Coal Quality Variation in Alberta Tertiary Coals: a Detailed Analysis of a Mining Pit at Highvale Mine

D. Nikols and S. Treasure

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Introduction

For the last several years, the Coal Geology Section of the Alberta Geological Survey has been investigating coal quality in regions in the province. These regions include the Cretaceous and Tertiary sediments of the plains region and the foothills/mountain region of Alberta. The coal quality project continues this investigation on a smaller and more detailed scale. The objective of this project is to make a preliminary inquiry into how geologic factors influence coal quality parameters pertinent to conventional and emerging utilization processes. This involves a detailed study on a seam by seam and intraseam basis of data from fifteen drill holes in Pit 3, with drill hole spacings averaging 100 metres, in the northern part of Highvale Mine, located 80 kilometres east of Edmonton, Alberta (Figure 1). The Highvale data, which is included in the Ardley Coal Zone, is being used as a starting point in the development of a coal quality predictive model to aid in the interpretation and evaluation of coal. Results of the statistical analysis will be integrated into the work completed in 1989 to assist in the determination of the limits, representativeness, and meaning of these statistical data. A thorough understanding of the data is necessary to determine what factors influence the variability and predictability of the coal quality parameters.

TransAlta Utilities Corporation provided proprietary geological information from Highvale Mine. This data set was selected for the coal quality study for a number of reasons including:

1) the Ardley Coal Zone is one of the best explored coal measures in Alberta and Highvale, being the largest producing coal mine in Canada, has extensive data available on coal quality,

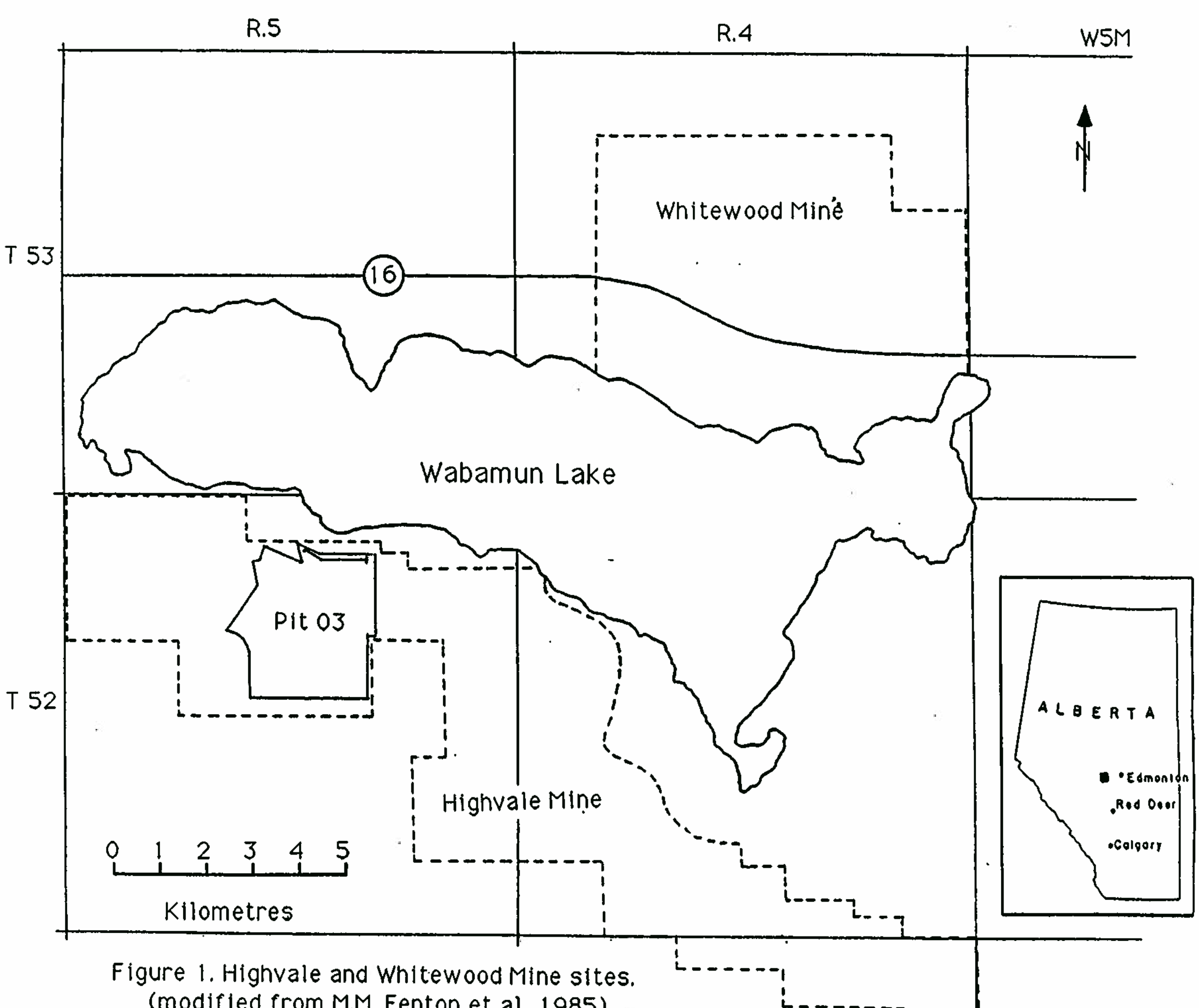


Figure 1. Highvale and Whitewood Mine sites.
(modified from M.M. Fenton et al, 1985)
Drill hole line

2) the Ardley Coal Zone has been analyzed on both a regional and deposit scale so comparison of the new detailed analysis to these broader scales will be relatively easy,

3) the geology and depositional controls are fairly well understood,

4) there is sufficient data in the TransAlta data set to allow for an in-depth analysis,

5) there is adequate consistency in the depositional setting, sample handling, processing methods, and laboratory and analytical procedures that variability in the coal quality data should primarily reflect inherent variability due to heterogeneities within the coal.

Following TransAlta Utilities Corporation's nomenclature Highvale mine has been further subdivided into North Highvale area and South Highvale area. This subdivision was made because the two areas show different coal quality relationships due to distinct depositional environments.

Plans for 1990/91 will focus on developing a predictive coal quality model for the Ardley coal zone. Data from the Judy Creek North deposit (courtesy of Esso Resources) will be analyzed using the procedures established during the past year and results compared to the Highvale study. The Judy Creek coal also belong to the Ardley zone but are located in a different part of the basin and were laid down in a different depositional environment than the Highvale coal. These data will be used to test the predictive model to see if coal from different depositional environments can be predicted by the same model and if not, what modifications must be made to accommodate for the differences. This work will illustrate the practical application of such a model if the environment of deposition is known or can be predicted.

The heterogeneity of coal affects the coal quality data on all scales of investigation, from regional to in-seam so understanding the factors influencing the variability of coal quality is a considerable undertaking. Comprehension of the geology of a coal deposit or zone aids in explaining the observed seam to seam variation and helps in the generation of geological models with respect to the formation of coal. Coal quality reported on regional scales are used to make province wide estimations of the range of the coal quality parameters. On a deposit scale, central tendencies and variation in coal quality can be addressed because of the higher confidence level that can be achieved at this scale. The significant difference between coal quality on a local scale to the statistically smoothed regional scale, namely the decrease in variability as the scale of observation decreases, make definitions of representativeness mandatory.

A number of studies have been conducted on the Ardley Coal Zone. Strobl et al, 1989 studied the Ardley coal quality in the plains region of Alberta. This particular study investigated coal quality on a regional level and consisted of comparisons between deposits, within a single deposit, between a single deposit and regional trends, and between two selected seams in the Highvale Mine. Wong et al., 1988 also studied the Ardley coal zone, but on a smaller scale, concentrating on the coal quality at the Highvale Mine site. This project studied the distributional characteristics, correlations and multivariate comparisons on data including proximate and ultimate analyses data on a seam by seam basis. TransAlta Utilities

Corporation conducted a detailed study of the coal quality in Pit 3 in the north part of Highvale mine (Figure 2) (Nichols et al, 1984). The object of the study was to gain an understanding of the mineralogy, paragenesis, and distribution of sulfur bearing minerals in the coal. The study analyzed fifteen drill cores with an along strike drill hole spacing of approximately 100 metres. For each drill core sample spacing was between 4 to 44 centimetres with an average of about 20 centimetres. From those assays, ash, calorific value, and sulfur have been examined in detail for the current coal quality study. Other studies including Richardson et al, 1988, Gibson, 1977, and Lyons et al, 1987 provide additional detailed information on the geology and depositional environment of the Ardley Coal Zone and the Wabamun Lake Coal Field, including the Highvale mine.

Geology

The Ardley Coal Zone is lower Tertiary in age and was deposited in the Alberta Basin. Expansive peat-forming swamps evolved in the Alberta Basin during a period of tectonic quiescence, and were not subjected to major clastic sediment deposition from the Rocky Mountains (Strobl et al, 1989). This coal zone is found in the Alberta plains and extends from Township 30 to 66 (Richardson et al, 1988). Stratigraphically, the coal zone is found in the upper part of the Scollard Member of the Paskapoo Formation (Figure 3) (Lyons et al., 1987).

Highvale Mine occurs at the subcrop edge of the Paskapoo Formation in west Central Alberta. Of the six seams occurring at Highvale, five are utilized (seams 1, 2, 3, 4, and 6). This subbituminous coal is relatively flat lying with a gentle dip of less than 0.5° to the

Pit 3 Highvale Mine

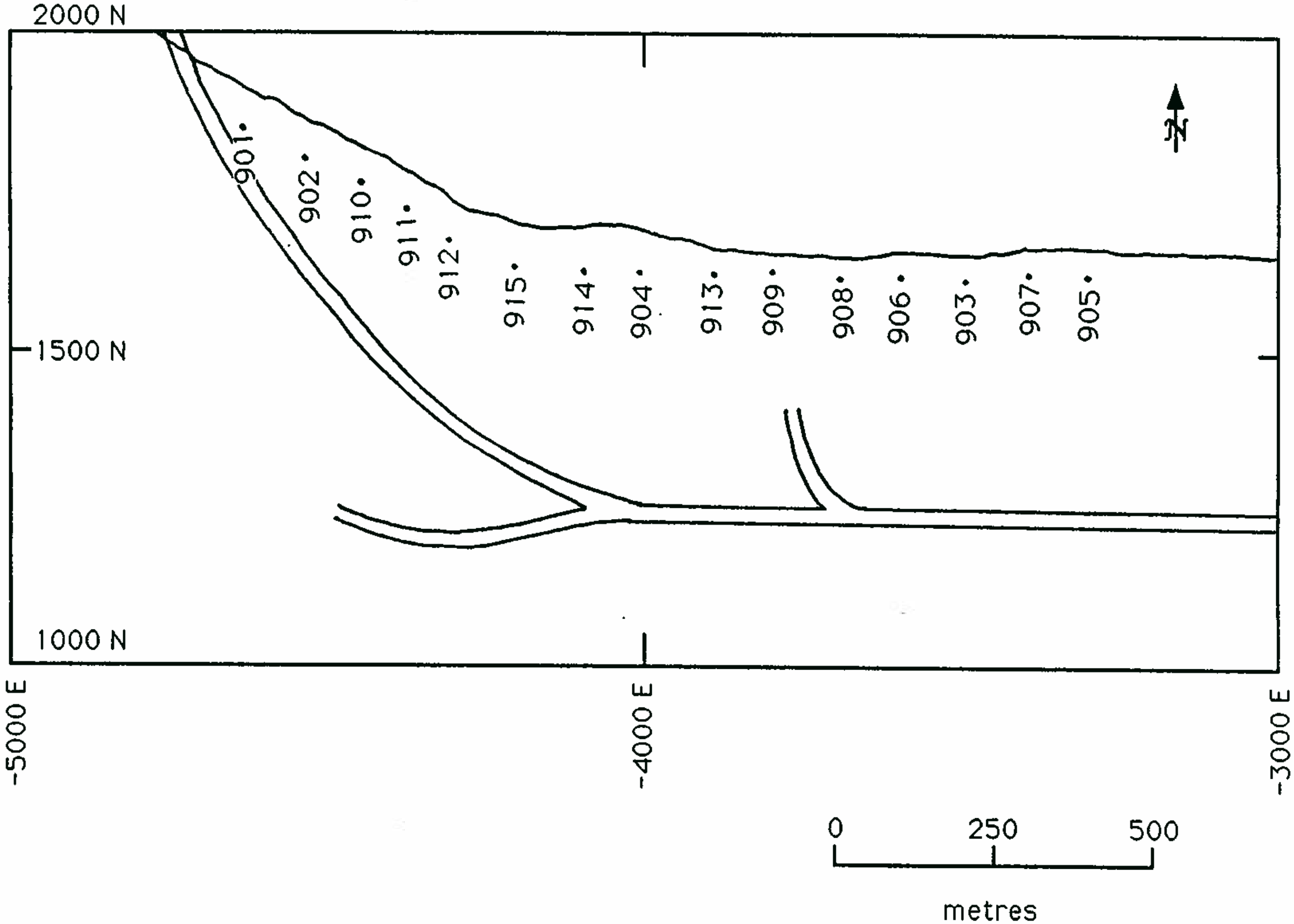


Figure 2 (modified from Nichols et al., 1984)

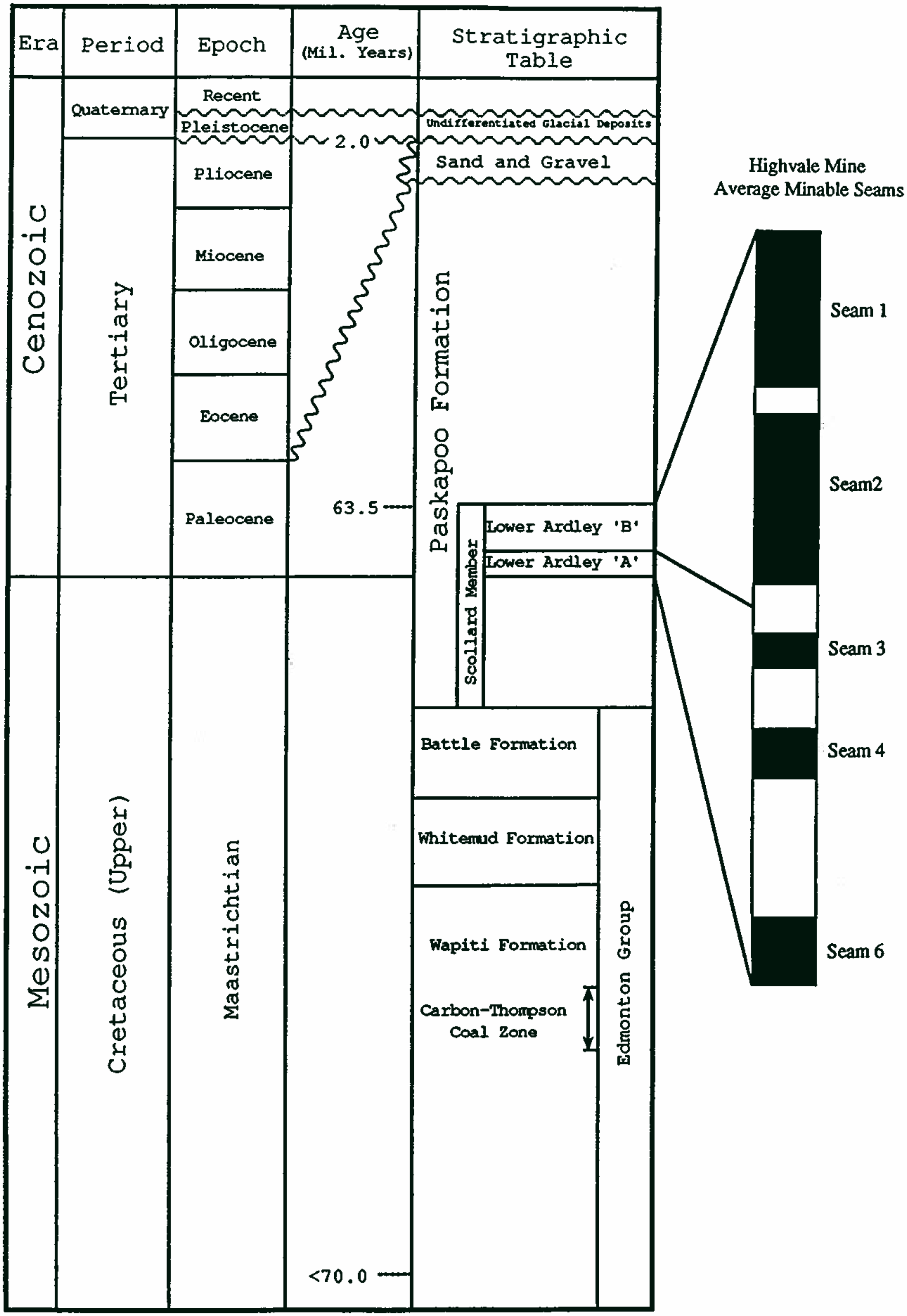


Figure 3. Stratagraphic Chart. (Lyons et al, 1987)

southwest (Wong et al, 1988). The Paskapoo Formation at the Highvale mine location consists of a series of continental deposits which are either lake or channel dominated facies (Lyons et al, 1987). The coal seams at Highvale Mine overlay deltaic-continental strata of the Edmonton Group which includes the Wapiti Formation, the Whitemud Formation, and the Battle Formation (Lyons et al, 1987).

The Wapiti Formation is about 760 metres thick at the mine site and is the start of a thick sequence of continental deposits in which the coal was deposited. Overlying the Wapiti Formation are the Whitemud and Battle Formations. The Whitemud Formation is a shale unit and is overlain by the Battle Formation which consists of a thin, widespread bentonitic shale unit, normally about 10 metres thick (Lyons et al, 1987).

The lowermost unit of the Paskapoo Formation at Highvale is the Scollard member, which includes the coal seams. The four lower coal seams are part of the Lower Ardley 'A' coal zone (Holter et al, 1975) and the base of this zone occurs just above the Cretaceous - Tertiary boundary. Seams 3, 4, 5, and 6 are included in this zone. There was a large amount of volcanic activity during the deposition of Lower Ardley 'A' coal zone illustrated by the frequent occurrence of bentonite throughout the Lower Ardley 'A' units. Seams 1 and 2 represent the Lower Ardley 'B' coal zone. The deposition of the strata in the Lower Ardley 'B' coal zone occurred under the influence of fluvial processes. The Upper Ardley coal zones are not present at Highvale (Lyons et al, 1987).

Seam 6 is stratigraphically the lowest Ardley coal unit at Highvale. It is laterally persistent throughout the mine and averages 1.2 metres in thickness in North Highvale and thins to 70 centimetres in South Highvale. This seam is divided into upper and lower subseams with a continuous 5 to 6 centimetre bentonitic parting (Lyons et al, 1987). In Pit 3 at North Highvale, seam 6 contains prominent bright and dull bands, amber fillings and aragonite/calcite on cleat surfaces. The bentonitic parting occurs in the lower half of the seam and ranges 6 to 31 centimetres in thickness. This parting is predominantly bentonitic clay but becomes siltier at the centre of the detailed study area line of drill holes (Nichols et al, 1984).

The interburden between seams 5 and 6 consists of 20 centimetres of bentonite overlain by 1.2 metres of carbonaceous bentonitic shale with coal stringers (Lyons et al, 1987). In Pit 3, this interburden ranges in thickness from 1.61 to 1.90 metres and is more complex lithologically than the general description for the entire area suggests. It contains shale, mudstone, carbonaceous shale, siltstone, carbonaceous siltstone, coaly shale, bentonite, coal fragments and coal stringers. The interburden varies from massive to laminated or banded with interbedding of any combination of lithologies mentioned above. At drill hole HV-83-902, on the west end of the line of drill holes, seam 5 separates into two seams, 5 and 5-a. Seam 5-a is a much softer coal with shale bands. The interburden separating seam 5 from 5-a is carbonaceous shale with thin bands of coal and is 67 centimetres in thickness (Nichols et al., 1984).

Seam 5 is poorly developed in the Wabamun Lake area and is not recovered in the mine operations because of a high ash content and a coal thickness of less than half a metre (Lyons et al, 1987). In Pit 3 this seam contains dull and bright bands and aragonite/calcite cleat surfaces (Nichols et al., 1984).

The interburden in Pit 3 between seams 4 and 5 ranges in thickness from 33 to 78 centimetres and contains carbonaceous shale, mudstone, siltstone, carbonaceous siltstone, shale, coal stringers, and bentonite (Nichols et al., 1984). For the entire Wabamun Lake area, the units between seams 4 and 6 display lateral continuity and indicate a stagnant swamp setting isolated from extensive sediment deposition (Lyons et al, 1987).

Seam 4 is laterally continuous in North Highvale and has a thickness of approximately 85 centimetres and an average ash content of 20%. The seam thins towards the south to 30 to 40 centimetres with an increase in ash content (Lyons et al, 1987). In Pit 3, a parting occurs in a few cores and ranges in thickness from 12 to 23 centimetres and is comprised of siltstone and shale with coal stringers and a few aragonite/calcite veins (Nichols et al., 1984).

Over the entire Wabamun Lake area, seam 4 is overlain by layers of bentonite and bentonitic mudstone (Lyons et al, 1987). The interburden between seams 3 and 4 at Pit 3 ranges in thickness from 1.03 to 1.85 metres and consists of shale, siltstone, mudstone, organic fragments, coal stringers, and bentonite which is swollen and cracked at some places (Nichols et al., 1984).

Seam 3 is one of the most uniform coal seams in the Highvale mine site. It ranges in thickness from 40 to 60 centimetres. This seam splits into seam 3 and 3-b in the southern part of the Highvale deposit. The split is caused by a parting of volcanic origin thickening to the south (Lyons et al, 1987). In Pit 3, seam 3 contains dull and bright bands. A 10 centimetre thick parting shows up at drill hole HV-83-909 and consists of dirty coal with some siltstone banding (Nichols et al., 1984).

The interburden between seams 2 and 3 is a mudstone and silty mudstone unit which thickens towards the northwest. It ranges in thickness from 20 centimetres at the southeast edge of South Highvale to over 5 metres at North Highvale. This unit marks the end of the Lower Ardley 'A' coal zone and the beginning of the Lower Ardley 'B' coal zone (Lyons et al, 1987). In Pit 3, the interburden ranges in thickness from 0.81 to 1.42 metres and consists of mudstone, shale, siltstone, bentonite, and coal stringers. The units are both massive at some locations and interbedded and laminated at others. The bentonite exhibits swelling and cracking (Nichols et al., 1984).

Seam 2 is one of the principal coal seams at Highvale mine. It is laterally continuous and has a range in thickness of 3.0 to 3.5 metres. The average ash content is usually less than 15 % with an increase in content stratigraphically (from bottom to top) up the seam (Lyons et al, 1987). In Pit 3, seam 2 contains aragonite/calcite along cleat surfaces and fracture infillings, discrete pyrite grains, amber fillings and prominent bright and dull bands. The seam contains a few discontinuous partings from 4 to 38 centimetres thick. The number of partings for a single drill core range from 0 to 5. The partings consist of carbonaceous shale, carbonaceous siltstone, mudstone, and coal stringers. Bentonite is noticeably absent (Nichols et al., 1984).

The interburden between seams 1 and 2 consists of a unit of mudstone, silty mudstone, and sandy siltstone which increases in thickness to the northwest (Lyons et al, 1987). In Pit 3, the interburden ranges in thickness from 40 to 108 centimetres and contains shale, siltstone, mudstone, coal stringers, and pyrite grains (Nichols et al., 1984)

Seam 1 has a range in ash content from 10% to 25%. In the Northwest periphery of the Whitewood mine area, just north of Highvale mine, seam 1 was not deposited and channel and overbank deposits occupy its stratigraphic position. The thickness of seam 1 is highly variable throughout the Highvale and Whitewood areas and ranges from 1 to 4 metres. Carbonaceous shale partings are common at Whitewood and at the northern boundaries of the North Highvale area. The thickest parting, averaging 20 to 40 centimetres, is found at Whitewood where it splits the seam into seam 1 upper and seam 1 lower. An equivalent parting is present in the Highvale area, but because it is less than 10 centimetres thick, seam 1 is not divided into upper and lower beds (Lyons et al, 1987). In Pit 3, seam 1 contains dull and bright bands, aragonite/calcite on cleat surfaces and in veins, splotches of pyrite along bedding and fracture planes, thin carbonaceous bands, closely spaced fractures, and amber fillings. A number of discontinuous partings occur in this unit consisting of shale, clay, siltstone, and mudstone. The number of these partings in each drill core range from 1 to 7 and range in thickness from 5 to 60 centimetres (Nichols et al., 1984).

Overlying the coal seams are several units belonging to the Paskapoo Formation. These units are composed of gently dipping successions of mudstones, siltstones, and sandstones. The lower mudstone unit called the lower shale conformably overlies coal seam 1 and is usually 2 to 10 metres thick. It consists of bedded mudstones and siltstones which are laterally continuous over most of the region (Lyons et al, 1987).

The lower shale unit is overlain by the middle sandstone unit, which locally may have an erosional base. It averages in thickness from 20 to 25 metres, but is up to 35 metres thick at some locations in the Wabamun Lake area. The unit grades laterally into a thinner siltstone facies. The middle sandstone unit is composed of three distinct types of deposits. The first type consists of medium to coarse grained sandstone. It is highly porous and may contain pebbles, especially at its base. This strata was deposited in the major trunk-channel of the fluvially dominated unit. The second type consists of fine to medium grained sandstone with a high clay matrix and contains concretionary horizons cemented by calcium carbonate. These sediments originated in tributary channels of the major trunk channel. These deposits are finer grained sandstones than the first type of sandstones and contain a significant percentage of clay matrix. The third type consists of siltstone and mudstone with minor concretionary horizons. These strata were deposited outside of the active channel system. The beds are composed of siltstone with minor amounts mudstones, deposited in overbank and lacustrine environments (Lyons et al, 1987).

The middle shale overlies the middle sandstone unit. It is composed almost entirely of mudstone and minor amounts of siltstone, with a relatively high proportion of bentonite. Bentonite or bentonitic mudstones within the unit are laterally continuous over the entire Highvale area. The thickness of this unit averages 15 to 20 metres with a maximum thickness of approximately 25 metres (Lyons et al, 1987).

The units that overlie the middle shale unit are not well defined because of the limited number of drill holes that have penetrated them. The upper sandstone unit is poorly developed in the North Highvale area. In the South Highvale area the unit is well developed and reaches a maximum thickness of 25 metres. This upper sandstone is typically composed of fine to coarse grained, poorly consolidated sandstone. The upper shale is stratigraphically the highest of the units in the Paskapoo Formation at the Wabamun Lake area. It consists of mudstone and bentonitic mudstone, with minor amounts of siltstone or sandstone (Lyons et al, 1987).

The Paskapoo Formation is overlain by glacially derived Pleistocene deposits. These deposits consist of clay-rich till containing ice rafted and displaced blocks of Cretaceous and Tertiary rocks. The glaciation has resulted in varying degrees and depths of bedrock deformation. Evidence of deformation may include minor faulting planes of weakness, folding, fracturing, and brecciation. The North Highvale and Whitewood areas are typically overlain by a thin cover of clay-rich glacial till. The combined thickness of till and displaced bedrock is approximately 10-15 metres. The situation in the South Highvale area is much less consistent and the glacial deposits there may be up to 40 metres thick (Lyons et al, 1987).

The strata overlying the coal zone in Pit 3 at North Highvale show local erosion and nondeposition of the units mentioned in the description for the entire Wabamun Lake area. The western edge of Pit 3, particularly drill holes HV-83-901, 910, 911 and 912 are missing the lower shale unit. The middle sandstone unit is present only on the western side of Pit 3. Towards the east end of the pit, only the upper shale is present. Glacial till covers the entire pit (Nichols et al., 1984).

The depositional environment represented by the sediments in the Paskapoo Formation in the Wabamun Lake area is understood to be an alluvial plain system with fluvial and lacustrine deposits (Strobl, personal communication). The facies shift from channel dominated to the north of Highvale mine to lacustrine/swamp dominated at Highvale. The principal deposits of swamp facies are coal, mudstone, siltstone, and bentonite. Swamp facies were formed during periods when fluvial activity had been largely restricted to trunk channels (Lyons et al, 1987).

Statistical Methodology

The main reason for conducting a statistical analysis on the coal quality data from Highvale Mine was to determine the distributional qualities of the data in order to aid in the development of a predictive model. The TransAlta Utilities data was entered into a statistical analysis program Data Desk® on a Macintosh computer. Once the coal quality data sets were entered, standard statistics including the sample mean, median, maximum, minimum, range, interquartile range, skewness coefficient, kurtosis coefficient, sample variance and the standard deviation were computed. A discussion of these standard statistics and the formulas are given in Wong et al, 1988.

For this coal quality study, the median and the variance are emphasized because they are considered the most representative due to non-gaussian distributions of the data. In this situation the median is more meaningful than the mean because it is the middle value and is not influenced by extreme data. The arithmetic mean accounts for all values and will only reflect the middle value in a normal distribution.

$$\text{Sample mean} = \bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

$$\text{Sample median} = \int_{-\infty}^{\text{median}} f(x)dx = \int_{\text{median}}^{\infty} f(x)dx = 0.5$$

The variance is meaningful because this is the statistical parameter that is of most concern in the development of the predictive model. The variance is the square of the standard deviation and is considered a measure of the spread.

$$\text{Sample variance} = s^2 = \sum_{i=1}^{n} \frac{(x-\bar{x})^2}{(n-1)}$$

The results from the statistical analysis were used to generate scatter plots, frequency histograms, and multiple box plots. Scatter plots were generated to determine the correlation between the coal quality parameters. These plots can be used as predictive tools, to predict one parameter on the basis of measuring another measured parameter, by using the correlation established in the scatter plot. The histograms were generated using both the median values and the variance. This was done on a number of scales, including individual seams within single drill holes, individual seams across all fifteen drill holes, every seam in single drill holes, and all values to obtain a composite histogram of Pit 3 (figures 4 and 5). The histograms reveal the distribution of values for percent sulfur (dry basis), percent ash (dry basis), and btu/lb (kJ/kg) (dry basis) throughout the entire pit. The multiple box plots were generated in a similar manner, but are more revealing than the histograms because the box plots provide a visual means of seeing the median, skewness, kurtosis, variance, percentiles, and ranges of the data (figures 9 to 26). Strobl et al, 1989 provides a discussion on box plots. The plots generated in the Coal Quality Study allow for quick visual comparison with the results from the studies by Wong et al, 1988 and Strobl et al, 1989 since both reports used similar graphical methods to display the results.

Statistical Results

Univariate and bivariate statistical analyses for the fifteen drill holes and further comparison to the results from the entire Highvale mine and the Ardley coal zone suggest a number of definite trends. At every scale, from regional to intraseam, variability of the coal quality occurs, but as the area of investigation becomes smaller, the range of values decreases. As shown in figure 4, a significant decrease in the range of ash values occurs when comparing the values from data outside Highvale in the Ardley coal zone, the entire Highvale deposit, Pit 3 in North Highvale, and Seam 1 at Pit 3 in North Highvale. The range of values for percent ash (dry basis) for the Ardley coal zone is 8% to 59%. For the Highvale mine area, the range is 9% to 29%. Within Pit 3, the range is 10% to 25%. Seam 1

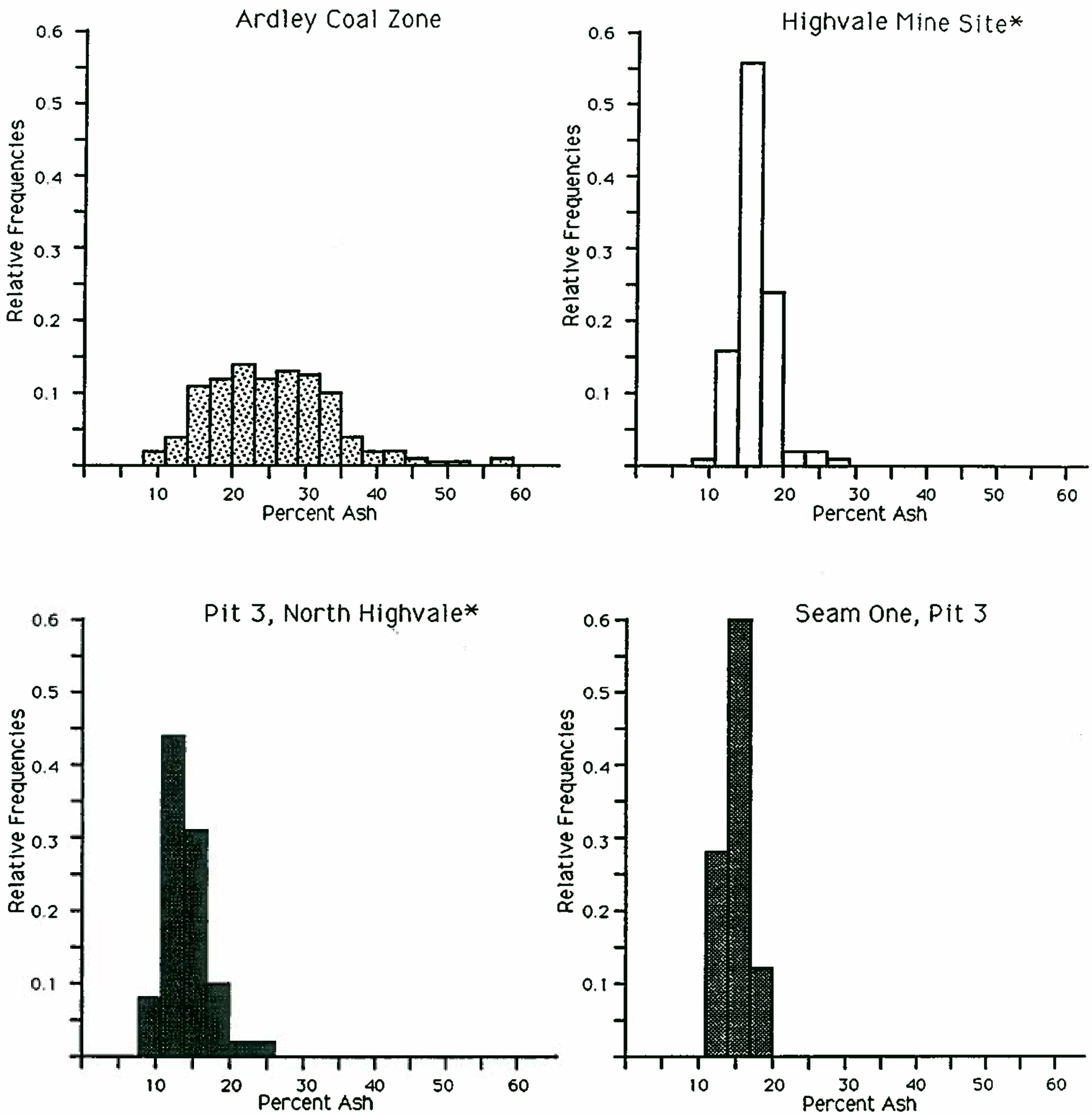


Figure 4. Histograms for Percent Ash (dry basis)
(* includes seams 1,2,3,4 and 6)

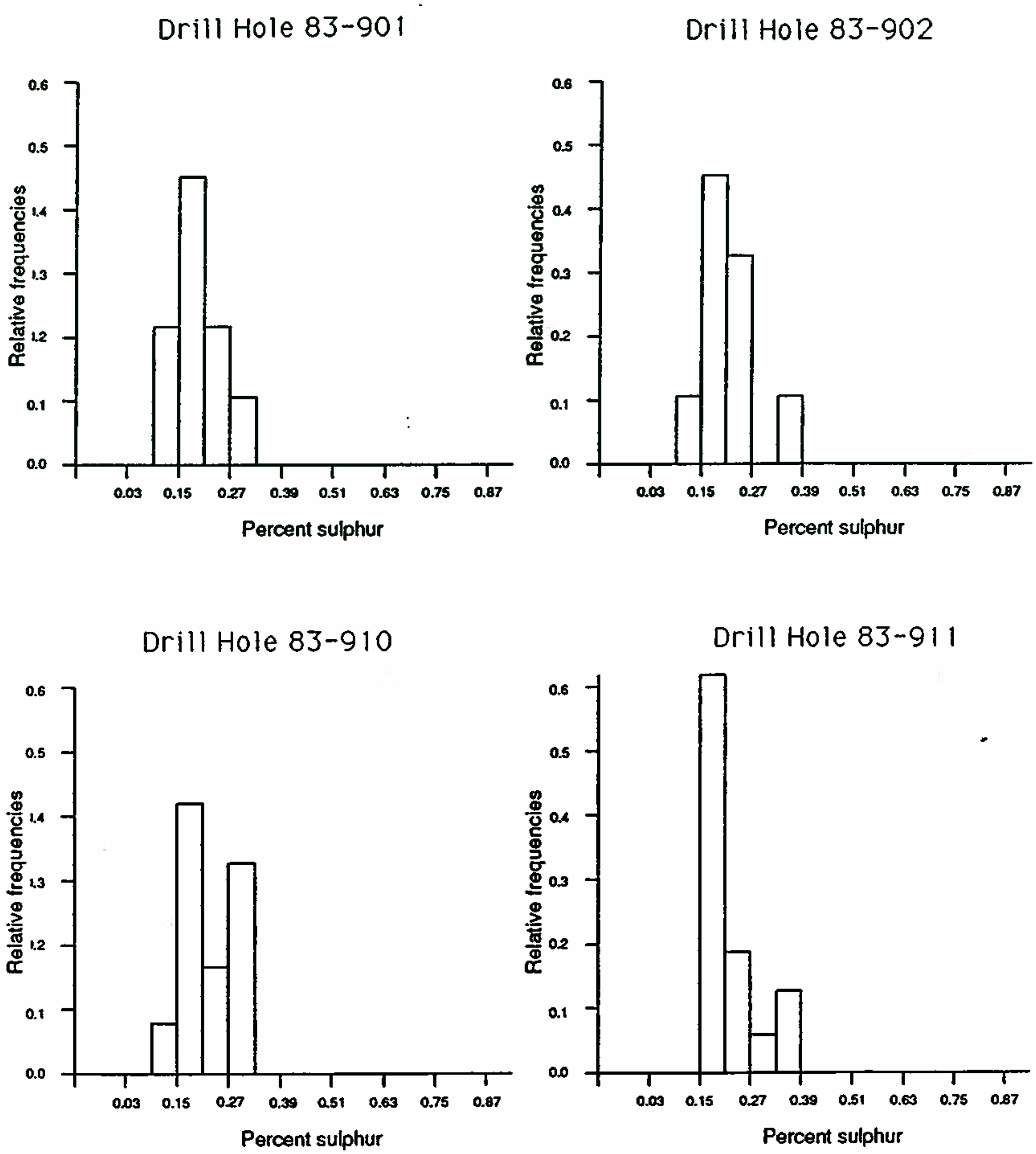
has a range from 12% to 19%. Similar results have been obtained for sulfur and calorific value.

The environment of deposition and diagenetic history of the coal influence the coal quality parameters being discussed, namely ash, sulfur and calorific value. It follows that on a larger scale of investigation, the depositional environment will be more variable than at a smaller scale of investigation, and therefore, the coal quality parameters will be more variable at the larger scale. Within one coal seam at a deposit, the depositional environment is more consistent than over the entire coal zone which includes all seams. This does not mean that coal becomes homogeneous at the smaller scale. A single coal seam shows variation, but not as much as across multiple coal seams.

Pit 3 is uniform in terms of coal quality and has a relatively constant depositional environment within single seams, which is expected because of the small scale being dealt with in this study area. Within individual drill holes, single seams have a small range of ash, sulfur and calorific values. As shown in figure 5, the range of percent sulfur values for seam 1 from four adjacent drill holes with a spacing of 100 metres is very similar, but the distribution of those values is different, with none of the histograms displaying a normal distribution.

Some variations within a seam in a single drill hole can be explained by the proximity to stringers within the seam and partings between seams. The data indicates that ash and sulfur are slightly higher and calorific value is slightly lower at the top and bottom of most seams than in the middle. The increase in ash and decrease in

Figure 5. Histograms showing Percent Sulphur in Seam One over 400 metres



calorific value is due to chemical changes that occur as sediment infringes on the mire. The increase in sulfur can be attributed to an increase in the oxidation state that occurs near the end of peat formation (Langenberg, 1989) This is shown in figure 6 where the percent sulfur profile of seam 1 at drill hole 83-901 shows the variation of values across the seam. Interseam partings or stringers will alter the coal quality parameters by increasing ash and reducing the calorific value. This is illustrated in figures 7 and 8 with the profiles of seam 1 and 2 for the calorific value for drill holes 901, 904, and 905, each approximately 500 metres apart In these figures, the spikes to the left or lower values of the calorific value indicate interseam partings within the seams.

Each individual seam has distinct characteristics throughout Pit 3 and the entire Highvale mine site. Although seams 1 and 2 are the most important seams in Pit 3 with respect to coal quality and volume, each seam is discussed below, including seam 5 which is not recovered in the mining process at Highvale. In each seam discussion, values obtained from obvious interseam partings are shown on the bar graphs but are excluded from the ranges.

Seam 1 - Seam 1 is the uppermost seam at Highvale mine and is one of the primary coal seams for mining purposes. Although the seam has been influenced by fluvial processes and had been replaced by channel and overbank deposits north of Highvale Mine, its coal quality is good and less variable than expected. The thickness of this coal seam across Pit 3 varies from 2.18 metres to 3.90 metres, much less variable than for the entire Highvale and Whitewood mines. The stringers that occur in seam one are related to an increase in the ash content and a decrease in the calorific value.

In-seam Profile for Seam One, Percent Sulphur

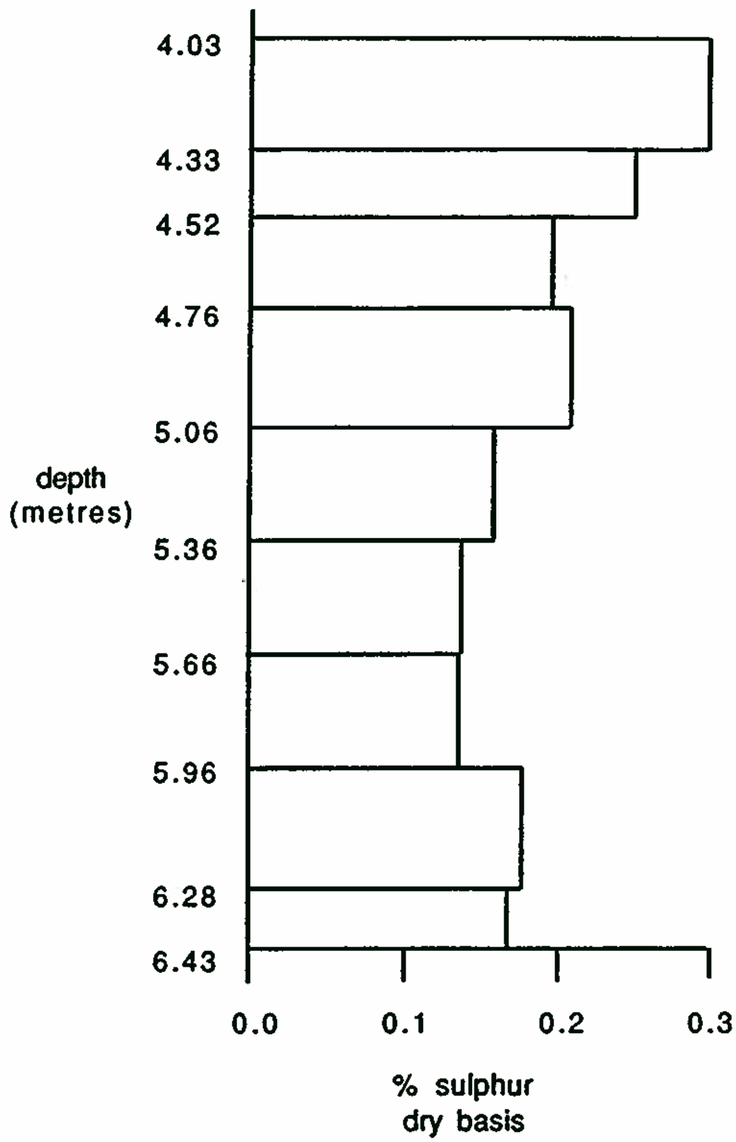
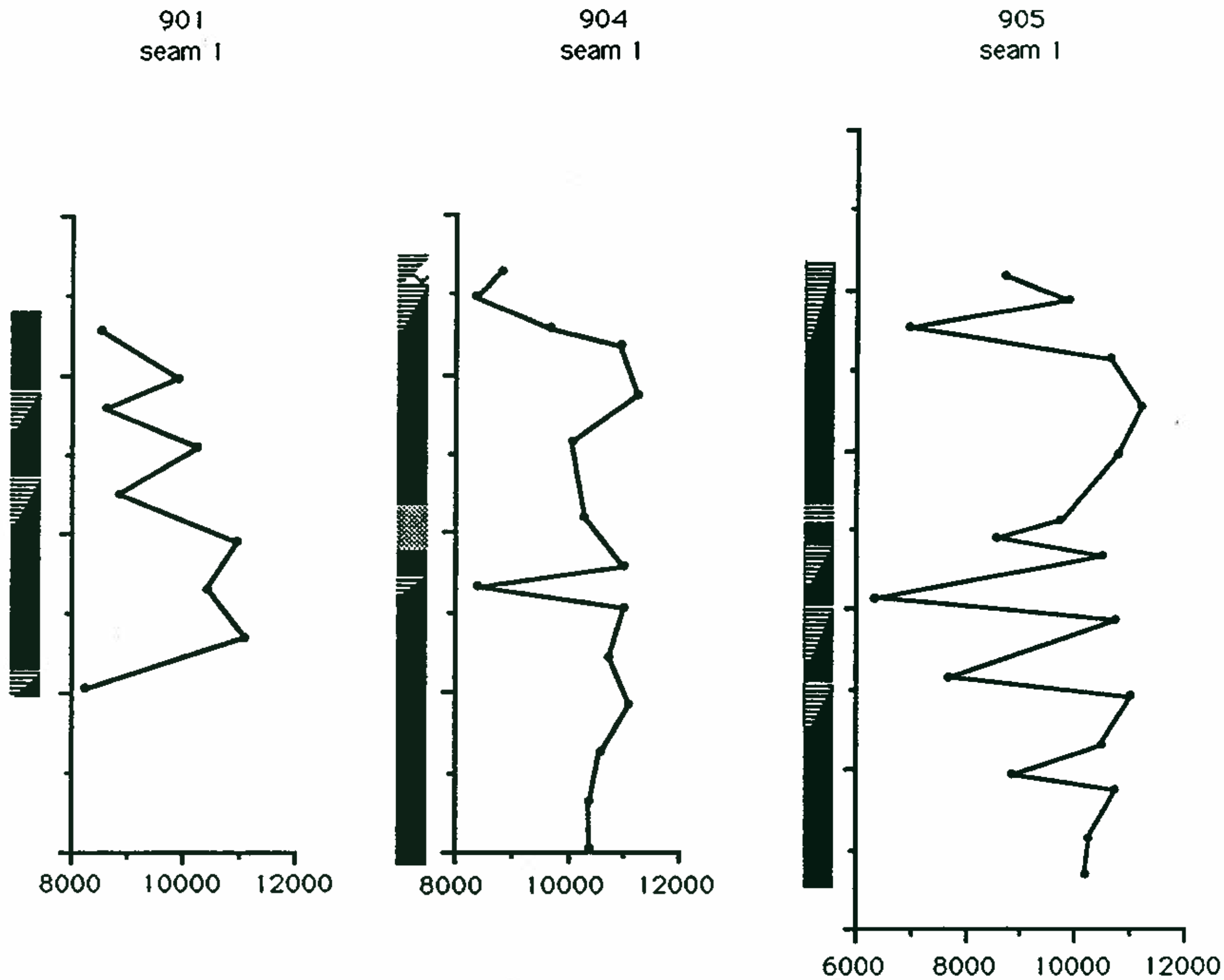


Figure 6

Btu/Lb for Seam One



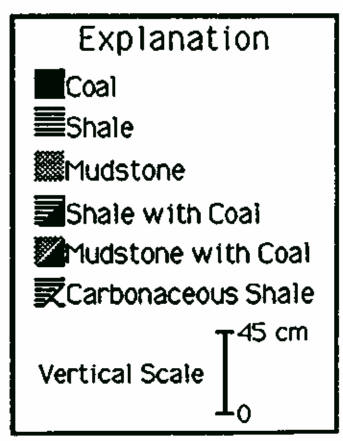
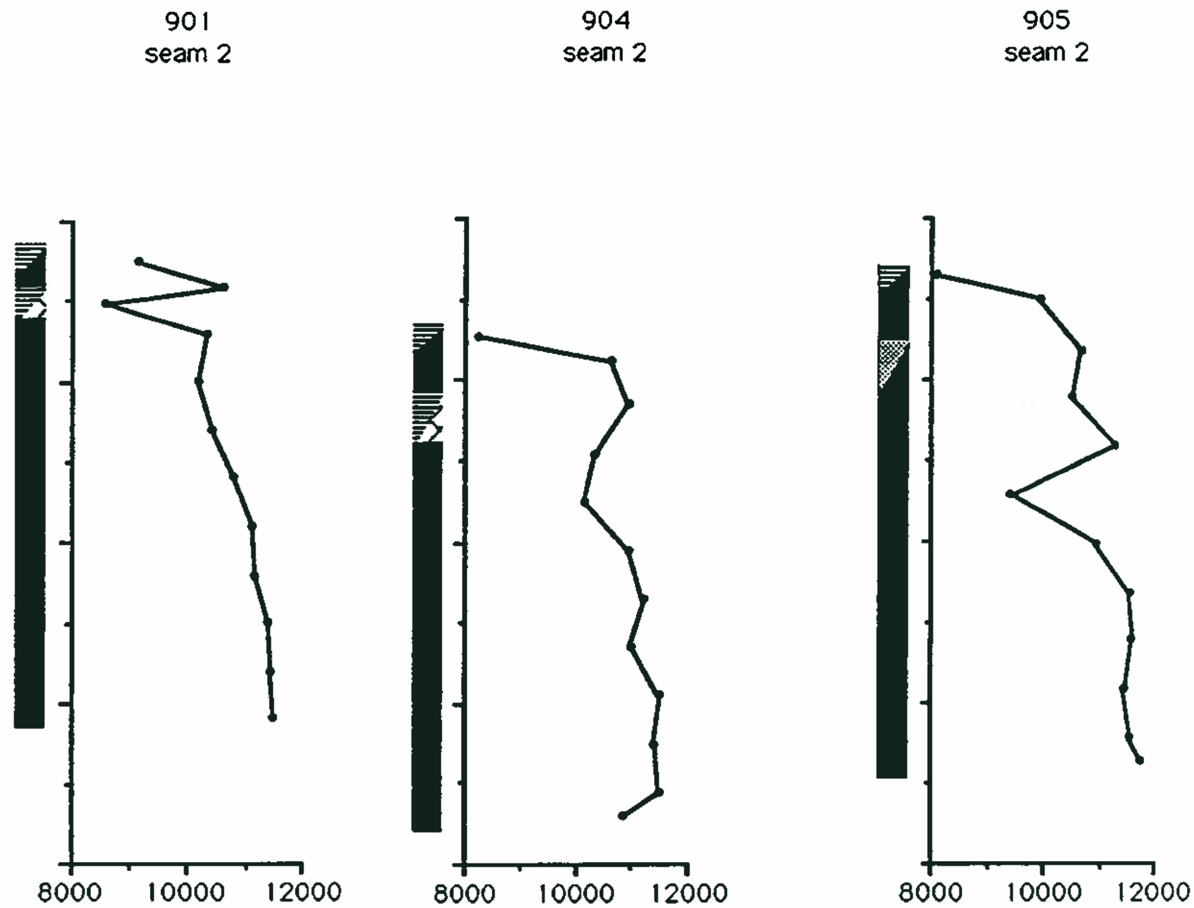


Figure 7. Comparison of calorific value for three drill holes for seam 1 (500 metre spacing).

Btu/Lb for Seam Two



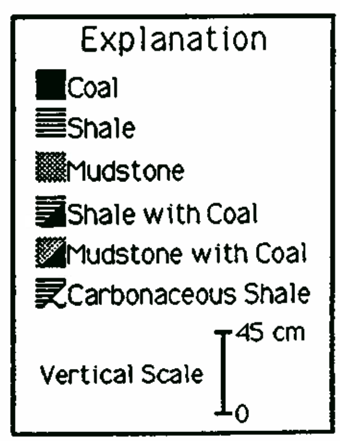


Figure 8. Comparison of calorific value for three drill holes for seam 2 (500 metre spacing).

Ash (dry basis) varies from 8.75% to 50.0% with a median value of 14.67% and a variance of 148.06 (figure 9). The range of median values for ash for all fifteen drill holes is 11.32% to 18.43%. Sulfur (dry basis) varies from 0.06% to 1.32% with a median value of 0.19% and a variance of 0.01917 (figure 10). The range of median values for sulfur for all fifteen drill holes is 0.16% to 0.245%. Calorific value (dry basis) varies from 3471 btu/lb (8074 kJ/kg) to 11548 btu/lb (26861 kJ/kg) with a median value of 10470 btu/lb (24353 kJ/kg) and a variance of 3180410 btu^2/lb^2 (7397634 kJ^2/kg^2) (figure 11). The range of median values for calorific value for all fifteen drill holes is 9913 btu/lb (23058 kJ/kg) to 10889.btu/lb (25328 kJ/kg).

Seam 2 - Seam 2 is stratigraphically the second highest seam at Highvale mine and is the other primary coal seam for mining purposes. This seam has also been influenced by fluvial processes but is even less variable than seam 1. Seams 1 and 2 represent the most extensive peat development episode of the six seams interrupted by an intrusion of mudstone and siltstone from the northwest The thickness of seam 2 across Pit 3 varies from 2.85 metres to 3.24 metres, very similar to the entire Highvale Mine. Ash (dry basis) varies from 5.8% to 45.42% with a median value of 12.53% and a variance of 52.042 (figure 12). The range of median values for ash for all fifteen drill holes is 10.34% to 15.54%. Sulfur (dry basis) varies from 0.04% to 0.51% with a median value of 0.19% and a variance of 0.0059 (figure 13). The range of median values for sulfur for all fifteen drill holes is 0.14% to 0.24%. Calorific value (dry basis) varies from 6107 btu/lb (144205 kJ/kg) to 11944 btu/lb (277782 kJ/kg) with a median value of 10781 btu/lb (25077 kJ/kg) and a variance of 1063433 btu^2/lb^2 (2473545 kJ^2/kg^2)(figure 14).

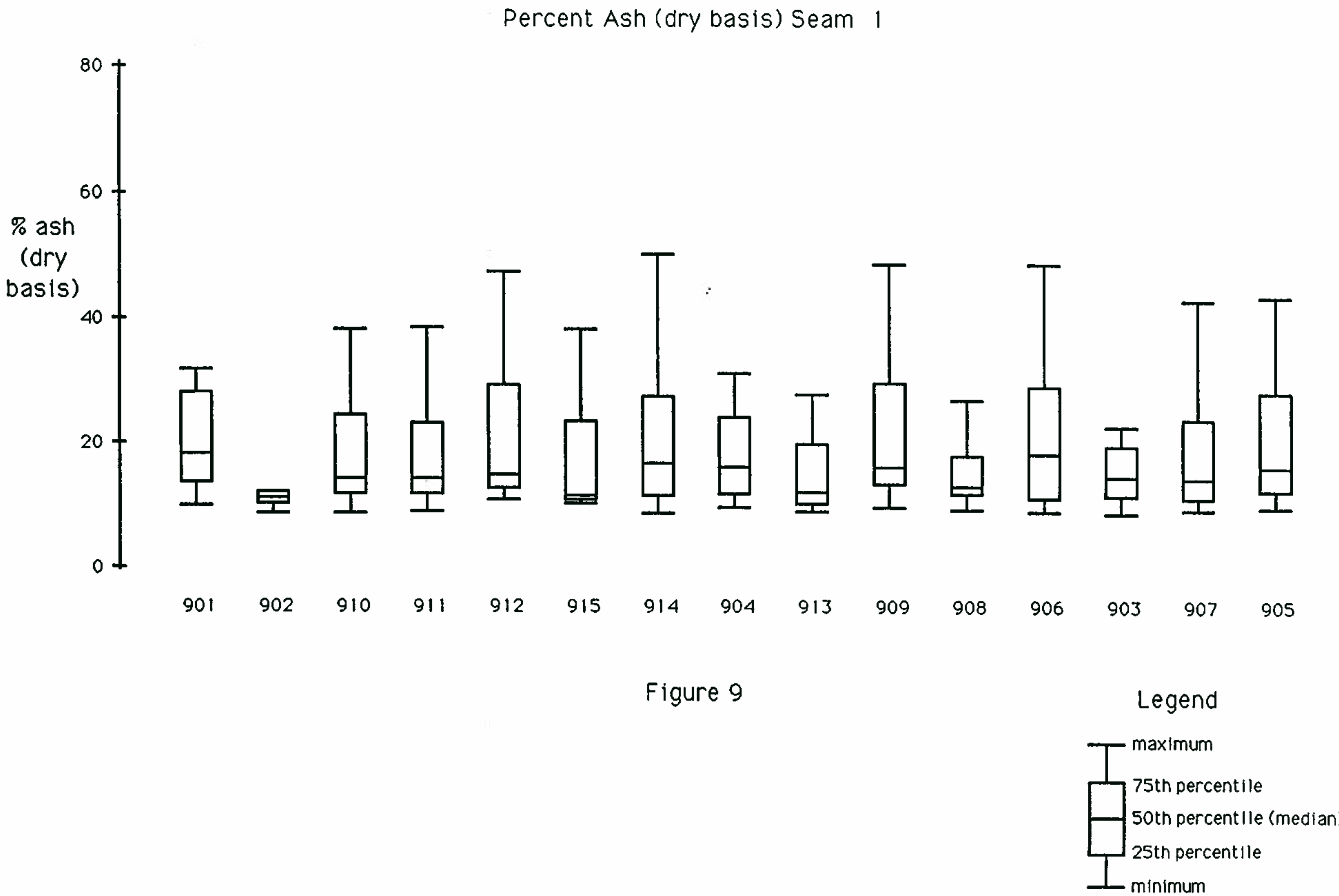

Percent Ash (dry basis) Seam 1
80
60
40
20
0
% ash (dry basis)
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 9

Percent Sulphur (dry basis) Seam 1

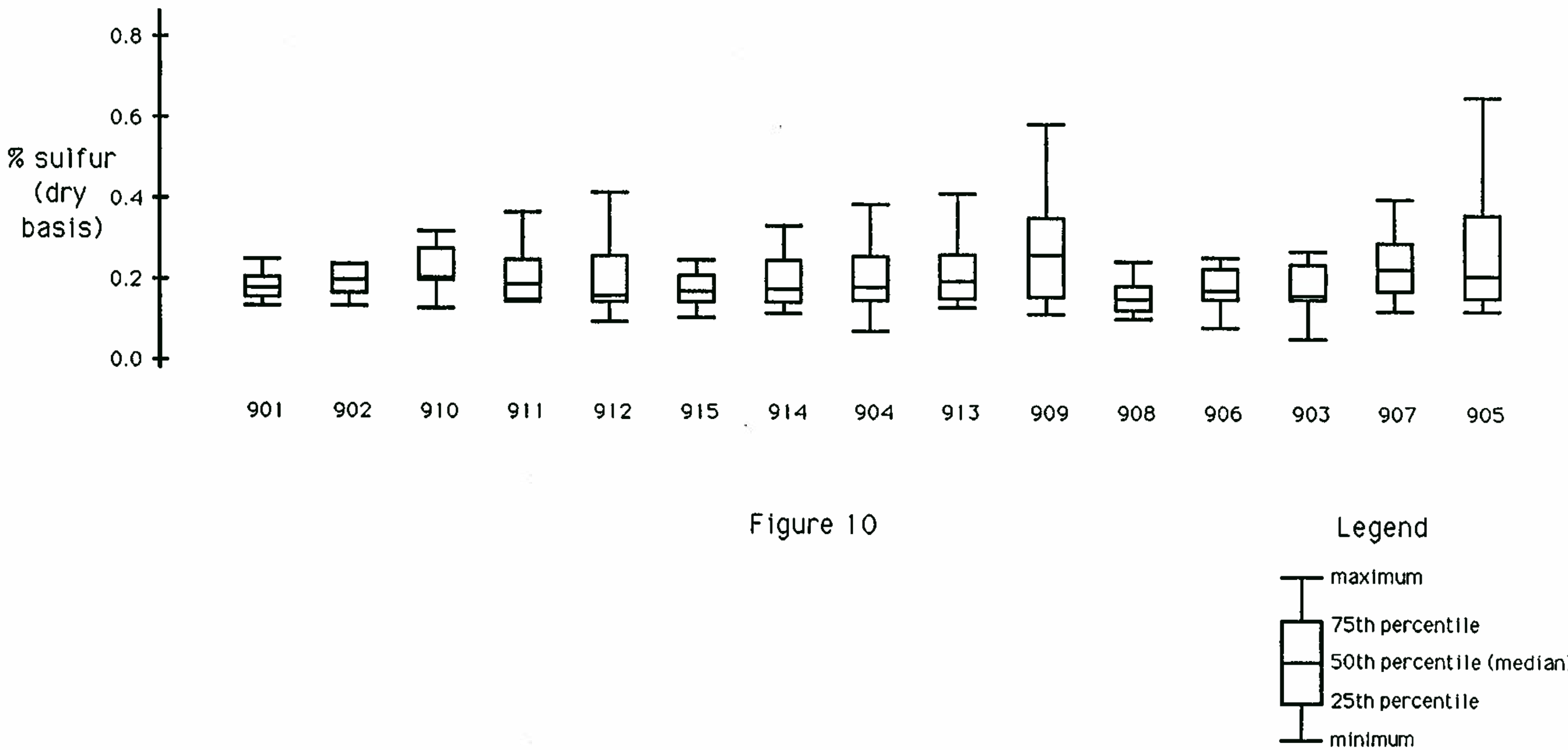


Figure 10

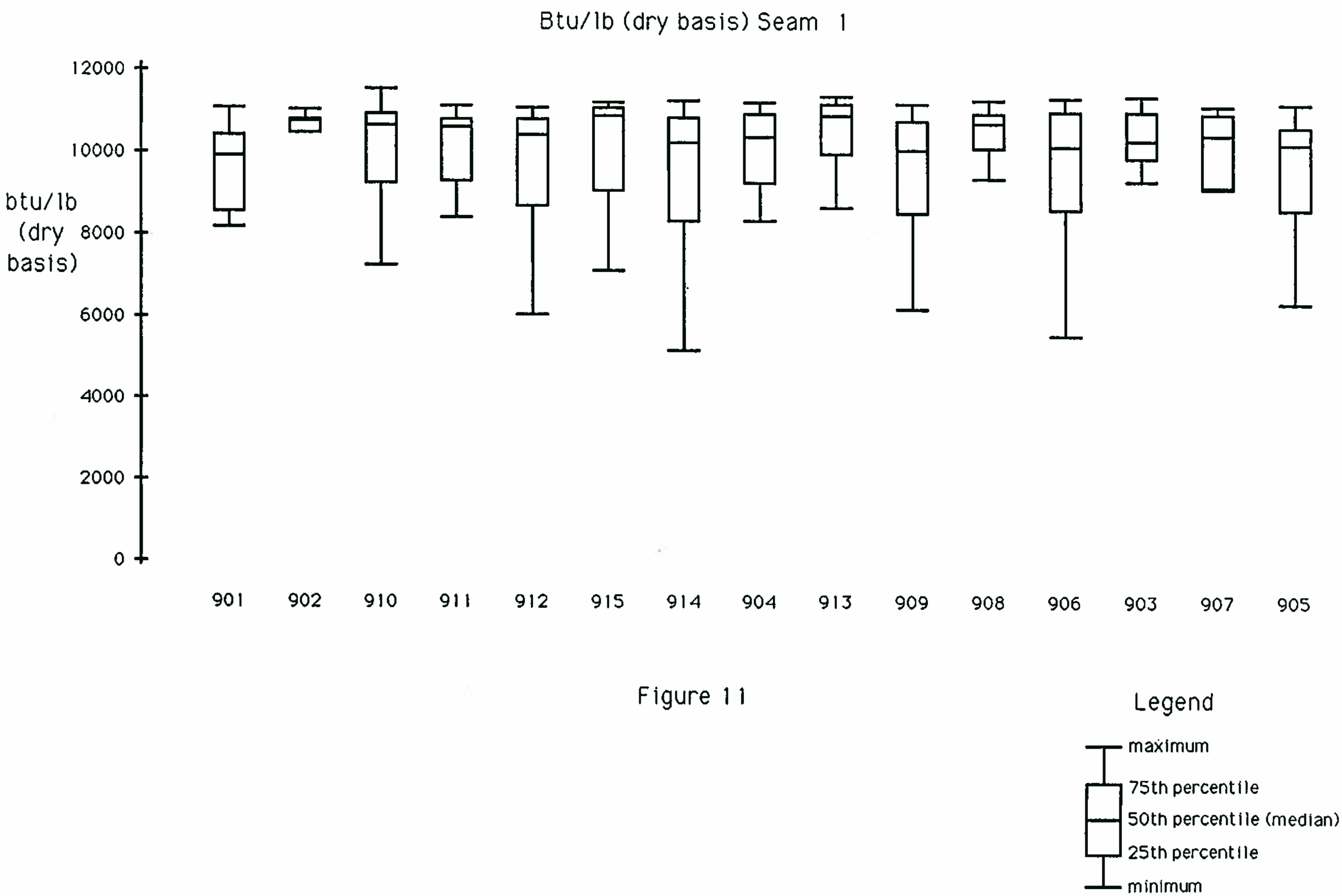

Btu/lb (dry basis) Seam 1
btu/lb (dry basis)
12000
10000
8000
6000
4000
2000
0
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 11

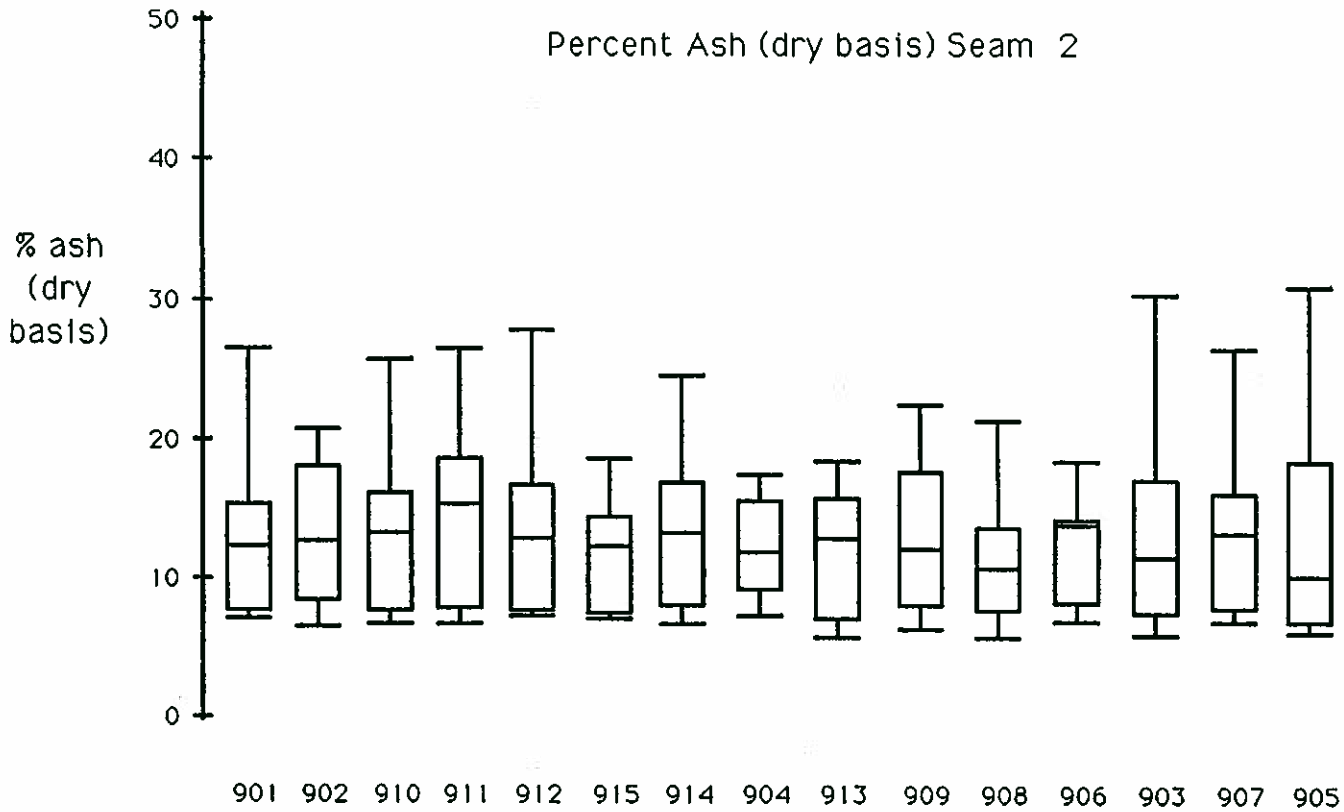
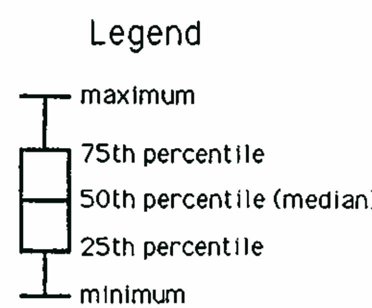

Percent Ash (dry basis) Seam 2
% ash (dry basis)
50
40
30
20
10
0
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905

Figure 12


Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Percent Sulphur (dry basis) Seam 2

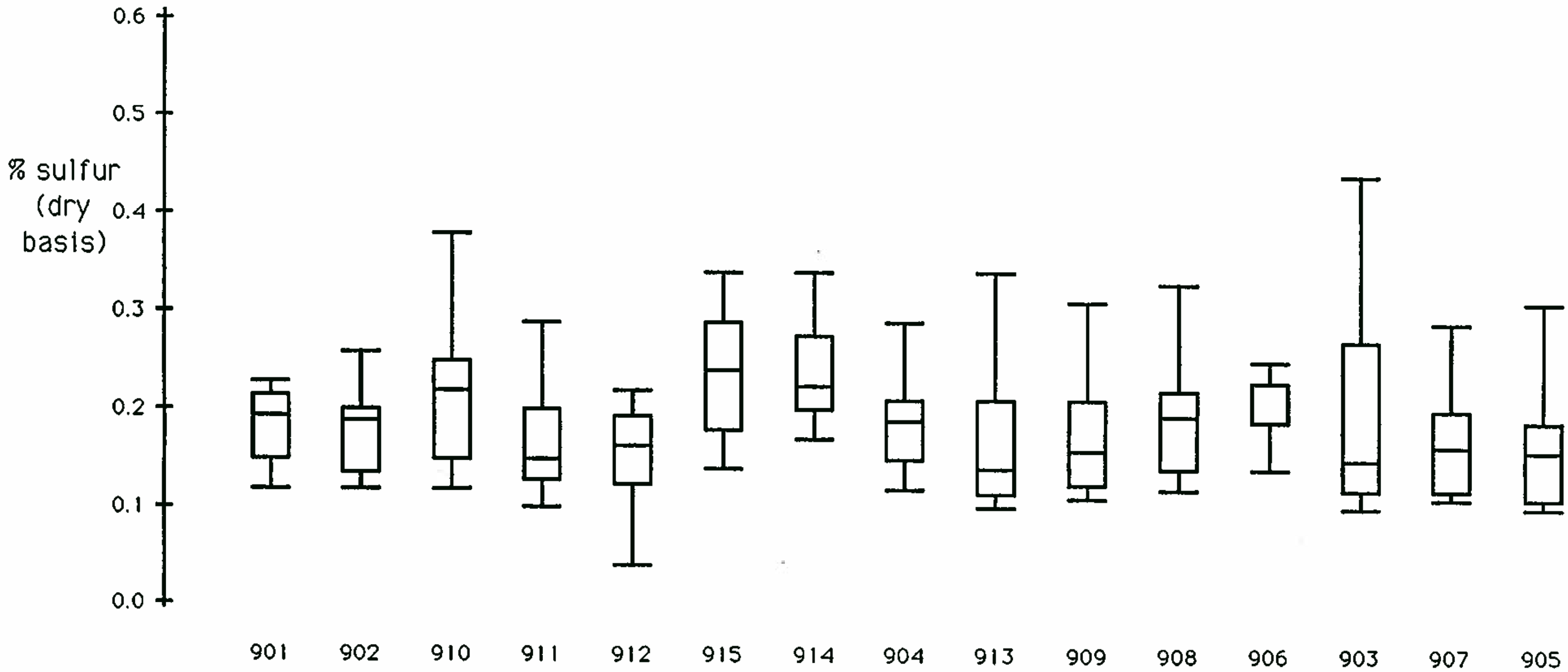
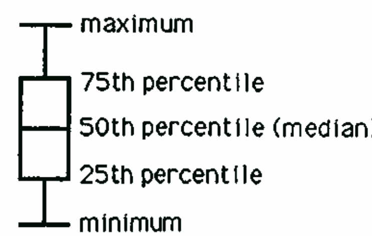


Figure 13

Legend



Btu/lb (dry basis) Seam 2

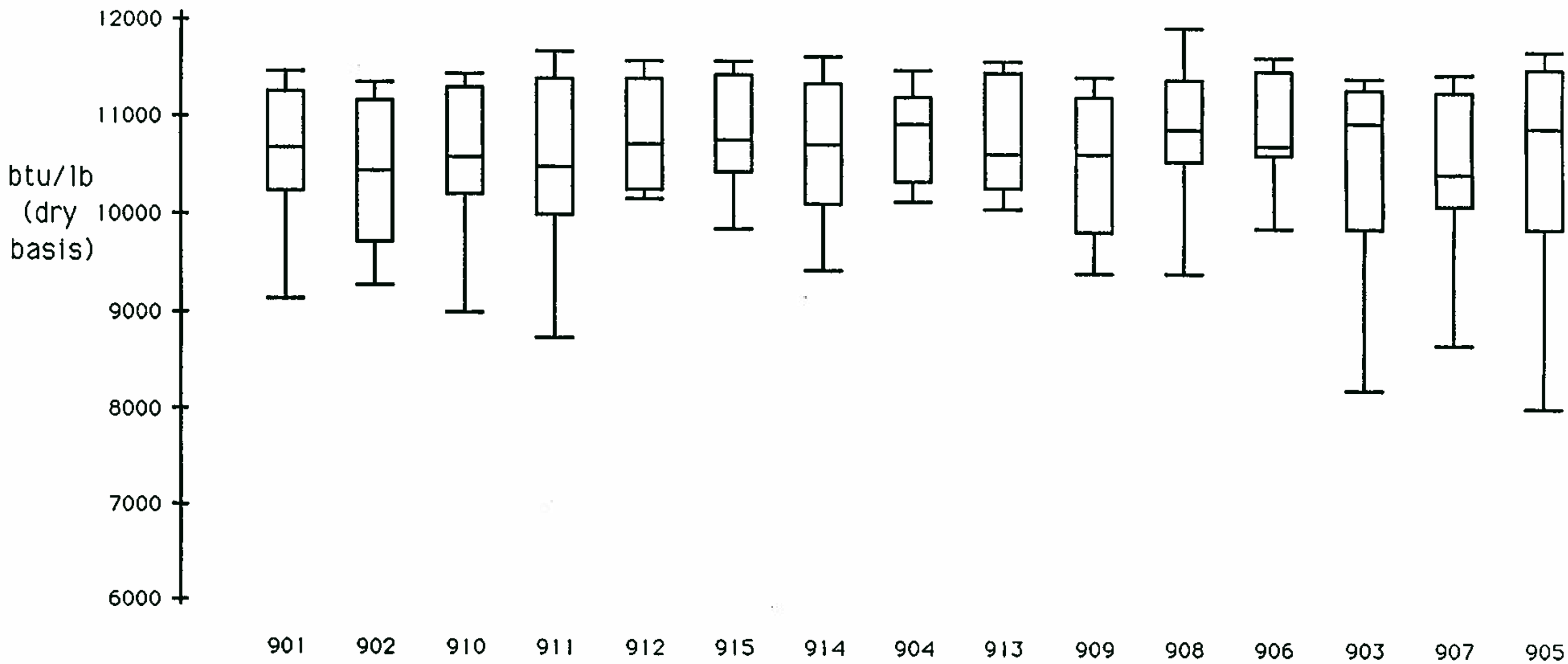
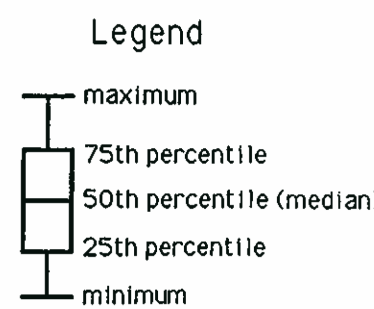


Figure 14



The range of median values for calorific value for all fifteen drill holes is 10453 btu/lb (24314 kJ/kg) to 10964 btu/lb (25502 kJ/kg).

Seam 3 - Seam 3 is much thinner than seams 1 and 2 but is still utilized in the mining operation. The thickness of seam 3 across Pit 3 varies from 0.30 metres to 0.57 metres. Ash (dry basis) varies from 8.03% to 29.37% with a median value of 14.22% and a variance of 23.878 (figure 15). The range of median values for ash for all fifteen drill holes is 8.955% to 19.85%. The volcanic activity absent in the overlying units shows up in seam three, in particular a parting of volcanic origin occurs south of Pit 3. Sulfur (dry basis) varies from 0.2% to 0.66% with a median value of 0.3% and a variance of 0.00891 (figure 16). The range of median values for sulfur for all fifteen drill holes is 0.26% to 0.495%. Calorific value (dry basis) varies from 8385 btu/lb (19504 kJ/kg) to 11481 btu/lb (26705 kJ/kg) with a median value of 10580 btu/lb (24609 kJ/kg) and a variance of 408985 btu^2/lb^2 (951299 kJ^2/kg^2) (figure 17). The range of median values for calorific value for all fifteen drill holes is 9739.5 btu/lb (22654 kJ/kg) to 11434 btu/lb (26595 kJ/kg). There are only 2 to 3 samples per drill hole for seam 3, so the variation of those samples has little statistical significance.

Seam 4 - Seam 4 is similar to seam 3 in thickness and number of samples but it is not as uniform as seam 3 across the entire mine. The thickness of seam 4 across pit 3 varies from 0.47 metres to 0.87 metres. Ash (dry basis) varies from 9.24% to 43.37% with a median value of 16.31% and a variance of 59.236 (figure 18). The range of median values for ash for all fifteen drill holes is 12.52% to 25.23%. Sulfur (dry basis) varies from 0.23% to 0.47% with a median value of 0.315% and a variance of 0.00407 (figure 19). The

Percent Ash (dry basis) Seam 3

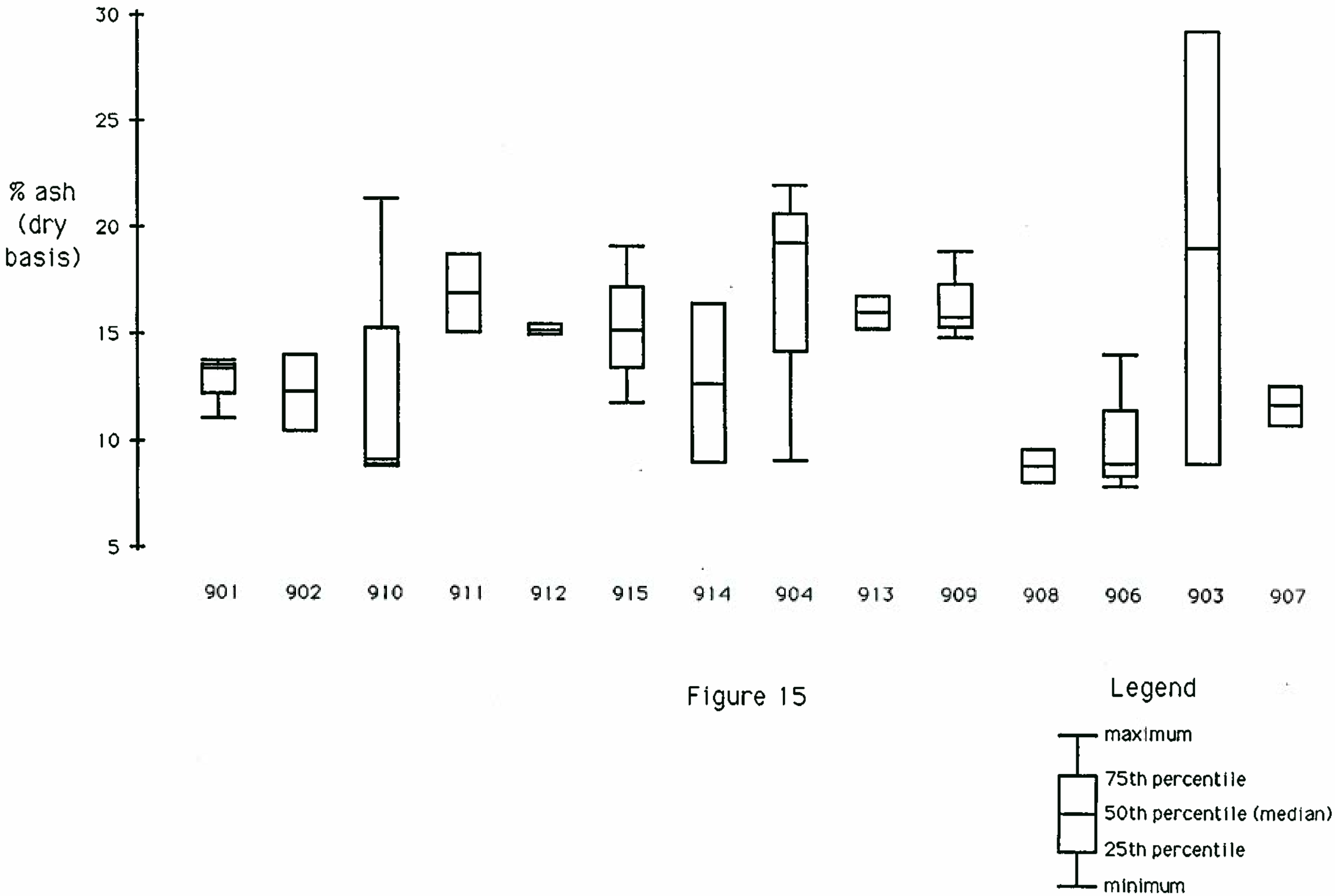


Figure 15

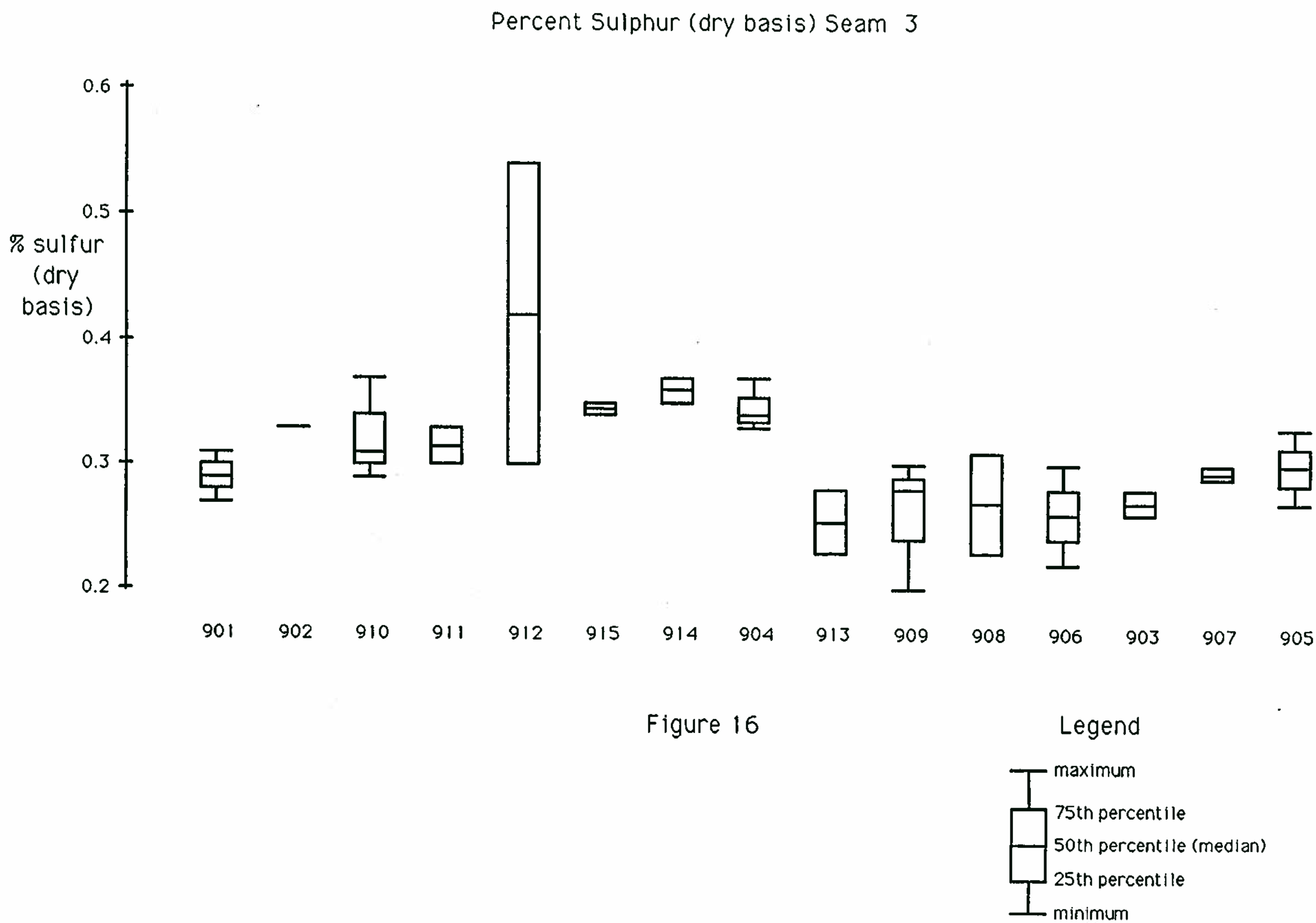

Percent Sulphur (dry basis) Seam 3
0.6
0.5
% sulfur
(dry
basis)
0.4
0.3
0.2
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 16

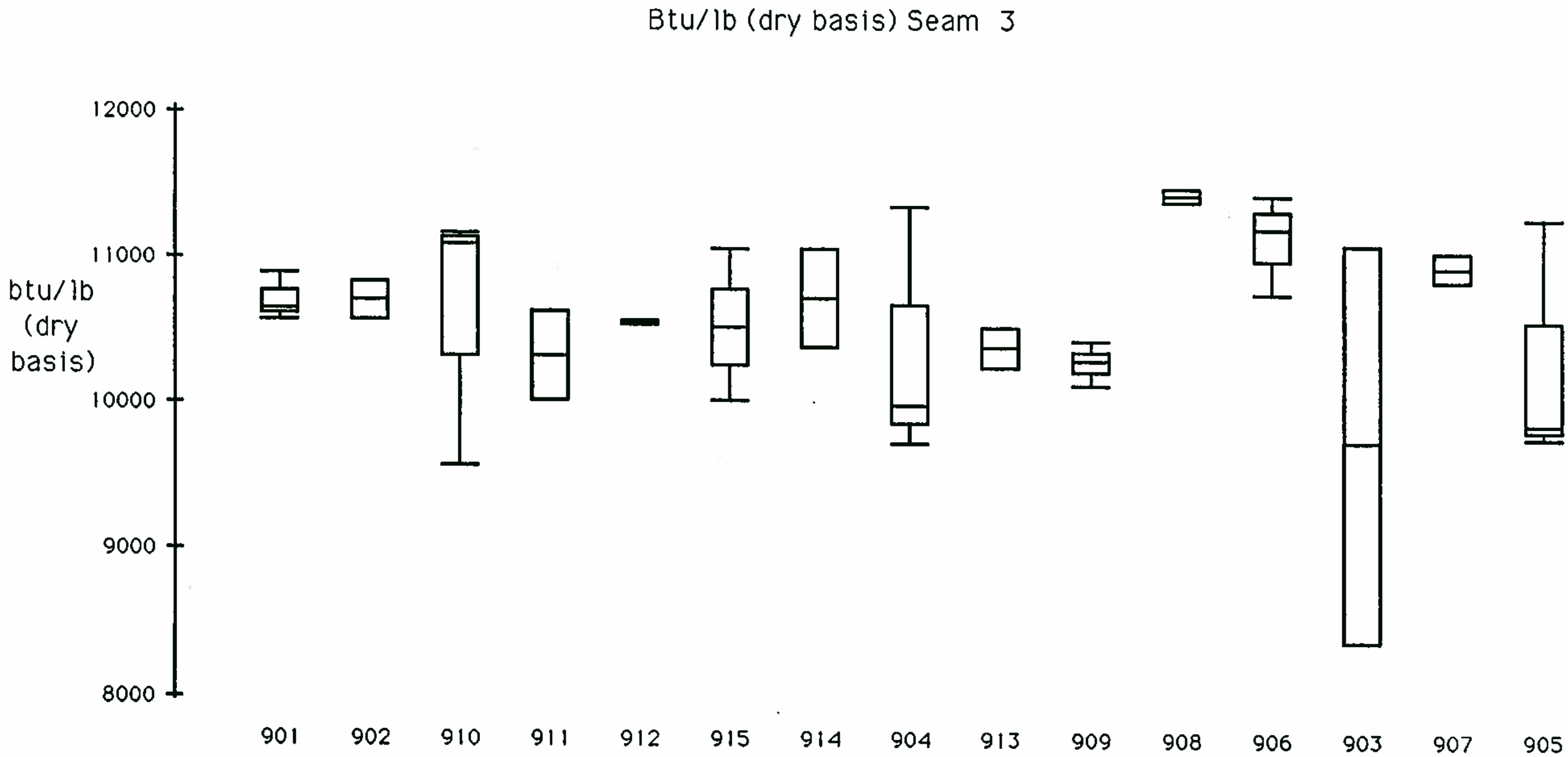
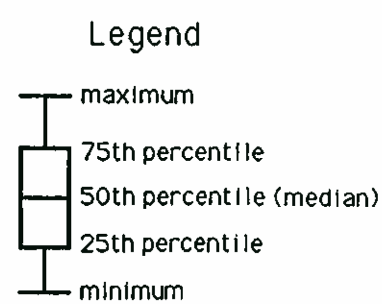

Btu/lb (dry basis) Seam 3
12000
11000
10000
9000
8000
btu/lb
(dry
basis)
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905

Figure 17


Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

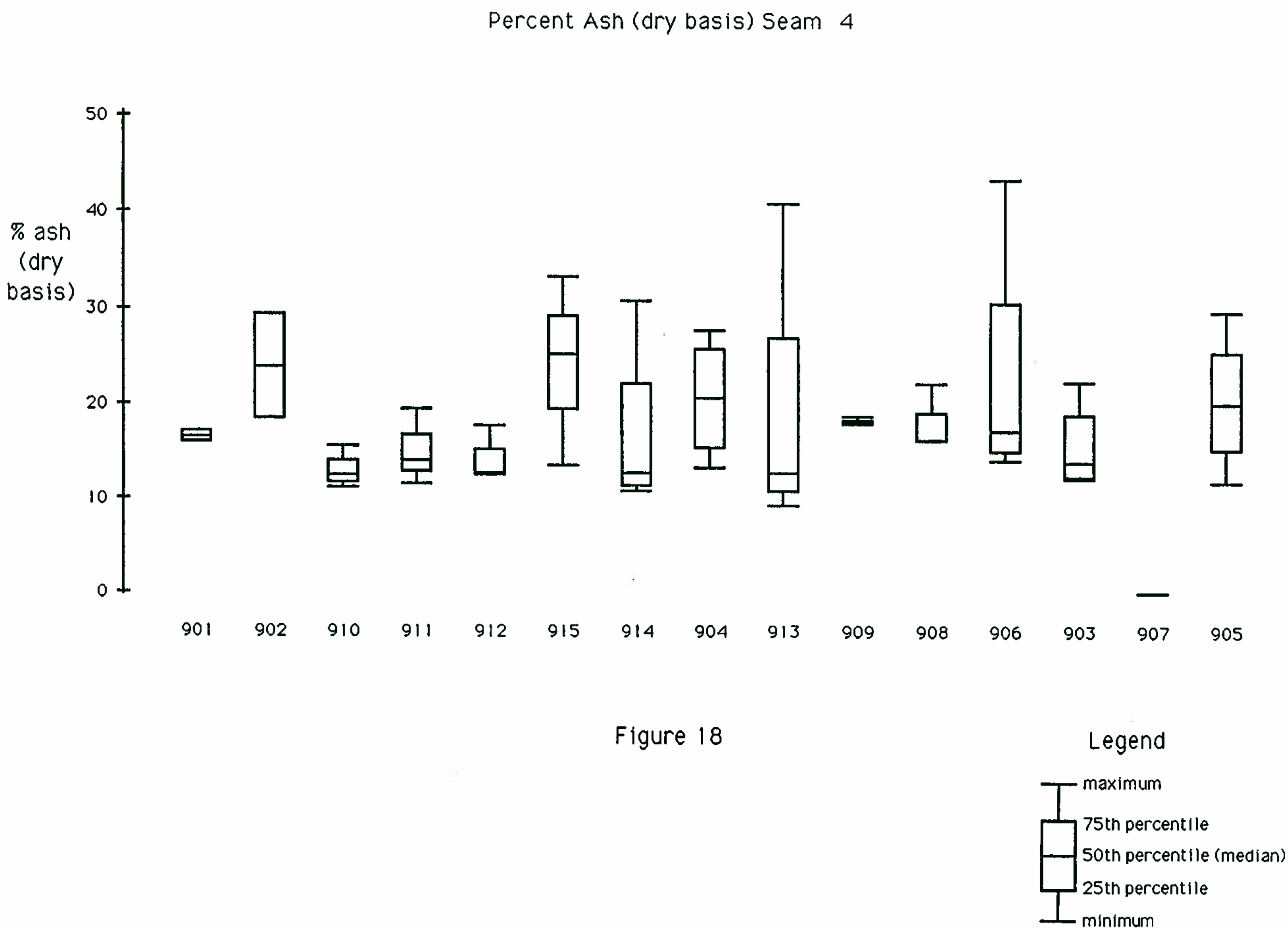

Percent Ash (dry basis) Seam 4
% ash (dry basis)
50
40
30
20
10
0
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 18

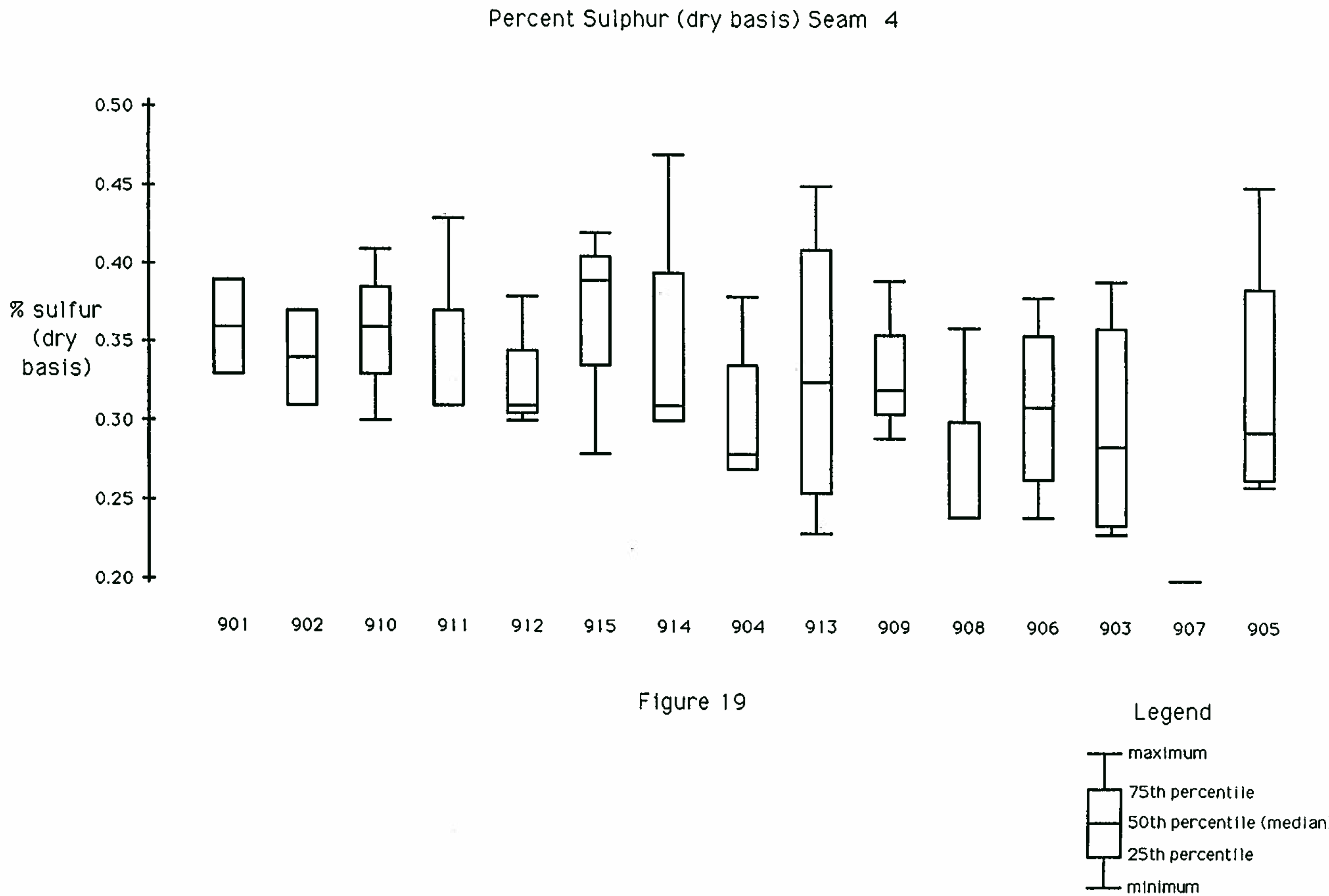
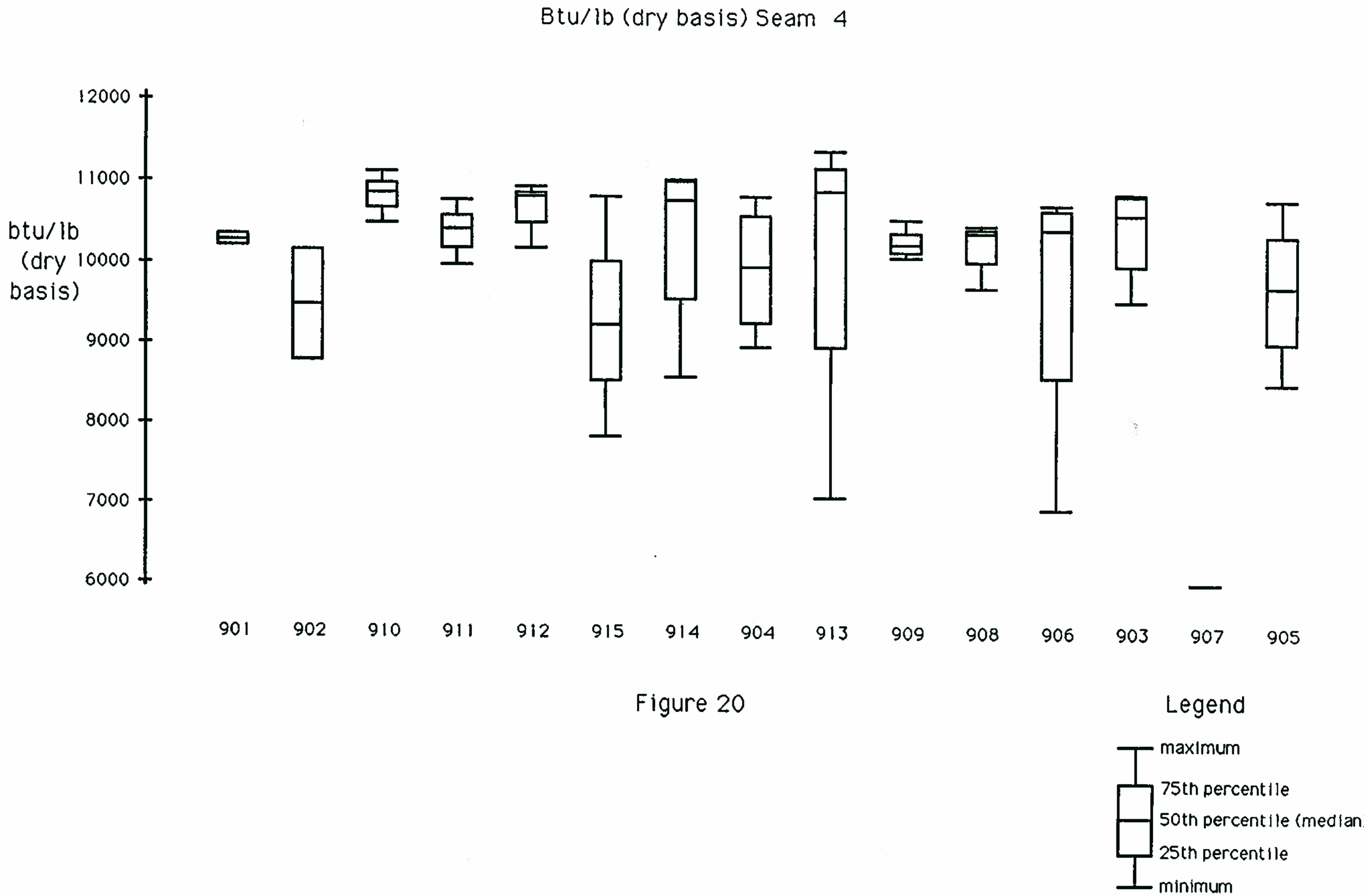

Percent Sulphur (dry basis) Seam 4
0.50
0.45
0.40
% sulfur (dry basis)
0.35
0.30
0.25
0.20
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 19

range of median values for sulfur for all fifteen drill holes is 0.24% to 0.39%. Calorific value (dry basis) varies from 6932 btu/lb (16124 kJ/kg) to 11382 btu/lb (264475 kJ/kg) with a median value of 10400 btu/lb (24190 kJ/kg) and a variance of 1025806 btu^2/lb^2 (2386025 kJ^2/kg^2) (figure 20). The range of median values for calorific value for all fifteen drill holes is 9242 btu/lb (21497 kJ/kg) to 10906 btu/lb (25367 kJ/kg). Seam 4 represents the end of the stagnant swamp which formed the units from seam 6 to seam 4.

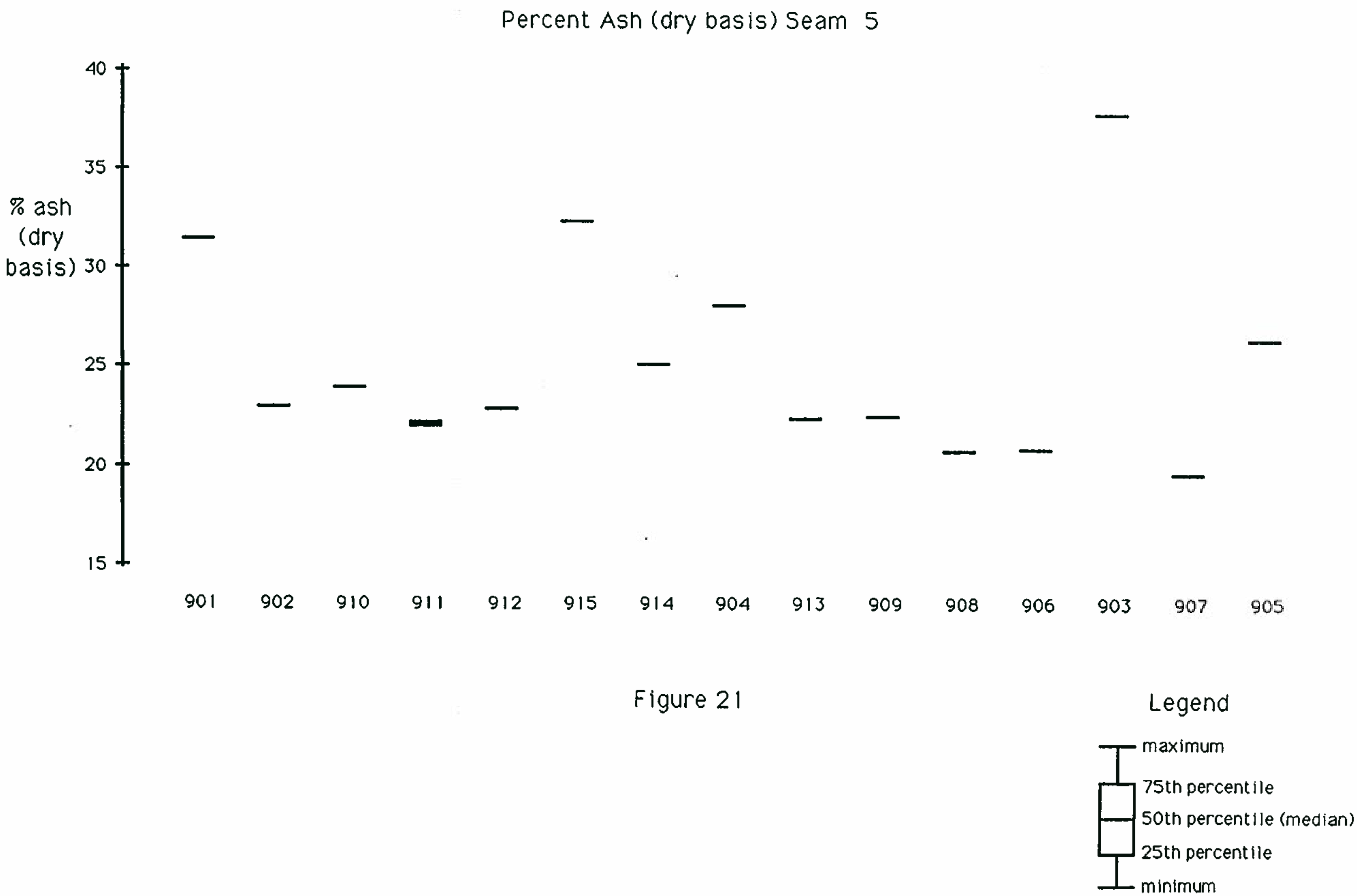
Seam 5 - Seam 5 was excluded from most of the plots because it is too thin to recover at Highvale. The amount of sampling for seam 5 is also too small to obtain meaningful results. The thickness of this coal seam across Pit 3 varies from 0.08 metres to 0.32 metres. Ash (dry basis) varies from 19.7% to 37.82% with a median value of 23% and a variance of 24.729 (figure 21). The range of median values for ash for all fifteen drill holes is 19.7% to 37.82%. Sulfur (dry basis) varies from 0.32% to 0.54% with a median value of 0.405% and a variance of 0.00268 (figure 22). The range of median values for sulfur for all fifteen drill holes is 0.32% to 0.54%. Calorific value (dry basis) varies from 7489 btu/lb (17419 kJ/kg) to 10009 btu/lb (23281 kJ/kg) with a median value of 9567.5 btu/lb (22254 kJ/kg) and a variance of 484090 btu^2/lb^2 (1125993 kJ^2/kg^2) (figure 23). The range of median values for calorific value for all fifteen drill holes is 7489 btu/lb (17419 kJ/kg) to 10009 btu/lb (232281 kJ/kg).

Seam 6 - Seam 6 is the lowest coal seam mined at Highvale mine. The thickness of seam 6 across Pit 3 varies from 0.97 metres to 1.21 metres, consistent with the rest of the mine. Ash (dry basis) varies from 5.3% to 59.78% with a median value of 13.66% and a variance of 80.97 (figure 24). The range of median values for ash for



Btu/lb (dry basis) Seam 4
btu/lb (dry basis)
12000
11000
10000
9000
8000
7000
6000
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 20



Percent Ash (dry basis) Seam 5
% ash (dry basis)
40
35
30
25
20
15
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 21

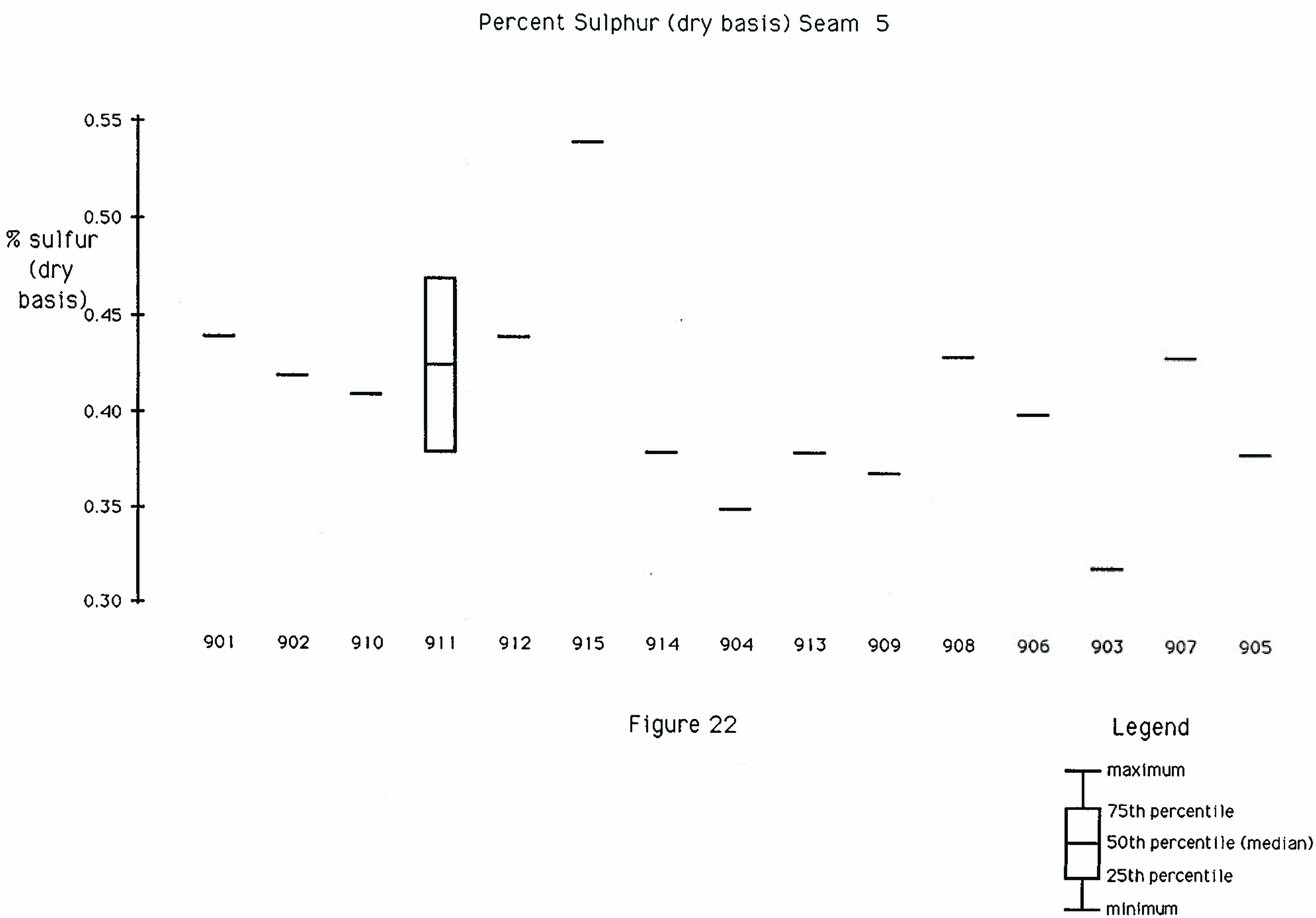

Percent Sulphur (dry basis) Seam 5
% sulfur (dry basis)
0.55
0.50
0.45
0.40
0.35
0.30
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 22

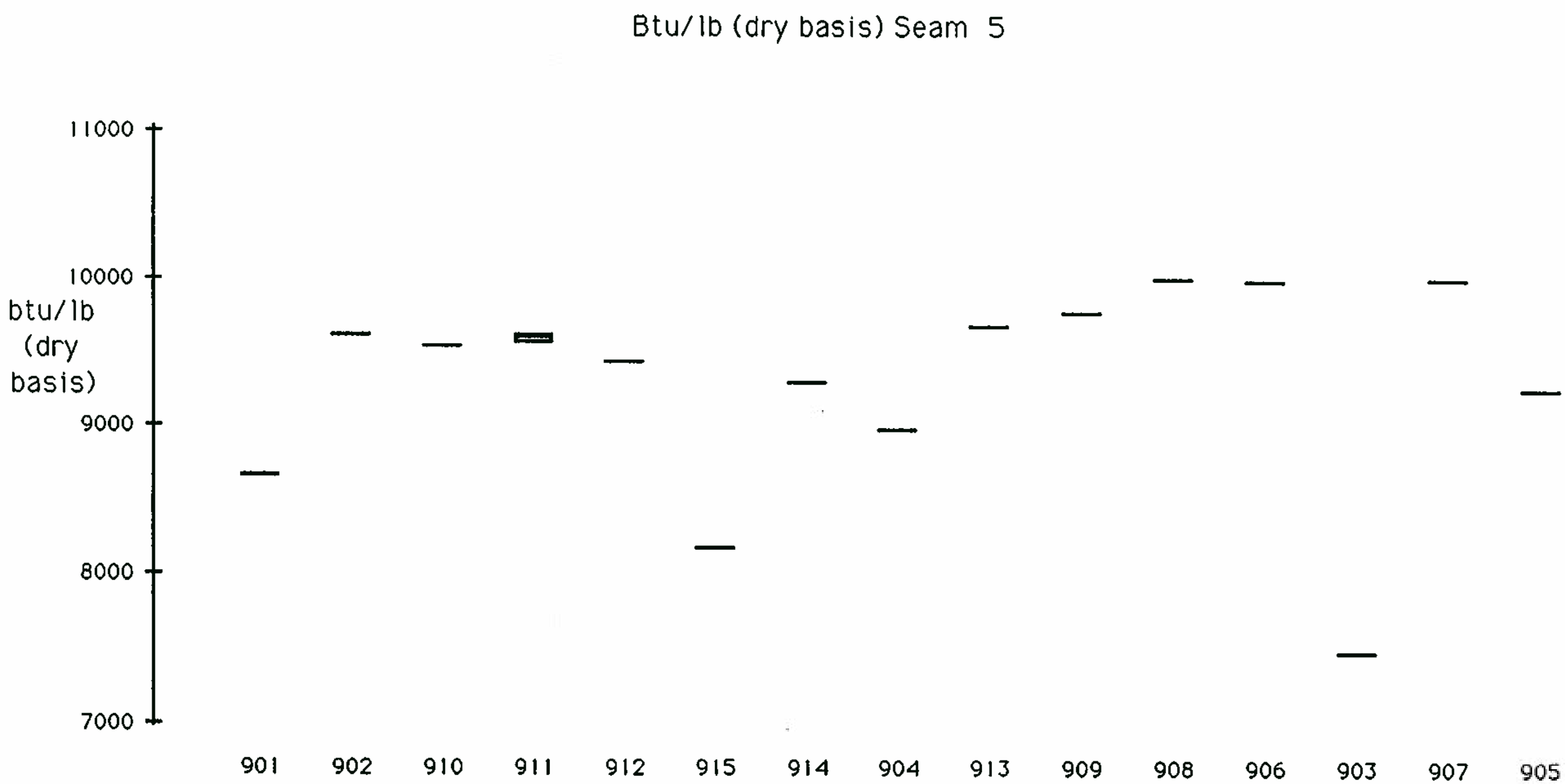


Figure 23

Legend

maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Percent Ash (dry basis) Seam 6

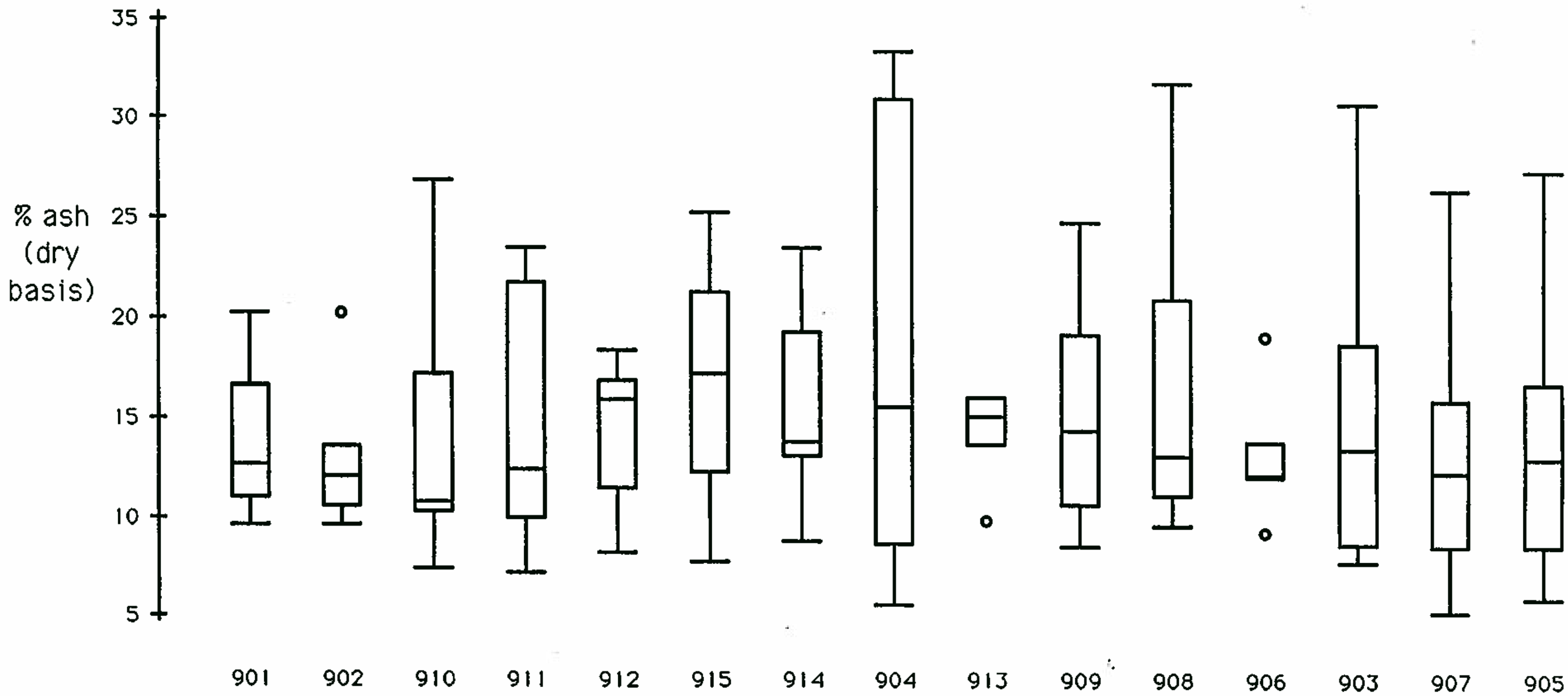
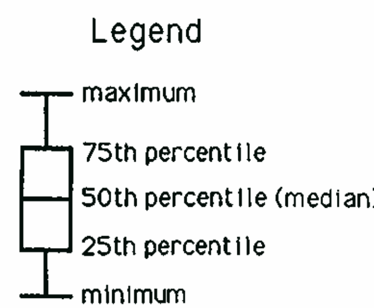


Figure 24



all fifteen drill holes is 10.86% to 17.21%. Sulfur (dry basis) varies from 0.12% to 0.48% with a median value of 0.32% and a variance of 0.00326 (figure 25). The range of median values for sulfur for all fifteen drill holes is 0.29% to 0.36%. Calorific value (dry basis) varies from 4150 btu/lb (9653 kJ/kg) to 12138 btu/lb (28233 kJ/kg) with a median value of 10839 btu/lb (25212 kJ/kg) and a variance of 1612540 btu^2/lb^2 (3750768 kJ^2/kg^2) (figure 26). The range of median values for calorific value for all fifteen drill holes is 10317 btu/lb (23997 kJ/kg) to 11394 btu/lb (265502 kJ/kg). The parting which divides this seam into a lower and upper subseam increases the ash and decreases the sulfur and calorific value.

Conclusions

The detailed study of the coal quality in Pit 3 at Highvale Mine and further comparison to the entire mine and the Ardley coal zone has shown that the heterogeneity of coal influences the variability of the coal quality at the smallest scale of investigation, in this case within one seam in a single drill core. When comparing the coal quality data from the fifteen drill holes to the data across the entire mine we notice an increase in range of values at the larger scale. There is a greater increase when we look at the entire Ardley coal zone. These comparisons between a single mining pit, a mine and an entire coal zone not only illustrate the increase in variability and range in values with an increase in scale of investigation but also aid in the determination of the representativeness of the coal quality study results when predicting coal quality parameters across a large area.

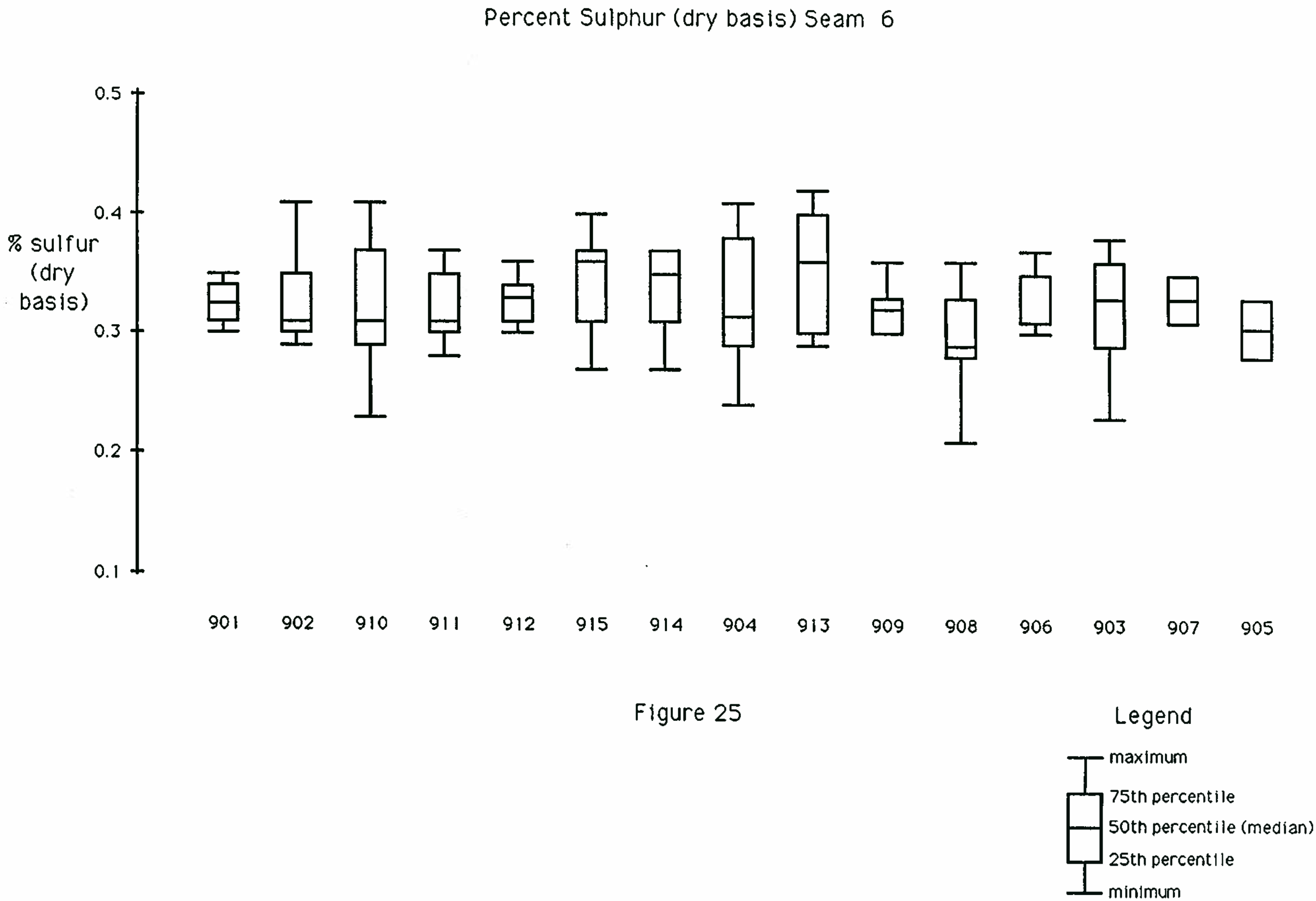

Percent Sulphur (dry basis) Seam 6
% sulfur (dry basis)
0.5
0.4
0.3
0.2
0.1
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 25

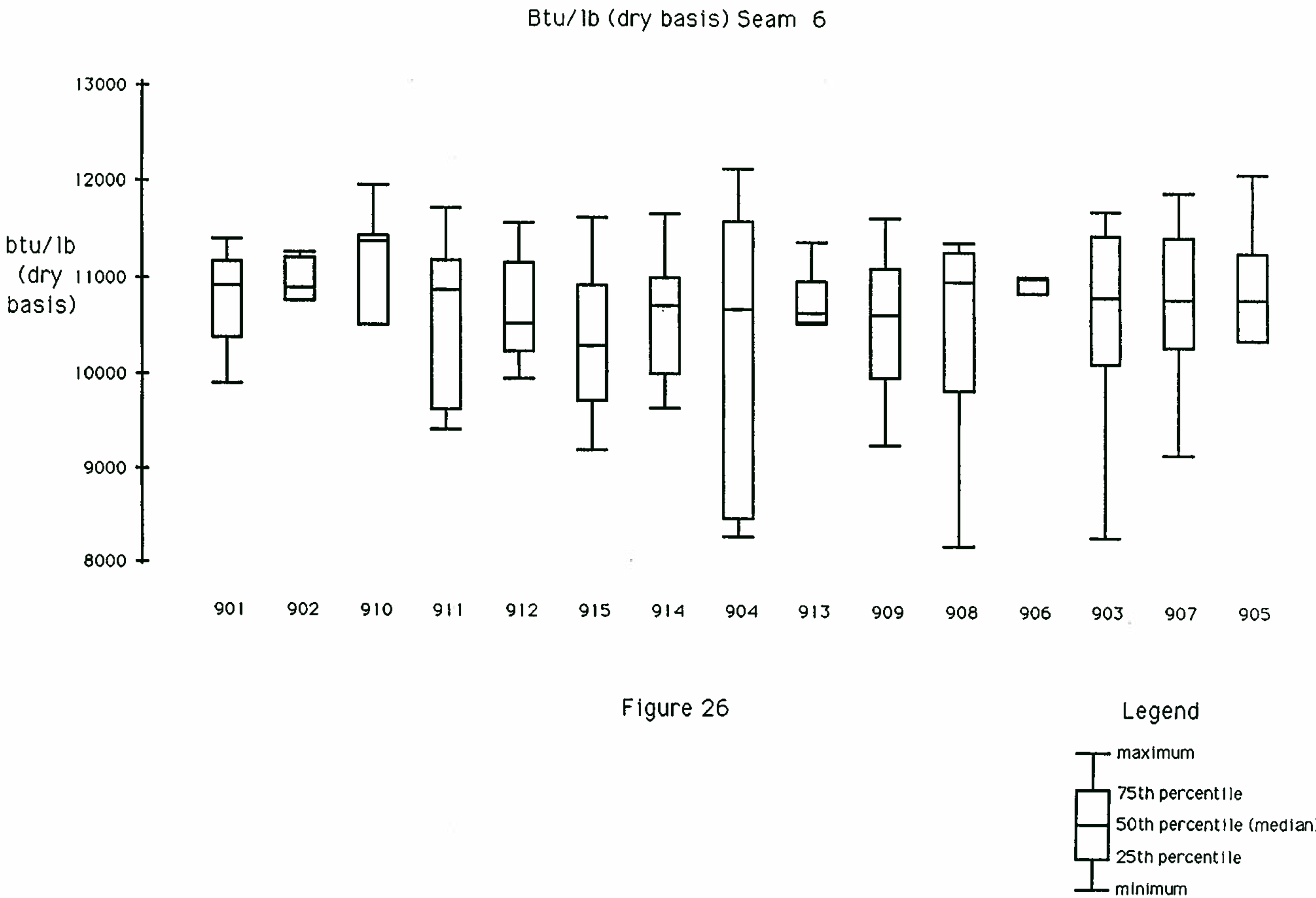

Btu/lb (dry basis) Seam 6
btu/lb (dry basis)
13000
12000
11000
10000
9000
8000
901
902
910
911
912
915
914
904
913
909
908
906
903
907
905
Legend
maximum
75th percentile
50th percentile (median)
25th percentile
minimum

Figure 26

Pit 3 reflects the results found for the entire mine, with less variation along the trend of the coal. Seams 1 and 2 exhibit the highest coal quality and have the greatest thickness making them the primary seams in the mining process. Seam 5 is not utilized in the mine and in Pit 3 exemplifies the poor quality and thinness that is seen throughout the mine. The remaining seams fall somewhere in between the two extremes. All of the seams remain fairly consistent in thickness along the entire pit except for seam 5 which splits creating an additional seam at drill hole 83-902.

To complete the objective of this study, namely to determine how geologic factors influence various coal quality parameters in conventional and emerging utilization processes, more study examining different settings of deposition is necessary. This is essential to fully understanding the exact effect that geology has on coal quality variation. At Highvale, we know that there was extensive swamp development with little sediment input. This is shown throughout the mine with the small range in values for the coal quality parameters and the low ash and sulphur found particularly near the middle of the seams.

We have looked at the variations in calorific value, sulfur and ash. If these values show wide or narrow ranges of variation, we can reasonably expect other measures of physical-chemical-petrography to also show similar ranges of variation. Given the differences observed within and between seams, pits, mines and zones, it should be obvious that any sample or set of samples would be truly representative of only themselves until or unless they were placed in some type of statistical relationship. All too often researchers have worked with a coal sample to find that conclusions found were not necessarily applicable to the next sample or mining pit as a whole, this is particularly true of relatively thin multiseam occurrences.

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