N° 5

THÈSES

PRÉSENTÉES

A LA FACULTÉ DES SCIENCES DE L'UNIVERSITÉ DE LILLE

Pour obtenir le grade de
Docteur ès-sciences naturelles d'Université

PAR

J. R. FANSHAWE,
BACHELOR OF ARTS, PRINCETON UNIVERSITY

1re THÈSE

A microscopical Study of Coal : Pennsylvania Anthracites and West Virginia Coking Coals

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2me THÈSE

Propositions données par la Faculté

Soutenues le 12 Juillet 1930, devant la Commission d'Examens

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AFFECTIONATELY

TO

« BILL »

AND

J. E. J. F.

GRATEFULLY

TO

Ch. BARROIS

P. PRUVOST

P. BERTRAND

A. DUPARQUE

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ILLUSTRATIONS

PREFACE

(*by* André Duparque)

The research work carried out by Mr. John R. Fanshawe at the geological laboratory of the University of Lille has produced an important contribution to the microscopical study of coal, and permits the deciding of certain divers controversies.

First of all, the *method of investigation* used in these researches — not having given satisfactory results to all who have employed it — has provoked criticism and has given rise to erroneous statements, entirely unjustified. The most serious of them is to admit with Legray, Turner, Randall, and Seyler that *attack only* can bring the structure of anthracites into evidence. The figures contained in plates I and II of this memoire, which have been obtened from surfaces *merely polished*, are sufficient to refute that statement and to show that one can obtain, by polish alone, structure much clearer than any other figures of anthracites which have been polished and attacked.

Although *the identity of origin of the bituminous coals and the anthracites* has been affirmed many times, the study of the intermediary coals (semi-bituminous or coking coals), which in this hypothesis constitute the link of the chain between these extreme types, has hardly been touched except in France where it has recieved a satisfactory explanation. The reasons for this lack of study must be found in the fact that these fragile coals have proved unworkable for nearly every other method of preparation for microscopical investigation and that the method of simple polish has proved effective. The study of American coking coals has allowed Mr. Fanshawe to show the identity of the structure of those combustibles with the same rank coals of the north of France, which I have described and pictured, and to show at the same time the differences that exist between them and the bituminous coals on the one hand, and on the other hand the presence of *ligno-cellulosic* coals in the American coal measures, which fact has been mentioned by Jeffrey.

Secondly, the study of the *anthracites* of Pennsylvania, which — like the *houilles anthraciteuses* of the north of France — reveals *their duality of origin* coming from deposits similar to those which have developed into coking coals (ligno-cellulosic deposits), and those which have become bituminous coals (deposits rich in cutine), shows that if, between the true anthracites and the semi-anthracites, there exists a difference in chemical composition *their lithological structures are strictly identical.*

The observations of Mr. Fanshawe on the American coking coals and anthracites go very nicely to complete Jeffrey's observations on the bituminous coals. From the combination of these works one can conclude that the American coals present exactly the same general characteristics as those from the north of France which are derived, as I have previously pointed out, from two types of initial deposit, one of which was chiefly rich in lignified tissues (wood, sclerenchyme) while the other contained almost exclusively cutinised vegetable bodies (spores, cuticles). The paleozoic American coals, then, fall naturally into two large combustible classes to which I have applied, in the northern and central parts of France, the terms *houilles ligno-cellulosiques* and *houilles de cutine.*

The plates with this mémoire show that, in the present stage of our developments, the method of preparation of surfaces of paleozoic coals for examination with the metallographic microscope *by polish alone* gives results much superior to those gotten by the other methods of investigation (thin-sections, microtome sections, macerations, and incineration or ash methods).

Moreover, this method, which has been used since 1922 at the University of Lille in the coal era museum and in the geological laboratory where all the organization is due to the initiative of M. Charles Barrois, recommends itself by its *great simplicity,* and can be used indiscriminately for paleozoic coals of all categories and for combustibles more recent. — Employing no process of attack or enrobage, this method has, above all, the advantage of violating in no way the natural structure of the combustible sediment so sensible to reagents, especially oxydants.

The contribution now brought forth by Mr. Fanshawe to aid our knowledge about paleozoic coals has the high merit of generalizing the results arrived at for the « Bassin houiller » of the north of France and of applying and verifying them with a certain number of American coals.

LILLE, June 10, 1930.

André DUPARQUE,

Laboratoire de Géologie et Minéralogie de l'Université de Lille.

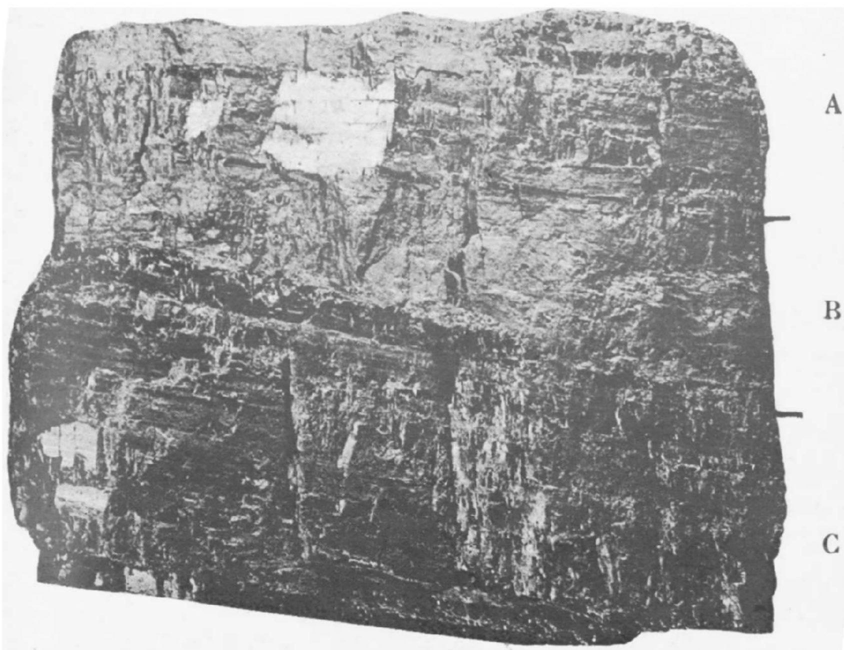


Figure 1

Typical coking coal from the Miller seam

I

INTRODUCTION

The purpose of this work is two-fold : to introduce a quick and useful method of preparing coal for study under the microscope ; and by the application of this method, to show certain relations and differences between coking coals and anthracites. I had also in mind to compare American semibituminous and anthracite coals with those of France, but as the former are nearly identical in form and structure, I have emphasised the more interesting and instructive problem of comparing the two ranks of coal mentioned. As far as I know, no work of any importance has been done on coking coals from the point of view of microscopical structure and contents (except for those of Duparque) [23] * on account of their fragility and the consequent difficulty in preparing specimens for scrutiny under the microscope, either as thin sections or polished surfaces.

(*) Numbers are references to the Bibliography at the end of the text.

That fact, together with new interesting data on the coals in question, are the reasons for presuming to present this work for publication. It is submitted in the hope of aiding and furthering our limited knowledge about coal.

As an interesting side issue, there will be found an attempted correlation between the Pennsylvania formations of the Appalachians and the Westphalian and Stephanian formations of France, especially those of the Bassin du Nord. It is difficult because of different names for some of the plants, and the different time ranges for some species ; so I can vouch for it as being only approximate. At present, not enough accurate data is to be had for a good comparative tabulation of the two regions.

I have spent one year at Lille in preparing this thesis, and I leave with regret. I wish to thank the Faculty for their cordiality to me, and above all to express my gratitude and appreciation to Professor Pierre Pruvost, because of whom I first came to Lille, for the assistance, friendly interest, and invaluable comradeship that he has continually had for me. Having made his acquaintance and worked with him are privileges never to be forgotten. To Professor André Duparque, whose excellent previous research has made this work possible and under whose instruction it has been prepared — especially the photographs — I am also indebted. Professor Charles Barrois, a one-time student of James Hall, although now retired from teaching geology, still occupies himself with the

students ; and has furnished many helpful ideas in discussions. Paul Bertrand, Professor of Paleobotany, has been very kind and aided me greatly in the work of chronological corelation.

In America, I want to thank Doctor W. T. Thom of Princeton University for his constant help and for the specimens he sent ; Professor H. G. Turner of Leheigh University, for his publications and coal samples ; Mr. J. H. Rose of the Koppers Company in Pittsburg for the samples of cokings coal so kindly forwarded ; and Professor Richard M. Field of Princeton University, who was responsible for selecting Lille, and who — in cöperation with Doctor Pruvost — made it possible for me to work in La Belle France.

II

COMPARISON OF THEORIES ON COAL FORMATION

All sciences are founded upon wrecks of discarded theories, and this is especially true of Geology. What was accepted as truth yesterday, is doubted today and discarded tomorrow, perhaps for ever or to reappear in later times in a changed form, again supreme. This changing path, the stepping stones from past to present, this evolution of common sense, presents a fascinating story on which is based our still imperfect science.

Unfortunately destruction is easier than construction, and while it is often an easy matter to point out faults in an existing or past thery, to reconstruct that idea or to produce another one that holds water more effectively is a problem often undertaken unsuccessfully.

To better present any work on coal formation, a résumé of two principal existing theories on coal formation would not be amiss. Men in whose works they can be found are H. Potonié [62], Jules Cornet [17] and Murray Stewart [76] ; and each theory has many supporters as well as proofs or points in its favour. An understanding of these large scale items is necessary before the study of the microstructure can be helpful ; for one must work with some hypothesis in mind, following the evidence presented — whether it destroys or strengthens one's beliefs of the moment.

Today, the fact that coal is of vegetable, not mineral, origin is generally accepted ; and all theories are based on that premise. The problem is : How did such huge masses of plants come to be accumulated ; and after the accumulation, how have they reached their present form ? A bed of coal, according to some savants, represents but one fourth of the original thickness ; so it can be easily appreciated what a stupendous primary deposit is represented by a vein two metres thick. To explain this, we must grant the existance of huge forests of rapid growing plants, in or near water, together with a climate favourable for their continued flourishing. The fossil stumps and tree trunks found throughout the World's carboniferous deposits show no seasonal growth rings, indicate a remarkable ability for absorbing much water, grew rapidly, and have a marked similarity to our present day torrid zone swamp flora. Professor P. Bertrand [13], because of these points, is of the opinion that the then climate was warm, humid or rainy, and uniform ; perhaps corresponding to our subtropical climate in Spring.

Doctor David White [88] agrees with these conclusions, and has noted the beginning of climatic variations in the Upper Stephanian because of the appearance of larger and stronger trees containing faint growth rings in their horizontal trunk cross-section. Although contrary to anything which exists today, that explanation seems to be the only one which can account for a source for the coal as we find it.

These things being so, we have a double split in the theories that are based on it. The origin of coal is vegetable, granted, but was it formed and deposited in (or nearly in) place ; or was it formed in one locality and deposited in another as any other geological sediment ? This is followed by the question : Was the original composition of the coal responsible for its present form ; or is that present form a result of mechanical and chemical forces of metamorphism in operation after its deposit ?

Coal formation is dependent on three major factors : type of vegetation : impurities present in the water or place of deposition ; and amount of bacterial decay, governed by drainage and locality. However, at a given instant in two neighbouring coal forming localities the conditions will vary. Amount of water ; speed of currents ; kind of water (salt, stagnant, or fresh) ; impurities present — such as mud, silt or minerals in solution ; kinds of vegetation ; degree of decay ; etc. ; all those things may be different, affecting the nature of the deposit. Whether this variation accounts for the present form of the coal, whether it is a modifier for the metamorphism to follow, or whether it is of no importance in the light of that metamorphism ; that is our second difficulty.

To Grand Eury [14] goes the credit for the best beginnings on the study of coal formation. His first work was done in the Loire district, and was good enough to clarify the very hazy ideas held on the subject at that time. He began publishing his geological discoveries in 1869, continuing until 1912. Among the very important items found are the following :

He was the first to show clearly the existence of successive stages in the « terrain houiller », well characteristic and easily recognisable by their flora.

He was also the first to show the all important rôle of fossil plants in the stratagraphical determination of that « terrain houiller ».

Due to his work on the coal basin of the Loire is the European term « Stephanian ».

After starting with a theory of autochtony, then — under the influence of Fayol — changing to allochtony to explain coal formation, he returns finally to his first idea of formation « in situ ». This idea was held by others (Lyell, Lindley, Hutton, Binney, Göppert, Stur, etc.) but to him belongs all credit because of his painstaking work and the definite proofs he established.

In 1900, B. Renault [66] presented the theory that the various types of coal were determined by their original composition. Lignite is always lignite, bituminous coal is always bituminous, etc. ; each type dependent on natural pressure to reach its form, with further change impossible because of the original constituants. According to him, coal formation consists of the following phases :

1. Maceration under the fermenting agents contained in the plants themselves, aided by bacteria.

2. In the substance thus formed, by « microbes aérobies », a fermentation occurs liberating CO^2 leaving a product rich in carbon.

3. Later, when the combustible has been covered by some sediments and deprived of air, a second fermentation by the « microbes anaérobies » occurs, desolving the cell walls, liberating marsh gas (CH^4) and more CO^2. This activity is terminated because by their excretions the microbes become suicides.

Carbonization is now finished. There exists a coal, formed of a « pâte » (which is the result of the dissolution of cellulose and vegetable material) and vegetable matter altered but not destroyed, with some mineral material or organic fossils enclosed therein. Then the type of coal is established, and pressure merely compacts it.

It was probably from this or a similar basis that evolved the opposing theories of Potonié — Cornet vs. that of Stewart. The former is autochtonist (formation of coal in place of growth) the latter allochtonist (formation by natural geological sedimentation) and the two theories are mutually not in accord.

Cornet was activated entirely by Potonié but he clarified his writings (that were difficult to read and understand) and added to them some original ideas.

To Potonié really belongs the credit of the theory so well propounded by Cornet. He accepts the proposal of Francis Nauman to divide all coal deposits into two classes : 1. Those formed in the vicinity and under the influence of the sea — paralic basins ; and 2. those formed inland — limnic basins. Examples of the former type are the basins of the Appalachians, of England Scotland, of France-Belgium-Westphalia, etc. ; of the latter type are those of Bohemia, central France (St. Etienne, Gard, etc.), Saxony (Zwickau), etc. Later deposits, up to the present day, also fit into this classification. The main difference between these two types is that the limnic basins are smaller, and the coal seams are more apt to vary in character and thickness. He states that the autochtonic formation of the seaboard division is incontestable, and that it constitutes the major portion of all localities of coal deposition. He presents his theory of formation in the paralic basins as follows :

There is a vast, gently rolling maritime plain, the surface of which is very nearly that of sea level, with the sea and the land occupying about equal portions. Inland there is a topography of strong relief. The lowness of the plain permits the formation of salty, stagnant, or fresh water lakes and lagoons, around and in which grow the coal flora. A sudden drop of the land surface permits the encroachment of the sea and natural sediments are deposited. A long period of calm now exists until the trees have again taken possession of the plain and the coal begins to be formed. Then the process repeats itself. He calls this down movement

« saccadée » which means a movement quick, abrupt, and not of great size. The coal belds represent periods of stability, and the roof is formed by this down movement, which causes shales, sandstones or conglomerates to be deposited over the new-born coal seam. The large amount of sandstones and conglomerates (especially in the Bassin du Nord from where he takes most of his proofs) must have been due to emergent continental masses, as many of the pebbles indicate a distant point of origin.

The above paragraph is a fairly accurate translation or paraphrase of his words, but before giving us this, he presents a number of interesting points in favour of autochtony. He begins by admitting that some coals are undoubtedly not formed in place, as well as some conglomerates containing coal pebbles, but that these isolated cases — though numerous (see Ch. Barrois [3, 4, 8]), are but a tiny portion of the majority of coals. He then cites the following items, taken chiefly from Belgium and France's Bassin du Nord.

1. Most coals present a quite remarkable stratified appearance, or are formed by alternating thin beds of vitrain and clarain, which suggest allochtony; but as definite stratification is observed in present peats of know autochtonic origin, this cannot be regarded as a proof either way. The alternation of the thin beds was due to momentary changes in the conditions of the place of deposit.

2. Some coal seams present a thickness fairly regular and extend for great distances (the Pittsburg

bed averages 1.80 metres and extends over 25.000 kilometres), so formation in such a case by running water would be difficult. Though irregular, the coal seam itself is much more even in texture and thickness than either its floor or roof.

3. When plant fossils in coal beds are recognisable, it must be due to rapid preservation, almost in place, for transport would destroy the characteristics.

4. In general, coals of known structure are composed of one or two plant species alone. This is difficult to explain by a transport theory.

5. The purity of the coal is remarkable. From a table of 2.658 analyses of coals of Europe and America, compiled by X. Stanier, it is shown that 50 % have less than 5 % of ash content, that 85 % of the analyses show less than 10 % ash, and that 5 % to 10 % is the most common ash content — a condition less than that found in most peats of today.

6. The study of floor and roof shows that one often finds Stigmaria in place in the floor with roots traversing it in all senses but never in the roof. The roof is more stratified and may be micaceous, usually shaley. The floor is not well stratified and has an irregular cleavage, typical even though the roof follows directly without any inter-coal seam.

7. Between the roof and floor there is a difference of 50 % in iron content, easily explicable if one grants that the floor represents an ancient soil of vegetation — not only containing little iron, but impoverished of its iron by the direct or indirect action of the vegetation...

Those are the mainstays of his theory of autochtony, the force of which we shall not dispute at the moment. We shall now look at Murray Stewart's opinion on deposits by transport. Thirty years after Jukes, that theory was brilliantly set forth by H. Fayol, who applied it to the Commentry coal deposits of central France ; and made many detailed observations and striking experiments. Whe refer those interested, to his famous memoir [98] on the « Théorie des Deltas ».

Stewart, citing theories that hold metamorphism alone responsible for the present variations in different coals, and those that claim the variations to be due to both plant content and metamorphism, arrives at the following conclusions, following the ideas of Jukes [54] some eighty years before him. Coal is uniquely dependent on the material forming it for its final form — that is, the past amount of bacterial action alone is responsible for the condition of coal as we find it today. It was a black carbonaceous mud, formed in a lagoon by decay or putrefaction of plant material ; and was carried out to sea by a broaching of the lagoon, caused by a land movement of the time. Remembering that the transportnig power of water varies with the cube of its speed, it will be seen that, with the salt water as a classifier of the materials, a sheet of sediment will result having nearest shore a conglomerate, and in unbroken series a sandstone, a shale (pure mud), coal (carbonaceous mud), and a limestone. Coal is thus a natural geological sediment, dependent on lagoonal action for its stage of putrefaction before the broaching of the lagoon and sequent open sea deposition.

He claims this to be a great advance on the old idea that vegetable matter, buried in geological sediments, underwent slow change through the stages of lignite and brown coal to true coal ; as it is know today how important is the rôle of the bacterial action in the formation of the sediment. Therefore, a lignite is a lignite because of that alteration which is also responsible for all variations in combustible fossils.

American geologists in general are of the opinion that the terms peat, lignite, brown coal (or sub-bituminous), bituminous coal, semi-bituminous, and anthracite represent stages in the evolution of a combustible of vegetable origin. The idea of lagoonal putrefaction *and* deposition is also generally accepted. Doctor W. T. Thom [82], of Princeton University, holds to the same beliefs as Jules Cornet, but he states definitely that the above terms are grades in natural coal changes. He cites the case of a peat bed cut by a lava intrusion. At the point of contact, the peat seam was altered to schungite and imperceptibly graded through anthracite, bituminous and lignite to peat. He believes the continued heat and pressure, culminating through the long eras that have passed after the deposition of the bed, to be responsible in a great measure, for the form of the coal as we now find it — modified somewhat by the variations in its composition. D. White [86] makes the observation that most of the U. S. Secondary and Tertiary coals repose on an anciens soil of vegetation, and is an autochtonist like Cornet and Potonié [62]. W. B. Scott [67], R. Thiessen [81], H. G.

Turner [84], and many other American savants are in accord with these ideas of formation in place.

In all the theories that exist, it is admitted that coal beds sometimes repose on an ancient soil of vegetation (in paralic basins). Fossil soil itself is universally granted to be of autochtonic origin, but the controversy arrives in determining whether the coal directly over it is a similar kind of deposit. One cannot answer this question without a close scrutiny of the true structure of many coal veins — so we propose now to turn to that source of information.

III

SPECIMENS EMPLOYED

The coal specimens, used in connection with this report, with my serial numbers, are tabulated below.

1. Anthracite. — *Buck Mt. Bed.* — Richards Colliery, West Mahanoy district, Pa. U. S. A.

2. Anthracite. — *Buck Mt. Bed.* — Olyphant Colliery, Carbondale district, Pa. U. S. A.

3. Anthracite. — *Mammouth Bed.* — Olyphant Colliery, Carbondale district, Pa. U. S. A.

4. Fusain. — *Forge Split of Mammouth Bed.* — Nantikole, Pa, U. S. A.

5. Anthracite. — *Top Split of Mammouth Bed.* — Glendower Colliery, West Schuylkill District, Pa. U. S. A.

6. Anthracite. — *Top Split of Mammouth Bed.* — Glendower Colliery, West Schuylkill District, Pa. U. S. A.

7. Anthracite. — *Primrose Bed.* — Lytle Colliery, West Schuylkill District, Pa. U. S. A.

8. Coking Coal. — *Veine Delloye.* — Fosse Dechy, Etage 511, Mines d'Aniche, Bassin du Nord, France.

9. Coking Coal. — *Veine N° 13.* — ditto.

10. Coking Coal. — *Veine Bernicourt.* — ditto.

11. Coking Coal. — *Veine Le François.* — ditto.

12. Coking Coal. — *Veine Lallier.* — ditto.

13. Coking Coal. — *Veine Dejardin.* — ditto.

21, Coking Coal. — Top of Seam *N°* 3 *Pocahontas*, Macdowell County, W. Va. U. S. A.

22. Coking Coal. — 16″ from top of seam N° 3 *Pocahontas*, ditto.

23. Coking Coal. — Bottom of seam *N°* 3 *Pocahontas*, ditto.

24. — Coking Coal. — Top of seam *N°* 4 *Pocahontas*, ditto.

25. Coking Coal. — 18″ from top of seam N° 4 *Pocahontas*, ditto.

26. Coking Coal. — 8″ from bottom of seam *N°* 4 *Pocahontas*, ditto.

27, 28, 29. Coking Coal. — 16″ from roof of *Sewell* seam, Raleigh County W. Va. U. S. A.

30, 31, 32. Coking Coal. — 36″ from roof of *Beckley* seam, ditto.

33. Coking Coal. — Centre of « *B* » *or Miller* seam, Fayette County, Pa. U. S. A.

34. Coking Coal. — 6″ from bottom of « *B* » *or Miller* Seam, ditto.

35. Coking Coal. — 6″ underneath bone coal of « *B* » *or Miller* Seam, ditto.

The ones from France previously described by Duparque are not figured in the report, having been studied with the intention of finding contrasting material for the same type of American coal. Being quite similar, I judget it best to concentrate on the comparison of the anthracies and coking coals from our Appalachian basin.

The photograph (fig. 1) is a natural size of specimen N° 35. The parts indicated by A and C show the characteristics common to all semi-bituminous coals, while B is a lenticular bed much more compact. Further description of this specimen will follow in the later discussion.

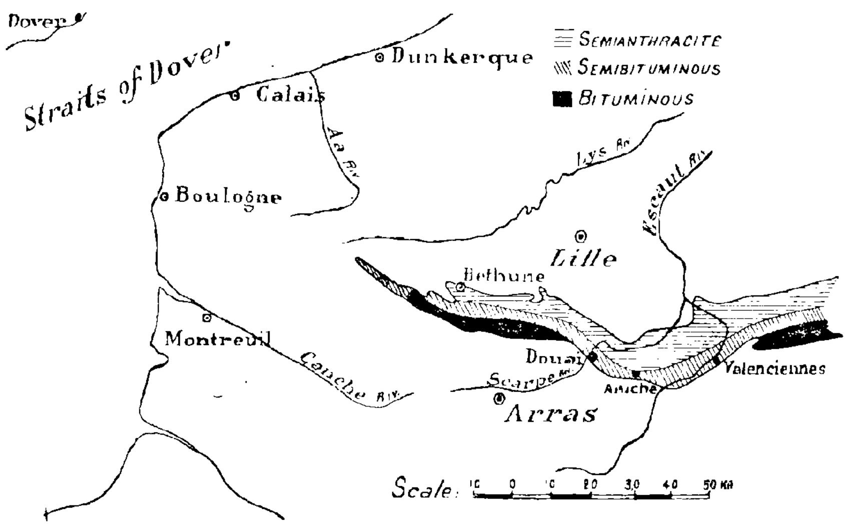


Figure 2

Bassin du Nord de la France

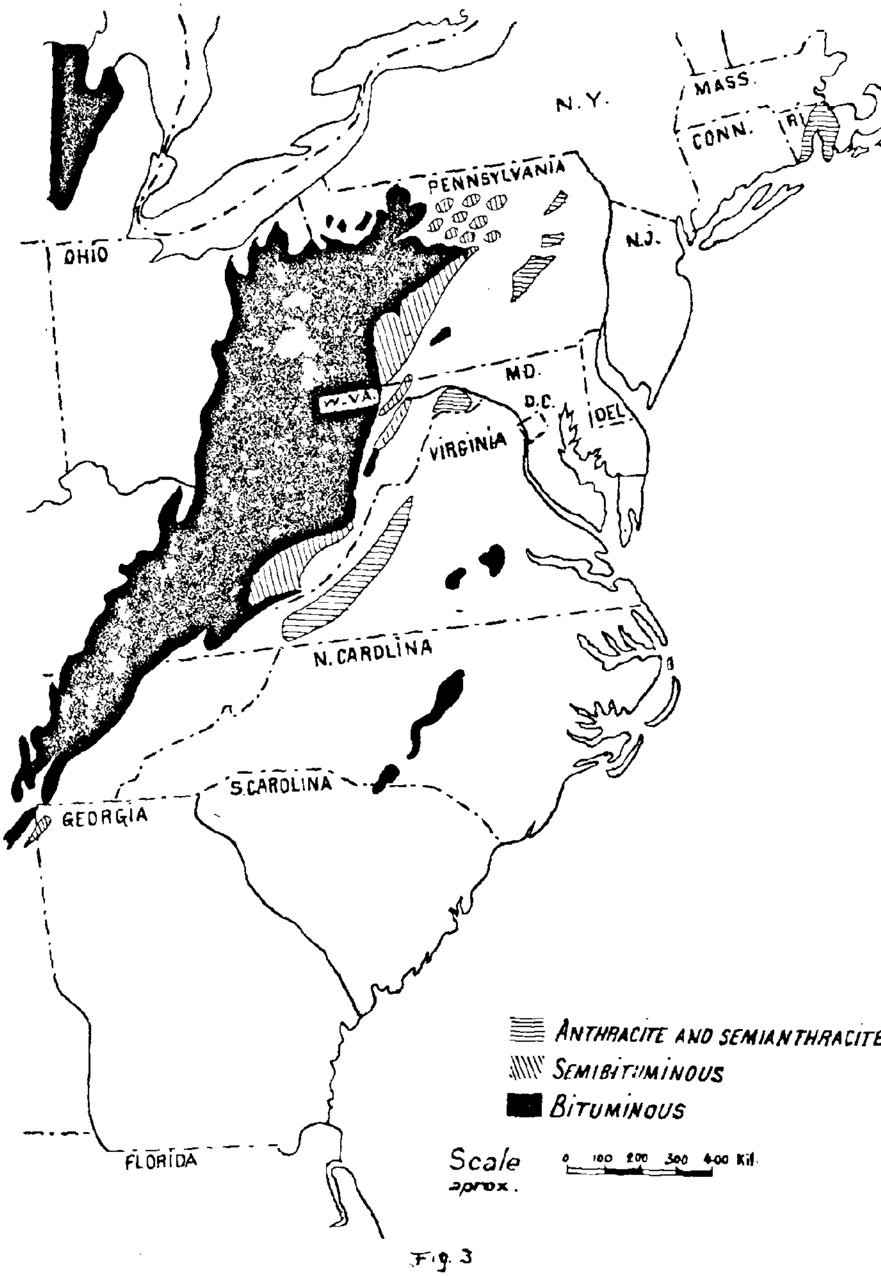


Fig. 3

Eastern U. S. Coal Fields, (after Daly)

IV

CHRONOLOGICAL CORRELATION

The fact that two of my specimens from the two countries were very close in respect to geologic age (those from the Miller Seam and from the Veine Delloye) led me to attempt a time corelation between the coal measures from which they came. The task soon proved to be one which I was incompetent to do with detailled accuracy, so the result shown in fig. 4 must be taken as a next best. The plant names are often different in in America and France, their ranges also may not be the same, and the thickness of the deposits is practically useless as a guide. However, after consulting the geological surveys of W. Va., Pa., and other references (especially numbers [15, 53], and [64]) and with the kind assistance of Professors Paul Bertrand and Pierre Pruvost the indicated time table evolved. I believe it to be essentially correct, but for a more exact work of its kind it is necessary that experienced paleobotanists spend much time on

Age	W. Va.	Penna	Age	Bassin Français
Permo-Carboniferous	Dunkard Series	*Lallne*	Permien *inf.* (Autunien)	Couches d'Autun
Pennsylvanian	Monongahela Series		Stéphanien	Assise de St Etienne Assise de Rive-de-Gier
	— Pittsburg bed —			
	Conemaugh Series	Orchard bed Primrose bed		
				Conglomérat de Holz
	Allegheny Series	Holmes Mammouth Skiomore Buck Mountain	Westphalien	Assise de La-Houve Assise de Bruay
				Niveau marin de Rimbert
	Kanawha Series	Kanwha		Assise d'Anzin: Veine Dejardin, Lallier, Le François, Bernicourt, N° 13, Delloye
				Niveau marin de Poissonnière
Pottsville	*Pottsville Series*: Miller, Sewell, Beckley; Pocahontas (9, 4, 3, 1)	Upper Lykns Series Lower Tranition Series Lower Lykns Series Pottsvill Congl.		Assise de Vicoigne
			Namurien	Assise de Flines Assise de Bruille
Mississippian	*Maunch Chunk Shaes*		Dinantien	Calcaire Carbonifère

Fig 4

a minute comparison of the characteristic fossil plant species of the far distant regions.

For me the chart serves its purpose in showing the ages of the specimens on which this report is based, and their approximate relations to each other. Their actual geographic source can be seen on the maps of the respective regions (Figs. 2 & 3), as well as the similar type distribution of the ranks of coal. It will be noticed that if one turns the French map so that the semi-anthracites are on the right, the sequence of anthracite, semi-bituminous, and bituminous localities is identical. Whether it indicates an increase of metamorphism on the anthracitic side in both cases, or whether it indicates a progressive change in the conditions of deposit, I do not know. Doctor Thom [82] is of the former opinion, Professor Duparque holds to the latter ; and both are logically possible. The fact that bituminous coals contain a multitude of spores and cuticles that are but rarely found in semi-bituminous coals is hard to explain if one attributes it to pressure alone. Some sort of compromise is clearly necessary but we shall leave this point until after we have looked at a few samples at close range.

V

METHODS OF MICROSTUDY

In any scientific research problem there are two very important considerations to be mastered before results can be produced. There must be a method of study adequate in making clear the facts on hand ; there must be the ability to interprete correctly those facts when revealed. The best of savants slip on one point or the other, but at last we are partly relieved from the former difficulty — at least when working on the microstructure of coal.

The controversy in coal microstudy now is one of thin sections and ordinary petrographic methods vs. polished surfaces and reflected right. We shall discuss each, beginning with the former.

ORDINARY PETROGRAPHIC METHODS

C. Eg. Bertrand [11] and B. Renault [66] were the first to study « combustible fossils » with a microscope. Their efforts were not directed towards coal proper but towards the bogheads or « charbons d'Algues ». They employed thin sections, Bertrand achieving some excellent results as a pioneer in that field of study.

J. Lomax [59], in 1914, produced a work on the composition of the banded bituminous coals in an article on spontaneous combustion, in which he published 80 figures of thin section photographs. The most obvious kinds of structure (such as macrospores and resins) are well shown, as is some of the finer structure, but evidently the sections were not thin or clear enough to permit exacting study or high-power enlargements. However, his figures are much better than many of those who published works more recently (Stopes and Grounds, for instance).

Marie Stopes [77] is largely responsible for the terminology used in Europe at the moment because of her concise work on the constituants of banded bituminous coal. With the cooperation of R. V. Wheeler

[77 bis], a similar work was published, using four of the same figures to illustrate it. The two works were a description of bituminous coal and their contents, containing the definitions and explanations of the terms Fusain, Durain, Clarain, and vitrain. The figures (microphotographs of thin sections) were very poor the ones illustrating Clarain and Vitrain showing practically nothing. They have a dull reddish yellow colour, caused by the thickness of the slides, which also accounts for their opaqueness and indistinctness. Even so, these two works are a reference-base for later ones and are the beginning of improved microscopical research. Before 1914 there was little published about coal structure, but Stopes' work marks the start of many other such investigations. Her method of study was the ordinary one of grinding thin sections, but Stopes and Wheeler remarked [77 bis] that the sections have a « most annoying amount of scratches » and are difficult to grind evenly. A look at their figures will show that it is only a beginning for better developments.

1923 marks the appearance of many coal students using both types of methods.

A. Grounds [48] tried thin sections with anthracites in studying them for ash content, but as far as method and photographic results were concerned, there is very little of good that can be said.

R. Thiessen [79, 79 bis] has developed an excellent method of study. He prepares thin and opaque sections, studies them under the microscope, then studies them further by splitting and dissecting them. By the use of Schulze's reagent, he has isolated many spores and cuticles from the coal. Whether that system can be applied to all ranks of coals is rather doubtful, but it is certainly very good with bituminous specimens — as his results show.

E. C. Jeffrey [50], as far as I have been able to find out, has produced the best results with thin sections. His method is applicable to all ranks of coals, but takes much time and care. The principal is to take out all impurities, impregnate the specimen with cellulose to harden it, and slice off thin sections of less than five micrometers. With bituminous and newer coals he gets very good results, but has difficulty with coking coals because of their fragility, and with anthracites because of their extreme hardness. From the description of his method, it seems that a minimum of 21 days is required for the preparation of a specimen, and to prepare anthracites may be a question of months. There is no doubt but that his figures and results are better than any others who have used petrographic methods — as well as most of those who have used polish or polish and attack (except for Duparque and Stach). Perhaps the question of time is not very important, but is must be annoying to work for a month on an anthracite specimen that could be better prepared by another method in twenty minutes.

The men previously mentioned are those who use petrographic methods of study. From any point of view this way of study is logically the correct one. The difficulty lies in preparing the specimens. At present, the sections are always too thick, being too opaque to show clearly the fine structure. If a section could be much thinner than hitherto has been accomplished, not destroying the intricacies of the cementing substance, study would be much facilitated, and much more knowledge about this sediment would be forthcoming. Also, a method of dissection is good for isolating some various types of vegetable débris composing the coal, but must destroy or give misconception about the structureless mass holding the coal together.

We shall now look at the works of those who use the metallographical microscope in their study.

METALLOGRAPHIC METHODS

1° Polish and attack

Winter may be considered as the originator of this method. He has been using it for over sixteen years with fair results. A specimen is ground to a plane on a revolving disc with successively finer emery powders, or on a stationary piece of plate glass by hand ; then it is polished on cloth covered discs with polishing powder. Schulze's reagent is then used to bring out the structure [92]. He claims the coal to have been formed from a colloidal glue or jelly, for which reason thin sections do not show well the structure — light being too powerful for the eye and frequently it cannot distinguish fine structure, even if visible. For that reason he uses a method of study with reflected light. In a later work [93] he uses thin sections to verify his attacked-surface results. The photographs that he has published are not too clear — certainly inferior to those of Seyler, Thiessen, Jeffrey, Stàch, and Duparque.

A. Gradenwitz published a note on coal [45] in which were four photographs, three of Cannel coals, one of bituminous, but they were all very vague. He follows Winter's method, but with less success.

Legraye [56] also uses a method of polish, and attack by acid, but he has not gotten extraordinary results. He claims that Pa. anthracites, even when attacked, show no structure [57], but a glance at my photographs will show an error somewhere.

Clarence A. Seyler uses the same procedure as Winter except for having substituted for Schulze's reagent a mixture of chromic and sulfuric acids and has some excellent results [68, 69]. In some figures the contents are hazy and his enlargements of over 400 diameters show structure, but it is never clean cut enough to determine. Generally they are better than those of the other men using the same method.

H. G. Turner [65, 83, 84] has evolved a complicated but fairly good method [83] of etching a polished surface. He deals mainly with anthracites, which — next to the coking coals — are the most difficult to study. A flat surface is cut and ground on an iron disc with carborundum powder, then smoothed by hand on plate glass using one minute tripoli powder and water, then polished by rubbing in one direction on a novaculite hone stone with a thick paste of rouge and water. A few brisk rubs on chamois with rouge, or broad cloth, finishes the polishing and leaves the specimen with a high gloss, but evidently very little structure is brought into evidence at this point and it is not free from scratches. It is heated to 220° C. to avoid splitting during the etching process. Then the polished surface is brought to a red heat by means of the blow pipe flame. This produces a differential oxydation, bringing out the structure without destroying the polish to any great extent, except for an imperceptible film of ash. On regarding the figures with his works, it will be seen that his method does bring out the structure, but a comparison with the figures in plates I, and II will show a large difference. My anthracite specimens are practically the same as those described by him in 1925 [83]. The originality of the method is remarkable, but the trouble of etching considerable.

Just recently Chozo Iwasaki [49] has published a report of his studies on the Japanese coals. He followed the method of Winter, with the new addition of attack by tetraline. His results however are inferior to those of Duparque and Stach.

2° Polish without attack

Duparque is the next one to be considered (having begun four years before Stach), but we shall speak of him a bit further on, as it is his method employed in this work.

Legray also used a method of simple polish [54, 55] but with poor results.

Stach [71-74] uses a method of polish without any attack and gets excellent results. He grinds specimens to a flat plane and polishes them by means of cloth-covered discs with finer and finer alumina. If the specimen is soft he hardens it by the introduction of a solution of Canada balsam and marine glue. This relief polishing produces a clean surface on which the structure is well brought out and which can be easily photographed even to 780 diameters as he has done.

I believe his method is good for any kind of coal except for our tough Pennsylvania anthracites. In his last work [74] the figures exhibit much the same structure as some of my photographs. His method is easily superior to the others discussed above and is a good example of the worth of polish without attack.

THE METHOD OF DUPARQUE

The method I have employed is that of A. Duparque [20-42], and it is also one of polish without the aid of reagents. As he is just about to publish a full and detailed account of this method, I shall only give it briefly. It evolved from that of Winter, being also metallographic. The specimen is cut parallel or perpendicular to the stratification plane whith a hack saw and ground to a perfectly flat surface by hand on squares of plate glass using successively finer emery and water. It is best to continue this smoothing on each plate until the paste formed by the emery, coal and water, is largely of coal dust so as to obliterate as many of the scratches as possible. Then it is often well to use a third piece of plate glass with nothing but water, so as to still further reduce the inevitable scratches. The specimen can be immediately put to the second or polishing part of the method, but it is best to let it dry first.

1° Method for coals proper

The polishing is accomplished by means of three leather discs, one dry, the other two for successively finer alumina in suspended solution. It requires a great deal of practice to know exactly how to obtain perfect results. It is a question of knowing the discs, how much solution to use, how much pressure to apply on the specimen, etc., and above all — when to stop. One may polish all day (as I did at first) and get nothing. It is a question of touch and knack in finishing the specimen quickly. Dirt from the solution may not be completely cleaned off in the polishing, and under the microscope it may make beds of vitrain look like fusain or bogen-structur ; or plays other tricks making one believe he has found some extraordinary new coal structure.

2° Method for anthracites

For semi-bituminous and bituminous coals this method is nearly perfect, as can be seen by plates III and IV and those figures of Duparque — but it was found that, with hard anthracites, it took too long and the scratches could never be sufficiently eliminated. Another procedure had to be found for them. After trying everything from soap to solutions on an iron disc, it was found that an ordinary liquid copper polish on a leather disc produced a surface so clear that one could see oneself in it. No (or very few) scratches, and the structure is exceptionally well visible (see plates I and II). Care must be taken not to employ the same discs used for the other coals, as the polish is not good for softer types.

It can be seen that this method has much merit, by looking at the photographic records of it. It is suitable for all ranks of coal, produces a surface nearly free from scratches, has no possible destroying or alterating effect on structure, resorts to no reagents, produces a surface ideal for study under the metallographic microscope, makes possible photographs of almost unlimited magnification (2,020 diameters have already been made by Duparque) and it is comparatively quick and easy. It is, I believe, a great advancement over former methods. The only one that is in the same class is that of Stach.

Of course, one cannot say that metallographic methods are superior to ordinary petrographic methods with thin sections ; only that, at the moment, we have made better progress along the former line.

VI

MACROSCOPIC AND MICROSCOPIC TERMINOLOGY EMPLOYED

CONSTITUANTS OF COAL

The French and American coal terminology differs ; but as the former is fuller, more exact and easier to manage, I am employing almost entirely that used by Duparque.

If one regards a piece of coal with the naked eye, it will be seen to be composed of alternating layers of brighter and duller material ; with occasionally a dull black fibrous substance, in lenticles or on parting surfaces, that crumbles on the fingers like the charred end of a burnt match stick ; and possibly some foreign minerals such as pyrite or a shale inclusion. In describing bituminous coals. Marie Stopes [77] produced the terminology of vitrain, clarain, and durain to apply to the three types of banding, and fusain for the fibrous substance. The aim was to give a concise and useful terminology to students of coal morphology that could be applied to all ranks of coal. It as fallen short because coals differ just enough to make the divisions between these terms very confusing. A macroscopic terminology has very little meaning in regard to coal, it is merely a concise way of stating the physical characteristics of a coal for a primary understanding. The large details are not what makes coal what it is: the minute particles forming them are all important factor. Just the same, one must have a convenient terminology for them ; one that is self explanatory, does not require discussion to find out the exact meaning of the terms, and that can be applied indescriminately to all ranks of coal. This is imperative, because generally anthracites and coking coals lack the durain of Stopes, and the two remaining bands present different characteristics. I am employing a translation of Duparque's terms which will, I think, be quite satisfactory as to qualifications. The figure N° 5 shows these terms and their existing equivalents as used in various countries.

The same piece of coal, after polish and having been put under the microscope, presents a very different appearance. One sees the various layers to be composed of much vegetable débris held or cemented in a « Pâte * ».

(*) Pâte will be used throughout this work uniquely to mean the cemening substance of coal. It is Duparque's « substance fondamentale ».

Various Systems of terms employed for the Nomenclature of the macroscopic constituants of coals. (After A. Duparque*)

Terminology of the Author	Terminology of A. Duparque, 1927	Terminology of M. C. Stopes 1919	Terminology of Thiessen 1920	Terminology of Ch. Lange 1926
Bright coal**	Houille brillante	Vitrain	Anthraxylon	Glanz (stein) kohle
Semi-Bright coal	Houille semi-brillante	Clarain		
Dull coal	Houille mate	Durain	Attritus	Matt (stein) kohle
Fusain or Mineral Charcoal	Fusain (Houille mate fibreuse)	Fusain	Mineral Charcoal	Faserkohle

* Bibliography n° 38, p. 275.

** Or Clear-Bright-coal.

Fig' 5

or ground mass, amorphous, with no visible structure even with an enlargement of 1.000 diameters. When it is found in beds, it is partly synonomous with anthraxylon or vitrain. On regarding many specimens one finds that the micro-constituants are as follows :

A. Plant débris :

1. Wood, fragments (Plates I to IV, text figs. 11, 12, 13).
   a) Fusain or mineral charcoal
   b) Partly gelified wood
   c) Gelified wood.
2. Cutinized vegetable matter.
   a) Exines of spores (text figs. 6, 7, 8).
   b) Cuticles (text fig. 9).
3. Resin (text fig. 10 ; Plates I to IV, figs. 1, 4, 7, 8, 9, 10, 12, 13, 14, 16, 17).

B. Algues

C. The Pâte. (esp. text fig. 13 and Plate IV, fig. 19).

ALGUES are very rare in coals proper but they are entirely responsible for the formation of the bogheads, and are important in some cannel coals.

As for the plant débris, it alone is responsible for the coal, being also the source for the pâte.

1. WOOD FRAGMENTS. — The frame work of plants is made up of woody tissue. These tissues with walls strengthened and thickened by lignine are of two kinds ;

A. In many present plants, especially the trees, the stiffness is insured by the nourishment-producing tissue itself. The woody arteries, by means of which the sap mounts osmisically, form the main parts of the plant (roots, trunk, branches) and give to the tree its rigidity.

B. With the coal flora, this was not the case, especially the huge swamp trees of the time (the sigillaria and lepidodendrons) whose trunk core held nothing but very thin walled soft woody arteries. The work of support was left for the lignified fibres situated in the outer bark zone. This part was formed of sclerenchyne — allongated, thick-walled, greatly lignified cells — and is often carbonized as a fossil ; flat, because the inner soft pulp could not resist pressure or decayed quickly ; or round with the inner space as a mould (except in rare cases of complete silicification). Parts of these lignified tissues are found in coal as minute débris. Even when they are present in great numbers, they are in small pieces at all angles to one another and always in the horizontal plane of the bedding. In vertical section these fragments are generally of a lenticular shape. A cross section parallel to the lenticular axis is different to one perpendicular to that axis ; as in the latter case they present a normal characteristic cell grouping and, in the former case, the cells are elongated. Naturally all gradations between the two extremes are found.

These wood fragments may be found in coal in the following stages of alteration :

a) Fusain, presenting a generally neat structure, the woody origin of which cannot be doubted.

b) Gelified wood still recognisable by form and shape, retaining a good or faint cell structure.

These terms represent stages in the arrested decay of these woody tissues. Sometimes the change from nearly gelified wood to pâte can be observed. Fusain may appear in a compressed, altered form called « structure étoilée » or « structure en arc ». Pieces of wood may be found in all sorts of odd forms. They can be in thin tiny strips with a high brilliance, completely gelified ; or in long curved pointed strips like cuticle ; or in ovals like spores, but with a more rigid appearance. The brilliance of the gelified pieces is the one main item that identifies them definitely, as they are brighter than the pâte, whereas the cuticles and spores are duller, having a greyish aspect. This is one advantage that a method of polish has over one of polish and attack, for with attack one is apt to spoil these distinctive characteristics so valuable in the determination of the particular kind of plant débris.

2. Cutinized Material. — Cutine is a substance related to fatty acids, and its chemical composition is imperfectly know. It forms an impermeable covering of protection on certain exposed parts of trees (leaves, young sprouts, spores, grains of pollen, etc.). It is very resistant to bacterial action, to such an extent that the microchemical reaction of cutine in anciens coals is similar to that of living plants (*). Cutine is quite abundant in some coals and is of two types :

a) Spore exines.

b) Cuticle.

(*) A. Brongniart, *Ann. Soc. Nat.* 1930.

a) *Spore exines.* — Most of the coal era plants were of the order of vascular cryptograms, which reproduced by spores. There were often two kinds, macrospores (female), and microspores (male), being practically alike except for size, and very well adapted to transportation by wind or water. They were composed of a relatively thick outer cutine membrane (exine) which is tough and resistant against agents of destruction, and a thinner inner cellulose membrane (intine) surrouding the protoplasm which contained a kernel.

In coal the macrospores are fairly easy to recognise. In horizontal section, they have a disc-like form ; in vertical section, they are like flattened sacks, lying parallel with the bedding plane. Most frequently the two walls are nearly touching and the former centre is represented by a thin line. The appearance of the spore may vary (thickness of the centre line, comparative vertical and horizontal axes) depending on whether the polished section happens to, have cut it well in the centre or along a shorter chord.

Microspores are more often in fragments but present the same general characteristics on a smaller scale when found whole.

These spore exines are always well parallel to each other. They are elongated and flattened with the plan of stratification of the coal bed, often curving against any other kind of débris present, being more pliable, and are sometimes so numerous that other kinds of vegetable débris present are in the minority, even in a bed a metre thick — except for the pâte (see text Figs. 6-8).

In the South of the Bassin du Nord in France, these spores are found in prodigious quantities. This must be only a part of the ones produced, as we know not what percentage were totally destroyed by decay or kept to their natural rôle as reproductive agents. This great abundance can only be explained by veritable rains of spores in those times, a phenomena for which we know no parallel case today.

b) *Cuticle.* — As is the case with our present plants, the leaves and young sprouts of the Carboniferous flora had a thin protecting layer of cutine. The external walls of the cellules, forming the outer layer of the epidermus, were changed into cutines where they were in contact with the atmosphere. This formed an impermeable envelope for the organ thus covered, and no exchange of substances between the air and the plant could be effected except through natural perforations (stomates).

Those particles in coal identified as cuticle represent that cover, or fragments of it, the parts adjacent having undergone a partial or total transformation by the decay agents. The exines of spores are also cuticles, but they will always be referred to as spore exines or spore débris. The term « cuticle » will be used in a restricted sense, applying only to those types of cutine here described.

According to Duparque [31], nearly all the cuticle in coal comes from the leaves of the coal forming forests. They may be found in more or less continuous bands or in isolated fragments. When present, the state of preservation of cuticle and spore exines is nearly perfect in great contrast to the almost total alteration of the adjacent tissues. The presence of cuticle, naturally argues a deposit of leaves and young sprouts, which in time were all transformed except the cutine covering. The converse of this fact has been suggested, but cannot be held as proof. If no cuticle is present, what is to prevent one from supposing that the conditions of deposit were the same as in the case of a coal containing cuticle, but that difference in the final product was due to a different type or intensity of bacterial action — on which latter fact the character of the humus deposit was greatly dependant. Thus cuticle presupposes a deposit of leaves, but absence of cuticle does *not* presuppose (though it is more probable than what I am here suggesting) an absence of cutine in the original deposit.

In reflected light, under the microscope, cutinized substances have a characteristic clear grey appearance and a good relief (see text fig. 9).

3. *Resin.* — Some plants produce a substance which on oxydation becomes a resin. This is an unputrifiable substance, very resistant to destructive agents and is often found in sedimentary rocks after all trace of the parent plant has been obliterated. Amber is an example, with the insects found in it as a proof of its fossilizing power. Sometimes in the coal-resins are found well preserved secreting organs of the coal plants. They may be isolated cells ; in spherical or irregular cell grouping ; or in broken lines ; or radiating.

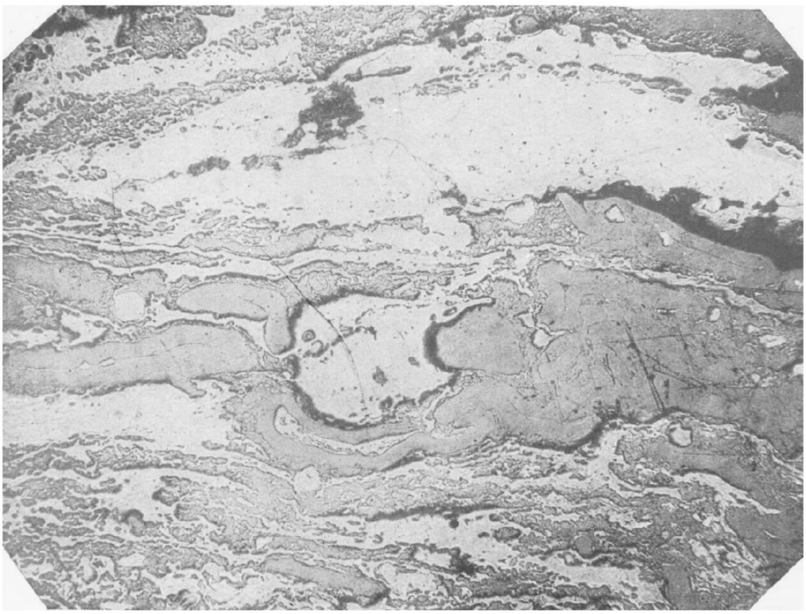
In all kinds of coal there are three common characteristics of resins.

1. Globular aspect in vertical section ; showing a great resistance to pressure and a displacement of the other plant débris around them.

2. They have a strong relief being paler and clearer than the pâte.

3. Their fossilizing rôle is well indicated by the preservation of the isolated secreting organs in contrast to the alteration of the other substances.

The Pate. — This when pure, composes Bright coal or vitrain and is the cementing substance, the ground mass, that occupies all spaces between the fragments of vegetable débris, and is always present in fairly large quantity. In some anthracites (Mammouth, for exemple), it is over 90 % of the whole bed. Under the microscope it presents a brilliant, amorphous, structureless aspect, even up to an enlargement of 1.000 diameters. It penetrates all cavities and in its earliest stages must have had a fluidity little more viscuous than water. It was formed by the complete alteration of the plant débris during the putrifying action of the bacteria. Its vegetable origin is not doubted as chemical analyses show it to be rich in hydrocarbures and poor in mineral substances (ash). It can vary in chemical composition in different beds, though keeping always the same appearance ; which is a good indication of the change in the vegetable matter composing it, or a change in the kind of bacterial action these plant débris had undergone. Often it appears in thin beds, alternating with beds containing spores, cuticle or wood tissue, and is always amorphous and structureless. Many Americans call it a layer composed of woody tissue, judging it

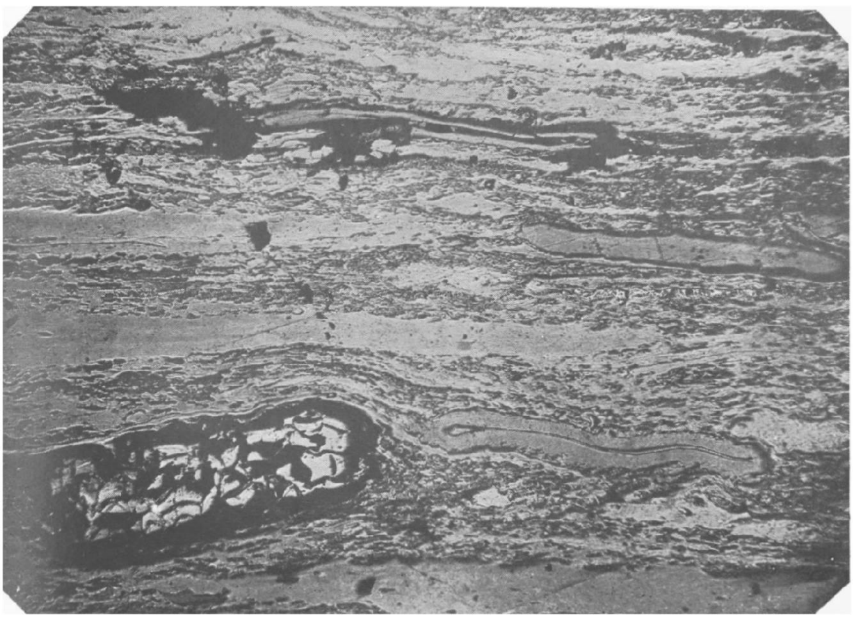


× 55

Figure 6

Spores in French Bituminous Coal.

(*after Duparque*, 37).



× 57

Figure 7

Spores in French Bituminous Coal

(*after Duparque*.

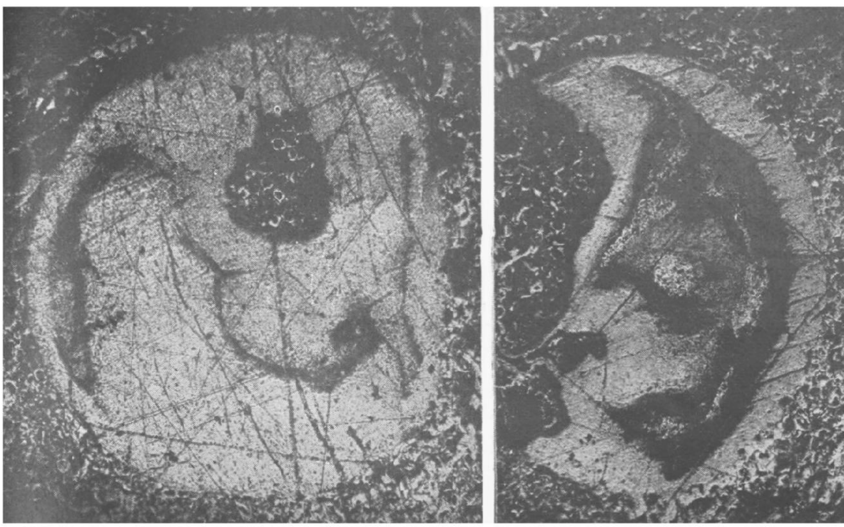


Figure 8

Spores, horizontal section

(after Duparque).

× 55

Figure 9

Cuticle in French Bituminous Coal

(*after Duparque* 31).

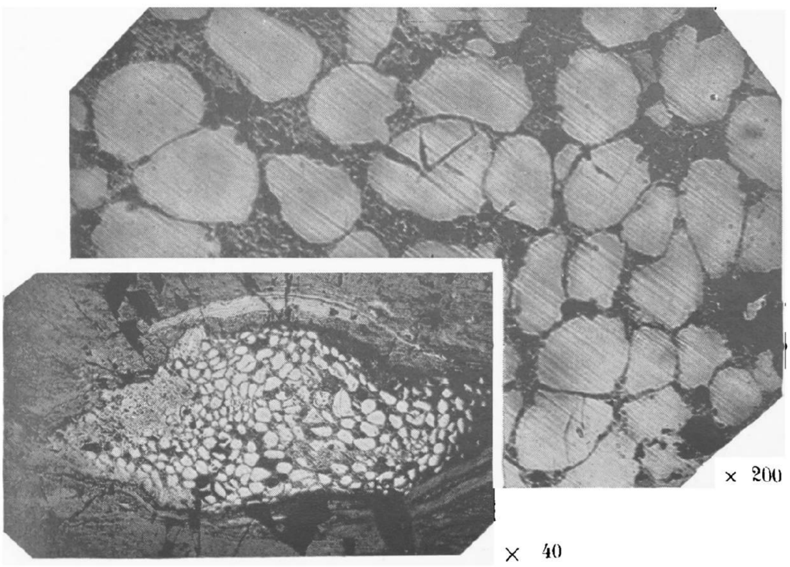
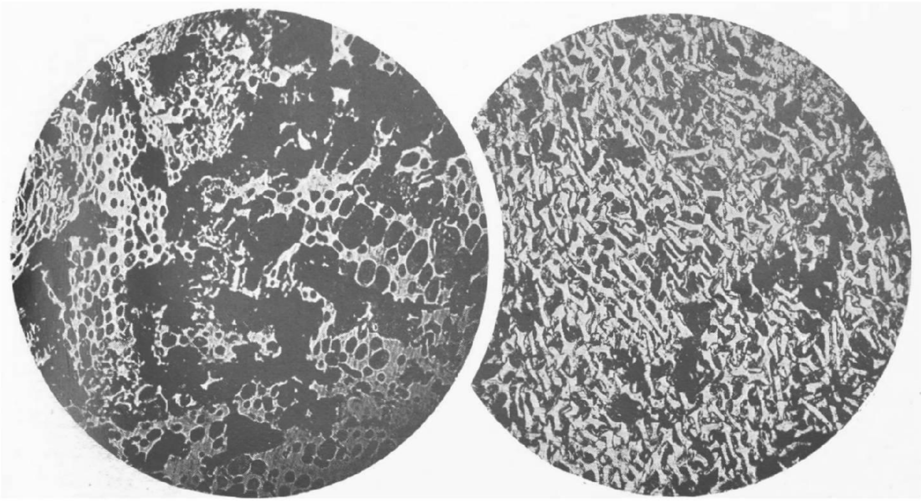


Figure 10

Resin in French Bituminous Coal

(*after Duparque*).

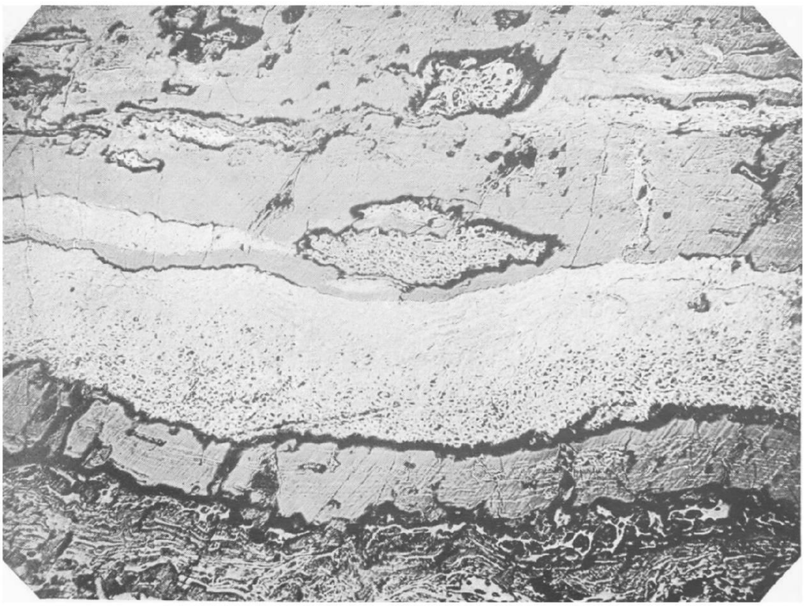


× 55

Figure 11

Fusain in French Coal

(after Duparque).

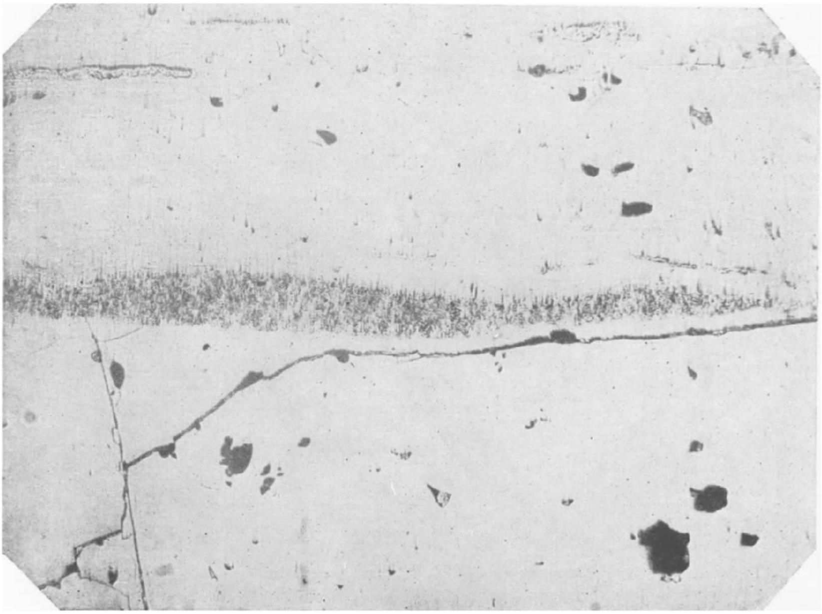


× 55

Figure 12

Wood in French Coking Coal

(*after Duparque*, 37).



× 55

Figure 13

Structure in French Anthracite

(*after Duparque*, 37).

entirely on shape. It seems that, since coal has been generally accepted to be of vegetable origin, and that the Dismal-Swamp of Virginia has been compared to ancient coal forming swamps, we are too anxious to label the constituants of coal « woody tissues » whenever possible.

This pâte is easily recognisable under the microscope by its brilliance and lack of structure but to give its exact source would be difficult. That wood sometimes forms it is true, as we can often note the gradual alteration in various stages from fusain through gellified stages to bright coal or vitrain (pure pâte). Most probably it was formed from all the plant matter present, after complete decay through bacterial action, having a great fluidity, permeating all open spaces, acting as the retainer for those bodies not totally transformed, and being a nearly pure hydrocarbon — a black colloidal mud. In shales, whenever a plant stem or some piece of vegetable débris is found to be carbonized, it is always found to be in the amorphous state of Bright coal (anthraxylon or pâte) which is a positive indication that wood fibres can and do form pâte, but I do not consider that that fact gives us the right to state that pâte is uniquely formed by that substance, though it may be largely due to wood. Bacterial action is undoubtedly a very strong factor in its formation, but naturally it is dependant on the débris present for the composition of the final product. We cannot say whether the bacterial action was of such a kind as to putrify cuticles or spores with a like facility. Certainly the bacterial developments could have varied with different localities. Compare a coal of spores with one composed of wood fragments, and the natural conclusion to draw is that in the deposit of the first there were many spores, in the other much wood; but on second thought one might be justified in deducing that all the deposits were originally similar and the resulting coal characteristics were due to differential bacterial activity.

If this idea can be granted to have even a vestige of possibility — and I firmly believe it to be true in some cases — our term « anthraxylon » for the bright layers of coal is a mis-nomer. It means « coal-wood » and therefore makes one presuppose that wood alone was responsible for its formation. Thiessen [79], with his method of splitting sections under the microscope, noticed that these bright bands always tapered off in a point, but so do the other bands present. The very fine bands of bright coal have just as much right to the term anhtraxylon as their larger brothers, and they are present in thin stringers, forking or ending in a point, and always surrounding the vegetable débris present. Therefore the term pâte should be used in talking of this bright structureless coal, Bright coal or vitrain should be applied to it when it forms definite layers, and anthraxylon could be discarded.

Pâte can be observed in most of the figures in the text and in the accompanying plates.

By the study of coals with reflected light, Duparque has found that each rank is formed of distinct and different types of vegetable debris cemented in a pâte which always bears the same aspect. He divides coals into three groups :

1° High in volatile matter (bituminous).

2° Volatile matter between 25 and 18 % (coking coals).

3° Low in volatile matter (anthracitic).

For the first group, he states that they are almost entirely formed by the accumulation of cutinized substances coming from the spores and leaves of the carboniferous plants; which in some places were so numerous as to have caused the formation of veins two meters thick. Resins and woody remains play but a feeble secondary rôle in the formation of these beds, but may have contributed to the pâte, which is generally not very abundant, forming the cement for the spores and cuticles. Besides the spore coals (text figures 6 and 7), which have been much studied, he was the first to draw attention to the fact that some coals having the same chemical composition are formed uniquely of an accumulation of leaves, leaving only the cuticles preserved (« charbons de cuticules » of Duparque, text figure 9).

The second group, the coking coals (text figures 11 and 12), he finds to be composed of many minute fragments of wood with a more or less evident preserved cellular structure ; some of them nearly identical to that structure found in the lignified tissues of living plants. Spores or cuticles are observed in exceptionally rare cases, while resin may occur throughout in minor quantities. These wood fragments, well stratified like the spores and cuticles in the first group, are cemented in a pâte quite abundant, which sometimes forms by itself the whole mass of some layers.

The third group, anthracitic coals, he describes as being characterized by woody tissues, well stratified as with the coking coals, but differing from them by the predominance of the colloidal structureless pâte and the more gelified appearance of the wood debris (text figure 13). He also states that this group can be formed by pressure and that he has found one locality where they are seen to contain spores.

As for this last group, I have been able to enlarge and modify some of the observations of M. Duparque by the study of American material. It is true that in France's Bassin du Nord anthracites proper do not exist, such as are found in Pennsylvania ; and with these latter coals his method of polish has revealed an origin and structure much more complex.

The first group has been studial in various countries. The observations of Jeffrey in America, and Duparque in France are similar in many respects ; but results in America on the coking coals have been nearly negligable, and this work is an effort to fill that gap.

The text figures 6 to 13 are from various of Duparque's works. They are of French coals and serve to illustrate the terminology employed in this work and the different types of coal, as well as to furnish a comparison with the American coals figured in the four plates following the text. The coking coals will be noticed to be essentially similar, and the anthracite coal from France resembles very much the photographs of the Mammouth vein (compare text fig. 13 with fig. 5, plate I).

VII

COKING COALS

Coal is the most obviously stratified of all sedimentary deposits known. Put a sandstone or a shale — vertical section — under a magnification of 500 diameters and the bedding plane becomes indistinct, while a magnification of that power on coal only serves to make more evident the parallel arrangement of its constituants.

A piece of coking coal presents a shiny brilliant aspect with two kinds of bands of stratification. One kind has a clear black brightness like obsidian or polished ebony, the other a silvery black brilliance. From to time there are small lenticles of a sooty black fibrous substance that soils the fingers, is soft, and pulverises easily. Sometimes there are dull black layers.

A translation for the terminology of Duparque for these respective bands may be ; Bright coal, Semi-Bright coal, Dull coal, Fusain or Mineral Charcoal.

The three kinds of bands may be noticed to end in tapering points, and the whole rock is a mass of thin beds, dividing or finally tapering off in every direction. There is always a pronounced cubicle cleavage perpendicular to the bedding plane which renders this coal so fragile, and therefore so difficult to prepare for study. If it has been subject to the pressure of thrust folding, as the French specimens have, this cleavage may be at many angles and therefore is more annoying for study because of increased fragility. The previous photograph (text fig. 1) shows this banding and cleavage very well in the typical portions marked A and C. Between the larger bands B and C on the right hand edge of the specimen, it will be noticed that one of the clear black bands divides around a portion of the dull coal in B and ends in a point in the lower part but continues in its upper extension. Thiessen, with his method of dissection, also noticed the tendency to end in points for the bands in bituminous coals — but for anthraxylon or vitrain only — and here it can be seen that both types of layers end in points as well as divide.

A magnification (without polishing the specimen) makes these facts more obvious, and it is seen that the division between the two types of banding is an irregular line, and that sometines there are substances that disturb the unity of colour of the clear black bands. The semi-bright bands seem to be made up of very fine threadlike constituants with the same characteristics as the other type described. The dull coal is infrequent in these specimens. The fusain or mineral charcoal shows its fibrous character more clearly and makes one wonder why it should have been preserved in such a manner. It is also found on horizontal parting surfaces and leaves no doubts as to its woody origin. Jeffrey [50] proposes a hypothesis of charring from forest fires to explain it, Turner [83] claims it is due to chemical action, and Stach [74] attributes it to rapidity of buriel. Grand Eury and Duparque claim it is due to drying in air before being submitted to bacterial action.

A microscopical study of the prepared surfaces shows very clearly what composes this banding in coal.

The coking coals are found to be composed of three things — always present, but in varying ratios — pâte, wood and resin. The pâte may appear in pure bands as bright coal (vitrain) or as a ground mass surrouding and holding the wood and resin. It may be in stringers, thin traces, or thick bands, but is always structureless, with a fluid appearance especially around the vegetable débris present. Any body recognisable in coal causes the pâte to displace itself and it does so much as the flow line of a gentle current would indicate.

The woody tissues are found in every conceivable example of arrested decay from fusain to nearly pâte. They may be present with almost perfectly preserved structure (fusain), with crushed cell structure (bogen-structure or structure-en-arc), partially decomposed but still retaining a thickened cell wall structure, or having completely lost all trace of structure, recognisable by form and characteristic brilliance which distinguishes wood from pâte and resins on the one hand and spores or cuticle on the other. It may be found in tiny fragments ; occasionally in long strips (rarely 1 cm in length) ; or in odd shapes, such as broken isolated cells or fractured tissues, which can resemble anything one desires (plate IV). A little practice and one soon learns to identify them with one of three typical characteristics : Cell structure, form, and kind of brilliance.

Resin is always found in these coals, but is scarce and not too important as a constituant. The amount present varies with each specimen but is never large enough to class it as an item of first-class value in determining the type of coal. In some specimens the polished surface may show two or three resinous bodies, in others they may run into the hundreds. Their rounded and rigid character makes them very easy to recognise, and therefore one is more apt to notice them than other plant débris. Thus their importance is subconsciously exaggerated ; but even in the case where hundreds are found in a polished face, the ratio of their importance in comparison to wood and the pâte as coal formers is about 1 to 10.000. What its importance is, we shall try to find out, as well as the value and meaning of the other coal constituants, from the detailed study of the samples.

Pocahontas N° 3

The vein Pocahontas N° 3 is one of America's finest coking coals. Our specimens are taken from the bottom (N° 23), centre portion (N° 22) and top (N° 21) of the seam. One logically begins at the bottom so we will start with N° 23.

The fact first noticed is a negative one — namely, the lack of resin. There are certainly not more than two such bodies present in an area of 1 cm × 3 cm and they are difficult to find unless a magnifying power of 180 diameters is used. This paucity is unusual, resin usually being found in some quantity in any kind of coal. The specimen is composed entirely (practically speaking) of wood fibre in all kinds of arrested decay and pâte. There are a few broad bands of Bright coal crossing the polished face (the largest less than 0.25 cm in thickness), but for the most part the pâte is in fine curving lines around the enclosed fragments of wood. The wood that is not completely pâte takes varied forms, and is present is quantity — but less than the pâte. There are the very tiny gellified strips found throughout, and a few larger pieces with a visible compressed cell structure. Looking at the specimen, one would be tempted to say that the stratification was overdone ; there is not a piece of wood the least bit out of line, no matter how much or little it has been altered, and there are no other kinds of plant débris present.

N° 22, from the centre of Pocahontas N° 3, is an extremely fragile piece with a more pronounced cleavage. It is finely stratified, with the wood concentrated in thin layers, and scattered throughout the thicker clear black layers of pâte. Here some of the pâte gives the impression of being of woody origin, as one sees from time to time a very faint porous cellike structure. The recognisable pieces of wood, always very small, are in all sorts of stages of arrested decay, and there is one thick semi-bright band in which there are several larger pieces in good cellular preservation. Some fusain partings are visible. No resin.

The top of the vein, N° 21 is very finely stratified and is almost entirely made up of the semi-bright bands. Vitrain is present in very thin strips and is infrequent. There are many pyrite inclusions, a sign of marine conditions of the deposit — or the deposit immediately following. It is found to be composed of wood and pâte — as are the other specimens from this bed. The bands are homogenous ; that is to say, if you trace a band of pâte in any direction, it remains pâte, but may thin or thicken, split around other structures and continue as two bands, or end in a point. This is also true of the silvery black bands (semi-bright coal) but they are always thicker than the bright bands and are made up of wood and pâte, illustrating on a more frequent and smaller scale the phenomena just mentioned above — which is typical of this rank of coal. Resin is present in very small amounts ; about three or four minute round bodies can be found on the polished surface.

The bed Pocahontas N° 3, then, is composed of wood and a structureless ground mass with resin in negligible quantities and some pyrite inclusions in its uppermost portion.

Pocahontas N° 4
(Plate IV, fig. 19.)

From Pocahontas N° 4 we have three specimens from the lower (N° 26), central (N° 25), and upper portions (N° 24). The physical characteristics are the same as those described in the first paragraphs with the addition that N° 25 and N° 26 have some pyrite stains along the cleavage partings.

The specimen from the bottom of the seam is very finely banded, with a few clear black bands visible to the eye, and is less fragile than the average of these samples. It is found to be composed of wood and pâte, its microscopic structure illustrating very clearly the rôle of the pâte as a ground mass for coal. The woody tissues are present in all varieties. When they are very minute they do not follow any special grouping, but when larger they are apt to be found in certain horizons and not isolated. This fact may be explained by some sort of a saturation theory on bacterial action. When conditions are favourable for complete putrefaction (that is, enough oxygen present) the vegetable débris falling into the shallow waters will be transformed into a black colloidal mud, with some pieces here and there that have resisted decay. If too much oxygen is used up by the bacteria, the next arrivals will be only partly putrified, until some small change occurs (a shifting of currents, for instance) to reestablish the former state of affairs. Thus the larger and better preserved pieces are found in bands, while the tiny fragments may be distributed anywhere. Naturally the partially altered pieces have more weight than the pâte in its early stage and they sank lightly into it, as its fluid character would easily allow that to occur. This specimen, when studied with a magnification of 180 diameters, bears out this idea very well. One or two tiny particles of pyrite are present, but no resin.

The sample from the centre of the seam (N° 25) is much the same — as is the top sample (N° 24), though they contain fewer bands of large pieces of wood, more pâte, and many of the tiny fragments. They again bear out the fact that the pâte is a ground mass. The small bits of altered wood end in sharp or rounded points are sometines slightly bent or curved and the pâte completely surrounds them. A few long fibrous pieces of wood are present, perhaps 6 m/m. in length — which is very rare. Resin is absent or negligible. Some pyrite is found in N° 25.

As just seen Pocahontas N° 4 possesses practically the same characteristics as the seam Pocahontas N° 3. They are both formed uniquely of wood tissue and pâte, with no visible impurities save for occasional beds of pyrite. The pyrite is more present in seam N° 4.

Sewell

From the Sewell seam we have three specimens from the same level, 16″ from the roof (N° 27, 28 and 29). The hand specimens present a slightly different aspect from the previous ones studied, being composed almost entirely of the semi-bright type of bands with no definite layers of bright coal or vitrain clearly visible. They have the same cubicle cleavage and annoying fragility.

Under the microscope they have similar type structure and contents. There are no layers of bright coal, yet the pâte is present everywhere in its rôle of ground mass. The pieces of wood are in every degree of arrested decay and are very numerous. The larger kind with well preserved cell structure are in great numbers, with the tiny fragments also distributed throughout the specimen. It would be impossible to draw a straight line, parallel to the bedding plane across the polished face (2 cm), that would not touch at least one of these woody tissues. Yet there is much pâte above and below each little fragment. The arrangement of these pieces is like that of the slabs of stone in an old country wall with cement (or air) space increased many times. The pâte is sometines slightly undulating when near a bent or wavy piece of wood. There is no pyrite in these specimens, nor did I notice any resin.

Beckley

The three samples from Beckley (N^os^ 30, 31 and 32) are all taken 36″ from the top of the seam. The rough specimens, and the polished surfaces before using the microscope are similar to those characteristics of the bottom of Pocahontas N° 3.

The microscope shows a structure similar to the other specimens. The constituents are wood and pâte, with nothing else present. The wood fibres sometimes have the shape of cuticles or pieces of spore exines, or are occasionally rounded like resin, but one can tell them under high power magnification by the cell structure, brilliance, or rigidity. These fragments are in various kinds of alteration, and two pieces nearly touching each other are often of different character. A piece may be almost structureless, a little above it will be another piece with clear cellular structure, above that will be a band of bright coal, and around it all will be the pâte. Bright coal or vitrain is absolutely amorphous. However, the pâte enrobing the plant débris is equally structureless, and is in no way different from the anthraxylon except for its stratification characteristics. It is this fact that makes me disagree with the theory that anthraxylon is uniquely formed from wood. If anthraxylon is nothing but a pure band of pâte (and it is identical except for size) it could very possibly be a hardened carbonized mud composed of the completely putrified vegetable substances that were present in the ancient swamp. That it was soft is evident, because it bends for other bodies on its edges, and even in anthracite it is seen that these débris have sunk into its one-time fluid mass. The figures (plate II, figs 9 and 10) show many resinous bodies that have partially occupied the normal line of stratification of a band of vitrain or anthraxylon, and this is more evident in the coking coals, as here the bands of vitrain divide around an occasional other type of structure, which can be seen with the naked eye (text fig. I between bands B and C)or with the microscope. Bright Coal (Vitrain) is really pâte in enlargement' with a less fluid character.

In these specimens from the Beckley seam there is no pyrite, and I have seen no resin or other types of plant débris.

« B » or Miller
(Plates III and IV)

From this seam we have two samples, one from the centre (N° 33) and one 6″ from the bottom (N° 34). A third sample was taken 6″ below the bonecoal (35) which in itself furnishes a full and interesting amount of study material (text fig. I). The specimens from the seam itself vary more than any other two samples in the collection. N° 34 is extremely fragile and seems to be made up largely of bands of the bright coal with the silvery or semi-bright coal present in lessen quantity. N° 33 is less fragile, more compact and contatains mostly the semi-bright type of banding, with less evident cleavage spaces on a freshly broken surface.

The former sample illustrates the undependability of macroscopic terminology. To look at it, even with a low power glass, one would say that there were many bands of bright coal and few of semi-bright coal, but the truth is the opposite. The terms used to designate physical aspects of coal are useful as cubby holes to store things in, but must never be taken as an exact lable for the constituents, which alone are important in determining the kind of coal. In this specimen there is much wood in all kinds of preservation, and two or three distinct bands of bright coal - which the eye sees more often than is the actual case before the polishing process. The fragments of wood are aligned and of varying sizes, some fairly large, always embedded in the pâte, which forms the greater part of the specimen thought not often as bands of bright coal. Resin and pyrite are conspicuous by their absence.

The more compact semi-bright specimen was not so deceptive as to content. Bands of bright coal are practically non-existent, and the pâte appears solely as an enrobing substance. Wood is present in great quantities. As usual it is in all sizes and all degrees of arrested decay. Some of the pieces are long and thin with the shape of cuticles, others, fractured across a cell, are a bit like spore fragments. Tiny fragments, larger pieces, broken or compressed fragments, all are held in the pâte — presenting a very fluid allure — and are very numerous. On this polished face also it would be difficult to draw a line parallel to the stratification plane without cutting some of the woody tissues. Resins appear in groups or as isolated bodies, with or without visible secreting canal structure. At an enlargement of 70 diameters, the larger ones appear the size of an « o » in this print. Pyrite inclusions are also present.

The sample N° 35 will be seen to have a lenticle of a different physical type from the other specimens. The photograph (text fig. I) is nearly natural size, and the three main layers are marked A, B and C. A and C are the same type as all the other coking coal specimens but B represents a change in the conditions of deposit. A and C are composed of alternating bright and semi-bright banding with the characteristic cubical cleavage and great fragility of coking coals, C being more fragile than A. The central layer, B, intermittently bounded above and below by pyrite, is compact with no banding, has a dull lustre, and is tougher than the other beds. This type of coal we call Dull coal, usually corresponding to the term durain of Stopes (spore coal) but here we have a lens of dull coal that is made up of wood.

Examining the specimen under the microscope, starting from the base of C, the following things were noticed. There are very small and infrequent bands of vitrain, much pâte enclosing the usual variety of woody débris. Resin is present in small quantities. As one approaches the compact centre zone, a vein of pyrite is encountered, then a band of bright coal, then another vein of pyrite — all parallel with the stratification of zone C. Immediately above this vein is the dull coal zone, and as soon as the pyrite has been passed the character of the microscopic field alters completely. We have a collection of wood débris in every imaginable kind of shape and state of preservation (recognisable or otherwise). Pseudo-spores (plate IV, fig. 16), pseudo-cuticles, more or less normal woody tissues (plate IV, fig. 15), and much resin in a mass of what at one time must have been wood pulp not entirely putrified. Cellular structure is beautiful in places (Plate IV fig. 18). The fragments are aligned in some parts only, being mostly at gentle angles or curves from the bedding plane. The small, nearly structureless pieces are very brilliant and numerous. Bands of vitrain or bright coal are totally lacking. The ground mass is a heterogeneous pulp of wood-pâte not completely amorphous where tiny isolated cellules or broken tissues are frequently found. Resins are included in quantity, being found isolated or with wood in groups (plate IV, fig. 17) and are generally small. The central part of zone B contains one or two lumps of pyrite.

On approaching the upper part of this layer, we again find a vein of pyrite. This one is not so continuous as the one below the central zone, and it is parallel with the stratification of the upper zone. Directly above the pyrite there is no change in the character of the constituents ; the change begins on encountering the first definite line of pâte. Then gradually we get a structure like that of C but with occasional fragmentary types of B still persisiting. Mounting a bit higher, we find the wood more plentiful, well stratified, and the pâte present in thin and enrobing lines. Resin in A is more than C but less than the great quantities in B. Pyrite is also present.

The central zone is evidently caused by a change in the conditions of deposit such as momentary contemporaneous erosion. The abrupt change from C to B makes this point evident. The upper border shows the gradual transition to normalcy (for this type of coal) and indicates the tendency of the forming processes to seek a uniform level of deposition. The pyrite indicates marine conditions and that it should be so pronounced on the lower border of B may partially indicate the reason for its formation. No spores or cuticles are found, nor are there any algues, the whole sample being wood and pâte, with some resin and impurities (pyrite).

The figure 19 of plate IV is typical of all coking coals, being taken from sample 26 of Pocahontas N° 4.

Conclusions

1. In all these specimens, I have observed no spores or cuticles ; and it seems that the vegetable constituents of a coking coal are always pâte and wood fragments, with resin sometimes present in unimportant quantity — *and nothing else*. This is much the same as that satted by Duparque in France and in America by Jeffrey, « Coking coals are predominantly of woody origin ».

2. The percentages of wood and pâte may vary from bottom to top of a vein, following no rule or law for any level.

3. All wood fragments of even faintly recognisable structure are minute. A piece of 1 cm. in length is exceptionally rare.

4. Bright coal or vitrain is pâte and not woody tissue. If it were wood, one would expect to find more than an occasional fragment of woody tissue recognisable longer than 1 cm.

5. Resin is of little importance in the light of the pâte and woody constituents.

6. The structure and contents of French coking coals are nearly identical to the same rank coals in America.

VIII

ANTHRACITES

These samples come from three of our finest anthracite beds ; Buck Mountain, Mammouth, and Primrose. They are exceptionally tough and hard to cut for polishing. The banding, so distinct in the coking coal is less obvious and has not the striking brilliance of the others. The samples from the Mammouth vein are almost entirely composed of clear-bright coal with the stratification made evident by occasional thin lines of the semi-bright or the dull coal. The Buck Mountain specimens are very distinctly banded, the clear bright layers being in a minority, noticeably ending in tapering ends on an unpolished surface, and seemingly enclosed by the other types of banding. One cannot distinguish between the dull and semi-bright coal before a polished surface has been obtained. They look like a compacted bituminous coal. The Primrose sample is also distinctly stratified, retaining some distorted traces of a cubicle cleavage. It is somewhat like a semi-biuminous specimen, as though compacted and glued together. It seems to be composed of bright and semi-bright layers only. Fusain occurs in all the veins. Each specimen has a high concoidal fracture (though Buck Mountain specimens tend to break parallel and perpendicular to the bedding more than most anthracites), is very hard, and difficult to cut for polishing. They present the appearance of hardened pitch.

Buck Mountain

(Plate I, fig. 1, 2, 3. Plate II)

With the first specimen under the microscope a great difference is observed from those coals previously studied. The plant débris and pâte are brought well into view, but determination is difficult because of the compactness of the rock and possible alteration of the contents by pressure — in spite of the extraordinary high polish one can put on a planed surface of this anthracite. To check up on the vertical faces, we made two horizontal cuts to see if we could be more certain in naming and discussing the constituents.

The sample from Olyphant Colliery, cut in vertical section and polished, shows a very clear and clean cut structure. The clear bright coal is in several distinct pure bands as well as in thin lines of pâte in the semi-bright and dull bands. A very interesting specimen, as it seems to contain a bit of everything, though in the dull bands one cannot definitely determine anything. The fig. 1, Plate I seems to contain cuticle fragments, but as they have not the characteristic grey colour and relief, those forms must be considered as pâte. Perhaps they have been plants formed into pâte by pressure or bacterial action before deposit but it is impossible to say. Not enough intensive work has been done on this coal seam, or we would be able to find points for comparison and be more sure. This specimen alone warrants much intensive study — in corelation with samples from many other localities of the seam.

There is structure that we can be sure of. Away from the bright bands (Plate I, fig. 2, B) there are fine strips of pâte and occasional good structure preserved in the enclosed piece of wood (same figure, SB, W). Most of this pâte is in long thin curving lines, forming the semi-bright layers. It takes all sorts of forms. Wood is found in all types — except the minute fragments remarked in the coking coals. If they existed they have been robbed of distinctive structure by compression. Good cell structure may be seen in Fig. 3 of plate I (an enlargement of Fig. 2, W).

The gelified wood is present also, but is difficult to recognise unless there is a bit of structure still visible. The wood does not seem to have any special grouping.

Resin is found quite frequently — always with its characteristic globular form and good relief (Fig. I, Plate I). There is no pyrite present.

The horizontal section of this sample gives little information on the dull coal. There are the little curved brilliant bits of débris and the long thin ones which we now take to be pâte. It does show very vividly wood and resin. The section was cut across a semi-bright band, but as the stratification is never exactly level, it may recut the same thin bed of pâte or distort woody structure, or present a cuticle in fragments.

The sample from Richards Colliery in cross section shows good structure but is less distinct than the one just discussed. It is more compressed, has a less aligned plan of stratification and fewer distinct bands of clear bright coal. There are some bands of dull coal (Plate II, fig. 9 and 10) present in the specimen but it is mostly composed of semi-bright layers. The plant débris is, for the most part, hardly distinguishable ; but wood with good cellular structure is found, as well as partly gelified pieces. The resins here are often ovalled (the long axis in the bedding plane), as well as round, and are quite frequent. The horizontal section shows them very well (Plate II, figs. 7, 8, R), in fact it is much more informative than the vertical section. The wood structure is shown clearly and it is often different in neighbouring fragments (Plate II, fig. 6, W, W1, W2), as well as the typical forms of the resins. Some very small wood fragments with unaltered cell formation are also visible (Plate II, fig. 8 W). The pâte has the same aspect in any section — always amorphous.

These samples are seen to present a well stratified appearance, containing mostly pâte and wood, with some resin. There are some bodies not yet identifiable ; but even so, the contents are chiefly those mentioned. The Buck Mountain bed is an anthracite which is very different from the coking coals studied. It contains much less wood, and many more layers of dull coal with much unidentifiable débris. It is equally well stratified less visible when fresh, but more evident and distinct than the other coals, even to the naked eye after polishing.

Mammouth
(Plate I, fig. 4, 5)

Of this great anthracite coal bed, we are using three samples all having a similar appearance. They are tough, hard and brittle. Stratification is only observed after careful scrutiny in a fresh specimen. They break with a hard concoidal fracture and the splinters are quite sharp. The best comparison is to liken them to obsidian, which they resemble in many ways, except for the mineral charcoal specimen (N° 4). Very thin and infrequent bands of dull or semi-bright coal may be observed.

The polished surfaces show mostly pâte, with occasional woody tissues and rarer resinous bodies singly or in groups (Plate I, fig. 4 R). The wood fragments are very often quite gelified, but sometimes present good structure, as well as compressed cells (Plate I, Fig. 4, 5 W). One can say that pâte is *the* constituent of this bed. The photographs represent phenomena not too frequent-and the upper part of fig. 5 is typical of the structure most often found. This pâte, in places, shows faint traces of not completely decayed plant débris, so faint as to be easily passed over unnoticed.

Once seen, there is no doubt about it. It is only visible in certain localities on the polished face, usually near distinct types of plant débris, It thins out and disappears on following it along a plan of stratification or in a vertical direction. There is so little contrast in such a type of structure, that it is difficult to photograph ; but close examination of the central part of fig. 4 plate I will show it quite well. In it can be distinguished faint resins, and gelified wood once in a while, but nothing else. It is probably due to the almost complete putrefaction of débris, and subsequent pressure.

The specimens present much the same appearance. This faint structure is a bit more clear in the ones from the Mammouth Top Split, but is still not definite enough to be well identified. This has been called, I believe, « ghost structure » by some authors — a very apt term. Whether it is due to pressure or bacterial activity is the question. Naturally both forces have operated, but decay must have been the most important formative agent, as these débris are very small, well altered and virtually structureless.

This bed is an astounding amassage of material. The size of the original deposit and the length of time for its formation are rather staggering considerations. It is not at all like Buck Mountain nor Primrose, being over 90 % pâte. The fact that these two beds (below and above) are well stratified and still preserve much structure, seems to prove that the agents of putrefaction must have been mainly responsable. It would have been anthracite even if there were many more semi-bright bands present, but undoubtedly the purity of the one-time carbonaceous mud was a great assistance towards its present development.

Primrose

This bed is the most recent, is composed of distinct bright and semi-bright layers only, yet the constituents are much more difficult to determine than those in the Buck Mountain bed. About all that one can say is that there is structure present, that there are wide bands of bright coal (or vitrain), that there is much pâte, that there are occasional pieces of wood with evident structure, some resinous bodies and a rare band of dull coal. For instance, you have a band of dull coal with its vague débris ; below this band is a confused and compressed mass of semi-bright coal, which is typical of the general aspect of the specimen. Above the dull band is a semi-bright region ; with some layers of clear bright coal present, and some uncertain cellular woody structure between them.

This bed is probably anthracitic mainly because of presure. Its make-up resembles the other rank of coal discussed, though one cannot state that it was once a coking coal — on acount of the present vagueness of the structure.

In the Bassin du Nord there are no true anthracites. The basin has undergone complicated thrust folding, but not the heavy pressure produced by the more rigid substratum of the Appalachians. The basin is much smaller than the American deposits, and the similar arrangement of the ranks of coal is here due to deposit and bacterial action, while in America both causes were effective — pressure being much more important than in France. However, the anthracites studied by Duparque resemble very much the Mammouth vein from the petrographic point of view.

Conclusions

1. Different anthracite beds may vary more in content than different beds of any other rank of coal.

2. Vague character of structure in some anthracites indicates an influence of pressure.

3. Metamorphic pressure is important in their formation ; but the greater the amount of pâte in the original deposit, the more rapid a transformation into anthracite is possible.

4. Resin may be present in any anthracite even in great amount without altering it appreciably.

5. The Mammouth bed is anthracitic chiefly because of its original constituants ; while the Buck Mountain and Primrose beds seem to owe their state to the results of pressure.

GENERAL CONCLUSIONS

I. FACTORS OF COAL DEPOSITION

1. Coals are too well stratified to be of autochtonic origin.

2. But, the constituants of coal are too well preserved to permit the possibility of transportation by rapid currents, or for any distance by gentle ones.

3. Coal is, then, *formed in shallow water, near its source of origin, and stratified by gravity and very gentle currents.*

II. FACTORS OF COAL COMPOSITION

1. The most important factors in determining the original composition of coal seem to have been both the mechanical classification of the débris and the selective bacterial action.

2. Coal must have been formed in a body of water at least partially isolated, to permit the various kinds

of incomplete putrefaction of the plant débris. The description by Jules Cornet is probably very close to those existing conditions.

3. The value of a coking coal is dependent on its purity and contents ; that is, it must be quite free from ash and be made up of wood debris — with the possible addition of resin.

III. FACTORS OF COAL EVOLUTION

1. The most important factor of coal evolution is the original contents — unless a coal becomes anthracitized.

2. Pressure is necessary to give a coal its present form (see Thom [82] and Turner [83]).

3. Both Bituminous and Semi-bituminous coals may become anthracites.

4. All coals proper are in a stage of evolution towards anthracite ; but to the present moment coals of the semi-bituminous rank (of M. V. 25-18 %) have not been observed to contain spores of cuticles, while all kinds of vegetable debris are found in various anthracites (see Turner [83, 84] and Duparque [35]).

5. The final stage of a coal, or anthracitization, is dependent on pressure, facilitated according to the percentage of pâte ; which accounts for the presence of anthracites in the Bassin du Nord.

EXPLANATION OF PLATES

Key to symbols employed

B. Bright Coal.

P. Pâte.

SB. Semi-Bright Coal.

D. Dull Coal.

W. Wood.

F. Fusain.

R. Resin.

Ms. Macrospore.

ms. Microspore.

C. Cuticle.

St. Structure-en-arc (bogenstruktur).

Wc. Woody cell.

Cc. Cell cavity.

Cm. Cell membrane.

Wr. Woody remains.

Sp. Space or parting.

PLATE I

Figure 1. — Anthracite, Buck Mountain bed, specimen 2, vertical section, × 55.

Typical banding in this anthracite, showing characteristic difficulty in identifying the plant bodies composing the dull coal.

B1 is the general aspect of pure pâte in layers (bright coal).

B2 a band of bright coal ending in a point.

B3 bright coal with resinous bodies partly in it.

P pâte, bearing the same aspect as the bright coal. Note the way the thin streamers of pâte sometimes branch into or away from the bright coal.

D dull coal. Center of the figure contains pâte shaped so as to suggest cuticles.

Figure 2. — Anthracite, Buck Mountain bed, specimen 2, vertical section, × 55.
Shows the aspect of the four macroscopic units of coal as seen in this anthracite.

B bright coal.

SB semi-bright coal.

D dull coal.

W wood in the state of fusain or mineral charcoal.

Note how well this anthracite is stratified.

Figure 3. — Enlargement of a portion of W in Figure 2 Plate I, × 440.

P pâte. Presents the same aspect as the bright bands in the previous figures.

W wood in the state of fusain, structure-en-arc or bogenstruktur (compressed cell structure).

Compare this wood with figures 5, 13, and 18.

Figure 4. — Anthracite, Mammouth bed, specimen 3, vertical section, × 55.

Note the very different character of this anthracite. It is predominately pâte, containing highly gelified woody tissues (esp, W2), Small bits of resin (R, R2), and very compacted, faint-structure, semi-bright coal (S B).

Sp space.

R resin with fossilized secreting canals.

R2 group of resins.

W, W1, W2, W3 — woody tissues with cell structure in various stages of preservation or gelification.

Figure 5. — Anthracite, Mammouth bed, specimen 3, vertical section, × 250.

P pâte. It forms the greater % of this vein.

W woody tissue.

St structure-en-arc.

Cc cell cavity.

Compare specimen with figures 3, 13, 18, and text figure 13.

PLATE II

Figure 6. — Anthracite, Buck Mountain bed, specimen 1, horizontal section, × 55.

P pâte. Similar appearance in any section.

W, W1, W2 pieces of wood showring typical elongated cell structure in horizontal section. W2 is probably partly pyritized.

Figure 7. — Anthracite, Buck Mountain bed, specimen 1, horizontal section, × 55.

Group of resins (R) showing how they may be oval, round, whole or in fragments.

Figure 8. — Anthracite, Buck Mountain bed, specimen 1, horizontal section, × 55.

More resinous bodies in semi-bright coal.

P pâte.

W small piece of wood with preserved structure.

Figure 9. — Anthracite, Buck Mountain bed, specimen 1, vertical section, × 55.

Different type of structure for different locality of the bed. Banding less distinct and determination more difficult.

B bright coal ; some bands ending in points. Compare with figure 1 (B2).

SB semi-bright coal, being made up of bright coal as well as pâte and vegetable debris.

D dull coal, contents not identifiable.

P pâte, always amorphous and similar to bright coal.

R1, R2, R3 resins. Compare with resins in figures 4, 14, 17, and text figure 11.

Vr Vegetable remains.

Figure 10. — Enlargement of R2 in previous figure, × 440.

Shows characteristic form of resins in anthracites, the difficulty of determining the compressed structure above them, the contact between the semi-bright and dull types of banding, and the indistinctness of the plant debris in the dull coal — even under fairly high power magnification.

In these previous photographs, it will be noticed that the structure and contents of the anthracites is clearly brought out by the method of polish employed; but that the difficulty lies in saying what it all is, because of the compressed character of the rock. In the following figures, as the structure is less complex, determination will be found to be easier.

PLATE III

Figure 11. — Coking Coal, « B » or Miller seam, specimen 33, vertical section, × 55.

Shows excellent preservation of wood fragments, as will as typical make up of the semi-bright bands. In this photograph it will be noticed that macerated woody tissues of all sizes are practically the only constituent of this coal at this particular spot. The pieces of wood marked F, F2, and F3 are in excellent preservation, and are remarkable because of their length. Fragments are usually very minute as in the semi-bright portions of this figure — or more often, as seen in figure 19. Notice the different stages of alteration of all the fragments - even when so close to one another.

SB. — semi-bright layers with tiny woody fragments.

W. — wood fragments.

F1, F2, F3. — fusain or mineral charcoal of differing characteristics.

Figure 12. — Enlargement of F 1 and F 2 of figure 11, plate III, × 250.

S B. — semi-bright coal ; note how it is present even between the nearly touching pieces of fusain (F 1 and F 2).

F 1, F 2. — fusain with elongated cell structure, evidently cut « with the grain ».

R. — resin.

Cc. — cell cavity.

Cm. — cell membrane.

Figure 13. — Enlargement of F 3 to the right of the figure 11, plate III, × 250.

F3. — fusain, cut « across grain ». Typical cellular structure. Compare with figures 3, 5, 18, and text figure 11.

P. — pâte.

R. — resin.

Note how pâte and semi-bright coal is found to have penetrated the broken cells in the center of the figure.

Figure 14. — Coking Coal, « B » or Miller seam, specimen 33, vertical section, × 55.

Group of resins, round or fractured, in a semi-bright area. Typical minute wood fragments also clearly visible as well as the pâte in its characteristic amorphous aspect. Compare with figures 4, 7, 9, 17, and text figure 10.

PLATE IV

Figure 15. — Coking Coal, under bone coal of « B » or Miller seam, specimen 35-B (see text figure 1), vertical section, × 55.

Aspect of a portion of the compact layer of the specimen. Shows the occasional good preservation of wood fragments as found in this onetime wood pulp. The semi-bright coal is also mostly wood fragments.

W1, W2, W3, W4. — wood in various types of preservation.

R. — resin with fossilized secreting canals.

Figure 16. — Same source previous figure, × 250.

Pseudo-spore. Shows the odd and deceptive aspects that can be presented by fractured or broken wood cells.

W_R, W_{R1}. — woody remains.

St. — isolated or separated fragments of structure-en-arc.

P. — pâte.

R. — resin.

Figure 17. — Same source as previous figure, × 250.

Odd shaped fragments of woody tissues and resins in the pulpy wood-pâte gorund mass from specimen 35 B.

W. — wood fragments.

R_1. — broken piece of resin with well preserved secreting canals.

Figure 18. — Same source as previous figure, × 250.

Fusain, compressed cell structure or « structure-en-arc ». Compare with figures 13, 5, 3, and text figure 11.

Figure 19. — Coking coal, Pocahontas N° 4, specimen 26, vertical section, × 55.

Typical aspect of coking coals. Characteristic arrangement and appearance of the wood fragments found in them.

P. — pâte, always the same.

W_1, W_2. — the most frequent type of wood found in coking coals.

W3, W4, W5. — other types often found.

Wr. — woody remains.

Sp. — space.

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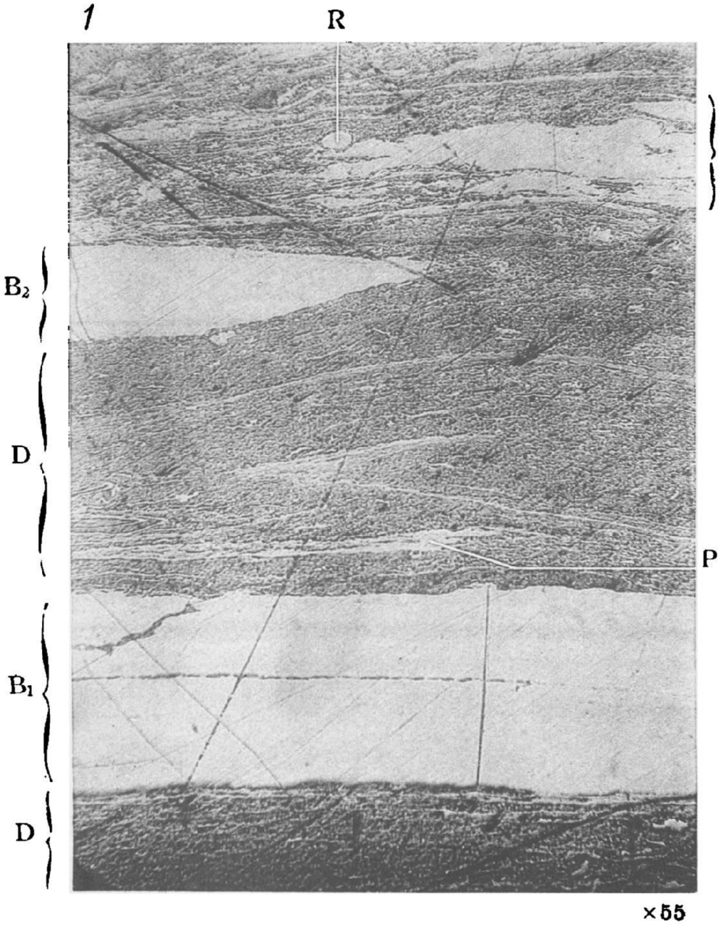
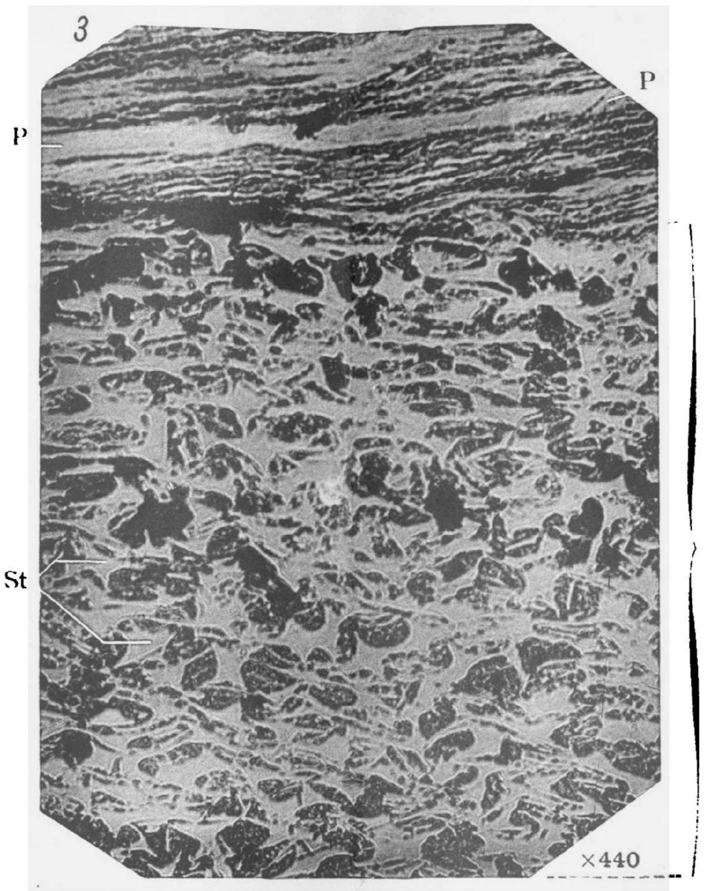
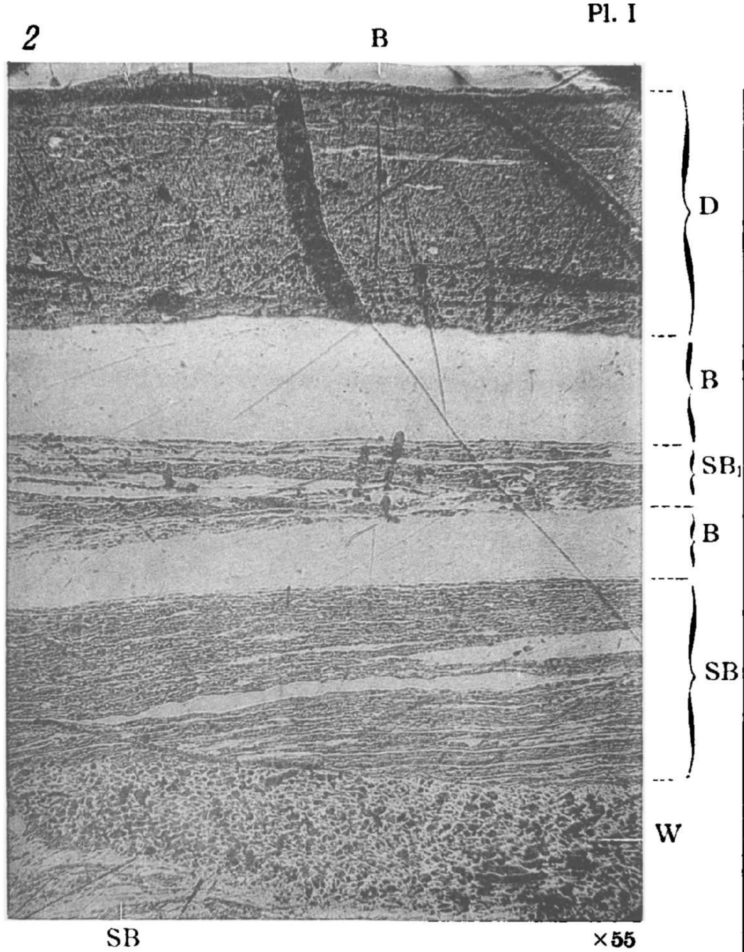
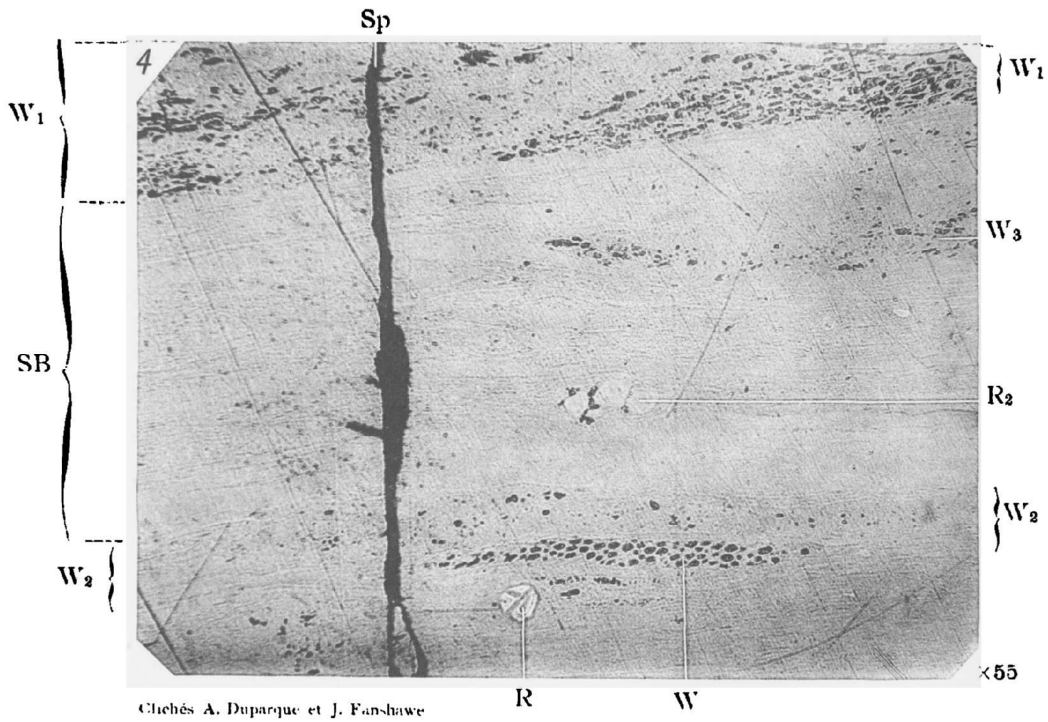
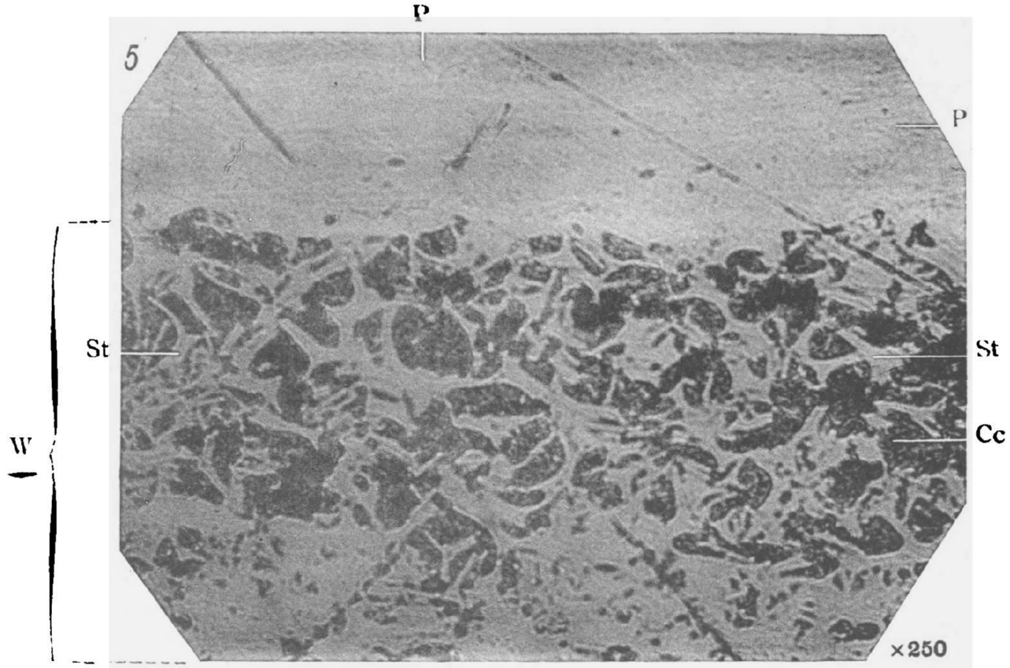
ANTHRACITES







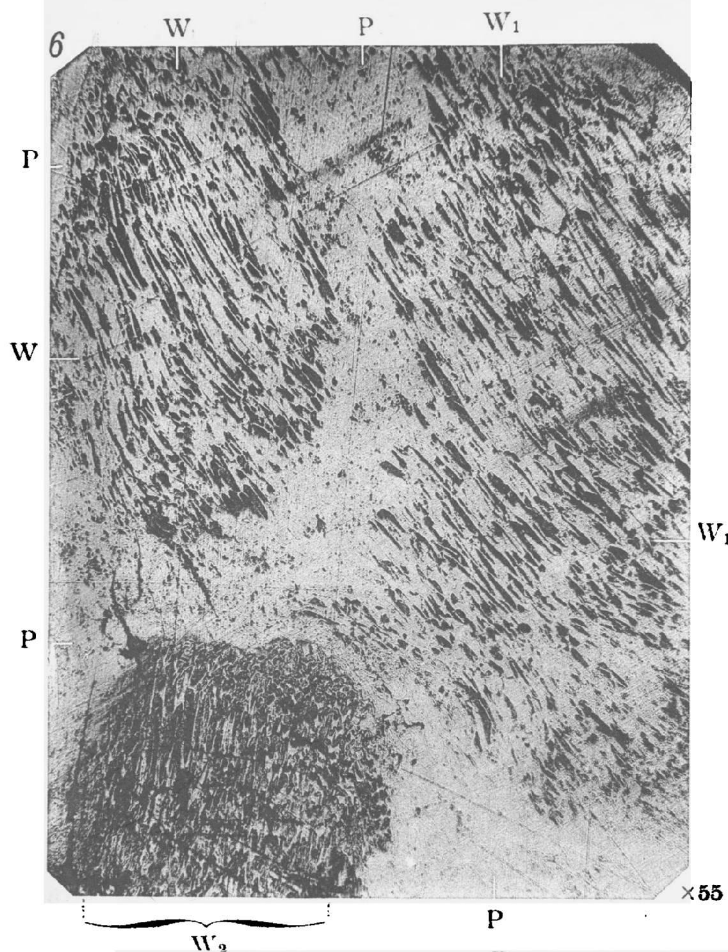


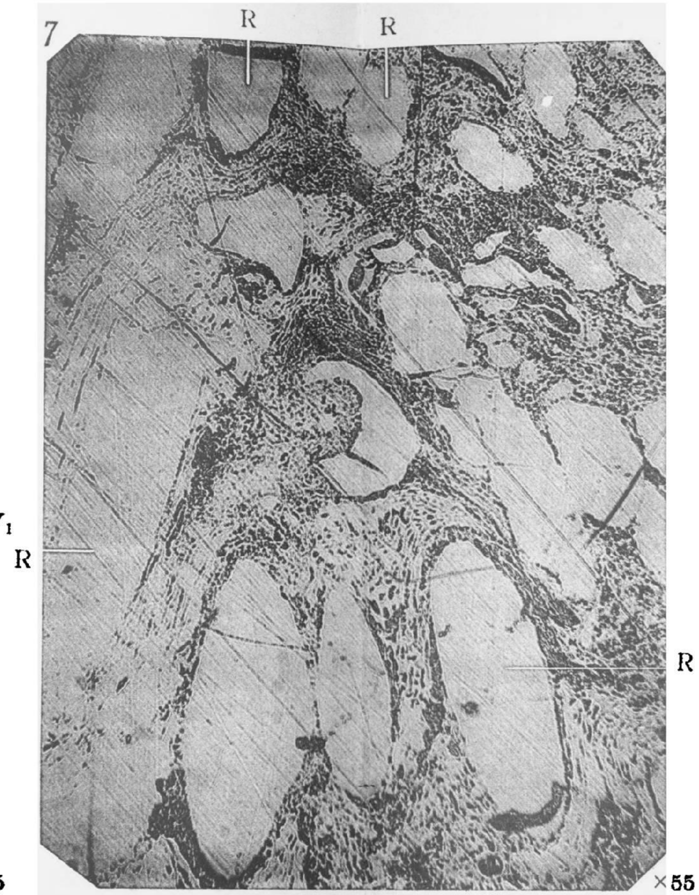


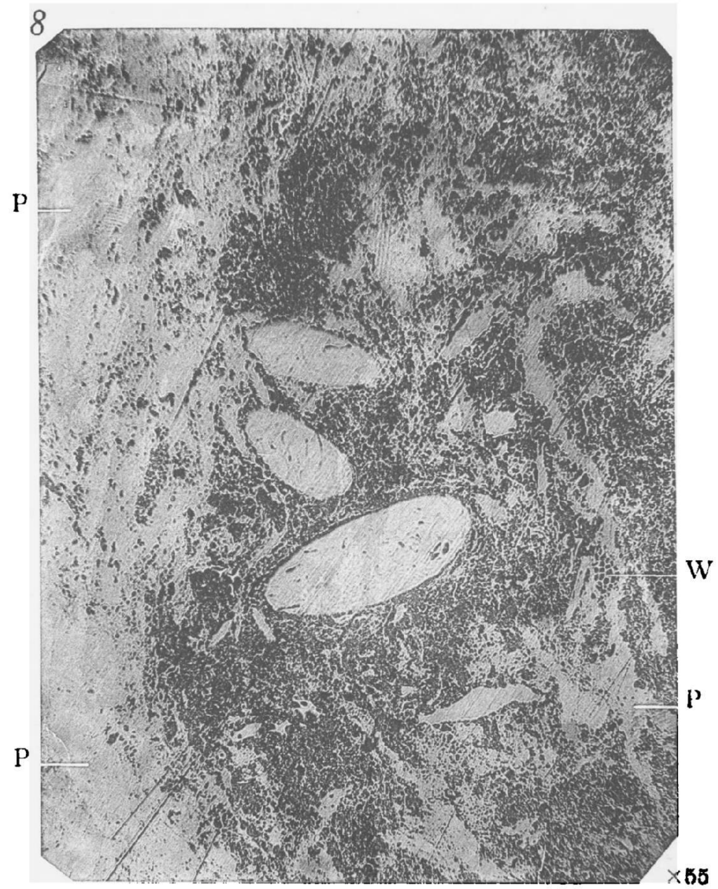
Clichés A. Duparque et J. Fanshawe

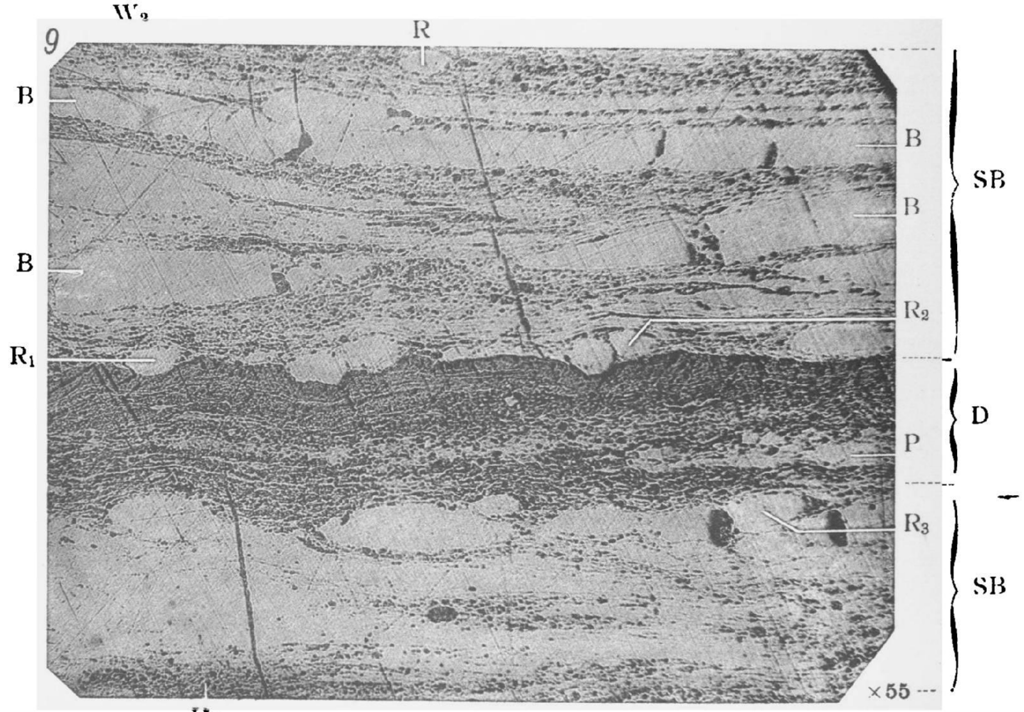
Imp. Tortellier et Cie, Arcueil (Seine)

Wood and Resinous bodies. — Bright, semi-bright and Dull Coal









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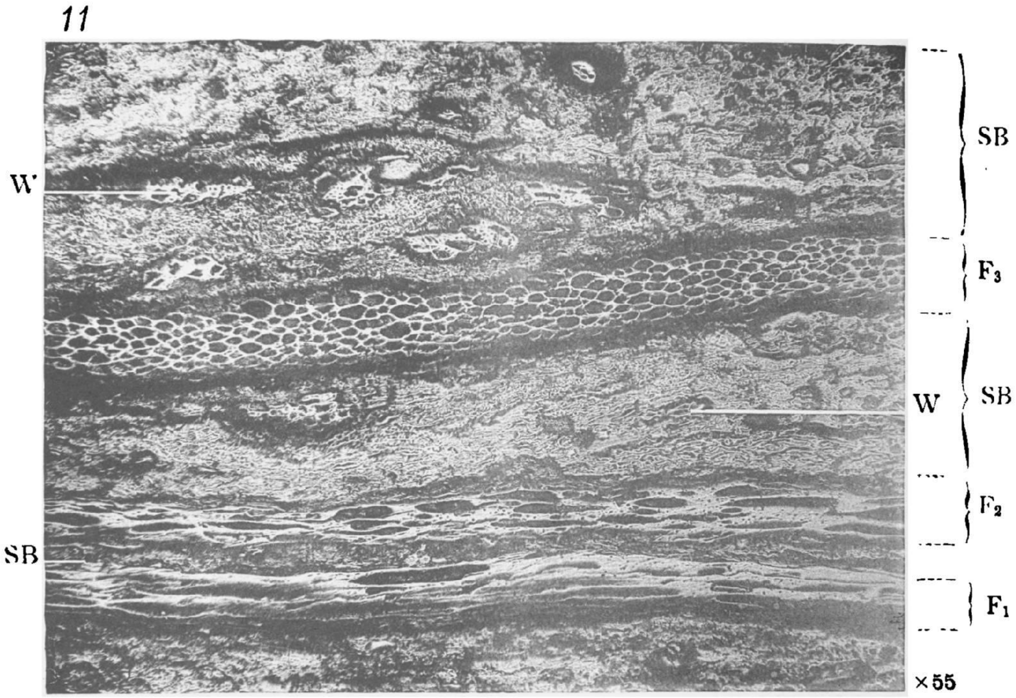
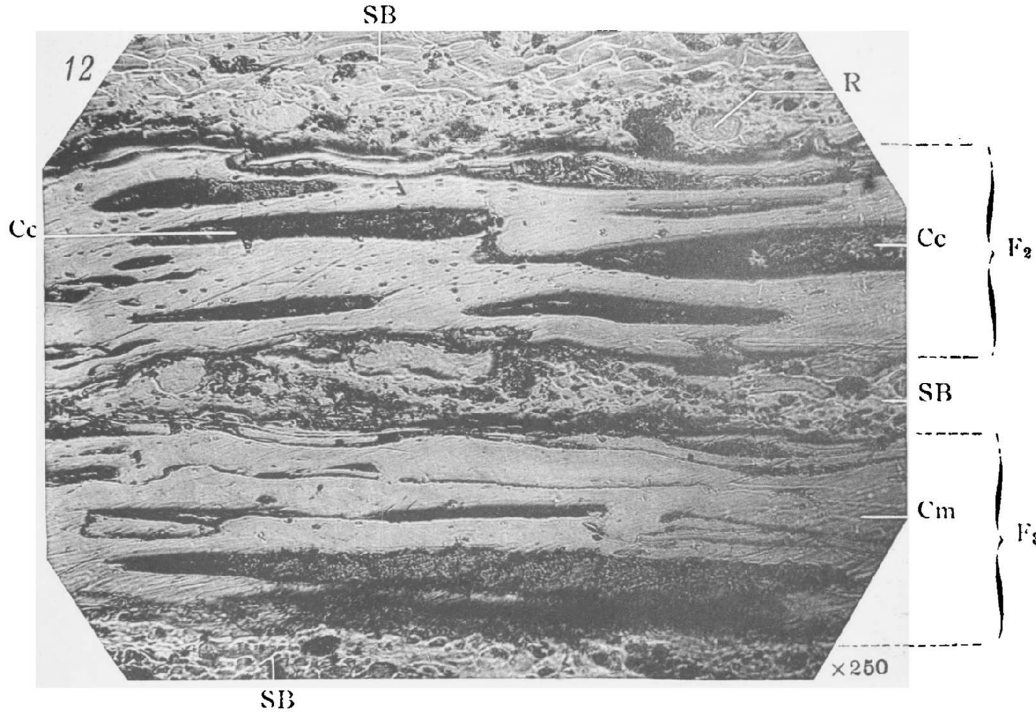
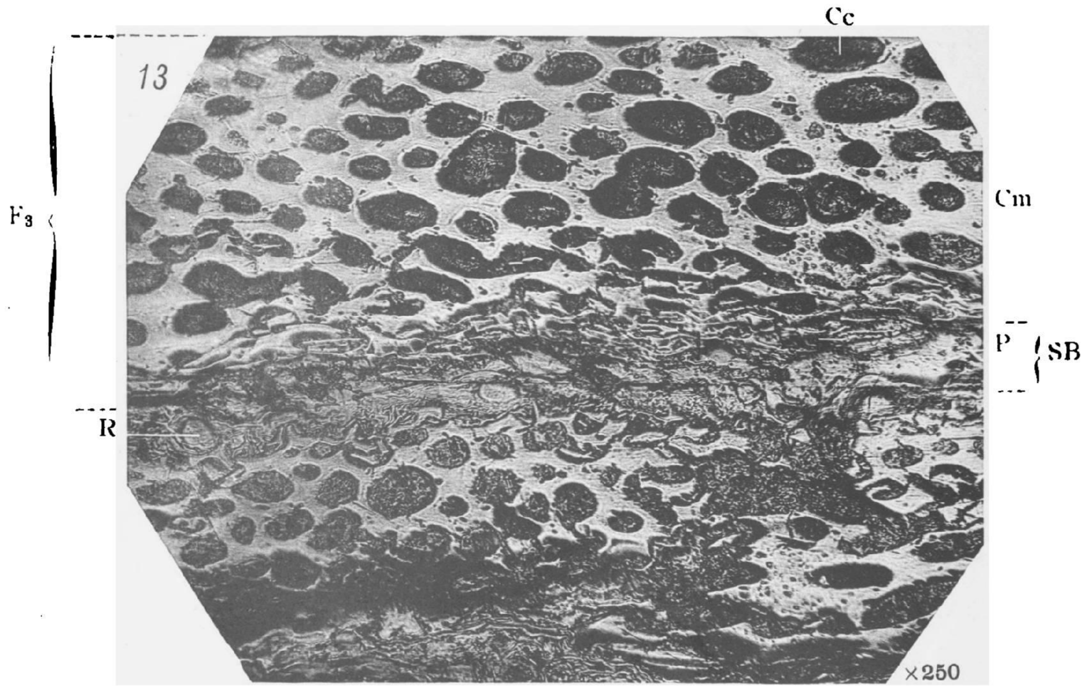
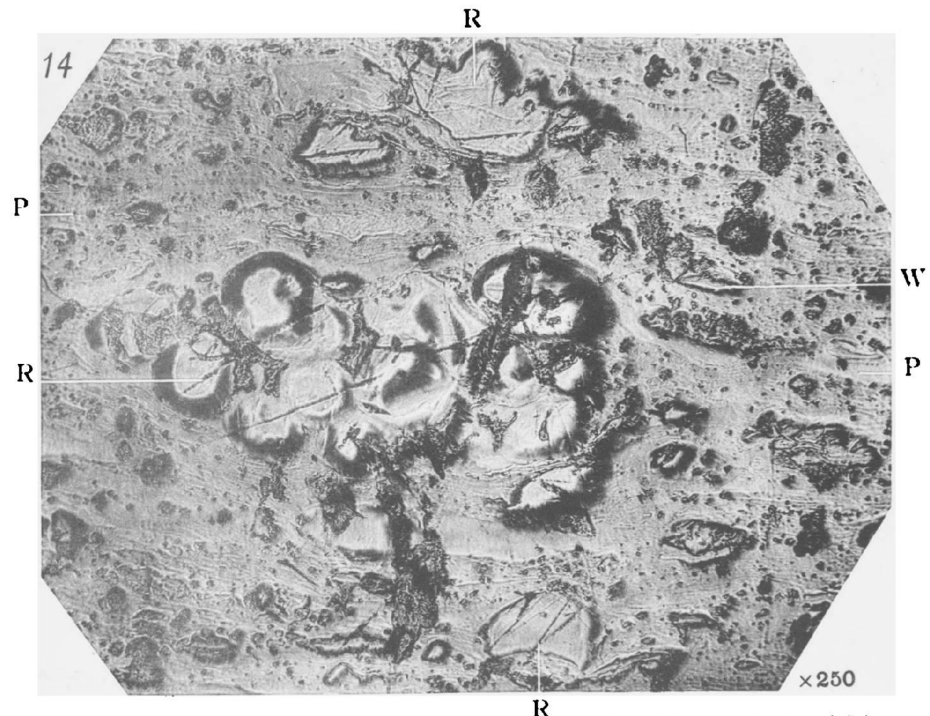
Imp. Tortellier et Cie, Arcueil (Seine)

Wood and Resinous bodies. — Semi-bright and Dull Coal.







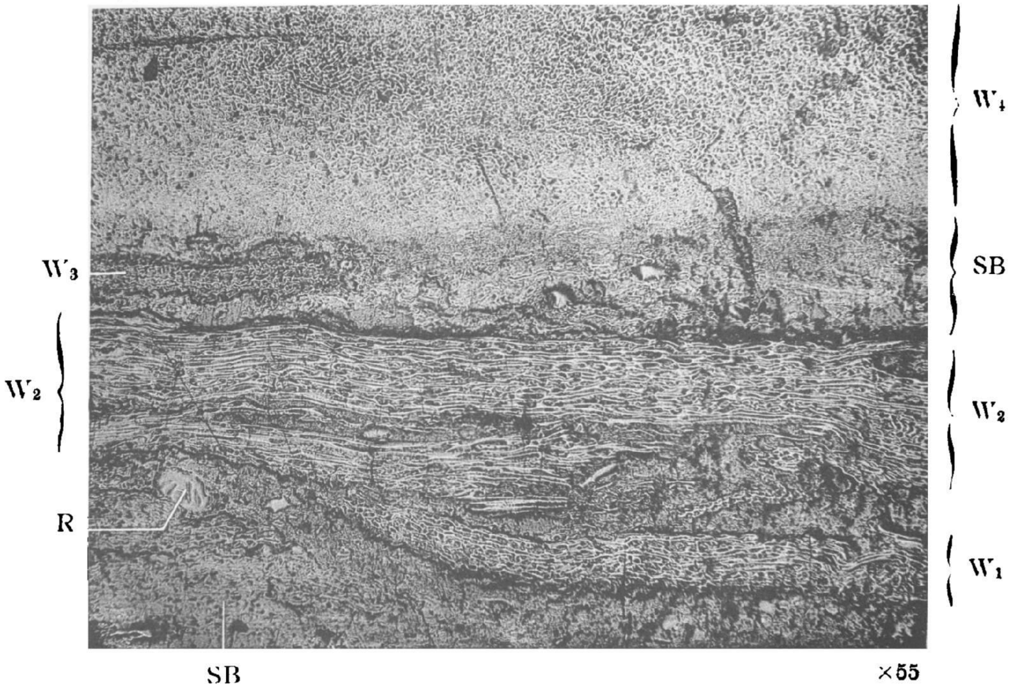


Clichés A. Duparque et J. Fanshawe

Imp. Tortellier et Cie. Arcueil (Seine)

Wood and Resinous bodies. — Fusain, Semi-bright and Dull Coal.

15



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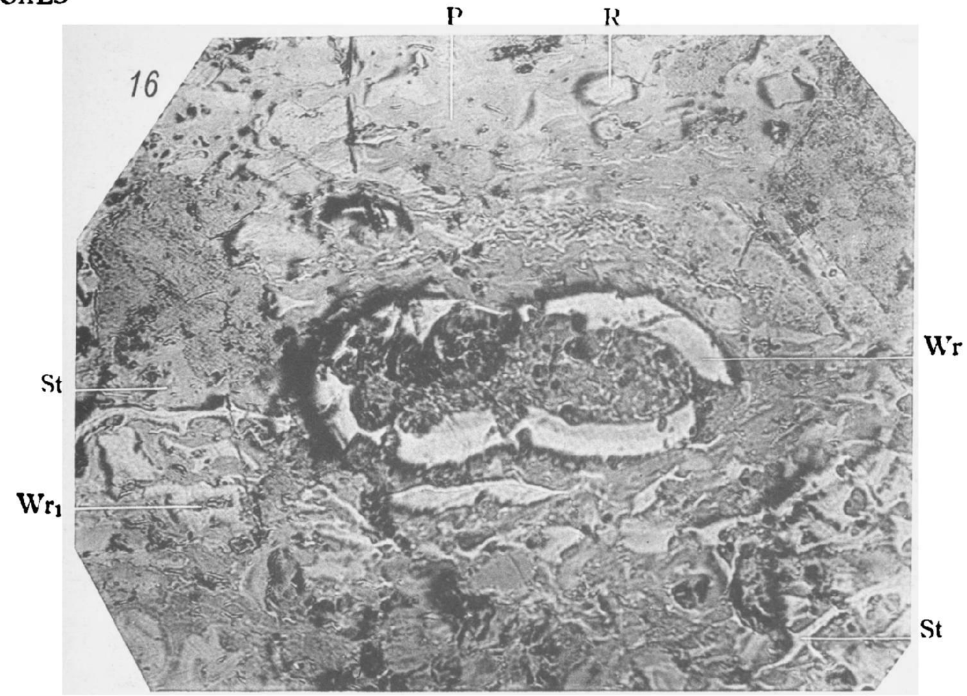

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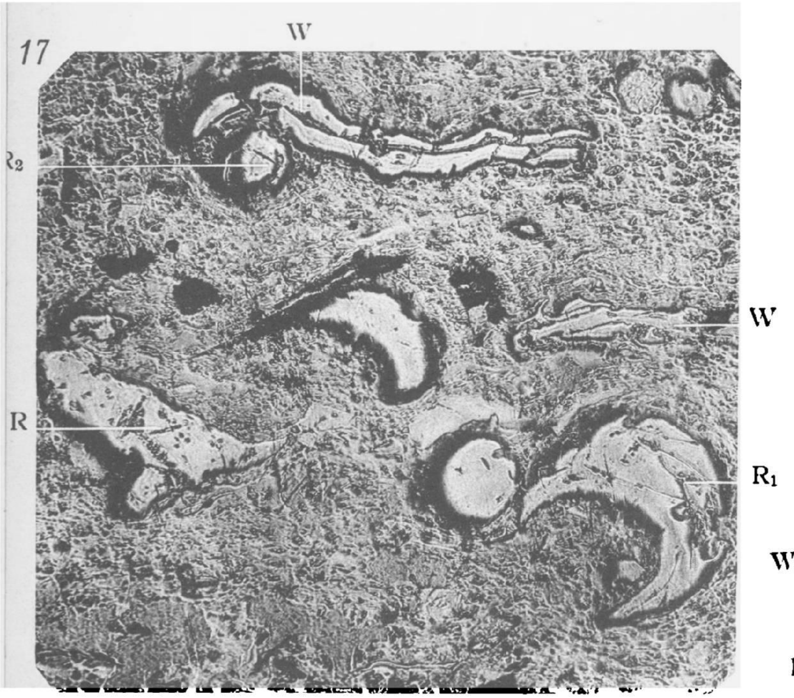

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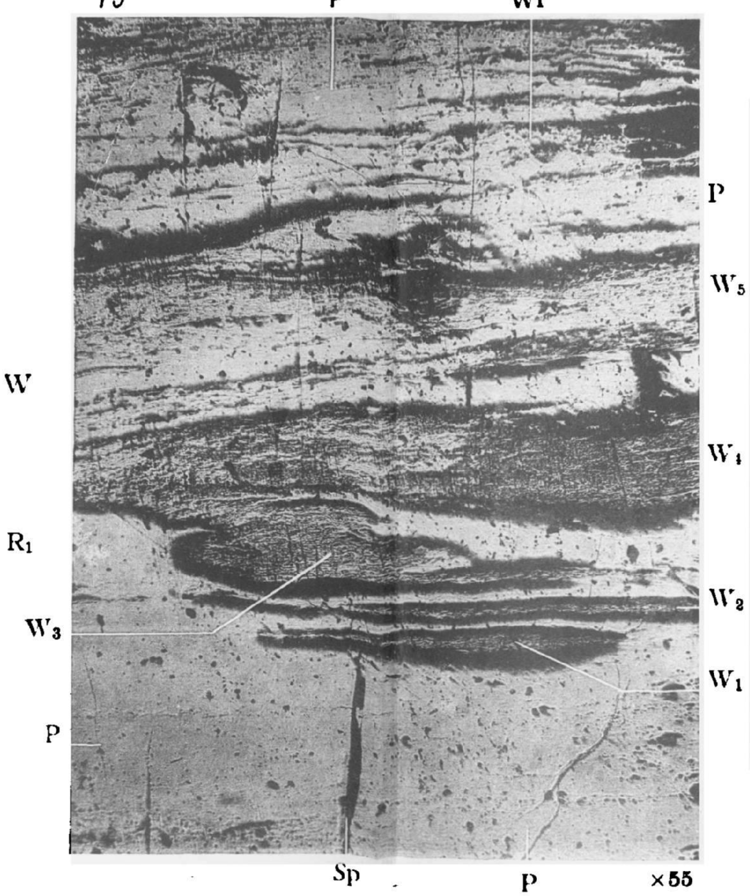

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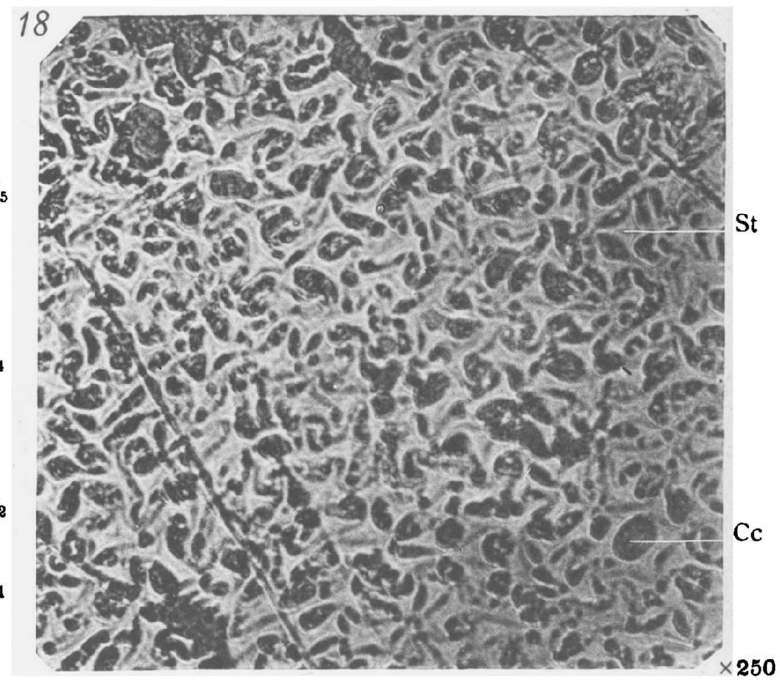

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×250

Imp. Tortellier et Cie, Arcueil (Seine)

Wood and Résinous bodies. — Bright, semi-bright and Dull Coal

2e THÈSE

PROPOSITIONS DONNÉES PAR LA FACULTÉ

1° Les différents types de gisements de pétrole en Amérique du Nord

2° Comparaison entre les caractères paléontologiques du terrain houiller en Europe occidentale et dans les Apalaches

Vu et approuvé :
Lille, le 7 Juin 1930,
Le Doyen de la Faculté des Sciences :
A. MAIGE.

Vu et permis d'imprimer :
Lille, le 10 Juin 1930,
Le Recteur de l'Académie :
A. CHATELET.

IMPRIMERIE G. SAUTAI
Lille-Paris-Bordeaux:: : :: :::