OPAQUE MATTER IN COAL.¹
P. A. HACQUEBARD.

CONTENTS.

PAGE

Abstract .............................................................. 494
Introduction ........................................................... 494
The determination of opaque matter under reflected light in bituminous coals and anthracites 495
The different classes of opaque constituents in coal .................................................... 497
  Fusain ............................................................ 501
  Fusinite .......................................................... 505
  Semifusinite ....................................................... 507
  Sclerotinite ........................................................ 508
  Micrinite .......................................................... 509
Quantitative microscopic measurements of opaque matter in coal ............................. 512
The effect of opaque matter on the proximate analysis of coal .................................. 513
Bibliography ......................................................... 515

ABSTRACT.

The polished surface technique is used to study the nature and occurrence of opaque matter in coal. The appearance of the opaque matter under reflected light was determined from a polished, thin section, in which the opaque constituents were first established under transmitted light.

Two distinctly different forms of opaque matter are recognized, namely, fusain lenses and opaque attritus. Based upon the presence or absence of a botanical structure, the opaque attritus is subdivided into two groups of opaque ingredients. For those devoid of structure the term micrinite is used. Micrinite occurs in three forms: finely divided granular, massive, and as groundmass. Opaque attritus with structure consists of fusinite, semifusinite, and sclerotinite (fungal matter).

Evidence for the origin of the opaque matter during the early stages of coal formation is given. A distinction is made between the opaque matter of “primary” origin, and the opacity of high-rank coals, which is due to increased coalification. It is shown that in anthracite the opaque matter of “primary” origin can be recognized under reflected light with the aid of etched, polished sections. No increase in the amount of “primary” opaque matter with increase in rank has been observed.

The percentage of opaque matter is determined with an integrating stage, using polished specimens of ground coal, mounted in lucite. The results are compared with the proximate analyses of the coal investigated. They show that a high percentage of opaque matter corresponds with a high percentage of fixed carbon and usually a high percentage of ash. Photomicrographs illustrate the paper.

INTRODUCTION.

In bituminous coals and lignites certain coal constituents do not transmit light in thin sections. Thiessen (27) ² described these constituents as opaque

¹ Published by permission of the Director-General of Scientific Services, Department of Mines and Technical Surveys, Ottawa, Ontario, Canada.
² Numbers in parentheses refer to Bibliography at end of paper.
matter and concluded that they are of botanical origin. They are more highly carbonized than the rest of the coal and stand out in sharp contrast on account of their opaqueness. Because opaque matter occurs in different concentrations throughout the section of a coal seam, its amount is used as a basis for determining the different types of coal. For the lower-rank coals the opaque matter can be recognized satisfactorily in thin sections. However, coals of higher rank, such as low volatile and anthracitic coals, are too dense and opaque to transmit light in thin sections. Increase in rank, which is accompanied by an increase in carbon, causes a general opacity of the coal. This poses the problem of the value of opaque matter as a basis for a type classification of coals of all ranks. Unless the opaque matter as observed in the lower-rank coals can still be detected in the higher-rank ones, its amount cannot be properly used as a general criterion for the different types of coal. In this respect, the effect of metamorphism on the amount of opaque matter is also highly important, because the type classification, as suggested by Thiessen, is based upon the origin of the coal (28).

Because the polished section technique of examining coal microscopically may be used regardless of rank, the author is of the opinion that the problems outlined above can best be studied by this method. Moreover, opaque substances in general, reveal details under reflected light, that cannot be observed under transmitted light. In this paper features observed in opaque matter of bituminous coals are described in detail, and illustrations are given of opaque matter in the higher-rank coals. A method to determine the amount of opaque matter under reflected light is presented, and the effect of opaque matter on the proximate analysis of the coal is discussed.

**THE DETERMINATION OF OPAQUE MATTER UNDER REFLECTED LIGHT IN BITUMINOUS COALS AND ANTHRACITES.**

The appearance of opaque matter under reflected light has been determined with the aid of polished, thin sections of high volatile “A” bituminous coal. In previous publications (5, 6), the author has shown, with photomicrographs, that those constituents which are opaque under transmitted light have the highest reflection indices under reflected light, and consequently appear white. This is illustrated again in Plate 1. In the lower-rank bituminous coals the opaque matter is further characterized by a greater hardness than the other coal constituents, which gives it a greater relief in polished sections. This may be used to advantage in certain cases where it is difficult to recognize opaque matter from vitrinite, which has the next highest reflection index, and which appears under reflected light slightly darker in color than the opaque constituents. The so-called “Becke Test,” as used in ordinary petrography, to determine the relative indices of refraction of two minerals lying in contact with each other, is also applicable under reflected light, and is in certain instances a most helpful device for recognition of opaque matter.

In low volatile bituminous coals the physical and optical differences between opaque matter and other macerals are less pronounced. However, by
using an oil immersion lens the difference in reflectivity can still be observed, and the opaque matter recognized. This method is extensively used by E. Stach and others in Germany, and the results are beautifully illustrated in the "Atlas For Applied Coal Petrography" (1).

In anthracitic coals the physical and optical properties of the different constituents are almost alike. Only by special methods, such as examination with etched, polished sections, or with polarized light through crossed nicols, is it possible to distinguish the macerals of coal as they are known from lower-rank groups. Seyler's (17) method of etching polished sections with a mixture of chromic acid and sulfuric acid is used in this paper. It was found that the acids attack the different constituents in a different degree, and that etching, to a certain extent, gives the anthracitic coals an appearance under reflected light, somewhat similar to that of non-etched, polished sections of lower-rank coals. The spores and cuticles are most severely etched and turn brown or black if the etching is carried out too long. The vitrinite remains light in color, but almost always reveals its cell-structure pattern. The opaque matter is very lightly affected by the etching, and as in the lower-rank coals, appears white in contrast to the darker color of the other macerals, which is accentuated by the etching. Morphological shape and botanical structure are further aids in recognizing opaque matter in etched polished sections of anthracitic coals (Pl. 2).

THE DIFFERENT CLASSES OF OPAQUE CONSTITUENTS IN COAL.

Opaque matter of organic origin occurs in coal in different forms that vary greatly in size and distribution, and that may or may not reveal a cellular structure, or resemble closely botanical entities. Two distinctly different forms of opaque matter are recognized: first, well defined lenticular bodies that

PLATE I.* OPAQUE MATTER UNDER REFLECTED AND TRANSMITTED LIGHT.

The photomicrographs of Plate I are from a polished, thin section of coal. Each pair are of the same view, those to left were taken under reflected light, those to the right under transmitted light. All are from high volatile “A” bituminous coals.

FIGS. 1, 2. Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 210.) The opaque matter in upper half represents fusinite, with cell cavities empty (or filled with gas); cavities are black in Figure 1 and white in Figure 2. In Figure 1 most cell walls are crushed, known as "bogen structure."

FIGS. 3, 4. Harbor seam, Sydney Mines district, Sydney coalfield, Nova Scotia, Canada. (× 150.) In center is a crushed sclerotoid and elongated strip of opaque matter underneath is semifusinite. Note difference in reflectance between the sclerotinite and semifusinite.

FIGS. 5, 6. Harbor seam, Sydney Mines district, Sydney coalfield, Nova Scotia, Canada. (× 150.) Particles that appear black (opaque) under transmitted light are white under reflected light; these represent granular micritine. At bottom is a much corroded sclerotoid with marked relief. Oval shaped body near the top is maceral collinite (vitrinite devoid of cellular structure). Under reflected light it is light gray without relief; under transmitted light it has the orange color of anthraxylon, without cellular structure.

* All pictures illustrated are from original photographs taken by the author and M. S. Barss, Technician, Fuels Resources Division, Geological Survey of Canada.

10 The magnifications indicated are those of original views, which have been reduced by ½.
generally can be separated easily from the rest of the coal, and secondly, finely
macerated particles, intimately mixed with the other coal ingredients. The
former constitute fusinite lenses, which are considered to be the rock type,
or banded ingredient fusain, when they are 1 mm or more thick, measured
across the bedding plane (5). The latter were designated by Thiessen (27)
as opaque attritus. The opaque attritus, which occurs in high concentrations
in splint coals, is divided by Thiessen (28) into two classes of opaque con-
stituents, namely, semi-translucent or brown matter and finely divided, or
granular opaque matter. These terms are entirely descriptive and do not
reveal any relation to botanical structures, which under transmitted light
cannot be detected very easily.

However, studies under reflected light, carried out in Germany, and by
the author, show that opaque attritus contains certain ingredients that have
retained their original plant structure. It was found that several macerals
of coal, as formulated by Stopes (24), constitute part of the opaque attritus.
These are: fusinite, semifusinite, and sclerotinite (10, 26). Those ingredi-
ents of opaque attritus that are devoid of structure represent the maceral
micrinite.

The above mentioned classes of opaque constituents in coal are summarized
in Table I, and are discussed in detail in the following paragraphs.

### TABLE I.

<table>
<thead>
<tr>
<th>Classification Diagram of Opaque Constituents in Coal.</th>
</tr>
</thead>
</table>
| Fusain \[
| | Soft variety |
| | Hard variety |
| Opaque attritus \[
| | With botanical structure |
| | Fusinite |
| | Semifusinite |
| | Sclerotinite |
| | Devoid of botanical structure |
| | Micrinite |
| | Granular |
| | Massive |
| | Groundmass |

### PLATE II. “PRIMARY” OPAQUE MATTER IN ANTHRACITE.

The photomicrographs of Plate II are taken under reflected light from polished
anthracite, those on the left are non-etched and those to the right are the same
views after etching the coal for 1½ minutes in boiling chromic-sulfuric acid. All
illustrations are from seam Merl, Domaniale Mine, South Limburg coalfield, Neth-
erlands (V.M.: 8.44 percent).

**Figs. 1, 2.** Upper half “primary” opaque matter is fusinite, white angular
particles below are micrinite. They possibly could represent broken cell walls
(fusinite) or fragments of sclerotiods (sclerotinite). The material in between is
vitrinite (thin, light-colored band underneath the fusinite), exinite (dark-colored
ingredients) and possibly sclerotinite (tissue with irregular cellular structure in
bottom right of photographs). (× 150.)

**Figs. 3, 4.** White material in center is interpreted as fungal tissue, and conse-
quently represents sclerotinite. Underneath it are four micrinite granules and at
bottom is fusinite. Note thin, light-colored vitrinite bands and dark-colored spore
material (exinite). Note how etching exposes opaque matter, and other coal con-
stituents in anthracite. (× 150.)

**Figs. 5, 6.** White particles and splinters in center are considered as micrinite.
The white ingredients near top are mostly sclerotinite. At bottom, there is a layer
composed of semifusinite. (× 150.)
Fusain.—Fusain occurs in lenses or irregular wedges lying on bedding planes at various angles. It has a typical fibrous structure, is very friable, and breaks down to a soiling black powder. It resembles charcoal in appearance. The lenses vary in thickness from 1 mm to about 2 inches, and can usually be separated easily from the rest of the coal. Under the microscope, fusain is of simple composition, inasmuch as it consists essentially of the same material throughout. This material consists of the coalified walls of cellular tissue which, unless disturbed by pressure, has retained its original pattern. It represents the maceral fusinite, as defined by the Heerlen, 1935, Round Table Conference (8). The fusinized tissues are characterized by the absence of organic material inside the cell cavities. In the so-called soft fusain, these cavities remained empty, or became filled with gas. When filled with mineral matter, such as for instance pyrite or calcite, the fusain is hard and is termed hard fusain (Pl. 3, Figs. 1, 2).

Fusain occurs predominantly in bright coal varieties, and may occur throughout the entire section of a seam. Regionally, its amount within any seam varies to an appreciable extent, although certain intervals of the seam which are relatively high in fusain may be traced for several miles. Regional variations of the amount of fusain in seams of different rank, and from different coalfields, are shown in Table II. From this table it appears that the fusain content of coal is independent of its rank. As fusain is found in coals

---

**PLATE III.** Fusain, Fusinite, and Semifusinite.

**Fig. 1.** Harbor seam, Sydney coalfield, Nova Scotia, Canada.† (x 150.) Soft fusain with empty (or gas-filled) cell cavities. Note woodcell structure with intercellular spaces. View is part of a fusain lens of 5 mm thickness and opaque (white) cell walls represent maceral fusinite.

**Fig. 2.** No. 2 seam, International Mine, Coleman, Alberta, Canada. Medium volatile bituminous coal of Lower Cretaceous age. (x 150.) Hard fusain with calcite in cell cavities. Note disturbed cellular structure near top.

**Fig. 3.** Harbor seam, Sydney coalfield, Nova Scotia. (x 150.) Fusinite in transverse section through a fusinized twig. Note wood tracheids with middle lamellae and plasmodesmata (minute channels through the cell walls). Underneath is semifusinite and another fragment of fusinite is curved around it near the top.

**Fig. 4.** Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn.† (x 130.) This shows the difference in reflectance between fusinite (near the top), semifusinite (in center), and vitrinite (in between). The fusinized tissue represents a tangential section through a small twig. Note that in the semifusinite only part of the cell cavities are empty.

**Fig. 5.** Harbor seam, Sydney coalfield, Nova Scotia, Canada. (x 100.) Transition between fusinite (top and bottom), semifusinite (adjoining fusinite) and vitrinite (in upper half). The fusinite at the top was too soft to be polished and therefore completely absorbed the light. Note cracks in vitrinite, which seem to indicate that it is not as strong under pressure as the opaque matter.

**Fig. 6.** Harbor seam, Sydney coalfield, Nova Scotia, Canada. (x 150.) An illustration of fragments of semifusinite in durain, surrounded by exinite and micrinite.

*Unless stated otherwise, all pictures of Plates 3-6 are taken under reflected light from non-etched polished sections, without using the oil immersion lens.

† All coal seams of the Sydney coalfield and the Pittsburgh coal bed of U. S. Experimental Mine, Allegheny County, Pennsylvania, are high volatile “A” bituminous coals of Pennsylvanian age.
<table>
<thead>
<tr>
<th>Name of seam</th>
<th>Coalfield</th>
<th>Country</th>
<th>Rank</th>
<th>Percentage of fusain in different samples</th>
<th>Average % of fusain</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Lignite seams</td>
<td>North Dakota</td>
<td>U. S. A.</td>
<td>Lignite</td>
<td>6 1 3 6</td>
<td>4</td>
</tr>
<tr>
<td>Harbor</td>
<td>Sydney</td>
<td>Canada</td>
<td>High volatile &quot;A&quot;</td>
<td>3 3 3 2 2 1 4 1 2 3</td>
<td>3</td>
</tr>
<tr>
<td>Boutilier</td>
<td>Sydney</td>
<td>Canada</td>
<td>Bituminous coal</td>
<td>7 16 13 8 13</td>
<td>11</td>
</tr>
<tr>
<td>Backpit</td>
<td>Sydney</td>
<td>Canada</td>
<td>Medium volatile</td>
<td>4 8 5 10 9 6 9 7 9 9</td>
<td>8</td>
</tr>
<tr>
<td>Phalen</td>
<td>Sydney</td>
<td>Canada</td>
<td>Low volatile</td>
<td>5 2 3 2 6</td>
<td>4</td>
</tr>
<tr>
<td>Grauweck</td>
<td>South Limburg</td>
<td>Netherlands</td>
<td>From medium volatile to semi-anthracite</td>
<td>9 7 7 5 6</td>
<td>7</td>
</tr>
<tr>
<td>Merl</td>
<td>South Limburg</td>
<td>Netherlands</td>
<td>Anthracite</td>
<td>11 10 12 7 5 11 7 10 11 7 13</td>
<td>9</td>
</tr>
<tr>
<td>Steinknipp</td>
<td>South Limburg</td>
<td>Netherlands</td>
<td>Low volatile</td>
<td>19 12 14 13 10 17 14 11 7 13</td>
<td>13</td>
</tr>
<tr>
<td>Finefrau A</td>
<td>South Limburg</td>
<td>Netherlands</td>
<td>High volatile &quot;A&quot;</td>
<td>3 5</td>
<td>4</td>
</tr>
<tr>
<td>Finefrau B</td>
<td>South Limburg</td>
<td>Netherlands</td>
<td>Medium volatile</td>
<td>14 9</td>
<td>12</td>
</tr>
<tr>
<td>Finefrau C</td>
<td>South Limburg</td>
<td>Netherlands</td>
<td>From medium volatile to semi-anthracite</td>
<td>11 8</td>
<td>10</td>
</tr>
<tr>
<td>Senteweck</td>
<td>South Limburg</td>
<td>Netherlands</td>
<td>Bituminous coal</td>
<td>3 7 2 5 3 11 8 3 6 4</td>
<td>5</td>
</tr>
</tbody>
</table>

*Samples represent complete section of seam and were taken over the entire coalfield, unless stated otherwise. The distance between samples varies from 1 to 3 miles.
* Samples from S. M. Maurits.
* Samples from O. N. Mines and mines farther east.
* Samples from Willem Sophia and Domaniale Mines.
* Figures taken from B. C. Parks (12).
* Figures pertaining to seams Grauweck and Senteweck were taken from A. L. F. J. Maurenbrecher (11).
* Figures pertaining to seams Merl, Steinknipp, and Finefrau A, B, and C are taken from P. A. Hacquebard (4).
of all ranks and occurs also in peat, there is no apparent relation between the degree of metamorphism of the coal and its amount of fusain. This is further illustrated graphically in Figure 1, showing the variation of fusain content in two seams, of which the Backpit seam of the Sydney coalfield is almost constant in rank, whereas the Senteweck seam of the South Limburg coalfield of the Netherlands is variable. In both seams the fusain content has been determined in ten complete channel samples, which are spaced at regular intervals over the entire coalfields. Because Figure 1 shows plainly that the variations in the percentage of fusain occur irrespective of the rank of the seam, it is concluded that fusain probably originated during the early stages of coal formation, and very likely before burial by overburden.

Several theories on the origin of fusain in a peat swamp have been advanced and were discussed by the author in a previous publication (4). That one specific cause alone is responsible for the formation of fusain seems highly improbable. It appears more likely that several of the current theories, as for instance, forest fires and partial submergence of vegetable debris, all played an important part in the origin of fusain.
The fusinization of plant material causes a concentration of carbon and elimination of oxygen and hydrogen, which makes fusain opaque in the lower-rank coals where other coal constituents are transparent. The chemical composition of the high-rank coals closely resembles that of fusain, and these coals are accordingly completely opaque. However, this opacity was largely caused by metamorphism, which affected predominantly the transparent constituents of the lower-rank coals. In other words, opaqueness in coal is caused by two different processes, which affected the organic material either at the initial stage of coal formation, or later during the metamorphic changes. The former may be designated as "primary" opaque matter to differentiate it from "secondary" opaque matter due to metamorphism. "Secondary" opaqueness starts in the medium volatile coals, at about 23–25 percent volatile matter, and rapidly increases when coals of anthracite rank are approached (15). The original botanic structure of those constituents that are affected by secondary opaqueness (vitrinite and exinite) can still be detected with the aid of etched polished sections (14) (Pl. 2). The changes that occur in coals with from 23–25 percent volatile matter are, in the author’s opinion, merely physical and chemical, and do not, as advanced by Schopf (15), alter the botanical pattern of the macerals involved.

_Fusinite._—The opaque cell walls present in fusain constitute the maceral fusinite. Besides being present in fusain lenses, fusinite also occurs finely dispersed in the coal and usually is an important component of durain. However, unlike fusain, it cannot be separated readily from the rest of the coal. It is found in fragments (smaller than 1 mm), which show beautifully preserved cellular structure, or it is present in small particles, which may represent broken and separated cell walls. (Pl. 3, Figs. 3, 4; Pl. 4, Fig. 1; Pl. 6, Fig. 4.)

**PLATE IV. SCLEROTINITE.**

**Fig. 1.** Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 150.) Fungal tissue with irregular cell structure pattern, cell wall material underneath is fusinite.

**Fig. 2.** Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (× 300.) Fungal tissue with sclerotoids, which form a genetic part of the fungal structure.

**Fig. 3.** Lower Jubilee seam, New Waterford district, Sydney coalfield, Nova Scotia, Canada. (× 110.) Sclerotoids in semifusinite, indicating a relationship between these "fungi" and wood. It appears as if the sclerotoids have destroyed parts of cellular structure of the original wood, suggesting they may represent wood-destroying fungi.

**Fig. 4.** Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 150.) Round and oval-shaped, smooth-walled sclerotoids, occurring like a colony, in one layer of the coal.

**Fig. 5.** No. 5 seam, St. Rose coalfield, Nova Scotia, Canada. High volatile "C" bituminous coal. (× 150.) Numerous sclerotoids preserved in the No. 5 seam. Note their peculiar carving, and the high shale content (black particles) associated with them.

**Fig. 6.** Harbor seam, Sydney Mines district, Nova Scotia, Canada. (× 100.) Large sclerotium with characteristic structure of a compact mass of fungal hyphae (white lines). The thin curved white lines immediately above it could possibly represent fungal hyphae in an initial stage of the formation of sclerotia.
According to Seyler (18), fusinite shows the highest reflectance of all coal constituents, and as such is usually easily recognized. However, when present in extremely small particles, fusinite and micrinite cannot be separated under ordinary microscopic examination, and it is quite possible that much of the material classed as micrinite represents fusinite in finely disseminated form. Reflectivity measurements, such as carried out by Seyler, could possibly prove to be of help in determining the identity of the finely divided opaque matter.

**Semifusinite.**—Material intermediate between fusinite and vitrinite is termed semifusinite (8). It is characterized by a generally well preserved cellular structure, that differs from fusinite structure, inasmuch as some of the cell cavities are filled with carbonized organic matter. Under transmitted light it is semi-opaque in bituminous coals, and possibly represents part of Thiessen's semi-translucent or brown matter. The reflective power of semifusinite is lower than that of fusinite, but a little higher than the reflectance of vitrinite (Pl. 3, Fig. 4). It is considered as a separate maceral because it occurs not only in transition zones between fusinite and vitrinite, but is also present in well defined units surrounded by other coal constituents (Pl. 3, Figs. 5, 6). Like fusinite, it is commonly an important component of durain and fusain. When it is present in lenses or layers thicker than 1 mm it may be considered as a separate rock type, which is named semifusain.

Semifusinite is present in coals of all ranks, and its microscopic appearance

---

**Plate V. SCLEROTINITE.**

**Fig. 1.** Harbor seam, Sydney Mines district, Nova Scotia, Canada. (X 140.) This illustrates the great hardness of the sclerotoids, which probably were affected very little by compaction from peat to coal, which caused the vitrinite groundmass and the microspores to become curved around the sclerotoid. The opaque stick (probably fusinite) immediately underneath it was apparently less flexible than other constituents, and like the sclerotiod is very hard. It broke in two at the very place where the sclerotiod exerted its greatest pressure during the coalification process.

**Fig. 2.** Harbor seam, Sydney Mines district, Nova Scotia, Canada. (X 150.) A sclerotiod showing what may possibly be cellular structure, and solid ring around the main body. As in Figure 1, the vitrinite and exinite are curved around the sclerotiod.

**Fig. 3.** Harbor seam, Sydney Mines district, Nova Scotia, Canada. (X 150.) Possibly the solid ring around a sclerotiod, similar to the one in Figure 2. However, this picture could also represent the sclerotesta or hard coat of a seed, only its size (230 X 160 microns) appears too small.

**Fig. 4.** Phalen seam, New Waterford district, Nova Scotia, Canada. (X 90.) Probably a very large sclerotium (770 X 240 microns) showing two big cavities. This is the largest sclerotium seen by the author.

**Fig. 5.** Merl seam, Domaniale Mine, South Limburg coalfield, Netherlands. Anthracite with 8.44 percent volatile matter of Carboniferous age. (X 150.) View of an etched, polished section of coal under reflected light, illustrating a carved sclerotiod in the upper half, and probably fungal tissue in the lower half. Both features were also discernible in the non-etched section, but the semifusinite and exinite were not.

**Fig. 6.** Hot Spring County, Arkansas, U.S.A. Tertiary lignite (Eocene). (X 700.) The sclerotium closely resembles *Sclerotites brandonianus*, which Stach (23) observed in Tertiary lignites from Columbia and Hungary. It may possibly represent a guide fossil for Tertiary coals.
indicates that its origin is closely connected with that of fusain. Only the carbonization of the plant material that turned into semifusinite has been less severe than in the material that gave rise to fusinite. As in fusinite, it is believed that this carbonization took place during the peat stage.

Sclerotinite.—The term sclerotinite, to describe the fungal matter in coal, has been introduced by Stach (1). At the Second Round Table Conference on Coal Petrography, held in June 1951, in Heerlen, Holland, the proposal to add sclerotinite as a new maceral of coal has been adopted (10, 26). Fungal matter in coal is represented as fungal tissues, sclerotia, or fragments of sclerotia. It occurs in coals of all ranks and of different ages (16, 22, 23). Sclerotinite has been described and well illustrated by Stach in his Textbook on Coal Petrography (23), and more recently in the Atlas for Applied Coal Petrography (1). Most of the following information has been obtained from this literature and from the author's own observations.

Fungal tissue is characterized by its irregular size and the abnormal pattern of its cellular structure. The tissues are considered to represent fungal hyphae and under the microscope are somewhat similar to semifusinite, because their reflective powers are very much alike (Pl. 4, Fig. 1). It occurs in isolated fragments or closely connected with semifusinite, fusinite, and vitrinite. In other words it occurs with the coal constituents that are related to woody parts of the original vegetation.

The sclerotia, for which the maceral has been named, were first observed in Tertiary lignites and Mesozoic coals (7, 20, 21) (Pl. 5, Fig. 6). Although probably present in almost every coal of Carboniferous age, they were not recognized as such until 1933, when Schulze (16) was able to establish their identity. Most of the Carboniferous "sclerotia" are ball-shaped and show, as a rule, no discernible structure. For this reason, several investigators, for instance Duparque (2) and Fanshawe (3), have interpreted them as resin globules. However, in thin sections of bituminous coals resin globules appear in a transparent, bright yellowish color, whereas the ball-shaped features under discussion do not transmit light, and are definitely opaque (Pl. 1, Figs. 3, 4, 5, 6, and illustrations that accompany the literature cited under 5 and 6). They are further characterized by a great hardness, that causes a very pronounced relief in the polished sections, which is greatly unlike the resin globules, which show hardly any relief whatsoever (Pl. 5, Fig. 1).

Because the ball-shaped features show a certain likeness with sclerotia, but in most cases do not reveal the typical structure of the fungal hyphae, the author has suggested use of the term "sclerotoids" (6). Only when the structure can be observed plainly is it justified to use the term sclerotium (Pl. 4, Fig. 6; Pl. 5, Fig. 6).

The sclerotoids occur in separated form scattered through the coal, in colonies, or within semifusinite and fusinite. They vary in size between 40 and 770 microns, and are smooth-walled or carved, or show a peculiar cellular structure (Pl. 4, Figs. 4, 5; Pl. 5, Figs. 1, 2, 3, 4). Where present in semifusinite or fusinite, their relation to the cellular structure is most instructive. As may be seen in Plate 4, Figures 2 and 3, the sclerotoids form an integral part of the carbonized tissue, but have destroyed the original cellular structure
in their immediate vicinity. This leads to the belief, as was first suggested by Schulze (16), and later affirmed by Stach (23), that the sclerotiods represent the remains of wood destroying fungi.

Although commonly a minor component of coal, certain seams may carry tremendous amounts of sclerotiods, as was found by the author in the No. 5 seam of the Saint Rose and Chimney Corner coalfields of Cape Breton Island, Nova Scotia, Canada (6). As many as 2,600 sclerotiods per square inch were counted in polished sections, cut across the bedding plane, in certain intervals of this seam. Where present in such great quantities it could be established that they have a favorable effect on the percentage of fixed carbon, and caused this high volatile "C" bituminous coal to burn almost like anthracite.

Because the sclerotiods have been found closely connected with semifusinite and fusinite, and are present in coals of all ranks, it appears evident that they originated during the peat stage. Fungal action in swamps is certainly not extraordinary. The fact that when present in great numbers the ash content of the coal is very high (6) might possibly indicate that subaquatic conditions were not favorable for these fungi, which therefore turned into the dormant state of the sclerotia.

Micrinite.—The term micrinite should be reserved for opaque attritus which is devoid of structure. It is not equivalent to the general term opaque matter, in which sense the author has mistakenly used it before (5).

At the Second Round Table Conference, held in June 1951 (10, 26) the proposal put forward by the German coal petrographers, to distinguish between granular and massive micrinite, was accepted. However, the term massive is not clearly defined. It could mean either one solid, fairly large patch of opaque matter, or several particles closely packed, giving a compact, or massive appearance. The latter interpretation appears to be the one used in the Atlas for Applied Coal Petrography (1).

Besides granular and massive, the author believes that micrinite rarely occurs as a groundmass in which the other macerals (mostly exinite) are embedded. The term groundmass, as used here, is considered as a bond or matrix that holds other components together. This meaning differs substantially from the one used in the Atlas for Applied Coal Petrography. According to this Atlas, the macerals of coal may be divided into two groups. The first group, which is considered as the groundmass of the coal, is composed of the macerals vitrinite, semifusinite, fusinite, sclerotinite, and micrinite; in other words of the opaque attritus. The second group constitutes the macerals exinite and resinite, which are considered as inclusions in the groundmass.

A groundmass, according to the author's conception, may commonly be amorphous. If crystalized, or composed of well defined particles, it is generally of a uniform and finely-grained texture, as for instance in certain igneous rocks, like porphyries. In porphyries, the larger crystals are known as phenocrysts, and the finer-grained material as the groundmass of the rock. These conditions are not encountered in coal, where the opaque matter may be either larger or smaller than the macerals exinite and resinite.

Therefore, it might be better to restrict the usage of the term groundmass
to a bond or matrix in which the other constituents are embedded. The maceral that generally forms the groundmass in coal, in this sense, is vitrinite.

With the aid of the photomicrographs, illustrated on Plate 6, the different forms of micrinite are discussed.

Granular micrinite is composed of finely divided granules, angular shaped particles, and splinters. The finely divided granules (Pl. 6, Figs. 1, 2) commonly form a most important ingredient of certain splint coals or durains. Their origin, according to Thiessen and Sprunk (29), is due to the disintegration of the secondary walls of the tracheids of wood cells. This disintegration takes place in an advanced state of decomposition of the plant material, and is caused by biological agencies.

The angular shaped particles and splinters (Pl. 6, Figs. 3, 4) may represent broken and separated cell walls or parts of fungal matter. In other words, small fragments of the macerals fusinite and sclerotinite. Because their identity as such often cannot definitely be established, these fragments are classed as micrinite.

Granular micrinite occurs most abundantly in the dull coal varieties (clarodurain and durain). The non-banded coals, such as boghead and cannel coals, generally contain micrinite in granular form. It is for this reason that its origin is believed to be closely connected with these coals, which most likely were laid down under sub-aquatic conditions (1, 25).

Massive micrinite is represented in coal by opaque particles or flakes closely packed and giving a compact or massive appearance (Pl. 6, Fig. 5). It is typical of many durains. The botanical identity of this material has as yet not been established. Consequently, its origin is a matter of speculation. According to the Atlas for Applied Coal Petrography, durains characterized by massive micrinite may have been formed in the peat swamp under partial

---

**PLATE VI. MICRINITE.**

**Fig. 1.** Tracy seam, Port Morien district, Nova Scotia, Canada. (×150.) Finely divided granular micrinite with granules embedded in a groundmass of vitrinite. The bean-shaped gray bodies are spores.

**Fig. 2.** Tracy seam, Port Morien district, Nova Scotia, Canada. (×150.) Photomicrograph under transmitted light from coal illustrated in Figure 1, but not the same view. The granular micrinite or granular opaque matter (black) does not appear so well defined in individual granules as in Figure 1. The oval-shaped white bodies in the center are spores (possibly isospores) which in this coal are usually found together with the granular micrinite.

**Fig. 3.** Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (×150.) Granular micrinite present in small angular shaped particles scattered throughout the coal, embedded in a groundmass of vitrinite.

**Fig. 4.** Pittsburgh coal bed, U. S. Experimental Mine, Allegheny Co., Penn. (×150.) Granular micrinite in splinters and particles that may possibly represent broken cell walls and fragments of sclerotoids. Because the identity of this material as fusinite and sclerotinite cannot definitely be established, it is considered as micrinite. Note semifusinite in the upper half of picture.

**Fig. 5.** Harbor seam, Sydney Mines district, Nova Scotia, Canada. (×210.) Massive micrinite, composed of closely packed opaque particles and flakes, in a groundmass of exinite. Some particles of semifusinite are present.

**Fig. 6.** Harbor seam, Sydney Mines district, Nova Scotia, Canada. (×210.) Exinite in a groundmass of micrinite.
access of air. This view is supported by the observation that massive micrinite generally occurs together with semifusinite and fusinite.

As groundmass, micrinite occurs occasionally in very dense durains, where, together with exinite, they may form the sole constituents (Pl. 6, Fig. 6). Because durains of this type are always high in ash, it is believed that they originated under sub-aquatic conditions. However, the actual mode of origin of the opaque groundmass, and the kinds of plant tissues from which it is derived, are not known. The material is devoid of cellular structure; at least with ordinary microscopic examination, no structure has been observed.

**QUANTITATIVE MICROSCOPIC MEASUREMENTS OF OPAQUE MATTER IN COAL.**

The method of using an integrating stage to determine the percentage of the banded ingredients in ground coal, as introduced by Kühlwein in 1934 (9), is adopted for the quantitative measurements of the coal macerals.

The coal to be examined, either from a storage pile, or from a specific petrographic interval of the seam, is first carefully ground to below 0.5 mm (32 mesh). The grinding should be carried out carefully in order to obtain particles of about equal size. After grinding, the sample is quartered down to about 3 or 4 grams, which are mixed with twice the amount of lucite powder (a transparent plastic material). This mixture is molded into a pellet with a mounting press under elevated pressure and temperature (3,000 lbs. per sq in and 130° C).

The pellet is examined under reflected light at a magnification of about 300 times, and with the aid of the integrating stage the percentages of the different constituents are determined. These constituents are: vitrinite, exinite, opaque attritus (fusinite, semifusinite, sclerotinite, and micrinite), and the visible mineral impurities, like carbonaceous shale, pyrite, calcite, etc. With opaque attritus are included fragments of hard fusain, that became broken during the grinding. Soft fusain, upon grinding, immediately turns into an extremely fine powder, which is very difficult to recover completely. It is for this reason that the percentage of soft fusain is determined from the polished sections that cover the same petrographic interval of the seam as the pellet.

If it is required to obtain accurate figures on the percentage of pyrite and shale, the following method is used. The original sample, after grinding below 32 mesh, is separated into a light and a heavy fraction, for which a solution with a specific gravity of 1.6 is used. The heavy fraction will then contain most of the visible mineral impurities. From both fractions, separate pellets are made, and more accurate figures on the percentage of pyrite and shale can be determined than if only one pellet of the original sample had been prepared. However, for the quantitative analyses of petrographic subdivisions of a coal seam, one pellet is generally considered sufficient. It was found, that the regional differences in comparable intervals of different samples show variations, that do not always justify the extra time involved in the examination of two pellets, which is needed for a slightly greater accuracy.

The great advantage of the method outlined here is the fact that it is
comparatively simple to carry out, and further, that it is far less time-con-
suming and tiresome than other methods currently in use.

THE EFFECT OF OPAQUE MATTER ON THE PROXIMATE ANALYSIS OF COAL.

With the method previously discussed, quantitative microscopic measure-
ments were made of the major coal components of several petrographic inter-
vals of the Tracy seam of the Sydney coalfield. The coal of this seam is
characterized by a relatively high percentage of opaque matter, which consists
predominantly of fusain lenses and granular micrinite (Pl. 6, Figs. 1, 2). To-
gether with micrinite, a peculiar type of spore, in size intermediate between
mega- and microspores, and possessing an unusually hard exine, that gives
it a high relief in polished surfaces, is found throughout the section of this
seam. The occurrence of these spores in combination with granular micrinite
is unique for the Tracy seam. So far it has not been observed in any of the
other seams of the Sydney coalfield. Due to this peculiar feature, which is
present almost throughout the entire section of the seam, and which could be
traced regionally over 8 miles, the author believes that even from a small, odd
block of coal, the Tracy seam may be identified. Although the spores are
present in great numbers, the percentage figure of exinite in the different
petrographic intervals of the seam remains low. It varies between 2 and
8 percent.

The petrographic composition of six different intervals of the Tracy seam,
expressed in percentage by weight on shale- and pyrite-free coal, is illustrated
in Table III. The corresponding proximate analyses of the intervals ex-
amined are also indicated. With the aid of the Parr formulae (13), the fixed
carbon is calculated on a mineral-matter-free coal basis. A comparison of the
fixed carbon figures thus computed, with the total opaque matter, shows that
undoubtedly there exists a relationship between the two. When the intervals
are high in total opaque matter, they generally show a correspondingly high
figure for fixed carbon. This figure may be lowered some, due to a relatively
high percentage of exinite, as is the case in interval X. However, a linear
relationship between opaque matter and fixed carbon does not occur, which
is due to the fact that fixed carbon is merely a calculated figure, that does not
express the total carbon that is present in the coal. Unfortunately, the author
has as yet not been able to obtain figures on total carbon, for which an ultimate
analysis of the coal is required.

In Table IV, the results of a number of analyses are illustrated, which
pertain to selected samples from the St. Rose and Chimney Corner coalfields,
Cape Breton Island, Nova Scotia, Canada. These samples have been de-
scribed previously (6), and have been selected for their different concentrations
of sclerotioids (Pl. 4, Fig. 5). They belong to two different seams, namely
the No. 5 seam (Nos. CC 1 and SR 1) and the No. 2 seam (No. SR 2),
which are of the same rank, namely high volatile "C" bituminous coal. The
opaque matter in all samples consists predominantly of sclerotioids, together
with a minor amount of granular micrinite. The relationship between opaque
matter and fixed carbon is essentially the same as in Table III. This in effect
<table>
<thead>
<tr>
<th>Number</th>
<th>Thickness (inches)</th>
<th>Vitrinite (percent)</th>
<th>Exinite (percent)</th>
<th>Fusain (percent)</th>
<th>Fixed carbon, dry basis (percent)</th>
<th>Ash (percent)</th>
<th>Sulfur (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VI</td>
<td>6.8</td>
<td>9.4</td>
<td>0.5</td>
<td>1.3</td>
<td>51.8</td>
<td>15</td>
<td>6.3</td>
</tr>
<tr>
<td>VII</td>
<td>9.2</td>
<td>6.5</td>
<td>2.0</td>
<td>2.0</td>
<td>55.4</td>
<td>12</td>
<td>3.6</td>
</tr>
<tr>
<td>VIII</td>
<td>9.3</td>
<td>6.9</td>
<td>2.4</td>
<td>1.1</td>
<td>58.9</td>
<td>14</td>
<td>2.9</td>
</tr>
<tr>
<td>IX</td>
<td>6.3</td>
<td>5.8</td>
<td>1.4</td>
<td>1.0</td>
<td>64.6</td>
<td>29</td>
<td>2.1</td>
</tr>
<tr>
<td>X</td>
<td>0.5</td>
<td>4.1</td>
<td>1.0</td>
<td>1.0</td>
<td>58.6</td>
<td>15</td>
<td>3.0</td>
</tr>
<tr>
<td>XII</td>
<td>3.6</td>
<td>5.2</td>
<td>0.0</td>
<td>1.0</td>
<td>62.8</td>
<td>15</td>
<td>2.1</td>
</tr>
</tbody>
</table>

P. A. HACQUEBARD.

**TABLE III.**

<table>
<thead>
<tr>
<th>Number</th>
<th>Thickness (inches)</th>
<th>Vitrinite (percent)</th>
<th>Opaque attaixis (percent)</th>
<th>Fusain (percent)</th>
<th>Fixed carbon, dry basis (percent)</th>
<th>Ash (percent)</th>
<th>Sulfur (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC 1</td>
<td>1.5</td>
<td>91</td>
<td>44</td>
<td>0.0</td>
<td>5.5</td>
<td>55</td>
<td>2.0</td>
</tr>
<tr>
<td>CC 2</td>
<td>1.5</td>
<td>84</td>
<td>76</td>
<td>0.0</td>
<td>5.0</td>
<td>45</td>
<td>2.0</td>
</tr>
<tr>
<td>CC 3</td>
<td>1.5</td>
<td>76</td>
<td>84</td>
<td>0.0</td>
<td>5.0</td>
<td>45</td>
<td>2.0</td>
</tr>
<tr>
<td>CC 4</td>
<td>1.5</td>
<td>84</td>
<td>76</td>
<td>0.0</td>
<td>5.0</td>
<td>45</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**TABLE IV.**

*Petrographic composition expressed in percentage by weight on shale- and pyrite-free coal. Specific gravity: vitrinite 1.3; extinite 1.2; opaque attaixis 1.5; fusain 1.5.*

*These figures were kindly supplied by M. M. Bates, Analytical Engineer, Chemical Laboratory of DOSCO, Glace Bay, Nova Scotia, Canada.*
is further proof that the sclerotioids indeed may be considered a part of the opaque matter in coal.

The results from both investigations are in accordance with observations made by Sprunk et al. (19), who noticed that the total carbon of splint coals is higher than that of associated bright coals. This was explained by the higher content in opaque matter of the splint coals. However, the amount of opaque matter present in these coals was not given.

To further verify the accuracy of quantitative microscopic measurements of the coal components, as outlined in this paper, it is intended to have ultimate analyses made of the samples investigated, in order to compare the percentage of total carbon with the percentage of opaque matter. It appears to the author that comparative studies in general, between petrographic and chemical analyses of coal, are of the utmost importance, and should be more actively pursued.

GEOLOGICAL SURVEY OF CANADA,
COAL RESEARCH DIVISION,
SYDNEY, NOVA SCOTIA, CANADA,
January 22, 1952.

BIBLIOGRAPHY.

6. ——, The correlation, by petrographic analyses, of No. 5 seam in the Saint Rose and Chimney Corner Coalfields, Inverness County, Cape Breton Island, Nova Scotia: Canada Geol. Survey Bull. 19, pp. 33, 1951.
516 P. A. HACQUEBARD.


