The Correlation of Kootenay Coal Seams[1]

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ABSTRACT

In the course of coal studies undertaken by the B.C. Department of Mines in southeastern British Columbia special attention was directed to problems of coal seam correlation. Methods that had been used successfully in other coalfields were found, in the Crowsnest area, to have a restricted use or furnished only additional evidence that might prove helpful when used in conjunction with other criteria.

A correlation technique involving semi-quantitative spectrographic analyses of coal ashes was developed. Elements detected in the ash include Si, B, P, Fe, Mg, Mn, Pb, Ti, Cr, Ga, Ca, Al, Ge, Ba, Mo, V, Ag, Yb, Na, Zn, Zr, Ni, Co, Sr, Cu, K. Of these the elements found to be most useful in correlation were, Na, Ba, Si, V, and Mg. The element Na was invariably detected in the ash from one of the seams but was not found in samples taken from the other coal seams. In all of the four seams sampled statistically significant differences in the amount of certain trace elements were noted. When the values obtained for these trace elements were portrayed in the form of histograms the resulting diagrams had a characteristic shape for each seam. The diagrams provided a basis for seam identification within the limited area (8000 feet by 4000 feet) that was investigated.

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INTRODUCTION

During the field seasons of 1946, 1947, and 1948 the British
Columbia Department of Mines undertook a geological investigation of the
coal measures of southeastern B.C. As field work progressed in the
Crowsnest area it was found that within the Kootenay formation, which
contains all the commercial seams of the region, that the coal beds
are the most persistent stratigraphic units. Because of relatively
rapid changes in both the thickness of the seams and the interval
between seams, difficulty has invariably been experienced in attempts
at correlation. Even short-range correlations by able geologists who
have worked in the Crowsnest Coal Basin have been (regarded with suspicion)
by the operating companies. It was apparent, therefore, that a more
dependable correlation technique was needed so that stratigraphic and
structural studies could be of greatest value.

This paper presents firstly a summary of the results obtained
in attempted correlations using methods that have been found effective
in other coalfields. Secondly, a method based on semi-quantitative
spectrographic analysis of coal ash is described and the apparently
promising results are discussed.

PART I - CORRELATION OF COAL SEAMS BY ESTABLISHED OR SUGGESTED METHODS

A survey of the literature showed that the following methods have been used with varying success in the correlation of coal seams.

1. Lithology and Stratigraphy

    (a) Cyclothems

    (b) Marine bands

    (c) Continuous tracing

2. Plant Remains

    (a) Distribution of Flora

    (b) Spore identification

    (c) Cellular plant debris

3. Non marine fossils

4. Inherent characters of the seam

5. Fuel Ratio

6. Coking characteristics

An attempt was made to apply or evaluate the effectiveness of each of these methods in the Crowsnest area.

1. Lithology and Stratigraphy

Comparison of carefully measured and described sections of the Coal Measures in the Coal Creek area showed a rapid lateral variation of the sediments. Binocular examination of samples of the Kootenay sediments failed to reveal useful marker horizons to which the coal seams could be related. However, several of the conglomerates were found to be useful marker beds within limited areas. Attempts to separate heavy minerals from several of the Kootenay sandstones yielded residues that were too small for a satisfactory identification. It was not found possible to study the roundness or sphericity of sand grains because of the tendency for the sandstones to break through rather than around the grains.

1. (a) Cyclothems

In the central and eastern United States Wanless (1932) made effective use of cyclical repetition of strata in the correlation of coal seams. Comparable conditions were not found to be present in the Crowsnest Coal Basin.

1. (b) Marine bands

With the possible exception of the Basal Kootenay sandstone, strata that could be regarded as marine were not discovered in the Kootenay formation.

1. (c) Continuous tracing

In both the Fernie and Michel areas it was found possible to follow a few of the seams from one area to another by walking along the outcrop. Unfortunately this positive method of extending known data was seldom practicable because the outcrops were often concealed by overburden or vegetation.

2. Plant Remains

2. (a) Distribution of flora

In the Nova Scotian coal fields Bell (1945) has used variations in number and variety of plant species collected from the roof shales of coal seams to establish a useful method of correlation. In the Fernie area plant remains were collected from coal seams throughout the Kootenay formation. The collections, which were identified by Dr. Bell at Ottawa, were found to contain only long-ranging species, none of which could be regarded as useful for correlation. Attempts to estimate the percentage distribution of species in several seams failed to give consistent or useful results.

2. (b) Spore studies

In England Raistrick (1933, 1934) and in the United States Thiessen (1924) have developed successful methods of correlation based on studies of the nature and distribution of microspores and megaspores in the coal seams. An attempt was made to apply the described methods to the Fernie and Michel coals.

Polished sections of cubes of coal from four of the Fernie coals were prepared for microscopic examination. A study of both polished and etched surfaces did not reveal the presence either of spores or of significant textural differences such as those described by Williams (1926).

Maceration of some 50 samples of coal from a number of the seams in both the Fernie and Michel areas was undertaken following a procedure suggested by Dr. L. R. Wilson at Amherst College. The following results were obtained.

(a) Although several strong oxidizing solutions were tried only a small percentage of the coal was disintegrated.

(b) The scarcity of microspores obtained in the separations (two or three microspores per slide as compared to several hundred obtained from Pennsylvania coal treated by the same procedure) suggests that few microspores are present in the Kootenay coals of the Crowsnest area. A similar conclusion was reached by I.W. Jones (1936) in his study of Kootenay coals of Alberta, and Fanshawe (1930) has observed that coking coals in general have a noticeably low spore content.

(c) Of the various microspore types that were distinguished no particular species or group of microspores was found to be restricted to a given coal seam.

The results indicated that spore studies would be unlikely to provide a satisfactory correlation technique.

2. (c) Cellular plant debris

Cellular plant material was readily recognized in the polished section and maceration studies. None of the material noted appeared to characterize any one coal seam.

3. Non marine fossils

The few non marine invertebrates that have been found in the Kootenay formation are long-ranging species that are apparently of little value for purposes of age determination or correlation.

4. Inherent characters of the seam

Such properties of the coal seam as its thickness, the nature of the roof or floor, character of the coal (e.g. the relative amounts of bright and dull coal), the nature and number of shale partings, may be of considerable aid in seam identification within limited areas. Unfortunately these characteristics are subject to rapid lateral variation, so that where such data are used as a basis for correlation the method is subject to an error that usually increases with the distance of projection involved.

5. Fuel Ratio

In a report on the Michel Coal Area B.R. MacKay (1933) has used as a basis for correlation the fuel ratio of several of the seams as well as the interval of the seams to a conglomerate marker bed. Because the interval to the marker bed was subject to variation, the fuel ratio became the deciding factor in the identifications made.

Inasmuch as numerous proximate analyses of several of the Coal Creek seams were available for reference at the offices of the Crow's Nest Pass Coal Company it was decided to tabulate some of them in order to see what variations might be expected within a given seam and between several seams. The seams investigated and their approximate stratigraphic position are as follows:

TOP

No. 10 Seam

    35 foot interval

No. 9 Seam

    350 foot interval

No. 5 Seam

      In the case of No. 10 seam proximate analyses were available from 4 different areas within the seam. Samples were obtainable from 3 separate areas from No. 9 seam. For each of the proximate analyses ~~XXXXXXXXXXXXXXX~~ the fuel ratio ($\frac{F.C.}{Vol.\ matter}$) was calculated. Values that appeared to be anomalous were discarded if the ash of the sample was greater than 25% or if the interval sampled did not include the greater part of the seam. For each of the groups of samples the highest and lowest values of the series together with the average value have been recorded in the following table.

Seam No.	Mine No.	No. of Samples	Fuel Ratios			
			Highest Value	Lowest Value	Mean Value	Seam Average
10	1 E	10	2.99	2.50	2.80	
10	1 N	15	2.68	2.14	2.43	2.57
10	1 S	30	2.79	2.16	2.53	
10	Old #1	26	2.84	2.13	2.52	
9	2	21	3.04	2.31	2.68	
9	3	6	3.72	2.91	3.06	2.80
9	Old #9	7	3.0	2.35	2.67	
5	5	36	3.12	2.57	2.82	2.82

From the tabulation it can be seen that the variation both of individual values and of averages of several samples within one seam is such as would exclude the possibility of seam identification in the Coal Creek area being based on the determination of fuel ratios. However, it is interesting to note that the seam average column indicates an increase of fuel ratio in the direction of the lower seams, which one would expect from Hilt's Law.

In the case of No. 10 seam the more easterly and more deeply covered part of the seam, represented by the samples from the No. 1 E mine, has the highest fuel ratios. A similar eastward increase exists in the No. 9 seam where the No. 3 mine is east of and down dip from the other two sampled areas. It appears that the variation in the load supported by the seams here considered has resulted in a situation where a part of the uppermost seam has a fuel ratio (2.80) that differs but slightly from the fuel ratio (2.82) of a seam several hundred feet lower in the section. Inasmuch as comparable conditions may exist in other parts of the Coal Basin, it seems unlikely that correlations based on fuel ratio determinations could be made successfully.

6. Coking characteristics

In the Peace River area of British Columbia variations in the tendency to coke of some of the seams have, according to Mathews (1949), proven helpful in the identification of certain seams. In the Coal Creek and Michel areas, however, many of the coals studied had rather similar coke-forming properties.

Because none of the foregoing methods appeared to provide a dependable basis for correlation it was decided to study other properties of the coals with the hope of developing a correlation technique that would permit the solution of local problems of identification and might also be of use in other coal areas. The methods studied involved:-

A. Determination of the radioactivity of certain coals.

B. Semi-quantitative spectrographic analyses of the ash from several coal seams.

A. Radioactivity Measurements

Six 30 gram coal samples from each of 4 of the seams at Michel were tested with the Geiger-Mueller counter at the Department of Mines laboratory. Each of the 24 samples was left in the counter for a period of 150 minutes, and the radioactivity count (less the background) was recorded.

It was found that when the values obtained were plotted on a graph of radioactivity content versus ash content, that a direct relationship existed. The higher ash samples showed correspondingly larger radioactive values. The results obtained, therefore, were considered useless for purposes of correlation.

PART II - CORRELATION OF COAL SEAMS BY SPECTROGRAPHIC ASH ANALYSES

Introduction

It had been noted that the ash from certain seams in both the Michel and Fernie areas appeared to have a colour that was distinctive. Some of the ash, for instance, was quite red; some pure white; others cream- or maroon-coloured. These colours could be attributed to the iron, silica or alumina content of the ash.

As may be seen in the following table determinations by Swartzman (1940) showed differences in the fusion point and chemical composition of the ash of two of the Michel coals.

Seam No.	Sample of	Size in.	SiO_2	Fe_2O_3	Al_2O_3	CaO + MnO	MgO	Na_2O	K_2O	P_2O_5	TiO_2	SO_3	Total	Ash Fusion Point Initial Deformation
"A"	Run of Mine	0-4	51.3	4.4	35.5	2.4	1.3	Nil	0.8	0.1	1.5	2.5	99.8	2650-2850 + °F
"B"		0-4	47.3	19.1	20.2	3.8	1.6	Nil	1.9	0.9	0.7	4.5	99.9	2040-2850 +

One wonders how consistent these differences might be, and whether certain metals might be present or concentrated only in one coal seam. It was felt that semi-quantitative analyses of the ash from various coal seams should provide an answer to this question. Moreover the use of spectrographic analyses as an aid to correlation of stratigraphic sections had been recently demonstrated in a paper by Sloss and Cooke (1946), to which the reader is referred for a more extensive treatment of analytical technique and theory than will be given here.

It was decided, therefore, to undertake a sampling and ash analysis program. The Michel area was selected for two reasons.

1. A problem of seam identification had arisen in the underground operations at the Michel colliery.

2. Accessible underground workings at Michel are the most extensive in the coal field.

In the ash from the coal seams sampled the following elements were detected in many of the samples:- Si, B, P, Fe, Mg, Mn, Pb, Ti, Cr, Ga, Ca, Al, Ge, Ba, Mo, V, Ag, Yb, Na, Zn, Zr, Ni, Co, Sr, Cu, K. In addition Be, Sc, Sb, Nd, La, Bi, Sn, were present in a few of the samples. The elements found to be most useful in correlation include Na, Ba, Si, V, and Mg. Variations in the Ni, Sr, and Al content were also helpful. It is interesting to note that the list of eight elements found effective in the correlation of coal seams includes Mg, Sr, and Al, the three elements found most dependable by Sloss and Cooke (1946a).

Previous Work

A rather extensive study of the rare elements present in coal ash has been made by V.M. Goldschmidt (1933). In his report Dr. Goldschmidt observed that an abundance of very different rare elements has been concentrated in coals and suggests that the most important processes responsible for this concentration are the following.

1. Concentration processes during the life of the plants.

2. Concentration processes after decay of the plant parts concerned, and during the rotting and decomposition of plant substance.

3. Concentration processes resulting from the circulation of aqueous solutions through the beds of coal.

The effect of such processes of concentration was shown by the following table.

Elements	Content in Coal Ash Highest Value – Mean Value		Average content in lithosphere	Concentration Factor Highest Value – Mean Value	
Be	0.1 %	0.03 %	0.0002-0.0001 %	100-500	30-150
B	0.3		0.0003	1000	
Sc	0.04	0.006	0.0003-0.0006	70-130	10-20
Co	0.15	0.03	0.001	150	30
Ni	0.8		0.01	80	
Zn	1.0		0.02	50	
Ga	0.04	0.01	0.001-0.0015	30-40	7-10
Ge	1.1	0.05	0.0004-0.0007	1600-2800	70-120
As	0.8		0.0005	1600	
Y	0.08	0.01	0.001	80	10
Mo	0.05	0.02	0.0015	30	13
Sn	0.05	0.02	0.005	10	4
Pb	0.1		0.0016	70	
Ag	5-10 g. per ton	2 g. per ton	0.19	50-100	20
Au	0.2-0.5 g. per ton		0.0059	40-100	

Goldschmidt believed that the tenfold to one hundred fold
increase of concentration was principally produced by the leaching of
rotting and decaying plant parts. In the case of Ge, however, both
Goldschmidt and Zgorov (1940) have suggested that the concentration
is due to the chemical effect of the coal on solutions circulating
next to it. Goldschmidt observed that some of the rare metals showed
an increase in concentration in the ash from low ash coals, particularly
in the case of Germanium, but made no attempt to demonstrate an increase
in concentration of certain metals in a particular seam.

An attempt was made, however, to use the trace metal content of coal ash to correlate seams in the Charleroi Basin in France by Legraye and Coheur (1944). These authors detected the presence of Al, Mg, Fe, Si, Ca, Cu, Na, K, Mn, Ni, Cr, Ti, Pb, Zn, Sn, Co, Sr, V, and Be in the ashes studied, but concluded that no element or group could serve to characterize any one bed. The spectrographic analyses made were on a qualitative basis only, so that variations in amount of the elements present was not observed.

Sampling Program

At the start of the investigation 12 samples from each of the two most extensively mined seams in the Michel area were obtained. Semi-quantitative spectrographic analyses of the ash from these samples of "A" and "B" seams showed that significant differences existed in the amount of some of the elements present in the two coals. It was decided, therefore, to obtain an additional 12 samples from each of these seams at points as far distant from the original areas sampled as was possible. In addition samples were obtained from two of the lower coal seams, upper number 3 (U3) and lower number 3 (L3) seams. A seam encountered near the face of the Michel rock tunnel, and believed to be either U3 or L3 seam, was also sampled with the hope that a positive identification could be made. This seam and the samples from it were given the designation U3?. Attempts to identify this seam based on determination of stratigraphic intervals had yielded inconclusive results because of local complex folding of the strata.

All of the samples taken were full channel samples of the coal seams. The face of the coal was first cleaned of visible impurities, such as rock dust, and a channel several inches wide and a few inches deep cut through the coal. The chips of coal thus obtained were quartered on a sampling cloth, placed in bags, and transferred to the grinding room at the Michel colliery. Here each sample was ground to minus 20 mesh, coned and quartered, and a representative amount placed in a pint glass sealer for shipment to the laboratory. The locations of the areas sampled are shown on the accompanying plans and cross-section. (figures 1, 2, and 3) The relative stratigraphic positions of the seams that were sampled are approximately as follows:

TOP

"B" seam - 6 feet thick

   120 foot interval

"A" seam - 22 feet thick

   260 foot interval

Upper #3 seam - 10 feet thick

   150 foot interval

Lower #3 seam - 7 feet thick

Analytical Technique

The analyses were made by the Chief Analyst of the B.C. Department of Mines on an A.R.L. Dietert spectrograph using an aluminized grating with a dispersion in the first order of seven-Ångstroms per millimeter. Only the ultra-violet spectra were obtained. "Super pure" grade graphite electrodes, one quarter inch in diameter were used, operating on a 10 ampere-220 volt direct-current source.
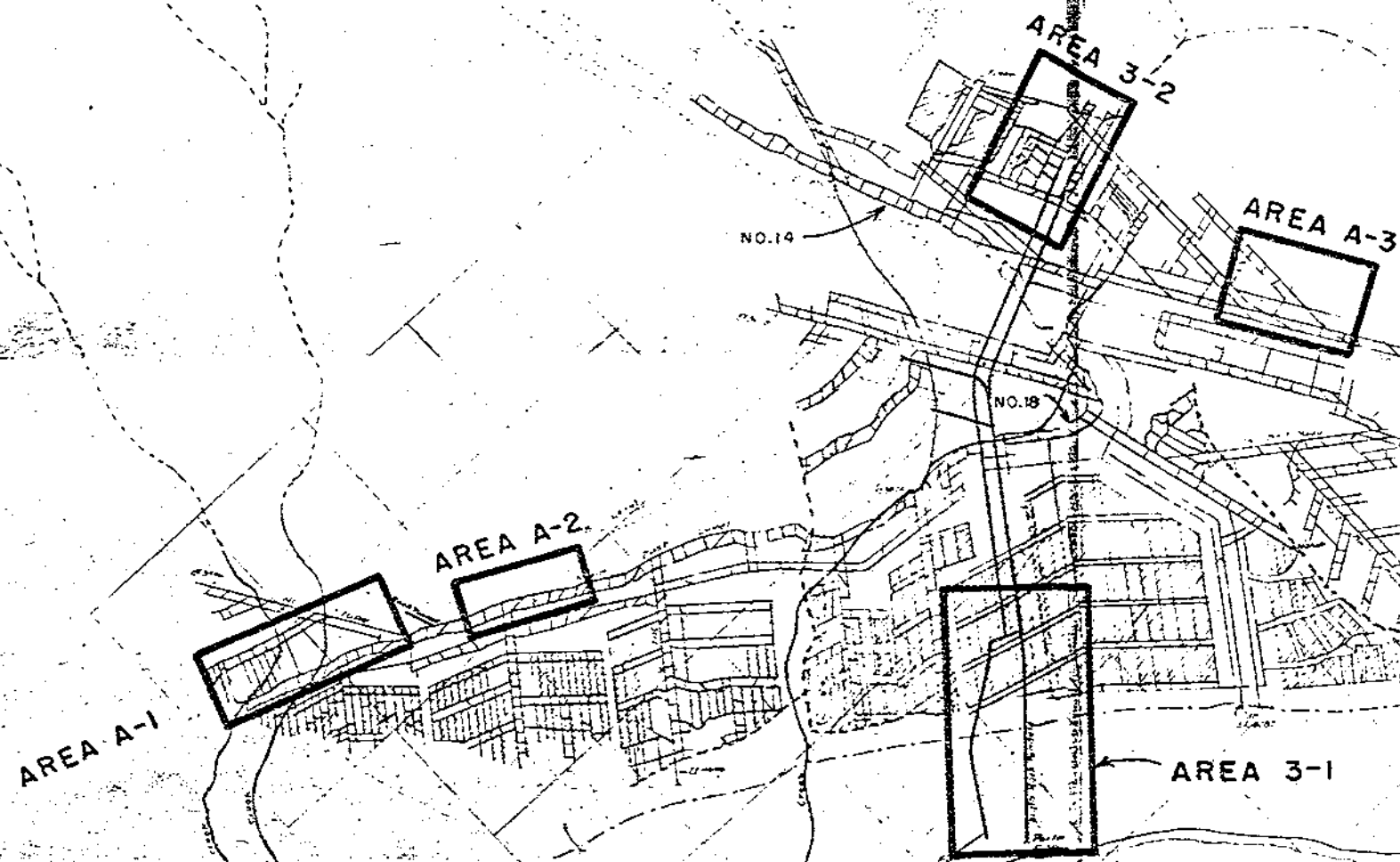
LOCATION OF SAMPLED AREAS

MICHEL COLLIERY

"A" MINE

SCALE 500 0 500 1000 FT.

AREA 3-2

AREA A-3

NO.14

NO.18

AREA A-2

AREA A-1

AREA 3-1

Figure (1)

FIGURE (1)

AREA B-2

AREA B-L

LOCATION OF SAMPLED AREAS

MICHEL COLLIERY

"B" MINE

SCALE 500 0 500 1000 FT.
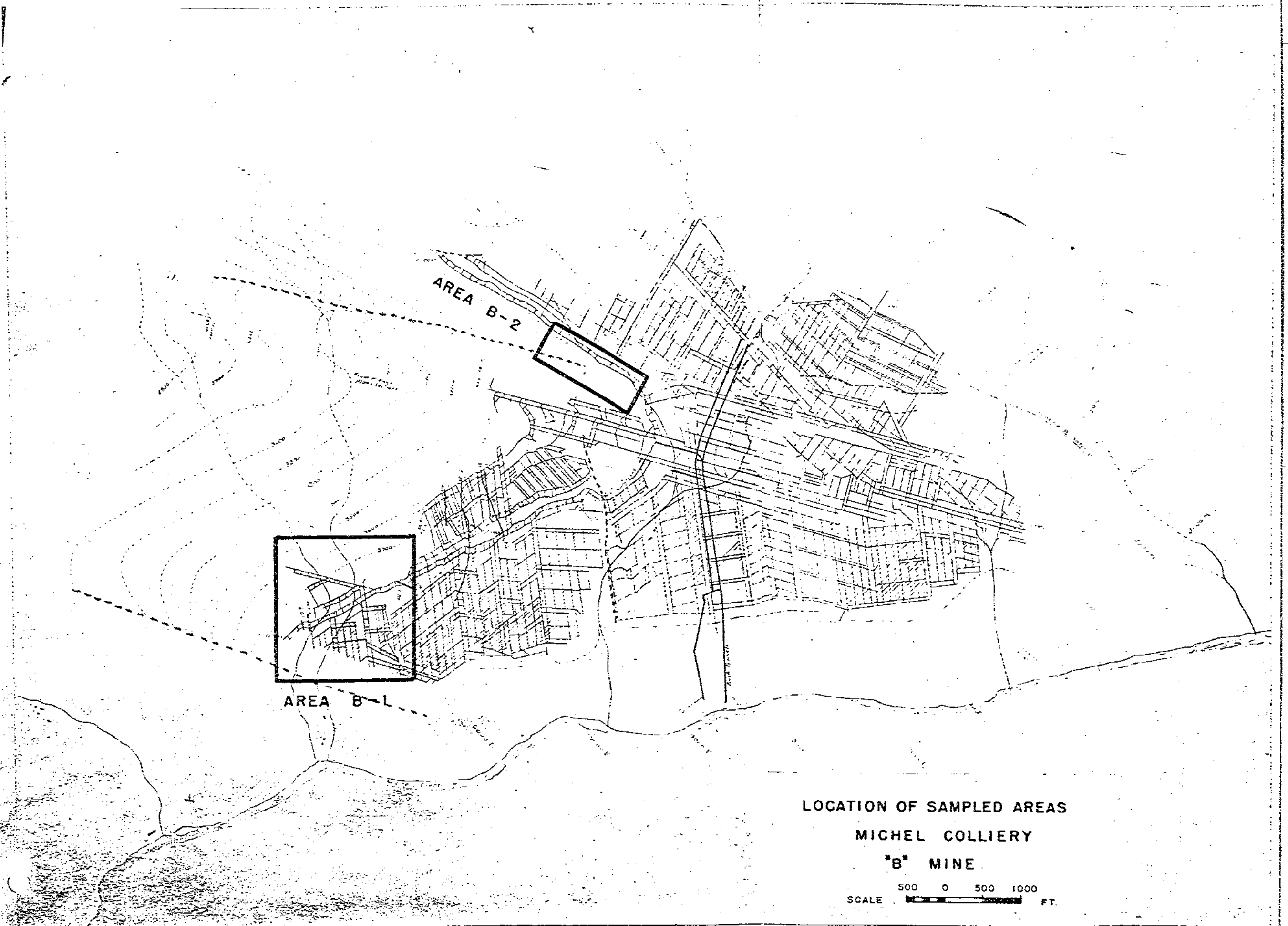
Figure (2)

FIGURE (2)
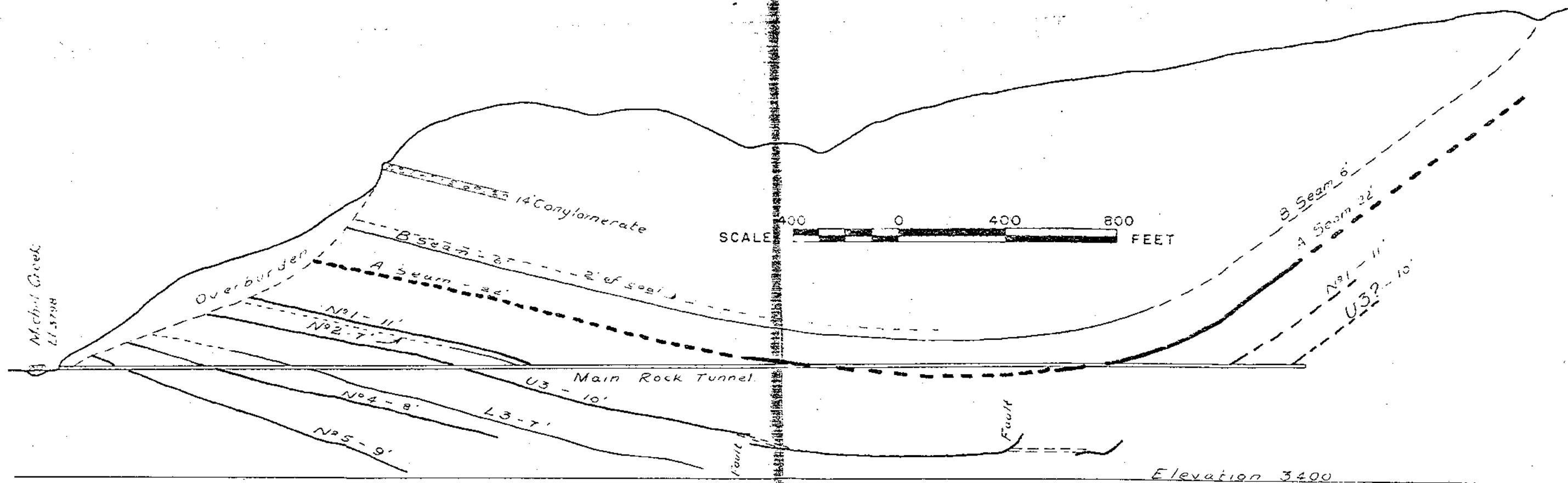
SECTION OF COAL MEASURES AT MICHEL, B.C.

The coal was further ground to minus 60 mesh, ashed at 750° C and after thorough mixing a 50 milligram sample was arced directly. With the arc burning a pie-sector was caused to rotate in the light beam thereby reducing the incident intensity to 30 per cent. After a 20 seconds exposure under these conditions the camera was racked and a 130 seconds exposure made using a 10 per cent. sector. The camera was again racked and the spectrum photographed with a 10 per cent. sector until the balance of the sample had been completely vaporized (approximately another 130 seconds). For each of the elements detected the relative concentration was recorded by densitometer readings which were converted to intensity readings by means of a characteristic intensity curve. These units were scaled down to arbitrary values between 1 and 10 for ease in comparison or statistical treatment of the results. The values given in the tabulation of results are closely proportional to the spectral line densities, which in turn are functions of the amount of the element present. The values may be used in comparing the concentrations of any selected element, but may not be used in comparing the concentrations of the different elements with each other. Because of this restriction the results have been termed "semi-quantitative".

Results Obtained

The spectrographic results of the coal ashes analyzed are given in Tables I, II, and III.

In Table I the results are arranged to facilitate a comparison between the uppermost pair of seams, "A" and "B". Average values for the areas sampled within each seam, as well as averages for the whole seam are given. Similarly Table II is arranged so that a comparison of U3 and L3 seams can be made. In addition samples from Area 3-2,

Spectrographic Analyses of Ash of Michel Coals Table 1

Sam No.	Area	Field No.	Lab No.	% Ash	2438.6 Si	2497.7 B	2553.2 P	2628.3 Fe	2776.7 Mg	2801.1 Mn	2833.1 Pb	2813.9 Ti	4254.5 Cr	2843.6 Ge	3006.9 Ca	3050.1 Al	3059.1 Ge	3071.59 Ba	3132.5 Mo	3383.4 V	3280.7 Ag	3289.2 Yb	3303 Na	3345 Zn	3392 Zr	3131.8 Hi	3453.5 Cg	3464.5 Sr	3273.9 Cu	4044.1 K	
B	B-1	33	11592	21.6	5	6	1	1	4	1	1	3	7	1	1	4	-	-	-	6	-	-	4	1	4	2	-	1	2	6	15
B	"	34	11601	18.5	6	6	1	2	3	1	1	2	6	1	1	3	-	-	1	6	1	-	3	3	2	3	-	-	3	6	15
D	"	35	11614	15.6	4	5	2	1	2	1	1	2	7	2	3	3	-	1	3	5	1	-	3	6	3	5	-	2	3	5	11
D	"	36	11626	18.5	5	7	4	1	3	1	2	3	4	5	3	3	-	-	2	4	2	-	1	6	3	3	-	6	3	4	12
B	"	37	11634	22.5	6	5	1	1	3	-	1	3	5	4	1	3	-	-	-	5	1	-	3	3	4	2	-	2	2	4	14
B	"	38	11644	16.5	5	6	1	1	5	1	7	5	8	7	4	3	-	-	5	7	2	-	9	2	5	3	-	-	3	10	17
B	"	39	11654	17.9	5	5	1	1	4	1	1	3	10	4	2	4	-	-	3	8	1	-	4	3	4	3	-	-	3	6	17
B	"	40	11668	15.3	5	5	1	2	5	1	1	3	6	3	2	3	-	-	1	5	1	-	3	1	5	3	-	1	2	6	15
B	"	41	11671	7.0	6	4	1	1	3	-	2	3	3	4	1	2	-	-	1	4	2	-	6	-	3	3	-	1	3	3	13
B	"	42	11681	13.3	5	5	2	1	4	1	1	5	7	6	4	6	2	-	4	8	1	-	5	3	8	4	-	6	3	4	17
B	"	43	11671	16.1	4	5	3	8	5	6	1	3	4	2	3	3	-	-	5	3	2	-	2	7	3	4	-	3	3	3	12
B	"	44	11704	17.5	4	6	3	10	4	7	1	2	4	4	1	3	-	-	5	6	2	-	4	5	4	4	-	3	3	3	14
B	B-1	Average		16.7	5.0	5.4	1.8	2.5	2.8	1.8	1.7	3.1	5.9	3.6	2.2	3.3	0.2	0.1	2.5	5.6	1.3	-	3.9	3.3	4.0	3.2	-	2.0	2.8	1.3	14.4
B	B-2	57	18501	5.0	4	6	8	4	4	7	8	4	4	5	9	5	10	4	3	2	5	-	10	10	7	.5	4	7	3	2	10
B	"	58	18511	9.3	4	6	2	8	5	9	10	6	6	7	8	6	2	-	10	5	9	10	10	4	10	10	10	5	4	-	14
B	"	59	18521	4.0	4	5	6	5	4	6	8	4	7	10	10	6	4	-	6	5	4	6	7	10	7	6	3	6	3	-	13
D	"	60	18531	3.0	3	5	6	4	3	5	7	4	3	1	8	5	-	-	5	4	2	6	8	3	7	7	4	3	4	-	10
D	"	61	18541	5.8	3	4	5	3	1	3	4	4	2	3	4	3	-	-	4	3	1	-	4	2	6	4	-	3	5	-	7
B	"	62	18591	4.5	5	5	5	2	2	3	4	5	6	8	5	5	2	-	2	4	2	6	4	4	8	5	-	3	4	-	11
B	"	63	18561	5.6	2	5	10	4	4	6	3	3	1	2	9	3	-	-	2	3	3	-	3	7	4	4	2	8	4	-	9
B	"	64	18571	3.8	4	4	3	1	2	1	7	6	10	2	5	7	2	-	2	6	10	7	9	3	10	8	-	5	5	-	12
B	"	65	18581	5.5	3	4	3	2	3	3	3	5	8	1	5	3	-	-	10	5	1	-	4	2	8	5	-	4	3	2	11
B	"	66	18591	3.8	3	4	6	4	2	5	3	5	2	4	4	3	-	-	10	6	6	6	7	8	8	9	4	7	5	-	13
B	"	67	18601	5.1	3	4	2	5	5	8	5	4	6	3	7	7	-	-	7	4	4	4	5	8	8	6	3	10	4	-	12
B	"	68	18611	3.7	3	8	7	2	3	3	7	2	9	8	6	1							8	6	1	4		9	4	2	14
D	B-2	Average		4.4	3.4	5.0	5.3	3.7	3.3	4.9	5.3	4.4	5.2	4.0	6.9	4.8	2.0	-	5.8	4.6	4.0	4.1	6.3	5.5	7.0	6.7	2.6	5.8	4.3	0.3	11.3	14.0
B	B1&2	Average		10.6	4.2	5.2	3.6	3.1	3.6	3.4	3.5	3.8	5.6	3.8	4.6	4.1	1.1	-	4.2	5.1	2.7	2.1	5.1	4.4	5.5	5.0	1.3	3.9	3.6	2.8	12.9
A	A-1	21	11361	13.7	2	3	7	2	1	2	1	4	1	1	5	4	-	-	4	7	-	-	7	4	2	1	3	10	-	7
A	A-1	22	11371	12.4	2	5	3	1	1	2	1	4	2	2	3	3	-	-	3	1	-	-	9	5	1	-	1	5	1	6
A	A-1	23	11381	14.5	2	2	3	4	3	9	1	4	1	1	4	4	-	-	1	2	-	-	-	5	-	-	3	2	-	7
A	A-1	24	11391	12.8	4	5	1	-	1	1	1	8	2	2	2	5	-	-	5	1	-	-	3	6	-	-	1	4	-	10
A	A-1	25	11401	11.1	1	4	4	5	2	3	2	4	1	2	4	4	-	-	2	3	1	-	2	6	1	-	2	5	-	6
A	A-1	26	11411	10.0	2	3	6	5	4	6	2	3	1	3	6	4	-	-	1	1	2	-	6	3	1	-	2	5	-	7
A	A-1	27	11421	9.7	2	3	4	5	4	6	1	5	1	2	3	5	-	-	1	4	-	-	4	6	1	-	1	4	-	10
A	A-1	28	11431	11.7	4	5	1	2	5	2	2	10	3	5	4	5	-	-	4	5	1	-	3	8	2	-	1	5	2	14
A	A-2	29	11441	10.1	2	4	4	3	1	4	2	4	1	4	8	5	-	-	3	4	1	-	8	5	2	2	3	4	-	7
A	A-2	30	11451	11.0	3	4	2	7	6	7	1	6	3	2	5	4	-	-	3	4	1	-	3	7	6	2	-	7	3		13
A	A-2	31	11461	15.8	4	5	1	1	3	1	1	4	6	2	2	3	-	-	1	5	3	-	3	4	2	-	-	4	4	12
A	A-2	32	11471	15.8	5	4	1	1	3	1	1	5	3	1	5	4	-	-	2	5	2	-	2	4	-	-	4	-		13
A	A1&2	Average		12.5	2.7	3.9	3.1	3.0	2.8	3.7	1.3	5.3	2.1	2.3	3.9	4.2	-	-	1.4	3.7	1.5	-	0.3	4.5	3.2	1.3	0.6	1.4	4.9	1.1	9.2
A	A-3	74	18671	12.3	7	8	1	1	3	1	1	4	6	4	2	9	-	-	1	6	-	5	-	4	7	1	-	2	4	2	14
A	"	75	18681	9.0	8	10	1	2	3	1	10	7	3	4	3	8	-	-	2	7	3	-	3	9	2	-	2	4	3	16
A	"	76	18691	15.7	6	4	2	1	1	1	1	5	5	4	2	10	-	-	2	3	-	4	-	3	6	1	1	1	2	-	10
A	"	77	18701	9.6	6	7	1	1	5	1	1	9	5	5	3	9	-	-	2	7	-	5	-	2	9	1	1	1	4	-	16
A	"	78	18711	12.6	7	8	1	1	5	1	1	7	2	5	3	9	-	-	1	5	-	-	2	8	1	1	-	4	-	17
A	"	79	18721	8.9	4	7	1	1	5	1	3	6	6	4	3	5	-	-	2	7	2	6	-	2	9	1	2	-	4	2	16
A	"	80	18731	12.2	5	6	1	1	3	1	1	5	3	3	3	6	-	-	2	5	-	3	-	3	8	1	-	-	3	1	13
A	"	81	18741	10.2	5	9	1	1	3	1	1	4	3	2	4	6	-	-	2	5	-	4	-	3	6	1	-	1	3	3	13
A	"	82	18751	11.0	4	5	1	1	2	1	1	4	3	1	2	8	-	-	2	4	2	-	-	4	7	1	-	1	3	-	14
A	A-3	Average		11.1	5.6	7.1	1.1	1.1	3.4	1.0	2.3	5.9	4.0	3.6	2.8	8.0	-	-	1.8	5.4	0.8	2.0	-	2.9	7.3	1.1	0.6	0.9	3.4	1.3	14.4
A	A1,2,3	Average		11.8	4.1	5.3	2.2	2.2	3.1	2.4	1.7	5.6				1.8	-	-	1.6	4.4	1.2	1.3	0.1	3.6	6.3	1.3	0.6	1.2	4.1	1.3	11.6

TABLE II

Seam No.	Area	Field No.	Lab. No.	% Ash	Si	B	P	Fe	Mg	Mn	Pb	Ti	Cr	Ga	Ca	Al	Ge	Ba	Mo	V	Ag	Yb	Na	Zn	Zr	Ni	Co	Sr	Cu	K	Si+V+Mg	Na+Ni+Sr÷1
U3?	3-2	45	1838K	10.7	3	2	4	2	2	1	4	2	2	1	3	3	-	5	1	2	1	-	-	-	3	1	-	2	4	3	7	0
U3?	"	46	1839M	10.5	5	4	2	2	5	1	7	5	3	1	-	5	-	-	3	4	1	-	-	-	6	2	-	-	4	4	14	-3
U3?	"	47	1840H	8.4	3	2	6	1	3	2	6	4	2	2	5	5	-	4	4	4	2	-	-	2	7	2	-	4	5	2	10	1
U3?	"	48	1841X	9.1	3	2	4	1	2	1	3	4	3	4	-	8	3	3	-	-	-	5	5	2	-	3	4	2	8	0
U3?	"	49	1842H	10.1	3	3	4	1	2	1	6	3	3	2	3	5	-	5	2	3	1	-	-	-	5	2	-	3	3	3	8	0
U3?	"	50	1843H	9.3	2	2	4	3	3	5	4	3	3	1	10	3	-	7	2	4	1	-	-	2	4	2	-	2	5	-	9	1
U3?	"	51	1844K	8.7	2	3	7	2	2	2	1	3	3	3	6	4	-	7	1	4	1	-	-	2	5	2	-	2	5	2	8	0
U3?	"	52	1845H	9.2	4	3	6	1	4	2	6	4	6	8	1.	6	-	5	6	7	10	-	-	7	7	3	3	3	4	6	15	0
U3?	"	53	1846H	9.5	3	3	4	1	4	1	7	3	6	3	3	5	-	10	4	5	1	-	-	3	5	2	-	3	8	3	17	-3
U3?	"	54	1847H	10.3	7	4	3	1	5	3	6	5	6	3	2	8	-	9	3	5	1	-	-	3	7	2	-	2	4	1	10	-1
U3?	"	55	1848H	9.2	5	3	5	2	2	3	4	3	4	1	3	5	-	3	2	3	-	-	-	-	7	2	-	2	4	2	14	-3
U3?	"	56	1849H	10.0	6	4	3	1	3	2	2	3	6	1	2	4	-	2	5	2	-	-	-	3	6	2	-	2	3	3		
U3?	3-2	Average		9.8	3.8	2.9	4.3	1.5	3.1	1.9	4.7	3.5	3.8	2.5	3.4	4.8	-	5.3	2.8	4.1	1.8	-	-	2.2	5.6	2.0	0.3	2.4	4.4	2.6	11.0	-0.4
U3	3-1	69	1862K	7.4	3	6	3	2	2	3	1	3	6	1	4	4	-	6	2	3	-	-	-	3	4	2	-	2	1	4	8	0
U3	"	70	1863H	8.7	2	3	2	3	3	5	1	3	7	2	5	4	-	5	6	4	-	-	-	5	1	1	1	1	2	1	9	-2
U3	"	71	1864H	6.1	4	6	5	1	3	1	-	5	4	3	3	5	-	8	3	5	-	-	-	-	6	3	1	3	4	1	12	1
U3	"	72	1865H	9.4	3	3	2	2	3	3	1	4	2	3	4	4	-	2	1	4	-	-	-	3	6	2	2	1	3	3	10	-1
U3	"	73	1866H	7.2	6	5	6	1	2	4	1	5	3	5	3	9	-	-	5	5	-	6	-	3	10	2	1	2	4	1	13	-5
U3	"	83	1876K	7.3	5	4	7	2	4	5	3	6	4	2	5	9	-	10	6	5	1	-	-	6	7	3	-	4	3	1	14	-2
U3	"	84	1877H	5.8	4	6	7	1	4	2	2	3	6	2	5	8	2	6	3	6	1	4	-	4	6	4	-	4	3	2	14	0
U3	"	85	1878H	9.4	3	6	2	2	4	4	10	2	5	5	5	7	-	8	6	6	2	-	-	2	5	5	-	2	4	5	13	0
U3	"	87	1882H	6.4	5	4	6	7	4	10	1	6	6	2	9	2	-	4	5	-	4	-	-	7	4	3	1	4	-	11	-4
U3	3-1	Average		7.5	3.9	5.2	4.4	2.3	3.2	4.1	2.2	4.1	4.8	2.8	5.0	6.6	0.2	5.4	4.1	4.7	0.4	1.6	-	2.9	5.6	2.9	0.7	2.2	3.1	2.0	11.8	-1.5
L3	3-1	86	1879K	28.2	5	5	1	1	5	2	2	3	3	-	2	6	-	-	2	8	-	-	-	7	5	2	-	-	3	2	16	-4
L3	"	87	1880H	18.7	4	3	1	1	5	1	2	7	5	8	2	6	-	4	3	9	6	5	-	3	5	3	2	1	2	6	14	-2
L3	"	88	1881H	35.0	10	8	1	1	6	1	1	5	4	8	9	6	-	-	2	-	-	-	5	2	-	-	3	5	23	-4		
L3	"	90	1883H	26.4	9	10	6	1	7	2	1	3	10	1	2	5	-	3	2	10	1	-	-	7	3	3	-	-	4	7	26	-2
L3	"	91	1884H	21.2	7	6	2	1	5	2	1	4	4	3	3	5	-	3	2	7	-	-	-	10	6	3	-	1	1	7	18	-1
L3	3-1	Average		25.9	7.0	6.4	2.2	1	5.6	1.6	1.4	4.4	5.1	3.2	1.8	5.6	-	2.0	1.8	8.2	1.4	1.0	-	5.4	4.8	2.6	0.4	0.4	3.0	5.4	20.8	-2.6

TABLE III

Average values – spectrochemical analyses of ash
from Michel coals   Table III.

Seam No.	No. of Samples	% Ash	Si	B	P	Fe	Mg	Mn	Pb	Ti	Cr	Ga	Ca	Al	Ge	Ba	Mo	V	Ag	Yb	Na	Zn	Zr	Ni	Co	Sr	Cu	K	Si+V+Mg	Na+Ni+Sr÷1
B	24	10.6	4.2	5.2	3.6	3.1	3.6	3.4	3.5	3.8	5.6	3.8	4.6	4.1	1.1	-	4.2	5.1	2.7	2.1	5.1	4.4	5.5	5.0	1.3	3.9	3.6	2.8	12.9	9.9
A	21	11.9	4.1	5.3	2.2	2.2	3.1	2.5	1.7	5.6	2.9	2.9	3.4	5.8	-	-	1.6	4.4	1.2	1.3	0.1	3.8	6.3	1.2	0.6	1.2	4.3	1.2	11.6	-3.3
U3?	12	9.8	3.8	2.9	4.3	1.5	3.1	1.9	4.7	3.5	3.8	2.5	3.4	4.8	-	5.3	2.8	4.1	1.8	-	-	2.2	5.6	2.0	0.3	2.4	4.4	2.6	11.0	-0.4
U3	9	7.5	3.9	5.2	4.4	2.3	3.2	4.1	2.2	4.1	4.8	2.8	5.0	6.6	0.2	5.4	4.1	4.7	0.4	1.6	-	2.9	5.8	2.9	0.7	2.2	3.1	2.0	11.8	-1.5
L3	5	25.9	7.0	6.4	2.2	1	5.6	1.6	1.4	4.4	5.1	3.2	1.8	5.6	-	2.0	1.8	8.2	1.4	1.0	-	5.4	4.8	2.6	0.4	0.4	3.0	5.4	20.8	-2.6

believed to represent either U3 or L3 seam and termed U3?, are here
presented. Table III is designed to permit a ready comparison of the
average values from Tables I and II. For each of the elements listed
the wave length at which the determinations were made is given in
Table I. The two columns at the right of each of the tables represent
combinations of element values that are useful in identifying L3 and
"B" seams.

Interpretation of Results

Before comparing the trace element content of the several coal
seams, an attempt should be made to determine what relationship, if any,
exists between the ash content of the coals and the element content of
the coal ashes. An examination of the tables reveals that the element
Germanium is recorded in few of the analyses. However, it is present
in half of the samples from area B-2 (samples 57-68) which were the
lowest ash coals studied. This concentration of values may be regarded
as corroborating Goldschmidt's observation that Ge tends to be concentrated
in the low ash coals.

With regard to the other elements present, no direct
relationship between ash content and trace element content was discerned.
The analyses given here were arranged in order of increasing ash content
for each of the coal seams, and graphs of ash content versus element
content were constructed. No definite trend was apparent. However, in
the case of Ni high values were generally present in the ash from coals
carrying less than 6 per cent. ash, but in coals greater than 6 per cent.
ash a diminution of Ni values with increasing ash was not apparent.
Average values of some of the elements regarded as useful for correlation
purposes for several of the seam areas, arranged in order of increasing
ash content, are given in the following table.

Seam No.	Area	No. of Samples	% Ash	Si	V	Mg	Na	Ni	Sr	Al	Ba	Zn
B	B-2	12	4.4	3.4	4.6	3.3	6.3	6.7	5.8	4.8	-	5.5
U3	3-1	9	7.5	3.9	4.7	3.2	-	5.8	2.9	6.6	5.4	2.9
U37	3-2	12	9.8	3.8	4.1	3.1	-	2.0	2.4	4.8	5.3	2.2
A	A-3	9	11.3	5.8	5.4	3.4	-	1.1	0.9	8.0	-	2.9
A	A1-2	12	12.5	2.7	3.7	2.8	0.3	1.3	1.4	4.2	-	4.5
B	B-1	12	16.7	5.0	5.6	3.8	3.9	3.2	2.0	3.3	0.1	3.3
L3	3-1	5	25.9	7.0	8.2	5.6	-	2.6	0.4	5.6	2.0	5.4

An examination of the average values in Table III shows that
few of the elements detected are concentrated in a single seam. However,
the distribution of Sodium and Barium constitute significant exceptions
to this general tendency, and hence provide a convenient basis for
correlation. On referring to tables I and II it may be seen that Na is
present in all samples from "B" seam but is absent from all samples of the
other seams with the exception of sample number 30. Ba is absent from
the samples of "A" and "B" seams (with one exception) but is present in
almost all of the samples from U3 and U37 seams and in 3 of the 5 samples
from L3 seam. From this distribution it follows that an ash analysis
could be recognized as being from "B", "A" or U3 seam with the following
criteria:

Presence of Na - Sample is from "B" seam

Absence of both Na and Ba - Sample is from "A" seam

Presence of Ba - Sample is from U3 seam

The three samples Nos. 35, 30 and 73, exceptions to the foregoing rules
represent a small percentage error inherent in applying the above criteria.

Some of the trace elements which are present in all four of the seams, show a marked increase in concentration, or may be present in only small amounts, in one of the coal seams. On referring to Table III it may be seen that the average value for Ni in "B" seam is much higher than in the other seams represented. A high value for Sr and a low value for Al also characterize "B" seam. The average values for Si, V, and Mg are distinctly higher in L3 than in the other 3 seams. Are these differences significant, and can they be used as a basis for seam recognition?

To answer this question a complete statistical analysis of all the results should be made. The writer has not attempted such an analysis, but a comparison of a few of the average values should give an indication of the results expected from a complete study of the values. The two cases here selected involve

(1) a statistical comparison of the average values for Ni, Sr, and Al of "A" and "B" seams, and (2) comparison of the average values for Si, V, and Mg of U3 and L3 seams. In case (1) the averages represent the two most extensively sampled areas, with 24 samples from "B" seam and 21 samples from "A" seam. In case (2) the averages are from the two smallest groups of values, with 9 samples from U3 seam and 5 samples from L3 seam.

To test whether the mean of one set of values is significantly different from the mean of another set, or whether the two sets of values are from the same parent population,

$$\text{Let} \quad x_i \quad (i = 1, 2 \ldots \ldots \ldots_n)$$

$$y_i \quad (i = 1, 2 \ldots \ldots \ldots_n^1)$$

be the two sets of samples. Then the mean of each set is:

$$\bar{x} = \frac{\sum\limits_{i=1}^{n} x_1}{n} \qquad \dots\dots\dots\dots\dots\dots(1)$$

$$\bar{y} = \frac{\sum\limits_{i=1}^{n'} y_1}{n'} \qquad \dots\dots\dots\dots\dots\dots(2)$$

Let μ^2 signify the "variance", which is given by the formula

$$\mu_x^2 = \frac{\sum\limits_{i=1}^{n}(\bar{x} - x_1)^2}{n} \qquad \dots\dots\dots\dots\dots(3)$$

$$\mu_y^2 = \frac{\sum\limits_{i=1}^{n'}(\bar{y} - y_1)^2}{n'} \qquad \dots\dots\dots\dots\dots(4)$$

Then let S_{xy} be defined by the formula

$\sqrt{\frac{n\mu_x^2 + n^1\mu y^2}{}}$

$$S_{xy} = \sqrt{\frac{n\mu_x^2 + n^1\mu_y^2}{n + n^1 - 2}} \qquad \dots\dots\dots\dots\dots(5)$$

and let "t" be defined by the formula

$$t = \frac{\bar{x} - \bar{y}}{S_{xy}}\sqrt{\frac{n\,n^1}{n+n^1}} \qquad \dots\dots\dots\dots\dots(6)$$

Then for case (1) $n = 24$ and $n^1 = 21$, the values of $\bar{x}$ and $\bar{y}$ are given in Table III, and with the application of formulas (3) to (6) the following values were obtained.

	"B" Seam			"A" Seam		
Element	$\bar{x}$ (mean)	μ_x^2 (variance)		$\bar{y}$ (mean)	μ_y^2 (variance)	t
Ni	5.0	4.5		1.2	0.57	7.6
Sr	3.9	8.4		1.2	1.01	3.97
Al	4.1	1.5		5.8	4.8	3.18

Then if t > 2.845 (Smith, 1945) there is only 1 chance in 100 that the values for x and y were from the same parent population, or in this case from the same coal seam. As the three "t" values are all greater than 2.845 then it follows that each of the average values for Ni, Sr, and Al provides a valid basis for differentiating "A" from "B" seam. By using all three values an even more positive recognition may be attained. In case (2) where n = 9 and n^1 = 5 the following values were calculated

| Element | U3 seam | | L3 seam | | |
	$\bar{x}$	μ_x^2	$\bar{y}$	μ_y^2	t
Si	3.9	1.4	7.0	5.2	3.10
V	4.7	0.89	8.2	1.36	5.67
Mg	3.2	0.47	5.6	0.64	5.50

Then if t > 2.776 there is 1 chance in 20, or if t > 4.604 there is 1 chance in 100 that the values for x and y were from the same parent population. As the "t" values for V and Mg are both greater than 4.604 then it follows that the significant difference in the averages may be used in differentiating U3 from L3 seam. The "t" value for Si, although lower than that for V and Mg, is still high enough to suggest its usefulness in seam recognition, particularly if it is used in conjunction with the evidence provided by the other two elements.

From this analysis it is evident that variations in the concentration of certain trace elements provides a method of recognizing particular coal seams. This technique may be used to identify L3 seam which is not characterized by the presence of an element not represented in the other three seams. On referring to Table III it will be seen that the average values for Si, V, and Mg are noticeably higher in L3 seam than in any of the other coal seams. When these averages are combined in the

formula $Si + V + Mg$ then a value is obtained which is approximately twice as high for L3 seam as it is for each of the other three seams (shown in the second column from the right in Table III). This value has been computed for each ash analysis in Tables I to III, and the results have been shown graphically in Figure (4). On referring to this graph it can be seen that the values for $Si + V + Mg$ for L3 seam are 18 or greater, and that the values for samples from the other seams are less than 18 with the exception of 2 samples from "A" seam.

If one prefers to avoid selecting a particular element as characterizing a given seam (because of occasional erratic values) then a combination of elements may be chosen. The recognition of "B" seam, for example, may be accomplished by application of the formula $Na + Ni + Sr - Al$. As can be seen from Table III this combination of elements is effective because the values for Na, Ni, and Sr are highest, and the Al values are lowest, in "B" seam. The values obtained by applying the formula are given in the right hand column of Tables I to III, and are shown graphically in Figure (5). On the graph it is evident that all the values for "B" seam lie above a value of +2, whereas values from the other seam samples are all below the +2 line.

Coal seam identification on the basis of a single ash analysis may be accomplished with the following criteria.

(1) If $(Si + V + Mg)$ is less than 18--the sample is from B, A, or U3 seam.

(2) Presence of Na--sample is from "B" seam.

(3) Absence of Na and Ba--sample is from "A" seam.

(4) Presence of Ba--sample is from U3 seam.

(5) $(Si + V + Mg)$ is 18 or greater--sample is from L3 seam.

Figure 4
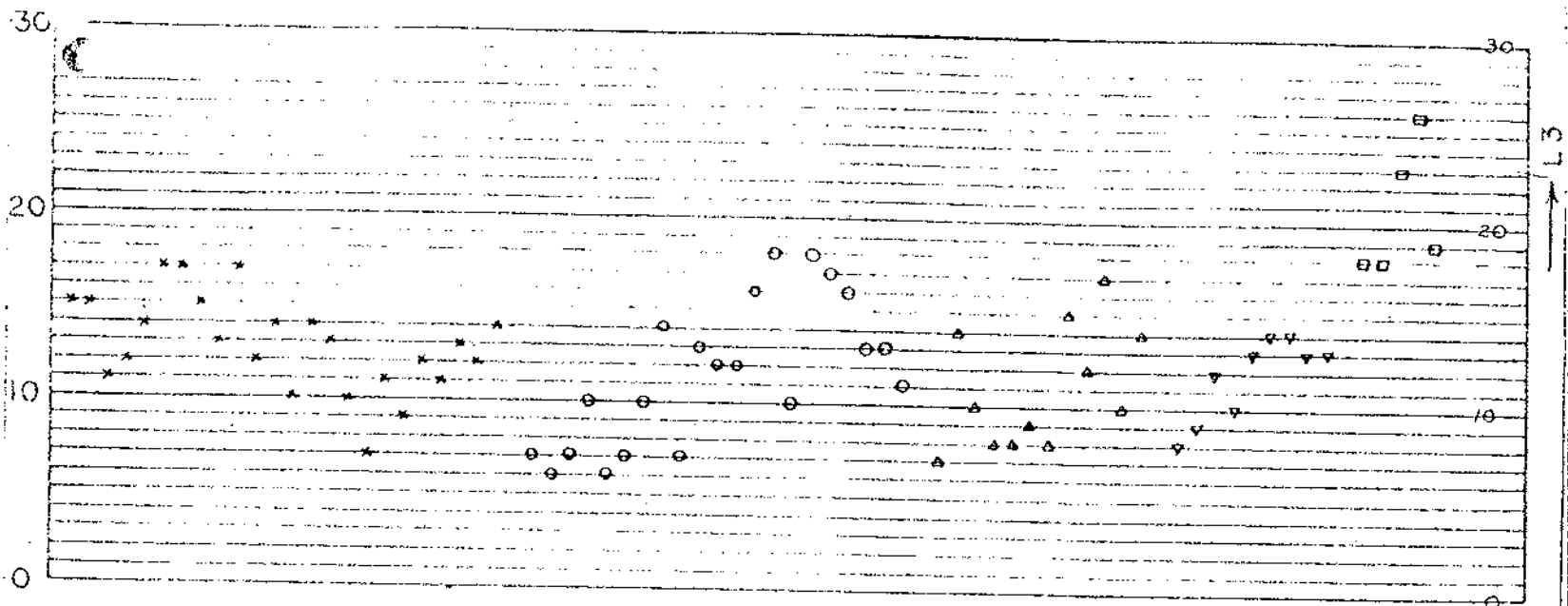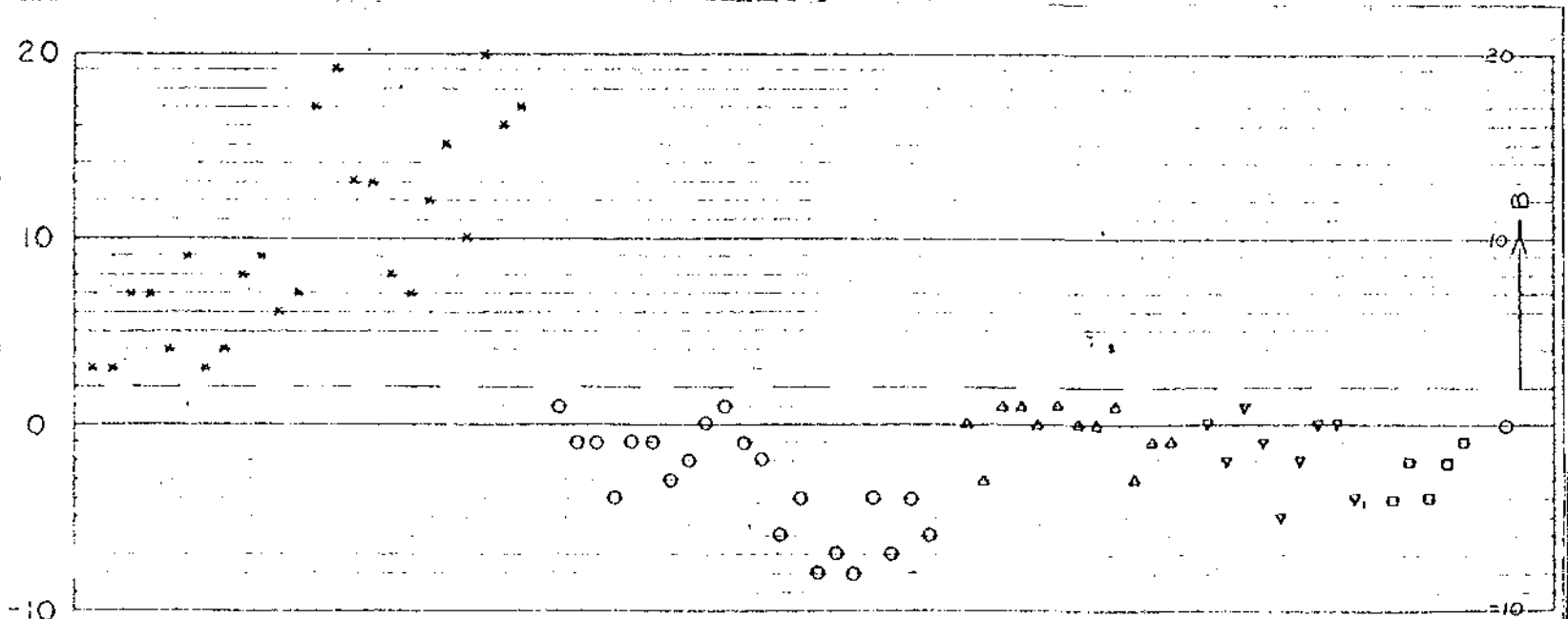

Graph showing range of values of $(Si + V + Mg)$ for all ash analyses.
Note high values in L3 seam.

x = B seam   o = A seam   △ = U3? seam   ▽ = U3 seam   □ = L3 seam

Figure 5

Graph showing range of values of $(Na + Ni + Sr - Al)$ for all ash analyses
High values are confined to B seam.

x = B seam   o = A seam   △ = U3? seam   ▽ = U3 seam   □ = L3 seam

Assuming that the values given in the accompanying tables are truly representative of the seams sampled, then recognition from one sample only may be made on the basis of the above criteria with an error of approximately 3 per cent. This error may be significantly reduced if several samples are obtained and the average of the results used.

The average values for those elements considered useful for correlation may be portrayed in the form of a histogram, which should have a distinctive shape for each coal seam. This has been done in Figure (6), each seam being represented by a three column diagram. The value for Na is plotted in column 1, the Ba value in column 2, and the (Si + V + Mg) in column 3. The marked similarity of the diagrams for U37 and U3 samples, suggests that the coal seam termed U37 may be correlated with U3 seam.

Conclusions

The preliminary results here presented suggest that correlation of coal seams may be made on the basis of spectrographic ash analyses. The correlations may be more surely established if several ash analyses for each seam can be obtained. The spectrographic method is of particular value in making correlation possible in areas where other known methods yield inconclusive results.

Because this investigation was limited to an area of only 6,000 feet by 4,000 feet many more analyses will be needed to ascertain whether the method can be applied in larger areas. It should also be determined whether the method will be useful where many more coal seams are involved, and whether it can be applied in other coal fields.

Figure 6
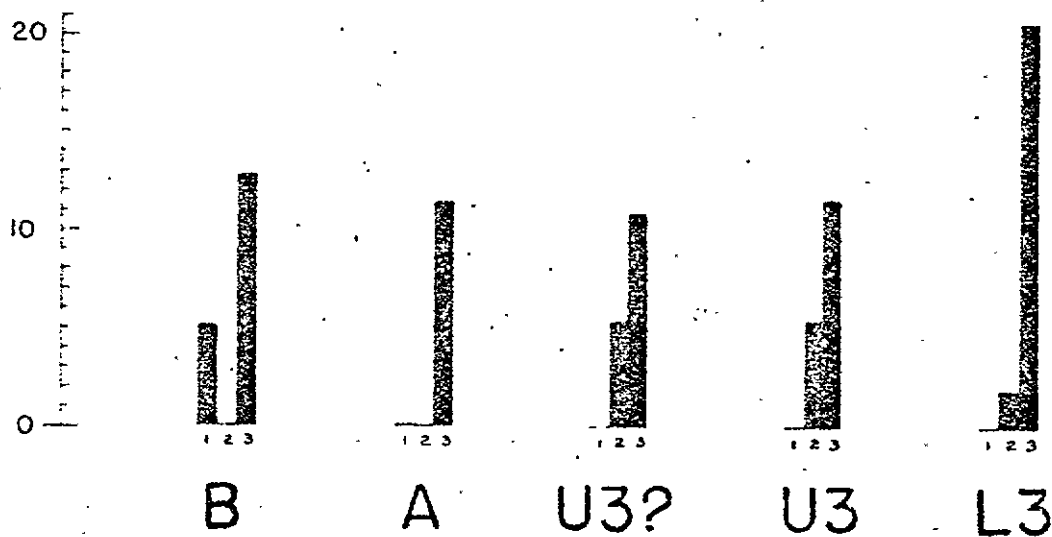
Histograms showing average values of Na.(1), Ba.(2), and Si + V + Mg (3) in the ash from the areas sampled. Note similarity of U3? and U3 diagrams.

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