Spectrographic Study of Some Nova Scotia Coals

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ABSTRACT

Spectrographic studies have been completed on nine major seams of the Sydney coalfield, and on a few character samples of the St. Rose and Port Hood seams in the western part of Cape Breton, Nova Scotia. Samples consisted of blocks previously classified into petrographic intervals by P. A. Hacquebard and results allow a study not only of constituents in individual intervals, but of weighted averages of the coal at each sample locality as well as averages on seams sampled at several places.

The average composition of all seams studied indicates the coals are relatively enriched in manganese, arsenic, and lead, compared with other coals, are slightly above average in zinc, but are lower in Be, B, V, Cr, Co, Ni, and Mo. They also have a relatively high content of Sr and Ba.

Analyses of the seams show some distinctive differences which may be used for correlation purposes though this is complicated by lateral variations, as shown in the Backpit, Harbour, and Phalen seams.

Variations in composition of petrographic intervals support the petrographic classification and show concentrations of Mn, As, Pb, and Ge particularly, and in places also of Co and Ni, in either top or bottom intervals, a feature noted in other coals for Ge.

Results of analyses on the Gardiner and Mullins seams show a great similarity, suggesting that, if these are not one and the same seam, they were certainly formed under very similar conditions. Analyses of the Lower Jubilee and lower portions of the Phalen seams, though not too decisive, favour a different age for these, and a study of the Blackrock section, correlated with the Backpit seam, shows some important differences which can only be explained by lateral variation of the one seam or the possibility that they are two separate seams.

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*Editor's Note.—This is the first of two papers on the use of the spectrographic analysis of trace elements in coals as a means for correlation of coal seams. It deals exclusively with Carboniferous coals of the Sydney coalfield, Nova Scotia. A second paper with reference to the Lower Cretaceous coals in the Crowsnest area of British Columbia is to be published at a later date. This study is sponsored by the Coal Research Committee of the Coal Division, C.I.M.

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Introduction

A STUDY of the trace elements in the ash of coals from nine seams in the Sydney coalfield, Nova Scotia, was undertaken at the suggestion of Dr. W. A. Bell, Geological Survey of Canada, as a part of a larger study of these and other Nova Scotia coals being made by the Geological Survey and the Nova Scotia Department of Mines under the direction of Dr. P. A. Hacquebard.

The main purpose of this investigation has been to determine if a knowledge of the trace element distribution might be of assistance in the recognition of individual seams, the distinction of which is not always easy or positive in folded and faulted strata by ordinary stratigraphic and structural means.

The study has been so conducted as to afford information on the variation of trace elements in individual petrographic intervals or divisions in each of the seams examined, intervals determined by Dr. Hacquebard on the basis of their banded ingredients, vitrain, clarain, durain, fusain, etc, as observed under the microscope in polished sections. The results, as well, indicate the trace element composition of the coals of the area as a whole, and quantitative data for fifteen elements are given, along with concentrations of thirteen other elements, stated in terms of intensity ratios. Data on distribution of germanium, though considered here along with other elements, are dealt with elsewhere*.

Acknowledgments

The research on this project has been made possible by the assistance of the Research Council of Ontario in establishing a spectrographic laboratory in the Department of Geological Sciences, Queen's University. Financial support for the work has also been received from the Geological Survey of Canada. In addition, Dr. W. A. Bell has contributed notes on the geology of the Sydney coalfield which are in part quoted and in part summarized. To Dr. P. A. Hacquebard the writer is much indebted for the acquisition of all coal samples, for assistance and suggestions on the application of the analytical results to various problems involved in the correlation of the seams, and for his critical review of the manuscript.

Miss Y. Rimaite, formerly spectrographer in our laboratory, prepared all samples and standards and carried out the spectrographic analyses.

*Hawley, J. E., *Germanium Content of Some Nova Scotian Coals;* Econ. Geol., Vol. 50, No. 5, pp. 517-532, 1955.

Geology

According to Bell†, the coal seams of the Sydney coalfield are contained within upper Pennsylvanian strata, of the Morien or Pictou group. This group outcrops on the northeastern coast of Cape Breton Island and extends thirty-four miles to the northwest from Bateson on the south shore of Mira bay (Figure 1). It varies in width from a few to twenty-five miles, the inner boundary following a sinuous course as a result of post-Pennsylvanian folding and erosion.

"On the basis of changes in facies within the coalfield from southeast to northwest, the group has been sub-divided on palaeontological evidence into three time-rock units' which contain the coal seams, indicated in the accompanying tabulation.

Zone	Thickness	Seams
Ptychocarpus unitus zone	1,200 ft.	Lloyd Cove Harbour Backpit Phalen Lr. Jubilee
Linopteris obliqua zone	2,300 feet	Emery Gardiner Mullins
Lonchopteris zone	3,000 feet	Tracy

†W. A. Bell, personal communication from which this section is abstracted in part and in part quoted.

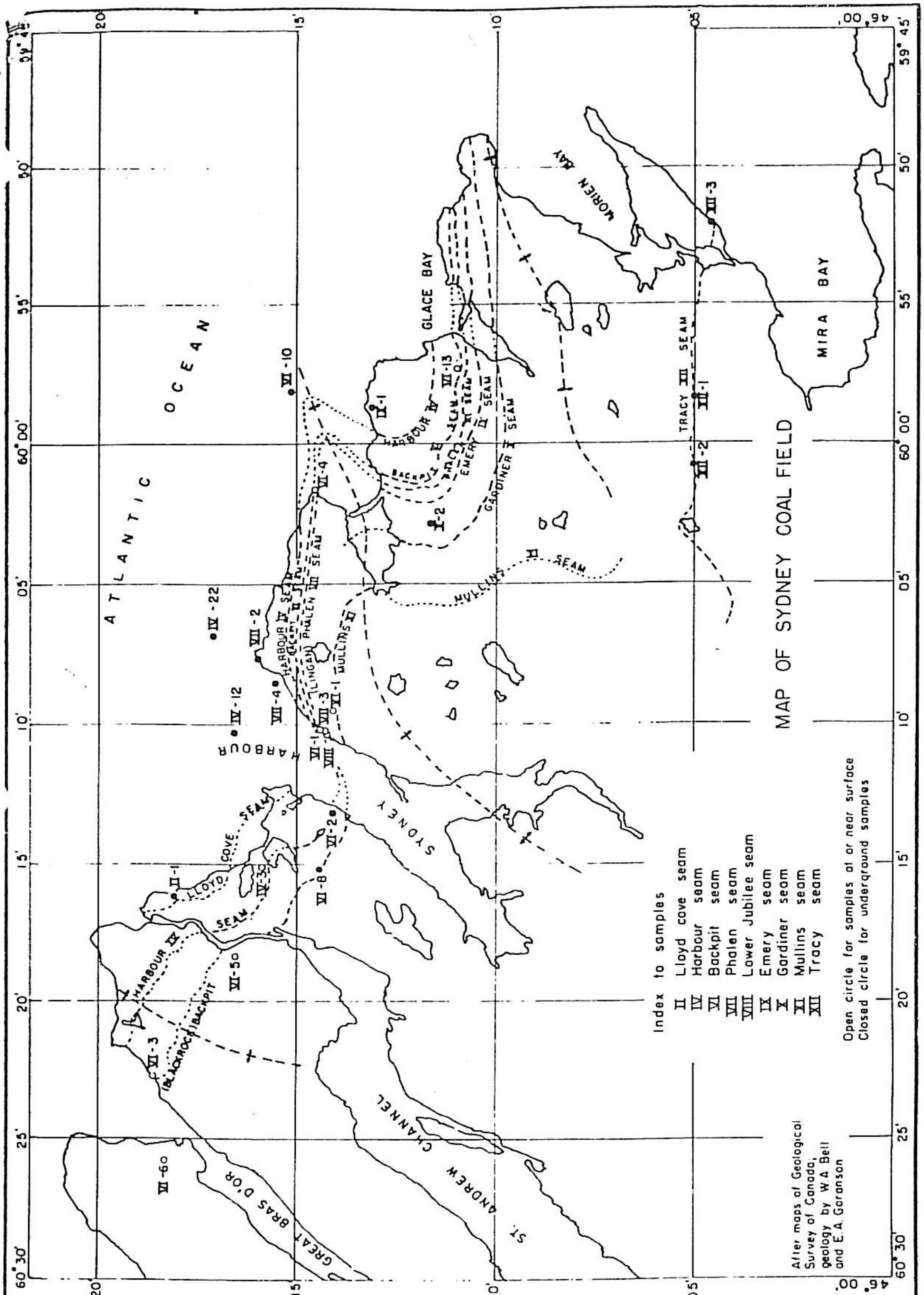

Figure 1.—Map of Sydney coalfield, showing location of coal seams and samples.

"The Morien group rests disconformably upon Mississippian rocks, in places upon the Upper Mississippian Canso group, but over larger [illegible] upon the earlier Upper Mississippian Windsor group". The southern and northwestern boundaries are marked by high-angle reverse faults, the older rocks (Windsor, and Cambrian, on the one hand, and Precambrian on the other) both to the northwest and to the south being thrust against those of the Morien group. Other faults, within the Morien group, are few and of small displacements, and include a number of low-angle thrusts that trend northwesterly.

"Post-Pennsylvanian orogeny developed open folds in the Morien group, the axes of which plunge gently seaward. Dips are generally low, but locally are as high as 45 degrees. As a result of folding and subsequent erosion, the major coal seams, in the upper half of the group, are restricted in the land areas to the major synclines. Local names were given to the seams in each such structural basin, and, where land areas of a single basin were interrupted by embayments of the sea, to each separate mining district. Correlation, however, of the major seams from one structural basin to another was made by the Geological Survey of Canada as early as 1876 (Robb, Charles, 1876, p. 250) and with few exceptions this is accepted today".

"The correlation of seams from the Morien district on the south to Sydney harbour on the northwest is reasonably well established. Sections on the northwestward shore of the Harbour, however, show splitting of the important Phalen and Hub seams, and, northwestward of Florence, the Harbour seam also splits into a number of seamlets".

Three specific correlation problems considered in this investigation consist of the relation of the Gardiner and Mullins seams, the relation of the lower part of the Phalen and the Lower Jubilee seams, and the relation of the Backpit to the Blackrock seam in the northwestern portion of the area.

A knowledge of the environmental conditions under which the coals were laid down is important not only with regard to their probable thickness and quality in submarine areas, but also with respect to their trace element content.

"A. O. Hayes and W. A. Bell (1923, pp. 55-56) ascribed the formation of the coal seams and accompanying strata of the Sydney coalfield to non-marine deposition on a progressively subsiding floodplain of a river or rivers. Bell (1938, p. 9; 1938*a*, marginal notes) subsequently noted evidence of transgressive overlap of strata of the Morien group in a northwesterly direction, whereby strata of the *Lonchopteris* zone were overstepped in that direction by strata of the *Linopteris obliqua* and succeeding zone. He considered it possible that uppermost strata of the *Linopteris obiqua* zone or succeeding strata of the *Ptychocarpus unitus* zone may have covered eventually a large part of a Pennsylvanian upland. Previously, this upland during deposition of more than half of the Morien group had bounded the coalfield on the north and west. Transgression of the Morien group apparently took place during the same time in a westerly direction, for coal-bearing strata equivalent in age to an upper part of the Morien group occur in the valleys of the Salmon and Gaspereaux rivers, south of East bay. Although arkosic debris from this southwestern and western upland area was abundantly incorporated in the clastic sediments of the Morien group, little as yet is known of the character of the southern border of the coalfield, nor of the contributions, if any, made to the Morien group from the early Palaeozoic volcanic rocks and sediments that presently occur south of the coalfield".

"T. B. Haites (1951, pp. 215-225), applying the principles of river deposition to coal partings, washouts, and character of coal roofs, was enabled to plot probable sites of some ancient stream channels during the deposition of the major coal seams within areas that are being actively exploited, and he projected some of these channels into the submarine area. In some instances he proved that the major seams were connected by seamlets. Haites also concluded that migration of the rivers and their meanderings, as well as differential composition of sediments and contemporaneous warping, were important factors in controlling coal deposition and mineral composition of individual coals".

Source rocks for the clastic portions of the coal seams and associated rocks thus consisted largely of the Mississippian Windsor limestone, gypsum, shales, sandstones, and conglomerates; Devonian conglomerate arkose, shale, tuff, and possibly more remote Devonian granites; Ordovician and Cambrian sediments; and Precambrian granitic intrusives, quartz diorite, pyroclastics, and both silicic and basic volcanics; crystalline limestone and gneisses.

Mineral Matter in Coals

The composition and origin of minerals in coal have been reviewed in some detail by Thiessen (1945) and require consideration in any trace element study designed to aid in the distinction and correlation of coal beds.

Mineral matter of coals is normally classified as of two types, inherent and extraneous. The former consists of those elements or oxides which have been contributed by the plants themselves and which to some extent may have been concentrated by plants from either the soils or earlier generations of decomposing plant remains in which they grew. Goldschmidt (1935) has indicated the wide variation in elements concentrated in low-ash coals, much of which must be attributed to inherent mineral matter of the original plants. Variations to some extent in soils and also in the plants themselves from place to place during the formation of even a single bed or even a petrographic interval of coal may be expected, but, the more uniform the soils and plant types, the more uniform should such mineral matter be.

Extraneous minerals, on the other hand, include those deposited either mechanically or chemically, from the air, as dust, or from the waters percolating or flowing into and over bog accumulations. The original character of this type may have been modified by seeping waters leaching the more soluble and leaving the less soluble, such as clays. It is conceivable that, even later in the history of the formation of coals, circulating ground-waters might still further modify the composition of the mineral constituents. Such extraneous mineral matter would normally be expected to vary in amount and in composition, depending on the vagaries of sedimentation, sources of water, and character of the lands undergoing erosion, and, again, uniformity in the amount and quality of the mineral constituents would depend on stable uniform conditions existing throughout the basin in which coal accumulation was proceeding.

Thus, because of the many variables present, it is difficult to predict the value and usefulness of a trace element study of this type. Some success has been attained, however, in other coal deposits, such as those of the Kootenay district of B.C. by Newmarch (1950), and certain coals have been shown to reflect the composition of adjacent land masses, as witness high vanadium in Russian Jurassic coals, considered as derived from the weathered products of basic rocks in the Ural range. These suggest, therefore, that this study might at least show some of the chemical characteristics of the coals in the Sydney coalfield and indicate the value of this approach to correlation problems of the various seams.

Coal Seam Samples

Samples from nine seams in the Sydney coalfield were secured from the Coal Research Division of the Geological Survey of Canada, Sydney, N.S. Samples include available material from all individual petrographic intervals or divisions studied by polished sections from a total of twenty-one localities. Actual sampling methods are described by P. A. Hacquebard (1951). These have come from various places, including one bore hole, surface exposures, such as at old pits and ex cliffs, and from underground ... both submarine and not ... details of which are given elsewhere by the writer*.

... seams — the Lloyd Cove, Lower Jubilee, Emery, Gardiner, and Mullins — were sampled at only one locality. Three were sampled at two or more places; those of the Backpit-Blackrock seam cover a lateral distance of approximately 26 miles, those of the Harbour seam 6 miles, and of the Phalen seam 2.8 miles. These will be considered in relation to the lateral variation of constituents within individual seams.

Character samples from three seams have also been analyzed. These include two from the Tracy seam from localities 2 miles west and 1½ miles east, respectively, from Tracy XII-1 locality, district of Port Morien. Three such samples of freshly mined coal from the St. Rose seam No. 2 (SR 2) on the west shore of Cape Breton, 10 miles northeast of Inverness, were also studied. In addition, one sample studied from the Port Hood seam, also on the west coast, is from the six-foot seam, Harbour View mine, and represents freshly mined coal from a submarine area. Both the St. Rose and Port Hood measures are considered to be the same age, Riversdale, and are older than those of the Sydney field.

In order to determine how concentrations of elements vary in the coaly matter as compared with the mineral matter of a given interval, a sample from the Lower Jubilee seam VII-1, interval II, was separated into light, medium, and heavy fractions with a heavy liquid, and each fraction was then ashed and the resulting ashes were analyzed separately and compared with that of an average sample, not so treated.

Preparation of Coal Ash

Finely ground coal samples were first dried over-night at 105°C. to determine loss of moisture.

Five to ten grams of each sample were then placed in aluminum trays and introduced into a cold electric furnace and ashed at 400°C. Depending on the type of coal and size of sample, time of ashing varied from 24 to 48 hours. Resulting ashes ranged in colour from red to grey, but in a few cases samples from the Tracy seam remained black and sticky even after a long period of heating. Results on the latter are considered less accurate, though ... of elements stated in terms of total coal are not affected by residual carbonaceous matter in the ash.

The relatively low temperature used was considered advisable, particularly in view of differences in opinion regarding losses of germanium and possibly of other volatile elements at higher temperatures (Stadnichenko *et al* 1953; Aubrey, K.V., and Payne, K.W., 1953).

Percentage of ash in each sample has been determined, and weighted averages of ash for each of the individual seams have been calculated. Prior to spectrographic analysis, the ash of each sample was ground in an agate mortar to a very fine homogeneous powder.

Spectrographic Analysis of Coal Ash

1.—*Method*

In view of the large number of analyses required, a spectrographic method was sought which would allow the maximum number of elements to be determined from one set of excitation conditions, even though such a method could not be expected to give the highest accuracy.

Samples of uniformly ground ash were mixed with equal quantities of spectrographically pure briquetting graphite to which 0.2 per cent rhodium black had been added as an internal standard.

Forty-milligram samples of this mixture were then compressed as flat-topped pellets in a pelleting mould onto the tops of ¼-inch-diameter graphite rods, at a pressure of 500 lb (Wark 1951). Each ash was then analyzed in quadruplicate, two photographic exposures being made over the low ultra-violet range of 2,200 — 3,900 Angstroms, and the other two covering the higher range of 2,800-4,500 Angstroms. Analytical lines of elements lying within the range of 2,800-3,900 Angstroms were thus available on all four runs, but, for those lying below or above this range, results were obtained only in duplicate.

Experimentation indicated that the spark method of analysis, with its greater precision, was adequate to detect a large number of the elements present, including V, Cr, Mn, Co, Ni, Mo, Pb, Zn, As, Ge, Be, Ba, Sr, B, Zr, and Ga, as well as the major constituents Si, Al, Fe, Mg, Ca, K, Na, Y, and Ti. On some samples, qualitative analyses with d.c. arc showed greater sensitivity for such elements as Ba, Sr, Sn, Be, Y, In, and Sc but this method was not used because of the time involved.

Spectrographic conditions used are as follows:

Spectrograph — 2-meter spectrograph with a 36,600 line per inch grating (dispersion in 1st order 3.5 Angstroms.

Source Unit — Applied Research Laboratories high-precision-source unit

Excitation — High voltage spark, 10,000 volts, 5 amp R.F., inductance 360 microhenries

Exposure — 20 seconds

Transmission — 80 per cent

Gap — 2 mm.

Slit — 60 microns

Electrodes — Sample: flat-topped pellet on ¼-in. graphite
Counter: special high-purity graphite, hemispherical tips

Film — Spectrum analysis No. 1 Eastman

Development —

D-19 developer — 5 min. at 21°C.
Stop bath — 30 sec.
Fix — 10 min.
Wash — 10 min.
Dry — 2.5 min. in dryer

Transmittance measurements were made on a film comparator-densitometer, and intensity ratios calculated on film emulsion calibration curves prepared by the two-step filter method. Full background corrections were made.

2.—*Preparation of Standards*

Standards containing known amounts of elements required were prepared for the most part in two ways, using certain lots of coal ash, graphite, and Applied Research Laboratories standard powders Nos. 100, 101, 102, and 104, to which rhodium black, diluted in graphite, was added in constant amounts (0.2 per cent Rh). For the determination of germanium, several standards were prepared using either A.R.L. Standard No. 104, or spectrographically pure GeO_2, with both rhodium, and later bismuth, as an inernal standard. In addition, tests were carried out on certain coal ashes by x-ray fluorescence methods for the determination of germanium and arsenic*.

3.—*Reproducibility*

Reproducibility tests were made on a total of 32 pellets of coal ash from St. Rose seam No. 5 (S.R. 1-29) mixed with equal quantities

*See footnote on first page.

*More complete details are given in a report on this research filed with the Geological Survey of Canada and the Nova Scotia Research Foundation.

of the internal standard (graphite plus rhodium). Four pellets of each lot were photographed in the range 2,200 — 3,900 Angstroms and four of each in the range 2,800—4,500 Angstroms.

The average percentage arithmetical deviation from the mean intensity ratio on the pellets of the four lots for 24 elements was found to vary from only 1 to 5 per cent. Maximum deviation percentages in practically all cases were under 10 per cent, again indicating the satisfactory character of the internal standard mixture and highly adequate reproducibility for the elements studied.

Accuracy

A measure of the accuracy of the quantitative determinations is in part gained by comparison of our results with those given for five elements in a similar, though not identical, sample of coal from the Harbour Rider seam, IV-24 R, by the United States Geological Survey, as noted above, and illustrated in Table I. A further comparison is afforded by analyses reported on granite and diabase (Fairbairn, H.W., U.S.G.S. Bulletin 980) and results obtained on samples of these rocks using working curves established with coal ash standards.

The results given in Table II, on oxides, as determined spectrographically and chemically by different analysts, in many cases show as great a divergence as do our results when compared with the closest figures given. Percentage differences range as high as 60, the results by our curves for cobalt and manganese being high and those for vanadium low. Part of the difference may be due to the difference in major constituents of the coal ash and igneous rocks used. None-the-less, though the accuracy may not average much better than 25 per cent, the quantities of trace elements given allow a valid comparison to be drawn between different petrographic intervals of the same seam and between different seams.

TABLE I. — COMPARISON OF ANALYSES ON HARBOUR RIDER SEAM

ELEMENT	PERCENTAGE ELEMENTS	
	U.S.G.S.	MILLER LABORATORY
Germanium	0.13	0.16
Zinc	0.14	0.15
Nickel	0.014	0.013
Cobalt	0.0078	0.0098
Molybdenum	0.002	0.005

TABLE II.— COMPARISON OF REPORTED TRACE ELEMENTS IN GRANITE (G-1) AND DIABASE (W-1) WITH RESULTS OBTAINED ON COAL ASH WORKING CURVES

	PERCENTAGE OXIDES		
	U.S.G.S. BULLETIN 980		MILLER LABORATORY COAL ASH CURVES
	Chemical	Spectrographic	Spectrographic
V_2O_3 (W-1)	—	0.032 - 0.05	0.018
Cr_2O_3 (G-1)	—	0.0015 - 0.0044	0.005
MnO (W-1)	0.10	0.20	0.26
MnO (G-1)	0.039	0.019 - 0.031	0.047
CoO (W-1)	0.002 - 0.005	0.003 - 0.0044	0.007
NiO (W-1)	0.02	0.006 - 0.011	0.0062

TABLE III.— COMPARISON OF TRACE ELEMENTS IN COALS, COAL ASH, AND IGNEOUS ROCKS
(g/ton or parts per million)

ELEMENT	AVERAGE IN RICH COAL ASH (1)	AVERAGE IN SYDNEY COALFIELD		AVERAGE IN IGNEOUS ROCKS (2)
		In ash p.p.m.-range	In coal p.p.m.-range	
Be	300	14	2 (1-2)	6
B	600	148 (52–220)	17 (6-25)	3
V	340-720 (3)	,120 (61–244)	14 (7-28)	150
Cr	180-300 (4)	45 (18–79)	5 (2-9)	200
Mn	290-540 (3)	1,200 (165–2200)	140 (9-254)	1000
Co	300	87 (26–196)	10 (3-34)	23
Ni	700	131 (52–645)	15 (6-74)	80
Zn	200	218 (115–550)	25 (13-64)	132
Ge	500	44 (9–70)	5 (1-8)	7
As	500	900 (280–2300)	100 (33-270)	5
Sr		560 (225-750)	65 (76-87)	300
Mo	200	60 (18–105)	7 (2-12)	15
Sn		9 (4–18)	1 (15-2)	40
Ba		300 (18-2,200)	35 (2-257)	250
Pb	100	572 (2,112–1,050)	66 (25-120)	16

(1) MASON, B., *Principles of Geochemistry* (1952) p. 209 - after Goldschmidt. for "rich" coals.

(2) RANKAMA and SAHAMA, *Geochemistry* (1950), p. p. 39-40.

(3) *Chemistry of Coal Utilization*, vol. 1, 1945, p. 491 (after ZILBERMINTZ, V. A., and RUSANOV, A. (1936) — average range in Russian coal ash.

(4) HUNTER, R. G., and HEADLEE, A. J. W., *West Virginia Coals*: Anal. Chem., Vol. 22, March, 1950

ANALYTICAL RESULTS

Average Trace Element Composition of Coal Ash and Coal, Sydney Coalfield

The weighted averages* of fifteen trace elements in 182 samples of coal from 21 different localities on 9 seams, representing some 1,100 inches of coal, are given in Table III in parts per million of ash as well as of total coal. Ranges in content are shown in brackets and give a measure of the variation in individual samples.

Comparison of the ash of Sydney coals with averages quoted from Goldschmidt and others for "rich coal ash" indicates the Sydney coals are especially enriched in Mn, As, and Pb and are high also in Sr and Ba, have the equivalent of Zn, but are much lower in Be, B, V, Cr, Co, Ni, Ge, and Mo. Comparing the amounts in total coal (coal plus ash) with the average content of igneous rocks, the coals are notably lower in all elements given except B, As and Pb, while Ge is about the same in both. On the other hand, if we compare the amounts present in the coal ash only with those in igneous rocks, a marked enrichment is evident, in the coal ash, of B, Co, Ni, Zn, Ge, As, Sr, Mo, and Pb; a slight or no enrichment in Be, Mn and Ba, and a deficiency in V, Cr and Sn. Amounts of Be, V, Mn, N

*After calculating p.p.m. of element in each petrographic interval which is a function of percentage ash, these quantities were weighted according to number of inches in each sample, and weighted averages of each seam and of all seams were calculated.

TABLE IV

WEIGHTED AVERAGE OF TRACE ELEMENTS IN COALS

in parts per million

Seam	Total Thickness in inches.	No. localities	No. samples in all intervals.	Avg. Ash %	V	Cr	Mn	Co	Ni	Mo	As	Ge	Ba	Sr	B	Pb	Zn	Sn
Lloyd Cove II.	90	1	12	10.74	7	2	117	7	13	5	270	1	2	26	25	121	64	1
Harbour IV....	216.32	3	27	5.79	11	5	57	4	6	2	33	4	17	45	6	25	13	1.1
Backpit VI	396.5	9	55	15.8	15	5	254	16	25	12	120	8	70	87	21	98	29	1.07
Phalen VII	168.47	3	37	10.02	20	6	77	3.5	7	6	106	1.6	9	55	22	20	14	0.7
Lr. Jubilee ... VIII	13.5	1	5	22.27	28	9	56	34	74	11	105	8	257	47	8	89	24	-
Emery IX....	28.3	1	5	12.6	13	6	19	17	17	4	160	6	14	49	10	48	21	0.5
Gardiner X ...	65.8	1	15	9.99	19	7	22	8	14	5	99	7	12	65	12	37	20	1.4
Mullins XI ...	66.6	1	14	8.35	8	4	36	5	8	6	73	2	20	80	20	95	15	1.3
Tracy XII ...	63.4	1	12	10.96	15	5	206	4	8	7	3	1	14	76	0	59	30	2
Sydney seams Average of 9 ..	1108.9	21	182	11.48	14	5	140	10	15	7	103	5	34	65	17	66	25	1.09
St Rose #2 ... 3 character samples.	-	1	3		19	7	79	8	8	4	50	2	52	26	107	134	62	tr
Port Hood .... (character)		1	1		11	6	23	5	5	3	-	3	6	16	8	100	21	-

and Ba in the two, however, are not greatly different.

Of the elements which appear in high concentrations in the ash of the Sydney coals, manganese appears most easily accounted for in view of the manganiferous character of certain horizons of the (Mississippian) Windsor limestones and gypsum of this region (Hanson, 1932) as well as of the still older sedimentary deposits of the Appalachians, and, according to Hanson, the higher than average manganese content of the Precambrian rocks from which the sediments of the Appalachian trough were derived.

It may also be surmised that some relation may exist between the high lead content of the ash and of the many Middle Devonian lead-zinc deposits of the Maritimes, listed by Alcock (1930), and between the high arsenic and the arsenical minerals found associated with Devonian granites of the same area (Hurst 1927).

On the other hand, the relatively low chromium and vanadium content of the coals compared with the average igneous rock suggests that basic rocks were scarce in the areas from which the minerals of the coal beds were in part derived.

Comparison of Trace Elements in Individual Coal Seams

A comparison of the trace elements in each of the nine seams of the Syney coalfield and of samples of the St. Rose and Port Hood seams is given in Table IV.

Those of the Sydney field are illustrated in Figure 2. Intensity ratios of 13 other elements were also determined, the distribution of nine of which is illustrated in Figure 3.

Though the number of samples and of localities sampled varies considerably, and, as will be shown later, individual seams vary in trace element content laterally, a comparison of individual seams and their overall trace element content on the basis of available data is of interest. In this, only the outstanding differences will be stressed.

Differences of individual seams in contents of V, Cr, Co, Mo, Ge, B, and Sn for the most part are not marked, except in one or two cases. Most important variations are in Mn, As, and Pb, rarely in Ba, with moderate variations in Ni, Sr, Zn, and B. These differences are summarized in Table V, including elements for which intensity ratios only were obtained.

As will be noted, the Co/Ni ratio for eight seams is close to 1:2 in contrast to a 1:1 ratio in the Emery, St. Rose, and Port Hood seams. The Pb/Zn ratio in all cases is greater than 1 and in the majority of cases is slightly above 2.

In terms of the three units into which W. A. Bell has divided the coalfield (see tabulation on p. 712), the Tracy seam in the lowest or Lonchopteris zone, compared with others, is decidedly low in As, is below average in Co, Ge, B, and Ba, but above average in Mn and is highest in Ca.

The Mullins, Gardiner, and Emery seams, in the middle, Linopteris zone, show steadily increasing As and Na, upward, very consistent amounts of Mo and to a lesser extent of Ba, B, and Zn, and all are relatively low in Mn.

In the upper, Ptycocarpus unitus zone, the Lower Jubilee, Phalen, Backpit, Harbour, and Lloyd Cove seams, in ascending order, show, with the exception of the Harbour, high As, variable, low to high Mn, and fairly uniform Sr and B. Excepting the Backpit, they are low in Ba but on the whole are higher in Mg and Ti than other seams.

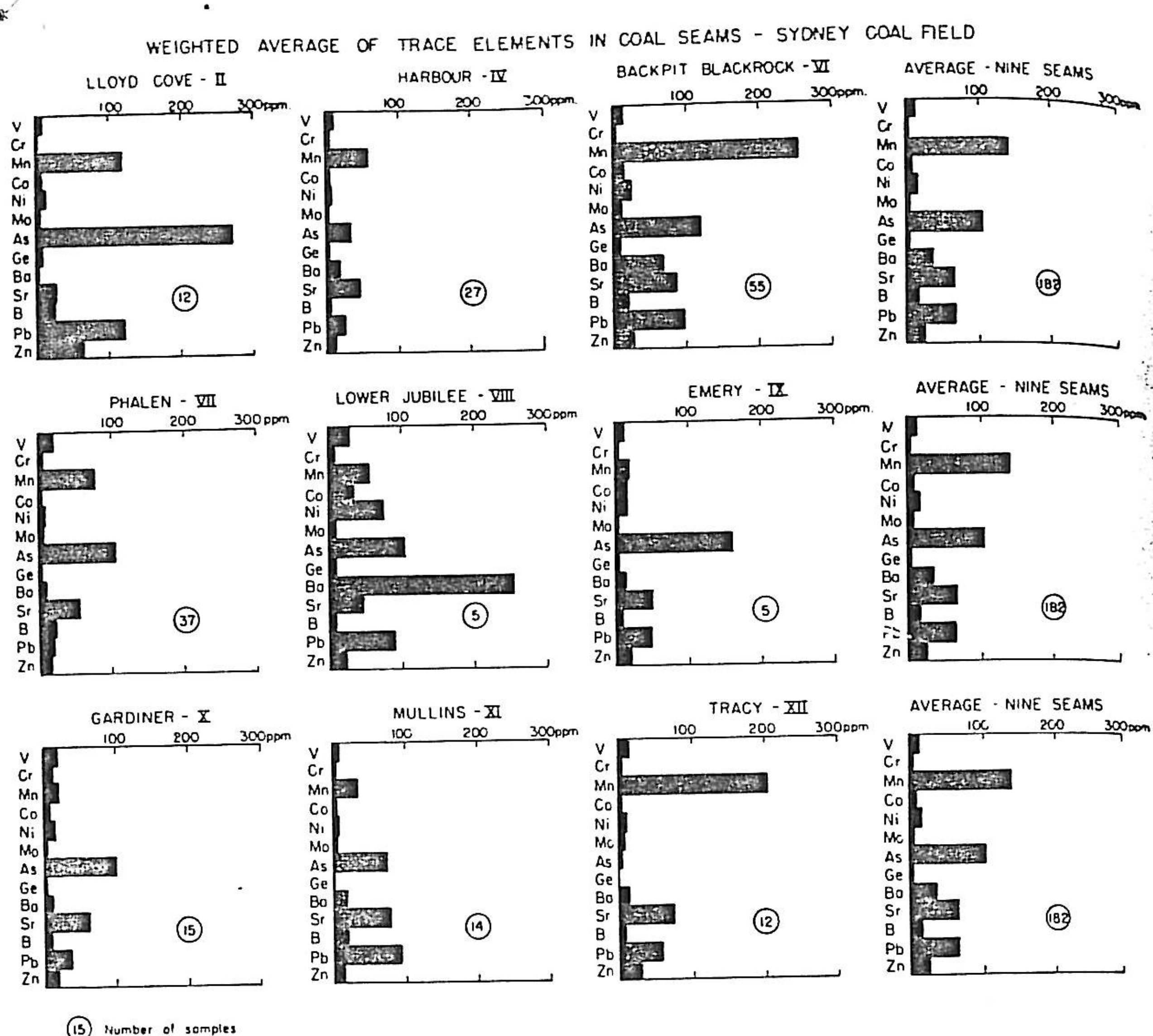

Figure 2.—Histograms of weighted averages of trace elements in coal seams, Sydney coalfield.

TABLE V.—MAJOR DIFFERENCES IN TRACE AND MAJOR CONSTITUTION ELEMENTS IN SYDNEY COAL SEAMS

LLOYD COVE	Highest in As; high Pb; moderately high Mn; highest in Zr; and lowest in Al, Na, K
HARBOUR	Relatively low in all trace elements, lowest ash, highest in Na, Ti, Ga, Y, Cu, and Ag
BACKPIT	Highest in Mn and Ge; moderately high in As, Pb; second highest in Fe and Ca
PHALEN	Highest in Mg; about average As; half the average of Mn; low in Pb, Zn, Ni, Co, and Al
LR. JUBILEE	Highest in V; erratic (?) high in Ba; no tin; highest ash; lowest Na, Ag
EMERY	Lowest in Mn; greater than average As; Co/Ni = 1; second highest in Ti
GARDINER	Second lowest in Mn; close to average in Cr, Co, Ni, Mo, Sr, B, Zn; highest in Al and K
MULLINS	Highest in Si and Fe; not greatly different from Gardiner, but higher in Mn, Ba, Sr, B, Pb, and lower than it in V, Co Ni, As, Ge, and Zn
TRACY	Highest in Ca; second highest in Mn; lowest of Sydney coals in As
ST. ROSE NO. 2	Exceptionally high in Ba; highest in Pb; second hgihest in Zn; trace only of Sn; and second lowest in Y; phosphorus detected only in this seam; Co/Ni = 1
PORT HOOD	Lowest in As, Ni, Sr, and in Y and Ga; low also in Ca; Co/Ni = 1

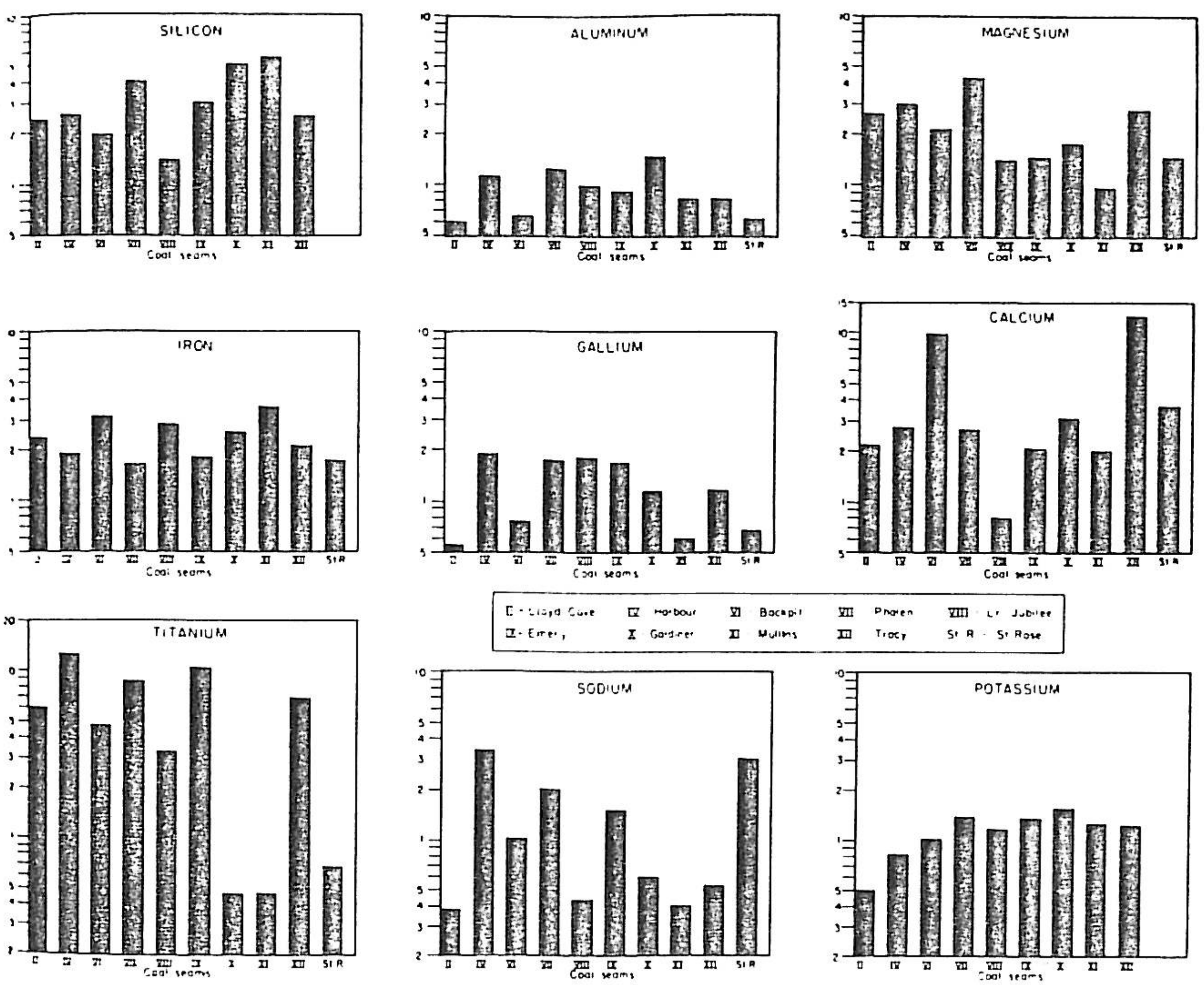

Figure 3.—Histograms showing variations in intensity ratios of elements in different seams.

Coals of the Riversdale age, which are believed to be older than those of the Sydney coalfield, though represented here by only a few character samples of the St. Rose No. 2 and Port Hood seams, are in themselves fairly similar in Cr, Co, Ni, Mo, Ge, Sr, Pb, and in intensity ratios of Mg, Y, and Ga. They differ from all the Sydney seams (with the exception of the Emery) in having a Co:Ni ratio = 1, but compared with the Emery have lower amounts of both these elements. As noted above, phosphorus was detected only in the St. Rose seam, in which also boron is exceptionally high, while both seams are well above the average of the Sydney seams in lead and below this average in Mn, Co, Ni, Mo, As, Ge, Sr, and Sn.

The above differences thus appear sufficient to distinguish the various seams one from another, but confirmation by more extensive sampling and analysis of several is still required.

Lateral Variation in Elements in Coal Seams

Samples of the Backpit, Harbour, and Phalen seams over distances of 26, 6, and 2.8 miles, respectively, have been examined to determine the lateral variation in trace element composition. Histograms (Figure 4) show the differences in three groups of samples of the Backpit (each group is an average of three) and in three individual samples in each of the Harbour and Phalen seams. As these are discussed in more detail elsewhere*, only a summary of the results will be given here.

Backpit Seam:

The general similarity of the three groups of samples is shown in Figure 4, particularly in content of V, Cr, Mo, and B. Manganese is relatively high in all, but somewhat lower in the Glace Bay section lying to the southeast. Co, Ni, Pb, and Zn are considerably higher in the Blackrock section while As, Ba, and Sr are higher in the Glace Bay section.

A striking similarity is shown in trace elements and even in major constituents in two of the Backpit samples, Nos. 8 and 2, located 1.75 miles apart, as illustrated in Figures 5*A* and 5*B*. In these two locations, the seam contains practically the same amount of V, Cr, Co, Ni, Mo, Ge, and Zn, though ash content varies by 2 per cent, while differences in As, Pb, and Sr are of a relatively small order. Similarly, the arithmetic averages of intensity ratios for eleven other elements show fair agreement, particularly in Al, Fe, Mg, Ca, K, Y, Ga, and Ag.

Table VI shows even more strikingly the similarity in results for eight elements determined in these two samples on ash from individual petrographic intervals, and it is clear that exceptionally stable condi-

*A complete report on this work is on file with the Geological Survey of Canada and the Nova Scotia Research Foundation tions must have prevailed over the two sites at the time of coal deposition.

Harbour Seam:

In Figure 4*B* and Table VII, a comparison is given of the trace element composition of three samples of the Harbour seam. Here variations in Mn, As, Ba, Pb, and Zn are evident, but in no case is the variation uniform in direction. All three samples are fairly similar in Co, Ni, Mo, and As, while, in at least two of the three, similar agreement is found in amounts of V, Cr, Mn, Pb, Ge, Be, Sr, B, and Zn.

Intensity ratio studies show fairly uniform K and Ti in all, but an increase in Fe and Zr and a decrease in Si, Ca, Ga, and Y from west to east.

The general similarity of the three samples agrees with the findings of Dr. Hacquebard (1951, p. 20), who notes for this seam that "certain characteristic horizons or divisions have almost the same petrographic composition over the entire coal field".

Phalen Seam:

In the three samples taken over a lateral distance of 2.8 miles, weighted averages of Cr, Co, Ni, Mo, Ge, and Zn are fairly uniform, though ash content increases from west to east. Mn shows the greatest variation, As and Ti increase eastward, and V, B, Pb, and Ga and Y decrease in this direction (Figure 4*C*).

This seam has a prominent parting below interval No. VIII and above interval No. III. Within it, in places, are minor coal layers. A comparison of the intervals Nos. XIV down to and including VIII of the three samples, and of the lower three intervals in each, is given in Table VIII for 14 elements. Variations in composition for the most part are relatively small, with the exception of amounts of Mn, As, and Sr.

Variations, in the same sections, of eleven elements determined as intensity ratios, though not detailed here, are small in many cases for at least two of the three samples, especially Nos. 4 and 2.

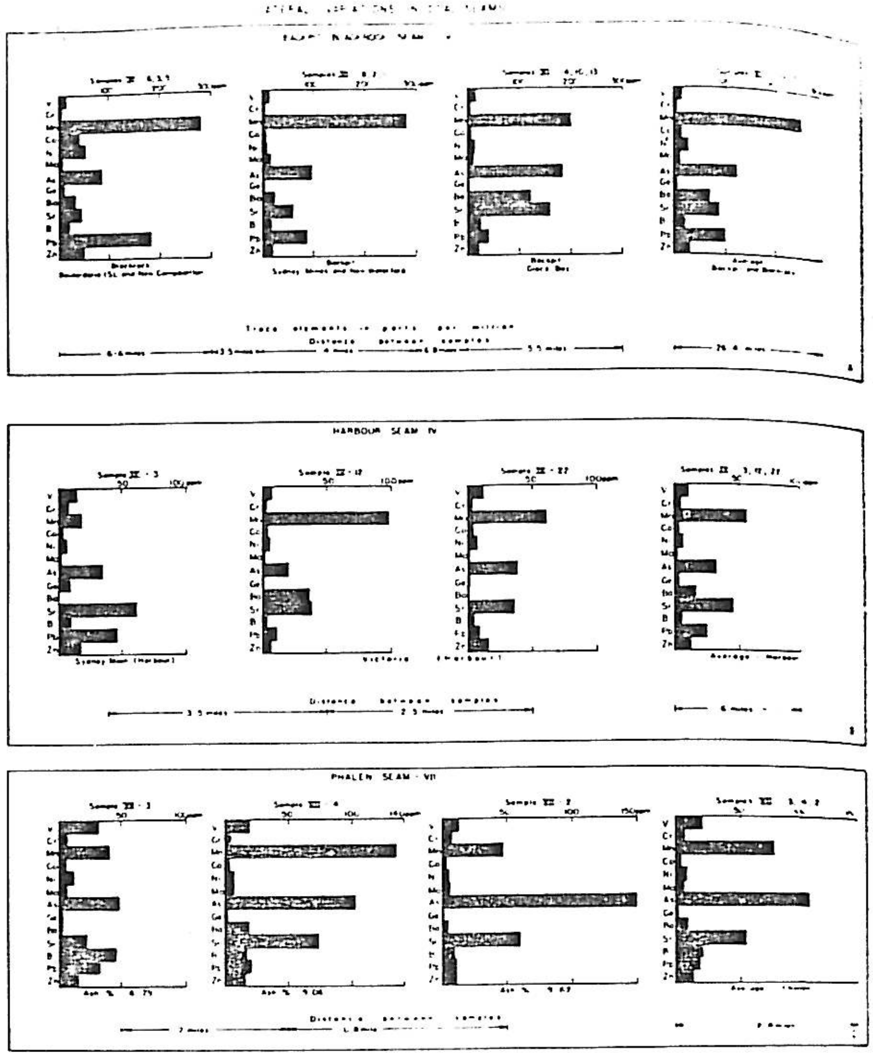

Figure 4.—Histograms showing lateral variations of trace elements in coal seams. A.—Blackrock-Backpit; B.—Harbour; C.—Phalen.

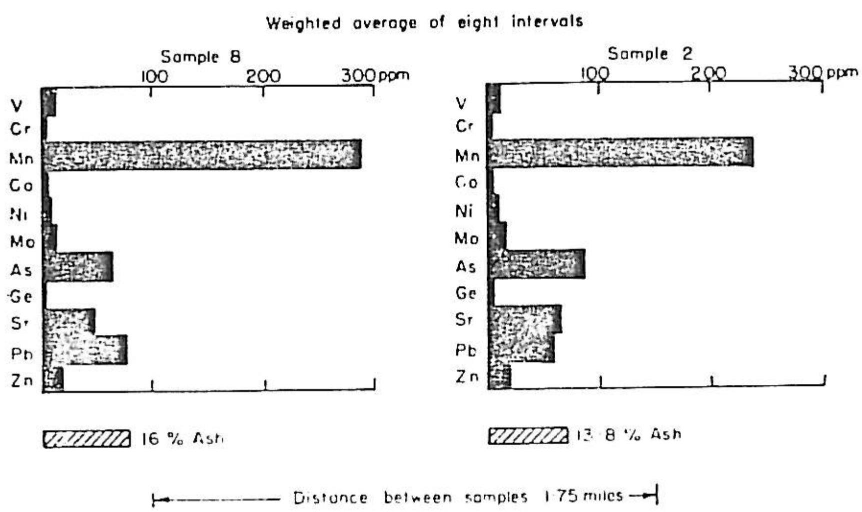

Figure 5*A*.—Histogram showing comparison of samples Nos. 8 and 2, Backpit seam.

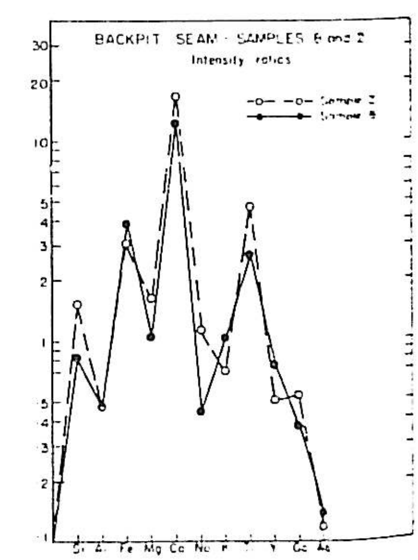

Figure 5*B*.—Intensity ratios of elements, samples 8 and 2, Backpit seam.

TABLE VI

BACKFIT SEAM SAMPLES VI - 8 and VI - 2

COMPARISON PARTS PER MILLION OF ELEMENTS IN COAL PLUS ASH

	% Ash		Vanadium		Manganese		Chromium		Cobalt		Nickel		Strontium		Boron		Molybdenum		Zinc	
Interval	8	2	8	2	8	2	8	2	8	2	8	2	8	2	8	2	8	2	8	2
VIII........	38	43	42	42	1210	781	12	14	14	15	33	39	76	96	15	30	18	26	38	56
VII........	34	17	32	17	429	536	12	8	13	7	17	8	86	74	12	14	27	23	38	23
VI........	15	13	8	9	291	334	3	4	12	7	9	10	46	60	.1	45	14	21	15	20
V........	10	11	10	9	156	133	5	5	2	4	5	7	34	71	22	57	9	15	17	17
IV.......	8.5	3.8	5	4	98	96	2	2	3	1	3	4	26	48	25	4	13	7	21	8
III.......	19	10.5	8	4	99	38	1	1	2	2	2	2	49	60	nd	19	16	8	15	12
II.......	10	14	6	7	58	94	3	3	1	4	2	5	30	14	7	3	6	11	12	19
I.......	17	15.6	15	20	391	218	2	2	3	2	3	3	71	80	nd	tr	11	15	15	20
Wt'd Average ..	16	13.8	12	11	285	238	4	4	6	5	8	8	47	64	11	30	13	16	19	20

TABLE VII

COMPARISON OF HARBOUR SEAM

Samples IV - 3,12,22

Elements in ppm (Weighted averages in Coal)

	Ash %	Inches	V	Cr	Mn	Co	Ni	Mo	As	Pb	Ge	Be	Ba	Sr	B	Zn	Sn
Sample 3	4.7	70.03	14	7	17	3	6	2	34	46	8	3	nd	61	9	17	1
Sample 12	4.34	64.3	7	3	98	4	5	2	20	11	0.6	0.4	37	38	3	6.0	2
Sample 22	8.0	78.88	12	4	60	4	7	2	38	9	1.4	0.5	1.5	36	5	16	0.3

Intensity Ratios - Arithmetic Averages in Ash

	Fe	Si	Al	Mg	Ca	Na	K	Ga	Y	Ti	Ag	Zr	Cu
Sample 3	.61	3.92	1.74	3.16	4.87	3.59	.89	3.26	3.5	13.76	0.46	0.86	7.3
Sample 12	1.57	1.94	0.78	4.14	1.94	5.31	.63	1.64	1.76	13.4	0.26	1.05	9.84
Sample 22	3.50	1.80	0.84	1.77	1.38	1.11	.93	.77	.90	10.8	0.07	1.82	4.91

In general, the lateral variations in these seams are what might be expected in any sedimentary series the sources of which may have varied from time to time. A much more extensive study would be required, however, to trace in detail fluctuations of this type. A knowledge of the variations is of more immediate importance in the problem of correlation and distinction of seams by trace element analysis.

Variations in Composition of Petrographic Intervals

Analyses of individual petrographic intervals for each locality sample have been determined both in terms of percentage ash and p.p.m. of total coal. In both cases, for all seams, it is found that very seldom do successive intervals show the same amount of any element, and variations from interval to interval are as great as twenty times. This fact strongly supports the subdivisions of the seams into such intervals as carried out by Hacquebard and associates on the basis of type of coaly matter present, as the variation in trace elements noted can only be interpreted as indicating either a change in trace elements, from time to time, in the original plants, or in the amounts and quality of the sedimentary mat-

TABLE VIII

COMPARISON OF PHALEN SAMPLES, ABOVE AND BELOW MAIN PARTING

Elements in Parts per Million

a. Average above parting - sample intervals VIII-XIV

Sample	Inches	V	Cr	Mn	Co	Ni	Mo	As	Pb	Ge	Be	Ba	Sr	B	Zn
Phalen ... VII 3	31.42	13	3	52	3	6	5	39	22	2	1.6	1.4	20	50	10
4 ...	30.1	11	3	154	1	3	2	14	6	4	1.2	3.7	15	15	6
2 ...	31.4	9	4	53	3	5	2	90	10	1.7	2.5	1.3	30	13	7

b. Average below parting - sample intervals I-III

Sample	Inches	V	Cr	Mn	Co	Ni	Mo	As	Pb	Ge	Be	Ba	Sr	B	Zn
Phalen .. VII 3	12.46	78	15	12	9	23	8	66	58	2	3	tr	25	31	24
4 ...	18.52	21	4	96	5	7	17	286	42	0	3	47	180	12	26
2 ...	15.2	7	2	66	1	2	13	28	10	.2	2	7	126	2	12

TABLE IX

VARIATION IN ELEMENTS IN PETROGRAPHIC INTERVALS

Lloyd Cove Seam - II-1
Percentage Elements in Coal Ash

Interval	% Ash	Inches	V	Cr	Mn	Co	Ni	Mo	As	Pb	Zn	Sn	Ge	Ag	Ba	Sr	B
XIV ..	26.8	5.5	.012	.003	.0175	.0062	.020	.003	.260	.140	.260		.007	.0001	tr	.010	tr
XIII .	30.5	6.8	.002	-	.020	.0008	.002	.002	.230	.100	.009		.002	. -	tr	.022	tr
XII ..	7.55	12.8	.006	.001	.400	.0008	.005	.003	.020	.050	.017	.001	.001	<.0001	tr	.021	.045
XI ...	5.7	0.5	.010	.004	.110	.0008	.010	.003	. -	.105	.033	-	-	-	-?	tr	- ?
X	4.0	8.0	.003	-	.400	-	.005	.003	.280	.190	.038	.004	.001	.0001	tr	.052	.100
IX ...	2.02	2.6	.011	.008	.140	.0020	.005	.002	.002	.070	.0490	.002	.005	.0003	.006	.028	.100
VIII	4.54	22.5	.003	.001	.094	.0008	.001	.003	.390	.120	.028	.003	.001	.0001	-	.029	.070
VII .	27.6	5.4	.013	.003	.160	.0300	.046	.007	.166	.105	.015	.001	-	<.0001	tr	.022	.009
IV ..	5.86	7.4	.005	.002	.075	.0015	.005	.011	.780	.135	.015	.001	.003	<.0001	.018	.029	.030
III ..	20.4	1.1	.006	.009	.094	.0008	.0026	.001	-	.023	.005	-	-	-	-	-	.037
II ..	8.41	8.9	.004	.001	.039	.0026	.0027	.005	.450	.082	.009	.001	.005	<.0001	.006	.024	.001
I ..	8.38	8.5	.007	.002	.055	.0017	.0027	.008	.450	>.200	>.260	.003	.080	.0001	.012	.037	.050

ter being deposited with each interval, or both.

Study of analyses of intervals in all seams shows another interesting feature in that certain elements appear to be enriched in the ash in one or other, or both, of the *top* and *bottom* intervals. This is particularly true of Mn, As, Pb, and Ge and is frequently the case in Co and Ni but more rarely for V, Cr, Mo, Ba. Other elements reach their highest concentration in intervening intervals. There are, of course, exceptions to this general rule and an explanation for it will not be attempted at this time*. A similar

*W. C. Gussow has suggested to the writer that bacterial action may account for this feature.

behaviour has been reported for germanium in other coal seams. Examination of these variations in intervals shows that percentages of some elements increase with percentage ash, as is sometimes the case for V, Cr, and Mn, but most other elements for which quantitative data are available seldom show such a relation, nor is the variation, even then, at all proportional to the difference in percentage ash. From this, the inference may be drawn that no great degree of uniformity existed in source of supply and in deposition of mineral matter during the accumulation of the different intervals nor in the amount of mineral matter contributed by various types of plants themselves.

As examples of these variations, the reader is referred to Table VI, for two samples of the Backpit seam, and Table IX, showing the results in the Lloyd Cove seam in which ash content in the intervals varies from 2 to 30 per cent.

Variations in Composition of Intervals with Varying Organic and Iron Sulphide Content

The organic content of petrographic intervals of several seams, stated in terms of fusain, vitrain, clarain, claro-durain, and durain, as well as the pyrite content, has been determined by P. A. Hacquebard* (1). A study of these and the germanium and zinc content has been made and is reported elsewhere by the writer† (2). Suffice it to say here that preliminary examination of coal constituents in some samples of the Backpit and Harbour seams fails to show any clear relationship between them and the trace elements.

That some relationship may exist between the pyrite (or marcasite) content of the coals and certain trace elements is suggested in three instances. Two pyrite-rich samples of the St. Rose seam show equal amounts of Co and Ni, but in a third sample in which no pyrite was observed the amount of these elements was double or treble that in the other two. In Harbour IV-3 sample, the top and bottom intervals are richer in pyrite, as they are in Co, Ni, Ge, and Pb, though not in proportion to the amount of pyrite. Interval II of the same seam, though low in pyrite, is also relatively rich in Co, Ni, and Pb. A part of a rider seam (IV-[illegible]), above the Harbour seam, containing high germanium, also carries marcasite which, on separate analysis, showed both zinc and germanium. Although the sulphide content of portions of certain seams may account for some of the trace elements such as Co, Ni, Ge, Pb, and Zn, it does not alone explain the distribution found.

Separation of organic constituents from the mineral matter of one interval of the Lower Jubilee seam, by means of heavy liquid, and analysis of ash subsequently obtained from light, medium, and heavy fractions, clearly shows more abundant Cr, Ge, Be, Zn, Sr, B, Ti, and Y in the light and intermediate fractions than in the heavy. Only Ga and K are most abundant in the lightest fraction, while V, Co, Ni, As, Pb, Ba, and Fe are highest in the heavy fraction, as might be expected. The intermediate fraction actually contains the greatest amounts of Mn, Be, Zn, Sr, B, Si, Mg, Na, Ga, Ti, and Y, while Mo and As are about equal in both light and heavy fractions. This distribution in light and intermediate fractions is about the same as noted by Goldschmidt (1937) in coals of low ash content.

Correlation Problems

Three correlation problems have been studied in the light of the trace element composition of coal seams in the Sydney field. One dealt with the relation of the Gardiner and Mullins seams, a second with the lower part of the Phalen and Lower Jubilee, and a third was raised during this investigation as to the exact relation of the Blackrock section to the main Backpit seam.

1.—*Gardiner-Mullins Seams*:

With regard to these seams, T. B. Haites (1952, p. 295) states:

'In the New Waterford district (the Mullins) seam is 6 feet thick. However, it has not been traced with certainty south of the Bridgeport basin. On the other hand, the Gardiner seam is known only from the Glace Bay district and has not been discovered in the New Waterford district except for the Robert's pit on the north shore of Bridgeport basin. In this area, both the Mullins and Gardiner seams have a 'rider' seam, and their thicknesses and stratigraphic positions match roughly. Moreover, their sections show certain coal petrographical similarities (P. A. Hacquebard)".

Since this statement appeared, Hacquebard* has indicated that additional samples do not contradict, but rather support, his earlier observation on the similarity in petrographic composition between the two seams. A comparison of their composition as shown by spectrographic analyses is therefore of some interest, particularly in view of the other similarities noted above.

Samples of the two seams analyzed are from localities six miles apart and obviously, even if the samples were from one and the same seam, some difference in trace element content would be expected.

Overall averages for all intervals in each of the two seams have been given in Table IV, and are illustrated in Figure 2. Dealing first with those elements noted as showing the greatest variations in the whole coalfield, namely, Mn, As, Pb, and Ba, differences in content of these elements in the Gardiner and Mullins seams are of a rather small order, except possibly for Pb. Differences also in Ni, Sr, B, and Zn, which vary moderately throughout the field, are likewise small, and, as is the case with the first group of elements, much greater variations are found in other seams than between these two. Greatest variations are in amounts of Pb, Ge, and V, for which differences are greater than two times. Greatest variations in intensity ratios are in Y, Ga, Mg, Cu, Fe, and Al, but again still greater divergence is found in other seams than between these two. The similarity in amounts or intensity ratios of Co, Mo, Sr, B, Zn, Si, Na, and especially of Ti, may be noted. Of all seams, as noted earlier, the Gardiner has the highest Al and K, and the Mullins, the highest Si and Fe and lowest Mg. On this basis, however, no very clear distinction can be made between the two samples, which have similar ash content, thickness, and coal contituents.

TABLE X.—COMPARISON OF GARDINER AND MULLINS SEAMS
Intervals III to XII only
(Weighted averages in parts per million)

	GARDINER	MULLINS
V	12	2
Cr	5	3
Mn	26	29
Co	6	3
Ni	10	7
Mo	5	2
As	81	93
Ge	2.4	3
Sr	67	105
Ba	15	26
Pb	45	109
Zn	22	13
Inches	31.3 in.	32.9 in.
Av. % ash	8.89%	6.73%

A further comparison of the two seams is given in Table X, in which the average of twelve elements in in-

*Personal communication.
†See footnote on first page.

*Personal communication.

intervals III to XII only, below the central parting, are presented. According to Dr. Hacquebard, the petrographic composition of these intervals is very similar. Here we see the close correspondence in Mn, Ni, As, and Ge. Four others, Cr, Sr, Ba, and Zn, vary by less than a factor of 2, while only V and Pb show a much greater divergence. From this it must be inferred that the two seams were formed under very similar conditions throughout their history. The trace element studies do not assist in distinguishing them, but rather may indicate that they are one and the same seam.

2.—*Lower Phalen and Lower Jubilee Seams*:

In the New Waterford district, on the east side of Sydney harbour, the Phalen seam outcrops in a cliff section from which sample VII-3 was taken. Stratigraphically, apparently, below this is a seam locally known as 'Below Phalen' and named the Lower Jubilee (VIII).

The question as to whether the Lower Jubilee seam (intervals I-IV) is the equivalent of the lower part of the Phalen is considered to be of much importance for tracing the Phalen seam in the area west of Sydney harbour. A comparison of trace element content of the Lower Jubilee (VIII) with samples VII-3 and VII-4 of the lower three to four intervals of the Phalen seam is given in Table XI. Sample VII-3 (Phalen) comes from about the same locality as the Lower Jubilee, but sample VII-4 is from a locality about two miles away.

The analyses given show that, of the fourteen elements listed in p.p.m., eight show differences by a factor of 2 or more as between the Lower Jubilee and either of the two samples of the Phalen seam. Seven of the elements are present in greater or smaller quantities in the former, one is in equal amounts, and six fall between the extremes of the two Phalen samples. Intensity ratios show higher Fe, lower Ca, and slightly lower Y and Ti, in the Lower Jubilee, but intermediate amounts for the other seven elements.

A clear-cut distinction on the above basis is not possible, though the balance is somewhat in favour of the seams being different entities*.

*This conclusion is confirmed by recent studies of fossil spores and petrographic character, the results of which will be published shortly by M. Grace Somers (Proceedings of the 2nd Coal Conference held at Crystal Cliffs, July, 1952, N.S. Dept. Mines and N.S. Research Foundation).

TABLE XI

COMPARISON OF LOWER JUBILEE AND LOWER INTERVALS OF THE PHALEN SEAM

Elements in Parts per Million

Element	Lower Jubilee Intervals I-IV 13.5"	Phalen VII-3 Intervals I-III 12.46"	Phalen VII-4 Intervals I-IV 18.52"
V	28	78	21
Cr	9	15	4
Mn	56	12	86
Co	34	9	5
Ni	74	23	7
Mo	11	6	17
As	105	66	286
Ge	8	2	-
Be	7	5	3
Ba	257	tr	47
Sr	47	25	180
B	8	31	12
Pb	89	58	42
Zn	24	24	26

Intensity Ratios

Element	Lower Jubilee Intervals I-IV 13.5"	Phalen VII-3 Intervals I-III 12.46"	Phalen VII-4 Intervals I-IV 18.52"
Si	1.39	4.93	1.17
Al	0.99	1.55	.38
Fe	2.85	1.85	1.60
Ca	0.80	4.76	1.82
Mg	1.39	.27	6.03
Na	.44	1.34	2.22
K	1.19	2.58	0.42
Ga	1.81	3.02	0.75
Y	2.10	3.16	2.70
Ti	3.31	7.09	4.12
Ag	tr	0.10	tr

3.—*Backpit and Blackrock Seam*:

The Backpit seam can be traced almost continuously from the Glace Bay area and through the Sydney Mines and New Waterford sections, over a distance of about 20 miles. Six column samples — Nos. 4, 10, 13, and 1, 2, 8 — of this portion have been analyzed. To the northwest, an unexplored gap exists between samples Nos. 8 and 5 (Figure 1), and the northwesterly three samples Nos. 5, 3, and 6 are from what is known locally as the Blackrock seam.

A study of the analytical results shows that there are sufficient differences between the Blackrock and the main Backpit seam to suggest that they may be different seams rather than one showing somewhat erratic lateral variation as discussed above. A comparison of averages of analyses for the different sections of these seams is shown in Figure 14.

Though the average of the Blackrock samples shows a rather similar content of V, Cr, Mn, B, and Sn to that of one or other of the Backpit sections, the Blackrock is lower in Mo, As, Ba, and Sr and distinctly higher in Co, Ni, Ge, Zn, and particularly higher in Pb, than the Backpit. In addition, intensity ratio studies of other elements show lower Ca, Na, and K and higher Mg in the Blackrock compared with the Backpit samples. It is true, however, that, within the Backpit proper, variations of about the same magnitude do occur and no conclusion is possible at this time. Dr. Hacquebard† has also raised the question as to what seam the Blackrock might be correlated with if it is not a part of the Backpit. Could it be a part of the Phalen seam? Nearest samples of the latter are about 8 miles away and are thus too distant for any justifiable correlation by these means. Available analyses of the

†Personal communication.

Phalen (VII-3) show it to be distinctly lower in nine elements and higher in one, so that no such correlation seems warranted. Possibly further study of petrographic intervals may shed some light on this problem.

In summary, trace element studies appear to confirm the similarity of the Gardiner and Mullins seams, two which are generally considered to be different seams. They also support to some extent the conclusion that the Lower Jubilee and lower part of the Phalen are not parts of one seam, and they raise the problem of the exact relation between the Blackrock and the main Backpit seam.

Conclusions

(1) In comparison with the ash of other coals, those of the Sydney coalfield are enriched especially in *manganese, arsenic* and *lead*, have about the same amount of zinc, but are lower in Be, B, V, Cr, Co, Ni, Ge, Mo, and Sn. They are much higher in *Sr* and *Ba* than the average of igneous rocks.

Enrichment of the Sydney coals in manganese and possibly in barium and strontium may be related to the manganiferous character of both the (Mississippian) Windsor limestones and still older sediments in the Appalachian region, on the one hand, and of the barite deposits, also developed by replacement in the Windsor rocks, on the other. Sources of high arsenic, lead (and zinc) may have been the arsenical and lead-zinc mineralization throughout New Brunswick and Nova Soctia, which are ascribed to mid-Devonian granitic intrusives.

(2) The average of individual coal seams shows distinctive differences in certain elements, but the usefulness of this as a means of correlation is somewhat limited by the lack of adequate sampling and analyses of several seams and by the known lateral variation in composition of ...ters. Most marked variations occur in content of Mn, As, Pb, and ...ly Ba; less marked are Ni, Sr, ..., and B. Individual seams vary ... in content of V, Cr, Co, Mn, ..., and Sn.

(3) Variations in trace elements of the seams occurring in the three ... rock units outlined by W. A. ... are as follows:

...est—*Lonchopteris zone*:
...ry low As; below average in ..., Ge, B, Ba; above average in ..., highest in Ca

Middle—*Linopteris zone*:
Steadily increasing As and Na, upward; relatively low in Mn

Upper—*Ptycocarpus unitus zone*:
High As with exception of Harbour seam; low to high Mn; low Ba and high Mg and Ti

Coals of an older (Riversdale) age, lying west of the Sydney coalfield — the St. Rose and Port Hood — on the basis only of character samples, differ from all but one of the Sydney seams in having a Co/Ni ratio = 1, and in all cases are well above the average in Pb and below the average in Mn, Co, Ni, Mo, As, Ge, Sr, and Sn.

(4) Lateral variation in composition of the Backpit seam over 26 miles, of the Harbour over 6 miles, and of the Phalen over 2.8 miles, is noted, but in general is not regular (with the exception of the Phalen) for most elements in any one direction. A strikingly similar content is shown for two samples of the Backpit seam, 1.75 miles apart.

(5) The variation in trace element composition of coal petrographic intervals in individual seams is rather pronounced and confirms the validity of this classification. Enrichment in either the top or bottom, or both, such intervals of many seams especially of Mn, As, Pb, Ge, and frequently of Co and Ni, is also evident, as noted by other investigators in other coals.

(6) No striking relation has yet been shown between trace element content and the organic (fusain, vitrain, clarain, etc.) content, as determined in the Backpit and Harbour (IV-3) intervals, but fractionation of one sample (Lower Jubilee) with heavy liquids showed a greater abundance of Cr, Ge, Ba, Zn, Sr, B, Ti, and Y in light and intermediate fractions than in the heavy fraction. These are among the elements indicated by Goldschmidt as commonly enriched in low-ash coals.

Though no consistent relation can be shown between Co and Ni and pyrite content, some relation is suggested by results on the St. Rose and Harbour (IV-3) seams. In the latter, pyrite is more abundant in the top and bottom intervals than in between.

(7) Three correlation problems have been studied in the light of trace element composition of the coals. The Gardiner and Mullins seams, similar in total thickness, ash, and petrographic composition, are also very similar in trace elements both in individual and overall average. If they are distinctly different seams they were formed under surprisingly similar sedimentary conditions.

Differences between the Lower Jubilee and two samples of the lower intervals of the Phalen are evident and support the conclusion that these are not to be related.

The Blackrock section of the Backpit seam shows sufficient differences from the more easterly part of the latter to suggest that these may not be simply due to lateral variations and that the Blackrock may be a separate seam. Further study of this is needed before any final conclusion is drawn.

(8) Study of the distribution of germanium in the ash of coals from this area has been made and shows it to be similar to that in other Pennsylvanian coals but well below that of Cretaceous coals. Details are given in a separate paper elsewhere.

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The Colonel John By Memorial Fountain

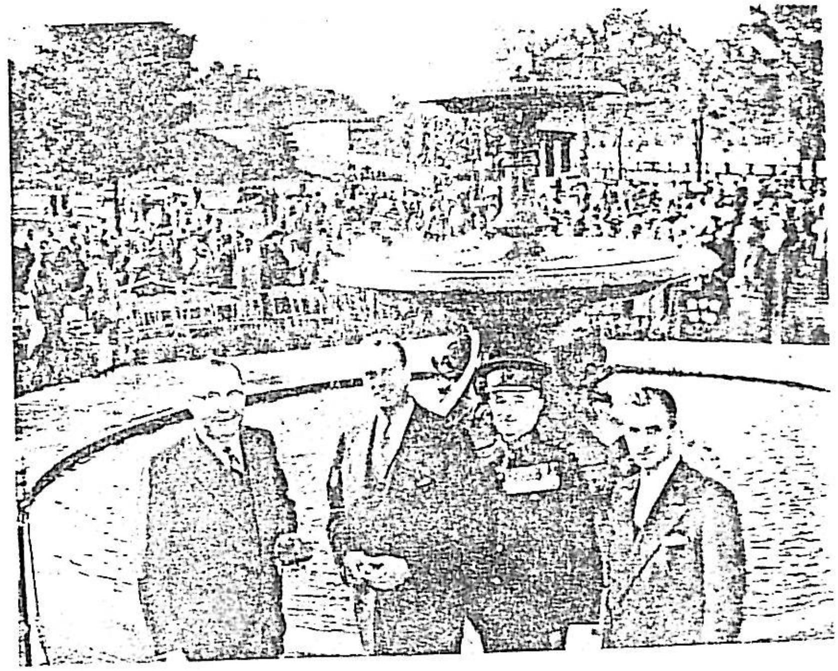
DEDICATION CEREMONY IN OTTAWA, OCTOBER 5TH, 1955

THE Engineering Institute of Canada paid impressive tribute to one of the greatest military engineers ever to set foot on Canadian soil when, on October 5th, they dedicated a magnificant memorial fountain honoring COLONEL JOHN BY, builder of the Rideau Canal and founder of Bytown, which became Ottawa and the capital of Canada in 1855. The fountain has been erected just off the Federal District Commission Driveway in the heart of Ottawa, and just a few hundred feet away from the canal itself.

Of red granite, the fountain was designed and built by SIR CHARLES BARRY, R.A., Architect of the British Houses of Parliament. It stood in Trafalgar Square, London, from 1845 until 1948, when the National Arts Collections Fund of England presented it to the National Gallery of Canada.

When The Engineering Institute of Canada sought a fitting memorial for Colonel By, the Gallery offered them the fountain. The Federal District Commission offered the present site and the City is providing the flood lighting and water supply.

DR. R. E. HEARTZ, President of The Engineering Institute of Canada, dedicated the fountain at a public ceremony attended by Federal, Provincial, and Municipal government representatives and officers of the Royal Corps of the Canadian Engineers.



The Colonel By Memorial Fountain.

In foreground (l. to r.) Dr. R. E. Heartz, President E.I.C., Hon. R. H. Winters, Minister of Public Works, Brig. J. L. Melville, Hon. Col. Commandant R.C.E., R. F. Legget, Chairman, Ottawa Branch E.I.C.

Public Works Minister R. H. WINTERS, unveiled a plaque at the fountain which tells its story, and BRIGADIER J. L. MELVILLE, Honorary Colonel Commandant, Royal Canadian Engineers, unveiled a second plaque commemorating the achievements of Colonel By.

Prior to the dedication ceremony Mayor Charlotte Whitton addressed members of the Engineering Institute and their over 400 guests at a luncheon in the Chateau Laurier.

The Royal Corps of Canadian Engineers provided an honour guard and the Royal Corps of Canadian Signals band played appropriate music during the unveiling ceremonies.