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NORSK POLARINSTITUTT

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Nr. 96

GEOCHEMICAL AFFINITIES OF SOME COALS FROM SVALBARD

BY

J. R. BUTLER

I KOMMISJON HOS
BRØGGERS BOKTRYKKERIS FORLAG
OSLO 1953

NORSK POLARINSTITUTT

(Formerly Norges Svalbard- og Ishavs-undersøkelser.)
Observatoriegaten 1, Oslo

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GEOCHEMICAL AFFINITIES OF SOME COALS FROM SVALBARD

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A. W. BRØGGERS BOKTRYKKERI A/S

1. Introduction.

Most publications concerning the inorganic chemistry of coal ash deal with the composition of specific coal seams or definite coal types, but little has been reported on the variation of chemical properties within a given seam except for non-metal constituents. The present study was undertaken to find what seam-variation occurs and whether element distribution for ash or coal in a particular seam is sufficiently distinctive to enable it to be correlated in different localities (and distinguished from another seam).

2. Description of Coals.

Coal is found in Svalbard in several formations from the Devonian right up to the Tertiary system, and coals from the Upper Devonian, Lower Carboniferous and Lower Cretaceous have from time to time been exploited (Horn, 1928). At present, however, only Tertiary coals and a Carboniferous coal are worked and the former are by far the most important.

The Tertiary in Svalbard, represented by Palaeocene and Eocene, is found in central Vestspitsbergen, where it forms a trough-like syncline, and in a few other smaller areas to the west deliminated by faults. The strongest development of coals in Svalbard appears at the base of this system (in the Lower Light Sandstone series) overlying the Cretaceous; subdivisions of the Lower Tertiary (after Orvin 1940) are shown in Table 1.

During the summer of 1949 H. Major of the Norsk Polarinstitutt, in studying the coals of Vestspitsbergen collected numerous Tertiary coals and samples from three of his localities are considered here. The Svea seam (Sveafløts) was sampled at locality E (Map 1) from a test adit, and also at locality 4 B (about 3 km. north of locality E) near the outcrop. The seam can be readily followed along the coast from the Svea East mine to the north-east and subsequently to the north-west on the western side of Höganesbreen, but it diminishes in thickness from over 4 metres at E to less than 2 metres at 4 B; to the west the seam thins out rapidly before it dips down below sea level. Some distance above

Table 1.

Lower Tertiary in Svalbard, after Orvin (1940).

Series	Thickness (metres) Max.	 Min.
Upper Plant-Bearing series. Ss., slaty ss., clay ironstones, marly shales and thin coals.	600	500
Flaggy Sandstones series. Fissile ss., black clays; plants and worm tracks.	200 (approx.)	200 (approx.)
Upper Black Shale series. Chert fragments; relatively deep deposition.	300	240
Green Sandstone series. Shallow marine deposition.	250	175
Lower Dark Shale series. Mainly marine; thins to the east.	113	0
Lower Light Sandstone series. Marine and non-marine. Coals low in series.	130	110

the Svea seam (8—15 metres) another coal seam occurs which was mined in Svea West mine (Svea Vestgruve) and samples (called T 1 to T 10) were taken from the mine cross-cut at locality BT 2. The thickness of this upper seam at BT 2 is just under 1 metre and, like the Svea seam, it becomes thinner to the north and east.

Descriptions of the coal samples are given in Tables 2, 5 and 8 and the former two of them are based on the microscopic studies of H. Major. The nomenclature adopted, after Stopes (1935), is as follows: —

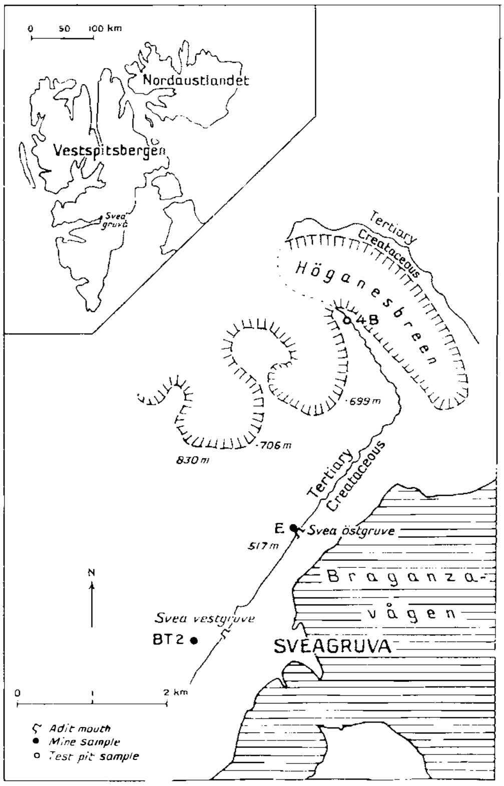
(1) Clarain consists of finely striated coal, mostly bright, breaking rectangularly.

(2) Durain consists of hard, compact, dull, greyish black coal, usually breaking with irregular fracture.

(3) Fusain consists of porous, dull, friable, charcoal-like coal, usually greyish black in colour. The pores may, or may not, be filled with mineral matter.

(4) Vitrain consists of macroscopically structureless, brilliant glossy or vitreous coal, usually with conchoidal fracture. It occurs in bands or lenticles of more than 1 mm. thickness.

In Tables 2 to 10 inclusive letters C, D, F, S or V following the sample numbers indicate the presence of clarain, durain, fusain, shale or vitrain respectively in the specimens. A bracketed symbol indicates subsidiary amounts.



Map I. Svea Mine Area.

3. Experimental Procedure.

Powdered specimens of the coal (after sampling) were moistened with HNO_3 (to oxidise any GeO to the involatile dioxide) and ashed at a temperature of 565° C. The major element concentrations in the ash were then determined spectrographically according to Kvalheim's method (1947) using the working curves prepared in his laboratory. All of the specimens from locality E were arced in duplicate (giving a standard error of ± 10 %) but some of the specimens from the other localities were only arced once (giving a standard error of up to ± 15 %). CO_3, Na, P and SO_4 were not determined quantitatively and this partly accounts for the low oxide summations for a number of the ashes quoted in Tables 3, 6 and 9; a further factor which may give a low total for the oxides of Si, Al, Ti, Fe, Mg, Ca and K is the difference in composition between a particular ash and the standards used in constructing the working curves. (Rocks and minerals but no plant ashes were used for the latter).

Minor elements were also determined spectrographically by arcing 1 : 1 mixtures of powdered carbon and ash to completion at 7.5 Amps., using carbon electrodes 3 mm. external diameter and 1½ × 4 mm. internal dimensions (the size used for the major determinations) and photographing the cathode later in the region 9000 Å to 2600 Å on a Mannkopff spectrograph. Minor element standards were prepared by mixing the carbonates of Ba, Li and Sr, the hydroxides of Sc and Zr, the nitrate of Ag, the alum of Rb, the chloride of Cs and the oxides of Be, Co, Cr, Cu, Ga, Ge, La, Mo, Ni, Sn, V and Yt in a base (called base A) heated to 600° C and of composition SiO_2 37.5 %, Al_2O_3 21 %, TiO_2 0.55 %, Fe_2O_3 21 %, CaO 8.5 %, MgO 8.0 % and NaCl 3.5 %.

The minor elements for a particular standard were in the ratio 10 (Ba, Cr, Li, Sr and V): 5 (Co, Cu, Cs, Ni, Rb and Zr): 1 (Ag, Be, Ga, Ge, La, Mo, Pb, Sc and Sn) and standards were mixed having concentrations of, say, 1 % Li, 4640 p.p.m. Li, 2154 p.p.m. Li etc. down to 1 p.p.m. in the base and proportionately as shown above for the other elements. Direct comparisons were made between line intensities from burns of the standards and of the ashes and the errors resulting therefrom are ± 30 % for all elements (except Li and Rb) up to concentrations of .1 % and ± 40 % for Li and Rb up to .1 %. For higher concentrations the accuracy falls off further and may reach ± 50 % for concentrations exceeding 1 %. Due to the effect the base composition may have on the strength of a trace element line (shown by the work of Scott 1945) the concentration estimations are, strictly, only correct for ashes having compositions similar to base A. For ashes with rather different compositions from that of base A, the estimations may be less correct. Boron was determined with substantial accuracy (± 10 %) using the method of Landergren (1945).

4. Previous Literature.

As long ago as 1887 Jensch (1887) published some remarkable analytical data concerning the composition of several coal ashes from coals of Upper Silesia. He determined Cd, Mn, Pb and Zn in six samples and found their concentrations to rise to 1.8 % Mn, 9000 p.p.m. Zn, 760 p.p.m. Pb and 70 p.p.m. Cd. The estimation of less common elements at that time was, however, tedious and, perhaps, not too reliable and it was not until the first quarter of the present century had elapsed, when spectrographic methods (optical and X-ray) were asserting themselves, that Jensch's discoveries were actively pursued. Goldschmidt's report on the occurrence of Ge in coal ashes in 1931 paved the way for his more comprehensive publications in 1933 and especially 1935 when the occurrence of very many less common elements in coal ashes was reported and discussed. Ge and B were shown to bear an inverse relation to the ash content for coals from a given seam and ash-poor coals were shown to contain the greatest concentration of the rarer elements in the ash although a low ash percentage did not necessarily mean the presence of the rare assemblages. The most obvious ways in which these elements became associated with coal ash were (1) concentration during life by the coal plants, (2) concentration during decay of organic material, (3) concentration after burying of the plant under sediments.

Before the turn of this half century the occurrence of more than 40 of the rare or less common elements had been reported in coal ashes and the data has been admirably reviewed by Gibson and Selvig (1944). More recently Azcona and Puig, in a short publication (1947), have claimed to be able to distinguish coals by the composition of their ashes but few analytical data were presented.

5. Svea Seam, Locality E.

(1) Coal and Ash Composition.

The thickness of the Svea seam at the East mine is 455 cm. and the 16 samples collected represent more than 30 % of thickness. The occurrence of durain is restricted to E 8 but clarain, fusain and vitrain are more common. As expected, vitrains show their strongest developments at the extremities of the seam and fusain is more prevalent in the lower half accounting partly for the higher ash contents there. Coals of clarain (E 6, E 9, and E 11) and clarain with vitrain (E 12, E 15 and E 16) show, in general, lower contents than do coals of vitrain alone (E 3, E 4 and E 14) and the finding of Lessing (1920) that clarain and vitrain in a South Staffordshire coal seam both had low ash contents (1.22 % and 1.11 % respectively) do not obtain here.

The major element contents of the ash (excluding CO_3, Na, P and SO_3) are shown in Table 3 and the results calculated for oxides in the coal are shown graphically in Figure 1. There is no definite trend in ash composition with increasing ash content up to 4 % ash but values for the impure coals E 2 with 10 % ash, high SiO_2 and Al_2O_3, and E 8 with 11 % ash, high CaO and MgO suggest that Al, Ca, Mg and Si are dominant in the mineral impurities associated with these and other coals; the presence of Mg and Ca sulphates in a number of coals was confirmed. Coals with similar ash contents may have very different compositions (E 11 and E 13) and ashes chemically similar may come from coals of distinct macroscopic or microscopic description. The ashes from the clarains E 6, E 9 and E 11, however, have comparable compositions (although the coals have ash contents 2.8, 0.9 and 2.1 % respectively) with SiO_2 averaging 11 %, Al_2O_3 averaging 23 % and Fe_2O_3 averaging 21 %. Ashes from the vitrain-containing coals E 2, E 3, E 12, E 14 and E 15 average an SiO_2 content of 5.2 % — well below that for ashes from the clarain — but the values for the other oxides vary widely.

Table 2.

Description of Coals From the Svea Seam, Locality E, Svalbard.

Sample No.	Distance of samples from footwall	Short macroscopic description	Ash content % (565° C)
E 16 CV	445—455 cm.	Hanging wall coal; banded clarain with distinct vitrain veins. Some brown incrustations along a few cracks.	1.4
E 15 VC	415—420 cm.	Vitrain and clarain, the latter not exceptionally brittle.	1.8
E 14 V	380—385 cm.	Brittle vitrain; non-dusty. An associated thin shale was discarded in selecting the coal sample for analysis.	1.5
E 13 CV(F)	345—361 cm.	Clarain and vitrain predominating; subordinate fusain.	2.3
E 12 CV	322—328 cm.	Clearly laminated clarain with vitrain layers.	1.4
E 11 CF	302—312 cm.	Clarain with a bright greasy lustre; disseminated fusain; sample not laminated.	2.1
E 10 CF	258—268 cm.	Principally clarain but a few discreet fusain streaks; a little copper mineral staining.	1.7
E 9 C		Clarain showing low reflectivity.	0.9
E 8 DC(F)	176—188 cm.	Durain, clarain and much fusain.	11.0
E 7 CF	155—166 cm.	Clarain, with a little fusain.	4.8
E 6 C	125—130 cm.	Clarain.	2.8
E 5 CV(F)	105—115 cm.	Clarain and vitrain with some fusain.	5.4
E 4 V	76—87 cm.	Mainly vitrain; lumps of "pure" vitrain selected for analysis.	4.9
E 3 V	55—63 cm.	Vitrain dominant; a thin shale (included in the sample for analysis) imparts some fissility. White staining suggests a slightly weathered nature.	4.5
E 2 C(F)	35—43 cm.	Clarain with some fusain.	10.0
E 1 S(V)	Zero cm.	Footwall coal-shale; with plant remains and a very thin vitrain coal exhibiting conchoidal fracture. Feathery aggregates of gypsum seen on some of the surface of the specimen.	31.2

Letters following sample numbers indicate clarain (C), durain (D), fusain (F), shale (S) and vitrain (V).

The coals in the seam tend to become ash-poorer as the hanging wall is approached (the fusain-rich coal E 8 being exceptional) but there is no obvious trend in coal composition in the seam except for marked increases in Si and Al in the footwall coal-shale (due to clay material) and in the hanging wall coal. Throughout the seam, however, there is a close sympathetic relationship between Ca and Mg and to a less extent between these and Fe contents. In general the SiO_2 and Al_2O_3 values are high when the Ca, Mg and Fe oxides are low and vice versa. TiO_2 varies from 0.05 % to over 1.5 % but apart from some of the higher concentrations being recorded for ashes near the footwall, the variation is haphazard.

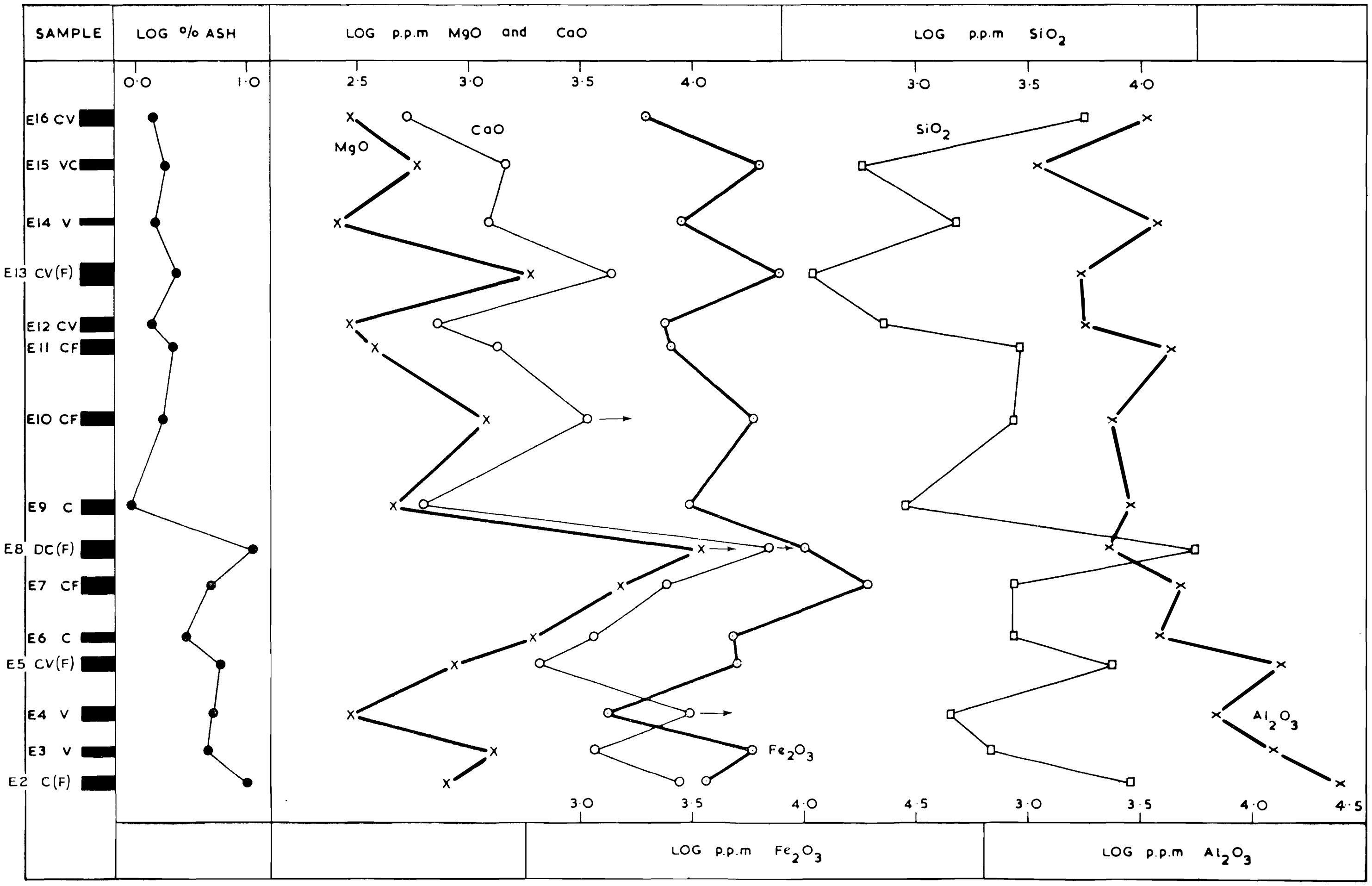


Figure 1. Concentrations of oxides in coals from the Svea seam, locality E, Svalbard.

Table 3.

Percentage Oxides in Ashed Coals From the Svea Seam, Locality E, Svalbard.

Distance from footwall (cm.)	Description and specimen	% Ash content	Percentage oxides							
			SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	CaO	K_2O	
445—455	E 16 CV	1.4	40	24	> 1.5	14	2.1	3.8	2.2	E 16
415—420	E 15 VC	1.8	3.2	6.2	.50	35	3.3	8.1	*	E 15
380—385	E 14 V	1.5	10	25	.74	19	1.7	8.1	*	E 14
345—361	E 13 CV(F)	2.3	1.5	7.5	.30	34	8.2	19	*	E 13
322—328	E 12 CV	1.4	5.2	13	.20	17	2.1	5.2	*	E 12
302—312	E 11 C(F)	2.1	14	22	1.5	12	1.8	6.3	*	E 11
258—268	E 10 CF	1.7	16	14	.20	35	7.0	> 20	*	E 10
205—215	E 9 C	0.9	10	32	> 1.5	34	5.1	7.0	*	E 9
176—188	E 8 DCF	11.0	16	2.1	.05	9.3	>10	> 20	*	E 8
155—166	E 7 CF	4.8	5.7	10	.50	40	10	16	*	E 7
125—130	E 6 C	2.8	10	14	.63	17	7	13	*	E 6
105—115	E 5 CV(F)	5.4	14	25	.74	9.3	1.6	3.8	*	E 5
76—87	E 4 V	4.9	2.9	14	.50	2.7	60	> 20	*	E 4
55—63	E 3 V	4.5	4.8	28	> 1.5	13	2.9	8.1	*	E 3
35—43	E 2 C(F)	10.0	9.2	25	> 1.5	3.6	80	8.8	*	E 2
Footwall Coal-Shale	E 1 S(V)	31.2	71	29	1.5	3.8	82	1.0	*	E 1

An asterisk (*) indicates K_2O below 1 %.

(2) Minor Elements in the Ashes.

Table 4 shows the concentration of numerous elements in the ash arranged alphabetically in groups of comparable concentration. The tendency for the hanging wall to be enriched in the rarer elements (Goldschmidt 1930) is clearly seen, especially for the elements Cr and V, Be, Ge, Mo and Yt.

(a) *B, Ba, Li and Sr.*

The concentrations of B are of interest since they vary inversely as the ash percentage (Figure 2), indicating that the original parts of the coal-producing vegetation, e. g. xylen, spores, fronds, etc., carried boron inversely proportional to their differing ash contents. The exceptionally high (absolute) values for B in some of the ashes from the upper part of the seam probably indicates that weathering by percolation of the organic residues as a whole (most effective during the peat and pre-compaction stage) was not marked. The structureless vitrains thus carry as much B as clarains with similar ash contents. Fairly high values for B in other coals have been reported: Nazarenko (1937) found up to 1 % in Russian coal ashes from the Kuznetsk and Don basins (with B constant throughout the seam) and Thilo (1934) found 0.3 % in a Newcastle coal ash; the value of 0.9 % B found in "average wood ashes"

Table 4.

Concentration of Minor Elements (p.p.m.) in Ashed Coals From the Svea Seam, Locality E, Svalbard.

Elements grouped alphabetically and according to concentration viz.

(a) B, Ba, Li and Sr. (0.1 % to 2.0 %)
(b) Cr, Mn, V and Zr. (100 p.p.m. to 1000 p.p.m.)
(c) Co, Cu, Ga, Ni and Yt (10 p.p.m. to 100 p.p.m.)
(d) Be, Ge, La, Mo, Pb, Rb and Sc (occurring occasionally)

An asterisk (*) indicates below sensitivity and a dash (—) indicates absence of data.

Description and specimen	% Ash content	Concentration in ash (p.p.m.)																				
		B	Ba	Li	Sr	Cr	Mn	V	Zr	Co	Cu	Ga	Ni	Yt	Be	Ge	La	Mo	Pb	Rb	Sc	
E 16 CV	1.4	7950	> 5000	700	4000	300	300	800	300	25	70	55	40	400	45	35	40?	10	35	150	*	E 16
E 15 VC	1.8	9800	2000	—	1800	40	490	70	100	25	50	30	50	*	*	*	*	5	*	*	*	E 15
E 14 V	1.5	10000	> 5000	5000	1600	100	100	80	*	20	40	10	75	*	*	*	*	5?	*	*	*	E 14
E 13 CV(F)	2.3	11500	3500	900	870	25	390	30	80	*	15	*	10	40	*	*	*	*	*	*	*	E 13
E 12 CV	1.4	20000	4000	1100	1600	20	40	45	40	15	80	20	50	40	10	25	*	25	*	*	30?	E 12
E 11 C(F)	2.1	6900	> 5000	4500	6000	175	30	60	1000	*	65	35	20	*	*	*	40?	*	15	50	*	E 11
E 10 CF	1.7	7500	3500	700	1600	65	420	40	*	15	90	15	40	*	*	*	*	*	15	*	30?	E 10
E 9 C	0.9	10200	> 5000	—	500	—	480	100	120	20	200	10	110	*	*	*	*	*	*	*	*	E 9
E 8 DCF	11.0	740	2000	2200	4700	—	230	140	*	4	40	*	8	*	*	*	*	*	*	*	*	E 8
E 7 CF	4.8	3000	2000	800	700	45	350	10	200	10	45	15	10	100	*	*	*	*	*	*	*	E 7
E 6 C	2.8	9200	> 5000	1700	4700	80	155	120	100	15	40	25	2	*	*	*	*	*	15	*	*	E 6
E 5 CV(F)	5.4	6000	> 5000	3000	> 5000	50	100	45	80	5	60	15	10	120	*	*	*	*	*	*	*	E 5
E 4 V	4.9	—	3000	1500	3300	50	55	120	400	20	35	30	10	150	*	15	*	*	50	*	*	E 4
E 3 V	4.5	5100	> 5000	4000	> 5000	200	290	400	400	30	75	55	20	100	*	20	*	*	75	*	150	E 3
E 2 C(F)	10.0	2200	> 5000	900	> 10000	125	45	400	1100	20	30	85	15	200	*	*	*	*	100	*	50	E 2
E 1 S(V)	10.0	540	450	400	600	600	25	620	300	10	65	60	10	*	*	*	40?	*	500	500	*	E 1
Sensitivity (p.p.m.)		10	10	1	10	1	10	10	40	5	10	10	1	40	10	10	60	5	10	50	40	

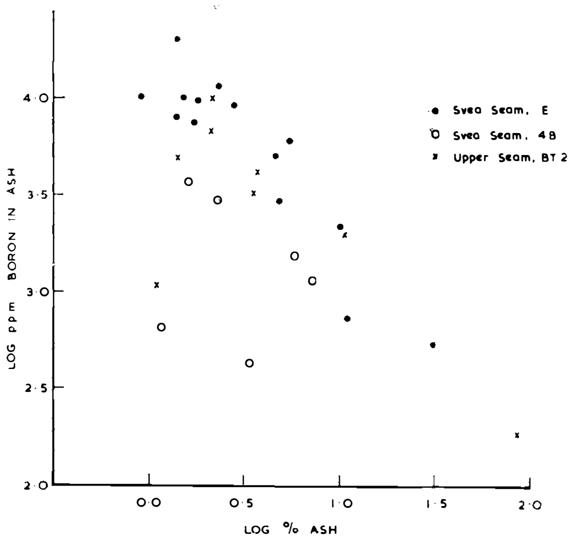


Figure 2. Relation of boron content in ash to percentage ash.

by Midgley and Dunklee (1941) shows that the tolerance of B by present-day plants can be appreciable. Both Ba and Sr are very prominent in the high-ash coals and occur substantially in the mineral matter; the content in the coal is thus not readily deduced, although it too must be fairly high as seen from the values for E 9, E 12 and E 16 (ash contents below 1.5 %) with Ba averaging over 0.5 % and somewhat in excess of Sr. Higher values for Ba in ash have, however, been recorded and Reynolds (1939) found up to 4 % Ba in British coal ashes. Li is not often recorded in coal ash analyses and the values found here of up to 0.1 % and more suggest it may be more common than previously supposed. It seems unlikely that much Li has been introduced subsequent to the death of the coal plants and it may be assumed that the Li was held by the plant parts themselves. It is of interest to note that Li is not an essential element to present-day plant growth and, indeed, it may be toxic in large amounts (Voelcker, 1901, reference wheat). Bertrand (1943) in studying the mode of distribution of Li found more Li in roots than in aerial parts of plants but there is no correlation between Li in the coal ashes and the types of coal producing the ash.

(b) *Cr, Mn, V and Zr.*

Cr and V vary in a broadly similar way up the seam; in the coal the concentrations are a maximum near the footwall, sink to a minimum in the middle of the seam, and rise sharply as the hanging wall is approached (but are less than the near-footwall values). The concentration-variations in the ash are also similar but ashes from E 1 and

E 16 give approximately equal maxima. The association of Cr and V has been noted by Reynolds (1948) who found them in vitrains yielding only 0.12 % ash. To some extent V seems to follow Si, e. g. in E 8 (high ash percentage) where both are substantial, and thus the ash values may not be due to original plant content alone but, possibly, to redistribution of V by solution. The figures of 1.95 % V for ash from Czechoslovakian anthracite (Koblic, 1950), however, shows that the V values for the Svea seam are not unusually high. Mn varies haphazardly in the coal seam; values for the coal are similar for the seam limit samples but vary from three to one tenth times these intermediately. Zr values, on the other hand, rise generally with ash content and the element may in some cases have been introduced as zircon (Gauger et al., 1934). The high concentration of 0.1 % Zr in the ash from a clarain (E 11), however, indicates that the Zr is not wholly detrital in origin.

(c) *Co, Cu, Ga, Ni and Yt.*

Co varies in the seam independently of ash content or of Fe (or Mg) content and there is little difference in Co values for extremes of the seam. Ni, however, tends to increase as the ash content decreases — although less regularly than does B — and the ratio Co/Ni in the ashes decreases as the hanging wall is approached. The figures for Ni (up to 110 p.p.m.) are comparable with those recorded for some Kuznetsk Basin coal ashes (Shakhov and Efendi, 1946) but are substantially less than values of up to 8000 p.p.m. Ni found by Mott and Wheeler (1927) in the ash of mineral-free and very pure coal. Cu, like Ni, is usually higher in ashes from ash-poor coals than from ash-rich ones but part of the Cu has been introduced after coal formation, as suggested by the description of E 10, and the approximate constancy of the product of the Cu concentration in the ash and percentage ash of the coal may be fortuitous. Ga in the ashes follows Al only to a limited extent and although Al/Ga bears no relation to the ash content, the ratio-variation is more than would be expected from (say) detrital associated clay and indicates that some portions or types of plants may have accumulated Al at the expense of Ga. Hutchinson and Woolack (1943) and later Chenery (1948, 1949) have shown that the longest established group of Pteridophytes (including club mosses and ferns) can be strong Al accumulators and the Cryptogams in general concentrate Al more readily than the more recent flowering plants; data concerning Ga in these plants are insufficient to decide how closely it follows Al.

Yt is absent (below 40 p.p.m.) from the ashes from the middle portion of the seam but reaches 400 p.p.m. in the ash from the hanging wall coal and is concentrated (up to 200 p.p.m.) in the ashes from the coals near the footwall. The behaviour of Yt is thus distinct from that of Zr and more resembles that of Ge and Pb.

Table 5.

Description of Coals From the Svea Seam, Locality 4B, Svalbard.

Letters following sample numbers indicate clarain (C), durain (D), fusain (F), shale (S), and vitrain (V); W indicates the sample is weathered.

Sample No.	Distance of samples from footwall	Short macroscopic description	Ash content % (565° C)
B 9 C(V)	165—170 cm.	Hanging wall coal; well layered non-dusty clarain (with a small vitrain seam). White weathering incrustations of gypsum not uncommon.	13.5
B 8 D	151—156 cm.	An apparently sheared durain; slightly weathered.	2.3
B 7 DW	140—150 cm.	The specimens selected consist of (i) very weathered durain with white incrustations common, and	7.2
B 6 D	140—150 cm.	(ii) the associated almost fresh durain slightly stained with a mineral probably containing Cu.	1.6
B 5 F(D)	118—131 cm.	Very powdery fusain with subordinate durain streaks; white feathery aggregates and yellow stainings. Representative sample. Carbonate present.	17.7
B 4 C	55—67 cm.	Clarain (forming the bulk of the coal at this part of the seam); associated thin fusain discarded.	11.5
B 3 D	22—30 cm.	Durain; somewhat weathered.	5.8
B 2 DW	16—20 cm.	Dull durain laminated at one end of the specimen and there stained more markedly with yellow, brown and white incrustations.	33.4
B 1 VD(S)	Zero cm.	Footwall coal-shale; a black carbonaceous shale with discreet layers of vitrain and durain.	11.5

(d) *Be, Ge, La, Mo, Pb, Rb and Sc.*

With the exception of Rb each of the elements of this group is occasionally found in coal ashes in concentration far exceeding these quoted in Table 4, as shown by Goldschmidt's findings for "rich" ashes. More recently Zilbermintz and Rusanov (1936) recorded Be values between 10 p.p.m. and 1000 p.p.m. for 38 samples out of 604 Russian coal ashes and Azcona (1947) reported La up to 1 % in coal ashes from Austurias. The distribution of the elements (except Rb) here confirms Goldschmidt's statement that the rarer elements are enriched in the base and at the top of the coal seam and, at the same time, in the vitrain and clarain coals. Rb occurs only in 3 ashes and evidently follows K. For the E 1 sample, with K/Rb (At.) = 47, appreciable orthoclase or illite may be present but this is hardly likely for the E 16 sample, with K/Rb (At.) = 260 and an ash content of 1.4 %. Potassium, whose simple compounds are nearly all soluble, is evidently very readily removed by percolation from the decaying coal vegetation and its comparative absence in the coal is not surprising. The larger ionic radius of Rb favours its removal relative to K and hence the ratio K/Rb is wider for the mineral-poor coal than for the impure footwall coal.

Table 6.

Percentage Oxides in Ashed Coals From Svea Seam, Locality 4B, Svalbard.

An asterisk (*) indicates K_2O below 1.0 %.

Distance from footwall (cm.)	Description and specimen	% Ash content	Percentage oxides							
			SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	CaO	K_2O	
165—170	B 9 C(V)	13.5	50	22	1.5	1.7	.66	8.1	3.5	B 9
151—156	B 8 D	2.3	25	28	.05	11	1.5	20	1.3	B 8
140—150	B 7 DW	7.2	5.7	16	.11	8.2	5.3	> 20	*	B 7
140—150	B 6 D	1.6	20	25	.40	17	3.1	20	1.3	B 6
118—131	B 5 F(D)	17.0	3.1	5.2	.16	4.4	1.6	> 20	*	B 5
55—67	B 4 C	11.5	36	28	> 1.5	6.4	1.6	3.3	*	B 4
22—30	B 3 D	5.8	55	> 30	> 1.5	6.0	2.8	4.1	*	B 3
16—20	B 2 DW	33.4	55	> 30	> 1.5	1.9	.58	.90	*	B 2
Footwall Coal-Shale	B 1 VD(S)	11.5	55	25	1 5	5.0	1.5	5.2	*	B 1

6. Svea Seam, Locality 4 B.

(1) Coal and Ash Composition.

At locality 4B, 3 km. N. of locality E, the thickness of the Svea seam is only 170 cm. and the 9 samples (selected from those collected by H. Major) represent over 30 % of the thickness as at E. The coals are taken from a quite shallow pit and are much less fresh than the coals described previously; many specimens have white incrustations of gypsum filling several of the numerous cracks and some of the fusain contain carbonates. The difficulty of thin section preparation of these weathered samples has limited microscopic determinations and the macroscopic descriptions (Table 5) are to be interpreted with this in mind. In particular, the occurrence of durain in 6 of the 9 specimens — contrasting with its restriction of locality E — may be suspect and clarain may also be present. Vitrain, recognised more easily, appears in the footwall coal (B 1) and the hanging wall coal (B 9) and recalls its distribution at the E locality.

The major element compositions (Table 6) are again difficult to match with particular coal types although fusain, which can act as a mineral depository, gives a very high Ca content to the ash. The variation of oxides in the coal according to the position in the seam (Figure 3) cannot be said to resemble that for the seam at locality E. CaO and MgO follow each other less closely than at E, and the antipathy of Si and Al to Mg and Ca is not marked at locality 4 B. The role of Fe_2O_3 is also distinct and its concentration in the coal decreases near the hanging wall when the other oxides show increases compared with the values

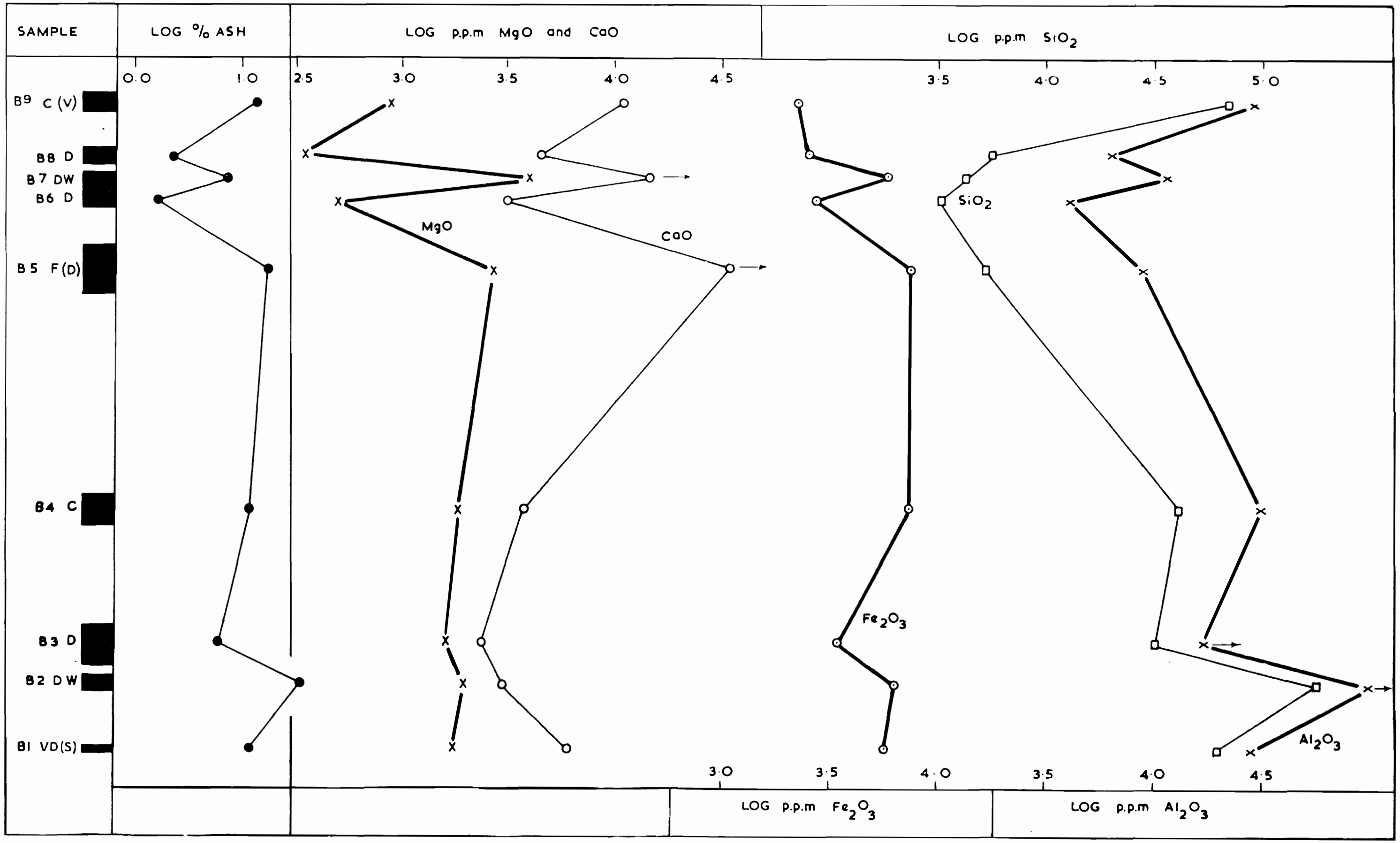


Figure 3. Concentration of oxides in coals from the Svea seam, locality 4B, Svalbard.

Table 7.

Concentration of Minor Elements (p.p.m.) in Ashed Coals From the Svea Seam, Locality 4B, Svalbard.

Elements grouped alphabetically and according to concentration viz.

(a) B, Ba, Sr and Zr (0.1 % to over 1 %)
(b) Cr, Li, Mn, V and Yt (100 p.p.m. to 1000 p.p.m.)
(c) Co, Cu, Ga, Ni, Pb and Sc (10 p.p.m. to 100 p.p.m.)
(d) Be, Ge, La, Mo and Rb (occurring occasionally).

An asterisk (*) indicates below sensitivity and a dash (—) indicates absence of data.

Specimen and description	Content % ash	Concentration in ash (p.p.m.)																				
		B	Ba	Sr	Cr	Zr	Li	Mn	V	Yt	Co	Cu	Ga	Ni	Pb	Sc	Be	Ge	La	Mo	Rb	
B 9 C(V)	13.5	—	4000	1000	450	350	750	75	1050	160	15	30	70	20	50	30?	*	*	40?	*	*	B 9
B 8 D	2.3	3000	5000	4500	180	120	400	300	120	250	30	60	135	150	75	30?	*	*	*	10	*	B 8
B 7 DW	7.2	1150	200	> 10000	100	30	120	4000	200	530	20	—	40	1000	15	50	*	*	60	*	*	B 7
B 6 D	1.6	3720	5000	> 5000	440	130	900	1500	140	210	130	90	10	370	100	*	*	*	*	45	*	B 6
B 5 F(D)	17	—	3500	> 10000	40	20	150	30	180	500	100	15	30	250	*	*	*	*	*	*	*	B 5
B 4 C	11.5	—	3000	1300	1000	140	2000	—	280	160	35	60	120	30	160	*	*	*	*	*	50	B 4
B 3 D	5.8	1550	1400	1300	1100	190	800	100	600	400	65	65	120	40	220	120	10	*	40?	*	50	B 3
B 2 DW	33.4	430	600	600	1200	70	2000	40	530	150	10	45	60	15	100	120	*	20	60	*	*	B 2
B 1 VD(S)	11.5	660	700	1700	1500	200	650	70	1200	290	70	65	135	80	800	50	20	*	*	35	*	B 1
Sensitivity (p.p.m.)		10	10	10	40	1	1	10	10	40	5	10	10	1	10	40	10	10	60	5	50	

for the coal 130 cm. from the footwall. TiO_2 varies from 0.05 % to over 1.5 % and is seen to be concentrated in the ashes from the coals near the footwall, comparing with the distribution in the locality E ashes.

(2) Minor Elements in the Ashes.

Table 7 shows the abundance of several elements in the ashes grouped alphabetically according to comparable concentrations. There is a clear resemblance between these groups and those for locality E ashes and the slight differences concern Pb, Sc, Yt and Zr which are in more abundant (and adjacent) concentration groups and Li which is less common in the ashes from the 4 B locality. The ash content of the hanging wall coal exceeds 10 % and it is thus not surprising that there is no relative concentration of the rarer elements in the ashes of this coal compared with those from below it (except Cr and V); there is, nevertheless, a relative concentration in the coal.

(a) *B, Ba, Sr and Zr.*

The inverse relationship of B concentration in ash to ash percentage is again fairly consistant although a coal with a given ash content holds less boron at locality 4 B than in a coal with the same ash content at locality E. Ba and Sr are prominent and retain their high values even in the ash of specimen B 6 (with 1.6 % ash), confirming the remarks made about their occurrence in the locality E ashes. Zr is high more particularly in the ashes from coals in the lower part of the seam and its presence due to introduced detrital mineral matter is again indicated.

(b) *Cr, Li, Mn, V and Yt.*

Profile variation of Cr and V follows that found for the E locality (with peaks of concentration at the hanging wall and footwall and a decline to a minimum intermediately) and the variation of V in the seam broadly resembles that for Si. Mn in both coal and ash varies rather irregularly up the seam and a comparison of B 6 and B 7 suggests that it may be introduced with the minerals formed in the coal after its consolidation (e.g. gypsum). Li is normally below 1000 p.p.m. (reckoned on the ash) but jumps to higher values, e.g. 2000 p.p.m. in B 2 and B 4 where the ash content is large (33 and 11 % respectively). Nevertheless it is substantial when the ash is low (B 3 and B 6) and can be small when the ash percentage is high. It seems probable that weathering solutions have reduced the Li and B contents of some of the coals. Yt occurs in all the coal ashes (unrelated to Zr) and contrasts with its sporadic occurrence at locality E.

Table 8.

Description of Coals From the Upper Seam, Locality BT2, Svalbard.

Letter following sample numbers clarain (C), durain (D), fusain (F), shale (S) and vitrain (V).

Sample No.	Distance of samples from footwall	Short macroscopic description	Ash content (565° C)
T 10 DV	82—87 cm.	Hanging wall coal; principally durain with less abundant vitrain.	10.5
T 9 V	74—79 cm.	Ill-layered vitrain with a little Fe staining along a few cracks.	1.4
T 8 VC(F)	66 74 cm.	Alternating layers of vitrain and clarain; thin fusain layers included in the averaged sample.	3.5
T 7 C(F)	51—65 cm.	Well-layered clarain with minor intercalations of fusain.	2.1
T 6 V	44—51 cm.	Fresh coal rich in vitrain.	2.1
T 5 V	29—38 cm.	Vitrain with faint striated structure. (Compressed wooded structure).	3.7
T 4 V(F)	16—21 cm.	Predominately a vitrain with subordinate layers of hard fusain.	2.0
T 3 DF	9—11 cm.	Two fine-grained fusain layers separated by columnar durain; averaged for analysis.	11.0
T 2 CV	2—8 cm.	Lowest 2 cm. vitrain, remaining 4 cm. clarain; averaged for analysis.	3.6
T 1 S	Zero cm.	Footwall shale.	85.6

(c) *Co, Cu, Ga, Ni, Pb and Sc.*

Both Co and Ni vary considerably up the seam, neither bearing much relation to the ash percentage, but the ratio Co/Ni decreases on ascent (as noted for locality E). Ga values range from 10 to 135 p.p.m. in the ashes and there is no close relation to the Al content. Sc is more concentrated in the lower parts of the seam, recalling its distribution in the E locality. Here, however, it does make a feeble attempt to show in ashes from coal near the hanging wall.

(d) *Be, Ge, La, Mo and Rb.*

More of this group of elements occurs in the ashes from the 3 lowest samples (B 1—B 3) than from the remainder of the specimens (B 4—B 9); excluding the hanging wall coal ash E 16, this concours with their occurrence in the seam at locality E.

7. Upper Seam, Locality BT 2.

(1) Coal and Ash Composition.

The upper seam in the Svea West mine sampled to give 10 specimens (T 1 to T 10) representing 70 % of the total thickness (87 cm.). The predominance of vitrain throughout the seam provides an immediate contrast with the coals from the Svea seam which are rich in vitrain only

Table 9.

Percentage Oxides in Ashed Coals From the Upper Seam, Locality BT2, Svalbard.

Distance from footwall (cm.)	Specimen and description	Ash content %	Percentage oxides						
			SiO_2	Al_2O_3	TiO_2	Fe_2O_3	MgO	CaO	
82—87	T 10 DV	10.5	10	5.2	.24	40	.27	3.3	T 10
74—79	T 9 V	1.4	3.6	11.4	.74	35	1.2	15	T 9
66—74	T 8 VC(F)	3.5	1.5	4.5	.28	40	1.5	> 20	T 8
51—65	T 7 C(F)	2.1	3.2	5.9	.35	32	.88	> 20	T 7
44—51	T 6 V	2.1	2.0	7.5	.24	24	1.2	> 20	T 6
29—38	T 5 V	3.7	1.5	1.8	.14	35	1.2	> 20	T 5
16—21	T 4 V(F)	2.0	9.0	9.8	.74	35	2.1	14	T 4
9—11	T 3 DF	11.0	.76	< 1.5	.05	19	1.4	> 20	T 3
2—8	T 2 CV	3.6	5.5	11.4	.35	27	1.6	> 20	T 2
footwall shale	T 1 S	85.6	> 60	16	1.1	1.7	.58	.5	T 1

at the seam extremities. The ash contents of the coals at locality BT2 and at locality E are, however, comparable and much of the Upper seam consists of coal yielding below 2.5 % ash.

The ashes of the ash-poor vitrains T 4, T 6 and T 9 have somewhat similar compositions (Table 9) but differ from the vitrain of Lessing (1920) (with 1.1 % ash) in having rather less Al_2O_3 and much more Fe_2O_3. The high Fe_2O_3 and low SiO_2 for the ashes persists throughout the parts of the seam sampled and the relative abundance of the oxides contrasts with that found for the Svea seam ashes; TiO_2 is also characteristic, being in general lower in the ashes from the Upper seam coals. Figure 4 shows the oxide content in the coals and the variation in the seam is seen to be modest especially if the fusain-rich T 3 coal and the high-ash T 10 hanging wall coal are considered apart. The general trends of Si and Al are similar to each other and to some extent distinct from that of Fe, particularly in the lower part of the seam. Ca and Mg vary sympathetically to Si and Al for most of the samples in the seam.

(2) Minor Elements in the Ashes.

Table 10 shows the minor element concentration of the ashes with the grouping alphabetically within four concentration groups. The subordination of Co, Cr, Ni, V and Yt compared with their values in the Svea seam ashes at both localities is striking and sufficient to allow a provisional distinction between ashes from the Upper seam and Svea seam coals.

(a) *B, Ba, Li and Sr.*

B in the ashes from the BT2 coals is again dependent on the ash content (Figure 2) and coals with similar ash percentages from this locality contain only slightly less B than those from the Svea seam,

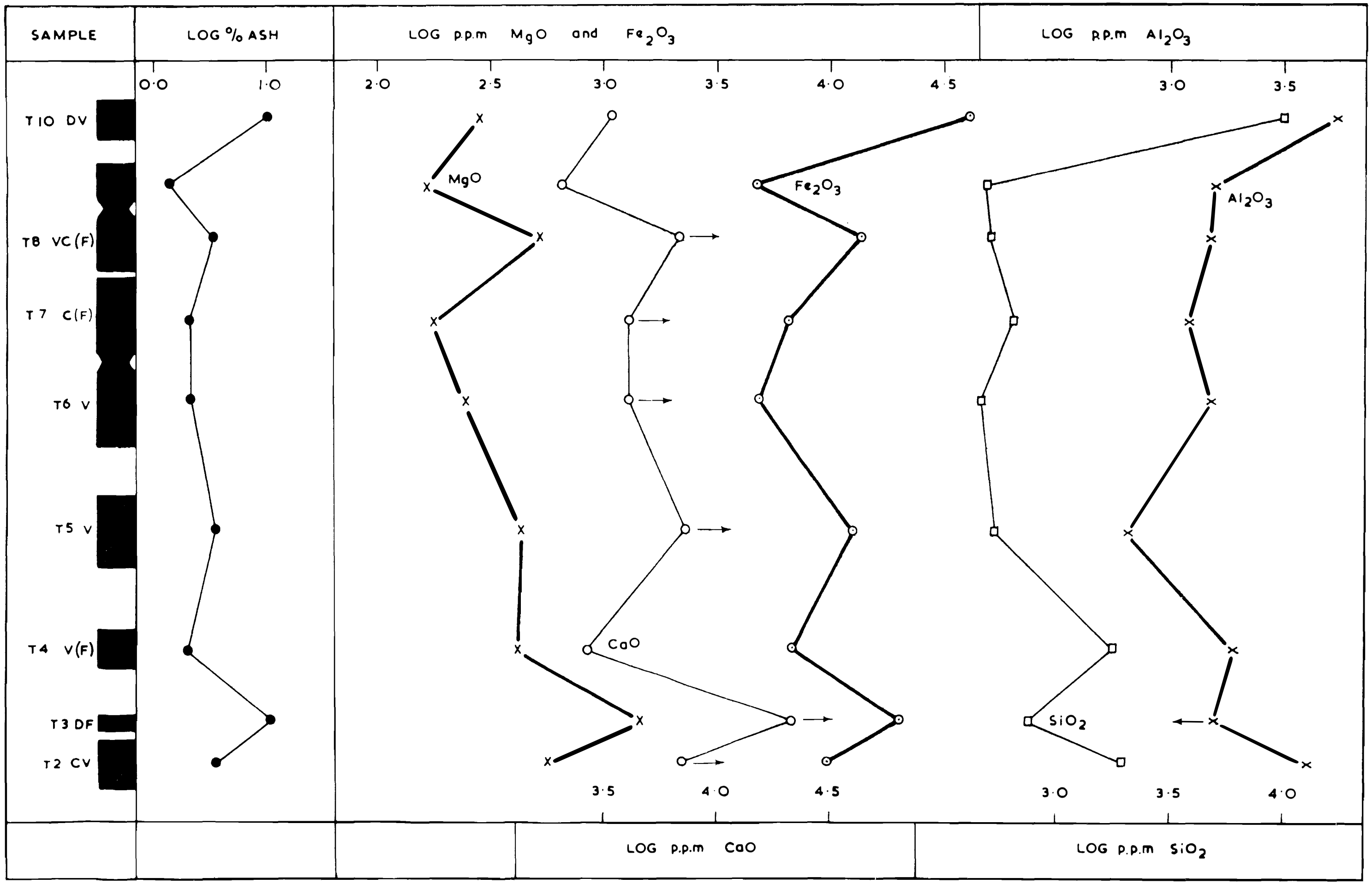


Figure 4. Concentrations of oxides in coals from the Upper seam, locality BT2, Svalbard.

Table 10.

Concentration of Minor Elements (p.p.m.) in Ashed Coals From the Upper Seam, Locality BT2, Svalbard.

Elements grouped alphabetically and according to concentration viz.

(a) B, Ba, Li and Sr (0.1 % to 1.0 %)
(b) Mn and Zr (50 p.p.m. to 500 p.p.m.)
(c) Cr, Cu, Pb and V (10 p.p.m. to 100 p.p.m.)
(d) Be, Ga, Ge, La, Mo, Ni, Rb, Sc and Yt (occurring occasionally).

An asterisk (*) indicates below sensitivity and a dash (—) indicates absence of data.

Specimen and description	% Ash content	Concentration in ash (p.p.m.)																			
		B	Ba	Li	Sr	Mn	Zr	Cr	Cu	Pb	V	Be	Co	Ga	Ge	La	Mo	Ni	Rb	Sc	Yt	
T 10 DV	10.5	2010	100	300	1500	35	400	20	—	*	—	*	—	—	—	40?	—	—	*	50	*	T 10
T 9 V	1.4	5000	5000	—	> 10000	130	300	40	90	50	140	*	25	45	*	*	45	10	50	*	160	T 9
T 8 VC(F)	3.5	3310	4000	50	1500	300	50	50	25	*	45	*	*	15	*	*	5	4	*	*	*	T 8
T 7 C(F)	2.1	6920	—	1100	2000	180	300	50	50	50	70	*	10	30	*	*	*	3	*	*	30	T 7
T 6 V	2.1	10200	5000	—	3900	100	50	10	15	15	30	*	*	*	*	*	*	*	*	*	*	T 6
T 5 V	3.7	4170	5000	2000	1700	18	40	40	10	25	20	*	*	*	*	*	*	*	*	*	*	T 5
T 4 V(F)	2.0	—	2500	1600	2500	15	40	20	5	25	*	*	*	*	30	*	*	*	*	*	*	T 4
T 3 DF	11.0	1100	3000	—	1700	360	*	5	—	*	50	*	*	*	*	*	*	*	*	*	*	T 3
T 2 CV	3.6	—	5000	400	5500	180	—	100	45	15	100	20	15	30	*	*	*	8	*	*	400	T 2
T 1 S	85.6	180	200	200	125	25	300	80	10	*	300	*	*	55	*	*	*	5	600	*	*	T 1
Sensitivity (p.p.m.)		10	10	1	10	10	40	1	10	10	10	10	5	10	10	60	5	1	50	40	40	

locality E, with identical ash percentages. Both Ba and Sr are high in all the ashes except that from the T 1 shale and the values reflect their fairly high content in the original plant. (The fusain T 3 ashes are not excessively enriched in Ba and Sr although, of course, their values of concentration in the coal itself are much higher than for most of the other coals). Li, where determined, may be of fairly high concentration as found in the Svea seam ashes (locality E); this probably indicates that weathering of the coal at BT2 is slight.

(b) *Mn and Zr.*

Mn shows marked variation in both coals and ashes and exhibits a pronounced decrease in the middle of the seam. It is clearly not entirely primary since it is enriched in the impure fusain coal ash from T 3. Similarly, Zr can be high in ash-high coals (e. g. T 10) but may also be high in the ashes of much purer coals (e.g. T 9).

(c) *Cr, Cu, Pb and V.*

Both Cr and V are relatively concentrated in the ashes from the coals near the footwall compared with those from the middle of the seam but only V shows an increase as the hanging wall is approached. The relation between V and Si noted for the Svea seam at locality E is not apparent here, the elements occurring more independently of each other. Variations in Cu and Pb are irregular and follow neither ash content nor coal type.

(d) *Be, Co, Ga, Ge, La, Mo, Ni, Rb, Sc and Yt.*

Ga, like Al, is generally lower than in the Svea seam ashes although the remarks on the variation of Al/Ga are still pertinent. Co and Ni are of quite low concentration in the ashes and there is no reduction of the ratio Co/Ni on ascending the seam. The occurrence of Be, Ge, La and Sc is limited to one occasion and it is evident that the Upper seam coals concentrated less of these rarer elements than did the Svea seam coals. The absence of the elements in the waters of the coal forest environment is an obvious cause of their lack in the coals, but more important may be the cation (or anion) exchange properties of the organic matter associated with the coal trees allowing differing amounts of iron absorption from very dilute solutions.

Summary and Conclusions.

Coal from the Svea seam at the Svea East mine (locality E) differs from that in the same seam at locality 4B in being comparatively fresh and about two and a half times as thick. Macroscopic observations show the coal specimens at locality 4B to consist principally of durain with some vitrain at the seam extremities and to be associated with gypsum and carbonate deposits. The latter occur sparsely in the locality E coals (except in the fusain-rich specimen) and the microscopic studies of H. Major show clarain to appear in the middle of the seam and vitrain to predominate near the footwall and hanging wall. The variation in the composition of the ashes from the coal samples is high and specimens rich in a particular coal type may yield ashes of differing and hence unpredictable composition. Ash contents also vary appreciably and independantly of coal type although fusain-rich specimens are usually ash-high.

In confirmation of their weathered and low-temperature mineralised nature, the ash contents of the locality 4B coals are, on average, much in excess of those of the locality E coals. Their Ca, Mg and Si contents are also higher and the alkaline earths have evidently been introduced into the seam cracks after coal compaction and weathering but Si may represent a detrital silicate deposited concurrently with the coal.

The variation of coal composition in the Svea seam from the two localities shows few similarities beyond an increase of Si and Al near the footwall (illustrated in Figures 2 and 3) compared with the rest of the seam and similar high values for TiO_2 in the bottom tenth of the seam. In both localities, however, Ca and Mg follow each other closely and to some extent they vary antipathetically with Si and Al.

The coal specimens of the Upper seam sampled from the Svea West mine (locality BT2) differ macroscopically from the locality E and 4B Svea seam coals by their usually rich vitrain content; vitrain is strongly represented even near the middle of the seam. Although the ash compositions are fairly variable at BT2, both low SiO_2 and high Fe_2O_3 values obtain for all but specimen T 1 (ashed), providing a means of distinguishing these ashes from those of the Svea seam which nearly always have higher SiO_2 contents (especially at 4B) and often higher TiO_2 and lower Fe_2O_3 contents.

The minor element concentrations in the ashes from the Svea seam present a few comparisons. In ashes from both localities (E and 4B), B, Ba and Sr constitute, in general, between 0.1 % and 2.0 %, Cr, Mn and V constitute between 100 p.p.m. and 1000 p.p.m., Co, Cu, Ga and Ni are present from 10 p.p.m. to 100 p.p.m. whilst Be, Ge, La, Mo and Rb occur occasionally. Li is more abundant in the locality E ashes than from the locality 4B ones but the reverse is true for the elements Pb, Sc, Yt and Zr; it is recalled that the 4B ashes contain less Li probably due to its removal by weathering solutions and more Zr, partly due to its introduction as detrital zircon.

It seems clear that the coal forest plants at the different localities had approximately equal facilities for concentrating their minor element constituents either from the swamp or the underlying seat-earth.

The minor element concentrations in the ashes vary, of course, in different specimens from different parts of the seam. B, however, increases in the ash as the ash content decreases and its concentration in the coal itself is approximately constant throughout. The other element concentrations (with the doubtful exception of Ni at locality E) are not so related to the ash content and their variation within the seam (based on ash or coal) is often haphazard. Ash-poor vitrain-rich coals tend to concentrate the rarer assemblages in their ash, but as these coals do not occur in similar relative positions in the seam at the two chosen localities, it is not surprising that the concentration-variations resemble each other but slightly.

Since the major element concentration in the ashes from the Upper seam showed definite differences when compared with those in the Svea seam ashes, it is to be expected that the minor element assemblages will also differ. Whilst B, Ba, Li and Sr remain fairly high (0.1 % to 1.0 %), Cr and V are less abundant and Co, Ga, Ni and Yt occur only occasionally; the elements Mn and Zr (50 p.p.m. to 500 p.p.m.), Cu (10 p.p.m. to 100 p.p.m.) and Be, Ge, La, Mo and Rb (occurring occasionally) are present in similar concentrations in the ashes from the 3 localities and Pb is the only element more common in the Upper seam ashes than in the Svea seam ashes. A further distinctive feature of the Upper seam analyses is the value of the V/Cr ratio which can sink to 1.5 or below (compared with the higher values from the Svea seam analyses). Bearing in mind that the low concentrations found for some elements in the Upper seam ashes are not due to high ash percentages, it is apparent that the plant environment in the younger coal forest was poorer in these elements. Alternatively the plants possessed less facility to accumulate these elements from their environment.

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