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PAPER 68-35

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(Report, 18 figures and 3 plates)

A. R. Cameron and S. K. Babu

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ABSTRACT

Three column and channel samples of the 55-foot thick No. 10 (Balmer) seam from the Michel-Natal area of British Columbia were studied petrographically. The study entailed both megascopic and microscopic methods. Petrographic composition was expressed in terms of lithotypes, macerals and microlithotypes. Reflectance determinations were also carried out. The analysis showed a coal high in the inertinite macerals, especially fusinite and semifusinite. Mean maximum reflectances ranged from 1.31 to 1.45. The seam was divided into 22 intervals based on petrographic composition, and a comparison of the three samples showed that the intervals could be traced laterally through the 2 1/2 miles covered by the sampling. Deposition in a paralic basin is suggested for the origin of the seam.

Chemical information was also obtained along with plasticity and swelling data on both vitrain and whole coal samples from various intervals in the seam. Fluidity values were relatively low, though significantly higher in the vitrain samples than in the whole coal. It was shown that fluidity in the pure vitrain samples was related to reflectance and mineral matter. A study was also carried out on fracture distribution in vitrain bands. Sieve analyses were carried out on coal from selected intervals and the results related to petrographic composition. The upper half of the seam with its higher content of bright coal appears to have the best coking potential.

THE PETROLOGY OF THE NO. 10 (BALMER) COAL SEAM IN THE NATAL AREA OF THE FERNIE BASIN, BRITISH COLUMBIA

INTRODUCTION

The Fernie Basin in southeastern British Columbia lies within the Rocky Mountains and contains the largest reserves of high quality coal in the province. Coal has been mined continuously in this basin since 1897, particularly in the vicinity of Natal and Michel.

In recent years one of the lower seams in the section, identified as the No. 10 seam or Balmer coal in the Natal-Michel area, has come into increasing prominence because of its potential as a coking coal. This seam is unusually thick, averaging 40-50 feet in the area covered by this report.

Because of the industrial importance of this seam, a study was undertaken to determine its petrographic composition and the nature of vertical and lateral changes in this composition within the rather small area of the Fernie Basin where the seam is presently being mined. Some of the samples studied were subjected to chemical analysis as well as swelling and fluidity tests. In addition several bulk samples were coked in a 500-pound experimental oven. The results of these carbonization tests will be published in a separate paper. The chemical and physical tests were carried out by the Fuels and Mining Practice Division of the Mines Branch in Ottawa.

Various aspects of the geology of the Fernie Basin and the characteristics of the coal seams contained within it have been reported on in a number of publications. Of these the reports of Crabb (1957), McEvoy (1901), MacKay (1931, 1934), Newmarch (1953), Norris (1964), Price (1962) and Rapson (1964) have been most frequently consulted in the preparation of this report.

The authors acknowledge with thanks the assistance and cooperation tendered them by personnel of the Crowsnest Industries Ltd. and they are grateful to members of the Fuels and Mining Practice Division of the Mines Branch who carried out chemical and physical tests. T. F. Birmingham and J. R. Donaldson of the Geological Survey assisted in the field phase of the study.

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GENERAL GEOLOGY

STRATIGRAPHY

The coal-bearing unit in the Fernie Basin is the Kootenay Formation and the No. 10 seam occurs near its base. Because of the tectonic history of the region, the Kootenay Formation in southeastern British Columbia and adjacent parts of Alberta occurs today as a number of disconnected patches, the largest of which is preserved as the Fernie Basin.

The Fernie Basin is a pear-shaped synclinorium. The shape of the basin corresponds roughly to the outcrop pattern of the Kootenay Formation and at its greatest length and breadth measures about thirty-six miles north-south and fifteen miles east-west. The town of Fernie is located at the western edge of the basin, roughly midway between its north and south extremities. The area studied in this report is in the northern part of the basin in the vicinity of Natal and Michel (<u>see</u> Fig. 1). The Kootenay Formation varies in thickness from about 1, 800 feet at the south end of the Fernie Basin to 3, 530 feet on Coal Creek near the town of Fernie (Price, 1962). MacKay (1933) measured 3, 600 feet of Kootenay beds near Michel.

According to Price (1962, p. 28) "The Kootenay Formation comprises grey and black carbonaceous sandstones, siltstones, mudstones and shales with interbeds of coal and quartz-chert pebble conglomerate and conglomeratic sandstone." The conglomerates occur most abundantly in the upper part of the formation in the western and northern parts of the basin (Norris, 1964). Norris proposed a fourfold division of the Kootenay Formation at its type section on Grassy Mountain in Alberta (Norris, 1959). These members in ascending order are named Moose Mountain, Adanac, Hillcrest and Mutz. Price (1962) discussed the Kootenay Formation in the Fernie Basin in terms of these members. An ammonite found in the Moose Mountain Member at Coal Creek near Fernie indicates a marine origin for this member. Marine beds have not been described at higher levels in the formation in the Fernie Basin.

The age of the Kootenay Formation has been a matter of some controversy. Based on floral and faunal evidence, it has been variously interpreted as Jurassic and/or Lower Cretaceous (Bell, 1956; Rouse, 1959; Frebold, 1957). The latest study bearing on this question has been that of Pocock (1964) who concluded from his examination of spore and pollen assemblages that the Kootenay at its type section on Grassy Mountain is entirely Jurassic in age. He also reported that the Kootenay Formation in other areas included Cretaceous beds.

As many as twelve mineable coal seams occur in the Kootenay Formation in the Fernie Basin, and a number of less important seams also occur, especially at the north end of the basin. There is a considerable

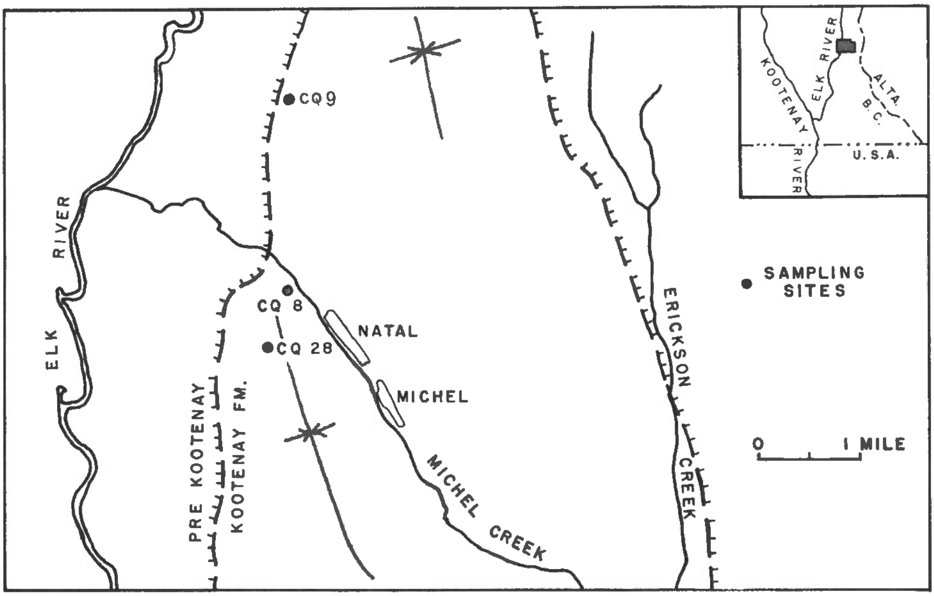

Figure 1. Sample location map, Michel-Natal area, British Columbia.

spread in the rank of the coals with the lowest coals including the No. 10 seam being low volatile bituminous, whereas the D seam near the top of the section is high volatile A bituminous. Most of the seams fall into the category of medium volatile bituminous.

Correlation of the seams within the basin has not been perfected partly because of the difficulty of isolating spores and pollen from coals of this high rank and partly because of structural complications within the field. In addition, some of the seams show considerable variations in thickness within a small area as well as a tendency to split. However, some of the seams appear to be relatively persistent. The No. 10 seam can be traced with some confidence over a large part of the basin and seems to maintain most of the thickness it shows at Michel. For example, on Morrissey Ridge eight miles south of Fernie the continuation of the No. 10 seam is still up to thirty-five feet thick including several shale partings.

STRUCTURE

The Fernie Basin is a broad doubly plunging synclinal fold. Its eastern margin is defined by a series of north-south trending normal faults, one of which follows the valley of Erickson Creek (see Fig. 1). The Fernie Basin to the west is on the downthrown side of these faults. The western margin of the basin is defined in part by thrust faults. According to Newmarch (1953) beds along the sides of the basin dip inward at angles of 20 to 45 degrees. "Within the basin anticlines and synclines constitute important structural elements and for the area studied in the present report, Price (1962) shows two relatively prominent synclines." One is a roughly north-south trending fold under Natal Ridge, the other is a fold of similar orientation lying west of Michel Creek. In between there is apparently some anticlinal folding and high angle thrusting as shown by Newmarch (1953) in his section of the Baldy Strip Mine. According to MacKay (1933) other north-trending, west-dipping faults, some with small upward movement on the west side, others with normal displacement, disrupt the synclinal structure at Michel.

SAMPLING

Material from three main samples was analyzed. The most complete sample and the first collected was a column sample taken underground in the Balmer Mine at Natal and identified as CQ 8 (see Fig. 1). This sample was taken as a series of blocks covering the entire thickness of the seam from roof to floor. In Ottawa a detailed megascopic examination was made of this sample and petrographic intervals were established; these are described in the following section.

The second sample, CQ 9, was collected in the Baldy Strip Mine on Natal Ridge. Because of the extremely friable nature of the coal at this location, it was not possible to collect a column sample. Instead one-foot channels of broken coal were collected covering the top 40 feet of the seam. It was not possible to collect from the bottom part of the seam. The third sample, CQ 28, was collected one year later. It was taken underground in the Balmer Mine. The lower 6 to 8 feet of the seam, which was not mined at the point of sampling, was not collected. At the site of CQ 28 the coal face was marked off in intervals which were thought to be extensions of those established by the megascopic description of CQ 8. Channel samples of various lengths were then collected at CQ 28 representative of the coal in these intervals.

MEGASCOPIC ANALYSIS OF CQ 8

SAMPLE PREPARATION AND METHODS OF ANALYSIS

From the column sample CQ 8 a master column was prepared covering the entire thickness of the seam. Four hundred and five blocks were cut from the main column and mounted in Periplex resin, an epoxy resin. These blocks were then labelled as to their position in the column, oriented with respect to top and bottom, and polished.

The column was then examined megascopically with the aid of a hand lens and a bright light reflected from the surface. The various layers in the column were identified according to their lustre and texture and the terms vitrain, clarain, claro-durain, durain and fusain were used to describe them. A summary of the megascopic characteristics of these coal types is as follows:

<u>Vitrain</u> - occurs in well-defined bands, brilliant vitreous lustre, conchoidal fracture;
<u>Clarain</u> - occurs in bands of variable thickness, has a pronounced gloss with a finely striated surface;
<u>Claro-durain</u> - occurs in bands of variable thickness with a lustre and texture midway between that of clarain and durain;
<u>Durain</u> - occurs in bands of variable thickness, dull lustre, dense firm texture, hard;
<u>Fusain</u> - occurs in lenses or lenticular bands, fibrous structure similar to charcoal.

The Handbook of Coal Petrology (International Committee for Coal Petrology, 1963) recommends that layers be measured to a minimum threshold of 3 mm. In the present study vitrain layers and dull layers were measured down to 1 mm.

In addition to the above described components, bone or impure coal and shale layers were also distinguished.

MEGASCOPIC DATA

Figure 2 is a graphic portrayal of the megascopic data derived from sample CQ 8. These data are also presented in Table I. On the basis of this information CQ 8 was divided into twenty-two petrographic intervals.

Vitrain and clarain may be classed as bright coal types and the heavy line drawn through the column (Fig. 2) separates these types from the combined contents of claro-durain, durain, and bone and shale, which contribute to the dull appearance of coal. Fusain has been included with the dull coal types.

The profile shows that megascopically the upper half of the seam is brighter than the bottom. Most of the intervals below X A have dull coal contents which approach or exceed 50 per cent. In intervals V and II A shale and bony coal contribute prominently to the dull character of the coal. It should also be noted that intervals XVI, XVII and XVIII, particularly the latter, constitute the thickest bright unit in the seam with a total thickness of over twelve feet.

TABLE I

Distribution of Megascopically Identifiable Constituents
in Petrographic Intervals of Sample CQ 8

Intervals	Vitrain	Clarain	Claro-durain	Durain	Bone and shale
XX	4.9	38.8	21.0	11.5	23.8
XIX	14.3	53.0	14.1	12.9	5.6
XVIII	19.4	58.1	14.2	6.0	2.3
XVII	26.0	41.5	22.8	8.9	0.7
XVI	21.8	51.0	21.3	5.9	-
XV	14.1	31.0	25.6	27.4	1.9
XIV	18.9	65.1	11.1	4.6	0.3
XIII	15.4	32.4	38.6	12.9	0.7
XII	34.2	36.1	18.6	5.2	5.9
XI	28.3	36.6	13.7	15.0	6.4
X A	4.2	28.1	42.4	17.8	7.5
X	18.8	23.0	26.0	22.5	9.7
IX	22.6	38.7	6.2	18.0	14.5
VIII	18.3	40.8	23.9	10.3	6.7
VII	9.6	49.3	10.1	26.1	4.9
VI	26.9	33.1	21.9	0.8	17.3
V	8.2	27.4	-	17.4	47.0
IV	24.6	62.3	-	11.8	1.3
III	20.9	37.3	-	28.6	13.2
II A	7.6	22.4	27.2	18.7	24.1
II	9.9	15.8	-	66.4	7.9
I	23.6	54.1	22.3	-	-

Detailed information on the number and thickness of the various layers in the coal was accumulated during the megascopic examination. These data provide an insight into the texture as well as the composition of the coal. In Figure 3 an attempt has been made to portray some of these textural aspects for the vitrain bands and for the durain and bone and shale layers. The data are also given in Table II. In the left half of Figure 3 the percentage distribution of the vitrain and dull bands are shown for the various intervals.

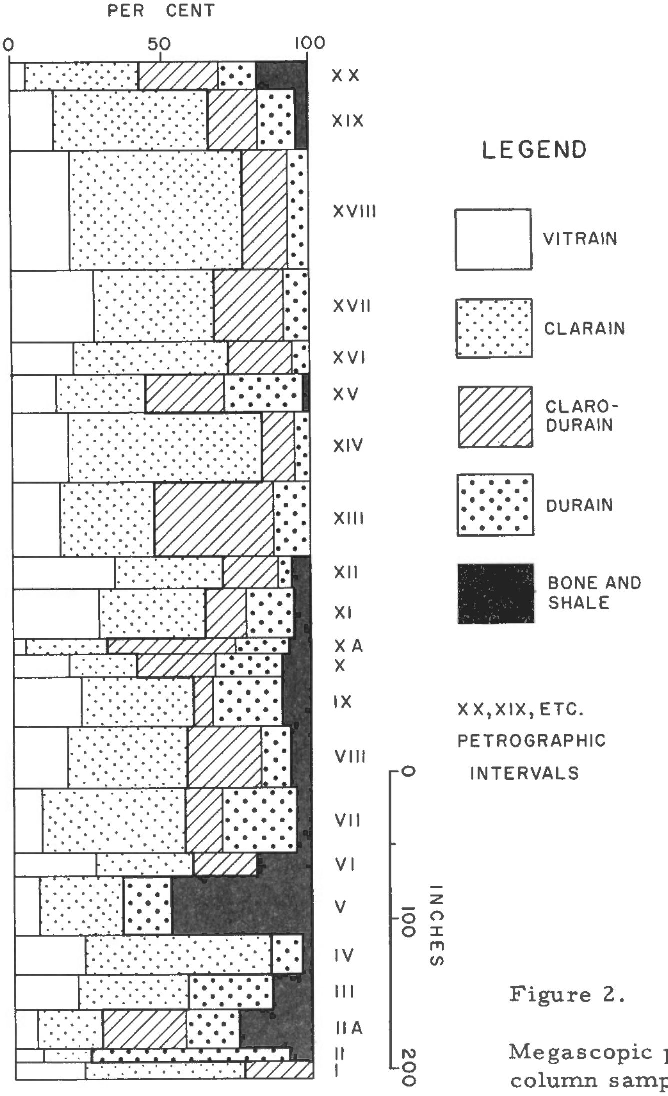

Figure 2.

Megascopic petrography of column sample CQ 8.

TABLE II

Distribution and Thicknesses of Vitrain and Dull Bands
in Petrographic Intervals of CQ 8

	Vitrain		Durain		Bone and Shale		
Interval	% of interval	Average thickness (mm)	% of interval	Average thickness (mm)	% of interval	Average thickness (mm)	Vitrain total dulls
XX	4.9	3.1	11.5	18.0	23.8	56.0	0.13
XIX	14.3	3.0	12.9	7.7	5.6	8.8	0.77
XVIII	19.4	3.3	6.0	9.3	2.3	7.0	2.34
XVII	26.0	6.5	8.9	10.9	0.7	3.0	2.71
XVI	21.8	4.7	5.9	5.7	-	-	3.69
XV	14.1	3.1	27.4	9.4	1.9	5.4	0.48
XIV	18.9	5.5	4.6	7.0	0.3	4.0	3.86
XIII	15.4	3.8	12.9	10.0	0.7	5.4	1.13
XII	34.2	6.4	5.2	6.9	5.9	10.3	3.08
XI	28.3	5.4	15.0	17.0	6.4	9.7	1.32
X A	4.2	1.5	17.8	8.7	7.5	5.5	0.17
X	18.8	3.9	22.5	9.4	9.7	10.6	0.58
IX	22.6	4.3	18.0	7.6	14.5	14.0	0.70
VIII	18.3	4.5	10.3	11.6	6.7	18.9	1.08
VII	9.6	2.1	26.1	16.7	4.9	23.5	0.31
VI	26.9	5.1	0.8	6.0	17.3	27.2	1.49
V	8.2	2.6	17.4	11.9	47.0	48.2	0.13
IV	24.6	4.0	11.8	8.8	1.3	5.4	1.88
III	20.9	5.4	28.6	19.2	13.2	13.3	0.50
II A	7.6	2.0	18.7	13.7	24.1	71.0	0.18
II	9.9	2.7	66.4	16.8	7.9	6.7	0.13
I	23.6	5.4	-	-	-	-	∞

The right half of Figure 3 shows the average thicknesses of the vitrain and dull bands in each interval as compared to the average thicknesses for these coal types for the whole seam. On the percentage graph vitrain shows no particular pattern of distribution, although there are two peaks in the upper half of the seam; one is broad and culminates in interval XVIII; the other is sharper and culminates in interval XII. On the other hand the distribution line for the dull bands shows a rather pronounced trend toward an increase in these constituents in the lower half of the seam below interval X. In most of these intervals the amount of dulls present exceeds the amount of vitrain. These data are the same as those presented in Figure 2, but are plotted in a different manner so that a direct comparison can be made between the proportions of the very bright component, vitrain, and the components which contribute to the dull character of coal, namely, durain, bone, and shale.

The right hand graph of Figure 3 shows an average thickness for the vitrain bands of 4.2 mm and an average thickness for the dull bands of 13.0 mm. This difference in average thicknesses may be somewhat misleading, because the thin, dull layers probably do not stand out as prominently as the thin vitrain layers. The distribution of the values for the individual intervals about the average values is rather interesting. The vitrain values fluctuate in rather random fashion about the average, though there is a tendency for them to be somewhat higher than the average in the section of the seam from interval XVII through interval XI. In the case of the dull layers however, there is a rather pronounced tendency for the thicker layers to occur in the lower half of the seam, especially from interval VIII to the floor. This goes along with an increase in the percentage of 'dulls' present as shown on the left side of Figure 3. Interval XV, which has a rather high percentage of dull layers, shows, for these layers, a mean thickness below the mean for the whole seam. This indicates the presence in this interval of a number of relatively thin, dull layers. A similar situation prevails in intervals IX and X in contrast to interval XI.

The textural character of the coal, as expressed by variability in the coarseness of fineness of the banding, could be of some importance in the crushing and cleaning behaviour of a coal as Mackowsky has pointed out (Mackowsky, 1958). For example, the above average thickness of the dull, and probably harder, layers in the lower part of sample CQ 8 might be utilized in the cleaning of this part of the seam. A minimum of crushing and a fairly coarse separation in screening and washing might suffice to produce a fairly clean coal from the basal part of the seam, providing that the coal between the dull layers is itself reasonably clean.

MICROSCOPIC ANALYSIS

SAMPLE PREPARATION AND METHODS OF ANALYSIS

Coal representing the intervals of CQ 8 and CQ 28 and the foot-by-foot samples from the Baldy Strip Mine (subsamples of CQ 9) was crushed and

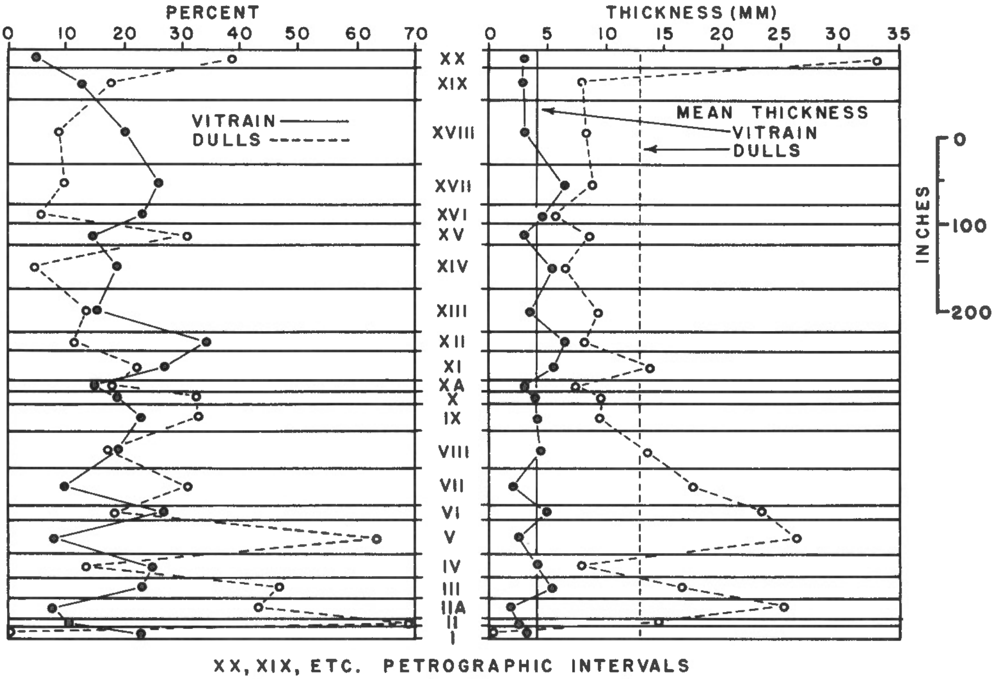

Figure 3. Distribution and thickness variations of vitrain and dull bands in intervals of sample CQ 8.

prepared into a series of grain mounts for microscopic analysis by reflected light. The coal was crushed to minus 20 mesh and three pellets were prepared for each interval and for each foot of the Baldy Strip sample. These pellets were then polished using a Buehler Automet for a major part of the procedure.

The pellets from all three of the main samples were analyzed for reflectivity data and for the composition in terms of macerals. In addition the pellets of CQ 8 were examined for microlithotypes. Macerals, the basic constituents of coal are analagous to the minerals of inorganic rocks, whereas microlithotypes represent a more complex order of coal constituents in that they are assemblages of macerals.

The first step in the microscopic examination was the measurement of reflectance. The instrumentation used and the procedure followed was essentially that which has become standard in coal petrology laboratories in North America and has been described in several publications (Schapiro and Gray, 1960; Harrison, et al., 1964). A series of glasses were used as standards such as described by Schapiro and Gray (1960) along with an immersion oil of 1.515 refractive index. On each pellet seventy-five points on vitrinite were analyzed for reflectance and the maximum reflectance was recorded for each point. Thus for each sample a total of 225 reflectance readings on vitrinite were made. From these data it was possible to subdivide the vitrinite into reflectance types or 'V' types and to calculate the percentages of the various types present. In addition the mean maximum reflectance was determined for each sample.

For the maceral analysis each pellet was analyzed by point count for its maceral content. This was done under oil immersion. One hundred and fifty points were read per pellet making a total of 450 points per sample. The macerals vitrinite, fusinite, semifusinite and micrinite were identified in this phase of the study. The latter three macerals are often considered together as the group maceral inertinite, so named because of its relatively inert behaviour in many technological processes. Mineral matter was also identified in this process. Later the pellets of CQ 8 were rerun dry to differentiate the quartz from the remainder of the minerals. Also the pellets of CQ 8 were rerun under oil to obtain a further breakdown of the inertinite macerals.

The third phase of the microscopic study involved the characterization of the intervals of CQ 8 in terms of microlithotypes. As mentioned earlier, microlithotypes are assemblages or associations of macerals, identified microscopically. Typically they represent various combinations of the three group macerals, vitrinite, exinite and inertinite. In the case of the No. 10 seam, however, they represent associations of vitrinite and inertinite only, as exinite has disappeared because of the rank of the coal. The microlithotypes recognized in the No. 10 seam are given in Table III. The microscopic appearance of both macerals and microlithotypes are shown in Plates I, II and III.

In the microlithotype analysis carried out whole particles were considered, that is, the composition of a particle in terms vitrinite, inertinite and mineral matter was estimated and on the basis of this composition, the particle was assigned to one of the microlithotypes defined in Table III. The proportions of individual microlithotypes were then determined by point count with 150 points being counted per pellet or a total of 450 points for each interval.

MACERAL ANALYSIS

The maceral composition of the various petrographic intervals in the only complete roof to floor sample, CQ 8, is given in Figure 4 and in Table IV. In Figure 4 semifusinite and fusinite have been grouped together because they appear to represent stages in a genetically related group of constituents. Examination of the profile in Figure 4 reveals the abundance of the inertinite group of macerals, especially fusinite and semifusinite. The relatively dusty nature of the coal on handling is likely due in part at least to the abundance of these two relatively fragile macerals. Micrinite, although present in substantial amounts, is subordinate to fusinite and semifusinite in nearly every interval. The relatively bright character of the upper part of the seam, as revealed by the megascopic analysis, shows up in the microscopic data, especially in intervals XVIII and XVI where the vitrinite content is higher than that of the adjacent intervals. Peaks in the content of mineral matter indicate the presence of thin shale partings within some of the intervals. Within intervals V and II shaly layers constitute a sizeable proportion of the interval.

TABLE III

Table of Microlithotypes

Microlithotypes	Proportions of constituent macerals
Vitrite	More than 95% vitrinite
Vitrinertite 1	90-95% vitrinite; 5-10% inertinite (fusinite, semi-fusinite, micrinite)
Vitrinertite 2	50-90% vitrinite; 10-50% inertinite
Vitrinertite 3	10-50% vitrinite; 50-90% inertinite
Vitrinertite 4	5-10% vitrinite; 90-95% inertinite
Fusite	Less than 5% vitrinite; more than 95% inertinite (commonly fusinite or semifusinite)
Carbargilite	Contains 20-60% by volume of mineral constituents, mostly clay minerals

In studying the profile it should be kept in mind that the composition as plotted represents a summary of considerable heterogeneity within each interval. Because of the thickness of the seam many of the intervals, if isolated, would represent fairly respectable coal seams in themselves.

Because the inertinite macerals fusinite, semifusinite and micrinite represent important constituents in this coal, an attempt was made to effect a further differentiation of these components. For this purpose the pellets of CQ 8 were rerun and only the above constituents were considered in a

TABLE IV

Maceral Distribution in Intervals of CQ 8

Interval	Vitrinite %	Semifusinite %	Fusinite %	Micrinite %	Mineral matter %	Thickness of interval in inches
XX	34.4	10.6	19.7	20.0	15.3	19
XIX	47.1	9.3	14.9	18.9	9.8	40
XVIII	61.4	12.5	14.5	8.7	2.9	72
XVII	53.2	12.9	17.2	12.3	4.4	48
XVI	60.0	6.7	11.1	17.5	4.7	22
XV	42.1	16.7	25.2	12.6	3.6	24
XIV	51.0	10.3	20.0	16.7	2.0	48
XIII	49.5	8.6	22.0	17.2	2.7	51
XII	66.6	7.3	12.4	2.3	11.4	22
XI	61.1	7.2	15.2	11.8	4.7	32
X A	49.3	15.5	16.0	16.2	3.0	10
X	40.0	18.5	21.9	13.8	5.8	18
IX	61.4	11.3	9.4	12.7	5.2	32
VIII	62.4	12.9	11.2	8.2	5.3	42
VII	41.2	19.5	22.8	9.6	6.9	42
VI	65.9	8.7	13.5	6.4	5.5	18
V	36.6	11.3	17.3	11.2	23.6	39
IV	57.1	14.6	9.0	12.4	6.9	26
III	52.0	16.8	16.7	9.7	4.8	25
II A	40.2	15.0	20.6	14.4	9.8	25
II	25.4	8.1	11.3	6.7	48.5	8
I	52.6	12.7	24.2	9.2	1.3	14

separate point count. Two varieties of fusinite were distinguished based on colour and three size categories of micrinite were distinguished. These five categories along with semifusinite are illustrated in Plates I-III and are described as follows:

Fusinite - Semifusinite

1. Yellow fusinite. Bright yellow in colour; high relief; prominently developed cell structure.

2. White fusinite. White to yellow in colour; lower relief than 1; cell structure well-developed.

3. Semifusinite. White in colour; low relief; cell structure often less regular than 1 and 2.

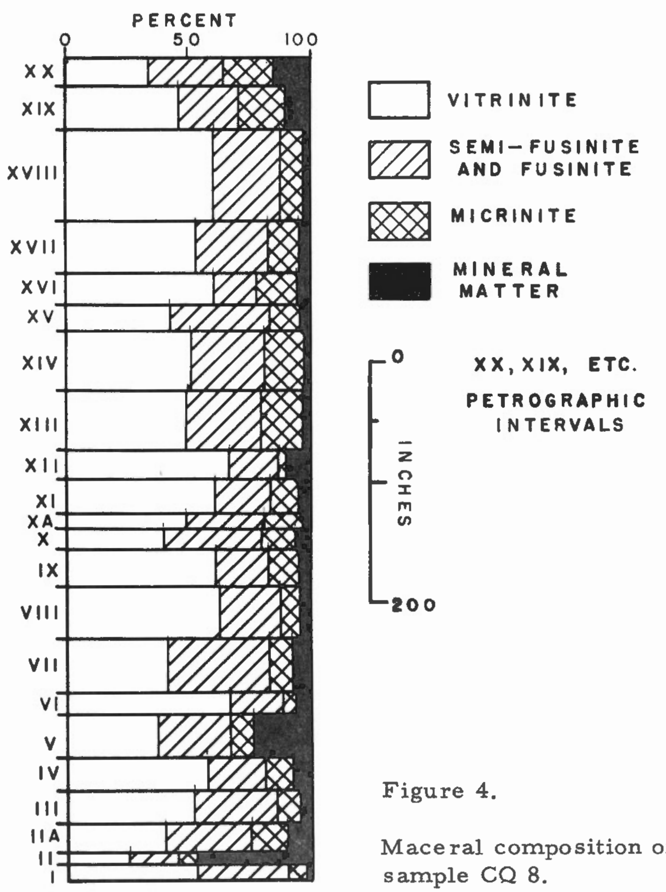

Figure 4.

Maceral composition of column sample CQ 8.

Micrinite

a. Massive

4. White to yellow in colour; no visible internal structure; masses with dimensions greater than 50 microns.

5. Same colour and structural features as 4 but occurs in masses smaller than 50 microns but larger than 10 microns.

b. Fine-grained micrinite

6. Same colour and structural features as 4 and 5 but occurs in masses smaller than 10 microns.

The vertical distribution of these constituents in the profile of CQ 8 is shown on Figure 5. The average content of each constituent for the whole seam is shown in the appropriate diagram and the contents of the constituents for the petrographic intervals are shown as deviations from these averages. In addition to diagrams for each of the six inertinite constituents, a seventh diagram similarly constructed, is presented to show the variation in total inertinite. All the data shown on Figure 5 and in Table V have been calculated to the mineral matter-free basis.

In the fusinite-semifusinite series it is clear that the so-called white fusinite and semifusinite dominate the composition with an average of 14 per cent for the former and 13 per cent for the latter whereas the yellow fusinite has an average value for the seam of only 4 per cent. A similar assessment for the micrinite content shows that about half of the micrinite in this column or 6.4 per cent out of a total micrinite content of 13.4 per cent is present in the fine-grained form.

The vertical distribution patterns in Figure 5 show no consistent concentrations of above average or below average values at any level of the seam for the total inertinite except for the above average values in intervals I, II and II A and intervals XIII, XIV and XV. The same observation is generally true for the yellow fusinite, white fusinite and the 50-10 micron massive micrinite.

"However with semifusinite the above average values seem to be concentrated in the intervals in the lower half of the seam (intervals II to X A) while the above average values for the massive micrinite greater than 50 microns and the fine grained micrinite are concentrated in the intervals in the upper half of the seam".

TABLE V

Distribution of Inertinite Macerals in Intervals of CQ 8

Interval	Fusinite (%)		Semifusinite (%)	Massive micrinite (%)		Fine-grained micrinite (%)
	Yellow	White		>50 microns	<50 >10 microns	
XX	2.1	21.1	12.5	9.2	5.9	8.6
XIX	1.9	14.6	10.3	5.0	5.0	11.0
XVIII	3.3	11.5	12.8	2.4	4.2	2.4
XVII	4.0	14.0	13.5	2.9	3.8	6.2
XVI	3.7	8.0	7.0	5.8	4.4	8.1
XV	7.3	18.9	17.1	4.5	3.1	5.5
XIV	5.3	15.1	10.5	5.3	3.4	8.4
XIII	2.5	20.1	8.8	2.5	4.4	10.8
XII	7.5	6.6	8.3	0.5	0.9	1.2
XI	2.8	13.1	7.6	1.8	4.3	6.3
X A	3.2	13.3	16.0	3.2	5.2	8.4
X	6.9	16.3	19.5	4.6	4.0	6.1
IX	2.3	7.6	11.9	2.1	2.6	8.7
VIII	6.9	5.0	13.6	1.8	2.8	4.1
VII	2.8	21.7	20.9	1.4	4.2	4.7
VI	4.6	9.7	9.2	0.7	3.2	2.9
V	5.2	17.4	14.8	2.9	4.5	7.3
IV	2.1	7.5	15.7	3.1	3.7	6.6
III	5.5	12.1	17.6	1.8	4.3	4.1
II A	2.6	20.3	16.7	4.2	4.2	7.5
II	1.6	20.5	15.8	2.5	4.9	5.7
I	6.1	18.4	12.9	2.5	3.2	3.6

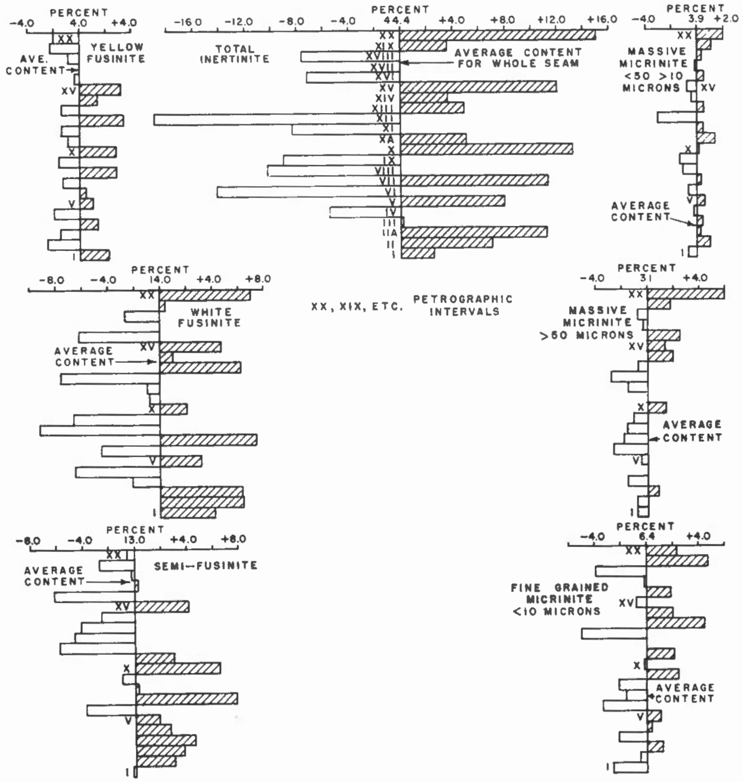

Figure 5. Variations in contents of inertinite constituents of petrographic intervals as compared to average values for the whole seam in sample CQ 8.

ANALYSIS OF MINERAL MATTER IN CQ 8

A special examination was made on the pellets of CQ 8 using a dry objective to determine some details of the mineral matter content. The dry objective was used in order to differentiate the quartz grains more clearly. Quartz grains are shown in Plate III B. Two pellets from each interval were analyzed by point count for this purpose. Minerals other than quartz were not differentiated but they consisted mainly of clay minerals. Pyrite is present in negligible amounts. These data are presented in Figure 6 and Table VI.

The format used in Figure 5 has also been used in Figure 6, that is, the average content for the whole column has been plotted as a base line with the contents for the individual petrographic intervals plotted as deviations from these average values. The upper diagram of Figure 6 shows that only

TABLE VI

Distribution of Quartz and other minerals in CQ 8

Interval	Quartz (%)	Other minerals (%)
XX	0.5	14.8
XIX	1.0	8.8
XVIII	0.4	2.5
XVII	1.1	3.3
XVI	0.6	4.1
XV	0.3	3.3
XIV	0.3	1.7
XIII	0.7	2.0
XII	1.6	9.9
XI	1.7	3.0
X A	1.0	2.1
X	1.4	4.4
IX	0.5	4.8
VIII	0.6	4.7
VII	2.3	4.6
VI	1.0	4.5
V	3.7	19.9
IV	2.0	4.9
III	0.6	4.1
II A	5.5	4.3
II	5.0	43.2
I	0.5	0.8

five intervals of twenty-two have above average values for minerals other than quartz. As already pointed out these are the intervals which contain a number of shaly partings. Such a distribution suggests that, on a whole seam basis, a substantial reduction in ash could be effected by the removal of such intervals in the cleaning process.

The quartz data are plotted in the lower half of Figure 6 and show a rather interesting distribution for this mineral. From petrographic interval XII down, the above average values are all in the lower part of the seam with the highest above average values occurring in the lower third of the seam. The No. 10 coal seam was laid down on a rather prominent quartzitic

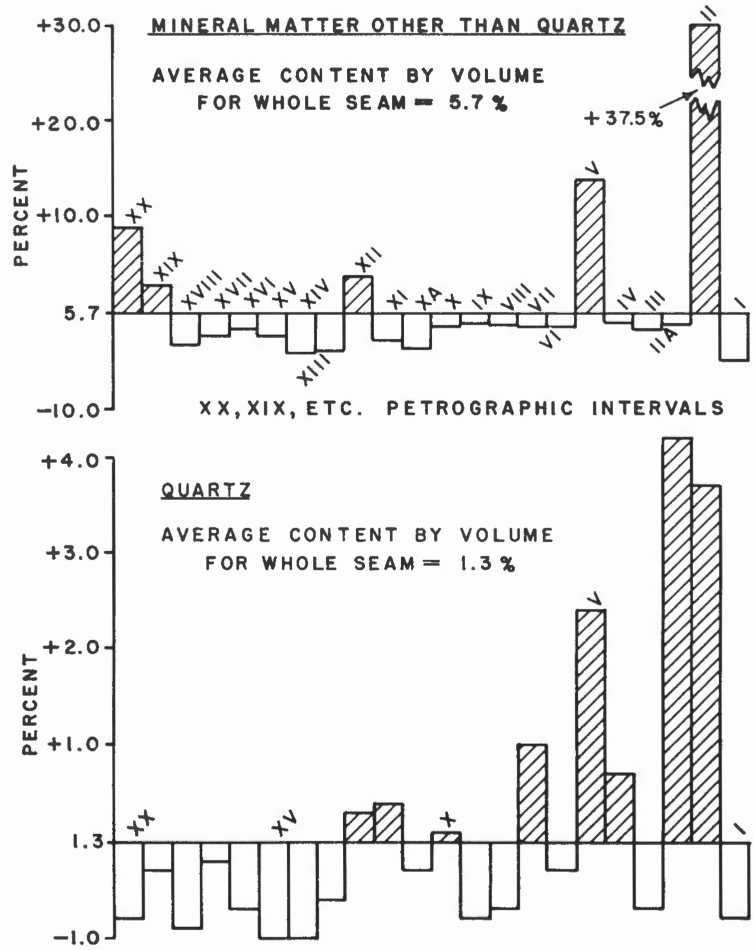

Figure 6. Distribution of mineral matter in intervals of CQ 8.

sandstone and the quartz distribution within the seam suggests that the movement of quartz into the basin continued, though with diminishing vigour, until about half of the peat represented by the seam had accumulated.

MICROLITHOTYPE ANALYSIS

In Figure 7 the vertical distribution of microlithotypes in CQ 8 are given. The data are also presented in Table VII. The figure shows a general similarity with the maceral data shown in Figure 4. As was evident in Figure 4, the abundance of semifusinite and fusinite in this coal is also brought out by the prominent content of the microlithotype fusinite shown in Figure 7. Much of the inertinite material in the vitrinertites is also fusinite and semifusinite.

COMPARISON OF MACERAL COMPOSITIONS FOR SAMPLES CQ 8, CQ 9, AND CQ 28

In Figure 8 the microscopic data in terms of macerals have been plotted for all three samples studied, namely CQ 8, CQ 9, and CQ 28. These data, also shown in Table VIII, have been arranged in Figure 8 in the form of a stratigraphic section in order to show the variation between samples. The geographic position of all three samples is shown in Figure 1. The profiles given in Figure 8 have been condensed somewhat from the profile given for CQ'8 in Figure 4 in that the intervals in some instances have been combined and are represented by letters. The relationship between numbered intervals and lettered zones is given in Table IX.

In Figure 8 the datum line is drawn at the top of zone K, a rather thin but relatively persistent dull layer. Figure 8 shows that the various zones can be traced, though with some changes, over the 2 1/2 miles covered by the section. The rather prominent bright zone L, first identified in sample CQ 8, appears to maintain a fairly constant thickness from sample to sample. The basal part of the seam is represented only in CQ 8. In CQ 9 some inconsistencies in the petrographic data near the base of the sampled coal in addition to field evidence has led to the conclusion that intervals G and H and possibly some of I has been faulted out.

REFLECTANCE DATA

The reflectance data obtained on the three main samples are shown graphically in Figure 9 and in tabular form in Table X. The reflectance data have been plotted in Figure 9 in terms of the major petrographic zones used in Figure 8. The left side of Figure 9 shows, in profile form, the average reflectances in oil for each zone of the three main samples ranging from A at

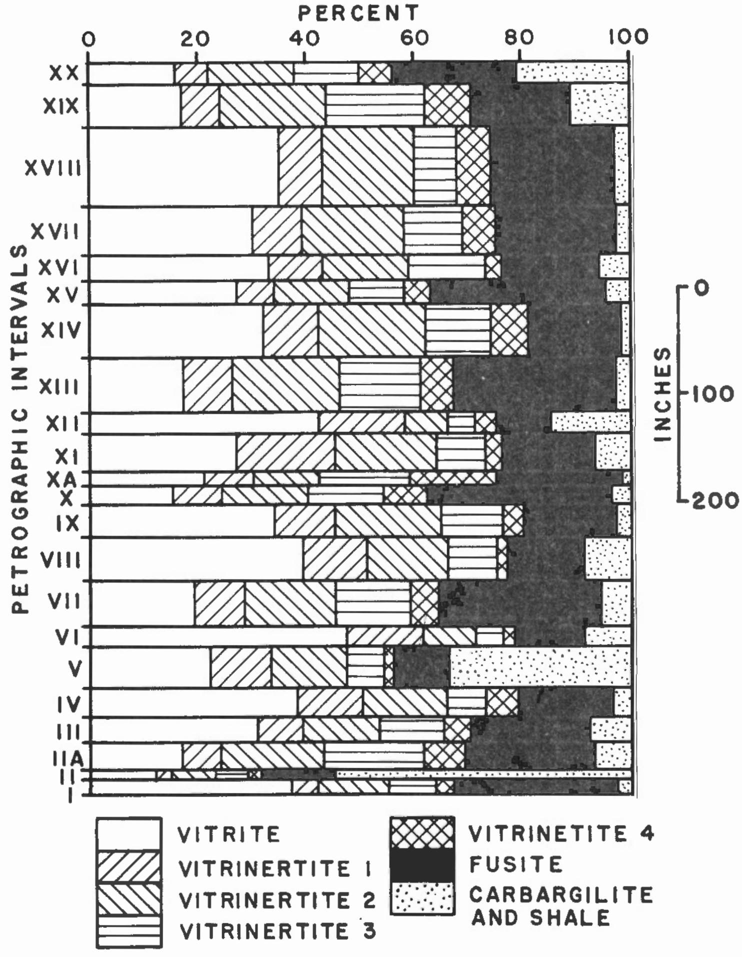

Figure 7. Distribution of microlithotypes in CQ 8.

the base of the seam to N at the top. The other three parts of Figure 9 show the distribution of the vitrinite reflectance types ('V' types) in the various zones of the three samples studied.

Of the three profiles showing average reflectance the one for CQ 8 varies most throughout the thickness of the seam. The upper parts of the seam (zones N to J) all show average reflectances of 1.40 and lower, whereas from zone I to the base of the seam the average reflectances are considerably higher. A rather anomalous peak, especially as expressed in the reflectance of zone I, was rechecked and was reproduced. This peak in the centre of the profile does not appear for samples CQ 9 and CQ 28. However a feature

TABLE VII

Microlithotype Content of Sample CQ 8
(per cent)

Interval	Vitrite	Vitrinertites				Fusite	Carbargilite	Shale
		1	2	3	4			
XX	15.4	6.0	16.4	12.4	6.0	22.2	15.8	6.0
XIX	16.8	6.9	20.2	18.1	8.3	18.7	6.5	4.5
XVIII	35.0	8.4	16.7	7.6	6.0	23.8	2.2	0.4
XVII	29.8	9.8	18.2	11.4	5.9	21.4	2.7	0.7
XVI	33.3	10.1	15.9	13.6	3.3	17.6	4.2	2.1
XV	26.6	7.0	14.0	10.5	3.2	33.4	3.2	2.0
XIV	31.7	10.6	19.8	12.1	6.5	17.9	1.2	0.1
XIII	16.6	9.4	20.3	14.2	6.9	29.3	2.6	0.7
XII	42.1	15.8	7.3	5.1	3.9	10.5	9.1	6.2
XI	36.9	8.3	18.7	8.9	3.3	17.1	5.4	1.4
X A	21.4	8.6	12.2	17.2	15.4	24.2	1.0	-
X	15.3	8.9	15.6	14.5	7.5	33.6	3.3	1.3
IX	33.9	11.1	19.7	11.0	4.2	17.1	2.4	0.7
VIII	39.1	11.6	15.0	9.4	2.1	13.7	6.0	3.1
VII	18.7	9.3	17.4	13.5	4.9	29.9	5.3	1.1
VI	47.0	14.3	9.3	5.4	1.8	13.1	6.0	3.0
V	21.8	11.0	14.4	7.1	1.8	10.2	27.8	6.0
IV	38.2	12.2	15.3	7.3	6.3	16.2	4.0	0.6
III	30.9	7.7	14.6	11.9	5.0	22.3	5.9	1.6
II A	17.3	6.7	19.3	18.2	7.5	23.6	5.8	1.6
II	12.0	2.4	8.5	6.1	1.8	13.1	14.7	41.3
I	36.8	4.7	13.5	8.9	2.9	30.7	2.4	0.2

common to all three samples is the somewhat arcuate pattern of the profiles in that the average reflectances in the top and bottom zones tend to be higher than those in the middle of the seam. Perhaps this is due to the greater potential for oxidation and degradation in those parts of the seam associated with the beginning and the end of peat accumulation.

It is interesting that the positions of the three profiles on the graph correspond to increasing opportunity for oxidation of more recent date. On an overall basis the lowest average reflectance values are in CQ 28, a sample collected underground at a fresh face. The more intermediate values tend to be those of CQ 8, which sample was also collected underground, but in an opening which had been idle for some months. The highest reflectance values are associated with CQ 9, the sample from the strip mine in which the extremely friable nature of the coal, as well as microscopic evidence in the form of oxidation rims, indicate weathering.

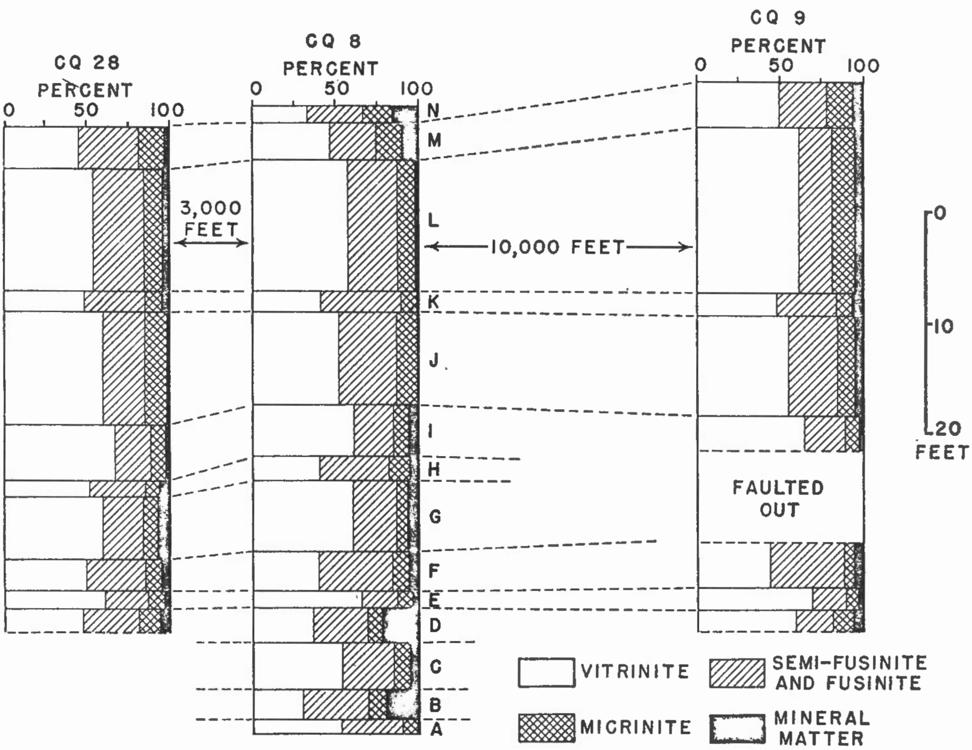

Figure 8. Comparison of maceral contents of CQ 8, CQ 9, and CQ 28.

TABLE VIII

Maceral Distribution in Samples CQ 8, CQ 9 and CQ 28

Zone	Vitrinite	Fusinite and semifusinite	Micrinite	Mineral matter
		CQ 8		
N	34.4	30.3	20.0	15.3
M	47.1	24.2	18.9	9.8
L	58.6	26.6	11.2	3.6
K	42.1	41.7	12.6	3.6
J	50.3	31.4	15.9	2.4
I	63.5	21.3	7.9	7.4
H	43.4	37.3	14.6	4.7
G	61.9	22.6	10.2	5.3
F	41.2	42.3	9.6	6.9
E	65.9	22.2	6.4	5.5
D	36.6	28.6	11.2	23.6
C	54.6	28.4	11.1	5.9
B	36.6	31.7	12.5	19.2
A	52.6	36.9	9.2	1.3
		CQ 9		
M	51.3	27.4	14.6	6.5
L	61.4	21.3	12.6	4.7
K	49.6	33.7	10.5	6.2
J	56.3	29.3	9.2	5.2
I	64.5	22.1	9.0	4.4
F	46.3	38.3	11.3	4.1
E	69.1	21.8	5.1	4.0
D	60.0	22.6	11.2	6.2
		CQ 28		
M	47.5	34.1	14.7	3.7
L	54.1	29.2	11.5	5.2
K	51.1	32.0	10.7	6.2
J	58.2	26.6	10.6	4.6
I	65.7	19.5	9.2	5.6
H	55.9	30.0	9.7	4.4
G	60.3	24.7	9.0	6.0
F	52.4	27.8	12.4	7.4
E	62.1	23.8	8.5	5.6
D	50.7	31.5	10.9	6.9

TABLE IX

Equivalence of Intervals and Zones

Intervals	Zones
XX	N
XIX	M
XVIII XVII XVI	L
XV	K
XIV XIII	J
XII XI	I
X A X	H
IX VIII	G
VII	F
VI	E
V	D
IV III	C
II A II	B
I	A

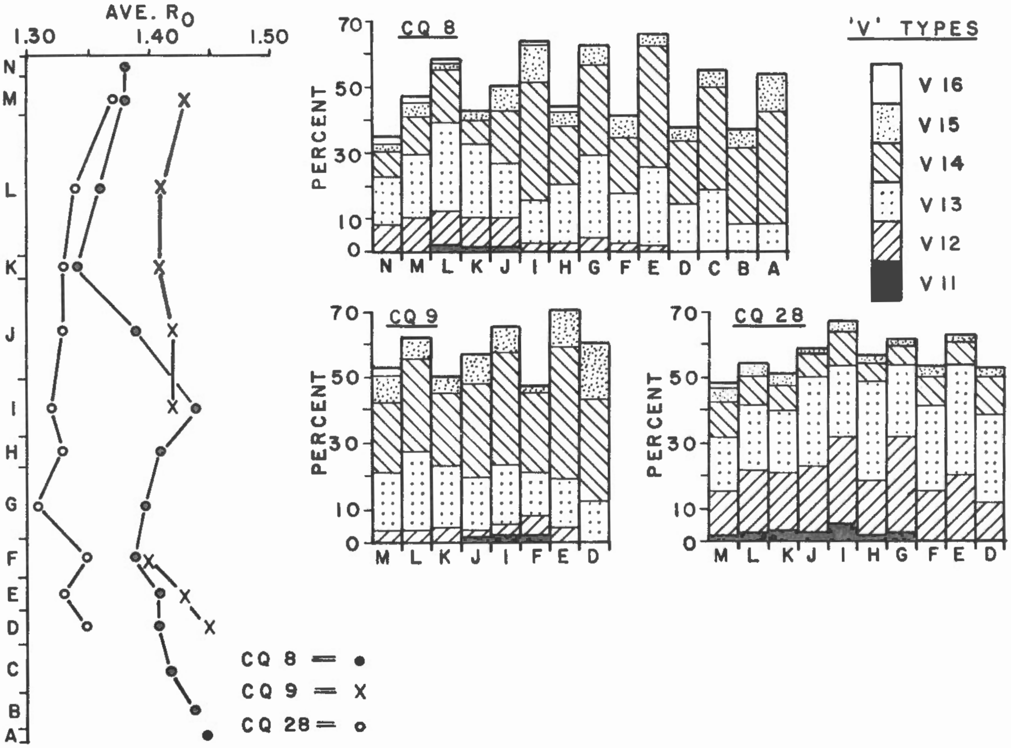

Figure 9. Average reflectance and distribution of 'V' types in major petrographic zones of samples CQ 8, CQ 9, and CQ 28.

The remaining three parts of Figure 9 show the breakdown of the vitrinite component into 'V' types or reflectance types for each major petrographic zone in the three main samples. The reflectance spectrum in the three samples ranges from V 11 to V 16. Not all types are present in each zone. The most abundant types are V 12, V 13 and V 14. Sample CQ 8 is dominated by V 13 and V 14 with the former being more abundant in the top zones, and gradually becoming subordinate to V 14 in the bottom zones. In sample CQ 9, V 13 and V 14 are again the dominant types with V 14 being the more abundant in all the zones. In contrast sample CQ 28 is characterized by a greater abundance of V 12 along with V 13.

TABLE X

Reflectance Data for Samples CQ 8, CQ 9, and CQ 28

	Zone	Vitrinite reflectance types (% vitrinite)						Mean maximum Reflectance R_o
		V 11	V 12	V 13	V 14	V 15	V 16	
CQ 8	N	–	21.8	42.1	21.8	6.7	7.6	1.38
	M	–	21.8	39.5	24.9	8.9	4.9	1.38
	L	2.4	17.5	47.5	27.1	3.2	2.3	1.36
	K	2.7	20.5	53.3	17.3	6.2	–	1.34
	J	2.1	17.5	33.4	31.4	15.6	–	1.39
	I	–	2.5	21.2	56.5	18.7	1.1	1.44
	H	–	4.3	42.6	41.2	10.6	1.3	1.41
	G	–	5.6	41.6	43.1	9.7	–	1.40
	F	–	4.0	36.5	43.1	16.4	–	1.39
	E	–	1.8	36.0	56.8	5.4	–	1.41
	D	–	–	36.9	54.2	8.9	–	1.41
	C	–	–	32.2	57.9	9.9	–	1.42
	B	–	–	22.6	60.8	16.6	–	1.44
	A	–	–	15.6	63.1	21.3	–	1.45
CQ 9	M	–	5.0	33.9	40.7	16.1	4.3	1.43
	L	–	4.6	39.2	45.9	10.3	–	1.41
	K	–	7.8	39.1	44.2	8.9	–	1.41
	J	0.4	4.9	28.6	51.9	14.2	–	1.42
	I	2.3	5.3	28.4	51.3	12.7	–	1.42
	F	4.2	10.5	29.6	52.1	3.6	–	1.40
	E	–	4.3	22.7	57.7	15.3	–	1.43
	D	–	–	20.3	51.4	28.3	–	1.45
CQ 28	M	2.7	28.3	33.2	23.2	10.4	2.2	1.37
	L	2.9	36.0	36.5	18.2	6.4	–	1.34
	K	4.9	36.0	36.4	14.7	8.0	–	1.33
	J	3.2	34.1	47.5	12.6	2.6	–	1.33
	I	6.9	40.4	33.8	15.2	3.7	–	1.32
	H	0.5	31.5	54.2	11.1	2.7	–	1.33
	G	3.1	47.6	37.3	9.3	2.7	–	1.31
	F	–	28.3	50.9	15.2	5.6	–	1.35
	E	–	32.9	52.0	13.3	1.8	–	1.33
	D	–	21.8	53.7	21.8	2.7	–	1.35

ENVIRONMENT OF DEPOSITION OF THE NO. 10 SEAM

A discussion of the conditions under which the No. 10 seam was deposited must take into consideration: 1. the high content of inertinite, particularly fusinite and semifusinite; 2. the relative lack of banding in the coal; 3. the abnormal thickness of the seam; and 4. the low sulphur content of the seam.

The abundance of inertinite macerals, especially fusinite and semifusinite, and their frequent occurrence in small and irregularly shaped masses is an important characteristic of this coal. To some extent it is also true for the vitrinite constituent. The irregular shape and attrital nature of the constituents is expressed megascopically by the inconspicuous banding or lack of banding in many intervals of the seam. These features suggest accumulation in an environment where the potential for oxidation was high and where relatively pronounced agitation of the water medium caused reworking of material during the peat stage. The low content of pyrite, a mineral whose formation is inhibited under oxidizing conditions, also implies such an environment. Possible environments might be a lagoon or a lake with large areas of relatively open water or a swampy area in which the water cover was extremely shallow or even virtually non-existent at times. In the case of the No. 10 seam the abundance of fusinite and semifusinite macerals, much of which may be equivalent to the German 'decay fusinite' (Zersetsungsfusinit) (Teichmuller, 1952), suggests that the latter environment may well have existed.

Studies on the petrology of the Kootenay Formation by Rapson (1964) indicate the continental origin of these sediments with accumulation under estuarine conditions or along coastal lowlands. However marine conditions may not have been far removed in time because it is suggested that the lower beds of the Kootenay may be marine (Norris, 1964). Therefore, the No. 10 seam probably accumulated in a paralic basin such as described by Hacquebard, Birmingham and Donaldson (in press). Deposition must have been accompanied by continuing subsidence with conditions favouring oxidation and reworking of the peat surface prevailing throughout much of the time, although the occurrence of a greater percentage of bright coal toward the top of the seam probably indicates conditions more closely resembling the classical forested-swamp situation. The subsidence must have been of the order of hundreds of feet as it is thought that the present thickness of the seam is largely original rather than thickening due to tectonic squeezing and flowage such as occurred locally in the anthracite fields of Pennsylvania. The fact that the No. 10 seam in the Morrissey Ridge area some 18 miles away is still relatively thick supports this conclusion.

Hacquebard, Birmingham and Donaldson (in press) compared the petrography of coals from six basins in Canada by plotting on a ternary diagram the composition of these coals in terms of microlithotypes. In a similar fashion the microlithotype composition of the various petrographic intervals of CQ 8 have been plotted in Figure 10. The compositional distribution is intermediate between that portrayed by the above mentioned authors for the St. Rose coalfield and for the coal from the Pictou field. The former is considered by Hacquebard, Birmingham and Donaldson to be paralic, the latter limnic in origin. However, Rapson's interpretation of the origin of the Kootenay Formation suggests that a limnic environment of deposition for the No. 10 seam is less likely than a paralic origin, although the latter may have had a special character.

CHEMICAL ANALYSIS

In order to obtain some chemical information on the samples under study and in order to do this on some relatively uniform petrographic component, vitrain was hand-picked from the petrographic intervals of CQ 8 and CQ 28 and submitted for proximate analyses to the Fuels and Mining Practice Division of the Mines Branch. A split of these vitrain samples was also submitted for plasticity and swelling tests along with whole coal samples, representing these same intervals. The results of the chemical analysis on the vitrains are given in Tables XI and XII.

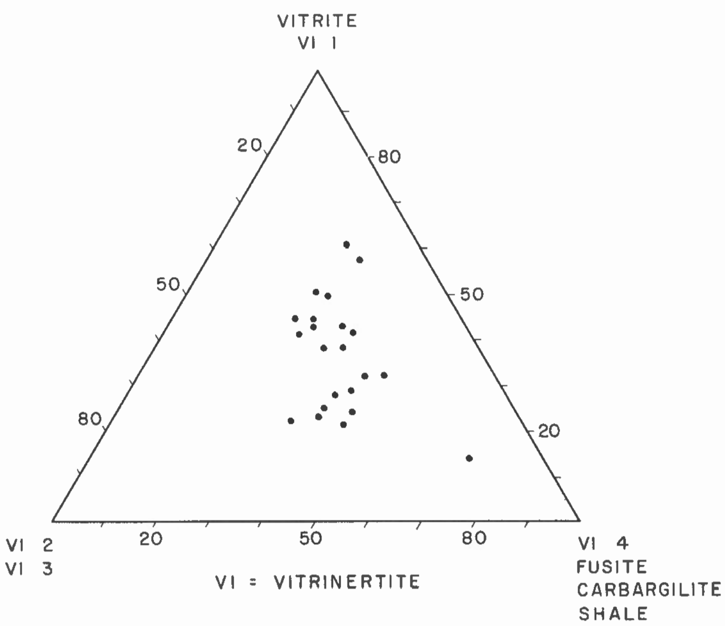

Figure 10. Microlithotype composition for intervals of CQ 8.

TABLE XI

Proximate Analyses on Hand-picked Vitrain from Petrographic Intervals of CQ 8 (as received)

Interval	Moisture %	Ash %	Volatile matter %	Fixed carbon %
XX	0.3	5.0	19.6	75.1
XIX	0.4	2.0	20.4	77.2
XVIII	0.4	2.1	20.8	76.7
XVII	0.5	1.7	20.7	77.1
XVI	0.7	2.1	20.1	77.1
XV	0.6	2.6	21.6	75.2
XIV	0.5	0.9	20.6	78.0
XIII	0.4	1.7	20.2	77.7
XII	0.4	1.7	20.8	77.1
XI	0.4	1.4	20.9	77.3
X A	0.3	1.6	21.1	77.0
X	0.3	3.8	19.7	76.2
IX	0.6	1.7	20.1	77.6
VIII	0.5	2.5	20.2	76.8
VII	0.5	2.6	20.3	76.6
VI	0.4	3.2	20.4	76.0
V	0.5	4.3	19.2	76.0
IV	0.5	0.9	20.2	78.4
III	0.5	1.2	20.2	78.1
II	0.4	1.6	19.3	78.7
I	0.4	1.5	19.2	78.9

TABLE XII

Proximate Analyses on Hand-picked Vitrain from
Petrographic Intervals of CQ 28

Interval	Moisture %	Ash %	Volatile matter %	Fixed carbon %
XX	0.54	5.22	17.95	76.29
XIX	0.33	3.83	20.14	75.70
XVIII	0.29	3.00	21.13	75.58
XVII	0.32	2.74	21.81	75.13
XVI	0.37	2.28	21.06	76.29
XV	0.62	3.51	20.60	75.27
XIV	0.67	4.81	20.78	73.74
XIII	0.67	3.13	21.80	74.40
XII	0.67	3.47	21.07	74.79
XI	0.59	2.44	21.53	75.44
X A	0.51	2.60	21.13	75.76
X	0.63	2.84	20.40	76.13
IX	0.54	4.64	20.23	74.59
VIII	0.50	6.09	18.87	74.54
VII	0.51	14.58	18.48	66.43
VI	0.63	15.02	18.80	65.55
V	0.60	8.46	18.60	72.34

Sulphur was not determined but it is relatively low in this coal. Other samples from this seam have given sulphur values ranging from 0.1 to 0.4 per cent. The analyses based on vitrain indicate that it is a low volatile bituminous coal according to ASTM standards but one close to the borderline between medium and low volatile bituminous.

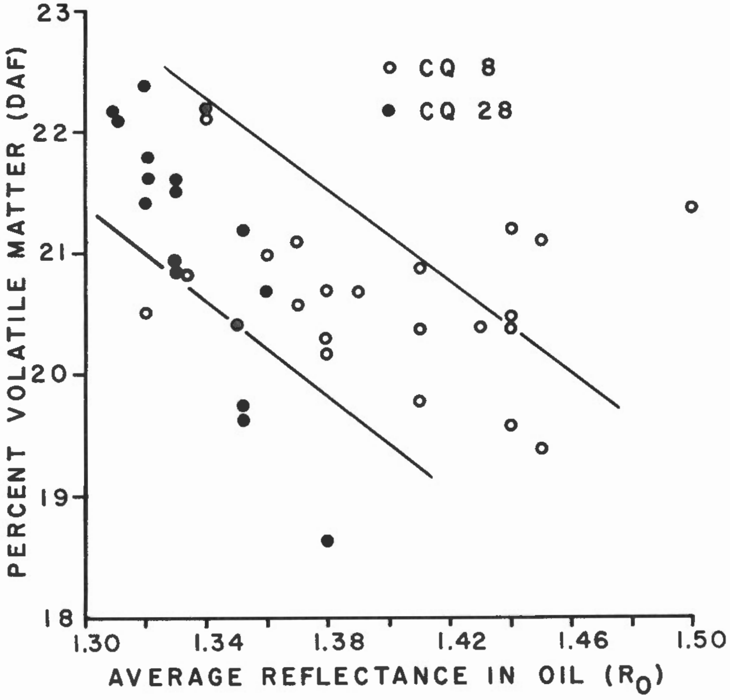

Figure 11. Relationship between reflectance and volatile matter in vitrain samples of CQ 8 and CQ 28.

In Figure 11 the mean maximum reflectances of the various intervals are plotted against per cent volatile matter as determined on the hand-picked vitrain samples. The points show a considerable degree of scatter but the normal tendency for the higher reflectance values to be associated with lower values of volatile matter is apparent. It is interesting that the black circles representing the points for sample CQ 28 show a better distribution in this regard than do the points for CQ 8. A possible explanation may be that the reflectivities of CQ 8 have been affected by oxidation and the possibility that CQ 8 may have been more affected in this respect than CQ 28 has been discussed already. With regard to the rather large degree of scatter of the points, it should also be mentioned that Figure 11 represents only a small part of the volatile matter-reflectance spectrum usually shown in this relationship and hence any scatter about the trend line is magnified.

FLUIDITY AND SWELLING

Fluidity and swelling data were determined by the Gieseler constant torque plastometer and the Free Swelling Index test respectively. These tests were carried out on hand-picked vitrain and whole coal from samples CQ 8 and CQ 28. For these tests various intervals in some instances were combined into single samples largely because of the small quantities of hand-picked vitrain available. These samples for fluidity and swelling were numbered 1 through 10 for CQ 8 and 1 through 8 for CQ 28. The relationship of the petrographic intervals and these fluidity and swelling samples is given in Table XIII.

TABLE XIII

Identification of Fluidity Samples with Intervals

CQ 8		CQ 28	
Petrographic interval	Combined into fluidity and swelling sample No.	Petrographic interval	Combined into fluidity and swelling sample No.
XX, XIX	1	XX, XIX	1
XVIII	2	XVIII	2
XVII, XVI, XV	3	XVII, XVI, XV	3
XIV	4	XIV	4
XIII	5	XIII	5
XII, XI	6	XII, XI	6
XA, X, IX	7	XA, X, IX	7
VIII, VII, VI	8	VIII, VII, VI, V	8
V, IV	9		
III, IIA, II, I	10		

Each fluidity and swelling sample indicated on the above table is actually two samples, one being hand-picked vitrain, the other whole coal. Where intervals were combined such combinations were weighted based on the thicknesses of the intervals involved. The fluidity and swelling data are given in Tables XIV and XV. The data in these tables dramatize the differences in plasticity and swelling properties between pure vitrain and the whole coal. They suggest that for coals which have low fluidities for the whole coal it is

TABLE XIV

Plasticity and Swelling Data for CQ 8

	Sample	Start. temp. °C >1 DD/M [1]	Temp. of max. fluidity °C	Final fluid temp. °C <1DD/M	Temp. of solid. °C; no movement	Melting range in °C	Max. fluidity DD/M	Total movement in dial divs.	F.S.I. [2]
1	Vitrain	466	487	504	510	38	8.3	59	9+
	Whole Coal	-	480	-	497	-	0.4	3	1
2	Vitrain	447	486	503	512	56	8.5	84	9+
	Whole Coal	480	480	486	501	6	1.2	11	4 1/2
3	Vitrain	468	471	475	500	7	1.1	12	8
	Whole Coal	-	469	-	498	-	0.6	6	3
4	Vitrain	466	492	505	514	39	11.8	73	9+
	Whole Coal	-	484	-	502	-	0.9	8	4
5	Vitrain	462	480	495	502	33	3.2	32	9+
	Whole Coal	-	480	-	501	-	0.5	5	2 1/2
6	Vitrain	474	497	512	522	38	52	41	9+
	Whole Coal	477	477	483	502	6	1.2	10	5
7	Vitrain	455	480	504	510	49	10.0	80	9+
	Whole Coal	-	477	-	501	-	0.9	8	3 1/2
8	Vitrain	458	481	501	508	43	13.0	79	9+
	Whole Coal	492	492	495	516	3	1.2	10	4 1/2
9	Vitrain	470	493	508	514	38	16.5	87	9+
	Whole Coal	463	481	488	503	7	1.3	14	3
10	Vitrain	465	486	501	510	36	3.8	32	9
	Whole Coal	-	494	-	510	-	0.5	5	1 1/2

1. DD/M = Dial Divisions/Minute.

2. F.S.I. = Free Swelling Index.

TABLE XV

Plasticity and Swelling Data for CQ 28

Sample		Start. temp. °C > 1 DD/M [1]	Temp. of max. fluidity °C	Final fluid temp. °C < 1 DD/M	Temp. of solidification; no movement, °C	Melting range in °C	Max. fluidity DD/M	Total movement in dial divs.	F.S.I. [2]
1	Vitrain	456	483	502	510	46	20	121	8
	Whole Coal	-	473	-	486	-	0.5	4	1
2	Vitrain	444	475	500	504	56	28	225	9+
	Whole Coal	456	468	473	492	17	1.6	15	4
3	Vitrain	436	473	501	505	65	85	642	9+
	Whole Coal	459	465	482	491	23	1.4	15	4
4	Vitrain	437	471	498	504	62	88	644	9+
	Whole Coal	447	474	492	498	45	11	77	7.5
5	Vitrain	438	475	500	504	62	81	622	9+
	Whole Coal	447	474	491	496	46	7.2	63	7+
6	Vitrain	438	474	499	505	61	67	486	9+
	Whole Coal	455	473	485	491	30	2.8	23	4.5
7	Vitrain	444	477	501	507	57	65	477	9+
	Whole Coal	450	474	490	499	40	5.7	50	7.5
8	Vitrain	446	474	495	501	49	17	119	9
	Whole Coal	456	474	485	498	29	2.3	21	4.5

1. DD/M = Dial Divisions/Minute.

2. F.S.I. = Free Swelling Index.

especially important to prepare fractions with the highest vitrain or vitrinite contents which can be practically obtained, in order to achieve an enhancement in fluidity.

There is considerable difference in the fluidities between the vitrains of CQ 8 and CQ 28 as well as between the whole coal samples of these two main samples. This is undoubtedly due to the greater oxidation of CQ 8. This sample, though stored as large blocks in plastic bags, was tested for fluidity and swelling about two years after it had been collected. On the other hand, sample CQ 28, which was stored in a similar manner, was tested for fluidity and swelling about a month after collection and although oxidation may also have affected its swelling and fluidity, such deterioration as it may have suffered would probably be much closer to that which this coal normally undergoes during transportation and storage before industrial use. It is interesting that the Free Swelling Indices do not seem to reflect these differences between CQ 8 and CQ 28 nearly as well as do the fluidity data.

In Figure 12 the maximum fluidities of the vitrain samples from CQ 8 and CQ 28 are compared to reflectance data and to ash contents. The latter have been calculated from the appropriate data for the intervals[1]. In Figures 12A and 12B are shown ash content, maximum fluidity and average reflectance for each subsample. The rather high ash contents of the CQ 28 vitrains as compared to those of CQ 8 is probably the result of the inclusion of some coal type other than vitrain in the samples. The ash content does not seem to be related to the fluidity of either CQ 8 or CQ 28 except that in a general way the vitrains of CQ 28 from the more central parts of the seam (samples 3 to 7 inclusive) have the highest fluidity and the lower ash content. An exception is sample 4. The average reflectance (R_0) also does not seem to show much relationship with fluidity except that the high fluidity vitrains of sample CQ 28 are those with the lowest average reflectances. The plots shown in parts C and D of Figure 12 indicate however that if the contents of the individual 'V' types, especially V 15 and V 16, are considered along with mineral matter, a somewhat better correlation with maximum fluidity is shown. The mineral matter has been calculated from the ash content by Parr's formula. The sulphur content of these samples was not determined but because, as indicated earlier, it is low in this coal, a sulphur content of 0.3 per cent was assumed for all samples and the Parr calculations made on that basis. In both of the vitrain series a decrease in the proportions of the two 'V' types of highest reflectance (V15 and V 16) along with a decrease in mineral matter is accompanied by an increase in maximum fluidity.

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[1] The petrographic data used in the preparation of Figure 12 and Figure 13 are shown in Table XVI.

TABLE XVI

Petrographic Data for Samples of CQ 8 and CQ 28 Tested for Fluidity

Sample	Vitrinite	Fusinite and semifusinite	Micrinite	Mineral matter	Reflectance Data % V 15 + V 16	Reflectance Data R_o
		CQ 8				
1	42.8	26.3	19.3	11.6	13.8	1.38
2	61.4	27.0	8.7	2.9	8.8	1.37
3	51.9	30.2	13.6	4.3	3.3	1.34
4	51.0	30.3	16.7	2.0	3.6	1.33
5	49.5	30.6	17.2	2.7	26.7	1.44
6	63.4	21.3	7.9	7.4	19.8	1.44
7	52.9	28.4	13.6	5.1	12.1	1.43
8	54.3	31.2	8.5	6.0	9.9	1.39
9	44.8	26.6	11.7	16.9	7.4	1.41
10	45.1	33.3	10.9	10.7	17.1	1.44
		CQ 28				
1	49.2	34.6	12.2	4.0	12.6	1.37
2	50.9	33.5	10.0	5.6	7.1	1.33
3	55.7	26.1	12.9	5.3	6.6	1.34
4	54.5	29.3	11.3	4.9	0.9	1.32
5	64.2	22.6	9.0	4.2	1.7	1.32
6	64.3	20.4	9.7	5.6	4.0	1.32
7	60.9	24.6	8.9	5.6	2.5	1.32
8	53.5	28.2	11.3	7.0	4.3	1.35

In Figure 13 the vitrinite contents of the whole coal samples from CQ 8 and CQ 28 are plotted against fluidity. Because the maximum fluidities are low, particularly that of CQ 8, the total movement in dial divisions has been used as the fluidity parameter. These two plots in Figure 13 show that for these two series of samples an increase in vitrinite content is accompanied by an increase in fluidity. This relationship is best shown in the plot for CQ 8 (Fig. 13A).

FRACTURE ANALYSIS OF VITRAIN

The No. 10 seam, at least in certain layers, is characterized by rather high friability. This is due partly to its rather high content of fusinite. It is also due to the existence within the seam of a rather prominent and irregular fracture system. This phenomenon of fracturing in coals has been

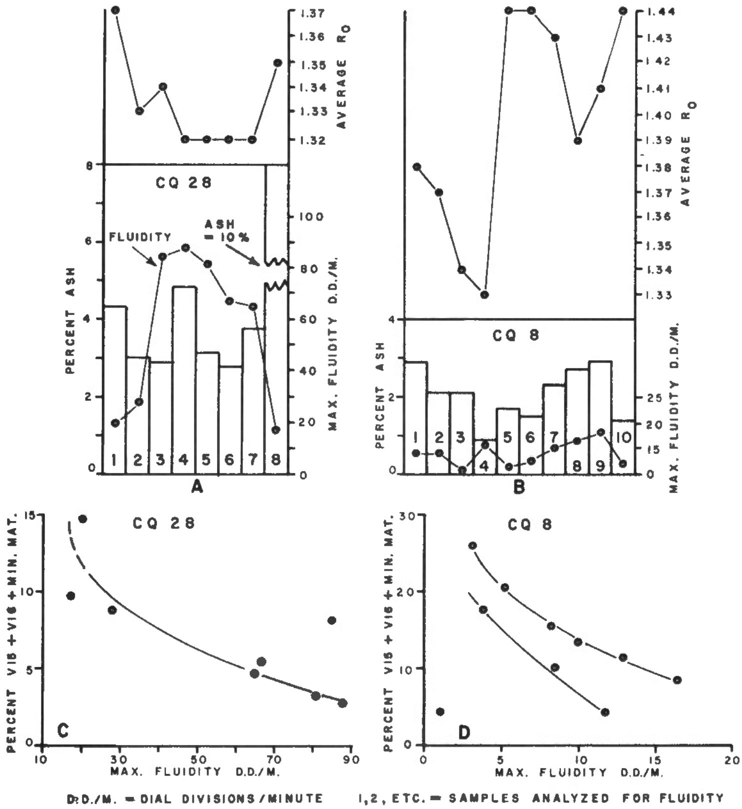

Figure 12. Ash content and reflectance data related to fluidity of vitrain samples from CQ 8 and CQ 28.

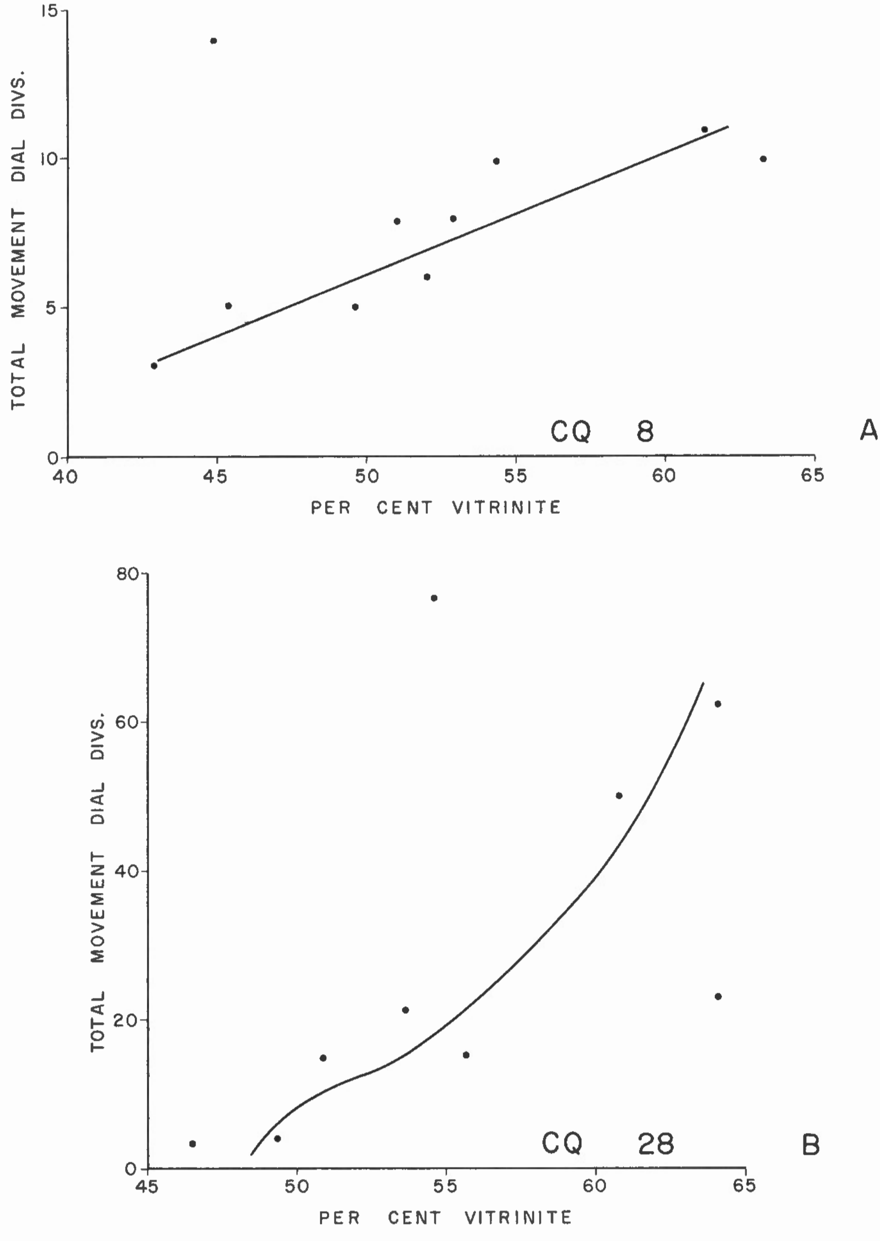

Figure 13. Relationship of vitrinite in whole coal samples to fluidity.

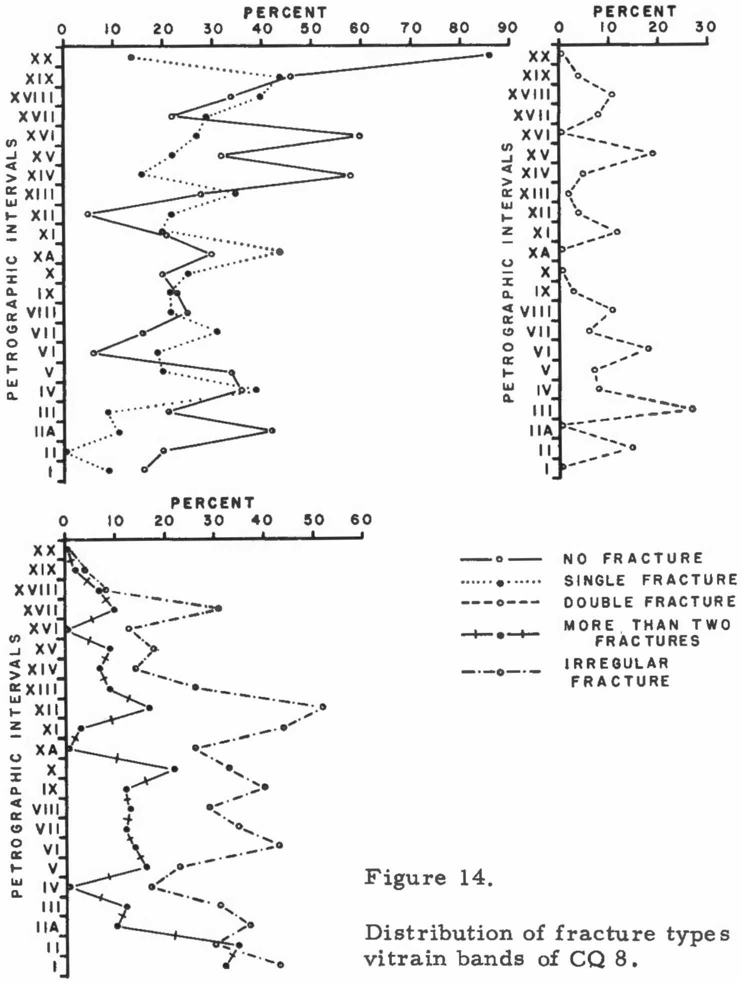

Figure 14.

Distribution of fracture types in vitrain bands of CQ 8.

studied in much detail for Soviet coals by Ammosov and Evemin (1960). Nothing as elaborate as their approach was tried with the No. 10 seam but an attempt was made to get some idea of the fracture pattern in the coal. With these objectives in mind the vitrain layers throughout the polished column of CQ 8 were examined megascopically and characterized in the following terms:

1. vitrain bands with no fracture,
2. vitrain bands with a single fracture,
3. vitrain bands with two fractures,
4. vitrain bands with more than two fractures,
5. vitrain bands with non-parallel irregular fracture.

Percentages of these types were then calculated on the different petrographic intervals and these data have been plotted in Figure 14. They are also given in Table XVII. Consideration of this figure shows that the percentage of vitrain bands with no fracture has three high points in intervals XX, XVI and XIV and then drops off, while the percentage of vitrain bands with more than two fractures increases in a somewhat irregular fashion toward the base of the seam. At the same time the percentage of vitrain with irregular fracture increases rather markedly in interval XII and remains fairly high to the base of the seam. Thus the incidence of fracturing in the vitrain of CQ 8 seems to be higher toward the base of the seam with a rather pronounced break at interval XII.

The percentages of various fracture types were plotted against a number of the parameters of petrographic composition. In none of these plots did a particularly good relationship stand out although in a number trends are apparent. A typical example is Figure 15 in which the average thicknesses of the vitrain bands (Table II) for each interval are plotted against the percentage of vitrain bands with single fracture. As would be expected, the proportions of vitrain bands with a single fracture only, increases as the average thickness of the vitrain bands in a given interval decreases.

SIZE FRACTION ANALYSIS

Sieve analyses were carried out on thirteen samples representing some of petrographic intervals of CQ 8. A series of six sieves were used ranging from 14 mesh to 150 mesh. The coal analyzed had already been crushed to minus 10 mesh and the objective of the sieving was to determine if any differences in size distribution patterns would show between samples, differences which might be tied in to petrographic parameters. Quantities of approximately 100 grams were riffled out of the crushed coal from each interval and this material was then placed in a nest of sieves and shaken in a laboratory sieve shaker for five minutes. The results are given in Table XVIII.

The data from these sieve analyses were plotted according to a method evolved by Rosin and Rammler (1933). This method involves the plotting on special log paper of the cumulative percentages retained on a series of sieves against the appropriate sieve sizes. From such a plot two factors can be determined which express the behaviour of a coal in a given size analysis. One of these factors is 'n' and it is the slope of the line drawn through the points plotted in the manner described above. The other factor is 'k', the size factor, and it is the size of the screen upon which 36.8 per cent of the sample is retained. According to Geer and Yancy (1938) small values of 'n' unless accompanied by large values of the size factor 'k' indicate the presence of considerable amounts of the finer sizes. Hence one would expect that coals rich in the friable components such as vitrain and fusain might, in a sieve

TABLE XVII

Fracture Distribution in Vitrain of CQ 8

Intervals	Per cent of vitrain bands with:				
	No fracture	Single fracture	Double fracture	More than two fractures	Irregular fracture
XX	86.7	13.3	-	-	-
XIX	45.8	44.2	4.5	2.0	3.5
XVIII	35.2	40.6	10.1	6.9	7.2
XVII	22.4	29.0	7.7	9.7	31.2
XVI	60.0	26.7	-	-	13.3
XV	31.8	21.8	19.1	9.1	18.2
XIV	58.6	15.8	5.8	7.0	12.8
XIII	28.1	35.4	1.8	9.3	25.4
XII	5.0	22.5	4.2	15.8	52.5
XI	21.4	20.0	12.1	2.9	43.6
X A	30.0	44.0	-	-	26.0
X	20.0	25.7	-	21.4	32.9
IX	23.3	21.7	3.3	11.7	40.0
VIII	25.0	22.4	10.5	12.6	29.5
VII	16.7	30.9	6.0	11.9	34.5
VI	5.6	18.9	18.3	13.4	43.8
V	32.5	20.0	6.9	15.9	24.7
IV	36.7	38.3	8.3	-	16.7
III	21.2	9.4	27.2	12.2	30.0
II A	42.2	11.1	-	10.0	36.7
II	20.0	-	15.0	35.0	30.0
I	16.3	8.8	-	32.5	42.4

analysis, tend to have lower values of 'n' than coals characterized by tougher constituents such as durain and bone or shaly coal. Smaller values of 'n' may also indicate a more uniform weight distribution of materials in the various size fractions.

The calculated values of 'n' for the samples examined ranged from 0.92 for interval XVI to 1.24 for interval VI (see Table XVIII). The actual plots for these two intervals are given in Figure 16.

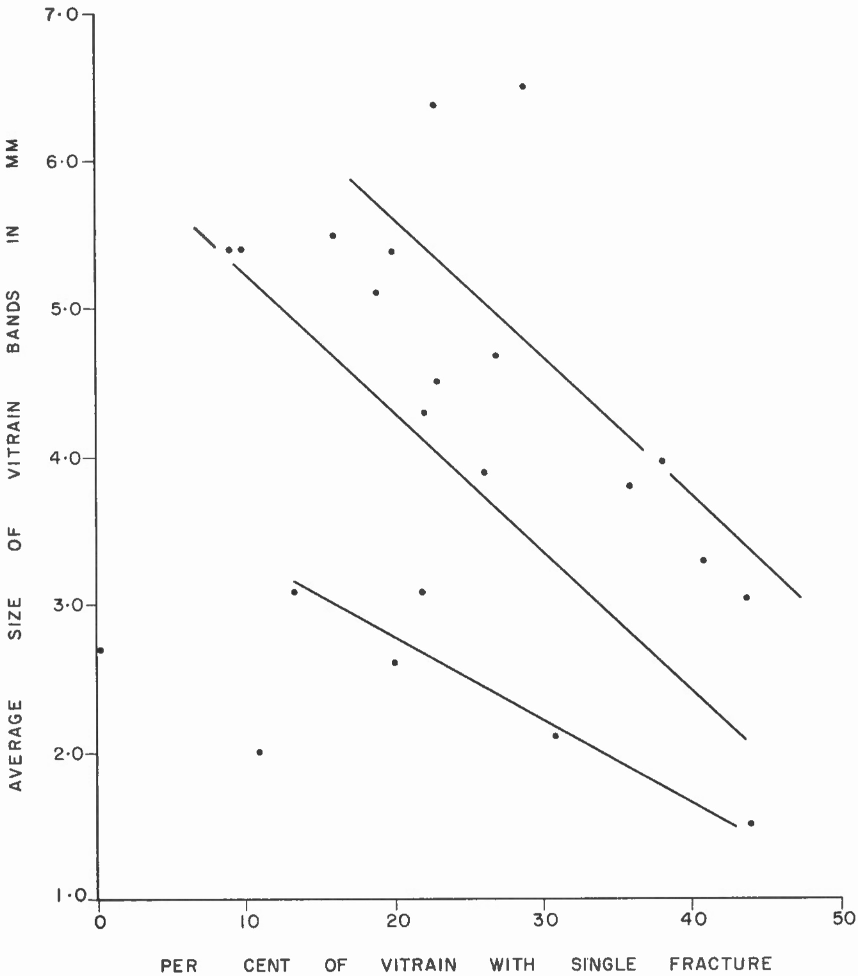

Figure 15. Comparison of content of single fracture vitrain with average size of vitrain bands for intervals of CQ 8.

TABLE XVIII

Sieve Analysis Data for Selected Intervals of CQ 8 (per cent by weight retained on mesh sizes)

Interval	+ 14		14 x 20		20 x 35		35 x 60		60 x 100		100 x 150		>150		n
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	
XIX	46.8	46.8	13.6	60.4	14.2	74.6	10.9	85.5	6.3	91.8	2.7	94.5	5.5	100.0	1.07
XVIII	41.3	41.3	13.6	54.9	15.5	70.4	12.7	83.1	7.2	90.3	3.1	93.4	6.7	100.0	1.06
XVII	35.4	35.4	13.4	48.8	17.2	66.0	14.2	80.2	8.4	88.6	3.7	92.3	7.7	100.0	1.06
XVI	26.8	26.8	11.3	38.1	17.4	55.5	15.6	71.1	10.4	81.5	6.9	88.4	11.6	100.0	0.92
XV	33.1	33.1	15.3	48.4	17.3	65.7	14.3	80.0	9.1	89.1	3.8	92.9	7.1	100.0	1.10
XIV	34.6	34.6	15.4	50.0	15.5	65.5	12.1	77.6	8.8	86.4	4.0	90.4	9.6	100.0	0.98
XIII	39.1	39.1	16.2	55.3	17.0	72.3	12.7	85.0	6.9	91.9	2.8	94.7	5.3	100.0	1.17
XI	38.2	38.2	14.3	52.5	16.5	69.0	13.3	82.3	7.8	90.1	3.4	93.5	6.5	100.0	1.10
X	51.1	51.1	13.6	64.7	13.4	78.1	10.2	88.3	5.5	93.8	2.3	96.1	3.9	100.0	1.16
IX	49.6	49.6	12.8	62.4	13.7	76.1	10.7	86.8	5.9	92.7	2.5	95.2	4.8	100.0	1.09
VIII	56.9	56.9	12.3	69.2	12.5	81.7	9.1	90.8	4.9	95.7	2.0	97.7	2.3	100.0	1.17
VII	47.2	47.2	15.6	62.8	14.6	77.4	10.6	88.0	5.7	93.7	2.3	96.0	4.0	100.0	1.21
VI	61.7	61.7	11.3	73.0	11.4	84.4	7.6	92.3	4.4	96.7	1.5	98.2	1.8	100.0	1.24

A – per cent by weight retained.

B – cumulative value for all preceding mesh sizes.

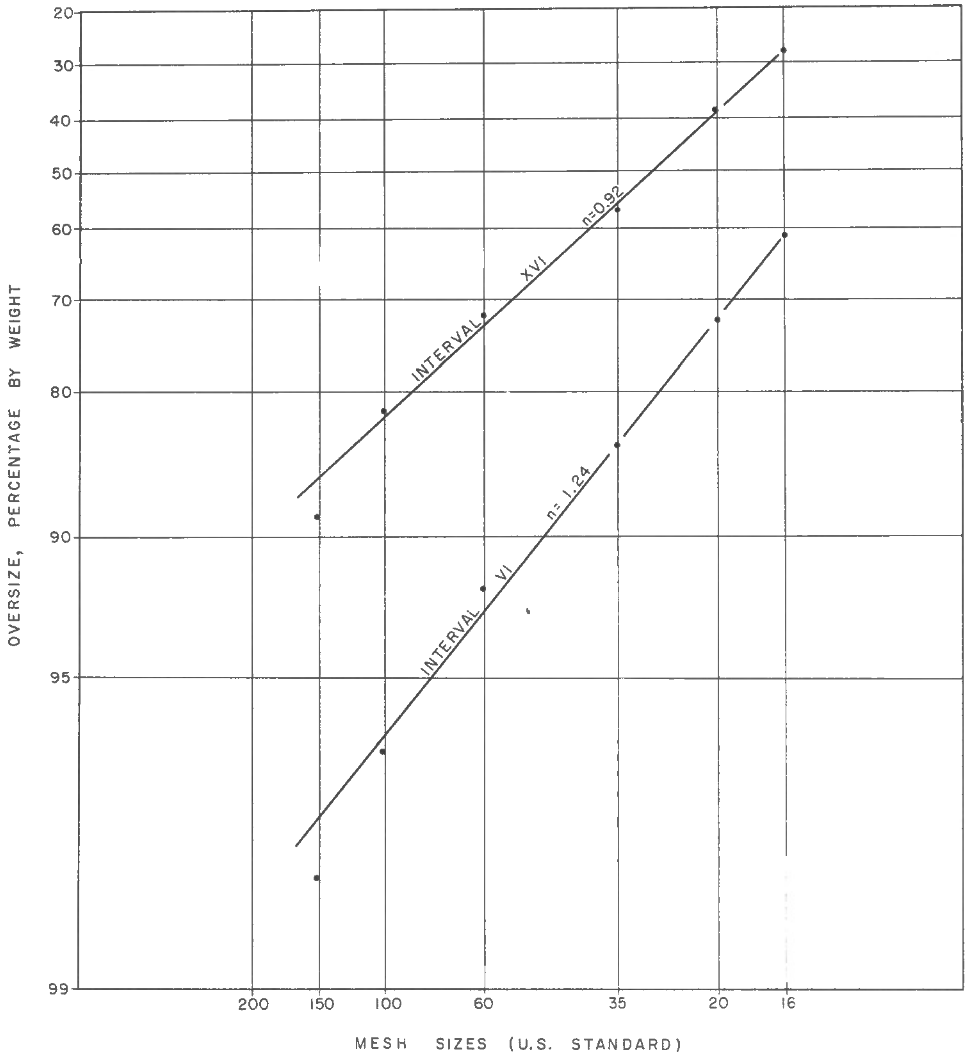

Figure 16. Rosin-Rammler plots for intervals XVI and VI of CQ 8.

A number of petrographic values and combinations of values were plotted against 'n' and Figures 17 and 18 are examples of relationships which appeared. In most cases individual components, whether macerals or micro-lithotypes or megascopically determined components, did not show good correlations with 'n'. In Figure 17A the ratio between megascopically determined vitrain and durain plus shale partings is plotted against 'n' and shows the expected result, when the proportion of vitrain increases relative to the

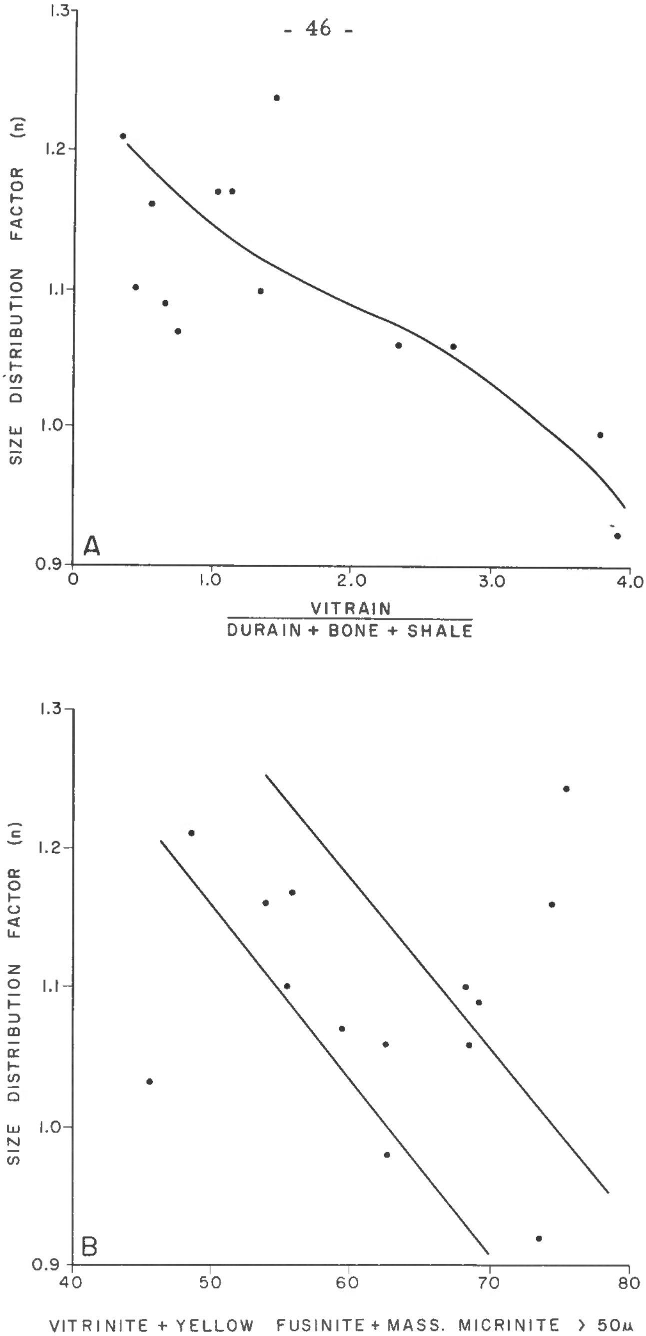

Figure 17. Petrographic data for selected intervals of CQ 8 plotted against size distribution factor 'n'.

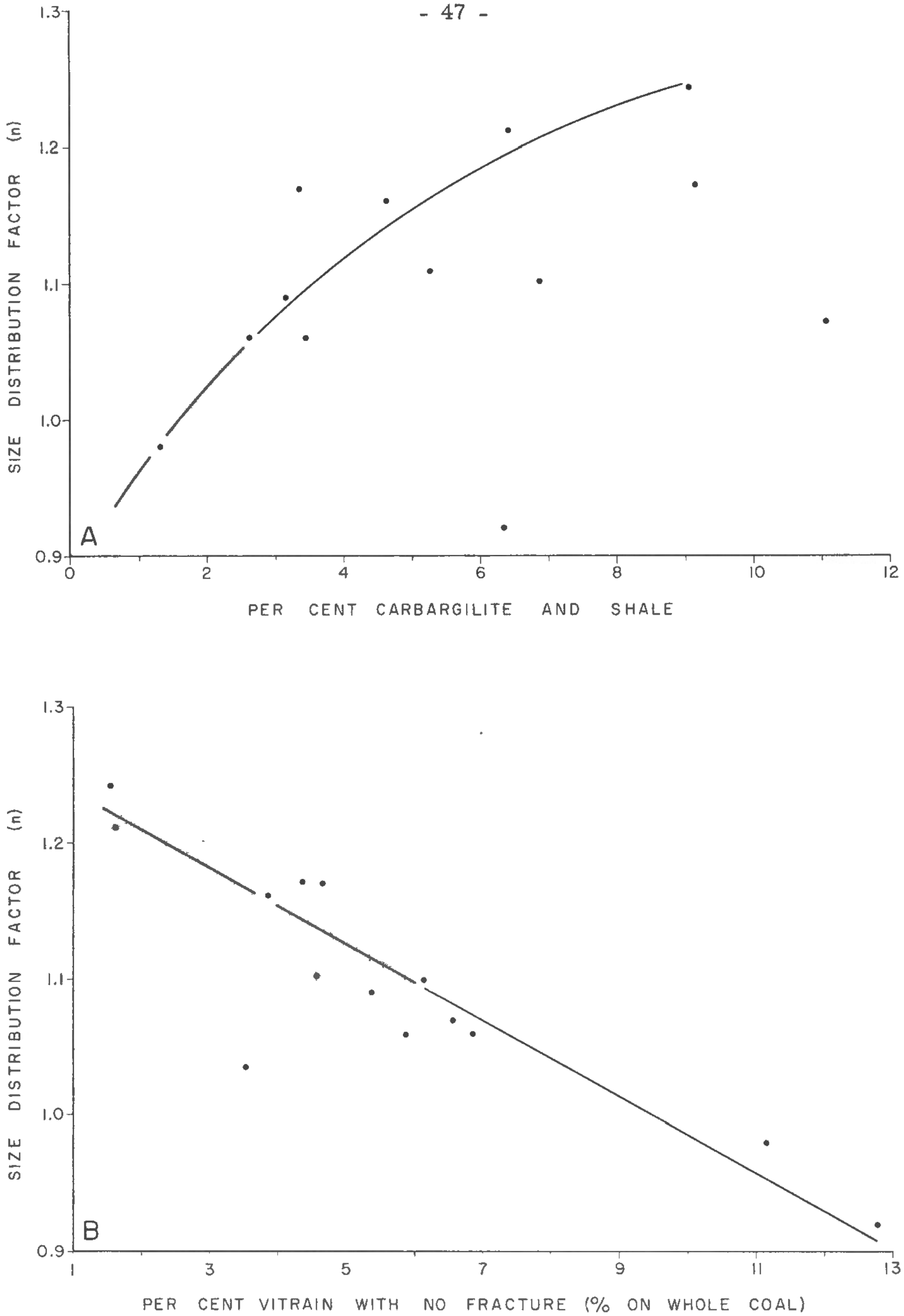

Figure 18. Petrographic data for selected intervals of CQ 8 plotted against size distribution factor 'n'.

dull entities, 'n' decreases. In Figure 17B an unusual combination of constituents seems to bear an inverse relationship to 'n'. As the proportions of the maceral vitrinite along with yellow fusinite and massive micrinite larger than 50 microns increases, 'n' decreases. Inclusion of the fusinite of intermediate reflectance tends to dilute the trend of the points as plotted.

It is interesting that the massive micrinite in masses larger than 50 microns appears to fit in with the fragile constituents vitrinite and fusinite. In this coal such micrinite often shows high reflectance and may represent material closely related to the yellow fusinite but lacking structure. Intervals VIII and VI are anomalous in Figure 17B in that their 'n' values appear too high for their corresponding vitrinite contents.

In Figure 18A carbargilite and shale as determined in the microlithotype analysis show more or less the expected relationship with 'n' although the points are rather scattered. In Figure 18B a curious relationship is shown. This plot indicates that an increase in the amount of unfractured vitrain is accompanied by a decrease in 'n', suggesting that such coals might show a large concentration of fines. This is the opposite of what one might expect. An explanation for this relationship is difficult to find but probably involves other factors such as the size of the vitrain bands and the total vitrain present in each interval as well as the amount of fusain.

These few data merely indicate possible petrographic parameters which might be related to Rosin-Rammler factors.

SUMMARY AND CONCLUSIONS

The three main samples of the No. 10 (Balmer) seam from the Natal-Michel area in the Crowsnest coalfield of British Columbia show a petrographic composition that is high in the inertinite macerals, fusinite, semifusinite and micrinite. The distribution of these varies through the thickness of the seam and there are certain intervals, especially in the top half of the seam, in which the vitrinite or 'reactive' component, is relatively high compared to the inertinite macerals.

The coal is low volatile bituminous by ASTM standards and mean maximum reflectances in oil determined on vitrinite range from 1.31 to 1.45.

Swelling and plasticity determinations carried out on both vitrains and whole coal samples show rather low values for the plasticity, although this may be related in part to oxidation. The vitrain was much more reactive in these tests than the whole coal.

Since this coal is of primary importance because of its coking possibilities, it is appropriate to refer briefly to these possibilities in the light of the data obtained through this study. The carbonization data obtained on samples coked from this coal are to be discussed more fully in a separate paper. The coking potential of two coals from the Michel area, one of them being the No. 10 seam, was reported on by Cameron and Botham (1966). That study showed that the coals tested appeared to be oversaturated with inerts relative both to the amount of vitrinite present and the reflectance classes of that vitrinite. It was also suggested by the above authors that some of the vitrinite might behave in part as an inert in the coking process. In general such conclusions hold true for the No. 10 seam samples examined in the present study. However, an abundance of inerts is not necessarily a disadvantage. Bright coals with an overabundance of reactive materials need to be blended with coal similar to the No. 10 seam in order to achieve the optimum balance between reactive and inert constituents necessary for good coke quality. If mining procedures restrict extraction for coke making to the upper half of the No. 10 seam, especially to the level of interval XVIII, where the vitrinite is relatively abundant compared to the inert macerals, the carbonization possibilities of this coal should be considerably improved.

In addition, relatively simple beneficiation by crushing and screening will probably still further increase the vitrinite content in the finer fractions. For example, Cameron and Botham (1966) showed that the content of vitrinite for a medium volatile coal from this same field increased considerably, relative to the inerts, in the minus 1/4-inch fraction of a size fraction series. In this regard useful information could probably be derived from studies related to the internal fracturing of the coal and distribution of material in a size fraction analysis. Such data could be combined with grindability information and petrography.

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PLATE I

Macerals and Microlithotypes in No. 10 Seam

A. This photograph illustrates two of the microlithotypes and several of the macerals discussed in this report. The smaller particle on the left represents the microlithotype vitrinertite 1 composed mainly of the maceral vitrinite (light grey groundmass) with accessory quantities of the maceral micrinite (small white patches). The large particle in the right half of the picture is composed principally of inertinite macerals with approximately 25 per cent vitrinite (grey material in right side of particle) and is assigned to the microlithotype vitrinertite 3. The white cellular material with high relief is yellow fusinite. The left half of the particle is made up mostly of semifusinite, characterized by a white colour and irregular cellular structure.

(Taken under oil immersion)

B. Photograph B shows a particle of the microlithotype vitrinertite 2. Its main maceral is vitrinite (grey groundmass). It also contains some fusinitic material (white areas with pores or remnant cell structures). In addition, it contains many small patches of white material belonging to the maceral micrinite. Many of these patches are in the category of fine-grained micrinite, that is, their greatest dimensions are less than 10 microns. A few with dimensions between 10 and 50 microns belong to the intermediate category of micrinite (massive micrinite > 10 < 50 microns).

(Taken under oil immersion)

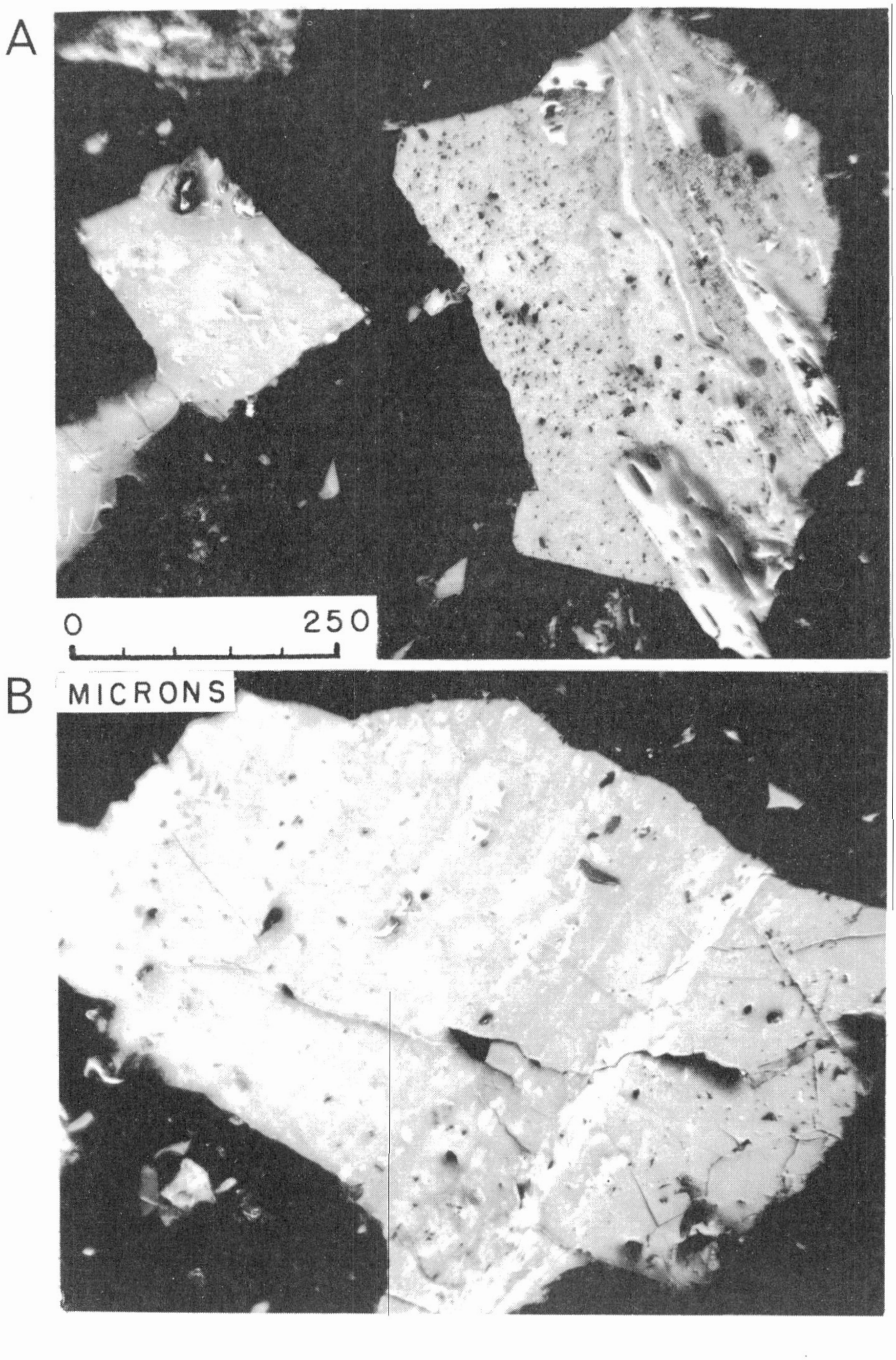

A
0
250
MICRONS
B

PLATE II

Macerals and Microlithotypes in No. 10 Seam

A. The particle in this photograph falls into the category of vitrinertite 4 (5-10% vitrinite). Most of the particle is composed of semi-fusinite (porous light coloured material in left half of particle).
(Taken under oil immersion)

B. The large particle in this photograph shows a concentration of the massive micrinite in the size category greater than 50 microns in dimension. Most of the particle is composed of this component with only a few stringers of grey vitrinite present.
(Taken under oil immersion)

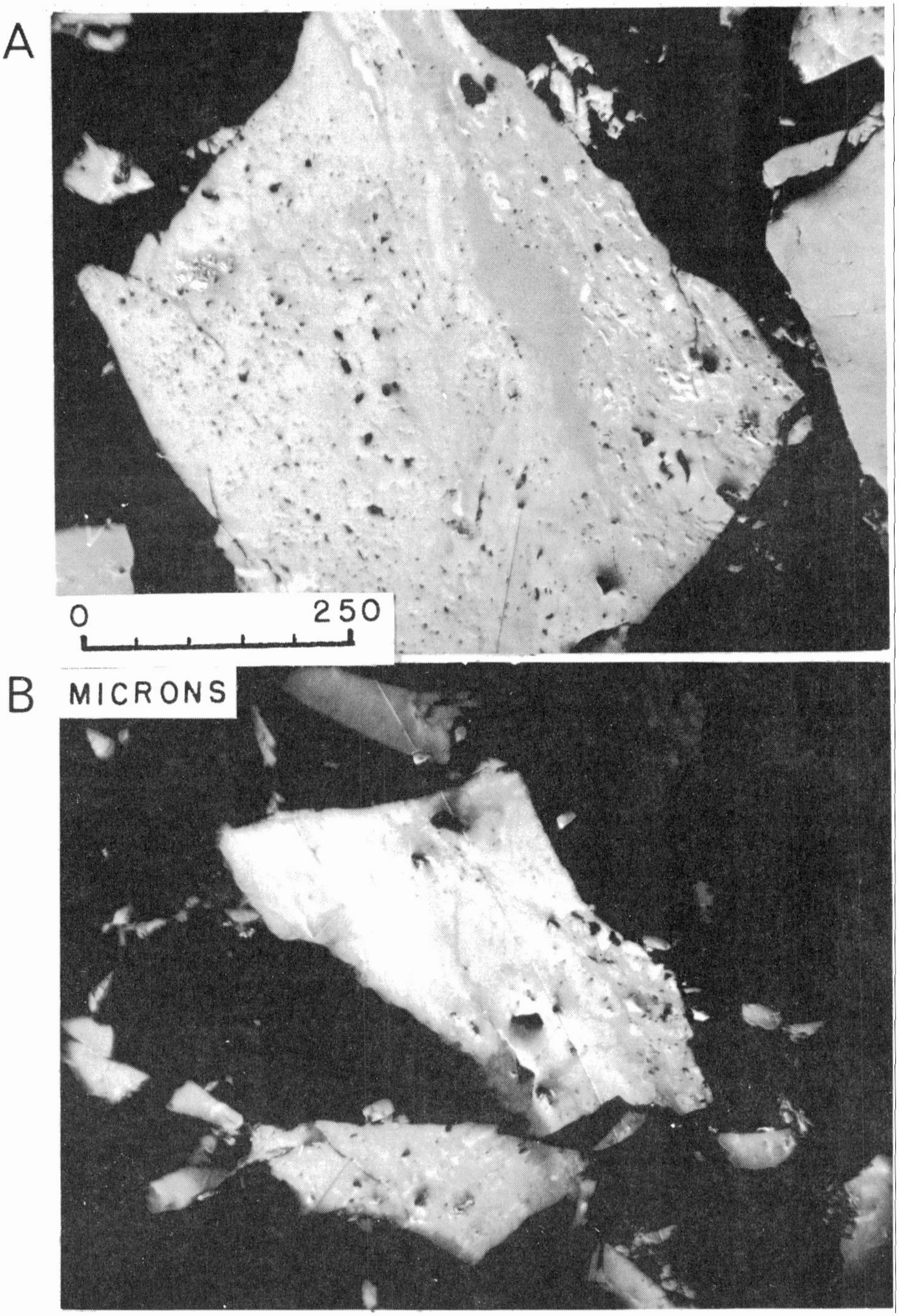

A
0 250
B MICRONS

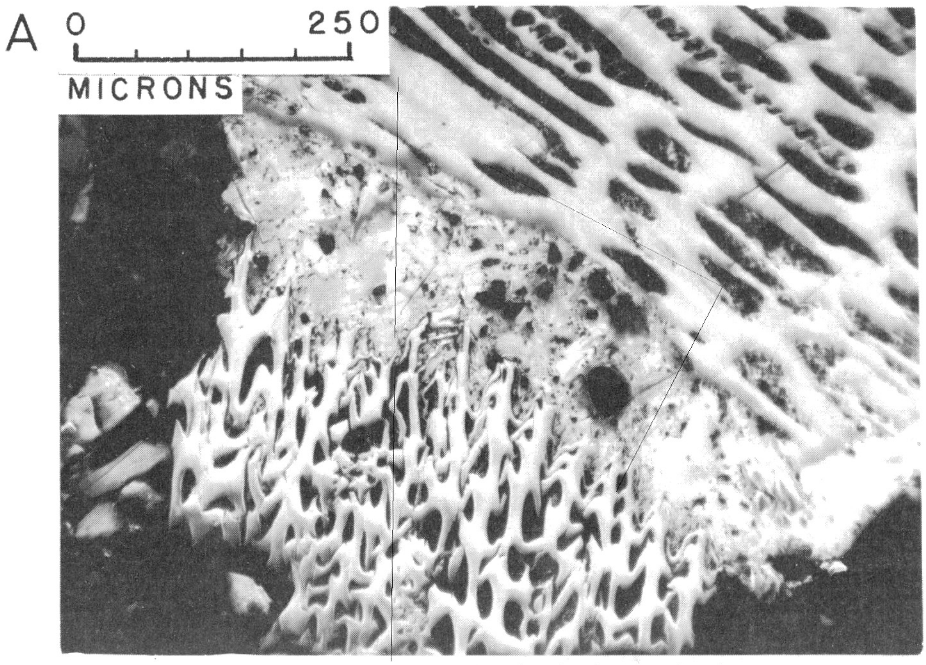
PLATE III

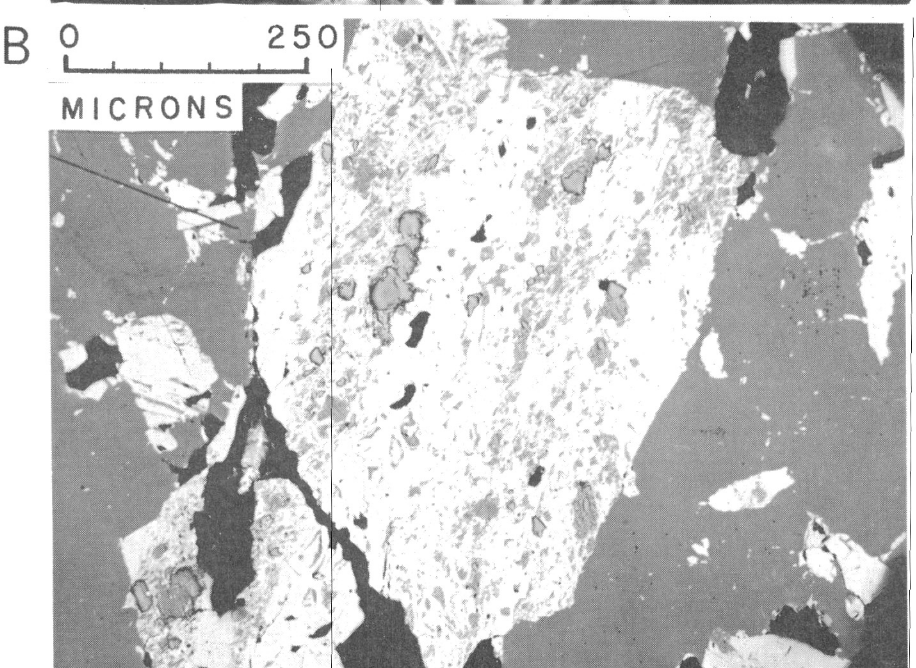
Macerals and Microlithotypes in No. 10 Seam

A. The particle in this photograph shows two varieties of fusinite. The lower half of the particle shows a light coloured material with prominent, though broken, cell structure and high relief. In polished section this has a golden yellow colour and has been assigned in this study to the category of yellow fusinite. The upper half of the particle also contains material with well-preserved cell structure, but with subdued colour and relief as compared to the yellow fusinite. In the present study it has been designated white fusinite.

(Taken under oil immersion)

B. The grey dark bordered bodies with high relief contained within the particles are quartz grains. This photograph was taken with a dry objective and hence the aspect of the organic materials in this picture is different from that seen in previous photographs where oil immersion enhances the contrast between macerals.


A
0
250
MICRONS


B
0
250
MICRONS