MICROSCOPIC COAL RESEARCH IN CANADA [1]

by

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Introduction

Since the industrial developments of Europe and North America in the nineteenth century, coal has been considered as the most important mineral wealth a country could possess. Coal was often referred to as King Coal, and it was not until around 1950 that its position as the major fuel for modern society was seriously threatened by oil, natural gas and hydro-electric power. Particularly on the North American continent the question is now raised: what will be the future of coal, and which part will it play in the ever increasing energy consumptions of modern civilization? A survey made in Canada by the Dominion Coal Board in 1953 on the future energy requirements of the country revealed some pertinent facts regarding the role that coal would play in this. After a careful evaluation of the future supply of oil, natural gas and hydro-power, it became apparent that the present coal consumption of 37,500,000 tons annually will be maintained until 1965, after which a substantial increase to 58,000,000 tons will be necessary to meet the energy demands. This conclusion, it should be pointed out, was arrived at on the basis of a population increase to 16,500,000 by 1965, an no *net* additions to the overall energy supply from atomic sources in that period (O'BRIAN, 1953). From this it may be seen that coal, although not the sole important fuel anymore, is still one of our major sources of energy, apart from being a large supplier of numerous organic compounds.

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Coal is a complex substance, both in its chemical and physical composition. Although coal may truly be defined as a rock, it is a most unusual one, because it does not consist of minerals, but of a petrified mass of vegetable matter, which has been modified chemically and physically in varying degrees. This mass consists of an agglomeration of all sorts of plant components, ranging from a simple cell to such highly modified forms as cuticles, spores and pollen grains. The proportion in which these components are present, -as well as their degree of metamorphism controls the chemical and physical properties of coal. Added to this, a greatly varying amount of inorganic matter is present which immediately affects the value of coal as a solid fuel.

The identity of the carbonized plant tissues, their morphology, origin, distribution and quantitative amounts can only be studied by visual examination.

The plant entities in coal being very minute, this study is carried out primarily with a microscope, and is referred to as coal microscopy or coal petrography in a more restricted sense.

At present such studies are actively pursued at laboratories or universities in Great Britain, France, Belgium, Holland, Germany, USSR, India, Japan, Australia, Canada and the United States. In most of these countries coal microscopy is carried out for several purposes, namely to arrive at the best possible utilization of coal, to study problems related to the actual mining of coal, to investigate the origin of the different coal components by integrating this work with studies on peat deposition, to collect data for palaeobotanical reasons and finally to contribute to the knowledge of the stratigraphy and sedimentation in different coal areas.

The microscopic study of isolated fossil spores is important for stratigraphic purposes. It is referred to by some as palynology and is here included with coal microscopy. This work is micropalaeontological in nature, because it deals with distinctly separate entities, which have their own morphological shape, and accordingly are considered as fossil remains of once living forms of life.

This paper deals with some aspects of microscopic coal research encountered since 1949 when these studies were initiated in Canada by the author at the Coal Research Division of the Geological Survey of Canada at Sydney Nova Scotia.

Coal petrography

Remarks on terminology and techniques

Both mega and microscopic examinations of coal reveal that it is a heterogeneous substance, composed of different units that can readily be observed as banded ingredients. These ingredients, called vitrain, clarain, clarodurain, durain, semifusain and fusain have different chemical and physical properties, and accordingly behave differently on carbonization. Their swelling indices, agglutinating values, gas and tar productions etc. vary widely, and are related to the constituents or macerals which they contain. The macerals originated from the plant debris which contributed to the formation of coal. They can only be observed through the microscope, and carry names, such as vitrinite, exinite, micrinite etc.; terms defined at the 1935 Heerlen Conference on Coal Petrology. This terminology is in general use in Western

Europe and in Canada. In the United States a different nomenclature has evolved which is based on the fundamental researches of REINHARDT THIESSEN, who was one of the most outstanding scientists in this field.

No universally accepted nomenclature exists, and this is mainly due to the fact that two different techniques of microscopic coal research are in use. In Western Europe and Canada the majority of the examinations are carried out with polished sections of coal, whereas in the United States and in Great Britain to a certain extent, the thin section technique has been standard practice. Both methods have their own advantages, depending upon the nature of the objectives. Examinations under reflected light with polished sections reveal greater detail of the opaque components of the coal, whereas the translucent ones (except in the high rank coals which are entirely opaque) can best be studied under transmitted light with the aid of thin sections.

Terms such as translucent attritus, which are descriptive for thin section work, lose their meaning in polished section studies, where the different coal components are recognized on the basis of their reflectivity. Likewise, the maceral micrinite, although originally introduced by STOPES (1935) on the basis of thin section work, cannot readily be identified as such under transmitted light, since it may easily be mistaken for some of the other opaque constituents, for example needles of fusinite which do not show a cellular structure.

It is, therefore, concluded that the Heerlen terms should be restricted to the polished section technique, and for thin section examinations the U. S. Bureau of Mines terminology can best be adhered to.

It is now generally contended that for quantitative petrographic analyses the polished section technique has distinct advantages. With this method small particles of crushed coal can readily be examined by mounting in a suitable medium, which is a very difficult procedure with the thin section technique. This is now also realized by the U. S. Bureau of Mines, where thin section work used to be the sole practice.

Quantitative petrographic analysis

A quantitative analysis of both banded ingredients and macerals is carried out at Sydney with the aid of finely crushed coal embedded in lucite (or some other plastic bond). These so-called lucite pellets are examined under reflected light and the relative proportions of the different coal components are recorded with a Leitz integrating stage (HACQUEBARD, 1952). The method, developed in Germany by KÜHLWEIN in 1934, has many advantages over others currently in use. It is equally accurate, and far less time consuming.

However, as FRANCIS (1954) has pointed out, all petrographic analyses are of necessity based on visual observations, and therefore liable to serious errors because of the difficulty of estimating the proportion of material present as an impregnant or as filling of cells or spaces. Also the position in which a component is transected has an immediate bearing on the volume and weight at which it is recorded. Thus, in the case of spore exines, the area of the disc or profile is taken as being proportional to the volume and weight of the spore exine. If, however, the spore exine is flattened, as is usually the case, the estimated weight of the exine by visual observations is very much greater than that obtained from maceration or estimation by other chemical means. In crushed coal these difficulties may partly be overcome, because particles randomly orientated are transected. Nevertheless, the discrepancies between a rational chemical analysis and a petrographic one are undoubtedly related to the difficulties just explained.

1. *Maceral analysis.* — Since the 1935 Heerlen Conference, the practice in polished section work has been to express the petrographic composition of coal in terms of three groups of coal macerals, namely vitrinite, exinite, and "inertinite" (a terms coined by the Germans, and analogous to all organic opaque matter contained in coal). SEYLER (1948), MACKOWSKI (1951) and VAN KREVELEN (1953) have accordingly suggested to plot this composition in a triaxial diagram using these three major components, of which vitrinite is always the most abundant. Vitrain bands contain from 95 to 100 percent vitrinite. It is also present in a high percentage in clarain and durain, where it lies between the spores, cuticles and opaque matter. The seams of the Sydney coalfield contain between 70 and 85 percent vitrinte.

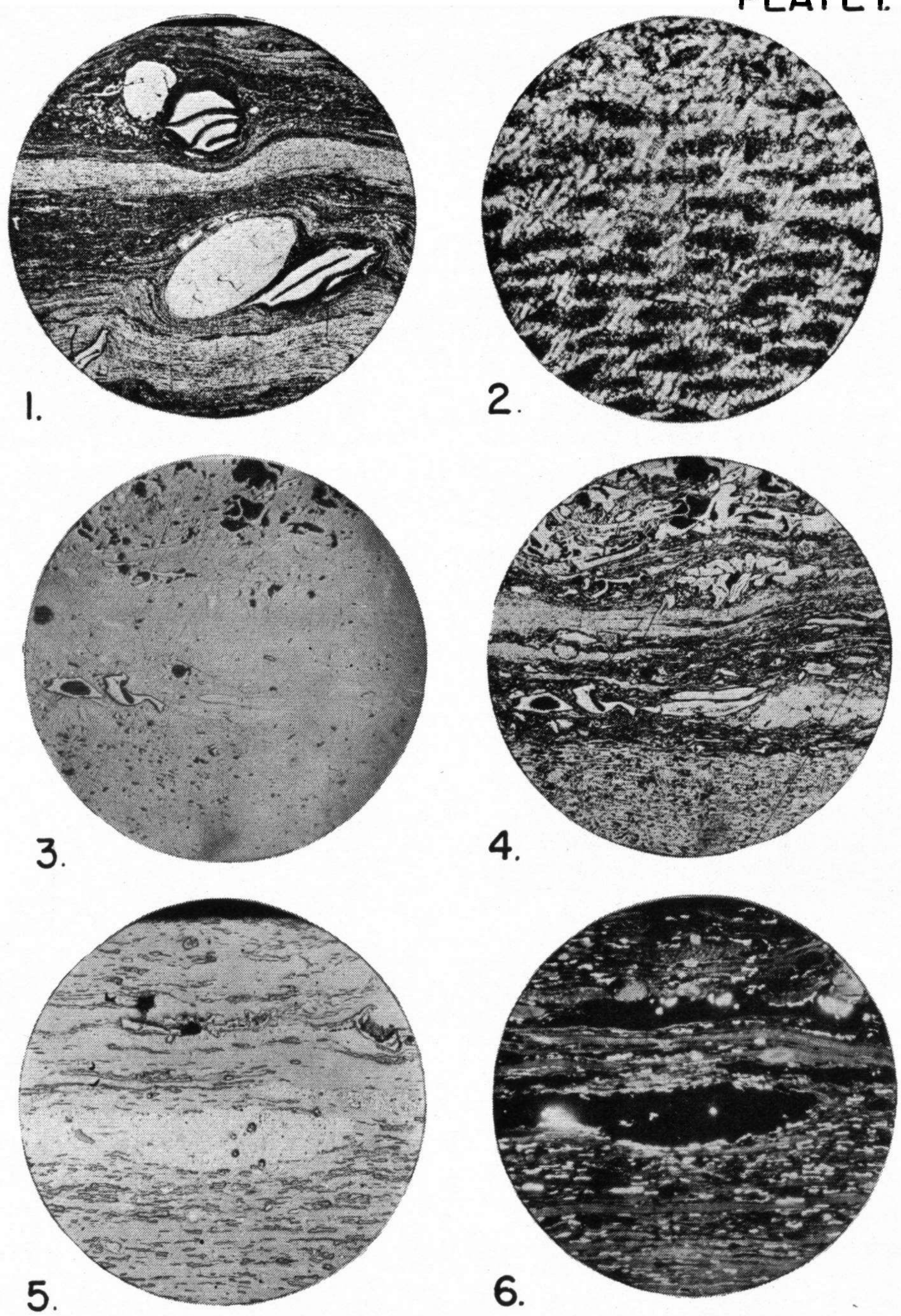
In thin section analyses the composition of the coal has also been expressed in terms of three major components, namely anthraxylon, translucent attritus and opaque attritus. However, the two compositions arrived at with the two techniques cannot be placed next to each other, because different units are combined. Therefore, the question arises which is the better way to express quantitatively the composition of coal?

The author is of the opinion that the polished section technique should not combine into one unit the vitrinite present in the vitrain bands, with the vitrinite that occurs in the clarain and durain bands. The thin section technique has kept the two forms of vitrinite separate, and refers to them as anthraxylon and humic degradation matter. THIESSEN (1920) has defined anthraxylon as bands of 14 microns thickness or more that usually show a cellular structure. Humic degradation matter is smaller than 14 microns, is devoid of a cellular structure, and probably consists of finely macerated cell wall material. However, THIESSEN states that in many instances the two components have a similar appearance and can only be differentiated on the basis of the arbitrary size distinction. In polished section work the separation of these two components is much more difficult, because vitrinite with cellular structure is only rarely noted under reflected light. In this method one has to rely almost entirely on the size distinction, when standard reflected light procedures are used.

However, the question may be raised: is there not a chemical difference between the two? From a study of etched polished sections the author is inclined to believe that the humic degradation matter is more readily oxidized than any other component in coal. It appears that most of the vitrinite that lies between the spores, etc. turns dark (or black) after etching, whereas the vitrinite present in the vitrain bands is much less affected. (*See* Pl. I, Fig. 1). In vitrain which has been etched using standard procedure, the cell lumens are affected while the cell walls are not noticeably changed. (*See* Pl. I, Fig. 2). This observation may indicate that the material that fills the cells in vitrain, may possibly be the same as much of the material that lies between the spores, i.e. as part of THIESSEN's humic degradation matter.

At Sydney, during the past two years, a great number of polished sections of Cretaceous coals from western Canada have been etched. These are nearly all of a low or medium volatile rank. Such coals can only be studied with etched sections, because without etching very little structural detail is revealed (*See* Pl. I, Figs. 3 and 4). Semi-quantitative determinations on the oxidized component show that it varies in amount between roof and pavement, and

PLATE I.



that in certain intervals it may be present in as much as 55 percent of the total composition.

Apparently the oxidizable material is an important component of our coals. At the present time it is not quantitatively expressed in the polished section work, where only the total amount of vitrinite is given. Accordingly the author is of the opinion that it is not entirely correct to express the composition of coal in the three components vitrinite, exinite and inertinite, but that a fourth component comparable to or at least in part identical with humic degradation matter should be included. The term ulminite, as mentioned by STOPES (1935), may perhaps be used to designate this component. Unfortunately the only method known to the author to bring out this component is by means of etching. This method greatly restricts accurate quantitative determinations. Such determinations may be possible through the use of phase contrast microscopy. Work on this is now in progress at the Sydney laboratory.

2. *Banded ingredient analysis.* — The macerals are not randomly distributed throughout the coal, but are concentrated in varying proportions in distinct layers or bands, referred to as banded ingredients. Vitrinite occurs in vitrain bands, fusinite in fusain bands or lenses, and all known macerals are combined in clarain, clarodurain and durain bands. A maceral analysis does not give information regarding the banded ingredients, and such an analysis alone is therefore insufficient to express the petrographic composition of coal.

Coals containing the same proportions of macerals may have different proportions of banded ingredients, as was found by HACQUEBARD and LAHIRI (1955) with their concentration experiments on screened and crushed coals. Whereas the amount of inertinite before and after the experiment was about the same, namely about 20 percent, the amount of durain was increased from 15 to 27 percent. From this result it was concluded that a different coal had been prepared, which possibly would react differently on carbonization. Unfortunately, in this particular case, the high ash and sulphur content of this coal did not warrant any coking tests.

As was previously mentioned, banded ingredient analyses are also carried out with lucite pellets of ground coal and a Leitz integrating stage. However,

PLATE I [1]

Figure 1. Harbour seam, Sydney coalfield, Canada.
Showing effect of etching on clarain (dark) and vitrain (light) bands. The white oval shaped ingredients are opaque matter (sclerotinite and fusinite). (Magn. × 150) [2].

Figure 2. Harbour seam, Sydney coalfield, Canada.
Etched vitrain, with oxidized material inside cell lumens. (Magn. × 625).

Figures 3 & 4. Seam Merl, South Limburg coalfield, Netherlands.
Non-etched and etched identical views of anthracitic coal. (Magn. × 150).

Figures 5 & 6. Harbour seam, Sydney coalfield, Canada.
Polished, thin section showing identical views under reflected (Fig. 5) and transmitted light (Fig. 6). (Magn. × 150).

[1] All pictures illustrated are from original photographs taken by the author and M. S. BARSS, Technician, Fuels Resources Division, Geological Survey of Canada; except Pl. II, Fig. 3 which was kindly supplied by Mr L. H. KING, geologist of the same organization.

[2] The magnifications indicated are those of original views, which have been reduced by 2/3.

in contrast to the maceral analyses individual units are not dealt with, but combinations of macerals that make up the different banded ingredients. These combinations should therefore be strictly defined, which according to the author can best be done on a percentage basis. At the 1935 Heerlen Conference the banded ingredients were defined only in a general way as to the macerals that they contain. However, in the same year STACH (1935) introduced a classification of banded ingredients on the basis of the percentage of vitrinite. Thus, durain (Opakdurit) was defined as having from 0 to 10 percent vitrinte. This classification only uses the one maceral as the deciding factor; it does not incorporate the percentage of inertinite (or opaque matter), which is surely equally important to the classification of the banded ingredients at the maceral vitrinite. The U. S. Bureau of Mines classification on the other hand is based entirely on the percentage of opaque matter. (PARKS and O'DONNELL, 1948). The author, being of the opinion that both vitrinite and inertinite are of decisive importance to the definition of the banded ingredients, introduced a compromise classification. This classification was presented at the first Conference on the Origin and Constitution of Coal, held in 1950 at Crystal Cliffs in Nova Sectia. (See Table I).

TABLE I. GERMAN, SYDNEY AND PITTSBURGH CLASSIFICATIONS OF THE BANDED INGREDIENTS OF COAL.[1]

<table>
<tr><th>Percentage of vitrinite</th><th>Germany (STACH, 1935)</th><th colspan="2">Sydney (HACQUEBARD, 1950)</th><th colspan="2">Pittsburgh (PARKS, 1948)</th><th>Percentage of opaque matter</th></tr>
<tr><td>100—95</td><td>vitrit</td><td>vitrain</td><td rowspan="2">bright coal</td><td colspan="2" rowspan="2">bright coal</td><td rowspan="2">less than 20</td></tr>
<tr><td>95—50</td><td>clarit</td><td>clarain</td></tr>
<tr><td>50—10</td><td>eudurit</td><td>claro-durain</td><td rowspan="2">dull coal</td><td>semi-splint</td><td rowspan="2">dull coal</td><td>from 20—30</td></tr>
<tr><td>10—0</td><td>durit</td><td>durain</td><td>splint</td><td>more than 30</td></tr>
</table>

[1] Fusain is omitted in this table, because no difference of opinion exists regarding this ingredient.

As may readily be noted from Table I the actual amounts in which vitrinite and opaque matter are present control the Sydney classification. This being the case, the question arises how accurately can these two components be determined, and are these determinations comparable when carried out under reflected and transmitted light? Regarding the vitrinite component no great difficulties are encountered, because in both methods this component is well defined. In the case of opaque matter determinations the type of microscopic examination greatly affects the percentage of this material that will be obtained. It is only recently, and after much controversy regarding this matter, that this has been fully realized. What may be classed as a durain or splint under transmitted light, on the basis of 30 percent opaque matter, may not necessarily be evaluated as such under reflected light. In thin sections the percentage of opaque matter is always higher than in polished sections. This is related to the thickness of the thin section, and to the fact that opaque mineral matter (like pyrite) is often erroneously included with opaque (coaly) matter. In polished sections, measurements are carried out in one plane only. This is not the case in thin sections, where underlying components are also visible. Furthermore, the possibility should not be overlooked that in thin sections of splint or durain coals, which usually are of uneven thickness, translucent material that lies between closely packed spores might remain opaque. The discrepancy between the two methods is indicated with a polished, thin section of coal. Figures 5 and 6 of Plate I, representing photomicrographs of exactly the same view, show that under transmitted light (Fig. 6) more opaque matter (black) is represented than under reflected light (Fig. 5, white). They also show that the opaque components reveal structural details under reflected light that cannot be noted under transmitted light.

The above observations indicate that the standard of 30 percent opaque matter, set by the U. S. Bureau of Mines for splint coal, and followed in Sydney to make splint analogous to durain, is no longer valid for polished section work. The 30 percent figure should be lowered by a considerable amount, and it is hoped that agreement on this can be reached in the near future.

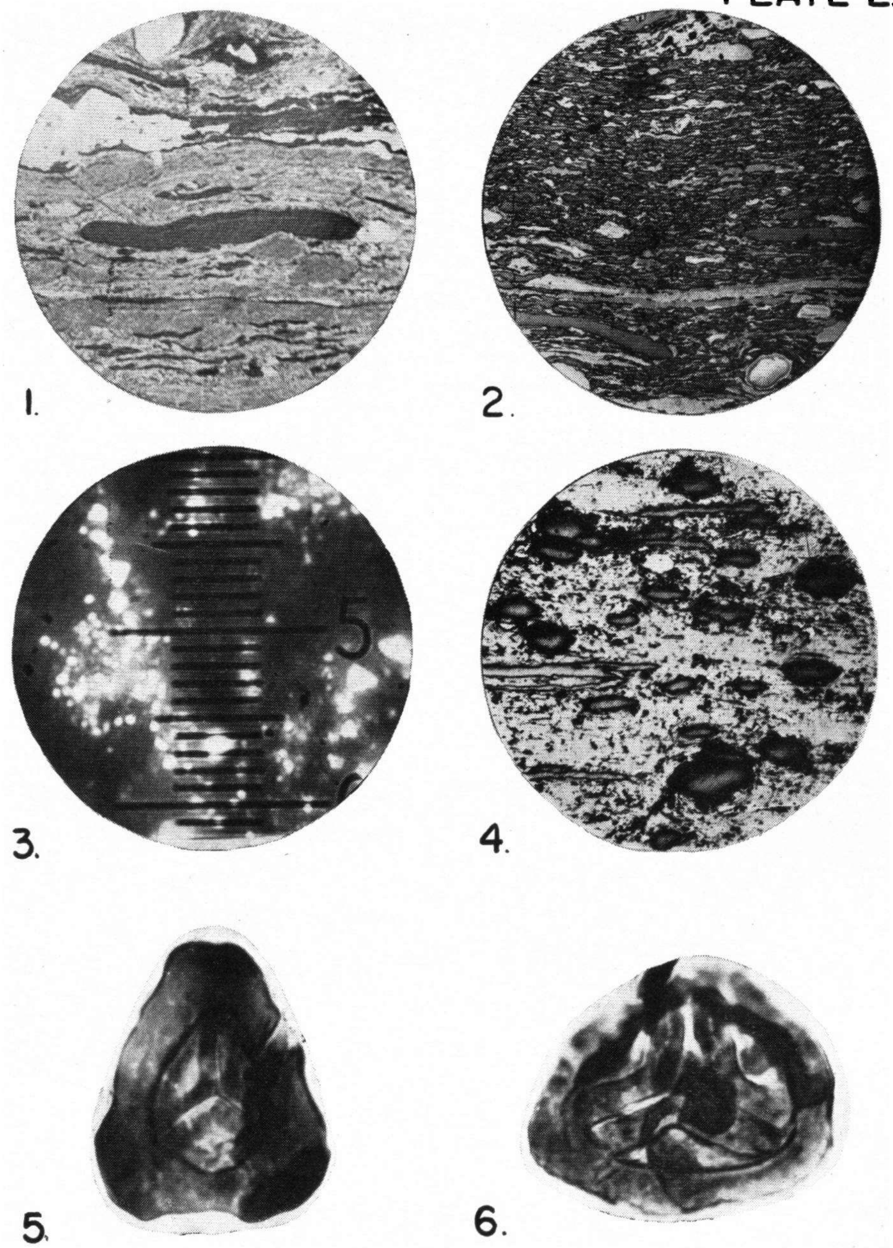
Another difficulty regarding the exact quantitative determinations of opaque matter in coal is related to the size of some of the opaque particles. Most coals contain extremely finely divided opaque matter (or granular micrinite). These particles, which are only 0.5 microns or less in diameter cannot be recorded with any accuracy. Under reflected light they can only be noted with the aid of an oil emersion lens. (*See* Pl. II, Fig. 1).

The opaque matter referred to here, is considered by the author as primary opaque matter, which consists of plant fragments that become opaque during the early stages of coal formation. Due to metamorphism during the coalification process a secondary opacity gradually evolves in coal. It is accompanied by an increase in fixed carbon and a decrease in volatile matter, resulting in almost complete opacity in such high rank coals as anthracite. Even in the high rank coals primary opaque matter can still be recognized in polished sections by its higher degree of reflectivity. (*See* Pl. I, Figs, 3, 4). This in effect poses the question how opaque is opaque? Chemical differences apparently also exist between the two forms of opaqueness, because the secondary opaque material appears to be affected by the etching solution, whereas the primary opaque matter is not (HACQUEBARD, 1952).

Applications of coal petrography

As was mentioned in the introduction, coal microscopy in general and coal petrography in particular have been applied to many problems related to the coal mining industry and to the coal substance itself. A great deal of credit for expanding the usefulness of this work goes to the Germans, who have been able to successfully integrate it with industry, particularly in the field of coal utilization. A most excellent survey of what can be done and what already has been attained may be found in Dr. HUGO FREUND's Handbook on Microscopy in Technology, of which volume II, part I is devoted to "Microscopy of Bituminous Coal, Coke and Brown Coal" (1952). Germany's most eminent coal petrographers, including STACH, KÜHLWEIN, TEICHMÜLLER,

PLATE 2.



HOFFMANN, ABRAMSKI, MACKOWSKY, RADMACHER, have contributed to this work, each with individual articles. Since it is entirely written in the German language the author of this paper prepared a short review in English, with the objective of introducing it to the Canadian coal mining industry and to those that are interested in coal research (HACQUEBARD, 1954).

At Sydney, only some of the many applications dealt with in Dr. FREUND's book have been carried out to date. A few examples are given below.

1. *Seam correlation.* — In previous studies, made in Holland during the war years by FABER (1943), MAURENBRECHER (1944) and the author (1943), it was shown that coal seams can be correlated with petrographic sections. Correlation of seams is naturally of importance to the stratigraphy of the coal area, as well as in finding the regional extent of the seams. In undeveloped areas where the coal has not been extracted, or where some initial development work has been abandoned, the seam correlation work becomes of great economic importance, because it will ultimately decide if extraction is economically feasible or not. Such an area is situated at Mabou on the west side of Cape Breton Island, Nova Scotia.

At Mabou a considerable amount of coal is present, but exposed and accessible only in a very small area of about $^1/_{10}$ square mile. It is bordered to the east by non-productive Carboniferous measures and to the west by the Gulf of St. Lawrence (NORMAN, 1935). The reserves of this coal area are all situated below the sea, and their extent is difficult to predict. Structurally the area is very complicated since it is dissected by several faults which make inter-seam correlations a hazardous undertaking. A considerable amount of petrographic, as well as spore work has been done on this field during the past two years, and is still in progress at he present time. The structural interpretation in this case will depend almost entirely on the correlation of the different seams that are present, and in turn will decide if extraction of the coal will be feasible.

In the Sydney coalfield the reserves, as well as the present mining are also submarine. Only one coal seam, namely the Tracy may have extensive mining possibilities within the land area. It is the oldest mineable seam in the stratigraphic section, and much of its regional extent is as yet unknown. A petrographic examination of this seam was carried out in 1952, and the results presented at the second Conference on the Origin and Constitution

PLATE II

Figure 1. Nahanni river coal, northwestern Canada.
View taken with oil emersion lens, showing very finely divided granular micrinite (white specks). (Magn. × 210).

Figure 2. Harbour seam, Sydney coalfield, Canada.
Clarodurain with numerous tightly packed spores. (Magn. × 150).

Figure3. Lloyd Cove seam, Sydney coalfield, Canada.
Very finely disseminated pyrite in coal. One division equals one micron. (after L. H. KING, 1953). (Magn. × 3400 with Vickers Projection Microscope).

Figure 4. Tracy seam, Sydney coalfield, Canada.
Squat bulky spores, together with finely divided micrinite (white specks). Magn. × 150).

Figcres 5 & 6. Nahanni river coal, northwestern Canada.
Small spores signifying a Lower Carboniferous age. (Magn. × 700).
Fig. 5. cf. *Zonotriletes auritus*, WALTZ, 1938.
Dimensions: 67.2 × 80.0 microns; maceration NAH, Slide 9.
Fig. 6. *Annulati-sporites literatus* (WALTZ), HACQUEBARD, comb. nov., 1955.
Dimensions: 70.4 × 89.6 microns; maceration NAH, Slide 7.

of Coal, held in the same year at Crystal Cliffs in Nova Scotia (HACQUEBARD, 1952). Three complete column samples of the Tracy seam were examined from three areas where the seam was definitely known to be the same. The petrographic composition of these samples was plotted in three percentage diagrams, illustrated in Figure 1. The diagrams show that the regional variation in petrographic composition, except for the shale and pyrite contents, is only minor over a distance of 7 miles. It is, therefore, contended that the pattern presented in the diagrams is characteristic for the Tracy seam, and that it can be used for identification purposes in the area where the definite position of this seam has not yet been determined. Unfortunately no column samples of possible equivalents of the Tracy seam are available in this area. They can only be obtained by drilling, which as yet has not been carried out.

The method that is used to plot the percentage diagrams is somewhat dfferent from the one that was originally proposed as a result of the petrographic studies carried out in Holland. Instead of breaking down the seam in rigid intervals of 5 cm thickness, intervals in which certain banded ingredients predominate are now grouped together in so-called petrographic divisions (HACQUEBARD, 1951). It is felt that this lithologic-layer type of subdivision is more in line with general stratigraphic practice than arbitrary subdivisions within the thickness of the seam.

Some of these layers or divisions have a very widespread distribution with very little change in petrographic composition as was noted e. g. in the Harbour seam of the Sydney coalfield. This seam has a 1 inch thick band of clarodurain with numerous tightly packed spores that can be traced over 20 miles (*See* Pl. II, Fig. 2). Such a layer provides an excellent time horizon within the seam, and data pertaining to its deposition and variations in thickness can be drawn from it (HAITES, 1952).

2. *Coal preparation.* — The coal seams of the Sydney coalfield are in several ways extraordinary, since no great differences occur either in rank or petrographic composition. Over a stratigraphic interval of 3800 feet the volatile matter content only varies from 36 to 39 percent (mineral matter free). In a similar stratigraphic interval in the Limburg coalfield this variation lies between 15 and 40 percent. Apparently the younger strata that once occurred above the productive coal measures at Sydney were removed at an early date.

All 12 seams, with the exception of one, may be classed as very bright coal containing between 73 and 84 percent vitrain plus bright clarain. However, each seam contains dull coal intervals high in opaque matter and/or exinite. These intervals have a different chemical composition than the seam as a whole, and their concentration is therefore of particular importance in a coalfield such as Sydney. Vitrain and fusain for instance, present in the same seam may differ as much as 24 percent in their volatile matter content.

Experiments on the concentration of dull coals by means of pounding, crushing and screening were carried out in Sydney by the author and K. C. LAHIRI [2]. Sizeable concentrations were obtained only when the coal was first pounded and then screened. Crushing and screening did not concentrate the dull components, since this procedure did not take advantage of the natural differences in strength of the different coal constituents. One of the results of the pounding experiments was the preparation of a coal

[2] Mr LAHIRI is a native of India who under the auspices of the United Nations spent some 8 months at the Sydney laboratory studying coal petrography.

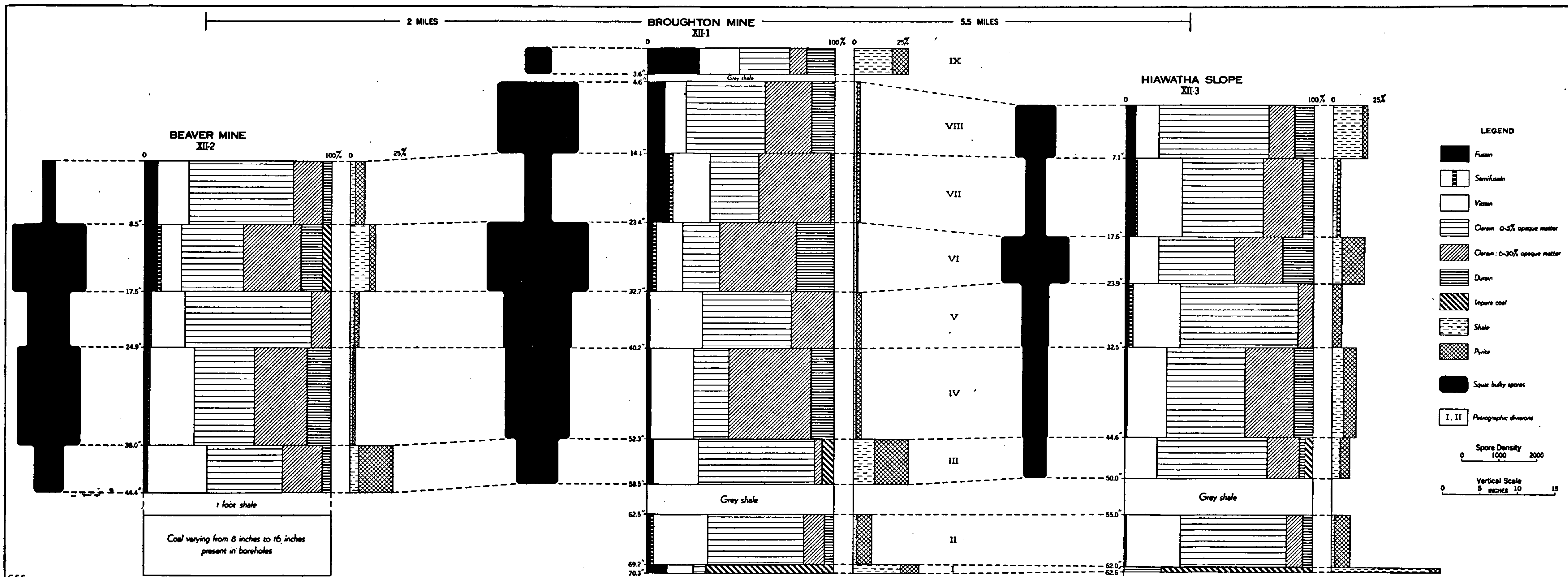


Figure 1.

Petrographic composition and spore densities of three column samples of the Tracy seam in the southeast part of the Sydney coalfield.

with 26 percent exinite and 44 percent volatile matter from one with only 7 percent exinite and 38 percent volatile matter (HACQUEBARD and LAHIRI, 1955). This work will be continued in the future, with the particular objective of preparing a lower volatile coal for blending purposes with Sydney coking coals. The Sydney metallurgical coke is of a rather weak nature, and can be improved in strength when lower volatile coals are added to the ones that are now used. Lower volatile coals are not present in the Sydney field. Only suitable coal preparation guided by petrographic advice may result in obtaining such coals from the ones that are now being mined.

3. *Studies on spontaneous combustion.* — All coals of the Sydney field, and of Nova Scotia in general will go on fire when not properly stored, altough some coals are more liable to this phenomena than others. Petrographic and physical investigations in this field are carried out in Sydney and Boston by LEWIS H. KING[3].

One phase of his studies has dealt with the pyrite problem. The main effect of the pyrite is that upon weathering it reduces the particle size of the coal and thus makes the coal more liable to spontaneous combustion. This effect is particularly noticeable when the pyrite occurs in finely disseminated form, as is very common in the Sydney coals. In the coals that were examined, pyrite particles below the range of 1—3 microns (*See* Pl. II, Fig. 3) weather very rapidly under laboratory conditions, whereas particles above this critical size range were hardly affected (KING, 1953).

Other aspects of coal petrography, for example the influence of the petrographic constituents on the friability of the coal, have been incorporated in his study.

Spore investigations

Spore studies are now generally carried out with isolated spores that are obtained with the aid of the maceration process. However, in 1930 SLATER, EVANS and EDDY carried out a spore investigation with the aid of thin sections. A similar study was made in Sydney in 1952 of spores contained in the Tracy seam, but polished sections were used in this instance. Also, only one spore referred to by SLATER et al. as "squat bulky spore", was used (*See* Pl. II, Fig. 4). From the start it was realized that spores can best be studied in isolated forms because their morphology can then be examined in a three dimensional fashion, rather than in a cross section, as is the case in polished section studies. Nevertheless, this work was undertaken because the squat bulky spores are an outstanding feature of the Tracy seam. Even though they are present in certain intervals of other seams of the Sydney coalfield, they do not occur in such great numbers and in combination with finely divided micrinite as is the case in the Tracy seam. The spore density diagrams, illustrated in Figure 1 show that the squat bulky spores are not restricted to one locality, but occur at least over a distance of 7 miles. They are not randomly distributed through the section of the seam, but occur in frequencies that in general coincide with the petrographic divisions. Their distribution throughout the section of the seam, with the exception of the bottom bench, provides the unique feature that the Tracy seam may be identified from a few odd blocks of coal alone.

[3] Mr KING is a graduate student of the Massachusetts Institute of Technology, and is writing his doctor's thesis on this subject.

In a recent spore study carried out by the author on coal from western Canada the worldwide possibilities of the small spores as guide fossils have been strikingly revealed. In coal from the Nahanni river area [4] a small spore assemblage was noted that is very similar to one reported by LUBER and WALTZ (1938) from coals of northern Russia. Two of these spores, occurring

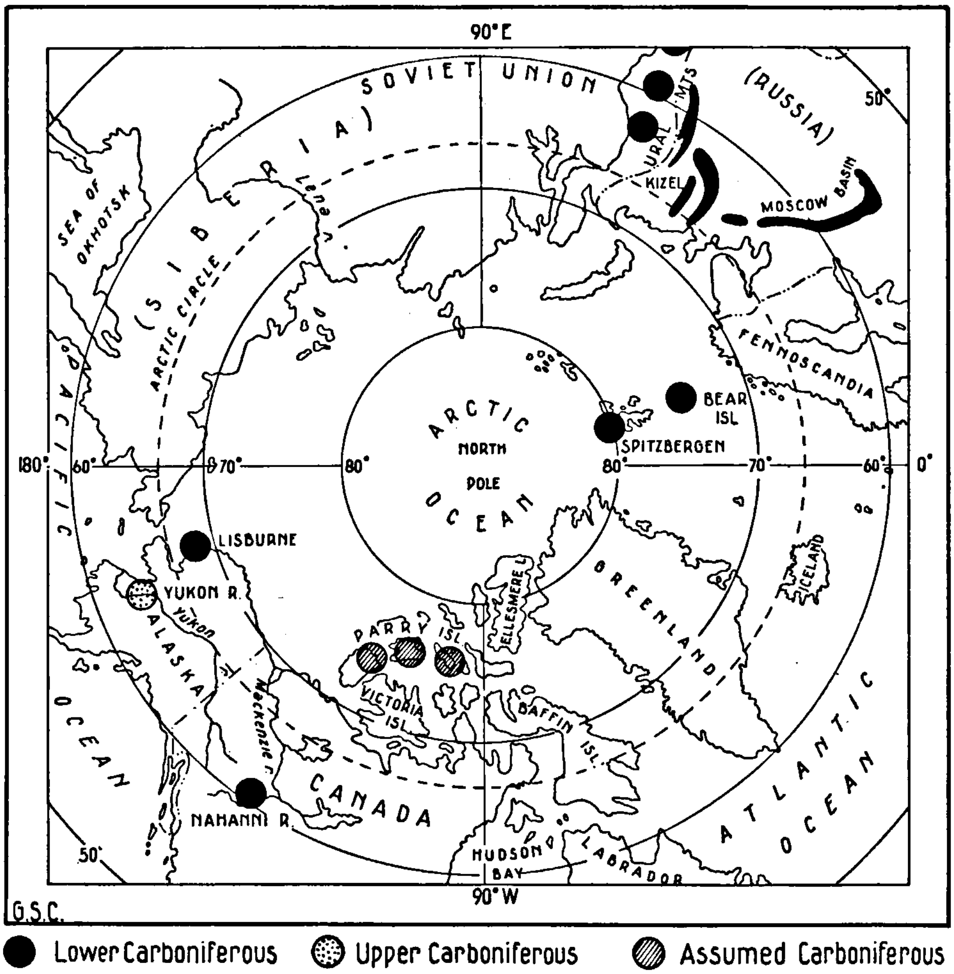


Fig. 2.

at both localities, are illustrated in Figures 5 and 6 of Plate II. They are typical for strata of Lower Carboniferous age, and on the basis of these and several others it was concluded that the Nahanni river coal belongs to this period. No other Carboniferous coal has as yet been reported from western

[4] A sample of coal from this area was collected by Mr W. J. H. PATTON, post graduate student at the University of Alberta and submitted to the author by Dr J. D. CAMPBELL, Palaeobotanist, Alberta Research Council, Edmonton Alberta.

Canada, and all known strata belonging to the Carboniferous are of marine or near shore deposition. It is therefore of interest to speculate on the possible extent and direction of a continental facies of Lower Carboniferous strata to which the Nahanni river coal belongs.

Figure 2 indicates other areas where Lower Carboniferous coals have been reported. They occur in a belt that may be projected from northwestern Canada through the arctic to northern Russia. The coal deposits in the Canadian Archipelago form an important link in this projected belt. The age of these arctic coal deposits is not yet definitely known, because of a lack of plant fossils in the sandstone formation in which they occur. In coal, however, a very prolific source, of palaeontological material is available in the form of fossil spores. It is therefore contemplated to carry out a spore investigation of these in the future.

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