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INFORMATION CIRCULAR NO. 22

ANTHRACOLOGIC ANALYSIS

A GUIDE TO THE APPLIED PETROLOGY
OF OHIO COALS

By
GILBERT H. CADY

COLUMBUS

1958

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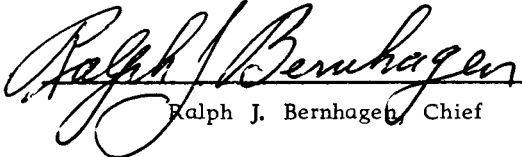
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FOREWORD

A more discerning understanding of the physical composition of Ohio coal beds is an inevitable necessity for the full realization of their usefulness. That the physical constitution of coal plays an important part in determining the chemical differences among coals, particularly with respect to variations that accompany differences in screen size is too little realized. The achievement of this better understanding of the physical heterogeneity of coal as a mass of coalified plant structures will depend upon the existence of individuals sufficiently interested and adequately trained to carry on careful and systematic examination of coal and to record their observations with the same care and system.

The present report provides those interested in our coal resources, including high school and college students, with a general picture of the nature of anthracology or coal petrology, the methods and apparatus used in its pursuit, the character of the information obtained, and the methods of its presentation. The incidental but not serious problems involving methods and terminologies that face the workers in this field are indicated. It will be apparent that some of the information obtained has to do with the identification and study of the coalified fossil plant forms found in the coal and hence has primary geological significance, but it should be realized that the main purpose of coal petrology is to gain an understanding of the fundamental variations in the kinds of coal material making up the coal bed. Such information provides a substantial basis for guiding coal preparation procedures toward the production of coal varieties best suited for specific types of utilization.



Ralph J. Bernhagen, Chief

ACKNOWLEDGMENTS

The preparation of this report was made possible through the support of the project by the Ohio Division of Geological Survey, Mr. John H. Melvin, Chief during 1956, and Mr. Ralph J. Bernhagen, Chief since 1957. Photographs of certain German language publications were supplied through the courtesy of the Illinois State Geological Survey to which I am also indebted for use of its library facilities. For some illustrations I wish to thank Dr. James M. Schopf of the U. S. Geological Survey, Columbus. Although the work on this report was started subsequent to the termination of the period of the National Science Foundation grant, in aid to the Ohio Department of Natural Resources for research on the petrography of Ohio coals (see Ohio Division of Geological Survey Report of Investigations No. 27), it represents in part the results of some of the work done under this grant. I am indebted to Mrs. Cady for the time and attention required for reading and correcting errors in the original manuscript.

To all these persons and organizations and to others who have been of occasional assistance, I wish to express my deep appreciation of the help provided.

Gilbert H. Cady

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SUMMARY

It is the purpose in part 1 of this report, as a general introduction to the subject of anthracologic or coal petrographic analysis, to indicate the general nature of the science and to point out the dissimilar aspects of American and European systems of coal description and analysis. The emphasis of American coal microscopy upon fundamental description and that of European coal petrology upon analysis and its practical applications is shown. An extended outline of anthracologic analysis is presented on page 5 and there are also tables explaining the meaning and relationship of terms in anthracologic literature and classifications in Europe (table 1) and in America (table 2) at the present time. The fundamental differences that separate the two systems of coal description and analysis are explained. It is also pointed out that differences in coal rank produce very important variations in the character of the different varieties of coal material composing a coal bed. This is a matter more or less aside from petrographic analysis except where such analysis is concerned with a mixture of granules of two or more coals of different rank. The practical importance of what is designated the modal analysis of coal is suggested but receives more consideration, particularly in part 4.

Part 2 is concerned with the techniques of graphic coal bed profiles or descriptions, otherwise designated simply as profile analyses, on the basis of both megascopic and microscopic criteria. This procedure provides not only for the reproduction of the textural pattern of the coal bed in a symbolic manner, but also analyses in terms of microscopic and megascopic entities proportionately by more or less even steps or in uneven units represented by natural benches of the coal bed. It is also shown that the graphic profile may be continuous and not proportional, thereby providing a better picture of the texture of the coal bed.

Part 3 deals with the procedures of the analysis of broken coal, or coal in granules, produced by the mining and preparation processes or by the deliberate crushing of column samples. The use of such broken coal to provide average petrographic analyses of coal beds is discussed. Much of the chapter is devoted to a description of methods of analyses of broken coal which has been mounted and polished, being concerned with the measurement of oriented and unoriented granules by the various types of apparatus available and by the point-count method.

Part 4 deals primarily with the application of profile and broken coal analyses in the academic or geological field and in the field of applied petrology. The relative value of the Bureau of Mines, European, and more recently used Ohio Geological Survey types of profiles in the geological and practical fields receive consideration, with a concluding statement on the practical value of both profile and broken coal analyses.

The general purpose of the study has been to describe and evaluate various procedures and techniques available for use in the petrographic description and analysis of Ohio coal beds which will inevitably be carried on more extensively. The present study indicates that it would be a mistake to restrict investigations entirely to one technique and thereby lose what advantage may lie in others. Since time and labor are usually outstanding considerations, methods should be selected that seem likely to give critical information in the shortest time and with the least labor. There is an increasing willingness to use both thin section and polished surface techniques in America so that probably the misunderstandings resulting from a double terminology will eventually disappear and the advantage of a single internationally recognized vocabulary will be realized.

INTRODUCTION

The anthracologic analysis of coal provides information concerning the proportion of physically distinguishable components which are present in coal. This information is essential for accurate description and classification of coal, for discriminating selection, and suitable preparation of coal for specific uses. The primary objective of such analysis is the classification of coal material in terms of paleobotanical or petrologic entities of distinctly different genesis or physical attributes. Thus, a type classification of coal irrespective of rank is provided, but one to which classification by rank can be added.

Universal unanimity in regard to the criteria upon which anthracologic description and analysis should be based is lacking. There is a similar lack of agreement in regard to the degree and nature of discrimination that should be employed in differentiating physical components; and, furthermore, there is by no means certainty that the discriminations that have been made necessarily embrace the entire range of critical variability. Anthracology is a comparatively young science with relatively few participants, some working in distant countries which are politically even more remote, so that consultation is difficult and at best infrequent. Hence, anthracologic terminology and analytical and classification methods lack that uniformity in usage and practice essential to their effective international use in the attainment of a common understanding of the physical structure and composition of coal.

Commendable effort has been made since 1953 by the International Committee of Coal Petrology, of which the author is a member, to give applied coal petrology a more international aspect. It has endeavored to establish a standard international system and terminology of coal petrology and petrography with the Continental system of coal petrology as a basis, but with recognition of the system of coal microscopy largely peculiar to the United States. The Glossary Sub-committee of this group* has issued a loose-leaf edition representing 40 to 50 terms of the International Glossary of Coal Petrology#. This may help to standardize description and analysis, but cannot be expected to solve all the problems resulting from different techniques and different languages and lack of agreement as to the significance and nature of the criteria necessary for discriminating differentiation of coal, particularly with respect to practical considerations.

*List of members of the Nomenclature Committee, June 1957:

- | | |
|-----------------------------------|-------------------------------------|
| 1. B. Alpern (France)* | 12. M. Legraye (Belgium) |
| 2. I. Ammossov (U.S.S.R.)* | 13. M. Th. Mackowsky (Germany)* |
| 3. K. Assai (Japan) | 14. B. Ch. Mukherjee (India) |
| 4. G. H. Cady (U.S.A.) | 15. R. Noel (Belgium)* |
| 5. D. Chandra (United Kingdom) | 16. B. C. Parks (U.S.A.) |
| 6. S. J. Dijkstra (Netherlands) | 17. R. Potonié (Germany) |
| 7. A. B. Duparque (France) | 18. J. M. Schopf (U.S.A.)* |
| 8. G. W. Fenton (United Kingdom)* | 19. C. A. Seyler (United Kingdom) |
| 9. E. H. Grand'ry (Belgium) | 20. A. H. V. Smith (United Kingdom) |
| 10. V. Hevia (Spain)* | 21. E. Stach (Germany)* Secretary |
| 11. P. A. Hacquebard (Canada) | 22. G. H. Taylor (Australia) |
| | 23. M. Teichmüller (Germany) |

The Glossary of Coal Petrology, edition of 1957, is available in French, German, and English editions for 1,500 fr each from Centre National de la Recherche Scientifique, 13 Quai Anatole France, Paris 7^e, France.

DIFFICULTIES OF LABORATORY OPERATION

PERSONNEL

The operation of anthracologic laboratories is considerably hampered by the lack of a source of academically trained personnel such as can usually be found for laboratories in other branches of science. Too commonly the success in establishing new laboratories in this field or of keeping existing laboratories in operation depends upon the ability to attract technicians from laboratories already in operation, which if successful means that the original laboratory must then train a new technician. In the past coal petrology laboratories in America have been started and maintained by individuals with botanical or geological training and this has tended to give a definite botanical aspect to the work carried on in the laboratories, with a considerable emphasis on the use of fossil spores in stratigraphic identification and correlation. In Europe geologists, mineralogists, and petrographers have had a greater influence on anthracology than has been the case in America, with a resulting greater emphasis on the study of coal as a rock than as an accumulation of fossil plant material.

EQUIPMENT

Satisfactory preparation equipment for the anthracologic laboratory, such as cut-off saws and grinding and polishing equipment suitable for preparing thin sections or polished surfaces, can be obtained in this country. The fine-grained Belgian hone, of foreign origin, used in the finishing stages of making thin sections, is becoming difficult to obtain and the grade has deteriorated within recent years. A good substitute is not easy to find. Some success in devising a substitute has been attained by embedding fine polishing powder in a plastic, but undoubtedly a good Belgian hone is to be preferred.

Satisfactory domestic microscopes are available for thin section microscopy, although foreign microscopes are in common use. The Leitz coal-microscopy microscope is as yet the only one available for polished surface studies. The six spindle integrating stages are also of foreign make. The necessary equipment of a coal petrography laboratory is relatively expensive and this is probably an important deterrent to a more general introduction of coal petrography into the academic field.

In addition to microscopic equipment, photographic equipment and dark room facilities must be included. In general, simple research facilities for one petrographic microscopist and one technician for preparing thin and polished sections, irrespective of housing, can scarcely be acquired for less than \$5,000, and possibly for not less than \$7,500. This will not include special equipment such as heating stages, apparatus for reflectivity studies, for hardness studies, and various other types of equipment found in some coal petrology laboratories in the United States and particularly abroad.

Point-count mechanical stages are generally constructed by skilled laboratory mechanics for domestic laboratories. More elaborate point-count apparatus of European manufacture is just beginning to enter the American market (see fig. 15).

AMERICAN COAL PETROLOGY LABORATORIES

Anthracologic investigations in America are restricted to the following eleven laboratories in United States and Canada:

1. U. S. Bureau of Mines, Special Research Section, Branch of Bituminous Coal, Pittsburgh: Mr. Bryan C. Parks, Geologist; Mr. H. J. O'Donnel, Associate.
2. U. S. Geological Survey, Fuels Branch, Coal Geology Laboratory, Orton Hall, Ohio State University, Columbus 10, Ohio: Dr. James M. Schopf *, Supervising Geologist.
3. Organic Sediments Laboratory, College of Mineral Industries, Department of Geology, Pennsylvania State University, University Park, Pennsylvania: Dr. William Spackman, Professor of Paleobotany in charge with W. F. Berry, Russell Dutcher, Dr. G. O. W. Kremp *, and Dr. Hilde Grebe *, associated scientists, with Dr. G. H. Cady, Advisory Consultant.
4. Coal Division, Illinois State Geological Survey, Urbana, Illinois : Mr. Jack A. Simon, Head, with Dr. Robert M. Kosanke * and John H. Harrison, Geologists, Associated Scientists.
5. Coal Research Laboratory, Geological Survey of Canada, Sydney, Nova Scotia : Dr. P. A. Hacquebard, Geologist in Charge.
6. Fuels Division, Mines Branch, Canadian Department of Mines and Technical Surveys, Ottawa, Ontario : Dr. Lewis H. King, in charge of coal petrography research.
7. U. S. Steel Corporation, Applied Research Laboratory, Monroeville, Pennsylvania : Dr. Norman Schapiro, Geologist, in charge of petrographic studies of coal, and Ralph J. Gray, Associate.
8. West Virginia University and Geological Survey, Morgantown, West Virginia : Dr. Aureal T. Cross, Coal Geologist and Paleobotanist, until recently, in charge, and Dr. Mart P. Schemel*, Associate. Both Dr. Cross and Dr. Schemel have left the West Virginia Geological Survey and at the present time Mr. Sanders Luttimer is the coal geologist with the West Virginia Survey.
9. Coal Petrography Laboratory, Ohio Division of Geological Survey, Orton Hall, The Ohio State University, Columbus 10, Ohio: Mr. George H. Denton *, Geologist in Charge; Dr. G. H. Cady, Advisory Consultant.
10. Pennsylvania Geological Survey, Harrisburg, Pennsylvania: Dr. Edwin F. Koppe, Geologist in charge of coal petrography research.
11. Indiana Geological Survey, Bloomington, Indiana; Mr. R. C. Neavell, in charge of coal petrographic studies.

An anthracologic laboratory in the field of lignite petrology formerly operated by the U. S. Bureau of Mines at Grand Forks, North Dakota, under the supervision of Dr. Alfred Traverse, and transferred to the Federal Center, Denver, Colorado in 1955, has not been operating in full scale since the resignation of Dr. Traverse later the same year.

Of the laboratories listed, No. 10 at Harrisburg, Pennsylvania, was started in 1956, as was, likewise, No. 7 at Monroeville, Pennsylvania. Laboratory No. 11, at Bloomington, was started in 1957. Laboratory No. 9 is operating on a part-time basis, and the work in laboratory No. 8 consisted largely of paleobotanical and stratigraphic

* Paleobotanists (Palynologists)

investigations of fossil spores. Investigations of fossil spores occupies more or less the attention of both laboratories at Columbus (Nos. 2 and 9), and at laboratory No. 4 at Urbana, laboratory No. 5 at Sydney, Nova Scotia, as well as laboratory No. 3 at University Park.

Studies in applied coal petrography have more or less occupied the attention of laboratories at Pittsburgh, Monroeville, University Park, Pennsylvania, and the laboratory at Urbana, Illinois (Nos. 1, 3, 4, and 7). Studies of the relation of coal components to the rare earths, including uranium, have occupied considerable attention of the Federal Coal Research Laboratory (No. 2) at Columbus, in recent years.

In an anthracologic laboratory established through the aid of a grant from the National Science Foundation in 1953, the Ohio Division of Geological Survey was enabled to carry on a brief exploratory investigation of the petrographic characteristics of four Ohio coal beds (Meigs Creek (No. 9), Pittsburgh (No. 8), Middle Kittanning (No. 6), and Clarion (No. 4-A)), with more extensive examination of the Meigs Creek coal than of the other three (1).

This investigation demonstrated that these four coal beds have the usual petrographic composition and structure of the bright banded bituminous coals of the western Appalachian and Interior coal fields and, hence, are amenable to description and analysis by the usual methods of anthracologic research. Consequently, no special difficulties are anticipated in a more extensive investigation of these and other coal beds in the field of applied petrology. Such investigations are necessary to an understanding of the physical factors controlling the successful preparation of these coals for particular and special uses.

METHODS OF RESEARCH IN AMERICAN ANTHRACOLOGIC LABORATORIES

Except for the coal research laboratory of the Geological Survey of Canada at Sydney, Nova Scotia, the methods and terminology of the Thiessen system of thin section microscopy, established by the U. S. Bureau of Mines, dominates American microscopic studies of coal. Some American laboratories consider the European system of applied coal petrology to be more convenient and to have a more appropriate symbolism, at least in connection with applied petrographic activities. The Illinois State Geological Survey has used European megascopic terminology more or less since the early nineteen-thirties. The Organic Sediments Laboratory at University Park, Pennsylvania, has found the symbols of the Thiessen terminology inadequate for describing critical aspects of bituminous coking coals (2). Although many of their investigations are carried on with thin sections, polished surface terminology has been applied to the varieties of coal structures. At Sydney, Hacquebard has continued to use European terminology with polished coal specimens, to the use of which he had been trained in the Netherlands. In general, there has undoubtedly been a greater increase in America toward the use of European methods and terminology than has been the case with American terminology and methods in Europe, where the use of thin section technique is exceptional.

NEED OF A PRE-VIEW OF METHODS OF ANTHRACOLOGIC ANALYSIS

Assuming that the bright-banded medium and low rank bituminous coals of Ohio partake of the usual characteristics of such coals in eastern and central United States, it is reasonable to believe that the petrographic structure

of the coal may provide a suitable basis for its selective preparation for particular uses. It is believed the validity of this statement can be substantiated by considering the methods of description and analysis and their subsequent results.

The extent of susceptibility of a coal to various preparation processes can probably be largely foretold, provided the description of the coal is clearly and adequately symbolized in terms of common understanding. It should be emphasized that an anthracologic analysis, whether a profile or broken coal analysis, may be accomplished on any one of a number of bases of particularity. From the possibilities available in the two systems of microscopy and petrography, the method or methods should be carefully selected to obtain the information desired. The present study of anthracologic analysis and description is a necessary preparation for any systematic study of the effect of preparation methods on the composition of a coal as represented by the various fractions produced by such preparation. It is believed that only on the basis of such preliminary consideration of the available practices and methods can the most useful type of analysis be selected.

PREVAILING ANALYTICAL PROCEDURES IN ANTHRACOLOGY

The following outline suggests the scope and details of petrologic procedure in various phases of anthracologic description and analysis. The outline is arranged so that both thin section and polished surface techniques are presented. It will be emphasized that selection of the method to be used depends upon its suitability to attain the objective desired. That clear-cut selection will always be made between thin section and polished surface systems is improbable. Some sort of compromise is practically inevitable.

The outline is set up in such a way as to indicate the character and scope of the classification procedure at the three common stages of observation; viz., megascopic; low magnification that is up to about 300 X; and high magnification, above 300 X. The greater part of work in coal petrography is at the intermediate stage. Megascopic observation may include observation with a binocular microscope and oblique illumination to magnification up to about 50 times; that is under conditions where the surface of the coal, although magnified, has essentially the same appearance as when viewed without magnification.

A second subdivision of the data in the outline is (1) on the basis of bed analysis, in terms of successive thin sections or polished blocks representing the complete profile of the bed or bench; and (2) on the basis of broken coal, such as results from the processes of mining and preparation. Bed profiles are believed to be fundamental to an understanding of the effect of preparation upon the petrographic composition of the prepared coal. The broken coal analysis reveals the effect of preparation upon the initial petrographic composition of the coal.

SUMMARY OF ANALYTICAL PROCEDURES IN ANTHRACOLOGY IN NORTH AMERICA AND WESTERN EUROPE

I. Bed profile analysis

A. Megascopic bed profile analysis by lithotypes (banded ingredients), using polished coal surfaces.

1. Preliminary graphic or photographic profile.
2. Summary graphic profile based upon graphic or photographic profile or upon original coal sample.
3. Megascopic volumetric analysis in terms of lithotypes, based upon transect measurements or summary profile.
4. Megascopic quantitative analysis in terms of lithotypes, by adjusting values representing volumetric analysis for differences in density of the lithotypes.

- B. Microscopic bed profile analysis in terms of microlithotypes using polished surfaces. Provided for by the International Glossary of Coal Petrology (published in 1957, see p. 1 of this report) and now available for general use.
- Possible arrangement :
1. Graphic profile by microlithotypes.
 2. Volumetric analysis by microlithotypes.
 3. Quantitative analysis by microlithotypes.
- C. Microscopic bed profile analysis, using polished surfaces, in terms of macerals, or group macerals, and mineral matter.
1. By use of ocular micrometer :
 - a. Transect bed profile recorded graphically or mechanically based upon convenient arbitrary units of measurement such as total length of the micrometer scale or convenient subdivisions thereof, such as 1/20th. Transects may be by bed, bench, or block.
 - b. Volumetric profile analysis of block, bench, or bed, based upon transect graphic bed profile (a). This is essentially the same as (a) when the latter is done mechanically.
 - c. Microscopic quantitative profile analysis of block, bench, or bed, based upon volumetric analysis (b) adjusted for differences in the density of the macerals or group macerals.
 2. By the use of the integration stage :
 - a. Analysis by microlithotypes - vitrit, clarit, durit, fusit, mineral matter (and pyrite), based upon results of several transects.
 - b. Analysis in terms of group macerals - vitrinite, exinite, inertinite, mineral matter (and pyrite), based upon results of several transects.
 - c. Analysis in terms of macerals - collinite, telinite, sporinite, cutinite, resinite, micrinite, sclerotinite, fusinite, semifusinite, pyrite, and other mineral matter.
 - d. Adjustment of volumetric to quantitative values.
 3. By the use of the "point-count" procedure:
 - a. Analysis in terms of microlithotypes.
 - b. Analysis in terms of group macerals.
 - c. Analysis in terms of macerals.
 - d. Adjustment of volumetric to quantitative values.
- D. Microscopic bed profile analysis using thin sections, in terms of coal constituents.
1. By the use of the ocular micrometer :
 - a. Bed profile analysis in terms of coal constituents: anthraxylon, translucent and opaque attritus, fusain, mineral matter, and pyrite. By graphic or mechanical methods.
 - b. Volumetric analysis derived from the graphic profile analysis or directly by mechanical methods.
 - c. Adjustment of volumetric to quantitative values.
 2. By use of the Whipple disc :
 - a. Volumetric measurement of quantity of anthraxylon (down to bands with a width of 14 microns or more) by block, bench, or bed.
 - b. Volumetric measurement of all opaque matter.
 - c. Volumetric measurement of amount of fusain (down to a width of 30 (39?) microns).
 - d. Determination of the amount of opaque matter by difference (b - c).
 - e. Volumetric determination of mineral matter other than pyrite.
 - f. Volumetric determination of amount of pyrite.
 - g. Volumetric determination of amount of translucent attritus by difference
(100% - (a + b + d + e + f))
 - h. Adjustment of volumetric to quantitative values based on density of constituents.
- E. Microscopic bed profiles and profile analyses using thin sections; in terms of coal components (phyterals).
1. Analysis by means of ocular micrometer.
 2. Analysis by means of Whipple disc.
 3. Analysis using the integration stage.
 4. Analysis by means of a "point-count" method.

- II. Petrographic analysis of broken coal (coal fragments or mounted and polished fragments of coal).
- A. Megascopic analysis of broken coal (coal particles):
1. Metallurgical method of analysis using relatively low magnification, classifying the coal particles piece by piece in terms of lithotypes (banded ingredients). For industrial applied purposes.
- B. Microscopic analysis of broken coal for coal bed profile determinations and check using polished surfaces.
1. Fragments oriented with respect to banding:
 - a. By use of ocular micrometer and graphic profile method with respect to 1) microlithotypes, 2) group macerals, and/or 3) macerals.
 - b. Analysis by means of integrating stage with respect to 1) microlithotypes, 2) group macerals, and/or 3) macerals.
 - c. Analysis by a "point-count" system (orientation of questionable significance).
 2. Fragments unoriented with respect to banding:
 - a. By use of ocular micrometer.
 - b. By use of integrating stage.
 - c. By a "point-count" system.
- C. Microscopic analysis of broken coal (polished surfaces); for industrial application in terms of microlithotypes.
1. Analysis of oriented particles:
 - a. By use of the integration stage in terms of the microlithotypes (vitrit, clarit, duro-clarit, claro-durit, durit, fusit, mineral matter, and pyrite).
 - b. Analysis by means of a "point-count" method with respect to the same categories of material.
 - c. Analysis by the use of an ocular micrometer and a laboratory counter.
 2. Analysis of unoriented fragments of broken coal:
 - a. By use of integration stage.
 - b. By a "point-count" method.
 - c. With the aid of an ocular micrometer and laboratory counter.
- D. Microscopic analysis of broken coal (polished surfaces); for industrial application in terms of group macerals.
1. Analysis of oriented fragments of broken coal:
 - a. By using the integration stage.
 - b. By using a "point-count" method.
 - c. By using an ocular micrometer and a laboratory counter.
 2. Analysis of unoriented fragments of broken coal:
 - a. By using the integration stage.
 - b. By using a "point-count" method.
 - c. By using the ocular micrometer.
- E. Microscopic analysis of broken coal (polished surfaces) for descriptive (and industrial?) purposes in terms of macerals.
1. Oriented sections:
 - a. By integration stage in terms of macerals.
 - b. By ocular micrometer, graphic profile, or laboratory counter.
 - c. By a "point-count" method.
 2. Unoriented sections:
 - a. Analysis by integration stage.
 - b. Analysis by ocular micrometer.
 - c. Analysis by "point-count" method.
- III. Petrographic analysis of broken coal using thin sections of mounted fragments.
- A. Microscopic analysis of broken coal for bed profile determinations and check, in terms of constituents and components (phyterals), or in terms of microlithotypes, group macerals, and/or macerals.

1. Oriented fragments:
 - a. By ocular micrometer.
 - b. By Whipple disc.
 - c. By integration stage.
 - d. By "point-count" method.
 2. Unoriented fragments by a, b, c, and d, as above.
- B. Microscopic analysis of broken coal (thin sections); for industrial application (components or phyterals)
1. Oriented fragments (Micrometric analysis), by a, b, c, and d, as above.
 2. Unoriented fragments, by a, b, c, and d, as above.

NOTE: The thin section technique is not yet amenable to the differentiation of the equivalent of the microlithotypes.

PURPOSE OF THE SUMMARY

The preceding outline of analytical procedures does not constitute an outline of the present report. It merely indicates the relative positions with respect to one another of the various operations and techniques that will be described. The remaining pages of part 1 concern the general characteristics of the American and European systems of anthracology with brief considerations of the practical value of anthracologic description and analysis and of the place of rank classification in coal petrography description and analysis.

ANTHRACOLOGIC DESCRIPTION VERSUS ANALYSIS

Considerable importance is placed in this report upon the value of bed profiles and profile analyses. The profile in itself constitutes a graphic description of a bed or bench of coal whereby the composition of the bed in petrographic symbols from layer to layer can be readily comprehended. Tabulated analyses may provide the same values numerically layer by layer or may be accumulated to provide average values for the entire bed or bench of coal. The ideas represented by the terms "profile" and "profile analysis" are so nearly identical that little reason for differentiation of the concepts exists. In the following pages the terms are used interchangeable unless the term analysis is definitely qualified as referring to an average value for the entire bed or bench.

AMERICAN VERSUS EUROPEAN SYSTEMS OF ANTHRACOLGY

Although there has been previous reference to the existence of two systems of anthracology in discussing the operations of coal petrography laboratories in North America, their essential characteristics and differences have not been described. Since the discussion of the petrologic analysis of coal can be understood only as the two systems of description and analysis are understood, some explanation is necessary.

The two types of anthracologic research techniques, although not equally suited for the diverse requirements of description and analysis, have developed more or less independently of one another, resulting in an American and a European technique and terminology. Both are useful in selecting a procedure most suitable for the particular purpose in mind. In general, parallel use of the two systems has not been the rule and the result has been the

development of a double but by no means a duplicate set of terms, each set being described or defined appropriately with respect to the technique to which it applies. The dissimilarity of the techniques largely precludes the possibility of exact duplication of terms so that some overlapping is inevitable, thereby providing one of the main sources of confusion.

COAL MICROSCOPY VERSUS COAL PETROGRAPHY

Had the fundamental concepts that actuated the study of coal on the two sides of the Atlantic been the same, agreement with respect to terms might readily have been accomplished. However, differences in methodology of description arose from, or were associated with, a diversity of concepts concerning the material studied. The American concept, for which Reinhardt Thiessen is mainly responsible, appears to be based upon a desire to provide an accurate description of the coal studied in terms of its initial organic components (3, 4).

At about the time that Thiessen was developing the thin section technique and the terminology associated with it on the basis of the microscopic aspects of coal, Dr. Marie C. Stopes, in England, was examining and describing coal as a rock-like petrologic substance which, irrespective of its initial botanical composition, was seen to consist of four kinds of coal material (5, 6, 7). These varieties of coal, called ingredients but later designated as rock types or lithotypes (8), made up the coal bed and, because of their percentage variability from coal bed to coal bed, produced differences other than those owing to differences in rank. These ingredients, or lithotypes, are the megascopically visible components of coal, that is, vitrain, clarain, durain, and fusain; this being the primary lithologic subdivision of coal material upon which the European classification has its rational basis.

In contrast to this lithologic or petrographic point of view, Thiessen regarded coal as an aggregate of various kinds of plant material in a coalified condition and, with certain exceptions, identifiable only with the aid of the microscope.

A difference, other than simply of method, is signified by the terminology of coal microscopy and coal petrography. Fundamentally, the coal microscopists represented by Thiessen and his close followers, as explained above, seem to have been chiefly concerned with the microscopically discoverable constituents of coal, such as plant organs or derivatives represented by coalified plant fossils. If Thiessen's choice of coal to study had been restricted to those coals of high rank from which thin sections are prepared only with difficulty, if at all, so that examination of polished surfaces would have been more convenient and more natural, his point of view as a botanist might still have been the same. That is, he might still have regarded coal with greatest interest as an aggregate of fossil plant material awaiting identification rather than as a rock substance.

Since the start made by Stopes in megascopic petrography by her differentiation of the principle ingredients or lithotypes, there has been a steady development of technique and terminology along petrographic lines. The application of the microscope to the study of the lithotypes, with constantly improving technique, particularly the demonstration of the value of oil immersion objectives by E. Stach (9, 10), made possible a more discriminating study of the macerals, those components of the lithotypes which Stopes (7) regarded as analogous to rocks. The more discriminating observation made possible by these improved techniques resulted in a more general recognition in Europe of the presence of botanical entities such as spores, cuticles, fungal bodies, etc., and to this extent tended somewhat to close the gap between the two systems of anthracology. However, the petrographic concepts were not materially modified, except possibly when observation was made at magnifications generally higher than those used in routine applied coal petrography. It was in this latter field that most of the investigations and routine work in anthracology was done. Nevertheless, the European petrographers have, from time to time, demonstrated the adequacy of polished surface technique as a source of botanical information, particularly in the case of opaque substances (11, 12) and spores (13).

Actuated by a desire for a system of coal petrology having a usefulness in applied science somewhat

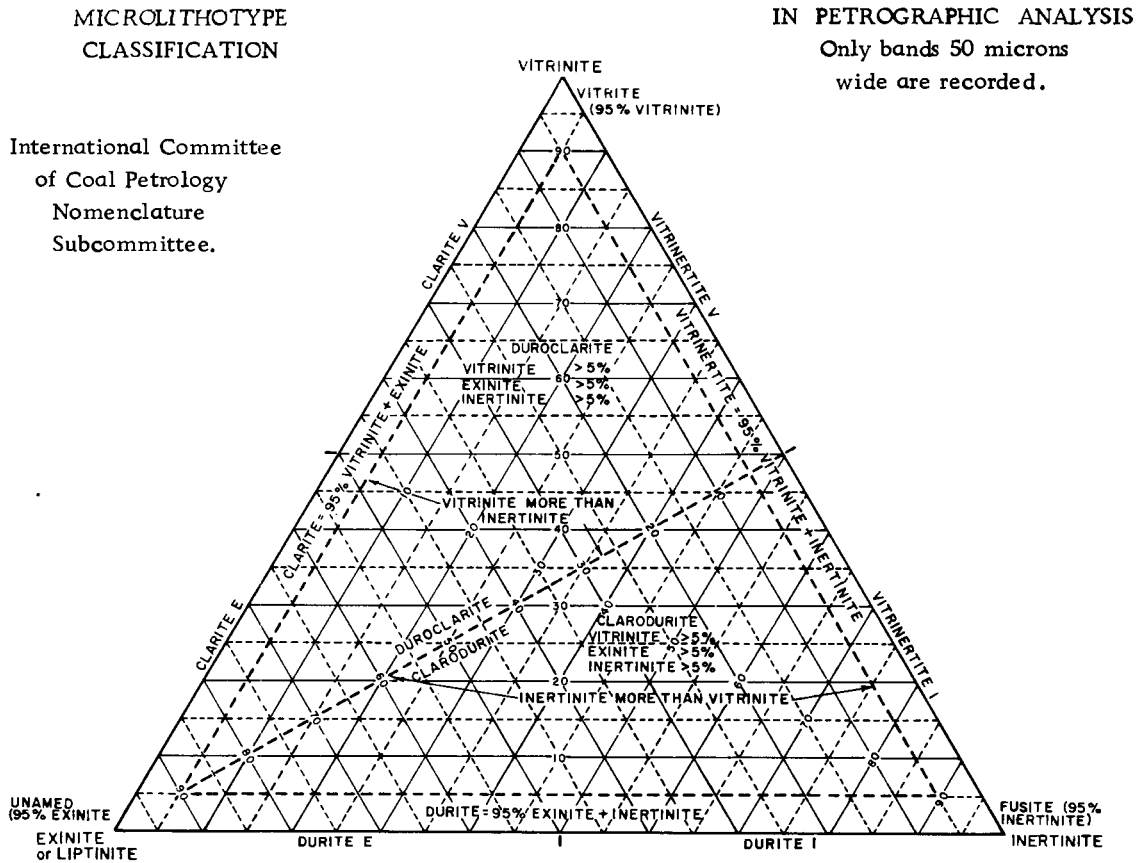


Fig. 1 - Triangular diagram showing the relation of the group macerals in microlithotype associations according to definitions in the preliminary (Essen, 1957) edition of the International Glossary of Coal Petrology. Note that since all banded coal must have five per cent anthraxylon, durite according to the American classification, therefore, belongs in the nonbanded canneloid type of coal, with humic cannel toward the exinite corner and splint-cannel toward the inertinite corner.

comparable to that of conventional rock petrology, the western European anthracologists have developed a fairly complete system of nomenclature and classification, in accordance with their practice, which has substantially the form shown in figure 1.

It may be noted in table 2 that the names of the lithotypes end in "-ain," those of the microlithotypes in "-ite," and those of the macerals in "-inite" (15).

The pattern of relationship of constituents and components in American coal microscopy has recently been explained by J. M. Schopf (16), as summarized in table 2.

The botanical entities, which in table 2 have been designated "components," have been called "phyterals" by the present writer (18). The use of this term overcomes the objectionable confusion that exists in the use of

Table 1

General Summary of the Petrographic Classification of Bituminous Coal Material
as Developed in Western Europe

I. Megascopic components or constituents of coal.

A. Lithotypes or banded ingredients: vitrain, clarain, durain, fusain, and mineral matter.

II. Microscopically identified components of the lithotypes.

A. Microlithotypes or "natural associations of macerals" (14), which are represented by vitrite, clarite, vitrinertite, duro-clarite, claro-durite, durite, and fusite. The composition of the microlithotypes in relation to the maceral associations is shown graphically in figure 1.*

B. Macerals, the fundamental units of which are :

1. Group macerals, consisting of macerals of general similarity in composition designated as vitrinite, exinite (or liptinite), and inertinite.

2. Individual macerals, consisting of coal entities derived from or formed by the individual botanical entities of the coal, to be regarded as coal material and not simply as plant fossils: collinite, telinite, sporinite, cutinite, alginite, resinite, micrinite, sclerotinite, semifusinite, and fusinite. (Analysis of coal in terms of the macerals appears necessary only for very discriminating description. In general practice differentiation is made on the basis of the group macerals.)

* What is designated as durite in the European classification, and as shown in figure 1, does not fall into the category of banded coal as recognized in American type classification. This is because it does not contain more than five per cent vitrinite (95 per cent exinite plus inertinite). Vitrinite includes both anthraxylon and collinite (humic degradation matter of the translucent attritus). Durite, not being a banded coal by definition set up by the U. S. Bureau of Mines (see reference 23, p. 28, 537), does not represent splint coal but is canneloid, the high exinite durite being humic cannel and the high inertinite durite being splint cannel. There is no means at present of determining the exact position of the boundary between banded and unbanded coals in the microlithotype classification (figure 1) or of the boundary between the splint-type of banded coals and bright banded coals.

Table 2

Relationship of Coal Constituents and Coal Components in the
Thiessen System of Coal Microscopy
(After J. M. Schopf)

CONSTITUENTS	COMPONENTS	
Anthraxylon	1. Megascopic anthraxylon (17): greater than 0.5 mm 2. Attrital anthraxylon: 0.5 mm to 14 microns	
Translucent Attritus	3. Translucent humic degradation matter (THDM): 14 to 3 microns (subanthraxylon.) 4. Humic matter: less than 3 microns. 5. "Light brown" matter	
	6. "Red" resinous matter. 7. Spore coats. 8. Cuticles. 9. Amorphous wax. 10. Suberin. 11. "Yellow" resinous matter.	Cereous or waxy matter
	12. Fungal matter.	
Opaque Attritus	13. "Dark brown" matter. 14. Granular opaque matter. 15. Amorphous opaque matter. 16. Fusinized opaque matter (less than 30 microns).	
Petrologic Fusain (17)	17. "Dark" semi-fusain: \pm 30 microns. 18. Attrital fusain: 30 microns to 1/2 mm. 19. Megascopic fusain: more than 1/2 mm.	
Visible Mineral Matter	20. Pyritic minerals. 21. Clay minerals 22. Others	

the words "component" and "constituent" in attempting to apply them arbitrarily to the larger and smaller units respectively of the coal structure. These words have been long used without restricted application; hence, it is quite improbable that their meanings can be successfully narrowed in the field of anthracology to apply only in the manner suggested by Schopf.

TERMINOLOGY CORRELATIONS PROPOSED BY HACQUEBARD

Efforts to clarify the relationship between European and American anthracologic nomenclature and classification are represented by contributions of P. A. Hacquebard (19, 20), one of the latest of which is represented by table 3 (21).

Table 3

Correlation of European and American Terminology of Coal Petrology *

Percentage of Vitrinite	Germany E. Stach (22) 1935	Sydney, N. S. Hacquebard	Pittsburgh Thiessen; Parks (23), 1948	Percentage of Opaque Matter
100 - 96	Vitrit	Vitrain	Bright Coal	Less Than 20 %
95 - 51	Humodurit	Clarain		
50 - 11	Eudurit	Claro-durain	Dull Coal	From 20 - 30 %
		Durain		More Than 30 %
10 - 0	Opakdurit		Splint	

Hacquebard differentiated variations of brightness of banded coal after the manner indicated in the following table (table 4) (24) :

Table 4

General Varieties of Banded Coal as Proposed by Hacquebard

General varieties of banded coal	Critical amounts of pure bright coal ingredients (vitrain, clarain, and fusain)
Bright coal	100 to 81 %
Semi-bright coal	80 to 61 %
Intermediate coal	60 to 41 %
Semi-dull coal	40 to 21 %
Dull coal	20 to 0 %

* Fusain is omitted in this table because no difference of opinion exists regarding this ingredient. Transitions between vitrain and fusain are designated as semi-fusain, as was suggested at the Heerlen Conference.

THE MICROSCOPIC APPROACH OF AMERICAN ANTHRACOLOGY

The American school of anthracologists approaches the description and analysis of coal from a microscopic point of view (25). There is actually no systematic American megascopic terminology. Therefore, American anthracologists have made considerable use of European megascopic terms. The Continental school of coal petrologists proceed from the megascopic point of view, with refinements in microscopic definition. Actually, the fundamental microscopic entities are essentially the same, whether thin sections and transmitted light or polished surfaces and reflected light (vertical illumination) are used. When polished thin sections are employed, so that both transmitted light and vertical illumination can be used for the same specimen, differences in identification and terminology are largely resolved (26, 27).

OCCASIONAL USE OF EUROPEAN TERMINOLOGY IN AMERICA

It has been previously noted that the use of the Stopes terminology, that is, the European terminology, has not been entirely rejected in North America. The Stopes' names for the megascopic ingredients, or lithotypes, largely because of the need for megascopic terms, have had considerable use. They were employed in reports of the Illinois State Geological Survey as early as 1934 (28), and since then have been used more or less by that and other state and federal bureaus and university laboratories (see list p. 3) along with the Thiessen system, the latter being used mainly for microscopic description. The European system has been more consistently used by the Geological Survey of Canada in investigations carried under the direction of P. A. Hacquebard than in any of the coal laboratories in the United States.

The occasional use of European terminology in the United States along with the more common use of the Thiessen terminology has not resolved all the difficulties arising from the fundamentally different points of view of the two systems. One of the difficulties resides in the fact that American terminology has remained essentially static for about two decades, whereas European anthracologists, particularly those on the Continent, have been endeavoring to establish a system of coal petrology and terminology which will have international scope. The result has been the recent introduction of a number of concepts and corresponding terms designed to aid differentiation, description, and analysis in the field of applied petrology in its various aspects. During the past ten years, new categories of classification have been proposed which have increased the difficulty of correlating American and European vocabularies of anthracology. Should the concepts represented by these new terms prove to have practical value, the use of European terminology in this country will be substantially encouraged.

SELECTION OF THE SYSTEM OF DESCRIPTION AND ANALYSIS

For the wise choice of the method to be employed in anthracologic analysis and description it is essential to have some knowledge of the nature of and the results obtained by each of the two prevailing systems of coal description and analysis and, also, to have a clear understanding of the purposes for which the information is to be employed. In the preceding pages the general character, scope, and objectives of the two prevailing systems of anthracologic analysis and description are indicated. Similarities and differences have been pointed out, the latter being largely owing to the fact that the two systems are based upon fundamentally different concepts in regard to the nature of the coal material. The uses made of the two systems of anthracology in coal description and analysis are explained in detail in Parts 2 and 3. It may be pointed out here that in contrast to analytical objectives, the main purpose of the many bed profiles of American coal made by Thiessen and others of the U. S. Bureau of Mines seems to have been mainly descriptive (29, 30).

IMPORTANCE OF RANK VARIATIONS

Variation in rank is one of the critical considerations in the description and analysis of coal. As long as coals of approximately the same rank are under consideration, petrographic differences are only those which in American nomenclature would be regarded as differences in type; that is, differences resulting from variations in the nature of the initial botanical material from which the coal was produced and the difference in the changes to which this material was subjected in the coal swamp before final burial and the start of the coalification processes. In the case involving the preparation of a bed profile, the rank of a coal is usually determined by means of a channel sample of the bed collected at the same general locality. On the basis of such information concerning the rank of coal beds for which petrographic profiles are made, it is then possible to compare the microscopic appearance of the same types of components from rank to rank.

Although coal rank is commonly determined by chemical procedures, microscopic methods for evaluating relative rank are in use. These consist of measuring reflectivity of selected portions of the coal under vertical illumination (31), the reflectivity of vitrain being regarded as the standard basis of comparison. The idea of a step-wise progress in the amount of reflectance with advancing rank, favored by Seyler, seems to be giving way to a progressive advance without steps (32, 33). In determinations made by McCartney (32), reflectance per cent of coal (vitrain) measured against the reflectance of sphalerite varied from between 0.25 and 0.5 per cent and about 3.0 per cent for coals varying in rank from sub-bituminous to anthracite. These variances were progressive, but only roughly so, with respect to rank as this is determined by the criteria for rank differentiation of coal set up by the American Society for Testing Materials. In either case, actual boundaries separating coals of different rank are largely arbitrary and based primarily upon practice and convenience.

A somewhat similar relative evaluation of rank can be made on the basis of the degree of polarization of incident light reflected from vitrain (34, 35, 36, 37). Provided suitable instruments are available, the former determination (reflectivity) is the easier and more commonly made.

Although, as noted above, the reflectance of vitrinite (collinite, telinite, or anthraxylon) is the basis for rank identification, it does not provide an absolute basis for rank determination except as data have been assembled to indicate by table or graph the relation between reflectivity and rank as chemically determined (38, 39).

Stach has shown that reflectivity procedures can be similarly applied to spore exines which also reveal a progress with rank similar to but not the same as that shown by vitrain (40, 41). Dahme and Mackowsky (42) join with McCartney in failing to find a step-wise progress in reflectivity with advancing rank (42).

The degree of reflectance of all components or macerals varies with rank but not uniformly; for all components it increases up to a point of close similarity. Hence, differentiation of macerals on the basis of difference in reflectance becomes increasingly difficult as the rank of the coal increases. This is another way of saying that with increasing rank the individual macerals become increasingly difficult to differentiate on polished surfaces. For this reason etching is often used to aid in such differentiation.

Translucency of thin sections of the same thickness tends to decrease as the rank of the coal increases, thin sections of anthracite being essentially opaque. Indeed, it takes a high technical skill to make satisfactory thin sections of low volatile coal with less than 15-18 per cent of volatile matter. Opacity of thin sections and reflectivity of polished surfaces are of the same general significance with respect to variation in rank. If a sample of broken coal from two beds of definitely different rank is under observation and suitable equipment is available, it is possible not only to identify the various petrographic components but also to separate granules of the higher from those of the lower rank coal.

Although coal rank is of great importance in determining the probable behavior of a coal in utilization, it is only in the case of coals of very high rank, such as the low volatile bituminous coals and anthracites, that little

or no differences seem to be produced by variations in the petrographic composition of coal. Even this statement must be accepted with some caution because of the lack of thorough investigation of the petrology of these high rank coals. Type differences, however, are of much significance in bituminous coals of medium and low rank, particularly the latter.

SUMMARY OF INTRODUCTION

It has been the purpose of the Introduction to acquaint the reader with the nature of the science of anthracology, the location and character of the laboratories in which anthracology is practiced, and the general character of the subject matter with which it is concerned. The general characteristics of the American and European systems of anthracology are indicated and classification and terminologies of the two systems are outlined. A table showing the general procedure of petrographic description and analysis of coal by the two systems is presented. The difficulties that exist because of the double, but not duplicate, terminologies are suggested. An explanation is made at the close of the relation of rank variation to coal description and analysis.

PART 2

ANALYTICAL PROCEDURES IN COAL BED DESCRIPTION

Part 2 of this report is concerned with the procedures of anthracologic coal bed analysis, which is of two general kinds. The first procedure is for the purposes of description and classification of coal material in the order in which it makes up a bed, bench, or selected block. The section is a discussion of procedures of microscopic analysis in classification and modal analysis of the coal in terms of volume or weight per cent of the components or constituents of coal irrespective of manner of occurrence (43).

The analytical description of the coal composing all or part of a bed or bench of a coal bed is commonly referred to as a profile analysis or description. Such a profile is commonly prepared in two ways. By one method the profile is compiled proportionally in steps, which may or may not be of uniform thickness. The other method is a continuous record representing the order and thickness of components. Both methods depend upon measurement along a vertical transect line or a very narrow ribbon; in either case the data are most commonly and conveniently recorded graphically, although they may be tabulated.

Such graphic profiles may serve as the basis for the modal analysis of the bed or bench expressed in terms of "relative amounts of the components actually present."

Analysis of what is designated as "broken coal" (see part 3) is not readily amenable to graphic representation and constitutes, in general, a modal analysis. The data are usually assembled in a tabulated form with the assistance of a laboratory counter for summarizing volumetric data as represented by transects of the mounted specimen.

BED PROFILES AND MODAL ANALYSES BASED UPON BED PROFILES

MEGASCOPIIC BED PROFILES

As explained above, a graphic profile provides a picture or symbolic representation of a coal bed or a portion of a coal bed. A simple form of profile is a photograph of a column or core of a bed, preferably after the surface has been ground even and polished so as to show clearly the various megascopic ingredients or lithotypes. Although such a photograph may clearly reproduce the appearance of the coal bed at natural scale, it provides no petrologic interpretation of the appearance in terms of lithotypes, mineral matter, etc. Such explanation can of course be appended to the photograph, or, preferably, it can be supplied by drafting a full scale graphic profile in which the identity of the various lithotypes is indicated by colors or patterns (fig. 2). In the case of a two-inch diamond drill core or a column cut to similar width, the profile can be conveniently represented on a strip of cross section paper (10 divisions per inch) having the length of the coal column and about 4 inches in width so as to leave a convenient margin on each side of the profile. On such a strip it is possible to represent with colors or symbols the pattern of the structure produced by the banded arrangement of the lithotypes.

Although it may be possible with a sharp pencil to show micro-vitrain bands less than one-half millimeter wide, bands of this width or less should, in general, be regarded as part of the clarain, contributing to the luster

of the clarain. Considerable uncertainty may be experienced in differentiating clarain and durain forming striated bands in the coal bed, because no definite boundaries have been established separating various degrees of luster. Since the presence of micro-vitrain is the main source of the bright luster, it is here proposed that distinctions might well be based upon criteria of frequency of occurrence applied in coal petrology (44), namely:

rare - where they occur in proportions of less than 5 per cent,

common - where they occur in proportions between 5 and 10 per cent,

very common - where they occur in proportions between 10 and 30 per cent,

abundant - where they occur in proportions between 30 and 60 per cent,

dominant - where they exceed 60 per cent.

On the basis of these categories of frequency it is proposed that the term vitrain be restricted in application to bright banded coal containing not more than 5 per cent of megascopically dull coal material, not including known mineral matter. Only bands 1/2 mm. or more in width will be regarded as vitrain. Thinner bands, or microvitrain, are included in the clarain or durain.

It is also proposed that the term clarain or bright striated coal be restricted to coal in which micro-vitrain or any other bright constituent makes up from 30 to 95 per cent of the coal; that clarain in which the micro-vitrain is dominant (60 to 95 per cent) be called vitro-clarain or bright clarain; and that part in which the micro-vitrain is abundant (30 to 60 per cent) be called duro-clarain or dull clarain.

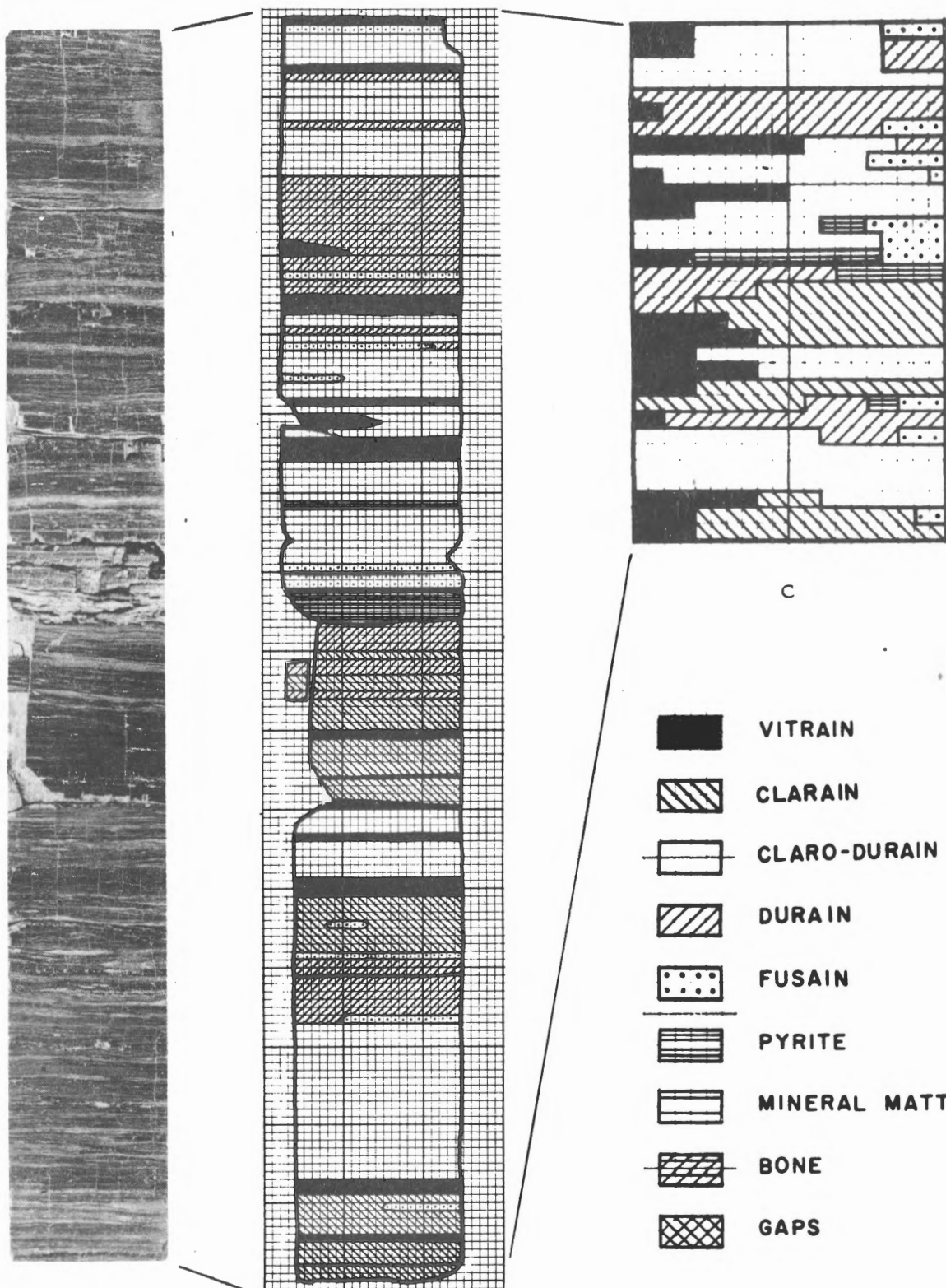
It is finally proposed that for the purposes of megascopic classification dull coal or durain will be regarded as that part of the coal in which micro-vitrain or any other bright ingredient appears to make up less than 30 per cent of the coal viewed megascopically (see also p. 22).

The degree to which these proposals may be of practical value remains to be determined, but it is possible that they will provide more satisfactory differentiation than is provided by the indefinite terms "bright" and "dull" without more specific limitations.

On the basis of the foregoing proposals and other obvious possibilities of differentiation of the megascopic structures of the coal, megascopic bed profiles reproduced in interpretive symbols should include recognition of at least the following materials megascopically discernible in the polished block or core of the coal bed: vitrain, vitro-clarain, duro-clarain, durain, fusain (\neq 1/2 mm), pyrite, and other mineral matter (clay, calcite - mainly in vertical facings, kaolinite - mainly in vertical facings, siderite, etc.). Such full scale profiles are usually too long for reproduction but are very useful in the laboratory if a considerable number of beds or sections of the same

Fig. 2 - Photograph (A) and megascopic graphic profile (B) both one-half natural size of a 16-inch section of a column of Meigs Creek (No. 9) coal bed (core No. 597-A) of Ohio. The summary graphic profile (C) is a proportional step profile showing the composition of the coal in one-half-inch steps, based upon measurements along a vertical transect in the middle of profile (B).



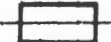






Note: Each 1/10-inch horizontal strip (C), divided into 20 parts by the vertical ruling represents a total of 100 per cent for that particular 1/2 inch. Since the vertical line of the transect on (B) is divided into only five parts, for each 1/2-inch of coal (actually shown as only 1/4 inch on B), a constituent with a width of only one unit will be represented by 1/5th the length of a horizontal strip in (C), that is by four of the 1/10-inch squares. (The first two upper bars in (C) represent the two upper half-inches (here 1/4-inch) in (B)). The constituents are always shown in the same order in each horizontal strip representing 1/2-inch of coal. (From reference 1: Cady and Smith, 1955, fig. 18, p. 40.)



A

B

C

-  VITRAIN
-  CLARAIN
-  CLARO-DURAIN
-  DURAIN
-  FUSAIN
-  PYRITE
-  MINERAL MATTER
-  BONE
-  GAPS

coal bed are under examination. They provide convenient and fairly precise information about the structure of the bed; they also provide a means of selecting those portions of the column or core which should be examined with more precise technique, particularly in the case of the duller portions of the bed; they are useful in comparing the general character of the petrology of bed with bed; these profiles also indicate that the column or core has received careful preliminary examination; and finally they are much more convenient for reference than the original bulky core or column since they can be conveniently filed in a relatively small space. As a means of partially overcoming the difficulties in publication of the natural size graphic profiles, summary profiles can be used, as will be explained. These summary profiles actually consist of proportional step profiles.

Full scale, symbolic, megascopic bed profiles based mainly on lithotypes have been made of cores or columns of numerous beds or of individual beds in various localities for coal beds of Illinois, Ohio, Kentucky, and Indiana. These profiles are on file in the laboratories of the Illinois and Ohio State Geological Surveys, in the personal files of the author, or in the files of the Reynolds Mining Company, Little Rock, Arkansas. The author knows of no other similar bed profiles available.

PROPORTIONAL BED PROFILE BY STEPS

The bed profile by steps is in a sense a modal analysis by steps of various lengths. In other words, the coal bed is divided into units long or short, even or uneven, as the case may be, and the proportions of the various components in the selected units are tabulated unit by unit, or shown graphically. The graphic proportional bed profile has been very widely used both on the basis of American classification and terminology and on the basis of European classification and terminology. In the graphic log, strips may be used similar to those employed in making the full scale symbolic bed profile just described. In this case, the 1/10-inch horizontal bands may represent any actual distance on the core or column that is preferred, such as 1/2-inch, 1 centimeter, 5 centimeters, or even as little as 1 millimeter.

It is obvious that length of the bed profile by steps will depend upon the scale of representation. In the case where 1/10-inch on the proportional bed profile represents 1/2-inch on the core or full scale bed profile, the proportional profile will be 1/5th the length of the original column or core. On the other hand, if the proportional profile is so constructed that 1/10-inch represents only 1 mm., the proportional profile will be three times the length of the original core or column.

When it is preferred to indicate modal analysis in terms of benches or selected proportions of the bed, the length of the proportional step profile may be relatively short, but with the thickness of each bench or block indicated in correct proportion (see fig. 5). This is a very common procedure in America. Although only a single reference is given (45) others might readily have been supplied.

Proportional bed profiles by steps can be prepared for graphic representation by ways other than using a single strip with the various components of a single step unit completely filling the unit strip, that is comprising 100 per cent of the horizontal strip. Proportions may also be represented by having a vertical column for each substance recorded indicated in terms of per cent. This method is the one favored by the U. S. Bureau of Mines in reports on the carbonization properties of American coals carried on in cooperation with the American Gas Association (see fig. 11 and reference 29). In this particular case the profile was based upon microscopic not megascopic observation, but the method could be employed for a megascopic graphic record.

Summary Graphic Profiles

The summary graphic profile was devised as a method of representing the modal analysis of a coal bed or

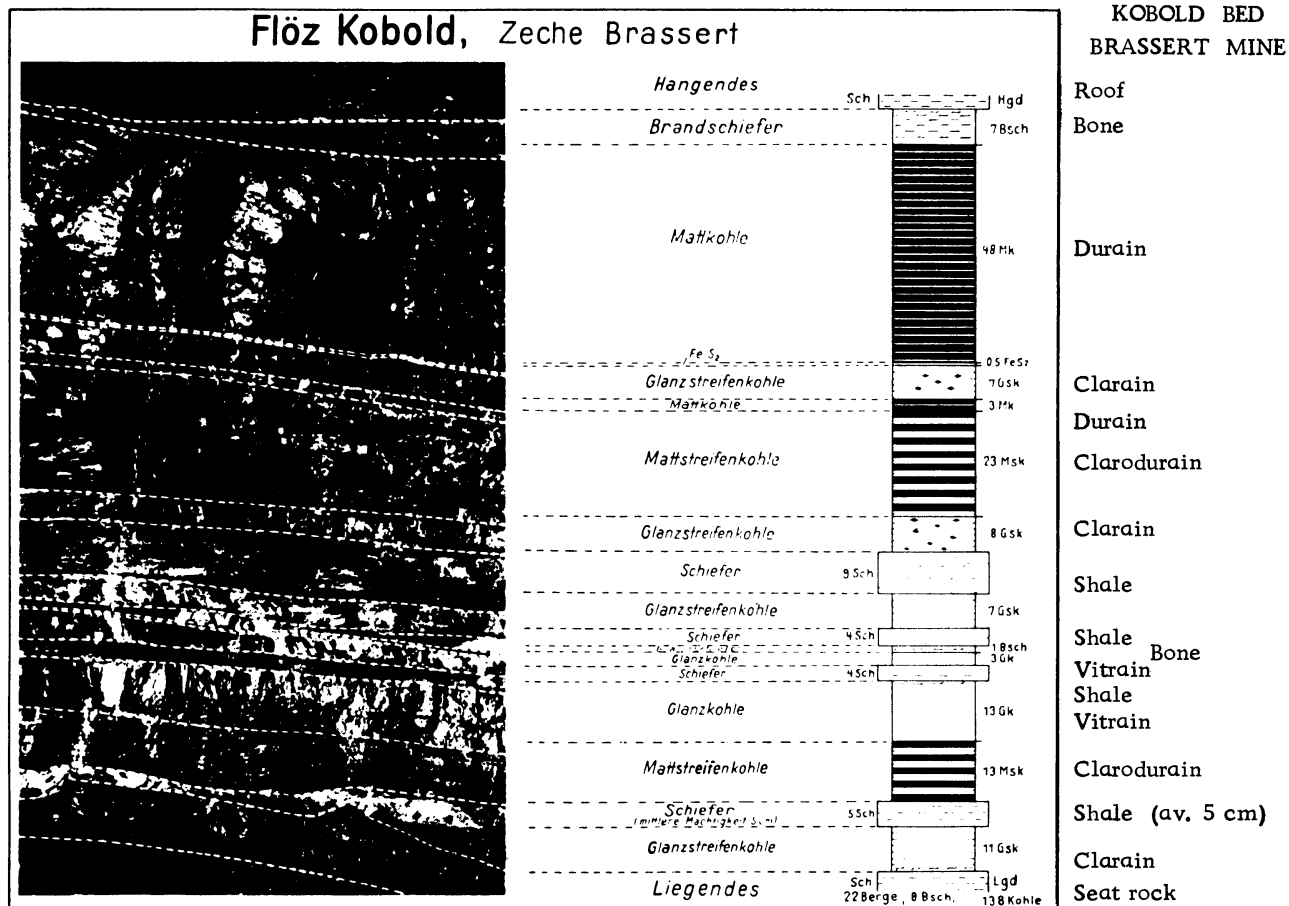


Abbildung 217: Makropetrographischer Flözschnitt eines Gasflammkohlenflözes.

Fig. 3 - Method of preparing a megascopic bed profile as applied to a gas-flame coal bed of the Ruhr Basin. (From reference 48: Atlas für angewandte Steinkohlenpetrographie, 1951, fig. 217, p. 262, with English equivalents added.)

bench by steps of 1/2-inch, as based either on actual measurement of the megascopic lithotypes and mineral matter along a vertical line traverse or by using the full scale symbolic profile of the bed described on the preceding page. The usual procedure has been to regard a single 1/10-inch horizontal strip across the 2-inch wide column of cross section paper as representing the composition of the coal for each 1/2-inch of the full scale symbolic profile. Since each half-inch is divided into five parts at 1/10-inch intervals it is fairly easy to estimate with fair accuracy the proportion of the 1/2-inch traverse crossed by the various lithotypes of mineral matter. These proportions can then be recorded graphically on the appropriate 1/10-inch strip of the summary profile, either in color or by a pattern. The total values recorded should be 100 per cent, so that the horizontal strip is completely filled (see fig. 2).

It may be desirable to arrange the symbols in such a way that the brighter lithotypes are at the left side of the diagram; that is, in the order vitrain, vitro-clarain, duro-clarain, durain, fusain, mineral matter, and pyrite, but other possibilities of systematic arrangement are recognized (see p. 58). Omissions due to cracks or loss of part of the core or column should be suitably recorded so that there will be a 100 per cent record for each unit step. Summary descriptions of a group of four Ohio coals appears in a recent report of the Ohio Division of Geological Survey (see fig. 12 and reference 46).

Pseudo-Megascopic Profiles at Low Magnification

Proportional, step-wise, megascopic description based upon the appearance, mainly the luster, of the polished coal as observed with the unaided eye can be extended to include examination under the low power magnification possible with the Greenough-type binocular microscope, using oblique illumination. In the dark field, thus observed, the coal ingredients or lithotypes have the same general appearance as when observed with the naked eye. By using low magnification, it is easier to differentiate micro-vitrain and vitrain at a minimum threshold of 1/2 mm. for the vitrain. It is also somewhat easier to estimate the amount of micro-vitrain in clarain or durain. Such a profile is based upon a vertical traverse lengthwise of the column or core and may be recorded for steps as small as 1 mm. by using an ocular micrometer or some other method of measuring the traverse. Such a profile may be plotted on a strip of cross section paper with the grid spaced 10 or 20 divisions per inch as preferred. With a spacing of 10 divisions per inch the profile will be about three times the actual length of the core and usually will require some sort of summarization for publication purposes. Profiles of this general type have recently been used by Schapiro in describing columns of the Lower Kittanning coal bed of West Virginia (47).

MEGASCOPIC COAL BED PROFILES OF THE EUROPEAN TYPE

What are designated as macropetrographic profiles (fig. 3) have been standardized in Germany (48, 49) for several years, as well as the symbols and abbreviations to accompany them. The method of preparing the profiles is indicated in the accompanying illustration (fig. 3) in which the equivalent terminology for the lithotypes is shown in German and English. In this case the profile consists of a narrow strip representing the composition of the coal along a vertical transect, or an average transect. In the illustration (fig. 3), the total thickness represented is about 6 feet 5 inches (196.5 cm.), the total thickness of the coal part of the column being about 5 feet 5 inches (138 cm.). Standard profiles are compiled in 5 centimeter units on a scale 1/10 of the original so that an original thickness of 5 centimeters of the coal is represented by 0.5 cm. (5 mm.) on the graphic profile. This is twice the reduction used in preparing summary profiles from the symbolic megascopic profiles first described on page 17. It is no doubt obvious that if the reduction in scale from the coal to the graphic profile is in a ratio of 10 to 1, it will be impossible to record bands much thinner than 1/2 cm. Hence, it would be impossible to differentiate vitrain and microvitrain at a minimum threshold for vitrain of 1/2 mm. To make possible a graphic record, bands must be classified in accordance with the standard megascopic terminology in units at least as thick as 1 cm. Examples of macroscopic petrographic coal bed profiles are fairly frequent in foreign coal petrography literature (see fig. 4 and references 50, 51, 52).

MEGASCOPIC PROPORTIONAL PROFILES BY BENCHES

Instead of or in addition to proportional profiles in steps of even length such as 1 cm. or 1/2-inch, etc., some coal petrography laboratories present megascopic graphic profiles in longer and usually uneven steps whereby the bed is subdivided into what are regarded, upon inspection or for other reasons, as natural subdivision of the particular coal bed. The results of megascopic modal petrographic analysis are then presented on a diagram (fig. 5) which lengthwise represents the full thickness of the bed but which is subdivided horizontally into successive sections proportionate to the height of the successive individual benches. The diagram is usually 2 inches (6 cm.) wide and is marked in steps of 10 per cent from 0 to 100 per cent from left to right. It is then possible to indicate by patterns the proportion of each of the petrographic constituents, mineral matter, bone, etc., in each bench. It is doubtful that such a bench profile would be prepared except as data are tabulated bench by bench. The resulting table would supply the critical data for graphic representation. Such bench profiles have some value as graphical representation of the petrographic variations from bench to bench. They are, of course, not a

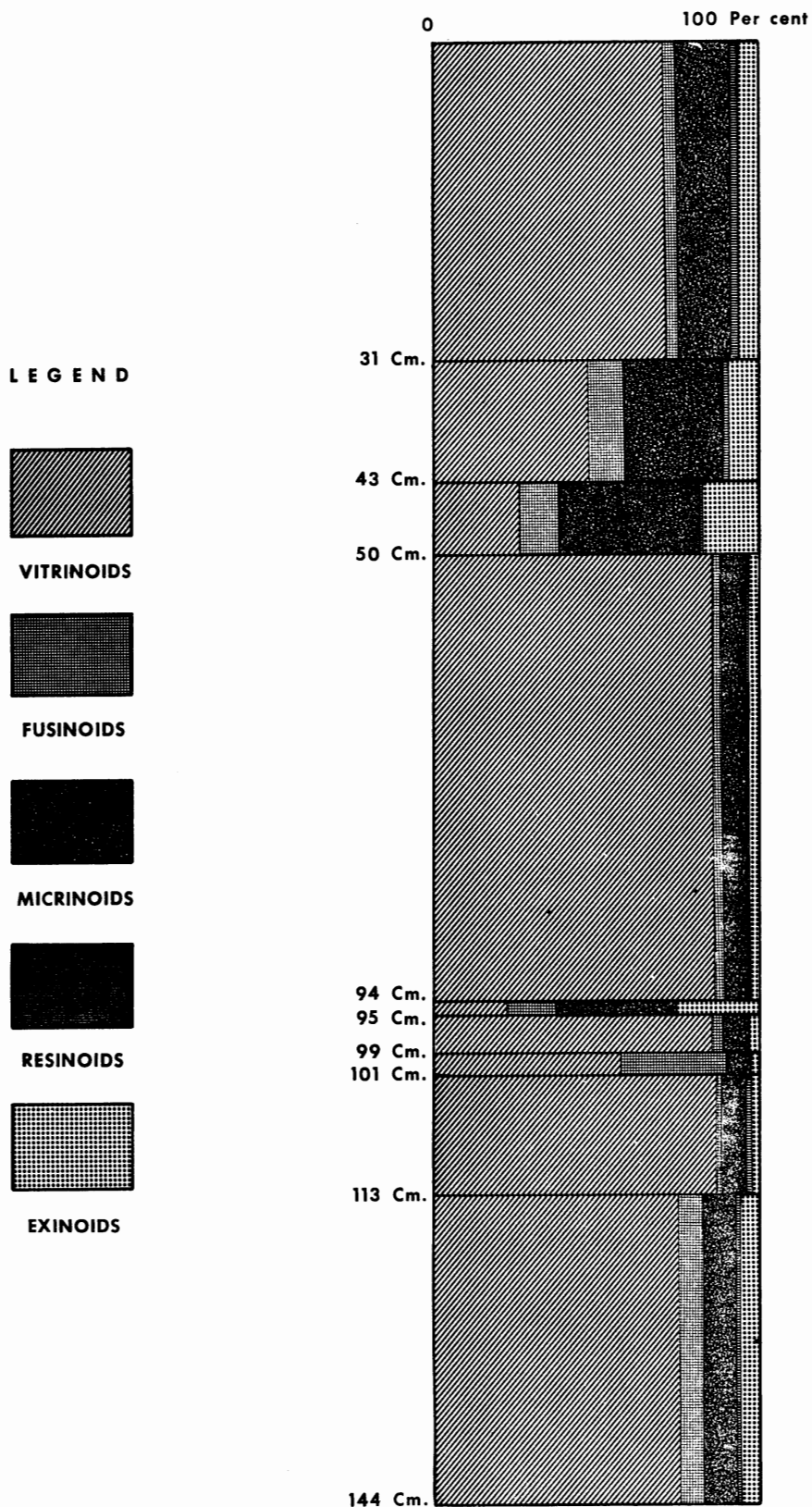


Fig. 5 - Example of a bench type proportional bed profile based on group macerals. "C" bed, Lynch, Kentucky. Supplied by the Organic Sediments Laboratory, Pennsylvania State University. Group macerals are those recognized at this laboratory.

satisfactory means of determining the proportion of the individual lithotypes in the coal as a whole, since proportions shown are simply in terms of the individual bench and no two benches may be of the same size. There is always some question as to whether the particular bench subdivision selected is valid. Other subdivisions might give equally impressive differences in pattern.

Use of the megascopic proportional profiles by benches has been quite general in America (53) and abroad (54).

COMBINED MEGASCOPIK AND MICROSCOPIC BED PROFILES

Although the megascopic graphic profile in terms of ingredients or lithotypes provides a picture of the major structural aspects of a coal bed, it is realized that there are certain features or components of the lithotypes which, if recorded, add considerably to the value of a profile. These are such components as resins, cuticles, and spores particularly, which, however, are not visible without magnification or other special treatment of the coal. With such information available the lithotypes can be described with greater precision. The Geologisch Bureau at Heerlen (Netherlands) has, therefore, prepared bed profiles after a somewhat different plan than is generally followed (55).

Roos describes the procedure as follows: "In the graphs obtained by this method the length of the seam is given natural size Text figure 1 (fig. 6) gives an example of the results obtained by this method. Bands of durain are represented by oblique hatching of the whole of the space between the two parallel lines (sides of the column) 2 cm. apart. Pure vitrain (telain) is represented by absence of any hatching; the quantity of durain in clarain is shown by the breadth of the hatched part of the graph; clarain rich in durain is plotted over nearly the whole width of the graph, while with decreasing quantity of durain the limit of the hatching shifts to the left.

" . . . the quantity of durain in clarain is only approximated.

"In the same way the amount of fusain and vitrofusain is estimated. Fusain is represented by black stripes, the thickness of which is that of the fusain bands and lenses. Vitrofusain* and telofusain* are indicated by black dashes and points respectively. Cannel-like coals are hatched in two directions, while shaly impurities are indicated by vertical hatching. The amount of these impurities is indicated by the number of these vertical lines.

"To the right of the graphs the presence of spores, cuticles and resinous matter is recorded: spores by circlets, cuticles by horizontal lines and resins by crosses. (Note: these components are determinable only with the aid of a microscope, G.H.C.) . The number of these indications agrees with the amount of these bodies: one circlet means: a few spores; two circlets: rather many spores; three circlets: a great amount of spores. The quantities of cuticles and resin are indicated in the same way by the number of lines and crosses. Finely granular durain (also microscopic, G.H.C.) is indicated by a number of small dots; the presence of mineral constituents by their chemical formula.

"When spores, resin, mineral matter, etc. are present over the whole length of a preparation, this is indicated by the mentioned signature immediately to the right of the graph in vertical direction.

"In our opinion the results obtained by our method of representing the constitution of a seam give a very good picture of its composition. The elimination of the influence of small variations by our method of estimation brings out the really important variations in the general constitution and accentuates the zones rich in durain and those rich in vitrain thereby making it possible to compare the graphs of different samples of the same seam and also samples of different seams" (56).

* Equivalent of semifusain.

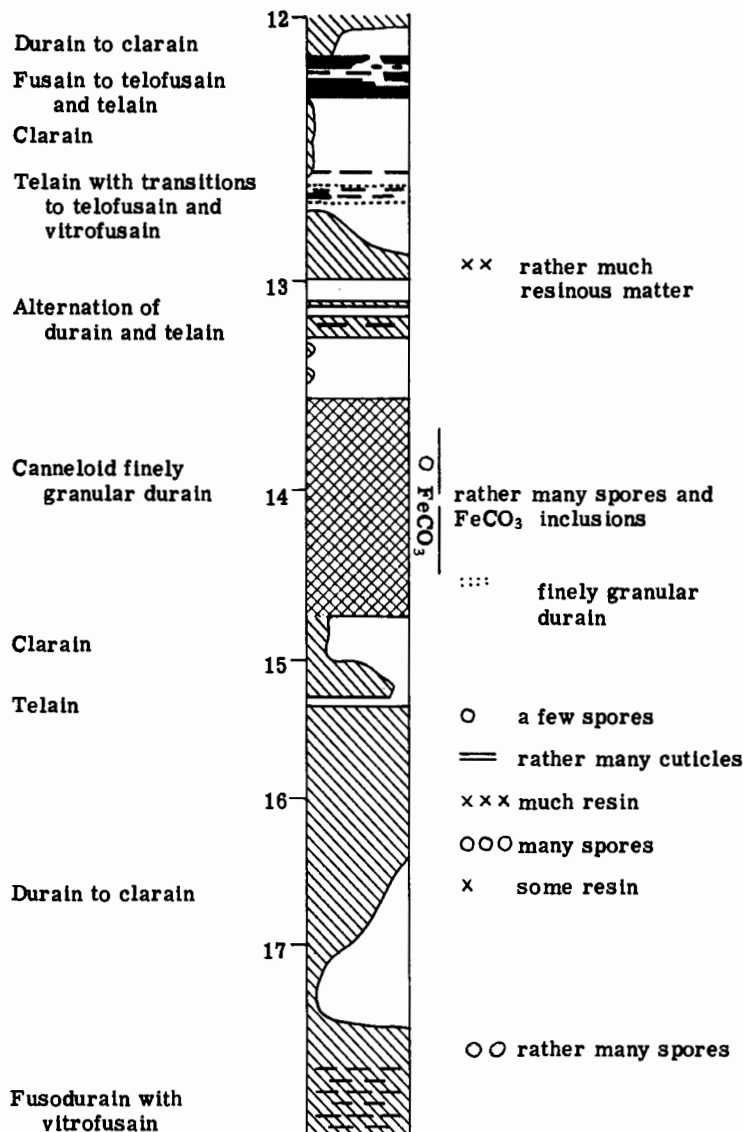


Fig. 6 - Method of presenting graphic bed profile by the Netherlands Geological Bureau.

(From Proc. 2nd Congress on Carboniferous Stratigraphy, Heerlen, 1935, p. 1106.)

(For explanation of symbols see text, p. 25.)

MICROSCOPIC BED PROFILES

IN TERMS OF MICROLITHOTYPES AND CONSTITUENTS

European System

Microscopic bed profiles may be running profiles, the components being recorded in their order of occurrence; or they may be recorded proportionately by steps, which is the more common method but not necessarily the most useful for all purposes.

Microscopic bed profiles can be tabulated but, even if so assembled, they probably eventually would be translated graphically. Such profiles represent the petrographic composition of the bed or portion of the bed studied in terms of microscopic constituents or components (phyterals), microlithotypes, group macerals, or macerals

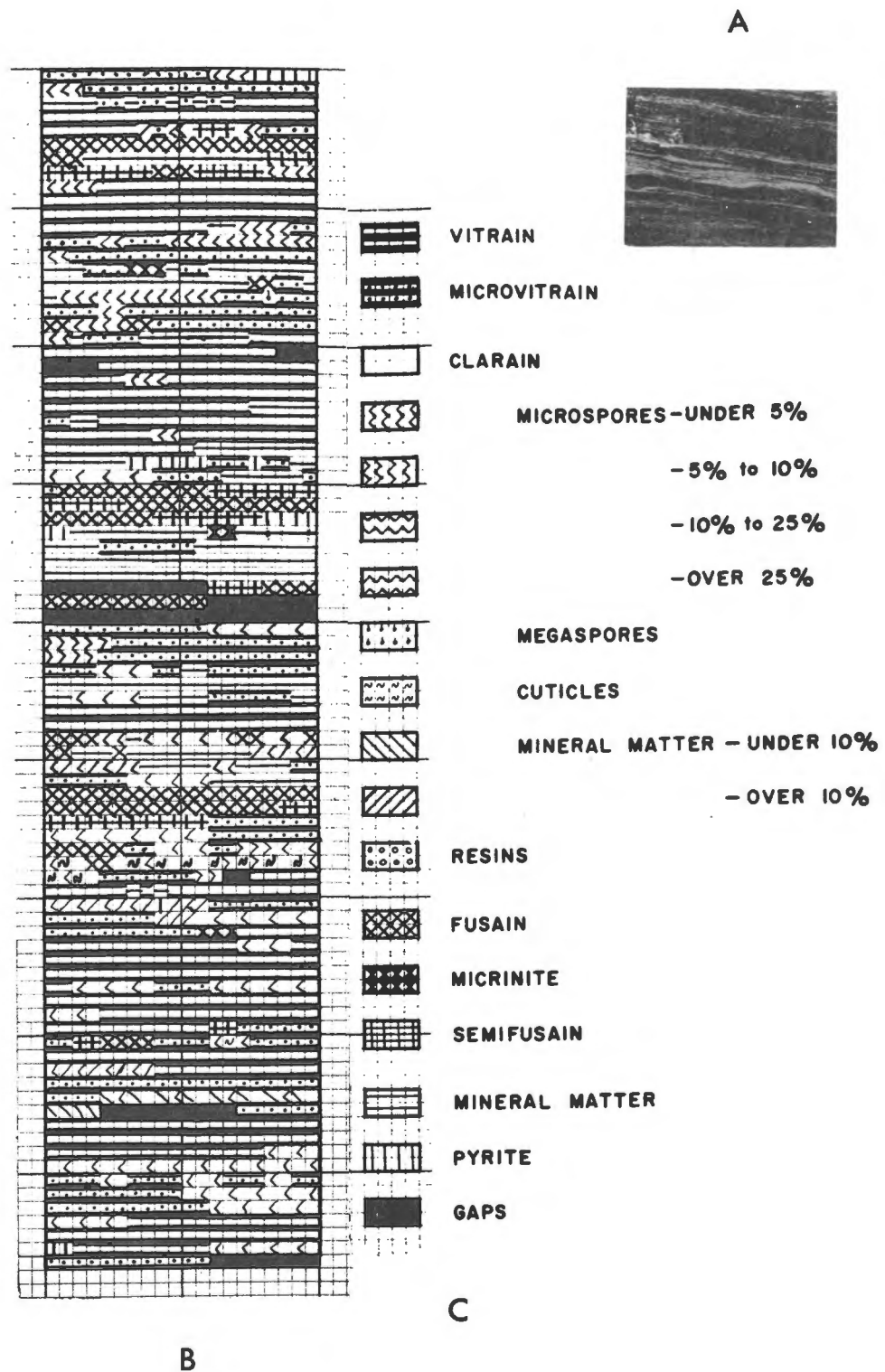


Fig. 7 - Natural size photograph of a 1-inch portion of a polished block of coal from column No. 603 Meigs Creek (No. 9) bed coal (A) with a continuous microscopic bed profile made at 125X magnification (B) and patterns used for designating various constituents (C). (From reference 1: Cady and Smith, 1955, fig. 21, p. 52.)

as measured along a line or ribbon transect. The profile is linear if the transect is along the line of a conventional ocular micrometer or step micrometer; it represents a narrow ribbon or belt if made with the use of a Whipple disc.

The microscopic profile (fig. 7) can be conveniently plotted on the same form as that used in plotting megascopic profiles, that is a four-inch strip of cross section paper two inches of which are used for plotting the profile, with a pattern of one hundred 1/10-inch squares to the square inch. A finer pattern may be used should this seem more convenient. Using the form suggested, the length of the ocular micrometer (or Whipple disc) is represented by one 1/10-inch strip across the profile form. The vertical value of this 1/10-inch strip varies, depending upon the magnification. With an 8X ocular and 16.5 objective it represents approximately 1/3 mm. (333 microns); using the 25X objective, 1/5 mm (200 microns). Since the horizontal 1/10-inch strip is subdivided by vertical lines of the cross section grid into 20 parts, it is convenient to use 1/20th of the micrometer scale (5 divisions) as the unit of measurement. For the 16.5 objective (8X ocular) such a division will equal (3.33×5) 16.6 microns, and for the 25X objective (2.00×5) 10 microns. Finer differentiation and recording requires higher magnification.

As in the case of the megascopic profile, the microscopic profile may be plotted proportionately by steps as measured on a line or narrow band transect. It may also be plotted to show the components (lithotypes, group macerals, macerals) in the order and relative dimensions in which they are encountered as crossed by the transect (fig. 7B). In the first case, the total length of each variety of component measured on the micrometer scale appears for each step of the profile thus being graphically expressed in proportions. In the alternative continuous profile method, the actual thickness of each component is recorded in the order transected, not in total thicknesses per step. Some compromise is necessary in this continuous profile method if the components recorded are less than 16 (at 16.5X) or 10 (at 25X) microns thick as crossed by the transect line. The compromise consists in designating the particular space of 16 (or 10) microns (5 units on the micrometer scale) in terms of the predominating component, the word component being used in a general sense and not in reference to phyterals only.

Obviously, the microscopic profile strip will be considerably longer than the original core or column since on one scale one inch on the strip represents only 3-1/3 mm. of coal and on the other only 2-1/2 mm.

Scales other than those suggested may be preferred in proportional graphic microscopic step profiles. In Germany such microscopic profiles are commonly presented in units of 5 centimeters (fig. 4B) although occasionally in units of 1 centimeter (57, 58, 59).

Where microscopic step profiles are made in steps of 1 to 5 centimeters the profiles are in the form of proportional step profiles and the thicknesses are usually determined with the aid of the integrating stage or a bed profile measurement stage (Leitz) (60, 61). Since the data recorded extend across the space covered by several fields of the microscope they must be recorded in a tabulated form, which table provides the basis for graphic representation (62, 63).

Table 5, after Kuhlwein, Hoffman, and Krüpe, indicates the method of tabulating data for 5 centimeter intervals based upon integration stage measurement, the data being similar to those used in preparing micropetrographic profiles such as shown in figure 4B.

Figure 4A illustrates standard patterns that have been adopted in Germany for presentation of graphic profiles on a microscopic (microlithotype basis). These patterns apply to each of the microlithotypes (Streifenarten) as recognized prior to 1951.

Fig. 8 - A bed profile analysis of the lower bench of Megis Creek (No. 9) bed coal from column No. 584 based upon thin sections prepared by the U. S. Bureau of Mines with analytical data assembled after the method of profile delineation employed by that bureau. The microscopically determined composition is shown in units each representing the thickness of the coal present in a single thin section, usually about 2 centimeters. (From reference 1: Cady and Smith, 1955, p. 19)

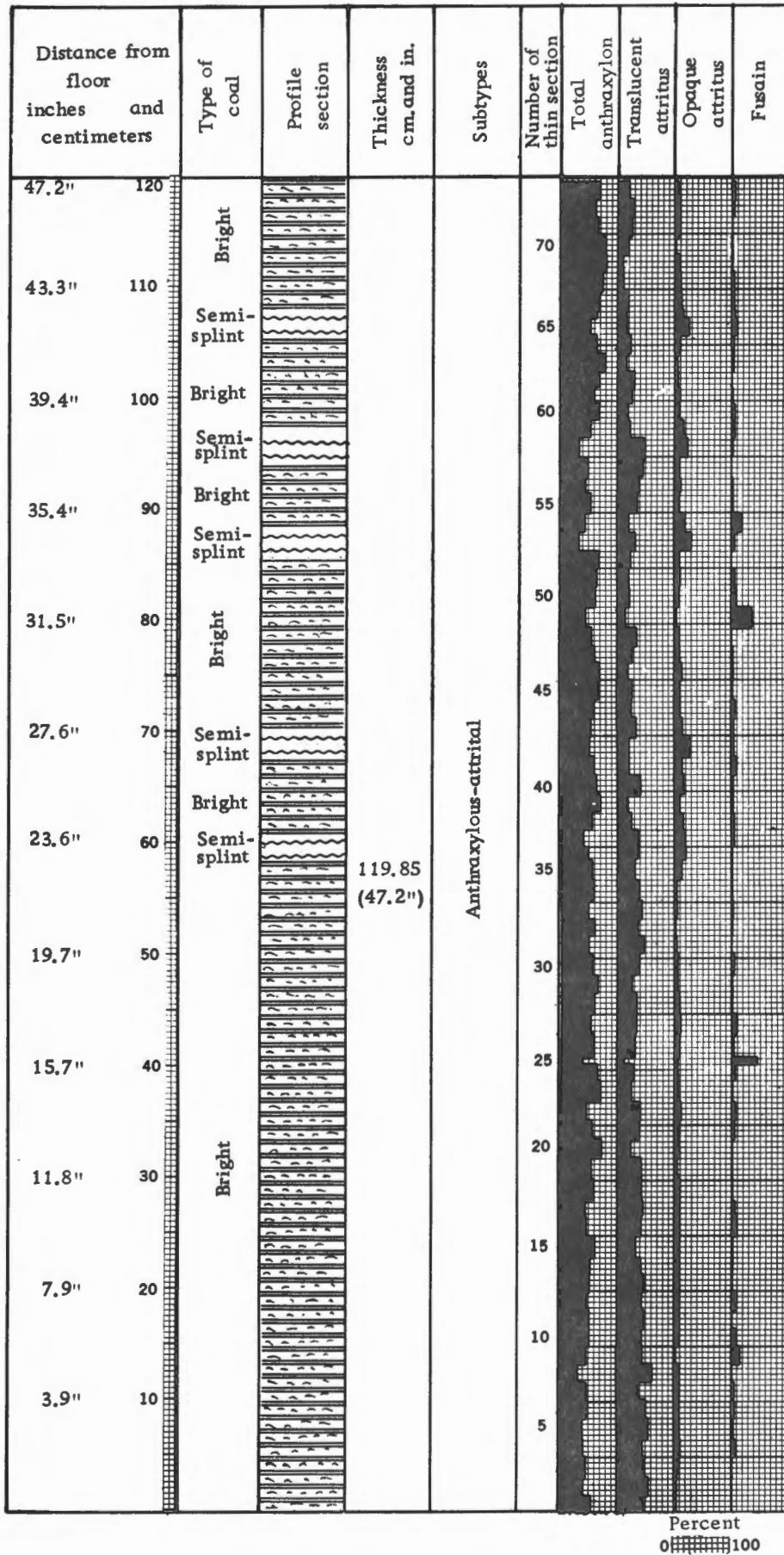


Table 5

Summary of the Upper Part of Mathilde Bed in 5 Centimeter Steps
in Terms of Microlithotypes and Mineral Matter

(After Kühlwein, Hoffman, and Krüpe)

Steps cm.	Vitrite per cent	Clarite per cent	Durite per cent	Intermediates per cent	Fusite per cent	Bone per cent	Mineral Matter per cent
0 - 5	22.5	68.4	-	0.9	-	8.2	-
6 - 10	39.5	20.6	0.5	2.8	-	36.6	-
11 - 15	33.4	31.8	8.5	9.1	17.2	-	-
16 - 20	18.0	7.3	41.2	19.0	14.5	-	-

56 - 60	6.8	3.2	- etc.	-	-	8.3	81.7

U. S. Bureau of Mines Microscopic Bed Profiles

The United States Bureau of Mines uses inches, tenths of inches, and centimeters as steps in profile sections. Their profiles are compiled on the basis of the thickness of the individual thin section, usually about two centimeters (64, 65). To provide a megascopic bed profile the coal bed is usually subdivided into layers or benches (see fig. 8) on the basis of the type of coal, that is, splint, semisplint, cannel, bright banded, and so forth. They are also subdivided on the basis of texture, as microbanded, fine banded, coarse banded, as the case may be.

The microscopic proportional step profiles prepared by the U. S. Bureau of Mines are based upon the analysis in terms of the constituents anthraxylon, translucent attritus, opaque attritus, and fusain; the degree of discrimination corresponding to that employed by the European petrologists when analysis is made in terms of microlithotypes (Streifenarten). Mineral matter does not usually show in the Bureau of Mines graphic bed profile. It has been previously pointed out (p. 20) that the microscopic composition is graphically shown in a series of parallel strips, each graduated horizontally into per cent, one constituent being shown in each strip (see fig. 8).* The same system has been used by Drath and Jaskolski in describing the Otto coal bed, Upper Silesia (66).

MICROSCOPIC PROPORTIONAL PETROGRAPHIC BED PROFILES BY BENCHES

It is a common procedure to graphically represent the microscopic composition of a coal bed and show proportions of constituents or microlithotypes by benches rather than by evenly spaced steps or by thickness of individual thin sections. As in the case of megascopic profiles by benches, the bed is usually subdivided into benches on the basis of conspicuous partings or obvious differences apparent by inspection either before or after the coal has been polished. Petrographic analysis of the coal is then made in bench units and, from the tabulated data thus provided, the graphical representation of the composition of the individual benches can then be compiled (see fig. 8 and references 67, 68).

* Further discussion of Bureau of Mines profiles in part 4 of this report.

GENERAL COMMENTS ON MICROSCOPIC PROPORTIONAL
STEP OR BENCH PROFILES

In Terms of Lithotypes, Constituents, and Microlithotypes

The microscopic proportional profiles that have been described are concerned primarily with those aspects of the coal that can be grouped together as constituents (Thiessen system) or as microlithotypes (Stopes system). On the basis of the Stopes system such grouping has by experience been found to supply the most satisfactory information in applied coal petrology. The microlithotypes in this system are identified in terms of the three group macerals, vitrinite (vitrinoid)*, exinite (exinoid)*, and inertinite (inertinoid)*. Depending upon the relative amount of these three group macerals the coal is classified as vitrite, fusite, duroclarite, clarodurite, vitrinertite, clarite, and durite, etc. (see fig. 1).

In the case of the constituents of the Thiessen system, subdivision is essentially a division into anthraxylon, fusain, and two varieties of attrital material, one variety being translucent and the other opaque. The system provides no possibility of subdivision in terms of materials comparable to vitrinite, exinite, and inertinite. It may be that for this reason the Thiessen system has less definite application to applied coal petrology than the European system. In view of the inherent capacity of thin section microscopy to identify many of the components of coal more satisfactorily than is possible even with oil immersion objectives, with the possible exception of opaque components, thin section technique should provide a more satisfactory basis for use in applied coal petrography by grouping in distinctive categories structural elements or coal components of a similar character. This, however, has only recently been attempted (see reference 16). The European coal petrographers, however, have done this in differentiating the three group macerals vitrinite, exinite, and inertinite. The fact that no similar grouping of microscopic components (phyterals) has been systematically made in the American system may, at least in part, be due to the importance that has been placed upon botanical or morphological differences. These have tended to diminish the importance of similarity in the character of the coal material into which these components have been converted. The American coal microscopists appear to be more impressed by the diversity of morphological relationships than by similarity of coal composition. It is quite probable that the simple and very convenient classification of coal material into three types can be worked as well, and possibly better, for thin section technique as for polished surface technique, although there may be considerable hesitancy about limiting differentiation into no more than three categories. Because of its usefulness in the field of applied coal petrography, the need for this sort of practical grouping of microscopically visible coal components may prove an important influence in the coordination of the two techniques and terminologies.

In Terms of Macerals or Phytals (Components)

Profiles can be prepared on the basis of microscopic components (phyterals) or macerals with sufficiently high magnification both in observation and in the graphic delineation. This is somewhat the nature of the procedure followed in preparing the profiles shown in figure 4, but in this case the dimensions of individual spores, resins, cuticles, etc., were not recorded since a considerably larger magnification would have been necessary both for observation and measurement and for graphic representation. Graphic representation, except for small portions of a coal bed, is impractical, dependence being placed on a tabulated analysis.

* Names applied by Organic Sediments Laboratory, Pennsylvania State University. See reference 2.

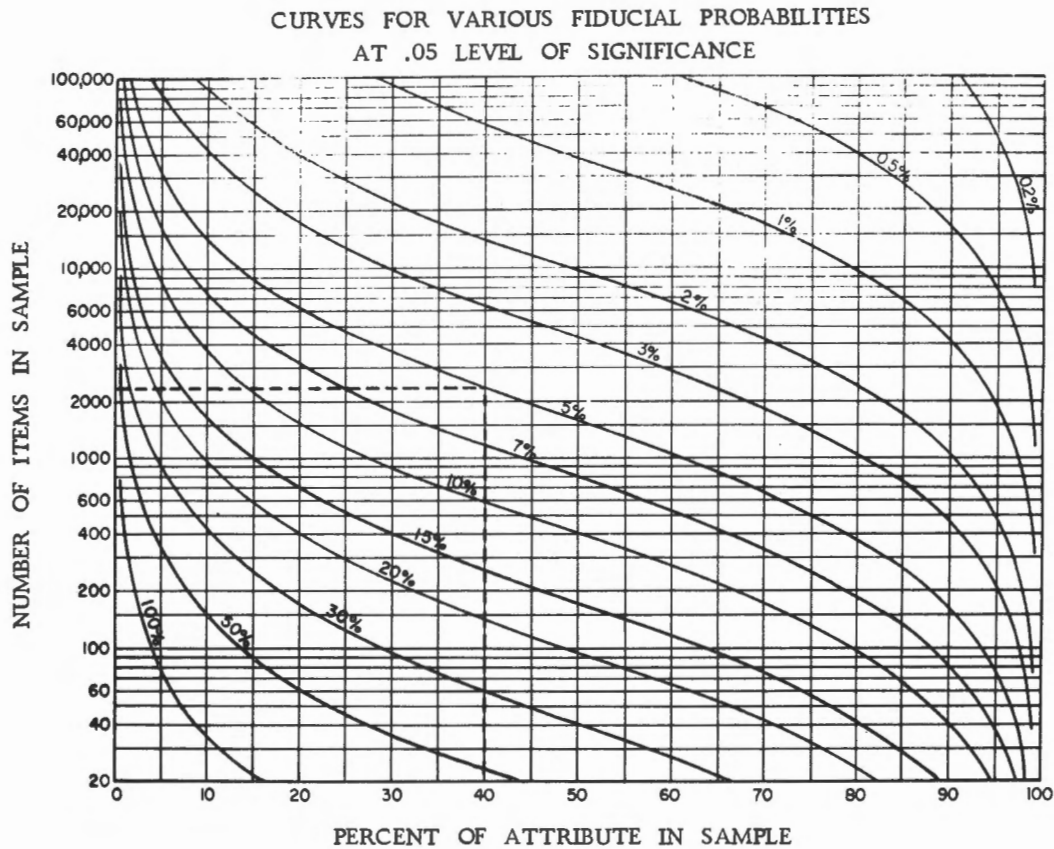


Fig. 9 - Fiducial chart for determining the number of points to be counted. For example: if 40 per cent of the total area is believed to be vitrain, and a selected accuracy within 5 per cent is desired for this material, 2400 points must be counted. Because the number of points counted can be based upon only one class of material, the one regarded as the most important is usually selected. Curves developed by the Northwestern Forest Experiment Station. (Chart shown in and explanation adapted from fig. 7, Tech. Paper No. 126, Central States Forest Experiment Station, U. S. Department of Agriculture.)

PROCEDURES OF MICROSCOPIC MEASUREMENT

PREVAILING METHODS

Measurement of the components is necessary for both graphic profiles and statistical anthracologic analysis of coal. The purpose of the measurement is actually to determine the volume of components measured. This is now generally accomplished by one of two ways: the planimetric survey (Rosiwal) method (69), which assumes that the thickness of the various components measured along a vertical transect is in direct relation to volume relationships; and the so-called point-count system. The use of the point-count method in petrographic analysis has been explained by Glagolev (70) and more recently by Chayes (71). The method is similar to that used by the Division of Forest Economics of the U. S. Department of Agriculture in timber crusing using aerial photographs (72). In this procedure dot templates are used with a stated number of evenly spaced

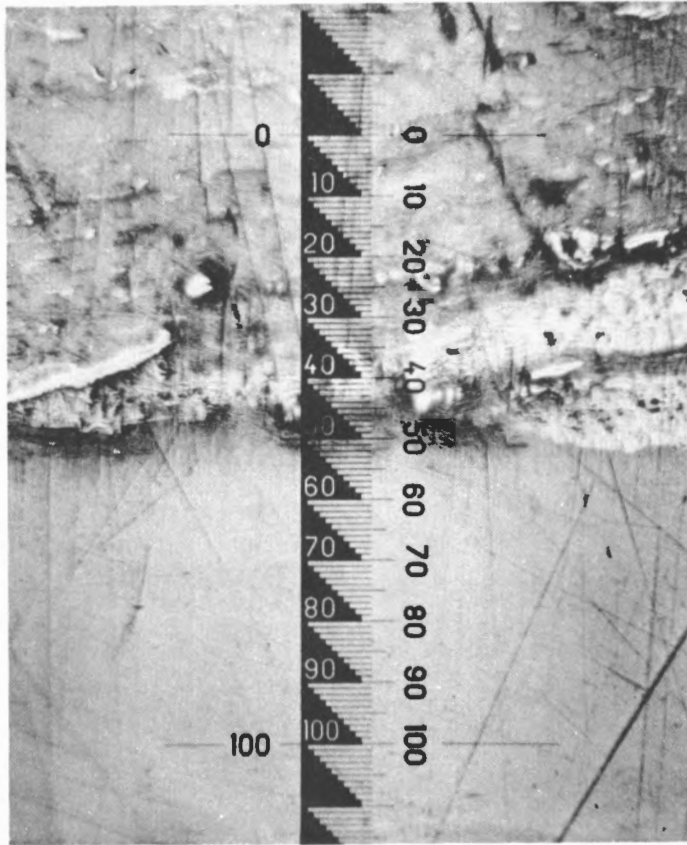


Fig. 10 - The step micrometer as applied to the measurement of a polished section showing vitrain (50-100), fusain (35-50), and clarite (0-35).

dots per unit area. The accompanying fiducial or reference chart (fig. 9) may be used to determine the various percentages of accuracy for 95 per cent of the cases. A different form of chart but one accomplishing essentially the same purpose has been published by Clapper and Pearson (Biometrika Office) and reprinted by Wilks (73).

VERTICAL TRANSECT METHODS

OCULAR MICROMETER AND INTEGRATING STAGE METHODS

Vertical transects or planimetric surveys can be made by two types of instruments, micrometers and the integrating stage. Micrometers of various kinds consist of mechanical stages for megascopic measurement or of ocular micrometers for microscopic measurement. The ocular micrometer may consist of the standard or conventional ocular micrometer divided into 100 parts (10 mm = 100 parts) with 5 and 10 per cent division specially marked, or the ocular step micrometer (74) (fig. 10). The Whipple disc (fig. 11) is another type of ocular micrometer much favored by the anthracologic laboratories in the United States but not commonly used abroad. The second commonly used types of measuring apparatus are the integrating stage (fig. 12) or the integrating ocular. The latter instrument is similar in appearance to the integrating stage but is mounted on the ocular and has the advantage of being somewhat less disturbed by vibrations of manipulations than the integrating stage.

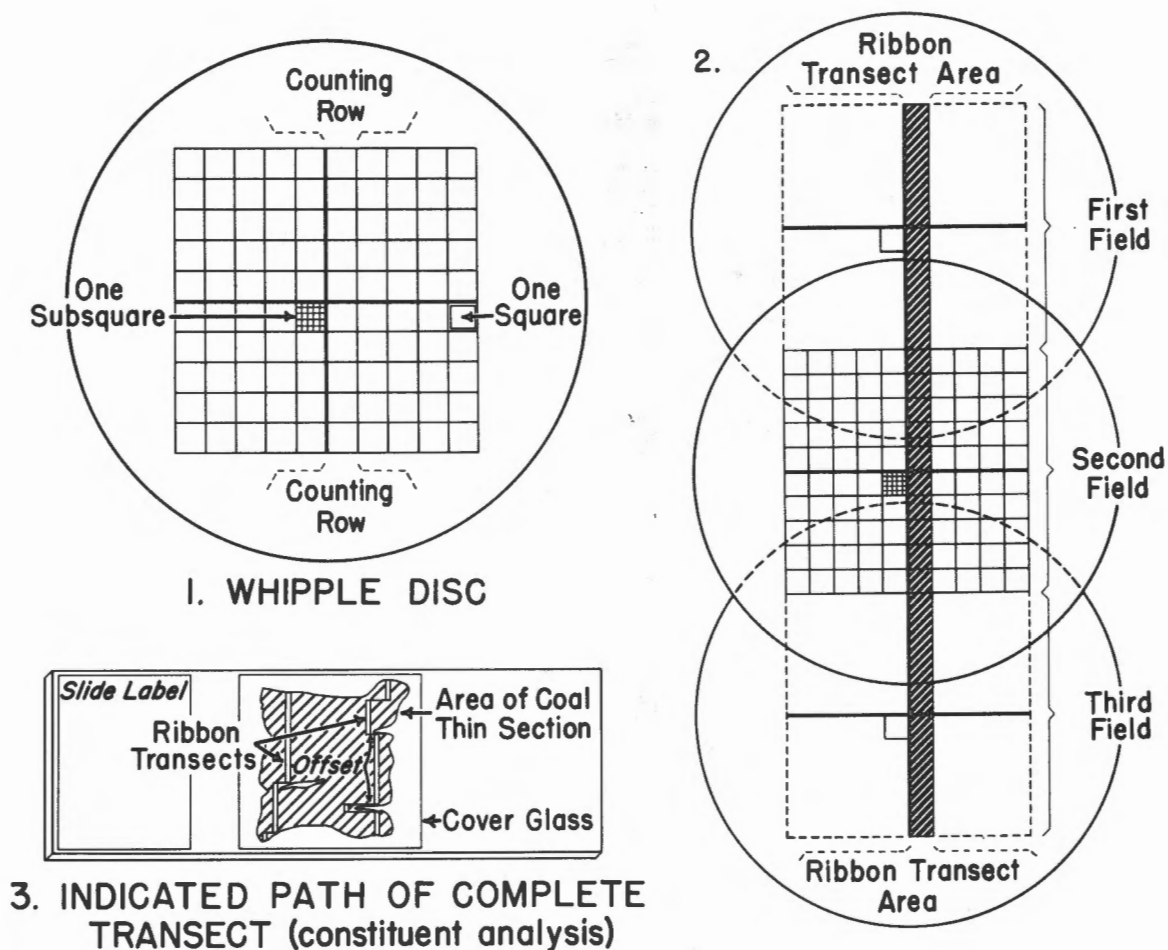


Fig. 11 - Application of the Whipple Disc to micro-analysis of coal. (Supplied by J. M. Schopf; also see: 1956 Trans. A. I. M. E. vol. 205 (Mining Branch), p. 633.)

Linear measurements are made by all these devices although measurement by the Whipple disc may be in terms of a very narrow band. Measurement is interpreted as both linear and (see p. 32) volumetric. Conversion to weight per cent measurements has in general been carried out only with respect to petrographic components identified in polished surfaces. The density of a number of these components (lithotypes, and group macerals) as given in the Atlas of Hard-coal Petrography (75) and by Stach (76) is as follows:

Vitrain, 1.30 ; Clarain, 1.30 ; Durain, 1.35
 Semifusain, 1.35 ; Fusain, 1.50 ; Bone (Brandschiefer), 1.70
 Exinite, 1.20 ; and Inertinite, 1.40

No similar values have been proposed for the components or constituents recognized in American coal microscopy, and in coal analyses volume is not usually converted into weight. In the report on the Meigs Creek (No. 9) coal of Ohio, in which the polished surface technique was followed, some tabulations presented values for both weight and volume (77). The differences may be quite considerable if "bone coal" and/or mineral matter are included in the analyses.

Point-count determinations are not in the nature of vertical linear transects but are areal determinations. It is, therefore, probable that results will agree no better than approximately. The question of what method to

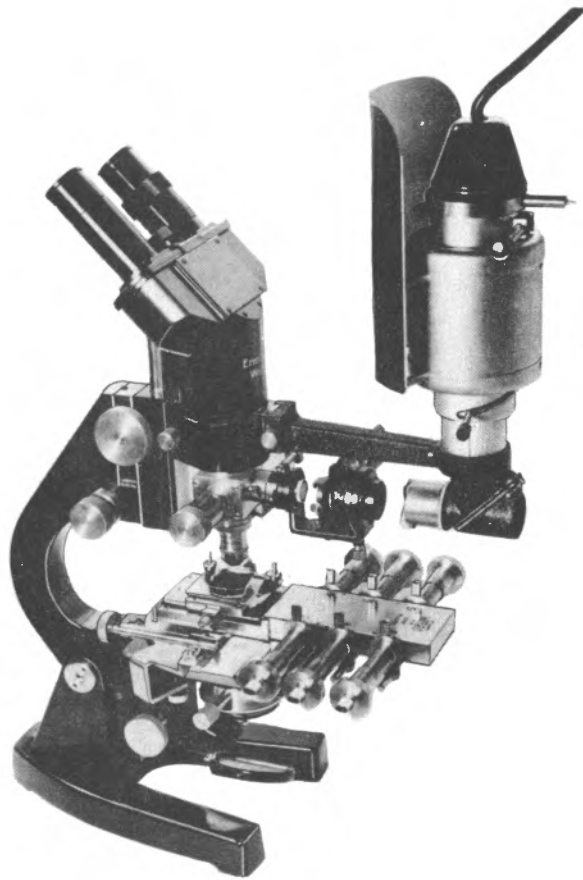


Fig. 12 - The Leitz six-spindle integrating stage mounted on the stand of the petrographic microscope designated KPM, showing also the lamp and method of attachment and the vertical illuminator with the intervening Stach disc diaphragm.

(Photograph by F. Twitty, Division of Geological Survey.)

use is one which rests mainly on the labor involved and the textural information sought; that is, whether a detailed single traverse recording the width of the components selected for measurement, or a point-count survey, requiring enough traverses to provide the required number of counts necessary for the accuracy desired for a particular component, requires the most time. However, the point-count method provides no basis for determination of texture and it is simply volumetric for the area surveyed.

Categories of Microscopic Differentiation

The degree of refinement of resolution of the coal components used in measurement for graphic profiles or petrographic analysis depends upon the purpose for which the profile or analysis is to be used and the time and facilities available. Frequently, conditions do not permit the preparation of more than a profile based upon lithotypes (banded ingredients), non-pyritic mineral matter, and pyrite. Too often in exploration work provision for such a profile is not made.

When it is possible to examine coals microscopically, coal beds can then be described at various degrees of magnification; the choice again depending upon the purpose of the examination and analysis and the time and facilities available. By far the larger number of analyses here and abroad have been in terms of microlithotypes (Streifenarten) as a basis for practical appraisal of the coal, although measurement in America has been mainly on the basis of constituents.

For the purpose of discussing the categories of microscopic differentiation observed in anthracologic

description and analysis it will be convenient to consider first those of the European polished surface technique and then those of the American or Thiessen technique.

Categories of Differentiation in Polished Surface Technique

The recently published "International Glossary of Coal Petrology" (see p. 1) contains terms used in polished surface technique which apply to three possible degrees of microscopic resolution. These are in addition to the fourth degree of resolution based upon megascopic observation and represented by the lithotypes or ingredients

The four degrees of resolution consist of :

- Megascopic resolution ;
- Microscopic resolution ,
 - Resolution in terms of microlithotypes ,
 - Resolution in terms of group macerals ,
 - Resolution in terms of macerals.

Megascopic Resolution

Megascopic resolution in terms of the lithotypes vitrain, clarain, durain, and fusain requires no further explanation as it was adequately described under megascopic bed profiles (see p. 17-25).

Microscopic Resolution

Resolution in Terms of Microlithotypes. - The first degree of micro-petrographic resolution of coal by the polished surface method for a bed profile or profile analysis is represented by the microlithotype categories vitrite, fusite, exinite, clarite, durite, vitrinertite, duroclarite, and clarodurite, with further possibilities of subdividing clarite, vitrinertite, and durite as shown in figure 1. The microlithotypes should not be regarded as simply the microscopic equivalents of the lithotypes vitrain, clarain, durain, and fusain. Thus, it is not correct to assume that a band of vitrain will necessarily be classified microscopically as vitrite or a band of clarain as clarite. This is one reason for the inadequacy of megascopic classification and profiles providing for a correct understanding of the composition of a coal bed, although they undoubtedly have value. The fact that identification of the microlithotypes is on the basis of microscopic rather than megascopic criteria, by vertical rather than by inclined illumination, and by maceral composition rather than mainly by difference in luster and structure (striated or non-striated), makes it necessary to identify them entirely independently of megascopic criteria. Identification is based upon the relative proportions of the three group macerals vitrinite, exinite (or liptinite*), and inertinite, with certain limitations in regard to size, at least when dealing with broken coal as will be explained ahead in part 3 of this report.

The methods of measurement and description employed in the microscopic bed profile delineation in the polished surface system is briefly explained in the Atlas (78). It is pointed out that such a bed profile is prepared from a single transect extending from the top to the bottom of the bed. The microlithotypes are recorded centimeter by centimeter using the profile measuring stage (Leitz) (79) and ocular micrometer (10 mm. = 100 parts); step micrometer, or a six-spindle integrating stage (Leitz or Fuess - electric). The profile analysis can also be made by use of a conventional mechanical stage and ocular micrometer or Whipple disc.

* A term suggested by J. J. Ammosov (U.S.S.R), May 1956, to take the place of exinite as being of more general meaning. Also spelled leiptinite. See fig. 13; and p. 38.

The bed profile is compiled from tabulated data based on units of one centimeter, generally summarized in units of five centimeters as shown in the proportional five-centimeter step profile illustrated in figure 4. There accompanies the step profile a graphic profile in steps of one centimeter based upon the original one centimeter measurements. If greater detail is desired the proportional step profile can be constructed in steps of one centimeter.

According to recent suggestions by Mackowsky (80), tabulations are made in deference to the limitations of the six spindle integrating stage as shown in the following table :

Table 6

Example of a Quantitative Petrographic Analysis of Coal

Components	Volume Per Cent	Spindle Values (a)	Density (b)	a x b	Weight Per Cent		
					Mineral Matter Free - Per Cent	Per Cent	With Mineral Matter
Vitrite	41.85	34.26	1.3	44.5	40.8	41	-
Clarite	25.93	21.23	1.3	27.6	25.4	25	-
Duroclarite Clarodurite Vitrinertite	21.38	17.50	1.35	23.6	21.7	21	-
Durite	4.67	3.82	1.35	5.2	4.8	5	-
Fusite	2.38	1.95	1.4	2.7	2.5	3	-
Bone (Brandschiefer)	3.79	3.10	1.7	5.3	4.8	5	-
Mineral Matter	-	-	-	-	-	-	-
	<u>100.00</u>	<u>81.86</u>		<u>108.9</u>	<u>100.0</u>	<u>100</u>	

In the corresponding form appearing in the Atlas (81), the six spindles are assigned to vitrite, clarite, durite, semifusinite, fusinite, and Brandschiefer (bone). Mineral matter appears to be determined by difference. This system made no provision for the intermediate microlithotypes duroclarite, clarodurite, and vitrinertite which are grouped together in table 6.

For calculating the weight of the pure minerals from spindle values the Atlas recommends the following values for specific gravity (82):

Clay and sandy shale.	2.5 - 2.6
Quartz	2.65
Calcite.	2.72
Siderite	3.8
Pyrite	5.0

The specific gravity of mixtures of coal and mineral matter should be calculated on the assumption of an average density of 1.3 for coal (83).

On the basis of the minimum threshold thickness of the microlithotypes recognized in European polished surface petrology, and as expressed in the 1957 (Essen) edition of the "International Glossary of Coal Petrology" (see p. 1), it may be assumed that coal bed petrographic profiles based upon microlithotypes will not recognize units less than 50 microns thick. This is the thickness represented by five divisions on the rotating verniers on the spindles of the Leitz integrating stage. Presumably, in making the transect upward from the bottom of the bed, the thickness of each band of distinctive microlithotype composition more than 50 microns thick will be measured with the appropriate spindle. A similarly distinctive or poorly distinctive band less than 50 microns thick is included with the adjacent band above or with as many bands above as will add up to 50 or more microns of thickness. The two or more bands are then classified in terms of the microlithotype represented by their combined composition. If the uppermost portion happens to be considerably more than 50 microns thick, the addition of the small portion of different material below may or may not modify the classification of the thicker uppermost microlithotype.

Thus, a 25-micron band of vitrinite plus a 25-micron band of exinite would represent a 50-micron band of clarite; a 10-micron band of fusinite, a 25-micron band of exinite, and a 15-micron band of inertinite (fusinite) would represent a 50-micron band of intermediate material (duroclarite, clarodurite, or vitrinertite). On the other hand, if a 10-micron band of exinite was combined with a 200-micron band of vitrinite, since 95 per cent of the band 210 microns wide was vitrinite, the band would be classified as vitrite, the small amount of exinite being less than five per cent of the whole.

Although this method of delineation of the coal bed profile is satisfactory for what might be called the "marginal" microlithotypes vitrite, clarite, exinite, durite, and inertite (see fig. 1), it is far from satisfactory for the intermediates, clarodurite, duroclarite, and vitrinertite. It also fails to differentiate clarain, which is predominately vitrinite, from clarain, which is predominantly exinite; and durite (cannel?), which is predominantly exinite, from that which is predominantly inertinite (opaque matter). Thus, there is a wide range of variation possible, particularly if the coal should happen to consist of a large amount of "intermediate" coal material.

Resolution in Terms of Group Macerals. - The convenience of classifying coals which are naturally heterogeneous in composition into a few characteristic associations of macerals has resulted in the development of the microlithotype concept just considered. It is apparent, however, from the dilemma created by the "intermediate" materials that the microlithotype idea is not fully satisfactory, simply because it does not provide adequate means for expressing all the relationships and distinctions that might be desired. Strict adherence to variations in the relative proportion of the group macerals might provide a more satisfactory basis for description.

The possibility exists of a more accurate and, hence, a more useful statement of association with respect to the three group macerals, that is between material represented by the humic substances (vitrinite), the carbonized substances (inertinite), and the so-called bituminous substances (exinite). Since these three materials, exclusive of mineral impurities, occur in coal in proportions varying from 0 to 100 per cent, it is possible to express their relationship with a triangular diagram as has so frequently been done (84).

J. J. Ammosov of the Academie of Sciences, Moskow, in a letter to E. Stach, Secretary of the International Committee of Coal Petrology, dated February 1956, proposed a system for showing the relationship of the three group macerals in coals and a means of "accurate and appropriate designation" of various combinations of the group macerals. This was to be carried out by reference to a diagram such as shown in the accompanying illustration (fig. 13A).

The diagram is explained as follows by Ammosov (translation from German): "The relation of the maceral groups in the banded ingredients is represented by a three-point diagram. The change in the content of each of the maceral groups in the banded ingredients is shown by figures on the sides of the triangle. The lines within the triangle designate intervals indicating changes of 10 per cent vitrinite, inertinite, and exinite contents. The small triangles within each row formed by the parallels to the three margins of the large triangle are all numbered.

Fig. 13A - A triangular diagram showing the procedure proposed by Ammossov (1956) (1956) for indicating by a system of letters and numbers the group maceral composition of a coal.

Vt = Vitrinite;
 E = Exinite (or Liptinite);
 I = Inertinite.
 Diagram supplied by J. M Schopf, after one by Ammossov.

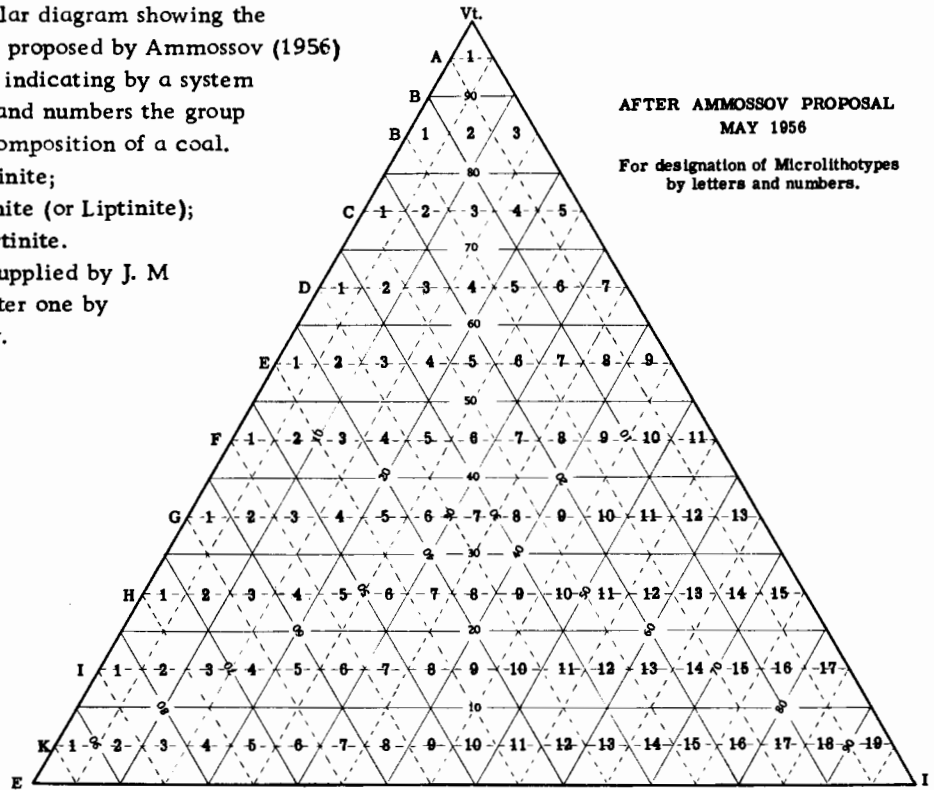
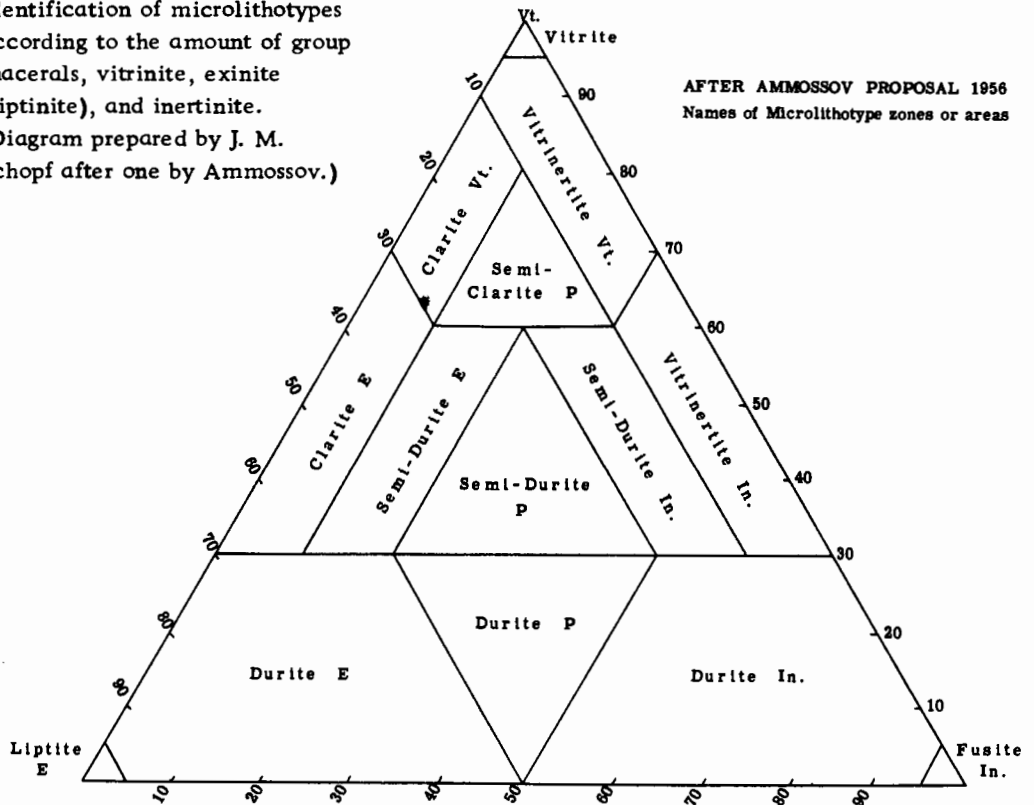


Fig. 13B - Identification of microlithotypes according to the amount of group macerals, vitrinite, exinite (liptinite), and inertinite. (Diagram prepared by J. M. Schopf after one by Ammossov.)



Each band of numbered triangles, between the lines running parallel to the base, and representing steps of 10 per cent variation in vitrain content, is lettered from 'A' at the top to 'K' at the base, the letter 'J' being omitted."

Each banded ingredient can be designated by a combination of numbers and letters. The letter indicates the amount of vitrinite and the number refers to the relationship between inertinite and exinite; for example, a banded component with 3 per cent inertinite, 65 per cent vitrinite, and 3 per cent exinite is located in triangle "D-7." A component with 40 per cent vitrinite, 25 per cent inertinite, and 35 per cent exinite is in triangle "F-5."

Ammossov has proposed certain "microlithotype" names (fig. 13B) to be applied to the various portions of the triangle as a matter of convenient generalization. These correspond, in general, with microlithotypes.

In recent years the temptation to allow the convenience of the representation of quantitative relationships in terms of three varieties of components to control the manner of classifying and describing coal has exercised a considerable influence upon petrographic investigations of coal. Differentiation of inert materials represented by fusain and other opaque substances from translucent substances represented by vitrinite on the one hand and exinite on the other probably rests upon valid distinctions. Less certainty exists as to the possibility of precision in the separation of materials classed as vitrinite from those classed as exinite or liptinite. Use should be made of this triadic system to the extent of its usefulness but an open mind should be kept in regard to other possibilities of classification.

Resolution in Terms of Macerals. - The description of coal and the resolution of its microscopic composition in terms of macerals requires more time, more exacting technique, and more special equipment than are thought to be justified in applied petrography. The possible usefulness of analysis on the scale of the group macerals should be thoroughly explored before extending analysis to include study and measurement of the individual macerals.

Assuming that need for study of the individual macerals does exist, it then is usually necessary to use higher magnification to make more discriminating identifications and more precise measurements. This would require the use of more expensive and special instruments.

It is important to realize in undertaking such studies that polished surface coal petrology, from the Stopes point of view, is the petrology of lithologic material, not primarily of botanical entities. Each material examined is regarded as a particular type of coal substance, and has the same relation to coal as a whole as do minerals to the rock which they compose. The concern, therefore, is with the aspects and dimensions of the macerals as coal material, although their origin as botanical entities is understood. Should the botanical interest predominate, it would appear more practical for the investigator to use thin sections, at least for those coals to which this method of preparation is practical.

When the polished surface petrographer moves into this field of very discriminating identification, he is closely approaching the special interests of the American thin section microscopist; that is, the identification and description of botanical entities and the analysis of the coal in terms of such initial entities irrespective of their character as coalified material. The excellent accomplishments in this field by observation of polished surfaces is demonstrated by the work of Stach and others (85).

The usefulness of precise maceral identification and measurement will be determined largely by the results of exploration directed toward the analysis and testing of coals of specific type because of the concentration or associations of certain macerals. Exploration of this kind is underway, but primarily in European laboratories (86, 87).

provide a somewhat better idea of the extent of the possible degree of variability in composition and properties residing in the group macerals.

Microscopic Resolution in Terms of Special Categories

The search for a method of describing the petrographic characteristics of certain Ohio coals using polished surface technique was conducted during a period of considerable confusion in regard to nomenclature and procedure (between 1953 and 1955). A tentative procedure was adopted for the description and analysis of coal bed profiles which depended primarily upon microscopic observation (91) and the use of polished surface lithotype terminology and transect measurements by the ocular micrometer.

The coal had essentially the same general petrographic characteristics as most of the high volatile bituminous banded coals in the midwestern and eastern part of the United States. This was determined by a preliminary examination of a suite of thin sections of the Meigs Creek (No. 9) coal by the Bureau of Mines coal microscopists, B. C. Parks and H. J. O'Donnell (92). It was thought that the essential characteristics of the coals, such as determined their behavior in the mining and preparation processes and in domestic and industrial utilization other than coke making, could be determined in relation to the occurrence and quantity of the following lithotypes and macerals and impurities: vitrain, microvitrain, clarain (essentially clarite, the microlithotype), fusain and semi-fusain, pyrite, and other mineral matter. It was, however, necessary to differentiate certain varieties of microscopic clarain which composed that part of the megascopic clarain not consisting of microvitrain. The microscopic clarain was therefore separated into that part having no spore or cuticular material and consisting of collinite (humic degradation matter), and those parts having up to five per cent, up to ten per cent and up to 25 per cent sporinite, respectively. Cuticular material, if present, rarely exceeded five per cent. When present, this percentage was assumed. The occasional occurrence of resin in either vitrain or microclarain was noted, as was also the presence of micrinite or sclerotinite (opaque matter), both of which were present in only small amounts.

The quantity of sporinite present was determined by comparison with photographs of clarain (microclarain) with determined quantities of spore material (93). The petrographic analysis was in graphic form (fig. 7), in continuous profiles, or in some cases in proportionate step profiles, the steps being the length of the ocular micrometer (10 mm. - 100 parts). The numerical analysis was derived mathematically from the graphic profile to determine the total distance represented by the individual components. These proportional results can, of course, be readily shown graphically by volume and by weight (94).

The observations and records were made in accordance with the items in the following list (95):

- Vitrain, Sp. gr. 1.3
 - Vitrain to 1/10 mm.
 - Microvitrain
 - Total
- Clarain (microclarain), Sp. gr. 1.3
 - less than 5% spores
 - 5-10% spores
 - 10-25% spores
 - more than 25% spores
 - Megaspores - separate measurement
 - with cuticles (called 5%)
 - with mineral matter up to 5%
 - Total
- Inert matter, Sp. gr. 1.35
 - Fusain

	Semifusain
	Total
Mineral Matter	
	Pyrite, Sp. gr. 5.0
	Other mineral matter, Sp. gr. 2.6
	Bone, impure clarain and fusain, Sp. gr. 1.7
	Total

Data are shown on both volumetric and weight basis.

It seemed desirable in some cases to know not only the total amount of the lithotype vitrain (vitrain plus microvitrain), but also the total amount of the lithotype clarain (clarain plus microvitrain) (96), or the total amount of exinite and mineral matter as related to what is called the microclarain, that is, the clarain without microvitrain (97).

This Ohio system of anthracologic analysis has not been sufficiently tested to determine its usefulness in applied anthracology. Certain possibilities of its description and analysis may be pointed out.

It provides information concerning the quantity of vitrain (+0.1 mm.) and thickness of the bands;

It shows the amount of microvitrain (-0.1 mm.);

It provides information on the amount of "micro-clarain" or clarain (lithotype) minus microvitrain;

It provides information concerning the amount of collinite (humic degradation matter) in "micro-clarain";

It provides information concerning position and thickness of dull clarain bands due to sporinite or to micrinite;

It shows the position and thickness of fusain and semifusain bands and particles;

It supplies information concerning the occurrence and quantity of pyrite and of mineral matter other than pyrite.

There was so little micrinite in the coal examined, its relation to clarain (microclarain) was not determined. However, a system similar to that applied to sporinite is possible in the case of micrinite.

At magnifications of 250 to 300 times, it was difficult to exactly measure small thicknesses of sporinite or micrinite. The method of determining frequency by comparison with photographs in which frequency has been systematically determined was thought to be a suitable way of attaining the desired objective.

The most serious objection that can be made to the "Ohio system" is the lack of precision in the measurement of micrinite and exinite when present in minute particles. This is particularly true if it is found that small proportions, up to 5 per cent or less, of these macerals exercise an important influence upon the behavior of coal in the preparation plant or in utilization. The amount of micrinite seemed to be considerably less than that reported by Parks and O'Donnell in thin sections of the Meigs Creek coal bed.

Categories of Differentiation in Thin Section Technique

Resolution in Terms of Constituents

Whereas the polished surface technique provides four categories of resolution in the description and analysis of coal by transect measurement, American or thin section coal microscopy proceeds in recognition of only two categories of resolution, both microscopic but at different degrees of magnification. The resolution of thin sections of coal at the lower magnification is in terms of what are called the constituents (98)--anthraxylon, translucent attritus, opaque attritus, fusain, and mineral matter. This resolution depends upon the recognition of vitrain down to a minimum width threshold of 14 microns and of fusain down to a minimum width threshold of 30 microns (99). The balance of the material not mineral matter is translucent or opaque attritus. Vitrain, fusain, total opaque matter, and mineral matter are the constituents toward which attention is directed in microscopic analysis of the coal and in the preparation of bed profiles. Opaque attritus and translucent attritus are determined by difference as explained by Schopf (99).

Resolution in Terms of Components or Phyterals

This stage of resolution of the coal in thin section microscopy at higher magnification is closely comparable to resolution in terms of macerals in polished surface anthracology, except that emphasis tends to be more upon the botanical aspects of identification rather than upon the petrology of coal material considered as such. Description and analysis of the components of phyterals, as in the case of maceral description and analysis, requires higher magnification, more skill, and much more time than description and analysis in terms of constituents. However, it may be well to point out again that since analysis in terms of the microscopic constituents fails to provide data in regard to the amount of exinite in the attritus, some degree of component analysis is necessary to satisfy this need.

WHIPPLE DISC METHOD OF MICROSCOPIC ANALYSIS

Current methods of thin section microscopy have recently been thoroughly explained by Schopf and need not be repeated here. The paper referred to, which is readily available, has an especially clear explanation of the use of the Whipple disc in transect analysis of coal thin sections (100). This method of volumetric analysis of components and constituents as observed in thin sections is in greatest favor at the Federal coal microscopy laboratories at Pittsburgh and Columbus and at the Organic Sediments Laboratory at Pennsylvania State University, and at West Virginia University at Morgantown.

One important advantage in the use of the Whipple disc is its relatively low cost (\$12-15) as compared with the very high cost of the integrating stage (\$600) or the integrating ocular (\$700). The cost of the conventional ocular micrometer or the step micrometer, however, is of the same order as the cost of the Whipple disc. Other advantages mentioned by Schopf are that its use is conducive to a more specific written record of observation; that it can be used with any satisfactory pair of optics; and that its use is not limited by the number of components to which it can be applied (six in the case of the integrating stage or integrating ocular).

Choice of transect survey analytical apparatus, if not one depending upon cost of equipment, should be determined by the extent to which textural data in terms of small units is essential, that is, detailed analysis for proportional or continuous profiles, or whether total bench or bed averages are sufficient. Time is certainly a very important consideration in analytical determinations and it is believed that the six spindle integrating stage or integrating ocular can perform transect analyses more rapidly than is possible with ocular micrometers of any type. The range of choice between the Whipple disc and the other two types of ocular micrometers is a very narrow one, and choice is most likely to be based on the training and experience of the technician.

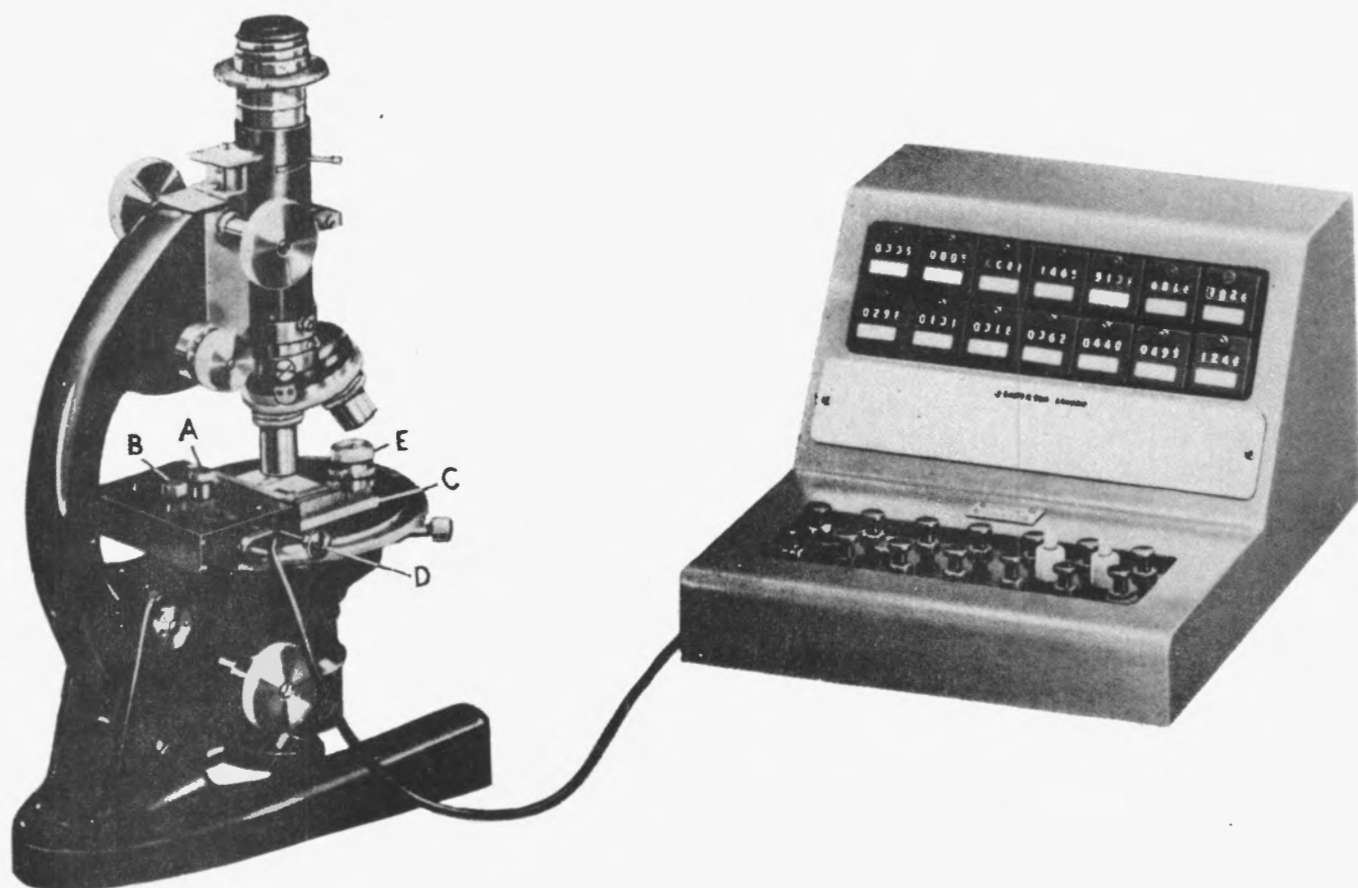


Fig. 15 - Point counter apparatus manufactured by James Swift & Son, Ltd., London, consisting of a point counter mechanical stage (with scales and verniers) with electrically actuated vertical traverse at 0.3 mm. steps and horizontal traverse with 1/3, 1/6, 1/10, or 1/20 mm. steps as specified when ordered. There is also a counting unit with 7 counters and 7 push buttons. This is equipped to operate at 200-250 volts but a transformer is available for 110 volts. Six counters are used to record six components; the seventh is used for mounting medium, holes, etc. The only coal petrology laboratory where this instrument has been tried is the Applied Research Laboratory, U. S. Steel Corporation, Monroeville, Pennsylvania, which reports that it prefers to use a simpler non-automatic design. The cost of the apparatus is in the order of \$300 (100-110 English pounds).

POINT-COUNT METHOD OF ANTHRACOLOGIC ANALYSIS

The use of the point-count system in profile analysis of coal columns or cores is practically restricted to modal analysis, which provides a statement of the composition of the total column, core, or particular portion of the coal bed under consideration. It can be applied to a thin section of usual size as a whole or to small polished blocks of coal of somewhat similar size. It is not practical for use in analysis of small units of such blocks requiring many counts in such an area. The results of the point-count analysis can be graphically shown in proportional bench or bed diagrams, but the analysis provides little or no information concerning the texture of the coal as indicated by coarseness or fineness of banding. The chief advantage in using the system lies in its relative rapidity for obtaining a close approximation of the modal composition of the coal.

American anthracologic laboratories using point-count procedures depend upon ocular micrometers for spacing along vertical transects and upon the mechanical stage for horizontal spacing; or in a few cases they have mechanical stages specially fitted with devices for automatically spacing the amount of advancement of the field of observation, using an ocular cross-hair for fixing the position of the center of the field. Much more elaborate apparatus of foreign manufacture is available, equipped with mechanical counters which reduce still further the time necessary for a petrographic analysis (fig. 15). One foreign instrument-maker (E. Leitz) also markets a mechanical stage equipped with point-count apparatus at a cost reported to be between \$100 and \$150.

CRITICAL CONSIDERATIONS IN POINT-COUNT ANALYSIS

It should be understood that in point-count analysis, irrespective of the area involved, it is the number of evenly spaced points counted that determines the degree of accuracy of the values obtained. Furthermore, the smaller the proportion of any critical component the larger the number of points it is necessary to count to obtain the same degree of accuracy for this component. For constituents comprising no more than 5 per cent of an area of coal about 5000 points must be counted to obtain an accuracy of 20 per cent. This degree of accuracy is not ordinarily required for very minor constituents. On the other hand, in the case of a constituent composing 40 per cent of an area, a count of 2400 points will assure an accuracy within 5 per cent about 95 per cent of the time.

If a mechanical stage equipped with a point-count device is used, steps may be in units of large or small fractions of a millimeter. It is reported (101) that the steps possible with the use of the point-count apparatus referred to above (fig. 15) are in the order of 50 to 100 microns ($1/20$ to $1/10$ mm.). The point-count steps possible with the special device attached to the mechanical stage are considerably greater than this, being commonly between 300 and 500 microns or $1/3$ to $1/2$ mm.

The procedure consists of making vertical runs on a polished block usually 3 to 5 centimeters in length and sufficiently wide to permit 10 to 20 parallel runs similarly spaced as the points on the vertical transect. Thus, there results a pattern of equally spaced points of sampling. If the block is five centimeters long this provides 150 points per vertical transect with points spaced at $1/3$ mm., or 1500 to 3000 points in all, depending upon whether 10 or 20 transects are run. An accuracy of within 7 per cent, on the basis of 1500 points, can be obtained from components composing about 35 per cent of the total area. For a component composing about 50 per cent of the coal, values for 95 per cent of the time should not vary more than $5-1/4$ per cent from accuracy; that is, they should be between $44-3/4$ and $55-1/4$ per cent if the true value is 50 per cent (fig. 9).

On the basis of 3000 points sampled, within 10 per cent of accuracy can be expected for a component making up 15 per cent of the coal. That is, the determined value may lie between 13.5 and 16.5. The number of points must be increased to the order of 10,000 where it is believed necessary to have an accuracy within 10 per cent for constituents occurring in amounts less than 10 per cent. In this case, the steps of the point-counter must be spaced at less than $1/3$ mm., or the area surveyed must be larger to permit more points at the $1/3$ mm. spacing.

Examples of Use of Point-Count System for American Coals

The only recorded study of the use of the point-count method of petrographic analysis of American coal is that made by Schapiro (102) of the Lower Kittanning coal bed. The analyses are based upon point counts along two vertical transects, using the Whipple disc for distributing the points at equally spaced intervals. The results were checked against those obtained by the use of the Bureau of Mines ribbon transect method of analysis (103), presumably along the same "ribbons"; and a fairly close agreement was obtained. However, had the points been distributed more evenly over the entire area of the specimen it is believed that the results would have been more representative of the actual percentages in the coal although the check with the ribbon transect might not have been as good.



Fig. 16 - Bands of clarain with 7 per cent (top), 12 per cent (center), and 27 per cent (bottom) of spore exines as determined by dot-count. Pittsburgh (No. 8) bed coal, block 2, column 604. (From reference 1: Cady and Smith, 1955, p. 26, fig. 5.)

Cady and Smith (104) recently used the dot-count method for determining the spore content as shown in a number of photographs of polished portions of the Pittsburgh (No. 8) bed coal (fig. 16). The analyses were made by using a template having 100 evenly spaced small dots per square inch. The results corresponded closely to those obtained by making equally transect surveys along 10 evenly spaced lines and comparing the length of a line representing the total width of spore exines crossed by the transect and the total length of the transect.

Use of Point-Count System in Profile Analysis

For coals of heterogeneous composition such as prevail in the interior of the United States from Pennsylvania and Alabama to Kansas and Oklahoma, it is believed that petrographic analysis of entire columns or of individual benches of such coal beds in terms of coal components measured at intermediate magnification (200 - 300 X) can be carried out by the point-count system to a satisfactory degree of accuracy, at least for some purposes. The relationships expressed by such analyses can be readily shown graphically but only as proportional bed or bench profiles. The point-count system does not provide the basis for constructing detailed step profiles in short units and, hence, does not reveal textural pattern.

SUMMARY STATEMENT RELATIVE TO PART 2

Part 2 has been concerned with coal bed description as revealed by bed profiles and analyses based upon transect measurements. Various types of profiles were described: megascopic bed profiles; proportional step profiles; pseudo-megascopic profiles, in which some microscopic data is included with the megascopic information; and microscopic profiles. Both the European and the U. S. Bureau of Mines profile systems were described.

In the second portion of part 2, various methods of measuring petrographic and microscopic entities were considered. Measurement of the microlithotypes, group macerals, macerals, constituents, and components were also considered. The various types of micrometers, including the Whipple disc, and the integrating stage were discussed, as was analysis by means of the point-count system. The latter method is useful in obtaining an over-all modal analysis of the column or core but provides little or no information about the texture of the coal bed, some idea of which is obtained from most of the other methods, except possibly the integrating stage.



ANALYTICAL PROCEDURES FOR BROKEN COAL

PRELIMINARY STATEMENT

The anthracologic or petrographic analysis of broken, that is fragmentary and granular coal, are of greater importance in the field of applied petrography than are profile descriptions and analyses. Yet the latter are of great importance as essential means for evaluating the effects of mining and preparation processes in terms of the petrologic composition of the coal. Without such information it is impossible to understand and evaluate petrographically the procedures and effects of preparation.

Information somewhat similar to that obtained from a profile analysis can be obtained from a petrographic analysis of a representative face sample of a bed like that collected for chemical analysis. Such an analysis is one variety of broken coal analysis. Determination of the average petrographic composition of a bed is probably more rapidly obtained from such a standard sample than by means of a systematic profile analysis. Unfortunately, this method does not provide the information concerning the texture of the bed, which is very important in planning coal preparation.

The petrographic analysis of broken coal has not been standardized. The method chosen will depend upon a variety of circumstances such as the size of the fragments; whether the fragments are loose or embedded in a mounting medium; whether observations are made on oriented or unoriented fragments; if mounted, whether they consist of polished blocks or thin sections; and upon the magnification used.

In general, when speaking of "broken coal," reference is to sizes not greater than 1 inch in maximum diameter. Pieces larger than this can be studied individually with traverses running vertical to the plane of the bedding. Coal fragments as small as 1/4 inch in maximum diameter can be mounted in wood-putty or plaster with a common orientation with respect to the plane of the bedding, but this requires considerable time. It is generally advisable to break down pieces 1/4 inch or more in diameter to a smaller size, at the same time producing the least possible amount of coal of less than 100 mesh. Such crushing is most effectively done by hand in a mortar, with frequent screening; a roller crusher with smooth rolls set at about 1/10 inch was used by Parks (195) with good results.

METHODS OF ILLUMINATION

Three methods of illumination are possible in the observation and analysis of broken coal depending upon how the material is handled. Unmounted coal fragments may be examined individually down to very small size under moderate magnification. Oblique illumination should be provided by a strong light directed onto the field from an oblique angle using a conventional microscope lamp unattached to the microscope. The small lamps that may be attached to the microscope rarely provide sufficient illumination. The fragments as seen in the microscope under such illumination have the general appearance of lumps of coal seen in a good light with the unaided eye. Identification of the coal will then be in terms of the banded ingredients or lithotypes.

The second method of illumination is that of vertical illumination as used in the study and analysis of polished surfaces of coal, with or without the use of immersion oil and oil immersion lenses. Such illumination is used to study polished surfaces of coal; that is, coal granules, mounted in wax, resin, or some other mounting media. The coal components are then identified from the appearance of surfaces of reflection, which vary from those from which reflection is nearly total to those from which there is little or no reflection, and hence appear gray to black. In general, reflectance of the maceral groups is least for the exinite, intermediate for vitrinite, and greatest for the micrinite. The amount of reflectance increases with the rank, but differences between the group macerals decrease with rank. The following data (106) show the general character of variations in reflectance in oil and water of vitrinite, exinite, and micrinite of two coals, one with a carbon content of 81.5 per cent and the other 91.2 per cent of vitrinite:

Carbon Per Cent Vitrinite		Reflectance (maximum)	
		Oil	Water
81.5	Vitrinite	0.67	7.91
	Exinite	0.13	5.71
	Micrinite	1.27	9.70
91.2	Vitrinite	1.64	10.63
	Exinite	1.64	10.63
	Micrinite	2.44	11.81

Since the carbon content of Ohio coals generally lies between about 79 and 84 per cent, it may be expected that there will be fairly high contrasting reflectivity between the macerals of the three groups.

Differences in form and outline will serve to identify the various macerals as well as differences in reflectivity. The appearance, however, is entirely different from that observed under oblique illumination.

The third method of illumination is by transmitted light and is only applicable to thin sections. It is possible to make thin sections of broken coal successfully if the coal is mounted in wax or resinous material, natural or synthetic, or if the coal is closely compacted under high pressure with the aid of an asphalt or pitch binder. This last procedure has not been used as much. Occasionally, it may be necessary to employ this technique to clarify uncertainties arising from the study of polished surfaces. Thin sections have the advantage of providing color as an additional basis for the identification of macerals (or phyterals). However, there are certain objections commonly raised against using thin sections of broken coal as a basis of analysis, particularly in the case of coal containing micrinite or opaque matter because the amount of opaque matter and degree of opacity is not based solely on surface occurrence and distribution. This effect may be produced equally well both by micrinite between the two surfaces of the thin section as well as by micrinite on the two surfaces. On polished surfaces only the micrinite on the one surface is seen and included in the analysis. Only procedures using oblique and vertical illumination will be considered in this report.

PARTICLE-COUNT METHOD OF BROKEN COAL ANALYSIS

Broken or granular coal can be analyzed petrographically in loose, unmounted, and unpolished fragments or granules by what is known as the particle-count method (105). In the studies made by Parks, the original samples of 1/2-inch x 8 mesh size coal were broken down by a roller crusher carefully set to a minimum distance between rollers of 0.10 inch, the amount of fine coal being kept at the lowest amount possible by frequent screening. The coal was then screened into 12 sizes from 8 - 10 mesh to minus 200 mesh. The standard procedure was to count the particles in lots of 100 on the stage of a Greenough-type ore-dressing binocular microscope until, in

general, about 1,500 pieces had been counted, using a laboratory counter with keys assigned to vitrain, clarain, durain, and fusain. Most of the mineral matter was previously eliminated by the use of a heavy liquid of 1.5 specific gravity.

"Small dissecting needles with modified points and fine-pointed tweezers were used to manipulate particles of coal and to move them out of the way when identified and counted. A Wetzlar-type microscope light with a 100-watt lamp was used. This light is so made that the amount of illumination in the microscope field can be varied by adjusting the focus. Three sets of ocular lenses 8X, 12.5X, and 18 X and five objective lenses 0.75 X, 1 X, 2 X, 3 X, and 6 X were used in the binocular to get the desired magnification" (105).

Since the illumination was oblique, particles were identified in terms of what are now designated as lithotypes, on the basis of difference in luster and structure as in the case of megascopic analysis of coal. The results obtained were essentially the same. Using the microscope, differentiation, even at the low powers used, could probably have been more discriminating than is indicated by a minimum threshold of 0.10 inch for vitrain.

The method of analysis is essentially one based upon megascopic criteria because of the character of illumination. The results are characterized by the same lack of critical discrimination that makes all megascopic analyses inadequate in petrographic description. Furthermore, the method is very laborious and time consuming.

The Ultropak (Leitz) and similar equipment provides a means of applying oblique illumination in the examination of coal at relatively high magnification. The usefulness of this apparatus for coal description and petrographic analysis has been very little explored in America. Stach (107) also reports that there is little use of this instrument in Europe for the study of polished surfaces of coal, although he regards it useful in the identification of certain minerals by their color, such as siderite and hematite. Further investigation of the possible usefulness of this type of equipment in coal petrology is desirable.

COAL PROFILE METHOD FOR COAL FRAGMENTS

The coal profile method is applicable to broken coal when the fragments are of sufficient size to set into plaster, wood-putty, wax, or some other medium that will harden, so that a polished surface can be produced which is perpendicular to the plane of the bedding. In general, such fragments should be at least one-quarter of an inch in minimum diameter. The fragments selected should be sufficient in number and selected so as to constitute a representative sample of the coal for which an analysis is desired. The petrographic analysis is then made piece by piece, using one of the methods described in the first part of part 2. A more accurate analysis would probably result if the coal sample were crushed to a smaller size than one-quarter of an inch and an analysis made of the representative sample mounted, polished, and analyzed by the method described in the following paragraphs.

ANALYSIS OF MOUNTED AND POLISHED BROKEN COAL OF GRANULE SIZE

For the microscopic or petrographic analysis of coal broken into sizes generally less than one-quarter of an inch in diameter, it is necessary that the coal fragments be embedded in some mounting medium such as Carnauba wax, or a synthetic plastic substance of which there is a large variety. The amount of coal should equal the quantity of the mounting medium by volume and the size of the resulting briquettes should be about 2 centimeters or a little less than one inch square and one-quarter to one-half inch thick. After mounting the coal, one of the larger two centimeter-square surfaces of the block is ground to produce a flat surface which crosses the fragments

of coal and this surface is then polished until the surface of the coal fragments is without scratches. A mounting medium is generally preferred which is slightly softer than the coal, so that the coal will stand in slight relief above the mounting medium. Carnauba wax has the desired hardness and is commonly used in western Europe. Also used are lucite, transoptic powder (108), castolite (109), and paraplex (110), the latter requiring a somewhat difficult to handle "accelerator" as well as a catalyst.

ANALYSIS WITH THE INTEGRATING STAGE

The integrating stage is the most satisfactory instrument to use for making petrographic analyses of mounted broken coal. In most cases it is unnecessary to measure more than the six constituents permitted by the available six spindles. The limit of vertical measurement is about two centimeters, hence the desirability of limiting the size of the mounts to this square dimension. There is no standard procedure for grinding and polishing the specimens of mounted coal (111). Each laboratory tends to develop by trial and error the polishing technique best suited to its personnel. The necessary result of the preparation is a highly polished scratch-free or nearly scratch-free surface.

The operation of the integrating stage (fig. 12) was described by Stach in 1949 (112) as follows: (transl.)

"The integrating stage is equipped with 6, in some cases 4, spindles, to each of which is assigned a particular petrographic component. Thus it is possible to measure each of the components vitrite, clarite, durite, semi-fusinite, fusinite, and bony coal (Brandschiefer). . . .

"All six spindles which are equipped with a scale and vernier, are started at zero. The polished block is so mounted on the supplementary stage that the horizontal cross hair in the ocular is parallel with the lower edge of the block and the vertical cross-hair is parallel with one side. By means of the extra thumb-screw on the supplementary or auxiliary stage, the specimen can be so adjusted that the horizontal cross-hair coincides with the margin of (first) granule of coal. Then the appropriate spindle is turned forward until the cross-hair coincides with the upper margin of the coal granule. The intervening mounting wax is now crossed by use of the extra thumb-screw on the supplementary stage up to the margin of the next coal granule, the thickness of which is then measured by the appropriate spindle. Thus there will be measured (by the spindles) only the width of the individual coal granules crossed in the vertical transect. With the completion of the measurement along this line the specimen is returned to its original position after loosening the set screws on the spindles, and it is then shifted two millimeters horizontally by the use of the transverse motion element. From this new starting position the individual structural components are measured as before along a line parallel with the first one. Thus 10 to 20 transects may be spaced over the entire width of the specimen and all particles of coal measured in terms of their appropriate categories. The total length of each type of components represents its volumetric contribution to the petrographic composition."

Although these directions describe the general procedure some additional explanation is necessary. A record of some kind must be kept on the total thickness of each of the components measured in each transect. This record is either in written form or made on a laboratory tally machine.

A second point to be noted is that after each transect is completed (approximately two centimeters) and the set screws are loosened, the specimen and auxiliary stage will spring back only to the amount that has been recorded by the spindles. Since it is desirable at the start of each vertical transect to return the specimen to the position where the lower margin of the mount coincides with the horizontal cross-hair, such adjustment must be made with the aid of the screw on the auxiliary stage. This adjustment will, of course, be the same as the total forward movement of this screw during the first transect. When the specimen is in this initial position it can then be shifted horizontally the predetermined distance separating adjacent transects preparatory to the next transect.

These directions amount to stating that once the upper or lower margin of the mount is carefully lined up with the horizontal cross hair and the position noted on the auxiliary stage vernier scale, the specimen is always turned back to this position before a new traverse is started. All spindles should be in a zero position and set screws tightened before starting a new traverse.

A third point for consideration concerns the limited capacity of free vertical motion allowed by each spindle. Actually each spindle moves forward in steps of only six millimeters. When a spindle has moved through this distance, either from 0, from 6, from 12, or from 18 mm., no further movement is possible without loosening the set screw. This will allow the auxiliary stage holding the specimen to snap back six millimeters towards its original position. It will be the original position only if the forward motion of the single spindle is all that has been applied. In order to continue measurement from the exact point reached in the traverse when the set screw was released, the auxiliary stage and specimen must be moved forward exactly six millimeters by the use of the thumb-screw on the auxiliary stage. In some instances the field has sufficiently characteristic features so that the extreme position reached can be recognized, but generally only by very careful manipulation can overlapping or omission be avoided.

It may be possible, with some practice, to so control the movement of the auxiliary stage that the movement resulting from the spindle release can be balanced by a forward movement controlled by the screw on the auxiliary stage. In this way the critical position in the specimen is kept continuously in essentially the same position in the field. However, it would probably save time and cause no great error to depend solely on the precision of the instrument to recover the six-millimeter backward motion. This can be accomplished with reasonable accuracy by the use of the screw on the auxiliary stage.

After the six-millimeter adjustment has been made the spindle set screw will stand out on its shaft six millimeters from its original position and should be tightened at this position. The spindle will now continue to move forward until it reaches twelve millimeters when the same sort of adjustment must be made. It can then move forward to 18 millimeters where a third adjustment will have to be made, but it can not move more than two millimeters beyond 18 millimeters. Any effort to produce a movement beyond 20 millimeters by turning the spindle forward will produce no movement in the auxiliary stage to displace the specimen in the field. Instead, it will be found that one of the set screws will be forced away from its position, but not necessarily the one on the spindle being turned. It will probably be the one most loosely fastened. This situation should not ordinarily arise if the limitations on the dimensions of the mount to 20 millimeters square are systematically adhered to.

Because part of the distance across a 20-millimeter square mount consists of passage across the mounting medium, which is usually made with the aid of the auxiliary thumb-screw, the individual transect may be completed without the readings on the spindles reaching a total of 20 millimeters. Even so, the set screws are released after the distances have been recorded, and the auxiliary stage is set back to zero and spindles also returned to zero. The specimen should then be in its initial position ready to be shifted laterally the selected transect interval by the thumb screw on the integrating stage provided for lateral movement, preparatory to the next traverse survey.

Should the number of items selected for measurement permit, one spindle may be assigned to record the thickness of the mounting medium, then the entire motion of the specimen will be spindle motion and should advance regularly in steps of six millimeters for the several spindles. In this case, proportions for the coal components will have to be adjusted to eliminate the distance represented by the mounting medium.

The method of tabulating integration stage data has been explained by Kùhlwein, Hoffman, and Krùpe (113), by Stach (114), and more recently by Mackowsky (115) whose paper is the source of the example given in table 6 (see also table 5).

Mackowsky, in the same paper (116), outlines the general procedure of broken coal analysis (granules less than 0.75 millimeter (1/32-inch) employed at Essen, as carried out in terms of microlithotypes vitrite, clarite, durite, fusite, intermediates (duroclarin, clarodurain, and vitrinertite grouped together), and bony coal

(Brandschiefer). Presumably, mineral matter is eliminated by gravity separation before the coal is mounted, leaving six items for measurement by the integrating stage. Each granule is classified on the basis of its composition as a lithotype, that is, as an association of macerals, hence as a unit. Any granule consisting of 95 per cent vitrinite or inertinite is classified and measured as vitrite or fusite. If the granule as a whole consists of less than 95 per cent of vitrinite or inertinite (fusinite), it is classified as clarite if it consists only of the two macerals vitrinite and exinite or as durite if it consists only of exinite and inertinite. All other associations are classified as intermediates (duroclarain, clarodurain, and/or vitrinertite) (see fig. 1).

Granules less than two divisions in width (20 microns) on the spindle vernier are ignored as unimportant and too difficult to measure and classify. If a single granule crossed by the transect extends beyond the boundary of the field the specimen should be moved sufficiently so that it can be measured as a unit. (Presumably, it should not be measured twice, that is, in both of two successive fields.)

The procedure falls considerably short of precise designation of the composition of the large percentage of coal that is probably intermediate in character, since they contain all three group macerals in amounts greater than five per cent. The method of classification on the basis of triangular relationships suggested by Ammosov (fig. 13) provides the means of more precise description, but rapid measurement of the different varieties by means of the integrating stage would probably not be within the capacity of that apparatus.

ANALYSIS AS RELATED TO ORIENTATION OF GRANULES IN BROKEN COAL

The most common practice in making transect surveys of mounted specimens of coal granules is to base measurements upon the random orientation of the particles with respect to bedding. There are, however, those who believe that for certain purposes an orientation with respect to bedding is necessary for the determination of particular relationships. Analysis based upon both procedures will be considered since inquiry into methods is of special concern.

ANALYSIS OF ORIENTED PARTICLES

The analysis of oriented particles involves the measurement of each granule in a direction perpendicular to the line of the bedding (117). This requires that in a transect measurement each particle of coal encountered in the transect must be rotated so that measurement through or across the particle is at right angles to the line of bedding. This must be done on a rotating stage equipped with a mechanical stage of such a character that the object under the cross-hairs will remain at that position when the stage is rotated. The traverse cannot be made with the integrating stage because this provides no means for rotating the specimen, hence measurements must be made with an ocular micrometer. As long as the granule being measured lies within the distance covered by the ocular micrometer, measurement can be made by turning the micrometer in the ocular at right angles to the line of the bedding. If the width of the granule exceeds the length of the micrometer scale, since movement of the specimen can only be vertical, it is necessary to have the specimen mounted so that it can be rotated with respect to the point of contact of transect line and margin of granule where measurement started. If the center of the rotating stage does not coincide with the center of the field, as indicated by the cross-hairs, it is then necessary to employ a set of two stages, both equipped with a mechanical stage. The upper stage is round and can be rotated to move the specimen from granule to granule. The lower stage moves the oriented granule so that it can be completely measured by the ocular micrometer.* The procedure is laborious and very time consuming.

* An arrangement, so far as known, used only by and constructed especially for the Illinois Geological Survey by the Survey mechanic, Mr. A. W. Gottstein.

This is the procedure recently employed by Marshall and Draycott (117, 118) in obtaining what they designate "micrometric" analyses of coal. The method is used as a means of determining the thickness of individual constituents perpendicular to the bedding. The data collected by Marshall and Draycott are usually in terms of lithotypes or may be in terms of group macerals vitrinite, exinite, and inertinite. The information is related to texture with the idea that size of the constituents or macerals may have some influence on behavior in coking. A recent report of the Illinois State Geological Survey (119) points out certain relationships that appear to exist between size and association of the group macerals and the behavior of the coal in laboratory coking tests. Data were collected not only with respect to the proportionate amount of each group maceral but also concerning the thickness (mean) of these macerals per sample examined. This latter information provided some idea of the texture of the coal as expressed in the granules, rather than in the bed itself, although this was also determined by microscopic profile analysis. The possibility that texture or fabric as well as modal composition may exercise an important influence upon the behavior of coal when heated, as in the coke oven, merits consideration and is probably at the root of the classification of coal into microlithotypes in units of 50 microns by the European anthracologists. In general, however, Marshall makes discriminations in units as small as four microns (see reference 118).

The value of making measurements perpendicular to the bedding in order to obtain more accurate thickness is invalidated to a certain extent by the impossibility of orienting the granules so that the measurement will actually be made perpendicular to the bedding. The best that can be done is to orient them to run at right angles to the intersection of the plane of the bedding with polished surface. For granules in which the plane of the bedding is parallel with the polished surface, no suggestions as to the evaluation of thickness are produced.

Orientation, furthermore, tends to vitiate the assumptions as to the accuracy of measurement of volumes based upon random orientation. It is doubtful, therefore, whether reliable modal analysis can be obtained from the measurement of oriented fragments. In either case actual measurements will be too large, but proportions would probably be more reliable based upon unoriented measurement.

ANALYSIS OF UNORIENTED PARTICLES

The integrating stage has become the most favored instrument for obtaining petrographic analyses of coal by transect measurement. Such an analysis is carried on most commonly without attempting to orient the individual granules so that measurement is at right angles to the line of intersection of the bedding with the polished surface. This procedure is based upon the assumption that the random orientation of particles will provide measurement along vertical transects which can be regarded as equivalent to volume in estimating volumetric proportions, as demonstrated by Rosiwal (69) and explained by Hock (120). The integration stage method of modal analysis, having already been described in some detail (p. 52-54), need not be considered further.

POINT-COUNT METHOD OF ANALYSIS OF BROKEN COAL

It is believed that the point-count method (see p. 45-47) is an appropriate procedure for petrographic analysis of coal granules as it is much faster than any of the methods previously described. It is sufficiently accurate for the purposes for which analyses made by the aid of the integration stage are usually used. If it is permissible for the amount of a component making up about five per cent of the surface of the mounted specimen to vary as much as about 15 per cent (from 4.25 - 5.75 per cent) without appreciably affecting the characteristics of the coal, then by reference to the fiducial chart (fig. 9) it will be found that the necessary number of points to achieve this degree of accuracy is about 3,500. There are 400 square millimeters within an area of 20 millimeters square, therefore, 9 to 10 points per square millimeter would be more than necessary for the desired accuracy.

Using a Whipple disc with an optical arrangement (8 X ocular, 16.5 objective) so that the field of the disc is approximately $1/3$ mm. square, there would be nine fields per square millimeter. It would be necessary to select the same point, such as the center, in every field on the point of observation to be counted as this would provide 3,600 points for the entire 400 square millimeters. This would, require manual shifting of the Whipple disc over the entire mount, probably by a series of ribbon transects. The analytical data should be accumulated on some type of laboratory counter.

If the mount is carefully made so that the coal and wax or plastic are in known proportions, the results should compare closely to those obtained with respect to the proportion of the mounting medium.

Use could be made of the conventional ocular micrometer or the step micrometer instead of the Whipple disc. In this case the position of the vertical transects would have to be spaced evenly at $1/3$ mm. steps, using the lateral motion of the stage micrometer.

If the mechanical stage is equipped with a point-count device, so that the vertical movement is in steps of $1/3$ mm. and vertical runs are made every $1/3$ mm., again 3,600 points would be counted. It would be desirable, in this case, to use a simple cross hair to fix the position of observation. It should be evident that the 15 per cent probability of error applies only to those components that are present to an amount of about five per cent. Components present in considerably larger amounts are more accurately determined. Thus, for a component making up 40 per cent of the sample, there is a statistical error of less than five per cent in 95 per cent of the cases.

Making 3,600 counts with the aid of a point-count equipment on the mechanical stage is accomplished in a much shorter time than is possible using one of the ocular micrometers or the integration stage. It appears to be the answer to the problem of devising some relatively rapid method of petrographic analysis of coal.

In determining the number of points necessary to count in making a point-count analysis of a mounted specimen of coal granules, the amount of mounting medium present must be taken into consideration. The mounting medium should be about equal to the amount of coal by volume. Hence, proportions of a critical component in the mounted specimen will be half those in the coal itself. This will considerably increase the required number of points to be counted to achieve a desired degree of accuracy for the coal material as determined from the fiducial graph (fig. 9).

APPLICATION OF ANTHRACOLOGICAL ANALYSIS IN GEOLOGICAL AND PRACTICAL FIELDS AND SELECTION OF METHODS

GEOLOGICAL APPLICATIONS

It has been repeatedly stated in this report that the analytical method employed in anthracologic profile and modal analysis depends upon the purpose for which the analysis is made and the nature of the values sought. The uses of such a coal analysis may be to fulfill geological purposes or to satisfy the need for information in the field of coal utilization.

Information concerning the petrographic or microscopic composition of coal has geological significance in two ways. One has to do with the origin of coal and the character and effect of metamorphism (carbonification) (121), as revealed by the nature and physical characteristics of the constituents, components, lithotypes, micro-lithotypes, and macerals. No thorough understanding of the nature of coal, coal formation, and coal metamorphism is possible without a knowledge of the nature of plant materials which contributed to the formation of coal so far as they are revealed by the composition of the coal.

The second way in which petrographic information has significance from a geological point of view is in connection with the problems of stratigraphy and correlation. As shown by Kosanke (122 and many others, plant fossils, such as spore coats, found in coal beds serve individually or in characteristic associations as key fossils in stratigraphic correlation. Not only plant fossils but coal bed profiles and profile analyses may be useful in coal bed correlation and identification (see p. 59), as well as providing a better understanding of the local and regional variations in the composition of an individual coal bed.

COAL BED PROFILES PUBLISHED BY THE U. S. BUREAU OF MINES

MICROSCOPIC BED PROFILES

There has been no systematic effort made to assemble an archive of detailed coal bed profiles for this country. Comparison is limited to the profiles of relatively few coal beds and these were prepared in accordance with the system established by the U. S. Bureau of Mines as shown in the accompanying chart (fig. 17). This chart, reproduced from technical papers of the Bureau of Mines (123), shows nine detailed proportional graphic profiles of coal beds in Alabama, Virginia, West Virginia, western Kentucky, and southern Illinois. The profiles are shown proportionally in steps, each step representing the thickness of a thin section or about two centimeters.

Construction of the Bureau of Mines Microscopic
Proportional Bed Profiles

The profiles reproduced in figure 17 are presented on the same vertical scale and are based upon certain criteria for the differentiation and measurement of the four types of constituents (see also p. 30). The extent to which these criteria prevailed at the time the earlier profiles were constructed is not known as they were not stated in the publications, but they seem to have been definitely adopted fairly early in the series. The most important of these concerns the minimum threshold for anthraxylon at 14 microns and for fusain at 38-39 microns (124). Anthraxylon and fusain of lesser dimensions and all other material except mineral matter was identified as either translucent or opaque attritus. In the case of the Mary Lee bed (No. 519) anthraxylon and fibrous anthraxylon were differentiated, the latter being between 0.2 mm. (200 microns) and 14 microns (0.014 mm.). All anthraxylon-like material less than 14 microns was included in the attritus.

The constituents were plotted individually by percentage on a mineral-matter-free basis by volume. Initially, the data were assembled in tabulated form and these tables were printed in many of the earlier papers. The graphic profile was a device for showing the tabulated results pictorially but the practical or even academic significance of the "picture" was not specifically pointed out. Indeed, the graphic profiles appeared to have insufficient importance to warrant their use in systematic comparison of different coal beds or to establish the general use of such profiles for coal bed comparison, correlation, or practical evaluation. Furthermore, there was insufficient interest in the profiles to determine the extent to which a particular profile was actually representative of the bed from which the column was taken.

MEGASCOPIC BED PROFILES

The microscopic profile, which has been described, was accompanied by a megascopic profile based upon luster and texture. Coal was regarded as banded and non-banded. Banded coal has a bright or dull luster, and contains more than five per cent of anthraxylon (see p. 11). The texture of the bright banded coals was determined mainly by the thickness of the anthraxylon bands (125): "When the anthraxylon in a coal consists of bands over 2 mm. (0.08 in.) in thickness, arbitrarily chosen, it is said to be coarsely banded; where of medium thickness (between 0.2 and 2 mm.) it is said to be finely banded; and when less than 0.2 mm. (0.008 in.) it is said to be micro-banded."

Thus, we find that bright banded coal is described as coarse, medium, and microbanded for various parts of the bed. Splint coal, which is a banded coal, can be differentiated only on the basis of its content of opaque matter, which is determined only microscopically. Whereas the petrographic or microscopic profile provides no satisfactory accurate means of classifying the bright banded coal, the profile (or the tabulated data upon which the profile is based) provided the only means of classifying the dull banded coals as semisplint or splint coals. Coals are not regarded as being of the splint type until the amount of opaque matter reaches 20 per cent and coals with 20 to 30 per cent opaque matter are designated as semisplint coal. Above 30 per cent of opaque matter, the coals are called splint coals. Although semisplint and splint coals may contain considerable amounts of vitrain and, hence, are more or less banded, no differentiation of these coals on the basis of width of banding or texture seems to have been made.

One other basis of classification has been used, at least in the case of some of the graphic profiles. For certain units of the bed, generally corresponding to the microscopic units described above, the coal is classified on the basis of the relative percentage of anthraxylon and attritus. Thus, coals are classified as anthraxylous, anthraxylous-attrital, and attrital, according to the following relationships (126):

<u>Subtype name</u>	<u>Ratio of anthraxylon to attritus</u>
1. Anthraxylous	Greater than 3 : 1

T. P. 524
HERRIN NO. 6
ILLINOIS

542
CHILTON
WEST
VIRGINIA

562
ALMA
WEST
VIRGINIA

519
MARYLEE
ALABAMA

548
NO. 2 GAS
WEST
VIRGINIA

570
CLINTWOOD
VIRGINIA

630
POWELLTON
WEST
VIRGINIA

628
BELL NO. 1
WESTERN
KENTUCKY

634
LOWER HIGNITE
EASTERN
KENTUCKY

VOL. MAT.
(A & M FREE)

39.5%

38.8%

41.6%

31.4%

36.6%

33.9%

35.0%

36.0%

40.1%

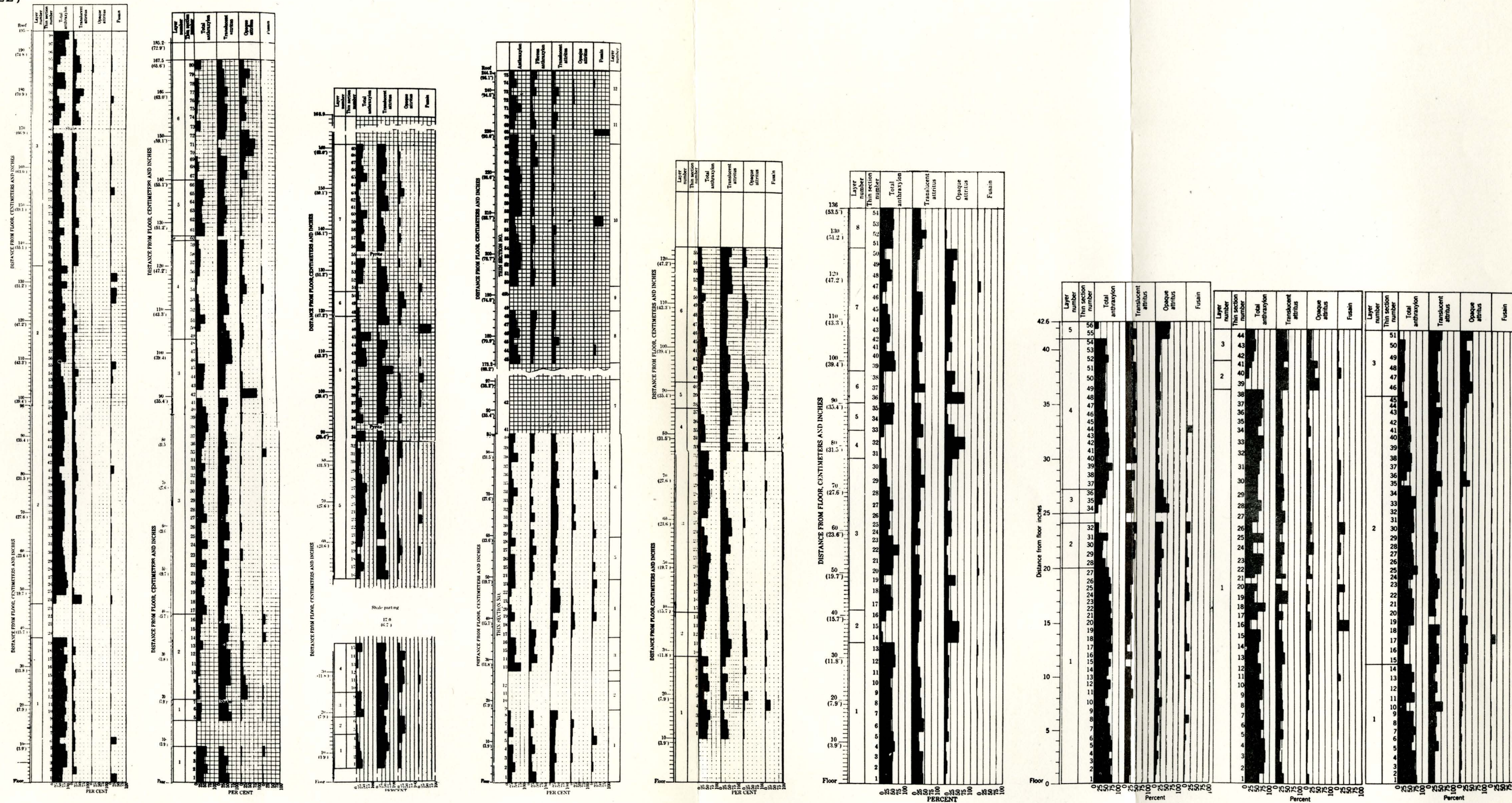


Fig. 17 - Graphic proportional step profiles of nine columns of American coal beds showing proportional contents of anthraxylon, translucent and opaque attritus, and fusain by thin section units (about 2 cm). Original illustrations in U. S. Bureau of Mines Technical Papers, with numbers given at top of each profile.

- | | |
|------------------------------------|-----------------|
| 2. Anthraxylous-atrital | 3 : 1 to 1 : 1 |
| 3. Attrital-anthraxylous | 1 : 1 to 1 : 3 |
| 4. Attrital | Less than 1 : 3 |

These relationships depend upon microscopically determined data. They can be roughly worked out by use of the graphic profiles but are more conveniently done by means of the tabulated data, if the data are available. The main value of such classification appears to be that it gives some idea of the distribution of vitrain in the various parts of the bed where it is present in fairly thick bands. This could be shown graphically for each thin section step by means of a continuous line running from the top to the bottom of the profile as done by Hacquebard (127) and Maurenbrecher (128).

EVALUATION OF THE U. S. BUREAU OF MINES TYPE OF PROFILE

Although little use has been made of the Thiessen-type profile, a consideration of its possible usefulness is pertinent to the present discussion now that a considerable number of these profiles are available for comparison. Usefulness in both the academic and practical fields will be considered.

Field of Geology

Graphic proportional step profiles have at least two interrelated possibilities of usefulness in the field of geology. They are a possible aid in the identification and correlation of coal beds, assuming that the available profile is actually representative of the petrographic sequence of the bed. Unfortunately, there are too few profiles of the same bed to be certain that the one available is actually representative. Bed profiles, even in the generalized form such as those produced by the Bureau of Mines (fig. 17), show conspicuous differences and suggest the possibility of their usefulness for identification and correlation, but by no means proves it.

The other possibility of usefulness in the geological field is in working out the depositional history of a coal bed, but depends upon the possibility of using such profiles in correlating the coal bed, bench by bench, over a considerable part of the area in which the bed is present. This procedure requires systematic collection of column or core samples and the similarly systematic preparation of coal bed profiles throughout the area of study. Such detailed studies of what may be called the parallelism (parallelization) of coal beds of the Netherlands have been made by Hacquebard (59) and by Maurenbrecher (128). Their work was based upon up to 25 bed profiles of the beds studied. The conclusions reached were based upon the assumption that the composition of the coal in terms of its content of coalified wood (anthraxylon, vitrain, fusain) on the one hand and the more resistant components represented by durain, opaque matter, waxes, and resins, on the other, was largely determined by the height of ground water level and the toxicity of the water; as pointed out by White (129) and recently reiterated by van Krevelen and Schuyer (130).

The argument is that only under conditions of relatively low ground-water level, when the surface is not flooded or not deeply flooded, can forest trees flourish, such as those that supplied the wood from which anthraxylon (vitrain) and fusain were derived. The presence of fusain, particularly such as occurs in extensive partings and bands, indicates that not only were trees an important component of the vegetation, but that the swamp surface was from time to time at least sufficiently dry for the formation of fusain as charcoal from forest fires or by oxidation.

Not only did the height of the ground-water level in the swamp determine the character of the vegetation, but the toxicity of the water that was present determined the extent to which such vegetation that fell to the surface and was covered by the water of the swamp decayed through bacterial action. Under conditions of low toxicity, where the water could become aerated by movement, decay would be extensive with the resulting

concentration of the more chemically inert substances such as waxy materials and opaque substances which might include disintegrated fusain. On the other hand, under conditions of stagnant drainage and high toxicity, even the wood material might be little affected by bacterial decay and by relatively rapid burial become preserved in the coal bed.

On the basis of such considerations, Hacquebard was not only able to trace and map the extent of distribution of individual benches in the four coal beds, but was able to differentiate coal bed from coal bed on the basis of petrographic profiles. He emphasizes the importance of numerous profiles.

Special Consideration of the Application of the Selected Bureau of Mines Bed Profiles to the Field of Geology

Inspection of the profiles reproduced in figure 17 finds very definite differences. If there was good evidence that the profiles shown are truly representative of the particular beds indicated, the distinctive characteristics of each might profitably be considered. Since this is not the case, only major differences need to be pointed out.

The Herrin No. 6 coal bed of Illinois (Profile No. 524), is distinctive in its relatively high vitrain content and a correspondingly low translucent attritus content. There are fairly thick bands of fusain at some levels. Megascopic description indicates that this is bright, coarse-banded coal with a faint indication of some semifusain in the upper few inches of the bed. Between the first and second benches is an extensive layer of shale known as the "blue band." This shale is 2 to 4 inches thick and represents a distinctive portion of this coal bed.

The No. 2 Gas, Clintwood, Powellton, Bell No. 1, and Lower Hignite beds (Profiles 548, 670, 630, 628, 634), are characterized by containing a considerable amount of semisplint or splint coal, that is, with opaque attritus in amounts greater than 20 per cent. The position in the bed profile of layers with critical amounts of opaque attritus varies from bed to bed, but this may be more or less characteristic for the individual bed. This would also provide a basis for identification and correlation.

Both the Bell No. 1 and the Powellton bed (Nos. 628 and 630) have a relatively high content of fusain. If this were characteristically distributed in the two beds, it would be an additional aid to correlation.

Of the remaining three beds, the Mary Lee (No. 519) has a prevailing low content of translucent attritus in the upper part of the bed, which is described megascopically as bright and coarse-banded, whereas the lower part is predominantly fine or micro-banded. This is the only column profile in which anthraxylon and fibrous anthraxylon are differentiated. The amount of "total anthraxylon" is markedly less in the lower than in the upper part of the bed. The Chilton bed (No. 542) has a fairly high content of opaque attritus in the upper half, hence, is designated as "splinty," whereas there is relatively little opaque attritus in the lower half except in layer No. 2 which is mainly semisplint. The Alma bed (No. 562) is characterized by a very uneven occurrence of anthraxylon and by scattered, fairly thin benches of semisplint and splint coal.

The characteristics displayed by some of the profiles are sufficiently distinctive, if they hold for the beds as a whole or even for considerable areas of the bed, to be useful for identification and correlation purposes and also for working out the geological history of deposition and preservation.

When it comes to the problem of working out the details of what the Europeans call "parallelization" of a coal bed, the bedded or benched character of some of the coal beds shown in figure 17 suggests many details of coal bed history that might be worked out if there were an adequate number of bed profiles available for individual beds. However, it might be necessary to base such profiles upon somewhat different criteria than those used by the Bureau of Mines. On the basis of the theories advanced by White, it would be necessary to recognize criteria which would enable systematic differentiation of material resulting from a low ground-water table with ground-

water of high toxicity from material resulting from a high water table with ground water or open water of low toxicity.

Consideration would have to be given to the category of coal material into which translucent attritus should be placed, and whether all or only part of this material and of opaque attritus represents the residue of disintegration under conditions of low toxic decay. Thiessen very definitely places materials constituting attritus in the category of substances which are "macerated and comminuted through the agencies of micro-organisms, lower forms of animal life, and weathering, and subsequently consolidated and changed into coal" (131). On this basis differentiation should be made between anthraxylon combined with fusain on the one hand and all attrital matter on the other. For this purpose a form of profile, totaling 100 per cent, with fusain and anthraxylon on the left and attritus differentiated into translucent and opaque on the right, might be more useful than the forms having the arrangement now in general use.

PRACTICAL SIGNIFICANCE OF THE BUREAU OF MINES BED PROFILES

The idea that the coal bed profiles shown in the Bureau of Mines publications might be of practical value seems to have received little or no consideration by the Bureau. No attention was given to this possibility in three important publications where it might have reasonably been expected: namely the opening bulletin of the American Gas Association cooperative research series (132); a later publication by Thiessen and Sprunk (133) describing the general character of the microscopic procedures; and, finally, in article by Sprunk (134) discussing the influence of physical constitution of coal upon its chemical, hydrogenation, and carbonization properties.

The information shown graphically in the graphic profiles may have been used as a basis for subtype classification as given on p. 58-59, but tabulated data might have been used equally well without reference to the graphic profiles.

This lack of use of graphic, proportional step profiles does not necessarily mean that practical use cannot be made of them. One of the more obvious uses is the determination of the location, distribution, and amount of opaque matter in the bed as determined microscopically by the use of thin sections. This is a matter of importance in the use of coal in coking and particularly in hydrogenation (135). In the case of the nine graphic profiles shown in figure 17 the coal beds containing bands or benches of splint or semisplint coal in important amounts are readily identified as 542, 570, 630, 628, and 634. Nos. 524 and 519 are non-splinty, bright-banded coals indicated by the large amount of anthraxylon as well as the low content of opaque attritus. The presence of bands of splint in several of the coal beds makes it very probable that in the preparation process there might be a fairly good separation by size of the bright and dull coal because of the difference in toughness of the two varieties.

As previously pointed out, graphic microscopic profiles do not make provision for any differentiation of the attrital material other than that between opaque and translucent attrital matter. This makes it impossible to use them for differentiation of coals with high from those with low resinous or waxy content. They do give information in regard to the amount and distribution of fusain, which is of importance in planning preparation procedure, particularly with respect to elimination of dust.

Schopf (136) has recently compiled lists of applications of coal petrology in geology, mining, and technology. He suggests 38 applications, many of which are based on data provided by coal bed profiles of the Bureau of Mines type and a number on broken coal analyses.

USEFULNESS OF GRAPHIC PROFILES OF THE OHIO SURVEY TYPE

The four megascopic graphic proportional profiles shown in figure 18 represent four important coal beds of Ohio: No. 9 (Meigs Creek), No. 8 (Pittsburgh), No. 6 (Middle Kittanning), and No. 4-A (Clarion). Differentiation is based roughly on lithotypes or banded ingredients with the minimum width of vitrain set at 0.5 millimeter, and clarain subdivided into bright, medium bright, and dull. The dull clarain is essentially dull coal or durain. The classification is based entirely on megascopic criteria, so that it is not possible to demonstrate whether the durain or dull coal owes its dullness solely to the lack of vitrinite, or in part also to the presence of inertinite in some form, or to a high exinite content.

GEOLOGICAL USEFULNESS

The general usefulness of profile construction has been presented on an earlier page (p. 17). This depends, for the most part, upon the detail with which the petrographic composition is and can be graphically portrayed. Little more can be provided on the basis of megascopic criteria than is provided by differentiation into the four lithotypes, pyrite, and other mineral matter. If the minimum threshold of vitrain is placed at 0.5 millimeter, clarain must then be subdivided into that which is bright and that which is intermediate in luster, with the possibility of a more refined subdivision as proposed on page 18. Dull striated coal is designated durain, but whether dullness is owing simply to lack of microvitrain, to presence of opaque matter (micrinite or other inertinite), to exinite, or to mineral matter, cannot be determined megascopically, although a float-and-sink separation at 1.50 specific gravity would probably provide a quick solution to the problem of mineral matter. Of the profiles shown, that for the Meigs Creek coal bed is one of seven summary profiles of this bed (137). The other three beds are represented by only two profiles each. The seven profiles of the Meigs Creek coal bed have a general similarity primarily in the scattered occurrence of a fairly large quantity of thin bands of vitrain. Two of the seven profiles are from localities somewhat remote from the general region in Noble and Morgan Counties, where the other five columns or cores were obtained, and are characterized by a common similarity of low vitrain content (138). This suggests a regional variation in conditions of accumulation. There is considerable similarity in the two profiles of the Clarion coal bed for both are fairly high in dull coal. Both are from the same general region in Jackson County. The areal distance separating the two columns of Middle Kittanning coal and the great difference in thickness of the coal bed at the two collecting sites, precludes any expectations of similarity in profiles. The two columns of Pittsburgh coal lacked similarity for these same reasons. The petrographic composition is not provided by megascopic observation in the detail necessary for parallelism studies such as have been made by Hacquebard (59) and by Maurenbrecher (128) for the coal beds of the Netherlands.

PRACTICAL USEFULNESS OF THE OHIO SURVEY TYPE OF PROFILE

The summary type of profile shown in figure 18 is not directly comparable with the Bureau of Mines type of profile (fig. 17) because the latter is based upon a more discriminating differentiation made possible by microscopic observation. For these latter profiles, other than the division of the bed into obvious benches or subdivisions, no profile is undertaken until the thin sections have been examined microscopically. It is thus possible to classify the dull coal microscopically as bony coal or as splinty coal in case it contains a considerable amount of opaque matter. On the other hand, the type of profile shown in figure 18 has some advantage in that it records only vitrain which is more than 0.5 millimeters thick, the microvitrain being included with the clarain, and particularly with the bright clarain.

For practical considerations, assuming that the four summary megascopic profiles (fig. 18) are truly representative of the four coal beds at the localities where the samples were taken and represent the occurrence of the megascopic lithotypes, mineral matter, and pyrite, they provide some idea of the possible behavior of the coal in the preparation process. In general, it is probably correct to assume, barring the presence of an unusual

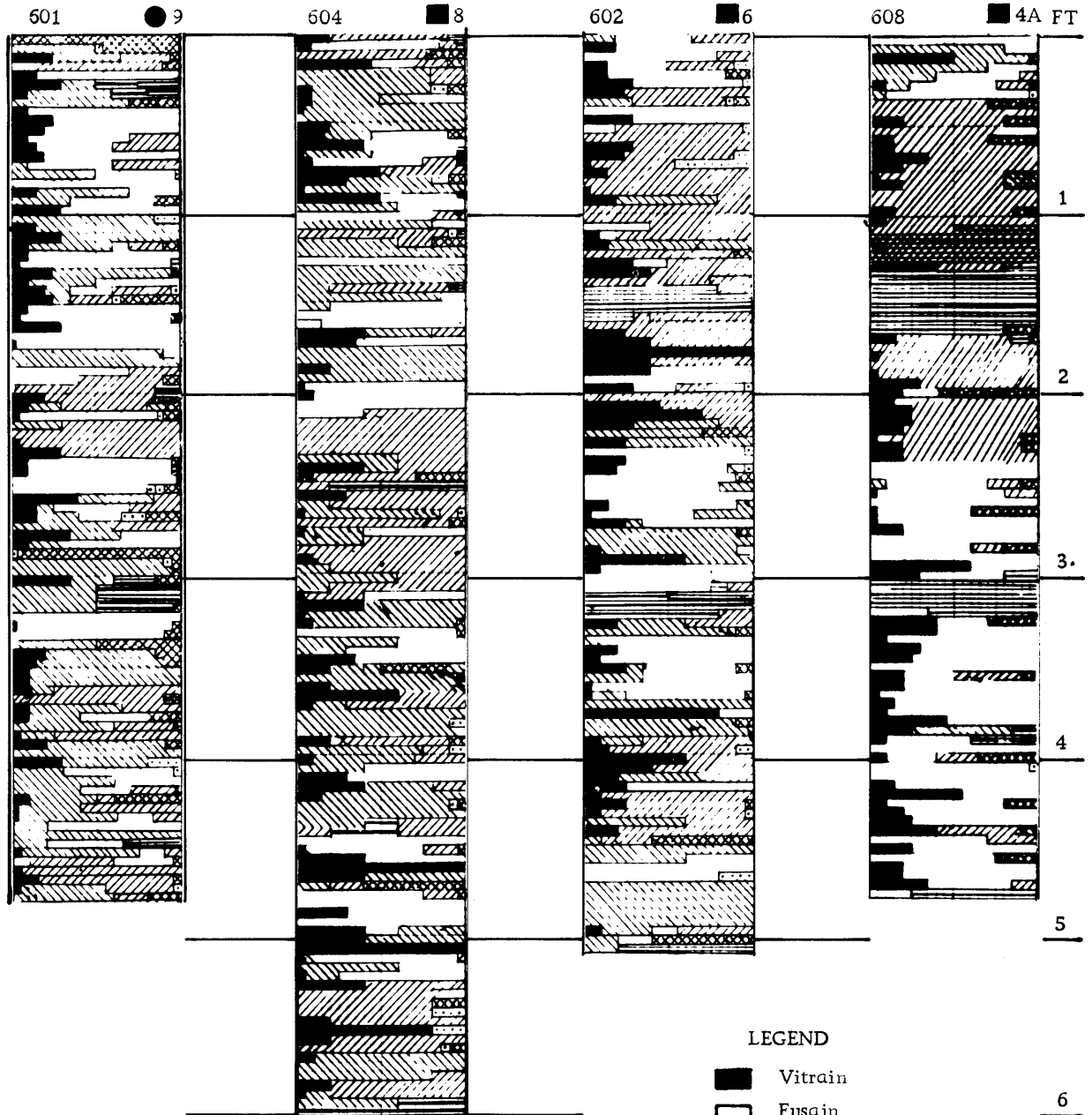


Fig. 18 - Summary megascopic profiles of four Ohio coal beds in one-half-inch steps: Meigs Creek (No. 9), Pittsburgh (No. 8), Middle Kittanning (No. 6), and Clarion (No. 4A) beds. (From Ohio Division of Geological Survey Report of Investigations 27, pl. I).

amount of disseminated pyrite, that coarseness of texture and wide variation in hardness and friability of individual bands will be conducive to the segregation of the softer and more friable lithotypes in the finer fractions of the prepared coal and of the harder, tougher lithotypes in the coarser fractions. On the other hand, if the coal is predominantly thin banded, even though the bands may vary from bright to dull and from tough to friable, the coal is less amenable to segregation by size on the basis of friability.

Of the four coals represented in figure 18, the Meigs Creek (No. 9) coal bed has the aspects of a relatively fine banded, bright coal with considerable finely, interlaminated, dull coal. It seems probable that in preparation coal of this type would result in a relatively low degree of segregation between fine (bright) and coarse (dull) coal sizes. The Clarion coal, on the other hand, is in sharp contrast, having a relatively coarse texture with respect to both vitrain and dull coal bands and, therefore, it might be expected to produce sharp differences in the petrographic composition of the coarse nut and fine sizes. In general, good possibilities of differential segregation by size seem to be indicated for both the Pittsburgh and Middle Kittanning coal bed profiles.

These general statements are made with full realization that disseminated pyrite will do much to interfere with the expected performance, since its presence will greatly enhance the hardness of vitrain and fusain.

Although the megascopic profile may provide some idea of the relation between size and petrographic composition in the nut and smaller sizes of coal, there still remains undetermined the character of the duller portions of the coal, particularly the extent to which mineral matter, opaque matter (inertinite), or exinite (waxy and resinous matter) contribute to the dullness of the luster. These are matters for microscopic determination although the presence of much mineral matter is readily revealed by gravity tests. Megascopic summary profiles are inadequate for discriminating description and classification of coal for the purposes of applied petrography.

ASSESSMENT OF VALUE OF EUROPEAN TYPE DETAILED STEP PROFILE ANALYSIS

Detailed step bed profiles are prepared in Europe only in general similarity to the European microlithotype (Streifenart) bed profile, based upon association, in accordance with certain rules, of the group macerals vitrinite, exinite, and inertinite.

GEOLOGICAL USES

Stach (139) has called attention to the various aspects of a coal bed profile that might be useful in coal bed correlation of "parallelization" as carried on by Hacquebard (59) and Maurenbrecher (140), the following items being listed (transl.) :

1. Layers of rock or clay characteristics of certain beds.
2. The normal petrographic bed profile.
3. Especially conspicuous petrographic layers.
Examples: Layer of fine quartz in the Ida bed;
Thick layer of fusain.
4. Bands or layers of durain.

5. Correlation of spore associations and frequencies.
6. So-called "Crassi-durain" bed (13).
7. Beds with little or no exinite.
8. Beds with many sclerotia.
9. Beds with special varieties of vitrain.
Examples: Lepidophyten vitrain;
Gymnospermous vitrain (141).
10. Characteristic occurrences of pyrite.
11. Characteristic bands of bony coal (Brandschiefer).
12. Maceral analysis based upon point-count of integrating stage analysis in terms of macerals.

Items 1 through 4 would probably appear in a graphic profile such as that prepared by the Bureau of Mines. Items 5 through 12 concern recognition of components involving discriminating resolution in terms of phytals or macerals; and items 5, 6, and 9 concern matters of a paleobotanical character.

PRACTICAL SIGNIFICANCE OF EUROPEAN TYPE OF BED PROFILES AND ANALYSES

We are largely dependent upon foreign (primarily German) literature (142 to 147) for information concerning the practical usefulness of the European type of coal bed profile as prepared on the basis of microlithotypes (Streifenarten).

H. R. Brown (148) describes some of the advantages of a detailed profile analysis of coal in a study of the industrial uses of Australian coals. Under the heading "Practical Applications of Coal Petrology" he says: "A coal seam may be regarded as an assemblage of several microlithotypes (vitrinite, durite, fusite, etc.), each of which is a mixture in varying proportions of the macerals vitrinite, exinite, carbinite, micrinite, etc. Each of these several coal components has its own characteristic pattern of behaviour during pyrolysis, burning, chemical treatment, etc. However, the properties of a coal may be governed, not only by the specific properties of the coal macerals present, but also by their mode of distribution. For example, equal amounts of vitrinite in a coal may have quite markedly different effects on the coking behaviour of a coal depending upon whether it is finely distributed throughout the clarite, durite, etc., or is present in these microlithotypes in larger assemblages as vitrite.

"It follows then that petrographic examination of coal seams should play a vital part in all investigations concerning the cleaning, carbonization, and burning of coal, and such studies must lead to a more economical or rational use of coal."

The studies made by the Coal Research Organization of the Commonwealth Government of Australia and described by Brown, involve the preparation of microscopic bed profiles from either polished blocks or thin sections using a point-count method of recording macerals and microlithotypes. These profiles, according to Brown (148), indicate:

- (i) the distinctive petrographic structure of the individual seams;
- (ii) the consistency in petrographic composition of the Bulli seam throughout the entire extent of its occurrence as at present worked (15 x 30 miles);

- (iii) the greater variability in petrographic composition of the Wongawalli seam;
- (iv) the greater amounts of vitrinite and minerals in the Wongawalli seam than in the Bulli seam and the greater amount of intermediates* in the Bulli seam."

CONCLUDING STATEMENT ON THE PRACTICAL VALUE OF COAL BED PROFILES

The preceding recently published statement from Australia is indicative of the increasing world-wide realization of the importance of carefully compiled coal bed profiles, preferably on a microscopic basis. Although interest is growing in North America, microscopic coal bed profiles receive little attention in journals concerned with the mining, preparation, and utilization of the coal. Hence, for discussion of the value of such information in regard to coal beds recourse must be very largely to publications of foreign origin.

The importance of information provided by the profile description and analysis should be more widely recognized in this country. It is a useful basis for the rational planning of coal mining and, particularly, coal preparation. This is especially true if the coal is to be prepared for special uses with specific and uniform characteristics other than just specific ash and sulphur contents. The technically designated components and constituents of coal (or lithotypes, microlithotypes, and macerals, whichever terminology is preferred) are readily differentiated by physical characteristics of luster, color, hardness, brittleness, density, etc., irrespective of form. This is particularly true of the high and medium volatile coal beds found in Ohio. It is reasonable to expect that such differences are indicative of differences in chemical structure and composition. At any rate, some of these physical differences provide a means of concentrating certain classes of components such as the group macerals vitrinite, exinite, and inertinite (including fusain), provided the coal is in a sufficiently highly divided form.

Kröger, Pohl, and Kuthe of the Technical High School at Aachen (149), have recently demonstrated the possibility of obtaining high concentrations of vitrinite, micrinite, and exinite from four Ruhr coal beds. This is indicated by the following representative example of result from bed "R" :

	<u>Purity</u>	<u>Diluents</u>
Vitrinite	98.8 %	1.2 % Fusinite and Micrinite
Micrinite	95.0 %	5.0 % Fusinite and bone (Brandschiefer)
Exinite	93.7 %	6.3 % Micrinite

Very similar concentrations between 91.3 and 97.0 per cent were obtained from the other three coals.

The coals were crushed so that the size of the vitrinite and micrinite varied between one and twenty microns and the largest size of the exinite was about 100 microns. The smallest size was at about the lower limit of practical microscopic discrimination. The possibility of such concentration of the group macerals can no longer be regarded as unattainable.

It is generally understood that unmineralized fusain is the most friable coal constituent or lithotype and vitrain is the most brittle, unless possibly hardened by the presence of pyrite. The relative toughness of dull striated

* Presumably mixtures represented by duroclarain, clarodurain. G.H.C.

coal such as splint or semisplint is also a matter of common knowledge. There is a usual predominance of dull coal in the coarser nut sizes when the bed contains both bright and dull attrital coals, as pointed out by McCabe (150). According to Stach (151), if the dull coal contains considerable quantities of exinite, particularly spore exines and waxy material, toughness is likely to be enhanced.

SELECTION OF METHOD FOR PREPARING THE COAL BED PROFILE

In selecting the technique upon which observation and measurement shall be based for the delineation of the bed profile, it is essential that the method chosen present those data necessary for achievement of the purpose for which the profile is prepared. It has been pointed out that in the case of geological objectives, the patterns of the profiles as determined by the manner of occurrence of the components is likely to be of much importance. Obviously, that technique will prove most useful which calls for a record of the largest variety of important components with the least difficulty and in line with the general system of profile construction. On the other hand, if geological comparisons are based upon evidence of a paleobotanical character, then that method is preferred which provides the most accurate determination of both translucent and opaque phytals.

On the basis of these considerations and in view of the fact that the thin section technique and method of profile delineation does not include a record of the three critical classes of material such as are represented by the vitrinite and exinite, although it may provide means of indicating inert material, general preference appears to lie with the European methods of description and delineation.

If it is necessary to prepare profiles based upon the more discriminating data provided by higher magnification and resolution into terms represented by macerals or phytals, there seems little question that differentiation on the basis of phytals is to be preferred to differentiation on the basis of macerals, except for opaque substances which will have to be explored by vertical illumination.

Similarly, in the determination of botanical criteria for stratigraphic identification and correlation, preference appears to lie with thin sections for the more abundant translucent substances, with necessary recourse to oblique or vertical illumination for the description and identification of opaque substances.

It is evident, therefore, that coal petrography or coal microscopy is dependent upon both thin and polished surface methods to achieve a complete understanding of the coal bed profile. However, when the coal petrographer is concerned mainly with practical consideration related to coal preparation and utilization, the polished surface method may provide facts of composition adequate to determine the methods of handling the coal to the best advantage.

BROKEN COAL ANALYSIS

PRELIMINARY STATEMENT

In considering broken coal, it has been pointed out that reference is usually to granules or particles too small to handle individually so as to orient each piece with respect to bedding. Such granules are usually less than one-quarter of an inch in diameter, and probably in most cases are one-tenth of an inch or less. Kröger

and associates (149), in recent investigations of maceral concentration, found it impractical to deal with particles one micron or less in size. In preparing samples of broken coal for analysis, where preliminary preparation of the sample by crushing is necessary, special care is taken to adopt a method of pulverizing that will reduce the quantity of very fine coal to the lowest possible minimum. It has been found that crushing by hand with mortar and pestle, or in a roller crusher that can be set precisely, give better results than do jaw-crushers. In any case, the sample should undergo very frequent screening to remove the fine particles.

Undoubtedly, the preferred method of studying broken coal is to mount it in some plastic medium as previously explained (p. 51). Polished surfaces or thin sections of the mounted coal, which usually composes at least half the volume of the mount, are then prepared, the choice being partly determined by the technique preferred by the individual laboratory and partly by the objectives in mind.

In discussing broken coal analysis, consideration will be given first to what might be called broken-coal face samples, and second to broken coal mine samples.

BROKEN COAL FACE SAMPLES

The simplest way to obtain a general knowledge of the over-all petrographic composition of a coal bed is to use a representative sample of a column or core of a coal bed, similar to a face sample that might be collected for a chemical analysis. Such an analysis will, of course, provide little or no information relative to the manner of occurrence of the constituents or lithotypes (texture), but this can usually be obtained by plotting the megascopic bed profile. The resulting analysis does provide important information in spite of its generalized character. It reveals the presence of unusual combinations of constituents or microlithotypes and, if carried out with special discrimination, unusual combinations of macerals or phyterals may be discovered. It provides a fairly rapidly executed check on suppositions based upon megascopic profiles. If the coal before mounting is subjected to float-and-sink procedure to remove the high-mineral-matter bone coal, the composition of dull coal is more accurately understood, particularly if the "sink" is microscopically examined. If the sample has been separated into screen sizes before mounting, some idea may result in regard to the capacity of the coal to produced size-fractions of different petrographic composition.

The usefulness of the bed profile as a means of comparing coal bed with coal bed for geological and practical purposes has been pointed out. The petrographic analysis of the broken coal face sample has a similar value, but it is of less value petrographically than is the corresponding chemical analysis. This is due to the realization that the petrographic components reported consist of more or less specific physical entities possible of individual concentration, so that petrologically one portion of the coal may be quite different from another. On the other hand, the individual chemical items of either the ultimate or proximate analysis cannot be similarly concentrated and separated by the usual methods of coal preparation. These differences are inherent in the character of the physical analysis as compared with the chemical analysis and doubtless are generally recognized.

This simple method of petrographic comparison of the physical or petrologic constitution of bed with bed appears never to have been systematically put into practice, at least for the American coal fields. Inasmuch as many thousand chemical analyses of face samples are made yearly in this country, the possibility of subjecting at least a small fraction of these to petrographic analysis merits consideration. The information provided would increase considerably the knowledge concerning the petrographic composition of American coal beds. This applies to Ohio coal beds as well as to coal beds of other coal fields. It would thus be possible to classify the coal beds, roughly, in terms of the ternary diagrams such as that suggested by the "International Glossary of Coal Petrography" (fig. 1) or that proposed by Tommossov (fig. 13).

BROKEN COAL MINE SAMPLES

Broken coal mine samples represent coal that has been subjected to various stages and various kinds of mining and preparation processes, and may consist of belt, tipple, car, or other types of mine samples, such as those commonly collected for chemical analysis. Others may have been collected for special examination of the effect upon the petrographic composition of particular types of equipment used at some stage in the preparation process. The purpose of such sampling and subsequent analysis is usually to determine the extent to which variations in the petrographic composition result from preparation or particular stages of preparation. The simplest objective is that of determining the petrologic effect of size separation when coal is subjected to no other preparation operation. The effect of fragmentation by such devices as the Bradford breaker, which is more or less selective with respect to hardness and brittleness, raises a petrographic problem. Because of the variability in the physical properties of the constituents of medium and high volatile coals, there are a number of possible ways of effecting concentration of the group macerals, as recently demonstrated by Kroger and his associates (149).

The application of coal petrology to the problems of coal preparation and utilization is necessarily made, to a considerable extent, through use of mine, tipple, belt, and car samples. Such samples are essential to a rational control of the character of the coal resulting from its initial composition and the processes to which it has been subjected. To make the use of such petrographic methods effective, they must be compared to profile analyses based upon columns or cores of the coal bed. Without such information about the coal bed it is impossible to understand the nature of the petrographic make-up of the bed and to determine its potential capacity for rational preparation in terms of critical components.

There is exceedingly little specific information concerning the petrographic character of Ohio coal beds. There is essentially no information of a public character concerning the composition of size and gravity fractions derived from different coal beds. Company information in this field is doubtless now being assembled to a limited extent. For the better understanding of Ohio coals further studies of coal bed profiles are essential, but no less necessary is a systematic study of the prepared coal at its different stages of preparation and under different conditions of preparation.

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which include a minimum band width (provisionally fixed at 50 microns) and limiting proportions of the constituent macerals."

15. It has recently been proposed that the ending "inoid" be employed for designating the group macerals (see reference 2), the proposal originating in the Organic Sediments Laboratory of Pennsylvania State University
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109. Sold by The Castolite Co., Manufacturing chemists, Woodstock, Illinois.
110. Sold by Rohm & Haas, Washington Square, Philadelphia, Pa.

Catalyst to be used with paraplex:

Methyl Ethyl Keton (MEK) Peroxide

Sold by Lucidol Division, 1740 Military Rd., Buffalo 5, N. Y.

Accelerator to be used with paraplex:

Nuodex cobalt naphthalate

Sold by Nuodex Products Co., Inc., Elizabeth, N. J.

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