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SOME PETROLOGICAL ASPECTS OF THE HARBOUR COAL SEAM, SYDNEY COALFIELD, NOVA SCOTIA

A. R. Cameron

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By
A. R. Cameron

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PREFACE

It has long been known that qualitatively the various petrographic components of coal react differently in industrial processes. Within the last 15 years, however, such knowledge has been placed on a much more exact basis, especially in the coking industry, and coal petrography is now used as a routine tool by industry to predict coal behaviour.

The value of such information is enhanced if the distribution and relations of coal components as they exist in the seam can be discovered so that mining can be planned more efficiently. This involves the study of facies changes in coal seams, including the character of such changes and their causes.

This report deals with facies changes in the Harbour coal seam of the Sydney coalfield, Nova Scotia. It presents information on the petrographic character of the various intervals into which the seam can be divided, and attempts to show lateral variation within such intervals. In addition, detailed microscopic data are presented on some of the dull layers found in the seam. These data show how these dull layers differ from one another petrographically, how they vary laterally within the limits of one mine, and suggest conditions of origin for them.

Y. O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, 1 October, 1966

BULLETIN 175 — Einige petrographische Wesenszüge des Hafen-Kohlenflözes aus dem Kohlenrevier Sydney in Neuschottland

A. R. Cameron

Mikroskopische Untersuchungen von Proben aus vielen Teilen des Hafen-Kohlenflözes führen zur Erkennung vieler in ihrer Zusammensetzung verschiedener Arten und zu dem Schluss, dass das Flöz unter Waldmoor- und Schilfmoorbedingungen entstanden ist.

БЮЛЛЕТЕНЬ 175 — Некоторые петрологические аспекты угольного пласта порта Сидней, Сиднейский угольный бассейн, Новая Шотландия.

А. Р. Камерон

Микроскопическое изучение образцов из многих участков сиднейского угольного пласта позволяют распознать мносие вариации его вещественного состава и заключить что этот пласт возник в условиях заболоченных лесов и тростниковых болот.

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Abstract

Facies changes within the Harbour seam of the Sydney coalfield, Nova Scotia, were investigated by megascopic and microscopic methods. The megascopic approach was applied to the laboratory examination of fourteen column samples representing a linear distance of 23 miles in the seam, and to the description of fifty-three in situ sections of the seam in the Princess, Florence, and No. 12 Collieries. The components identified were vitrain, claro-durain, durain, bone, and three varieties of clarain. This part of the study showed that areas of significant changes in petrographic composition could be distinguished laterally and vertically in the seam.

Microscopic studies by transmitted light were confined to the dull layers sampled in the Princess Colliery. Compositions were determined by both maceral and microlithotype content. In this process the microlithotype concept, as conventionally used, was revised to more clearly define natural assemblages of macerals. Two orders of microlithotypes were distinguished: simple and complex. Sixty simple and nine complex types have been defined.

On the basis of the megascopic and microscopic data, the writer concludes that much of the Harbour seam originated under forested-moor and reed-moor conditions. Deviations from these conditions are represented by the dull bands, one group of which appears to have originated during flooding or excessive subsidence. A second group is interpreted to be the product of short-lived dry periods, and a third group appears to represent a transitional phase between the reed moor and open water.

Résumé

On a étudié à l'échelle mégascopique et microscopique les changements de faciès dans le gisement Harbour du bassin houiller de Sydney en Nouvelle-Écosse. L'étude mégascopique s'est faite par l'examen en laboratoire de 14 échantillons de colonne représentant dans la veine une distance linéaire de 23 milles, et par la description de 53 coupes dans la veine aux houillères Princess, Florence et nº 12. On a identifié les composants suivants: vitrain, claro-durain, durain, os et trois variétés de clarain. Cette partie de l'étude a démontré que l'on pouvait distinguer dans la veine, latéralement et verticalement, des zones de changements importants dans la composition pétrographique.

Les études au microscope, par lumière transmise, se sont limitées aux couches ternes échantillonnées dans la houillère Princess. On a déterminé la composition par la teneur en éléments macéraux et en microlithotypes. Dans ce procédé, on a révisé le concept traditionnel des microlithotypes afin de dégager plus nettement les assemblages naturels d'éléments macéraux. Deux classes de microlithotypes, simple et complexe, ont été identifiées. On a déterminé 60 types simples et 9 complexes.

D'après les données mégascopiques et microscopiques, l'auteur conclut qu'une grande partie du gisement Harbour tire son origine de tourbières recouvertes d'arbres et de roseaux. Les déviations à cette règle se trouvent représentées par les zones ternes dont un groupe semble avoir pris naissance lors d'inondation ou d'affaissement extrême. L'auteur est d'avis que le deuxième groupe est le résultat de courtes périodes de sécheresse et que le troisième semble représenter une phase de transition entre la tourbière recouverte de roseaux et la submersion totale.

Chapter 1

INTRODUCTION

This report describes the analysis of facies patterns in the Harbour coal seam, Sydney coalfield, Nova Scotia. The report consists of two parts.

The first part deals with a facies analysis of the whole seam based on *megascopic* data, including descriptions made of the coal face in the mine and descriptions prepared in the laboratory using polished specimens. The area covered by these descriptions extends virtually from one end of the coalfield to the other.

The second part is concerned with the detailed *microscopic* analysis of certain dull layers in the Harbour seam and is restricted to samples collected within one mine. The data from this phase of the investigation have been studied to try to discover whether natural populations or associations of entities exist in these dull layers, and an attempt has been made to classify them in a manner that may relate to environmental patterns and genetic affiliation.

The author gratefully acknowledges the assistance and advice of P. A. Hacquebard, Geological Survey of Canada, who initially suggested a problem on the Harbour seam, and maintained interest and contact during the course of study; and the encouragement and advice of W. Spackman, Department of Geology, The Pennsylvania State University. The Coal Research Section of The Pennsylvania State University made research facilities available and assisted in the preparation of thin sections. The Dominion Steel and Coal Corporation provided assistance in the procurement of coal samples and allowed use of its mine plans. The writer is indebted to M. S. Barss, Geological Survey of Canada, for assistance with photography, and to Karl Marsh who capably assisted the writer in the field in 1957 and 1958, and also helped in the preparation of some of the samples.

General Geology of the Sydney Coalfield

The Sydney coalfield contains the largest reserves of coal in eastern Canada. Figure 1 shows its position in the extreme eastern part of Nova Scotia, some of the geological structures, and the surface pattern made by both the coal-bearing Morien Group and the important seams contained within it.

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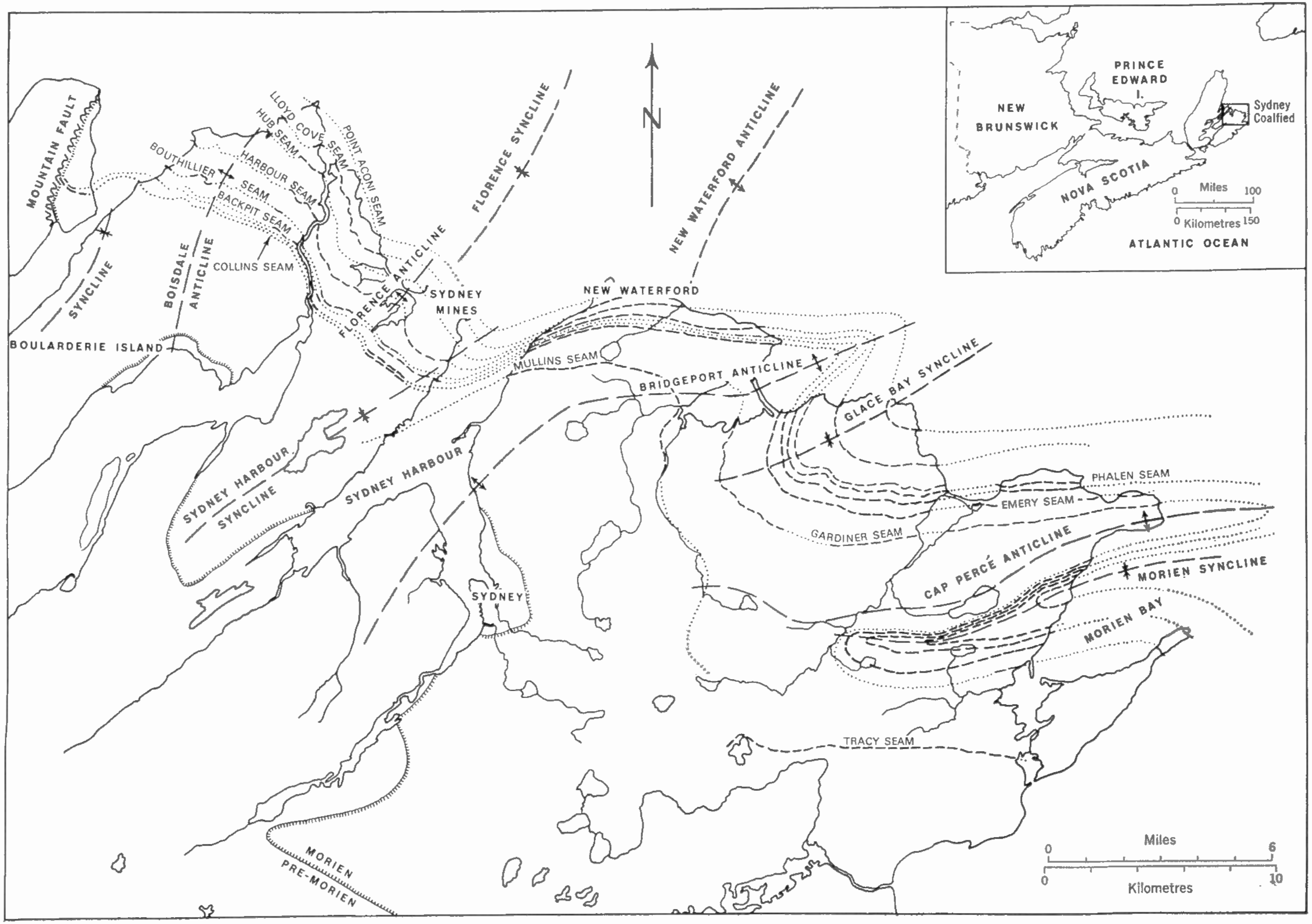


FIGURE 1. Sydney coalfield.

The Sydney coalfield consists of two components: a band of coal-bearing strata 30 miles long and as much as 10 miles wide along the coast, and a part of unknown dimensions under the sea. The coals in the Sydney field are Pennsylvanian in age and occur in about 6,400 feet of strata, known locally as the Morien Group. This body of rocks is partly equivalent to the better known and more widely distributed Pictou Group. The Morien Group is of continental origin and consists mainly of red and grey sandstones and shales and grey grits (Fig. 2). A comprehensive study by Bell (1938) of the fossil floral assemblages enabled him to subdivide the Morien Group by zones as shown on Figure 2. The Harbour seam occurs in the uppermost of these subdivisions, namely the *Ptychocarpus unitus* zone.

Structurally the Sydney field is relatively uncomplicated. A number of folds, whose axes strike at about right angles to the present coastline, are superimposed on a gentle seaward dip of the coal-bearing rocks. Locally the dips on the flanks of these folds may be as much as 50 degrees, although the prevailing dips are considerably lower, ranging between 4 and 10 degrees (Bell, 1938). As the folds diverge seaward, other folds appear between them that have no expression on the landward side of the basin. Thus an anticline in the New Waterford district and a syncline between the Princess and Florence Collieries are known only from the submarine areas. Haites (1951) suggested that folding may have been initiated contemporaneously with deposition, although in his opinion the major phase of folding took place after deposition was completed.

There is evidence of transgression in the Morien Group. Bell (1938) felt that deposition commenced in the southeast and spread northwest during the development of the Sydney coal basin. This northwest encroachment may eventually have covered much of the area of the present upland surrounding the coal basin, an area from which the Pennsylvanian rocks were later stripped by erosion. This northwest encroachment was apparently duplicated on a smaller scale within the Harbour seam.

The stratigraphic position of the Harbour seam is indicated on Figure 2. On the basis of fossil evidence (both spores and megaflora), the Harbour seam is considered to be Westphalian D; using North American terminology, it is approximately equivalent in age to beds of the basal McLeansboro of Illinois (Hacquebard, *et al.*, 1960).

Of the twelve mineable seams in the Sydney field, the Harbour seam is the most important; it yields more than 95 per cent of the production in the Sydney field. Before seam correlation in the field was well established, the Harbour seam was known by such names as Sydney Main, Victoria, and Blockhouse. Today these names persist only in the more or less isolated Morien district where the extension of the Harbour coal is known as the Blockhouse seam.

Within much of the area studied the Harbour seam averages 6 feet in thickness. Thicknesses of 9 to 10 feet, however, are found in synclinal areas, namely No. 26 Colliery in Glace Bay and in the Morien Bay area (Fig. 3). There seems to be thicker coal in the synclinal area along the east side of the Florence Colliery[1], although the picture there is complicated by the appearance of partings. Reduced thicknesses of coal occur on the southeast side of No. 20 Colliery in Glace Bay, and on the west side

[1] The Florence Colliery closed in 1961.

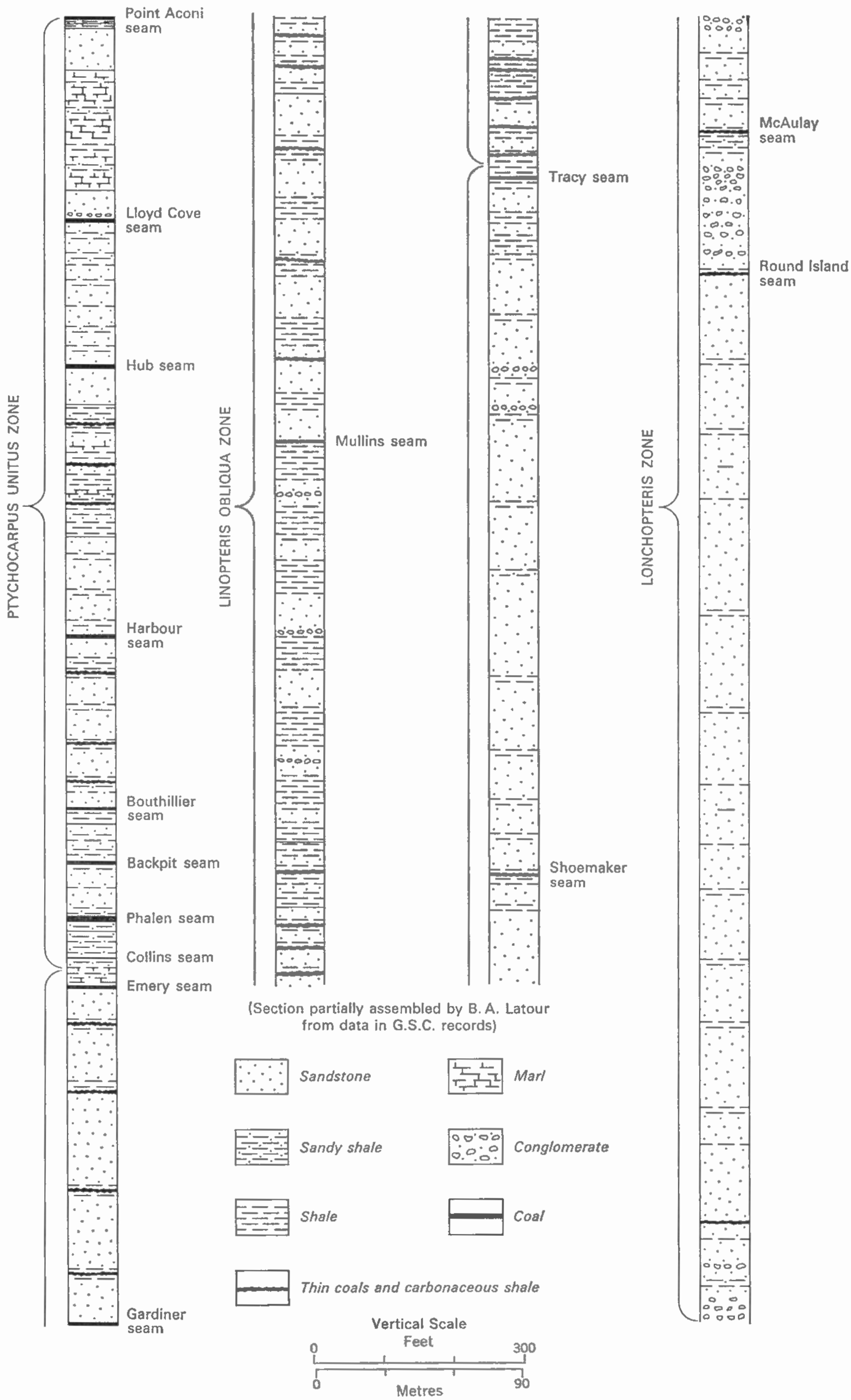


FIGURE 2. Generalized section of Morien Group, Sydney coalfield.

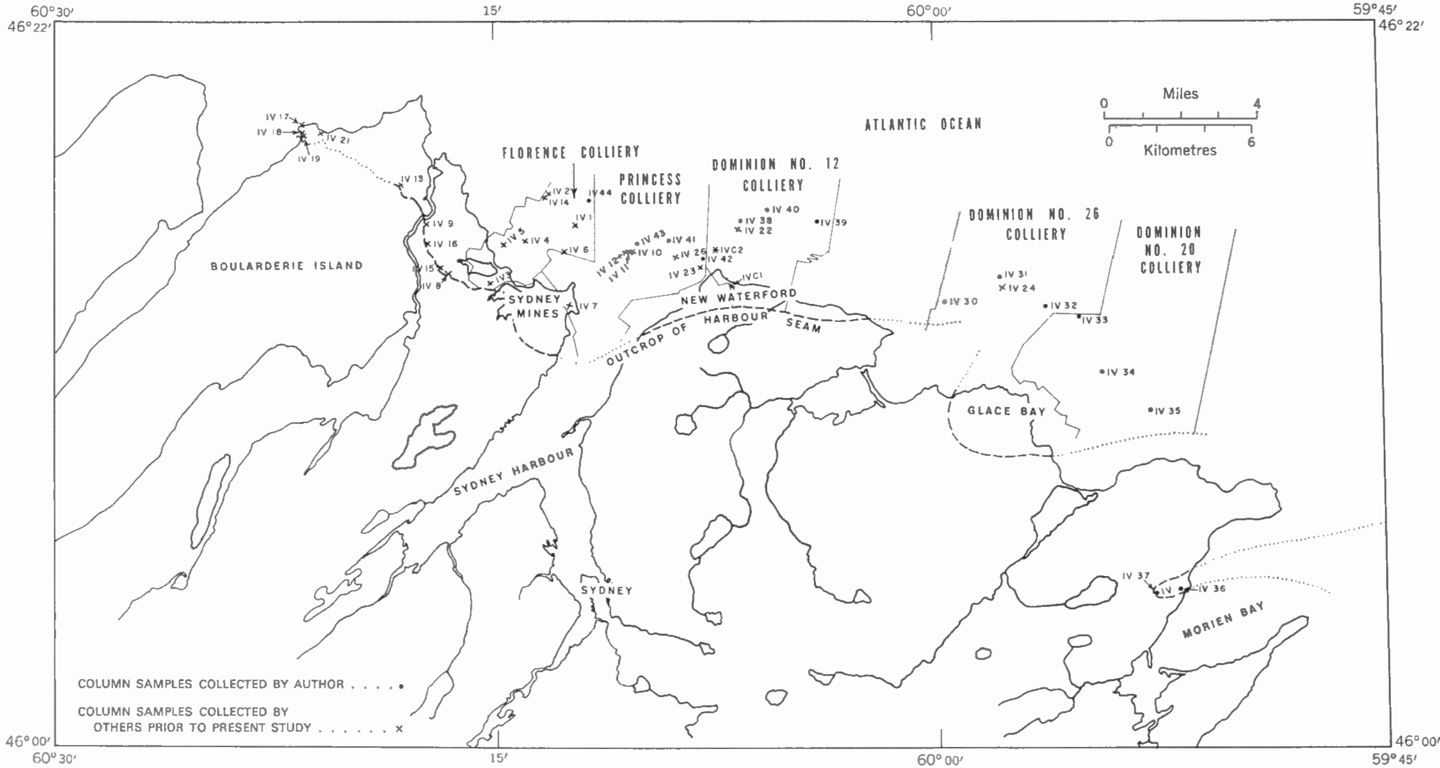


FIGURE 3. Sydney coalfield showing positions of sampling sites and mines on the Harbour seam.

of the Florence Colliery, although in the latter place the reduced thickness is the result of washout phenomena. The seam also thins on the east side of No. 12 Colliery in New Waterford.

The Harbour seam is uncomplicated by major partings, except near the Florence Colliery where at least two partings are found that separate rider seams from the main body of the coal. The extent of the workable coal on the northwest side of the Florence Colliery is controlled by a northeast-trending channel sandstone—the deposit of a stream that cut deeply into the seam and in some places removed it completely. Operations on this side of the Florence Colliery stopped where the thickness of coal was reduced to 2 feet by the sandstone. Toward the northwest, beyond the former stream channel, the seam again thickens somewhat, but is so split by partings that mining has not been extensive. Several partings occur near the base of the seam in the New Waterford, Glace Bay, and Morien districts.

The Harbour seam is high volatile bituminous A in rank (Table I).

TABLE I | *Typical Analysis of Harbour Seam Coal (after Swartzman, 1953)*

Proximate analysis[1], %		Ultimate analysis[1], %	
Moisture	4.0	Carbon	76.3
Ash	5.2	Hydrogen	5.0
Volatile matter	36.1	Nitrogen	1.5
Fixed carbon	54.7	Sulphur	2.0
		Oxygen	6.0
Cal. value (BTU/lb.)[1]	13,545		

[1]As received.

Chapter II

MEGASCOPIC INVESTIGATIONS

Megascopic data on the Harbour seam were provided by the examination of polished column samples in the laboratory, and by the measurement and description of the seam in place. The area studied extended from the Florence Colliery to near Morien Bay (Fig. 3).

Terminology

In accordance with the recommendation of the Glossary of Coal Petrology (International Committee for Coal Petrology, 1957) the author has restricted his use of the terms *vitrain*, *clarain*, *durain*, and *fusain* to megascopic analysis in the present study. He has also followed the suggestion in the Glossary that a minimum band width of 3 mm be set for individual masses of these megascopic entities.

The Glossary definitions of vitrain, clarain, durain, and fusain are given below. They are virtually the same as proposed by Stopes in 1919 except for the numerical thresholds.

Vitrain: "very bright bands or lenses, usually a few mm (3–5) in width: thick bands are rare. Clean to the touch. In many coals the vitrain is permeated with numerous fine cracks at right angles to stratification, and consequently breaks cubically,—with conchoidal surfaces."

Clarain: "bands of variable thickness having a lustre between that of vitrain and durain. Conventionally the thicknesses of the fine bright and dull striations must be less than 3 mm, ..."

Durain: "grey to brownish black . . . rough surface with dull or faintly greasy lustre: reflection is diffuse: . . . markedly less fissured than bands of vitrain and generally shows granular fracture."

Fusain: "black or grey . . . silky lustre . . . fibrous structure . . . extreme friability. It is the only constituent of coal which marks and blackens objects with which it comes in contact."

Two additional varieties of material were identified in the megascopic phase of this investigation. One is coal of intermediate lustre between clarain and durain that has been designated claro-durain, a term adapted from Cady (1942). The other is shaly or impure coal, to which the term bone was applied. The 3-mm threshold was applied to both claro-durain and bone.

Separation of varieties of clarain on the basis of texture was attempted because of the wide compositional range encompassed by this term. Also, clarain is volumetrically the major constituent of most coal seams. The parameter measured for this separation was the thickness of the vitrinitic bands contained in clarain. Where more than 50 per cent of these vitrinitic bands was less than 1 mm thick, the unit was described as finely banded; where more than 50 per cent was between 1 and 2 mm thick, the unit was classified as medium banded; and where most of the bands were between 2 and 3 mm thick, the unit was described as coarsely banded.

Megascopic descriptions of the seam in the mine were not as precise as those obtained in the laboratory. The term vitrain was not used in the mine, nor was any attempt made to distinguish varieties of clarain based on thicknesses of the vitrinitic layers. The other terms, however, were applied as used in the laboratory.

The terms *lithotype* and *microlithotype* are used often in this report. The former is used in the megascopic investigations; the latter is defined and used in Chapter III on the microscopic studies.

The term lithotype was proposed for use in coal petrology by Seyler in 1954 to designate the megascopically recognizable varieties of humic coals (International Committee for Coal Petrology, 1957). This term refers to the four "visible ingredients" described by Stopes in 1919. The term is synonymous with "rock type" or the German term *Streifenarten*. The author has applied the lithotype concept in a somewhat more flexible sense than that implied by the glossary definition. For example, such terms as claro-durain and bone are used in this report as lithotypes of equal rank with vitrain, clarain, durain, and fusain.

Sampling and Sample Preparation

Initially, fifteen column samples (numbered IV 30 to IV 44) were collected along the strike of the seam for approximately 21 miles. These samples were spaced as regularly as possible (Fig. 3), and with two exceptions, were taken from areas in the seam being mined at the time of sampling so that the original material was essentially unoxidized. The two exceptions—samples IV 36 and IV 37—were obtained in the Morien area from small pits located at or near the outcrop. Each of the fifteen samples was collected as a series of oriented, overlapping blocks that collectively covered the entire seam from roof to pavement.

In addition to the initial sampling, a restricted part of the Harbour seam in the Princess and Florence Collieries was studied during the summer of 1958, and measurements and megascopic descriptions of the seam were made at a number of places. The map on Figure 4 (*in pocket*) shows the sites of these described sections as well as the places where the prominent dull bands were sampled for microscopic analysis. The megascopic data so obtained are plotted on the various cross-sections of Figures 4, 6 (*in pocket*), and 8.

In the laboratory, parts were cut from the column samples, mounted in plaster of paris, and polished. The remaining coal in these columns was retained as general reference material and for possible microscopic and chemical work. The columns embedded for megascopic examination were polished according to a standardized technique employed in the coal research laboratory of the Geological Survey of Canada. The steps in this procedure are:

1. Rough grind on carborundum lap to remove large surface irregularities
2. Fine grind for several minutes on glass plate with 320 grit silicon carbide powder
3. Fine grind on glass plate with 600 grit silicon carbide powder to remove last of visible scratches
4. Rough polish on lap covered with billiard cloth using jeweller's rouge
5. Further polishing on lap covered with velvet using an aqueous solution of Silvo powder (B.L.E. polishing earth)
6. Final polishing with hydrated alumina on Selvyt cloth

After each step the specimen must be thoroughly washed to remove all polishing and grinding compounds, thus avoiding contamination during the following steps when different compounds are used. After they have been dried the specimens are ready for study.

Analytical Procedures

Petrographic

A simple technique was used to describe megascopically the embedded polished columns. With a hand lens and a strong light directed on the surface of the coal, the bands in each column were measured and identified, using the megascopic terms and the 3-mm threshold mentioned previously. The data were then plotted in log form with a 1:1 scale (Fig. 5). These strips of paper, when completed, represent true scale reproductions of the petrographic character of the seam. Various types of supplementary information were also recorded, such as the presence and abundance of pyrite and other forms of mineral matter, and the presence and position of unusual structures and bodies.

To supplement the detailed descriptions made in the laboratory, additional megascopic data were provided by in situ descriptions of the seam at a number of places. The seam in the mine displayed a variety of states of oxidation and weathering that commonly obscured the banding on the coal surfaces. Where the seam was to be measured, the face was first cleaned to produce a uniform flat surface from roof to pavement and to remove the more intensely oxidized coal. The banded character of the coal was then measured and described.

Ashing

Representative portions of dull coal samples collected in the Princess and Florence Collieries, as well as dull material selected from the column samples, were ashed to study the variation in ash content within the dull bands and between them. The procedure differed from that recommended by the American Society for Testing

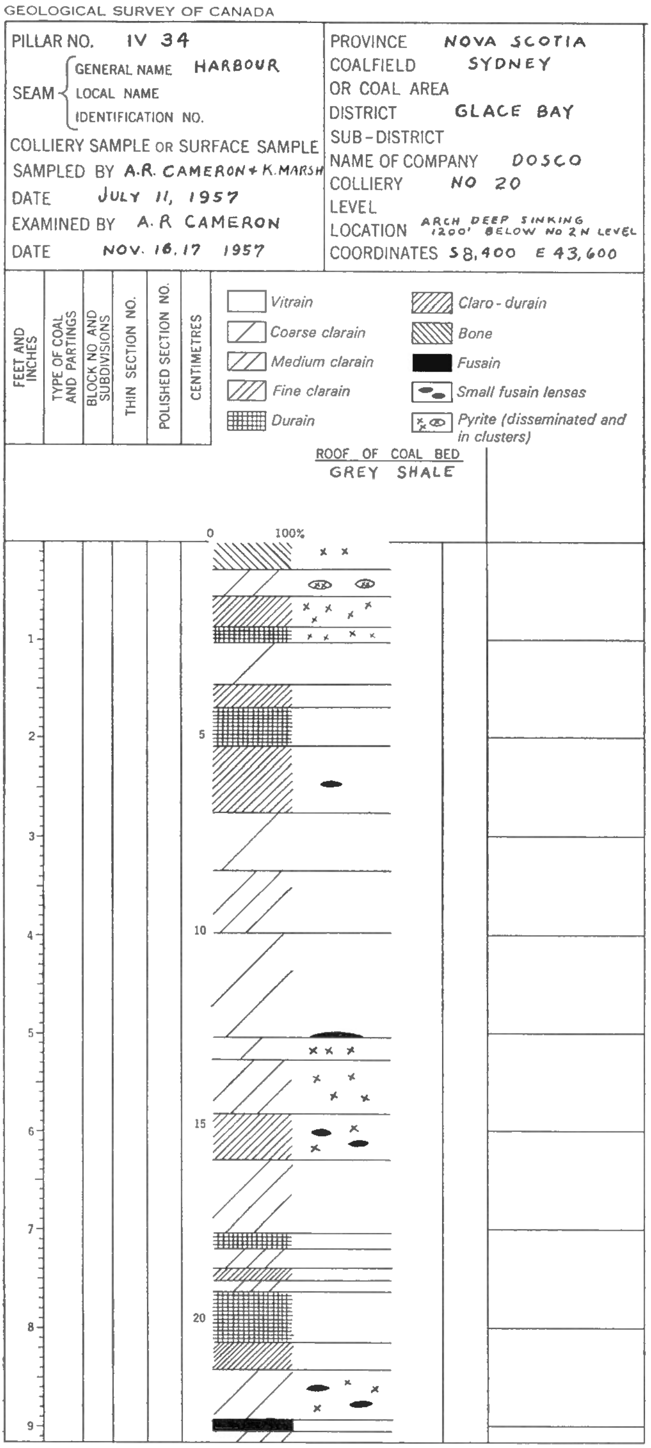


FIGURE 5

Part of petrographic log showing method of recording data from polished column samples.

Materials (1959), especially with reference to the quantity of coal used in the tests. Because it was hoped that the resulting ash would be examined by X-ray spectroscopy to determine elemental composition, sufficient coal (3- to 4-gram duplicate portions from each sample) was ignited to ensure an adequate amount of ash.

Representative material from the dull coal layers in each sample was crushed to pass through a 60-mesh sieve. Then duplicate portions were taken from this crushed sample, placed in porcelain crucibles, and heated in an electric muffle furnace to a temperature of 750°C for 12 hours. Normally, constant weight is obtained in less than 12 hours, but longer time was needed for the larger sample. At the end of the heating period the crucibles containing the ash were withdrawn from the oven, cooled in a desiccator, and weighed as soon as possible. The ash from each pair of duplicate samples was then placed in vials and stored for possible future analysis.

Results

The results of the megascopic investigations are divided into two parts. The first deals with the Princess and Florence Collieries (northwestern sector); the second includes Glace Bay, Morien Bay, and most of New Waterford (southeastern sector) (*see* Fig. 3). There are less data for the southeastern part than for the northwestern, and variation in the Harbour seam is consequently not as well documented as it is toward the northwest.

Northwestern Part of the Sydney Coalfield

Figure 4 shows the sites in the Princess and Florence Collieries at which seam descriptions and measurements were made of the coal in place, and also the locations at which column samples were collected by the author. The sites where column samples were collected by other investigators are also indicated, because some data derived from these older samples have been used to supplement information assembled by the author.

Three stratigraphic cross-sections were prepared from these seam descriptions (Fig. 4). Their locations are shown on the index map of Figure 4 (sections A–A^1, B–B^1, and C–C^1). For simplicity, some of the measured sections have been omitted from Figure 4; they are included on Figure 6, however.

The layers of dull coal (i.e., the layers of durain, claro-durain, and bone) have been labelled A, B, C, etc., on Figure 4, beginning with the lowest of such bands in the seam. Many of these bands are relatively simple, but some are complex, such as zone J, which is an intricate mixture of bright and dull lenses with an over all dull aspect. Several dull and semi-dull layers in this mixture are more conspicuously dull than the rest and show some evidence of lateral continuity. One of these, sampled at many sites, is indicated on the cross-sections of Figure 4 as band J_1.

The datum selected for these stratigraphic sections is the layer designated as band I (shown on Pl. I). This is the prominent upper "bone" layer mentioned frequently by Hacquebard (1949) and Haites (1950). It is an outstanding megascopic feature in the seam and probably one of the more persistent.

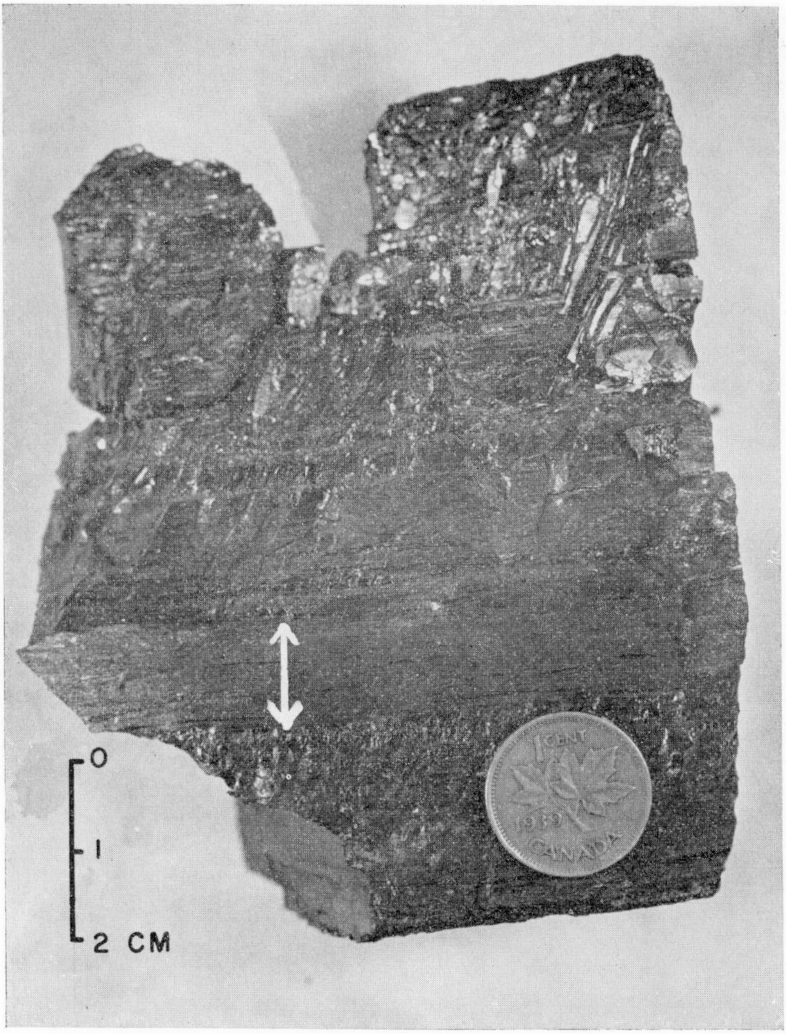


PLATE I

Prominent dull layer (band I) in Harbour seam.

Figures 4 and 6 reveal the following features: (1) the Harbour seam in general is relatively bright, that is, it is composed of fairly thick clarain layers separated by relatively thin dull bands; (2) the upper part of the seam is duller than the lower part, particularly in the Princess Colliery, chiefly because of the presence of zone J; (3) some layers maintain a certain megascopic identity over a relatively wide area, whereas others are irregular and have no constant distinguishing characteristics; (4) the upper part of the seam in the Florence Colliery is complicated by several shale partings that are not present in the Princess Colliery, or else thicken markedly and become part of the roof strata; (5) there is a tendency for the thickness of coal below band I to decrease in a northwestern direction (i.e., from the Princess Colliery to the Florence Colliery) with a corresponding increase in the thickness of coal overlying band I.

The most prominent dull bands or zones of the Harbour seam are those labelled C, I, J, and K (Fig. 4). Of these, bands C, I, and K are considered key layers because they can be easily traced in the mine, and because they are separated sufficiently from each other to permit a useful subdivision of the seam. Each dull band is discussed briefly in the following paragraphs.

Below band C are two dull bands of intermittent character. The lowest of these has been designated band A. This relatively thin layer seems to have its best development in the Princess Colliery. At most sites within the coalfield it was described in the writer's field notes as durain.

The B layer is generally located 4 or 5 cm above band A. It is more variable than A in its thickness and also in its megascopic appearance, for at a number of sites (e.g., IVA 8, IVB 8 on Fig. 4) it is a composite of claro-durain and durain. Like band A, its development in the Florence Colliery appears to have been inhibited.

Band C is one of the prominent dull layers in the seam and is widespread in both the Princess and Florence Collieries. This is the lower "bone" band described by Haites (1950). The thickness of coal fluctuates between this layer and the floor, but decreases in a northwestern direction, varying from 42 cm at site IVA 11 in the Princess Colliery, to 8 cm at site IV 4 in the Florence Colliery (Fig. 4). One of the characteristics of band C is its high ash content. Haites (1950) mentioned that locally it passes into shale. Band C was identified by the author as durain at nearly every site where it was described. At some sites (e.g., IVA 8, IVA 15, and IVA 21 on Fig. 4) the durain is associated with variable thicknesses of claro-durain. The thickness of band C ranges from 1 to 4 cm. In the vicinity of IVA 15, IVA 16, IVA 17, and IVA 18 (*see* Fig. 4, section C–C[1]) the coal underlying this band is characterized by substantial amounts of pyrite.

Band D is a rather persistent, thin band, present in many places in the Princess and Florence Collieries. The thickness of coal between this layer and band C is fairly constant, averaging about 8 cm. Most often band D was described by the writer as durain.

The E and F layers occur above band D and are separated from it by a variable thickness (16 to 20 cm) of bright coal. These two bands are not always present and correlation is uncertain. The data suggest the existence at this stratigraphic level of a number of unconnected dull lenses, commonly 1 cm or less in thickness. They are chiefly durain.

The next dull layer is band G, which constitutes the lowest unit of a trio of dull bands associated with and including the important band I. The G layer is often associated with fusain and seems to be the least prominent of the three, although it is fairly widespread in the Princess and Florence Collieries. An average of 15 cm of coal occurs between band G and band F.

The H and I layers are important and persistent units. The characteristics of band I have already been described. Band H, which is separated from band I by 3–5 cm of bright coal, appears to accompany it at nearly every site. At most localities both layers are durain, although at many sites the durain is accompanied by transitional semi-dull material. Band I, usually the thicker of the two, is 1 to 2 cm thick.

The complex J zone, separated from band I by 8 to 12 cm of bright coal, is mainly claro-durain. It is relatively thick, encompassing 20 to 25 cm of coal in the upper part of the seam. The complex intercalation of thin, bright and dull laminae, when observed by microscope, prompted Hacquebard (pers. com.) to refer to this unit as the zone of rapid alternation. Figure 7 is a plot of the megascopic aspect of this part of the Harbour seam based on data from the Princess Colliery. It shows the extreme degree of intertonguing of the various components, and also that this J zone is dullest on the eastern side of the Princess Colliery. In the Florence Colliery some of its dull character reappears. The basal part of the zone, which is more continuous and contains more durain than the rest of the zone, has been designated subzone J_1 (Fig. 7, *in pocket;* also cross-sections on Fig. 4).

The prominent K band is the highest dull layer in the Harbour seam in the Princess Colliery and rivals band I in its dull character. It is more erratic than band I in its distribution, however. At a number of localities two or more durain bands are present at this general stratigraphic horizon. In the Princess Colliery band K occurs close to the roof, but at some places it is absent or its position is occupied by shale or sandstone. At localities IVA 25 and IVA 31 (Fig. 4, section C–C^1) it is absent and the Harbour seam is immediately overlain by sandstone. At IVA 29 (Fig. 4) a sandstone tongue is intercalated at the position of band K. At IVA 4 (Fig. 4, section A–A^1) the position of band K in the seam is occupied by 1½ cm of shale that thickens to 16½ cm at site IVA 5 only 250 feet down the coal face from IVA 4. Near site IVA 33 in the Princess Colliery the thickness of coal between bands K and I seems to be reduced rather drastically as compared with that found at most other localities. In the Florence Colliery band K is prominent and separated from the roof by varying thicknesses of bright coal. These thicknesses are generally greater than those found between band K and the roof in the Princess Colliery.

Several rider seams are present above the main Harbour seam in the Florence Colliery. Although some of these appear to be of local extent only and probably represent splits off the main seam, at least one and possibly two can be traced to the Glace Bay area (Fig. 3, *in* Hacquebard, *et al.*, 1964). Haites (1950) discussed in some detail the relationship of these rider seams to each other and to the main Harbour seam.

A few comments should be made about fusain distribution in the Harbour seam. Most of the megascopically visible masses of this component are concentrated between bands C and G. The distribution of fusain between these two bands is not uniform. In some places individual bands or groups of bands of fusain appear to be traceable at least for short distances. Fusain occurs not only in thick layers, but also as small lenses that are locally concentrated in great numbers in certain clarain zones. Some prominent fusain bands occur below the C layer. Evidence indicates that no single fusain layer in the investigated part of the Harbour seam has much lateral continuity, however, although some zones enriched with both large and small fusain masses have greater lateral extent. Some rather striking masses of fusain are present; one such mass, occurring at site IVA 15 (Fig. 4) was about 32 cm long and as much as 4 cm thick. This lens and others similar to it are invariably heavily impregnated with pyrite.

Southeastern Part of the Sydney Coalfield

Stratigraphic section D–D[1], shown on Figure 8 (*in pocket*), illustrates the character of the Harbour seam in the area from New Waterford to Morien Bay. The data for this section have been derived from eleven column samples and two in situ seam descriptions. Ten of the eleven column samples were collected by the author; the other, IV 24, was collected by P. Hacquebard in 1950. His data, which were derived microscopically, have been summarized for inclusion in Figure 8. The two in situ seam descriptions are IVA 36 and IVC 2. The latter is from Dominion No. 12 Colliery in New Waterford; the former is located in the Princess Colliery and was also used in the preparation of stratigraphic section A–A[1] on Figure 4.

The column samples collected by the author are listed as IV 30 to IV 40 inclusive. Their positions, relative to the important mines, are indicated on Figure 3. Column IV 36, from the Morien area, is an anomalous sample in terms of its thickness and the nature of the roof material; 50 inches of coal is exposed at the site of sampling, and the upper part of the seam merges with glacial drift. It was not polished or described megascopically.

A gap between Dominion No. 12 and Dominion No. 26 Collieries is indicated on Figure 8 (between columns IV 39 and IV 30). This block of coal is approximately 3½ miles wide. Mining operations on this reserve have but recently commenced, and no compositional data on the Harbour seam are available from this area.

Figure 8 shows some rather interesting changes within a distance of approximately 17 miles, covered by the arcuate shape of the stratigraphic section. Starting at section IVA 36 in the eastern extremity of the Princess Colliery where most of the dull layers have been reasonably well identified, the eastward extension of these layers, particularly the marker bands, can be followed without great difficulty into Dominion No. 12 Colliery (sections IVC 2, IV 38, IV 40, IV 39).

The lowest of these key beds, band C, is identified in No. 12 Colliery by its stratigraphic position, characteristically dense megascopic appearance, and high ash content. In columns IV 38 and IV 39, two high-ash layers are present at the general level where band C might be expected to occur. One is probably the eastward continuation of the C band; the other is either a split of band C or a separate high-ash lens of more or less local extent.

The basal part of the seam in No. 12 Colliery—the coal below the C band—is complicated by the appearance of several shale partings. The westward extension of these beds appears to be below the main part of the seam in the Princess and Florence Collieries. Haites (1950) described a bone layer in No. 12 Colliery in the basal part of the seam. He reported that this layer increased in thickness and became shaly when traced toward the Princess Colliery; this trend was accompanied by deterioration in the quality of the underlying coal. This bone layer is probably equivalent to one of the three basal partings shown in column sample IV 40 (Fig. 8), possibly the upper one. This parting also occurs in column sample IV 22, located midway between IVC 2 and IV 38, where it consists of 9 cm of shale separating the main seam from 20 cm of impure coal. This impure bottom coal is probably also present in the vicinity of IVC 2 and IV 38, but was not sampled. As the profile of the seam at IV 40 shows (Fig. 8), the bottom coal was included in the sample at this site where it occurs as a mixture of bright coal and bone with three small shale partings.

In the Glace Bay area the basal section of the Harbour seam undergoes marked changes. The tracing of the eastward extension of band C is important in interpreting the changes that occur between No. 12 Colliery and the mines in Glace Bay. It can be recognized rather easily to the eastern boundary of No. 12 Colliery. In No. 26 Colliery, a bony, high-ash layer underlies the upper half of the seam. A second high-ash band occurs lower in the seam, but appears to have a lower ash content than the upper band. The upper band is considered to be the eastward extension of band C for two reasons: the general nature of the petrographic profiles in the Glace Bay mines compares best with those in No. 12 Colliery if this upper band is assumed to be the C band; and Haites' (1950) statements regarding the existence of band C in the Glace Bay area agree with the correlation as established above. Within the Glace Bay area the C band can be traced reasonably well from section to section. At one point (IV 33, Fig. 8) it is apparently a parting, for it contains 70 per cent ash. In some of the nearby sections, for example IV 24, it has been described by Hacquebard (pers. com.) as a shale parting or bone. East of IV 33 the ash content decreases, but remains high enough to be an identifying characteristic.

The lower high-ash band mentioned above may be equivalent to the basal bone-shale parting in No. 12 Colliery. The data on these two bands are rather meagre, however, and such a correlation is at best speculative. If band C has been correctly traced into the Glace Bay area, a marked thickening of the coal below this layer is indicated in this direction. Some of this coal is probably equivalent to the impure coal found beneath the basal parting in No. 12 Colliery. Much of this additional coal is bright.

Figure 8 shows a variety of seamlets and partings below the main seam in the Glace Bay area (from sample IV 30 eastward). The data from which this lowest part of section D–D^1 was plotted were taken from Haites (1950). The writer believes that there is one seamlet near No. 26 Colliery that splits into three seamlets when traced eastward. The top split may join the main seam. The author has correlated the lower split or splits with a seamlet a foot thick (recorded in the sections of Hayes and Bell, 1923) occurring below the main seam in the Morien area. The increased thickness of the basal part of the seam in the Morien column (IV 37, Fig. 8) may result from the joining of another split of the seamlets (IV 32–34, Fig. 8) beneath the main seam in the Glace Bay area to the main seam, though this is not well documented.

The A and B layers are rapidly lost in No. 12 Colliery, and to the east are not recognizable. Band D occurs above band C in about the same position as it is found in the Princess and Florence Collieries. It is not reported in IV 38, but a dull layer reappears at this general position in the seam in the Glace Bay area, and as the correlation on Figure 8 indicates, it can be traced toward IV 37 in the Morien area. In the Glace Bay area, particularly in No. 20 Colliery (samples IV 33 – IV 35), this dull layer is found in association with a number of other dull bands.

In No. 12 Colliery the E and F layers are characterized by the same lack of continuity as was evident in the Princess Colliery. In No. 26 Colliery (Glace Bay) column

IV 30 (Fig. 8) shows that dull layers occur at the predicted stratigraphic level; these may be the lateral extensions of bands E and F. East of IV 30 they disappear.

Bands G, H, and I can be traced into the southeastern part of the Sydney coalfield from the Princess Colliery; band I seems to retain some of its characteristics, as apparently do bands G and H. Haites (1950) indicated that band I forms the "roof splint" in No. 20 Colliery and in part of No. 26 Colliery. The author's data support this view.

Band H is a fairly constant companion of band I in the southeastern part of the field, although the distance between them fluctuates appreciably. Band G appears to be present in No. 12 Colliery, and occurs sporadically in No. 20 and No. 26 Collieries. In these latter mines, however, a number of other dull layers are found at the stratigraphic levels of G and H, and correlation is therefore difficult.

The thickening of the upper part of the seam, as well as a thickening of the seam as a whole, on the north side of No. 26 Colliery (column IV 30 westward) was attributed by Haites (1950) to the possible development of a syncline just northwest of the limits of No. 26 Colliery. The evidence for the existence of such a structure is rather sparse, although one might expect to find a syncline between the well-developed New Waterford and Bridgeport anticlines (*see* Fig. 1). Haites suggested the name Lingan syncline for this structure. Some data, from old workings on another seam located within the reserved area of the Harbour seam, indicate that such a downfold might exist in the neighbourhood.

Haites (1951) felt that the Sydney field provided the following evidence for synchronous sedimentation and folding.

1. The Harbour seam thickens in the Morien syncline and to some extent also in the Florence syncline (along which a number of the profiles incorporated in section B–B^1, Fig. 4, are located).
2. The Harbour seam also seems to thin near some of the anticlines, as for example, in section IV 32 (Fig. 8) near the Bridgeport anticline (Fig. 1) and section IV 39 (Fig. 8) located near the New Waterford anticline (Fig. 1). Some seams, such as the Bouthillier, Gardiner, and Toronto (Phalen), were mined only in synclinal areas where apparently the coal reaches workable thicknesses.
3. A number of small synclines or "lags" show thickening of the seam toward the axis without evidence of faulting.
4. Reconstructions of fossil river channels, on not only the Harbour seam, but also the Mullins, Gardiner, and Phalen seams, show these channels bending landward in the synclinal areas and outward in the vicinity of anticlines.

The complex J zone may be traced easily from the eastern workings of the Princess Colliery into No. 12 Colliery in New Waterford. It is dull in general appearance—a continuation of the tendency to dullness observed in the extreme eastern part of the Princess Colliery (*see* Fig. 7). It is also traceable into No. 26 Colliery in Glace Bay in sections IV 24, IV 30, and IV 31 (Fig. 8); east of IV 31 it disappears.

The K band can be easily traced through No. 12 Colliery (IVC 2, IV 38, IV 40, and IV 39, Fig. 8); it appears to be split in IVC 2 through IV 40. Its eastward extension into the Glace Bay area (Nos. 20 and 26 Collieries) is uncertain.

At some localities, where the first few tens of feet of roof strata can be observed in the area depicted in section D–D[1], two rider seams are found above the main seam. These may be the extensions of rider seams found in the Florence Colliery. Haites (1950) also described overlying seamlets in the Glace Bay area and in the Princess Colliery, but was in doubt as to their whereabouts in New Waterford, and was unwilling to state that the seamlets in the Glace Bay area might be equivalent to those encountered above the seam in the Florence Colliery. Section IV 40 (Fig. 8) shows that two rider seams exist in the New Waterford area; this strengthens the possibility that the two rider seams in the Florence Colliery extend eastward continuously to Glace Bay.

Discussion of Megascopic Petrography

To facilitate discussion, the Harbour seam is arbitrarily divided into six units or divisions bounded by more or less continuous, easily identifiable bands and/or differentiated by marked lithological characteristics (*see* Fig. 8; division boundaries indicated beside column IV 30). These divisions are described as follows.

Division 1 is composed of the complex of partings and seamlets traceable from the western margin of No. 26 Colliery, in the town of Glace Bay, to the vicinity of Morien Bay. This unit has probably contributed mineable coal to the main seam only in the Morien area, as indicated by sample IV 37 (Fig. 8), by the incorporation into the main seam of at least one of the seamlets described as occurring below the main seam near No. 20 Colliery. The petrographic nature of these seamlets is poorly known, but the descriptions indicate that they contain some bone or impure coal. The stratigraphic equivalent of division 1 is probably well below the main seam from No. 12 Colliery westward.

Division 2 immediately overlies division 1, and the boundary in the Glace Bay area is the top of the highest basal parting. The upper boundary of division 2 is placed at what the author regards as the eastward equivalent of the basal parting in No. 12 Colliery. Division 2 thins drastically in No. 12 Colliery, and is represented by the impure "bench" coal that wedges out near the barrier between the Princess and No. 12 Collieries.

Division 3 overlies division 2 in the Morien, Glace Bay, and New Waterford areas. It overlaps division 2 and constitutes the lowest unit in the seam in the Princess and Florence Collieries. It is one of the two divisions that extend completely across that part of the Harbour seam investigated in this study. Division 3 thins in the Princess and Florence Collieries. It is bright, but not as bright as division 2. In addition to the C band, it contains other durain and claro-durain layers of more limited extent.

Division 4 extends from the top of band C to the top of band I. It is the lowest division in the Harbour seam that does not show evidence of thinning toward the northwest. In addition to dull band I, it contains the persistent layers D and H and the more irregular bands E, F, and G.

Division 5 is bounded basally by the top of band I and extends to the roof. It differs from the above-mentioned units in that its best development appears to be in the northwestern part of the field. It maintains a fairly uniform thickness from the Florence Colliery to the vicinity of sampling site IV 31 in the No. 26 Colliery. East of this site it undergoes striking changes in thickness, and is reduced to only a few inches in the eastern part of No. 26 Colliery and in much of No. 20 Colliery. Included in this division is the prominent K band and zone J. Division 5 contains the highest proportion of dull coal in the seam.

Division 6 includes the rider seams and partings overlying the main seam. These are best exposed and perhaps best developed in the Florence Colliery, but they have also been described in the collieries to the southeast as shown by the sections IVA 32 (Princess Colliery, *see* Figs. 4 and 6), IV 40 (No. 12 Colliery, *see* Figs. 4 and 8), and IV 24 (No. 26 Colliery, *see* Figs. 4 and 8). The relationship of these partings and seamlets has been discussed to some extent in the previous section.

This sixfold division of the Harbour seam provides a framework for examining, more or less independently, various levels of the seam for lateral variation. Figures 9 (*in pocket*) and 10 show such lateral variations for the megascopically identifiable constituents within each division. Changes in the proportions of the "bright" constituents, namely vitrain, and coarse, medium, and fine clarain, are plotted on Figure 9. The variations in the "dull" components, that is claro-durain and durain, are similarly portrayed on Figure 10. The data from which these plots have been made are presented in Table II.

From Figure 9 it is apparent, that of the bright lithotypes, vitrain is generally present in the smallest quantity volumetrically, coarse clarain is next most abundant, and then medium clarain. The total quantity of vitrain, coarse clarain, and medium clarain is usually smaller than the quantity of fine clarain. The volume of claro-durain in the dull components generally exceeds durain (Fig. 10).

Figure 10 shows the variation within each division of the dull lithotypes durain and claro-durain. There is a gradual increase in the percentages of these components from the bottom of the seam to the top, and within each division there are lateral fluctuations. In division 2 these fluctuations follow no regular pattern. In division 3 the content of these dull components is invariable through No. 12, No. 26, and No. 20 Collieries (samples IV 38 to IV 35), but seems to increase in the Princess and Florence Collieries. This increase is not due to an increase in the thickness and number of these dull layers, but to a decrease in the thickness of the division and corresponding decreases in the proportions of the bright components. In division 4 a peak in the dull layer content exists in the area of samples IV 42 through IV 40. This peak is more strongly developed in the overlying division 5 and covers a wider area.

Figure 11 is a cross-section of the Harbour seam extending from the Florence Colliery (sample IV 44) to Morien Bay (sample IV 37). This figure shows facies patterns based on megascopic data for the fourteen column samples examined in this study. The data are arranged in the petrographic dimensions referred to earlier. This figure is a condensed version of one shown by Hacquebard, Cameron, and Donaldson (1964). Only those divisions that have contributed to the main body of the seam (namely divisions 2, 3, 4, and 5) are shown on Figure 11.

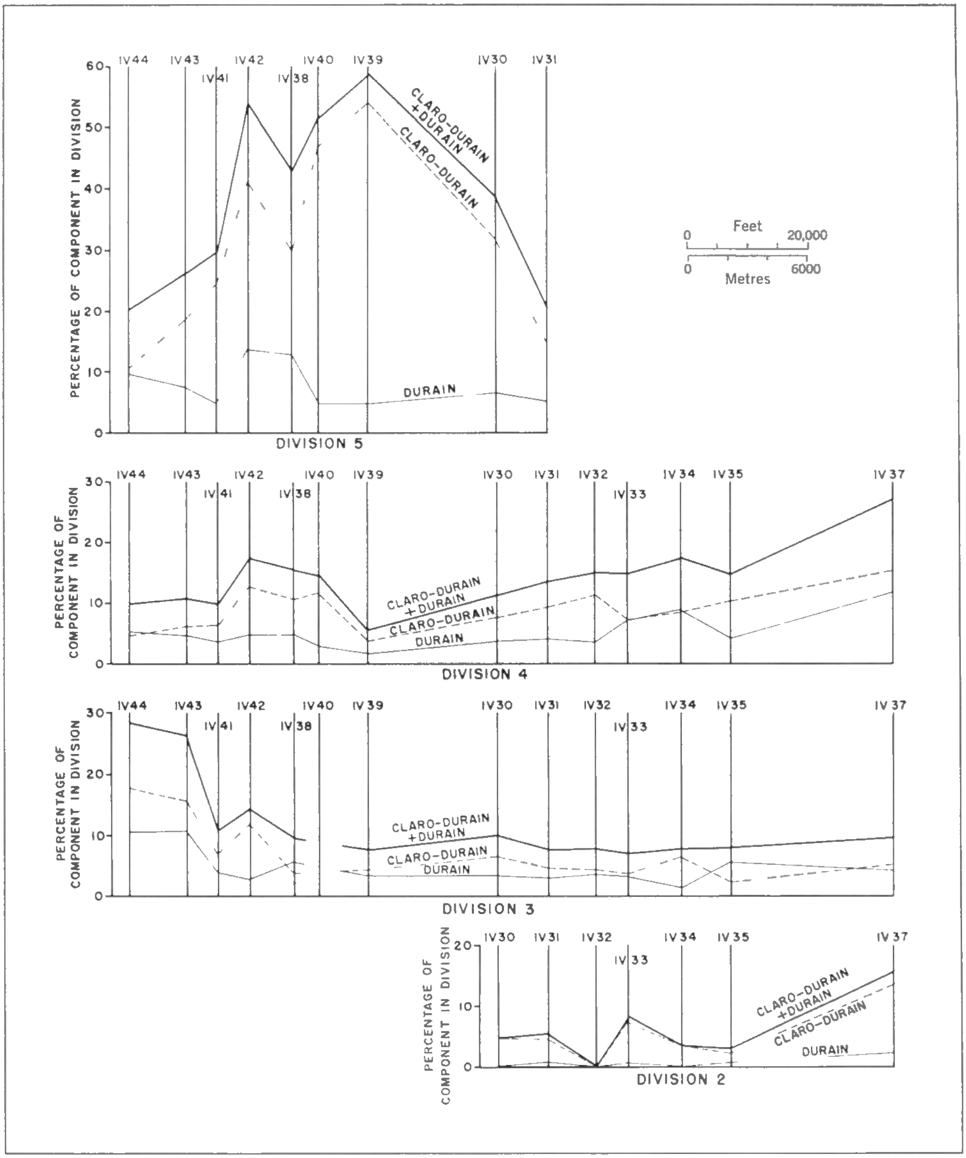


FIGURE 10. Proportions of claro-durain and durain (including bone) in divisions 2 to 5 of the Harbour seam.

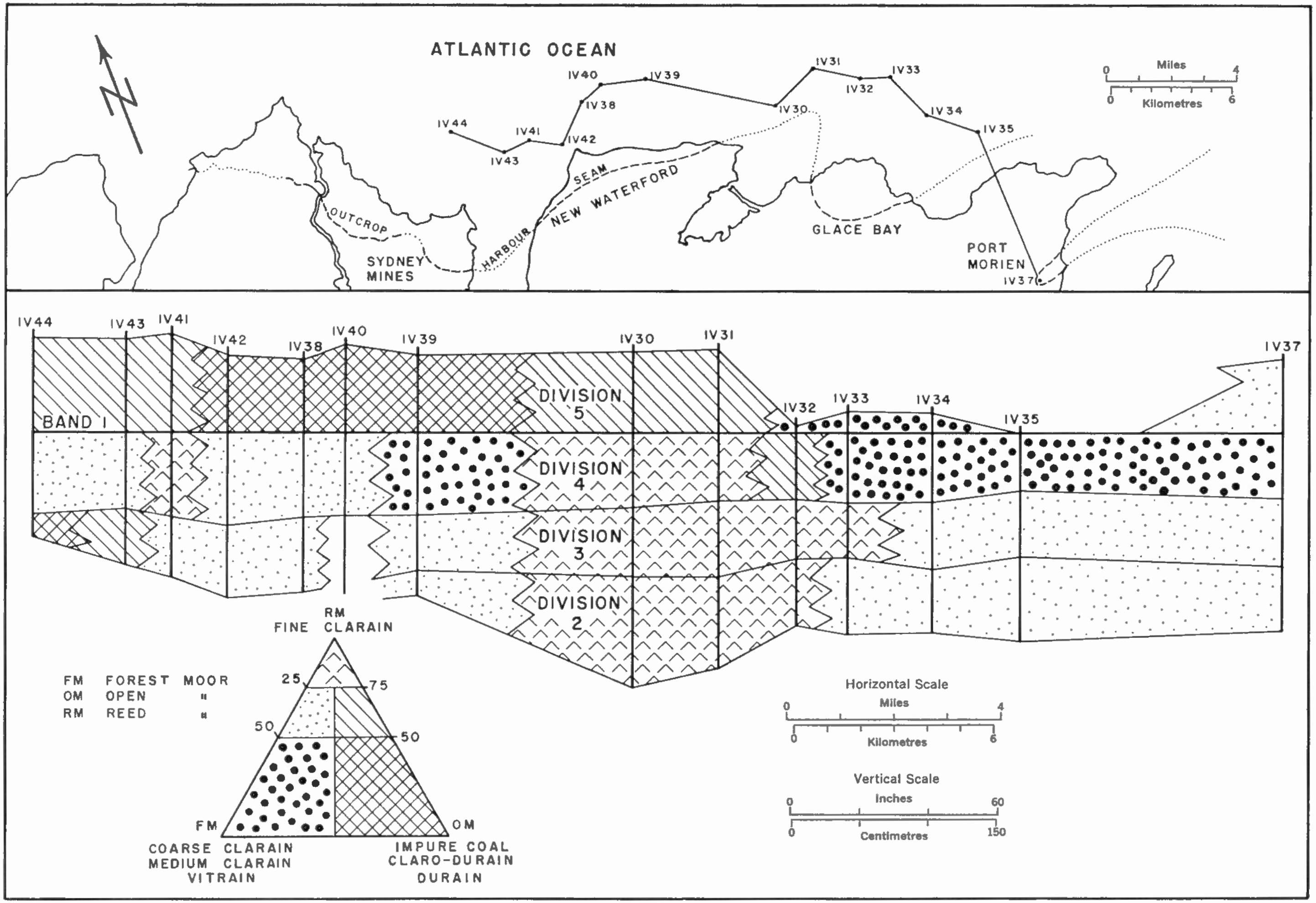


FIGURE 11. Lithotype variation in petrographic divisions of the Harbour seam.

TABLE II *Summary of Megascopic Data by Petrographic Divisions*

Column (IV)	Division	Thickness of div., cm	Composition of divisions in volumetric percentages of components							Bright[1] / Dull
			Vitrain	Coarse clarain	Medium clarain	Fine clarain	Fusain	Durain	Claro-durain	
30	2	82	7.6	2.9	7.6	77.1	—	—	4.8	19.8
	3	51	8.2	—	3.3	77.2	1.2	3.5	6.6	7.8
	4	55	3.1	2.0	6.3	76.5	0.8	3.8	7.5	7.3
	5	60	2.0	7.5	1.8	50.1	1.0	6.3	31.3	1.6
31	2	68	8.2	—	4.6	81.9	—	0.6	4.7	17.8
	3	56	6.0	4.6	3.0	77.9	0.7	3.0	4.8	10.8
	4	50	1.0	3.0	1.1	79.2	2.3	4.1	9.3	5.4
	5	61	3.9	5.2	7.7	65.2	—	4.9	13.1	4.6
32	2	50	2.0	12.6	6.6	77.8	1.0	—	—	99.0
	3	44	1.5	1.1	1.1	87.1	0.9	3.8	4.5	10.0
	4	49	1.4	3.9	9.0	70.5	—	3.9	11.3	5.6
33	2	57	2.5	3.5	23.7	62.2	—	0.7	7.4	11.3
	3	40	3.7	2.2	6.4	80.6	—	3.2	3.9	13.0
	4	52	4.0	15.4	28.6	36.5	0.8	7.3	7.4	5.5
	5	16	2.6	8.9	16.8	42.9	—	2.6	26.2	2.9
34	2	46	4.1	9.3	11.0	70.5	1.5	—	3.6	18.6
	3	50	3.0	5.3	14.3	68.3	1.2	1.4	6.5	10.0
	4	51	4.5	16.2	15.5	45.8	0.6	8.8	8.6	4.6
	5	15	—	21.7	23.0	20.2	—	14.2	20.9	1.8
35	2	63	2.3	0.9	26.5	66.5	0.8	0.8	2.2	40.6
	3	49	3.2	5.2	13.8	69.5	—	5.9	2.4	11.1
	4	42	3.3	8.1	20.5	51.1	1.4	4.3	11.3	4.9

37	2	47	13.5	2.1	10.5	56.7	1.2	2.1	13.9	4.6
	3	51	5.5	11.0	5.5	65.9	2.1	4.7	5.3	7.3
	4	48	10.3	12.8	7.6	40.8	—	11.9	16.6	2.5
38	3	56	7.5	12.5	9.1	57.6	3.7	5.9	3.7	6.5
	4	63	15.1	6.6	5.5	54.6	3.1	4.5	10.6	4.5
	5	55	0.7	3.6	14.3	39.3	0.5	12.7	28.9	1.2
39	2	18	4.9	6.0	13.7	59.9	—	—	15.4	5.5
	3	41	4.9	16.3	18.4	51.9	1.2	3.2	4.1	10.7
	4	61	8.5	30.2	30.5	22.3	2.8	1.8	3.9	10.7
	5	57	0.5	—	12.2	29.0	—	4.4	53.9	0.7
40	4	61	3.1	2.8	9.2	69.1	1.5	2.9	11.4	5.3
	5	65	1.1	0.9	0.9	45.7	—	4.8	46.6	0.9
41	3	45	12.1	6.8	9.9	61.0	—	3.7	6.5	8.8
	4	62	5.9	—	5.9	76.3	1.9	3.7	6.3	7.4
	5	73	1.2	1.2	2.4	63.6	2.2	4.8	24.6	2.2
42	3	54	5.7	4.8	19.1	54.5	1.3	2.9	11.7	5.3
	4	69	4.0	5.5	8.5	64.6	0.3	4.9	12.3	4.7
	5	57	2.6	—	5.3	36.8	0.7	13.8	40.8	0.8
43	3	42	6.8	1.4	8.2	57.5	—	10.5	15.6	2.8
	4	56	3.1	12.6	3.0	64.8	5.6	4.7	6.2	5.1
	5	70	5.1	—	3.0	61.5	4.3	7.3	18.8	2.3
44	3	17	6.5	3.0	16.1	46.7	—	10.1	17.6	2.6
	4	61	8.8	4.2	7.5	68.0	1.5	5.2	4.8	7.7
	5	65	2.7	4.1	7.4	66.0	—	9.6	10.2	4.1

[1]Bright = vitrain; coarse, medium, and fine clarain
Dull = fusain, claro-durain, and durain

The facies types shown are based on the studies of Karmasin (1952), Teichmüller (1950, 1952b), and Teichmüller and Thomson (1958) in Germany. Three types of environment within a peat-forming swamp are considered: the forested moor (FM), the reed moor (RM), and the open moor (OM). Vitrain and clarain with thick vitrinitic lenses are considered to be products of the forested-moor environment; the reed moor produces clarain with fine microbanding; spore-rich varieties of durain and coal types, in which the constituents are finely comminuted and degraded, result from open-moor accumulations. In the terminology of the present study, the writer believes that vitrain, coarse clarain, and medium clarain represent the forested moor; fine clarain the reed moor; and durain, claro-durain, and bone or impure coal the open moor. These three environments and the coal types resulting from them form the end members of the facies triangle included in Figure 11, and the compositions of the various divisions in each sample have been plotted according to their proportions of coal types.

Several aspects of the Harbour seam as portrayed on Figure 11 should be pointed out. The first is the concentration of fine clarain in divisions 2, 3, and 4 in samples IV 30, IV 31, and IV 32, indicative of the persistence of a reed-moor environment in this area through a major part of Harbour seam time. Hacquebard, *et al.* (1964) showed that this area was apparently a levee-flank depression controlled by an elongate sandstone body underlying the seam immediately to the west of samples IV 30 and IV 31. Fisk (1960) discussed the significance of such levee-flank depressions in the accumulation of thick peat deposits in the Mississippi delta. It is interesting to note that the vertical propagation of this fine clarain facies takes place across dull layers, namely those at the top of divisions 2 and 3. These dull layers must represent radical though short-lived changes in peat-swamp environments. These changes (perhaps a period of flooding or desiccation), however, seem to have been superimposed on a factor of longer duration, which again became operative when 'normal' peat accumulation resumed. In the area under discussion, such a factor might have been the influence of the old levee.

The second point to be noted is the rather sharp break in coal types at the top of division 4. The overlying division 5 is characterized by an increase in dull coal types as compared with the underlying divisions. The dull types (durain, claro-durain, etc.) are especially prominent in samples IV 42 to IV 39.

A third point of interest is that the Harbour seam is duller in the Florence, Princess, and New Waterford areas (samples IV 44 – IV 39) than in the Glace Bay area (IV 30 – IV 35). This is partly the result of an increase laterally in the dull coal content of divisions 3 and 4; but a more important reason is the appearance of the dull unit, division 5, at the top of the seam in the western end of the field and the disappearance of the brighter division 2 from the base of the seam. This reflects the dominance of mixed forested- and reed-moor environments during the deposition of the lower part of the main seam (divisions 2, 3, and 4) with divisions 2 and 3 being most fully developed in the Glace Bay area (samples IV 30 – IV 37). In contrast, more open-moor conditions prevailed during the formation of division 5 with contemporaneous deposition of lacustrine sediments in the Glace Bay area (Hacquebard, *et al.*, 1964).

Depositional History of the Harbour Seam

The data presented and discussed in the foregoing sections of this chapter permit a sketchy interpretation of the sequence of events involved in the deposition of the Harbour seam.

Deposition began first in the Morien Bay and Glace Bay area. In this early phase, represented by division 1 of Figure 8, peat accumulation was hampered periodically by the influx of inorganic sediments. Finally, conditions were such that prolonged accumulation of peat was possible in the Morien Bay area (IV 37), and deposition of the main seam began. The abortive beginnings have been preserved as the underlying seamlets. West of site IV 30, deposition of sand and clay dominated, and at this time the previously mentioned natural levee was formed near IV 30 and IV 31.

Division 2 indicates an encroachment of peat formation to the west. Peat accumulation, which would eventually contribute to the main seam, had now spread from Morien Bay (sample IV 37) to the New Waterford area (samples IV 40 and IV 39). The coal in the division is quite bright indicating good preservation conditions. There are few dull layers. The concentration of fine clarain was beginning to develop on the levee flank near IV 30 and IV 31. The end of this division's history was marked by a moderate resurgence of detrital deposition indicated today by the bony layer that forms the top of the division. The proportion of detrital material supplied to this bony layer increased toward the west, until near sample IV 40 it changed into a true parting.

The formation of division 3 saw further and probably gradual encroachment of peat formation to the west. Several rather drastic changes in environmental conditions took place, particularly toward the northwest, and several varieties of dull layers were formed. These changes probably represent local subsidence or desiccation. Division 3 ended with a resurgence of detrital sedimentation, that apparently spread over the whole area and is represented by the high-ash band C.

Division 4 contains the products of extensive and relatively uniform peat accumulation throughout the entire area. There were breaks in this uniformity to produce bands D, E, F, G, H, and I. Of these, band I is the most significant; it marked the end of the mixed reed moor – forested moor environment, and ushered in a period dominated by mixed open-moor and reed-moor environments in the northwest. In the Glace Bay area it virtually marked the end of all peat accumulation (Fig. 11).

Division 5 is the product of the above mentioned mixed open moor – reed moor environment. The many alternations exhibited by this division suggest rapid changes in swamp conditions, perhaps a prelude to the changes that would stop peat accumulation. The deposition of division 5 ended with the formation of band K. In places this band passes into shale, indicating that the supply of detrital material to the swamp was increasing; this interfered with peat accumulation and finally terminated it.

Peat accumulation was to flourish briefly two more times, however, especially in the area of the Florence Colliery where these two periods are represented by the two rider seams. Apparently these conditions spread beyond the area of the Florence Colliery, because two rider seams have been found elsewhere, but their development was not as pronounced as in the Florence Colliery.

Chapter III

MICROSCOPIC INVESTIGATIONS OF SELECTED DULL LAYERS IN THE HARBOUR SEAM

Terminology

The microscopy of the sampled dull layers in the Harbour seam involved the study and identification of macerals and microlithotypes (maceral associations).

The term maceral was proposed by Stopes (1935) to designate the microscopically identifiable components in coal that she considered analogous to the minerals of inorganic rocks. Spackman (1958) defined macerals as "... organic substances, or optically homogeneous aggregates of organic substances, possessing distinctive physical and chemical properties and occurring naturally in the sedimentary, metamorphic, and igneous rocks of the earth's crust". In effect, Spackman's definition implied the existence of many macerals, and suggested that the entities hitherto considered macerals were in fact suites and groups of macerals.

Spackman's concept of the nature of macerals has been followed to a certain extent in this study. The following entities have been identified, and their proportions recorded in the microscopy of the dull bands.

a. *Red vitrinite* is generally thought to be derived from wood or bark, and most coal petrographers consider it to be the product of environmental conditions that minimized decay—absence of oxygen and reduced bacterial and fungal activity. It is a red-orange material (light grey in reflected light) that forms the bulk of most bituminous coals. An attempt was made to indicate microscopic texture based on the sizes of the lenses or 'particles' of this material. Four size categories were arbitrarily established: (a) >350 microns, (b) $<350>$ 70 microns, (c) thin stringers <70 microns, (d) <70 microns and of limited areal extent (*see* Pls. II and III for microscopic appearance of macerals).

b. *Brown vitrinite* occurs as isolated lenses enclosed with red vitrinite, or as the groundmass of some of the dull layers. There appear to be some optical differences between the materials in these two associations, and two macerals may be represented. Many of these brown substances may represent Thiessen's "brown matter" (Thiessen and Sprunk, 1935). Occasionally, as in the darker varieties found as matrix material in some of the dull layers, brown vitrinite may correspond to the massive micrinite and/or the "decay fusinite" described by Karmasin (1952) and Teichmüller (1952a). Massive micrinite and decay fusinite are thought to be derived from humic or woody material under aerobic or at least partly aerobic conditions; decay fusinite seems to be the product of more extreme conditions (Mackowsky, 1949; Teichmüller, 1944). Stach (1952) indicated that in thin section massive micrinite is dark brown.

c. *Semi-fusinite* is the third major component identified; it is similar in some optical properties to brown vitrinite. When viewed in transmitted light, semi-fusinite ranges from medium brown to dark red-brown. A critical feature is the relatively well preserved cellular structure; this indicates close correspondence with the generally accepted description of semi-fusinite as defined in the Glossary of the International Committee for Coal Petrology (1957).

d. *Fusinite* is the fourth component identified in this study. Several materials, or substances derived from several types of parent materials, appear to be included under this heading. One of these is the cellular opaque material conforming to the Glossary definition of fusinite (International Committee for Coal Petrology, 1957). Also included are large non-cellular opaque masses, similar to bodies considered by Schopf (1948, 1952) to be fusinized secretions, possibly of resinous origin. The common association of semi-fusinite with cellular fusinite suggests a genetic relationship in which semi-fusinite is the product of conditions of intermediate severity, whereas fusinite is the product of intense devolatilization. The genesis of fusinite is a subject of debate. The two main groups of hypotheses are those that suggest an origin by gradual chemical or biochemical activity, and those that suggest a more rapid mode of formation by fire. Most coal petrographers now feel that fusinitic material can be formed through either of the two processes mentioned above, and the Germans speak of "Brandfusinit" (fire fusinite) and "Zersetzungsfusinit" (decay fusinite) (Teichmüller, 1952a).

e. *Micrinite* includes all other opaque materials except pyrite. It occurs both as small discrete granules and lenses, or as a more or less amorphous mass forming the matrix of some durain bands.

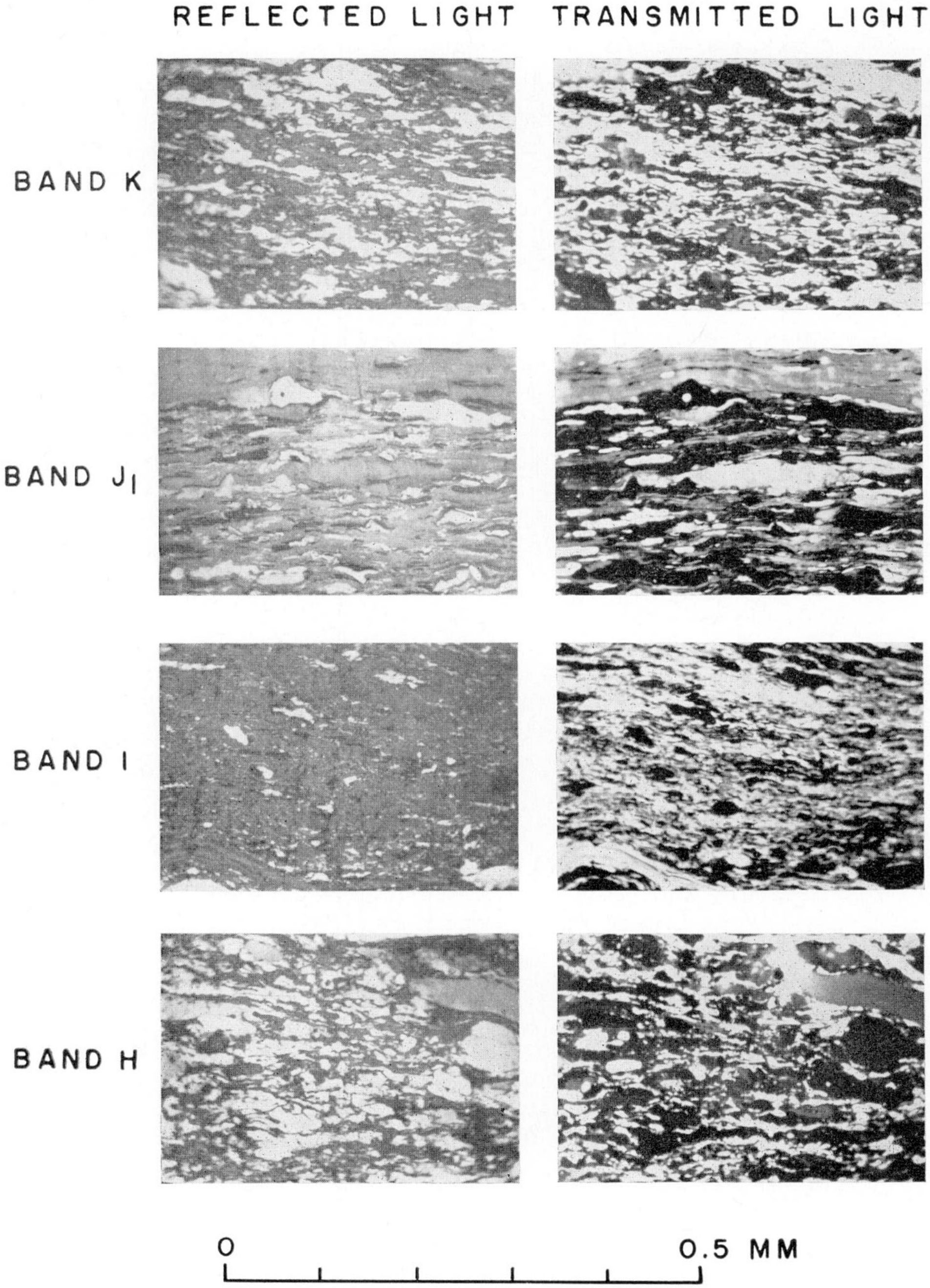
f. *Resinite* includes several types of material, among which are red-orange, oval bodies exhibiting a clear, glass-like texture, as well as dark red, characteristically crescent-shaped masses. Small amounts of a brilliant yellow clear material are also included.

g. *Exinite* is the term used to designate the remains of spores and cuticles; yellow to orange materials preserving the remnant structure of spores and cuticles fall into this category. Also included is the rather complex, reticulated, yellowish mass forming the groundmass of bands I and K.

h. *Mineral matter*—pyrite, quartz, feldspar, muscovite, other micaceous and clay minerals, and calcite—is the eighth and last type of material recorded in this study.

Because the maceral analysis failed to produce as definitive a description of the dull bands as was desired, the compositions of these bands were also depicted in terms of microlithotypes. The term microlithotype, as defined in the Glossary (International Committee for Coal Petrology, 1957) "... designates in the microscopy of humic coals the typical associations of macerals, the minimum band width of which has been fixed provisionally at 50 microns". The description further stated that though the delimitation of these maceral associations is arbitrary, it appears to agree well with technological behaviour. A table of the microlithotypes included in the Glossary description is reproduced here as Table III.

PLATE II



Typical microscopic views of the seven dull bands that were examined in detail (*see also* Pl. III). A pair of photographs is shown for each band to illustrate the reflected and transmitted appearance of the same microscopic field. The photographs were made on polished thin sections using an oil immersion objective.

Band K: This band is high in exinite (spore remains), which in reflected light shows dark grey and in transmitted light shows white. Massive micrinite appears as irregularly shaped white patches in the reflected light photograph while in the transmitted light photograph they appear black (actually brown to dark brown in transmitted light).

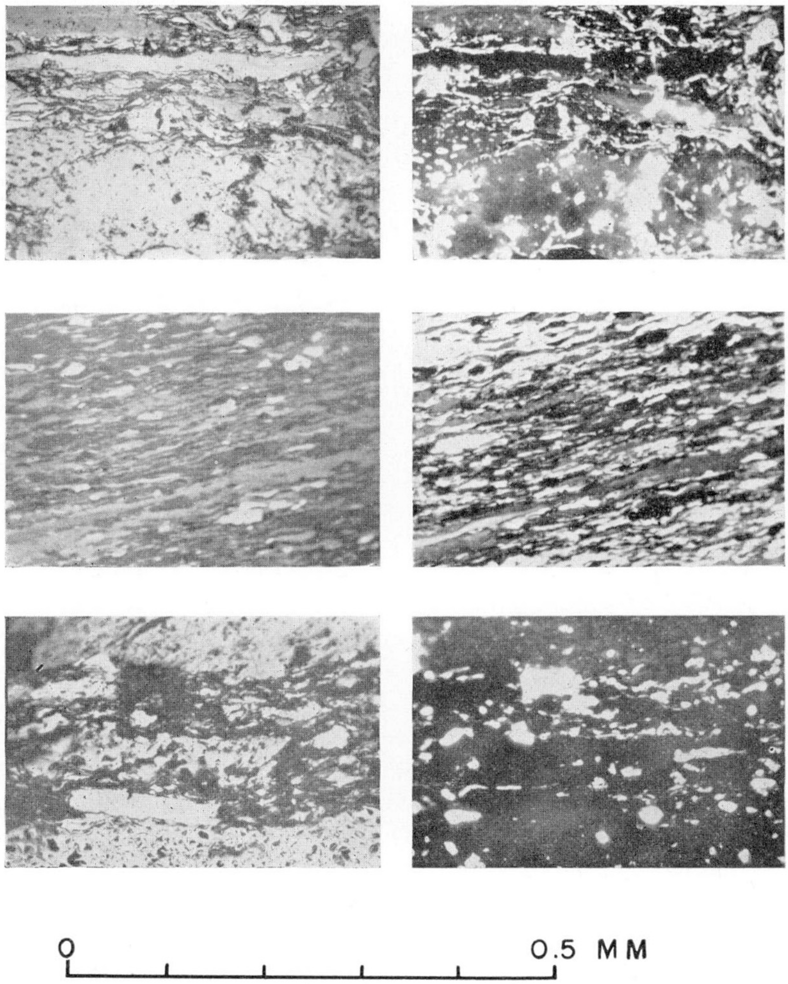
PLATE III

REFLECTED LIGHT TRANSMITTED LIGHT

BAND E

BAND D

BAND C



Band E: Band E is typically a mixture of fusinite, semi-fusinite, and micrinite associated with small amounts of exinite. The lower halves of the photographs show a large mass of semi-fusinite with a smaller mass of fusinite immediately above it to the left (fusinite is light grey and shows well-developed cell structure in reflected light).

Band D: This band is somewhat similar to J_1 in that it contains a fairly large percentage of red vitrinite occurring in thin strands and lenses (light grey groundmass in reflected light). Exinite is also abundant (dark grey bodies in reflected light), and quantities of opaque and semi-opaque macerals (micrinite, semi-fusinite, and fusinite) are small.

Band C: This band is characterized by an abundance of opaque macerals, and patches of fusinite (bottom of reflected light photo) and semi-fusinite (top of photo) are common. In transmitted light these are black and dark red or dark brown respectively. Exinite is relatively scarce.

Band J_1: The typical appearance of this band is that of thin stringers and lenses of red vitrinite (light grey ground mass in reflected light) associated with moderate quantities of spores and opaque macerals. Individual spores (dark grey elongate bodies in the reflected light; white in transmitted light) are easily seen. The white patches in the reflected light photo are micrinite.

Band I: Band I is similar to K in that it contains a massive concentration of exinite. The matted, dense nature of the exinite shows in both reflected and transmitted light. Individual spores are difficult to see, although the discrete outlines of several small spores can be picked out in the transmitted light photo. The curved outline of a large spore can be seen in the lower left corner of both photographs.

Band H: This band is characterized by an abundance of opaque and semi-opaque macerals; these show as white or very light grey patches in reflected light. In transmitted light these areas are brown to dark brown. Exinite is markedly less abundant than in band I.

TABLE III *Table of Microlithotypes*[1]

Microlithotype	Principal groups of constituent macerals and their proportions
Vitrite	Contains at least 95% vitrinite
Fusite	Contains at least 95% inertinite[2] except micrinite
Clarite	Contains at least 95% vitrinite and exinite; each must be greater than proportion of inertinite
Durite	Contains at least 95% inertinite and exinite; each must be greater than proportion of vitrinite
Vitrinertite	Contains at least 95% vitrinite and inertinite; each must be greater than proportion of exinite
Duroclarite	More than 5% each of vitrinite, exinite, and inertinite; vitrinite must exceed inertinite
Clarodurite	More than 5% each of vitrinite, exinite, and inertinite; inertinite must exceed vitrinite

[1]International Committee for Coal Petrology, Glossary of Coal Petrology, 1957.
[2]Inertinite is group designation for these macerals: micrinite, semi-fusinite, fusinite, sclerotinite.

The term microlithotype, as used in this study, represents an extension of the concept embodied in the above phrase "typical associations of macerals". The author has attempted to identify the typical associations that characterize the dull layers of the Harbour seam without trying to fit these into the seven types listed in Table III. This attempt to define the "natural microlithotypes" introduces a degree of flexibility that permits a more precise description of the variation that can occur within a coal seam. It should be emphasized that the microlithotype system as described in the International Glossary was not intended as a device to be used in such academic problems as the nature of lateral variation in coal seams and the working out of facies patterns. Rather, it was designed for the analysis of coking coals, and as such it has apparently been a rather useful tool (Mackowsky, 1956, 1958).

The microlithotypes discussed in the following sections are identified by letters and numbers. They are distinct from one another by virtue of variations in their content of macerals. They have also been grouped into categories characterized by broad compositional similarities. The manner in which this has been done will be dealt with more fully in the section on classification.

Sample Preparation

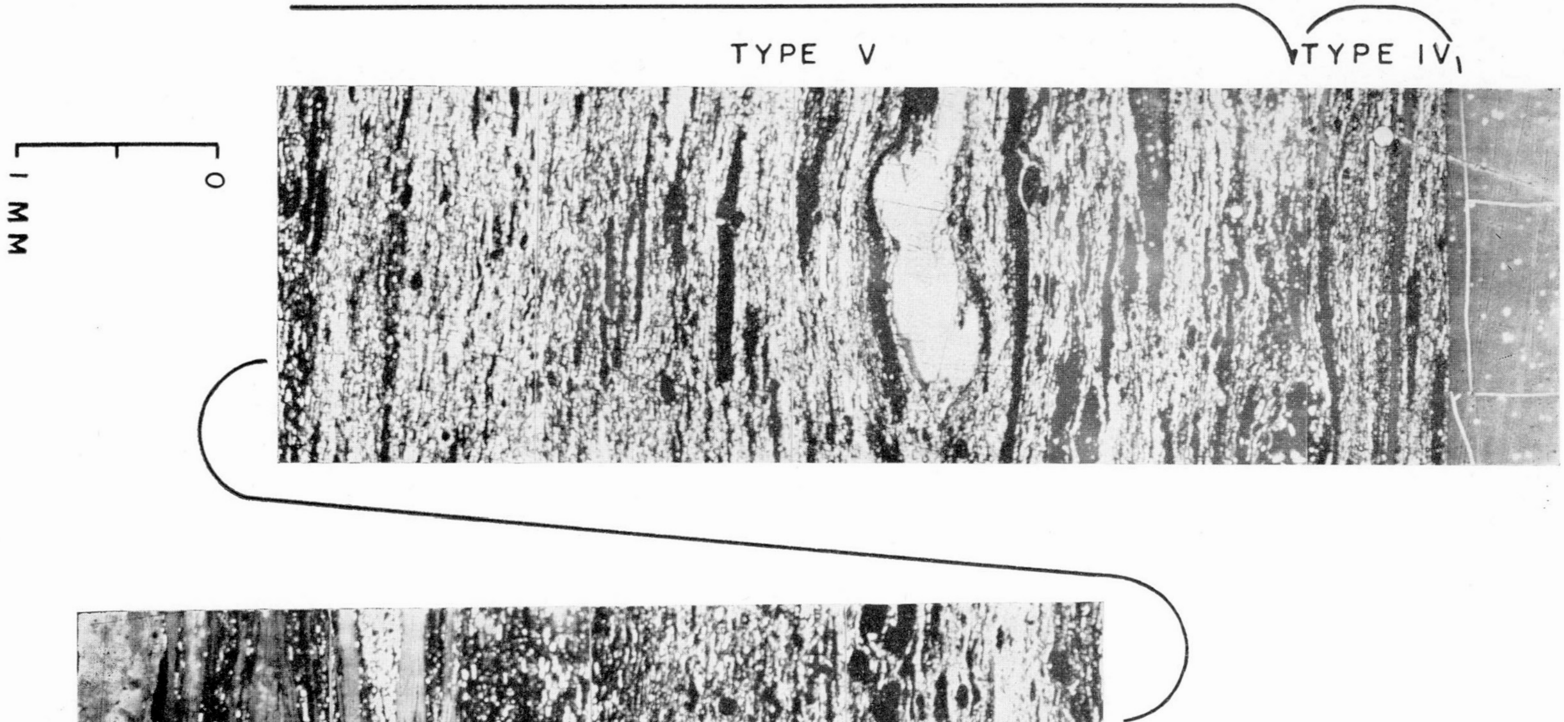
Thin sections were prepared in the coal petrology laboratory of The Pennsylvania State University. From each sample, which usually consisted of a number of fragments, a piece was selected that represented the entire width of the dull band. Preference was given to pieces that included bright coal on both sides of the dull material, thus ensuring that the full thickness of the dull layer was covered, and also enabling the writer to study both dull and bright coal and the transition between them.

Each small piece was rough ground on a carborundum wheel and fine ground on a Belgian hone, then dried at 100°C for 6 to 8 hours to remove moisture picked up during the grinding process. Dried specimens were immediately mounted on glass slides with a cold-setting epoxy resin, Biggs Bonding agent R-313. This resin permits relatively easy preparation of bubble-free mounts. After the specimens had been allowed to set for 24 hours the excess coal was cut off with a diamond saw and the surface was ground on a carborundum wheel and finished on a Belgian hone. A cover glass was then mounted on the section with Canada Balsam. Within a few hours the excess balsam was removed with xylol, and the specimen was ready for microscopic analysis.

Analytical Procedure

The technique employed by the writer for the microscopic analyses was one that has been used for a number of years at The Pennsylvania State University. It is an adaptation of a method developed by the United States Bureau of Mines in which the simple device of a Whipple disc inserted in the ocular of the microscope is used to estimate components. The method differs from that suggested by the United States Bureau of Mines in that the entire grid area of the Whipple disc is used for estimation instead of only the central vertical tier of squares, and only one traverse is made across the thin section as opposed to two (Parks and O'Donnell, 1948). By this method the composition of the dull bands in terms of macerals was obtained.

The analyses in terms of microlithotypes required a different approach. The thin sections of the dull bands were scanned to establish the number and character of the lenses or sublayers occurring within them. Any one of the dull bands at a given site might be composed of a single uniform assemblage of macerals, or more commonly, it might be a composite of several maceral associations (*see* Pl. IV). For example, a dull band at a particular site might show a high exinite lens at the base, immediately overlain by another lens with increased quantities of the opaque macerals and reduced amounts of exinite. This in turn might be overlain by a thin lens containing equal amounts of red vitrinite, exinite, and opaque macerals. These three lenses are all part of the dull band, but in the microlithotype analysis each part was considered separately. The maceral composition of each lens was determined; this was done for all samples of the dull bands. These sets of data were then grouped by preparing simple bar diagrams, each representing the composition of one of the component lenses in terms of the eight maceralic constituents. These bar diagrams were then grouped by visual examination. The petrographic aspect peculiar to each group is considered a microlithotype and may be represented by a bar diagram in which the composition of the group is reduced to mean values. The minimum width of the lenses described was arbitrarily set at 750 microns. This is not a natural threshold, but it was convenient to select this value in terms of the magnification used and for the purposes of the study.



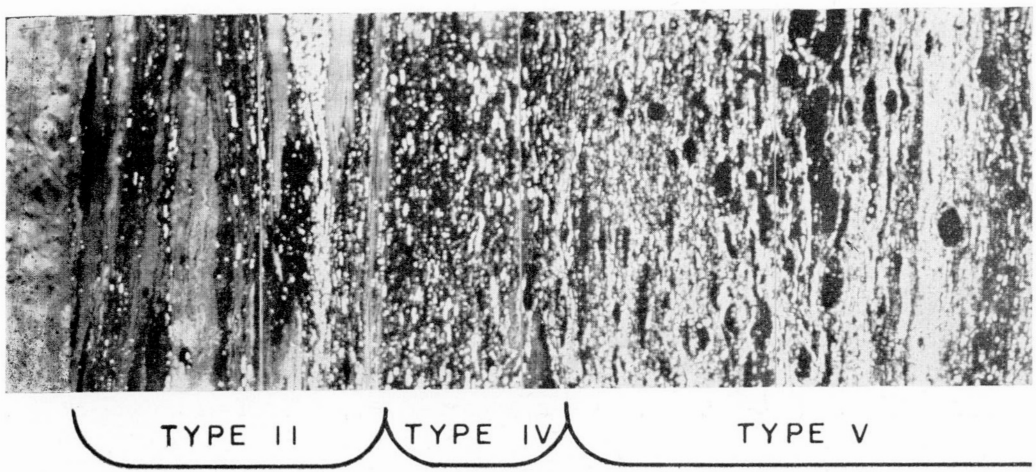


PLATE IV

Typical cross-section of dull band I from the Princess Colliery, Nova Scotia. The plate is a composite of overlapping photomicrographs taken in transmitted light and shows the character and arrangement of various complex microlithotypes. The white areas and bodies are exinite, the grey and mottled areas at the top and bottom of the transect are red vitrinite, while the black masses and the groundmass in which much of the exinite occurs is composed of opaque macerals, mainly micrinite.

Results

Classification of Microlithotypes

The results of microscopic examination of coal specimens from the Harbour seam include descriptions of seven dull bands in the seam. These descriptions involve the recognition and classification of various microlithotypes. A total of sixty microlithotypes was identified. Some of these occurred many times, a few were found only once.

Figure 12 (*in pocket*) is a graphic representation of the classification proposed, and is intended to show relationships between the different microlithotypes and to facilitate discussion of them. The major criterion governing the manner in which this system is constructed is the petrographic character of the microlithotypes themselves. By inspection of their petrographic nature the microlithotypes are grouped in classes to show particular compositional trends or patterns. The trends and characteristics of the various classes are as follows.

CLASS A. Characteristic feature: dominance of red vitrinite; none of subordinate constituents acquires any prominence over the others.

CLASS B. Important macerals: red vitrinite, brown vitrinite, some participation by exinite; characteristic trend: red vitrinite decreases, brown vitrinite increases; characteristic of end-member microlithotypes: brown vitrinite dominant.

CLASS C. Important macerals: red vitrinite and fusinite, some participation by micrinite; characteristic trend: red vitrinite decreases, fusinite increases; characteristic of end-member microlithotypes: fusinite-rich.

CLASS D. Important macerals: red vitrinite, semi-fusinite and fusinite; characteristic trend: red vitrinite decreases, semi-fusinite and fusinite increase; characteristic of end-member microlithotypes: semi-fusinite dominant.

CLASS E. Important macerals: red vitrinite, micrinite, semi-fusinite, some participation by exinite; characteristic trend: red vitrinite decreases, semi-fusinite and micrinite increase; characteristic of end-member microlithotypes: red vitrinite and micrinite of equal proportions.

CLASS F. Important macerals: red vitrinite, exinite, and micrinite; characteristic trend: red vitrinite decreases, exinite and micrinite increase; characteristic of end-member microlithotypes: red vitrinite, micrinite, and exinite of approximately equal proportions.

CLASS G. Important macerals: red vitrinite, brown vitrinite, micrinite, and exinite, some participation by fusinite and semi-fusinite; characteristic trend: decrease in red vitrinite, increase particularly of brown vitrinite, micrinite, and exinite; characteristic of end-member microlithotypes: all macerals of approximately equal proportion.

CLASS H. Important macerals: red vitrinite, brown vitrinite, micrinite, and exinite; characteristic trend: decrease in red vitrinite, increase first in brown vitrinite, then micrinite, then exinite; characteristic of end-member microlithotypes: exinite-dominant associations.

Figure 12 may be roughly divided into two halves. On the left side are those microlithotypes in which exinite does not play a significant compositional role. These include classes B, C, D, and possibly E. The right side of the diagram, on the other hand, involves those microlithotypes in which exinite is an important contributor, combined with varying amounts of red vitrinite, brown vitrinite, and micrinite. The classes on the left side were relatively easy to distinguish because they mainly involve the variations between two macerals or maceral groups. For example, class B involves the red vitrinite – brown vitrinite series. The classes on the right side of the diagram contain microlithotypes that are more difficult to group because variations in more than two macerals are involved. Class F differs from classes G and H in that the brown vitrinite does not play a significant role. Class G, however, involves variations in red vitrinite, brown vitrinite, micrinite, and exinite, with some participation by fusinite and semi-fusinite. In class G no one constituent, or even two constituents exerts an appreciable dominance over the others. Class H includes microlithotypes that seem to form a continuous series conforming to a pattern of increasing severity of decay conditions, starting with microlithotypes high in red vitrinite and ending with those in which exinite is dominant.

Because the exact relationships of these microlithotypes to one another is not well known, the genetic implications of the classification system as constructed on Figure 12 should not be stressed. The arrows indicating compositional trends within the classes are not intended to suggest that one microlithotype is an actual descendant of another, for example C3 from C2. Instead these arrows indicate, in a general way, increasing decay or increasing conditions of degradation and/or carbon enrichment for the whole class. Because of this, the class A microlithotypes were chosen as the focal point of the whole system. Class A is dominated by a preponderance of red vitrinite, which is generally acknowledged to be the coalified derivative of woody tissues. An abundance of red vitrinite implies favourable conditions of preservation. Also, the wood-rich parent materials, under different sets of conditions, could possibly produce all the microlithotypes shown on Figure 12. These class A microlithotypes probably form most clarain; and because clarain is the predominant constituent of most coals, the other classes pictured on Figure 12, and especially the microlithotypes forming their extremities, must be regarded as abnormalities in the total picture of coal seam formation. Thus, material that would eventually become clarain was typically deposited in peat swamps. Deviations from these normal conditions produced dull bands containing microlithotypes of those classes other than class A. In most swamps these anomalous conditions shortly changed to those in which clarain progenitors could again be formed.

Class A may be divided into two groups; one containing those microlithotypes (A1, A2, A3) in which red vitrinite is present in amounts exceeding 70 per cent, and one containing microlithotype A4 in which a less prominent amount of red vitrinite is present. Microlithotypes within the first group, that is, A1, A2, A3, are differentiated on the basis of the texture of the red vitrinite.

A rather large group of microlithotypes exists in which the content of red vitrinite is as high as it is in A4. This group includes B1, C1, D1, E1, F1, G1, and H1; its members differ from A4 in that certain of the secondary constituents are present in conspicuously greater proportions than the other subordinate components. This group provides the links by which those microlithotypes with low contents of red vitrinite are related to class A.

Explanation of Panel Diagrams

As only the dull band samples collected in the Princess Colliery were thin sectioned and examined microscopically, the series of panel diagrams (Figs. 13–19, *in pocket*) are concerned only with material originating within the confines of this colliery. These seven figures illustrate lateral changes in seven of the more prominent dull layers, namely, C, D, E, H, I, J_1, and K. The plots are in terms of a modified representation of the microlithotype composition; to achieve this modification the sixty microlithotypes were arranged in nine groups. To these larger units the term 'complex microlithotype' has been applied; the lower order maceral associations of which they are composed are referred to as 'simple microlithotypes'. The complex microlithotypes differ from the simple microlithotypes in that they encompass a greater compositional range, and their delimitation is therefore more arbitrary than that of the simple microlithotypes. In the following pages the term complex microlithotype will often be shortened for the sake of convenience to complex type. Table IV shows this grouping of the simple microlithotypes into complex types. Reference may be made to Figure 12 for the composition of each simple microlithotype.

TABLE IV | *Composition of Complex Microlithotypes*

Complex types	Simple types
I	A1, A2, A3
II	A4, B1, B7, C1, C6, D2, E1, E2, E6, F1, G1, H1
III	C4, C5, C8, C9, D4, D5, D6, D7, D8, D10, E5
IV	H4, H8, H9
V	B10, H5, H6, H7
VI	C2, C3, C7, D1, D3, D9
VII	B2, B3, B4, B5, B6, B8, B9
VIII	E3, E4, E7, H2, H3, H10
IX	F2, F3, G2, G3, G4, G5, G6, G7

A brief description of the general features of the complex type is as follows:

Type I: Most prominent feature is its high vitrinite content ($>$70 per cent).

II: Red vitrinite content subdued, generally between 50 and 60 per cent; secondary constituents become more prominent.

III: Characterized by fusinite and/or semi-fusinite.

IV: Micrinite and exinite contents about equal and dominant over the other constituents.

V: Exinite dominant over other constituents; generally present in amounts exceeding 50 per cent.

VI: Characterized by a red vitrinite content of 40–50 per cent and a fusinite plus semi-fusinite content of 20–30 per cent.

VII: Brown vitrinite is the dominant constituent.

VIII: Micrinite present in largest proportion, generally near 40 per cent; other constituents all of lower proportions.

IX: Red vitrinite, micrinite, and exinite present in equal proportions; range between 25 and 35 per cent.

The panel diagrams (Figs. 13–19) are 45° projections, so that all distances measured on them are true distances. Each figure consists of two parts; a panel diagram, and a group of bar diagrams that express the average composition of the various complex microlithotypes within the layer. These bar diagrams vary in detail from band to band, but the general pattern and characteristics of the complex types remain the same.

The most important bands, C, H, I, and K, have been covered completely within the limits of the sampling program in the Princess Colliery. Bands D, E, and J_1 were not sampled as completely as the four mentioned above, but the data obtained on the available samples have been plotted to indicate at least some features of their composition. Not all complex microlithotypes are present in each band; certain bands are characterized by an abundance of one microlithotype. This variation between bands forms the basis of much of the remaining discussion.

The complex association, type I, with its extreme abundance of red vitrinite, does not constitute part of the dull band except in a few places. It is considered to be part of the adjacent clarain or bright coal. The type II association, on the other hand, is thought to be a part of the dull layer; in some bands it is the principal constituent. The other complex types are all considered to be dull band components. The datum in each case has been selected as the base of the lowest dull lens at each sampling site.

Description of Individual Layers

Band C. See Figure 13 for panel diagram, Figure 4 for position in seam, and Tables V and XII for microlithotype and maceral composition. See also Plate III.

This band consists of a core dominated compositionally by microlithotypes rich in fusinite and micrinite. A less dull part of the band contains material belonging to type IX in which exinite, micrinite, and red vitrinite are present in about equal proportions. In a few places this assemblage passes laterally into the type IV association in which red vitrinite decreases markedly, and micrinite and exinite increase.

The fusinite–micrinite-rich parts of band C have a characteristic texture. Fusinite occurs as fragments surrounded by a mixture of amorphous opaque material intimately associated with a relatively high proportion of detrital mineral matter. Much of the visible and identifiable mineral matter is quartz. The over all aspect of this part of the band is one of pronounced degradation. A few spore remains appear in the mixture, but all are distorted and disoriented with respect to bedding, and are commonly fragmented and corroded. Fragments and stringers of reddish or brownish material occur in a few samples. These probably represent the coalified remains of wood or bark, but are somewhat less degraded and carbonized than the matrix in which they are found.

The abundance of detrital mineral matter, and its association with fusinite particles, indicate a possible detrital or clastic phase in the deposition of the fusinite. Skolnik (1958) showed that certain inorganic sedimentary rocks may contain considerable amounts of detrital fusain, much of which he believed to be of char of fire origin. In the case of band C the large amount of detrital mineral matter suggests that there was a significant invigoration of the drainage conditions in the swamp. Under such conditions charcoal or fusain, produced perhaps by fire on the higher and drier areas peripheral to the swamp, might have been carried in and deposited with the resultant distribution being largely controlled by drainage.

The amorphous opaque material, which forms the matrix that contains the fusinite fragments and mineral grains, may itself be partly of fusinitic origin. The inherently fragile fusinitic fragments occur in all sizes; some could easily become finely comminuted in the process of transportation and deposition. The remainder may be derived from finely divided organic matter carried into the swamp in suspension, or may be the product of excessive degradation of the vegetation growing in the swamp before and after flooding.

Figure 13 shows a concentration of some of the complex microlithotypes in certain areas. The high-fusinite type III seems to be present in greatest concentration in the western part of the Princess Colliery, that is, in the triangular area from IVA 18 to IVA 27 to IVA 30. It is also present, though somewhat less abundant, in the eastern part of the mine; in the centre type III seems to be replaced in prominence by type VIII which is rich in micrinite and brown vitrinite.

Band D. See Figure 14 for panel diagram, Figure 4 for position in seam, Tables VI and XIII for microlithotype and maceral compositions. See also Plate III.

Band D, though a relatively thin, dull layer, possesses remarkable lateral continuity. The sampling program on this band was incomplete, but enough samples were obtained to yield some information as to its character.

Band D is markedly different from band C in its microscopic petrography and obviously experienced far less drastic changes in the peat swamp environment. Three complex types—II, V, and IX—constitute most of band D. The most abundant constituents belong to type II. Pods of material belonging to other complex types with lower contents of red vitrinite are scattered throughout the samples investigated, but are more or less isolated and disconnected. In several specimens these pods are composed of the high exinite association of type V, and type IX is also represented.

Two striking features characterize this band. One is the prominence of the two complex types II and V in the formation of the "dull" core of the band with relatively little material rich in the opaque macerals. Apparently the environment in which this layer was formed was not conducive to the production of large amounts of micrinite and brown vitrinite. The second striking feature is that a band containing only a narrow dull part, and which has in most places a relatively high content of red vitrinite, should be so persistent and identifiable not only within this mine, but in the Florence Colliery to the west and No. 12 Colliery to the east. It is remarkable that a band averaging less than a centimetre in thickness could be traced along the strike of the seam for 7 to 8 miles. This must indicate unusually uniform conditions of short duration, even though the presence of several different microlithotypes indicates variations within this uniform pattern.

One reason why this band stands out is probably the extremely bright character of the material adjacent to it, which in nearly all samples examined consisted largely of thick vitrain bands. Within band D the red vitrinite is in a finely divided state. This textural characteristic has the effect of reducing the lustre of the coal involved without a great decrease in the content of the vitrinitic constituent (Taylor and Warne, 1960).

Band E. See Figure 15 for panel diagram, Figure 4 for position in seam, and Tables VII and XIV for microlithotype and maceral compositions. See also Plate III.

In Chapter II attention was called to the difficulty in tracing laterally bands E and F. It was also mentioned that of the two bands, the one designated as E appeared to be the more continuous. Figure 15 should therefore be viewed with these reservations in mind. Figure 15 shows that band E contains an abundance of microlithotypes in which the opaque and semi-opaque constituents are dominant. These belong to types III, VIII, and VII, the last named being dominated by a high percentage of brown vitrinite. Microlithotypes in which exinite is an important constituent are of minor importance. Examination of Figure 15 shows that there is no discernible pattern in the distribution of the important microlithotypes.

Band H. See Figure 16 for panel diagram, Figure 4 for position in seam, and Tables VIII and XV for microlithotype and maceral composition. See also Plate II.

Band H is one of the most easily traceable bands in the seam, partly because of its more or less consistent relationship with band I, the key index bed in this seam. This band is another in which microlithotypes high in opaque and semi-opaque constituents are important. Thus type VII with an abundance of brown vitrinite and the micrinite-rich type VIII are important components in this band. Associations that contain intermediate amounts of exinite are of moderate importance and are included in the occurrences of types IV and IX. Type II material, in which red vitrinite is dominant, is also present. Nearly all the microlithotypes, however, contain important amounts of brown vitrinite, even as accessory components.

Band H has a central core containing a massive mixture of brown vitrinite and micrinite. The microbedding in this part of the band is vague and distorted and few exinitic remains occur. On either side of this central part and transitional to the enclosing bright coal are intermediate zones dominated by red vitrinite, but characterized also by a number of brown vitrinite lenses. Spore material in this transitional zone is locally abundant, reaching 25 to 30 per cent. Few megaspores or cuticles are found. At the top of band H an interesting concentration of the thick-walled microspores belonging to the genus *Torispora* has been found (Hacquebard, Cameron, and Donaldson, 1964). This concentration within a few millimetres is remarkable, because this genus is rarely represented in the rest of the seam.

Laterally, the dull character of this band, as represented by microlithotypes belonging to other than types I and II, decreases eastward. Lenses high in the opaque and semi-opaque macerals become discontinuous as the band is traced from west to east.

Band I. See Figure 17 for panel diagram, Figure 4 for position in seam, and Tables IX and XVI for microlithotype and maceral composition. See also Plate II.

Band I is the prominent durain band whose importance as an index bed in this seam was mentioned in Chapter II. The most outstanding characteristic of this band is its high exinite content, represented by numerous occurrences of types IV and V microlithotypes, particularly the latter. This exinitic material has some rather peculiar features. It resembles a vaguely reticulated mass of yellowish strands, but the precise identification of these strands with spore remains is obscure. Even at high magnification it is difficult to separate the strand-like material into individual spores. It is similar in some respects to material that Berry (1959) described as a yellow vitrinoid. Bayer (1960) found similar material in the Freeport seam of Pennsylvania and identified it as a yellow vitrinoid. Microscopic tests, done on the yellow material in band I, utilizing a heating stage, indicated a behaviour more closely akin to exinite than to vitrinite, and it has tentatively been identified as exinite. An algal origin is also possible, although the strand-like material differs from what might be considered typical algal remains as described by Thiessen (1925) or as pictured by Abramski, *et al.* (1951) and Marshall (1955).

The density of this yellow reticulum varies considerably, and the interstices are filled with lenses of micrinite and brown vitrinite. Red vitrinite tongues were observed in a few places, especially near the borders of the band. Fusinitic lenses are scattered randomly throughout the layer. A number of oval and crescent-shaped bodies encompassing a complete range from red-brown to black, are also found. The opaque members of this morphological entity have been included in fusinite; the others have been classified as red resinite. Some of these oval bodies, particularly those that are opaque, may not be resinitic, but may correspond to the sclerotia described by some writers (Stach, 1956; Hacquebard, 1952). Kosanke and Harrison (1957) showed the resinous affinity of many such bodies whose morphological characteristics were similar to those ascribed to substances of fungal or sclerotial origin. Material derived from a fungal source does exist in coal, however, and in the present study has probably been included in fusinite. Megaspore and cuticle remains are comparatively rare in this band, although the latter are found near the top and bottom of the band.

Band I, like most of the bands examined, is variable laterally. The exinite-rich type V associations appear to be most prominent in the western part of the investigated area, especially through sampling sites IVA 31 – IVA 30 – IVA 8. In the eastern part of the Princess Colliery these exinite-rich tongues become narrow and less conspicuous. There, the core of the band, though still containing prominent quantities of exinite, includes a greater proportion of microlithotypes of type IV in which the exinite is accompanied by large amounts of the opaque macerals.

Band J_1. See Figure 18 for panel diagram, Figure 4 for position in seam, Tables X and XVII for microlithotype and maceral composition. See also Plate II.

Band J_1 is the slightly duller basal part of the larger unit, zone J. It is not a well-defined band, but rather has the appearance of a series of overlapping and intertongued lenses, which taken together form in a somewhat loose fashion the band or layer designated as J_1. In some respects this band is similar to band D, particularly in its generally high content of red vitrinite. It is unlike band D in that the exinite content is lower and appears to be more evenly distributed. Fusinite is relatively prominent and with red vitrinite forms associations that belong to type VI. The exinite content reaches about 30 per cent at some sites and is represented by microlithotypes of type IX. Brown vitrinite and granular micrinite are scattered randomly throughout the extent of the band. The ash content is very low, the lowest of any band examined. Pyrite is rare.

The general microscopic nature of the band is that of finely textured red vitrinite, with associated micrinite, fusinite, and brown vitrinite intercalated with lenses of a coarser texture in which red vitrinite is present in greater abundance.

Band K. See Figure 19 for panel diagram, Figure 4 for position in seam, Tables XI, XVIII, and XIX for microlithotype and maceral compositions. See also Plate II.

Band K is a prominent durain layer close to the roof in most of the Princess Colliery. Microscopically it is similar to band I; both are high-exinite layers, and the exinite in K has much the same appearance as in band I, that is, it exists as a tangled and continuous yellow mass with indications of corrosion or alteration. Because of the high exinite content of this band, type V microlithotypes are important, as are those of type IV in which exinite is of intermediate abundance and occurs with equal amounts of micrinite. Types II and IX microlithotypes form the transition material from the exinite-rich core of the band to the surrounding clarain. The distribution of the high-exinite microlithotypes of band K appears to be somewhat more widespread and erratic than in band I.

The brown vitrinite content of this band is higher than that of band I. Nearly all the complex types show higher contents of brown vitrinite than do comparable types in band I. The ash contents of most of the samples in band K are higher than those of band I. Visible pyrite is also more abundant in band K, and clusters of crystals are not uncommon.

Discussion of the Microscopic Characteristics of Durainic Bands

On Figure 20 the results shown on the panel diagrams (Figs. 13–19) have been summarized to compare the composition of the seven dull layers in terms of their complex microlithotype content. The data show the relative concentration of each complex type in the samples studied. The proportions of the clarainic type I material are not represented in these diagrams. A comparison of these diagrams indicates that four different types of dull coal seem to be present. Environmental differences are thus reflected, so that this comparison really represents four types of environment involving critical changes in such factors as water level, oxidation effects, and vegetation.

The first type is represented by band C. This band has been discussed in detail and the matter of its origin considered. It is thought to represent a period of flooding and deposition of clastic fusinitic material and mineral matter. This may have been accompanied by considerable oxidation producing substantial quantities of the amorphous opaque components and brown vitrinite.

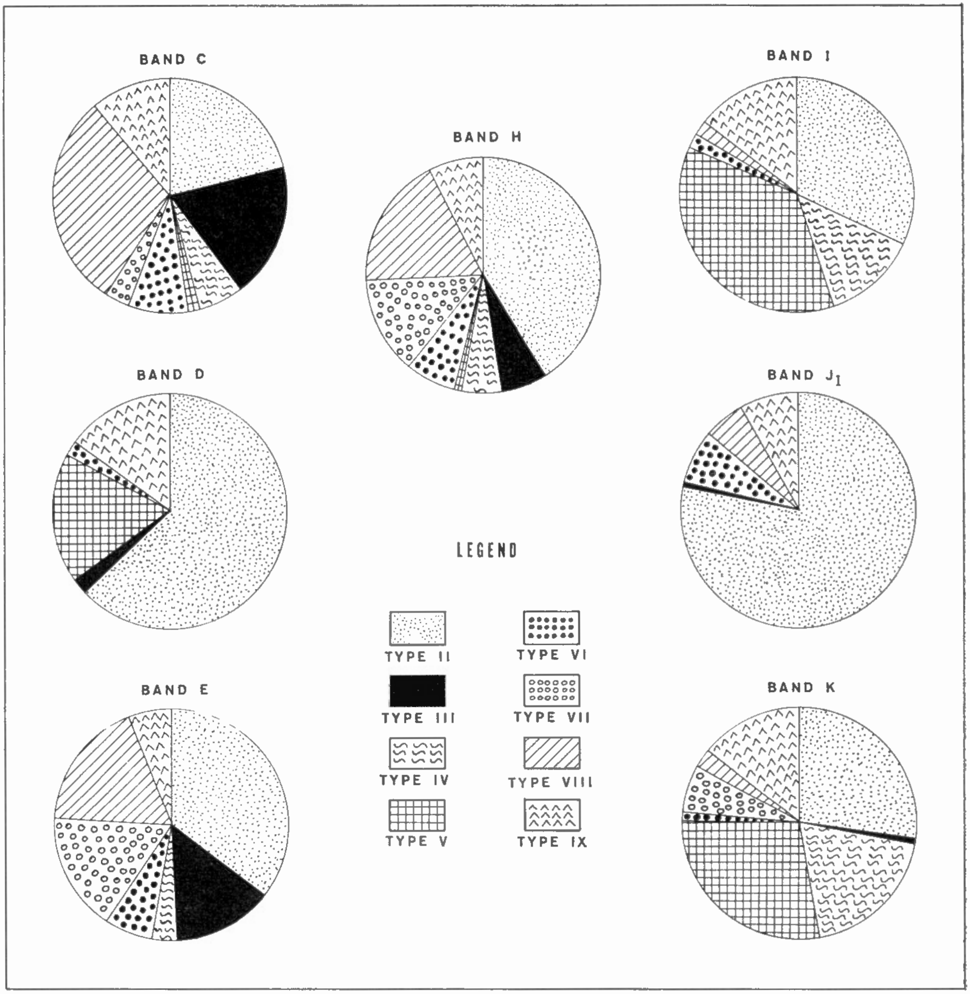


FIGURE 20. Summarized composition of selected dull bands of Harbour seam, Princess Colliery, in terms of complex microlithotypes.

The second type includes those bands characterized by an abundance of complex type II. Bands D and J_1 are of this type. In these bands the red vitrinite component of complex type II is characterized by a fine or fibrous texture. This property, coupled with increased amounts of the other macerals, suggests an environment dominated by herbaceous plants, the general type of environment described by Teichmüller (1950) as "riedmoor". Band D, because of its higher exinite content, is probably more nearly the type of deposit Teichmüller had in mind as resulting from this kind of environment.

The composition of the third type, which includes bands E and H, suggests rather dry conditions in which relatively large quantities of brown vitrinite could develop to the apparent detriment of the exinitic components. These two bands are characterized by an abundance of complex types VII and VIII in which brown vitrinite and micrinite are the dominant constituents. These two bands have similar compositions except that a greater content of the fusinite-dominated type III occurs in band E. These bands correspond to the type of coal described by Karmasin (1952) as probably resulting from desiccation because of a drop in water level in the swamp. A similar coal type is the "trockendurit" or "dry durain" described by Teichmüller (1952a).

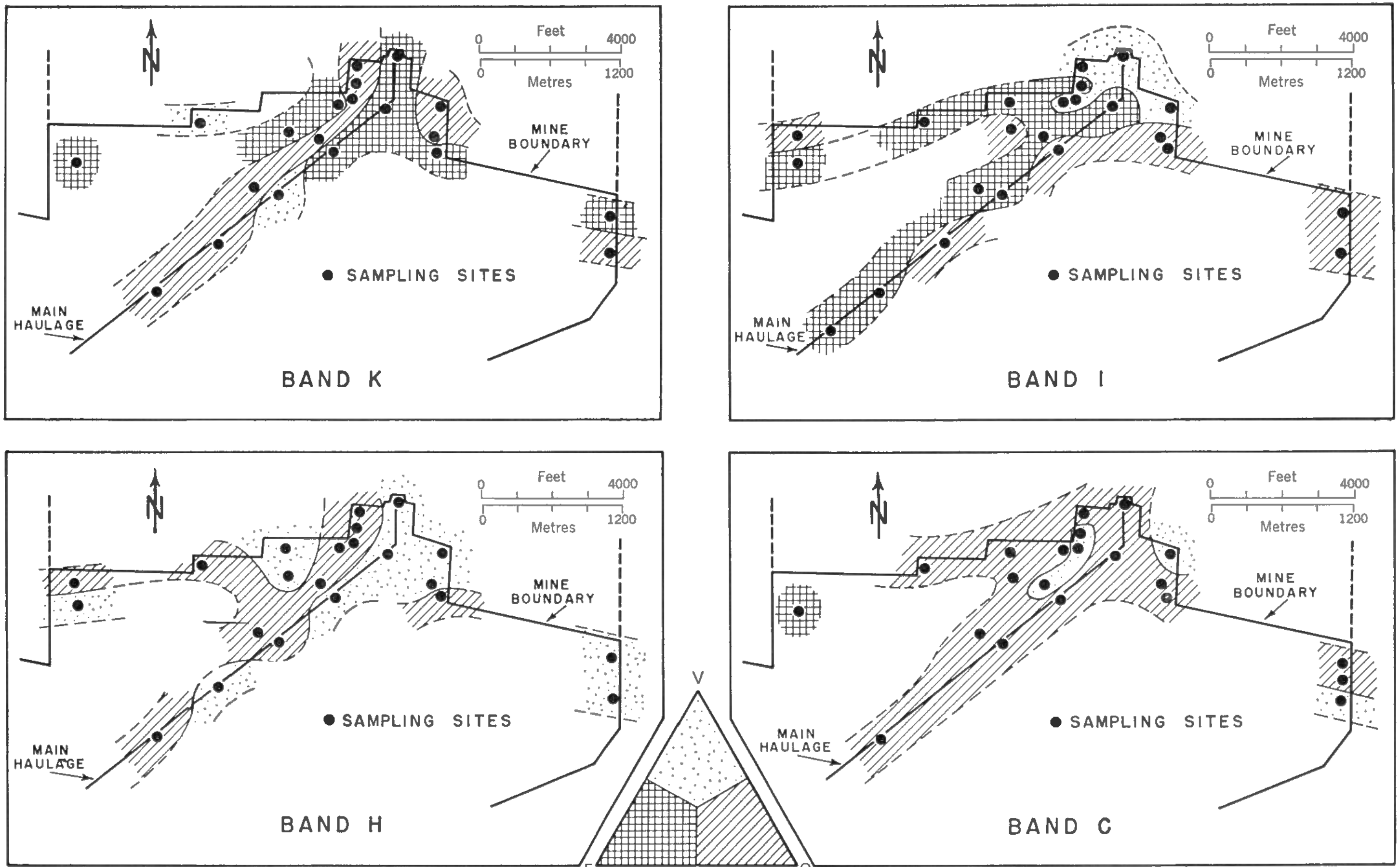
The fourth type, represented by bands I and K, are high-exinite bands. Because they contain exinite in a peculiar matted condition which may be the result of degradation, and because they contain relatively high proportions of brown vitrinite (especially band K), a complex environmental situation must have produced them. Possibly rapid fluctuations in the water level are responsible, permitting both the accumulation of spores and the development of brown vitrinite.

The major bands C, H, I, and K exhibit lateral compositional changes within the Princess Colliery (*see* Figs. 13, 16, 17, and 19). To summarize these changes and to compare these bands on a common compositional basis, the microlithotype data from each sample have been plotted in a facies triangle and the results portrayed as facies maps on Figure 21. The axes of the triangle represent microlithotypes high in red vitrinite (II, VI), those high in exinite (V), and those in which the opaque and semi-opaque constituents are predominant (III, IV, VII, VIII, IX).

Figure 21 shows first the marked difference between bands C and H and bands I and K. Of the samples in bands C and H, only one in band C is dominated by microlithotypes rich in exinite (Fig. 21, band C), in contrast to bands I and K in which types high in exinite are common. Band C is the dullest of all the bands in terms of opaque constituents. Five samples of this band are dominated by red vitrinite microlithotypes, and of these, three occur in a cluster along the main haulage way.

The map for band H shows clearly that the samples high in opaque matter are concentrated in an arcuate pattern on the west side of the mine, whereas most of the samples containing microlithotypes high in red vitrinite occur in the east part of the mine. Because the opaque constituents of band H consist of a large proportion of brown vitrinite, and because it is thought this component is the product of desiccation, the data presented on the map are interpreted to indicate that conditions of relative dryness prevailed in the area of the western side of the mine during the formation of band H. Band I shows a marked concentration of exinite-rich microlithotypes on the west side of the Princess Colliery; the samples toward the east show a dominance of microlithotypes high in the opaque macerals. In addition, a cluster of samples near the centre of the mine shows a dominance of red vitrinite microlithotypes. Teichmüller (1950) postulated that spore-rich durains are formed as "Schlamm" (slime) accumulations in more or less open areas of a peat swamp. This would suggest that the area on the western side of the Princess Colliery was a lake or pond during the formation of this band, whereas those areas in the mine where band I is dominated compositionally by other microlithotypes probably represent less open areas with more indigenous vegetation.

For band K an origin similar to that of band I is postulated, although the locale of extensive exinite preservation seems to have shifted to the eastern part of the mine. The pattern of microlithotype distribution is more irregular and broken in band K



E MICROLITHOTYPES RICH IN THE EXINITE
V MICROLITHOTYPES RICH IN THE RED VITRINITE
O MICROLITHOTYPES RICH IN THE OPAQUE MACERALS

FIGURE 21. Distribution of microlithotypes in selected dull bands of the Harbour seam, Princess Colliery.

than in band I, indicating the existence of several small patches of open water in this area of the swamp at the time of deposition. The presence of relatively large amounts of brown vitrinite in all the microlithotypes of band K is not in line with Teichmüller's ideas of origin for high-exinite bands, and suggests that desiccation may have played a part in the formation of band K.

Figure 22 shows the distribution of ash within the Princess Colliery for the four main bands examined, namely C, H, I, and K. Also shown on the small maps of this figure are distribution data for some of the opaque macerals in these bands. The ash contents for each of the four bands have been divided into three groups of low, intermediate, and high, and the values for the opaque materials have been divided at a median value for each band into a group with high contents and a group with low.

The maps show that the distribution of ash values for any of the bands is not random, but can instead be resolved into patterns that must reflect to some degree the movement and deposition of inorganic materials in the swamp. Ash is made up of two components: that derived from the plants themselves (inherent ash), and that contributed by wind- and water-borne detritus. The former is obviously proportionately greater in those samples with low ash contents. Raistrick and Marshall (1939) quoted a figure of 1 per cent for inherent ash, but this must be viewed with some reservation, depending as it does upon the type of vegetation involved, the amount of degradation of plant material in the swamp, and removal or concentration of inherent mineral matter. Given these considerations, it is still fairly certain that a high percentage of the ash shown for all the bands of this study is derived from adventitious or detrital mineral matter.

The patterns of ash distribution vary widely from band to band, although this may be attributed in part to sparseness of samples. These patterns probably reflect variations in the drainage patterns during different times in the swamp development. It is of interest to note that in each of the bands the low ash contents occur near what is now the centre of the Princess Colliery. Apparently this was an area that was at least partly protected from deposition of mineral matter during the formation of all four of the investigated bands.

Bands C and K show a more or less equal distribution of high and intermediate ash contents on both east and west sides of the mine. Band H and especially band I show a concentration of high and intermediate values on the west side of the mine; this suggests that the source of inorganic detrital material lay toward the west during the deposition of these two bands.

Superimposed on the four maps of Figure 22 are symbols denoting for each sampling site its content of opaque macerals, whether high or low relative to the median content of opaque macerals for that band. Not all the opaque and semi-opaque macerals are represented. For bands C, H, and I, the lower contents of fusinite and micrinite are associated with the lower ash contents. This relationship is expected because mineral matter tends to accumulate in the more open parts of the swamp, which is also where vegetal remains tend to be more degraded and carbon-rich constituents such as fusinite and micrinite become concentrated. It is difficult to explain, at this point, why this relationship does not come out with band K, and is replaced by one between brown vitrinite and ash.

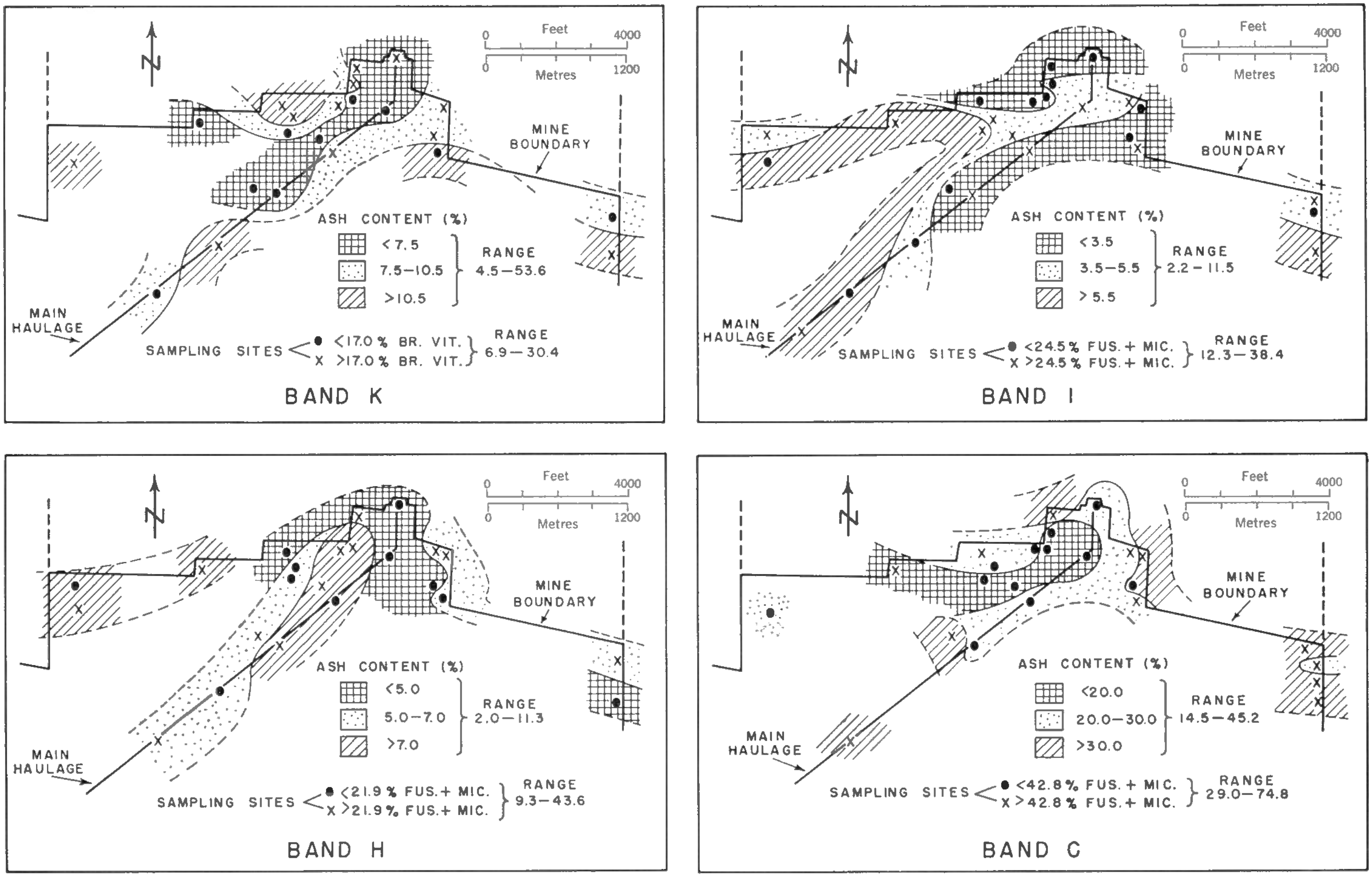


FIGURE 22. Distribution of ash and some opaque macerals in selected dull bands of the Harbour seam, Princess Colliery.

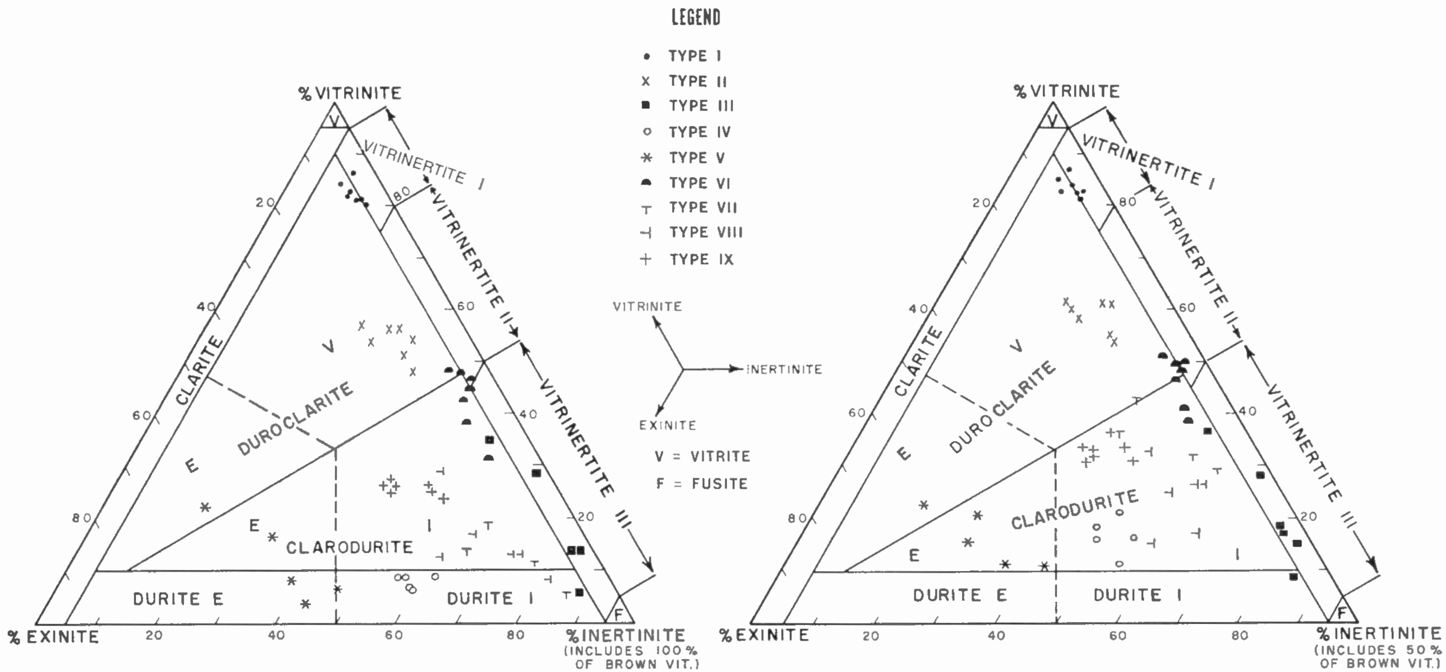
The microscopic analysis of all seven dull bands reveals some of the features that can give coal a dull appearance. These are an abundance of: (1) fusain, (2) mineral matter, (3) opaque and semi-opaque micrinite, (4) exinitic material, and (5) finely divided red vitrinite. One might expect these characteristics to be expressed by different megascopic appearances. These have not been quantitatively assessed, except that the high-spore layers, bands I and K, have the most compact and dull appearance, whereas bands D and J_1, characterized by an abundance of finely divided red vitrinite, have the brightest appearance. Wandless and Macrae (1934) distinguished between black durain, in which a great abundance of microspores were embedded in an opaque or feebly translucent groundmass, and grey durain, which had fewer spore remains and contained a considerable amount of fusain. The excellent photographs shown by these authors of the megascopic appearance of these two types do not indicate a correspondence with the megascopic appearance of the bands of roughly similar microscopic constitution examined in the present study. The high-exinite durains in the Harbour seam have a definite 'grey' appearance as compared with the 'black' character shown in the photographs of Wandless and Macrae.

Comments on Classification Procedures Followed in This Study

The value in describing the great number of simple microlithotypes shown on Figure 12 is worthy of discussion, especially because for the description of facies relationships they were regrouped into nine complex types. Such discussion involves the objectives and the method followed in examining the coal petrographically. The writer believes that the sixty simple microlithotypes represent natural populations in the coal, and the manner in which they were selected reduces to a minimum the forced classification of entities. It might be said, in this connection, that the complexity lies not in the method, but rather that the method revealed the complexity of the coal examined.

It should be pointed out that although each band is composed of a large number of simple microlithotypes, a relatively small number constitute the bulk of the band. Table XX shows the composition of the bands in terms of the simple microlithotypes. The 50 per cent or greater line is indicated on the table. In every band no more than five simple microlithotypes constitute over 50 per cent of the layer. The particular characteristics that distinguish each band are vested largely in these major constituents. The remaining constituent microlithotypes are generally variants of the major entities, commonly related assemblages in the same class.

The International Committee for Coal Petrology shows the composition and relationship of microlithotypes on a ternary diagram. On Figure 23, the compositions, in terms of macerals, of the nine complex microlithotypes from each of the seven bands investigated in the present study have been plotted on such diagrams. For example, complex type I is represented by a series of black dots near the apices of the triangles. Each dot represents the composition of complex type I from one of the investigated bands, that is, it represents the composition of this microlithotype as shown by the



(1957 EDITION EMENDED)

FIGURE 23. Comparison of complex microlithotypes with Glossary system of nomenclature and classification.

bar graph associated with the appropriate panel diagram. Complex type I was present in each of the seven bands investigated, thus there are seven black dots representing the slight variations between the seven bands.

These triangular diagrams are based on the grouping of macerals. The International Committee uses the three group macerals: vitrinite, exinite, and inertinite. The maceral materials encountered in this study would be classified into these groups as follows:

Vitrinite:	red vitrinite
Exinite:	exinite and resinite
Inertinite:	brown vitrinite, semi-fusinite, fusinite, micrinite, and mineral matter

The difference between the two diagrams plotted on Figure 23 is that on one triangle 100 per cent of the brown vitrinite has been included in inertinite, whereas on the other triangle 50 per cent has been placed in inertinite and 50 per cent in vitrinite. The former arrangement is probably more appropriate for comparison with the Glossary system. It should be noted that in the present study the mineral matter has been included with inertinite. This is not done in the grouping proposed by the International Committee.

The form of the diagram proposed by the International Committee has been emended by Hacquebard (pers. com.) for practical reasons in connection with the petrographic work carried out by him and under his direction. The original line separating durite from clarodurite was drawn at the 5 per cent vitrinite line. Hacquebard felt that if he used this threshold only the extremely well developed durainic material would fall below the line, leaving a great compositional spread in clarodurite and duroclarite. For this reason he raised the threshold to 10 per cent vitrinite. Hacquebard also divided vitrinertite into three subdivisions so the wide range in vitrinertite was more manageable.

As shown on the two diagrams (Fig. 23), the areas designated as clarodurite and durite have been subdivided by dashed lines into compartments designated E (exinite-rich) and I (inertinite-rich). Duroclarite has also been divided into duroclarite E (exinite-rich) and duroclarite V (vitrinite-rich).

In the present investigation the placement of the various complex microlithotypes on the ternary diagram shows some interesting features. Types I, II, IV, and IX occur in rather well defined clusters; types III, V, and VI display a somewhat elongated pattern; and types VII and VIII occur as a somewhat diffused group that cannot be separated on this diagram. There are some problems and disadvantages associated with the representation of coal composition within the arbitrary division lines of the ternary plot. Though most of the complex types of the present study show a rather well defined grouping, this grouping in many instances shows no regard for the division lines on the diagram. For example, one or more of the type I compositions fall into the category of vitrinertite I; the remainder belong to duroclarite V. On the other hand, all type II occurrences would be classified as duroclarite V. Thus some of the distinction between types I and II is lost. Similarly the single natural assemblage represented by the exinite-rich type V is unfortunately spread over four compartments on the ternary diagram. In using this diagram it is necessary to group macerals. In the present study, this prevents the separation of types such as VII and VIII which are distinguished on the basis of the brown vitrinite content. Such a distinction might be important particularly in view of the different genetic implications embodied in these constituents as discussed earlier. This has the unfortunate result of placing in four separate categories occurrences which in the Harbour seam belong to a single natural assemblage. The diagram shows, however, the essentially bimaceral character of types III and VI where the main variation is between vitrinite and inertinite, which in this example happens to be composed largely of fusinite. The rather well defined clusters, shown by most of the complex microlithotypes on this diagram, indicate that the manner whereby the simple microlithotypes were grouped into the complex types was fairly effective in delineating populations of preferred constituent associations. Thus the form of the diagram itself is useful in summarizing petrographic data, although in the present study it appears to be more meaningful if the various arbitrary lines separating microlithotype boundaries are ignored.

Chapter IV

SUMMARY AND CONCLUSIONS

The objectives of this study were twofold: (1) the investigation of lateral and vertical changes in a coal seam, utilizing megascopic techniques; and (2) the exploration of similar changes on a more refined scale in selected dull layers from within the seam, using microscopic methods. In the course of the second part of the study, a new approach was attempted in the identification and description of microlithotypes. The Harbour seam of the Sydney coalfield, Nova Scotia is early Pennsylvanian (Allegheny) in age and high volatile A in rank.

In the first phase of the research thirteen column samples were collected over a linear distance of approximately 23 miles. These were polished and examined in the laboratory and their composition described in terms of the components vitrain, clarain, claro-durain, durain, fusain, and bone. A minimum band width of 3 mm was set for these components as advocated by the International Committee on Coal Petrology. The clarain was subdivided on the basis of the texture of the contained vitrinitic bands into coarse, medium, and fine. This textural breakdown is summarized as follows:

Fine clarain—over 50 per cent of vitrinitic lenses <1 mm
Medium clarain—over 50 per cent of vitrinitic lenses >1 mm <2 mm
Coarse clarain—over 50 per cent of vitrinitic lenses >2 mm <3 mm

To provide additional data and closer control over the variation in some of the important dull layers, fifty-three in situ sections of the seam were measured and described megascopically in the Florence, Princess, and No. 12 Collieries. From these descriptions and the data from the thirteen column samples, the writer plotted seven stratigraphic sections covering the seam from the Florence Colliery to Morien Bay. These showed the nature and degree of variation within the entire Harbour seam. The seam was then divided into benches or divisions, each bounded by persistent and easily identifiable dull layers, and the variation within these divisions was examined in terms of the components described above. All samples of the dull bands collected in the course of the in situ descriptions were ashed, as well as samples of the dull layers encountered in the column samples. Rather large duplicates (3 to 4 gm of coal) of each sample were ashed to provide sufficient material for possible X-ray spectroscopy. The ash data reported are on the air-dried coal and are not corrected for moisture content.

The second part of the study involved the analysis by thin sections of the dull layer samples collected in the Princess Colliery. These were analyzed in terms of the following eight constituents: red vitrinite, brown vitrinite, semi-fusinite, fusinite, micrinite, resinite, exinite, and mineral matter. Four textural variations of red vitrinite were established, and their amounts determined in the samples analyzed.

The data, in terms of macerals and maceral groups, were analyzed to determine whether natural associations of these basic components existed in coal. The procedure followed was based on the assumption that coal seams are great systems of lenses of widely varying size and composition. The dull layers studied by the writer are composed of smaller sublayers and lenses differentiated from one another in terms of composition and texture. The dull-layer samples studied microscopically were examined to outline these petrographically different lenses. The compositions of these lenses, in terms of macerals and maceral groups, were then calculated from the maceral data already at hand. Bar diagrams representing the composition of each lens were plotted and grouped visually. The mean petrographic aspect of each group that so emerged was considered a microlithotype. The microlithotype data were used to prepare fence diagrams of the seven most important dull layers analyzed to show lateral variation. The layers were compared on the basis of their microlithotype composition, and speculative interpretations regarding their geneses were made. These various endeavours produced the following results and conclusions.

1. On the basis of megascopic examination the Harbour seam was shown to be predominantly a bright coal, that is, composed to a large extent of clarain. The dull layers encountered were generally relatively thin and form a relatively small percentage of the total seam.

2. The megascopic examination provided new information on the areal extent of the dull layers, some of which had been identified and discussed by previous workers. Other less prominent layers were more precisely identified and their areal distribution revealed, as was the relatively non-persistent character of some of the dull bands. A total of eleven dull layers exists in the Harbour seam; these have been labelled A to K inclusively. Bands C, H, I, and K are prominent, widespread, and easily traced. Band D is less conspicuous, but nearly as widespread. Bands E, G, F, and J_1 are less conspicuous, and apparently less well developed in their areal extent. Bands A and B are even more erratic in areal distribution and megascopic appearance.

3. One of the megascopic units identified was band J_1, the basal part of a complexly intertongued semi-dull zone, zone J, that occurs in the upper part of the seam and extends from the Florence Colliery to No. 12 Colliery in New Waterford. It appears to have its best development in the eastern part of the Princess Colliery and in No. 12 Colliery.

4. The megascopic data, as summarized in the stratigraphic cross-sections, show that peat accumulation first began in the Glace Bay and Morien Bay areas and gradually spread toward the northwest. Band C, which occurs but a few centimetres above the base of the seam in the Florence Colliery, occurs higher and higher above the base as the seam is traced toward the southeast. Thus the 90–100 cm of coal below what is thought to be the eastward extension of band C in No. 20 Colliery in Glace Bay is represented by about 7 cm on the western side of the Florence Colliery. On the

other hand, the upper 80 cm of coal overlying band I in the Florence Colliery is represented by only a few centimetres at the top of the seam in No. 20 Colliery.

5. Additional information in the Princess and No. 12 Collieries suggests that the two rider seams occurring over the main seam in the Florence Colliery may be equivalent to the rider seams that are found over the main seam in the Glace Bay area.

6. The breakdown of the seam into divisions bounded by prominent dull layers, and the comparison of these divisions in terms of volume percentages of megascopic components contained within them, show some rather significant variations laterally and vertically. These are listed as follows.

(a) Of the "bright" components, vitrain is the least abundant generally, coarse clarain is the next most abundant, followed by medium clarain, then fine clarain, the latter being the most abundant of all;
(b) Of the "dull" components, claro-durain is the most abundant;
(c) Facies patterns based on the relation of coal types to environments of accumulation show that the lower part of the seam from the pavement up to band I appears to be dominated by coal types derived from a mixed reed-moor and forested-moor environment. In contrast, the part of the seam occurring above band I appears to be the product of a mixed reed-moor and open-moor environment;
(d) The same facies patterns show a concentration of fine clarain in three of the four divisions examined in No. 26 Colliery. It is suggested that this concentration is related to a levee-flank deposit (Hacquebard, *et al.*, 1964);
(e) Laterally the seam appears to be dullest in the western part of the field, though this varies from division to division and is greatly influenced by the maximum development of division 5 in the western part of the field.

7. The writer has concluded that megascopic methods can be effectively used in coal petrography. Such methods have generally produced satisfactory and useful results in the present study of Harbour seam petrography. Practically all the dull or semi-dull layers described microscopically in previous work were also revealed megascopically in this study.

8. The microscopic work indicated the existence of sixty naturally delimited maceral and mineral associations or microlithotypes. These varied greatly in frequency of occurrence, ranging from 345 to 1. These microlithotypes were arranged in classes, each class being characterized by a certain type of petrographic trend involving certain macerals. The classes were labelled A to H inclusively, the class A or red vitrinite-dominant microlithotypes being selected as the starting point and all other classes being related to them. The characteristics of these various classes are summarized on page 33.

9. The sixty microlithotypes discussed above were also classified a second way by a somewhat different approach. Whereas the classification system described in (8) attempted to show certain trends or relationships, this second classification grouped the microlithotypes according to compositional similarity. Thus, for example, microlithotypes with high exinite contents were grouped together, whereas those with a moderate content of red vitrinite were placed in another group. Nine such groups

were established. The term complex microlithotype is used to describe these groups, and the sixty microlithotypes of which they are composed are termed simple microlithotypes.

10. The seven dull layers for which panel diagrams were plotted differed compositionally in terms of the percentages of their complex microlithotypes. Four different categories of dull layers were distinguishable. They were: (a) layers characterized by an abundance of complex type II (bands D and J_1); (b) layers characterized by an abundance of complex types VII and VIII (bands E and H); (c) layers characterized by an abundance of complex types IV, V, and IX (bands I and K); and (d) one layer characterized by an abundance of complex types III and VIII (band C).

11. An effort was made to interpret something of the genesis of these dull layers on the basis of their composition. These interpretations can be summarized as follows.

(a) Band C is characterized by a high content of fusinitic and micrinitic material along with a high content of mineral matter, as shown by its high-ash values. It is suggested that this layer is the product of a period of flooding, during which fusinitic material was, by the processes of sedimentation, intimately mixed with detrital mineral matter. This mixing was accompanied by considerable comminution and perhaps oxidation of organic matter, resulting in a high content of amorphous opaque material.

(b) Bands D and J_1 are similar in that they are dominated by an abundance of complex type II. The red vitrinite in both bands is in a state of fine division, though it is associated in band D with considerable quantities of exinite as represented by complex type V. Band J_1 may be the product of a transitional zone between the forested bog and the more open swamp. Band D may represent a somewhat more open variant of this same type of environment containing small pools or ponds in which spores accumulated.

(c) Bands E and H contain considerable quantities of brown vitrinite and relatively low percentages of exinite. Consequently they have been interpreted as resulting from conditions of relative dryness. A considerable part of the brown vitrinite is thought to be equivalent to the massive micrinite and/or decay fusinite mentioned by other authors. A number of authors have expressed the opinion that these materials are products of aerobic conditions.

(d) Bands I and K are high-exinite layers; they contain appreciable amounts of brown vitrinite, especially band K. The exinite has a somewhat corroded appearance. Band I contains little pyrite; band K contains a considerable quantity. Band I is relatively low in ash; band K is higher. The genesis of these two layers is difficult to interpret because of the somewhat contradictory nature of some of the evidence, but it is thought to represent an alternation between relatively moist conditions in which exinite accumulated, and relatively dry conditions in which brown vitrinite had an opportunity to develop and exinitic material tended to become corroded.

12. There appears to be a facies change laterally in the principal investigated layers, C, H, I, and K, from west to east in the Princess Colliery. Band C shows a

concentration of fusinite-rich microlithotypes in the western part of the mine. Band H shows a concentration in the same area of microlithotypes high in opaque and semi-opaque macerals (mainly brown vitrinite). Band I shows a concentration of exinite toward the west. The exinite distribution in band K is less pronounced in concentration in the western part of the mine. The implication is that the western part of the Princess Colliery had a deeper water cover during the deposition of bands C and I. Band H, on the other hand, suggests a reduced water cover on the west side during its formation, whereas for band K the areas with a deeper water cover are less well defined and seem to have shifted somewhat from the west.

13. Ash-distribution maps for the four main dull bands, C, H, I, and K, show what appears to be a concentration of low-ash areas for all four bands in the centre of the mine. Bands H and I, especially the latter, show a concentration of high-ash contents on the west side of the Princess Colliery. For bands C, H, and I, the samples with low-ash contents also generally seem to have lower fusinite and micrinite values.

14. Comparison of the complex microlithotypes with the microlithotype system of the International Committee for Coal Petrology, as expressed on a ternary diagram, reveals these features:

(a) Some of the complex microlithotypes show well-defined clusters or linear patterns on the diagrams; others are less well defined.

(b) The less well defined complex microlithotypes have characteristics that depend on the differentiation of brown vitrinite, micrinite, and fusinite. This differentiation cannot be done on the ternary diagram, because all these components are included under the single heading of inertinite.

(c) The distribution of the complex types does not correspond to the arbitrary boundary lines drawn on the diagram. The diagram would therefore be more meaningful if the boundaries of microlithotypes were drawn to encompass natural populations of material, or if the boundaries were dispensed with completely.

15. Although many simple microlithotypes participate in the formation of any particular layer, relatively few (never more than five) constitute over 50 per cent of that layer. These few major constituent microlithotypes represent the characteristic compositional nature of the layer in which they occur. Of these simple microlithotypes, A4 is the most widespread and the most common. It is the simple microlithotype in which red vitrinite is moderately dominant. Thus, even in very dull layers, such as bands C, I, and K, a great deal of transitional material represented by this microlithotype is present.

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APPENDIX I

Microlithotype Data on Dull Layers

TABLE V — *Microlithotype Composition of Band C*

Complex types[1] in layer, %		Simple microlithotypes in layer, %						
II	21.2	A4 13.3	F1 3.3	E1 1.7	E6 1.2	H1 0.9	E2 0.5	D2 0.3
III	18.9	C9 11.1	C5 4.2	C4 1.2	D5 0.7	E5 0.7	D4 0.5	D6 0.5
IV	6.3	H9 5.8	H4 0.5					
V	1.6	H6 1.6						
VI	8.2	C8 3.0	D1 2.3	C3 1.9	C7 1.0			
VII	3.5	B4 3.0	B5 0.5					
VIII	29.3	H10 13.6	H3 10.1	E4 2.1	E7 1.6	H2 1.4	E3 0.5	
IX	11.0	G5 3.2	F3 2.9	F2 1.7	G2 1.7	G4 1.5		

Maceral Composition of Complex Types in Band C

Type	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter
I	83.3	1.9	0.8	2.7	4.8	0.4	4.9	1.2
II	51.4	6.6	3.5	8.2	13.3	1.1	11.8	4.1
III	5.2	8.3	9.8	37.2	21.6	0.2	5.9	11.8
IV	5.7	9.7	2.2	8.0	33.6	0.9	33.1	6.8
V	7.0	8.0	—	4.0	26.0	—	47.0	8.0
VI	38.3	6.6	6.6	22.7	14.6	0.5	7.8	2.9
VII	4.9	48.2	7.6	4.3	20.1	1.3	7.2	6.4
VIII	7.9	17.9	4.9	11.9	33.8	0.8	9.5	13.3
IX	24.2	12.8	7.9	9.2	19.8	0.7	20.2	5.2

[1]Complex type I excluded from calculations on "dull" parts of band

TABLE VI *Microlithotype Composition of Band D*

Complex types[1] in layer, %		Simple microlithotypes in layer, %				
II	63.0	F1 30.2	A4 20.8	C1 6.3	E1 3.8	C6 1.9
III	2.0	C4 2.0				
V	18.0	H6 9.5	H7 5.9	H5 2.6		
VI	2.0	C7 2.0				
IX	15.0	F3 5.0	F2 3.8	G2 3.8	G3 2.4	

Maceral Composition of Complex Types in Band D

Type	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter
I	84.3	1.6	0.6	1.7	3.9	0.4	6.7	0.8
II	56.8	7.1	0.9	7.9	8.6	0.2	17.2	1.3
III	35.0	2.5	—	50.5	5.0	0.5	6.0	0.5
V	17.1	8.2	0.3	4.4	16.1	0.9	51.0	2.0
VI	48.0	3.0	7.0	27.0	6.0	—	5.0	4.0
IX	26.1	11.9	3.8	8.2	20.1	1.2	27.1	1.6

[1]Complex type I excluded from calculations on "dull" parts of band.

TABLE VII | *Microlithotype Composition of Band E*

Complex types[1] in layer, %		Simple microlithotypes in layer, %				
II	35.6	B1 14.9	A4 10.8	D2 7.4	H1 1.7	F1 0.8
III	14.0	D4 4.9	C5 4.1	D7 3.4	D8 1.6	
IV	3.3	H4 3.3				
VI	6.6	C3 5.0	D1 1.6			
VII	16.5	B5 6.6	B8 4.1	B6 3.3	B9 2.5	
VIII	18.2	H3 10.8	H10 6.5	H2 0.8		
IX	5.8	G5 3.3	G2 2.5			

Maceral Composition of Complex Types in Band E

Type	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter
I	86.1	2.3	0.7	2.1	4.4	0.6	3.5	0.3
II	54.5	13.7	7.3	6.4	7.8	2.0	7.6	0.7
III	13.8	7.3	29.5	38.8	5.4	—	4.0	1.2
IV	9.0	18.0	3.0	6.0	28.0	5.0	28.0	3.0
VI	46.9	7.2	3.0	31.9	7.2	—	3.5	0.3
VII	11.3	41.6	17.7	9.4	9.1	1.5	9.1	0.3
VIII	12.8	26.8	7.2	6.8	31.0	1.1	12.4	1.9
IX	26.9	14.2	10.7	7.5	18.3	3.1	17.8	1.5

[1]Complex type I excluded from calculations on "dull" parts of band.

TABLE VIII | *Microlithotype Composition of Band H*

Complex types[1] in layer, %		Simple microlithotypes in layer, %					
II	41.2	A4 25.8	B1 5.6	G1 5.6	E6 2.6	D2 0.9	F1 0.7
III	6.4	C5 3.0	C4 1.7	C8 1.7			
IV	5.5	H4 4.2	H9 1.3				
V	0.7	H7 0.7					
VI	6.8	D3 2.4	G3 2.2	D1 2.2			
VII	13.3	B3 3.9	B8 2.9	B2 2.6	B9 1.7	B4 1.4	B5 0.8
VIII	18.4	H3 12.8	H10 2.6	E3 1.3	E7 0.9	H2 0.8	
IX	7.7	G2 2.5	F3 2.1	G4 2.1	F2 1.0		

Maceral Composition of Complex Types in Band H

Type	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter
I	80.9	3.7	0.7	3.5	4.5	1.1	4.1	1.5
II	48.2	14.7	5.1	6.5	10.5	2.4	11.0	1.6
III	13.8	2.9	28.8	46.3	3.4	0.7	2.3	1.8
IV	8.7	25.0	5.2	6.1	23.5	3.4	26.0	2.1
V	23.0	—	9.0	2.0	6.0	—	60.0	—
VI	32.0	13.7	16.1	20.5	9.2	2.0	6.2	0.3
VII	19.2	46.5	3.4	6.2	9.7	2.9	11.9	0.2
VIII	12.5	26.3	6.6	8.9	32.1	2.2	10.6	0.8
IX	25.2	21.6	2.8	9.5	17.6	2.6	19.9	0.8

[1]Complex type I excluded from calculations on "dull" parts of band.

TABLE IX | *Microlithotype Composition of Band I*

Complex types[1] in layer, %		Simple microlithotypes in layer, %					
		A4	F1	G1	E1	E2	D2
II	31.3	18.9	6.4	3.3	1.1	1.1	0.5
		H9	H4	H8			
IV	13.7	10.8	2.3	0.6			
		H6	H7	H5			
V	36.5	15.2	13.6	7.7			
		D1	C2	C3			
VI	1.9	0.9	0.5	0.5			
		H10					
VIII	1.9	1.9					
		F2	G2	G5	G4	F3	G7
IX	14.7	4.7	4.4	2.5	1.6	0.8	0.7

Maceral Composition of Complex Types in Band I

Type	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter
I	82.0	2.7	0.4	2.1	4.5	1.4	5.4	1.5
II	54.0	8.9	2.0	6.4	10.0	1.8	15.0	1.9
IV	9.4	13.1	3.4	8.1	30.0	1.5	33.0	1.5
V	8.3	10.6	1.2	7.1	17.9	1.4	51.5	2.0
VI	48.7	6.9	2.9	25.7	7.8	1.0	5.1	1.9
VIII	11.9	6.0	—	10.8	45.1	1.6	24.6	—
IX	27.5	12.7	2.9	7.5	18.0	1.8	26.2	3.4

[1]Complex type I excluded from calculations on "dull" parts of band.

TABLE X | *Microlithotype Composition of Band J_1*

Complex types[1] in layer, %		Simple microlithotypes in layer, %					
II	78.4	A4 55.4	B1 8.0	C1 6.4	E1 4.2	E6 2.2	H1 2.2
III	0.6	C4 0.6					
VI	7.5	C7 4.0	C3 1.5	C2 1.0	D8 1.0		
VIII	5.5	E7 5.5					
IX	8.0	G5 2.5	G6 1.5	G2 1.5	G4 1.5	F2 1.0	

Maceral Composition of Complex Types in Band J_1

Type	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter
I	81.0	3.5	0.3	3.0	5.4	0.5	4.8	1.5
II	56.6	10.4	1.0	8.3	10.6	0.7	10.1	2.3
III	28.0	—	—	64.0	6.0	—	2.0	—
VI	42.9	9.5	—	31.9	7.5	1.3	5.3	1.6
VIII	29.0	7.4	—	12.3	32.0	1.0	16.1	2.2
IX	25.2	9.1	5.3	9.1	20.6	2.3	25.6	2.8

[1]Complex type I excluded from calculations on "dull" parts of band.

TABLE XI | *Microlithotype Composition of Band K*

Complex types[1] in layer, %		Simple microlithotypes in layer, %								
II	27.4	A4 15.6	F1 3.3	G1 2.7	E1 1.6	H1 1.6	E2 1.3	E6 0.7	B1 0.5	B7 0.1
III	0.6	C8 0.3	D6 0.3							
IV	19.3	H9 9.7	H4 9.6							
V	28.0	H5 12.5	H6 10.4	H7 4.3	B10 0.8					
VI	1.1	D9 0.8	D1 0.3							
VII	6.8	B9 3.7	B8 1.7	B4 0.7	B3 0.7					
VIII	2.5	E7 0.9	H10 0.9	H3 0.7						
IX	14.3	F3 6.4	G2 5.3	F2 2.0	G6 0.6					

Maceral Composition of Complex Types in Band K

Type	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter
I	80.1	3.0	0.9	3.0	5.3	0.6	4.2	2.9
II	55.8	10.8	1.3	5.1	11.9	0.8	12.2	2.1
III	12.8	9.8	27.0	35.9	7.4	—	4.4	2.7
IV	6.6	19.0	1.3	4.0	32.2	0.7	33.4	2.8
V	4.3	14.4	0.4	3.2	21.9	0.6	52.3	2.9
VI	45.2	4.8	20.7	6.6	7.7	—	5.3	9.7
VII	14.4	43.9	2.4	3.4	13.6	1.2	19.6	1.5
VIII	17.0	16.3	2.3	8.0	31.7	1.3	17.0	6.4
IX	25.2	13.6	1.6	4.4	25.0	1.2	26.5	2.5

[1]Complex type I excluded from calculations on "dull" parts of band.

APPENDIX II

Maceral Data on Dull Layer Samples

TABLE XII | *Maceral Composition and Ash of Band C, %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 1	29.8	20.7	3.6	18.0	15.4	0.9	8.0	3.6	17.6
IVA 4	21.7	7.7	10.1	10.4	31.0	0.8	8.6	9.7	22.9
IVA 6	20.7	21.6	4.4	7.1	24.1	0.9	14.0	7.2	25.7
IVA 8	14.0	12.4	4.2	28.9	26.5	0.3	8.3	5.4	14.5
IVA 10	47.6	5.3	3.9	12.5	14.5	1.3	8.0	6.9	20.0
IVA 11	32.1	14.6	5.3	9.1	20.6	0.8	11.7	5.8	18.2
IVA 12	37.5	13.2	4.6	14.0	14.5	0.7	12.0	3.5	17.4
IVA 13	10.8	10.4	6.9	17.7	31.2	0.3	11.0	11.7	37.6
IVA 15	10.9	21.3	6.7	6.2	27.4	0.2	17.6	9.7	22.4
IVA 17	20.2	24.3	2.8	10.7	21.5	0.7	12.8	7.0	19.7
IVA 18	21.7	9.5	8.8	15.8	18.2	0.6	8.5	16.9	30.1
IVA 21	19.3	9.2	10.1	13.1	24.3	0.7	13.1	10.2	22.5
IVA 26	11.7	3.9	5.3	32.6	29.9	0.9	9.4	6.3	39.9
IVA 27	27.9	6.0	3.4	17.3	15.7	0.3	23.7	5.7	28.3
IVA 30	11.9	9.3	7.4	28.8	18.5	0.8	10.7	12.6	37.9
IVA 32	35.0	5.7	3.0	12.4	27.8	0.5	9.1	6.5	28.6
IVA 34	22.4	6.0	2.2	11.2	28.1	0.3	23.7	6.1	33.6
IVA 35	7.4	19.9	13.2	15.8	23.2	0.3	10.0	10.2	27.6
IVA 36	7.6	16.5	3.8	10.3	35.5	0.5	7.3	18.5	25.3
IVA 37	18.6	1.2	0.2	21.8	32.2	0.2	20.5	5.3	41.7
IVA 38	25.4	7.1	5.9	17.9	21.2	0.6	12.2	9.7	35.3
Total Maceral Composition of Band C									
	21.5	12.4	5.9	15.4	23.5	0.6	12.2	8.5	

TABLE XIII — *Maceral Composition and Ash of Band D, %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 12	79.9	1.8	1.4	1.0	4.8	0.1	9.9	1.1	2.5
IVA 13	51.2	10.1	4.4	5.8	9.0	0.5	17.0	2.0	2.9
IVA 15	30.0	6.0	—	14.0	20.0	—	27.0	3.0	3.3
IVA 17	49.3	6.0	—	5.0	7.6	0.2	30.2	1.7	2.5
IVA 18	30.8	6.1	4.2	15.7	10.2	0.7	30.4	1.9	2.8
IVA 23	48.9	10.3	0.7	11.0	16.1	0.8	11.4	0.8	2.3
IVA 26	66.4	2.0	1.0	3.3	15.0	—	12.0	0.3	18.5
IVA 27	29.6	2.8	—	2.4	18.4	1.4	43.4	2.0	4.0
IVA 29	76.4	3.0	1.4	2.4	5.7	0.2	10.4	0.5	3.1
IVA 30	39.5	10.3	2.5	3.5	9.3	0.3	31.6	3.0	4.1
IVA 32	41.6	4.4	—	6.4	10.3	0.5	35.4	1.4	1.8
IVA 34	40.2	1.8	—	5.2	8.8	0.2	42.4	1.4	2.1
IVA 35	45.3	11.3	—	4.1	15.0	0.8	21.8	1.7	1.8
IVA 36	52.5	1.0	—	22.0	6.5	—	16.5	1.5	2.6
IVA 37	33.6	8.4	0.9	7.1	11.9	0.7	36.1	1.3	11.7
IVA 38	57.0	6.7	—	2.0	5.7	0.3	27.6	0.7	2.2
Total Maceral Composition of Band D									
	49.9	6.3	1.4	6.5	10.4	0.4	23.7	1.4	

TABLE XIV — *Maceral Composition and Ash of Band E, %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 8	25.1	28.8	6.7	10.5	15.8	1.6	10.8	0.7	5.8
IVA 10	52.2	23.0	0.5	3.1	9.6	2.5	8.3	0.8	2.7
IVA 11	22.5	44.3	6.2	5.4	7.6	2.2	11.4	0.4	4.3
IVA 12	60.3	19.2	1.8	3.7	4.7	2.5	6.8	1.0	6.4
IVA 13	23.1	7.3	2.3	8.3	48.0	1.0	7.7	2.3	4.1
IVA 15	44.7	18.3	14.0	4.7	6.3	2.5	9.3	0.2	5.2
IVA 17	26.4	25.7	12.8	8.2	17.1	0.8	8.5	0.5	3.8
IVA 18	21.8	6.7	6.5	32.9	20.3	0.3	9.3	2.2	3.2
IVA 23	26.0	15.4	11.7	19.0	13.8	1.3	11.4	1.4	4.3
IVA 26	68.8	1.0	—	5.0	9.8	1.0	14.1	0.3	2.5
IVA 30	44.4	4.1	18.3	23.9	5.4	0.5	2.0	1.4	3.5
IVA 35	26.6	30.8	3.4	7.7	19.0	1.4	10.4	0.7	2.8
IVA 36	21.8	24.8	31.4	3.5	11.0	1.1	5.9	0.5	2.8
IVA 38	17.8	35.1	2.0	3.7	22.4	3.1	14.0	1.9	4.2
Total Maceral Composition of Band E									
	32.1	19.8	10.3	12.2	13.9	1.4	9.2	1.1	

TABLE XV *Maceral Composition and Ash of Band H, %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 1	45.3	15.9	4.8	5.5	14.2	2.8	10.4	1.1	5.8
IVA 4	31.4	18.4	7.4	12.9	12.8	3.4	12.5	1.2	4.3
IVA 6	17.0	24.3	3.0	7.4	26.5	2.6	15.3	3.9	7.7
IVA 8	44.3	15.6	3.0	16.0	5.7	2.1	12.5	0.8	7.0
IVA 10	23.8	22.0	3.1	6.9	27.9	1.4	13.9	1.0	7.2
IVA 11	25.0	20.6	7.7	6.6	17.4	2.5	18.7	1.5	—
IVA 12	36.9	23.2	2.0	6.1	17.6	1.4	12.5	0.3	7.0
IVA 13	25.2	17.3	21.2	7.0	15.3	2.5	10.2	1.3	5.0
IVA 15	55.1	10.7	6.4	5.5	7.4	3.2	9.9	1.8	3.8
IVA 17	65.8	7.2	3.2	9.8	4.6	2.8	5.1	1.5	2.0
IVA 18	34.9	17.2	2.8	9.2	19.1	1.3	14.8	0.7	7.1
IVA 21	6.7	33.5	4.3	7.9	24.9	2.3	19.3	1.1	7.4
IVA 23	43.6	19.7	3.2	8.4	8.8	3.0	12.1	1.2	6.3
IVA 26	21.4	39.9	4.7	15.4	6.7	2.6	8.9	0.3	5.3
IVA 27	30.8	16.5	13.8	16.8	10.4	1.7	9.5	0.5	8.5
IVA 29	26.4	30.3	3.0	8.2	10.8	3.1	18.1	0.1	7.6
IVA 30	24.0	16.8	2.2	10.4	33.2	1.0	12.4	—	6.8
IVA 32	30.5	21.5	14.5	6.0	17.5	2.1	7.0	0.9	5.9
IVA 34	60.2	9.1	2.6	9.7	10.2	1.6	5.6	1.0	4.1
IVA 35	41.5	25.1	4.3	15.4	6.3	1.9	5.2	0.3	5.9
IVA 36	29.6	7.2	14.6	17.3	18.3	4.4	7.3	1.3	5.3
IVA 38	77.5	5.7	0.5	2.7	6.5	1.1	4.5	1.5	3.9
Total Maceral Composition of Band H									
	37.3	19.3	6.4	9.3	13.6	2.2	10.9	1.0	

TABLE XVI | *Maceral Composition and Ash of Band I, %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 1	30.2	13.1	1.8	6.6	23.1	1.0	21.0	3.2	10.8
IVA 4	19.6	18.4	1.4	7.0	14.5	1.7	36.6	0.8	2.4
IVA 6	63.5	4.3	0.2	9.5	10.5	0.9	10.0	1.1	2.9
IVA 8	5.6	9.5	0.8	5.7	19.4	0.6	56.3	2.1	6.3
IVA 10	19.3	13.0	5.5	9.5	22.4	1.0	28.5	0.8	3.9
IVA 11	29.3	9.8	—	9.1	12.7	1.8	35.9	1.4	3.1
IVA 12	10.9	10.8	2.9	6.7	16.4	1.7	49.4	1.2	3.6
IVA 13	42.6	14.5	2.1	8.2	9.4	1.0	20.7	1.5	3.2
IVA 15	27.4	14.6	1.9	8.1	14.2	1.0	31.8	1.0	2.2
IVA 17	26.9	8.3	0.5	14.0	12.8	2.5	33.9	1.1	3.9
IVA 18	31.5	3.0	1.1	7.9	30.1	2.2	23.2	1.0	3.0
IVA 21	22.7	5.4	3.7	5.7	21.0	2.0	38.9	0.6	2.2
IVA 23	43.9	12.5	2.4	9.0	11.9	1.7	15.7	2.9	4.2
IVA 26	12.8	15.2	3.7	6.4	19.4	1.1	40.9	0.5	3.0
IVA 27	23.6	8.3	1.4	7.8	11.8	1.8	30.9	14.4	5.7
IVA 29	27.1	12.3	5.0	3.5	20.7	2.5	27.4	1.5	4.4
IVA 30	17.0	7.5	1.0	7.9	15.7	1.3	48.5	1.1	6.0
IVA 31	16.2	7.3	0.4	4.7	19.0	0.6	41.8	10.0	11.5
IVA 32	43.5	8.8	4.6	7.4	10.1	0.8	23.7	1.1	1.7
IVA 34	35.2	12.2	0.2	4.2	16.7	2.3	28.5	0.7	3.5
IVA 35	32.8	7.4	0.6	5.8	19.7	1.2	31.0	1.5	3.0
IVA 36	32.5	10.1	—	5.7	15.0	2.5	32.1	2.1	3.6
IVA 38	27.4	12.6	4.3	7.2	21.9	1.2	24.3	1.1	7.4
Total Maceral Composition of Band I									
	27.9	10.9	1.9	7.1	17.0	1.5	31.7	2.0	

TABLE XVII *Maceral Composition and Ash of Band J_1, %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 1	58.1	10.9	—	13.6	8.9	1.3	5.5	1.7	3.5
IVA 6	59.5	14.5	—	3.5	9.6	0.9	10.5	1.5	1.3
IVA 8	46.4	10.6	0.4	8.5	17.9	1.1	12.7	2.4	3.4
IVA 10	52.6	7.8	—	21.5	9.6	0.4	6.2	1.9	1.5
IVA 11	50.3	15.7	—	12.8	10.7	0.7	7.5	2.3	2.5
IVA 13	55.3	14.5	—	3.5	10.2	0.4	14.1	2.0	4.2
IVA 17	48.9	10.7	1.9	14.2	13.4	0.6	9.2	1.1	1.7
IVA 18	61.4	8.1	—	8.9	7.7	0.4	9.4	4.1	1.2
IVA 27	58.3	7.8	0.7	15.8	8.5	0.2	6.3	2.4	3.9
IVA 29	54.7	8.3	—	7.5	10.9	0.8	14.1	3.7	5.5
IVA 30	39.0	6.6	3.2	12.1	20.2	0.8	15.6	2.5	1.3
IVA 31	58.2	6.8	—	8.8	11.1	1.9	10.0	3.2	3.2
IVA 32	59.2	9.4	1.6	1.8	12.6	0.2	14.0	1.2	1.0
IVA 34	43.9	13.7	6.1	8.1	10.0	0.5	16.4	1.3	2.1
IVA 35	57.0	11.7	—	5.8	10.5	—	13.0	2.0	2.3
IVA 36	66.9	10.0	1.3	3.1	7.9	0.2	9.8	0.8	2.2
IVA 38	54.6	10.8	1.4	7.6	11.9	0.5	11.9	1.3	3.3
Total Maceral Composition of Band J_1									
	53.2	9.8	1.2	11.0	11.7	0.8	10.1	2.2	

TABLE XVIII | *Maceral Composition and Ash of Band K (Lower Split), %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 1	31.1	9.9	—	3.9	19.3	0.9	33.1	1.8	10.2
IVA 6	25.6	16.6	0.1	3.0	19.1	0.6	30.4	4.6	8.3
IVA 8	33.4	16.2	0.2	3.9	18.6	1.0	25.7	1.0	5.9
IVA 10	38.9	6.7	3.2	4.3	23.4	0.7	20.6	2.2	7.8
IVA 11	23.4	15.5	1.0	4.7	19.2	0.9	33.3	2.0	7.4
IVA 12	20.1	19.1	1.8	6.1	19.8	0.5	31.2	1.4	9.1
IVA 13	28.2	26.9	—	3.7	13.2	1.6	22.9	3.5	6.9
IVA 15	17.4	18.3	—	1.9	21.4	0.7	38.5	1.8	7.0
IVA 17	47.9	8.8	—	3.1	15.8	0.4	22.9	1.1	5.9
IVA 18	4.5	18.7	2.1	4.6	24.3	0.8	42.9	2.1	10.2
IVA 21	37.7	13.4	0.2	3.5	20.4	0.6	22.8	1.4	4.5
IVA 23	22.8	29.1	3.0	2.1	14.4	0.6	23.7	4.3	18.1
IVA 26	21.6	10.8	1.0	5.8	22.8	1.0	34.3	2.7	6.5
IVA 27	25.2	17.9	—	3.4	15.8	0.9	32.2	4.6	12.4
IVA 30	13.7	15.3	0.5	3.9	34.6	1.3	28.8	1.9	8.2
IVA 32	14.1	18.7	2.7	3.2	26.1	0.6	32.1	2.5	9.1
IVA 34	19.8	21.5	1.5	2.0	22.1	0.5	29.7	2.9	10.1
IVA 35	14.8	14.5	0.7	2.9	26.0	1.0	38.0	2.1	20.3
IVA 36	18.8	15.9	1.0	4.4	17.4	0.7	39.8	2.0	8.0
IVA 38	23.3	22.7	1.5	1.9	20.8	0.7	26.7	2.4	18.9
Total Maceral Composition of Lower Split									
	24.6	17.1	1.0	3.6	20.1	0.8	30.4	2.4	

TABLE XIX | *Maceral Composition and Ash of Band K (Upper Split), %*

Sample	Red vitrinite	Brown vitrinite	Semi-fusinite	Fusinite	Micrinite	Resinite	Exinite	Mineral matter	Ash
IVA 1	24.9	12.1	3.1	9.4	22.7	0.6	25.2	2.0	14.8
IVA 6	48.8	3.1	0.8	10.5	19.6	0.1	15.1	2.0	46.2
IVA 10	23.9	10.0	0.2	4.3	14.2	1.2	44.3	1.9	13.0
IVA 11	44.9	9.9	8.9	5.8	10.4	1.3	12.8	6.0	14.8
IVA 12	25.3	12.9	7.6	3.1	20.0	0.4	30.4	0.3	33.2
IVA 13	29.6	10.4	1.1	14.0	21.6	0.6	20.1	2.6	12.4
IVA 15	28.4	11.5	0.6	3.1	23.4	1.3	29.6	2.1	—
IVA 17	1.1	13.0	7.4	7.4	21.9	0.5	46.1	2.6	9.2
IVA 21	6.3	7.0	0.4	6.7	30.0	0.5	47.5	1.6	7.4
IVA 26	22.8	3.8	5.2	6.3	32.5	1.0	22.1	6.3	12.6
Total Maceral Composition of Upper Split									
	23.5	9.0	3.9	6.9	22.5	0.7	30.5	3.0	

TABLE XX *Composition of Bands in Terms of Simple Microlithotypes, %*

Band C		Band D		Band E		Band H		Band I		Band J_1		Band K	
A	B	A	B	A	B	A	B	A	B	A	B	A	B
H10	13.6	F1	30.2	B1	14.9	A4	25.8	A4	18.9	A4	55.4	A4	15.6
										— — —			
A4	13.3	A4	20.8	A4	10.8	H3	12.8	H6	15.2	B1	8.0	H5	12.5
		— — —											
C9	11.1	H6	9.5	H3	10.8	B1	5.6	H7	13.6	C1	6.4	H6	10.4
H3	10.1	C1	6.3	D2	7.4	G1	5.6	H9	10.8	E7	5.5	H9	9.7
								— — —					
H9	5.8	H7	5.9	B5	6.6	H4	4.2	H5	7.7	E1	4.2	H4	9.6
— — —				— — —		— — —						— — —	
C5	4.2	F3	5.0	H10	6.5	B3	3.9	F1	6.4	C7	4.0	F3	6.4
F1	3.3	E1	3.8	C3	5.0	C5	3.0	F2	4.7	G5	2.5	G2	5.3
G5	3.2	F2	3.8	D4	4.9	B8	2.9	G2	4.4	E6	2.2	H7	4.3
B4	3.0	G2	3.8	B8	4.1	B2	2.6	G1	3.3	H1	2.2	B9	3.7
C8	3.0	H5	2.6	C5	4.1	E6	2.6	G5	2.5	*****		F1	3.3
F3	2.9	G3	2.4	D7	3.4	H10	2.6	H4	2.3			G1	2.7
D1	2.3	C4	2.0	B6	3.3	G2	2.5	****				F2	2.0
E4	2.1	C7	2.0	G5	3.3	D3	2.4					******	
*		C6	1.9	H4	3.3	D1	2.2						
				B9	2.5	G3	2.2						
				G2	2.5	F3	2.1						
				**		G4	2.1						
						***							

A = constituent microlithotypes; B = percentage of microlithotype in layer.
*plus 21 others present in amounts less than 2%.
**plus 5 others present in amounts less than 2%.
***plus 13 others present in amounts less than 2%.
****plus 11 others present in amounts less than 2%.
*****plus 8 others present in amounts less than 2%.
******plus 18 others present in amounts less than 2%.

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