A REGIONAL EVALUATION OF COAL QUALITY IN THE NORTHERN FOOTHILLS/MOUNTAINS REGION OF ALBERTA

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FORWARD

This report forms the second in a three part series of publications that attempts to document and provide a geological understanding of coal quality variations in the Foothills and Mountains region of Alberta. The first in this series dealt with coals in the central and southern Foothills/Mountains region (Macdonald et al., 1987). The present report deals with all coals in the northern Foothills/Mountains. A final publication will summarize coal quality variations throughout the entire region.

ACKNOWLEDGMENTS

The Alberta Office of Coal Research and Technology (AOCRT) and the Alberta Research Council (ARC) provided joint funding for all phases of this project. The Energy Resources Conservation Board (ERCB) provided coal quality data in digital and microfiche formats. Access to the Coal Valley, Cardinal River, Gregg River, Obed-Marsh and Smoky River minesites was very generously provided by the respective companies. The following minesite geologists and engineers are thanked for their very cooperative assistance during field investigations: Mr. Gary Johnson (Coal Valley), Mr. Ken Holmes (Cardinal River), Mr. Ron Woolf (Gregg River), Mr. Chuck Williams (Obed) and Mr. Richard Dawson (Smoky River). Mr. D. Nikols and R. Paterson (ERCB) provided many constructive comments on the manuscript.

Coal quality analyses were performed at the Alberta Research Council's Devon facility by N. Truony, R. Estigoy, K. Nesbitt, C. Murray and M. Carmichel under the supervision of A. Iachelli. Part of the petrographic analysis was performed by K. Lali and D. Kirste. D. Goulet, Alberta Geological Survey, provided sample preparation and X-ray diffraction analysis. Maps and some statistical analyses were performed by N. Chidambaram and B. Bahnsen. Field assistance was ably provided by G. Mandryk and S. Treasure. M. FitzGerald and J. Moir prepared the final manuscript and the Graphics staff at the Alberta Research Council drafted most of the diagrams.

EXECUTIVE SUMMARY

This report is the second of a three-part series that describes and attempts to explain regional coal quality variations within the northern Foothills/Mountains region of Alberta. Proximate and ultimate analysis variables, plus some vitrinite reflectance and maceral analyses, are examined for the Lower Cretaceous Luscar Group, 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 available from 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 geologic perspective. The first component is intended to describe, characterize, and set limits for the coal quality variables, while the second component is intended to provide a geologic insight as to why and how these quality parameters vary as they do.

The statistical and map analyses for coal rank related variables (e.g. volatile matter, fixed carbon, calorific value and vitrinite reflectance) shows that coals in this area range in rank from low-volatile bituminous to subbituminous "A" and that the present suite of data is sufficient to describe the regional rank variations within the three coal-bearing units. Coal quality variables related to the original depositional environment (e.g. ash and sulfur) show a highly variable regional and statistical distribution. These variables must be examined on a local, individual seam and in-seam basis. On a regional scale, there really is an 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.

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

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

Both ash and sulfur can be related to clastic and geochemical models to better explain and predict coal quality trends.

INTRODUCTION

OBJECTIVES

The overall objective of this project is to document and provide a geological understanding of coal quality variations in the Foothills and Mountains areas of Alberta. Coal quality parameters such as ash and sulfur content are primarily controlled by the original depositional environment; while others, such as volatile matter, calorific value, and moisture content are controlled by the subsequent burial history.

The specific objectives of this phase of the project is to meet the general project objectives within the northern Foothills/Mountains region of Alberta (north of township 46 to the B.C./Alberta border, figure 1).

SCOPE

The three main coal-bearing formations evaluated were 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). For the purposes of this study, it was decided to include the Obed-Marsh coal zone in the analysis because of their proximity and similarity in rank to the true Foothills coals.

This phase of the study was undertaken by a team of geologists, statisticians, computing specialists, coal chemists and coal petrographers over a ten-month period.

PREVIOUS WORK

The most recent comprehensive coal quality study in this area is the work by Langenberg et al. (1988), which deals with the Cadomin-Luscar coalfield. Prior to this, Steiner et al. (1972) and

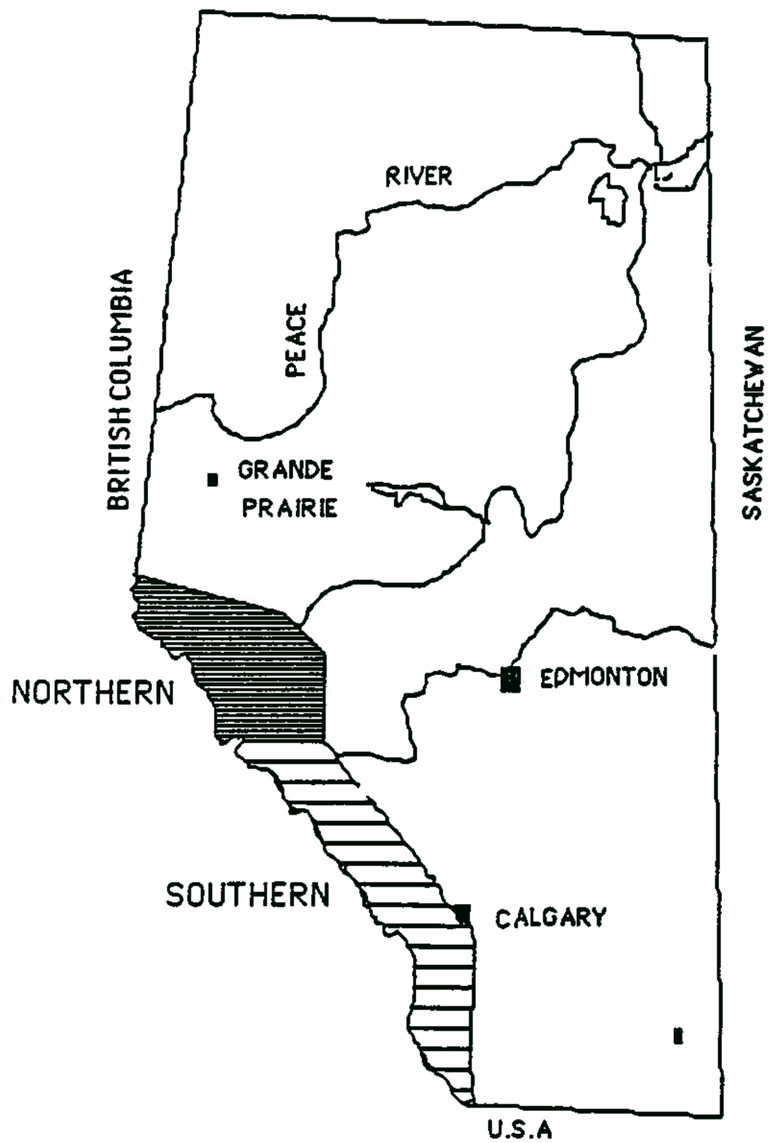


Figure 1. Coal quality variations in the northern Mountains/Foothills - study area.

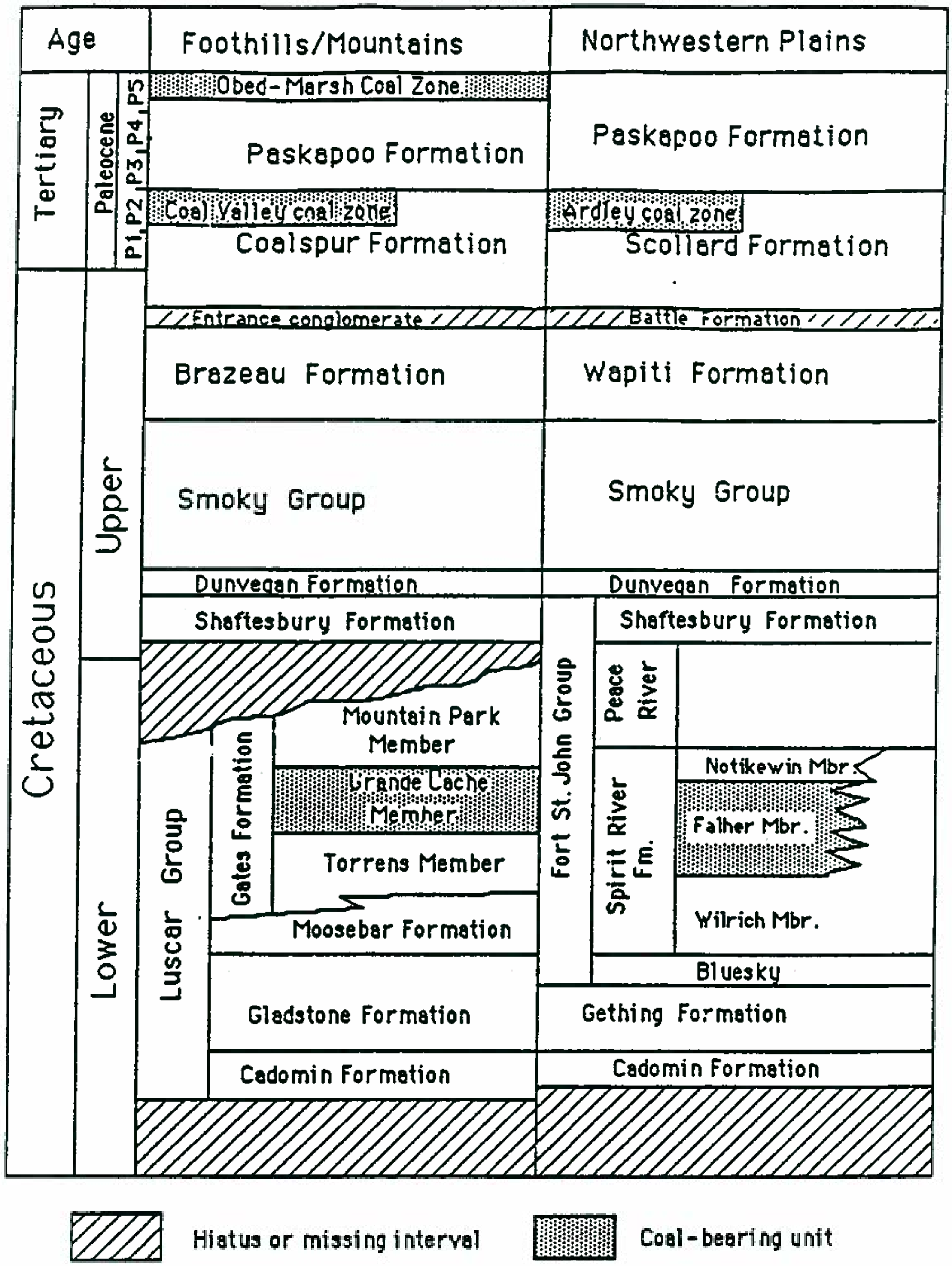


Figure 2. Stratigraphic nomenclature adopted - this study (modified from ERCB, 1987; Langenberg and McMechan, 1985; Dawson, 1986; and Demchuk, 1986).

earlier Stansfield and Lang (1944), dealt with coal quality in the northern Foothills/Mountains region as part of province-wide coal quality study. Recent studies have tended to focus on coal rank variations, primarily in the Luscar Group coals (Langenberg et al., 1987, Kalkreuth and Langenberg, 1986 and Kalkreuth and McMechan, 1984).

DATA SOURCES AND PROCESSING

Data sources

Coal quality data for this study came from three sources; the March 1988 version of the ERCB data file, data collected by the authors during the 1988 summer field season, and some data contributed by coal companies in the area. The ERCB data was used primarily to document coal quality variations in a statistical and geographic sense; while the new data collected in the field, and the industry data, was used to provide the geologic understanding of coal quality variations.

The ERCB data file used contains coal quality determinations from several different coal sample types, including raw, washed, screened, washed and screened, and float-sink. From the whole data set a smaller data subset, based only on the raw sample types was selected for analyses, hereafter referred to as the "raw data set". The raw data set contains 2044 proximate analyses from over 400 locations and 1260 ultimate analyses from 313 locations. The raw data set appears as appendices 1 to 6, on an IBM PC floppy diskette at the back of this report. The whole data set contains some analyses with greater than 50% ash reported, whereas, the raw data set contains only those analyses with less than or equal to 50% ash present.

Other coal quality data available within the ERCB data set such as rheological, washability, etc., were not examined as it was felt that these would be beyond the scope of the project.

The coal quality data collected by the authors during the 1988 field season were analyzed at the Alberta Research Council's coal laboratory in Devon, and the GSC laboratory in Calgary. The data were used for two purposes: 1) inseam channel samples were collected across individual seams to relate some coal quality parameters to depositional environments and, 2) grab samples were collected to show regional rank variations. In-seam channel samples were generally collected so as to exclude visible partings. These data appears as appendices 13 to 15 on diskette format.

Processing

The ERCB provided the Alberta Geological Survey with a magnetic tape in mixed data format; an in-house computer program was written to reformat the data into a more readable standard ASCII format. As the ERCB data does not have any publicly available geological or stratigraphic identifiers attached to the coal quality data, another program was written to select and write to separate files the locations of coal holes, and all associated quality data, which penetrated either the Luscar Group, Coalspur Formation or Obed-Marsh coal zone. This was done by noting the townships where the different units cropped out and then selecting coal holes coinciding with these townships.

The raw data set was used to calculate thickness weighted averages of ash, sulfur, volatile matter, fixed carbon, calorific value and residual moisture for each coal hole (appendices 7 to 12, on diskette in back). These values are plotted beside the coal hole locations and are represented in a series of regional coal quality maps (figures 3 to 8, in pocket). In less than 5% of the holes only a single value was present for a seam; this single value was included in the weighted averages.

Most of the statistical analyses were performed using the STATGRAPHICS Statistical Analysis program on a microcomputer. Postings of coal quality variables were produced with the in-house GEOPLOTTER software, run on a VAX mini-mainframe computer.

Reporting bases

Coal quality can be reported upon in at least five different bases, depending upon the intended use and to some extent, the laboratory performing the analysis. The most common bases include "as analyzed", "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 comparing coal quality data and compilation studies is the lack of uniformity in reporting the basis, or worse yet, not reporting the basis at all. In this study most of the coal quality data is expressed as either "dry basis" (db) or "dry-ash-free" (daf).

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 and is based mainly on physiography and coal rank. The traditional subdivisions are used in this report.

Changes in structural style have traditionally provided the basis of distinguishing a series of diverse sub-parallel geological regions in the Rocky Mountains. Each is characterized by particular features of topography and stratigraphy, as well as structure, and are called Foothills, Front Ranges, and Main Ranges. Mountains will be considered equivalent to Front Ranges in this report and the general term "Foothills/Mountains" will be used for the 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 that of Cretaceous rocks, the structure at the surface is characterized by folding and thrusting in central and northern Alberta. The Obed-Marsh coal zone forms part of the Plains region. However, it is included in this report for comparison with the Coalspur Formation coals.

Throughout the study area, the boundary between 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 Front Ranges proper.

STRATIGRAPHIC UNITS

The three major coal-bearing geological units in this area are the Luscar Group, the Coalspur Formation and the Obed-Marsh coal zone (figure 2).

Luscar Group

The Luscar Group, as recently defined by Langenberg and McMechan (1985), is the northern coal-bearing equivalent of the Blairmore Group of southern Rocky Mountains. The Luscar Group is also equivalent to the subsurface Mannville Group of the Plains region. The Luscar Group is Lower Cretaceous in age and disconformably overlies marine and nonmarine sandstones and shales of the Nikanassin Formation and is disconformably overlain by marine shales of the Blackstone Formation. The Luscar Group consists of the Cadomin, Gladstone, Moosebar and Gates Formations (figure 2). The Gates Formation, Grande Cache member, contains 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 minor marine transgression that divides the Luscar Group into the two major continental units, i.e. Cadomin/Gladstone Formations and the Gates Formation.

Moosebar Formation

The Moosebar Formation abruptly and disconformably overlies the Gladstone Formation and grades upward into the Torrens Member of the Gates Formation (McLean 1982). The Moosebar Formation is comprised of marine shales and at least three upward-coarsening sequences (Macdonald, et al., 1988). Very thin coal seams are present in the Moosebar Formation in the Cadomin-Luscar coalfield (Langenberg et al., 1988). McLean and Wall (1981) have shown that the Moosebar Formation thickens to the north.

Gates Formation

The Gates Formation conformably overlies the Moosebar Formation and is disconformably overlain by the Blackstone Formation south of the Athabasca River. The formation is divided into the Torrens, Grande Cache, and Mountain Park Members. The Grande Cache Member contains the economically important coal seams.

The Grande Cache Member conformably overlies the Torrens Member and is finer grained and recessive in comparison. In some places a coal seam directly overlies the Torrens Member. The Grande Cache Member consists of thick coal seams interbedded with mudstone, siltstone and very fine-grained sandstone.

Coal seam correlations in the Grande Cache Member throughout this area are not well understood. Macdonald et al. (1988) suggests that the Jewel Seam at Cadomin may correlate with the Numbers 3 and 4 seam in Grande Cache and with unnamed seams in the subsurface Elmworth Deep Basin. Earlier, McLean (1982) showed how the coal zone was thought to be correlated, from Grande Cache to the Nordegg area - 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 have been informally termed the Coal Valley Coal Zone (ERCB, 1987). The Coalspur Formation is stratigraphically correlative with the Ardley coal zone found in the Plains region. The Coalspur Formation is simply the upthrust expression of the Ardley coal zone. Engler (1986) has show how the informally named coal seams in the Coal Valley area are correlated throughout the Foothills region, while Rogan (1983) provided a detailed description of these seams in the same area. Industry drilling of 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 1985). Therefore, most of the coals are actually Paleocene in age. Demchuk (1987) has provided 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 aerial extent. The coal zone is transitionally subbituminous "A" to high-volatile bituminous "C" in rank and has proven 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 (Demchuk, 1986). At present, only the lower Numbers 1 and 2 seam are being mined.

The Obed-Marsh coal zone has been palynologically zoned to be upper Paleocene in age, contrasting with a lower Paleocene age for the

Coalspur Formation (Demchuk, 1986).

COAL QUALITY VARIATIONS

INTRODUCTION

It is well known that the major aspects of coal quality are determined by original depositional environment, diagenesis, depth of burial, duration of coalification, geothermal gradient and structural deformation (table 1).

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 Structural setting	- calorific value, rank, fixed carbon, moisture, volatile matter, ash content

Table 1. Coal quality parameters and controlling factors.

The original depositional environment of coals has been shown to determine or influence, the quality of the coal. For example, the relationship of marine depositional environments to sulfur content in coals is well known (e.g. Davies and Raymond 1983). The paleobotanical assemblage and the paleoclimate are also known to influence coal quality (Demchuk and Strobl 1989).

Diagenesis has been shown to influence some coal quality parameters, for example, 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 composition.

Moisture and volatile matter contents of coals progressively decreases with increasing rank. Rank is determined by temperature and length of time of heating during burial. In most stratigraphic sequences, the deeper the coals have been buried, the higher the temperature they have been exposed to, and usually, the greater their rank.

PROXIMATE, ULTIMATE AND CALORIFIC ANALYSES

The majority of the ERCB coal quality data, is proximate and washability analysis. Very little trace element data are present. The analytical results of Bonnell and Janke (1986) are used throughout this section to provide a comparative measure with other works. It should be pointed out, however, that the work of Bonnell and Jenke (1986) was generally based on only a few samples collected at existing mines at a single time. The present work includes a much larger data set.

Statistical analysis

Statistical analyses were performed on proximate and ultimate analysis data for the Luscar Group, Coalspur Formation and Obed-Marsh coals. Analyses were performed separately by geologic formation using the raw coal data set.

Data analyses included descriptive statistics (tables 2 and 3), histograms to describe how data are distributed, and box-and-whisker plots. The descriptive statistics are expressed on a dry and dry-ash free basis, as such variables (e.g. volatile matter) are most meaningful compared on this basis. Box-and-whisker plots show details of the maximum, minimum, 25th percentile, the median, and 75th percentiles for each variable (see Wong et al., 1988 for details). The variables examined were ash, moisture, volatile matter, fixed carbon, calorific value and sulfur. Some regression analyses and scatter plots were used to explore relationships between variables.

Moisture

As determined (residual), moisture contents from the raw coal data set were used to calculate a weighted average value for each sampling location. Figure 8 shows this distribution throughout the study area for the Luscar, Coalspur and Obed-Marsh coals. No discernable regional pattern can be recognized. The map (figure 8) is best used to gain a general impression about residual moisture values for a particular localized area.

Table 2

Variable/Analysis	N	Av.	Med.	Mode	Var.	Sd.	Min.	Max.	Range	Skew	Kurt
<u>Luscar Group</u>											
Moisture, AR	217	6.6	4.0	2.2	41.7	6.5	0.5	26.5	26.0	1.5	1.1
Moisture, AD	235	0.9	0.9	1.0	0.3	0.5	0.1	4.0	3.9	1.4	5.6
Ash, db	430	20.8	17.6	10.9	125.1	11.2	4.1	50.0	45.9	0.8	-0.5
Fixed C., db	353	63.7	67.0	71.8	100.9	10.0	33.2	76.4	43.2	-1.0	0.1
Fixed C., daf	353	78.4	79.7	80.4	78.3	4.0	55.7	83.7	28.0	-1.7	4.7
Vol.Mat, db	353	17.2	16.4	15.6	7.8	2.8	11.7	27.0	15.3	1.4	1.6
Vol.Mat., daf	353	21.5	20.3	19.6	14.3	3.8	16.3	44.2	27.9	1.6	4.0
Cal.Val., db*	265	28.8	30.4	32.5	17.4	4.2	16.5	34.8	18.3	-1.0	0.2
Cal.Val., daf*	265	35.5	35.7	35.7	0.8	0.9	31.4	37.0	5.6	-1.8	3.3
<u>Coalspur Formation</u>											
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	-1.8	17.7

	N	Av.	Med.	Mode	Var.	Sd.	Min.	Max.	Range	Skew	Kurt
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

Table 3

Variable/Analyses	N	Av.	Med.	Mode	Var.	Sd.	Min.	Max.	Range	Skew	Kurt
Luscar Group											
Carbon, db											
Carbon, daf											
Sulfur, db	406	0.4	0.4	0.3	0.04	0.2	0.1	2.6	2.5	3.5	28.1
Sulfur, daf	406	0.6	0.5	0.4	0.1	0.3	0.1	2.7	2.6	2.3	9.0
Hydrogen, db											
Hydrogen, daf											
Vitrogen, db											
Vitrogen, 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
Vitrogen, db	50	0.9	0.9	0.9	0.04	0.2	0.3	1.3	1.0	-0.2	0.1
Vitrogen, 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

	N	Av.	Med.	Mode	Var.	Sd.	Min.	Max.	Range	Skew	Kurt
<u>Obed-Marsh coal zone</u>											
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											
Vitrogen, db											
Vitrogen, daf											
Oxygen, db											
Oxygen, daf											

Luscar Group

Statistical analysis of Luscar Group coals shows histograms with a bi-modal distribution; whereas, moisture contents on an "as determined" basis are positively skewed (figure 9). Box-and-whisker plots, describe this distribution more quantitatively (figure 9). As received moisture varies between 0.5 and 26.5%, with a median of 4.0%; whereas, as determined moisture values vary from 0.1 to 4.0%, with a median of 0.9% (table 2).

Coalspur Formation

Moisture contents appear, from the histograms, to be normally distributed on an "as determined" basis and positively skewed on an "as received" basis (figure 10). Mean, mode and range of values for the Coalspur Formation coals appear in table 2.

Obed-Marsh coal zone

Moisture contents, both on an "as received and as determined" basis within the Obed-Marsh coal zone show a bi-modal distribution (figure 11). Median values occur around 3 and 7% (as determined) and 7 and 15% (as received). The median is 4.4% (as determined) and 8.5% (as received, table 2). This bi-modal distribution may be related to the mix in sampling of several seams within the Obed-Marsh coal zone. The box-and-whisker plots for the raw data set appear in figure 11.

Equilibrium moisture values, while not present in the present ERCB data set, are reported by Bonnell and Janke (1986) to be in the 12.66 - 13.61% range for the Numbers 1 and 2 seam within the Obed-Marsh zone (channel samples from the mine face).

Summary

The distribution of the "as determined" and "as received" moisture values (raw data set) from the three coal-bearing units are summarized on figure 12 as a multiple box-and-whisker plot. The "as determined"

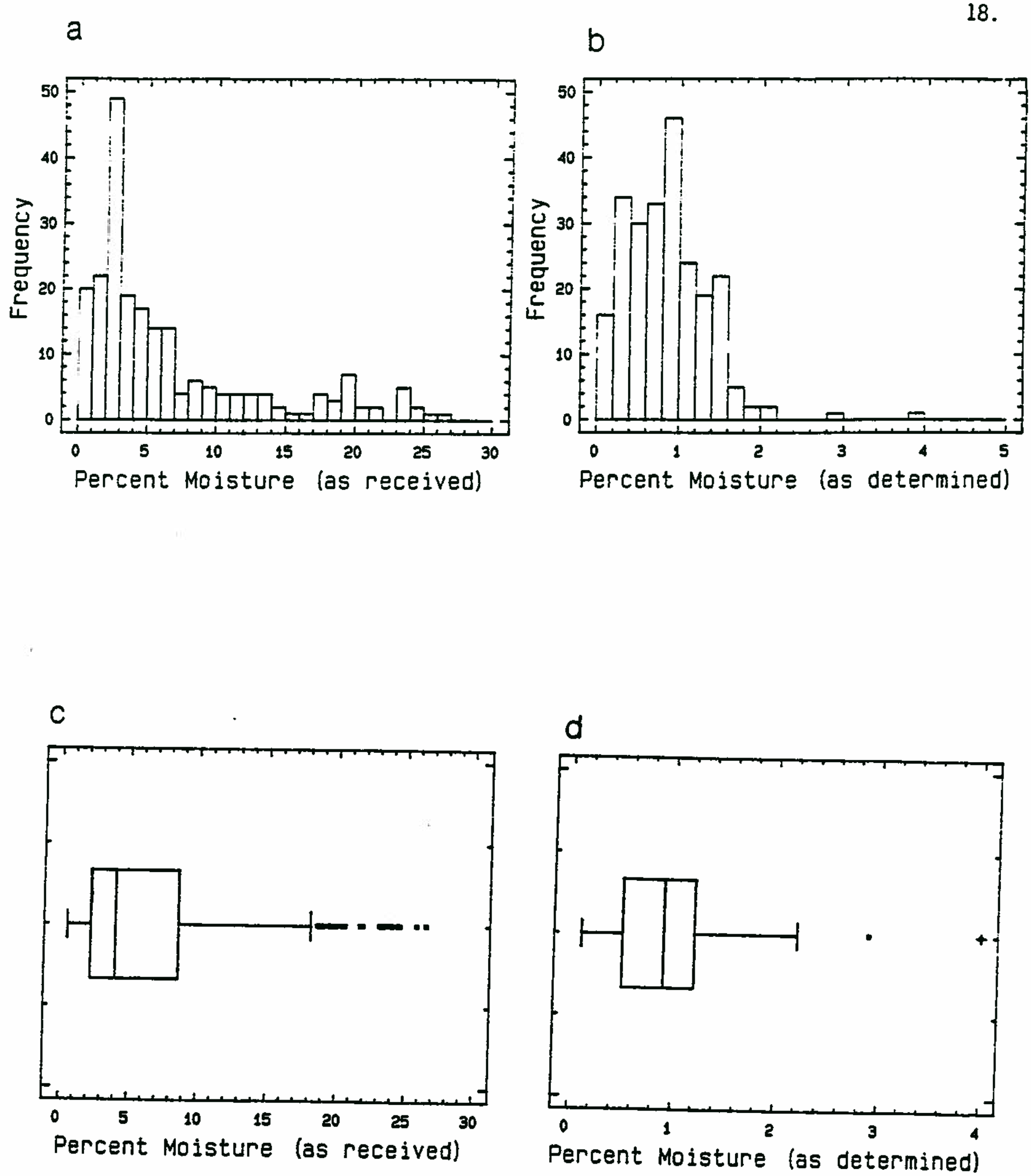


Figure 9. Histograms and box-and-whisker plots of moisture contents for the Luscar Group coals from the raw coal dataset, (a) histogram of moisture, as received, (b) histogram of moisture, as determined, (c) box-and-whisker plot of moisture, as received, and (d) box-and-whisker plot of moisture, as determined.

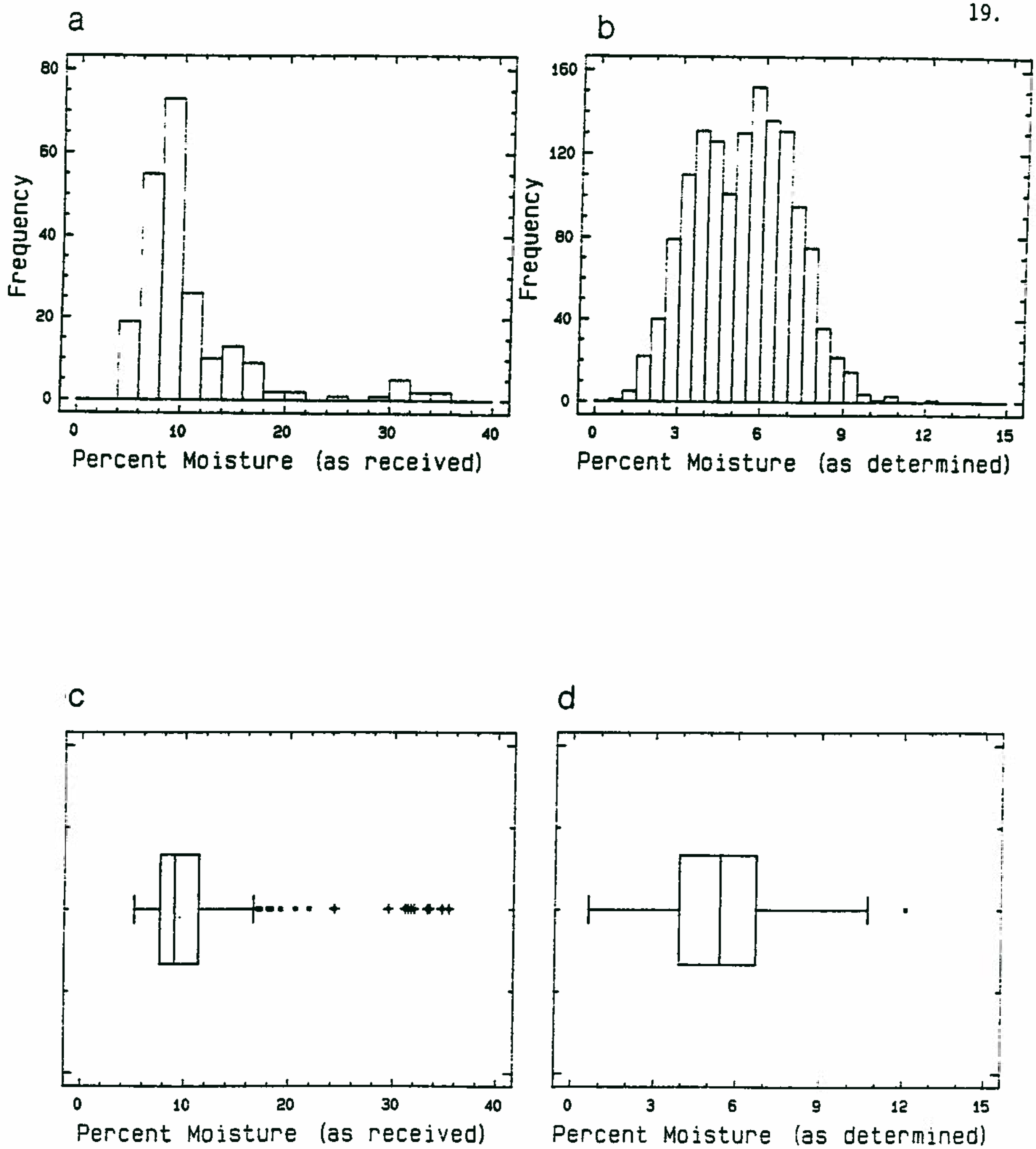


Figure 10. Histograms and box-and-whisker plots of moisture contents for the Coalspur Formation coals from the raw coal dataset, (a) histogram of moisture, as received, (b) histogram of moisture, as determined, (c) box-and-whisker plot of moisture, as received, and (d) box-and-whisker plot of moisture, as determined.

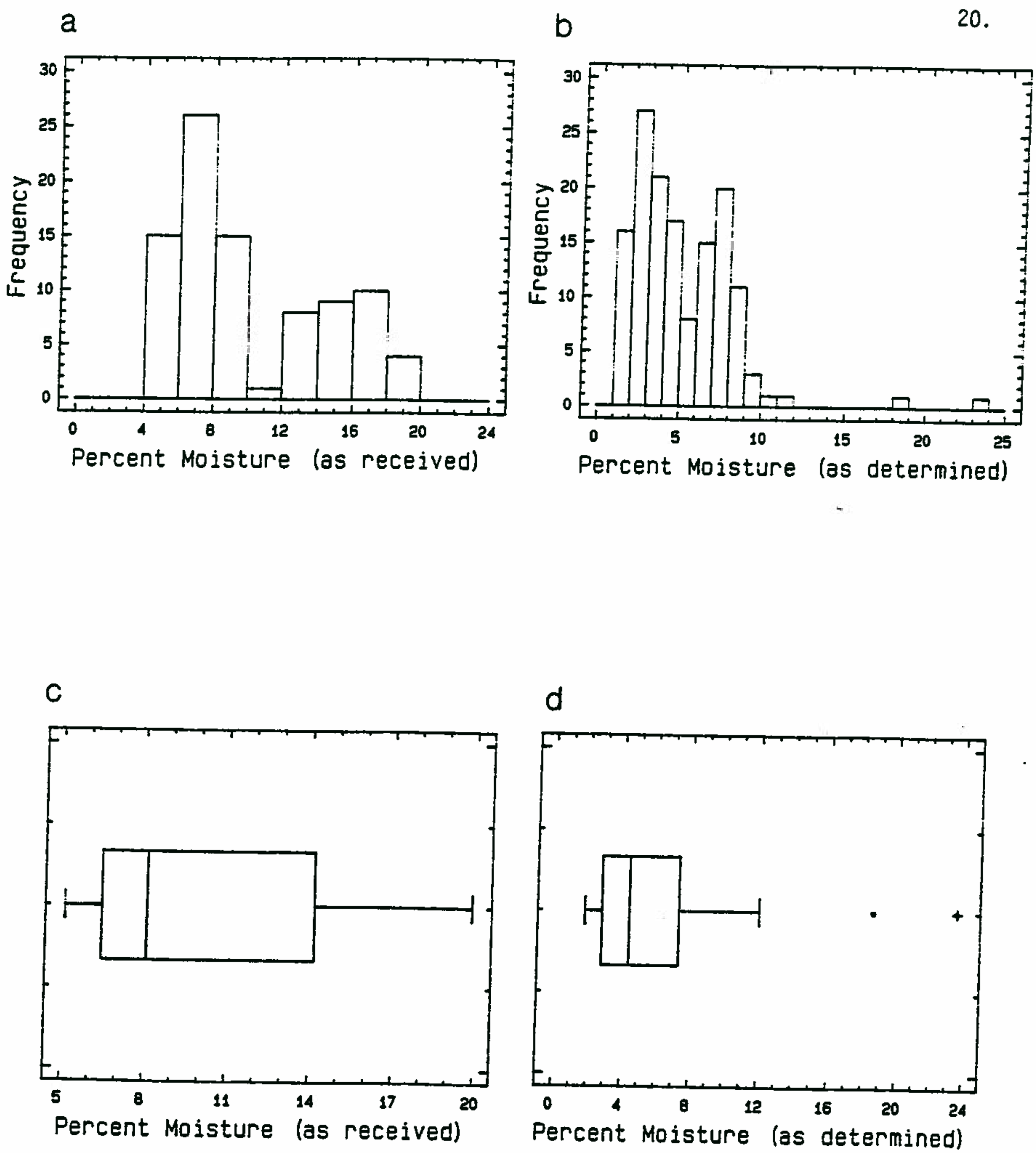


Figure 11. Histograms and box-and-whisker plots of moisture contents for the Obed-Marsh coals from the raw coal dataset, (a) histogram of moisture, as received, (b) histogram of moisture, as determined, (c) box-and-whisker plot of moisture, as received, and (d) box-and-whisker plot of moisture, as determined.

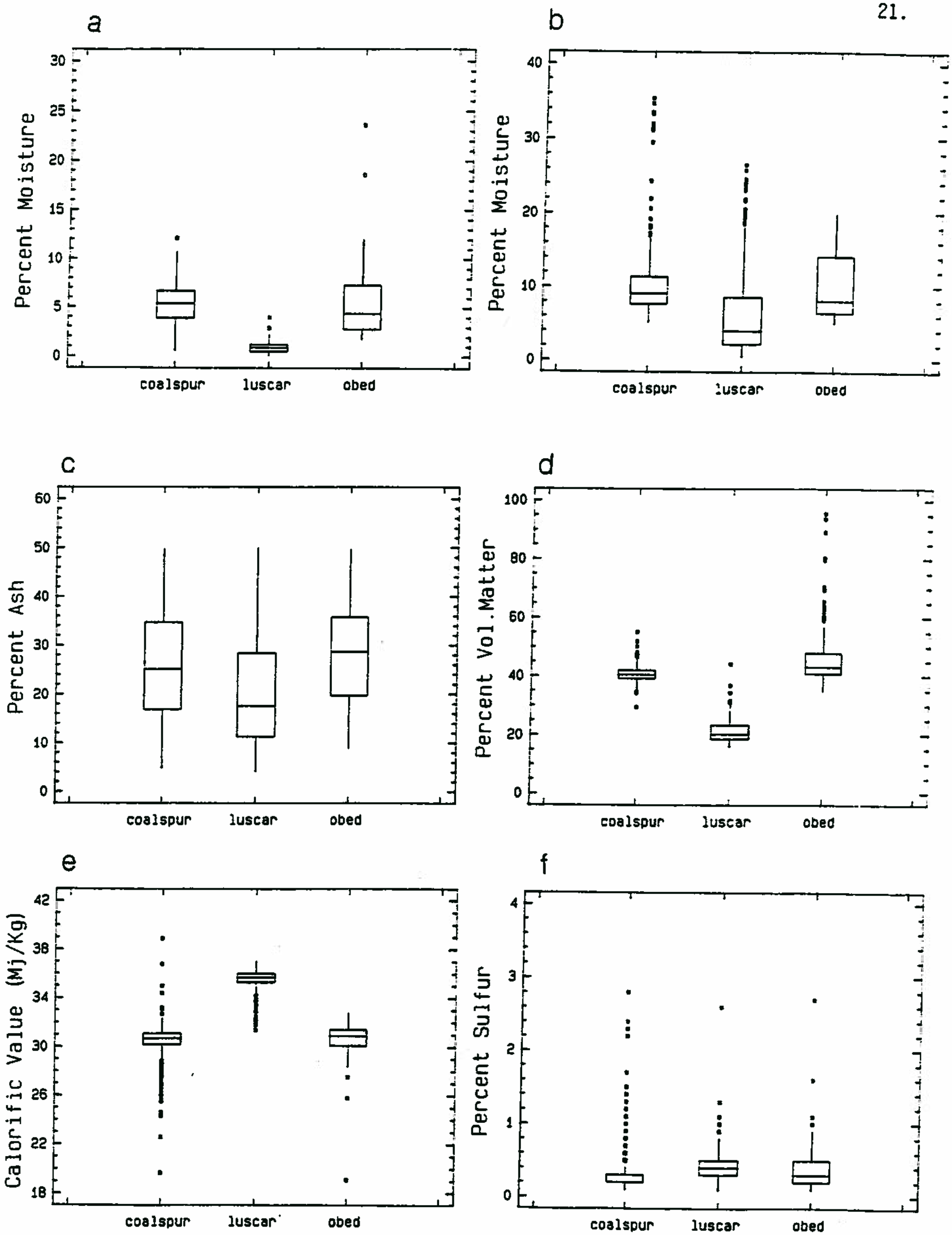


Figure 12. Multiple box-and-whisker plots comparing ash, moisture, volatile matter, calorific value and sulfur between the Luscar Group, Coalspur Formation and Obed-Marsh coals. (a) moisture (as determined), (b) moisture (as received), (c) ash (db), (d) volatile matter (daf), (e) calorific value (daf) and (f)

plot shows the tight and low values for the Luscar Group coals, in contrast to wider distributions and higher values for the Coalspur and Obed-Marsh coals. These findings are expected, given the higher rank of Luscar coals which should have lower moisture contents.

Ash

Mineral matter in coals is derived almost exclusively from the original sedimentary environment, and can be divided into two main groups; finely disseminated mineral matter in the coal itself, and discreet clastic partings. Ash contents reported in 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 from the raw coal data set were calulated for ash and these values appear on figure 3. No information on the number of seams averaged or the sampling procedure undertaken is available. The map should, therefore, be used with caution and only taken as an approximate guide to ash values which might be expected in a given area. Langenberg et al. (1988) has shown that ash can vary quite dramaticaly over a very small coal field and within a single coal seam. Regional evaluations of ash should ideally be done with much more geological information (i.e. stratigraphic position of seams and presences of partings).

Luscar Group

The raw data set for the Luscar Group coals shows a positively skewed histogram with 75% of the population having less than 28% ash, as seen in the box-and-whisker plot (figure 13). The median is calculated to be 17.6% and the mode to be 10.9% (table 2). The chi squared test for normality confirms that this data is not normally distributed.

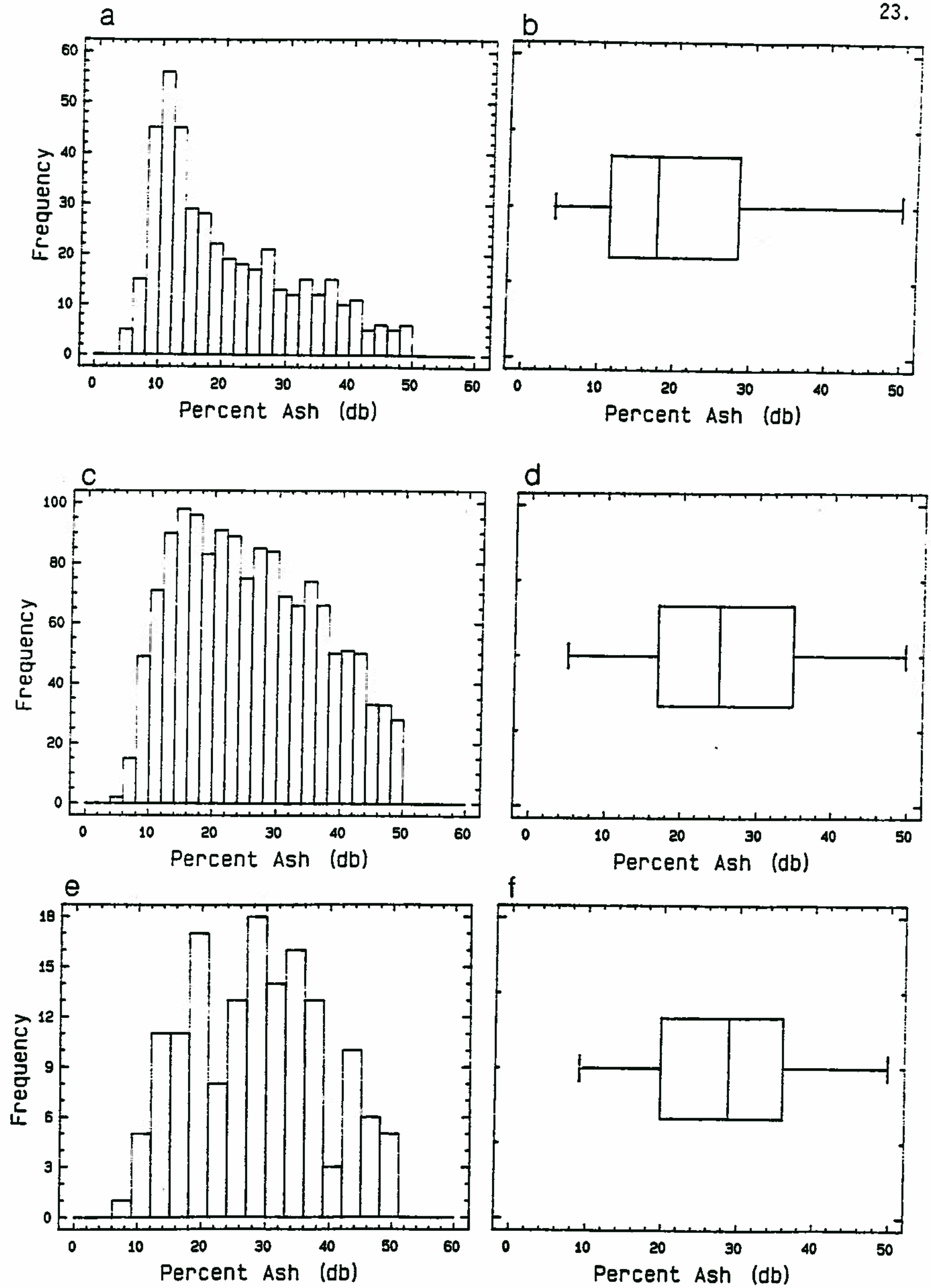


Figure 13. Histograms and box-and-whisker plots of ash contents for the Luscar Group, Coalspur Formation, and Obed-Marsh coals from the raw coal dataset, (a) histogram of ash in Luscar coals, (b) box-and-whisker plot of ash in Luscar coals, (c) histogram of ash in Coalspur coals, (d) box-and-whisker plot of ash in Coalspur coals, (e) histogram of ash in Obed-Marsh coals, (f) box-and-whisker plot of ash in Obed-Marsh coals.

With this statistical distribution, the mode value may be more meaningful than the median, as this represents the most frequently occurring value. It may also be more meaningful from a geologic/economic sense in that it suggests that any economic coal seam sampled within the Luscar Group is likely to have an ash value around 10%. Samples collected during the course of this study at the Smoky River mine support this conclusion, as only few values exceed 15% (appendix 13). Langenberg et al. (1988) reports median ash values from the Luscar Group - Jewel Seam in the Cadomin-Luscar coal field to be 13.6% (db), which would also tend to support this conclusion. Macdonald et al. (1987), however, reports mean ash values for Luscar Group coals in Nordegg area to be 25.3% (db, no-ash values greater than 50% are included). This is consistent with the mean ash value for this study of 20.8%. Therefore, the mean and median may not be the best prediction of ash in Luscar Group coals. It also indicates that the ERCB data set contains several uneconomic seams with many partings.

Coalspur Formation

Coals within the Coalspur Formation show an ash histogram that is non-normally distributed (figure 13), with this non-normality being confirmed by the chi-squared test. The box-and-whisker plot shows that 75% of this population has ash values less than 35% (figure 13). In this distribution, the mean and median are about the same (25 - 26%, table 2) with the mode being somewhat lower (14.3%). With this distribution using the mode value alone, as was suggested for the Luscar Group coals, would probably not be a reliable predictor of ash in the Coalspur coals.

Bonnell and Janke (1986) report ash values from channel mineface samples from the Coal Valley mine ranging between 13.6 and 18.4% (db), which suggest that a 14% ash estimate would represent the lowest ash coals coming from this mine. A glance at the analyses from samples collected during this study (appendix 14) support this conclusion, with very few samples having less than 15% ash.

Obed-Marsh coal zone

The raw data set for the Obed-Marsh coal zone shows a histogram with a bi-modal or perhaps tri-modal distribution, with the box-and-whisker plot showing that 75% of the population has an ash value less than 36% (figure 13). Like the Coalspur Formation coals, the Obed-Marsh coals have similar mean and and median values (28% db, table 2), with a slightly lower mode value (17.1%, db). Bonnell and Janke (1985) report channel samples from the mineface with ash values between 19 and 20% (db), with clean coal ash values closer to 12% (db). The sampling undertaken at the Obed Mountain mine during this study (visible partings excluded, appendix 15) shows ash values varying from 9 to 42%, which is consistent with the distribution seen in the ERCB raw coal data set (figure 13).

Summary

The distribution of the ash values (raw coal data set) from the three coal-bearing units are summarized on figure 12 as a multiple box-and-whisker plot. It must be remembered that these values are in situ, and do not represent a marketable "clean coal" product. All of the producers in this area clean their coal to individual contract specifications. The Luscar Group coals stand out as having markedly lower median ash values as compared to the Coalspur and Obed-Marsh coals and the range of values is similarly lower. The Coalspur and Obed-Marsh coals show a very similar distribution and median values, with respect to ash.

The Wilcoxon-Mann-Whitney test was used to compare median ash values between the three coal-bearing units, i.e. Luscar Group, Coalspur Formation and Obed-Marsh for the whole data set. This test, applied to ash contents (db), shows that there is significant differences in median ash values between the three units (table 4).

Units Compared	Ash (db) p - value	Sulfur (db) p - value
Coalspur vs. Obed	0.0000	0.0000
Coalspur vs. Luscar	0.0000	0.0000
Obed vs. Luscar	0.0000	0.0773
Coalspur vs. Obed vs. Luscar	0.0000	0.0001

*N.B. p - value less than 0.05 implies statistical difference.

Table 4. Wilcoxon-Mann-Whitney test results comparing median ash and sulfur values between the Luscar, Coalspur and Obed-Marsh coal-bearing units.

Volatile Matter/Fixed Carbon

Thickness weighted average values from the raw coal data set were calulated for volatile matter and these values appear on a regional map (figure 5). As was the case with ash, no information on the number of seams averaged or the sampling procedure is available. The implications of this map are discussed in detail under a later section in this report.

Luscar Group

The raw data set histograms for the Luscar Group coals shows volatile matter values (daf) to be positively skewed, and the box-and-whisker plot shows that 75% of the sample population has values between 16 and 23% (figure 14). In this data set the mean, mode and median are all similar (19 to 21%, table 2).

The relatively wide range of values for this variable is related to the Luscar Group coals having a rank variation from High Volatile "A" Bituminous to low volatile bitumimous (see later section for details). It can also be deduced from the mode value that most of the Luscar Group coals in this data set are Low Volatile Bituminous in rank.

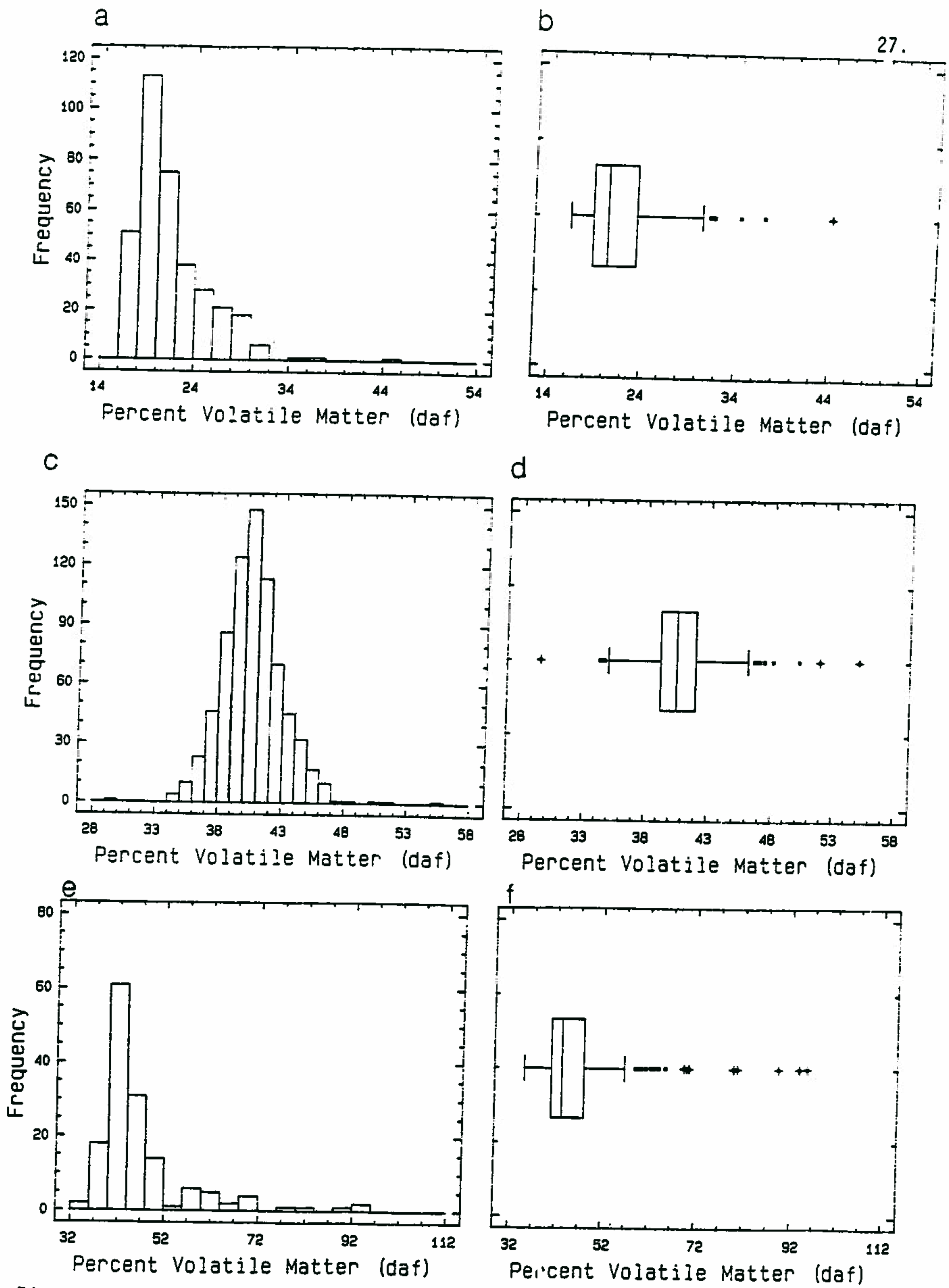


Figure 14. Histograms and box-and-whisker plots of volatile matter contents for the Luscar Group, Coalspur Formation, and Obed-Marsh coals from the raw coal dataset, (a) histogram of volatile matter in Luscar coals, (b) box-and-whisker plot of volatile matter in Luscar coals, (c) histogram of volatile matter in Coalspur coals, (d) box-and-whisker plot of volatile matter in Coalspur coals, (e) histogram of volatile matter in Obed-Marsh coals, (f) box-and-whisker plot of volatile matter in Obed-Marsh coals.

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 (figure 14). 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.

Obed-Marsh coal zone

Volatile matter values obtained from the Obed-Marsh coals show a near normal distribution on the histogram, with the exception of some outliers greater than 58% (figure 14). The box-and-whisker plot shows that 75% of the sample population lies in the 35 - 58% range (figure 14). The mean, median and mode are 47.0, 43.2, 48.0, respectfully (table 2). The mode value comes very close to predicting the "clean coal" production 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) from channel samples from the Numbers 1 and 2 seam of 38.93/41.77% (db) and 48.80/51.82% (daf). Samples collected during this study at the Obed mine varied from 42.7 to 47.5% (daf, appendix 15), with these values being very close to the mean, median and mode described previously.

Summary

The distribution of volatile matter values (raw coal data set) from the three coal-bearing units are summarized on figure 12 as a multiple box-and-whisker plot. The plot shows the lower volatile matter values of the Luscar coals is largely a reflection of the higher rank of the coals, relative to the Coalspur and Obed-Marsh coals. The tighter range and higher rank of the Coalspur versus the Obed-Marsh coals is also apparent.

Calorific value

Thickness weighted average values from the raw coal data set were calculated for calorific value and these values appear on a regional map (figure 7). As is the case with the other variables, no information as to the number of seams averaged or the sampling procedure undertaken is available. The paucity of data values for the Luscar Group coals is a reflection of its main utilization, as a metallurgical coking coal, for which calorific value determinations are seldom undertaken.

Luscar Group

The Luscar Group coals show a negatively skewed distribution, however, if the low value outliers are ignored the distribution is very close to normal (figure 15). This near normal distribution is apparent on the box-and-whisker plot (figure 15). This plot 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 related to and consistent with, the generally accepted observation that coals in this rank range (i.e. low to medium volatile bituminous) do not vary greatly in their calorific value.

Coalspur Formation

The histogram for the distribution of calorific values for the Coalspur Formation coals shows a very tight, non-normal distribution (figure 15). The box-and-whisker plot suggests normality if one ignores the outliers at both ends of the diagram (figure 15). The plot also shows that 75% of the calorific value values lie in the 28.8 to 31.0 Mj/Kg (daf) range. The mean, median and mode values are 30.5, 30.7 and 31.1 Mj/Kg (daf, table 2) respectfully.

Bonnell and Janke (1986) report calorific values of 30.62 to 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 an important criteria in assigning ASTM rank classification.

Obed-Marsh coal zone

The histogram and box-and-whisker plot for the Obed-Marsh coal zone shows a near normal distribution of calorific value determinations, with 75% of the data population lying between 28.5 and 32.8 Mj/Kg (daf, figure 15). The median, mean and mode values are very close to the those determined for the whole data set at 30.9, 30.7 and 31.2 Mj/Kg (daf) respectfully.

These findings are consistent with the Subbituminous "A" classification of this coal. This compares well with Bonnell and Janke (1986) who report values of 30.45 and 30.28 Mj/Kg for channel samples taken at the mine face in the Numbers 1 and 2 seam.

Summary

The distribution of calorific values (raw coal data set) from the three coal-bearing units are summarized on figure 12 as a multiple box-and-whisker plot. The Luscar Group coals stand out as having the highest calorific values, with the tightest range, and the least number of outliers. The Coalspur Formation and Obed-Marsh coals show a very similar distribution.

Ultimate analyses

Ultimate analyses data for foothills/mountains coals is generally sparsely present (except sulfur) in the ERCB data set used for this study. Some new ultimate analyses data were collected in the field by the Alberta Geological Survey in 1988 (appendices 13, 14 and 15).

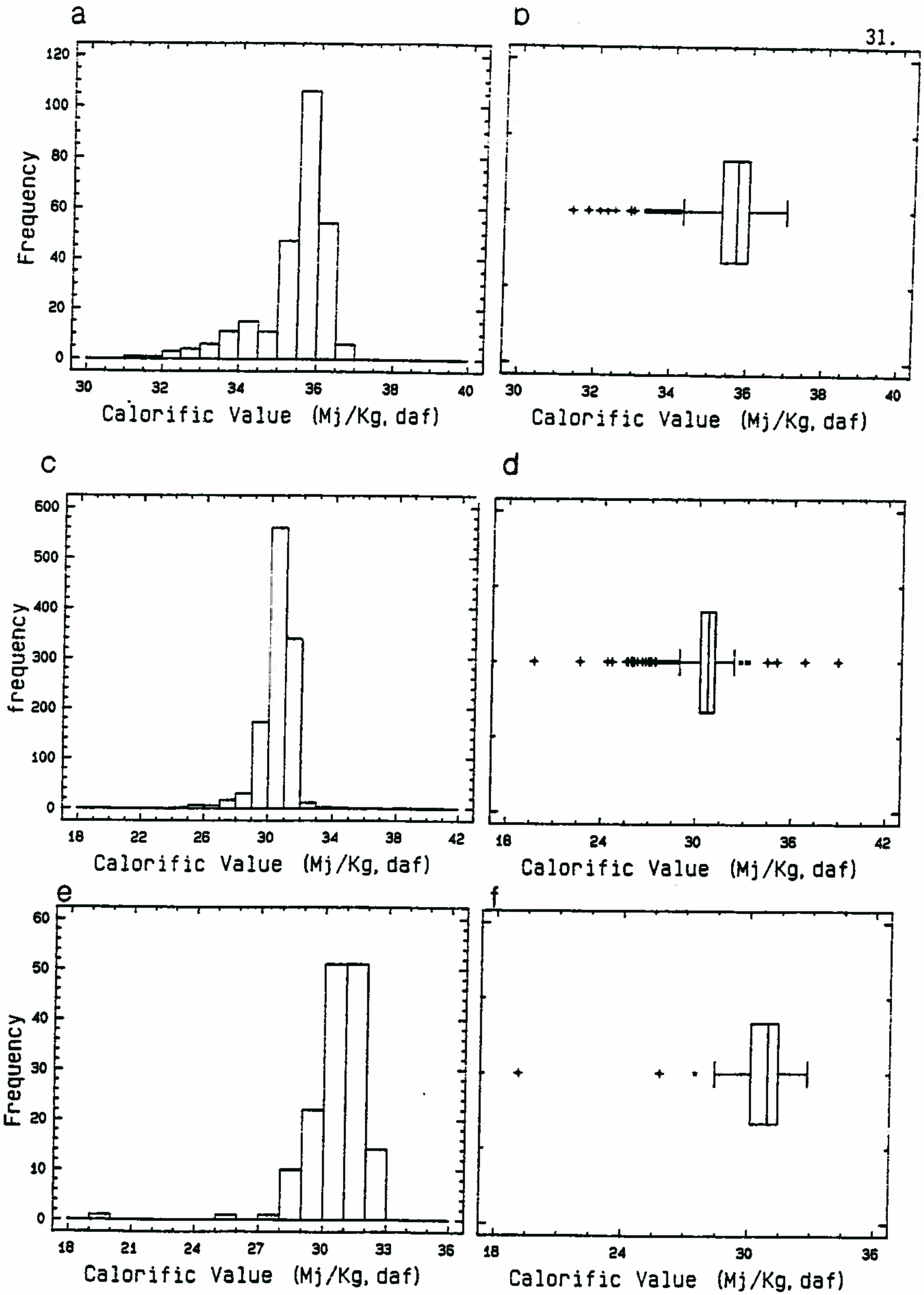


Figure 15. Histograms and box-and-whisker plots of calorific value contents for the Luscar Group, Coalspur Formation, and Obed-Marsh coals from the raw coal dataset, (a) histogram of calorific value in Luscar coals, (b) box-and-whisker plot of calorific value in Luscar coals, (c) histogram of calorific value in Coalspur coals, (d) box-and-whisker plot of calorific value in Coalspur coals, (e) histogram of calorific value in Obed-Marsh coals, (f) box-and-whisker plot of calorific value in Obed-Marsh coals.

Luscar Group

Less than two complete ultimate analyses determinations are present in this data set, making statistical analysis impossible (table 3). Sixteen ultimate analyses from Luscar Group coals sampled during the course of this study, from the Smoky River mine, appear in appendix 13. Overall this data set is so small that its representativeness must be questioned. A detailed coal quality study by Langenberg et al. (1988) used 104 ultimate analyses, from the Jewel coal seam in the Cadomin-Luscar coal field, 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 have non-normal distributions (figure 16). Descriptive statistics appear in table 3. Eight complete ultimate analyses from samples collected in the Coal Valley - Robb area characterize the Arbour, Val D'Or, Mynheer, Silkstone, and McPherson Seams within the Coalspur Formation coal zone (appendix 14).

Obed-Marsh coal zone

No ultimate analyses data from the Obed-Marsh coal zone are present in the data set used. Two additional complete ultimate analyses collected from from the Obed mine during the course of this study, indicates values for the Numbers 1 and 2 seam within the Obed-Marsh coal zone (appendix 15).

Sulfur

Thickness weighted average values from the raw coal data set were calulated for sulfur and these values appear on figure 4. No information on the number of seams averaged or the sampling procedure undertaken is available. This map should, as was the case for ash,

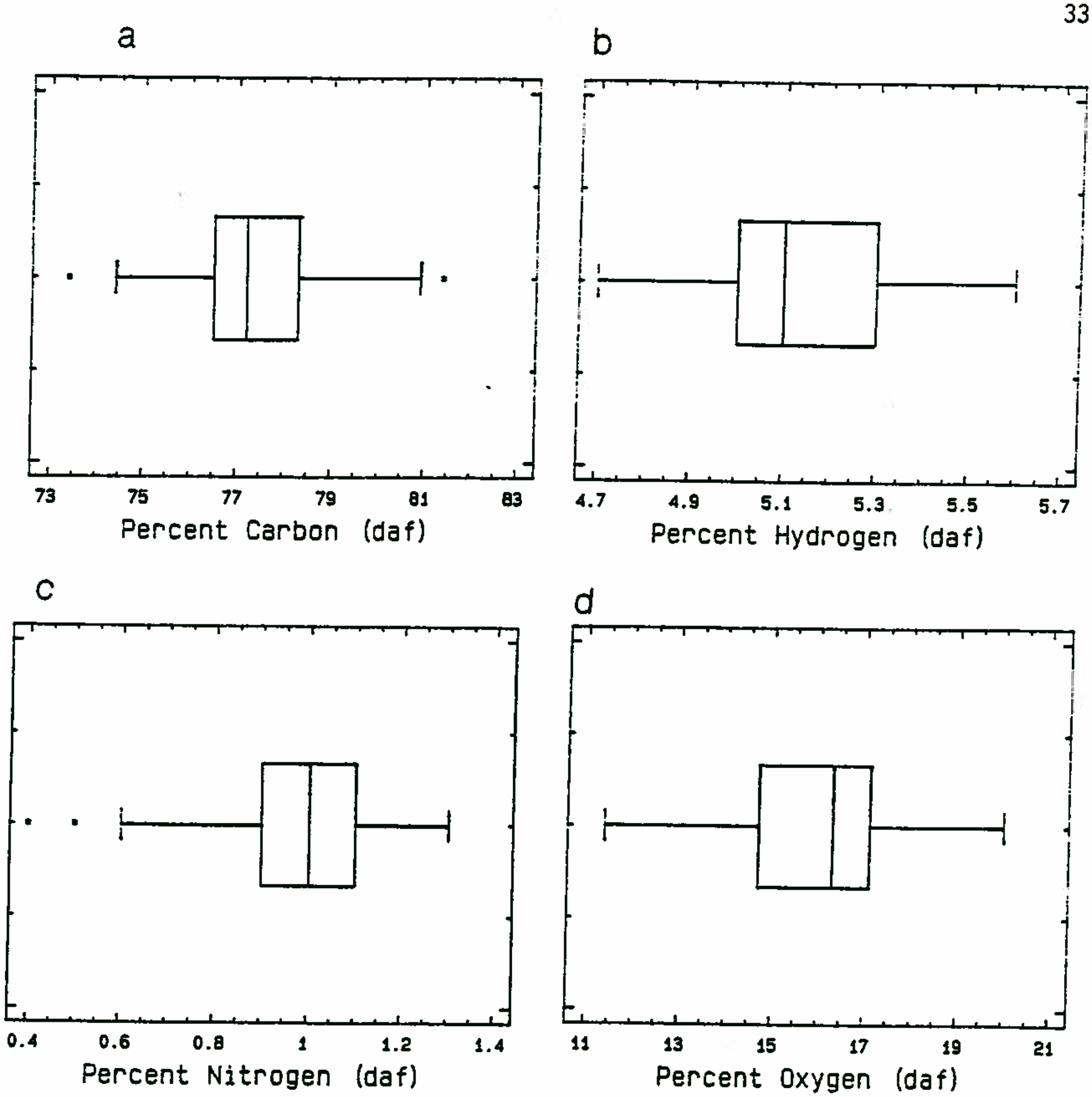


Figure 16. Box-and-whisker plots of ultimate analyses for the Coalspur Formation coals from the raw coal dataset, (a) box-and-whisker plot of carbon, (b) box-and-whisker plot of hydrogen, (c) box-and-whisker plot of nitrogen, and (d) box-and-whisker plot of oxygen (by difference).

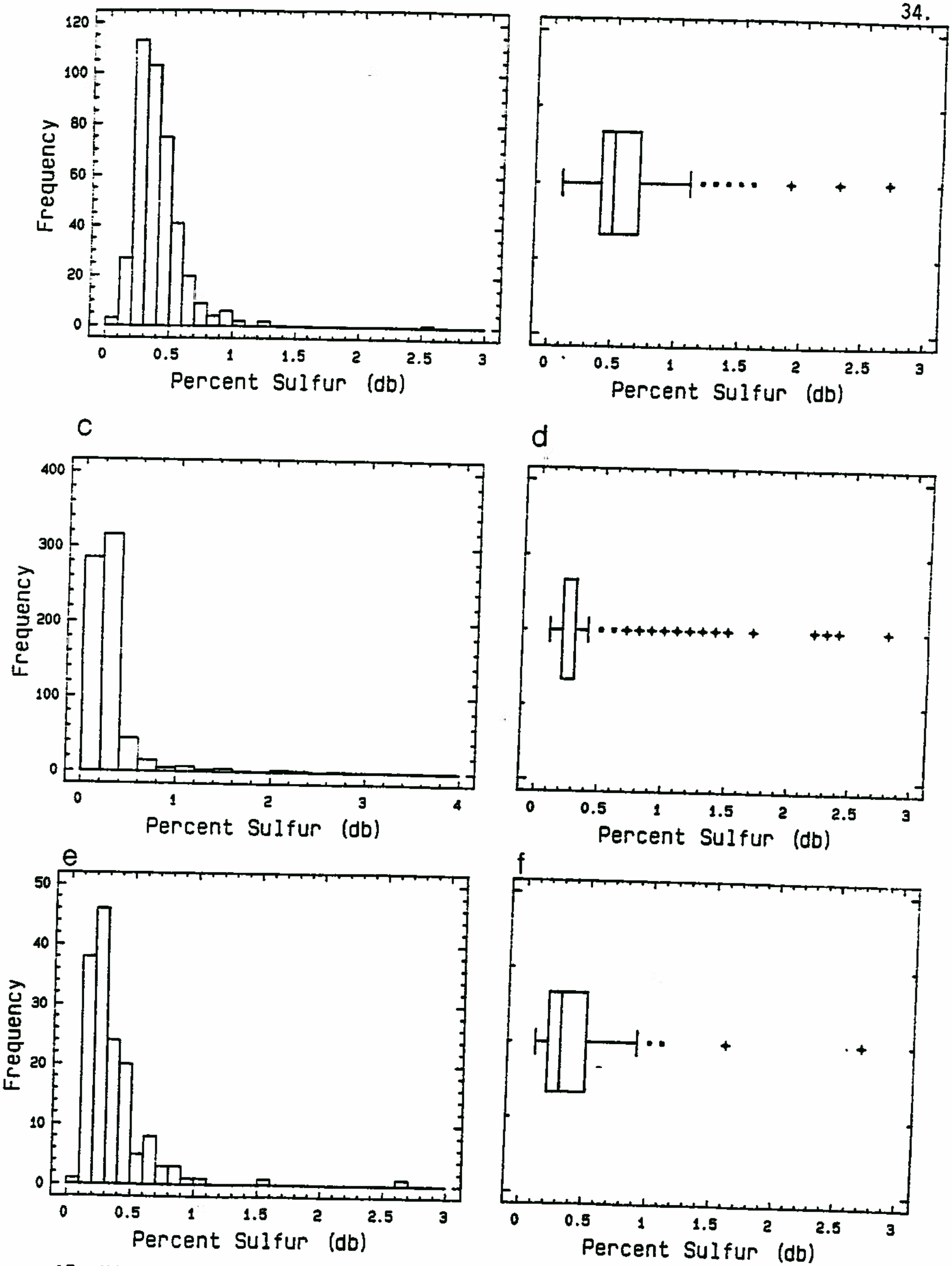


Figure 17. Histograms and box-and-whisker plots of sulfur contents for the Luscar Group, Coalspur Formation, and Obed-Marsh coals from the raw coal dataset, (a) histogram of sulfur in Luscar coals, (b) box-and-whisker plot of sulfur in Luscar coals, (c) histogram of sulfur in Coalspur coals, (d) box-and-whisker plot of sulfur in Coalspur coals, (e) histogram of sulfur in Obed-Marsh coals, (f) box-and-whisker plot of sulfur in Obed-Marsh coals.

should be used with caution and only taken as an approximate guide to sulfur values which might be expected in a given area. Langenberg et al. (1988) have shown that sulfur values, over 3 - 4 seams within the Luscar Group, can vary between 0.1 to 2.9% (db) over the Cadomin-Luscar coal field. As was the case with ash, regional evaluations of sulfur should ideally be done with a much larger data set than is presently available.

Luscar Group

Luscar Group coals show a sulfur distribution that is positively skewed, with the box-and-whisker plot showing that 75% of the samples fall between 0.1 to 0.7% (db, figure 17). The mean, median and mode values for sulfur in the Luscar Group coals are 0.4, 0.4 and 0.3 (n=406, 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, raw coal). With the limited number of samples taken, organic sulfur predominates over pyritic sulfur, except when total sulfur exceeds about 0.5% (db), at which time the excess sulfur is made up of pyritic sulfur and proportions are roughly equal. Langenberg et al. (1988) reports sulfur values for the Cadomin-Luscar coal field Jewel Seam to be in the 0.1 - 0.6% (db) range with a median and average of 0.3% (db).

Coalspur Beds

The Coalspur coal zone has a positively skewed histogram for sulfur, with the box-and-whisker plot showing that 75% of the population has sulfur contents between 0.1 and 0.4% (db, figure 17). The mean, median and mode sulfur values are 0.3, 0.3 and 0.2 respectfully (db,n=686, table 3).

Bonnell and Janke (1985) report total sulfur values from the Coalspur coals at the Coal Valley Mine between 0.17 and 0.33% (db, raw coal, channel samples). The same authors report that in the samples taken, the sulfur is usually expressed evenly between pyritic and organic varieties, with the exception of the Silkstone Seam in which the pyritic form predominates. Vertical in-seam total sulfur profiles and raw coal data collected during the course of this study appear in a later section and in appendix 14.

Obed-Marsh coal zone

The Obed-Marsh coal zone sulfur data has a positively skewed histogram, with the box-and-whisker plot also showing 75% of the population with sulfur values between 0.1 and 0.5% (db, figure 17). The median and mode are both 0.3% (db) with the mean being 0.39% (db, table 3). The controls on sulfur distribution are discussed in a later section of this report.

Bonnell and Janke (1986) report surface channel samples from the Obed Mountain mine having 0.33 and 0.91% (db) sulfur, which agrees well with the overall distribution seen in this study. The same authors report that forms of sulfur in samples taken are as organic and pyritic, with organic sulfur composing a little more than half the total (e.g. pyritic - 0.13%, organic - 0.20%, db). This same relationship seems to hold true at higher total sulfur values, with pyritic sulfur rising as organic sulfur rises (e.g. pyritic - 0.35%, organic - 0.47% db).

Summary

The distribution of sulfur values (raw coal data set) from the three coal-bearing units are summarized on figure 12 as a multiple box-and-whisker plot. The Coalspur Formation coals stand out as having lower median sulfur values as compared to the Luscar and Obed-Marsh coals. The Coalspur, Luscar and Obed-Marsh coals all show a similar distribution of outliers and also show the same maximum sulfur values (i.e. a little less than 3.0%, db).

Sulfur median variations between the three coal-bearing units were also examined with the Wilcoxon-Mann-Whitney test (table 4). The results show that only in the Obed vs. Luscar comparison, do median sulfur values not significantly differ. The other combinations show that median sulfur values do vary significantly between the various coal-bearing units.

VITRINITE REFLECTANCE

The Geological Survey of Canada and the Alberta Geological Survey have been collecting coal samples for petrographic analysis in the study area since 1981. Results have been published in Kalkreuth and McMechan (1984 and 1988), Kalkreuth and Langenberg (1986) and Langenberg et al. (1987 and 1988). During the summers of 1986, 1987 and 1988 additional channel and grab samples were collected in the Coalspur, Mountain Park, Brule, Pocahontas, Folding Mountain, Moon Creek, Willmore Wilderness Park, Copton and Grande Cache areas. Most analyses are from the Luscar Group, but some additional results from the Coalspur Formation and Obed-Marsh coals are included (table 5). The sample sites can be put in a stratigraphic framework by observations of the local geology. Petrographic analysis was performed at the Institute of Sedimentary and Petroleum Geology in Calgary. For this pupose the samples were crushed, mounted in epoxy resin, then ground and polished. From these pellets the percentage maximum vitrinite reflectance was measured.

Most of the analyses selected for this report are from near the base of the Gates Formation of the Luscar Group. They include the Jewel Seam of the Cadomin area, the Kennedy Seam of the Mountain Park area, the Numbers 3 and 4 seam of the Grande Cache area and equivalent seams of adjacent areas (table 5). The maximum vitrinite reflectance for the base of the Gates Formation ranges from 0.86 (Willmore Park) - 1.97 % (at 2779 m depth in the CS ET AL. SHERMAN 11-3-62-12-W6 oil and gas well). This indicates a rank range from high to low volatile bituminous. The volatile matter content (dry and ash free) can be estimated from the maximum vitrinite reflectance. The relationship is not linear (Bustin et al., 1983), but for restricted rank ranges it can be approached by a linear curve. The Cadomin area gave the relation

VM(daf)=58-27*Rmax for the range of 0.9 - 1.4% Rmax (Langenberg et al., 1988). For the range of 1.4 - 1.8% Rmax the relation is VM(daf)=38-11*Rmax, as estimated from unpublished GSC data from the Grande Cache area.

These relationships can only be established from samples on which both proximate analysis and reflectance determinations are 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 of figure 5. There is a systematic variation in vitrinite reflectance and rank for the base of the Gates Formation, which will be discussed in the section on regional coalification.

COAL QUALITY RELATIONSHIPS

ASH AND SULFUR RELATIONSHIPS

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

VOLATILE MATTER/FIXED CARBON AND ASH

Volatile matter and fixed carbon are primarily related to coal rank; however, it was found that for some coals, volatile matter content reported is sometimes contolled by ash content. Nurkowski (1985) cites erroneously high volatile matter values increasing with increasing ash values, where chemically bonded water is released during analysis.

Table 5. Coal rank data

Map	zone	UTM	Area	Fm	Seam	Mtr	Pellet	Sample	Rmax	SD	VM
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

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

<u>Coalspur and Obed coals</u>

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.

Approximately 11% of the volatile matter content variation reported in the Obed-Marsh coals can be explained by the ash content (table 6). However, within the Luscar Group coals, up to 25% of the volatile matter content (i.e. r^2) can be explained by the ash content. Where ash is less than 25% in the Luscar coals, r^2 drops to 1.9% and rises to 16.8% for ash contents in the 25 - 50% (db) range (table 6).

This relationship of volatile matter content being, at least partly controlled by ash content in the Luscar Group coals, may be related to high amounts of clay minerals in these coals. High clay mineral content is suggested by the ash analysis results of Bonnell and Janke (1986) which suggest that Luscar Group coals tend to have Al_2O_3 contents greater than 20%, whereas Obed-Marsh and Coalspur Formation coals tend to be less than 20%.

High amounts of calcite may also, in theory, cause erroneously high volatile matter values. Abundant calcite was observed at the Coal Valley mine on cleats and in thin beds within the Val D'Or and Myhneer Seams during the field program conducted 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 perhaps have a higher r^2 value than it does (table 6). This does not seem to be the case and suggests that calcite has had a minimal affect on volatile matter values.

Table 6. Correlation coefficients between volatile matter contents (daf) and ash contents (db) for the Luscar, Coalspur and Obed-Marsh coals.

Geologic unit	Sample ash	n	r
Obed-Marsh	0 - 50%	148	0.33
Obed-Marsh	0 - 25%	56	0.12
Obed-Marsh	25 - 50%	92	0.30
Coalspur	*0 - 50%	-	-
Coalspur	0 - 25%	360	0.12
Coalspur	25 - 50%	373	0.30
Luscar	0 - 50%	352	0.50
Luscar	0 - 25%	261	0.14
Luscar	25 - 50%	91	0.41

* Data set too large to calculate with hardware/software available.

CALORIFIC VALUE AND ASH

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

A regression analysis and scatter plot on calorific value vs. ash for the Luscar Group, Coalspur Formation and Obed-Marsh coals all show a nearly perfect negative, linear relationship, with correlation coefficent between -0.92 and -0.99 (figure 18). The formula to predict calorific value based solely on ash content for the Coalspur and Obed-Marsh coals is nearly identical (figure 18). The very large data set for the Coalspur Formation coals necessitated considering only those coals with ash content less than 30%. The formula to predict calorific value from ash within the Luscar Group coals is slightly different than

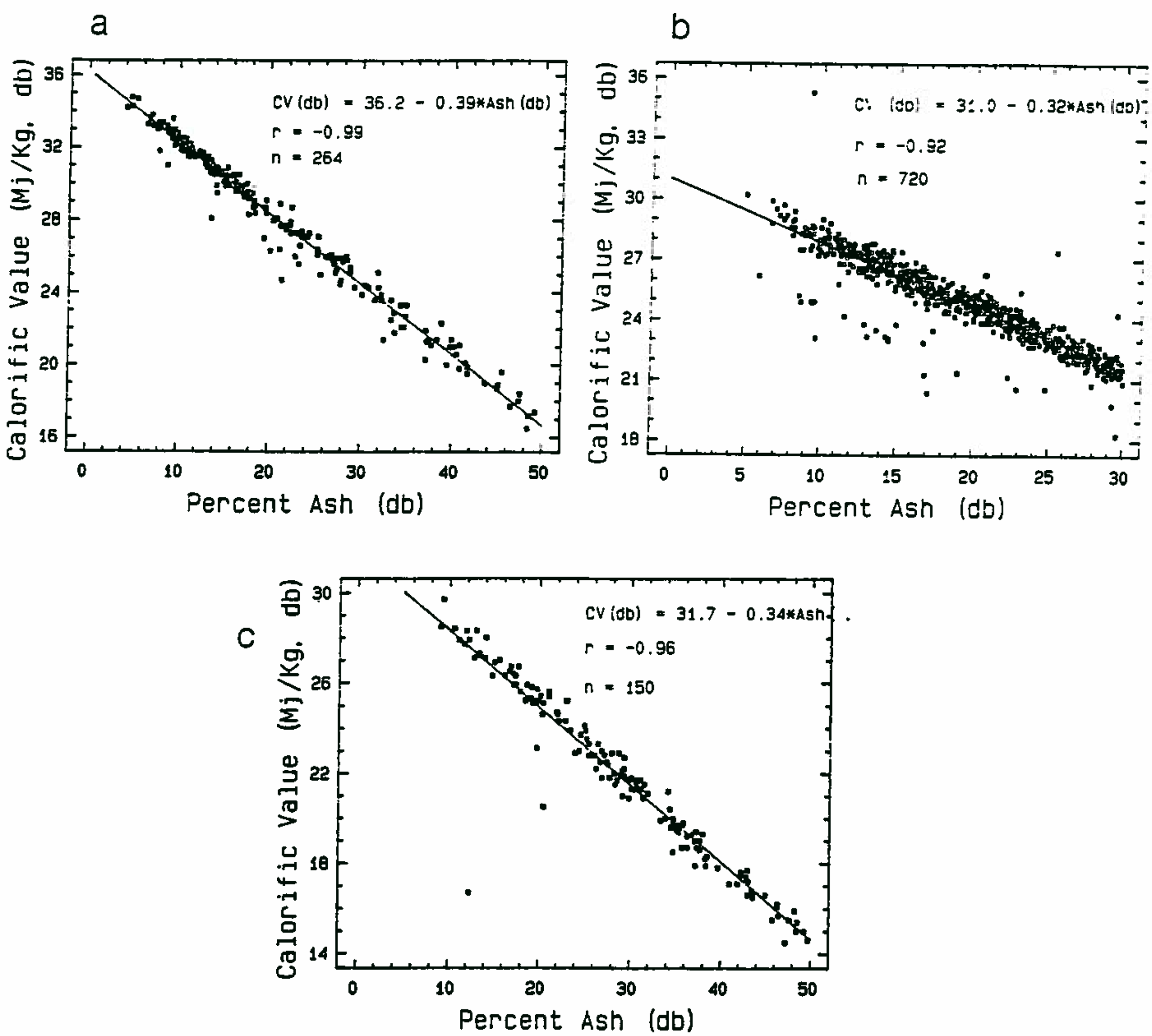


Figure 18. Cross plot and best fit linear correlations between calorific value (db) and ash (db) for the Luscar Group, Coalspur Formation and Obed-Marsh coals (a) Luscar Group plot, (b) Coalspur Formation plot, and (c) Obed-Marsh plot.

the Coalspur or Obed-Marsh; however, it has the highest correlation coefficient of all three coal-bearing units.

UNDERSTANDING QUALITY VARIATIONS - MODELS

DEPOSITIONAL ENVIRONMENTS AND IN-SEAM VARIATIONS

Introduction

This section discusses coal quality variations and controls on coal quality. As was described in an earlier section (table 1) coal quality variables can loosely be classified into two groups; those variables that were primarily controlled by the original depositional environment, and those variables that owe their variation to later burial history. This section specifically deals with the first group of variables, primarily ash and sulfur.

These questions, as they relate to ash and sulfur, were addressed by measuring stratigraphic sections and collecting in-seam coal samples from the Smoky River mine at Grande Cache, the Coal Valley mine and surrounding Robb area, and from the Obed Mountain mine near Hinton. This strategy was designed to address these questions for the Luscar Group, Coalspur Formation and Obed-Marsh coals respectively.

Luscar Group Coals

Introduction

The Smoky River minesite at Grande Cache was chosen as an area to examine in-seam coal quality variations within the Luscar Group to better address the questions posed above 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 19). Several continuous stratigraphic sections through the coal-bearing portion of the Luscar Group were also measured.

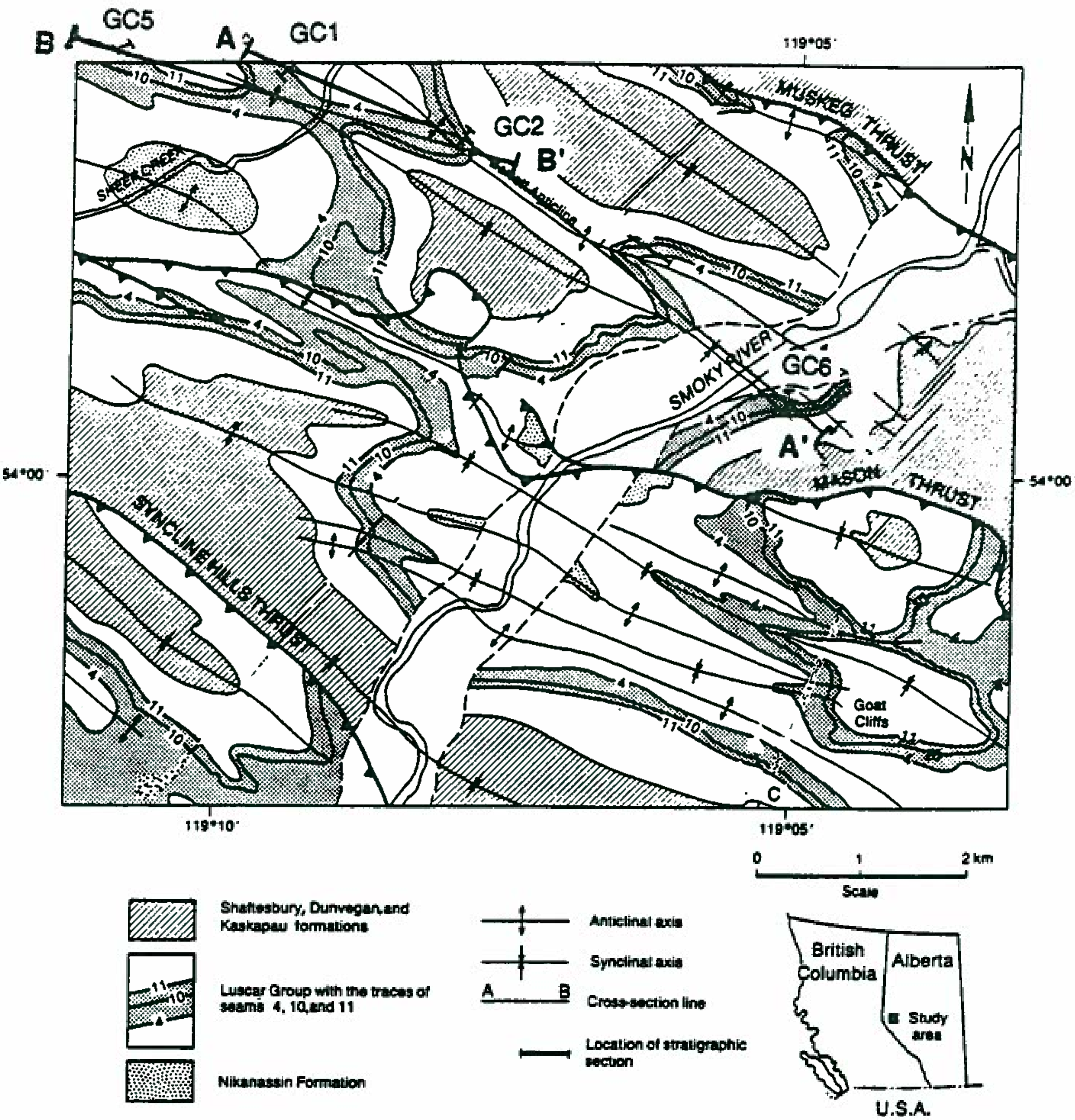


Figure 19. Location map and stratigraphic sections measured at the Smoky River mine, Luscar Group coals (modified from Kalkreuth and Langenberg, 1986).

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) suggests a low-energy, coastal or delta plain environment behind shorelines as a likely 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 report figure 20). Macdonald et al. (1988) recognizes six marine cycles of sedimentation within the Luscar (or Mannville) Group in the Grande Cache area, which correlate to several of the Falher Members in the Peace River arch/Deep Basin area (figure 20).

Coal Forming Environments

Kalkreuth and Leckie (in press) 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 10's to 100's of kilometers away from the active shoreline. Macdonald et al. further argues that the overall stratigraphic architecture of the Gates Formation (figure 20) supports this conclusion because the active shorelines were confined to the Peace River Arch/Elmworth Deep Basin area (Falher gas-bearing sands). 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, in this interpretation then, are thought to have formed in association with a series of wave-dominated deltas or strandplains, but removed some distance (and perhaps time) from the active shoreline progradation.

Langenberg et al. (in press) has suggested that the Jewel Seam in the Cadomin area was deposited in relatively dry, planar, low-lying forest swamp conditions, based on maceral and geochemical evidence.

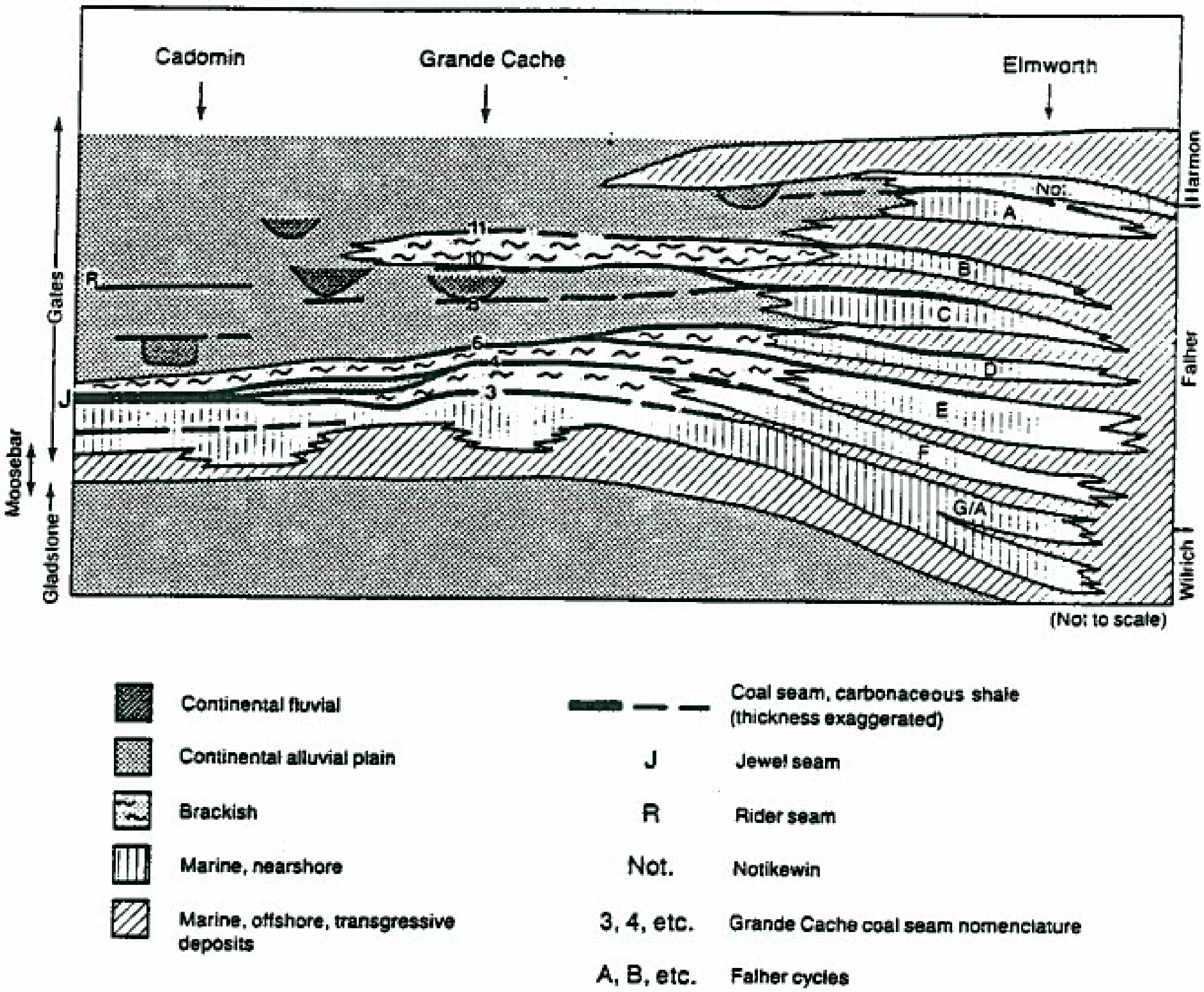


Figure 20. Schematic diagram of the Luscar/Spirit River clastic wedge between the Moosebar and Harmon transgressions in the Cadomin to Grande Prairie region (modified from Macdonald et al. 1988, Smith et al., 1984; and Stott, 1984).

This supports the contention of Macdonald et al. (1988) of the swamps having formed some distance removed from the active shoreline.

Ash Variations

In-seam ash variations were examined within the Numbers 4 and 10 seam at the Smoky River mine. Sampling was generally undertaken so as to exclude visible partings, except for composite type samples, to better understand the inherent ash. The Number4 seam is thought to be approximately stratigraphically equivalent, though not necessarily time equivalent, to the Jewel Seam in the Cadomin area described by Macdonald et al. (1988). In-seam ash variations within the Jewel Seam, at Cadomin, have been documented by Langenberg (1988) and show variations on pit, intra-pit and coal field scales.

The Number 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 (figure 21, between sections GC2 and GC6). The most abrupt facies change occurs between sections GC6 and GC6A, where in less than 100 m, nearly the entire Number 4 seam changes to an interbedded clay shale/coal sequence. Throughout most of the cross-section A-A' (figure 21) 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 (<10%) and low-ash (11 - 20%) correlative zones. The upper portion of the seam is consistently very low in ash, except for the uppermost 0.5 m which becomes characteristically high in ash, due to interbedding with clastics.

The Number 10 seam is much higher up stratigraphically in the Gates Formation and was sampled in two locations (figure 19). Cross section B-B' 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 becoming interbedded with clastics in the upper half of the coal-bearing section (figure 22). The proportion of clastic material within the Number 10 seam is seen to increase toward section GC2.

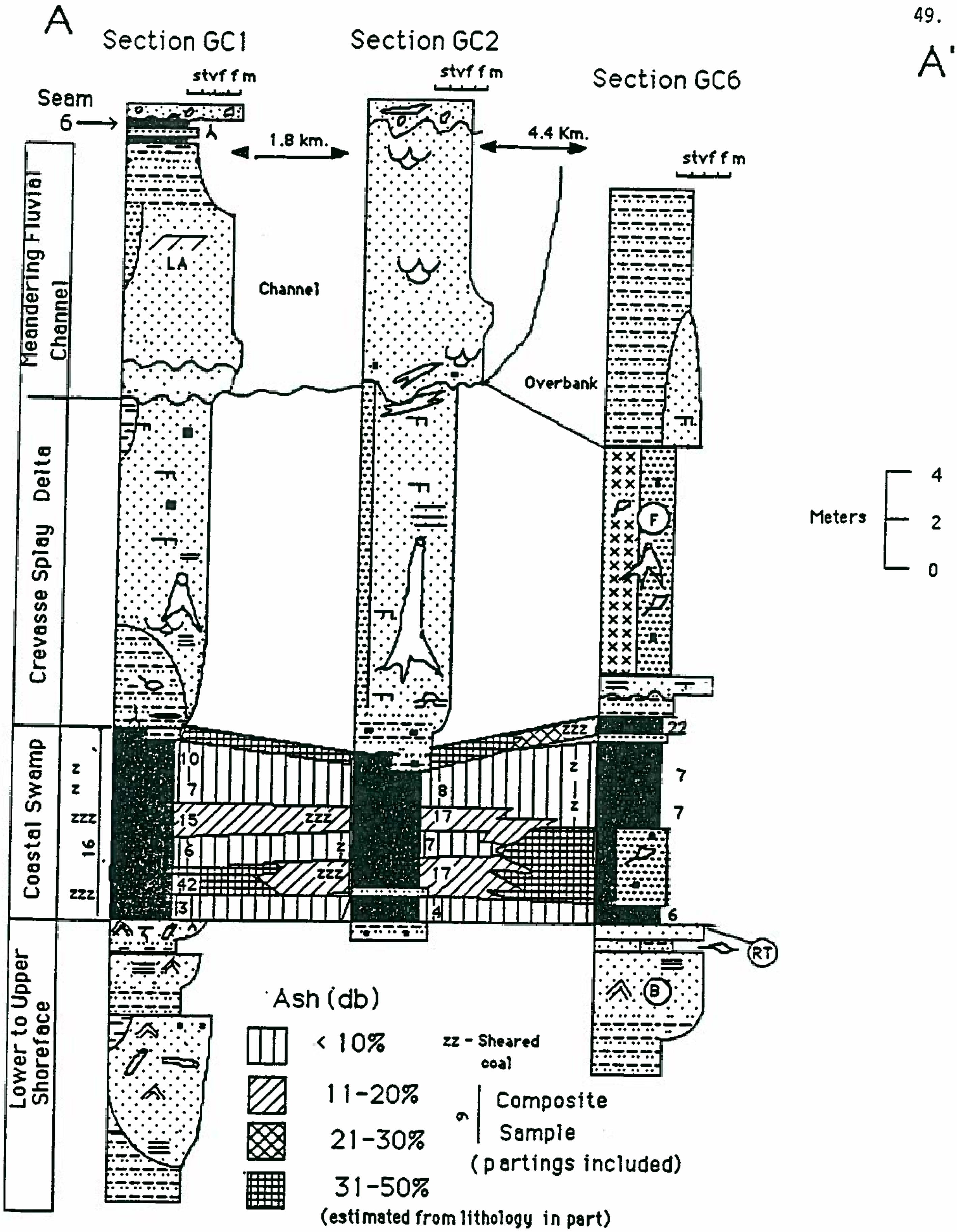


Figure 21. Stratigraphic cross section A-A' showing inseam ash variations within the number 4 seam and associated clastic depositional facies, Smoky River mine, Luscar Group coals .

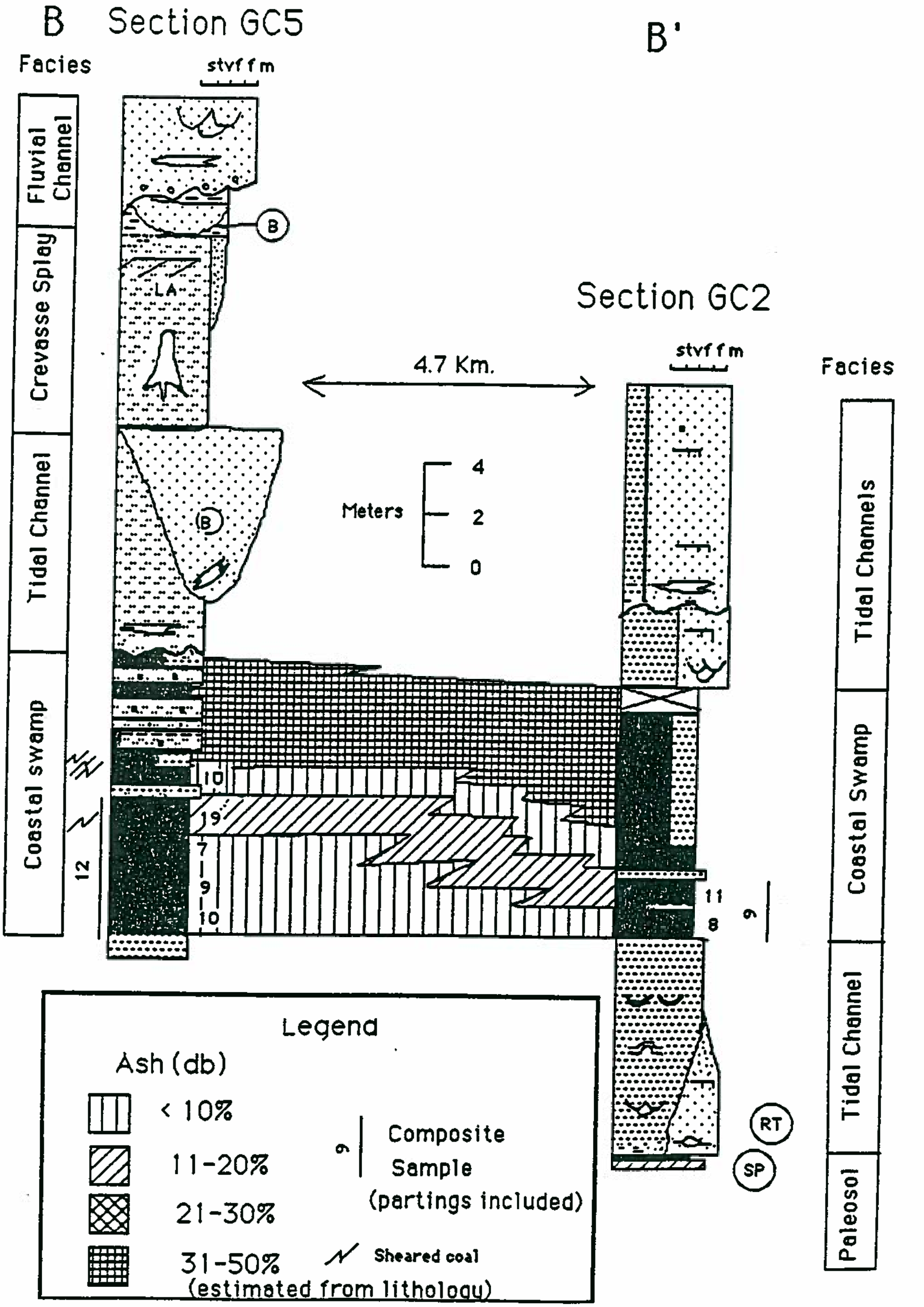


Figure 22. Stratigraphic cross section B-B' showing inseam ash variations within the number 10 seam and associated clastic depositional facies, Smoky River mine, Luscar Group coals.

From a mining perspective it is interesting to note that, for example the mineable portion of the Number 4 seam at section GC1 averages 16% ash (db, partings included), whereas the vertical in-seam inherent ash content varies from 3 to 42% (db). Similarly, the mineable portion of the Number 10 seam at section GC5 averages 12% ash (db), yet the vertical in-seam inherent ash varies from 7 to 19% (db). Being aware of these in-seam ash variations may help mine operators to exploit these differences through selective mining or through blending at preparation plants.

From these two examples it can be seen that the mean, median and weighted ash values reported on the regional maps and tables earlier in this report 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 Number 4 seam are only very slight (figure 23). 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 throughout the entire mineable portion of the seam at section GC1 shows, however, that these slightly elevated basal and upper sulfur zones do tend to increase the overall "as mined" sulfur content to around 0.5% (figure 21).

The sulfur values in the Number 10 seam are very consistently around 0.3% (db, figure 24). Again, slightly elevated sulfur values are sometimes present near the top of the seam, though not apparently so at the base. In this seam the "as mined" channel sample shows a consistent sulfur value of 0.3% (db).

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

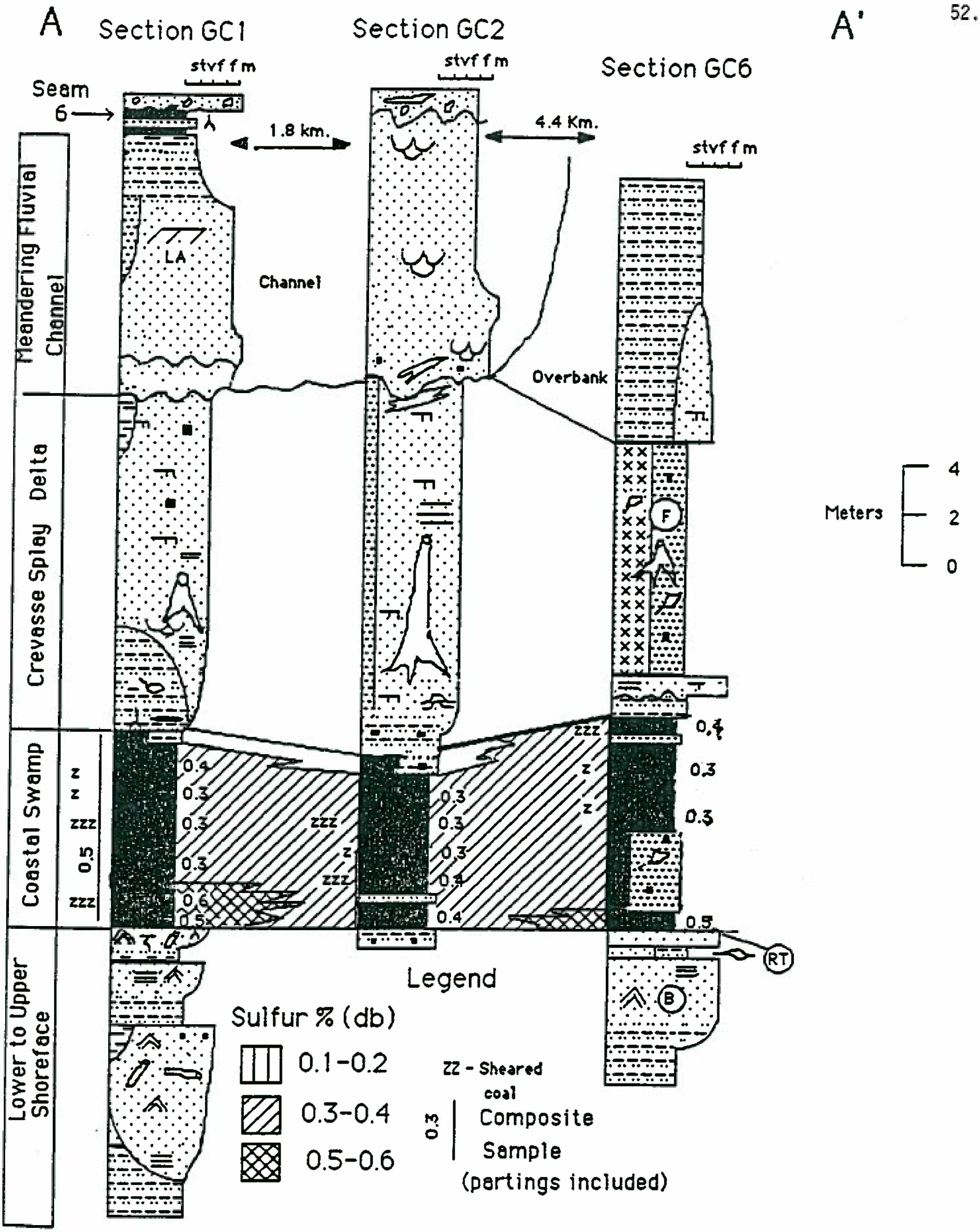


Figure 23. Stratigraphic cross section A-A' showing inseam sulfur variations within the number 4 seam and associated clastic depositional facies, Smoky River mine, Luscar Group coals.

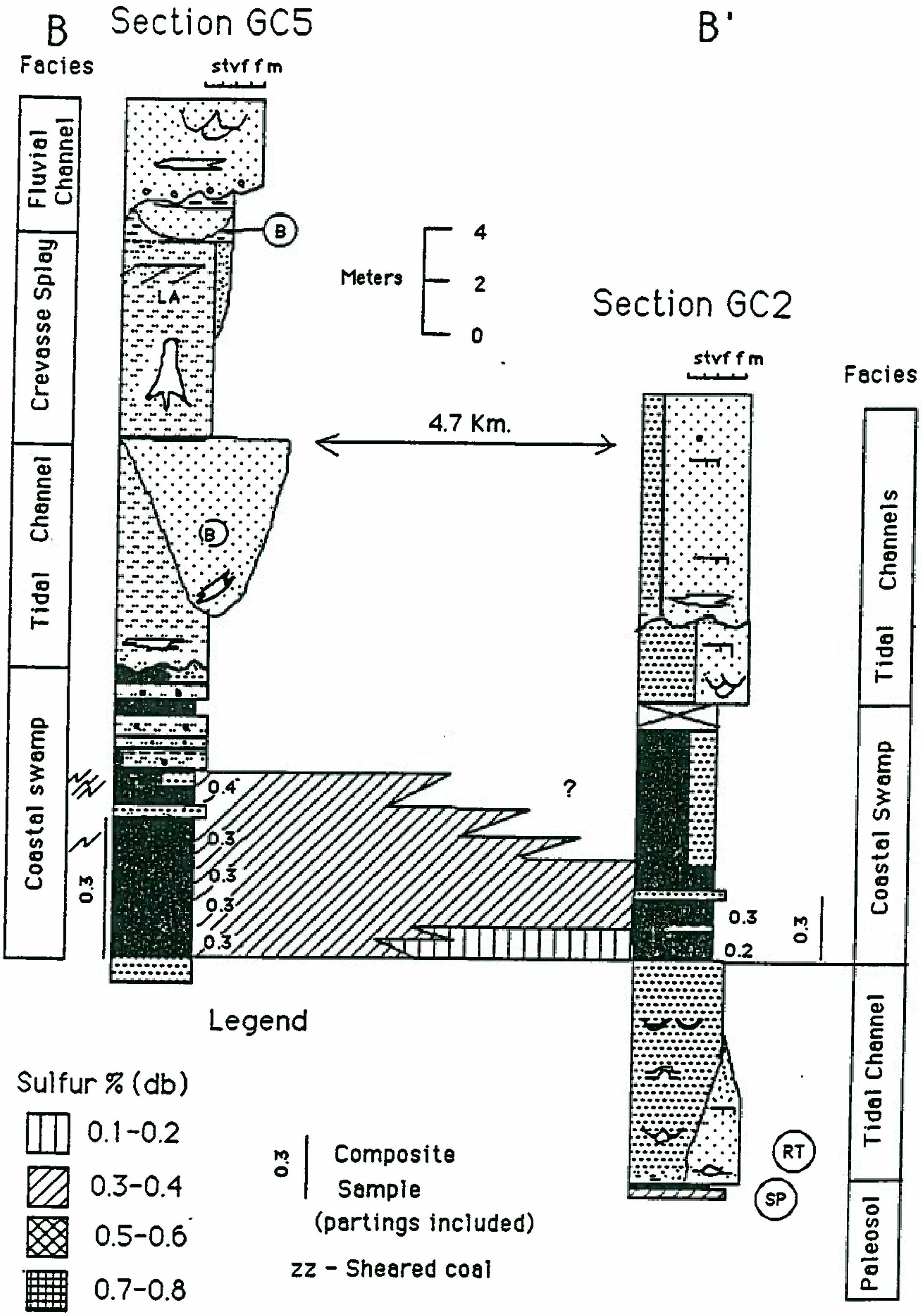


Figure 24. Stratigraphic cross section B-B' showing inseam sulfur variations within the number 10 seam and associated clastic depositional facies, Smoky River mine, Luscar Group coals.

Coalspur Formation Coals

Introduction

The Coalspur-Robb area was selected to study in-seam ash and sulfur variations within the Coalspur Formation coal zone (figure 25). 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 this area and informal names have been established along with regional stratigraphic correlations (figure 26).

The sampling strategy employed was to attempt 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 not only provide vertical profiles, but also to provide in-seam lateral variations (figure 27 and 28).

Depositional environments

Richardson et al. (1987) recognized that the Ardley coal zone thickened to the west - up to 600 m as did the total thickness of coal in the zone. The Ardley coal zone was said to have formed in a rapidly subsiding foreland basin during late Cretaceous to Paleocene time (Richardson et al. 1987). The same authors suggest that rapid subsidence near the basin axis (i.e. somewhere west of the present day Coalspur Formation 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 accumulate in a relatively quiet alluvial plain environment. Jerzykiewicz and McLean (1980) agree with the alluvial interpretation for coal formation in the Coalspur Formation and further suggest the following three sub-environments: 1) in abandoned channels; 2) in the overbank area of active channels and 3) on the floodplain, isolated from fluvial channels.

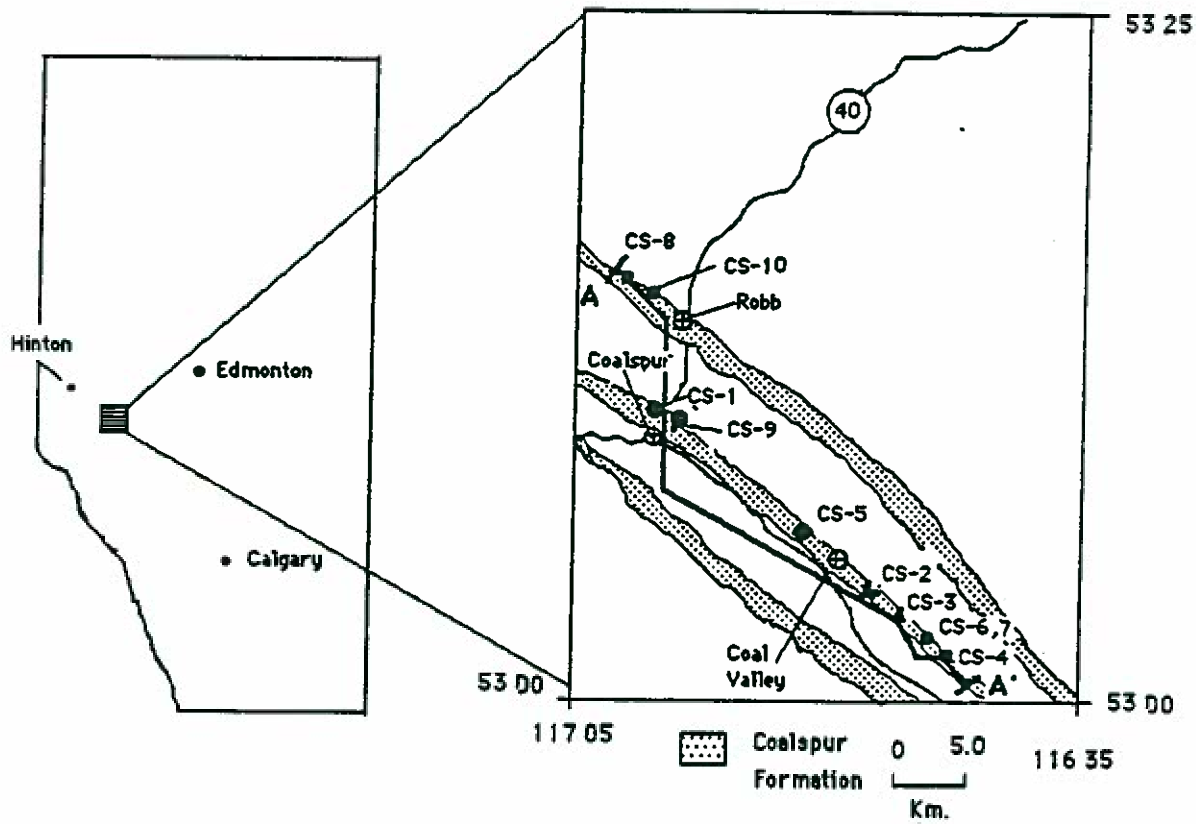


Figure 25. Location map of stratigraphic sections measured in the Coalspur-Robb area, Coalspur Formation coals.

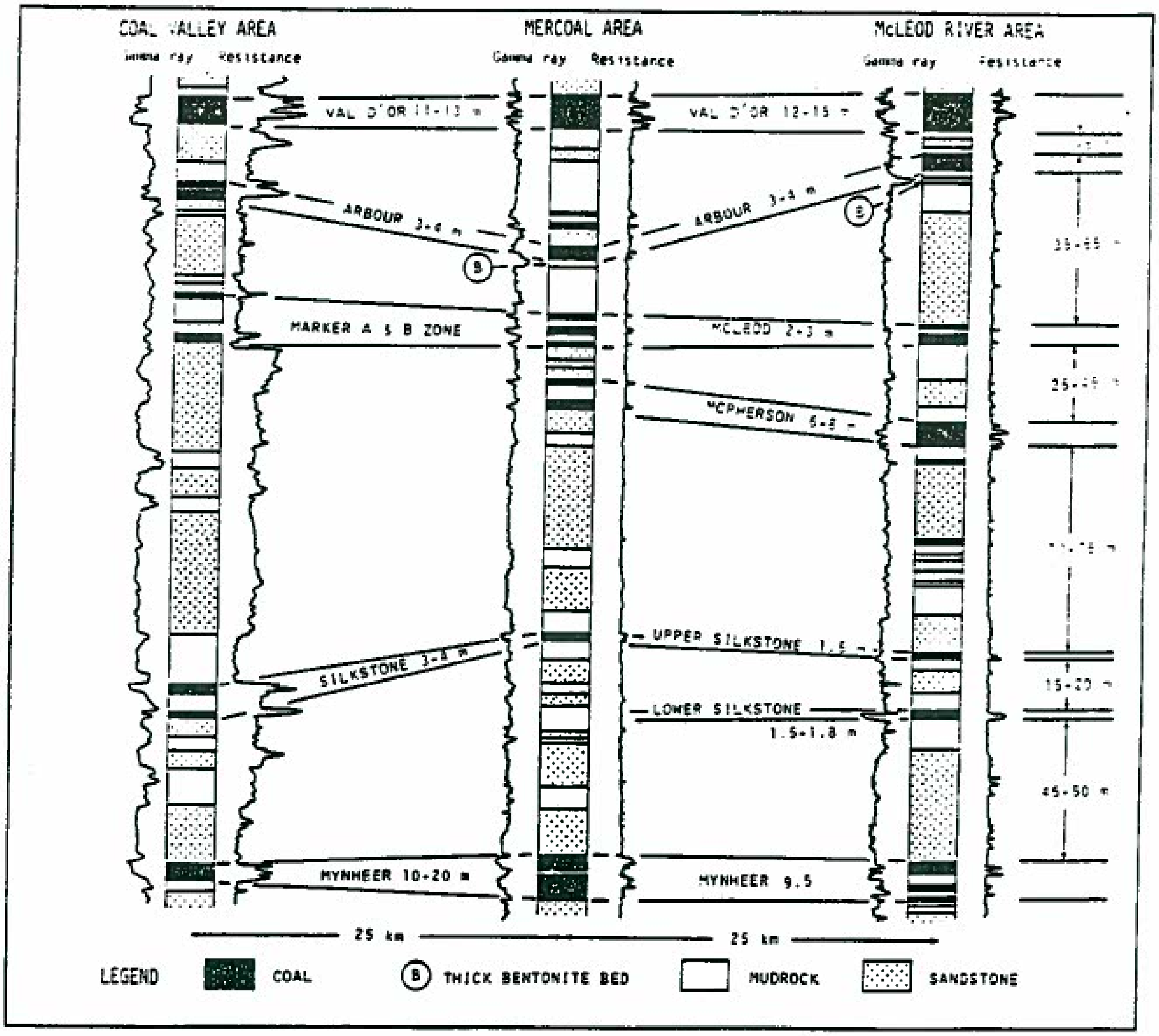


Figure 26. Coalspur Formation coal zone seam nomenclature and correlations on geophysical logs, Coalspur-Robb area (modified from Dawson et al. 1986).

Ash variations

Ash variations that can be attributed to the original sedimentary environment, within the Val D'Or Seam, are composed of mineral matter derived from at least three principal sources: as water transported clastic partings, as wind deposited volcanic ash beds and as inherent mineral matter derived from the original plant material (figure 27).

The majority of the discreet partings seen within the Val D'Or are bentonitic, derived from volcanic ash beds. The volcanic ash interpretation is supported by X-ray diffraction analysis performed on three of these beds, which show that they are composed of montmorillonite, quartz and cristobalite. The clay size fraction of these samples is between 95 - 100% montmorillonite, and <5% illite and or kaolinite. These partings are generally thin (<10cm) and are generally not possible to remove during mining operations.

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

The in-seam lateral ash variations shown on figure 27 are believed to be largely inherent plant derived mineral matter, as partings were generally excluded during sampling. It can be seen that this ash is generally moderate (11 - 34%, db) throughout much of the seam below the major crevasse splay deposit. Above this same splay unit, inherent ash contents are low to very low (<10%, db).

Again, from a mining perspective, channel samples taken through the entire seam that included the thin volcanic ash horizons, but excluded the thicker splay deposits show this "as mined" ash to be higher than the inherent ash. This is exemplified at section CS-4 in which the inclusion of the six volcanic ash beds nearly doubles the inherent ash values to give a relatively high "as mined" ash content (figure 27, 28%, db).

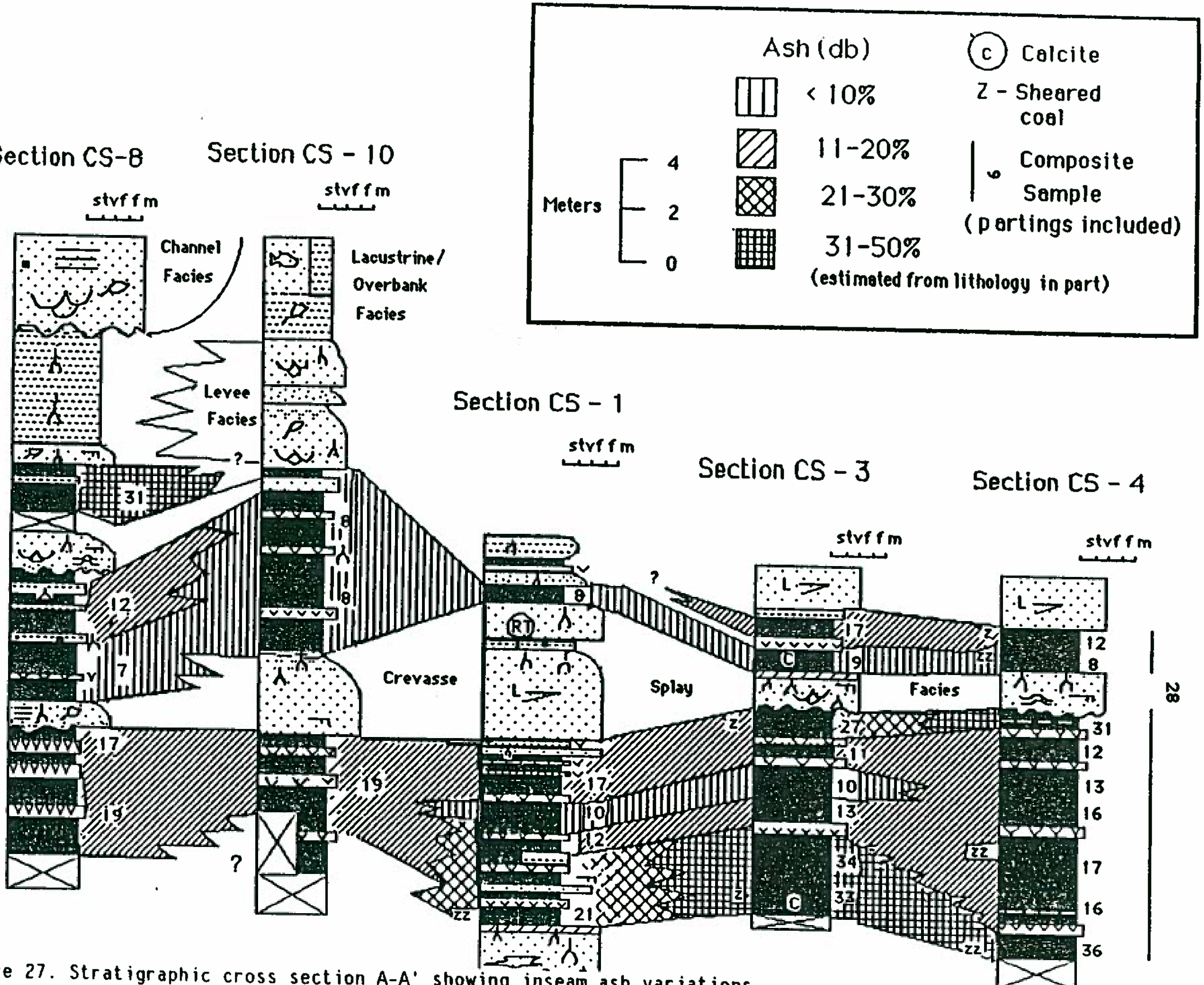


Figure 27. Stratigraphic cross section A-A' showing inseam ash variations within the Val D'Or seam and associated clastic depositional facies, Coalspur Formation coals.

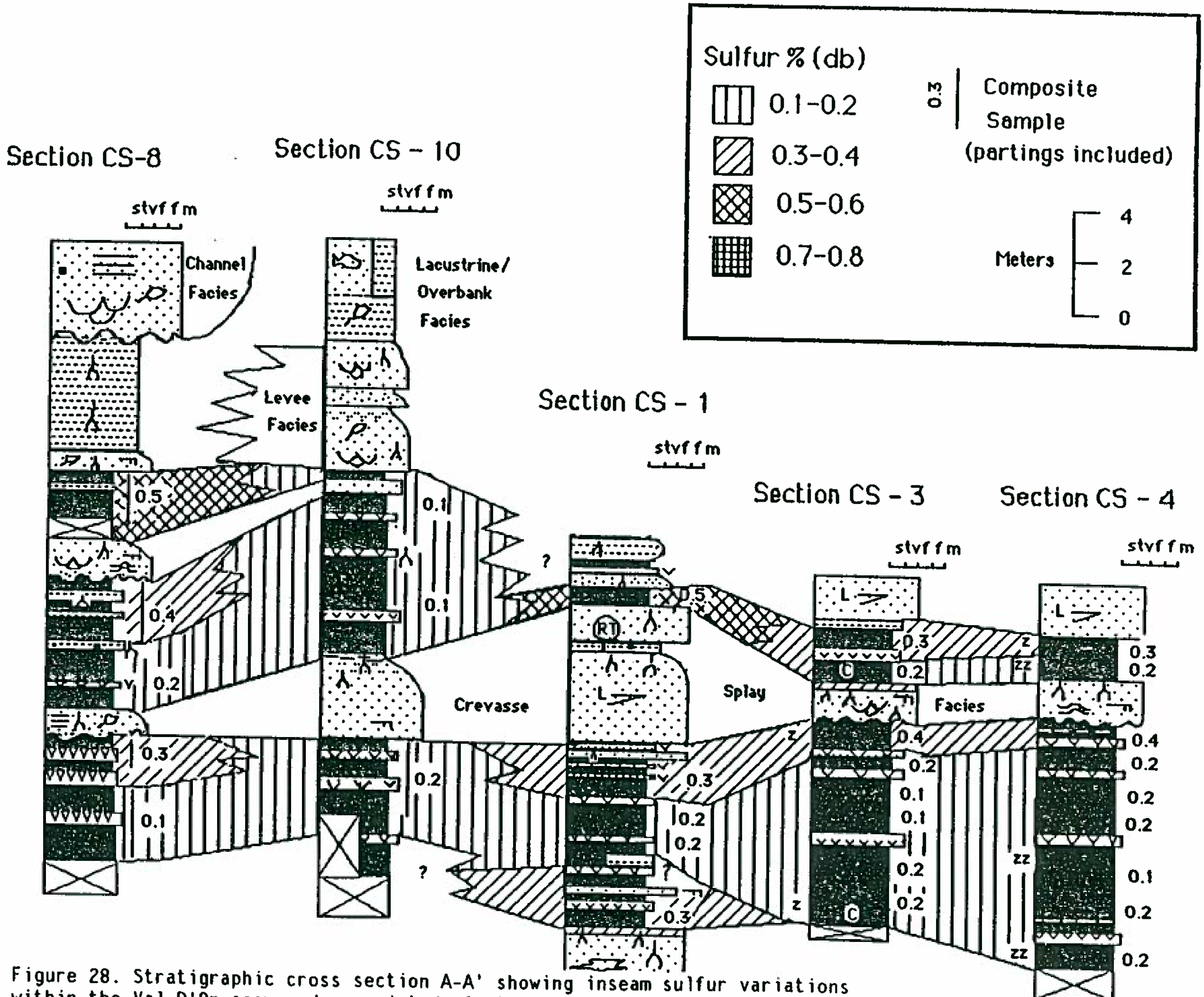


Figure 28. Stratigraphic cross section A-A' showing inseam sulfur variations within the Val D'Or seam and associated clastic depositional facies, Coalspur Formation coals.

Structural shearing and thrusting of coals into duplex and similar structures are believed to contribute to unpredictable ash contents, beyond what might be expected from the foregoing depositionally derived mineral matter. This structural influence has been documented in Kootenay Group coals by Bustin (1982) and Macdonald et al.(1987) and for the Luscar Group coals in the Cadomin-Luscar coalfield by Langenberg et al.(1988). This structural influence on ash content occurs through two mechanisms; 1) physical thrust repeating of partings into the coal, and 2) crushed and sheared coal being more susceptible to surface groundwater oxidation processes that reduce carbon content, leaving a relative enrichment in mineral matter.

Vertical in-seam ash distributions within the Upper Mynheer Seam show two cycles of decreasing-upward inherent ash values, with the top of the seam very high in ash (figure 29). The Upper Mynheer contains five volcanic ash partings, generally less than 10 cm thick each. The overall "as mined" section contains 23.1% ash, based on a channel sample throughout the entire seam - with the partings included.

The Arbour Seam, sampled along the Robb highway roadcut, contains up to seven thin volcanic ash horizons (generally less than 5 cm). When all of these partings are taken together to form a composite "as mined" channel sample the seam has an ash content of 24.7% (db, figure 29). 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 29).

The Silkstone or Wee Seam shows a characteristic reduction in inherent ash upward toward the center of the seam, and an increase again near the top (figure 30). All of the inherent ash 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 30).

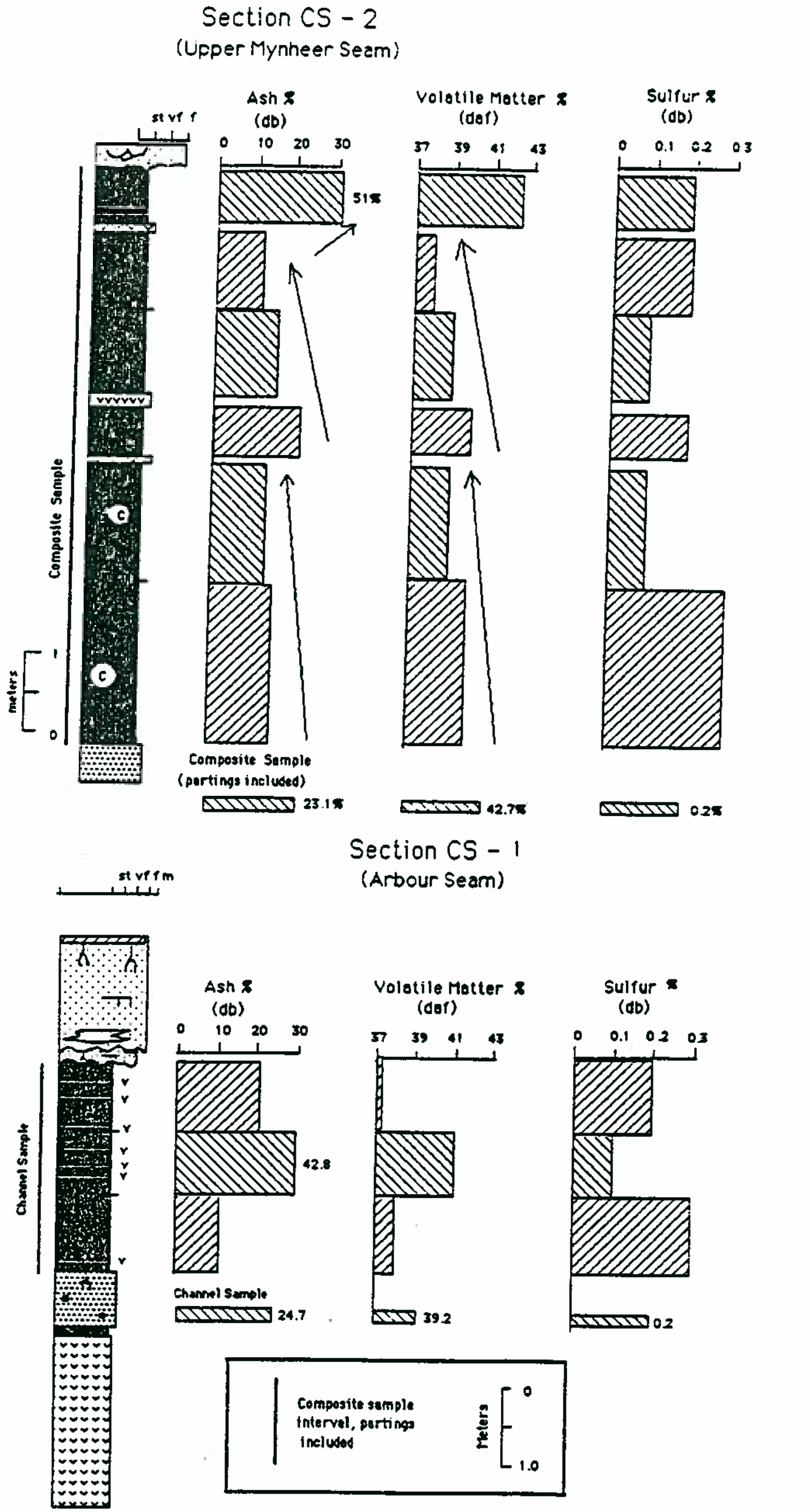


Figure 29. Vertical inseam ash and sulfur profiles for the Upper Myneer and Arbour seams, Coalspur Formation coals.

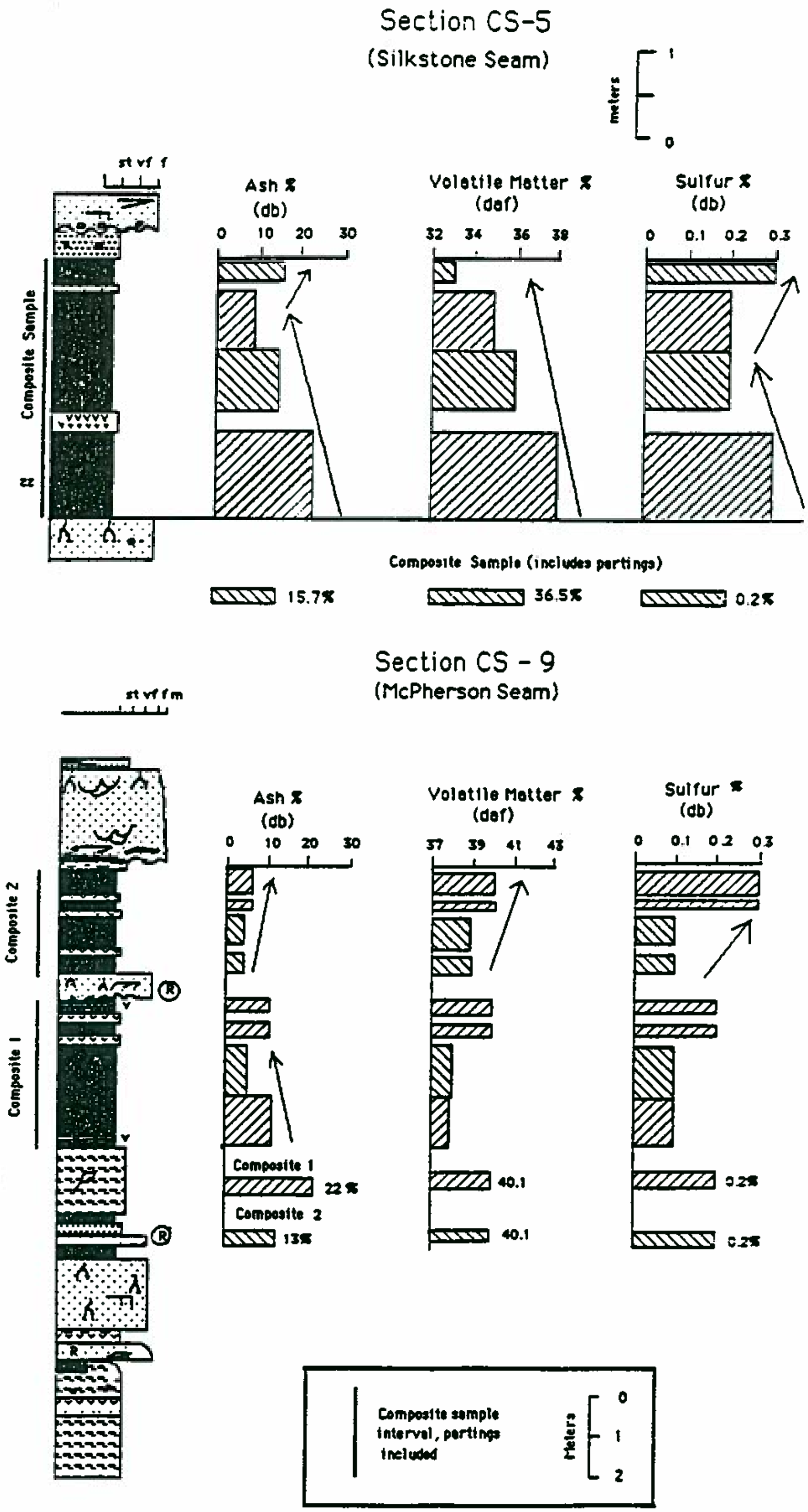


Figure 30. Vertical inseam ash and sulfur profiles for the Silkstone and McPherson seams, Coalspur Formation coals.

The McPherson Seam was sampled in an abandoned pit above the town of Coalspur (section CS-9, figure 25). This seam contains one major clastic crevasse splay partings, and six thin volcanic ash partings (each less than 5 cm). The splay deposit divides the seam into an upper and lower units, both having generally low inherent ash values (<10%, db). The upper seam has a composite "as mined" ash content (partings included) of 13%, while the lower has a composite of 22% (db, figure 30). The higher composite values for the lower seam are related to the slightly more numerous and thicker volcanic and clastic partings.

Sulfur variations

Sulfur variations within the Val D'Or Seam show a complex pattern of vertical and lateral in-seam variations (figure 28). Overall, the Val D'Or contains some of the lowest sulfur values encountered in this study, with most of the seam containing 0.1 - 0.2% (db) sulfur. Relatively "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 generalities 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 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 slight, with no values above 0.3% (db). Sulfur values seem to follow ash contents, to some degree, with increasing sulfur related to increasing ash. An "as mined" composite sample, that included partings, shows a sulfur value of 0.2% (db).

The Arbour Seam also shows a very slight in-seam sulfur variations; however, seemingly having an inverse relationship with ash (figure 29). The "as mined" composite sample has 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 30). "As mined" composite sulfur values are 0.2% (db) for the Silkstone Seam. Bonnell and Janke (1986) report that most of the sulfur in the Silkstone is of the pyritic variety.

The McPherson Seam shows the same "as mined" sulfur value as for the Silkstone (0.2%, db, figure 30). Vertical in-seam sulfur variations are predictable within the lower and upper seam splits and are low at the base and increase upward (figure 30). A relationship with ash is not apparent except in a few cases.

Volatile matter

In-seam vertical volatile matter content variation was examined within the Upper Mynheer, Arbour, Silkstone and McPherson Seams (figures 29 and 30). Volatile matter values seem to vary consistently within a 6% (daf) range within all of these seams. This in-seam variation helps to explain the statistical variation for the regional volatile matter contents within the Coalspur Formation described in an earlier section of this report.

Obed-Marsh coal zone

Introduction

The Obed-Marsh coal deposit is located approximately 24 kms. northeast of Hinton, Alberta, at the boundary between the Alberta Plains and the Foothills (figure 31). 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 the above 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 are preserved in the Marsh Block (figure 31).

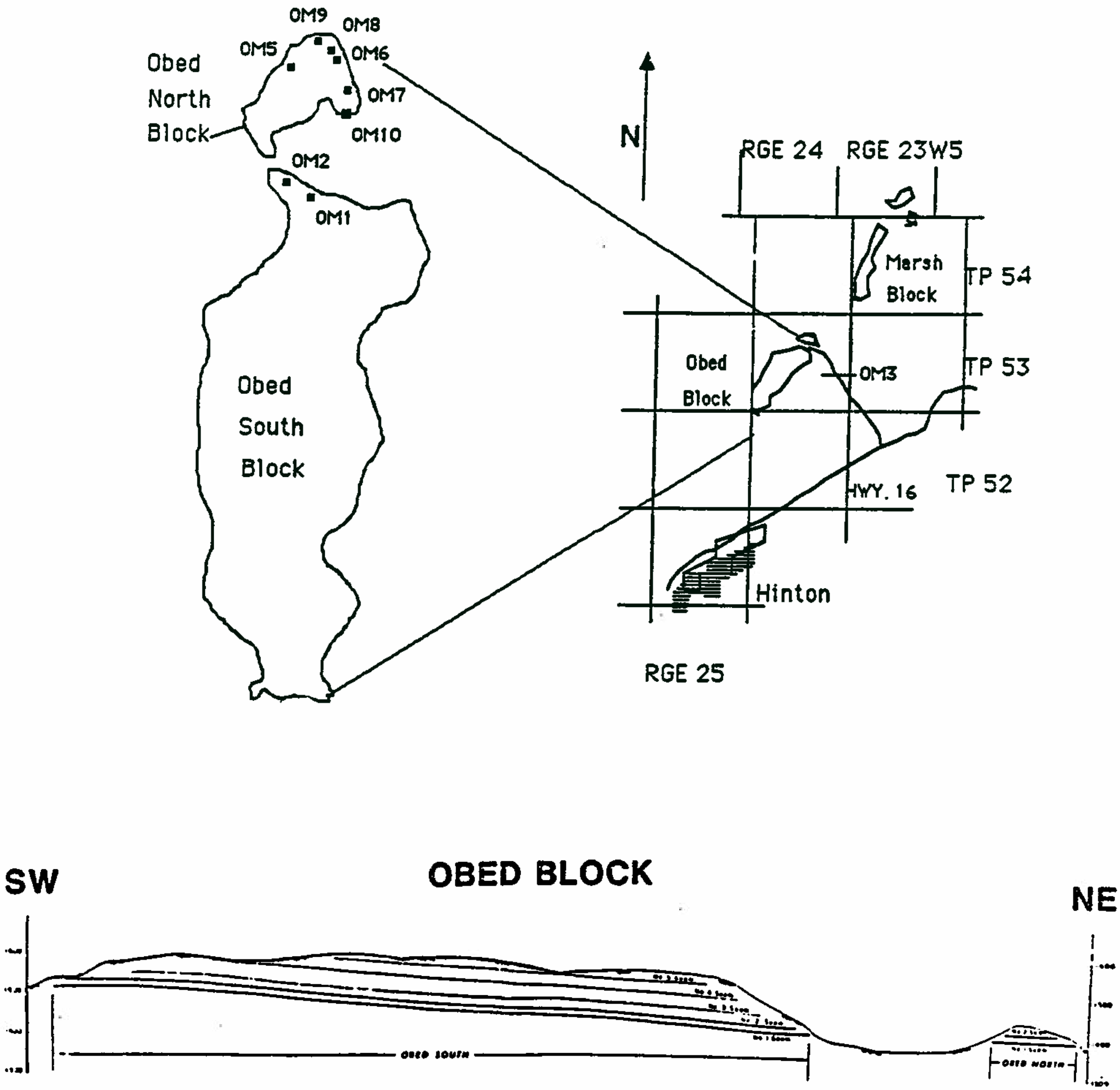


Figure 31. Location map, sections examined and generalized stratigraphic cross section of the Obed Mountain deposit and mine (from Dawson et al. 1986).

Three seam profiles taken from two exposures of seam 1 (sections 1 and 2, approximately 1.5 km apart) and one from seam 2 were measured and sampled. Only bands showing major lithotype changes were distinguished and each sample collected represents a lithotype interval within the seam profile. The coal and interbedded sediment samples were prepared, polished and analyzed for their maceral composition according to the ICCP (1971) procedures and classification. Some compositing of samples for coal quality determinations was done based on the sampling for maceral analysis.

Depositional environments

The environments of deposition surrounding the Obed-Marsh coals is separable into three time/lithostratigraphic units; 1) clastics which immediately preceded the coal-forming time, 2) the time of clastics which are found interbedded with the coal zone and, 3) the time of coal formation itself.

The clastics which immediately preceded the coal formation are the, largely non-coal bearing, Paskapoo Formation. Several excellent roadcut exposures of this unit are exposed along the road to the Obed Mountain mine (figure 32). Such exposures are typically fine to medium grained sandstones showing 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 fining-upward sequences (figure 32). Regionally, the Paskapoo Formation is recognized as being largely sandy in composition and having a very wide geographic extent (Green, 1972). A braid-plain or slightly meandering sands fluvial river system would be consistent with this evidence. Jerzykiewicz (1985) envisaged an anastomosing fluvial system for the sequence in general and attributes the coal zone and interbedded clastics sediments to the fine-grained coaly termination of a major depositional cycle.

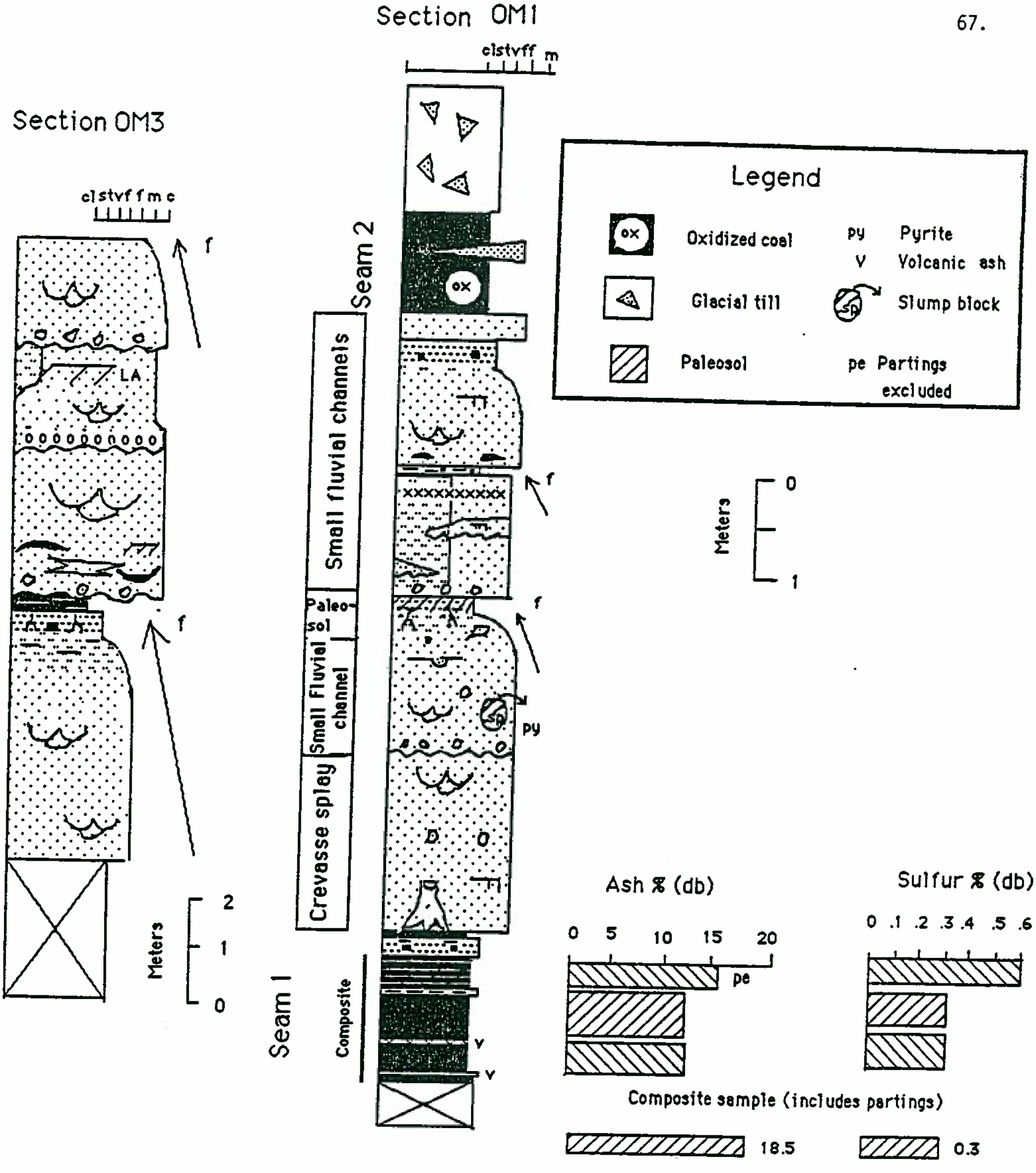


Figure 32. Stratigraphic sections OM3 and OM1 showing vertical in-seam ash and sulfur profiles through the No.1 seam and the sedimentology of the overlying and underlying strata within the Obed-Marsh coal zone.

The sedimentological interpretation for the clastics interbedded with the Numbers 1 and 2 seam is shown on a representative section from the mine (section OM1, figure 32). The sequence from the upper part of the Number 1 seam to the base of the Number 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 environmental interpretation, must then be consistent with the braid-plain interpretation for the underlying strata and with the smaller fluvial interpretation for the interburden sediments. The use of coal petrographic techniques was used to help establish an interpretation for the coal-forming environments of the Numbers 1 and 2 seam (figures 33 to 37).

Seam 1 Petrology

Humotelinite and humocollinite are by far the dominant macerals observed in most samples, followed by humodetrinite (figure 38, E). The cell structure of humotelinite is visible and the cell lumens are often impregnated by porigelinite, resinite and mineral matter (figure 38, A). Humocollinite has a range of 3.0 - 63.0% in most samples. Next to humocollinite, humodetrinite is the most abundant maceral ranging from 2.0 - 13.0%. It is present in the form of densinite and forms the groundmass for the intimate mixing of humic detritus with other liptinite and inertinite macerals (figure 38, D). Phlobaphinite is almost exclusively associated with suberinite or corkified cell walls and never exceeds 1.0% (figure 38, C). Humocollinite is the only maceral in the huminite group that shows any consistent variation within the seam, that being a generally increasing proportion up to the base of the major clastic split (figures 33, 34 and 36).

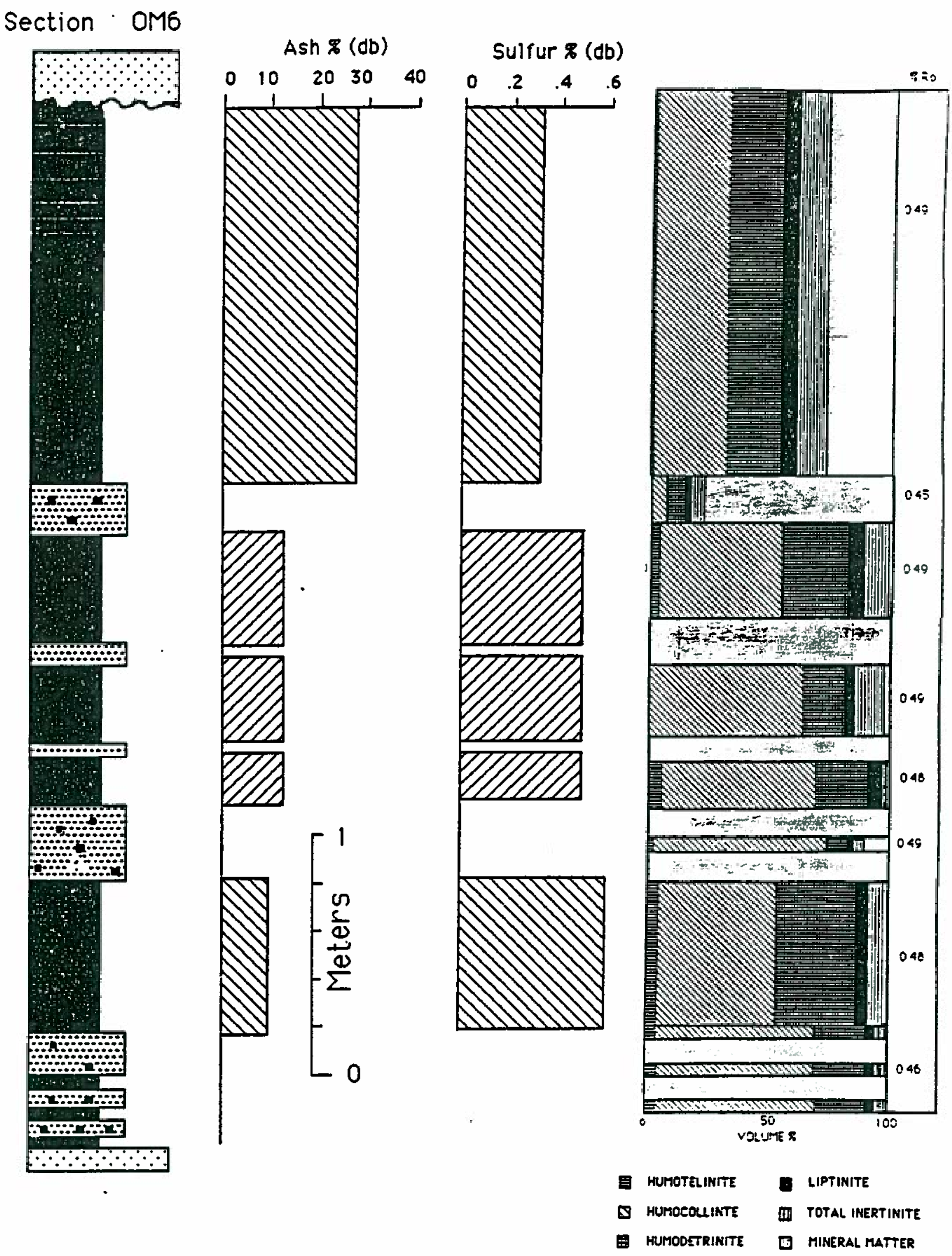


Figure 33. Vertical in-seam coal profile showing chemical and petrographic maceral distributions within the No.1 seam, stratigraphic Section OM6, Obed-Marsh coal zone.

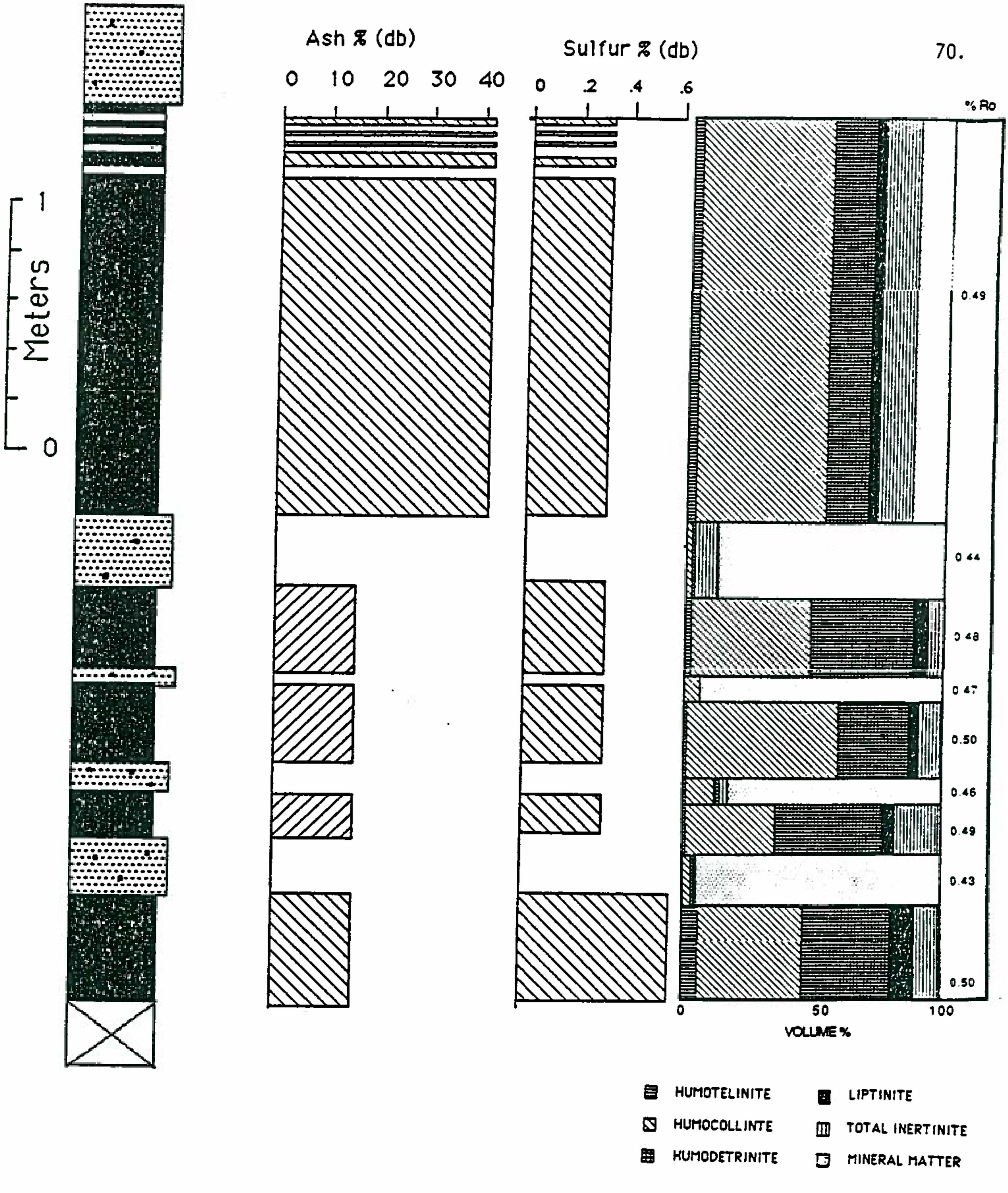


Figure 34. Vertical in-seam coal profile showing chemical and petrographic maceral distributions within the No.1 seam, stratigraphic Section OM7, Obed-Marsh coal zone.

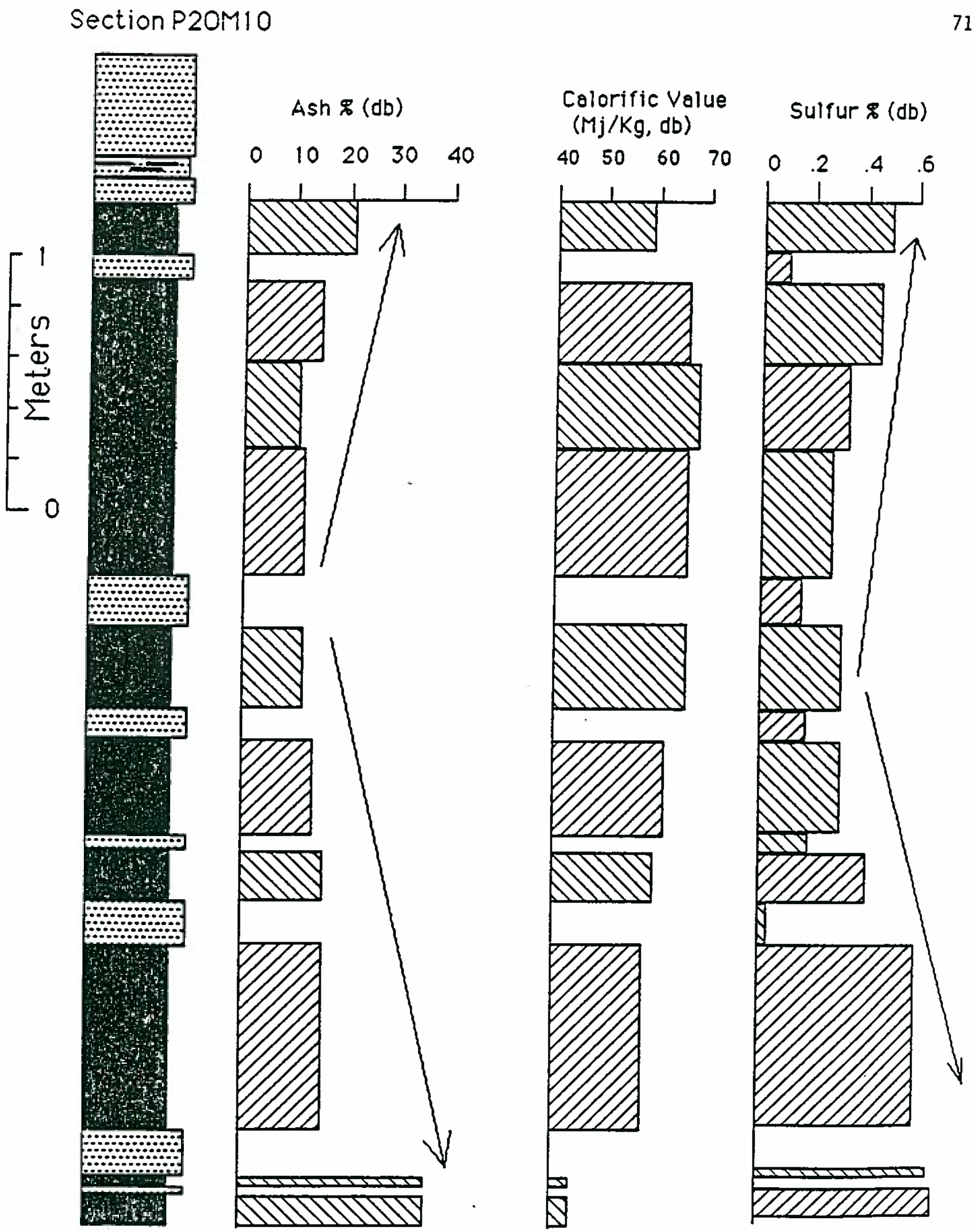


Figure 35. Vertical in-seam coal profile showing ash, calorific value and sulfur distributions within the No.1 seam, stratigraphic Section OM10. Obed-Marsh coal zone.

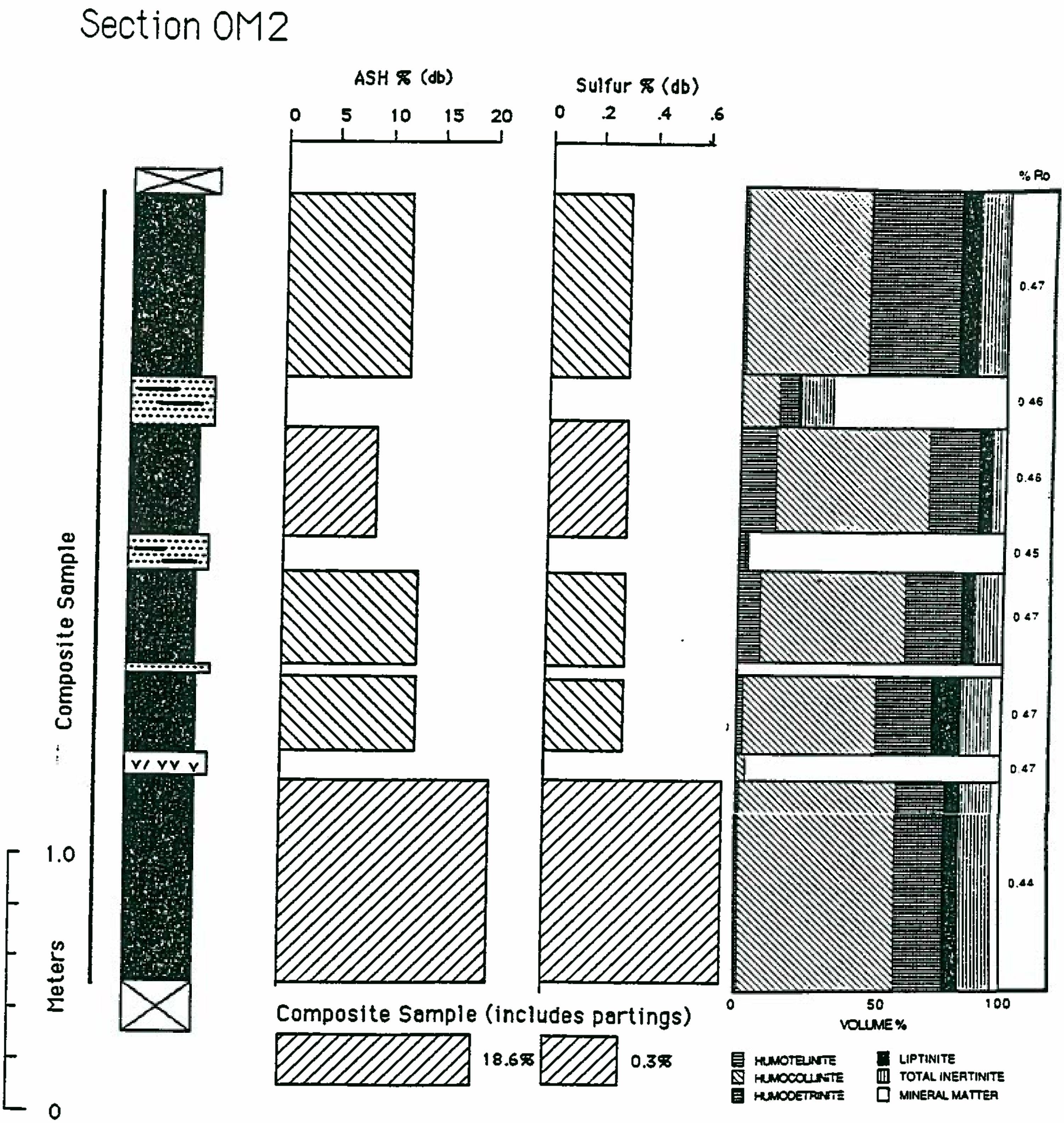


Figure 36. Vertical in-seam coal profile showing chemical and petrographic maceral distributions within the No.1 seam, stratigraphic Section OM2, Obed-Marsh coal zone.

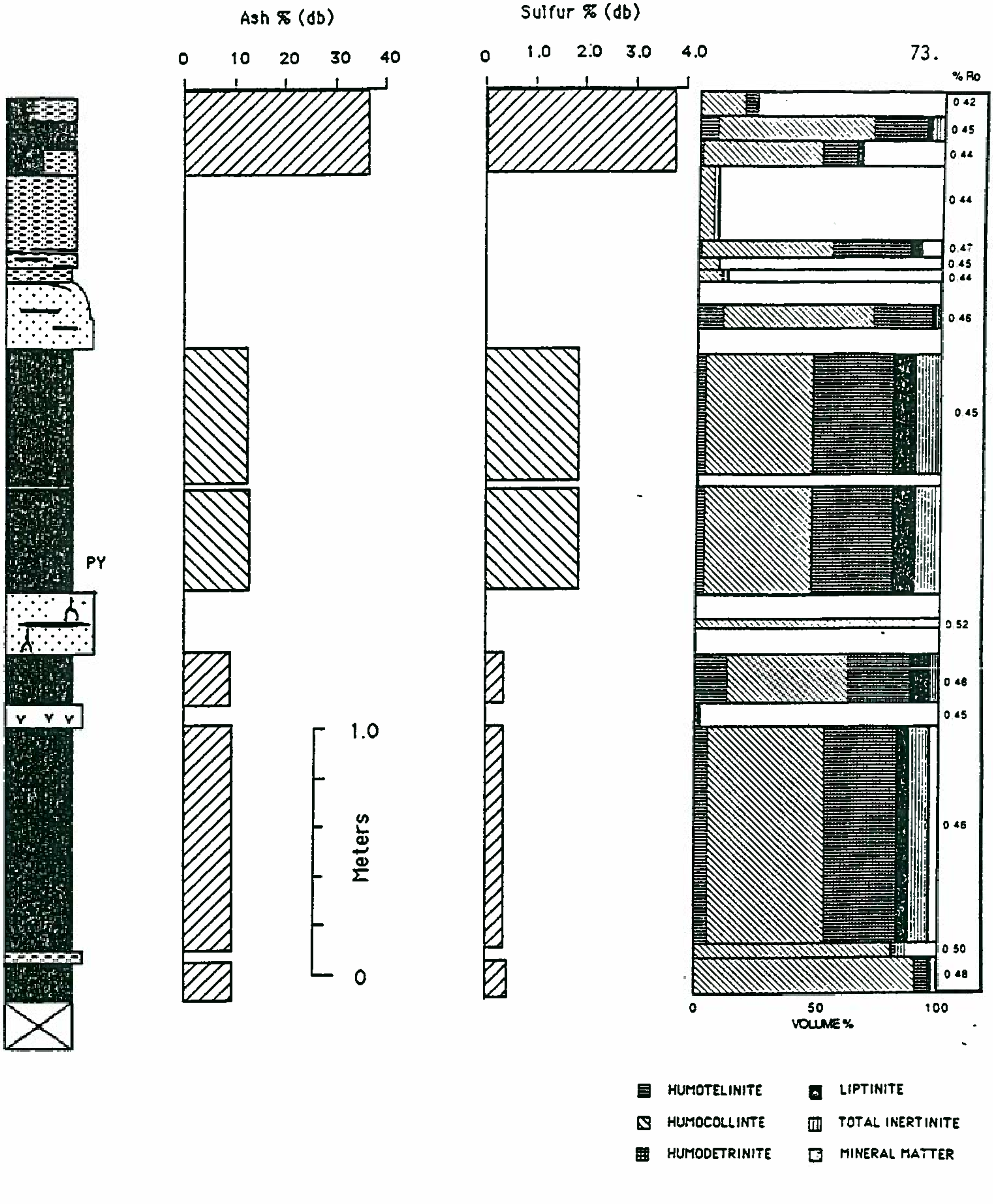
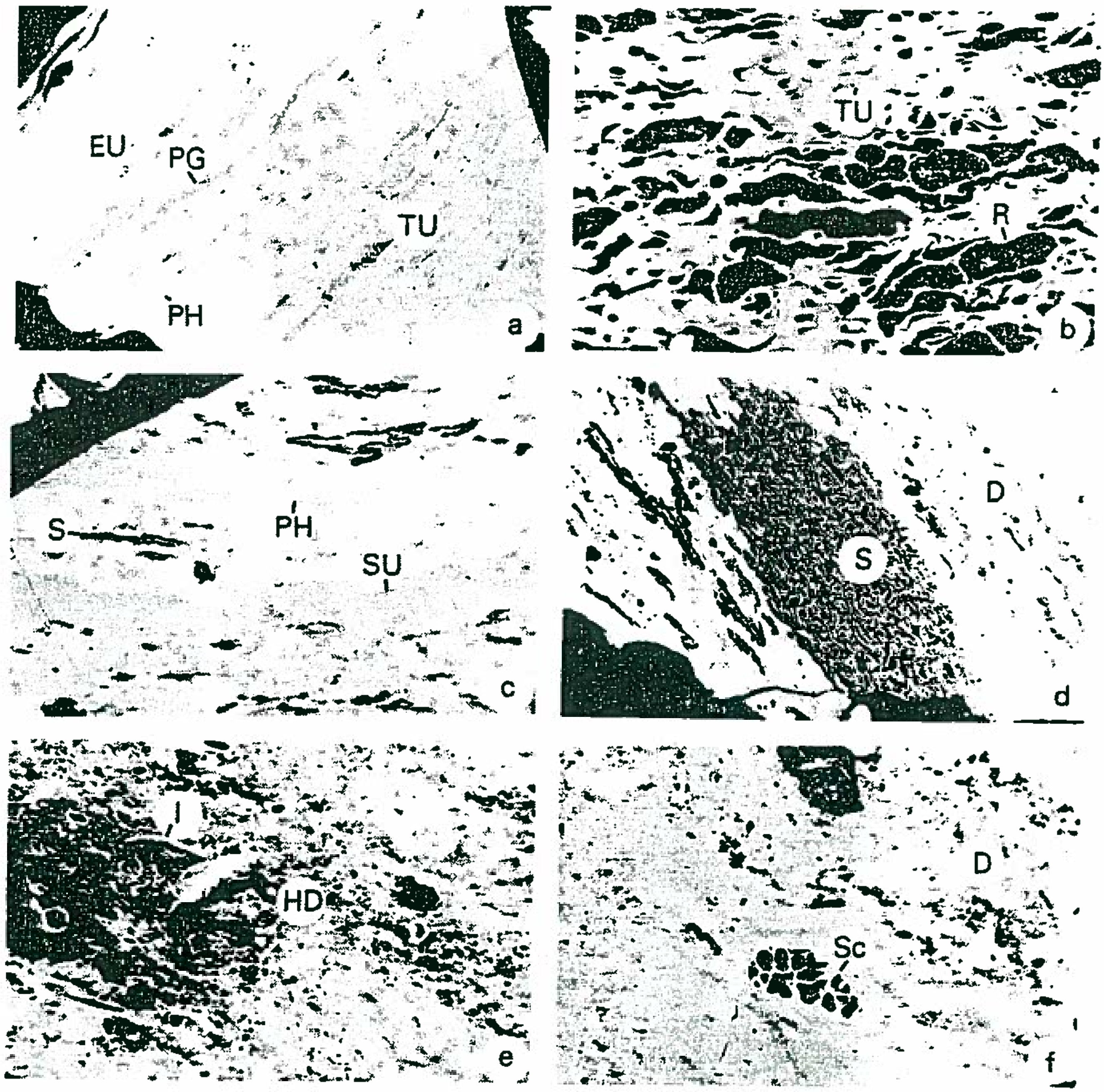


Figure 37. Vertical in-seam coal profile showing chemical and petrographic maceral distributions within the No.2 seam, stratigraphic Section OM5, Obed-Marsh coal zone.



All photomicrographs taken in black and white, under plane polarized light, oil immersion, 640X. a) phlobaphinite (PH) and porigelinite (PG) infilling cell cavities of texto-ulminite (TU). Note the transition from texto-elminite to eu-ulminite (EU). b) oval resinite bodies (R) infilling cell cavities of texto-ulminite (TU). c) association of phlobaphinite (PH) and suberinite (SU) in a cross section of a corkified cell wall. Note the presence of sporinite (S) in the huminitic matrix. d) a concentration of microspores (sporangia) (S) in association with densinite (D). e) humodetrinite (HD) enclosing fragments of inertinite (I). f) Sclerotinite (SC) in a densinitic groundmass (D).

Figure 38. Photographs of macerals, Obed marsh

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 (figure 38, F). Finally, low amounts of anisotropic inertinite occur throughout the coal seam. Pyrolytic carbon has been noted to be intimately associated with seemingly unaltered humocollinite. Inertinite content generally decreases from the base of the seam to the base of the major clastic split at section OM2 and OM7 (figures 36 and 34), and increases up to the same split at section OM6. The inertinite content above the major split is consistently relatively high, although the sampling interval was probably not sensitive enough to detect internal variations within this section.

Primary liptinitic macerals include sporinite (occasionally sporangia, figure 38, D), cutinite, resinite, fluorinite, and suberinite. Exsudatinite or secondary resinite is generally associated with primary resinite and amorphous fluorescing matrix. Total liptinite content ranges from 1.0 - 12.0%. Sporinite is the most abundant, followed by cutinite, resinite (figure 38, B), fluorinite and suberinite. Chitin has been informally, but suitably placed with the liptinite, and is very rare. Liptinite content remains relatively constant throughout the seam at sections OM6 and OM2 (figures 33 and 36), and decreases from the base to the uppermost top at section OM7 (figure 34).

Mineral matter content consists mainly of clays with minor pyrite. Mineral matter shows a good positive linear correlation with ash content profiles at all three sections, and is also positively related to inertinite contents at sections OM6 and OM7 (figures 33 and 34).

Seam 2 Petrology

Humocollinite is the most abundant maceral (44 - 93%), followed by humodetrinite (4 - 35%), and humotelinite (<15%) in the Number 2 seam. The relative proportions of these three macerals remain constant throughout most of the seam, except near the top and base (figure 37). Liptinite and inertinite are generally less than 10%. Liptinite increases upward to a maximum near the center of the seam, just above the major clastic parting, and then drops off again toward the top of the seam. The inertinite content is relatively constant throughout the seam, except immediately below the major clastic parting and at the top and base of the seam (figure 37).

Ash variations

The Number 1 seam contains 4 to 6 clastic and volcanic partings, which, when composited together to form an "as mined" sample show 18.5% (db) ash (figure 32). The vertical in-seam inherent ash varies from approximately 12 - 40% (figures 32 to 36), with high values typically occurring at either the top or base of the seam. It can also be seen from the maceral profiles on figures 33 to 36, that the high ash zones are associated with high mineral matter contents and high inertinite portions of the seam.

The Number 2 seam is not well exposed, at present in the minesite, and so only one section was available for study (figure 37). The seam contains only three partings of any significance. Inherent in-seam vertical ash contents are generally less than 12% (db), except for the uppermost portions of the seam, which rises to 38% (db). An overall upward increase in inherent ash is present throughout the seam. The accompanying maceral profile shows that the very high ash contents in the uppermost portion of the seam are due to both an increase in clastic partings and to plant derived mineral matter.

Sulfur variations

Sulfur variations within the Number 1 seam range from 0.2 - 0.6% (db), with the higher values almost always occurring at the top and/or the base of the seam (figures 33 to 36). Three out of the five sections sampled showed elevated basal sulfur values (up to 0.6%, db, figures 33, 34, and 36). One of the sections has elevated sulfur only at the top (figure 32), and one section has higher sulfur values at the top and bottom of the seam (figure 35). The partings, where sampled, generally have very low sulfur values (<0.2%, db, figure 35). Bonnell and Janke (1986) report that, from limited samples collected, organic and pyritic varieties of sulfur are in roughly equal proportions within the Number 1 seam.

The Number 2 seam was only sampled at one location and is unique in that it contains some of the highest sulfur values encountered throughout the course of this study (figure 37). Section OM5 (figure 37) is probably not representative of all sulfur values in the Number 2 seam. The in-seam sulfur profile shows a fairly typical upward increase in sulfur from the base of the seam, which corresponds to an increase in ash in the same direction. Bonnell and Janke (1986) report approximately equal proportions of organic and pyritic sulfur for the Number 2 seam, even when sulfur values become elevated. Field observations, however, show a large amount of visible pyrite on cleat faces within this seam.

Coal forming environments

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

Inertinite macerals, on the other hand, are mainly derived from the same plant components that form huminite. They do not undergo humification and gelification but are subjected to the process of fusinitization which 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 which have been subjected either to swamp fires or strong oxidation. The high inertinite content of some intervals in Number 1 and 2 indicates severe oxidation and the overall predominance of fusinite over semifusinite is indicative of the strong oxidation which completely fusinitized plant cell walls.

The generally persistent high ratio of huminite macerals to liptinite and inertinite macerals indicates a relatively constant reducing environment, a feature expressed also by the relatively low inertinite content of the coal. The bright and brittle bands observed macroscopically were formed under stable preservation conditions, not allowing rafting, mixing and oxidation. The above features suggest that conditions in the Obed peat swamp were such that the peat was covered by stagnant water, most likely resulting from a locally high water table. In addition, the well preserved cell lumens in huminite, the phlobaphinite-suberinite association which 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 a certain fraction of the plant matter experienced drier conditions, possibly in areas of slightly higher elevation.

Humotelinite has formed *in situ* (autochthonous) in areas inhabited by trees, whereas humodetrinite and the intervals rich in sporinite and cutinite associated with densinite attest to the presence of a reed marsh type of coal depositional environment. This area was inhabited by herbaceous vegetation (mainly shrubs) which produced large quantities of spores.

The prerequisites for accumulation of thick peat deposits are: 1) an adequate supply of plant matter, 2) a delicate balance between the groundwater level and peat surface, and 3) 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) has pointed out it is highly unlikely that thick, low-ash peats will accumulate adjacent to such an environment, because of the almost continuous flooding events, typical of such systems. This objection can be addressed for coals found in an alluvial setting by suggesting that the swamps were protected in time and/or space from such clastic flooding events. Raised swamps, with their upward domed shape, and very low ash and sulfur values have recently been suggested by several authors to explain how swamps might be spacially protected.

The coal-forming depositional environment for the Numbers 1 and 2 seam is envisaged to be a distal floodplain, generally isolated from active channels, except during deposition of the interburden. The Numbers 1 and 2 seam, crevasse splay and small fluvial channels lying between them, suggest periods of relative quiescence which permitted the establishment of forested peat lands punctuated with periods of brief periods of minor fluvial activity.

The evidence from the Number 1 seam suggests there was a balance between the water level fluctuation, rate of subsidence and accumulation of vegetal matter during peat deposition, which resulted in the formation of uninterrupted, thick and moderately low-ash coal with minor quantities of mineral matter. The combined petrographic/chemical evidence points to an evolution from; an initially restricted, alkaline swamp conditions at the base - yielding high-ash, low sulfur coals; to the central portions of the seam which represented the maximum extent of the swamp - yielding low-ash, very low-sulfur coals; and finally to the upper part of the seam which again became alkaline due to the encroachment of the small fluvial and crevasse splay systems - yielding a high-ash, low sulfur coal. The moderately high inherent ash contents, coupled with the presence of some water-derived clastic partings preclude a raised swamp model, in favor of a low-lying swamp for the Number 1 seam (Cecil et al. 1985).

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 indicate a high degree of autochthony (Teichmuller, 1982; Goodarzi and Gentzis, 1987). Most of the thin partings are thought to be volcanic ash in origin and because of the very low sulfur values present (figure 35, <0.2%, db), a strongly acidic environment was probably produced shortly after the ash fall.

The Number 2 seam likely developed as a low-lying, planar swamp that was intermittently flooded with clastic material. Strongly oxidizing peat swamp conditions toward the end of the Number 2 seam time, would lead to a high-inherent ash and high-sulfur peat as suggested in the general geochemical model of Donaldson et al. (1980).

REGIONAL COALIFICATION

The map of regional variations in volatile matter contents (figure 5) provides information about levels of coalification in the study area.

Luscar Group

The information from proximate analyses in the ERCB data set is concentrated in the four designated coal fields, i.e. from southeast to northwest the Cadomin-Luscar, Moberly, Smoky River and Kakwa River coal fields. Information about the Cadomin-Luscar coal field in the ERCB data set is very limited, however, recent fieldwork by the Alberta Geological Survey has filled this gap (Langenberg et al., 1988). 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 by vitrinite reflectance measurements from samples collected in areas in between these coal fields (for example in the Willmore Wilderness Park, see figure 5).

Although no stratigraphic information is available in the ERCB coal quality data files, it is safe to assume that a lot of samples are from the basal part of the Gates Formation (base of Grande Cache Member). Most of the commercial coal is from that part of the section. Examples are the Jewel Seam of the Cadomin area and the Number 4 seam of the

Grande Cache area. The Numbers 10 and 11 seam of the Grande Cache area and seams higher in the section of the Kakwa area were probably also sampled. Consequently, the volatile matter content for the base of the Gates Formation in the Kakwa and Grande Cache areas, estimated from drill holes, may be somewhat lower than the true values. However, the consistency with volatile matter contents, determined from vitrinite reflectance of outcrop samples that have good stratigraphic control, indicate that these deviations are small. The contoured map of figure 39 shows a very consistent rank pattern, where the highest rank (low volatile bituminous) is along the northeastern side and the lowest rank (high volatile A bituminous) along the southwestern part of the area. It should be noted that no sudden changes in rank across major thrust faults can be observed.

A pattern of westwards decreasing rank for the Gates Formation was observed by Kalkreuth and McMechan (1984) in the area northwest of Grande Cache. This decrease in level of coalification westwards was explained as 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 eastwards 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 was largely pre-deformational on a local scale.

In the Cadomin-Luscar coal field, 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 coal field, with a decrease in rank both to the southwest and the northeast. This pattern may be compared with the westward and eastward decrease in maturation of the Lower Cretaceous from a maximum near the edge of the deformed belt (Kalkreuth and McMechan, 1988). The interesting fact to notice is that the maximum rank is exposed at the surface in the Foothills of the

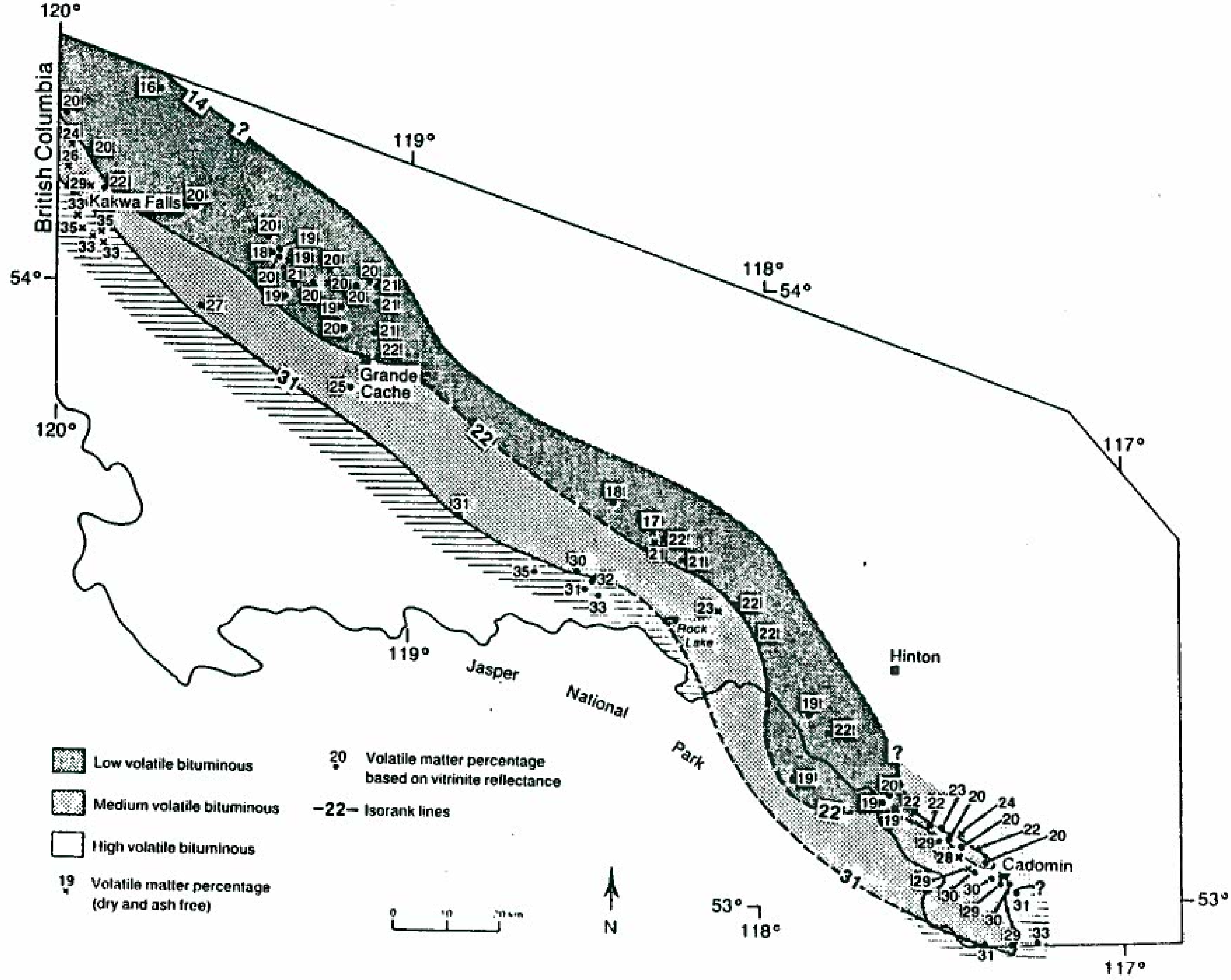


Figure 39. Volatile matter variations at the base of the Grande Cache member.

Cadomin area, while in the Grande Cache area the highest rank was determined in the subsurface of the interior plains. Information from oil wells will have to be collected to verify if the decrease in rank eastward continues in the subsurface northeast of Cadomin.

The rank variation of the base of the Grande Cache Member displayed on figure 39 can be explained by variation in three possible parameters: 1) paleo-geothermal gradients, 2) depth and duration of stratigraphic burial, 3) tectonic burial history, or a combination of these parameters. Unfortunately, no detailed information on paleo-geothermal gradients is available for the study area (some suggestions can be found in Hitchon, 1984). Kalkreuth and McMechan (1984) assumed a paleo-geothermal gradient similar to the present day geothermal gradient of 27°C/km for the area northwest of Grande Cache. This may also apply for the present study area and consequently the rank variation would not be explained by variations in geothermal gradients. However, the deflection of the isorank lines southwest of Hinton may not fit this model and could possibly result from a 'hot spot' related to a high geothermal gradient (Jones et al., 1985).

There are insufficient exposed sections or drill holes to construct isopachs for the Luscar Group (see also McLean, 1982) and consequently, little information is available on variation in depth of stratigraphic burial because of extensive erosion. It seems reasonable to assume about 5500 m of burial for the base of the Gates Formation (see also Kalkreuth and McMechan, 1984). The isorank lines run largely parallel to the trend of the foothills, indicating that they may be related to burial in a linear foreland basin during late Cretaceous and Paleocene 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 by this basinal model. The rank distribution likely result from components of syndeformational coalification (Langenberg et al., 1988). It is concluded that the rank variation shown on figure 39 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 5). Rank determinations based on vitrinite reflectance indicates a slightly higher coalification for 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 of the two locations. This might indicate that vitrinite reflectance is better suited to indicate 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 show an average random vitrinite reflectance of 0.47% in a range from 0.43 - 0.52%. These reflectance measurements were performed on the maceral eu-ulminite B. From this random reflectance the average maximum vitrinite reflectance can be estimated at 0.50% (table 5) by the formula Rmax=1.066*Rm (Bustin et al., 1983, p. 109). Based on its reflectance the coal is classified on the boundary of bituminous and subbituminous coals 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 than Coalspur coals for the Obed coals. This conclusion is substantiated by Bonnell and Janke (1986), who show differences in equilibrium moisture between Obed coals (mean of 4 samples is 13.3%) and Coalspur coals (mean of 6 samples is 9.2%), indicating slightly lower rank for the Obed coals.

CONCLUSIONS

Several conclusions can be drawn from this study. These are presented below and organized by selected topics.

COAL QUALITY DATA SET

The publicly available Energy Resources Conservation Board, raw coal data set has sufficient information, when combined with recently collected Alberta Geological Survey data, to describe the regional coal rank trends throughout this area. Calorific value is adequately described with this data set for the Coalspur and Obed-Marsh coals; however, not for the Luscar Group. This shortcoming is directly related to the present use of Luscar Group coals, i.e. as metallurgical coals. Industry, the main data source has largely ignored their future potential as possible thermal coals (except at Smoky River). Ash content for all three coal zones cannot meaningfully be described, on a regional scale, with the present data set. This is due to the lack of: numbers of measurements, information on stratigraphic position, and in-seam variations. Sulfur variations are generally very small and the present data set is adequate to characterize the coals, in a statistical and regional sense - but not in a stratigraphic or mine-scale sense. Ultimate analyses data is almost nonexistent for all coal zones.

COAL RANK

The rank of the Luscar Group coals has been defined to be in the low volatile to high volatile "A" bituminous range, using volatile matter and vitrinite reflectance. 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, together with minor effects of tectonic burial. The rank of Coalspur Formation coals is generally high volatile bituminous "C", and shows a slightly higher degree of coalification in the southwest versus northeast (at least in the Coalspur-Robb area). This coalification pattern is believed be pre-deformational, with maximum coal rank derived from 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 pre-deformational and is related to post-Paleocene final infilling of the basin.

CALORIFIC VALUE

Calorific value is highest in the Luscar Group coals (mean 35.5 Mj/Kg) and approximately the same for the Coalspur and Obed-Marsh coals (30.0 - 31.0 Mj/Kg). Within a given seam, of fixed rank, calorific value is almost directly related to ash content. A vertical in-seam profile at the Obed Mine shows how this variation occurs at a single location from the bottom to top of the seam. Linear regressions suggest these relationship to be: CV(db) = 36.2 - 0.39*Ash (db) for Luscar Group coals, CV(db) = 31.0 - 0.32*Ash (db) for Coalspur Formation coals with <30% ash, and CV(db) = 31.7 - 0.34*Ash (db) for Obed-Marsh coals. Correlation coefficients for the three zones are; -0.99, -0.92 and -0.96 respectively.

ASH

Ash content reported for coals is a complex problem. Ash content in these coals is generally separable into three components; inherent ash derived from original plant mineral matter, water-lain 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. the peat, however, total ash or "as mined" ash (which would include all non-removeable partings) should be examined if the coal is being evaluated from a mining perspective. For this reason, it is very difficult to report an average, mean or median ash value that has any meaning at all. Notwithstanding the above, the reported ash values in this data set suggest a similar range of ash values for all three coal-bearing units, with the Luscar Group coals having the lowest median value. Inherent in-seam ash variations, for all three coal zones, generally ranges from 5 - 20% (db), this reflecting the original geochemical swamp conditions. The lowest inherent ash values tend to be found at the center of seams and is related to the original maximum extent of the coal swamp. Total or "as mined" ash starts with this range of inherent ash values and is then governed by the thickness and number of non-removeable partings present. Partings in the Luscar Group tend to be water-lain clastics, those in the Coalspur Formation tend to be of volcanic ash origin, and those in the Obed-Marsh tend to be of mixed origin. Ash has also been statistically related to calorific value and to a minor extent to volatile matter.

SULFUR

Sulfur values reported in this study generally support the widely held belief of Western Canadian coals being low-sulfur in nature. Statistically, 75% of the sample populations from all coal zones, have sulfur values less than 0.5% (db). All three zones, however, have sulfur value outliers (i.e. the other 25%) which can range up to nearly 3.0% (db). The Coalspur Formation coals have the largest percentage of their sample population with the lowest sulfur values (i.e. 75% of the population less than 0.4% db) among the three coal-bearing units. In-seam sulfur studies of the three coal-bearing units, at three small areas, show that elevated values do commonly occur at the base; top; and immediately below major water-borne clastic partings or underlying fluvial or tidal channel deposits. These elevated values are typically only in the 0.5 - 0.7% (db) range, however, knowing where such values exist stratigraphically within a seam, may become significant if very low-sulfur export coals are being marketed. At least one of the mine operators in this area has been selectively mining for this type of coal. With growing concerns for the environment and low-sulfur emissions from thermal coals, it may in the near future not be sufficient to say Western Canada has .."low sulfur 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 were largely determined by the original depositional environment and vary considerably both vertically and laterally within a given coal seam - let alone a coal zone. For these variables, the regional maps should only be used as guidelines in local areas to suggest what the ash or sulfur contents might be. The rank related variables, volatile matter, vitrinite reflectance and fixed carbon do show real regional trends and can be used to predict coal rank throughout this area. Moisture content is a function of rank, reporting basis and sampling procedure and so caution should be used in interpreting moisture from the regional maps. Calorific value is a function of both rank and ash content and should therefore only be compared, on a regional basis, within a given coal rank. Within this restriction, however, one does not know how the ash content is varying in an in-seam vertical or lateral sense, and so again caution is advised.

RECOMMENDATIONS

The results of this study suggest a number of recommendations for future coal quality related work in the northern foothills/mountains region.

1. The Energy Resources Conservation Board (ERCB) coal quality data set would be of much greater value if more geological data were collected to help put the coal quality data into context. Details such as: coal zone identification, seam name (if known), structural orientation of drill hole samples were derived from stratigraphic member names, etc., would all greatly help to enhance the data set.

2. The ERCB collect more in-seam coal quality data from sections that are believed not to be structurally thickened, and to also ensure that the seam name is identified. This would help to understand the inherent coal quality heterogeneities, i.e., those imparted by the original depositional environment and burial, from later structural deformation imparted heterogeneities. Doing this, would start the process of characterizing the quality of Alberta coal seams on an individual basis, which might help producers exploit new utilizations. Using different portions of a single coal seam for several different utilizations is a very new area. This individual in-seam quality characterization is in a well advanced state in some of the more well developed coal basins of the world (e.g. eastern U.S.).

3. A wider variety of coal quality data should be routinely collected by both industry and government to be better able to capitalize on new opportunities in coal utilization when they arise. For example, the Luscar Group has the highest calorific value of any of the coals in this region; however, the regional distribution of calorific value is only known of in the Grande

Cache area. Other examples show that there is very little information on ultimate analysis or trace elements in these coals, severely limiting future opportunities.

4. Regional coal quality variations can not really be adequately described with the present data set for most variables. The approaches outlined in this report, which involve examining more detailed in-seam vertical and lateral quality variations at the coalfield scale, will eventually lead to a more thorough understanding of regional coal quality variations.

5. Detailed geologic mapping should be undertaken for all the major foothills/mountains coalfields in Alberta on a 1:50 000 or more detailed scale. This would provide a better stratigraphic and structural framework for understanding coal quality variations. At present, only two such coal fields have been mapped at this scale (Grande Cache and Cadomin-Luscar).

6. The representativeness, scale of examination and why the samples are being evaluated are three factors which must always be kept in mind during any coal quality evaluation. In situ single spot samples, such as those documented by Bonnell and Janke (1986) for most producing coal mines in Canada, while generally falling within regionally established values, are really only representative of coal quality at the specific sampling location at that particular time. Coal quality from this study and others (Langenberg et al. 1989) have shown that coal quality varies on the regional, coalfield, pit, seam and centimeter scales. Channel samples collected for mining purposes are not suitable for swamp depositional model related work - the "why" of sample collection is very important.

7. There is a common perception among the public and the coal industry that Alberta coals are low in sulfur and of no concern. This study has shown that this belief, as a generality, is true. However, with the growing concern over the environment, it will

likely become necessary in the very near future for export thermal coal producers to know precisely where in the seam, the very low sulfur coals occur, in order to remain competitive. In-seam vertical and lateral sulfur profiles will become increasingly important. Metallurgical coal producers in an increasingly competitive market may need to have an increased awareness of vertical and lateral in-seam coking properties in order to meet contract specifications. In-seam ash variations and their prediction will continue to be important to both export thermal and metallurgical coal producers.

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