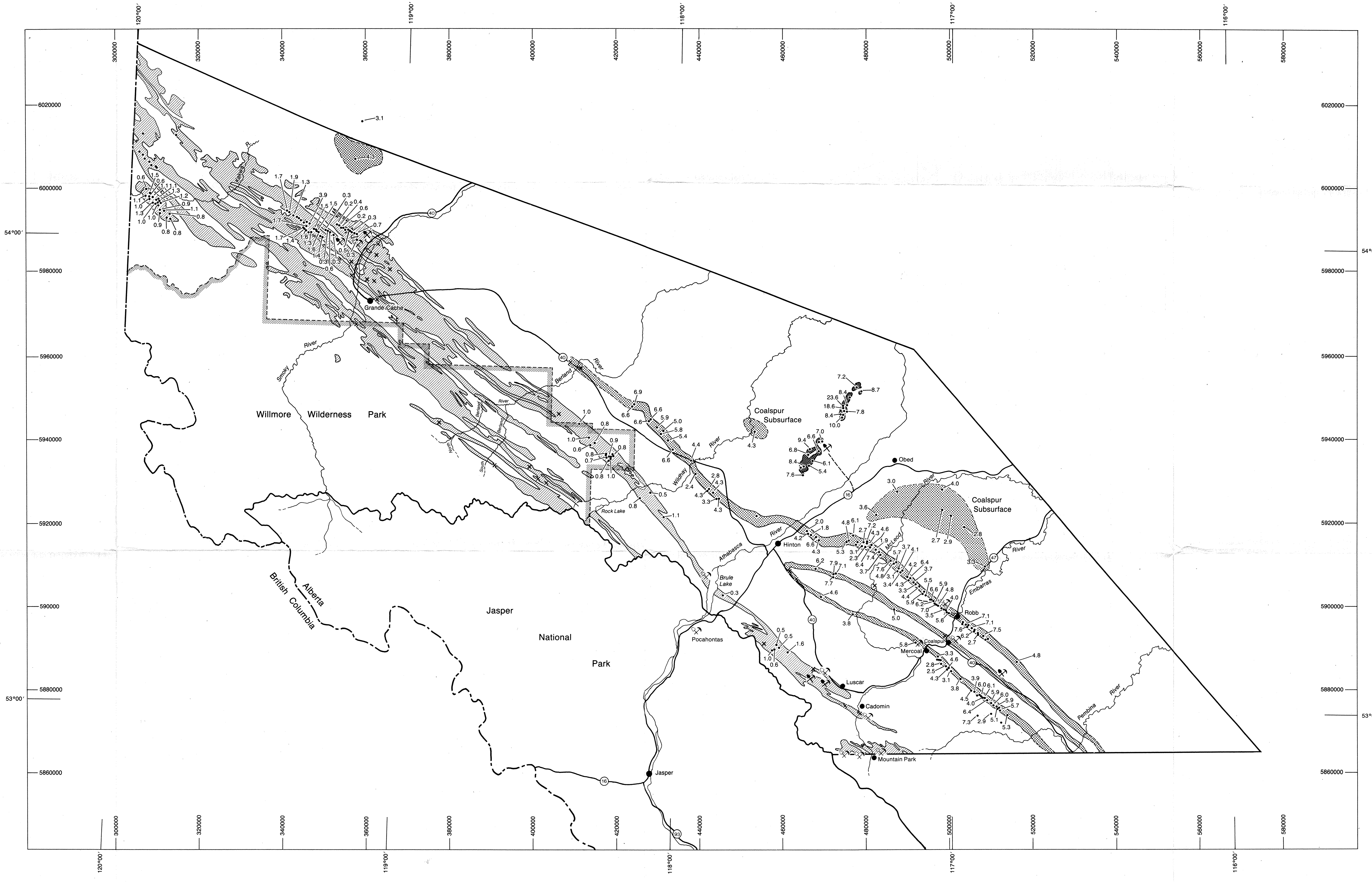

Figure 8

Regional Moisture Variations (residual) Luscar, Coalspur and Obed-Marsh coals, Alberta

Northern Rocky Mountains

D.E. Macdonald, C.W. Langenberg, T. Gentzis, W. Kalkreuth

Published 1988

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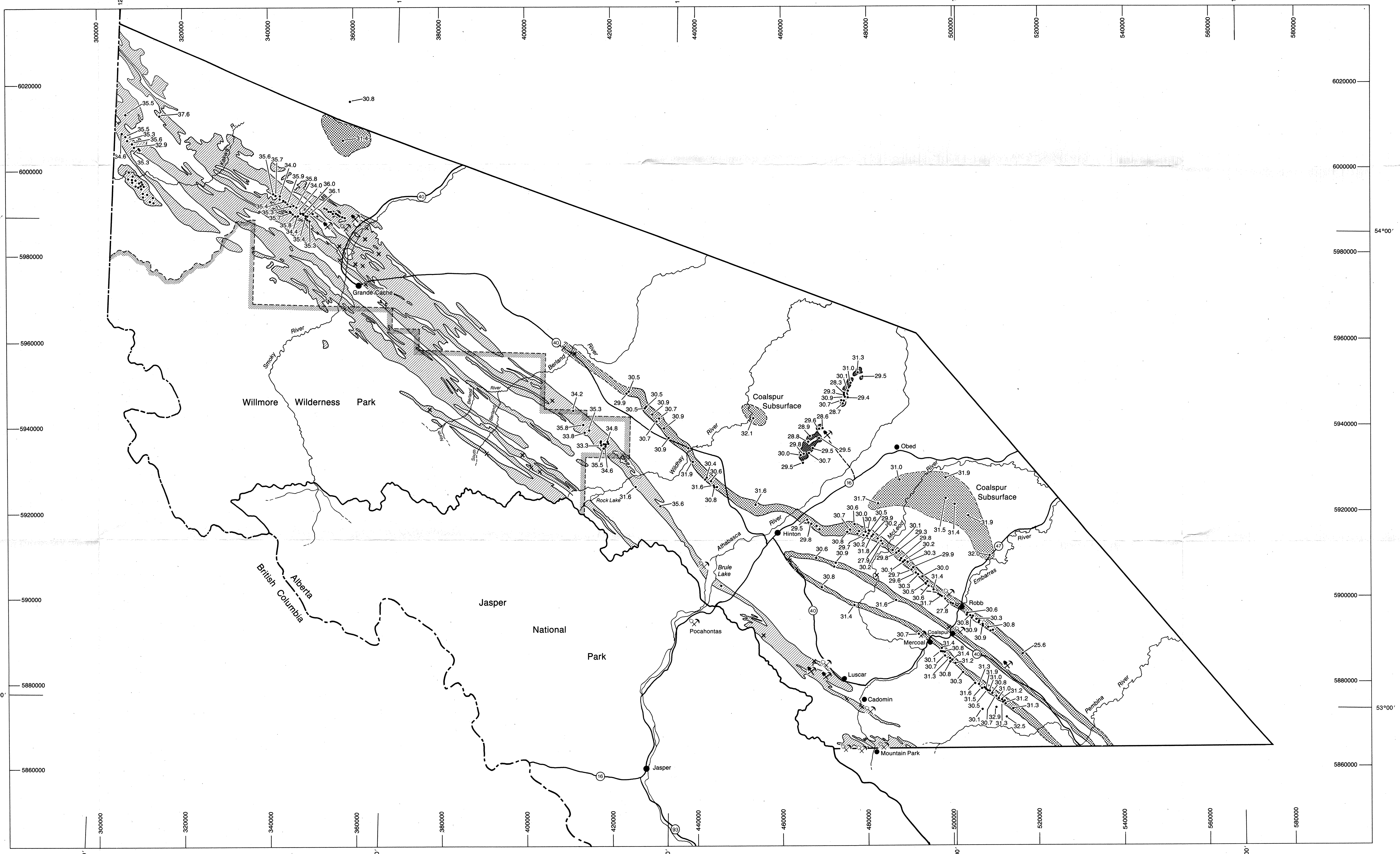

Legend

- Obed-Marsh coal zone (Paskapoo Formation) — Tertiary
- Coalspur Formation — Tertiary
- Luscar Group — Lower Cretaceous
- × Coal outcrop (1987 or 1988)
- Coal mine - active
- Coal mine - abandoned
- • Sample location

Sample locations and values from Energy Resources Conservation Board coal hole data file, March 1988 version

N

5 0 5 10 15 20 Miles

5 0 10 20 30 Kilometres

Scale 1:500 000

Figure 7

Regional Calorific Value Variations in MJ/kg (dry ash-free basis) Luscar, Coalspur and Obed-Marsh coals, Alberta

Northern Rocky Mountains

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Legend

- Obed-Marsh coal zone (Paskapoo Formation) — Tertiary
- Coalspur Formation — Tertiary
- Luscar Group — Lower Cretaceous
- × Coal outcrop (1987 or 1988)
- Coal mine - active
- Coal mine - abandoned
- • Sample location

Sample locations and values from Energy Resources Conservation Board coal hole data file, March 1988 version

N

Miles: 5 0 5 10 15 20
Kilometres: 5 0 10 20 30

Scale 1:500 000

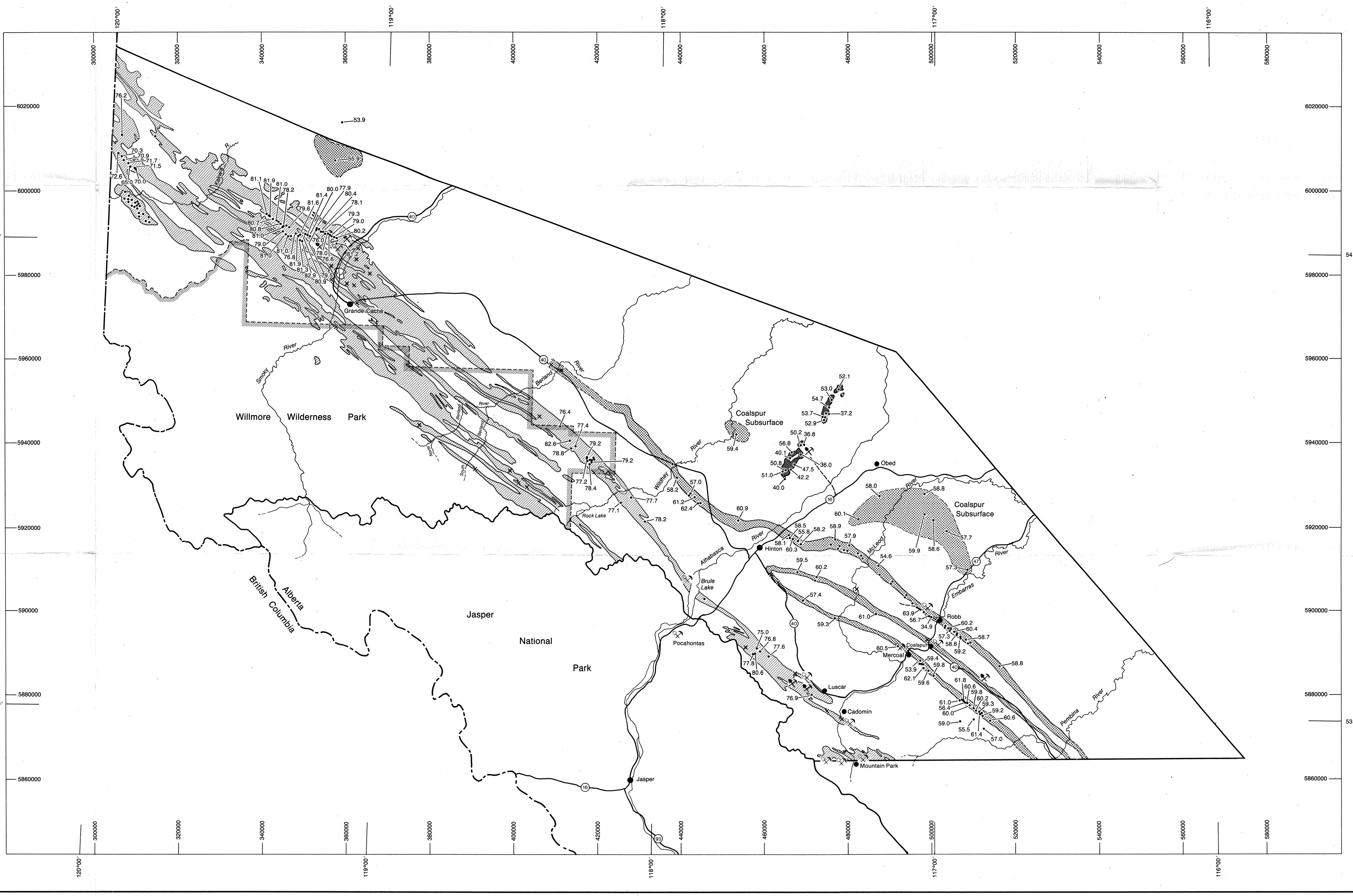

Figure 6

Regional Fixed Carbon Variations (dry ash-free basis) Luscar, Coalspur and Obed-Marsh coals, Alberta

Northern Rocky Mountains

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Legend

Obed-Marsh coal zone (Paskapoo Formation)	Tertiary	
Coalspur Formation		
Luscar Group	Lower Cretaceous	

× Coal outcrop (1987 or 1988)

Coal mine - active

Coal mine - abandoned

• Sample location

Sample locations and values from Energy Resources Conservation Board coal hole data file, March 1988 version

31 Volatile Matter estimated from vitrinite reflectance.

N

5 0 5 10 15 20 Miles

5 0 10 20 30 Kilometres

Scale 1:500 000

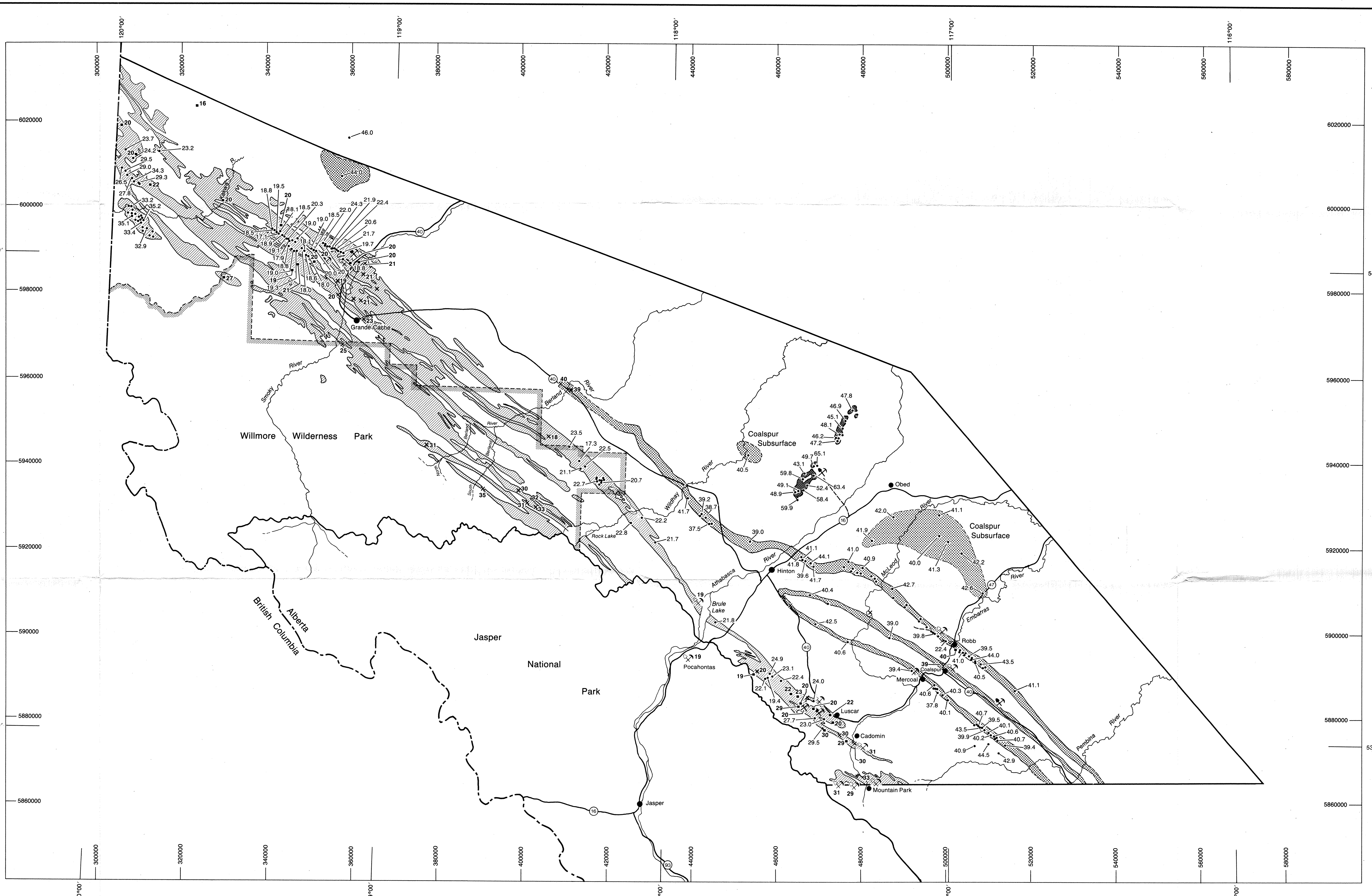

Figure 5

Regional Volatile Matter Variations (dry ash-free basis) Luscar, Coalspur and Obed-Marsh coals, Alberta

Northern Rocky Mountains

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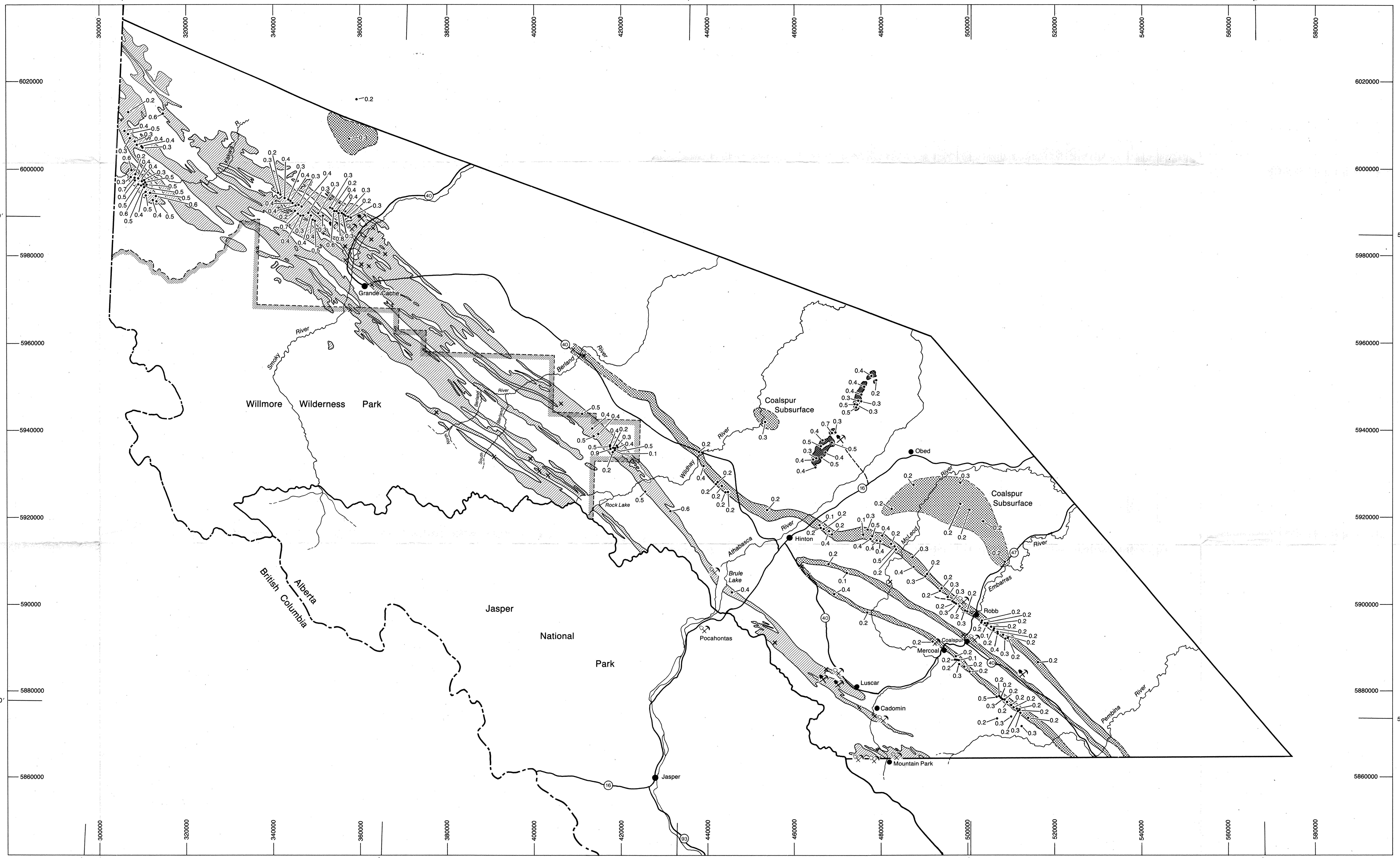

Legend

- Obed-Marsh coal zone (Paskapoo Formation) } Tertiary
- Coalspur Formation } Tertiary
- Luscar Group } Lower Cretaceous
- × Coal outcrop (1987 or 1988)
- Coal mine - active
- Coal mine - abandoned
- • Sample location

Sample locations and values from Energy Resources Conservation Board coal hole data file, March 1988 version

N

5 0 5 10 15 20 Miles

5 0 10 20 30 Kilometres

Scale 1:500 000

Figure 4

Regional Sulfur Variations (dry basis) Luscar, Coalspur and Obed-Marsh coals, Alberta

Northern Rocky Mountains

D.E. Macdonald, C.W. Langenberg, T. Gentzis, W. Kalkreuth

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