Coal Quality In The Ardley Coal Zone, Plains Region of Alberta

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FOREWORD

The Coal Geology Group of the Alberta Geological Survey is completing studies on coal quality of the Ardley coal zone in the plains region. This work is part of a three-year contract from 1986 to 1989, jointly funded by the Alberta Office of Coal Research and Technology and the Alberta Research Council. The objectives are to characterize Ardley coal quality and to quantify observed variations.

The assessment of Alberta's coal resources is an on-going and important process requiring input from geologists, mining engineers, preparation engineers and marketing experts. The goal of resource assessment is to provide a technical basis on which to make an economic evaluation of the coal resources. Required input includes estimates of the available coal reserves, coal quality and minability. Predicting the range in coal quality, is fundamental to this assessment because the first step in marketing these coal resources is to identify the product being sold. No economic evaluations can proceed without reliable coal quality information. Estimates of coal quality depend on the extrapolation of a relatively small number of samples to vast coal resources. Because of the limited number of samples, it is important that resource assessment teams interact at all levels and use all tools available including depositional modeling, statistics, and geological interpretation.

Exploratory statistical evaluations of the Ardley coal zone indicate that significant coal quality variations occur at regional and detailed scales. In this report the issue of "representativeness" comes into play because of these variations. The confidence assigned to central tendencies and range in coal quality values depends on the scale of investigation and the amount of data on which the estimates are based.

A detailed evaluation of coal quality on a minesite scale (Highvale mine) was provided by Wong et al. (1988) in the Alberta Research Council Report OFR 1988-09, in which the variation in quality between seams was investigated. A regional evaluation, a comparison between ten major coal deposits and a comparison between coal quality at the Highvale mine to the regional coal quality in the Ardley coal zone, is provided in this report.

EXECUTIVE SUMMARY

This report addresses the coal quality of the Ardley coal zone in the Alberta plains. The Ardley coal zone is lower Tertiary in age and is one of Alberta's most important sources of thermal coal. Along the eastern and northern erosional edges of the Paskapoo Formation, subbituminous coal resources of the Ardley zone are found at shallow depths. Currently, three major mines are producing coal from the Ardley zone, (the Whitewood, Highvale and Genesee mines) to produce thermal electric power for the province. The Highvale mine alone produces over 13 million tonnes/year of coal making it the largest coal mine in Canada.

With the objectives of characterizing the coal quality of the Ardley coal zone in the plains region and to quantify observed variations, the following substudies are presented: (1) a regional coal quality evaluation in which all coal quality data available for the Ardley zone are included; (2) a comparison of coal quality between ten identified deposits. These deposits are Ardley Bend, Wetaskiwin, Genesee, Low Water Lake, South Highvale, North Highvale, Whitewood, Swan Hills, Fox Creek and Musreau Lake; (3) an investigation of variability between and within seams on a deposit scale (North Highvale); (4) a comparison between coal quality variation in North Highvale and regional trends; and (5) a geostatistical substudy to determine the spatial variation in coal quality and optimal sample spacing of two selected seams in the North Highvale deposit.

Coal quality data used in this study were obtained from the Energy Resources Conservation Board (ERCB), the Alberta Geological Survey, and TransAlta Utilities Corporation (Highvale data). Since coal exploration and coal mining companies are required by law to submit their drilling data and coal quality information to the ERCB, considerable coal quality data are publicly available within Alberta. After the confidential status expires, these data become public.

One of the major challenges faced in this investigation is the extreme variability in reported values of coal quality and the dependencies between variables, especially the proximate and ultimate analyses. Nonparametric statistical techniques were employed due to these data dependencies and non-Gaussian data distributions.

A further challenge is the clustering of data. Coal quality data tend to be concentrated within identified deposits while intervening areas have little or no data, resulting in irregular sample spacings. For this reason, emphasis is placed on the assessments of the ten deposits outlined.

Since seam by seam correlations are impracticable over large distances, composite coal quality data sets were created. Composite data sets were derived, for each deposit and for the regional (basin-wide) substudies, from the weighted average based on seam thickness for each drill hole. The statistical assessments include box plots, histograms, and summary tables. The measure used to report central tendency is the median value and variability is expressed most commonly using the interquantile range. The dry basis (moisture-free) is the preferred method of reporting and comparing statistical results.

General trends of coal quality in the province are outlined in the regional and deposit substudies. The Genesee, Low Water Lake, South Highvale, North Highvale and Whitewood deposits, generally contain the highest quality thermal coals. Median values obtained from the composite data sets indicate that these coals are likely to contain less than 20% ash (dry basis), and less than 0.30% total sulphur (dry basis). These deposits also contain some of the highest volatile matter contents and heat of combustion. The other deposits, Ardley Bend, Wetaskiwin, Swan Hills, Fox Creek, and Musreau Lake appear to contain higher ash contents for composite samples. Median ash contents are between 27% and 37% (dry basis). Median sulphur contents are 0.31% to 0.39% (dry basis). A basin-wide tectonic and geologic model is presented in this paper to explain the observed trends in coal quality for the ten deposits and for the deeper subsurface. Currently, coal quality data is only available at shallow depths. The coal quality model for the deeper subsurface must be tested at a future date when these data become available.

Coal quality variation within a deposit clearly indicate that in every deposit and every drill hole in Alberta, we can expect a wide range in coal quality between seams. For the North Highvale deposit, for example, the median value for ash composite samples is 16.0% (dry basis). Ash content for individual seams vary from a median of 13.9% to 38.0% (dry basis). For any estimates requiring a relatively high confidence level, seam by seam assessments are strongly recommended.

A geostatistical substudy investigated the spatial dependencies on coal quality in seams 1 and 2 in the Highvale Mine. Results indicate that the optimal sample spacing for estimating coal quality in these two seams is 800 to 900 m. From a mine planning or development perspective, samples spacing, may have to be more closely spaced. Further studies and comparisons of other deposits on a seam by seam basis are recommended for more definitive results.

Coal quality reported on a regional scale are used to estimate the range in coal quality that can be expected throughout the province. Assessments of deposits provide a higher confidence level so that central tendencies and variation in coal quality can be addressed. Detailed geological and statistical studies on a seam by seam basis provide the most accurate estimates of central tendencies and a much better understanding of coal quality variation.

The systematic approach in this investigation reveals that coal quality trends and previous coal resource evaluations (produced by the Alberta Geological Survey prior to 1986), can be used to predict coal quality of the Ardley coal zone in the Alberta plains. This study points out that more and better coal quality information are deemed essential, for the completion of a comprehensive coal quality assessment. This study must be revisited when these new data become available.

ACKNOWLEDGMENTS

The Authors would like to express their appreciation to TransAlta Utilities for making the Highvale Mine data available for study. This work was made possible through joint funding by the Alberta Office of Coal Research and Technology and the Alberta Research Council. Special thanks go to Jan Boon and Dennis Nikols for reviewing this paper. Maureen Fitzgerald typed the manuscript.

1.0 INTRODUCTION

1.1 Coal Quality Program

Between 1986 and 1989, the Coal Geology Group of the Alberta Geological Survey has been involved in a program investigating coal quality in the province. The objectives of the present study are to characterize systematically the Ardley coal quality in the plains region of Alberta and to quantify observed variations. This investigation is done from five different perspectives: (1) A regional coal quality evaluation where all data are included and reported on a township basis; (2) A comparison of coal quality between deposits (that is, areas where coal quality data are clustered); (3) A discussion of variability within an individual deposit. This includes an evaluation of coal quality variation between seams at the Highvale Mine; (4) A comparison between coal quality variation in the Highvale Mine and regional trends; and (5) A geostatistical substudy investigating spatial variation in coal quality and optimal sample spacing of two selected seams in the Highvale Mine.

1.2 Methods of measuring coal quality (proximate and ultimate analyses)

The overall grade of coal is commonly expressed by proximate analysis. Proximate analysis estimates the composition of coal as percentages of four main constituents: moisture, fixed carbon, volatile matter and ash. These parameters are generally expressed on an as-received basis (which includes moisture), on a dry basis (moisture-free), dry ash-free basis (moisture and ash removed) or dry mineral matter free basis (See ASTM, 1981 for the Parr formulae to convert each component to the selected bases). Fixed carbon and volatile matter represent mainly the organic fraction of coal; ash is the inorganic residue remaining after combustion. Calorific values (mj/kg) are commonly presented with proximate analysis and for the most part is dependent on ash and moisture contents.

Comparing values with varying moisture levels gives an added bias and is further complicated by varying methods of reporting moisture. Equilibrium moisture, for example, differs from as-received moisture and air-dried moisture (ASTM, 1981). Consider also the variation due to different sampling techniques (core vs cuttings for example), length of time in storage before analysis and sample handling which affect measured moistures. Evaluations which include as-received coal quality should be restricted to detailed minesite studies where sampling and reporting techniques are more consistent. The detailed evaluation of the Highvale mine, for example, includes as-received (moisture on an air-dried basis) evaluations of coal quality (Wong et al., 1988). In the present evaluations, coal quality is expressed on a dry basis and on a dry ash-free basis, for consistency.

Another common method of measuring coal quality is ultimate analysis. The composition of coal from ultimate analysis is expressed as

PROXIMATE DATA

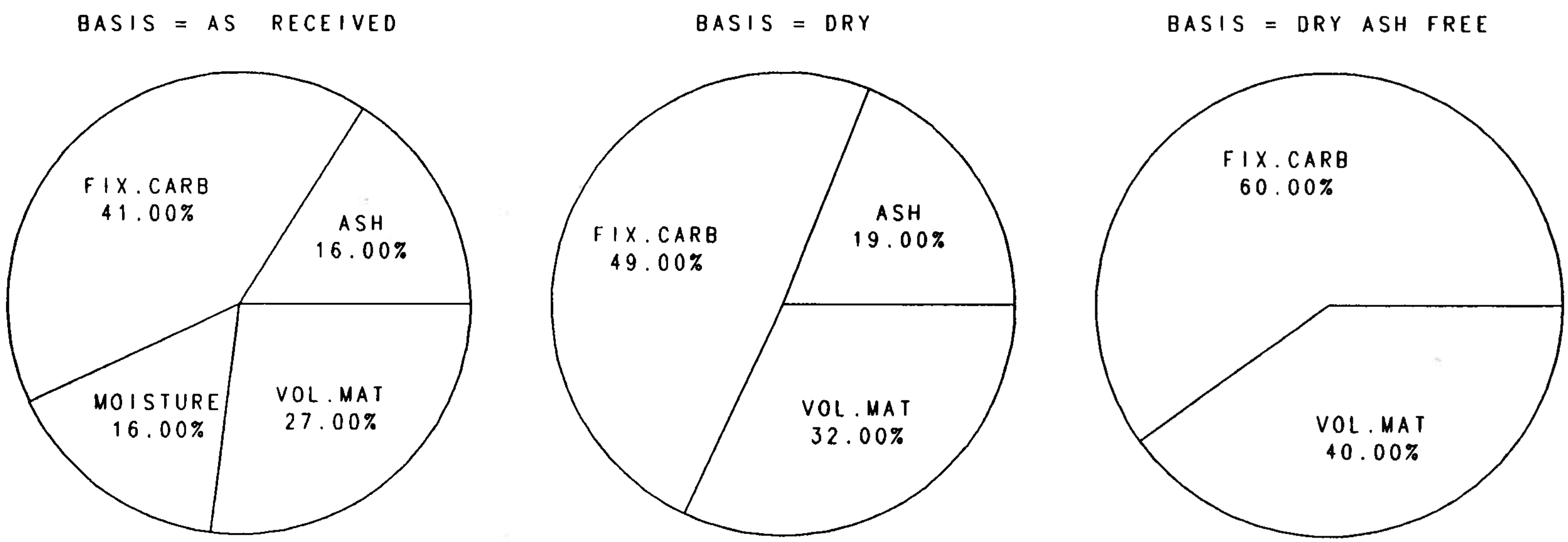


Figure 1. Proximate analysis (as-received) expresses the composition of coal as weight percentages of ash, fixed carbon, volatile matter and moisture. Note the increase in weight percent of the remaining components on the dry and dry, ash-free bases.

percentages of carbon, hydrogen, nitrogen, oxygen and sulphur. The organic material contains most of the carbon, hydrogen and nitrogen. Both the organic and inorganic fractions contain sulphur and oxygen. When ash content and moisture are added to the sum of these elements, the result will total 100 percent. Oxygen and some hydrogen are present as free water within the coal. Oxygen content is calculated by difference because no simple method of direct determination is available. Any errors made in analyzing the other components, especially moisture, affect the calculation of oxygen content. Because of these dependencies, ultimate analyses are commonly expressed on a dry, mineral matter free basis. Mineral matter content is calculated by using the Parr Formula (ASTM, 1981):

Mineral matter = (1.08 X dry ash percent) + (0.55 X dry total sulphur)

In the present evaluation, ultimate analyses are expressed on dry and dry, ash-free bases because of recognized inconsistencies in sampling procedures and limitations in the regional data sets. Studies using ultimate analysis on a dry, mineral matter free basis, may be better suited for detailed minesite studies where sample processing and handling techniques are more consistent.

1.3 Other methods of characterizing coal quality

A common method of characterizing the quality of thermal coals is the Hardgrove Grindability Index, which measures the ease of grinding. Another important characterization tool is high temperature ash analysis which measures the proportions of major oxides. The oxides commonly evaluated include P_2O_5, SiO_2, Fe_2O_3, Al_2O_3, TiO_2, CaO, MgO, SO_3, K_2O, and Na_2O. Measuring the proportions of alkali metals (sodium and potassium), as one example, can give indications of slagging and fouling behavior of coal feedstock in burners.

Data on the relative amounts of trace elements in coal are extremely important for characterizing coal resources, especially since the effects on air quality caused by burning coal and disposing of the ash have become important issues throughout the world. Petrographic analysis of coals, which includes estimations of vitrinite reflectance and maceral contents is recognized as a valuable tool for characterizing coal. The publicly accessible data bases for Alberta's thermal coals do not commonly contain the kinds of data described above, at least in sufficient quantity for regional statistical evaluations. Over the next few decades these data will be essential in order to compete for the coal export markets and to answer environmental and coal processing concerns.

1.4 Properties of a "high" quality coal

A high grade thermal coal (that is, coal used for combustion purposes) should have a relatively low ash content, relatively low inherent moisture, a large percentage of fixed carbon, a relatively high volatile matter content and an associated high calorific value. The amount of ash and moisture in coal directly affects the calorific value (Tewalt, 1986),

Ultimate Data

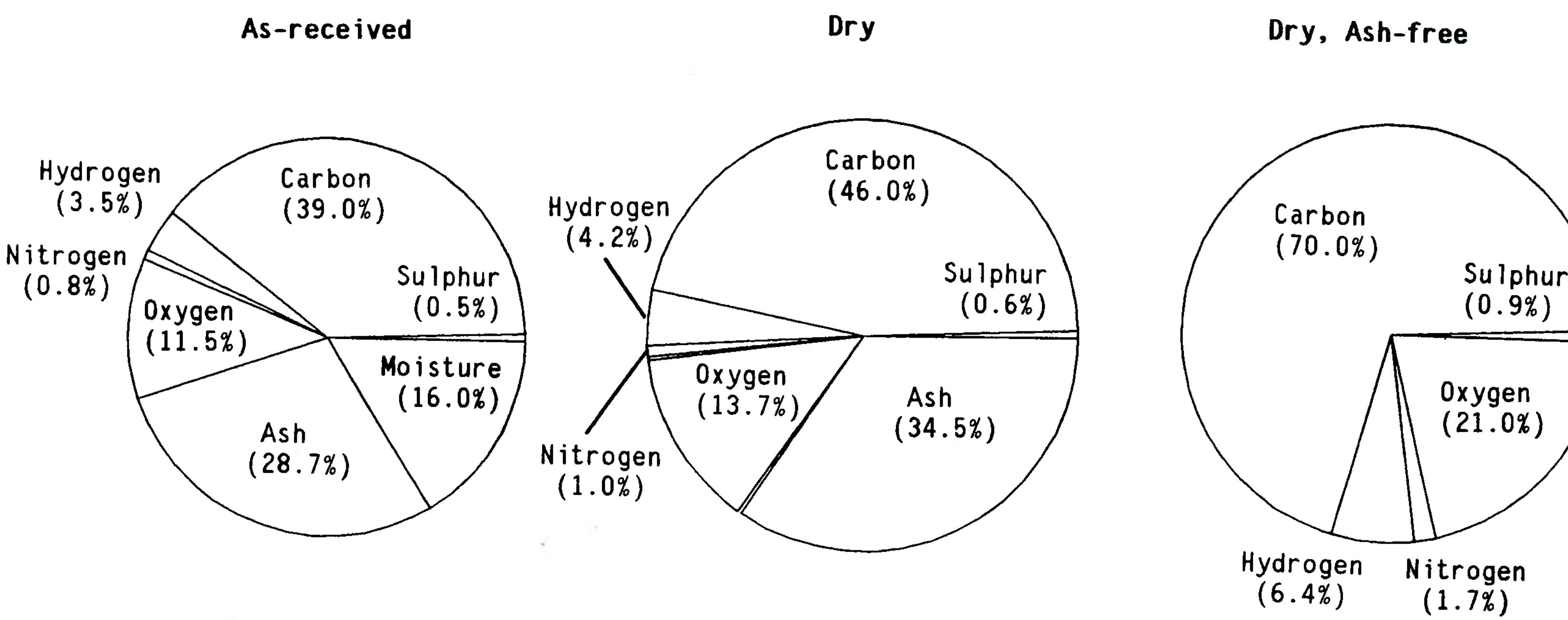


Figure 2. Ultimate analysis (as-received) expresses the composition of coal as weight percentages of ash, moisture, carbon, hydrogen, nitrogen, and sulphur. A proportion of the hydrogen and oxygen are present as free water in the coal. Note the increase in weight percent of the remaining components on the dry and dry, ash-free bases.

so coal quality evaluations of deposits should include "as received" results, if available, in addition to dry and dry, ash-free comparisons. When looking at uses such as thermal electric power generation, location and minability are of equal importance as coal quality. The team work between the economists, engineers and geologists will ensure that all aspects are considered in deposit assessments.

For other uses of coal such as liquefaction and gasification, volatile matter content, hydrogen to carbon and oxygen to carbon atomic ratios, and petrographic analyses are important quality parameters to evaluate (Macdonald et al., [A] in press). The summary statistics of proximate and ultimate analyses, from this report are only a partial and preliminary step for evaluating the quality and potential of Ardley coals in the Alberta plains. Further detailed evaluations with coal quality data differentiated by seam, will be required for mine planning and other feasibility studies. Regional evaluations like this one will target areas for those more detailed studies.

1.5 Nature of coal quality data

Much is known about the distribution of coal in the province, as well as about the resources and measured reserves. Less is known about coal quality and considerably less coal quality data than coal resource data are available. Coal quality data tend to be concentrated in relatively small specific project areas (operating mines and known deposits of economic interest) with relatively large intervening areas of sparse data. For this reason, coal quality evaluations for each deposit and a comparison between deposits were completed in this study. Broadly based studies which include the intervening areas give a picture of coal quality trends, rather than the predictive capabilities provided by evaluations on a deposit scale.

Coal is a complex mixture of organic and inorganic constituents. This by itself leads to inherent variability due to inhomogeneities within the coal. Other sources of variability include differences in depositional settings (that is, geological controls and spatial variation), sample handling, processing methods, and laboratory and analytical procedures. Large variation in coal quality values is observed at all scales of investigation. For these reasons, this report specifically addresses variability, more so than central tendency.

The authors recognize the need for a systematic assessment of regional coal quality in the province. This systematic approach to coal quality will add to the available coal information base for industry and government. Provided that the limitations at the given scale are recognized, the regional and deposit assessments can be used to evaluate trends and to characterize coal quality of the Ardley zone in the plains region.

1.6 Sources of data

Coal quality data used in this study were obtained from the Energy Resources Conservation Board (ERCB), TransAlta Utilities Corporation, and the Alberta Research Council (ARC). The ERCB collects coal quality information from all mineral exploration and mining companies in the province. These companies submit their drilling data, geophysical logs and coal quality information as required by law. After the confidential status expires, the ERCB makes these data available to the public. The Alberta Geological Survey, (a department of the Alberta Research Council), has conducted regional coal resource studies, on a 1 well per township basis, throughout the province for about 15 years. The coal quality data obtained from the Alberta Research Council fill in some of the gaps in the intervening areas between known deposits. The regional coal quality assessment of this study uses a combined ERCB and ARC coal quality data set.

TransAlta Utilities kindly provided detailed geologic and coal quality data from the Highvale mine. The seam by seam comparisons and detailed evaluation of in-seam coal quality variation are products from this study (Wong et al., 1988). Other coal quality information for individual minesites were obtained from published reports.

1.7 Previous work

Coal quality studies are an important area of research in all coal producing countries. Within North America, valuable lessons can be learned from other research agencies which have been evaluating coal quality over the last two decades. The West Virginia Geological Survey, the Kentucky Centre for Energy Research, the Pennsylvania State University, the New Mexico Bureau of Mines and Mineral Resources, the Illinois Geological Survey, the Bureau of Economic Geology (University of Texas at Austin) and the United States Geological Survey (USGS), to name a few, have a long history of coal quality research. Comprehensive coal quality studies in Alberta are just beginning.

One of the biggest challenges associated with coal quality evaluations is the extreme variability in reported values and the dependencies between the variables. We are not dealing with Gaussian distributions or random values, therefore, many classical statistical techniques are not appropriate. Many of the coal quality reports produced by other geological surveys and coal research agencies address coal quality variability and dependencies by characterizing on a seam by seam basis in detailed study areas. Some examples include reports by the Illinois Geological Survey (Kuhm et al., 1978) in which the report focuses on the Rosebud and Pittsburgh No. 8 seams. The high variability, dependencies, and sparse data led to many coal quality studies that list coal quality for specific sample locations. Examples include publications by the West Virginia Geological and Economic Survey (Smith et al., 1977) and the Pennsylvania Department of Environmental Resources (Skema et al., 1975). One study directly compares individual seams in representative areas (Irwin, 1986) using bar charts (Figure 3).

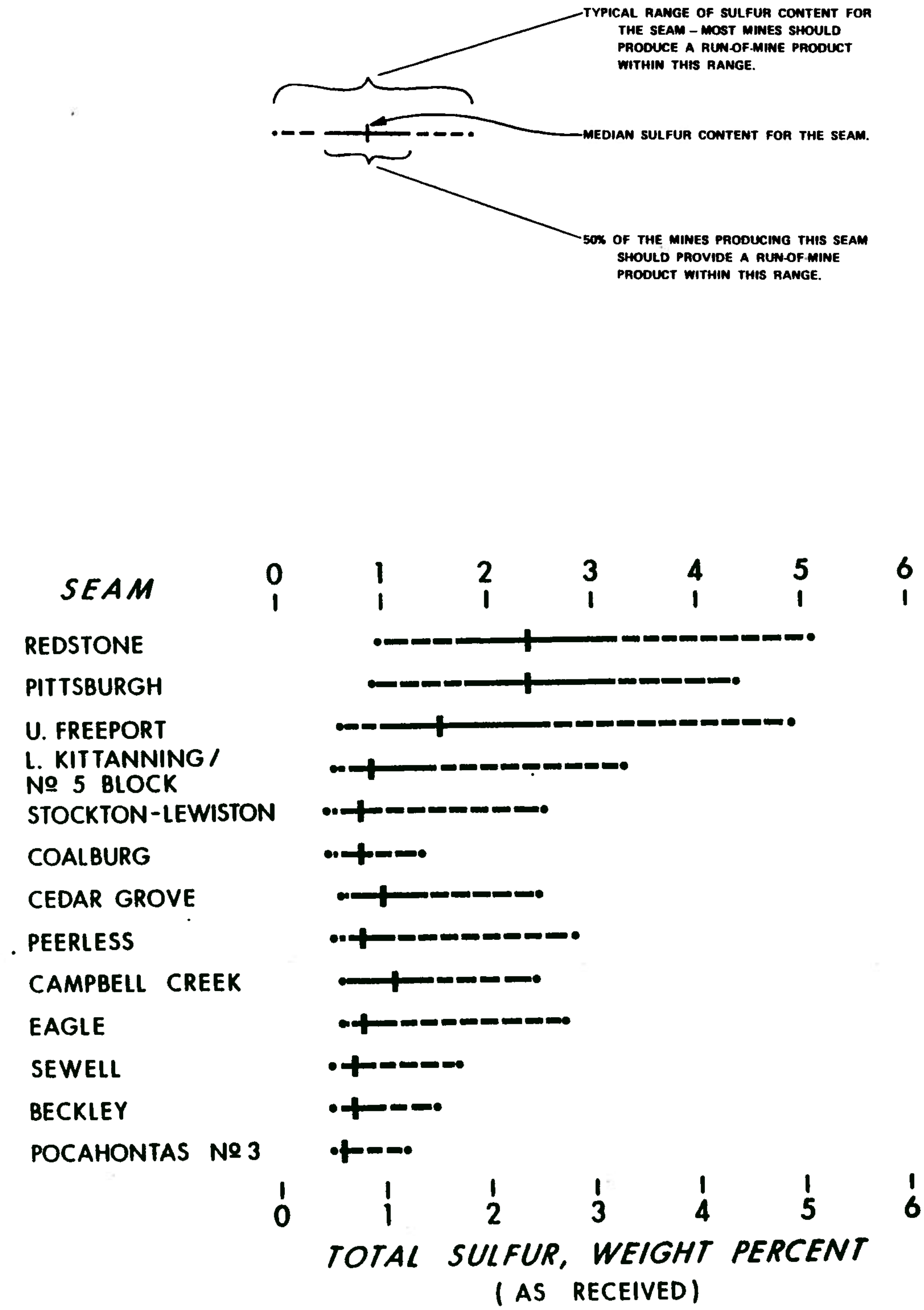


Figure 3. Direct comparison of individual seams in a Pennsylvania coal quality study (from Irwin, 1986).

The preference for seam by seam assessments is due to the high variation in quality within and between seams. A Canadian example of seam by seam characterization is an elemental distribution study at the Fording coal mine, in British Columbia by Goodarzi, (1988). An evaluation of coal quality of selected Ardley coal seams at the Highvale mine, in Alberta is offered in Wong et al., (1988) and of coal quality in Alberta's southern and central foothills regions by Macdonald et al., (1987) and Macdonald et al, [B] (in press).

For province-wide or state-wide regional studies, it is not practicable to differentiate seams. A broadly based comparison approach is commonly used in order to address variability and representativeness of results. In these studies, detailed evaluations are compared to regional trends. In an assessment of coal quality in New Mexico, Roybal et al., (1986) stress the importance of including petrographic and geologic information as an aid in developing predictive models to explain lateral and vertical variations in coal seams. In a regional assessment of the Texas Gulf coast, Tewalt et al., (1983) and Tewalt (1986), compare individual seam quality to regional trends. Similar evaluations are available from the West Virginia Geological and Economic Survey (Renton and Hidalgo, 1975), and the United States Geological Survey (Dulong et al., 1986) in western Pennsylvania. In each of these studies, the striking differences between coal quality on a local scale (that is, seams and deposits) to the statistically smoothed regional scale, make definitions of representativeness essential.

Regional studies which use composite data (all seams combined) and with no differentiation of deposits, are used primarily as a guide to illustrate the range in quality available in a particular state or province. The coal quality and rank variation by Nurkowski (1985), for example, offers a broad brush approach to characterizing Alberta plains coals. What is needed now are regional and detailed comparisons. When looking at feasibility studies for potential minesites, assessments will require seam coal quality data, detailed geology, and preferably geostatistics (that is, spatial statistics) to accurately estimate central tendencies and variation.

Coal quality evaluations in Alberta cover very large study areas compared to many of the coal quality studies conducted elsewhere in the world. The study area for Pennsylvanian or New Mexico coals, for example, would fit into about 1/2 or 1/4 of the study area of Alberta's Ardley coal zone. These examples were chosen simply to illustrate the magnitude of the job at hand. At least three levels of study are recommended for further coal quality evaluations in Alberta. The first level would evaluate coal quality of the Ardley coal zone on a province-wide scale, investigating the range in quality and the effects of basinal controls on coal quality variation. A second level would evaluate central tendencies, geologic controls, and coal quality variation between deposits in defined coal fields (that is, fields as outlined by the Energy Resources Conservation Board, 1987). The third level of investigation would evaluate and compare coal quality of correlated seams on a deposit scale.

For the most part, this report addresses the first scale and touches on the second level of investigation. The exploratory geostatistical study of optimal sample spacing provided in this report and the detailed evaluation of the coal quality at the Highvale Mine (Wong et al., 1988) are preliminary attempts to address the third level of investigation. As more coal quality data are acquired either directly from participating companies or from the Energy Resources Conservation Board and as results from new exploration programs become available, more work at all three scales of investigation is deemed essential.

2.0 REGIONAL COAL QUALITY

2.1 General geology

The Ardley coal zone is of Paleocene (lower Tertiary) age. In terms of stratigraphy, the Ardley coal zone lies near the base of the Paskapoo Formation in the Alberta plains (Figure 4). The coal zone is present between Township 30 and Township 66, and from the Paskapoo Formation erosional edge to the deep subsurface (Figure 5). In the plains region, the Ardley coal zone is currently of most economic interest along the eastern and northern erosional edges of the Paskapoo Formation, where coals are found at shallow depths. The Whitewood, Highvale and Genessee mines, located directly west of Edmonton produce subbituminous coal for electric power generation. The Highvale mine alone produces over 13 million tonnes/year of coal, making it the largest coal mine in Canada.

Paleocene sediments of Alberta are entirely nonmarine. Strata associated with the Ardley coals are generally described as alluvial plain sediments (Gibson, 1977; Irish, 1970) and lacustrine (Baofang and Dawson, 1988) with widespread paleosol intervals (Richardson et al. 1988). Following the deposition of Ardley coals, a thick overlying succession of unconformable Paskapoo sandstones was laid down, characterized by erosional downcutting and coarse-grained fluvial sediments.

The Paleocene sediments were deposited in a foreland basin setting, situated between the Rocky Mountains to the west and the Canadian Shield to the east. It has been suggested that the Ardley coal zone was formed during a period of tectonic quiescence (Jerzykiewicz, in press). General coal development within the majority of the basin stopped during a period of major tectonic uplift and the resulting advance of the Paskapoo sandstone succession (Richardson et al, 1988).

2.2 Depositional controls

A regional depositional model for Ardley coals (Figure 6) was developed by Richardson et al., (1988). Major depositional controls appear to be relative subsidence rates, isolation from the effects of clastics during the formation of the Ardley coal zone, and climate. Greater subsidence towards the west and southwest, due to loading along the western basin margin, resulted in the coal zone widening and the number of seams increasing towards the west and southwest.

Coal seams of the Ardley zone are remarkably continuous. Some examples from detailed substudies in Richardson et al., (1988) suggest that individual seams can be correlated over an area of 100 km^2 or more. During Ardley time, extensive peat-forming mires were developed in the basin. In conjunction with subsidence, the model suggests the development of major river systems running parallel to the mountain front (Figure 6), much like the modern day Ganges river which runs parallel to the Himalayas. This is one possible mechanism for sheltering widespread peat-forming mires from clastics being shed from the mountain front.

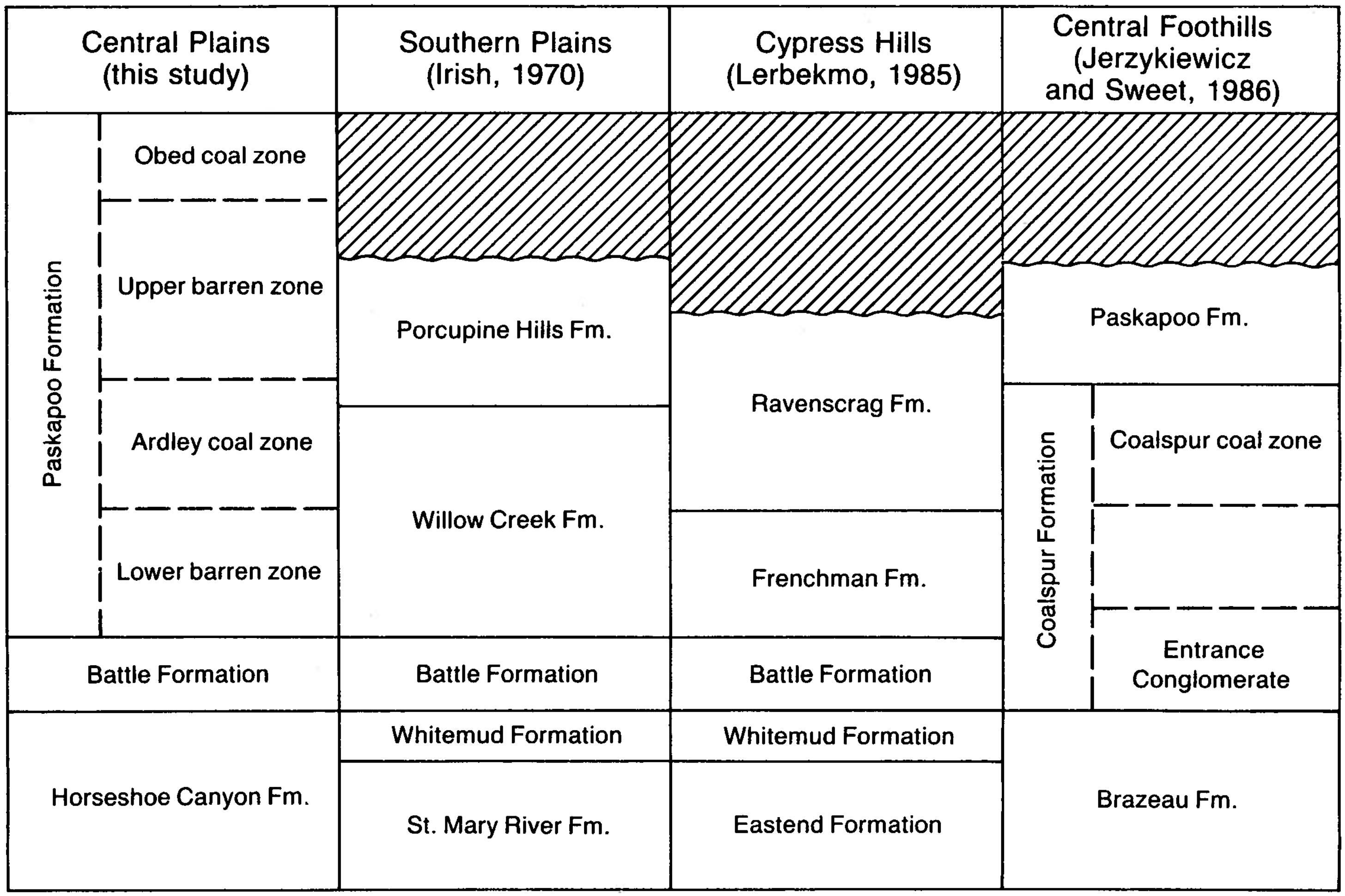


Figure 4. Stratigraphic nomenclature of Alberta's uppermost Cretaceous and Tertiary coal-bearing strata. The Ardley coal zone in the plains region is equivalent to the Coalspur coal zone in the central foothills.

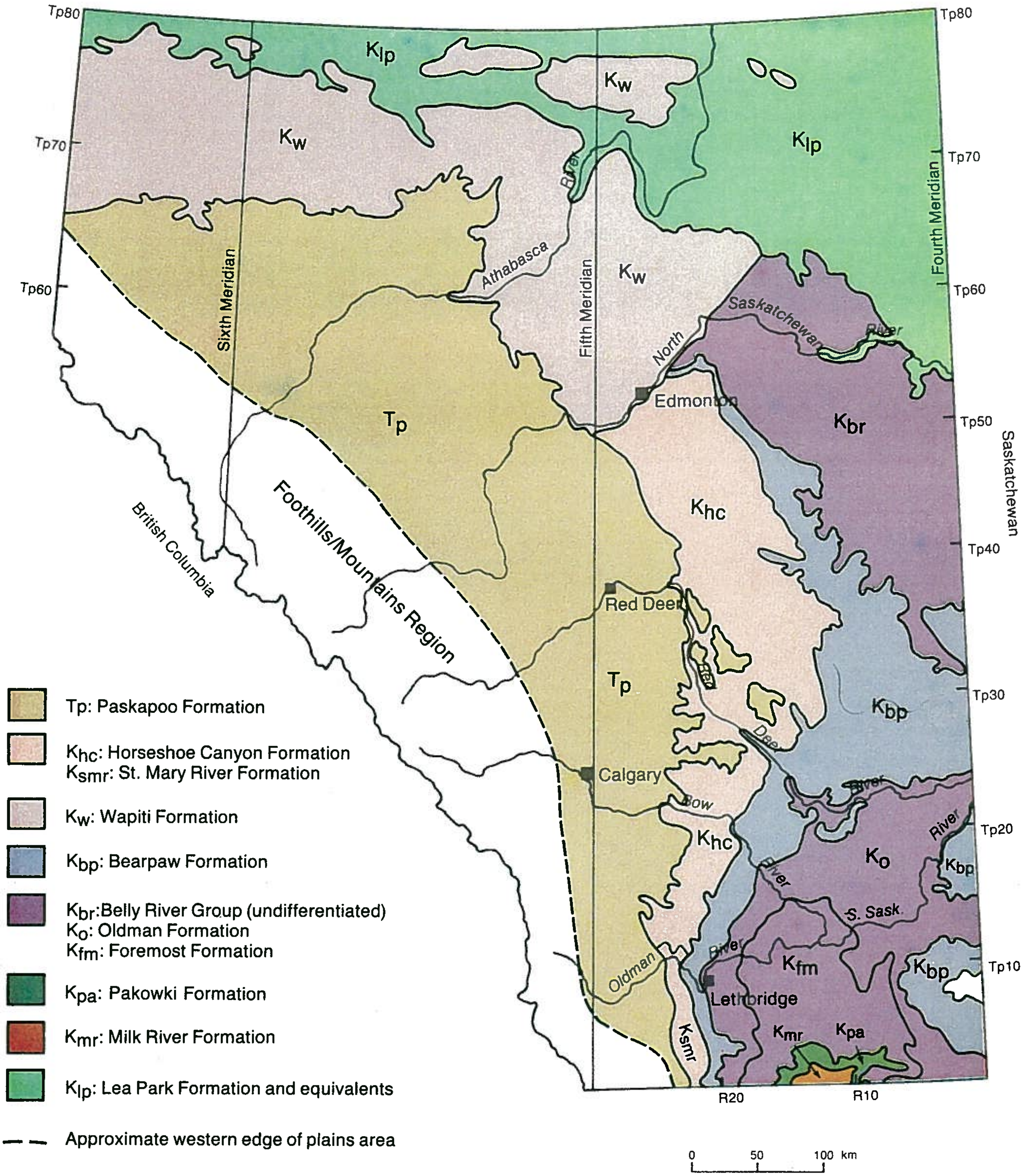


Figure 5. Geologic map of the plains region of southern Alberta. The Ardley coal zone lies at surface mineable depths along the outcrop edge of the Paskapoo Formation from Township 30 to Township 66.

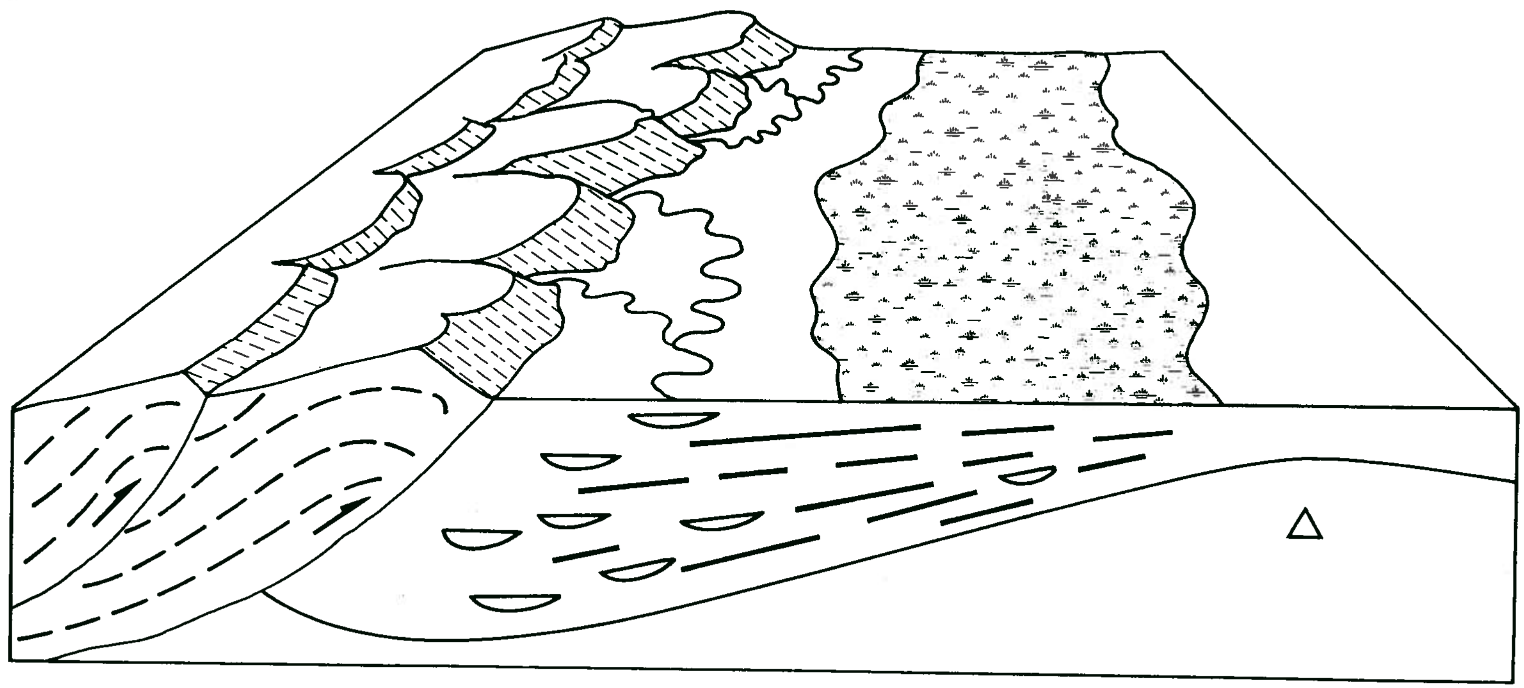


Figure 6. Schematic sketch showing the possible tectonic controls on Ardley coal deposition. Increased subsidence rates towards the disturbed belt and confinement of major river systems are possible regional controls leading to extensive coal development of the Ardley coal zone (After Richardson <u>et al</u>., 1988).

Little or no Ardley coal development is found south of Township 30 in Alberta (Richardson et al., 1988). Jerzykiewicz and Sweet (1986) suggest that a major environmental difference may have existed between the central and southern portions of the basin during the time of deposition of the Ardley coal zone. While central and northern portions of the basin were under the influence of a wetter, more humid climate, the southern portion of the basin may have experienced semi-arid conditions. In Ardley equivalent strata in southern Alberta, there are caliche zones, red beds and impoverished palynological assemblages, indicating this climatic condition. A modern analogy may be the present climatic differences between Northern and Southern Alberta (Jerzykiewicz, in press).

From the regional resource evaluation maps available in Richardson et al., (1988), two areas have been identified with particularly thick accumulations. An east-west trending area between Lodgepole and Coalspur (along Township 45) has cumulative coal measures of up to 21 m and individual seam thicknesses to 4 m. A northeast-southwest trending area between Obed and Whitecourt (along range 20 W 5M), has cumulative coal measures to 24 m and individual seam thicknesses to 3 m (Figure 7). These areas also contain the greatest number of seams.

The areas of thicker cumulative coal development appear to coincide with areas of thick seams, containing some of the lowest ash and sulphur values in the Ardley coal zone. This relationship will be shown in the discussion of coal quality maps on a township basis (section 2.3) and in the evaluation and comparison of deposits (section 3.3). If a similar relationship is observed for the deeper subsurface along these two trends, then we have a predictive model for understanding coal quality throughout a large portion of the basin. Currently, studies are limited to the near surface because of little or no data are available deeper in the basin. The authors look forward to seeing this model tested over the next 15 years as the deeper subsurface data become available.

2.3 Regional Ash and sulphur coal quality maps - Township basis.

Data for the regional coal quality study are based on the Energy Resources Conservation Board (ERCB), TransAlta and Alberta Research Council coal quality data sets. Since seam differentiation is not practicable, coal quality variables were reported on a weighted average value based on seam thickness at each drill hole location. This removes the bias contributed by the sample length to the composite value at each drill hole. See Appendices 1 and 2 for the calculation program to derive the ultimate and proximate data sets, respectively. The resulting data sets for the regional study represent coal quality for all seams combined at each drill hole location, and assumes that all seams in the coal zone are included in the calculation.

One approach used to characterize coal quality of the Ardley coal zone was to plot the value of ash (dry basis) and total sulphur (dry, ash-free basis) at each drill hole location. In this way we hoped to pick up trends and to observe variation controlled by position in the basin.

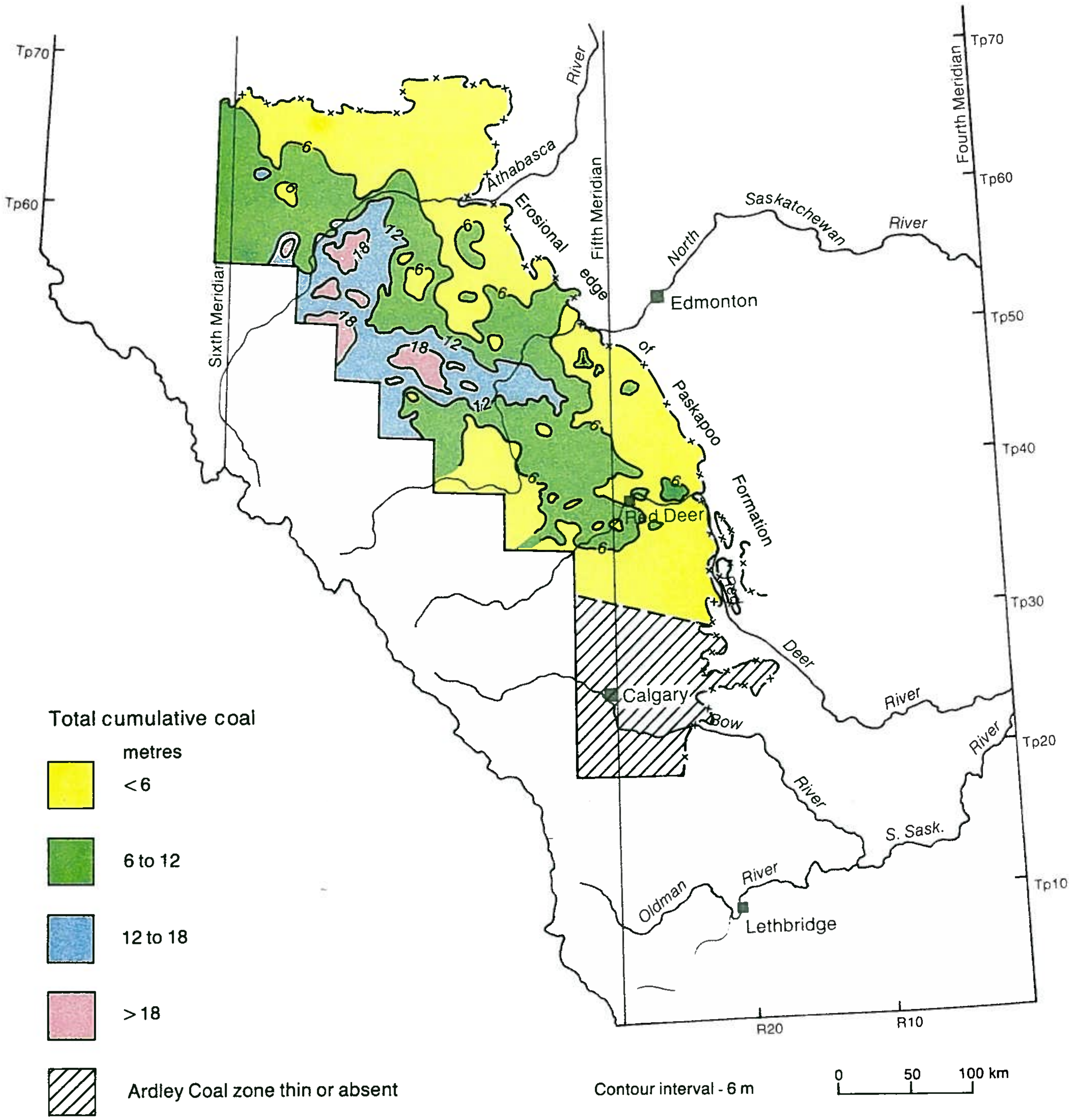


Figure 7. Isopach map showing the total cumulative coal in the Ardley zone. Note the east-west and north-south oriented trends of thick coal measures, indicating that these areas had particularly favourable depositional conditions for high quality coal development (After Richardson et al., 1988).

Much of the coal quality data is clustered within known deposits, with the intervening areas having relatively sparse data distributions (1 hole/township).

Ash was reported on a dry basis to normalize values as much as possible. Similarly, sulphur was reported on a dry, ash-free basis. The values plotted, even for nearby wells, displayed extreme variation. Initial runs using this method were not successful. The variation is likely due to inhomogeneities in the coal, differences in sampling techniques, different analytical procedures, and/or real variation in sulphur and ash contents between data locations. Coal quality values are extremely variable and require statistical smoothing in order to pick up trends.

A second attempt used a median ash and median sulphur value for each township calculated for the weighted averages for each drill hole. On each map, the smaller number attached to the median gives the absolute deviation from the median (Figures 8 and 9). See appendix 3 for the program used to calculate weighted averages for each sample location. The absolute deviation from the median illustrates the variability, where multiple data points are available in a township. By subdividing the median values into four classes, well-defined regional coal quality trends are exhibited.

For the median ash map (dry basis), the four classes are 5.3% to 16.6%, 16.7% to 22.5%, 22.6% to 29.6% and 29.7% to 56.2% ash (Figure 8, in pocket). For the sulphur map (dry, ash-free basis), the four classes are 0.16% to 0.33%, 0.34% to 0.43%, 0.44% to 0.53% and 0.54% to 1.74% (Figure 9, in pocket). These classes correspond to the 1st, 2nd, 3rd and 4th quantiles respectively.

One trend in the median ash and sulphur maps is the relatively low values observed immediately west and southwest of Edmonton. The regional geologic model predicts that this area will have the thickest coal zone and thickest individual seams. This trend coincides with the best coal quality as defined by ash and sulphur in Figures 8 and 9. Further studies of deposit comparisons between Whitewood, North Highvale, South Highvale and Genessee agree with these findings. These two maps appear to be very useful to delineate coal quality trends along the outcrop of the Ardley coal zone in a regional context.

The coal explorationist must be careful when interpreting these regional maps. Some townships contain only one value, and a wide variety of sampling techniques are used to derive the large number of coal quality estimates. In the productive mine areas, for example, the reported coal quality results usually include the economic mineable seams but exclude the uneconomic seams. In exploration areas, all seams in the coal zone are commonly sampled, and the results for all seams reported to the Energy Resources Conservation Board. Also, the values reported on the regional map are composite medians for each township, which represent statistically smoothed data. Every drill hole in every township on the map will contain seams which vary considerably in thickness, minability and quality. Townships identified as having very low median ash coals will contain some seams which have very low ash and seams with relatively high ash contents. The same is true for townships identified as having relatively high median ash contents. The maps were produced to pick up regional trends. Estimates of coal quality on a seam basis are required for economic assessments of individual properties and deposits.

3.0 COMPARISON BETWEEN DEPOSITS

3.1 Data description

Data for this substudy are derived from the Energy Resources Conservation Board, the Alberta Research Council and TransAlta Utilities Corporation. It is recognized that seam differentiation is not practicable in these comparisons because of difficulties in correlating individual seams over broad study areas. In this study, composite coal quality values were derived from the weighted average based on thickness (Figure 10). This reporting method removes the bias contributed to the composite value by sample length. The resulting data sets for the regional study represent coal quality for all seams combined at each drill hole location, and assume that the drill holes reach the base of the coal zone.

3.2 Deposit locations

Coal quality data from ten identified deposits were compared. The areas are Ardley Bend, Fox Creek, Genesee, Low Water, Musreau Lake, Swan Hills, Wetaskiwin, Whitewood, North Highvale and South Highvale (Figure 11). These deposit locations were chosen because of their mining potential and effectively represent the major data clusters currently available for coal quality of the Ardley coal zone. Intervening areas commonly do not have enough data to evaluate coal quality on a deposit scale. Both proximate and ultimate analyses were included in the evaluation. Table 1 lists the number of sample sites for each variable at each deposit. Insufficient sample size is a major obstacle, especially for ultimate variables. It is important to note the differences in the sizes of samples compared. While many of the statistical tests used can accommodate unequal sizes, the likelihood of bias in sampling exists. It will be worthwhile to revisit this comparison study, in the future, when more and better data become available.

The summary statistics of coal quality variables at each deposit are listed in Tables 2 and 3. The median (Table 2) was selected to represent central tendency because it does not depend on the normality assumption. The coal quality data typically display non-normal (or non-Gaussian) distributions and highly variable skewness. The median is less affected by outliers, and therefore, can be a better measure of central tendency than the mean for skewed data.

The interquantile range (Table 3) is used to measure the amount of variability in the data. It is defined as the difference between the 25th percentile and 75th percentile in the data distribution. Both the median and the interquantile range are considered "distribution-free" methods, as opposed to the mean and standard deviation which assume Gaussian distributions.

The data contained in the tables can be summarized visually using box plots. Box plots are simple diagrams showing the maximum, minimum, 75th percentile, the median (or 50th percentile) and the 25th percentile (Figure 12). The nth percentile is the value which is not exceeded by

In this example, total sample length is 100 cm. Sample intervals are 20 cm, 50 cm and 30 cm. The weighted average value for the composite is calculated in the following manner:

$$\frac{0.2}{\text{Total sample length}} \times \text{Coal quality parameter}$$

$$\frac{0.5}{\text{Total sample length}} \times \text{Coal quality parameter}$$

$$\frac{0.3}{\text{Total sample length}} \times \text{Coal quality parameter}$$

Figure 10. Method of calculating the weighted average based on sample length for each drill hole. This removes the bias contributed by the thickness of coal seams in the composite value.

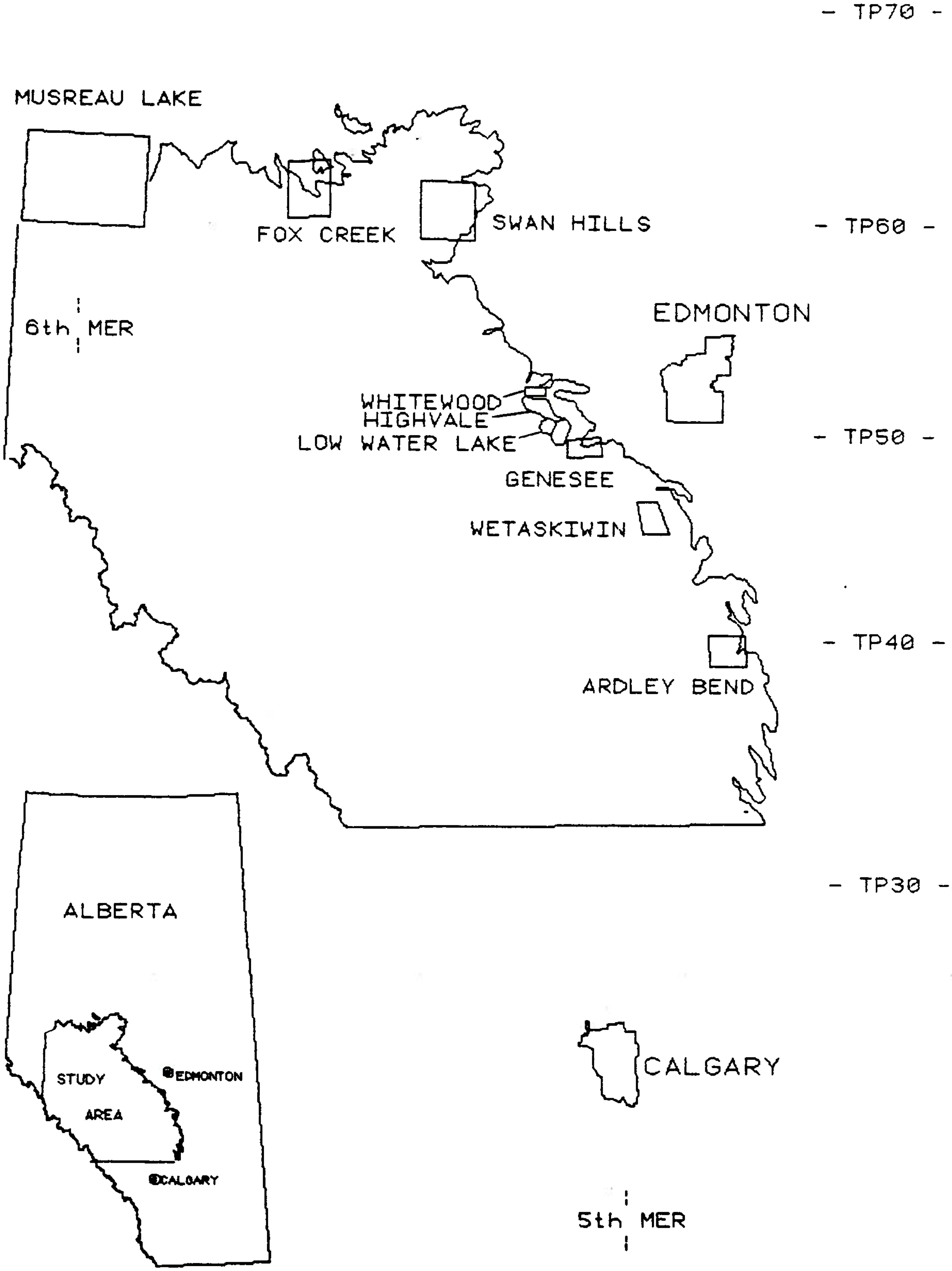


Figure 11. Location of the Ardley coal zone deposits. These deposits represent the major data clusters currently available for coal quality of the Ardley coal zone. Intervening areas commonly do not have enough data for evaluations on a deposit scale.

n percent of the sample population when the data have been arranged in order from lowest to highest. The 25th percentile for example is the value not exceeded by 25 percent of the distribution. The median value (or 50th percentile) is the halfway point in the set of values. The 75th percentile is the value not exceeded by 75 percent of the sample distribution, and so on.

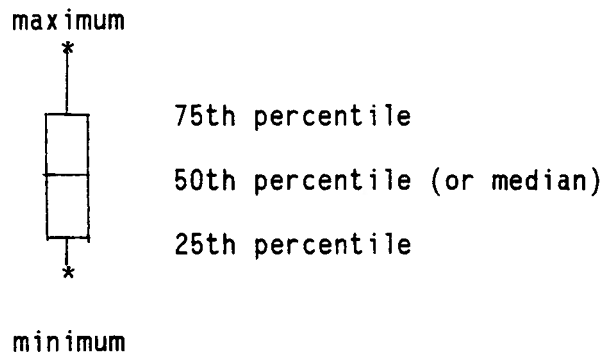


Figure 12. Features of box plots used in this study.

Box plots for the ten deposits for ash, volatile matter, and fixed carbon (proximate analysis), calorific value and ultimate sulphur, all on a dry basis are given in Figures 13 through 17, respectively. Box plots of volatile matter, fixed carbon and ultimate sulphur all on a dry, ash-free basis are given in Figures 18 to 21, respectively.

In the box plots, the amount of variability is indicated by the relative size of the boxes. The smaller the box, the lower the variability associated with each coal quality parameter. Since 50% of the data is contained within each box, the relative position of the box gives a good indication of central tendency. One can also refer to the middle line of the box which is the median. The skewness of the distribution is represented by the spacings between the horizontal bars of the box and the lengths of the "whiskers" that link the box to the maximum and minimum points. The box plots offer the reader easy reference to see central tendencies, maximum and minimum values, amount of variation from the median, and most importantly, provide ready comparison between deposits. For more precise values of the median and interquartile range, the reader can refer to Tables 2 and 3, respectively. Sample size for each coal quality parameter is provided in Table 1.

Table 1. Sample sizes (drill holes with coal quality data) from the ten deposits used in the regional statistical evaluation. The proximate variables are ash (ASH), volatile matter (VM), and fixed carbon (FxC). Calorific value (CV) is included for comparison purposes. Ultimate variables are carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S). The variables are reported on a dry basis (DRY) and on a dry, ash-free basis (DAF).

	Ardley Bend	Fox Creek	Genesee	Low Water	Musreau Lake	Swan Hills	Wetaskiwin	Whitewood	North Highvale	South Highvale
<u>Proximate</u>										
Ash (DRY)	147	15	62	38	23	51	25	49	148	18
VM (DRY)	147	15	62	38	23	51	25	49	148	18
FxC (DRY)	147	15	62	38	23	51	25	49	148	18
CV (DRY)	147	15	62	38	23	50	25	49	143	18
VM (DAF)	147	15	62	38	23	50	25	49	148	18
FxC (DAF)	147	15	62	38	23	50	25	49	148	18
CV (DAF)	147	15	62	38	23	49	25	49	143	18
<u>Ultimate</u>										
Ash (DRY)	68	16	62	10	16	52	25	48	54	18
C (DRY)	1	1	22	4	0	26	4	9	9	0
H (DRY)	1	1	22	4	0	26	4	9	9	0
O (DRY)	1	1	22	4	0	26	4	9	9	0
N (DRY)	1	1	22	4	0	26	4	9	9	0
S (DRY)	68	16	62	10	16	52	25	48	54	18
C (DAF)	1	1	22	4	0	25	4	9	9	0
H (DAF)	1	1	22	4	0	25	4	9	9	0
O (DAF)	1	1	22	4	0	25	4	9	9	0
N (DAF)	1	1	22	4	0	25	4	9	9	0
S (DAF)	68	16	62	16	16	51	25	48	54	18

Table 2. The **median** (weighted average based on thickness) for proximate and ultimate variables. These values are derived from data available through the Energy Resources Conservation Board. Analysis results are from raw/untreated samples. Proximate ash (ASH), volatile matter (VM), fixed carbon (FxC) and ultimate carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) are expressed in weight percent. Calorific value (CV) is expressed in mj/kg. The variables are reported on a dry basis (DRY) and on a dry, ash-free basis (DAF).

	Ardley Bend	Fox Creek	Genesee	Low Water	Musreau Lake	Swan Hills	Wetaskiwin	Whitewood	North Highvale	South Highvale
Proximate										
Ash (DRY)	30.7	36.6	14.8	18.5	34.9	29.5	27.0	19.8	16.0	17.4
VM (DRY)	30.4	27.4	33.7	32.9	27.3	32.1	30.6	35.1	36.2	34.0
FxC (DRY)	39.2	34.9	51.6	49.1	38.4	37.3	41.0	45.1	47.3	48.7
CV (DRY)	20.4	18.4	25.4	23.7	19.5	19.6	21.7	22.9	24.1	23.9
VM (DAF)	43.8	45.1	39.5	40.4	42.1	46.1	43.6	43.8	43.2	41.5
FxC (DAF)	56.2	54.9	60.4	59.6	57.9	53.9	55.6	56.2	56.7	58.5
CV (DAF)	29.2	28.5	29.8	28.9	29.8	27.7	29.8	28.4	28.6	28.8
Ultimate										
C (DRY)	-1	-1	65.19	60.47	-1	48.49	52.20	54.76	64.15	-1
H (DRY)	-1	-1	3.58	3.60	-1	3.14	3.40	3.61	3.72	-1
O (DRY)	-1	-1	16.84	15.86	-1	14.41	13.14	16.13	16.16	-1
N (DRY)	-1	-1	0.94	0.77	-1	0.62	0.75	0.73	0.75	-1
S (DRY)	0.36	0.35	0.26	0.25	0.48	0.34	0.39	0.31	0.24	0.25
C (DAF)	-1	-1	75.22	74.80	-1	72.58	74.55	72.49	74.30	-1
H (DAF)	-1	-1	4.18	4.52	-1	4.41	4.83	4.59	4.40	-1
O (DAF)	-1	-1	19.19	19.43	-1	20.63	18.27	20.46	17.97	-1
N (DAF)	-1	-1	1.10	0.95	-1	0.90	1.05	0.95	0.90	-1
S (DAF)	0.55	0.57	0.32	0.31	0.73	0.48	0.53	0.40	0.29	0.31

(-1 denotes a sample population too small for calculation)

Table 3. The **interquantile range** for proximate and ultimate variables. The interquantile range is defined as the difference between the 25th and 75th percentiles. These values are derived from data available through the Energy Resources Conservation Board. Analysis results are from raw/untreated samples. Proximate ash (ASH), volatile matter (VM), fixed carbon (FxC) and ultimate carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) are expressed in weight percent. Calorific value (CV) is expressed in mj/kg. The variables are reported on a dry basis (DRY) and on a dry, ash-free basis (DAF).

	Ardley Bend	Fox Creek	Genesee	Low Water	Musreau Lake	Swan Hills	Wetaskiwin	Whitewood	North Highvale	South Highvale
Proximate										
Ash (DRY)	6.7	12.5	4.3	3.8	11.9	7.4	8.1	8.5	2.9	3.7
VM (DRY)	2.6	4.8	1.8	1.9	4.5	2.5	5.5	4.2	4.9	1.6
FxC (DRY)	4.5	7.9	3.2	2.7	7.2	6.7	3.6	4.9	4.9	2.9
CV (DRY)	2.8	4.3	1.5	1.2	3.7	2.4	2.4	2.4	0.9	1.2
VM (DAF)	1.9	1.9	1.7	1.4	2.0	3.8	7.7	2.0	5.1	0.9
FxC (DAF)	1.9	1.9	1.6	1.4	2.0	3.8	6.7	2.0	5.2	0.9
CV (DAF)	2.0	1.2	0.6	0.2	1.4	0.7	0.2	0.5	0.4	0.3
Ultimate										
C (DRY)	-1	-1	3.27	3.83	-1	12.29	5.47	8.27	4.73	-1
H (DRY)	-1	-1	0.44	0.35	-1	0.64	0.18	6.74	0.49	-1
O (DRY)	-1	-1	1.05	1.52	-1	2.61	0.21	0.92	3.40	-1
N (DRY)	-1	-1	0.10	0.10	-1	0.24	0.14	1.83	0.10	-1
S (DRY)	0.06	0.07	0.10	0.03	0.11	0.06	0.10	0.10	0.10	0.09
C (DAF)	-1	-1	1.11	2.00	-1	5.43	8.46	1.80	4.93	-1
H (DAF)	-1	-1	0.42	0.23	-1	0.47	0.39	0.79	0.59	-1
O (DAF)	-1	-1	1.55	2.06	-1	3.54	1.58	1.83	4.48	-1
N (DAF)	-1	-1	0.09	0.10	-1	0.20	0.19	0.05	0.14	-1
S (DAF)	0.08	0.11	0.12	0.05	0.21	0.10	0.08	0.13	0.13	0.09

(-1 denotes a sample population too small for calculation)

3.3 Proximate and ultimate analyses

3.3.1 Ash (dry basis)

In Figure 13, the relatively low variability in ash content in the Genesee, Low Water, South Highvale and North Highvale is indicated by the smaller size of the boxes. The relative positions of the boxes for these deposits also indicate that they have the lowest ash contents. The Fox Creek and Musreau Lake deposits, on the other hand, exhibit more variability and higher levels of ash. The Whitewood, Swan Hills, Ardley Bend and Wetaskiwin deposits have ash values that fall in between.

The lower median ash values reported on a dry basis (See Table 2) for Genesee (14.8%), Low Water Lake (18.5%), South Highvale (17.4%), North Highvale (16.0%) and Whitewood (19.8%) are expected from the geologic model discussed in Richardson et al., 1988. From a regional perspective, the model predicts relatively thick, low ash coal seams in these areas (Figure 7). Published reports on the geology of the Genesee deposit (Mills, 1987), Highvale deposit (Wong et al., 1988; Lyons et al. 1987), and Whitewood (Lyons et al., 1987; Keele, 1985) confirm that the cumulative coal thickness of the Ardley zone in these areas is made up dominantly of relatively thick low ash coal seams. Coal resource trends of the thicker coal measures correspond to the best coal quality trends observed in this study.

North and south of the Genesee, Low Water and Highvale and Whitewood deposits, coal resource maps indicate that the Ardley coal zone consists of thinner seams with lower cumulative coal measures. The higher median ash values for Ardley Bend (30.7%), Wetaskiwin (27.0%), Swan Hills (29.5%), Fox Creek (36.6%) and Musreau Lake (34.9%) reflect differences in the geology. Less data are available on the geology of these deposits and many of the exploration results are proprietary at this time. Subsequent work by the authors and personal correspondence with exploration geologists who have studied these areas appear to confirm that the coal zones in these areas are made up predominantly of thinner, higher-ash seams. A published report from the Swan Hills deposit (Baofang and Dawson, 1988), as one example, outlines a series of laterally continuous but relatively thin seams. Coal seams in the Swan Hills area are commonly less than 1 m thick and seldom exceed 2 m in thickness. These trends contrast with the higher quality principal coal seams in North Highvale, such as seams 1 and 2, which average 3 to 4 metres in thickness (Wong et al., 1988). Further detailed studies of coal quality within all of these deposits are needed to verify the spatial dependence and geologic controls proposed.

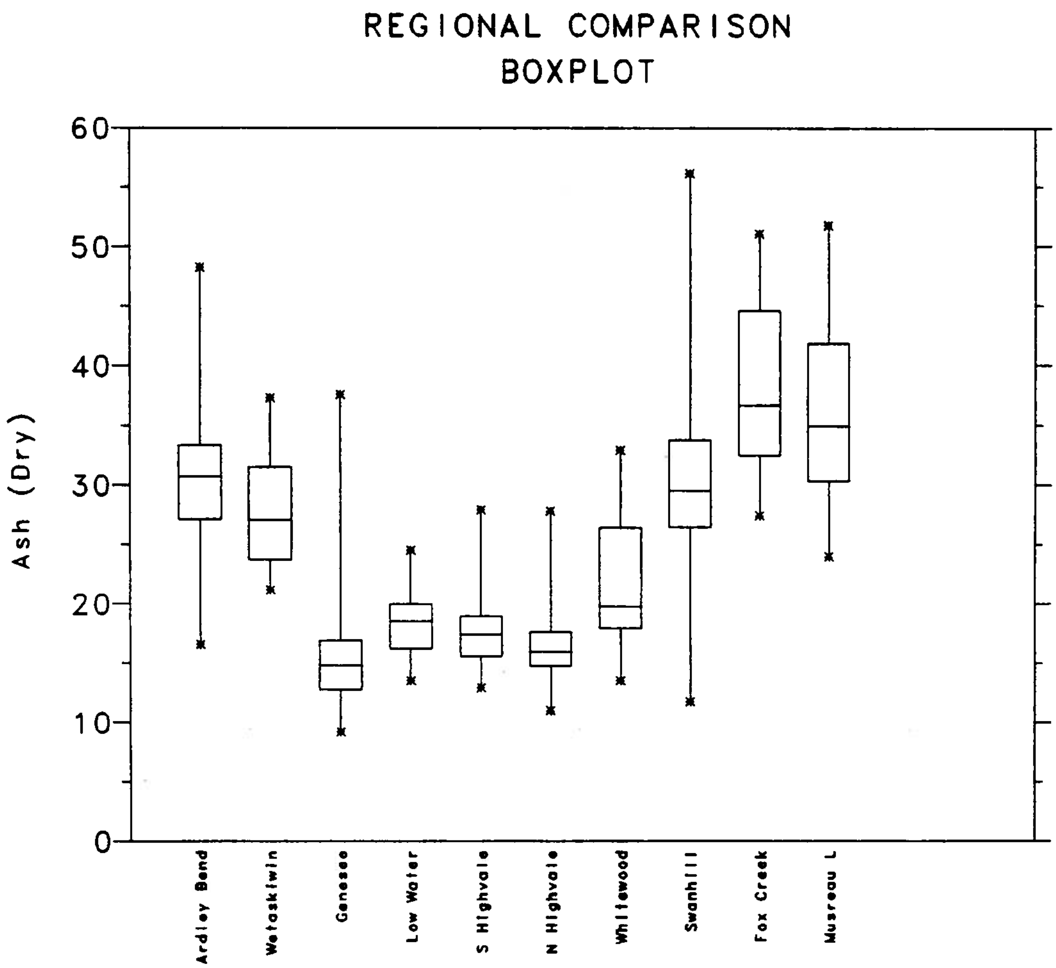


Figure 13. Box plots for **ash (dry basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

3.3.2 Volatile matter (dry basis)

Comparisons of volatile matter contents, on a dry basis between deposits, show similar trends to those noted for ash (Figure 14). The median values of volatile matter in Genesee (33.7%), Low Water Lake (32.9%), South Highvale (34.0%), North Highvale (36.2%), Whitewood (35.1%) and Swan Hills (32.1%) stand out with the highest levels. Median volatile matter values on a dry basis for the Ardley Bend (30.4%), Wetaskiwin (30.6%), Fox Creek (27.4%) and Musreau Lake (27.3%) deposits are generally lower.

A higher degree of variability is observed for volatile matter than for ash in all deposits, which may be a reflection of the inhomogeneities and complexities in coal composition. The volatile matter content represents the components of the coal, except for the moisture, that are liberated at high temperature in the absence of air. This material may be released from the organic compounds (ie. vitrinite, liptinite and semi-fusinite maceral groups) and from mineral impurities (Ward, 1984).

From a geologic perspective, large variation in coal composition is expected between seams and for the different locations in each deposit. On the deposit scale of investigation and the selected method of reporting volatile matter (dry basis), we prefer not to make definitive interpretations. We prefer simply to report the levels and variation observed. The calculated medians and interquantile ranges for each deposit are listed in Tables 2 and 3, respectively.

3.3.3 Fixed carbon (dry basis)

The box plots (Figure 15) for fixed carbon on a dry basis show similar trends to the plots for ash. Median composite values of fixed carbon for Genesee (51.6%), Low Water Lake (49.1%), South Highvale (48.7%), North Highvale (47.3%) and Whitewood (45.1%) are significantly higher than the other deposits. Ardley Bend (39.2%), Wetaskiwin (41.0%), Swan Hills (37.3%), Fox Creek (34.9%) and Musreau Lake (38.4%) generally have lower levels of fixed carbon. Since fixed carbon is not determined directly, but is calculated by subtracting the percent by weight of the other components (volatile matter and ash) from 100% , trends observed for fixed carbon will depend directly on the volatile matter and ash values. The calculated medians and interquantile ranges for each deposit are listed in Tables 2 and 3, respectively.

3.3.4 Calorific value (heat of combustion, mj/kg)

The box plots for calorific value on a dry basis (Figure 16), are almost mirror images of those for ash (Figure 13). Median values for calorific value (mj/kg) on a dry basis for Genesee (25.4%), Low Water Lake (23.7%), South Highvale (23.9%) and North Highvale (24.1%) stand out with the highest levels and lowest variability. Ardley Bend (20.4%), Wetaskiwin (21.7%), Whitewood (22.9%), Swan Hills (20.0%), Fox Creek (18.4%) and Musreau Lake (19.5%) have lower levels of calorific value and more

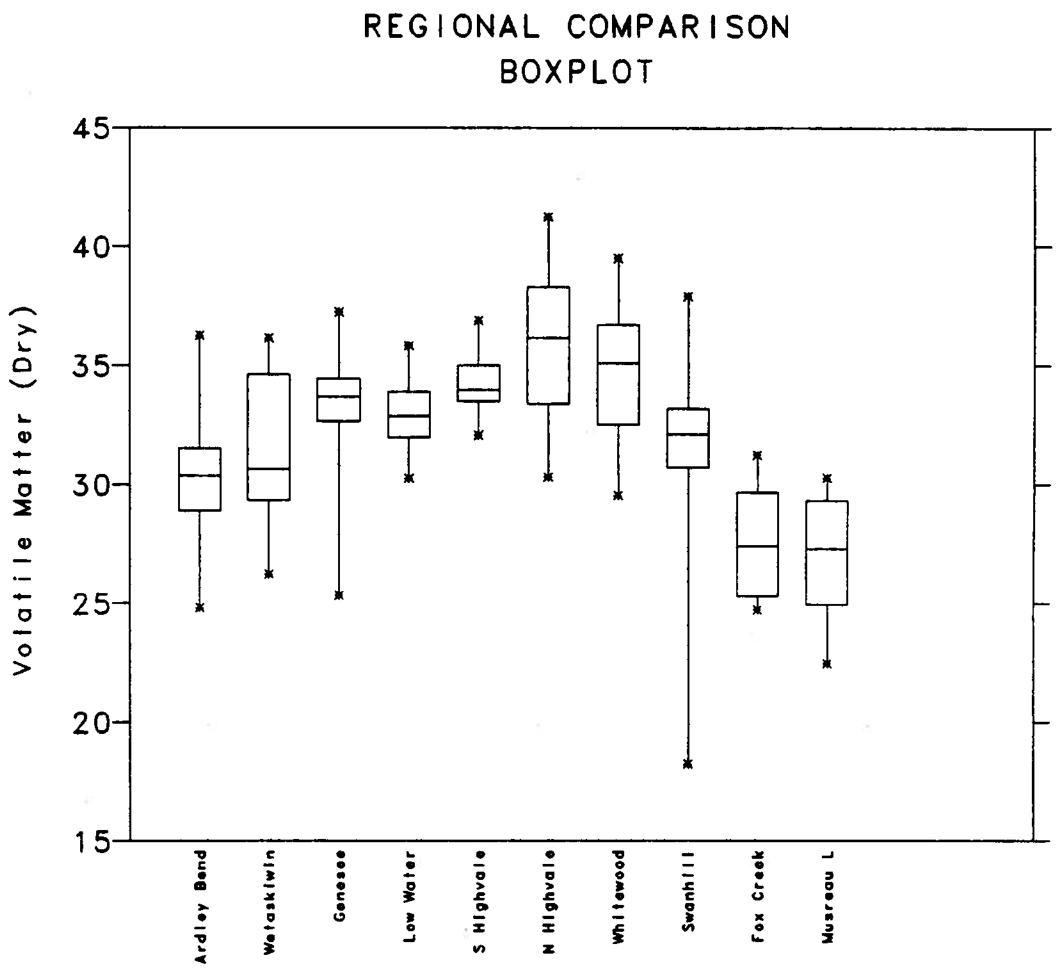


Figure 14. Box plots for **volatile matter (dry basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

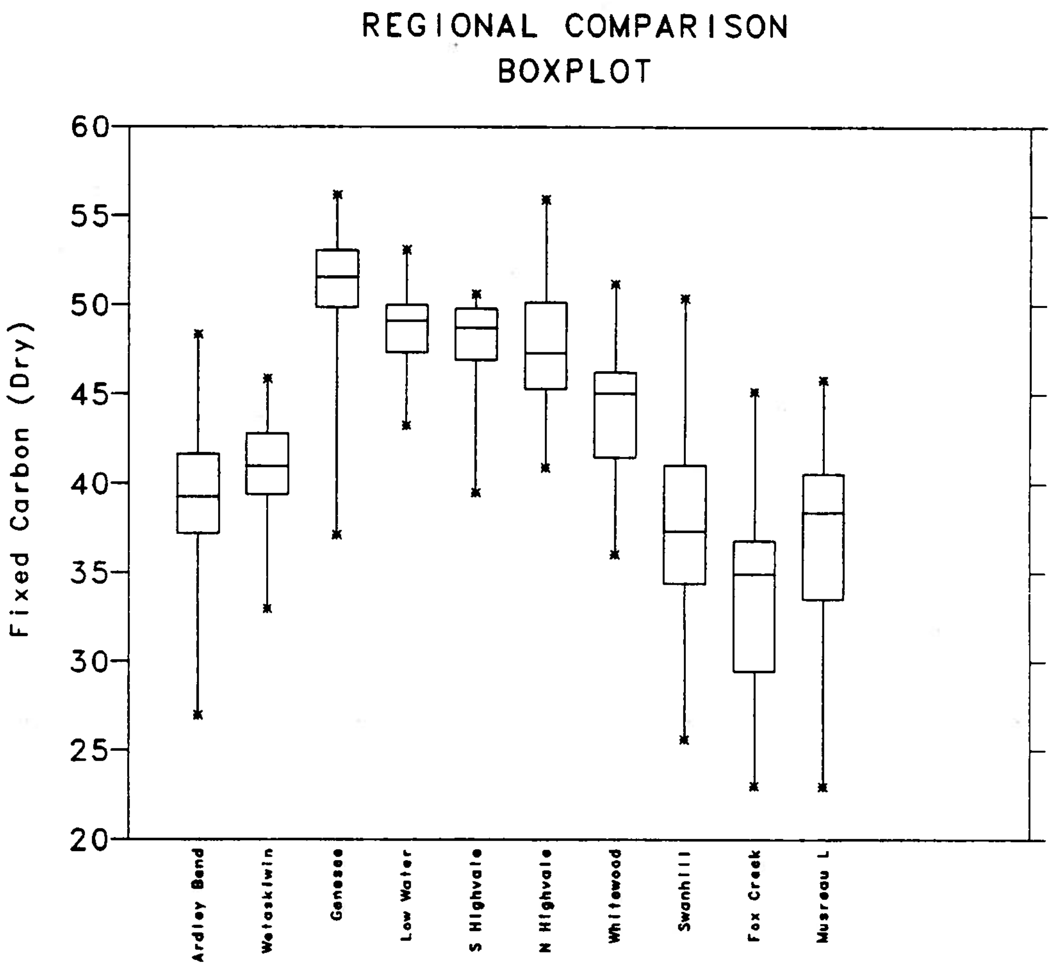


Figure 15. Box plots for **fixed carbon (dry basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

variability.

Although ash and calorific value are determined from independent tests, the close relationship between ash and calorific value is expected. Calorific value is commonly plotted against ash in coal quality studies because of the nearly perfect linear correlations that result. Examples of the ash content vs calorific value plots for the Highvale data set and the combined regional data set, are given in section 5.4.3. Calorific value is dependent on the ash content. Outliers or values which do not fall on or near the regression line are suspect, and are examined to see if data entry errors or sampling errors have occurred. The calculated median and interquantile range for calorific value in each deposit are provided in Tables 2 and 3, respectively.

3.3.5 Ultimate analysis (sulphur, dry basis)

Levels of total sulphur content on a dry basis are very low for all deposits (Figure 17). Deposits with the lowest calculated median values are Genesee (0.26%), Low Water Lake (0.25%), South Highvale (0.25%) and North Highvale (0.24%). Other deposits including Ardley Bend (0.36%), Wetaskiwin (0.39%), Whitewood (0.31%), Swan Hills (0.34%), Fox Creek (0.35%) and Musreau Lake (0.48%) generally contain slightly higher median sulphur values.

All values are on a weight percent basis, and represent the composite median (Figure 10). The sulphur content of individual seams within each deposit, vary considerably from the composite median. Generally, the thickest seams are likely to have the lowest total sulphur content. In Highvale North, for example, seam 2 commonly contains less than the composite median of 0.24%, with a median value of 0.18% sulphur (all on a dry basis). Seams 4 and 6 at Highvale contain median sulphur values ranging from 0.31% to 0.37% on a dry basis (Wong et al., 1988).

Similar variation in sulphur levels is observed for the composite data sets for the deposits (Figure 17). In the case of sulphur at the deposit scale, perhaps the range in values (ie. 25th to 75th percentiles) are more appropriate than the median for characterizing sulphur content. The calculated medians and interquartile ranges for sulphur in each deposit are listed in Tables 2 and 3, respectively.

3.3.6 Volatile matter (dry ash-free basis)

The variations in volatile matter expressed on a dry basis (Figure 14) are completely different from those of volatile matter expressed on a dry, ash-free basis (Figure 18). The deposits which clearly have the highest volatile matter (dry basis), such as Genesee, Low Water Lake, South Highvale and North Highvale, stand out as having the lowest levels of volatile matter (dry ash-free basis). The reason for the sudden shift can be seen in Figure 1. Coals with very low ash content (dry basis) receive a much smaller percentage adjustment in volatile matter and fixed carbon on a dry ash-free basis. High ash coals (dry basis) receive a much larger percentage adjustment in volatile matter and fixed carbon on

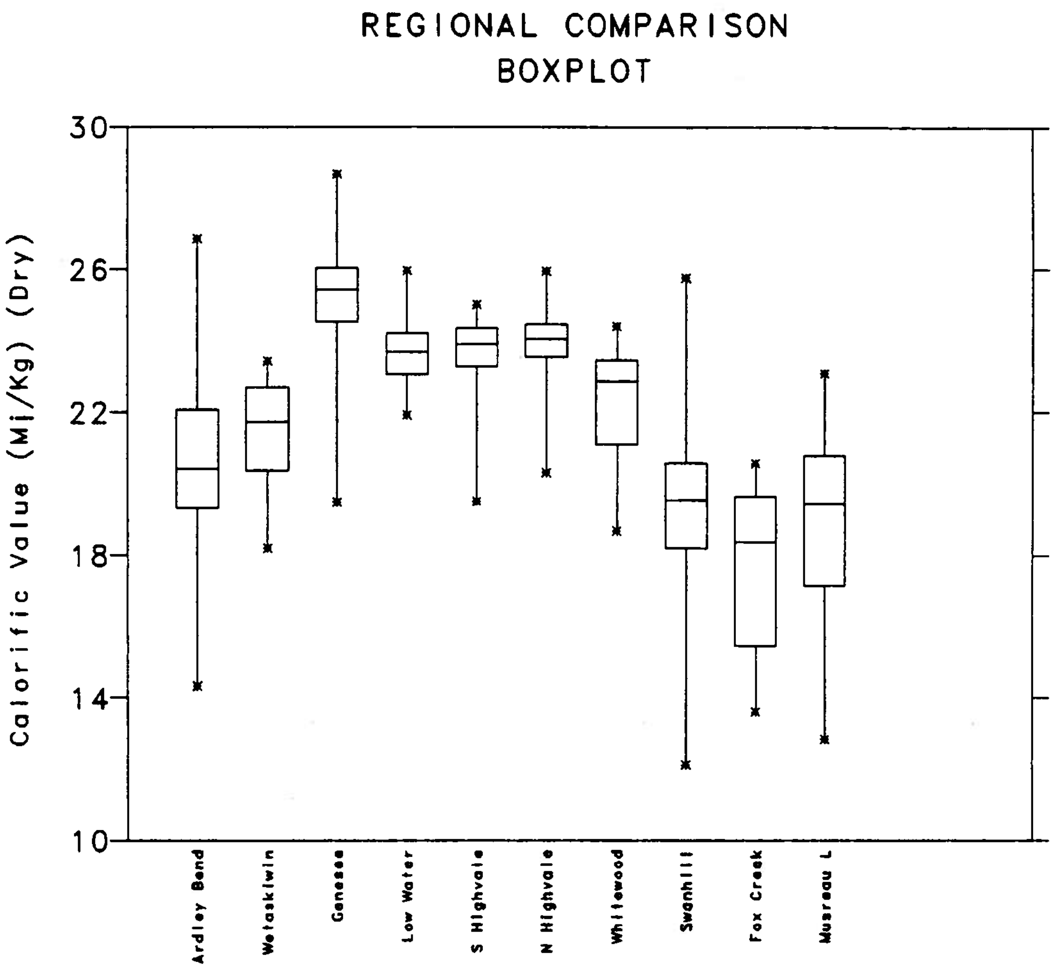


Figure 16. Box plots for **calorific value (dry basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

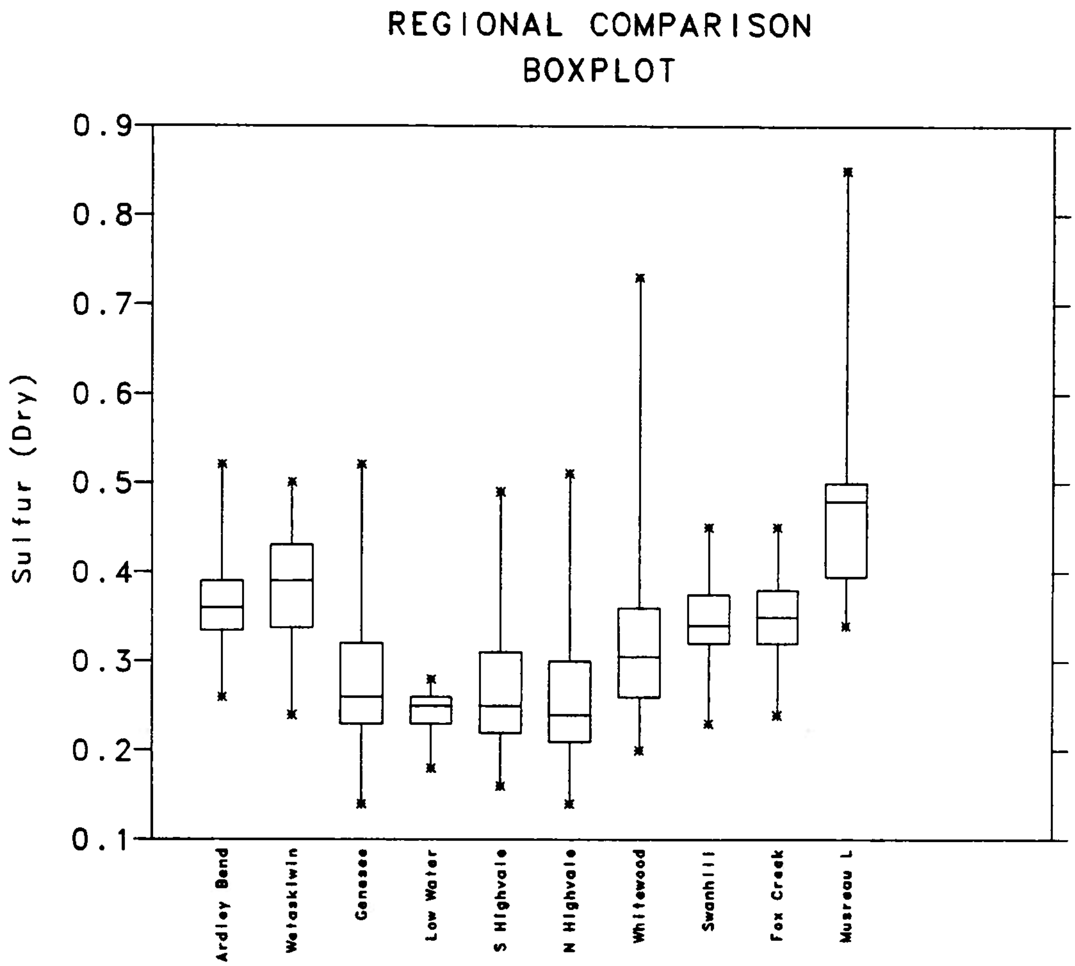


Figure 17. Box plots for total **sulphur (dry basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

a dry ash-free basis. The same is true for the adjustment from the dry basis to the dry mineral matter-free basis.

Many coal quality researchers recommend reporting volatile matter on a dry, mineral matter-free basis (Ward, 1984). Because ultimate sulphur values are required in the calculation, and with so few sulphur data available (for example, 16 data locations for sulphur in the Fox Creek, Low Water and Musreau Lake deposits), the dry mineral matter-free data sets would be reduced in size to 1/2 or less (See Table 1 for the number of sulphur data locations). Therefore, volatile matter was not reported on a dry mineral matter-free basis.

For the characterization of thermal properties of the Ardley coal zone, the dry basis is recommended. One reason for choosing the dry basis is that these coals are most likely to be burned untreated. Just as importantly, coal quality values reported on a dry, ash-free basis or dry mineral matter-free basis, are more likely to be misinterpreted in broad resource characterization studies. Coals from the Genesee area, for example, are noted for their low ash and relatively high volatile contents (dry basis) compared to the high ash and lower volatile contents (dry basis) of coals in the Fox Creek area (Figure 14). Comparison of the volatile matter in the same coals reported on the dry, ash-free basis show opposite characteristics. The higher volatile content of the Fox Creek coals reported on a dry, ash-free basis, may be reflecting the bias created by the higher ash contents, and therefore the larger percentage adjustment in volatile matter and fixed carbon in the conversion to dry, ash-free values. The calculated means and interquantile ranges on a dry, ash-free basis for volatile matter (Tables 2 and 3) are included in this report for comparison purposes only.

3.3.7 Proximate analysis (fixed carbon, dry ash-free basis)

Box plots for fixed carbon on a dry basis (Figure 15) also differ significantly from fixed carbon reported on a dry, ash-free basis for the same reason given in section 3.3.6 (Figure 19). Much of the variation is due to differing ash contents. Reporting fixed carbon on a dry ash-free basis is not recommended for characterizing the thermal properties of the Alberta plains coals. Calculated medians and interquantile ranges in Tables 2 and 3, respectively, are included for comparison purposes only.

3.3.8 Ultimate analysis (sulphur, dry ash-free basis)

Box plots for total sulphur content on a dry ash-free basis (Figure 20) for each deposit, show similar trends to the box plots reported on a dry basis (Figure 17). Levels of total sulphur are slightly elevated when reported on the dry ash-free basis because of the adjustment of the weight percent values with the removal of ash (ASTM, 1981). As Figure 2 and logic points out, one must be careful in interpreting sulphur values on a dry ash-free basis because a larger adjustment is given to the sulphur value in high ash coals than the adjustment in low ash coals.

There appears to be no "best" way to report sulphur. Ideally, the total

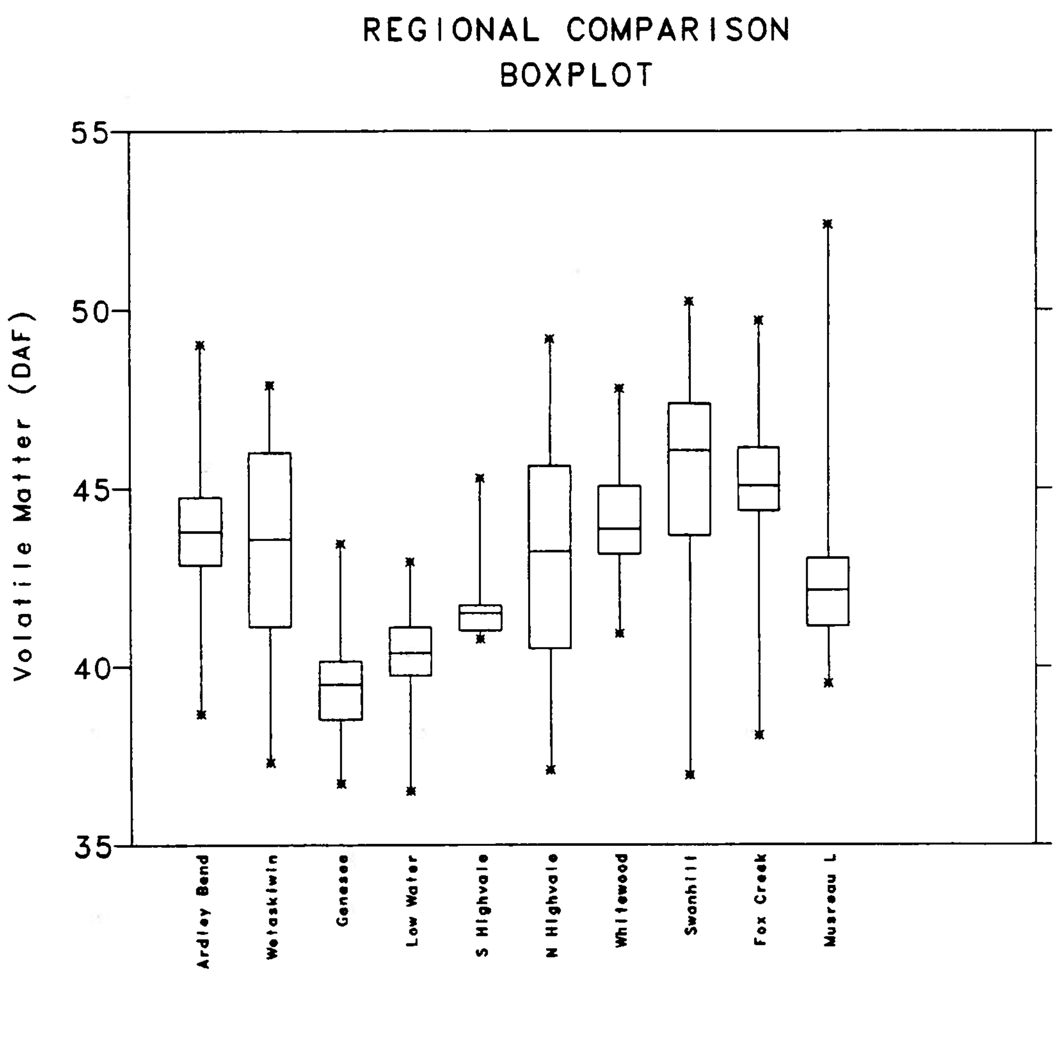


Figure 18. Box plots for **volatile matter (dry, ash-free basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

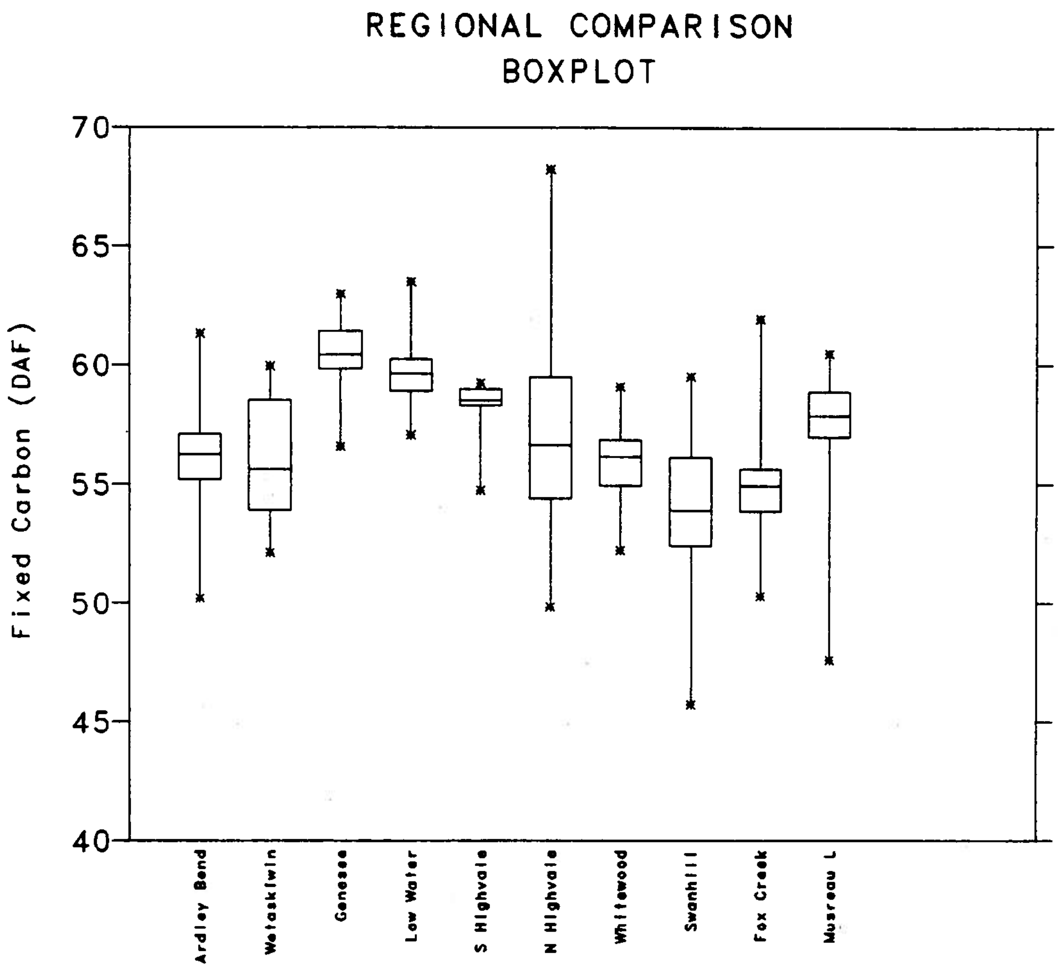


Figure 19. Box plots for **fixed carbon (dry, ash-free basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

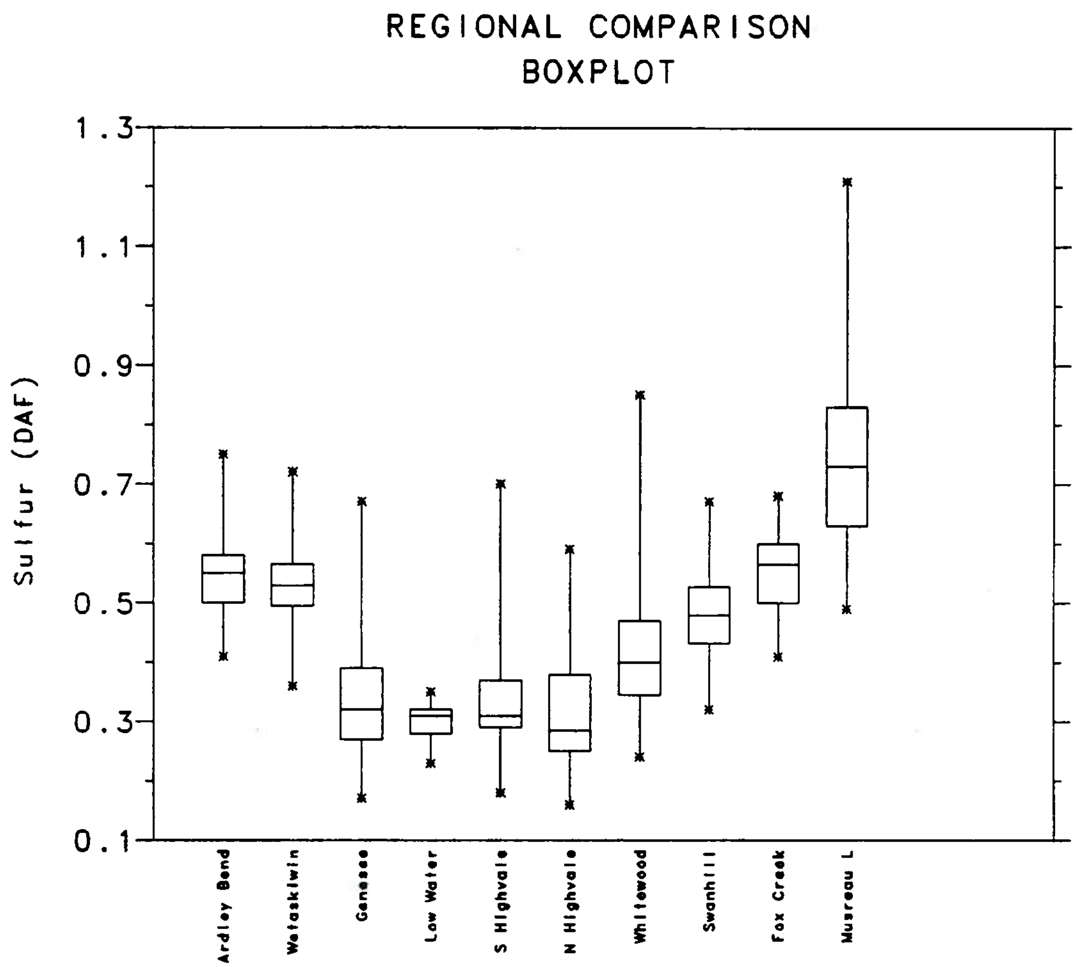


Figure 20. Box plots for **total sulphur (dry, ash-free basis)** for the ten deposits studied. These data represent composite values derived from the calculated weighted averages based on sample length for each drill hole.

sulphur content would be reported on a volume or weight percent/ heat value (ie. grams sulphur/mj). A higher rank coal, for example, may have the same weight percent sulphur content as a lower rank coal. For the same heat value, the higher rank coal could release less sulphur because less coal is burned. This method of reporting was not used in this evaluation because of limited amounts of available data.

Similar variation in sulphur levels is observed for the composite data sets for the deposits (Figure 20). As outlined in the discussion for sulphur on a dry basis, perhaps median sulphur levels are less representative than the range in values. The range in values between the 25th and 75th percentiles, for example may be more appropriate for characterizing total sulphur content. The calculated medians and interquartile ranges for sulphur in each deposit are listed in Tables 2 and 3, respectively.

3.4 Interpretation of results

A relatively small number of samples are used to characterize the coal resources of each deposit. Because of the limited amount of data, one must be very careful in interpreting the results of this study. Keeping in mind that the estimates given are for composite samples (all seams combined) and that sampling methods vary between active mining areas and exploration areas, there are confidence limits in the reported results. Detailed evaluations on a seam by seam basis are strongly recommended for accurate estimates of coal quality in all of the deposits studied.

The reporting of data on the dry, ash-free basis and dry, mineral matter-free basis is common in coal quality studies. From an coal explorationist's point of view, the dry basis is recommended because these coals are likely to be burned untreated. Reporting on the dry, ash-free and dry, mineral matter-free bases gives adjusted values for proximate and ultimate variables that may be more appropriate for coal processing studies. Also, when comparing coal quality values from different areas of the basin, a bias is introduced because coals of differing ash contents are each adjusted differently. The higher the ash, the greater the adjustment made to recalculate the remaining components in the proximate and ultimate analyses to 100 percent. The relatively high volatile matter contents reported for high ash and high moisture coals, for example, may reflect the calculated adjustment for ash and moisture, more so than the true volatile matter content. Coal quality reported on any basis must be interpreted carefully.

4.0 Coal Quality Variation Within A Deposit

4.1 Coal quality variation between seams

A detailed substudy of coal quality in the Highvale Mine (Wong et al., 1988) indicates that within a deposit, coal quality exhibits large variation from seam to seam. The Highvale study evaluates each seam individually and is based on coal quality information from approximately 315 core holes. The abundant coal quality data, detailed geological information and the laterally extensive nature of the seams, make the Highvale mine area ideal for detailed evaluation.

In the Highvale mine, 6 coal seams were evaluated and compared. Of these, seams 1, 2, 3, 4 and 6 are mined (Figure 21). Coal isopach maps and cross sections, based on over 500 development and exploration holes, describe the lateral continuity, thickness variation and geometry of these seams (Lyons et al, 1987, Wong et al., 1988). Samples are all derived from core, and sample handling and preparation are consistent, so we have a high degree of confidence in these data.

For the purpose of visually comparing the coal quality of each seam, multiple box plots are given (Figure 22). As with the deposits substudy, proximate analyses (volatile matter, fixed carbon and ash), calorific value and ultimate sulphur are compared on a dry basis. For Highvale, coal quality statistics are also available for the "as-received" basis (air-dried moisture classification). A discussion of coal quality on an "as-received" basis is given in Wong et al., (1988). Selected portions of results on a dry basis from Wong et al., (1988) are included in this report for comparison and to discuss the issue of representativeness.

In Figure 22, the relatively low variability in ash, volatile matter, fixed carbon and total sulphur, in seams 1 and 2, is indicated by the smaller size of the boxes. The relative positions of the boxes indicate that these seams have the highest quality of all seams in the mine, in terms of their thermal properties. Seams 1 and 2 are the thickest, nearest to surface, have the highest volatile matter, fixed carbon and heat of combustion and the lowest levels of ash and total sulphur.

More detailed studies of seam 1, illustrates the importance of understanding the geology of the deposit and the effects of geological controls on coal quality. Subsequent investigations by the authors and TransAlta Utilities geologists (Nikols, personal communication), indicate that the coal quality of seam 1 in Highvale North differs significantly from the quality in Highvale South. In Highvale North, seam 1 and seam 2 have very similar coal quality characteristics. Both have very low levels of ash and sulphur, and relatively low variability in all components. In Highvale South, seam 1 changes in composition, containing higher ash and sulphur contents and is more variable in quality. Because of significant differences in the geology and associated coal quality characteristics between Highvale North and Highvale South, more representative estimates of coal quality in seam 1 can be achieved by

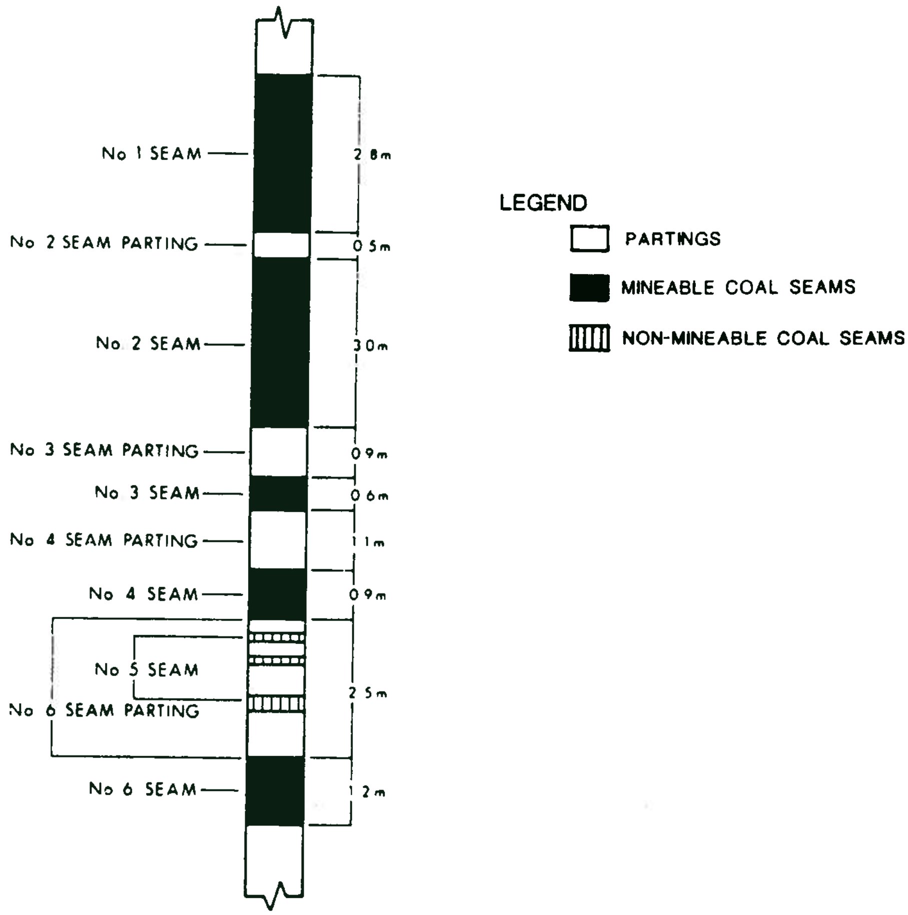


Figure 21. Numbering system and thickness comparison of the Ardley coal seams in the Highvale Mine. Seams are numbered 1 through 6, from the top to base, respectively, in the succession (after Taylor. 1985).

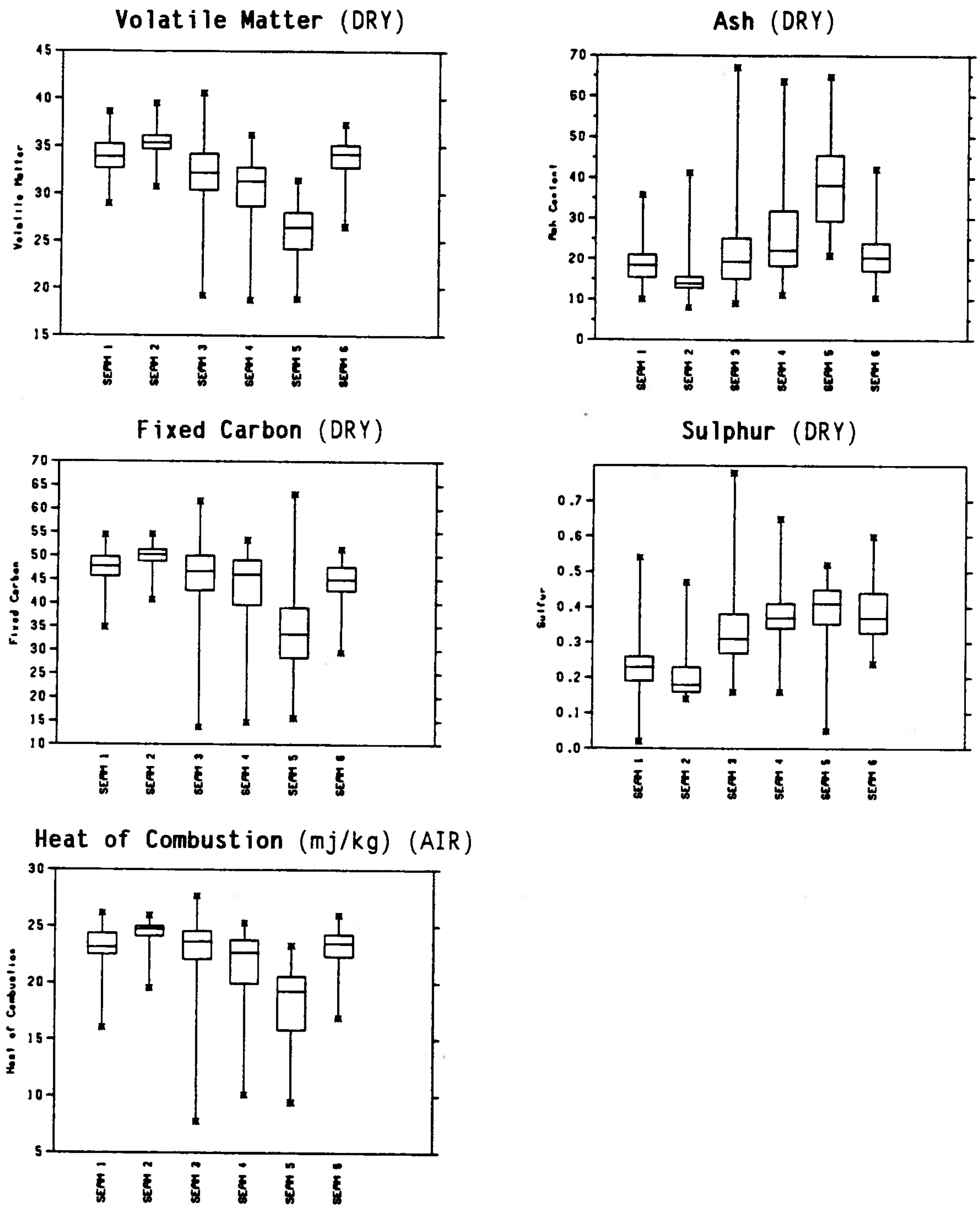


Figure 22. Box plots for volatile matter, ash, fixed carbon, calorific value and total sulphur (all on a dry basis), for seams 1 to 6 in the Highvale Mine.

studying the two areas separately. Geostatistics performed after the seam comparisons were made concentrated on North Highvale because of the noted differences between areas.

At the other extreme, seam 5, which is not mined in Highvale due to its poor quality and uneconomic thickness, has much higher ash and sulphur contents and the lowest levels of volatile matter, fixed carbon, and calorific value. It is interesting to note that although seam 5 is not economic to mine in Highvale, the seam 5 equivalent in the Whitewood Mine (approximately 10 km northeast of Highvale) is mined. The seam 5 equivalent is much thicker and of better quality in the Whitewood Mine (Lyons et al., 1987). This example stresses the importance of studying coal quality on a seam basis and limiting the study area to a deposit scale or even to part of a deposit, in order to obtain the most accurate estimates.

Seams 3, 4 and 6 in Highvale typically contain higher ash contents than seam 1 and 2, and are generally more variable in all coal quality parameters. Table 4 provides a listing of the median values for all seams and Table 5 gives the interquantile ranges, which are measures of the amount of variability.

4.2 Representativeness of statistical results

Large variability is observed from seam to seam for most variables. Variations are expressed in terms of levels (medians) and the interquantile range. When evaluating coal quality, representativeness is an important consideration. On a deposit scale, coal quality values should be clearly differentiated as to which seam they are from, their sampling method and their location within the deposit. On a regional scale of investigation, less detailed data are available so less confidence can be assigned to regional estimates.

As one example of the importance of representativeness, consider the comparison between the median ash and sulphur values for composite samples (ie. all seams combined, weighted average based on length) to the more detailed estimates available on a seam basis. The median composite value for ash (dry basis) in Highvale North is 16.0% with an interquantile range of 2.9% (dry basis). Individual seams within the Highvale area reflect a slightly different picture. Median values of weight% ash (dry basis) in seams 1 to 6 are 18.4%, 13.9%, 19.3%, 22.2%, 38.0% and 20.3%, respectively (Table 4). Interquantile ranges for ash are 5.7%, 2.8%, 10.0%, 13.6%, 16.2% and 6.8%, respectively (Table 5).

Notable variation in total sulphur content is also displayed. The regional estimate of the median sulphur (dry basis) is 0.24% with an interquantile range of 0.10% (dry basis). Individual seams within the Highvale area have median values of 0.25%, 0.18%, 0.31%, 0.37%, 0.41% and 0.37%, respectively, for seams 1 to 6. Interquantile range for total sulphur is 0.07%, 0.07%, 0.11%, 0.07%, 0.10% and 0.12%, respectively, for seams 1 to 6. Comparison of the other coal quality parameters, including fixed carbon, volatile matter and calorific value, display similar differences between the regional and detailed scales.

Table 4. The **median** value for seams 1 to 6 at Highvale Mine. The data are derived from TransAlta Utilities. Analysis results are from raw/untreated composite core samples and reported on a dry basis. The proximate variables ash (ASH), fixed carbon (FxC), volatile matter (VM) and ultimate sulphur (S) are expressed in weight percent. Calorific value is expressed in mj/kg. The complete table is available in Wong et al., (1988).

	Seam 1	**Seam 2**	**Seam 3**	**Seam 4**	**Seam 5**	**Seam 6**
Ash (dry)	18.4	13.9	19.3	22.2	38.0	20.3
FxC (dry)	47.7	50.2	46.8	46.0	33.4	45.0
VM (dry)	33.9	35.4	32.2	31.3	26.4	34.1
CV (dry)	23.2	24.8	23.7	22.7	19.2	23.5
Ultimate						
S (dry)	0.25	0.18	0.31	0.37	0.41	0.37

Table 5. The **interquantile range** for seams 1 to 6 at Highvale Mine. The data are derived from TransAlta Utilities. Analysis results are from raw/untreated composite core samples and reported on a dry basis. The proximate variables ash (ASH), fixed carbon (FxC), volatile matter (VM) and ultimate sulphur (S) are expressed in weight percent. Calorific value is expressed in mj/kg. The complete table is available in Wong et al., (1988).

	Seam 1	**Seam 2**	**Seam 3**	**Seam 4**	**Seam 5**	**Seam 6**
Ash (dry)	5.7	2.8	10.0	13.6	16.2	6.8
FxC (dry)	4.2	2.5	7.4	9.5	10.8	5.1
VM (dry)	2.5	1.6	3.9	4.2	4.0	2.4
CV (dry)	1.9	0.9	2.5	3.9	4.8	1.9
Ultimate						
S (dry)	0.07	0.07	0.11	0.07	0.10	0.12

4.3 Definition of confidence limits

Regional composite estimates serve as a guide to measure expected ranges in values. Detailed data on a deposit scale, with seams differentiated and with detailed geological information available, provide higher confidence levels so that central tendencies and variation can be evaluated. Detailed studies on a mine site scale are recommended for the most reliable estimates and to gain a better understanding of coal quality variation and its controls.

At every deposit and every drill hole in Alberta, we can expect a large range in coal quality between seams. A comprehensive statistical and geological study of the Highvale mine (Wong et al., 1988), clearly indicates the amount of variability that can be expected between seams. Ash analyses for Highvale North, for example, will vary from as low as 11% by weight (Seam 2) to 40% or more (Seam 5) in the same drill hole location. In addition, some deposits must be further subdivided into separate study areas (Highvale North and South, for example) for more accurate estimates of coal quality on an individual seam basis.

Similar findings are noted for the Genesee deposit by Mills (1987), in which four mineable coal seams are described. In the Genesee evaluation, the study area is divided into eastern and western regions. The variation in thickness and quality of the coal seams between regions as well as the addition of seams, make separation of study areas essential, even on a deposit scale. The median value calculated for composite samples (ie. all seams combined in each drill hole) is 14.8% (Table 2). This value compares with estimates of individual seams which vary from a low of less than 12% to 30% or more, all on a dry basis (Mills, 1987).

Less detailed coal quality data is publicly available for the other deposits such as Musreau Lake, Fox Creek, And Swan Hills but similar results are expected. The composite median ash value serves more as a guide. More accurate estimations of coal quality are given on a seam by seam analysis. Knowing the detailed geology will provide confidence in the estimations and lay the foundation for interpreting statistical results.

5.0 Comparison Between Highvale and Regional Trends

5.1 Introduction

The purpose of this part of the analysis is to compare coal quality between the Highvale area to the rest of the Ardley coal zone. It has been suggested earlier in this paper that the coal quality in the Highvale area may be anomalous compared to regional trends. This evaluation combines North and South Highvale into one data set (inside Highvale) and compares the proximate and ultimate parameters to the regional Ardley coal quality data set (outside Highvale). The following discussion looks at observed differences and attempts to explain those differences.

5.2 Definition of the data sets

For each coal quality variable, a weighted average value based on thickness, is calculated for each drill hole location for the inside Highvale and outside Highvale data sets. Table 6 lists the sample sizes for each variable. There are abundant proximate analyses but fewer ultimate analyses available for comparison. It must be noted from Table 6, that all of these comparisons involve considerable differences in the sizes of samples compared. While the statistical tests used can accommodate unequal sizes, the likelihood of bias in sampling exists. The likelihood of bias may be especially true for the ultimate carbon, hydrogen, oxygen and nitrogen, in which only 8 values (inside Highvale) are available for comparison.

5.3 Wilcoxon Test

The purpose of this portion of the evaluation is to find out if differences can be detected statistically between the coal quality inside Highvale and outside Highvale. Since most of the coal quality data are not normally distributed, the Wilcoxon (Mann-Whitney) nonparametric test was applied in each case (SAS Users Guide, 1985; Kalbfleisch and Prentice, 1980). In Table 7, the calculated P-values for ash, fixed carbon, volatile matter, calorific value and ultimate sulphur (on a dry basis) are less than 0.05, so one can assume that these variables are significantly different. The probability of being wrong (ie. probability of a type 1 error) is at the 5% level.

Examination of coal quality parameters reported on a dry, ash-free basis shows mixed results. The fixed carbon on a dry, ash-free basis, for example has a P-value of 0.0633. Differences between observations for proximate dry ash-free values from inside and those outside Highvale can be considered significant at the 7% level. Table 6 indicates that while a reasonable sample size is available for ash, fixed carbon, volatile matter, calorific value and ultimate sulphur, the other variables, notably ultimate carbon, hydrogen and oxygen did not have enough observations for meaningful comparisons.

Table 6. Sample sizes (drill holes with coal quality data) from inside and outside Highvale. The proximate variables are ash (ASH), volatile matter (VM), and fixed carbon (FxC). Calorific value (CV) is included for comparison purposes. Ultimate variables are carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S). The variables are reported for raw/untreated samples on a dry basis (DRY) and on a dry, ash-free basis (DAF).

Variables	Inside Highvale	Outside Highvale
Proximate		
ASH (DRY)	145	728
VM (DRY)	145	699
CV (DRY)	140	726
FxC (DRY)	145	699
VM (DAF)	145	698
CV (DAF)	140	725
FxC (DAF)	145	698
Ultimate		
C (DRY)	8	164
H (DRY)	8	164
O (DRY)	8	155
N (DRY)	8	159
S (DRY)	55	602
C (DAF)	8	163
H (DAF)	8	163
O (DAF)	8	154
N (DAF)	8	158
S (DAF)	55	601

Table 7. Results of comparisons between the Highvale Mine and the rest of the Ardley coal zone. (Entries are P-values from the Wilcoxon Test). The proximate variables are ash (ASH), volatile matter (VM), and fixed carbon (FxC). Calorific value (CV) is included for comparison purposes. Ultimate variables are carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S). The variables are reported on a dry basis (DRY) and on a dry, ash-free basis (DAF).

Proximate Analysis			Ultimate Analysis		
ASH	(DRY)	0.0000	C	(DRY)	0.0023
FxC	(DRY)	0.0000	H	(DRY)	0.0221
VM	(DRY)	0.0000	O	(DRY)	0.2015
CV	(DRY)	0.0000	N	(DRY)	0.5009
			S	(DRY)	0.0000
FxC	(DAF)	0.0633	C	(DAF)	0.5269
VM	(DAF)	0.0031	H	(DAF)	0.9562
CV	(DAF)	0.0000	O	(DAF)	0.7193
			N	(DAF)	0.0049
			S	(DAF)	0.0000

5.4 Nature of the differences in coal quality between inside and outside Highvale

Since the Wilcoxon tests do not give details of the nature of the differences between data sets, it is useful to examine summary statistics for indications of where the differences are. The statistics presented in Table 8 list the median and interquantile range for each coal quality parameter inside and outside Highvale. The median (or 50th percentile) is a measure of central tendency and interquantile range is a measure of variability. Interquantile range is defined as the difference between the 25th percentile and 75th percentile of the data distribution.

5.4.1 Ash comparison

From Table 8, one can see that the differences in ash content between inside and outside Highvale can be attributed to both central tendency and variability. The median ash content inside Highvale with a value of 16.0% (dry basis), is much lower than 24.5% (dry basis) calculated regionally. Less variability is observed inside Highvale, with an interquantile range of 2.8% compared to 12.1% outside Highvale.

The striking differences in ash content inside Highvale compared to outside Highvale, are also observed in the histograms (Figures 23 and 24, respectively). Although ash contents inside Highvale range from 8% to 29% (dry basis), most of the values are between 14% and 17% (Figure 23). The ash values for outside Highvale range from 8% to more than 50% (dry basis). No well defined central tendency is evident in the outside Highvale data set (Figure 24). The ash contents inside Highvale are clearly at the lowermost end of the scale, compared to outside Highvale.

5.4.2 Sulphur comparison

For the ultimate analyses, only total sulphur is considered to have a large enough sample size for discussion. Median sulphur content inside Highvale is 0.24% (dry basis) compared to 0.33% (dry basis) outside Highvale. The interquantile ranges for inside and outside Highvale are 0.11% and 0.12% (dry basis), respectively, suggesting similar variability in both data sets.

Comparison of sulphur analyses between inside and outside Highvale on a dry ash-free basis show similar trends to those reported on a dry basis. The median value for sulphur on a dry ash-free basis for inside Highvale is 0.29% compared to 0.46% outside Highvale. The interquantile ranges for inside and outside Highvale are 0.14% and 0.19% (dry basis), respectively. The larger variation observed on a dry ash-free basis compared to the dry basis is due largely to the higher ash contents in the regional data. When sulphur is recalculated to the dry ash-free basis, the regional data has a larger adjustment.

Histograms showing the distribution of sulphur values inside and outside Highvale are given in Figures 25 and 26, respectively. Inside Highvale, the most frequently occurring value for sulphur is 0.2% to 0.3% (dry,

Table 8. Summary statistics from inside Highvale (IN) and outside Highvale (OUT). The proximate variables are ash (ASH), volatile matter (VM), and fixed carbon (FxC) are reported as weight percent. Calorific value (CV) is reported as mj/kg. The ultimate variables carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) are reported as weight percent. The data sets contain the weighted averages for each drill hole based on thickness (ie. all seams combined). The variables are reported on a dry basis (DRY) and on a dry, ash-free basis (DAF).

	Median		**Interquantile Range**	
	IN	**OUT**	**IN**	**OUT**
Proximate				
ASH (DRY)	16.0	24.5	2.8	12.1
FxC (DRY)	47.6	43.5	4.7	9.0
VM (DRY)	36.1	31.3	4.7	4.0
CV (DRY)	24.1	22.2	0.9	3.7
FxC (DAF)	56.7	57.6	5.0	4.2
VM (DAF)	43.3	42.1	5.0	4.1
CV (DAF)	28.7	29.3	0.4	1.4
Ultimate				
C (DRY)	64.25	56.67	3.62	12.22
H (DRY)	3.78	3.45	0.52	0.81
O (DRY)	15.77	14.72	3.68	3.39
N (DRY)	0.73	0.76	0.09	0.22
S (DRY)	0.24	0.33	0.11	0.12
C (DAF)	74.84	74.54	5.17	3.96
H (DAF)	4.40	4.41	0.63	0.81
O (DAF)	17.88	19.20	4.20	3.31
N (DAF)	0.87	1.00	0.11	0.21
S (DAF)	0.29	0.46	0.14	0.19

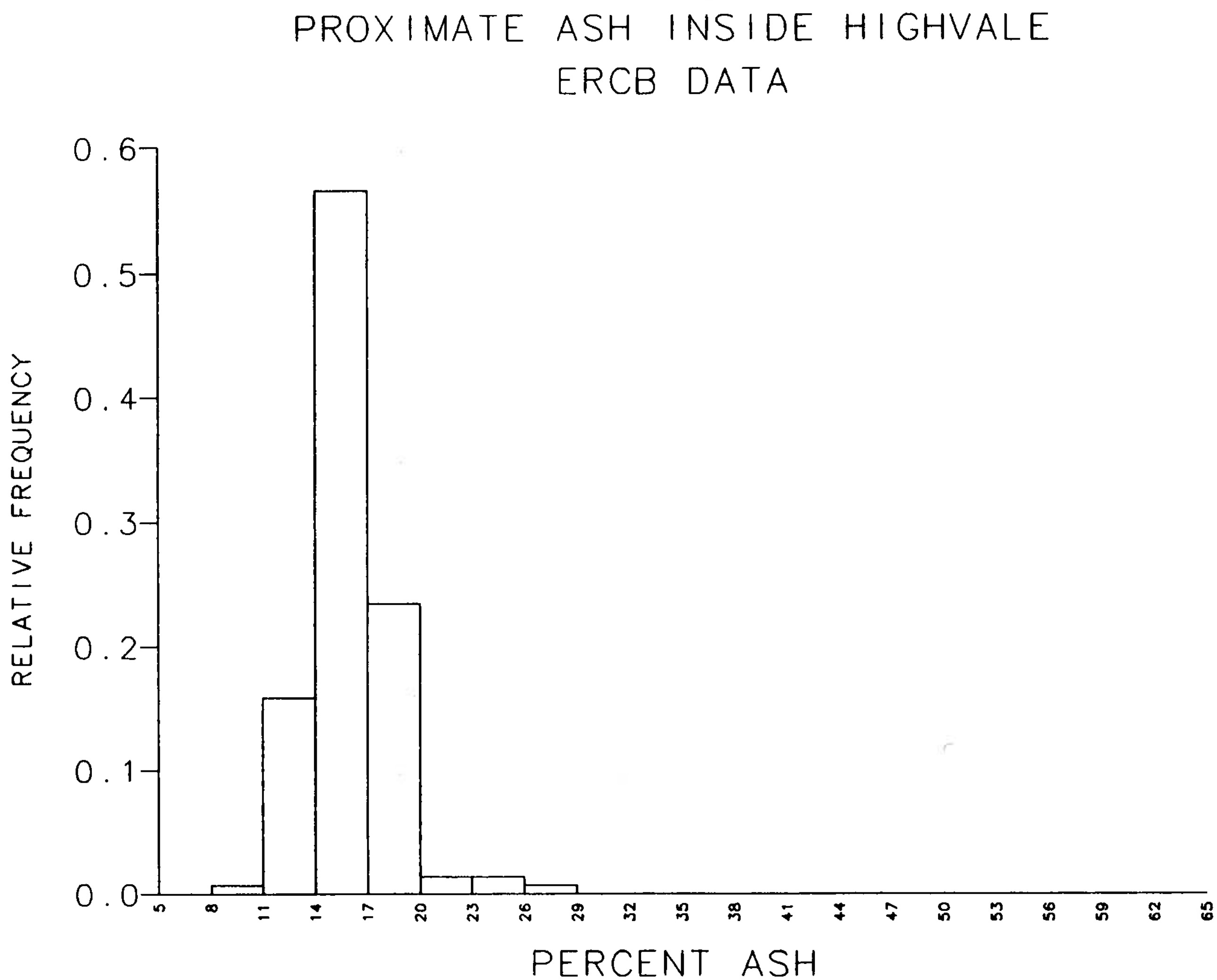


Figure 23. Relative frequency distribution of the **ash** content **(dry basis) inside Highvale.** This distribution is based on 145 composite samples (ie. all seams combined in each drill hole).

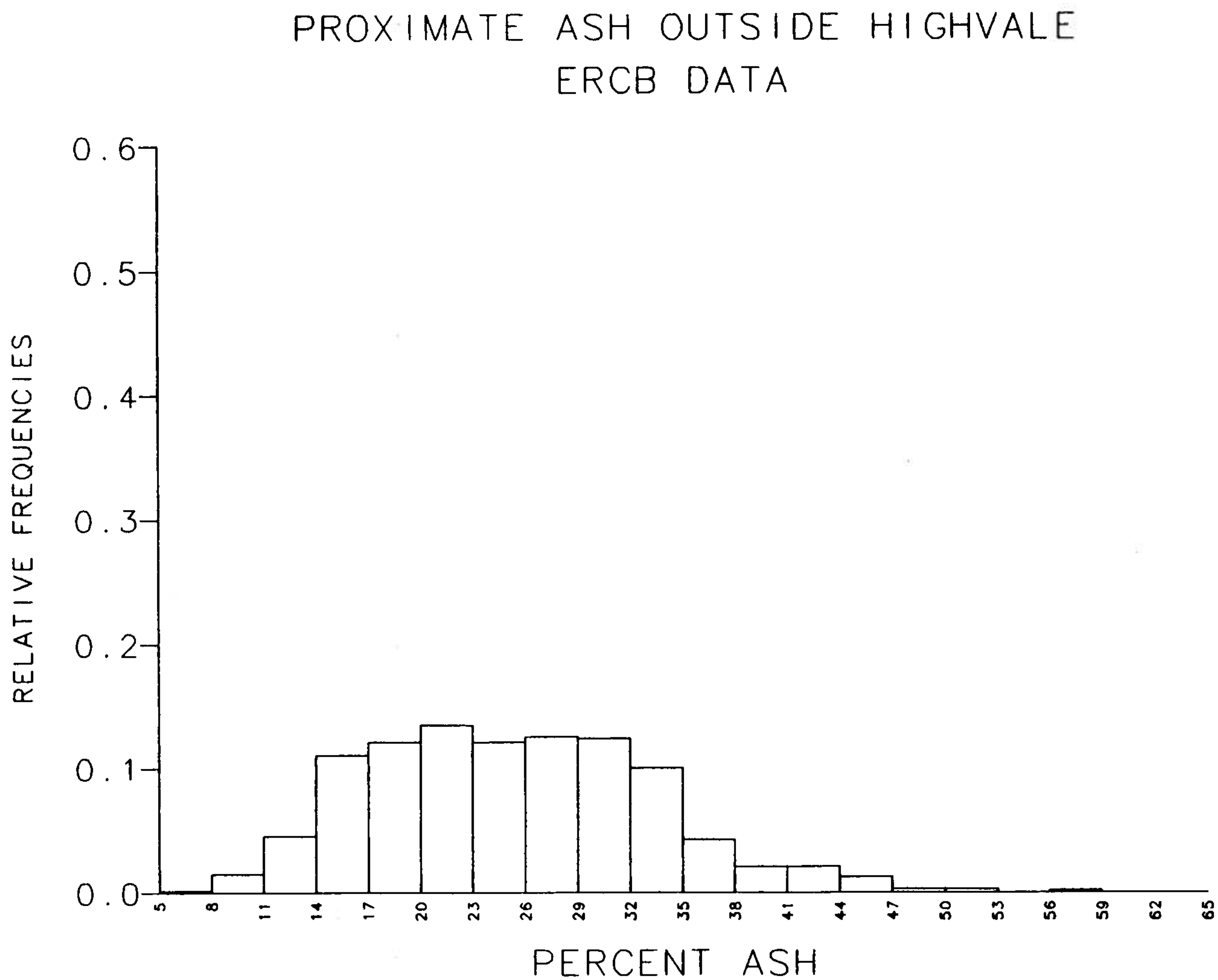


Figure 24. Relative frequency distribution of the **ash** content **(dry basis) outside Highvale.** This distribution is based on 728 composite samples (ie. all seams combined in each drill hole).

ash-free basis). Outside Highvale, the 0.2% to 0.3% values occur at the bottom end of the scale. The total sulphur contents inside Highvale are clearly the lowest, compared to outside Highvale.

5.4.3 Calorific value comparison

When the calorific value of a coal of similar rank (ie. all subbituminous) is evaluated, the amount of variation is dependent largely on ash content and to some extent, the moisture content. In Table 8, the median calorific value (measured as mj/kg) inside Highvale is 24.10 compared to 22.19 outside Highvale, all on a dry basis. The interquantile range for inside Highvale is 0.92% compared to 3.72% outside Highvale. These differences are expected because of similar variations observed in the ash contents.

Rather than producing histograms for calorific value (which will mirror histograms produce for ash), crossplots were derived for inside and outside Highvale (Figures 27 and 28, respectively). The linear relationship between ash percent (dry basis) to calorific value (dry basis) emphasize the dependency on ash content. These plots are useful to find outliers or possible data entry errors. Four points on Figure 28, for example, plot along the percent ash axis rather than along the regression line. These points are suspect and the values are likely in error. In this particular example, because there are only four values, these outliers will not significantly effect statistical results. In every coal quality data set, there will be some sampling or data entry errors.

Comparing Figures 27 and 28, one observes that the calorific value and ash contents for inside Highvale are anomalous compared to outside Highvale. In addition, each of the plots can be used to predict calorific value in any given location if the ash content is known. The equations applied to predict calorific value from ash content are provided at the top of each plot.

5.4.4 Fixed carbon and volatile matter comparison

Comparison of fixed carbon and volatile matter (all on a dry basis) indicate that inside Highvale, the calculated medians are slightly higher than for outside Highvale (See Table 8). Differences for these coal quality parameters are more difficult to interpret because of inherent sampling biases and dependencies. This is explained in more detail in section 3.3.3 and 3.3.7 of this paper.

The median value for fixed carbon is 47.6% (inside Highvale) compared to 43.5% (outside Highvale), all on a dry basis. The interquantile range for fixed carbon is 4.7% (inside Highvale) compared to 9.0% (outside Highvale). The median value for volatile matter is 36.1% (inside Highvale) compared to 43.5% (outside Highvale), all on a dry basis. The interquantile range for volatile matter (inside Highvale) is 4.7% compared to 4.0% (outside Highvale), all on a dry basis.

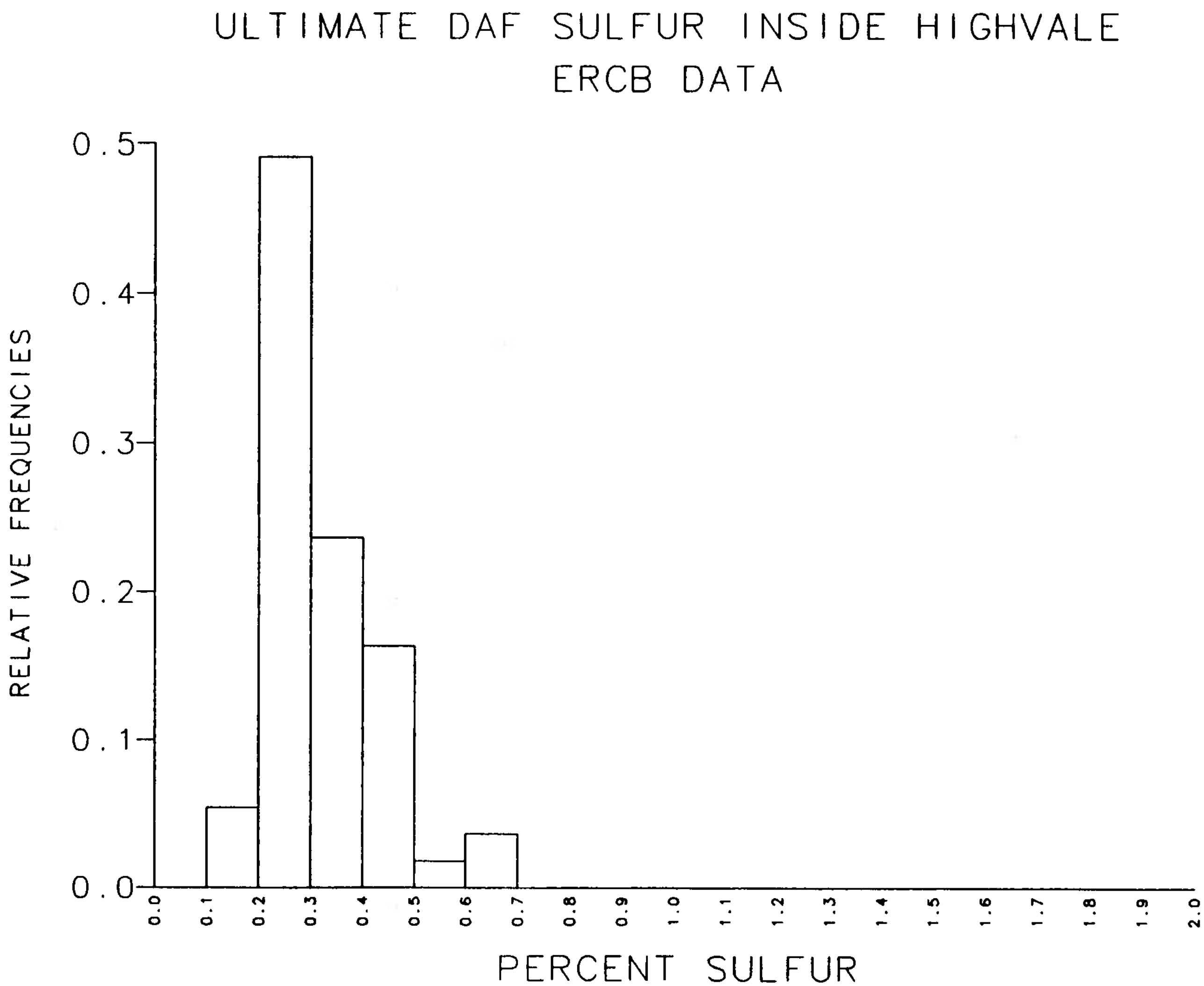


Figure 25. Relative frequency distribution of the total **sulphur** content **(dry, ash-free basis) inside Highvale.** This distribution is based on 55 composite samples (ie. all seams combined in each drill hole).

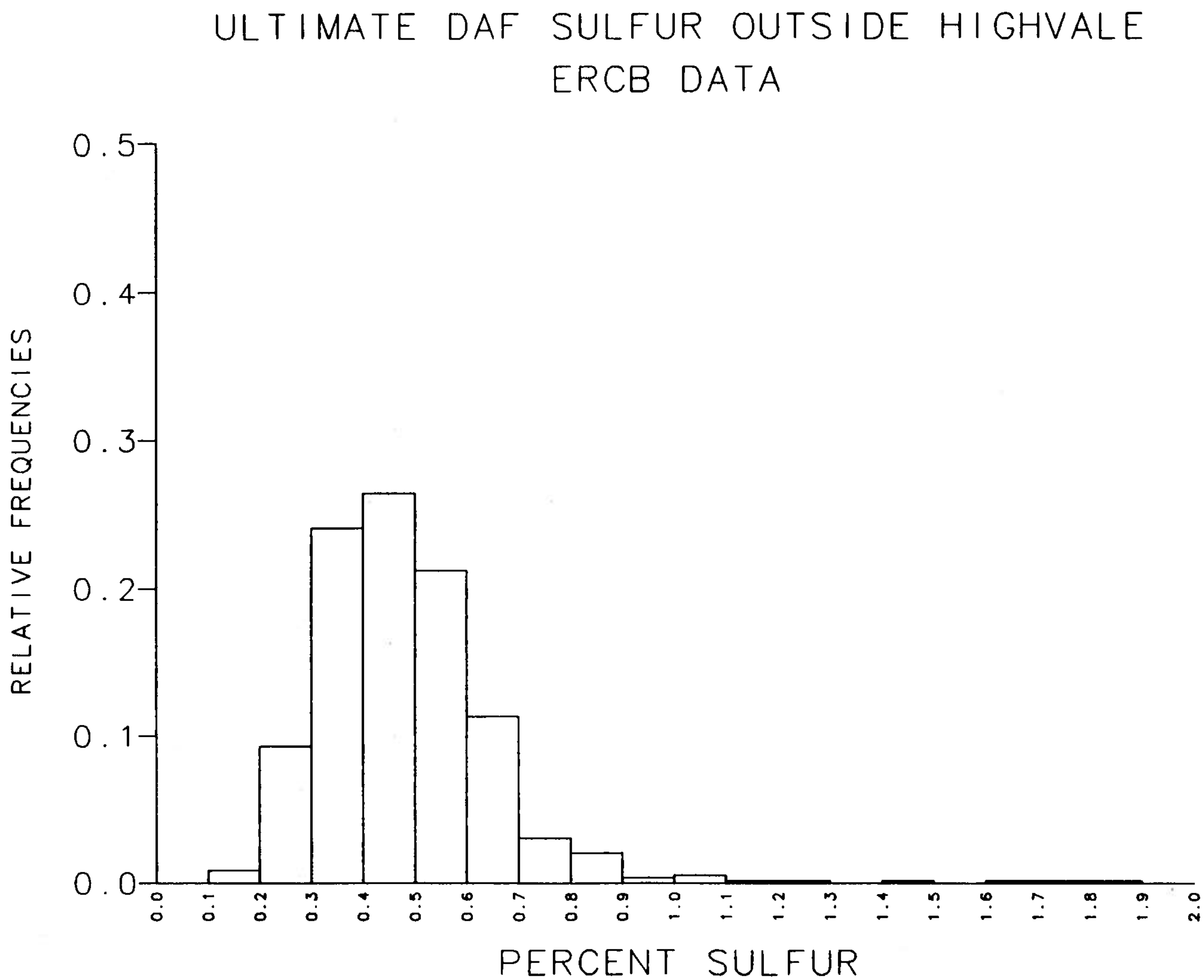


Figure 26. Relative frequency distribution of the total **sulphur** content **(dry, ash-free basis) outside Highvale.** This distribution is based on 601 composite samples (ie. all seams combined in each drill hole).

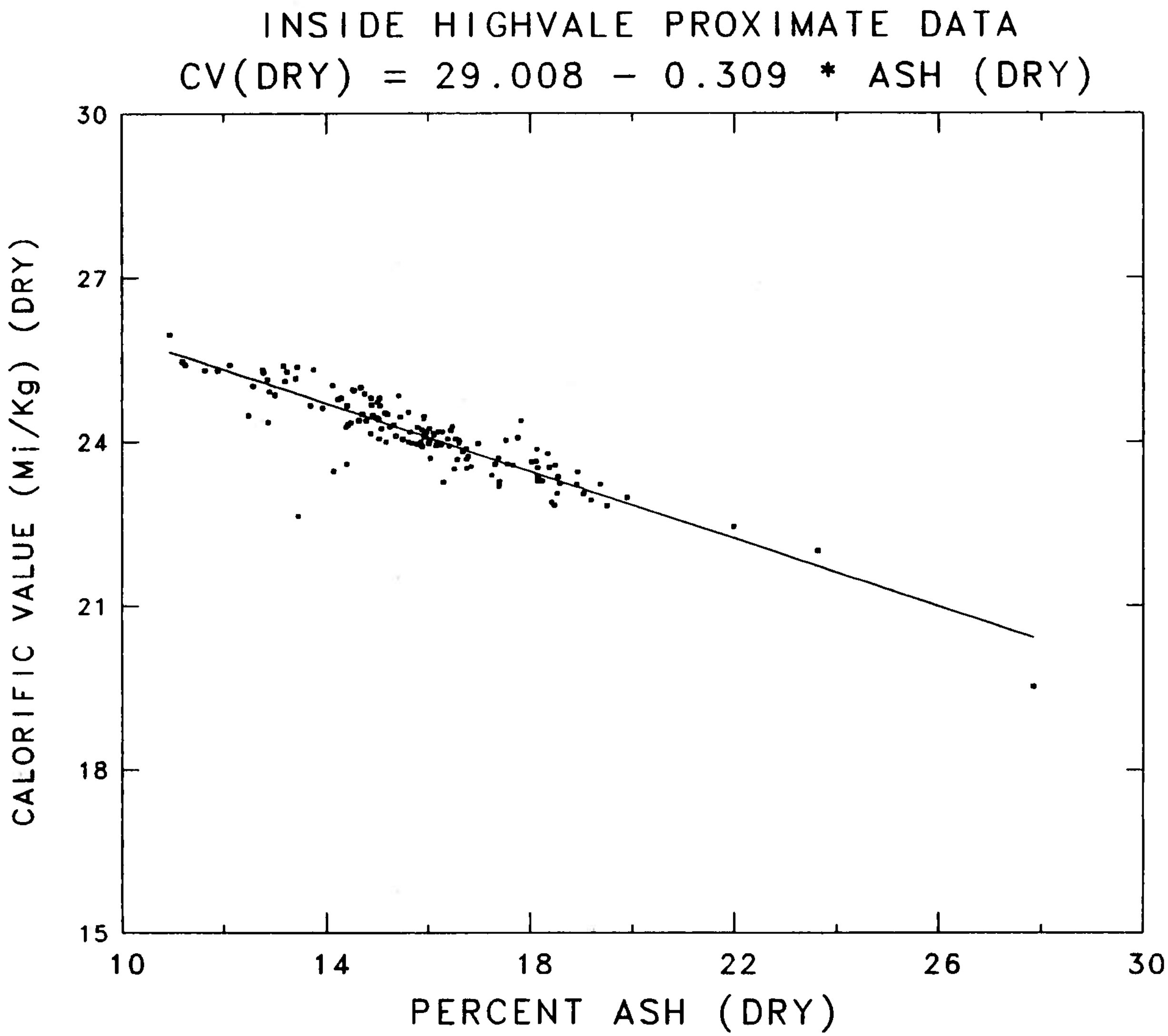


Figure 27. Plot of **percent ash versus calorific value** (all on a dry basis) **inside Highvale.** The predicted calorific value based on ash content can be calculated using the equation provided.

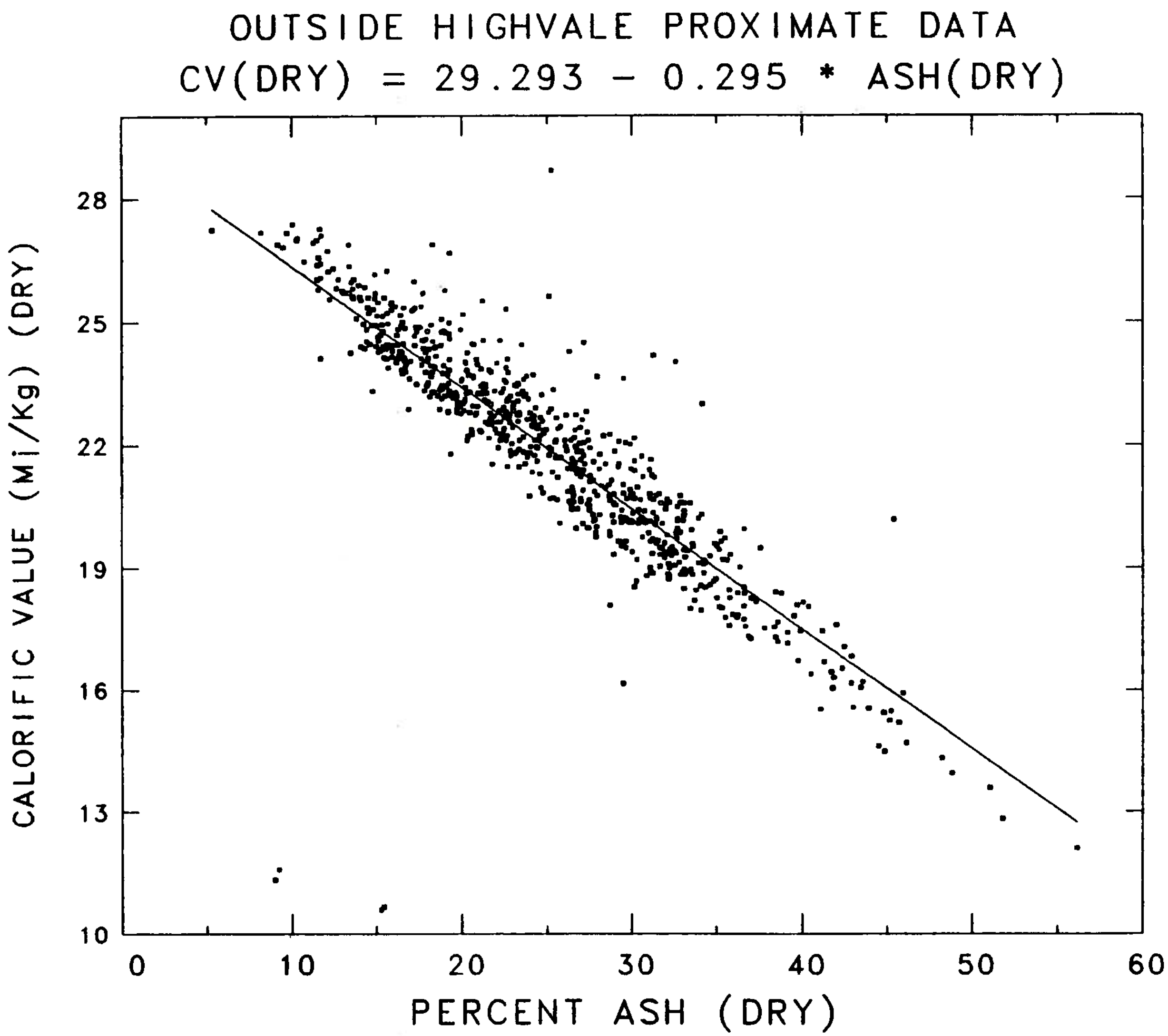


Figure 28. Plot of **percent ash versus calorific value** (all on a dry basis) **outside Highvale.** The predicted calorific value based on ash content can be calculated using the equation provided.

5.4.5 Geological component

The results of the above comparison show that there are significant differences in sulphur, ash, fixed carbon, volatile matter, and calorific value (all on a dry basis) between the Highvale region and the rest of the Ardley coal zone. In terms of its thermal properties, Ardley coals in the Highvale area stand out, with better quality than that observed regionally. As discussed earlier in this paper, the Highvale mine as well as the nearby Genesee and Whitewood mines, are situated within a trend of thick cumulative coal measures (Richardson et al., 1988). From a geological and statistical perspective, the coal quality in the Whitewood, North Highvale, South Highvale, Low Water Lake and Genesee deposits areas is anomalous. These deposits contain some of the thickest and most laterally continuous coal seams compared to the Ardley Bend, Wetaskiwin, Swan Hills, Fox Creek and Musreau Lake deposits, and consistently stands out in regional statistical analysis as having the highest coal quality.

5.5 Probability models for ash and sulphur contents

Of the variables studied in the comparison, ash and sulphur have the largest sample populations. These two variables have reasonable sample sizes which allows more detailed analyses, particularly in the fitting of probability models. Because of the differences found in sulphur (dry, ash-free basis) and ash (dry basis), separate probability models were fitted in each case. In doing so, it was accepted that samples from inside Highvale came from a different population than outside Highvale.

5.5.1 Identification of the probability density function

In the preliminary analysis of the data sets, histograms were drawn for each sample showing the frequency distributions of the variables. All of the histograms are positively skewed. Three types of probability density functions are capable of fitting positively skewed data sets were selected. These are (1) the gamma distribution, (2) the lognormal distribution and (3) the Weibull distribution (Appendix 4). These three types of probability distributions provide a wide range of fitting possibilities.

5.5.2 Estimation of parameters and model selection

This is the computation of the distribution parameters based on the available data set. Common computation procedures include those which are based on the quantile method, the moments method, the least squares methods, the maximum entropy method and the maximum likelihood method. The software used in the present study were based on the method of maximum likelihood estimation, which can produce better estimates although it is computationally more involved.

Each sample was subjected to analysis by fitting the data with each of the three types of models. The outcomes were compared and the best fit model was selected. The criterion for comparison was the logarithm of the likelihood function, which indicated which of the 3 types of models was the most appropriate for the given data set. The best fit model was represented by the maximum value of the logarithm of the likelihood function. The results for ash and sulphur are listed in Tables 9 and 10, respectively.

For ash content inside Highvale (dry basis), the lognormal probability distribution is the preferred model. For the evaluation of ash content outside Highvale (dry basis), the Weibull distribution is the preferred model (Table 9). For both inside Highvale and outside Highvale, the preferred probability model for sulphur (dry, ash-free basis) is the lognormal distribution (Table 10).

5.5.3 Cumulative distribution functions

Based on the above results, the cumulative distribution functions for ash (dry basis), for inside and outside Highvale (Figures 29 and 30) were developed. Similarly for sulphur (dry, ash-free basis), cumulative distribution functions for inside and outside Highvale (Figures 31 and 32) were prepared. The dashed lines on each figure represent the predicted values based on the lognormal or Weibull distributions. The solid lines are derived from the actual data. In all cases, the predicted is very close to actual. Appendix 4 gives the equations of the Weibull and lognormal cumulative distribution functions.

4.5.4 Prediction of ash and sulphur values inside and outside Highvale

The cumulative distribution functions are useful from a resource characterization point of view, for first approximation in predicting the probability of occurrence of sulphur and ash. Keeping in mind that the data used to derive these plots are based on the weighted average based on thickness for each drill hole, the following results were obtained. Coal quality within individual seams will vary from these composite estimations.

As one example of how to use the cumulative distribution functions, consider ash content. In Figure 29 (inside Highvale) a probability of 95% is given for encountering coal with an ash content of less than 20% on a dry basis. More specifically, the weighted average sample based on thickness (ie. composite sample), in virtually every drill hole inside Highvale, is likely to have a median value of less than 20% ash. Outside Highvale (Figure 30), the probability is only 50% for encountering a composite coal sample with less than 20% ash on a dry basis. When evaluating the coal resources of the province, planners who investigate coal quality can pick ash cut off values to determine how much of the resource can be utilized under differing economic conditions.

Sulphur content can be evaluated in much the same way as ash. In Figure 31, for example, a composite sample from any drill inside Highvale, has a 95% probability of containing less than 0.06% sulphur on a dry, ash-free basis. The probability is also about 95% for finding

Table 9. The goodness-of-fit comparisons of the probability models for **ash (dry basis).** The criterion used is the logarithm of the likelihood function (ln) L. The sample for outside Highvale was transformed to improve fit.

	Shape (alpha)	Scale (beta)	(ln)L
Inside Highvale			
gamma	45.4800	0.3527	-329.8932
lognormal	0.1466	15.8636	-328.0906*
Weibull	5.7498	17.1148	-355.4499
Outside Highvale			
gamma	5.5600	3.6296	-2550.0980
lognormal	0.4665	18.3966	-2597.8851
Weibull	2.6859	22.6981	-2539.6302*

* Maximum (ln)L for best fit.

Table 10 The goodness-of-fit comparisons of the probability models for **Sulphur (Dry, ash-free basis).** The criterion used is the logarithm of the likelihood function (ln) L.

	Shape (alpha)	Scale (beta)	(ln)L
Inside Highvale			
gamma	10.3857	0.0311	50.2358
lognormal	0.3047	0.3080	52.0832*
Weibull	3.0276	0.3613	44.1340
Outside Highvale	0000000	0000000	0000000
gamma	8.5031	0.0559	261.4737
lognormal	0.3404	0.4480	277.3794*
Weibull	2.5698	0.5325	182.0299

* Maximum (ln)L for best fit.

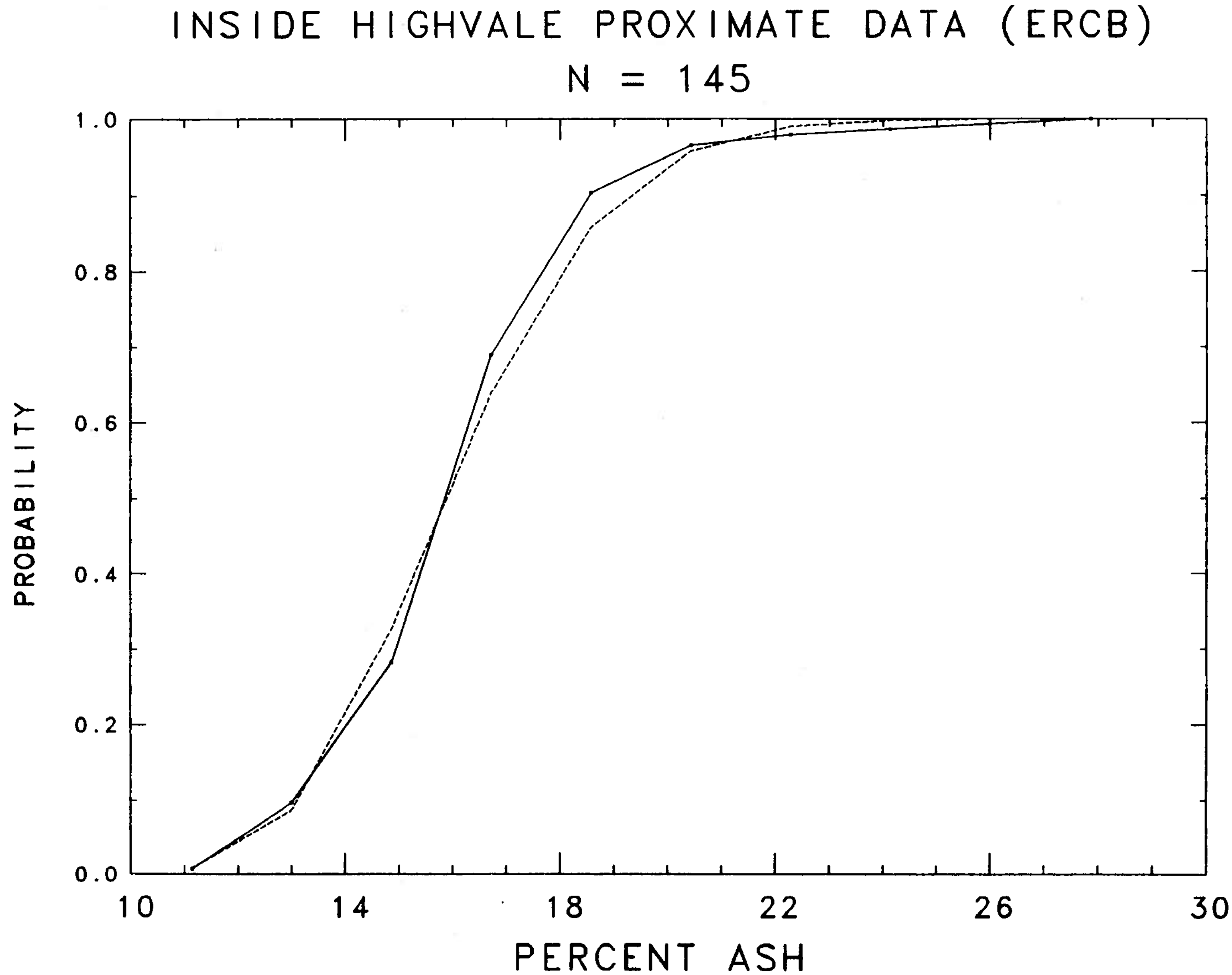


Figure 29. Cumulative distribution function for **ash** (dry basis) **inside Highvale.** The predicted (dashed line) and actual (solid line) cumulative curves describe the probability of occurrence for any given ash value. This graph is based on 145 data locations.

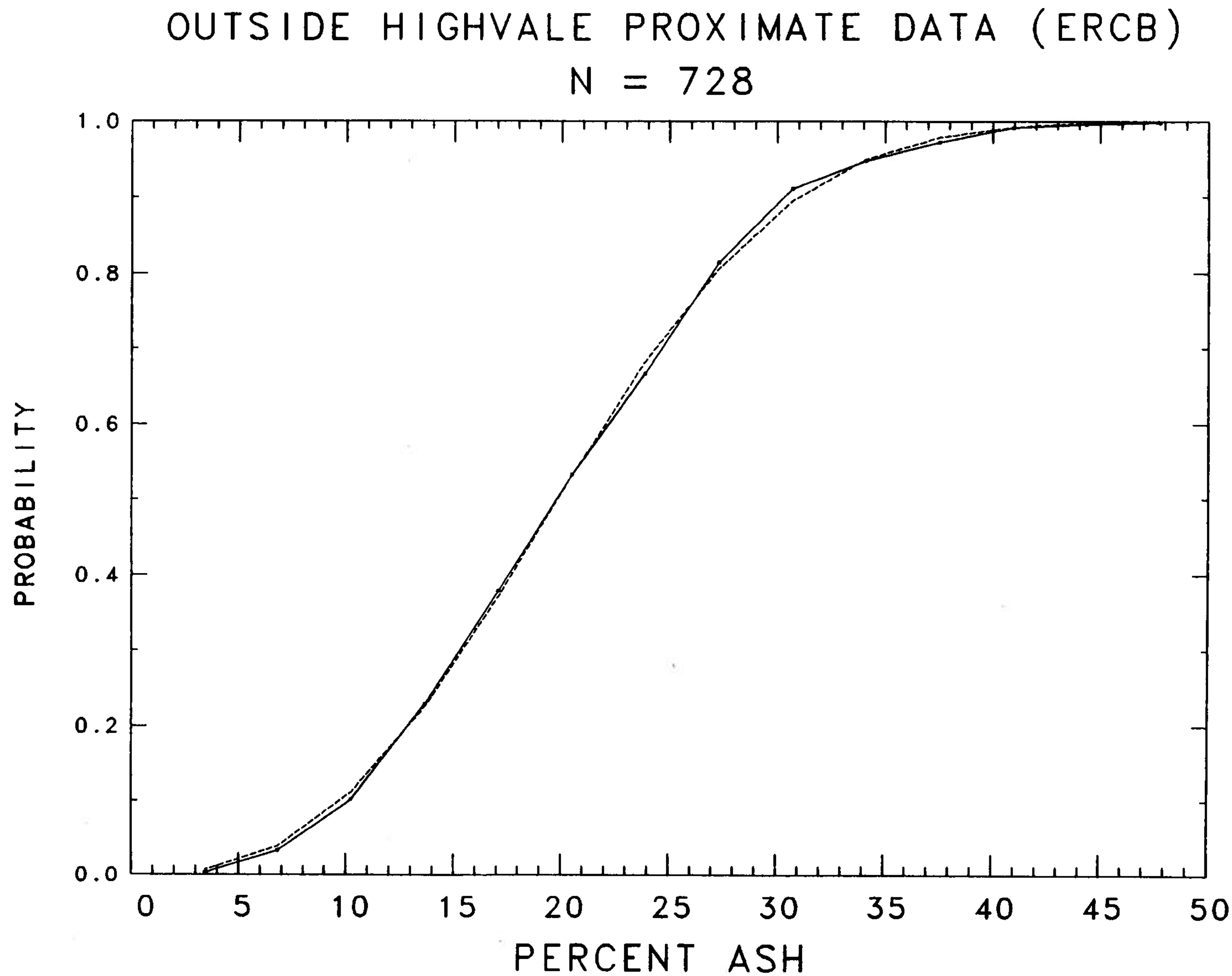


Figure 30. Cumulative distribution function for **ash** (dry basis) **outside Highvale.** The predicted (dashed line) and actual (solid line) cumulative curves describe the probability of occurrence for any given ash value. This graph is based on 728 data locations.

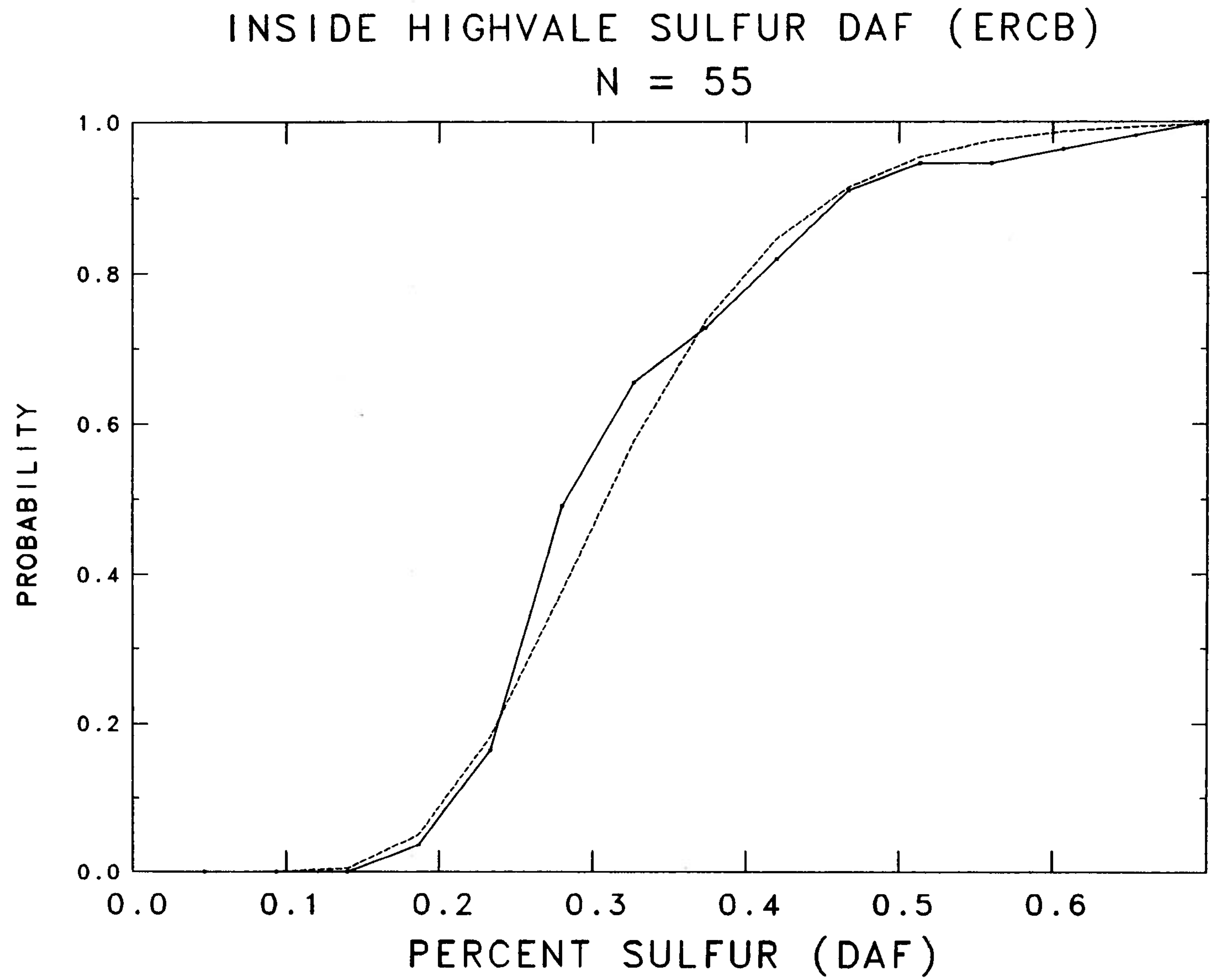


Figure 31. Cumulative distribution function for total **sulphur** (dry, ash-free basis) **inside Highvale.** The predicted (dashed line) and actual (solid line) cumulative curves describe the probability of occurrence for any given sulphur value. This graph is based on 55 data locations.

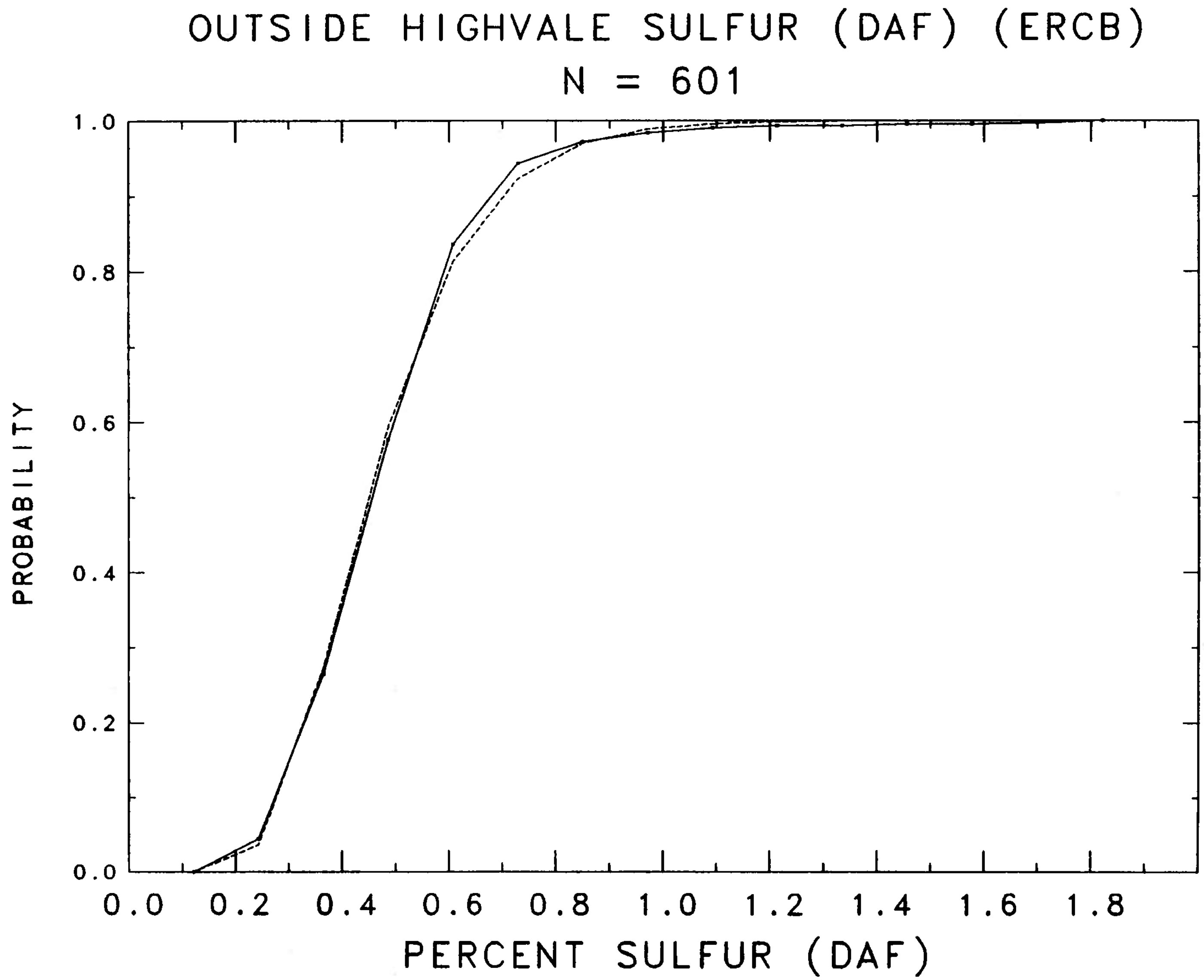


Figure 32. Cumulative distribution function for total **sulphur** (dry, ash-free basis) **outside Highvale.** The predicted (dashed line) and actual (solid line) cumulative curves describe the probability of occurrence for any given sulphur value. This graph is based on 601 data locations.

similar values for the regional area. Throughout the Ardley coal zone, total sulphur values are very low. Looking for extremely low sulphur coal (dry, ash-free basis) such as 0.03% or less for example, the probability inside Highvale is approximately 50% and for outside Highvale the probability is approximately 35%. These graphs are an additional tool for broad resource characterization of the Ardley coal zone.

6.0 Geostatistical Applications

6.1 Role of geostatistics in coal quality characterization

Many classical statistical methods are relatively simple and well accepted in coal quality studies. These methods include the calculations of the medians and interquantile ranges used in this paper and some of the more sophisticated multivariate statistics. Considerable amounts of information can be obtained from the use of these methods and they are an integral part of coal quality studies. These evaluations, however, do not generally take into account the spatial dependencies of coal quality. When analyzing a deposit, coal quality values measured in two drill holes located very close to each other can be expected to be similar, whereas a greater dissimilarity should be observed as the spacing between holes increases (Rendu, 1982). The underlying premise is that the coal quality values will display some degree of continuity in the area of study and behave as the "regionalized variable" defined by Journel and Huijbregts (1978). Properties of coal quality that are typically evaluated are thickness, moisture, ash and sulphur contents. Geostatistical methods, including variogram analysis and kriging, specifically address spatial dependence in coal quality.

A further advantage of a geostatistical approach is that it can permit the coal quality researcher to assign a confidence level (amount and likelihood of error) to each estimate. Geostatistical techniques cannot, however, be applied indiscriminately to an untreated data set. For meaningful results, the data set must be analyzed carefully, and are commonly subdivided into two or more subsets. The importance of data preparation is discussed in the next section.

6.2 Data set preparation for geostatistical evaluation

A geostatistical evaluation requires a detailed geological understanding of the deposit and separation of the data into relatively homogeneous groups. Data from a coal deposit, for example, is commonly subdivided according to seam (Pierce et al., 1983; Junyong et al., 1982) and to selected substudy areas within the deposit (Kim et al., 1981; Sabourin, 1975; and Kauffman et al., 1981). The original data are reworked so that the final data sets evaluated, are relatively free of sampling biases and outliers. Some of the sampling biases encountered, include distinguishable sample populations created by the effects of weathering, erosion, post-depositional channelling or differing environments of deposition. One subarea, for example, may need to be evaluated separately because it is characterized by coal seams that have developed multiple splits in a certain portions of the deposit.

Another requirement to meet, when selecting the study area for geostatistical evaluation, is adequate sample coverage. Large spacings between drill holes and portions of the study areas with few sample locations are common in coal quality studies. Coal quality data tend to be clustered and are typically irregularly distributed within deposits. The coal quality researcher is commonly faced with a decision of either doing separate substudies for each cluster or to be somewhat more practical and incorporate a larger study area with some gaps in the data distribution.

Two areas with significant differences in coal quality due to anomalies and outliers should be separated, hence the need for detailed understanding of the geology before geostatistical studies begin. In a computer modeling study of the Judy Creek Coalfield in Alberta, Noland and Dunn (in press), emphasize the importance of data integrity and state further that over 70% of time needed in the geological modeling process, is spent working and reworking the original data to bring it as close to a "clean status" as possible.

The production of variograms or further analysis involving kriging take time and consideration. Commonly, after the outliers are removed and relatively homogeneous data sets are derived, several iterations of variograms are produced. Suspect data are reevaluated in each phase. The model variograms produced for this report are based on more than one hundred experimental variograms. Knowing the detailed geology of the deposit and understanding the controls on coal quality are critical components of the geostatistical analysis process.

6.3 Interpretation of variograms.

The geostatistical tool used to quantify the dissimilarity between drill hole values as a function of the distance between holes is the variogram (Rendu, 1982). Inherent in the variogram are answers to coal quality concerns including the (1) continuity of data, (2) direction of continuity, (3) area of influence or range and (4) data isotropy and anisotropy (Kerbs, 1986).

The variogram can be thought of as an "average difference squared" between data, a given distance apart in a given direction (Kerbs, 1986; Journel and Huijbregts (1978), Clark (1979). A full explanation of model variograms and the applications of variograms to coal quality are given by Rendu (1982) and Kerbs (1986).

6.4 Variograms obtained for seams 1 and 2 (North Highvale deposit)

Five variables are reported for seams 1 and 2 in the Highvale North deposit on an "as received" (air-dried basis). The variables are moisture, volatile matter, ash, fixed carbon and sulphur. Data are derived from 58 and 62 locations for seams 1 and 2, respectively, within the deposit. Preliminary statistical analysis and outliers analysis showed that all the data have non-Gaussian distributions and typically exhibit large variations. The sampling pattern (drill hole distribution) is shown in Figure 33.

Five directional variograms have been calculated for each variable. Parameters of the experimental variograms have been established by analysis of optimal lag and the smoothing windows. Lags beyond 4000 m were not considered in this study because of the small number of samples defining those ranges.

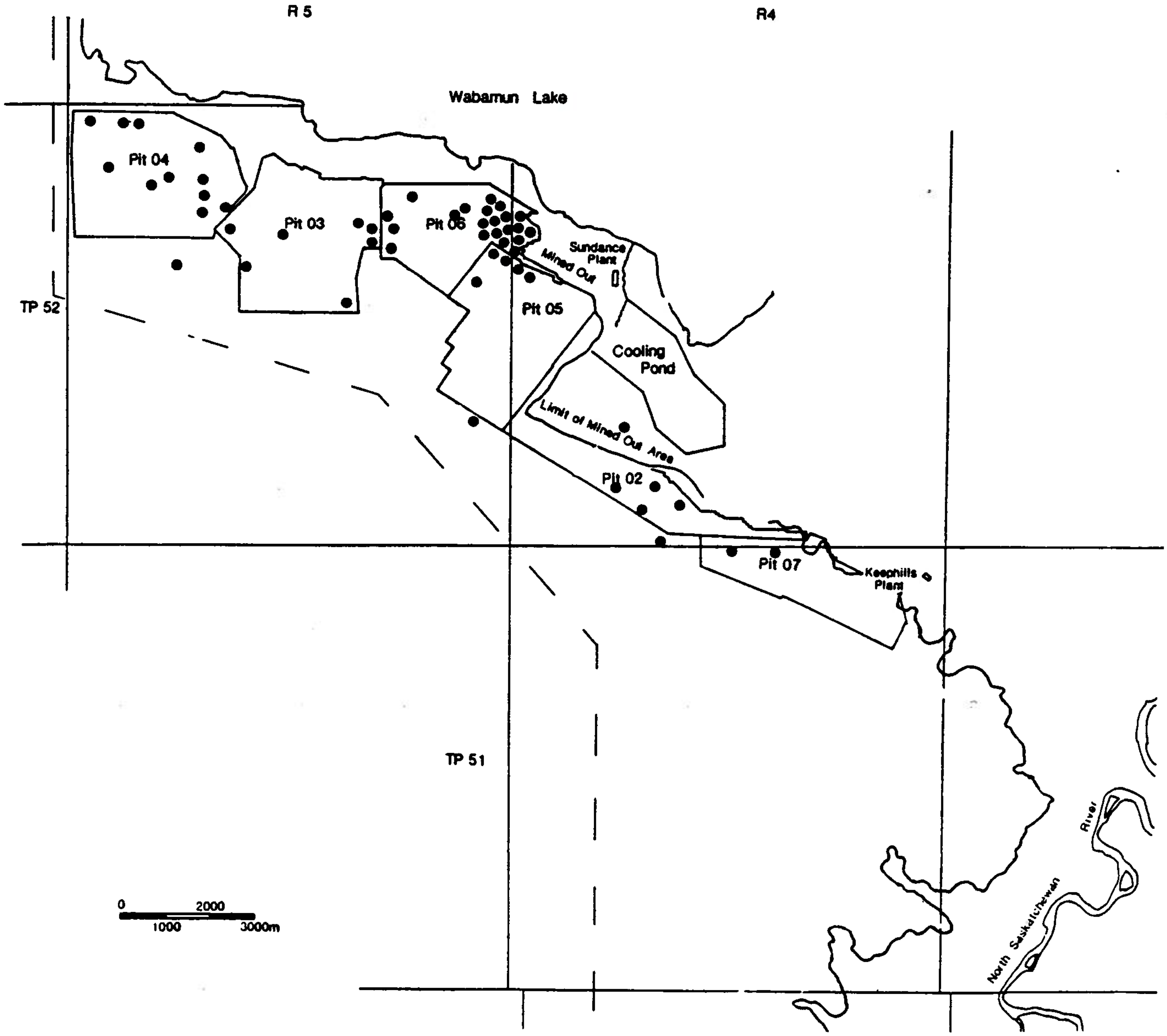


Figure 33. Sample distribution for the North Highvale geostatistical substudy.

In general, the variograms were represented by their omnidirectional counterparts and those variograms were the basis for model selection. Cross-validation procedures used the "average residual error" and "average error ratio" as indices for variogram selection. All the models selected were of the spherical type. Anisotropy (or continuity in certain directions), continuity (degree of randomness) and range (distance over which samples are dependent) were used to estimate the interpolation method for the studied variable.

6.4.1 Moisture content (Seams 1 and 2)

To define the spatial continuity of moisture content, five directional variograms have been calculated for each seam. Experimental variograms are plotted in Figures 34 and 35 for seams 1 and 2, respectively. All of the variograms exhibit high nugget effect and high variability. No anisotropy was detected. The selected variogram models have the following properties:

Seam 1 nugget effect = 2.53
sill = 6.53
range = 1500 m

Seam 2 nugget effect = 2.13
sill = 3.33
range = 1600 m

6.4.2 Volatile matter (Seams 1 and 2)

Five directional, experimental variograms have been calculated for volatile matter (as-received, air-dried basis). The variograms are shown in Figures 36 and 37. The variograms are highly irregular and do not display clear structure. All curves except for the north-south direction fall closely together so no clearly defined anisotropy is recognized. The north-south curves are the least reliable because it is based on the smallest number of samples/pair per lag (few samples in the north-south directions). The selected variogram models have the following parameters:

Seam 1 nugget effect = 1.0
sill = 2.35
range = 1800 m

Seam 2 nugget effect = 2.13
sill = 3.33
range = 1600 m

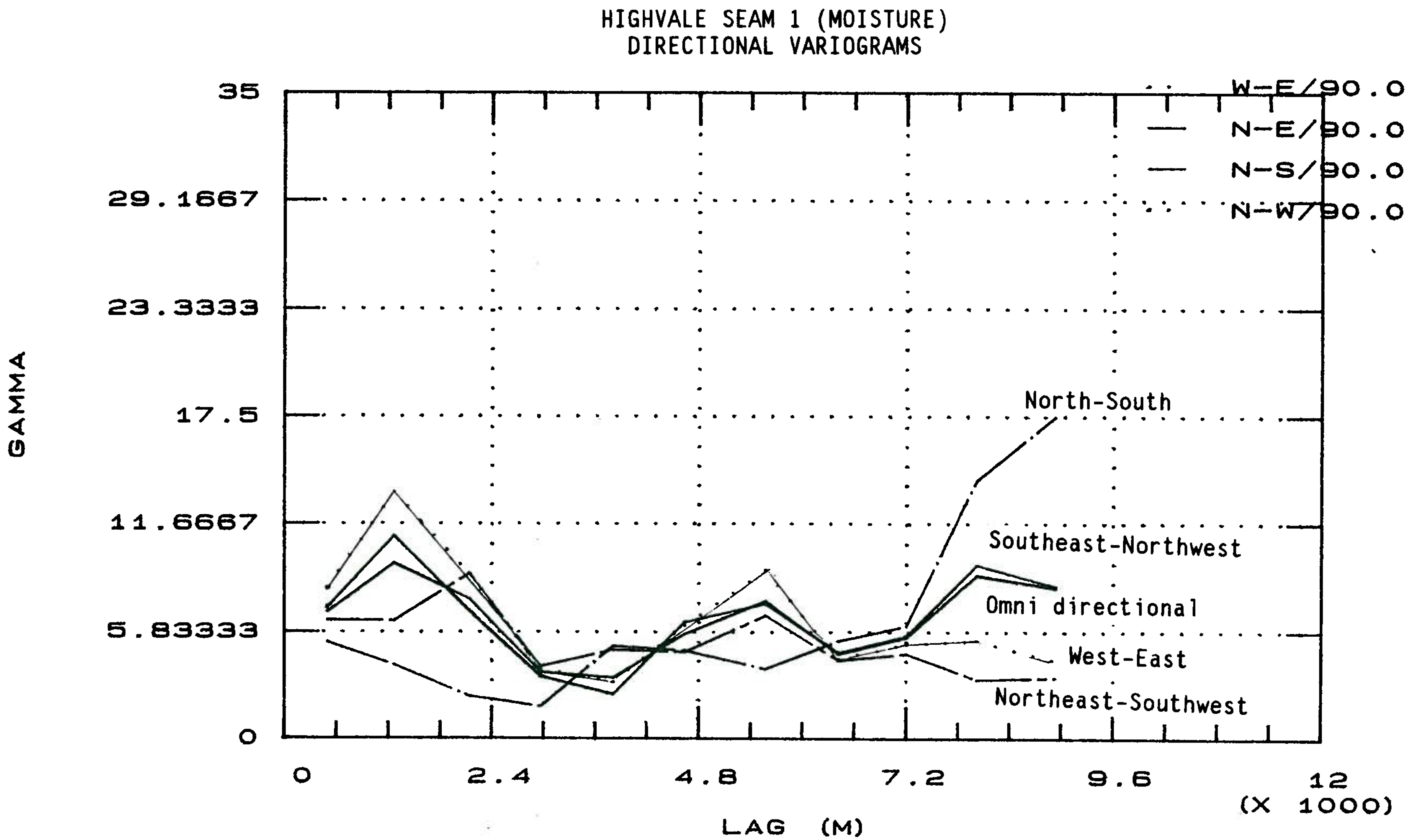


Figure 34. Directional variogram for moisture (seam 1), North Highvale deposit. Results are reported on an air-dried basis.

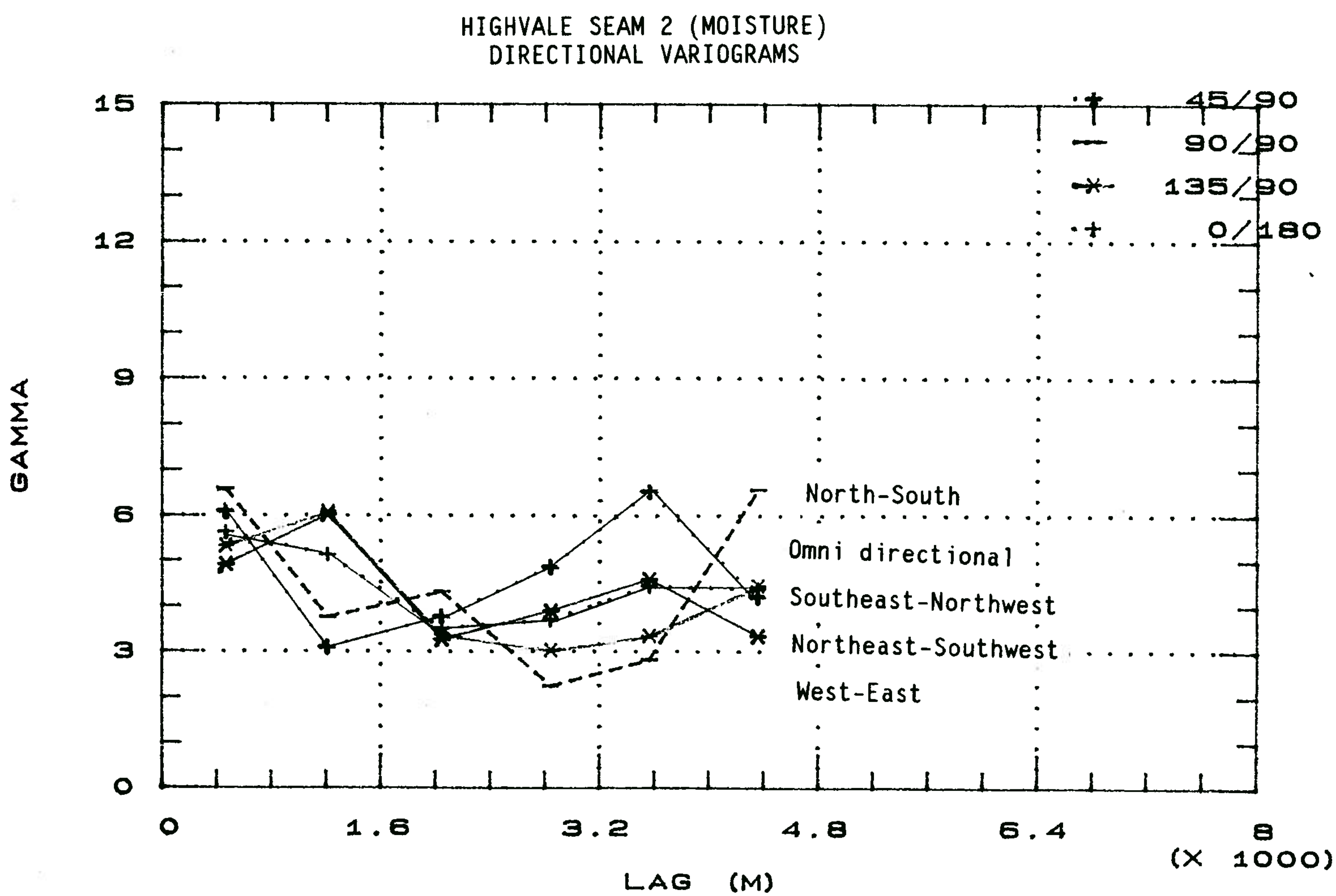


Figure 35. Directional variogram for moisture (seam 2), North Highvale deposit. Results are reported on an air-dried basis.

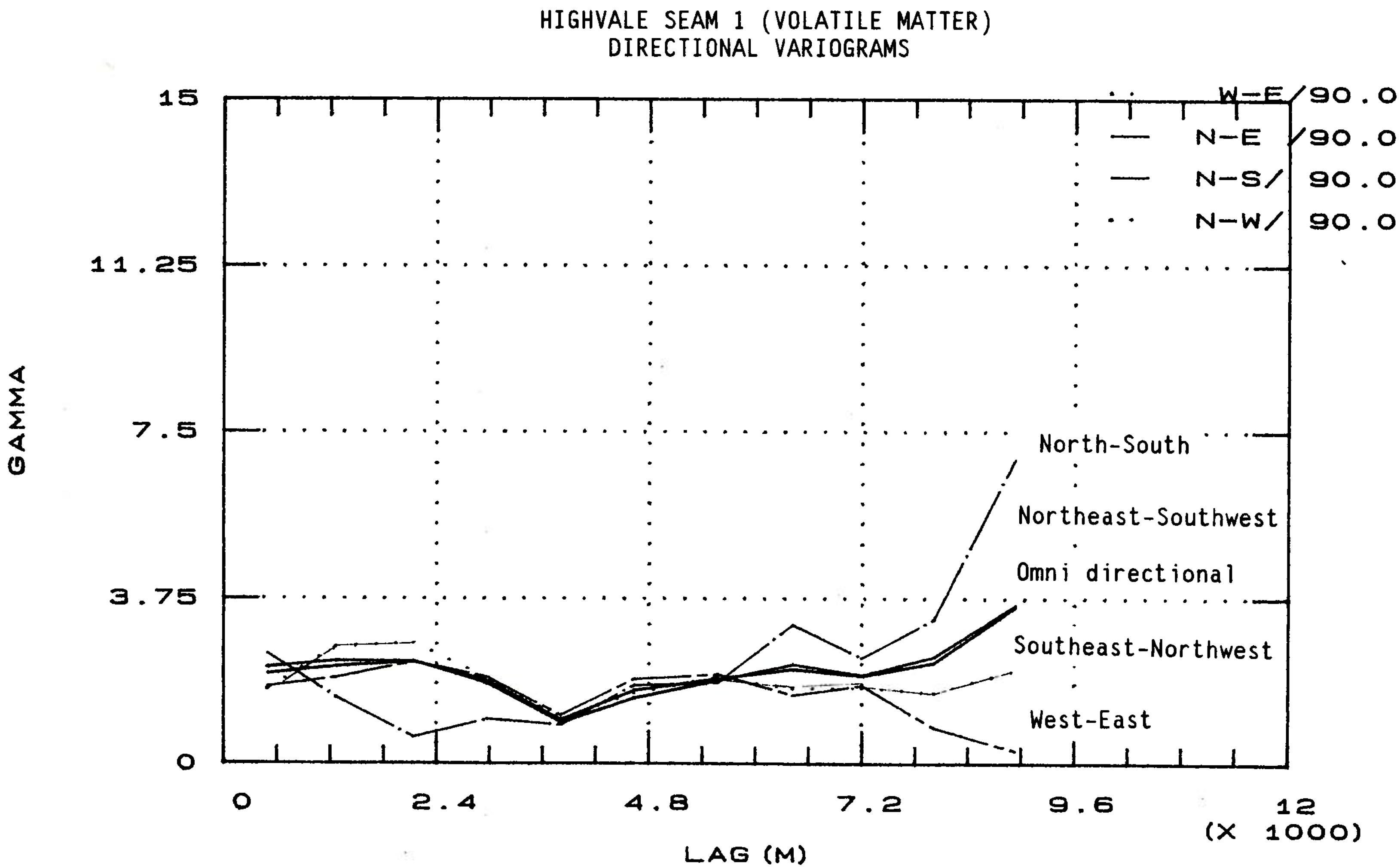


Figure 36. Directional variogram for volatile matter (seam 1), North Highvale deposit. Results are reported on an air-dried basis.

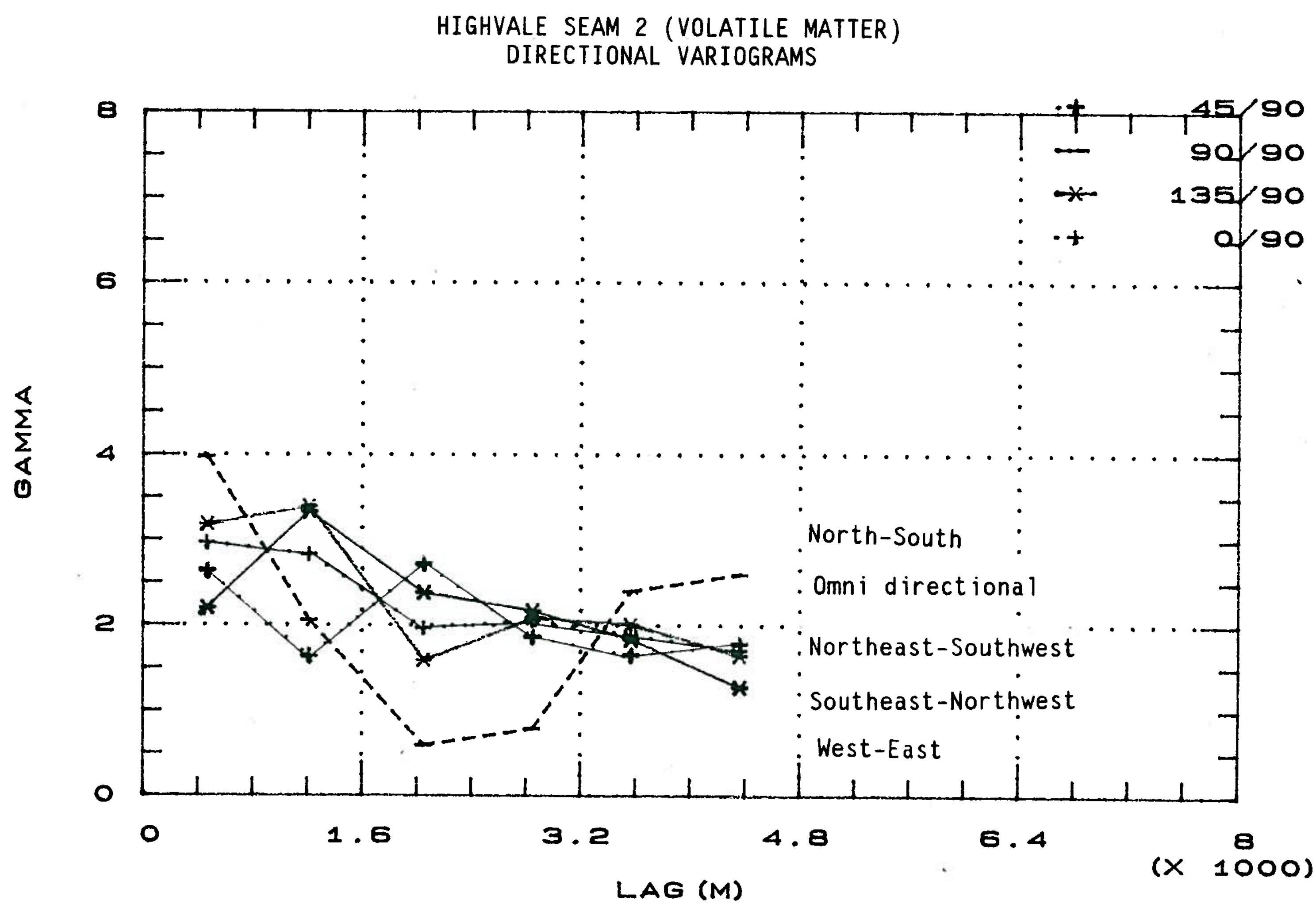


Figure 37. Directional variogram for volatile matter (seam 2), North Highvale deposit. Results are reported on an air-dried basis.

6.4.3 Ash content (Seams 1 and 2)

Five directional, experimental variograms have been calculated for ash content (as-received, air-dried basis). The variograms are shown in Figures 38 and 39. The variograms are highly variable but do display a better defined structure than the other variograms. The omnidirectional variogram represents the variations in the studied area and it was used to provide parameters of variogram modeling. The selected variogram models have the following parameters:

Seam 1	nugget effect	= 2.4
	sill	= 5.1
	range	= 2800 m
Seam 2	nugget effect	= 4.21
	sill	= 4.56
	range	= 2400 m

6.4.4 Fixed carbon (Seams 1 and 2)

Five directional, experimental variograms have been calculated for fixed carbon (as-received, air-dried basis). The variograms are shown in Figures 40 and 41. The variograms are highly variable and do not exhibit clear structure. The omnidirectional variogram is used to represent the variations in the studied area and to provide parameters for variogram modeling. The selected variogram models have the following parameters:

Seam 1	nugget effect	= 4.8
	sill	= 7.29
	range	= 1600 m
Seam 2	nugget effect	= 1.80
	sill	= 3.23
	range	= 3600 m

6.4.5 Sulphur content (Seams 1 and 2)

Five directional, experimental variograms have been calculated for sulphur (as-received, air-dried basis). The variograms are shown in Figures 42 and 43. The variograms are highly variable and do not exhibit clear structure. No anisotropy is detected. The omnidirectional variogram represents the variations in the studied area and it was used to provide parameters of variogram modeling. The selected variogram models have the following parameters:

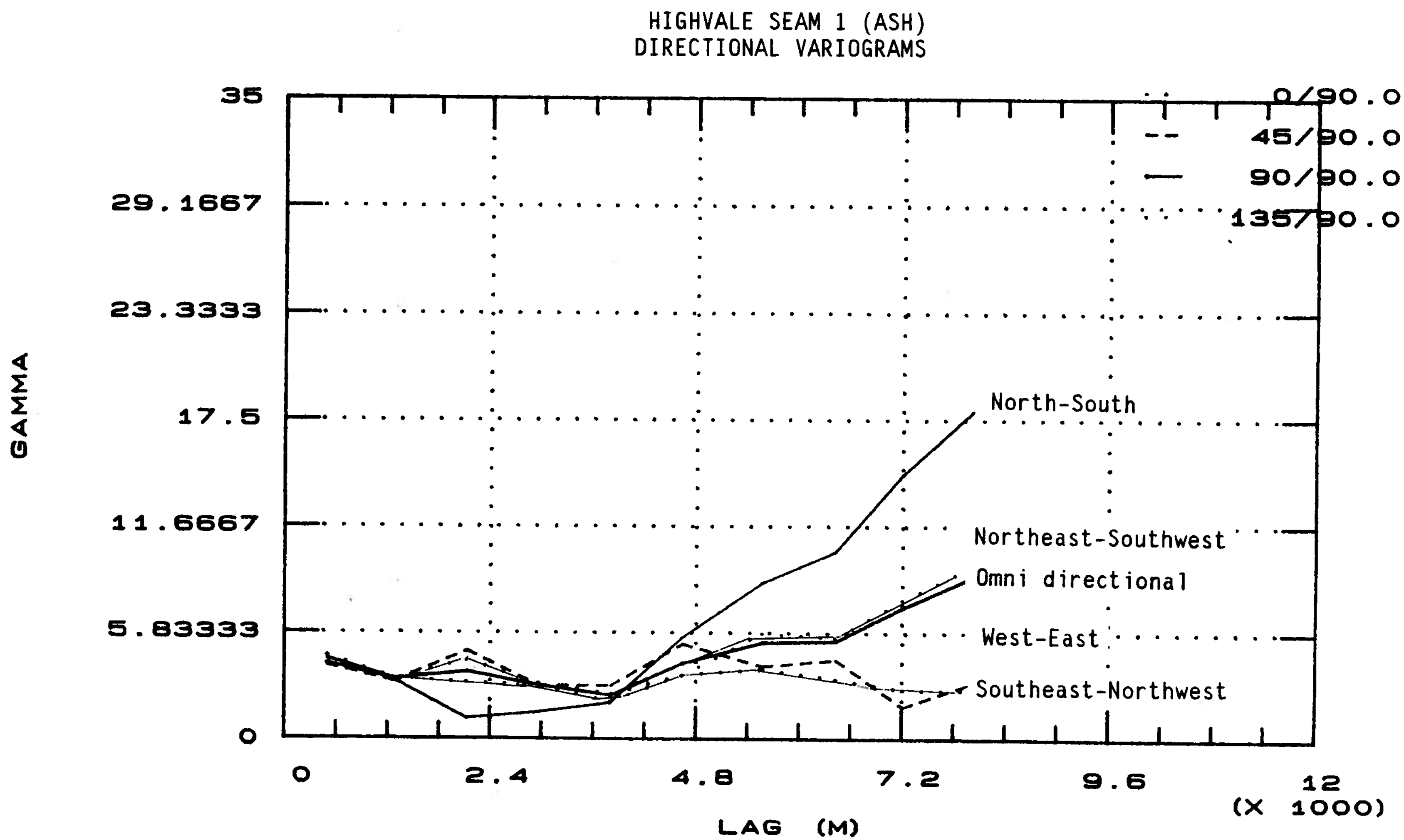


Figure 38. Directional variogram for ash content (seam 1), North Highvale deposit. Results are reported on an air-dried basis.

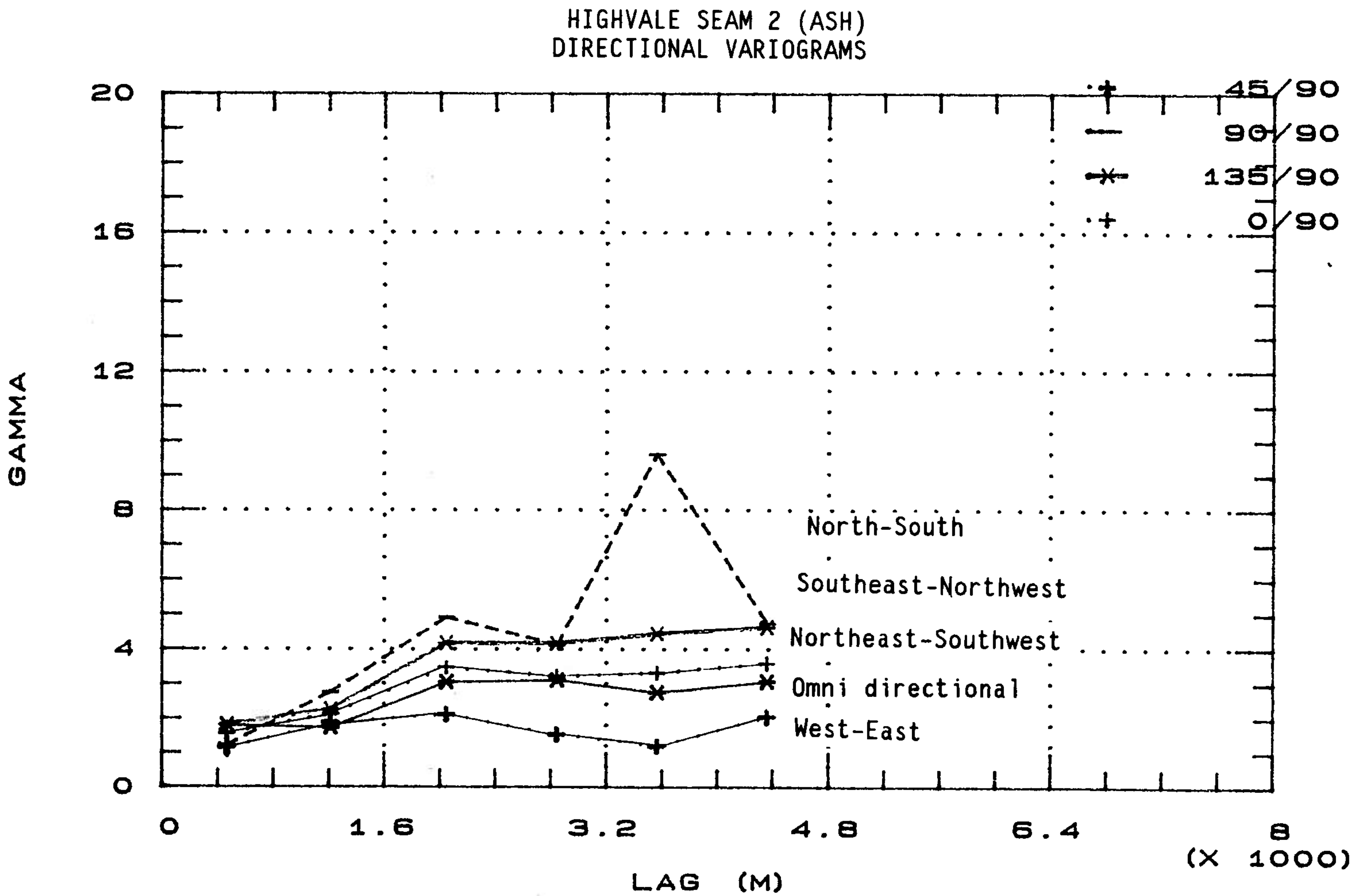


Figure 39. Directional variogram for ash content (seam 2), North Highvale deposit. Results are reported on an air-dried basis.

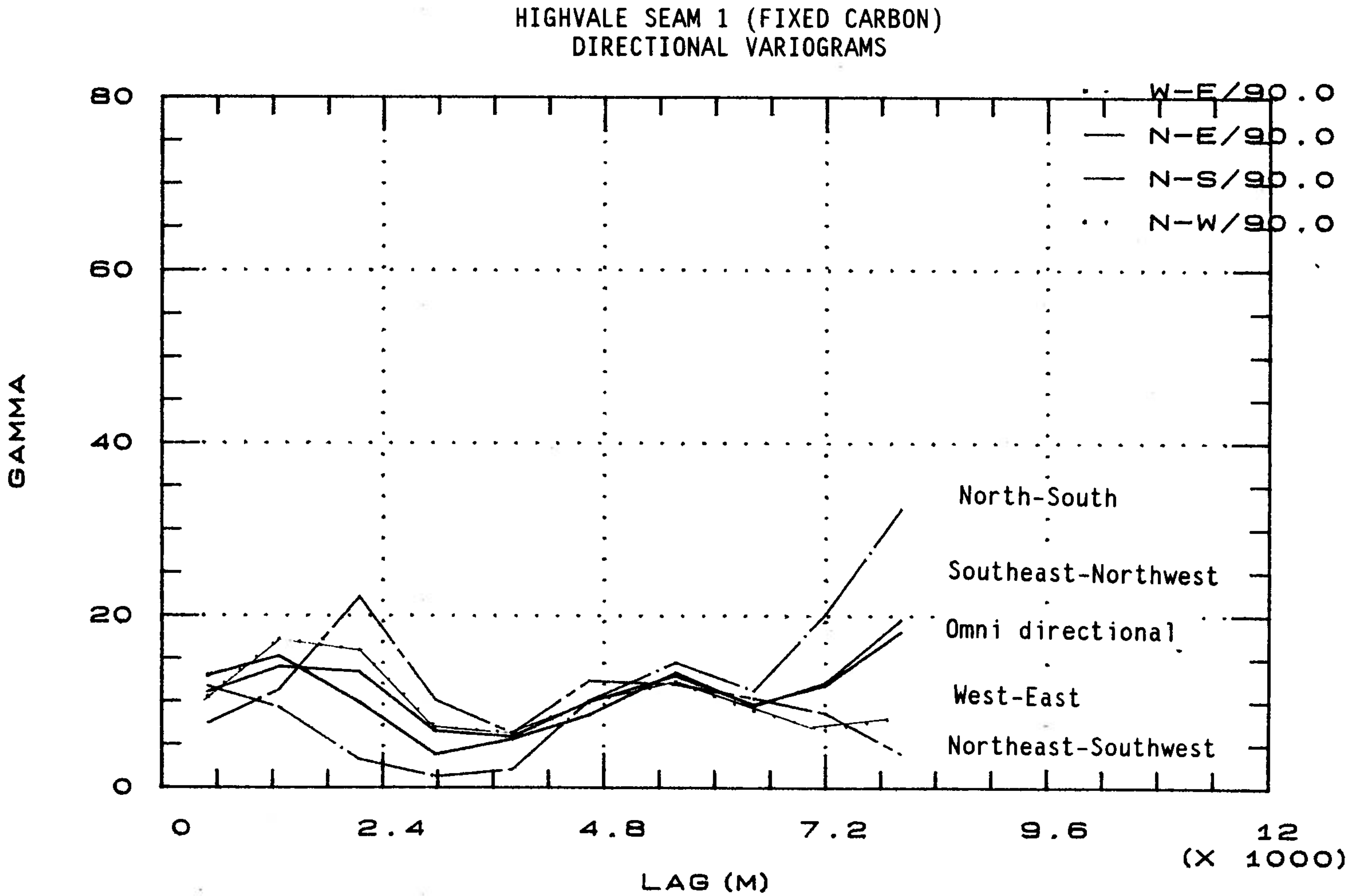


Figure 40. Directional variogram for fixed carbon (seam 1), North Highvale deposit. Results are reported on an air-dried basis.

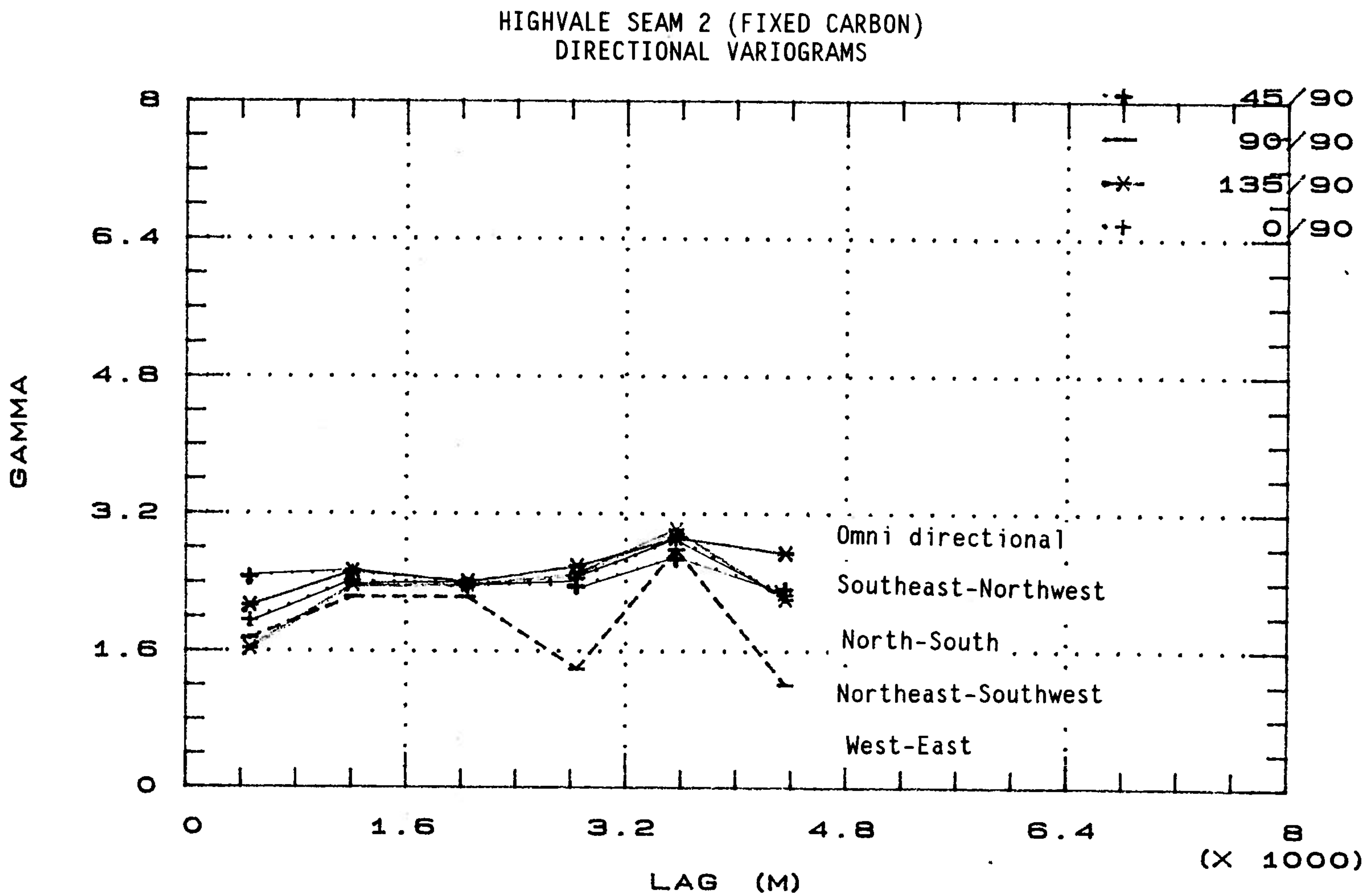


Figure 41. Directional variogram for fixed carbon (seam 2), North Highvale deposit. Results are reported on an air-dried basis.

Seam 1 nugget effect = 1 X 10^{-2}
sill = 0.017
range = 1800 m

Seam 2 nugget effect = 1.80
sill = 3.23
range = 3600 m

6.4.6 Summary of results

In the case of the seam 1 and seam 2 data sets, there are a number of inconsistencies. The clustering of data within the northern most portion of the study area may have affected analysis. Non-Gaussian data distributions in the data sets may also be affecting variogram calculations. All of the subsequent results must be viewed with the above conditions in mind.

In general, variability in seam 1 is higher than in seam 2 and seam 2 is characterized by a more uniform distribution. The high nugget effect in all the analysis may be the result of data bias and data distribution. It may also due to the relatively low correlation between samples. The calculated correlation ranges are generally between 1600 and 2500 metres for most coal quality parameters in both seam 1 and seam 2. Location in the studied domain and differences in direction, on this scale of investigation and for the particular seams studied, do not appear to be dominent controls.

6.5 Optimal sample spacing

Drill holes located a short distance apart in which similar sampling procedures are used (core samples from the same seam, for example) are likely to indicate similar coal qualities, and this similarity will decrease when the distance between holes increases. Through geostatistics, we can estimate an optimal sample spacing. This is a distance beyond which additional sampling is unlikely to provide a significantly more accurate estimate. This distance may vary between deposits, between seams and commonly varies with direction of sampling. The goal of this exercise is to derive drilling patterns and drill hole spacings that will provide maximum information at minimum exploration cost for the two coal seams investigated.

In this study, the calculations are based on optimization of the standard error of the global mean. In addition, for comparison purposes, a classical standard error for the mean estimate is also computed. The analysis of the estimation error for square and triangular grids is summarized in Figures 44, 45 and 46. These graphs may be used to select the optimal sampling spacing for the deposit and variable of interest. The use of the graphs is explained below:

The optimal sample spacing is the spacing with the lowest estimation error for the given sample intensity. In Figures 44 and 45, for example,

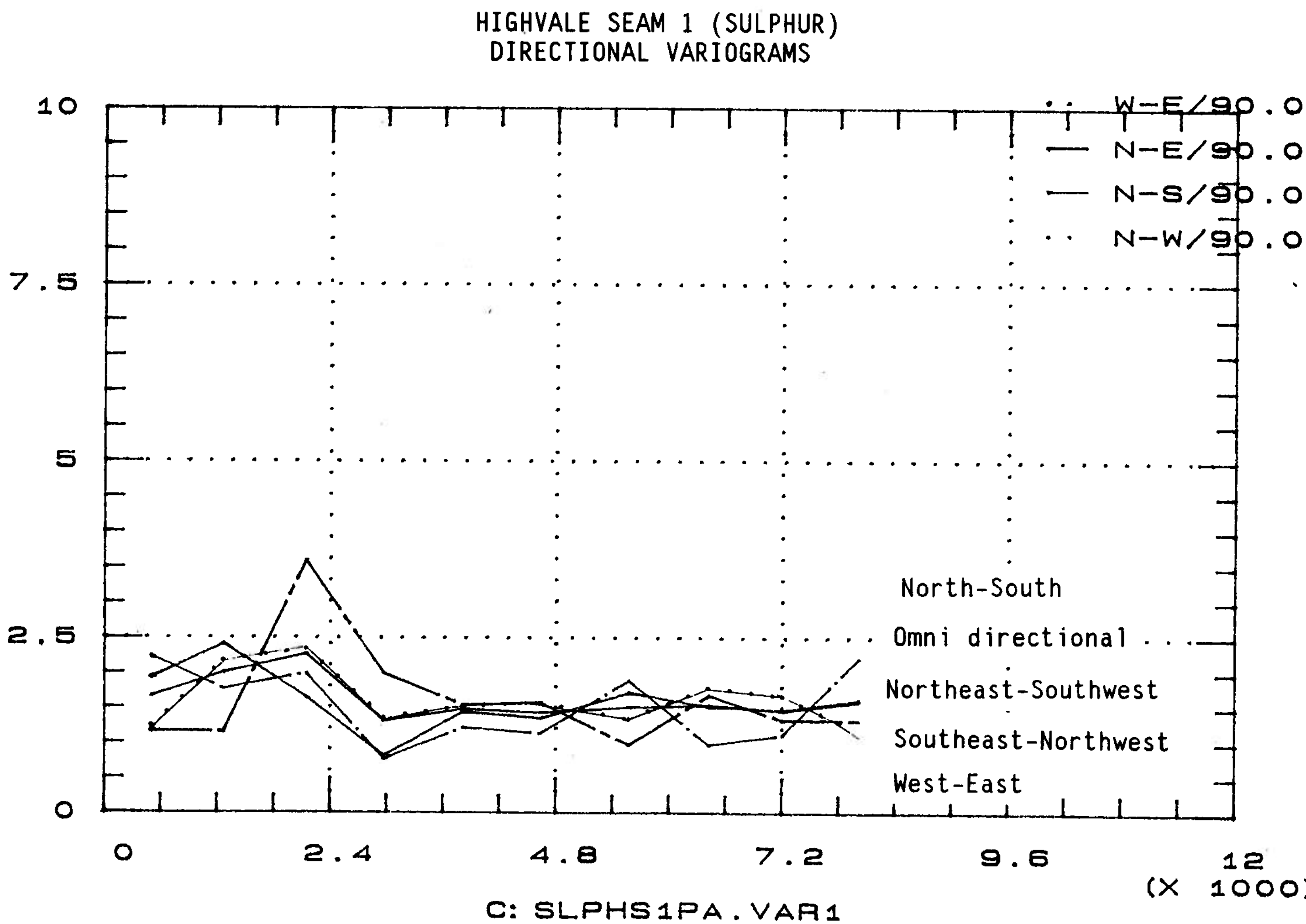


Figure 42. Directional variogram for sulphur (seam 1), North Highvale deposit. Results are reported on an air-dried basis.

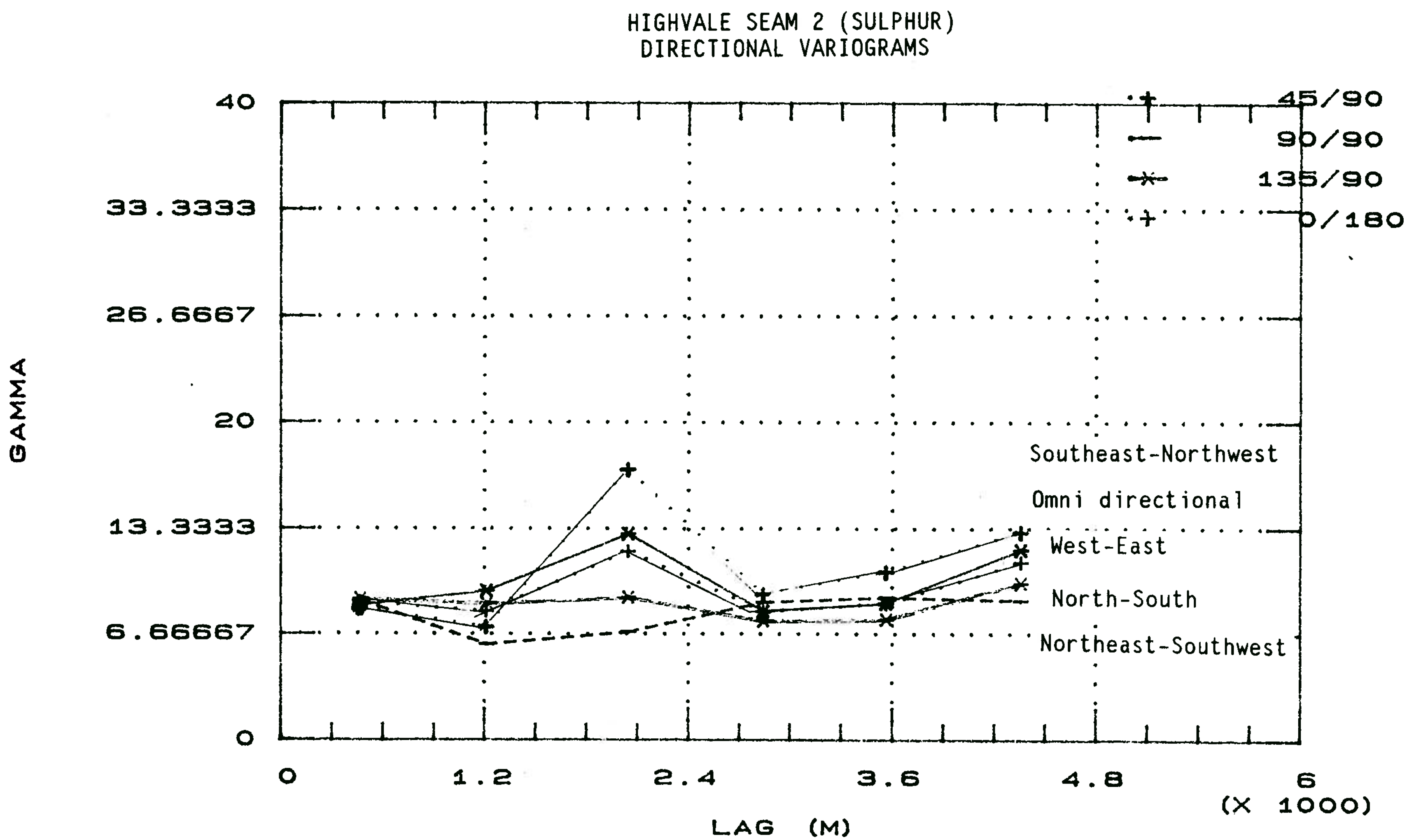


Figure 43. Directional variogram for sulphur (seam 2), North Highvale deposit. Results are reported on an air-dried basis.

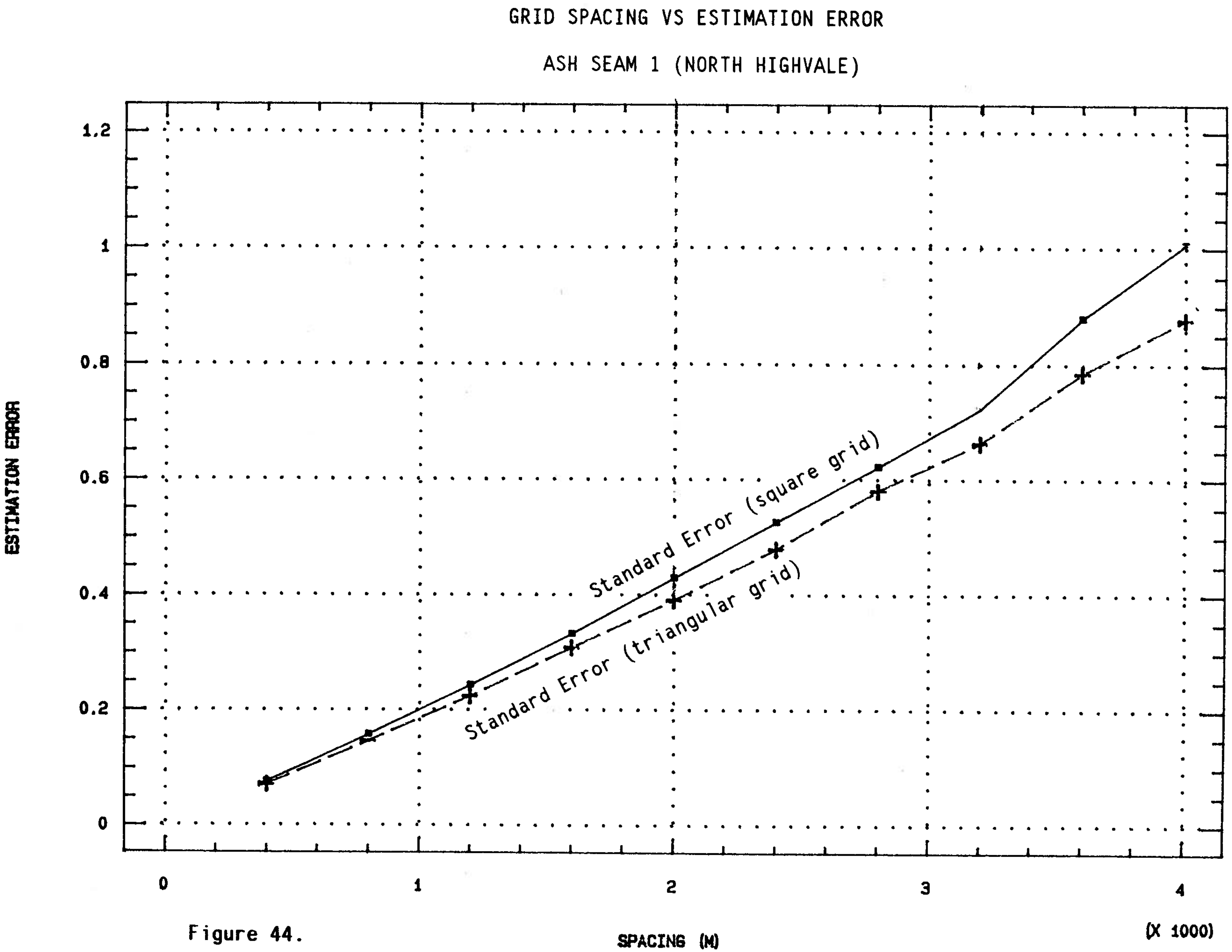
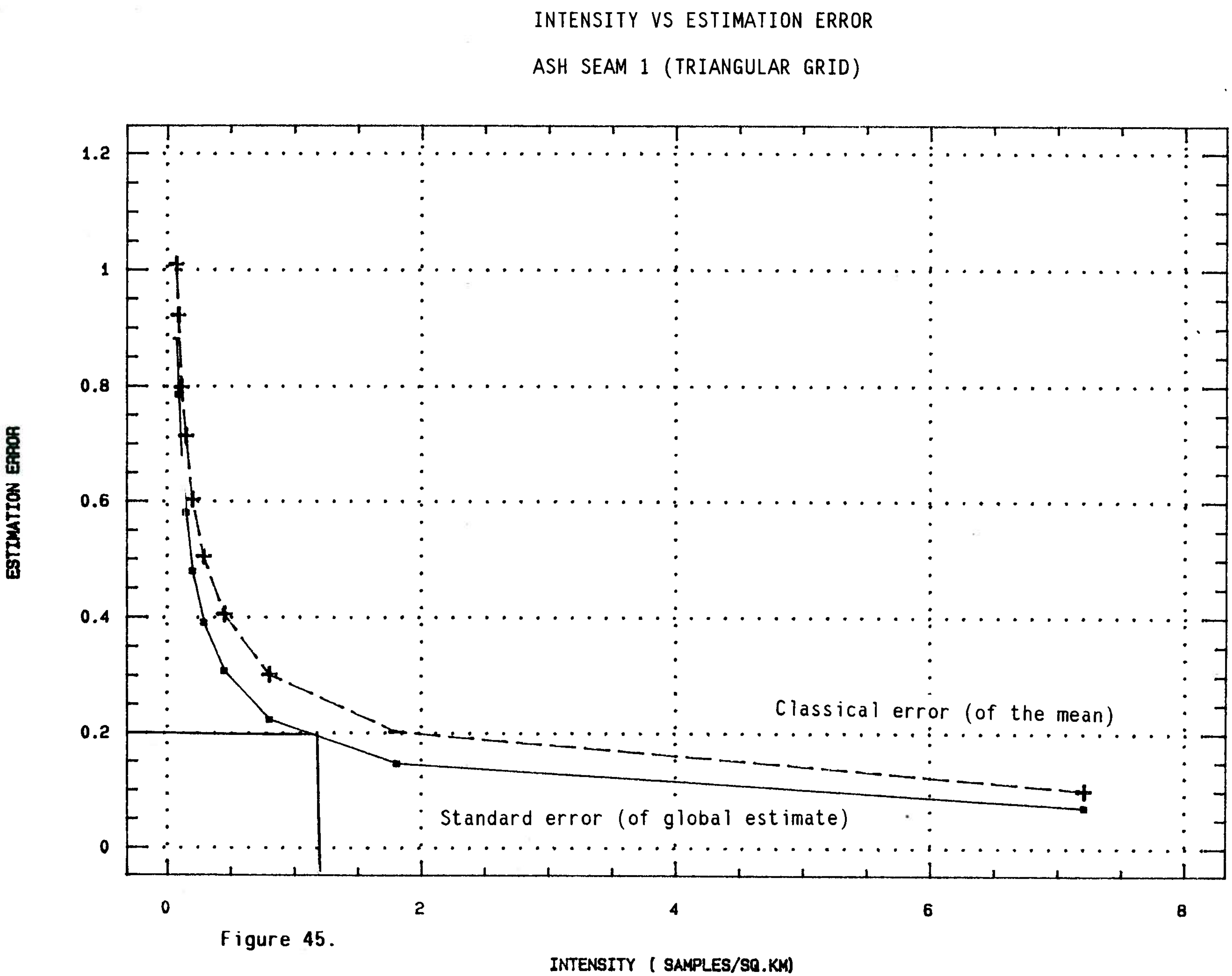
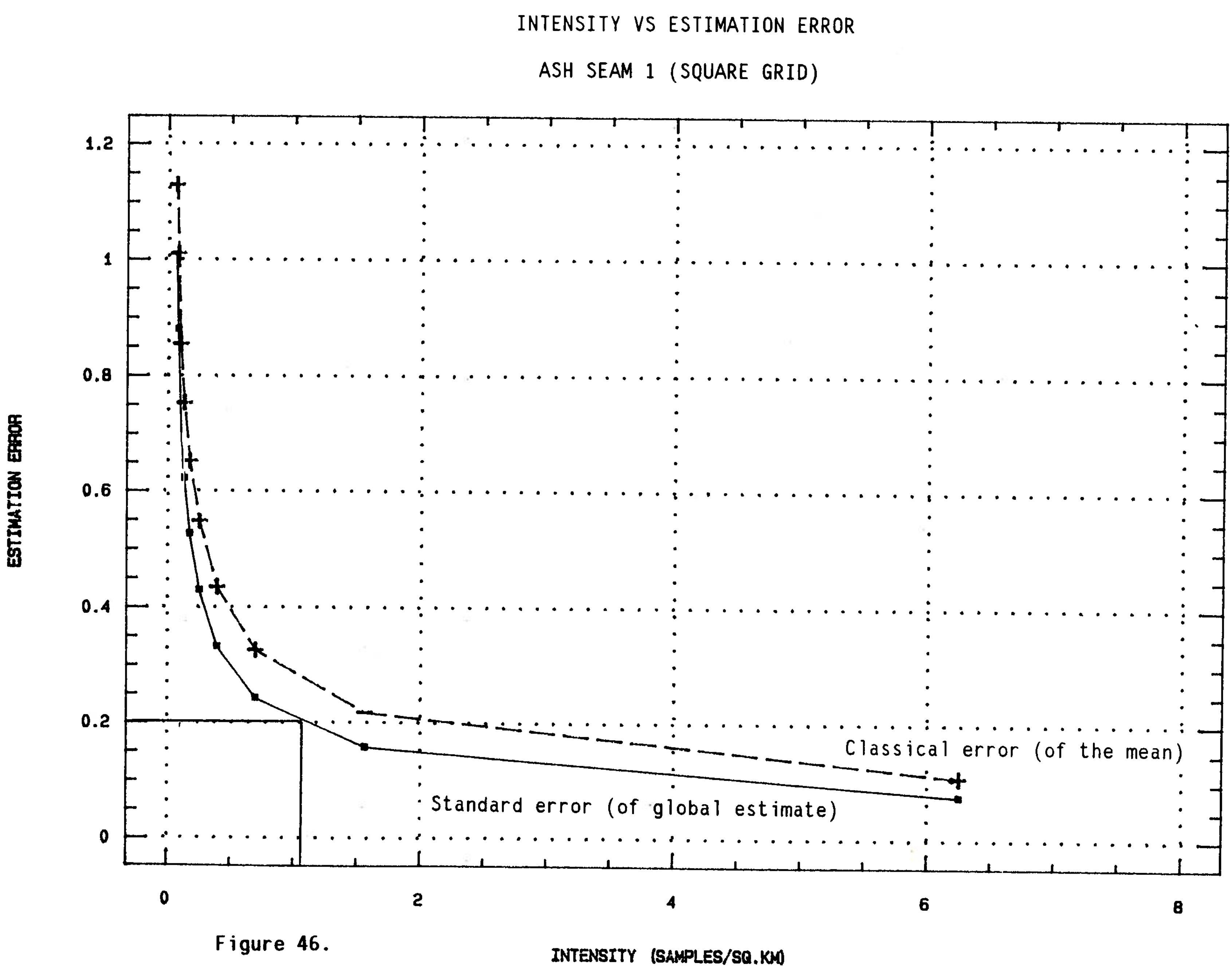

GRID SPACING VS ESTIMATION ERROR
ASH SEAM 1 (NORTH HIGHVALE)
ESTIMATION ERROR
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
SPACING (M)
(X 1000)
Standard Error (square grid)
Standard Error (triangular grid)

Figure 44.



INTENSITY VS ESTIMATION ERROR
ASH SEAM 1 (TRIANGULAR GRID)
ESTIMATION ERROR
1.2
1
0.8
0.6
0.4
0.2
0
Classical error (of the mean)
Standard error (of global estimate)
0
2
4
6
8
INTENSITY (SAMPLES/SQ.KM)

Figure 45.



INTENSITY VS ESTIMATION ERROR
ASH SEAM 1 (SQUARE GRID)
ESTIMATION ERROR
1.2
1
0.8
0.6
0.4
0.2
0
Classical error (of the mean)
Standard error (of global estimate)
0
2
4
6
8
INTENSITY (SAMPLES/SQ.KM)

Figure 46.

the optimal sample spacing is along the area of flattening of the curve (within the boxed outlines provided in the figures). Beyond the optimal sample spacing, additional samples are unlikely to provide a significantly lower estimation error.

To select optimal sampling strategy, the intensity of sampling for square and for a triangular grid is compared. For a standard error of 0.2 the intensity of samples is approximately 1 sample/ km^2 for the triangular grid (Figure 44) and 1.2 samples/ km^2 for the rectangular grid. Using Figure 45, assuming an estimation error of 0.2, the sample spacing is approximately 1000 m and 1100 m for the triangular and rectangular grids, respectively. The example shown here is for ash content, Seam 1. Similar graphs were produced for the other variables for seam 1 and 2. Table 11 summarizes the results of optimal sample spacing for the other variables.

6.5.1 Results of optimal sample spacing substudy

On the basis of analysis of sampling patterns for square and triangular grids, the following conclusions were derived. The difference between the standard error of estimate using kriging and the classical statistical approach is proportional to the nugget variance of the related variogram model. The greater the nugget variance, the smaller the difference between standard errors. Estimates for the number of samples needed should be interpreted as approximations only. Estimates for optimal sampling distances for seams 1 and 2, in the North Highvale deposit vary from 780 to 900 m, for most coal quality parameters (Table 11). Generally, the square (or rectangular) grid appears to require less samples than the triangular grid, and is the recommended sampling method.

Results are preliminary and more work is required to validate results. In addition, further studies of optimal sample spacings in other Ardley coal deposits and other seams would be useful for comparison. As more data becomes available for study and more comparisons are made, optimal sample spacings for Ardley coal seams will be better defined.

Seam	Variable	Standard Error		Sampling Intensity		Sampling distance		Number of samples	
	–	TR	SQ	TR	SQ	TR	SQ	TR	SQ
				[#/sq.km]		[m]			
I	H2O	0.16	0.18	1.8	1.5	850	800	125	104
	VLT	0.10	0.133	1.66	1.5	900	800	115	104
	ASH	0.15	0.15	1.75	1.5	900	800	121	104
	FXC	0.22	0.25	1.9	1.8	800	780	132	125
	S	0.003	0.003	1.8	1.5	850	800	125	104
II	H2O	0.15	0.17	1.8	1.6	850	800	125	111
	VLT	0.13	0.14	1.9	1.5	800	800	132	104
	ASH	0.14	0.15	1.85	1.8	800	780	128	125
	FXC	0.12	0.14	1.9	1.75	800	780	132	122
	S	0.0028	0.0029	1.9	1.8	800	780	132	125

TR – triangular grid; SQ – square grid; H2O – moisture content ; VLT – volatile matter content; ASH – ash content; FXC – fixed carbon content; S – sulphur content
(area used in calculation of number of samples – 69.44 sq.km)

Table 11. Optimal sample intensity and distances calculated for triangular (TR) and square (SQ) grids. These calculations apply to seams 1 and 2 in the North Highvale deposit.

7.0 Conclusions and Recommendations

The results of this show that classical statistical techniques based on the normality assumption, may not be appropriate in the analysis of coal quality of the Ardley coal zone. Statistical methods must be chosen carefully, taking into account the dependencies between variables and the confidence limits assigned to the reported values. The components in proximate and ultimate analyses, for example, must be adjusted so that the sum is equal 100% on the dry, dry ash-free and dry mineral matter-free bases. Each component in each sample is recalculated differently, because each sample has a different moisture and ash content. There is a built in bias for each reporting method. Some values examined such as fixed carbon in proximate analysis and oxygen in ultimate analysis have an additional bias because they are calculated by difference rather than being measured. Clearly, the coal quality parameters being evaluated are not random, yet randomness is a basic assumption used in many classical statistical techniques.

For the most part in this evaluation, exploratory nonparametric statistical methods are used. The preferred estimate of central tendency at all scales of investigation is the median. The interquantile range, which is a measure of the departure from the sample median, is useful for indicating the amount of variability in the reported estimates. The median and interquantile range are used because they can accommodate non-normal distributions and are commonly less effected by outliers in the data. Generally, statistical analysis of both regional and detailed coal quality data sets, is limited to nonparametric methods.

Spatial dependence of variables can be partially accommodated by nonparametric statistics, by separate studies of deposits or portions of deposits. For more accurate and systematic evaluations, geostatistics can be applied. Regardless of the methods used, a detailed understanding of the geology is critical.

One concern in this study is the representativeness of the data. Central tendencies and range in coal quality values vary depending on the scale of investigation and amount of accuracy desired. As one example, consider the central tendencies and variation in ash and sulphur contents. On the regional scale of investigation, the median value of ash for composite samples is 24.5% (dry basis). The median value for total sulphur content is 0.33% (dry basis). These represent broad brush estimates for Ardley coals in Alberta.

In estimates for deposits, the median ash content for composite samples vary between 30.7% (Ardley Bend), 27.0% (Wetaskiwin), 14.8% (Genesee), 18.5% (Low Water Lake), 17.4% (South Highvale), 16.0% (North Highvale), 19.8% (Whitewood), 29.5% (Swan Hills), 36.6% (Fox Creek) and 34.9% (Musreau Lake), all on a dry basis. Similar variation is observed for total sulphur content. The median sulphur content for composite samples vary between 0.36% (Ardley Bend), 0.39% (Wetaskiwin), 0.26% (Genesee), 0.25% (Low Water Lake), 0.25% (South Highvale), 0.24% (North Highvale), 0.31% (Whitewood), 0.34% (Swan Hills), 0.35% (Fox Creek) and 0.48% (Musreau Lake), all on a dry basis. The picture changes remarkably with the scale of investigation.

Estimates given above are for composites samples (ie. weighted averages for all seams combined) because seam differentiation is not practicable over broad areas. Consider now the coal quality variation within a deposit. In Highvale North, for example, the median ash content is 16.0% (dry basis). The median sulphur content for composite samples is 0.24% (dry basis). Examination of coal quality on a seam basis indicates that in any location within the North Highvale deposit, ash content can vary between 18.4% (seam 1), 13.9% (seam 2), 19.3% (seam 3), 22.2% (seam 4), 38.0% (seam 5) and 20.3% (seam 6), all on a dry basis. Similar variation is observed for total sulphur content. The median sulphur content on a seam basis varies between 0.25% (seam 1), 0.18% (seam 2), 0.31% (seam 3), 0.37% (seam 4), 0.41% (seam 5) and 0.37% (seam 6), all on a dry basis.

So what is representative and how do we interpret statistical results? Obviously, the scale of investigation, amount of data, and type of data (seam basis vs composites) determines the accuracy and confidence attributed to each estimate. Since seam correlations are not practicable in regional assessments, composite samples are evaluated. Coal quality reported on a regional scale are used as a guide to measure expected ranges in values. Detailed studies in which coal quality is evaluated on a seam basis, and where detailed geological interpretation is available, provide more accurate estimates of central tendencies and a better understanding of coal quality variation.

A systematic approach is used in this assessment of coal quality. Provided that the limitations at the given scales are recognized, the estimates given will be useful for coal resource characterization and for the evaluation of the mining potential of Alberta's Ardley coal zone. Whether coal quality is reported on an as-received, dry, dry ash-free, or dry mineral matter-free basis, all results must be interpreted carefully.

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APPENDIX ONE

(Program used to calculate the weighted mean of ultimate variables, based on sample length in each drill hole).

```
C       THIS IS A WEIGHTED AVERAGE PROGRAM FOR THE ULTIMATE DATA.
C       INPUT FILE (FOR002) MUST BE GENERATED BY THE ERCB_COAL.FOR
C       PROGRAM (FOR004.DAT). THERE WILL BE 10 OUTPUT FILES :
C       FOR020:SINK FLOAT SAMPLES ON DRY BASES
C       FOR021:SCREENED SAMPLES ON DRY BASES
C       FOR022:WASHED SAMPLES ON DRY BASES
C       FOR023:SCREENED AND WASHED SAMPLES ON DRY BASES
C       FOR024:RAW SAMPLES ON DRY BASES
C       FOR025:SINK FLOAT SAMPLES ON DAF BASES
C       FOR026:SCREENED SAMPLES ON DAF BASES
C       FOR027:WASHED SAMPLES ON DAF BASES
C       FOR028:SCREENED AND WASHED SAMPLES ON DAF BASES
C       FOR029:RAW SAMPLES ON DAF BASES
C       THE ADDRESS OF THIS PROGRAM IS AT:
C       USERS:[AGSCDB.CHAO]WEIGHT-ULT.FOR
C
        DOUBLE PRECISION LAT(100),LONG(100)
        CHARACTER STRING20*135,SMC(100)*2,ID(100)*8
C
C       THE ORIGINAL INPUT OF DATAS
        REAL BOT(100),TOP(100),UDEPTH,LDEPTH,
     * C(100),H(100),O(100),N(100),
     * S(100),OR(100),PY(100),SU(100),ULT_MOIST(100),ULT_ASH(100)
        INTEGER U_SAMPLE(100),C_CODE(100)
C
C       DATA FOR RAW SAMPLES
        CHARACTER SMC5(100)*2,ID5(100)*8
        REAL TOP5(100),BOT5(100),
     * C5(100),H5(100),O5(100),N5(100),S5(100),OR5(100),
     * PY5(100),SU5(100),ULT_MOIST5(100),ULT_ASH5(100)
        INTEGER SAMPLE5(100),K5,C_CODE5(100)
C
C       DATA FOR SINK FLOAT SAMPLES
        CHARACTER SMC1(100)*2,ID1(100)*8
        REAL TOP1(100),BOT1(100),
     * C1(100),H1(100),N1(100),O1(100),S1(100),OR1(100),
     * PY1(100),SU1(100),ULT_MOIST1(100),ULT_ASH1(100)
        INTEGER SAMPLE1(100),K1,C_CODE1(100)
C
C       DATA FOR SCREENED SAMPLES
        CHARACTER SMC2(100)*2,ID2(100)*8
        REAL TOP2(100),BOT2(100),
     * C2(100),H2(100),O2(100),N2(100),S2(100),OR2(100),
     * PY2(100),SU2(100),ULT_MOIST2(100),ULT_ASH2(100)
        INTEGER SAMPLE2(100),K2,C_CODE2(100)
C
C       DATA FOR WASHED SAMPLES
        CHARACTER SMC3(100)*2,ID3(100)*8
        REAL TOP3(100),BOT3(100),
     * C3(100),H3(100),O3(100),N3(100),S3(100),OR3(100),
     * PY3(100),SU3(100),ULT_MOIST3(100),ULT_ASH3(100)
        INTEGER SAMPLE3(100),K3,C_CODE3(100)
C
C       DATA FOR SCREENED AND WASHED SAMPLES
        CHARACTER SMC4(100)*2,ID4(100)*8
        REAL TOP4(100),BOT4(100),
     * C4(100),H4(100),O4(100),N4(100),S4(100),OR4(100),
     * PY4(100),SU4(100),ULT_MOIST4(100),ULT_ASH4(100)
        INTEGER SAMPLE4(100),K4,C_CODE4(100)
C
C       WEIGHTED AVERAGE
```

```
      REAL AS_D,C_D,H_D,N_D,O_D,S_D,OR_D,PY_D,SU_D,
     * C_DAF,H_DAF,N_DAF,O_DAF,S_DAF,OR_DAF,PY_DAF,SU_DAF
C
C     GENERAL COUNTERS
      INTEGER M,X,A
      X=1
      M=1
      AS_D=0.0
      C_D=0.0
      H_D=0.0
      N_D=0.0
      O_D=0.0
      S_D=0.0
      OR_D=0.0
      PY_D=0.0
      SU_D=0.0
      C_DAF=0.0
      H_DAF=0.0
      N_DAF=0.0
      O_DAF=0.0
      S_DAF=0.0
      OR_DAF=0.0
      PY_DAF=0.0
      SU_DAF=0.0
      OPEN(UNIT=2,STATUS='OLD')
      OPEN(UNIT=20,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=21,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=22,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=23,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=24,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=25,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=26,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=27,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=28,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=29,STATUS='NEW',CARRIAGECONTROL='LIST')
C
      READ(2,'(A)',IOSTAT=IOS)STRING20
C
C     CHECKING FOR HOLES
C
      READ(STRING20(10:132),1)ID(X),LAT(X),LONG(X),TOP(X),BOT(X),
     * U_SAMPLE(X),ULT_ASH(X),C(X),H(X),O(X),N(X),S(X),OR(X),
     * PY(X),SU(X),ULT_MOIST(X),SMC(X),C_CODE(X)
 5    IF (IOS.EQ.-1) GO TO 8
      READ(2,'(A)',IOSTAT=IOS)STRING20
      READ(STRING20(10:132),1)ID(X+1),LAT(X+1),LONG(X+1),TOP(X+1),
     * BOT(X+1),U_SAMPLE(X+1),ULT_ASH(X+1),C(X+1),H(X+1),
     * O(X+1),N(X+1),S(X+1),OR(X+1),PY(X+1),SU(X+1),ULT_MOIST(X+1),
     * SMC(X+1),C_CODE(X+1)
 1    FORMAT(A8,1X,F9.6,1X,F10.6,9X,2(F7.2,1X),I1,5X,2(F5.2,1X),
     * F4.2,1X,F5.2,1X,2(F4.2,1X),3(F3.1,1X),F5.2,1X,3X,A2,1X,I1)
 8    IF (LAT(X).NE.LAT(X+1)) THEN
C
C     CHECK FOR THE UPPER-MOST AND LOWER-MOST LEVELS
C
      UDEPTH=1000.0
      LDEPTH=0.0
      DO 10 M=1,X
      IF (TOP(M).LE.UDEPTH) THEN
      UDEPTH=TOP(M)
      END IF
```

```
      IF (BOT(M).GE.LDEPTH) THEN
      LDEPTH=BOT(M)
      END IF
 10   CONTINUE
C
C     CHECK FOR SAMPLE TYPE
C
      K1=0
      K2=0
      K3=0
      K4=0
      K5=0
      DO 20 M=1,X
      IF (U_SAMPLE(M).EQ.0 .OR. U_SAMPLE(M).EQ.5) THEN
       K5=K5+1
       TOP5(K5)=TOP(M)
       BOT5(K5)=BOT(M)
       ULT_ASH5(K5)=ULT_ASH(M)
       C5(K5)=C(M)
       H5(K5)=H(M)
       O5(K5)=O(M)
       N5(K5)=N(M)
       S5(K5)=S(M)
       PY5(K5)=PY(M)
       OR5(K5)=OR(M)
       SU5(K5)=SU(M)
       ULT_MOIST5(K5)=ULT_MOIST(M)
       C_CODE5(K5)=C_CODE(M)
       SMC5(K5)=SMC(M)
       SAMPLE5(K5)=U_SAMPLE(M)
       ID5(K5)=ID(M)
      ELSE IF (U_SAMPLE(M).EQ.1) THEN
       K1=K1+1
       TOP1(K1)=TOP(M)
       BOT1(K1)=BOT(M)
       ULT_ASH1(K1)=ULT_ASH(M)
       C1(K1)=C(M)
       H1(K1)=H(M)
       O1(K1)=O(M)
       N1(K1)=N(M)
       S1(K1)=S(M)
       PY1(K1)=PY(M)
       OR1(K1)=OR(M)
       SU1(K1)=SU(M)
       ULT_MOIST1(K1)=ULT_MOIST(M)
       C_CODE1(K1)=C_CODE(M)
       SMC1(K1)=SMC(M)
       SAMPLE1(K1)=U_SAMPLE(M)
       ID1(K1)=ID(M)
      ELSE IF(U_SAMPLE(M).EQ.2) THEN
       K2=K2+1
       TOP2(K2)=TOP(M)
       BOT2(K2)=BOT(M)
       ULT_ASH2(K2)=ULT_ASH(M)
       C2(K2)=C(M)
       H2(K2)=H(M)
       O2(K2)=O(M)
       N2(K2)=N(M)
       S2(K2)=S(M)
       PY2(K2)=PY(M)
       OR2(K2)=OR(M)
```

```
         SU2(K2)=SU(M)
         ULT_MOIST2(K2)=ULT_MOIST(M)
         C_CODE2(K2)=C_CODE(M)
         SMC2(K2)=SMC(M)
         SAMPLE2(K2)=U_SAMPLE(M)
         ID2(K2)=ID(M)
        ELSE IF(U_SAMPLE(M).EQ.3) THEN
         K3=K3+1
         TOP3(K3)=TOP(M)
         BOT3(K3)=BOT(M)
         ULT_ASH3(K3)=ULT_ASH(M)
         C3(K3)=C(M)
         H3(K3)=H(M)
         O3(K3)=O(M)
         N3(K3)=N(M)
         S3(K3)=S(M)
         PY3(K3)=PY(M)
         OR3(K3)=OR(M)
         SU3(K3)=SU(M)
         ULT_MOIST3(K3)=ULT_MOIST(M)
         C_CODE3(K3)=C_CODE(M)
         SMC3(K3)=SMC(M)
         SAMPLE3(K3)=U_SAMPLE(M)
         ID3(K3)=ID(M)
        ELSE IF(U_SAMPLE(M).EQ.4) THEN
         K4=K4+1
         TOP4(K4)=TOP(M)
         BOT4(K4)=BOT(M)
         ULT_ASH4(K4)=ULT_ASH(M)
         C4(K4)=C(M)
         H4(K4)=H(M)
         O4(K4)=O(M)
         N4(K4)=N(M)
         S4(K4)=S(M)
         PY4(K4)=PY(K4)
         OR4(K4)=OR(M)
         SU4(K4)=SU(M)
         ULT_MOIST4(K4)=ULT_MOIST(M)
         C_CODE4(K4)=C_CODE(M)
         SMC4(K4)=SMC(M)
         SAMPLE4(K4)=U_SAMPLE(M)
         ID4(K4)=ID(M)
        END IF
20      CONTINUE
        IF (K1.GT.0) THEN
        CALL OVERLAPPING(TOP1,BOT1,ULT_ASH1,C1,H1,O1,N1,S1,PY1,OR1,
     *  SU1,ULT_MOIST1,K1)
        CALL DAF(TOP1,BOT1,ULT_MOIST1,ULT_ASH1,C1,H1,O1,N1,S1,PY1,
     *  OR1,SU1,K1,AS_D,C_D,C_DAF,H_D,H_DAF,O_D,O_DAF,N_D,N_DAF,
     *  S_D,S_DAF,PY_D,PY_DAF;OR_D,OR_DAF,SU_D,SU_DAF)
        WRITE(20,2)ID1(K1),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,C_D,H_D,
     *  O_D,N_D,S_D,PY_D,OR_D,SU_D,SAMPLE1(K1),C_CODE1(K1),SMC1(K1)
        WRITE(25,3)ID1(K1),LAT(1),LONG(1),UDEPTH,LDEPTH,C_DAF,H_DAF,
     *  O_DAF,N_DAF,S_DAF,PY_DAF,OR_DAF,SU_DAF,SAMPLE1(K1),C_CODE1(K1),
     *  SMC1(K1)
        END IF
        IF (K2.GT.0) THEN
        CALL OVERLAPPING(TOP2,BOT2,ULT_ASH2,C2,H2,O2,N2,S2,PY2,OR2,
     *  SU2,ULT_MOIST2,K2)
        CALL DAF(TOP2,BOT2,ULT_MOIST2,ULT_ASH2,C2,H2,O2,N2,S2,PY2,
     *  OR2,SU2,K2,AS_D,C_D,C_DAF,H_D,H_DAF,O_D,O_DAF,N_D,N_DAF,
```

```
     * S_D,S_DAF,PY_D,PY_DAF,OR_D,OR_DAF,SU_D,SU_DAF)
       WRITE(21,2)ID2(K2),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,C_D,H_D,
     * O_D,N_D,S_D,PY_D,OR_D,SU_D,SAMPLE2(K2),C_CODE2(K2),SMC2(K2)
       WRITE(26,3)ID2(K2),LAT(1),LONG(1),UDEPTH,LDEPTH,C_DAF,H_DAF,
     * O_DAF,N_DAF,S_DAF,PY_DAF,OR_DAF,SU_DAF,SAMPLE2(K2),C_CODE2(K2),
     * SMC2(K2)
       END IF
       IF (K3.GT.0) THEN
       CALL OVERLAPPING(TOP3,BOT3,ULT_ASH3,C3,H3,O3,N3,S3,PY3,OR3,
     * SU3,ULT_MOIST3,K3)
       CALL DAF(TOP3,BOT3,ULT_MOIST3,ULT_ASH3,C3,H3,O3,N3,S3,PY3,
     * OR3,SU3,K3,AS_D,C_D,C_DAF,H_D,H_DAF,O_D,O_DAF,N_D,N_DAF,
     * S_D,S_DAF,PY_D,PY_DAF,OR_D,OR_DAF,SU_D,SU_DAF)
       WRITE(22,2)ID3(K3),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,C_D,H_D,
     * O_D,N_D,S_D,PY_D,OR_D,SU_D,SAMPLE3(K3),C_CODE3(K3),SMC3(K3)
       WRITE(27,3)ID3(K3),LAT(1),LONG(1),UDEPTH,LDEPTH,C_DAF,H_DAF,
     * O_DAF,N_DAF,S_DAF,PY_DAF,OR_DAF,SU_DAF,SAMPLE3(K3),C_CODE3(K3),
     * SMC3(K3)
       END IF
       IF (K4.GT.0) THEN
       CALL OVERLAPPING(TOP4,BOT4,ULT_ASH4,C4,H4,O4,N4,S4,PY4,OR2,
     * SU4,ULT_MOIST4,K4)
       CALL DAF(TOP4,BOT4,ULT_MOIST4,ULT_ASH4,C4,H4,O4,N4,S4,PY4,
     * OR4,SU4,K4,AS_D,C_D,C_DAF,H_D,H_DAF,O_D,O_DAF,N_D,N_DAF,
     * S_D,S_DAF,PY_D,PY_DAF,OR_D,OR_DAF,SU_D,SU_DAF)
       WRITE(23,2)ID4(K4),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,C_D,H_D,
     * O_D,N_D,S_D,PY_D,OR_D,SU_D,SAMPLE4(K4),C_CODE4(K4),SMC4(K4)
       WRITE(28,3)ID4(K4),LAT(1),LONG(1),UDEPTH,LDEPTH,C_DAF,H_DAF,
     * O_DAF,N_DAF,S_DAF,PY_DAF,OR_DAF,SU_DAF,SAMPLE4(K4),C_CODE4(K4),
     * SMC4(K4)
       END IF
       IF (K5.GT.0) THEN
       CALL OVERLAPPING(TOP5,BOT5,ULT_ASH5,C5,H5,O5,N5,S5,PY5,OR5,
     * SU5,ULT_MOIST5,K5)
       CALL DAF(TOP5,BOT5,ULT_MOIST5,ULT_ASH5,C5,H5,O5,N5,S5,PY5,
     * OR5,SU5,K5,AS_D,C_D,C_DAF,H_D,H_DAF,O_D,O_DAF,N_D,N_DAF,
     * S_D,S_DAF,PY_D,PY_DAF,OR_D,OR_DAF,SU_D,SU_DAF)
       WRITE(24,2)ID5(K5),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,C_D,H_D,
     * O_D,N_D,S_D,PY_D,OR_D,SU_D,SAMPLE5(K5),C_CODE5(K5),SMC5(K5)
       WRITE(29,3)ID5(K5),LAT(1),LONG(1),UDEPTH,LDEPTH,C_DAF,H_DAF,
     * O_DAF,N_DAF,S_DAF,PY_DAF,OR_DAF,SU_DAF,SAMPLE5(K5),C_CODE5(K5),
     * SMC5(K5)
       END IF
 2     FORMAT(A8,1X,F9.6,1X,F10.6,1X,2(F7.2,1X),9(F5.2,1X),I1,1X,I1,
     *        1X,A2)
 3     FORMAT(A8,1X,F9.6,1X,F10.6,1X,2(F7.2,1X),8(F5.2,1X),I1,1X,I1,
     *        1X,A2)
       IF (IOS.EQ.-1) GO TO 80
       LAT(1)=LAT(X+1)
       LONG(1)=LONG(X+1)
       TOP(1)=TOP(X+1)
       BOT(1)=BOT(X+1)
       U_SAMPLE(1)=U_SAMPLE(X+1)
       ULT_MOIST(1)=ULT_MOIST(X+1)
       ULT_ASH(1)=ULT_ASH(X+1)
       C(1)=C(X+1)
       H(1)=H(X+1)
       O(1)=O(X+1)
       N(1)=N(X+1)
       S(1)=S(X+1)
       PY(1)=PY(X+1)
```

```
      OR(1)=OR(X+1)
      SU(1)=SU(X+1)
      C_CODE(1)=C_CODE(X+1)
      SMC(1)=SMC(X+1)
      ID(1)=ID(X+1)
      X=0
      END IF
      X=X+1
      GO TO 5
 80   STOP
      END
C
C
      SUBROUTINE OVERLAPPING(TOP,BOT,X1,X2,X3,X4,X5,X6,X7,X8,X9,
     * X10,X)
      REAL TOP(100),BOT(100),X1(100),X2(100),X3(100),
     * X4(100),X5(100),X6(100),X7(100),X8(100),X9(100),
     * X10(100),DIF,T1,T2,B1,B2
      INTEGER F,SE,X,M
      F=1
      SE=2
      IF (X.EQ.0 .OR. X.EQ.1) GO TO 16
 14   DO 15 M=SE,X
      IF (BOT(F).GT.TOP(M)) THEN
       IF(BOT(F).LE.BOT(M).AND.TOP(F).GT.TOP(M)) THEN
       T1=TOP(F)
       T2=TOP(M)
       B1=BOT(F)
       B2=BOT(M)
       CALL OVERLAP3(B1,B2,T1,T2,X1,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X2,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X3,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X4,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X5,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X6,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X7,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X8,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X9,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X10,F,M)
       TOP(F)=0.0
       BOT(F)=0.0
       GO TO 13
      ELSE IF(BOT(F).LT.BOT(M).AND.TOP(F).GE.TOP(M)) THEN
       T1=TOP(F)
       T2=TOP(M)
       B1=BOT(F)
       B2=BOT(M)
       CALL OVERLAP3(B1,B2,T1,T2,X1,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X2,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X3,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X4,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X5,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X6,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X7,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X8,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X9,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X10,F,M)
       TOP(F)=0.0
       BOT(F)=0.0
       GO TO 13
      ELSE IF(TOP(F).LE.TOP(M) .AND. BOT(F).GT.BOT(M)) THEN
```

```
 T1=TOP(F)
 T2=TOP(M)
 B1=BOT(F)
 B2=BOT(M)
 CALL OVERLAP2(B1,B2,T1,T2,X1,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X2,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X3,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X4,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X5,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X6,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X7,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X8,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X9,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X10,F,M)
 TOP(M)=0.0
 BOT(M)=0.0
ELSE IF(TOP(F).LT.TOP(M) .AND. BOT(F).GE.BOT(M)) THEN
 T1=TOP(F)
 T2=TOP(M)
 B1=BOT(F)
 B2=BOT(M)
 CALL OVERLAP2(B1,B2,T1,T2,X1,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X2,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X3,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X4,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X5,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X6,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X7,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X8,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X9,F,M)
 CALL OVERLAP2(B1,B2,T1,T2,X10,F,M)
 TOP(M)=0.0
 BOT(M)=0.0
ELSE IF(TOP(F).LT.BOT(M).AND.TOP(F).LT.TOP(M)) THEN
     IF(BOT(F).LT.BOT(M)) THEN
 DIF=BOT(M)-TOP(F)
 IF(DIF.GE.0.01) THEN
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X1,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X2,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X3,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X4,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X5,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X6,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X7,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X8,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X9,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X10,F,M,DIF)
 TOP(F)=T1
 TOP(M)=T2
 BOT(F)=B1
 BOT(M)=B2
 END IF
     END IF
ELSE IF(TOP(F).LT.BOT(M).AND.TOP(F).GT.TOP(M)) THEN
     IF(BOT(F).GT.BOT(M)) THEN
 DIF=BOT(F)-TOP(M)
 IF (DIF.GE.0.01) THEN
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X1,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X2,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X3,F,M,DIF)
 CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X4,F,M,DIF)
```

```
       CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X5,F,M,DIF)
       CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X6,F,M,DIF)
       CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X7,F,M,DIF)
       CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X8,F,M,DIF)
       CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X9,F,M,DIF)
       CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X10,F,M,DIF)
       TOP(F)=T1
       TOP(M)=T2
       BOT(F)=B1
       BOT(M)=B2
       END IF
           END IF
      ELSE IF (TOP(F).GE.BOT(M)) THEN
           GO TO 15
      ELSE IF (TOP(F).EQ.TOP(M) .AND. BOT(F).EQ.BOT(M)) THEN
       X1(F)=(X1(F)+X1(M))/2
       X2(F)=(X2(F)+X2(M))/2
       X3(F)=(X3(F)+X3(M))/2
       X4(F)=(X4(F)+X4(M))/2
       X5(F)=(X5(F)+X5(M))/2
       X6(F)=(X6(F)+X6(M))/2
       X7(F)=(X7(F)+X7(M))/2
       X8(F)=(X8(F)+X8(M))/2
       X9(F)=(X9(F)+X9(M))/2
       X10(F)=(X10(F)+X10(M))/2
       X1(M)=0.0
       X2(M)=0.0
       X3(M)=0.0
       X4(M)=0.0
       X5(M)=0.0
       X6(M)=0.0
       X7(M)=0.0
       X8(M)=0.0
       X9(M)=0.0
       X10(M)=0.0
       TOP(M)=0.0
       BOT(M)=0.0
      END IF
      END IF
 15   CONTINUE
 13   IF (SE.NE.X) THEN
       F=F+1
       SE=SE+1
       GO TO 14
      END IF
 16   RETURN
      END
C
      SUBROUTINE OVERLAP1(TOP,BOT,B1,B2,T1,T2,Y,F,M,DIF)
      REAL B1,B2,T1,T2,Y(100),DIF1,DIF2,OLAP,DIF,TOP(100),
     * BOT(100),TOP1,BOT1
      INTEGER F,M
      T1=TOP(F)
      T2=TOP(M)
      B1=BOT(F)
      B2=BOT(M)
      IF(T1.LT.T2) THEN
       DIF1=T2-T1
       DIF2=B1-T2
       DIF3=B2-B1
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
```

```
       TOP1=(DIF1/DIF)*Y(F)
       BOT1=(DIF3/DIF)*Y(M)
       Y(F)=TOP1+OLAP+BOT1
       Y(M)=0.0
       B2=0.0
       T2=0.0
      ELSE IF(T1.GT.T2) THEN
       DIF1=T1-T2
       DIF2=B2-T1
       DIF3=B1-B2
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
       TOP1=(DIF1/DIF)*Y(M)
       BOT1=(DIF3/DIF)*Y(F)
       Y(M)=TOP1+OLAP+BOT1
       Y(F)=0.0
       B1=0.0
       T1=0.0
      END IF
      RETURN
      END
C
      SUBROUTINE OVERLAP2(B1,B2,T1,T2,Y,F,M)
      REAL B1,B2,T1,T2,Y(100),DIF1,DIF2,DIF3,DIF,OLAP,AVE
      INTEGER F,M
      IF(Y(F).EQ.0.0 .OR. Y(M).EQ.0.0) GO TO 100
      IF(T1.LT.T2 .AND. B1.GT.B2) THEN
       DIF=B1-T1
       DIF1=T2-T1
       DIF2=B2-T2
       DIF3=B1-B2
       TOP=(DIF1/DIF)*Y(F)
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
       BOT=(DIF3/DIF)*Y(F)
       AVE=TOP+OLAP+BOT
      ELSE IF(T1.EQ.T2 .AND. B1.GT.B2) THEN
       DIF=B1-T1
       DIF2=B2-T2
       DIF3=B1-B2
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
       BOT=(DIF3/DIF)*Y(F)
       AVE=OLAP+BOT
      ELSE IF(T1.LT.T2 .AND. B1.EQ.B2) THEN
       DIF=B1-T1
       DIF1=T2-T1
       DIF2=B2-T2
       TOP=(DIF1/DIF)*Y(F)
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
       AVE=TOP+OLAP
      END IF
      Y(F)=AVE
      Y(M)=0.0
  100 RETURN
      END
C
      SUBROUTINE OVERLAP3(B1,B2,T1,T2,Y,F,M)
      REAL B1,B2,T1,T2,Y(100),DIF1,DIF2,DIF3,DIF,OLAP,AVE
      INTEGER F,M
      IF(Y(F).EQ.0.0 .OR. Y(M).EQ.0.0) GO TO 100
      IF(T1.GT.T2 .AND. B1.LT.B2) THEN
       DIF=B2-T2
       DIF1=T1-T2
```

```
      DIF2=B1-T1
      DIF3=B2-B1
      TOP=(DIF1/DIF)*Y(M)
      OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
      BOT=(DIF3/DIF)*Y(M)
      Y(M)=TOP+OLAP+BOT
      Y(F)=0.0
     ELSE IF(T1.EQ.T2 .AND. B1.LT.B2) THEN
      DIF=B2-T2
      DIF2=B1-T1
      DIF3=B2-B1
      OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
      BOT=(DIF3/DIF)*Y(M)
      Y(M)=OLAP+BOT
      Y(F)=0.0
     ELSE IF(T1.GT.T2 .AND. B1.EQ.B2) THEN
      DIF=B2-T2
      DIF1=T1-T2
      DIF2=B1-T1
      TOP=(DIF1/DIF)*Y(M)
      OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
      Y(M)=TOP+OLAP
      Y(F)=0.0
     END IF
 100 RETURN
     END
C
      SUBROUTINE DAF(T,B,UM,AS,C,H,O,N,S,PY,OR,SU,K,AS_D,C_D,
     * C_DAF,H_D,H_DAF,O_D,O_DAF,N_D,N_DAF,S_D,S_DAF,PY_D,PY_DAF,
     * OR_D,OR_DAF,SU_D,SU_DAF)
      CHARACTER SMC(100)*2
      REAL T(100),B(100),UM(100),AS(100),C(100),
     * H(100),O(100),N(100),S(100),PY(100),OR(100),SU(100),AS1(100),
     * C_1(100),H_1(100),O_1(100),N_1(100),S_1(100),PY_1(100),
     * OR_1(100),SU_1(100),C_2(100),H_2(100),O_2(100),
     * N_2(100),S_2(100),PY_2(100),OR_2(100),SU_2(100),
     * AS_D,C_D,H_D,O_D,N_D,S_D,PY_D,OR_D,SU_D,C_DAF,H_DAF,O_DAF,
     * N_DAF,S_DAF,PY_DAF,OR_DAF,SU_DAF,DRY,FAC
      INTEGER SAM(100),K,CC(100),M
      DO 45 M=1,100
      C_1(M)=0.0
      C_2(M)=0.0
      H_1(M)=0.0
      H_2(M)=0.0
      O_1(M)=0.0
      O_2(M)=0.0
      N_1(M)=0.0
      N_2(M)=0.0
      S_1(M)=0.0
      S_2(M)=0.0
      PY_1(M)=0.0
      PY_2(M)=0.0
      OR_1(M)=0.0
      OR_2(M)=0.0
      SU_1(M)=0.0
      SU_2(M)=0.0
      AS1(M)=0.0
 45   CONTINUE
      DO 90 M=1,K
C
C     CONVERTING DATA (WITH RESID. MOIST.) INTO DRY AND DRY-ASH
```

```
C      FREE BASES
C
       IF (UM(M) .NE. 0.0) THEN
       DRY=100.0/(100.0-UM(M))
       AS1(M)=AS(M)*DRY
       C_1(M)=C(M)*DRY
       H_1(M)=H(M)*DRY
       O_1(M)=O(M)*DRY
       N_1(M)=N(M)*DRY
       S_1(M)=S(M)*DRY
       PY_1(M)=PY(M)*DRY
       OR_1(M)=OR(M)*DRY
       SU_1(M)=SU(M)*DRY
        IF (AS(M) .NE. 0.00) THEN
        IF( AS(M) .GT. 50.00) GO TO 90
        FAC=100.0/(100.0-UM(M)-AS(M))
        C_2(M)=C(M)*FAC
        H_2(M)=H(M)*FAC
        O_2(M)=O(M)*FAC
        N_2(M)=N(M)*FAC
        S_2(M)=S(M)*FAC
        PY_2(M)=PY(M)*FAC
        OR_2(M)=OR(M)*FAC
        SU_2(M)=SU(M)*FAC
        ELSE IF (AS(M) .EQ. 0.00) THEN
        C_2(M)=C_1(M)
        H_2(M)=H_1(M)
        O_2(M)=O_1(M)
        N_2(M)=N_1(M)
        S_2(M)=S_1(M)
        PY_2(M)=PY_1(M)
        OR_2(M)=OR_1(M)
        SU_2(M)=SU_1(M)
        END IF
C
C     CONVERTING DATA (WITHOUT RESID. MOIST.) INTO DRY AND DRY-ASH
C     FREE BASES
C
      ELSE IF(UM(M) .EQ. 0.0) THEN
        AS1(M)=AS(M)
        C_1(M)=C(M)
        H_1(M)=H(M)
        O_1(M)=O(M)
        N_1(M)=N(M)
        S_1(M)=S(M)
        PY_1(M)=PY(M)
        OR_1(M)=OR(M)
        SU_1(M)=SU(M)
         IF (AS(M) .NE. 0.00) THEN
         IF( AS(M) .GT. 50.00) GO TO 90
         FAC=100.0/(100.0-AS(M))
         C_2(M)=C(M)*FAC
         H_2(M)=H(M)*FAC
         O_2(M)=O(M)*FAC
         N_2(M)=N(M)*FAC
         S_2(M)=S(M)*FAC
         PY_2(M)=PY(M)*FAC
         OR_2(M)=OR(M)*FAC
         SU_2(M)=SU(M)*FAC
         ELSE IF (AS(M) .EQ. 0.00) THEN
         C_2(M)=C_1(M)
```

```
        H_2(M)=H_1(M)
        O_2(M)=O_1(M)
        N_2(M)=N_1(M)
        S_2(M)=S_1(M)
        PY_2(M)=PY_1(M)
        OR_2(M)=OR_1(M)
        SU_2(M)=SU_1(M)
        END IF
      END IF
90    CONTINUE
      CALL WEIGHT(T,B,K,AS1,AS_D)
      CALL WEIGHT(T,B,K,C_1,C_D)
      CALL WEIGHT(T,B,K,H_1,H_D)
      CALL WEIGHT(T,B,K,O_1,O_D)
      CALL WEIGHT(T,B,K,N_1,N_D)
      CALL WEIGHT(T,B,K,S_1,S_D)
      CALL WEIGHT(T,B,K,PY_1,PY_D)
      CALL WEIGHT(T,B,K,OR_1,OR_D)
      CALL WEIGHT(T,B,K,SU_1,SU_D)
      CALL WEIGHT(T,B,K,C_2,C_DAF)
      CALL WEIGHT(T,B,K,H_2,H_DAF)
      CALL WEIGHT(T,B,K,O_2,O_DAF)
      CALL WEIGHT(T,B,K,N_2,N_DAF)
      CALL WEIGHT(T,B,K,S_2,S_DAF)
      CALL WEIGHT(T,B,K,PY_2,PY_DAF)
      CALL WEIGHT(T,B,K,OR_2,OR_DAF)
      CALL WEIGHT(T,B,K,SU_2,SU_DAF)
      RETURN
      END
C
      SUBROUTINE WEIGHT(T,BO,A,B,SUMW)
      REAL T(30),BO(30),SUMW,SUMDIF,DIFF,B(30)
      INTEGER J,A
      SUMW=0.0
      SUMDIF=0.0
      DO 55 J=1,A
      IF (B(J) .EQ. 0.0) GO TO 55
      DIFF=BO(J)-T(J)
      IF (DIFF .EQ. 0.0) DIFF=1.0
      IF (T(J).EQ.-1 .AND. BO(J).EQ.-1) DIFF=1.0
      SUMDIF=SUMDIF+DIFF
      SUMW=SUMW+DIFF*B(J)
55    CONTINUE
      IF (SUMDIF .EQ. 0.0 .OR. SUMW .EQ. 0.0) THEN
      SUMW=-1.0
      ELSE
      SUMW=SUMW/SUMDIF
      END IF
      RETURN
      END
```

APPENDIX TWO

(Program used to calculate the weighted mean
of proximate variables, based on sample length
in each drill hole).

```
C       THIS IS A WEIGHTED AVERAGE PROGRAM FOR THE PROXIMATE DATA.
C       THE INPUT FILE (FOR001) MUST BE GENERATED BY THE ERCB-COAL.FOR
C       PROGRAM (FOR002.DAT). THERE WILL BE 5 OUTPUT FILES:
C       FOR011.DAT: SINK FLOAT SAMPLES ON DRY AND DAF BASES
C       FOR012.DAT: SCREENED SAMPLES ON DRY AND DAF BASES
C       FOR013.DAT: WASHED SAMPLES ON DRY AND DAF BASES
C       FOR014.DAT: SCREENED AND WASHED SAMPLES ON DRY AND DAF BASES
C       FOR015.DAT: RAW SAMPLES ON DRY AND DAF BASES
C       THE ADDRESS OF THIS PROGRAM IS AT:
C       USERS:[AGSCDB.CHAO]WEIGHT-PROX.FOR
C
        DOUBLE PRECISION LAT(100),LONG(100)
        CHARACTER STRING10*132,STRING20*132,SMC(100)*2
C
C       THE ORIGINAL INPUT OF DATAS
        REAL BOT(100),TOP(100),UDEPTH,LDEPTH,AS_MOIST(100),FXC(100),
     * ASH(100),VOLM(100),RE_MOIST(100)
        INTEGER PROX_MOIST(100),P_SAMPLE(100),ID(100),
     * C_CODE(100),CALVAL(100)
C
C       DATA FOR RAW SAMPLES
        CHARACTER SMC5(30)*2
        REAL TOP5(100),BOT5(100),ASH5(100),FXC5(100),VOLM5(100),
     * AS_MOIST5(100),CALVAL5(100),RE_MOIST5(100)
        INTEGER PRO_MOIST5(100),SAMPLE5(100),K5,C_CODE5(100),ID5(100)
C
C       DATA FOR SINK FLOAT SAMPLES
        CHARACTER SMC1(100)*2
        REAL TOP1(100),BOT1(100),ASH1(100),FXC1(100),VOLM1(100),
     * AS_MOIST1(100),CALVAL1(100),RE_MOIST1(100)
        INTEGER PRO_MOIST1(100),SAMPLE1(100),K1,C_CODE1(100),ID1(100)
C
C       DATA FOR SCREENED SAMPLES
        CHARACTER SMC2(100)*2
        REAL TOP2(100),BOT2(100),ASH2(100),FXC2(100),VOLM2(100),
     * AS_MOIST2(100),CALVAL2(100),RE_MOIST2(100)
        INTEGER PRO_MOIST2(100),SAMPLE2(100),K2,C_CODE2(100),ID2(100)
C
C       DATA FOR WASHED SAMPLES
        CHARACTER SMC3(100)*2
        REAL TOP3(100),BOT3(100),ASH3(100),FXC3(100),VOLM3(100),
     * AS_MOIST3(100),CALVAL3(100),RE_MOIST3(100)
        INTEGER PRO_MOIST3(100),SAMPLE3(100),K3,C_CODE3(100),ID3(100)
C
C       DATA FOR SCREENED AND WASHED SAMPLES
        CHARACTER SMC4(100)*2
        REAL TOP4(100),BOT4(100),ASH4(100),FXC4(100),VOLM4(100),
     * AS_MOIST4(100),CALVAL4(100),RE_MOIST4(100)
        INTEGER PRO_MOIST4(100),SAMPLE4(100),K4,C_CODE4(100),ID4(100)
C
C       WEIGHTED AVERAGE
        REAL AS_D,VM_D,CV_D,FX_D,VM_DAF,CV_DAF,FX_DAF
C
C       GENERAL COUNTERS
        INTEGER M,X,A
        X=1
        M=1
        AS_D=0.0
        VM_D=0.0
        CV_D=0.0
        FX_D=0.0
```

```
      VM_DAF=0.0
      CV_DAF=0.0
      FX_DAF=0.0
      OPEN(UNIT=1,STATUS='OLD')
      OPEN(UNIT=11,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=12,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=13,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=14,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=15,STATUS='NEW',CARRIAGECONTROL='LIST')
C
      READ(1,'(A)',IOSTAT=IOS)STRING10
C
C     CHECKING FOR HOLES
C
      READ(STRING10(10:117),1)ID(X),LAT(X),LONG(X),TOP(X),BOT(X),
     * P_SAMPLE(X),PROX_MOIST(X),AS_MOIST(X),RE_MOIST(X),ASH(X),VOLM(X),
     * FXC(X),CALVAL(X),SMC(X),C_CODE(X)
 5    IF (IOS.EQ.-1) GO TO 8
      READ(1,'(A)',IOSTAT=IOS)STRING10
      READ(STRING10(10:117),1)ID(X+1),LAT(X+1),LONG(X+1),TOP(X+1),
     * BOT(X+1),P_SAMPLE(X+1),PROX_MOIST(X+1),AS_MOIST(X+1),
     * RE_MOIST(X+1),ASH(X+1),VOLM(X+1),FXC(X+1),CALVAL(X+1),SMC(X+1),
     * C_CODE(X+1)
 1    FORMAT(I8,1X,F9.6,1X,F10.6,9X,2(F7.2,1X),I1,5X,I1,1X,F5.2,1X,
     * F5.2,7X,3(F5.2,1X),I5,1X,A2,1X,I1)
 8    IF (LAT(X).NE.LAT(X+1)) THEN
C
C     CHECK FOR THE UPPER-MOST AND LOWER-MOST LEVELS
C
      UDEPTH=1000.0
      LDEPTH=0.0
      DO 10 M=1,X
      IF (TOP(M).LE.UDEPTH) THEN
      UDEPTH=TOP(M)
      END IF
      IF (BOT(M).GE.LDEPTH) THEN
      LDEPTH=BOT(M)
      END IF
 10   CONTINUE
C
C     CHECK FOR SAMPLE TYPE
C
      K1=0
      K2=0
      K3=0
      K4=0
      K5=0
      DO 20 M=1,X
      IF (P_SAMPLE(M).EQ.0 .OR. P_SAMPLE(M).EQ.5) THEN
       K5=K5+1
       TOP5(K5)=TOP(M)
       BOT5(K5)=BOT(M)
       ASH5(K5)=ASH(M)
       VOLM5(K5)=VOLM(M)
       FXC5(K5)=FXC(M)
       CALVAL5(K5)=CALVAL(M)/1000.00
       PRO_MOIST5(K5)=PROX_MOIST(M)
       AS_MOIST5(K5)=AS_MOIST(M)
       RE_MOIST5(K5)=RE_MOIST(M)
       C_CODE5(K5)=C_CODE(M)
       SMC5(K5)=SMC(M)
```

```
 SAMPLE5(K5)=P_SAMPLE(M)
 ID5(K5)=ID(M)
ELSE IF (P_SAMPLE(M).EQ.1) THEN
 K1=K1+1
 TOP1(K1)=TOP(M)
 BOT1(K1)=BOT(M)
 ASH1(K1)=ASH(M)
 VOLM1(K1)=VOLM(M)
 FXC1(K1)=FXC(M)
 CALVAL1(K1)=CALVAL(M)/1000.00
 PRO_MOIST1(K1)=PROX_MOIST(M)
 AS_MOIST1(K1)=AS_MOIST(M)
 RE_MOIST1(K1)=RE_MOIST(M)
 C_CODE1(K1)=C_CODE(M)
 SMC1(K1)=SMC(M)
 SAMPLE1(K1)=P_SAMPLE(M)
 ID1(K1)=ID(M)
ELSE IF(P_SAMPLE(M).EQ.2) THEN
 K2=K2+1
 TOP2(K2)=TOP(M)
 BOT2(K2)=BOT(M)
 ASH2(K2)=ASH(M)
 VOLM2(K2)=VOLM(M)
 FXC2(K2)=FXC(M)
 CALVAL2(K2)=CALVAL(M)/1000.00
 PRO_MOIST2(K2)=PROX_MOIST(M)
 AS_MOIST2(K2)=AS_MOIST(M)
 RE_MOIST2(K2)=RE_MOIST(M)
 C_CODE2(K2)=C_CODE(M)
 SMC2(K2)=SMC(M)
 SAMPLE2(K2)=P_SAMPLE(M)
 ID2(K2)=ID(M)
ELSE IF(P_SAMPLE(M).EQ.3) THEN
 K3=K3+1
 TOP3(K3)=TOP(M)
 BOT3(K3)=BOT(M)
 ASH3(K3)=ASH(M)
 VOLM3(K3)=VOLM(M)
 FXC3(K3)=FXC(M)
 CALVAL3(K3)=CALVAL(M)/1000.00
 PRO_MOIST3(K3)=PROX_MOIST(M)
 AS_MOIST3(K3)=AS_MOIST(M)
 RE_MOIST3(K3)=RE_MOIST(M)
 C_CODE3(K3)=C_CODE(M)
 SMC3(K3)=SMC(M)
 SAMPLE3(K3)=P_SAMPLE(M)
 ID3(K3)=ID(M)
ELSE IF(P_SAMPLE(M).EQ.4) THEN
 K4=K4+1
 TOP4(K4)=TOP(M)
 BOT4(K4)=BOT(M)
 ASH4(K4)=ASH(M)
 VOLM4(K4)=VOLM(M)
 FXC4(K4)=FXC(M)
 CALVAL4(K4)=CALVAL(M)/1000.00
 PRO_MOIST4(K4)=PROX_MOIST(M)
 C_CODE4(K4)=C_CODE(M)
 SMC4(K4)=SMC(M)
 AS_MOIST4(K4)=AS_MOIST(M)
 RE_MOIST4(K4)=RE_MOIST(M)
 SAMPLE4(K4)=P_SAMPLE(M)
```

```
       ID4(K4)=ID(M)
      END IF
20    CONTINUE
      IF (K1.GT.0) THEN
      CALL OVERLAPPING(TOP1,BOT1,ASH1,VOLM1,CALVAL1,FXC1,AS_MOIST1,
     * RE_MOIST1,K1)
      CALL DAF(TOP1,BOT1,PRO_MOIST1,AS_MOIST1,RE_MOIST1,ASH1,VOLM1,
     * CALVAL1,FXC1,K1,AS_D,VM_D,VM_DAF,CV_D,CV_DAF,FX_D,FX_DAF)
      WRITE(11,2)ID1(K1),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,VM_D,CV_D,
     * FX_D,VM_DAF,CV_DAF,FX_DAF,SAMPLE1(K1),C_CODE1(K1),SMC1(K1)
      END IF
      IF (K2.GT.0) THEN
      CALL OVERLAPPING(TOP2,BOT2,ASH2,VOLM2,CALVAL2,FXC2,AS_MOIST2,
     * RE_MOIST2,K2)
      CALL DAF(TOP2,BOT2,PRO_MOIST2,AS_MOIST2,RE_MOIST2,ASH2,VOLM2,
     * CALVAL2,FXC2,K2,AS_D,VM_D,VM_DAF,CV_D,CV_DAF,FX_D,FX_DAF)
      WRITE(12,2)ID2(K2),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,VM_D,CV_D,
     * FX_D,VM_DAF,CV_DAF,FX_DAF,SAMPLE2(K2),C_CODE2(K2),SMC2(K2)
      END IF
      IF (K3.GT.0) THEN
      CALL OVERLAPPING(TOP3,BOT3,ASH3,VOLM3,CALVAL3,FXC3,AS_MOIST3,
     * RE_MOIST3,K3)
      CALL DAF(TOP3,BOT3,PRO_MOIST3,AS_MOIST3,RE_MOIST3,ASH3,VOLM3,
     * CALVAL3,FXC3,K3,AS_D,VM_D,VM_DAF,CV_D,CV_DAF,FX_D,FX_DAF)
      WRITE(13,2)ID3(K3),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,VM_D,CV_D,
     * FX_D,VM_DAF,CV_DAF,FX_DAF,SAMPLE3(K3),C_CODE3(K3),SMC3(K3)
      END IF
      IF (K4.GT.0) THEN
      CALL OVERLAPPING(TOP4,BOT4,ASH4,VOLM4,CALVAL4,FXC4,AS_MOIST4,
     * RE_MOIST4,K4)
      CALL DAF(TOP4,BOT4,PRO_MOIST4,AS_MOIST4,RE_MOIST4,ASH4,VOLM4,
     * CALVAL4,FXC4,K4,AS_D,VM_D,VM_DAF,CV_D,CV_DAF,FX_D,FX_DAF)
      WRITE(14,2)ID4(K4),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,VM_D,CV_D,
     * FX_D,VM_DAF,CV_DAF,FX_DAF,SAMPLE4(K4),C_CODE4(K4),SMC4(K4)
      END IF
      IF (K5.GT.0) THEN
      CALL OVERLAPPING(TOP5,BOT5,ASH5,VOLM5,CALVAL5,FXC5,AS_MOIST5,
     * RE_MOIST5,K5)
      CALL DAF(TOP5,BOT5,PRO_MOIST5,AS_MOIST5,RE_MOIST5,ASH5,VOLM5,
     * CALVAL5,FXC5,K5,AS_D,VM_D,VM_DAF,CV_D,CV_DAF,FX_D,FX_DAF)
      WRITE(15,2)ID5(K5),LAT(1),LONG(1),UDEPTH,LDEPTH,AS_D,VM_D,CV_D,
     * FX_D,VM_DAF,CV_DAF,FX_DAF,SAMPLE5(K5),C_CODE5(K5),SMC5(K5)
      END IF
2     FORMAT(I8,1X,F9.6,1X,F10.6,1X,2(F7.2,1X),7(F5.2,1X),I1,1X,I1,
     *        1X,A2)
      IF (IOS.EQ.-1) GO TO 80
      LAT(1)=LAT(X+1)
      LONG(1)=LONG(X+1)
      TOP(1)=TOP(X+1)
      BOT(1)=BOT(X+1)
      P_SAMPLE(1)=P_SAMPLE(X+1)
      PROX_MOIST(1)=PROX_MOIST(X+1)
      AS_MOIST(1)=AS_MOIST(X+1)
      RE_MOIST(1)=RE_MOIST(X+1)
      ASH(1)=ASH(X+1)
      VOLM(1)=VOLM(X+1)
      FXC(1)=FXC(X+1)
      CALVAL(1)=CALVAL(X+1)
      C_CODE(1)=C_CODE(X+1)
      SMC(1)=SMC(X+1)
      ID(1)=ID(X+1)
```

```
      X=0
      END IF
      X=X+1
      GO TO 5
 80   STOP
      END
C
C
      SUBROUTINE OVERLAPPING(TOP,BOT,X1,X2,X3,X4,X5,X6,X)
      REAL TOP(100),BOT(100),X1(100),X2(100),X3(100),X4(100),
     * T1,DIF,X5(100),T2,B1,B2,X6(100)
      INTEGER F,SE,X,M
      F=1
      SE=2
      IF (X.EQ.0 .OR. X.EQ.1) GO TO 16
 14   DO 15 M=SE,X
      IF (BOT(F).GT.TOP(M)) THEN
       IF(BOT(F).LE.BOT(M).AND.TOP(F).GT.TOP(M)) THEN
       T1=TOP(F)
       T2=TOP(M)
       B1=BOT(F)
       B2=BOT(M)
       CALL OVERLAP3(B1,B2,T1,T2,X1,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X2,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X3,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X4,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X5,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X6,F,M)
       TOP(F)=0.0
       BOT(F)=0.0
       GO TO 13
      ELSE IF(BOT(F).LT.BOT(M).AND.TOP(F).GE.TOP(M)) THEN
       T1=TOP(F)
       T2=TOP(M)
       B1=BOT(F)
       B2=BOT(M)
       CALL OVERLAP3(B1,B2,T1,T2,X1,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X2,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X3,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X4,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X5,F,M)
       CALL OVERLAP3(B1,B2,T1,T2,X6,F,M)
       TOP(F)=0.0
       BOT(F)=0.0
       GO TO 13
      ELSE IF(TOP(F).LE.TOP(M) .AND. BOT(F).GT.BOT(M)) THEN
       T1=TOP(F)
       T2=TOP(M)
       B1=BOT(F)
       B2=BOT(M)
       CALL OVERLAP2(B1,B2,T1,T2,X1,F,M)
       CALL OVERLAP2(B1,B2,T1,T2,X2,F,M)
       CALL OVERLAP2(B1,B2,T1,T2,X3,F,M)
       CALL OVERLAP2(B1,B2,T1,T2,X4,F,M)
       CALL OVERLAP2(B1,B2,T1,T2,X5,F,M)
       CALL OVERLAP2(B1,B2,T1,T2,X6,F,M)
       TOP(M)=0.0
       BOT(M)=0.0
      ELSE IF(TOP(F).LT.TOP(M) .AND. BOT(F).GE.BOT(M)) THEN
       T1=TOP(F)
       T2=TOP(M)
```

```
  B1=BOT(F)
  B2=BOT(M)
  CALL OVERLAP2(B1,B2,T1,T2,X1,F,M)
  CALL OVERLAP2(B1,B2,T1,T2,X2,F,M)
  CALL OVERLAP2(B1,B2,T1,T2,X3,F,M)
  CALL OVERLAP2(B1,B2,T1,T2,X4,F,M)
  CALL OVERLAP2(B1,B2,T1,T2,X5,F,M)
  CALL OVERLAP2(B1,B2,T1,T2,X6,F,M)
  TOP(M)=0.0
  BOT(M)=0.0
 ELSE IF(TOP(F).LT.BOT(M).AND.TOP(F).LT.TOP(M)) THEN
      IF(BOT(F).LT.BOT(M)) THEN
  DIF=BOT(M)-TOP(F)
  IF(DIF.GE.0.01) THEN
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X1,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X2,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X3,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X4,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X5,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X6,F,M,DIF)
  TOP(F)=T1
  TOP(M)=T2
  BOT(F)=B1
  BOT(M)=B2
  END IF
      END IF
 ELSE IF(TOP(F).LT.BOT(M).AND.TOP(F).GT.TOP(M)) THEN
      IF(BOT(F).GT.BOT(M)) THEN
  DIF=BOT(F)-TOP(M)
  IF (DIF.GE.0.01) THEN
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X1,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X2,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X3,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X4,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X5,F,M,DIF)
  CALL OVERLAP1(TOP,BOT,B1,B2,T1,T2,X6,F,M,DIF)
  TOP(F)=T1
  TOP(M)=T2
  BOT(F)=B1
  BOT(M)=B2
  END IF
      END IF
 ELSE IF (TOP(F).GE.BOT(M)) THEN
      GO TO 15
 ELSE IF (TOP(F).EQ.TOP(M) .AND. BOT(F).EQ.BOT(M)) THEN
  X1(F)=(X1(F)+X1(M))/2
  X2(F)=(X2(F)+X2(M))/2
  X3(F)=(X3(F)+X3(M))/2
  X4(F)=(X4(F)+X4(M))/2
  X5(F)=(X5(F)+X5(M))/2
  X6(F)=(X6(F)+X6(M))/2
  X1(M)=0.0
  X2(M)=0.0
  X3(M)=0.0
  X4(M)=0.0
  X5(M)=0.0
  X6(M)=0.0
  TOP(M)=0.0
  BOT(M)=0.0
END IF
END IF
```

```
 15   CONTINUE
 13   IF (SE.NE.X) THEN
       F=F+1
       SE=SE+1
       GO TO 14
      END IF
 16   RETURN
      END
C
      SUBROUTINE OVERLAP1(TOP,BOT,B1,B2,T1,T2,Y,F,M,DIF)
      REAL B1,B2,T1,T2,Y(100),DIF1,DIF2,DIF3,OLAP,DIF,AVE,TOP(100),
     *BOT(100),TOP1,BOT1
      INTEGER F,M
      IF(Y(F).EQ.0.0 .OR. Y(M).EQ.0.0) GO TO 100
      T1=TOP(F)
      T2=TOP(M)
      B1=BOT(F)
      B2=BOT(M)
      IF(T1.LT.T2) THEN
       DIF1=T2-T1
       DIF2=B1-T2
       DIF3=B2-B1
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
       TOP1=(DIF1/DIF)*Y(F)
       BOT1=(DIF3/DIF)*Y(M)
       AVE=TOP1+OLAP+BOT1
       Y(F)=AVE
       Y(M)=0.0
       B2=0.0
       T2=0.0
      ELSE IF(T1.GT.T2) THEN
       DIF1=T1-T2
       DIF2=B2-T1
       DIF3=B1-B2
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
       TOP1=(DIF1/DIF)*Y(M)
       BOT1=(DIF3/DIF)*Y(F)
       AVE=TOP1+OLAP+BOT1
       Y(M)=AVE
       Y(F)=0.0
       B1=0.0
       T1=0.0
      END IF
 100  RETURN
      END
C
      SUBROUTINE OVERLAP2(B1,B2,T1,T2,Y,F,M)
      REAL B1,B2,T1,T2,Y(100),DIF1,DIF2,DIF3,DIF,OLAP,AVE,
     * TOP,BOT
      INTEGER F,M
      IF(Y(F).EQ.0.0 .OR. Y(M).EQ.0.0) GO TO 100
      IF(T1.LT.T2 .AND. B1.GT.B2) THEN
       DIF=B1-T1
       DIF1=T2-T1
       DIF2=B2-T2
       DIF3=B1-B2
       TOP=(DIF1/DIF)*Y(F)
       OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
       BOT=(DIF3/DIF)*Y(F)
       AVE=TOP+OLAP+BOT
      ELSE IF(T1.EQ.T2 .AND. B1.GT.B2) THEN
```

```
        DIF=B1-T1
        DIF2=B2-T2
        DIF3=B1-B2
        OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
        BOT=(DIF3/DIF)*Y(F)
        AVE=OLAP+BOT
       ELSE IF(T1.LT.T2 .AND. B1.EQ.B2) THEN
        DIF=B1-T1
        DIF1=T2-T1
        DIF2=B2-T2
        TOP=(DIF1/DIF)*Y(F)
        OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
        AVE=TOP+OLAP
       END IF
       Y(F)=AVE
       Y(M)=0.0
 100   RETURN
       END
C
       SUBROUTINE OVERLAP3(B1,B2,T1,T2,Y,F,M)
       REAL B1,B2,T1,T2,Y(100),DIF1,DIF2,DIF3,DIF,OLAP,AVE,
      * TOP,BOT
       INTEGER F,M
       IF(Y(F).EQ.0.0 .OR. Y(M).EQ.0.0) GO TO 100
       IF(T1.GT.T2 .AND. B1.LT.B2) THEN
        DIF=B2-T2
        DIF1=T1-T2
        DIF2=B1-T1
        DIF3=B2-B1
        TOP=(DIF1/DIF)*Y(M)
        OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
        BOT=(DIF3/DIF)*Y(M)
        Y(M)=TOP+OLAP+BOT
        Y(F)=0.0
       ELSE IF(T1.EQ.T2 .AND. B1.LT.B2) THEN
        DIF=B2-T2
        DIF3=B2-B1
        DIF2=B1-T1
        OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
        BOT=(DIF3/DIF)*Y(M)
        Y(M)=OLAP+BOT
        Y(F)=0.0
       ELSE IF(T1.GT.T2 .AND. B1.EQ.B2) THEN
        DIF=B2-T2
        DIF1=T1-T2
        DIF2=B1-T1
        TOP=(DIF1/DIF)*Y(M)
        OLAP=((DIF2/DIF)*Y(F)+(DIF2/DIF)*Y(M))/2
        Y(M)=TOP+OLAP
        Y(F)=0.0
       END IF
 100   RETURN
       END
C
C
        SUBROUTINE DAF(T,B,PM,AM,RM,AS,VM,CV,FX,K,AS_D,VM_D,VM_DAF,
      * CV_D,CV_DAF,FX_D,FX_DAF)
        CHARACTER SMC(100)*2
        REAL T(100),B(100),RM(100),AS(100),VM(100),AM(100),
      * CV(100),FX(100),AS1(100),VM1(100),CV1(100),FX1(100),
      * VM2(100),CV2(100),
```

```
     * FX2(100),AS_D,VM_D,CV_D,FX_D,VM_DAF,CV_DAF,FX_DAF,DRY,FAC
       INTEGER PM(100),SAM(100),K,CC(100),M
       DO 45 M=1,100
       CV1(M)=0.0
       CV2(M)=0.0
       VM1(M)=0.0
       VM2(M)=0.0
       FX1(M)=0.0
       FX2(M)=0.0
       AS1(M)=0.0
 45    CONTINUE
       DO 90 M=1,K
C
C      CONVERTING DATA (WITH RESID. MOIST.) INTO DRY AND DRY-ASH
C      FREE BASES
C
       IF (AS(M) .GT. 50.00) GO TO 90
       IF (PM(M).EQ.1) THEN
       DRY=100.0/(100.0-RM(M))
       AS1(M)=AS(M)*DRY
       CV1(M)=(CV(M)*DRY)
       VM1(M)=VM(M)*DRY
       FX1(M)=FX(M)*DRY
        IF (AS(M) .NE. 0.00 ) THEN
        FAC=100.0/(100.0-RM(M)-AS(M))
        VM2(M)=VM(M)*FAC
        FX2(M)=FX(M)*FAC
        CV2(M)=(CV(M)*FAC)
        ELSE IF (AS(M) .EQ. 0.00) THEN
        VM2(M)=VM1(M)
        FX2(M)=FX1(M)
        CV2(M)=CV1(M)
        END IF
C
C      CONVERTING DATA (WITH AS REC. MOIST.) INTO DRY AND DRY-ASH
C      FREE BASES
C
      ELSE IF (PM(M).EQ.0) THEN
       DRY=100.0/(100.0-AM(M))
       AS1(M)=AS(M)*DRY
       CV1(M)=(CV(M)*DRY)
       VM1(M)=VM(M)*DRY
       FX1(M)=FX(M)*DRY
        IF (AS(M) .NE. 0.00 ) THEN
        FAC=100.0/(100.0-AM(M)-AS(M))
        VM2(M)=VM(M)*FAC
        FX2(M)=FX(M)*FAC
        CV2(M)=(CV(M)*FAC)
        ELSE IF (AS(M) .EQ. 0.00 ) THEN
        VM2(M)=VM1(M)
        FX2(M)=FX1(M)
        CV2(M)=CV1(M)
        END IF
C
C     CONVERTING DATA (WITHOUT RESID. MOIST.) INTO DRY AND DRY-ASH
C     FREE BASES
C
      ELSE IF(PM(M).EQ.3) THEN
        AS1(M)=AS(M)
        CV1(M)=CV(M)
        VM1(M)=VM(M)
```

```
      FX1(M)=FX(M)
       IF (AS(M) .NE. 0.00) THEN
       FAC=100.0/(100.0-AS(M))
       VM2(M)=VM(M)*FAC
       FX2(M)=FX(M)*FAC
       CV2(M)=(CV(M)*FAC)
       ELSE IF (AS(M) .EQ. 0.00) THEN
       VM2(M)=VM1(M)
       CV2(M)=CV1(M)
       FX2(M)=FX1(M)
       END IF
      END IF
 90   CONTINUE
      CALL WEIGHT(T,B,K,AS1,AS_D)
      CALL WEIGHT(T,B,K,VM1,VM_D)
      CALL WEIGHT(T,B,K,CV1,CV_D)
      CALL WEIGHT(T,B,K,FX1,FX_D)
      CALL WEIGHT(T,B,K,VM2,VM_DAF)
      CALL WEIGHT(T,B,K,FX2,FX_DAF)
      CALL WEIGHT(T,B,K,CV2,CV_DAF)
      RETURN
      END
C
      SUBROUTINE WEIGHT(T,BO,A,B,SUMW)
      REAL T(100),BO(100),SUMW,SUMDIF,DIFF,B(30)
      INTEGER J,A
      SUMW=0.0
      SUMDIF=0.0
      DO 55 J=1,A
      IF (B(J) .EQ. 0.0) GO TO 55
      DIFF=BO(J)-T(J)
      IF (DIFF .EQ. 0.0) DIFF=1.0
      IF (T(J).EQ.-1 .AND. BO(J).EQ.-1) DIFF=1.0
      SUMDIF=SUMDIF+DIFF
      SUMW=SUMW+DIFF*B(J)
 55   CONTINUE
      IF (SUMDIF .EQ. 0.0 .OR. SUMW .EQ. 0.0) THEN
      SUMW=-1.0
      ELSE
      SUMW=SUMW/SUMDIF
      END IF
      RETURN
      END
```

APPENDIX THREE

(Program used to calculate the median and absolute deviation from the median for ash and sulphur, in the regional study).

```
C       THIS PROGRAM WILL DECLUSTER ALL THE HOLES FOR EACH TOWNSHIP
C       BY CALCULATING THE MEDIAN AND ABSOLUTE DEVIATION OF THAT
C       TOWNSHIP.
C       INPUT FILE MUST BE GENERATED BY GEO_DLS_PT.EXE LOCATED AT
C       [COALPLNS.CHAO.PLOT]
C       FOR002 IS THE MAIN OUTPUT FOR THE PURPOSE OF THIS PROGRAM
C       FOR003 IS A SPECIAL OUTPUT FOR OTHER PURPOSES
C       ADDRESS: USERS2;[COALPLNS.CHAO]COMPOSITE.FOR
C
        CHARACTER*132 LINE
        REAL DASH(100),DVM(100),DFXC(100),VM1(100),FXC1(100),
     * DAFVM(100),DAFFXC(100),VM2(100),FXC2(100),ASH1(100),
     * DAF_VM,DAF_FXC,DRY_ASH,DRY_VM,DRY_FXC,ABSDEV1,ABSDEV2,
     * ABSDEV3,ABSDEV4,ABSDEV5
        INTEGER MER(2),TWP(2),RANGE(2),MER1(100),TWP1(100),C,
     * RANGE1(100),X,Y,Q,SEC(2),LSD(2),SEC1(100),LSD1(100),COUNT
        OPEN(UNIT=1,STATUS='OLD')
        READ(1,'(A132)',IOSTAT=IOS)LINE
        IF(IOS.EQ.-1) GO TO 100
        Y=0
        X=1
        READ(LINE(18:103),1)MER(X),TWP(X),RANGE(X),SEC(X),LSD(X),
     * DASH(X),DVM(X),DFXC(X),DAFVM(X),DAFFXC(X)
  1     FORMAT(I1,1X,I3,1X,I2,1X,I2,1X,I2,19X,F5.2,3X,F5.2,11X,F5.2,3X,
     * F5.2,11X,F5.2)
  2     READ(1,'(A132)',IOSTAT=IOS)LINE
        READ(LINE(18:103),1)MER(X+1),TWP(X+1),RANGE(X+1),SEC(X+1),
     * LSD(X+1),DASH(X+1),DVM(X+1),DFXC(X+1),DAFVM(X+1),DAFFXC(X+1)
        IF(MER(X).EQ.MER(X+1)) THEN
         IF(TWP(X).EQ.TWP(X+1)) THEN
          IF(RANGE(X).EQ.RANGE(X+1)) THEN
          Y=Y+1
          MER1(Y)=MER(X)
          TWP1(Y)=TWP(X)
          RANGE1(Y)=RANGE(X)
          SEC1(Y)=SEC(X)
          LSD1(Y)=LSD(X)
          ASH1(Y)=DASH(X)
          VM1(Y)=DVM(X)
          FXC1(Y)=DFXC(X)
          VM2(Y)=DAFVM(X)
          FXC2(Y)=DAFFXC(X)
          IF (IOS.EQ.-1) GO TO 100
          MER(1)=MER(X+1)
          TWP(1)=TWP(X+1)
          RANGE(1)=RANGE(X+1)
          SEC(1)=SEC(X+1)
          LSD(1)=LSD(X+1)
          DASH(1)=DASH(X+1)
          DVM(1)=DVM(X+1)
          DFXC(1)=DFXC(X+1)
          DAFVM(1)=DAFVM(X+1)
          DAFFXC(1)=DAFFXC(X+1)
          GO TO 2

          ELSE IF(Y.GE.1) THEN
          Y=Y+1
          MER1(Y)=MER(X)
          TWP1(Y)=TWP(X)
          RANGE1(Y)=RANGE(X)
          SEC1(Y)=SEC(X)
```

```
      LSD1(Y)=LSD(X)
      ASH1(Y)=DASH(X)
      VM1(Y)=DVM(X)
      FXC1(Y)=DFXC(X)
      VM2(Y)=DAFVM(X)
      FXC2(Y)=DAFFXC(X)
      OPEN(UNIT=2,STATUS='NEW',CARRIAGECONTROL='LIST')
      OPEN(UNIT=3,STATUS='NEW',CARRIAGECONTROL='LIST')
      CALL MEDIAN(Y,ASH1,DRY_ASH,ABSDEV1,COUNT)
      CALL MEDIAN(Y,VM1,DRY_VM,ABSDEV2,COUNT)
      CALL MEDIAN(Y,FXC1,DRY_FXC,ABSDEV3,COUNT)
      CALL MEDIAN(Y,VM2,DAF_VM,ABSDEV4,COUNT)
      CALL MEDIAN(Y,FXC2,DAF_FXC,ABSDEV5,COUNT)
      WRITE(2,3)MER(X),TWP(X),RANGE(X),'16','6',DRY_ASH,ABSDEV1,
     *  DRY_VM,ABSDEV2,DRY_FXC,ABSDEV3,DAF_VM,ABSDEV4,DAF_FXC,ABSDEV5
3     FORMAT(1X,I1,I3,I2,A2,A1,10(1X,F5.2))
      DO 70 C=1,Y
      WRITE(3,5)MER1(C),TWP1(C),RANGE1(C),SEC1(C),LSD1(C),ASH1(C),
     *  ASH1(C)-DRY_ASH,VM1(C),VM1(C)-DRY_VM,FXC1(C),FXC1(C)-DRY_FXC,
     *  VM2(C),VM2(C)-DAF_VM,FXC2(C),FXC2(C)-DAF_FXC
70    CONTINUE
5     FORMAT(I1,I3,3(I2),10(1X,F6.2))
72    IF(IOS.EQ.-1) GO TO 100
      MER(1)=MER(X+1)
      TWP(1)=TWP(X+1)
      RANGE(1)=RANGE(X+1)
      SEC(1)=SEC(X+1)
      LSD(1)=LSD(X+1)
      DASH(1)=DASH(X+1)
      DVM(1)=DVM(X+1)
      DFXC(1)=DFXC(X+1)
      DAFVM(1)=DAFVM(X+1)
      DAFFXC(1)=DAFFXC(X+1)
      Y=0
      GO TO 2

      ELSE
      IF(DASH(X).EQ.-1 .AND. DVM(X).EQ.-1 .AND. DFXC(X).EQ.-1 ) THEN
       GO TO 74
      END IF
      WRITE(2,4)MER(X),TWP(X),RANGE(X),'16','6',DASH(X),DVM(X),
     *  DFXC(X),DAFVM(X),DAFFXC(X)
4     FORMAT(1X,I1,I3,I2,A2,A1,1X,5(F5.2,7X))
74    IF(IOS.EQ.-1) GO TO 100
      MER(1)=MER(X+1)
      TWP(1)=TWP(X+1)
      RANGE(1)=RANGE(X+1)
      SEC(1)=SEC(X+1)
      LSD(1)=LSD(X+1)
      DASH(1)=DASH(X+1)
      DVM(1)=DVM(X+1)
      DFXC(1)=DFXC(X+1)
      DAFVM(1)=DAFVM(X+1)
      DAFFXC(1)=DAFFXC(X+1)
      Y=0
      GO TO 2
      END IF
C     END IF FOR RANGE

     ELSE IF(Y.EQ.0) THEN
```

```
      IF(DASH(X).EQ.-1 .AND. DVM(X).EQ.-1 .AND. DFXC(X).EQ.-1 ) THEN
       GO TO 77
      END IF
      WRITE(2,4)MER(X),TWP(X),RANGE(X),'16','6',DASH(X),DVM(X),
     * DFXC(X),DAFVM(X),DAFFXC(X)
 77   IF (IOS.EQ.-1) GO TO 100
      MER(1)=MER(X+1)
      TWP(1)=TWP(X+1)
      RANGE(1)=RANGE(X+1)
      SEC(1)=SEC(X+1)
      LSD(1)=LSD(X+1)
      DASH(1)=DASH(X+1)
      DVM(1)=DVM(X+1)
      DFXC(1)=DFXC(X+1)
      DAFVM(1)=DAFVM(X+1)
      DAFFXC(1)=DAFFXC(X+1)
      Y=0
      GO TO 2

      ELSE IF (Y.GT.0) THEN
      Y=Y+1
      MER1(Y)=MER(X)
      TWP1(Y)=TWP(X)
      RANGE1(Y)=RANGE(X)
      SEC1(Y)=SEC(X)
      LSD1(Y)=LSD(X)
      ASH1(Y)=DASH(X)
      VM1(Y)=DVM(X)
      FXC1(Y)=DFXC(X)
      VM2(Y)=DAFVM(X)
      FXC2(Y)=DAFFXC(X)
      CALL MEDIAN(Y,ASH1,DRY_ASH,ABSDEV1,COUNT)
      CALL MEDIAN(Y,VM1,DRY_VM,ABSDEV2,COUNT)
      CALL MEDIAN(Y,FXC1,DRY_FXC,ABSDEV3,COUNT)
      CALL MEDIAN(Y,VM2,DAF_VM,ABSDEV4,COUNT)
      CALL MEDIAN(Y,FXC2,DAF_FXC,ABSDEV5,COUNT)
      WRITE(2,3)MER(X),TWP(X),RANGE(X),'16','6',DRY_ASH,ABSDEV1,
     * DRY_VM,ABSDEV2,DRY_FXC,ABSDEV3,DAF_VM,ABSDEV4,DAF_FXC,ABSDEV5
      DO 75 C=1,Y
      WRITE(3,5)MER1(C),TWP1(C),RANGE1(C),SEC1(C),LSD1(C),ASH1(C),
     * ASH1(C)-DRY_ASH,VM1(C),VM1(C)-DRY_VM,FXC1(C),FXC1(C)-DRY_FXC,
     * VM2(C),VM2(C)-DAF_VM,FXC2(C),FXC2(C)-DAF_FXC
 75   CONTINUE
 78   IF (IOS.EQ.-1) GO TO 100
      MER(1)=MER(X+1)
      TWP(1)=TWP(X+1)
      RANGE(1)=RANGE(X+1)
      SEC(1)=SEC(X+1)
      LSD(1)=LSD(X+1)
      DASH(1)=DASH(X+1)
      DVM(1)=DVM(X+1)
      DFXC(1)=DFXC(X+1)
      DAFVM(1)=DAFVM(X+1)
      DAFFXC(1)=DAFFXC(X+1)
      Y=0
      GO TO 2
      END IF
C     END IF FOR TWP

      ELSE IF(Y.EQ.0) THEN
```

```
      IF(DASH(X).EQ.-1 .AND. DVM(X).EQ.-1 .AND. DFXC(X).EQ.-1 ) THEN
       GO TO 79
      END IF
      WRITE(2,4)MER(X),TWP(X),RANGE(X),'16','6',DASH(X),DVM(X),
     * DFXC(X),DAFVM(X),DAFFXC(X)
 79   IF (IOS.EQ.-1) GO TO 100
      MER(1)=MER(X+1)
      TWP(1)=TWP(X+1)
      RANGE(1)=RANGE(X+1)
      SEC(1)=SEC(X+1)
      LSD(1)=LSD(X+1)
      DASH(1)=DASH(X+1)
      DVM(1)=DVM(X+1)
      DFXC(1)=DFXC(X+1)
      DAFVM(1)=DAFVM(X+1)
      DAFFXC(1)=DAFFXC(X+1)
      Y=0
      GO TO 2

      ELSE IF (Y.GT.0) THEN
      Y=Y+1
      MER1(Y)=MER(X)
      TWP1(Y)=TWP(X)
      RANGE1(Y)=RANGE(X)
      SEC1(Y)=SEC(X)
      LSD1(Y)=LSD(X)
      ASH1(Y)=DASH(X)
      VM1(Y)=DVM(X)
      FXC1(Y)=DFXC(X)
      VM2(Y)=DAFVM(X)
      FXC2(Y)=DAFFXC(X)
      CALL MEDIAN(Y,ASH1,DRY_ASH,ABSDEV1,COUNT)
      CALL MEDIAN(Y,VM1,DRY_VM,ABSDEV2,COUNT)
      CALL MEDIAN(Y,FXC1,DRY_FXC,ABSDEV3,COUNT)
      CALL MEDIAN(Y,VM2,DAF_VM,ABSDEV4,COUNT)
      CALL MEDIAN(Y,FXC2,DAF_FXC,ABSDEV5,COUNT)
      WRITE(2,3)MER(X),TWP(X),RANGE(X),'16','6',DRY_ASH,ABSDEV1,
     * DRY_VM,ABSDEV2,DRY_FXC,ABSDEV3,DAF_VM,ABSDEV4,DAF_FXC,ABSDEV5
      IF (IOS.EQ.-1) GO TO 100
      MER(1)=MER(X+1)
      TWP(1)=TWP(X+1)
      RANGE(1)=RANGE(X+1)
      SEC(1)=SEC(X+1)
      LSD(1)=LSD(X+1)
      DASH(1)=DASH(X+1)
      DVM(1)=DVM(X+1)
      DFXC(1)=DFXC(X+1)
      DAFVM(1)=DAFVM(X+1)
      DAFFXC(1)=DAFFXC(X+1)
      GO TO 2
      END IF
C     END IF FOR MER

 100  IF (Y.LE.1) THEN
      IF(DASH(X).EQ.-1 .AND. DVM(X).EQ.-1 .AND. DFXC(X).EQ.-1 ) THEN
       GO TO 81
      END IF
      WRITE(2,4)MER(X),TWP(X),RANGE(X),'16','6',DASH(X),DVM(X),
     * DFXC(X),DAFVM(X),DAFFXC(X)
      ELSE
      CALL MEDIAN(Y,ASH1,DRY_ASH,ABSDEV1,COUNT)
```

```
      CALL MEDIAN(Y,VM1,DRY_VM,ABSDEV2,COUNT)
      CALL MEDIAN(Y,FXC1,DRY_FXC,ABSDEV3,COUNT)
      CALL MEDIAN(Y,VM2,DAF_VM,ABSDEV4,COUNT)
      CALL MEDIAN(Y,FXC2,DAF_FXC,ABSDEV5,COUNT)
      WRITE(2,3)MER(X),TWP(X),RANGE(X),'16','6',DRY_ASH,ABSDEV1,
     * DRY_VM,ABSDEV2,DRY_FXC,ABSDEV3,DAF_VM,ABSDEV4,DAF_FXC,ABSDEV5
      DO 76 C=1,Y
      WRITE(3,5)MER1(C),TWP1(C),RANGE1(C),SEC1(C),LSD1(C),ASH1(C),
     * ASH1(C)-DRY_ASH,VM1(C),VM1(C)-DRY_VM,FXC1(C),FXC1(C)-DRY_FXC,
     * VM2(C),VM2(C)-DAF_VM,FXC2(C),FXC2(C)-DAF_FXC
   76 CONTINUE
      END IF
   81 STOP
      END

      SUBROUTINE MEDIAN(X,X1,Y1,Z1,COUNT)
      REAL X1(100),W(100),Y1,Z1,LTEMP,TEMP1
      INTEGER X,B,C,V,MED,MED1,MED2,CHECK,COUNT
C
C     RANKING THE VARIABLES FROM LOW TO HIGH IN ORDER TO CALCULATE
C     THE MEDIAN
C
      Y1=-1.00
      Z1=-1.00
      DO 40 B=1,(X-1)
       DO 50 C=(B+1),X
       IF (X1(B).GT.X1(C)) THEN
       LTEMP=X1(B)
       X1(B)=X1(C)
       X1(C)=LTEMP
       END IF
   50  CONTINUE
   40 CONTINUE
C
C     CHECKING FOR -1S
C
      COUNT=0
      DO 45 V=1,X
      IF (X1(V).EQ.-1.0) THEN
      COUNT=COUNT+1
      END IF
   45 CONTINUE
C
C     SEARCHING FOR MEDIAN
C
       IF (X.EQ.COUNT) GO TO 110
       IF(MOD((X-COUNT),2).EQ.0) THEN
       MED1=((X-COUNT)+2)/2
       MED1=MED1+COUNT
       MED2=(X-COUNT)/2
       MED2=MED2+COUNT
       Y1=(X1(MED1)+X1(MED2))/2
      ELSE
       MED=((X-COUNT)+1)/2
       MED=MED+COUNT
       Y1=X1(MED)
      END IF
C
C     CALCULATING THE ABSOLUTE DEVIATION
C
      TEMP1=0.0
```

```
      CHECK=0
      DO 60 V=1,X
      IF(X1(V).EQ.-1) GO TO 60
      CHECK=CHECK+1
      W(V)=ABS(X1(V)-Y1)
      TEMP1=TEMP1+W(V)
60    CONTINUE
      IF (CHECK.EQ.0) GO TO 110
      Z1=TEMP1/CHECK
110   RETURN
      END
```

APPENDIX FOUR

(Probability distribution functions used to derive Figures 29 to 32).

The probability distributions used in fitting S(DAF) and ASH(DRY) data from inside and outside highvale.

(1) The gamma probability density function:

$$f_1(x) = \frac{1}{\Gamma(\alpha)\beta^\alpha} x^{\alpha-1} exp\left[-\frac{x}{\beta}\right]$$

where

$$\alpha > 0,$$
$$\beta > 0,$$
$$x \geq 0.$$

(2) The lognormal probability density function:

$$f_2(x) = \frac{1}{\alpha\sqrt{2\pi}}\ exp\left[-\left(ln\frac{x}{\beta}\right)^2 / \left(2\alpha^2\right)\right]$$

where

$$\alpha > 0,$$
$$\beta > 0,$$
$$x \geq 0.$$

(3) The Weibull probability density function:

$$f_3(x) = \left(\frac{\alpha}{\beta}\right)\left(\frac{x}{\beta}\right)^{\alpha-1} exp\left[-\left(\frac{x}{\beta}\right)^\alpha\right]$$

where

$$\alpha > 0,$$
$$\beta > 0,$$
$$x \geq 0.$$

The cumulative distribution functions of the lognormal and Weibull distribution.

$$\text{Weibull}: F(x) = 1 - exp\left[-(\frac{x}{\beta})^{\alpha}\right], \quad x \geq 0,\ \alpha > 0,\ \beta > 0$$

$$= 0, \ \text{elsewhere}$$

$$\text{Lognormal}: F(x) = \frac{1}{\alpha\sqrt{2\pi}} \int_0^x exp\left[-\left(ln\frac{t}{\beta}\right)^2 / \left(2\alpha^2\right)\right] dt, \quad x \geq 0,\ \alpha > 0,\ \beta > 0$$

$$= 0, \ \text{elsewhere}$$

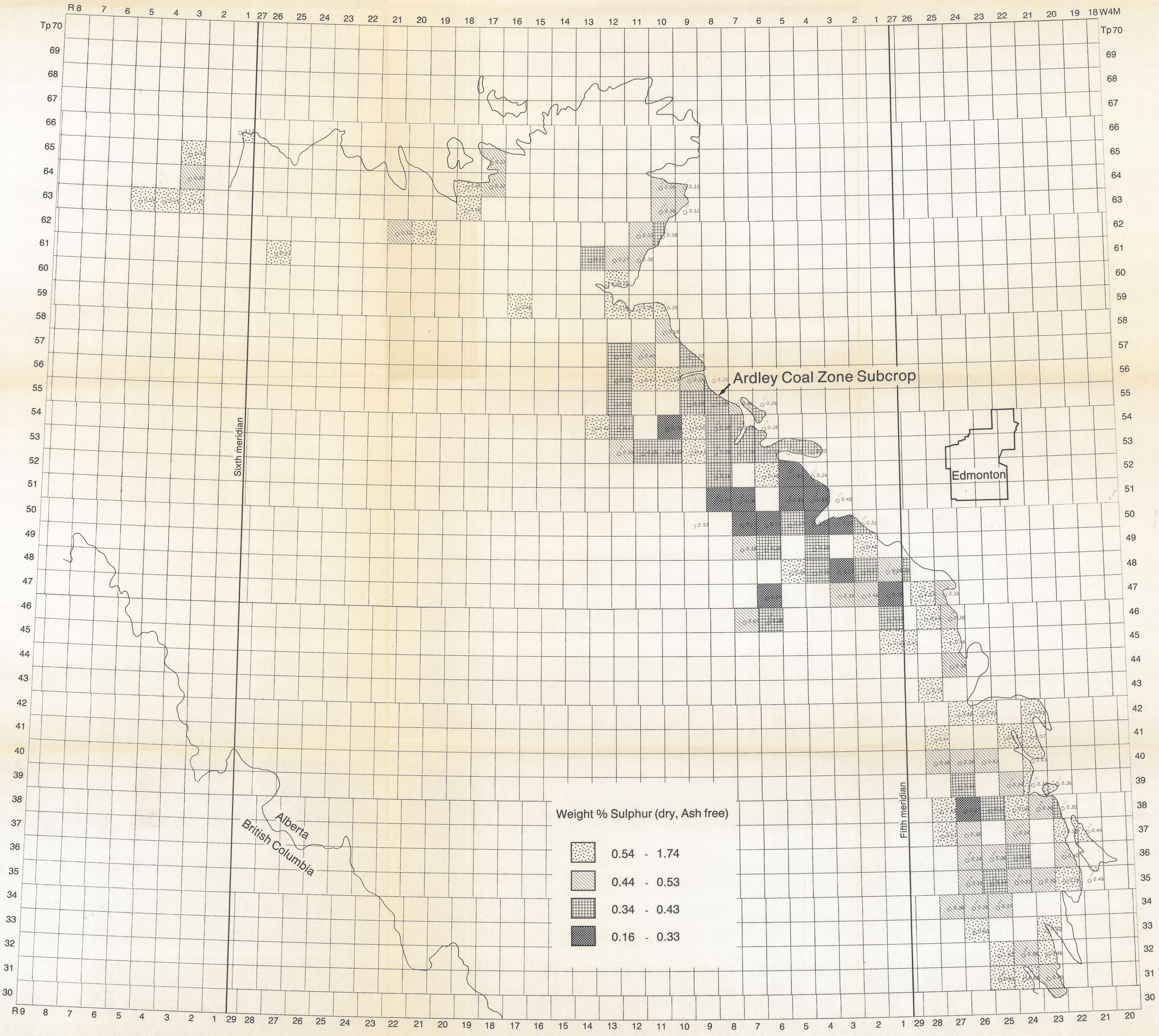

Figure 9. Median sulphur values (dry, ash-free basis) for each township in the regional evaluation of Ardley coal quality. The median sulphur value is derived from the weighted average based on sample thickness in each drill hole. The smaller second number represents the absolute deviation from the median and illustrates the amount of variability in sulphur content wherever multiple points are available in a township.

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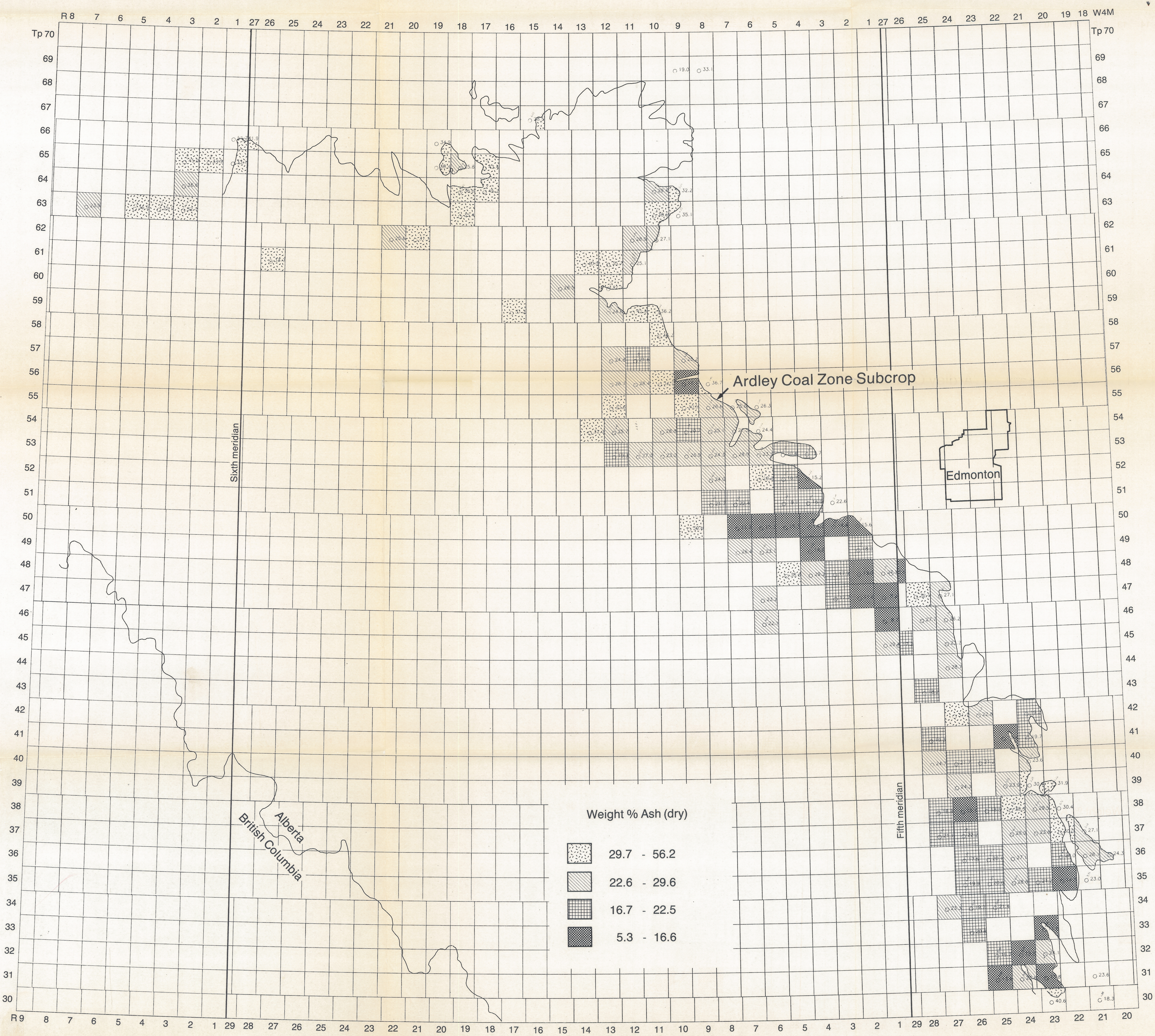

Figure 8. Median ash values (dry basis) for each township in the regional evaluation of Ardley coal quality. The median ash value is derived from the weighted average based on sample thickness in each drill hole. The smaller second number represents the absolute deviation from the median and illustrates the amount of variability in ash content wherever multiple points are available in a township.

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