PETROGRAPHIC STUDY OF SOUTHEASTERN KANSAS COALS

By

William W. Hambleton

State Geological Survey of Kansas, Bulletin 102, Part 1
UNIVERSITY OF KANSAS PUBLICATIONS
LAWRENCE, KANSAS
1953

STATE OF KANSAS

EDWARD F. ARN, *Governor*

STATE BOARD OF REGENTS

WALTER FEES, *Chairman*

MRS. LEO HAUGHEY
A. W. HERSHBERGER
WILLIS N. KELLY
DREW MCLAUGHLIN
LESTER MCCOY
GROVER POOLE
LAVERNE B. SPAKE
OSCAR STAUFFER

MINERAL INDUSTRIES COUNCIL

B. O. WEAVER ('53), *Chairman*
K. A. SPENCER ('53)
W. L. STRYKER ('53)
M. L. BREIDENTHAL ('54)
HOWARD CAREY ('54)
JOHN L. GARLOUGH ('54)
BRIAN O'BRIAN ('55), *Vice-Chairman*
O. W. BILHARZ ('55)
GEORGE K. MACKIE, JR. ('55)
CHARLES COOK ('56)
DANE HANSEN ('56)
JOE E. DENHAM ('56)

STATE GEOLOGICAL SURVEY OF KANSAS

FRANKLIN D. MURPHY, M.D., Chancellor of the University of Kansas, and ex officio Director of the Survey

JOHN C. FRYE, Ph.D.
Executive Director and State Geologist

RAYMOND C. MOORE, Ph.D., Sc.D.
Director of Research and State Geologist

BASIC GEOLOGY

STRATIGRAPHY, AREAL GEOLOGY, AND PALEONTOLOGY
John M. Jewett, Ph.D., Geologist
A. B. Leonard, Ph.D., Paleontologist*
Ruth L. Breazeal, Stenographer

PUBLICATIONS AND RECORDS
Betty J. Hagerman, Secretary
Grace Muilenburg, B.S., Journalist
Alice M. White, B.F.A., Draftsman
Joan Jaeger, B.F.A., Draftsman
Regina Rodina, Draftsman
Jane Christenson, Draftsman
James Monroe, A.B., Draftsman
Phyllis Miskimen, Clerk-Typist
Shirley Baker, Clerk-Typist

MINERAL RESOURCES
W. H. Schoewe, Ph.D., Coal Geologist
R. O. Kulstad, M.S., Econ. Geologist
Kenneth E. Rose, M.S., Met. Engineer*
H. E. Risser, E.M., Mining Engineer*

PETROGRAPHY
Ada Swineford, M.S., Petrographer
Carrie B. Thurber, Laboratory Asst.

MINERAL RESOURCES

OIL AND GAS
Edwin D. Goebel, M.S., Geologist
Walter A. Ver Wiebe, Ph.D., Geologist*
C. F. Weinaug, Ph.D., Petro. Engineer*
J. P. Everett, M.S., Petro. Engineer*
Ruby Marcellus, Well Sample Curator
Barbara Bradley, Clerk-Typist
Lois Rissman, Clerk-Typist
Vernon O. Cooper, Laboratory Asst.

WICHITA WELL SAMPLE LIBRARY
Ethelyn McDonald, M.A., Curator
Della B. Cummings, Clerk

CERAMICS
Norman Plummer, A.B., Ceramist
William B. Hladik, Asst. Ceramist
J. Sheldon Carey, A.M., Ceramist*
Clarence Edmonds, Laboratory Asst.

GEOCHEMISTRY
Russell T. Runnels, M.S., Chemist
John Schleicher, B.S., Chemist
H. S. Van Nortwick, B.S., Chemist

SOUTHEASTERN KANSAS FIELD OFFICE
Allison Hornbaker, M.S., Geologist
Joan Trumbule, Stenographer

COOPERATIVE DEPARTMENTS WITH UNITED STATES GEOLOGICAL SURVEY

GROUND-WATER RESOURCES
V. C. Fishel, B.S., Engineer in Charge
Howard G. O'Connor, B.S., Geologist
Glenn C. Prescott, M.S., Geologist
Kenneth Walters, B.S., Geologist
Charles K. Bayne, A.B., Geologist
Willis D. Waterman, M.S., Geologist
W. W. Wilson, Scientific Aide
William Connor, Core Driller
Betty Henderson, A.B., Stenographer

MINERAL FUELS RESOURCES
Wallace Lee, E.M., Geologist in charge
Daniel F. Merriam, M.S., Geologist
Holly C. Wagner, M.A., Geologist
Nancy Dabbagh, Draftsman

TOPOGRAPHIC SURVEYS
D. L. Kennedy, Division Engineer
Max J. Gleissner, Section Chief
J. P. Rydeen, Topographer

SPECIAL CONSULTANTS: Robert M. Dreyer, Ph.D., Geophysics; Eugene A. Stephenson, Ph.D., Petroleum Engineering; Robert W. Wilson, Ph.D., Vertebrate Paleontology.

COOPERATIVE STATE AGENCIES: *State Board of Agriculture, Division of Water Resources*, Robert Smrha, Chief Engineer; *State Board of Health, Division of Sanitation*, Dwight Metzler, Chief Engineer and Director, and Willard O. Hilton, Geologist.

*Intermittent employment only.

STATE GEOLOGICAL SURVEY OF KANSAS, BULLETIN 102
1953 REPORTS OF STUDIES, PART 1, PAGES 1-76, FIGURES 1-5, PLATES 1-12
MAY 15, 1953

PETROGRAPHIC STUDY OF SOUTHEASTERN KANSAS COALS

By

WILLIAM W. HAMBLETON

CONTENTS

ILLUSTRATIONS

TABLES

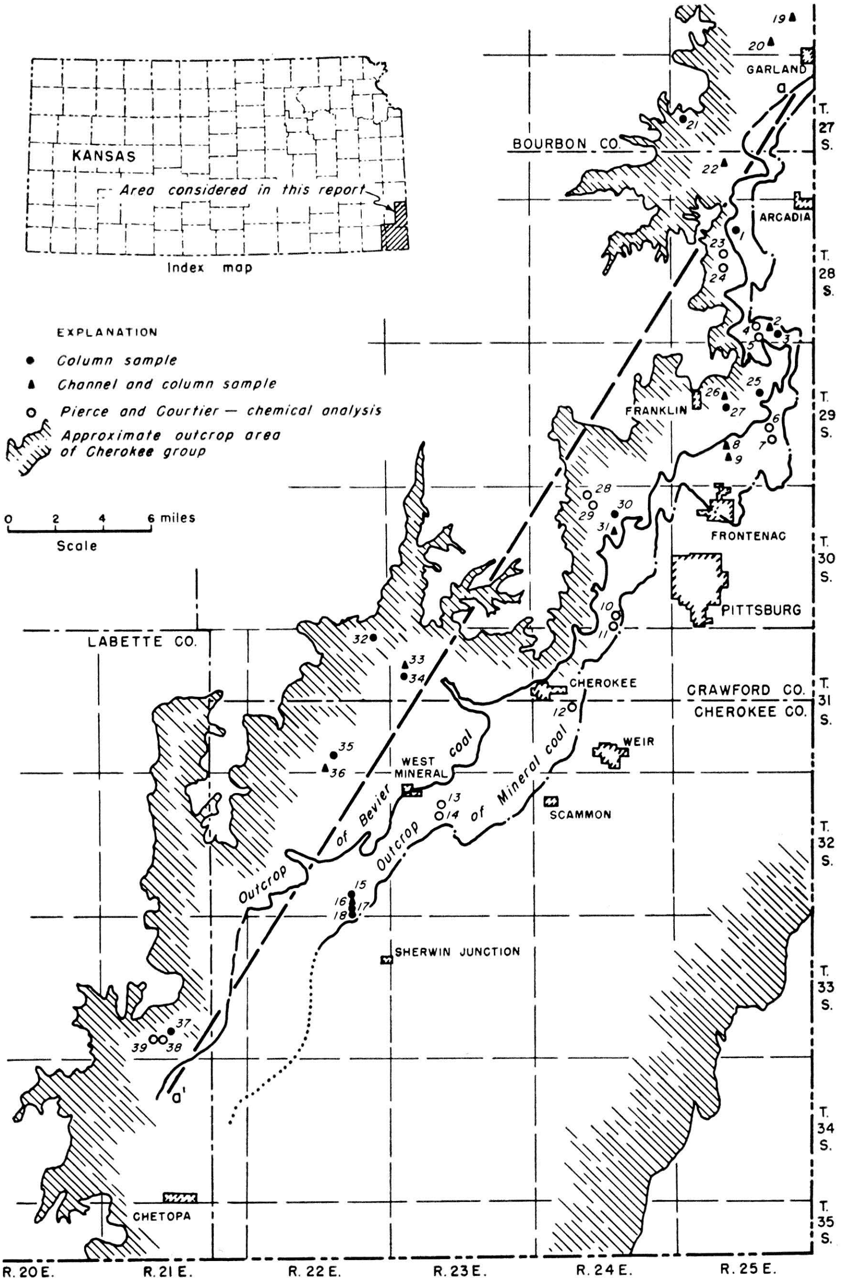


FIG. 1.—Southeastern Kansas coal field, general geology and sample locations. (Details concerning locations, numbered 1 through 39, are given in Table 5.)

ABSTRACT

As a coal state, Kansas ranks 16th in the nation, producing about $8,000,000 worth of coal annually. Most of the coal is produced from rocks of Pennsylvanian age in southeastern Kansas. Because most of these coals are thin and considerable overburden must be removed in mining them, effective utilization is important. Coal petrography, a branch of geology dealing with the constitution of coal as determined with the microscope, has contributed greatly to a better understanding of the nature of coal and has supplied much information concerning coal utilization. This report represents data on the petrographic constitution of the Mineral, Croweburg, and Bevier coals of southeastern Kansas and correlates these data with coal utilization.

A summary of coal classifications and petrographic techniques is followed by a description of the lithology and chemical composition of the coals. The coals were analyzed by a petrographic evaluation of several coal components (anthraxylon, attritus, and fusain) from 400 thin sections and 22 column samples. The results are summarized in bar diagrams which show that the coals are relatively uniform in petrographic composition and are characterized by a high content of finely banded translucent attrital material. The occurrence and distribution of mineral matter is described.

The petrographic composition is related to several chemical and physical properties which affect coal utilization. Particular consideration is given to the friability of the coals and to their amenability to hydrogenation. The effect of the mineral matter on the preparation of a low ash coal concentrate is also discussed.

INTRODUCTION

Coal petrography is a branch of geology dealing with the constitution of coal as determined with the microscope. Investigations in this field of geology have contributed greatly to a better understanding of the nature of coal and have supplied much information concerning its origin and proper utilization. Since coal utilization has become increasingly important in modern technological processes, much attention has been devoted to studies of the relationship between the various chemical and physical properties of coal and the selection of the best coals for particular purposes. Coals do not, however, exhibit uniform chemical and physical properties even within a single bed. Petrographic studies have been invaluable in revealing the reasons for this lack of uniformity and have established correlation of chemical and physical properties with the constituents of coal as seen under the microscope.

As a coal state, Kansas ranks 16th in the nation, producing about $8,000,000 worth of coal annually. Most of the coals are thin and considerable overburden must be removed in mining them. It is therefore especially important that Kansas coals be utilized to best advantage. This report correlates detailed coal petrography with some physical and chemical properties of several selected commercial coals from southeastern Kansas.

The Southeastern Kansas coal field (chiefly in Crawford and Cherokee Counties, but partly in Bourbon and Labette Counties) is the oldest and most important coal-mining area in Kansas. All the rocks exposed in this area belong to the Pennsylvanian System except for some Mississippian limestone in the southeast corner of Cherokee County. The coals occur in the Cherokee group of the middle Pennsylvanian Desmoinesian Series. The Cherokee group is defined (Moore, 1936, p. 55) to include strata between the upper unconformable surface of the Mississippian rocks and the base of the Fort Scott limestone. The average thickness of Cherokee rocks in southeastern Kansas is about 400 feet. The outcrop area is about 20 miles wide, extending northeast into Missouri and southwest into Oklahoma. Cherokee rocks are mainly clastic and consist of gray and black shales with lesser amounts of sandstone and a few thin beds of limestone.

Of the 15 coal beds which have been identified (Abernathy, 1937) in the section (Fig. 2), the most economically important coals are the Weir-Pittsburg, Mineral, and Bevier. According to Abernathy, Jewett, and Schoewe (1947, p. 6), the Weir-Pittsburg is the thickest coal in the State and has had the largest total production. It lies 175 to 250 feet above the base of the Cherokee and dips northeastward about 20 feet to the mile. The Mineral coal (sometimes called the "Upper" Weir-Pittsburg) lies from 65 to 80 feet above the Weir-Pittsburg and is now the most actively mined coal in Kansas. The Bevier lies about 100 feet below the top of the Cherokee group and holds second position in current production.

Scope of investigation.—The Mineral and Bevier coals were selected for study because they are most actively mined at present and would therefore yield a better distribution of samples for petrographic analysis. Moreover, the results of the study would be of greater value to coal producers. One sample of Croweburg coal was included in the study because the sample was easily obtained in a strip mine where the Mineral coal also was sampled. Twentyfour column samples of coal were cut from fresh exposures in Crawford, Cherokee, Labette, and Bourbon Counties. The distribution of samples, determined largely by strip-mine activity, extends in a northwest-southeast belt from Garland to Sherwin Junc-

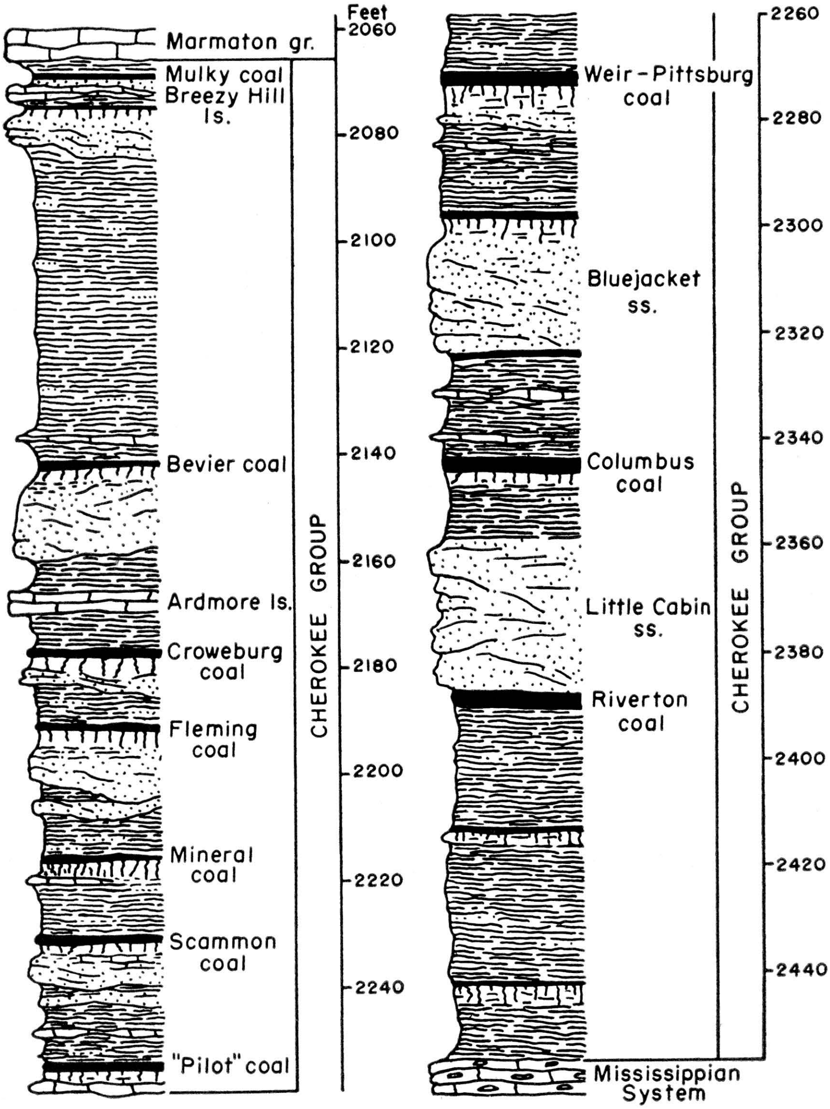


FIG. 2.—Generalized columnar section showing coals of the Cherokee group. (After Moore and others, 1951.)

tion. At 11 localities, composite channel samples for chemical analysis were taken immediately adjacent to the column samples. The outcrop of the coals and the location of samples are shown on Figure 1.

Previous work.—The first comprehensive report on Kansas coal, written by Haworth and Crane (1898), deals largely with the Southeastern Kansas coal field in its early stage of development. Young and Allen (1925) furnished information on engineering and production methods and included data from proximate and ultimate analyses and carbonization and distillation tests. Moore and Landes (1927) discussed the coal of southeastern Kansas in their report on the underground resources of Kansas. Pierce and Courtier (1938) published an excellent report on the geology and resources of the field and included a structural map on the Weir-Pittsburg coal and numerous chemical analyses. In the same year, Abernathy (1938) published on cyclothems in the Cherokee group. Subsequent publications have included a paper by Jewett and Schoewe (1942), a map of mined areas in the Weir-Pittsburg bed (Abernathy, 1944), a discussion of the strip-mined areas by Abernathy (1946), and a summary of the coal reserves in Kansas by Abernathy, Jewett, and Schoewe (1947). The State Geological Survey now has in preparation reports on the coal reserves of the Cherokee group and on the stratigraphy of these rocks.

Since 1942 the State Geological Survey has been engaged in a detailed inventory of all coal reserves in Kansas. Published reports on coals other than those in the Cherokee rocks include reports on coals of the Douglas group (Bowsher and Jewett, 1943), the Wabaunsee group (Schoewe, 1946), the Thayer bed (Schoewe, 1944), and the Permian rocks (Schoewe, 1951), and the lignite coal resources of the Cretaceous rocks of Kansas (Schoewe, 1952).

Acknowledgments.—Appreciation is expressed to Robert M. Dreyer for his considerable help and critical reading of the manuscript and to Gilbert H. Cady (Illinois Geological Survey) and Bryan C. Parks (U. S. Bureau of Mines) for helpful suggestions and advice. I further wish to acknowledge the financial assistance of the Pittsburg and Midway Coal Mining Company, the Hume-Sinclair Coal Mining Company, and the Shell Oil Company. Chemical analyses were made under the supervision of Russell T. Runnels of the Kansas Geological Survey and Prescott Underwood and James Lammons assisted in the preparation of thin sections.

COAL CLASSIFICATION

HETEROGENEITY IN COAL

The sum character of any coal may be considered the result of the collective operation of physical, chemical, and biological processes (Schopf, 1948a) and must include both contemporaneous and post-depositional changes. Differences in the history of formation of coal are reflected in its present lithology and properties. The coal inherits certain initial attributes due to plant morphology and environment. It acquires additional attributes resulting from diagenetic and metamorphic processes. Factors operating in the growth and depositional environment include depth of water, temperature, boundary conditions, chemical character of the depositional medium, and rate of burial. These factors largely determine the growth and distribution of the biological population, its death, degree, and manner of decomposition, and its accumulation and preservation. This combination of physical, chemical, and biological processes determines the initial attributes of the accumulating vegetable material.

Subsequent to deposition and prior to consolidation, certain diagenetic processes, which are largely biochemical, alter the vegetable accumulation to peat and superimpose additional attributes on the coalified material.

In the final stage of coalification, metamorphic processes become more and more intensive and may indeed proceed so far as to obliterate the early character of the coal.

The inherited and acquired attributes therefore produce a physical and chemical heterogeneity in coal which is called its constitution. Two general categories of variation in coal constitution are now recognized as the result of efforts to classify coals on the basis of their physical and chemical properties.

RANK VARIATION

In the first category are rank variations which are established on the basis of carefully selected chemical criteria. The rank of coal is its stage of coalification in the series peat, lignite, bituminous coal, and anthracite coal. It depends largely on the extent to which metamorphic processes have affected the inherited attributes of a coal. An increase in rank is marked by the relative decrease of such constituents as moisture, oxygen, and volatile matter and the relative increase in carbon. Transitions in physical properties are also evident. The rank classification adopted by the American Society for Testing Materials (1938), as illustrated in Table 1, is in current usage. It is based on proximate analysis and calorific determinations calculated to the mineral-matter-free basis according to the

TABLE 1.—*Modified A.S.T.M. classification by rank* (A.S.T.M., 1938, p. 2)

Class	Group	Limits of fixed carbon or B.t.u. on mineral-matter-free basis	Requisite physical properties
I Anthracite	1. Metanthracite	Dry F. C. 98 percent or more	
	2. Anthracite	Dry F. C. 92 percent or more and less than 98 percent	Nonagglomerating
	3. Semianthracite	Dry F. C. 86 percent or more and less than 92 percent	
II Bituminous	1. Low-volatile bituminous	Dry F. C. 78 percent or more and less than 86 percent	
	2. Medium-volatile bituminous	Dry F. C. 69 percent or more and less than 78 percent	
	3. High-volatile A bituminous	Dry F. C. less than 69 percent* and moist B.t.u.** 14,000 or more	
	4. High-volatile B bituminous	Moist B.t.u. 13,000 or more but less than 14,000	
	5. High-volatile C bituminous	Moist B.t.u. 11,000 or more but less than 13,000	Either agglomerating or nonweathering
III Subbituminous	1. Subbituminous A coal	Moist B.t.u. 11,000 or more but less than 13,000	Both weathering and nonagglomerating
	2. Subbituminous B coal	Moist B.t.u. 9,500 or more but less than 11,000	
	3. Subbituminous C coal	Moist B.t.u. 8,300 or more but less than 9,500	
IV Lignitic	1. Lignite	Moist B.t.u. less than 8,300	Consolidated
	2. Brown coal	Moist B.t.u. less than 8,300	Unconsolidated

* Coals having 69 percent or more fixed carbon (F.C.) on the dry, mineral-matter-free basis are classified according to fixed carbon regardless of B.t.u.

** Moist B.t.u. refers to coal having its natural bed moisture but not including visible water on the surface of the coal.

Parr (1928) formulas. Physical criteria for differentiation also exist but are more difficult in application. McCabe (1937), for example, has shown that the angle of polarization and the index of refraction vary systematically with increase in rank.

TYPE VARIATION

Of a more fundamental nature are those variations caused by differences in the physical constitution of coal. These are called type variations and are most commonly determined by petrographic methods. Type variations are due to the properties acquired through the interplay of plant morphology, environment, and diagenetic processes. The importance of type variation declines with increasing rank since effects of progressive metamorphism tend to obliterate the original characteristics. Anthracites of a similar rank therefore display great similarity in appearance.

However, most low-rank coals are banded in appearance. Such coals consist of fine laminae and thicker bands of bright material alternating with duller material. The characterization of these banded ingredients has been the basis for classification according to type.

Dawson (1859) observed the banded materials megascopically and concluded that they were separate entities. Somewhat later, Muck (1881) recognized that there were at least three distinctly different components which he called "glanzkohle," "mattkohle," and "faserkohle" (bright coal, dull coal, and mineral charcoal).

The application of the microscope to the investigation of coal is first recorded in the work of Witham (1833) and Hutton (1833), who demonstrated the vegetable origin of bituminous coals beyond question and supplied many data on the kinds of plants and plant structures preserved in coal. These early observations provided the background for modern research on the physical constitution of coal up to the time of the microscopic studies of White and Thiessen (1914).

Two different classes of petrographic entities have been recognized in coal. Those based on recognition of plant parts and pieces as well as some kinds of decomposition products, have been called "phyterals" by Cady (1942, p. 347). The identity of a phyteral does not change throughout the metamorphic stages of coal formation although its chemical and physical composition vary in a pronounced manner. Phyteral content is therefore fixed at the beginning of coalification. However, recognition of a phyteral usually becomes more difficult with advanced metamorphism.

Entities based on the recognition of physical and chemical similarities were called "macerals" by Stopes (1935). They are identified on the basis of similarity in composition, as are minerals. A given phyteral may be represented by several kinds of macerals and a given maceral may be constituted from different types of phyterals.

Although the phyteral and maceral concepts were not expressed in the classifications of Stopes (1919) and Thiessen (1920), the implications were nevertheless present.

MACERAL CLASSIFICATION

In her original classification, Stopes (1919) recognized four ingredients which she named vitrain, clarain, durain, and fusain. Definition and identification were based upon the properties of the hand specimen, supplemented by microscopic observations. The terminology was widely used in Europe although controversy was aroused by Stopes' observations concerning the nature and origin of vitrain. In 1935, Stopes expanded her original classification to reclassify vitrain, clarain, fusain, and durain as coal types and proposed an additional series of names to characterize the macerals or organic units of the coal types. This classification was adopted by the Second International Conference on Carboniferous Stratigraphy at Heerlen in 1935. All coals were regarded as aggregates of one or more of the primary types.

Vitrain.—Vitrain occurs in thin horizontal bands up to 20 mm thick and has a brilliant glossy luster. It is microscopically structureless, homogeneous, and breaks with a conchoidal fracture. Vitrain was originally described as translucent in thin sections and microscopically structureless. In response to the controversy regarding microscopic structure, the term was expanded to include eu-vitrain (or structureless vitrain) and pro-vitrain (which shows structure). The maceral of vitrain is vitrinite. It is subdivided into collinite (vitrinite devoid of structure) and tellinite (vitrinite showing structure on polishing, etching, or in thin sectioning). Stopes also proposed that each recognizable plant tissue, organ, or secretion be given a distinct name within the general category vitrinite. Thus corky tissue in vitrain is called suberinite; material thought to be resin, resinite; exine material, exinite; cuticular material, cutinite.

Clarain.—Clarain is a bright striated coal with a silky luster, not as brilliant or homogeneous as vitrain, lacking in conchoidal fracture, and consisting of thin bands stratified parallel to the bedding plane. It is predominantly translucent in thin section and may be composed of a variety of macerals of small size and concentrated to a varying degree. Vitrinite plus micronite (an opaque maceral) and fusinite (the maceral of fusain) are the usual constituents.

Durain.—Durain is a hard, compact, dull coal which is megascopically structureless and gray to dull black in color. It is largely opaque in thin section since the predominant maceral is micronite. However, other macerals may be present in minor amount.

Fusain.—Fusain consists of irregular wedges lying on bedding planes at various angles. It is fibrous and dull in appearance and consists of a porous, friable material resembling charcoal which breaks down to a fine dust. It is cellular and opaque in thin section and composed of the maceral fusinite.

Boghead and cannel coal.—In addition to the banded coals, the nonbanded varieties, cannel and boghead, were recognized. Nonbanded coals contain essentially no vitrain but are composed of clarain and durain microdebris with large quantities of spore exines, pollen, and oil algae. If the algal content is low, the coal is a cannel; if high, it is a boghead. Megascopically, they are clean, compact blocks of massive structure and fine-grained texture. Usually they are dark gray to black, have a greasy luster, and a marked conchoidal fracture.

PHYTERAL CLASSIFICATION

Thiessen (1920) considered coal to be composed of two visibly different major components present in various types of coal in varying proportions. He named these components anthraxylon and attritus. He accepted the well-established term fusain for designating the third (and minor) component. Thiessen's classification is held to be genetic in origin since the microscopically differentiated components (petrographic components) can be related to plant morphologic units now called phyterals.

Anthraxylon.—Anthraxylon was described as relatively simple in structure and essentially homogeneous in appearance. It was recognized to be the fairly well-preserved cellular tissues of stems, branches, twigs, roots, sporangia, and leaves which survived plant decay in the early stages of coal formation. Anthraxylon bands are identified megascopically by their bright luster, black color, brittleness, and smooth fracture. In thin section anthraxylon appears in bright-orange, red, or brownish bands and often exhibits well-preserved cellular structure.

Attritus.—Attritus was defined as a mixture of macerated plant debris, finely divided during the process of plant decay and subsequently coalified. Its composition is not simple and thin sections show that it is composed of many ingredients. Most attritus is translucent and exhibits the orange, red, and brown colors of anthraxylon although some of it is nearly or completely opaque at standard thicknesses of 10 microns. The opaque ingredients are called opaque attritus whereas the translucent material is translucent attritus. Translucent attritus includes humic degradation matter, a term applied to the cellulosic or lignocellulosic fragments of wood, phloem, cortex, and leaves; resin bodies, the dark-yellow to light-brown globules of resin which were once the cell contents of xylem and leaves; spore and pollen exines, the brilliant-orange to yellow cases of spores and pollen which have become flattened during coalification and appear as flattened rings in section; and cuticle, the bright yellow-golden bands with serrated edges which were the former coverings of leaves and stems. Megascopically, attrital coal is characterized by its dull color and striated appearance when interbanded with fine shreds of anthraxylon. It breaks irregularly into large fragments.

Fusain.—The fusain of Thiessen's classification has the same meaning as it did in that of Stopes. It is a minor component of most coals and is characterized by its friability and softness. It resembles charred wood and is sometimes referred to as mineral charcoal. In thin section it is distinguished by its opaqueness and cellular structure.

Thiessen's system of classifying coal into types after thin section analysis is based on the aggregate character of the coal in terms of limiting quantities of the petrographic components or ingredients. It should be recognized that the term "coal type" as used by the Bureau of Mines differs from the "rock or coal type" of Stopes in which all coals are regarded as aggregates of one or more primary coal types. The Bureau of Mines (Table 2) now recognizes five types of coal and has established the critical limits for each type as recently stated by Parks and O'Donnell (1948, p. 537).

Despite claims to the contrary, it seems that only a few of the common petrographic terms used in either classification have either a precise botanical or compositional implication. Some of the maceral terms clearly denote parts of plants while others infer a chemical relation which can scarcely be determined petrographically. The terms opaque attritus and fusain as used by Thiessen are not botanical in origin. In addition, much uncertainty has existed concerning the significance of one set of names in terms of the other. Table 3 is an effort to show the correlation between the two different terminologies as suggested by Raistrick and Marshall (1939, p. 271). Several authors, in recent years, have attempted to resolve and clarify these differences and to develop the history of the nomenclature. Among these are Roos (1937), Cady (1945, pp. 86-102), and Raistrick and Marshall (1939, p. 178-205). Such efforts may be futile since there is still basic disagreement as to the meaning of the term "coal type."

In general, it may be said that both classifications depend to a certain extent on maceral and phyteral criteria. However, if the theoretical limitations of each are understood, there is no essential reason why either one cannot be used for certain types of petrographic analysis.

In the discussion and analyses of Kansas coals which follow, the phyteral classification of Thiessen and the Bureau of Mines will be used exclusively. The scheme is simple and, in addition, numerous petrographic analyses on a wide variety of coals have been made by the Bureau of Mines. These petrographic analyses provide a ready basis for comparison with this study.

PREPARATION TECHNIQUES FOR MICROSCOPIC STUDY

Several preparation techniques have been used widely for the microscopic examination of coal. Thin sections are generally preferred by investigators in the United States since their use makes possible the more certain identification of the various macerals and phyterals. However, specimens are sometimes prepared by polishing and by maceration. Polished section techniques have been

TABLE 2.—*Type classification of coals*
(U.S. Bureau of Mines) (Parks and O'Donnell, 1948, p. 537)

Type	Critical amounts of components
Cannel coal	Less than 5 percent anthraxylon and predominantly transluscent attritus with little or no oil algae.
Boghead coal	Less than 5 percent anthraxylon and the transluscent attritus predominantly oil algae.
Bright coal	More than 5 percent anthraxylon and less than 20 percent opaque attritus.
Semisplint coal	More than 5 percent anthraxylon and 20 to 30 percent opaque attritus.
Splint coal	More than 5 percent anthraxylon and more than 30 percent opaque attritus.

TABLE 3.—*Nomenclature of coal petrology** (Raistrick and Marshall, 1939, p. 271)

	British nomenclature		German nomenclature			American nomenclature
Macroscopic character of the coal	Rock types	Macerals (constituents)	Streifenarten	Gefuegebestandteile	Coal types	Constituents
Uniform brilliant black bands	Vitrain	Vitrinite: translucent in thin section; cellular structure may or may not be well preserved: a. Collinite—structureless; b. Tellinite—structure preserved; i. Xylinite-formed from wood tissues;	Vitrit	Vitrinit		Anthraxylon. Term used to include the uniform brilliant bands (or their counterparts) in coals of all ages

		ii. Periblinite-formed from cortical tissues; iii. Suberinite-formed from cork tissues				
Charcoal-like layers and fragments which readily soil the fingers	Fusain	Fusinite: cell structure well preserved. Cell walls opaque; cell cavities either empty or occupied by mineral matter	Fusit	Fusinit		Fusain
Bright coal: clearly laminated; composed of innumerable brilliant fragments and bands with some duller material	Clarain	Containing (translucent orange or yellow in thin section): Vitrinite; Resinite—resin bodies; Exinite—which includes i. Cutinite—from cuticles, ii. Sporinite—from spores; together with a little: Micrinite-granular opaque matter Fusinite	Clarit	Micrinit Fusinit	Bright coal	Containing: Anthraxylon; spores; cuticles; resins; etc., together with opaque and semi-translucent attritus; and fusain
Dull coal: dull and nonreflecting in the hand specimen; lamination poor or absent	Durain	Containing: Fusinite; Micrinite; Resinite; Exinite i. Cutinite, ii. Sporinite; and a very little Vitrinite	Durit		Splint coal	Very largely opaque and semi-translucent attritus with spores, cuticles, resins, and a little anthraxylon

---

* British and German terminology as recommended by the International Committee at Heerlen, 1935. Corresponding American terms are those used by U.S. Bureau of Mines.

described by Winter (1923), Stach (1928), Duparque (1933), and Roos (1937). The method involves the production of a plane, highly polished surface on the coal which may be modified by relief polishing or etching. The surface is then studied with a reflecting microscope. McCartney (1949) has suggested a refinement of the method for use with the electron microscope. The maceration technique was introduced by Schulze (1855) and has been discussed by von Gumbel (1883), White and Thiessen (1914, pp. 216-218), Schopf (1938), and others. It involves oxidizing the humic portions of coal and leaching them with alkaline solutions so as to leave the less soluble, translucent portions for microscopic examination.

THIN SECTION TECHNIQUE

The method of preparing a representative sequence of thin sections from a column sample of coal was developed at the Bureau of Mines by Thiessen, Sprunk, and O'Donnell (1938) for use in the quantitative microscopic determination of petrographic components. The technique used in this study was the same except for minor variations. Other petrographic work has demonstrated that optimum analytical results are obtained when the coal is sampled in such a manner as to preserve the stratification of the coal. The ideal sample is an unbroken column of coal, about 12 inches square in cross-section, cut perpendicularly to the bedding plane and including all the coal from the top to the bottom of the bed. Since petrographic studies are usually made in conjunction with other tests, a channel sample may be taken immediately adjacent to the column sample. In the laboratory, a subcolumn approximately 3 inches wide and 3 inches deep is cut with a 12 x 0.0625 inch resinoid-bonded Crystolen cut-off wheel (standard designation C46-P-8B) operating dry at about 12,000 surface feet per minute. The subcolumn is then mounted in plaster of paris and cut into two parts normal to the bedding. One part of the subcolumn is reserved for polishing and the other for thin sectioning.

Mention should be made of the necessity of eliminating the coal dust resulting from dry cutting. A special saw was designed for the purpose. The cut-off wheel was mounted on a ⅝-inch belt-driven mandrel so as to project through a slotted table top. The lower part of the wheel was enclosed and connected by flexible tubing to the intake end of a motor-driven blower and the blower in turn connected to a 30 x 30 x 16 inch galvanized steel tank equipped with a series of baffles and fiberglass filter. A plexiglass shield one-half inch thick provided protection from the exposed part of the wheel.

Preliminary polishing of one mounted subcolumn is done on a 3 x 3 foot piece of plate glass using successively finer carborundum powder sludges. The final polish is achieved by stroking the column with a fine-grained, yellow Belgian hone and then buffing it with a Selvyt cloth and a paste of Lakeside polishing compound No. 27. After a thorough drying, the polished surface is painted with a 5 percent solution of water-soluble polyvinyl alcohol (Dupont Elvanol 51-05) to prevent surface oxidation. The polished columns thus serve as permanent sample specimens and can also be used for macroscopic studies.

Thin sections are prepared from the remaining part of the subcolumn. Beginning at the top and continuing to the bottom, parallel lines spaced about 0.8 inch apart are marked on the coal with a red wax pencil and small numbered blocks are cut with an 8 x 0.0312 inch cut-off wheel (standard designation C80-P-5B) using the lines as a guide. Each block is trimmed to a length of about 1 inch.

One face of each block is then ground on rotating laps with successively finer abrasives, polished on a yellow Belgian hone, and buffed on a mounted Selvyt cloth with Lakeside polishing compound No. 27. After thorough drying in an oven and proper orientation, the block is cemented to a frosted standard glass slide with Lakeside No. 70 cement. Frosting of the slides has proved to be especially beneficial in securing good sections as suggested by Gibbs and Evans (1950, p. 2). The excess coal is next sawed off with the 8-inch cut-off wheel leaving about one-fourth inch of coal on the slide.

The mounted blocks are then ground to a thickness of about 10 microns. This is done by using successively finer carborundum sludges on rotating laps until the section just begins to transmit light. This is a somewhat critical point and can be determined only by experience. Too close grinding on the lap will ruin the section.

After trimming the superfluous cement from around the edges of the section with a razor blade, the section is transferred to the yellow Belgian hone. The hone is mounted in a wooden block sloping away from the worker and a stream of water is played on it.

The section is honed with forward strokes and slight pressure until it transmits light uniformly and shows an orange to red color. The section is then transferred to a light box and gently rubbed with a cork dipped in Lakeside polishing compound No. 27 to produce an even section. The section is finally labeled and painted with polyvinyl alcohol.

In previous work, each section had been ground to completion by a single operator. It was found that this procedure does not lend itself well to the production of a large number of sections. Consequently, the sections were ground in column lots with one operator doing the coarse grinding on the laps and a second the work on the hone and light box. However, in the interval between the two stages of preparation, the section frequently dried out, oxidized, and contracted so that a useless section resulted. On the suggestion of B. C. Parks of the Bureau of Mines (personal communication) the slides were immersed in glycerine except when being improved.

MICROSCOPIC ANALYSIS BY THE RIBBON TRANSECT METHOD

In 1930, Thiessen set up a method of microscopic analysis and a type classification of coal that has been generally followed as standard practice by the coal petrography laboratory of the Bureau of Mines. It has subsequently undergone such changes that Parks and O'Donnell (1948) have described the modified procedure. In the discussion which follows, this procedure is described, modified, and evaluated.

The sequence of thin sections, prepared in the manner described earlier, is essentially a disconnected, transparent, ribbon-like sample of coal about 10 microns thick and 1 inch wide, representing the entire coal bed. The ribbon sample of sections is not, however, a complete representation because of some loss from sawing and polishing. A recovery of 90 to 95 percent of the height of the original column is considered not unusual by the Bureau of Mines.

The ribbon transect method of statistically evaluating the relative amounts of anthraxylon, opaque attritus, translucent attritus, and fusain in a coal bed is nothing more than refined visual estimate employing the principle of the Rosiwal analysis (Head and others,1932). It is based on the assumption that the sum of the areas of each of the components in a random section of uniform rock is proportional to the volume of that constituent in the rock. In practice, actual areas are seldom measured, but rather a linear traverse is made. Coal is inherently heterogeneous so that the assumption of uniformity is not valid. Nevertheless, it is probably valid to assume that each increment of the coal parallel to the bedding plane will exhibit homogeneity over a limited area. Thin sections cut normal to the bedding should therefore represent statistically the coal in the area and Rosiwal analysis may be used if its limitations are appreciated.

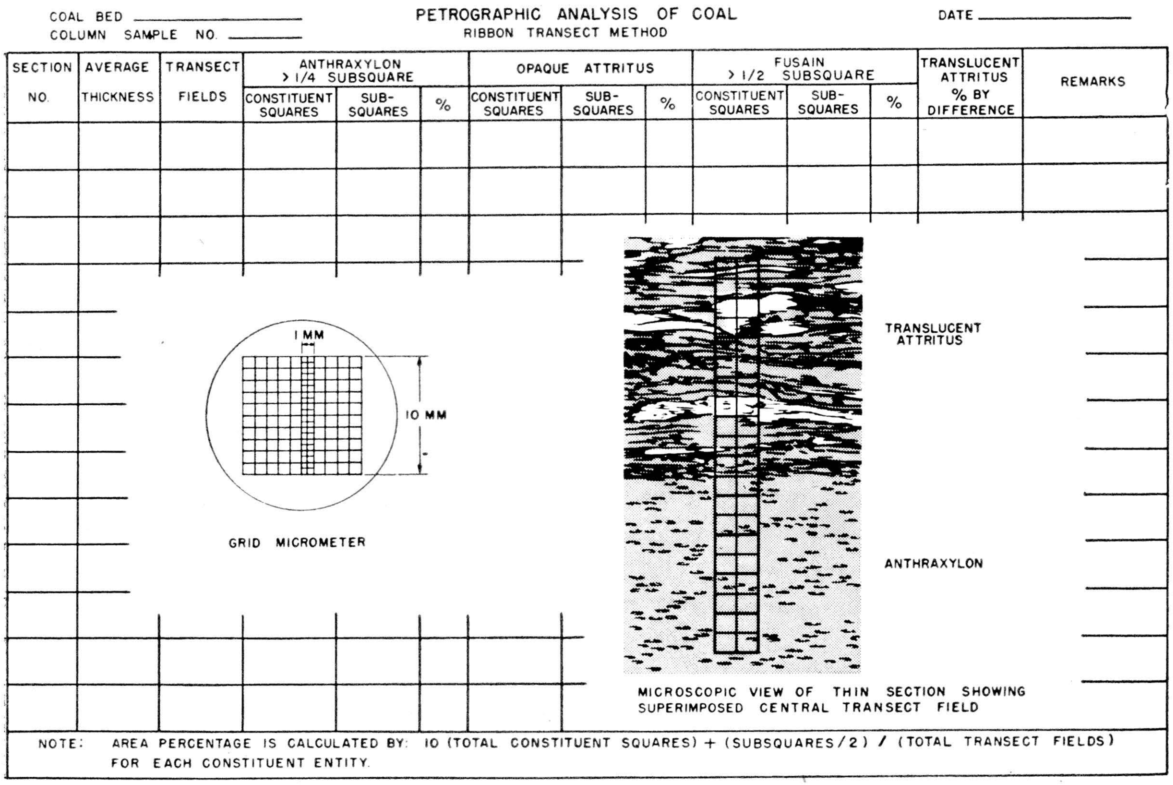
Any type of microscope equipped with a mechanical stage is satisfactory for the measurements. Although the Bureau of Mines prefers the binocular type, a petrographic microscope was used in this work since it facilitated identification of mineral components of the coal. A grid micrometer disc on which is centered a 10 mm square field divided into 100 1.0 x 1.0 mm constituent squares is inserted in the ocular. Each square is further subdivided into four subsquares 0.5 x 0.5 mm on a side. The values represent the real dimensions of the squares scribed on the disc. Since only one central vertical tier of squares is used, each transect field is 10 mm long by 1.0 mm wide and consists of 10 major 1.0 x 1.0 mm constituent squares and 20 1.0 x 0.5 mm subsquares. Because it is pertinent to later discussion, mention is made that the Bureau of Mines employs a Whipple disc, which is a 7 mm square field divided into 100 0.7 mm squares with the central one subdivided into 25 0.14 mm squares. Usage is largely a matter of convenience.

Under microscopic magnification, the dimensions change; therefore it is necessary to calibrate the disc with a stage micrometer for different powers of magnification as shown in Table 4.

It has been the practice of the Bureau of Mines to measure opaque attritus and fusain at a magnification of 60X and anthraxylon at 150X. Translucent attritus is determined by difference. Since it seems doubtful that any unique advantage is gained by

TABLE 4.—*Calibrated values of grid micrometer with petrographic microscope B&L LM5919*

Magnification	Central vertical transect field length, mm	1 Constituent square length, mm	1 Subsquare length, mm
0	10.0	1.00	0.500
40	5.35	0.535	0.268
100	1.33	0.133	0.067



COAL BED ______
COLUMN SAMPLE NO. ______

PETROGRAPHIC ANALYSIS OF COAL
RIBBON TRANSECT METHOD

DATE ______

SECTION	AVERAGE	TRANSECT	ANTHRAXYLON > 1/4 SUBSQUARE			OPAQUE ATTRITUS			FUSAIN > 1/2 SUBSQUARE			TRANSLUCENT ATTRITUS	REMARKS
NO.	THICKNESS	FIELDS	CONSTITUENT SQUARES	SUB-SQUARES	%	CONSTITUENT SQUARES	SUB-SQUARES	%	CONSTITUENT SQUARES	SUB-SQUARES	%	% BY DIFFERENCE	

NOTE: AREA PERCENTAGE IS CALCULATED BY: 10 (TOTAL CONSTITUENT SQUARES) + (SUBSQUARES/2) / (TOTAL TRANSECT FIELDS) FOR EACH CONSTITUENT ENTITY.

FIG. 3.—Sample data sheet and illustration of microscopic measurement of coal components.

changing magnifications, all components have been determined at 100X in this study.

Measurements are made by turning the mechanical stage of the microscope so as to move the central vertical transect field of the grid micrometer along a line extending from the bottom to the top of the section. Two such traverses are made for a better statistical average; one near the middle of the right half of the section and the other near the middle of the left half. The traverse is not made continuously; the thin section is moved a distance equal to the length of the transect field and when the number of constituent squares and subsquares occupied by each of the coal components has been estimated and tabulated, the section is again moved the length of the transect field. These field moves are continued until the section is crossed. A horizontal shift of the stage brings the section into position for the second traverse. The total number of transect fields is tabulated and checked against the total distance traversed as determined with the mechanical stage vernier by multiplying the number of transect fields by the calibrated length of each transect field. A sample data sheet and an illustration of the use of the grid micrometer are shown in Figure 3.

After all the thin sections representing the column sample have been measured in this manner, the data for the components of each slide are converted to percentages using the relation:

$$\begin{array}{l}\text{Area percentage}\\ \text{for each component}\end{array} = \frac{10\ (\text{No. constituent squares}) + (\text{No. subsquares}/2)}{\text{Total number of transect fields}}$$

The percentage distribution of anthraxylon, translucent attritus, opaque attritus, and fusain in each thin section is tabulated graphically by bar diagram as illustrated in Plate 1. On the basis of this distribution, the coal is classified according to type and a profile of the coal results. Due to loss in cutting and grinding, the tabulated distances and lengths on the bar diagrams are in error by the amount of loss.

CRITICAL LIMITS

Although the Bureau of Mines has published the results of numerous petrographic studies of coal, actual determinative procedures have always been omitted from the reports. Considerable uncertainty had existed regarding the validity of the method until

Parks and O'Donnell (1948) fully described procedures and evaluated the influence of such factors as microscopic magnification, thin section coverage, and errors arising from the personal element. However, several important considerations were overlooked in the paper by Parks and O'Donnell. Personal communication with the authors and reference to a discussion of the paper by Schopf (1948) have contributed to the following examination of critical limits.

Subsize thresholds.—Parks and O'Donnell (1948, p. 536) state:

> No particular difficulty is experienced in recognizing attritus in thin sections under the microscope. The heterogeneous mixture of ingredients of different shape, structure, translucence, and color occur in layers that are easy to distinguish from the other banded components.

They further say:

> Anthraxylon can also be easily recognized in a thin section when seen with transmitted light under the microscope. It is present in prominent orange bands, sometimes shaded toward brown to red, and usually shows well-preserved cellular structures of a woody tissue seen in cross-sectional or longitudinal view.

These statements are substantially true when the anthraxylon bands are wide and the attritus extremely fine. However, difficulty is experienced in deciding whether certain fairly fine translucent components of attritus shall be classified with the atrital or the anthraxylous material. In other words, at what point does the translucent component cease being preserved cellular tissues of stems, branches, twigs, etc., and become part of a mixture of finely divided plant debris. Realizing the question was largely one of size, Schopf discovered that according to standard practice of the Bureau of Mines laboratory, anthraxylon is not identified in any particles or strands thinner than 0.014 mm. This subsize threshold was chosen empirically because the subsquares of the calibrated Whipple disc were determined to be about 0.014 mm at a magnification of approximately 150X—the magnification used to measure anthraxylon.

It seems entirely possible that the use of this arbitrary limit may constitute a source of error which has been overlooked. It was earlier stated that all determinations for components other than anthraxylon were made at a magnification of 60X. At this magnification, the subsquares are no longer 0.014 mm but 0.037 mm. Hence, in traversing attrital material, it would be possible to miss strands of anthraxylon 0.014 mm wide.

Schopf also gives the subsize threshold for the microscopic determination of fusain as 0.037 mm—the size of a subsquare at a magnification of 60X. All smaller opaque material is assigned to opaque attritus.

In view of the large accumulation of data using these limiting values, it seems necessary for comparison purposes that they be tentatively accepted as part of the definition of anthraxylon and fusain in quantitative work. However, since they are only visual estimates, certain liberties may be taken for the sake of convenience. Anthraxylon is here defined as any translucent strand larger than one-fourth of a subsquare at a magnification of 100X. A subsquare at this magnification is 0.067 mm high; therefore one-fourth of a subsquare is 0.017 mm as compared with the Bureau of Mines value of 0.014 mm. Similarly, the subsize threshold for fusain is given as one-half of a subsquare at a magnification of 100X. This is 0.033 mm as compared with the Bureau of Mines value of 0.037 mm.

The problem of establishing limiting subsize thresholds for certain of the petrographic components is not unique to the Bureau of Mines and should be subjected to closer scrutiny since it stems from some very fundamental considerations. Cady (1942, pp. 343-346), in discussing a parallel situation involving the Stopes classification, pointed out that uncertainty had developed concerning the application of the term "vitrain" to vitrainlike material of small dimension which may make up a considerable portion of a clarain band. He also concluded that the distinction was one of size and that limiting values were necessary. In an attempt to resolve the situation, he suggested that all the thin vitrainlike bands composing clarain be called "micro-vitrain" and set the lower limiting value for vitrain at 2 mm with a tolerance of 1 mm. Justification for this is based on the fact that, in the natural breakage of coal, the thicker vitrain bands tend to break away from the rest of the coal and concentrate in the small screen sizes whereas the finer bands tend to remain intimately associated with the clarain which concentrates in the larger sizes. The limiting value is thus a function of the physical properties of vitrain and clarain since vitrain is characteristically friable and clarain is not. This approach is not necessarily the complete answer but is at least suggestive that limits should be established on the basis of physical or chemical behavior.

Color, thickness, and opacity.—Another important point which has not received sufficient consideration is the question of color and light transmission in connection with quantitative analytical work. In the description of each of the petrographic components, reference was made to its color or opacity. Essentially then, color comparison is an important basis for identification and can be appreciated only by direct examination since most photographs of thin sections are not reproduced in color. However, accurate comparison precludes that all sections be ground to the same thickness since light transmission is partially a function of the thickness of the section. This factor is of relatively minor importance in the identification of anthraxylon and translucent attritus but becomes extremely important for opaque attritus and fusain where identification is based largely on opacity. These components cannot, however, be regarded as totally opaque but only as possessing varying degrees of opacity since all of them probably can be made to transmit light if cut thin enough. There is, then, a very real problem for the petrographer who, for example, attempts to classify a dark-brown attrital material as opaque or translucent attritus when it is almost impossible to achieve uniformity in thickness of the section. He is beset by the same problem when he tries to classify opaque attritus and fusain since there is ample evidence that they, too, are gradational. The question involves not only the establishment of criteria for opacity but also a reconsideration of the fundamental basis of the classification. It is now apparent that opacity is an attribute which may be acquired by all kinds of plant materials to a varying degree and is dependent upon the activity and duration of the process which produced it. Study of numerous thin sections indicates that much so-called opaque attritus is actually crushed fusinized material and that cellular fusain maintains its open cell structure only because the spaces have been filled with mineral matter at an early stage in the process of coalification. This problem will be considered further in the discussion of the petrography of Kansas coals.

LITHOLOGY AND CHEMICAL COMPOSITION OF THE MINERAL, CROWEBURG, AND BEVIER COALS

MINERAL COAL

Lithology.—The Mineral coal is named from the town of Mineral in northwestern Cherokee County, where it has been mined extensively. The outcrop of the Mineral coal follows a generally northeast trend from a point 2 miles northwest of Sherwin Junction to a point west of Franklin where it turns north and parallels the State line until it swings into Missouri south of Garland. Column samples were collected at eight localities along this trend and, at three places, composite channel samples for chemical analysis were collected immediately adjacent to the column samples. The chemical analyses from these samples are supplemented by data from the analyses of Pierce and Courtier (1938, table 1.) On the map showing the location and distribution of samples (Fig. 1) the localities are numbered in sequence from northeast to southwest and all tabulated data are arranged in a similar manner for easy comparison. Table 5 gives the exact location of the samples.

The coal is obtained from strip mines with an overburden of about 20 feet of dark-gray to black shale. In some places, the coal is capped by a discontinuous dark-gray fossiliferous limestone which locally thickens and cuts out the coal as at the Mackie-Clemens operation (Loc. 9, Fig. 1).

The thickness of the Mineral coal averages 15.2 inches, ranging from 10.4, to 21.1 inches. Pierce and Courtier (1938, p. 71) indicate that the limits are between 17 and 24 inches but it is apparent that these thicknesses include several inches of bone or shaly coal which is characteristically present at the top of the bed. This material is usually removed in mining operations and should not be included as coal.

The Mineral coal is a typical, finely banded, attrital coal. Wide anthraxylon bands are scarce and seldom exceed 1 mm in thickness. Megascopic fusain is readily observable, but randomly distributed. The fusain is usually concentrated at several horizons in any particular sample, but appears lenticular. It is found at a different horizon in adjacent samples. Vertical butt and face cleats as well as other fractures are filled with calcite which partially accounts for the unusually high ash content. The calcite acts as a binder permitting the mining of large lumps which would otherwise fall into smaller sizes. Much pyrite is present in nodules and lenticular bodies parallel to the bedding. The coal at the south end of the field is of particular interest because of these pyrite nodules and associated "coal balls." "Coal balls" have been found principally in the Pittsburg-Midway No. 15 mine (Locs. 15, 16, 17, 18, Fig. 1) where they always occur in the upper 6 inches of the coal. This subject is discussed further under "Mineral Matter in Coal."

Chemical composition and rank—Proximate chemical analyses of 12 samples of Mineral coal are tabulated in Table 6 as determined by the method of Stanton, Fieldner, and Selvig (1939). For purposes of comparison, all analyses have been calculated to the moisture and ash-free basis and are so designated in the following dis-

TABLE 5.—*Location of samples*

Locality no.	Sample no.	Bed	County	Description
1	Cr-2-M**	Mineral	Crawford	NE¼ NE¼ sec. 9, T. 28 S., R. 25 E.; abandoned strip mine
2	Cr-4-M†	do	do	NE¼ SW¼ sec. 35, T. 28 S., R. 25 E., one-half mi. northwest Mulberry; strip mine, Palmer Coal Co.
3	Cr-3-M**	do	do	Cen. sec. 35, T. 28 S., R. 25 E., one-half mi. northwest Mulberry; strip mine, Palmer Coal Co.
4	B-2659*	do	do	NE¼ sec. 34, T. 28 S., R. 25 E.; abandoned strip mine, A. B. McKay Coal Co.
5	B-2660*	do	do	Near Cen. E. line sec. 34, T. 28 S., R. 25 E.; abandoned strip mine, A. B. McKay Coal Co.
6	B-2655*	do	do	SW¼ sec. 23, T. 29 S., R. 25 E.; abandoned strip mine, Clemens Coal Co. No. 23
7	B-2656*	do	do	SW¼ sec. 23, T. 29 S., R. 25 E.; abandoned strip mine, Clemens Coal Co.
8	Cr-1-C†	Croweburg	do	SE¼ NW¼ sec. 28, T. 29 S., R. 25 E., 1 mi. north highway 160 at Frontenac; center of strip mine, Mackie Clemens Fuel Co.
9	Cr-8-M†	Mineral	do	SE¼ SW¼ sec. 28, T. 29 S., R. 25 E., 1 mi. north highway 160 at Frontenac; south end of strip mine, Mackie Clemens Fuel Co.
10	B-2665*	do	do	SW¼ sec. 34, T. 30 S., R. 24 E.; abandoned strip mine, Pittsburg-Midway No. 17
11	B-2666*	do	do	SW¼ sec. 34, T. 30 S., R. 24 E.; abandoned strip mine, Pittsburg-Midway No. 17
12	B-2652*	do	Cherokee	700 ft. west, 15 ft. south of NE cor. sec. 20, T. 31 S., R. 24 E.; abandoned strip mine, Commercial Fuel No. 2
13	B-2667*	do	do	SW¼ NW¼ sec. 9, T. 32 S., R. 23 E.; abandoned strip mine, Pittsburg-Midway No. 15
14	B-2668*	do	do	NW¼ sec. 9, T. 32 S., R. 23 E.; abandoned strip mine, Pittsburg-Midway No. 15
15	Ck-5-M**	do	do	NE¼ NW¼ sec. 35, T. 32 S., R. 22 E., active strip mine, Pittsburg-Midway No. 15
16	Ck-4-M†	do	do	SE¼ NW¼ sec. 35, T. 32 S., R. 22 E., 2½ mi. north Sherwin Junction; active, Pittsburg-Midway No. 15
17	Ck-3-M**	do	do	SE¼ SW¼ sec. 35, T. 32 S., R. 22 E.; active, Pittsburg-Midway No. 15
18	Ck-2-M**	do	do	SE¼ SW¼ sec. 35, T. 32 S., R. 22 E.; 300 yds. south of Ck-3-M, active Pittsburg-Midway No. 15

19	Bn-3-B†	Bevier	Bourbon	SW¼ NW¼ sec. 25, T. 26 S., R. 25 E.; 1.7 mi. north Kansas highway 7 at Garland; custom strip mine
20	Bn-2-B†	do	do	SE¼ NW¼ sec. 35, T. 26 S., R. 25 E., 1 mi. northwest Garland; active strip mine, Kelly-Carter Coal Co.
21	Bn-1-B**	do	do	NW¼ SE¼ sec. 18, T. 27 S., R. 25 E., west of highway 69, 1.3 mi. north of Crawford Co. line, custom strip mine, Pellet Coal Co.
22	Cr-9-B†	do	Crawford	SW¼ NE¼ sec. 28, T. 27 S., R. 25 E., active strip mine, Pryor Coal Co.
23	B-2669*	do	do	Cen. S. line NW¼ sec. 16, T. 28 S., R. 25 E., abandoned strip mine, Pioneer Coal Co.
24	B-2670*	do	do	Near Cen. SW¼ sec. 16, T. 28 S., R. 25 E.; abandoned strip mine, Pioneer Coal Co.
25	Cr-5-B**	do	do	NW¼ NE¼ sec. 15, T. 29 S., R. 25 E., 2.7 mi. west Franklin; active strip mine, Mackie Clemens Fuel Co.
26	Cr-6-B†	do	do	SE¼ NW¼ sec. 16, T. 29 S., R. 25 E., 1.5 mi. east Franklin; active strip mine, Mackie Clemens Fuel Co.
27	Cr-7-B**	do	do	NE¼ SW¼ sec. 16, T. 29 S., R. 25 E., 1.2 mi. east Franklin; active strip mine, Mackie Clemens Fuel Co.
28	B-2658*	do	do	Sec. 4, T. 30 S., R. 24 E., abandoned strip mine, Eagle-Cherokee Coal Mining Co.
29	B-2657*	do	do	SE¼ sec. 4, T. 30 S., R. 24 E., abandoned strip mine, Eagle-Cherokee Coal Mining Co.
30	Cr-12-B**	do	do	NW¼ NE¼ sec. 10, T. 30 S., R. 24 E., 3.5 mi. west Frontenac; active strip mine, Eagle-Cherokee Coal Mining Co.
31	Cr-14-B†	do	do	NE¼ SW¼ sec. 10, T. 30 S., R. 24 E., active strip mine, Eagle-Cherokee Coal Mining Co.
32	Cr-11-B**	do	do	SE¼ NW¼ sec. 1, T. 31 S., R. 22 E., 1 mi. northwest Monmouth; active strip mine, Lightening Creek Coal Co.
33	Cr-13-B†	do	do	NW¼ SE¼ sec. 7, T. 31 S., R. 23 E., 0.75 mi. southeast Monmouth; active strip mine, Apex Coal Co.
34	Cr-10-B**	do	do	SW¼ SE¼ sec. 7, T. 31 S., R. 23 E., 400 yds. south of Cr-13-B, active strip mine, Apex Coal Co.
35	Ck-1-B**	do	Cherokee	SE¼ NE¼ sec. 34, T. 31 S., R. 22 E., 4 mi. northwest Mineral; active strip mine, Pittsburg-Midway No. 18
36	Ck-6-B†	do	do	NW¼ SE¼ sec. 34, T. 31 S., R. 22 E., 4 mi. northwest Mineral; active strip mine, Pittsburg-Midway No. 18
37	Lt-1-B**	do	Labette	SW¼ SW¼ sec. 27, T. 33 S., R. 21 E., active strip mine, Gallagher Coal Co.
38	B-2664*	do	do	NE¼ sec. 33, T. 33 S., R. 21 E., abandoned strip mine, Vanduker Coal Co.
39	B-2663*	do	do	NE¼ sec. 33, T. 33 S., R. 21 E., abandoned strip mine, Vanduker Coal Co.

Samples are designated as follows: *Chemical analysis from Pierce and Courtier (1938 table 1), **column sample; †column sample and composite channel sample for chemical analysis.

cussion unless otherwise stated. This has been done for several reasons: (1) some of the samples were analyzed after air drying so that the actual bed moisture is not known, and (2) irregularities due to variable ash content are eliminated and the actual coal material may be compared.

The average fixed carbon content is 58.7 percent and the coal has an average calorific value of 14,980 B.t.u. Sulfur is high, averaging 5.1 percent. The ash is unusually high, averaging 13.4 percent on the moisture-free basis. However, comparison of the analyses indicates that the coal is remarkably uniform in composition over a

TABLE 6.—*Chemical analyses of coal from the Southeastern Kansas coal field*

									Mineral matter-free basis		
Locality	Sample no.	Condition*	Moisture	Volatile	Fixed carbon	Ash	Sulfur	Calorific value B.t.u.	Moist B.t.u.	Dry fixed carbon	Rank
						Mineral coal					
2	Cr-4-M	b	1.5	32.1	50.2	16.3	6.2	11,960	....	......	....
		c		32.6	51.0	16.5	6.3	12,140			
		d		39.0	61.0	......	10.8	14,540			
4	B-2659**	a	4.8	33.9	49.5	11.8	3.5	12,530	14,510	60.8	High vol. A bituminous
		c		35.6	52.1	12.3	3.7	13,150			
		d		40.6	59.4	......	4.2	15,010			
5	B-2660**	a	4.3	34.3	40.8	13.4	4.6	12,300	14,560	66.2	High vol. A bituminous
		c		35.8	50.2	14.0	4.8	12,850			
		d		41.6	58.4	......	5.6	14,940			
6	B-2655**	a	4.4	34.2	48.8	12.6	4.8	12,420	14,550	61.0	High vol. A bituminous
		c		35.8	51.0	13.2	5.1	13,000			
		d		41.3	58.7	......	5.8	14,960			
7	B-2656**	a	5.1	34.7	48.7	11.5	3.6	12,490	14,360	59.8	High vol. A bituminous
		c		36.6	51.3	12.1	3.8	13,160			
		d		41.6	58.4	......	4.4	14,970			
9	Cr-8-M	b	1.1	33.9	51.5	13.6	4.3	12,910	....	......	....
		c		34.3	52.1	13.8	4.3	13,050			
		d		39.7	60.3	......	5.0	15,140			
10	B-2665**	a	4.4	33.5	45.7	16.4	3.3	11,930	14,610	59.2	High vol. A bituminous
		c		35.1	47.7	17.2	3.5	12,480			
		d		42.4	57.6	......	4.2	15,080			
11	B-2666**	a	4.0	35.8	49.3	10.9	3.9	12,690	14,500	59.2	High vol. A bituminous
		c		37.3	51.3	11.4	4.0	13,220			
		d		42.1	57.9	......	4.6	14,920			
12	B-2652**	a	5.1	33.2	46.8	14.9	3.6	12,060	14,520	60.0	High vol. A bituminous
		c		35.0	49.3	15.7	3.8	12,710			
		d		41.5	58.5	......	4.5	15,080			
13	B-2667**	a	3.6	34.3	50.5	11.6	3.4	12,870	14,850	61.5	High vol. A bituminous
		c		35.5	52.5	12.0	3.5	13,350			
		d		40.4	59.6	......	4.0	15,160			
14	B-2668**	a	2.9	35.1	51.5	10.5	2.8	13,110	14,950	60.5	High vol. A bituminous
		c		36.2	53.0	10.8	2.9	13,510			
		d		40.6	59.4	......	3.2	15,140			

16	Ck-4-M	b	1.1	38.7	48.2	12.0	4.5	12,910	....	......	....
		c		39.1	48.7	12.1	4.6	13,050			
		d		44.5	55.4	......	5.2	14,850			
Average moisture, ash-free				41.3	58.7	13.4	5.1	14,980			
						Bevier coal					
19	Bn-3-B	b	1.4	34.4	49.9	14.2	8.8	12,570	....	......	....
		c		34.9	50.6	14.4	8.9	12,750			
		d		40.8	59.1	......	10.4	14,890			
20	Bn-2-B	b	1.3	35.8	47.0	16.0	2.8	11,820	....	......	....
		c		36.3	47.6	16.2	2.8	11,980			
		d		43.3	56.8	......	3.3	14,300			
22	Cr-9-B	b	1.1	36.8	52.1	10.0	2.5	13,910	....	......	....
		c		37.2	52.6	10.1	2.5	14,060			
		d		41.4	58.5	......	2.8	15,640			
23	B-2669**	a	3.4	37.6	50.6	8.4	2.8	13,250	14,650	58.4	High vol. A bituminous
		c		38.9	52.4	8.7	2.9	13,720			
		d		42.6	57.4	......	3.1	15,030			
24	B-2670**	a	4.6	36.9	48.6	9.9	2.4	12,940	14,570	57.5	High vol. A bituminous
		c		38.7	51.0	10.3	2.5	13,570			
		d		43.1	56.9	......	2.8	15,140			
26	Cr-6-B	b	1.4	35.1	50.3	13.2	2.7	13,310	....	......	....
		c		35.6	51.0	13.4	2.7	13,500			
		d		41.1	58.9	......	3.1	15,590			
28	B-2658**	a	3.4	34.3	49.6	12.7	2.4	12,700	14,860	60.3	High vol. A bituminous
		c		35.5	51.3	13.2	2.5	13,150			
		d		40.9	59.1	......	2.9	15,140			
29	B-2657**	a	4.3	35.4	46.4	13.9	2.3	12,280	14,580	58.0	High vol. A bituminous
		c		36.9	48.6	14.5	2.4	12,830			
		d		43.2	56.8	......	2.8	15,010			
31	Cr-14-B	b	1.1	35.0	47.2	16.7	4.2	12,250	....	......	....
		c		35.4	47.7	16.9	4.2	12,380			
		d		42.6	57.4	......	5.1	14,900			
33	Cr-13-B	b	1.4	35.1	47.9	15.6	2.7	12,290	....	......	....
		c		35.6	48.6	15.8	2.7	12,460			
		d		42.3	57.7	......	3.2	14,800			
36	Ck-6-B	b	1.5	36.3	45.1	17.2	4.2	11,340	....	......	....
		c		36.9	45.8	17.5	4.3	11,510			
		d		44.7	55.5	......	5.2	13,950			
38	B-2664**	a	3.5	42.0	48.6	5.9	3.1	13,660	14,720	59.7	High vol. A bituminous
		c		43.5	50.4	6.1	3.2	14,150			
		d		46.3	53.7	......	3.4	15,070			
39	B-2663**	a	3.7	40.8	47.7	7.8	3.1	13,330	14,700	55.0	High vol. A bituminous
		c		42.4	49.5	8.1	3.2	13,850			
		d		46.1	53.9	......	3.5	15,070			
Average moisture, ash-free				43.0	57.1	17.7	3.9	14,690			
						Croweburg coal					
8	Cr-1-C	b	0.9	35.3	49.0	14.8	7.3	11,450	....	......	....
		c		35.6	49.4	14.9	7.4	11,550			
		d		41.8	58.0	......	8.7	13,570			

---

*The form of analysis is denoted as follows: a, as received at the laboratory; b, air dried; c, moisture free; d, moisture and ash free.

**Analyses from Pierce and Courtier (1938, table 1).

large area. With the exception of one sample, the calorific values do not differ from the average by more than several hundred B.t.u. and the fixed carbon values are within a few percent of the average. Sulfur and ash are somewhat more variable, as might be expected.

The chemical analyses for which the bed moisture is known have also been calculated to the mineral-matter-free basis so that the coal could be classified according to A.S. T.M. rank designation (Table 1). Rank designation is determined by moist mineral-matter-free B.t.u. and dry mineral-matter-free fixed carbon according to the Parr (1928) equations as follows:

$$\text{1) Moist mineral-matter-free B.t.u.} = \frac{\text{B.t.u. (as received)} - 50\ \text{S}}{100 - (1.08 \times \text{ash} + 0.55\ \text{S})} \times 100$$

$$\text{2) Dry mineral-matter-free fixed carbon} = \frac{\text{fixed carbon (as received)} - 0.15\ \text{S}}{100 - (\text{moisture} + 1.08 \times \text{ash} + 0.55\ \text{S})} \times 100$$

These equations result from efforts to increase the ash value to represent the original quantity of mineral matter present in the raw coal.

The mineral-matter-free tabulations of Table 6 indicate that the Mineral coal is a high volatile A bituminous coal according to the A. S. T. M. classification.

Although no coking tests on the coal were made, the agglomerating index was determined as described by Stanton, Fieldner, and Selvig (1939, pp. 36-37). The agglomerating index (Table 7) indicates the coking and caking properties of bituminous coal and is found by examination of the residue left in the platinum crucible from the volatile matter determination. It is of limited value for indicating coking properties since the coal is heated much more rapidly than that coked in commercial ovens. Thus, coals that yield good cokes in commercial practice always give well-coked residues from the volatile-matter determination, but the reverse is not always true. As shown in Table 8, the Mineral coal is classed as Cg or Cf, which means that it is a good to fair caking agglomerate coal—e.g., it will produce a button showing medium to strong swelling and good cell structure, has a characteristic metallic lustre, and generally will support a 500 gram weight. The buttons barely meet the 500 gram weight requirement since the cell walls tend to be thin and are easily crushed although the button supports the weight. It is doubtful that the coal would make good metallurgical grade coke since it is not particularly strong and has a high sulfur content which is 3 to 4 percent higher than the maximum tolerance of 1.5 percent sulfur.

BEVIER COAL

Lithology.—The Bevier coal lies just above the Ardmore limestone and its outcrop is practically coincident with that of the Ardmore. It roughly parallels the Mineral coal beginning at a point several miles southeast of Oswego and continuing northeasterly until it crosses the State line into Missouri north of Garland.

Column samples were collected at 14 localities along the outcrop in strip mines and at 7 places composite channel samples for chemical analysis were collected immediately adjacent to the column samples. The chemical analyses are supplemented by data from Pierce and Courtier (1938, table 1).

TABLE 7.—*Agglomerating and coking properties of coals based on examination of residue incident to the volatile-matter determination* (Stanton, Fieldner, and Selvig, 1939, p. 37)

Designation		Appearance of residue from standard method for determination of volatile matter in coal
Class	Group	
Nonagglomerating (button shows no swelling or cell structure and will not support 500 g without pulverizing)	NA (nonagglomerate)	NAa-noncoherent residue NAb-coke button shows no swelling or cell structure and after removal from crucible will pulverize under a weight of 500 grams
Agglomerating (button shows swelling or cell structure or will support 500 g without pulverizing)	A (agglomerate) button dull black and sintered; shows no swelling or cell structure	Aw (weak agglomerate)—buttons come out of crucible in more than one piece Af (firm agglomerate) — buttons come out of crucible in one piece
	C (caking) shows swelling or cell structure	Cp (poor caking)—button shows slight swelling with small cells; has slight gray luster Cf (fair caking)—button shows medium swelling and good cell structure; has characteristic metallic luster Cg (good caking)—button shows strong swelling and pronounced cell structure, with numerous large cavities and cells; has a characteristic metallic luster

The Bevier coal lies 80 to 100 feet below the top of the Cherokee shale and is mined from strip pits having an overburden of 25 to 30 feet of dark-gray to black shale. The shale may contain several beds of dark shaley limestone ranging from 2 to 30 inches in thickness. These thin limestones are most prominent in the northern part of the field. Locally, as much as 50 feet of overburden may be removed. A typical underclay is found immediately below the coal and this is, in turn, underlain by the Ardmore limestone.

The average thickness of the coal where sampled is 14.7 inches; its thickness ranges from 12 to 17.5 inches. Like the Mineral coal, it is finely attrital with few anthraxylon bands exceeding a thickness of 1 mm. It contains numerous megascopic lenses of fusain. It also contains many vertical calcite-filled fractures which are even more prominent than in the Mineral coal and probably account for the higher ash content of the Bevier. Pyrite nodules are not so numerous and the coal consequently has a lower sulfur content.

There is some evidence of structural deformation in the Bevier. At least four faults were encountered in the Pryor Coal Company operation at the north end of the field northwest of Arcadia (Loc. 22, Fig. 1). The faults had an east-west strike and dipped steeply to the south. Vertical displacement was about 2 feet so that the coal had to be mined at several levels. The coal also had a rolling or gently folded surface.

Chemical composition and rank.—Chemical analyses of 13 samples of Bevier coal are listed in Table 6. The average fixed carbon content is 57.1 percent and the average calorific value is 14,690 B.t.u. Sulfur averages 3.9 percent and the ash is 17.7 percent on the moisture-free basis. In comparison with averaged Mineral coal analyses (Table 6) the Bevier is lower in calorific value, fixed carbon, and sulfur but higher in ash. The differences are not large but may be an indication of the operation of Hilt's law, which predicts that stratigraphically lower coals have higher fixed carbon (lower volatile) and calorific values due to increasing pressure and temperature rather than initial differences in the coal materials.

Comparison of individual Bevier analyses shows that the coal does not exhibit quite the same areal uniformity as does the Mineral. Although fixed carbon values have a range of about 5 percent and deviate from the average by only a few percent, the calorific values are quite variable and range from 13,950 to 15,640 B.t.u.

Chemical analyses calculated to the mineral-matter-free basis classify the Bevier coal as a high volatile A bituminous coal according to A.S.T.M. rank designation.

The agglomerating index is given for seven samples in Table 8. The Bevier is an agglomerate Cf to Cg or good to fair caking coal and exhibits approximately the characteristics of the Mineral coal. Although the lower sulfur content would make it more desirable as a domestic coke, the sulfur is still above the limit of 1.5 percent set for metallurgical coke.

CROWEBURG COAL

Lithology.—The Croweburg coal is named from the town of Croweburg in northeastern Crawford County, where it was mined extensively at one time. It lies about 25 feet above the Mineral coal between the Mineral and Bevier so that its outcrop is between and roughly parallel to these coals. Only a small quantity of Croweburg coal is produced at the present time and good exposures are rare.

A column sample with an adjoining composite sample for chemical analysis was collected at the Mackie Clemens strip mine (Loc. 8, Fig. 1) where both the Mineral and Croweburg coals are mined in a single operation. The Fleming coal also is exposed in the same mine but is so thin and of such poor quality that is rejected as refuse.

About 12 feet of shale overlies the Croweburg. It is dark gray at the base and grades upward into a lighter gray color. The top consists of about 3 feet of black fissile shale containing numerous concretions and phosphate nodules.

The coal is about 12 inches thick at the locality where sampled. Pierce and Courtier (1938, p. 75) report that this thickness is average for the bed. It is a finely attrital coal with few wide anthraxylon bands and several distinct layers of fusain.

Chemical composition and rank.—Average analyses of the Croweburg coal are not available so that its chemical composition is reported here from a single determination (Table 6) which may not be representative. At a single locality, the coal has a fixed carbon content of 58.0 percent, an ash content of 14.9 percent, and a calorific value of 13,570 B.t.u. Sulfur comprised 8.7 percent on a moisture-free basis. It is roughly comparable to the Mineral coal (Table 6) although the calorific value is considerably lower.

TABLE 8.—*Agglomerating index from volatile matter residue from Kansas coal*

Sample	Coal	Agglomerating index	Support 500 grams
Bn-3-B	Bevier	Cf	Yes
Bn-2-B	do	Cg	Yes
Cr-9-B	do	Cg	Yes
Cr-6-B	do	Cf	Yes
Cr-14-B	do	Cg	Yes
Cr-13-B	do	Cg	Yes
Ck-6-B	do	Cf	Yes
Cr-4-M	Mineral	Cf	Yes
Cr-8-M	do	Cg	Yes
Ck-4-M	do	Cg	Broke in several pieces
Cr-1-C	Croweburg	Cg	Yes

The "as received" analysis has not been converted to the mineral-matter-free basis for purposes of rank designation because the bed moisture is not known. However, rough approximation indicates that the calorific value would fall between 13,000 and 14,000 B.t.u. and that fixed carbon would be less than 69 percent so that the coal is probably high volatile B bituminous.

The agglomerating index (Table 8) rates the coal as an agglomerate Cg or good caking coal. However, the sulfur content is far too high for metallurgical purposes.

REGIONAL VARIATION IN CHEMICAL PROPERTIES

A knowledge of the regional variation in coal is of considerable importance to the producer since it enables him to predict the quality of his product in new ventures or in the extension of old fields. The chemical analyses of the Mineral and Bevier coals have shown that the Mineral is relatively uniform along the strike and that the Bevier is somewhat more variable. Variations in fixed carbon and volatile matter are commonly regarded as an indication of the stage of coalification or rank. Calorific variations arise in the same manner but may be a more sensitive index of coal type variation since the calorific value of hydrogen is greater than that of carbon.

The possibility that a small systematic variation might be discernible in the raw data resulted in the plot of fixed carbon and calorific value versus distance as shown in Figure 4. The Mineral

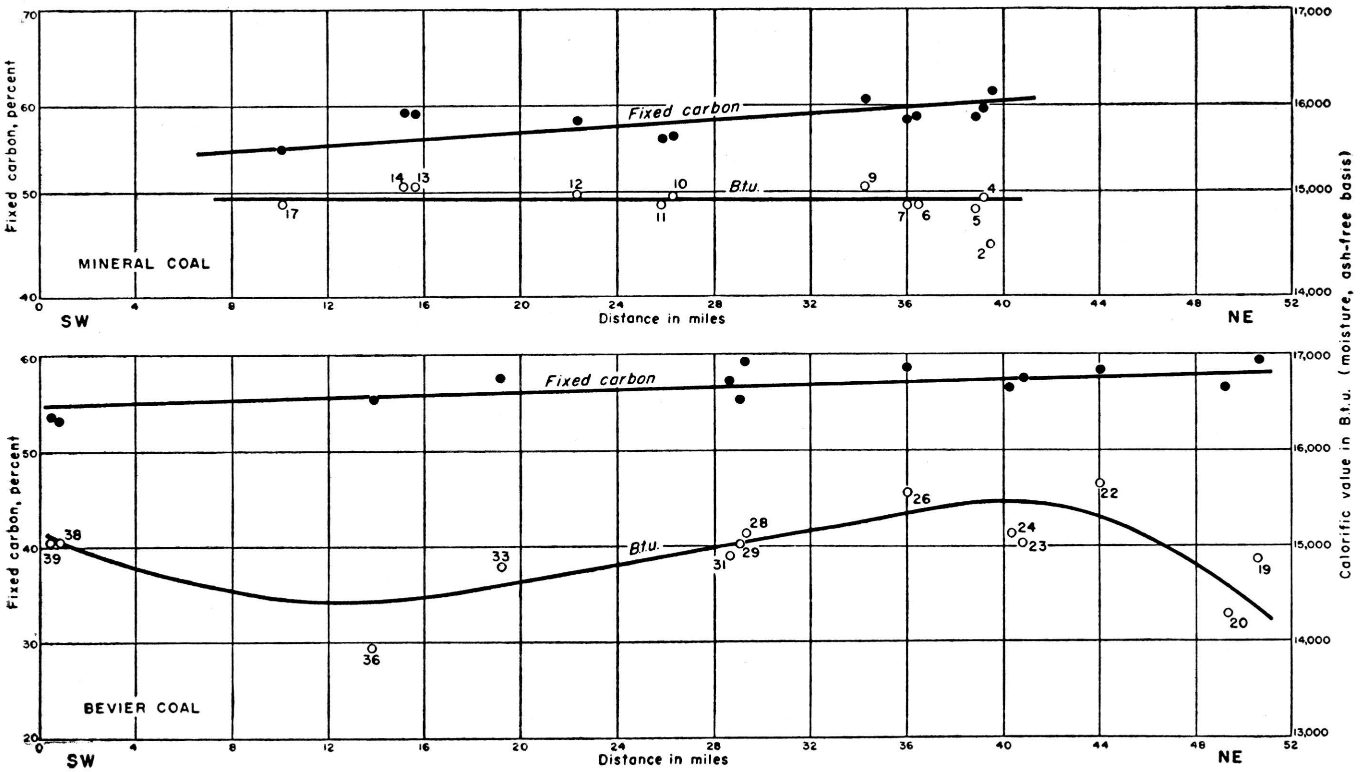


FIG. 4.—Regional variation of fixed carbon and B.t.u. values in Mineral and Bevier coals. (Numbers refer to locations projected to line a-a′, Fig. 1.)

and Bevier sample locations have been projected to the line a-a′ of Figure 1.

There are not a sufficient number of plotted points to define clearly regional variation but smooth curves which have been drawn at least suggest that the fixed carbon content of both coals increases from south to north. The calorific value of the Mineral coal is so uniform that the curve has almost no slope whereas the calorific value of the Bevier shows relatively wide variation.

Interpretation of these curves is speculative, but is considered in order to indicate the results which might be expected with a greater number and wider distribution of samples.

The Cherokee basin, in which coal accumulation took place, came into existence after Mississippian time. It was bounded on the north by the Bourbon arch which separated it from the Forest City basin. Within the basin are several known or inferred structural elements. Pierce and Courtier (1938, p. 53) have described the northwest-trending Pittsburg anticline and Dreyer (1947) has shown the probable existence of additional features through geophysical investigation. Since it has been demonstrated that the increased temperatures and pressures which accompany orogenic activity may produce an increase in the rank of coal, the effect of the above structural elements should be considered.

Little is known of the orogenic activity during Cherokee time. Nevertheless, tentative suggestion is made that activity of the Bourbon arch may have accounted for the increase in fixed carbon from south to north. One line of evidence lies in the structure of the Bevier coal mentioned earlier. Four faults were described at the north end of the field. These faults roughly parallel the Bourbon arch and may have been produced by movement of the arch.

However, at least part of the variation is probably due to analytical technique. The Bureau of Mines (Stanton, Fieldner, and Selvig, 1939, p. 59) permits difference of 0.5 percent for two volatile-matter determinations made in the same laboratory and 1.0 percent for determinations made in different laboratories. The fixed carbon tolerances should therefore be of the same order of magnitude. Differences of 0.3 and 0.5 percent are allowed for two calorific determinations made in the same laboratory and in different laboratories respectively. The overall differences between maximum and minimum values for the Mineral and Bevier coals are more of the order of 5 percent. Some part of this variation is systematic, but some is undoubtedly analytical.

PETROGRAPHY OF THE MINERAL, CROWEBURG, AND BEVIER COALS

DESCRIPTION OF COMPONENTS

The Mineral, Croweburg, and Bevier coals were studied petrographically from approximately 400 thin sections and from 22 column samples. Since the three coals show marked similarities, they are discussed here as a group rather than individually.

The outstanding characteristic of the coals is their finely banded appearance. The anthraxylon bands range from a maximum width of about 5 mm to the arbitrary lower limit of 0.017 mm and rarely exceed 1 mm. Typical bands of anthraxylon are shown in Plate 2, A and B. The relatively homogeneous nature of the anthraxylon is distinctive and aids in separating it from adjacent attrital coal. The bands are characteristically bright orange to red and in places are bounded by brilliant orange or yellow cuticular material having a serrated edge on its proximal side (Pl. 5, A and B). Anthraxylon exhibits several forms which depend on the part of the plant sectioned, the direction of the section, and the state of preservation of the material. Many bands are not continuous, but pinch out within a short distance or split into a number of finer bands due to branching or degradation. Lenticular bands are indicative of transverse sections. Some bands are double because the original stems were hollow cylinders.

Cell structure was not seen in most sections of anthraxylon either because the plant material had undergone considerable alteration before coalification or because of lack of contrast between the cell walls and the material filling the lumens. Plate 2 C is a section of anthraxylon showing traces of deformed cell structure. Plate 2 D is a section of anthraxylon cut parallel to the bedding and in a direction longitudinal to the plant cells. The boxlike nature of the cells can be seen clearly.

Translucent attritus is usually heterogeneous. It consists of a closely knit debris of anthraxylon fragments, spore exines, bits of cuticle, resin bodies, and other degradation products plus extremely fine particles of calcite, pyrite, quartz, and clay minerals. Typical examples of translucent attritus are shown in Plates 3, 4, and

8C. Some translucent attritus consists entirely of small fragments which are distinguished from anthraxylon solely on the basis of size. Since most of the anthraxylon falls in the fine size range, distinction between attritus and anthraxylon is difficult. The constituents of Plate 3A are similar in appearance but the band in the middle of the section is classified as anthraxylon whereas the remainder of the material is translucent attritus.

Although the spore content of the coal is remarkably low, the megaspore exines can be distinguished easily when they do occur. Megaspores are brilliant yellow bodies, up to 1 mm in length, resembling a flattened tube in cross section. The ends may be invaginated as shown in Plate 5D. Plate 5C shows a cluster of megaspores at a lower magnification. The microspores are much smaller and may be mistaken for fragments of cuticle.

Bright red globular resin bodies are abundant in both translucent attritus and anthraxylon. Plate 4 illustrates how bands of anthraxylon and attritus have been compressed around more resistant resin bodies.

Fusain is one of the most striking components of these coals and, in places, one of the most difficult to distinguish because of its similarity to certain types of opaque attritus. At its best, it consists of cellular material with opaque cell walls and translucent spaces between the walls which have been filled with calcite. Some types of fusain are clearly transverse sections of altered wood or cortex (Pl. 6A, lower part of B, and C) since the same kinds of cells can be seen in unaltered plants. Fusain has a fibrous appearance if the cells have been cut in a longitudinal direction (Pl. 6, upper part of B) or if the original material consisted of resin rodlets. Other fusain occurs in fine irregular fragments derived from the deformation or crushing of the cellular type or from the alteration of finer woody debris. Plate 7B shows fusain in which the cell walls have been deformed so that the calcite-filled spaces no longer exhibit regularity. Fusain, in many cases, occurs in lenticular bodies (Pl. 7A).

Opaque attritus is a relatively minor constituent of the coals. When it does occur, it is found, in most places, near the top or bottom of the column. Clearly recognizable opaque attritus contains translucent anthraxylon-like fragments, cuticle, and spore exines in addition to the opaque constituents. Plate 3C shows opaque attritus intercalated with translucent material. Plate 5, C and D, shows examples of opaque attritus containing spore exines and fragments of cuticular material.

The most perplexing problem in the petrographic analysis of the coal was the differentiation of the opaque or semiopaque constituents. Opaque attritus may have a transitional relation with translucent attritus or anthraxylon. In such cases, the translucent constituents become progressively more opaque and grade into fusainlike material. Plate 7D is a typical example of this transition. The material at the bottom of the section is clearly anthraxylon. It changes upward into semiopaque matter which in turn becomes progressively more opaque and acquires the expanded structure of fusain. Since the boundaries of these constituents are not defined clearly, the analytical results are dependent, to a large measure, on the judgment of the observer. Plate 7C shows that other coal constituents may alter to fusain. The round opaque body is a fusinized resin globule.

ORIGIN OF OPAQUE COMPONENTS

Because the opaque components are of considerable importance in both coal classification and coal utilization, it is pertinent to review briefly the ideas concerning the origin of these constituents. In general, two schools of thought have existed (Hendricks, 1945, pp. 19-21) concerning fusain. The first attributed the origin to forest fires, and the second to some form of chemical alteration prior to burial. The forest-fire theory has found little favor because of the improbability of extensive fires in typical peat swamps and the absence of ash layers. In addition, fragile plant structures are fusinized and plant stems are found with fusain on the interior. The chemical alteration theories include dehydration during periods of dryness or by sulfuric acid, carbonization as the result of catalytic action, impregnation with various salts or gases which promote carbonization and inhibit aerobic decay, and the local action of thermophilic bacteria.

The origin of opaque attritus has received relatively little attention and most investigators have considered it a separate entity from fusain. Thiessen and Sprunk (1936) observed a transitional relation between opaque and translucent constituents in their studies of the Upper and Lower Cedar Grove coals of West Virginia. Fieldner and Schmidt (1941, p. 12) suggested that opaque attritus resulted from advanced decomposition due to the action of biological agencies and that as decay progressed, the attritus became more opaque.

Certain observations may be made concerning the origin of the opaque constituents as illustrated in Kansas coals.

(1) The process or processes which produce fusain may act upon any of the plant materials and the resulting degree of opacity is dependent upon the intensity and duration of the process. In addition, it is likely that certain plant tissues are more susceptible to fusinization than others. Thin sections show the gradation of anthraxylon and translucent attritus into opaque attritus and fusain. It seems probable that had the process producing the gradation been of sufficient intensity and duration, all the material would have been fusinized. Since fusinized resin bodies have been found, it is evident that even the more resistant plant materials are susceptible to fusinization.

(2) The process of fusinization was operative in the early stages of coalification. Cellular fusain is able to maintain its open structure because the cells are filled with calcite. The other coal material is seen to be compressed around the structurally supported fusain. Therefore fusinization and impregnation took place prior to compaction of the surrounding coal and the process may be regarded as diagenetic. If coalification had proceeded in a normal manner, cell cavities would have filled with humic material and later fusinization would have produced a homogeneous rather than a cellular fusain.

(3) Fusinization can be local in nature. Most fusain in Kansas coals cannot be traced for any distance laterally whereas, in some coals, fusain bands are persistent. It would seem that fusain is produced by a number of processes, some of which are local in action whereas others are not.

(4) Much that has been classed as opaque attritus is probably crushed and compacted fusain. In cases where no calcite impregnation of cells took place, the structurally weak fusain was not able to maintain its open spaces. Undoubtedly much of the crushed fusain has been classified as opaque attritus since fusain is identified largely on the basis of its open cell structure.

ANALYSIS OF COMPONENTS

In Plate 1, the type of coal and the percentage of components in each thin section have been shown graphically for 22 column samples. As illustrated in Plate 1A, the type of coal is designated at the left side of the figure. Distances from the top of the bed are given at the left margin. The thickness of each lithologic unit and its description number are shown in the next two columns. The percentage loss in the lower left corner is an indication of the amount of coal lost through sawing and grinding. It was determined by dividing the thickness of the column sample after grinding (as determined from the sum of the thin section widths) by the original thickness of the column before grinding. Approximately true thickness can be found by multiplying the diagram thickness by the percent loss and adding the product to the diagram thickness. The percentages of anthraxylon, translucent attritus, opaque attritus, and fusain are shown by bar diagram to the right of the figure.

MINERAL COAL

Petrographic analyses of the Mineral coal are shown in Plate 1, A to G. With few exceptions, the Mineral coal is a uniformly bright coal. It is characterized by a relatively large content of translucent attritus. Opaque attritus and fusain are minor constituents. In the few cases where opaque attritus increases to the extent that parts of the coal are classified as semisplint or cannel, these constituents are confined to the top or bottom of the bed. Sample Ck-3-M (Pl. 1C) contains 0.8 inch of semisplint at the top of the column. Sample Cr-8-M (Pl. 1D) has 0.6 inch of semisplint about 1.4 inches from the top and another semisplint band 0.8 inch wide at the bottom of the bed. Sample Ck-5-M (Pl. 1E) is somewhat peculiar in that it contains a thin band of cannel coal at the bottom of the bed. Although this band meets the petrographic requirements of a cannel, it does not have the typical compact and nonbanded canneloid appearance. About 1.4 inches of the column is missing since part of the coal was too friable to section or polish.

Banded or nodular pyrite is relatively rare in the Mineral coal except at the south end of the field. Although these impurities are described as pyrite in the diagrams, they are actually "coal balls" and contain considerable calcite. Samples Ck-4-M (Pl. 1F) and Ck-

2-M (Pl. 1G) both show that the nodules are confined to the upper portion of the coal bed.

The average analysis for each column is tabulated in Table 9 and the average of these analyses is shown at the bottom of the table. It is interesting to note that opaque attritus increases from north to south until it reaches a maximum of 9.0 percent just north of Frontenac (sample Cr-8-M) and then decreases to the south. This variation may not be significant since relatively few Mineral coal samples have been analyzed. Nevertheless, the opaque attritus content of the coal is lower in the north and south ends of the field.

TABLE 9.—*Summary of data on petrographic analyses of column samples of coals from the Southeastern Kansas coal field*

Locality no.	Sample no.	Thickness, inches	Anthraxylon, percent	Translucent attritus, percent	Opaque attritus, percent	Fusain, percent
			Mineral coal			
1	Cr-2-M	10.4	26.1	66.9	2.6	4.4
2	Cr-4-M	13.5	21.3	69.0	1.4	8.2
3	Cr-3-M	18.5	24.1	64.3	3.9	7.6
9	Cr-8-M	21.1	33.5	50.9	9.0	10.3
15	Ck-5-M	14.3	31.2	59.4	2.7	6.6
16	Ck-4-M	18.4	41.1	51.6	1.4	5.9
18	Ck-2-M	10.4	34.4	58.6	1.5	5.5
	Average	15.2	30.2	60.1	3.2	6.9
			Bevier coal			
19	Bn-3-B	12.9	45.5	40.4	8.0	6.1
20	Bn-2-B	14.0	54.4	35.4	4.8	5.4
21	Bn-1-B	12.1	41.7	40.7	1.6	16.0
22	Cr-9-B	15.9	38.3	53.8	4.4	3.5
25	Cr-5-B	16.8	27.5	53.9	4.2	14.4
26	Cr-6-B	17.5	33.7	55.5	5.8	5.1
27	Cr-7-B	15.0	36.2	55.6	4.5	3.8
30	Cr-12-B	16.1	36.1	52.7	4.4	6.8
31	Cr-14-B	15.4	32.0	53.7	9.7	4.7
32	Cr-11-B	14.1	36.8	53.1	5.1	5.0
33	Cr-13-B	15.4	35.4	49.8	4.2	10.5
34	Cr-10-B	15.7	31.7	55.7	6.9	5.7
35	CK-1-B	13.4	36.2	50.3	8.2	5.3
37	Lt-1-B	12.0	44.4	38.2	11.4	6.0
	Average	14.7	37.9	49.2	5.9	7.0
			Croweburg coal			
8	Cr-1-C	11.5	21.0	58.2	7.7	13.1

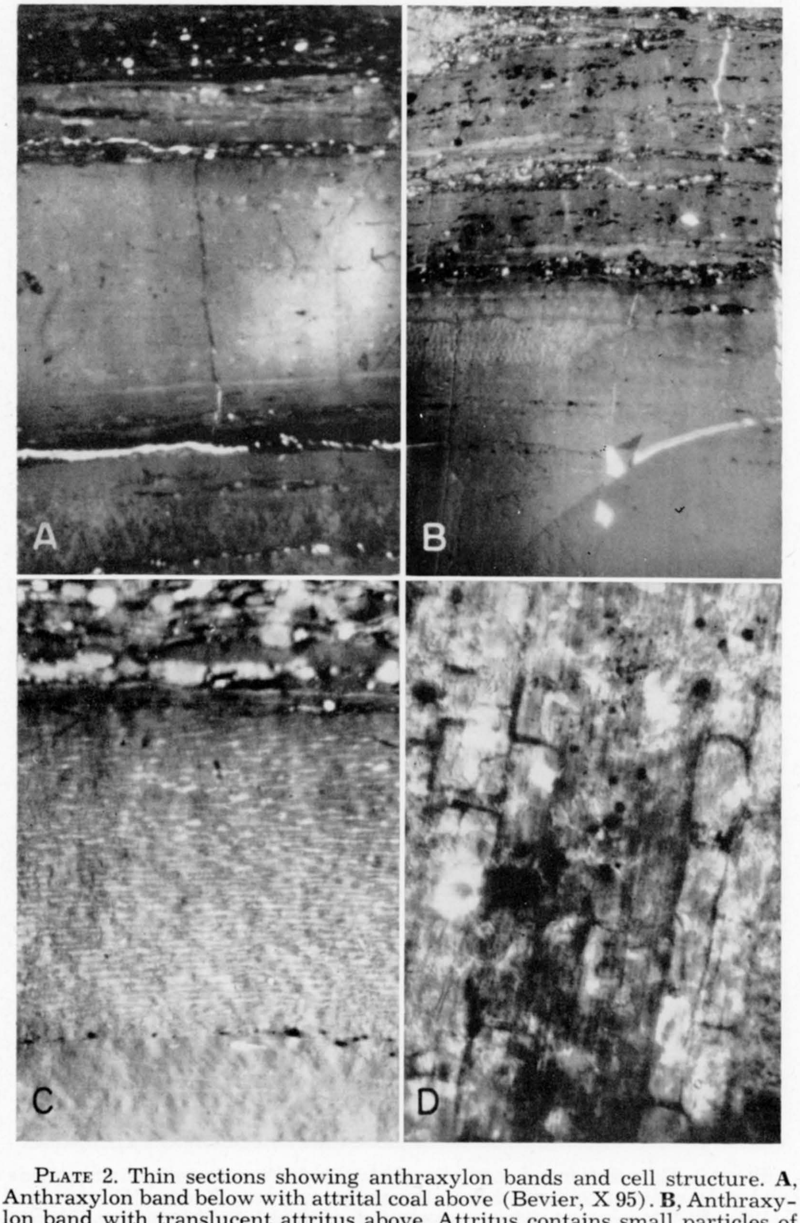


PLATE 2. Thin sections showing anthraxylon bands and cell structure. **A**, Anthraxylon band below with attrital coal above (Bevier, X 95). **B**, Anthraxylon band with translucent attritus above. Attritus contains small particles of opaque pyrite and translucent calcite and clay minerals (Mineral coal, X 95). **C**, Deformed cell structure in anthraxylon (Bevier coal, X 350). **D**, Anthraxylon band cut parallel to bedding. Boxlike nature of cells is evident (Mineral coal, X 150).

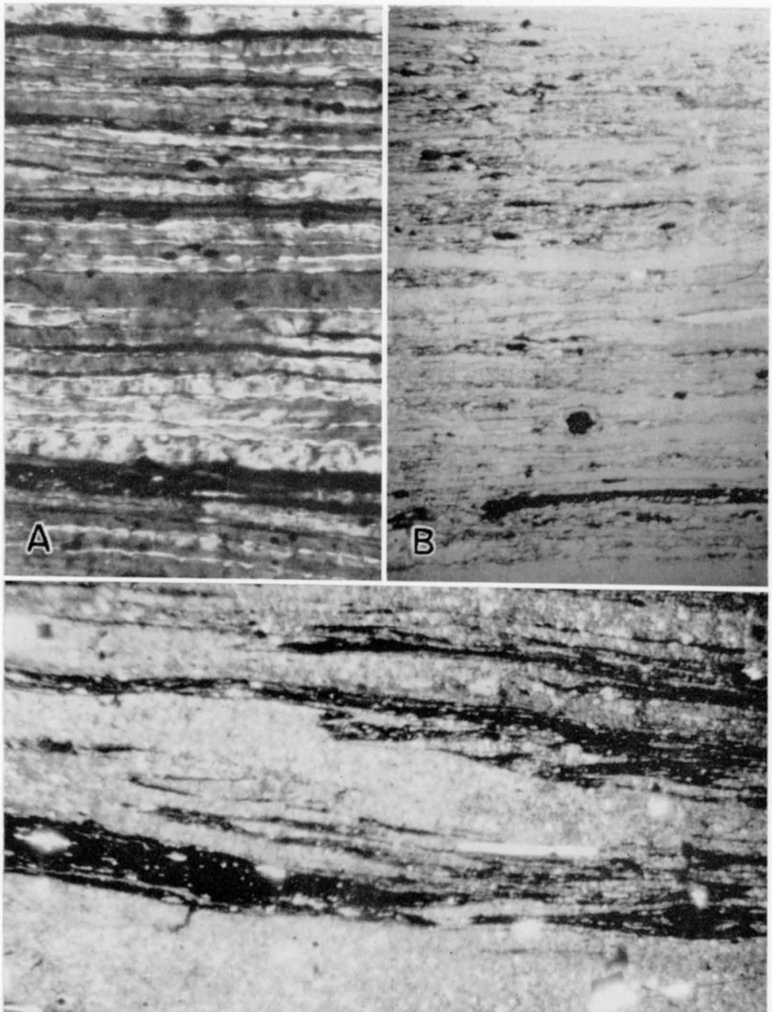


PLATE 3. Thin sections of attrital coal. **A**, Banded translucent attritus. Wide band near center is classified as anthraxylon on basis of size (Mineral coal, X 125). **B**, Translucent attritus composed of shredlike fragments. Opaque bodies are pyrite (Mineral coal, X 125). **C**, Opaque attritus intercalcated with bands of anthraxylon and translucent attritus (Bevier coal, X 95).

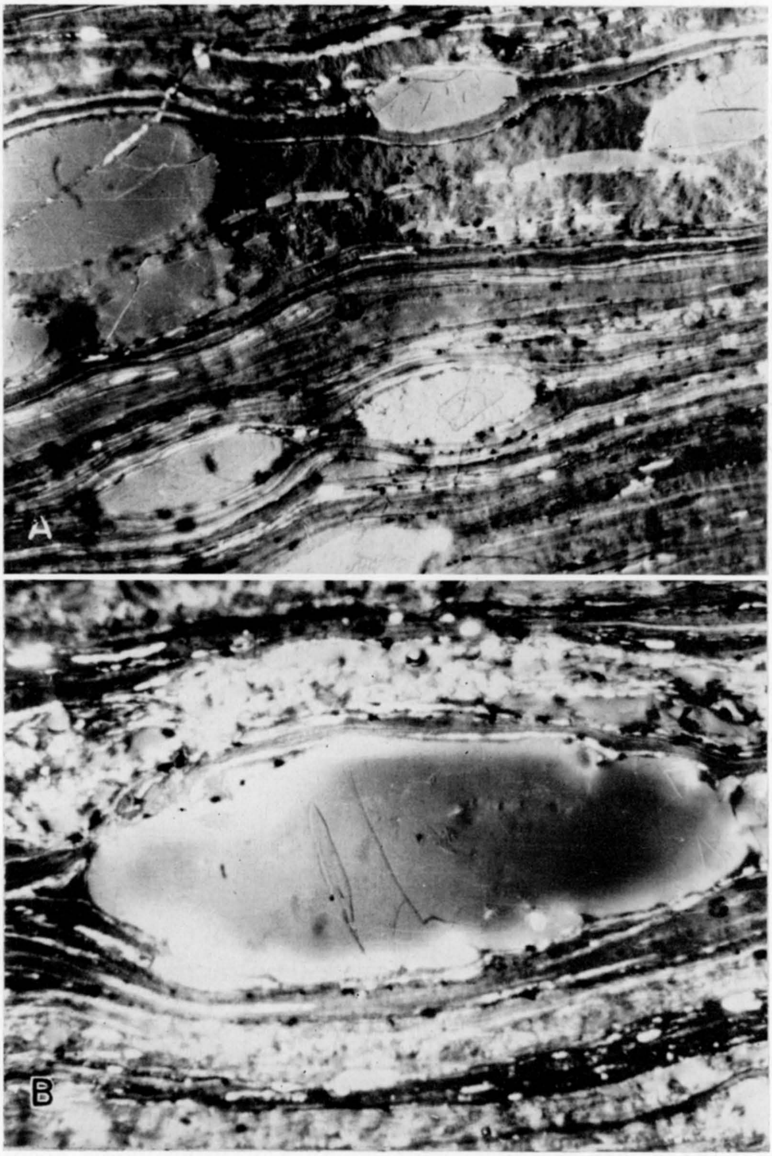


PLATE 4. Resin bodies. **A,** Resin bodies in anthraxylon and translucent attritus. Note how bands have been compressed around resistant resin bodies (Bevier coal, X 125). **B,** Large resin body in translucent attritus (Bevier coal, X 125).

BEVIER COAL

Petrographic analyses of the Bevier coal are shown in Plate 1, H to U. The Bevier is also a uniformly bright coal except for a few thin bands of splint and semisplint coal. Translucent attritus again predominates whereas opaque attritus and fusain are relatively minor constituuents. No splint or semisplint coal is encountered north of Franklin in Crawford County. The first occurrence is in sample Cr-5-B (Pl. 1L) which has a thin band of semisplint near the top of the bed. There is also a layer of almost pure fusain about 11.5 inches from the top of the bed which does not fit into the type classification scheme. Other samples to the south show small amounts of splint or semisplint near the top or bottom of the bed. Samples Cr-14-B (Pl. 1P) and Cr-11-B (Pl. 1Q) are exceptions to this general rule since semisplint coal occurs near the middle of the bed.

Nodular or banded pyrite is rare in the Bevier coal. The only occurrence was in sample Ck-1-B (Pl. 1T) about 8 inches from the top of the sample.

The average analysis for each column sample is tabulated in Table 9 and the average of the analyses for all the columns is shown at the bottom of the table. The distribution of components is somewhat erratic and there is no apparent systematic variation.

CROWEBURG COAL

A single analysis of the Croweburg coal is shown in Plate 1V. It is similar in most respects to the Mineral and Bevier coals. The most abundant constituent is translucent attritus. A relatively thick band of splint coal occurs near the bottom of the bed. The average analysis of the column is tabulated in the lower part of Table 9.

COMPARISON OF THE COALS

In comparing the analyses of the coals, it is important to note that the Bevier coal is somewhat higher in anthraxylon, opaque attritus, and fusain than the Mineral coal. The economic significance of these differences will be discussed later in reference to coal utilization. Since the distribution of splint and semisplint coal is similar for all the beds, it may be pertinent to mention that

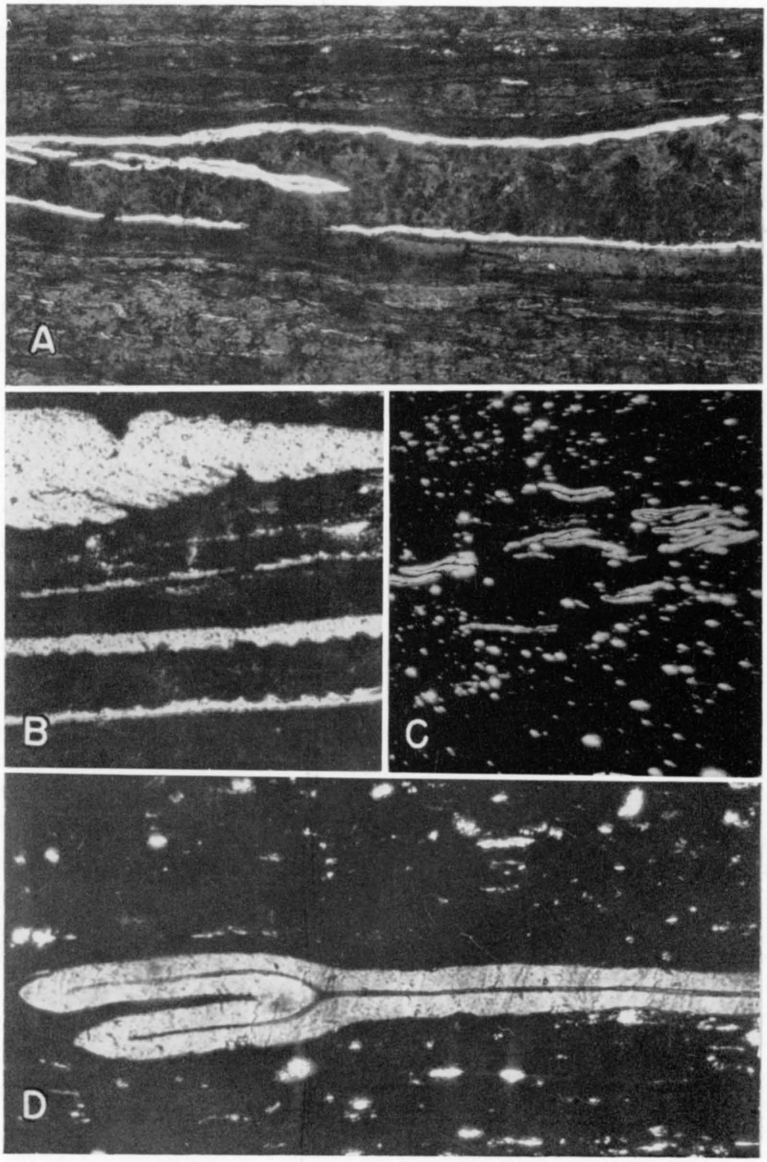


PLATE 5. Thin sections showing cuticle and spores. **A,** White material is cuticle which surrounds a stem, in longitudinal section (Mineral coal, X 50). **B,** Fragments of cuticle. Lower double layer is a longitudinal section of a stem. Note the characteristic serrated edge on the inner side of each layer (Mineral coal, X 125). **C,** Cluster of megaspore exines or cases in opaque attritus (Mineral coal, X 100). **D,** Megaspore in opaque attritus. The double character of the spore case is clearly evident. Note the invaginated end of the case (Mineral coal, X 190).

one of the advantages of column analysis is to show the distribution of coal types so that selective mining may be employed intelligently. The value of such a practice in mining Kansas coals is doubtful, however, because of the thinness of the beds and the relatively small contribution of the splints and semisplints to the overall character of the coal.

Mineral Matter

Chemical analyses of the Mineral, Croweburg, and Bevier coals already have indicated their relatively high ash content. However, the ash value contributes little to an understanding of the identity and distribution of the mineral matter which is responsible for the ash. Such information is important for several reasons: (1) it aids in determining the extent of economical coal beneficiation; (2) the chemical and physical properties of coal are influenced by the character of the mineral matter; (3) it is a reflection of the geologic history of the coal bed.

KINDS OF MINERAL MATTER

Two kinds of mineral matter are generally found in all coals. The first is called "inherent mineral matter" and refers to that portion organically combined with the coal. It cannot be determined petrographically and includes those elements which have been assimilated by plants for nutritive purposes. The second is known as "extraneous mineral matter" and includes that portion which is foreign to the plant material. Extraneous mineral matter is the larger contributor to the total ash content. It consists of detrital minerals deposited during coal accumulation and minerals deposited from solution or suspension during and after coal accumulation. Most of the mineral matter in Kansas coal is of the latter type.

METHOD OF STUDY

The techniques used in the study of the mineral constituents are outlined as follows:

(1) Approximately a 25 gram sample, crushed to minus 60 mesh size, was split from each of the channel samples used for chemical analysis. After weighing, the sample was placed in a large separa-

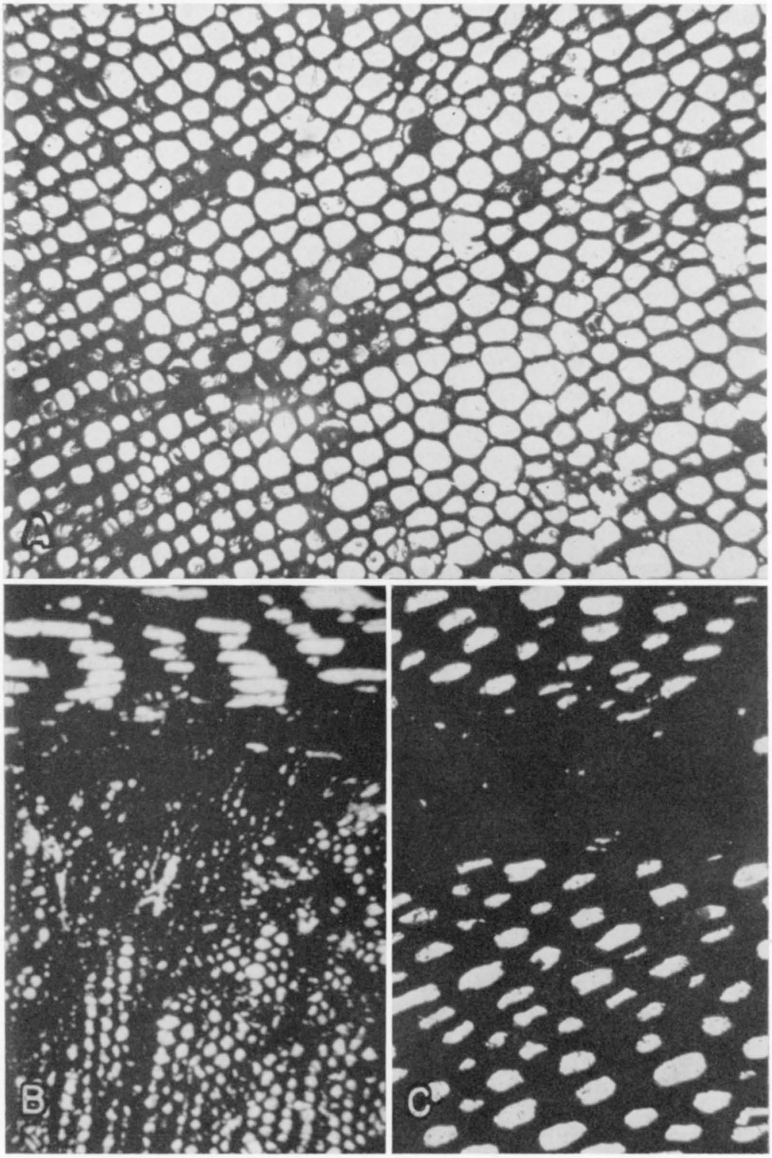


Plate 6. Thin sections of fusain. **A**, Transverse section of fusinized cortex. The plant cells are filled with calcite (Bevier coal, X 125). **B**, Upper part shows longitudinal section of fusinized plant material. Lower part shows transverse section. Cells are filled with calcite (Mineral coal, X 50). **C**, Transverse section of fusinized thick-walled plant cells (Bevier coal, X 125).

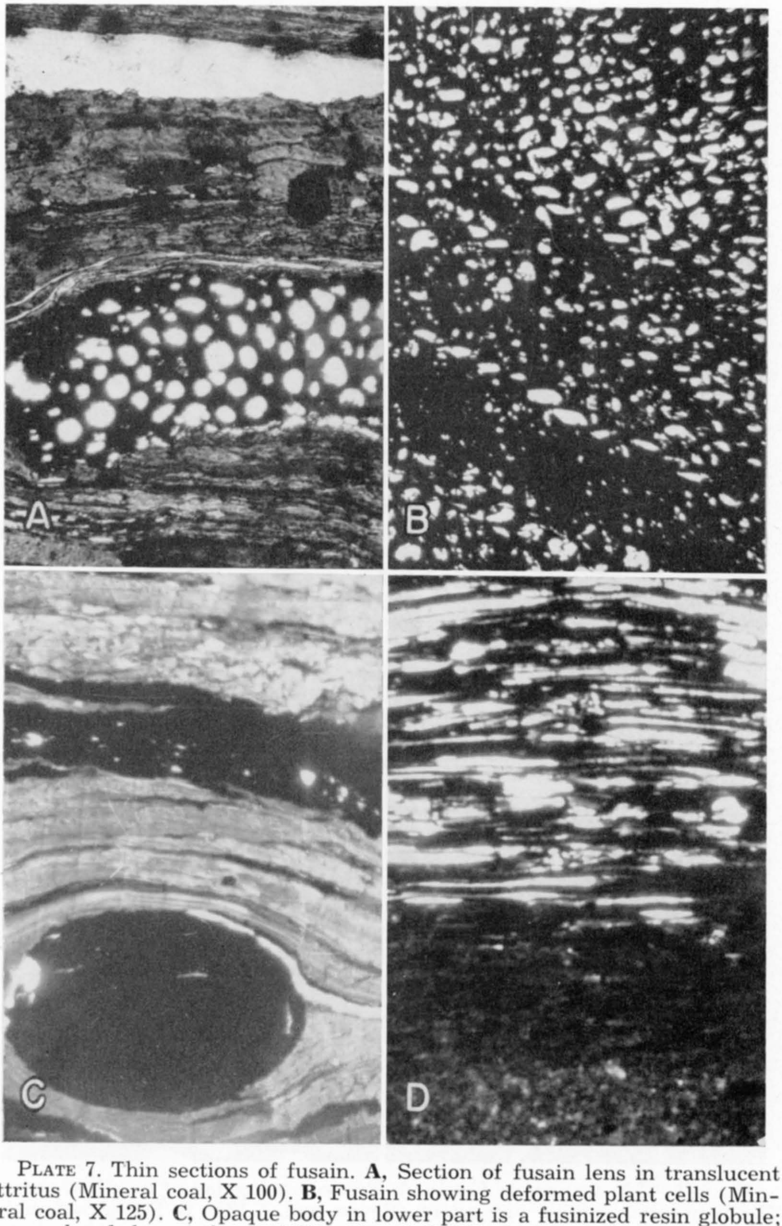


PLATE 7. Thin sections of fusain. **A,** Section of fusain lens in translucent attritus (Mineral coal, X 100). **B,** Fusain showing deformed plant cells (Mineral coal, X 125). **C,** Opaque body in lower part is a fusinized resin globule; opaque band above is fusain (Mineral coal, X 135). **D,** Material at bottom is anthraxylon. Note the change upward into opaque attritus and fusain (Mineral coal, X 50).

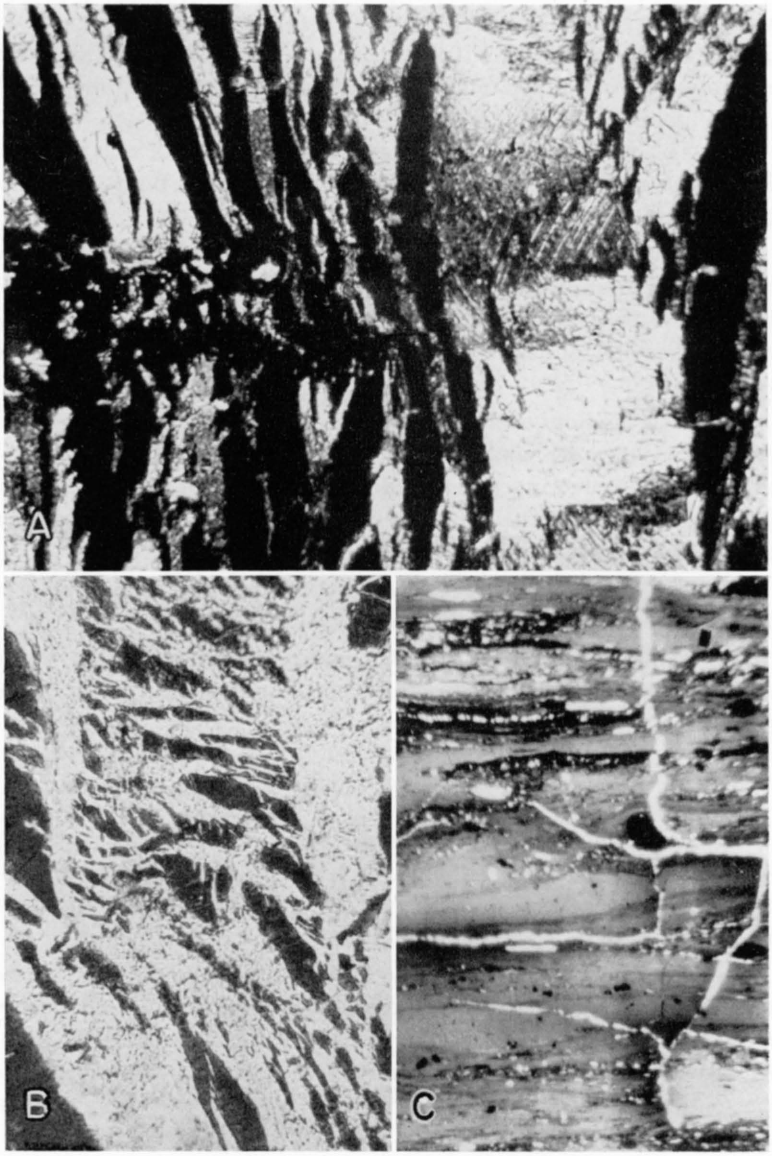


PLATE 8. Thin sections of mineral matter in coal. **A**, Intricate pattern of calcite in minute fractures in coal, under crossed nicols. Note cleavage and twinning in calcite (Mineral coal, X 125). **B**, Calcite filling fractures in coal (Mineral coal, X 125). **C**, Section shows distribution of minerals along banding in translucent attritus. Small opaque bodies are pyrite; lighter bodies consist largely of clay minerals. Notice the cube of pyrite in the upper right corner (Mineral coal, X 120).

tory funnel containing a 1.70 specific gravity solution of bromoform and carbon tetrachloride. Upon complete separation, the float-sink fractions were collected on filter paper, washed with acetone, dried, and weighed.

(2) The sink fraction was placed in a 2.90 specific gravity solution of tetrabrom-ethane and after separation, the float-sink fractions were collected and washed.

(3) Part of the 2.90 sink fraction was mixed with bakelite powder and mounted in a bakelite disc for polishing. The polished section was studied with a reflecting microscope. Color, hardness, internal reflection, and anisotropism were used to identify the opaque minerals.

(4) Both the float and sink fractions from the 2.90 specific gravity separation were examined with the aid of binocular, petrographic, and reflecting microscopes. Hydrochloric acid solubility, flame reactions, optical properties, and microchemical tests were used to identify the minerals.

(5) The thin sections prepared for column analysis were used to study the form and distribution of the minerals.

(6) Polished sections of pyrite nodules were made for study with the reflecting microscope and peels of the "coal balls" were made.

MINERAL ASSEMBLAGE AND DISTRIBUTION

Although the mineral content of Kansas coals is high, the kinds of minerals are few. Calcite and pyrite are the most important constituents. There are also lesser amounts of aragonite, marcasite, sphalerite, quartz, apatite, and clay minerals.

Detrital minerals.—The only known detrital minerals in the coals are quartz, apatite, and clay minerals. They are found mainly in the attrital portions of the coal and along bedding planes. A number of well-rounded grains of quartz and apatite were seen in the float-sink fractions of several samples. Clay minerals are the most abundant detrital constituents.

Calcite.—Calcite is the most important mineral constituent of the coals. It has two different modes of occurrence. The largest amount of calcite is found in cleats and dessication fractures where it may be associated with aragonite. The fractures usually traverse the coal normal to the bedding and may exhibit intricate, branching

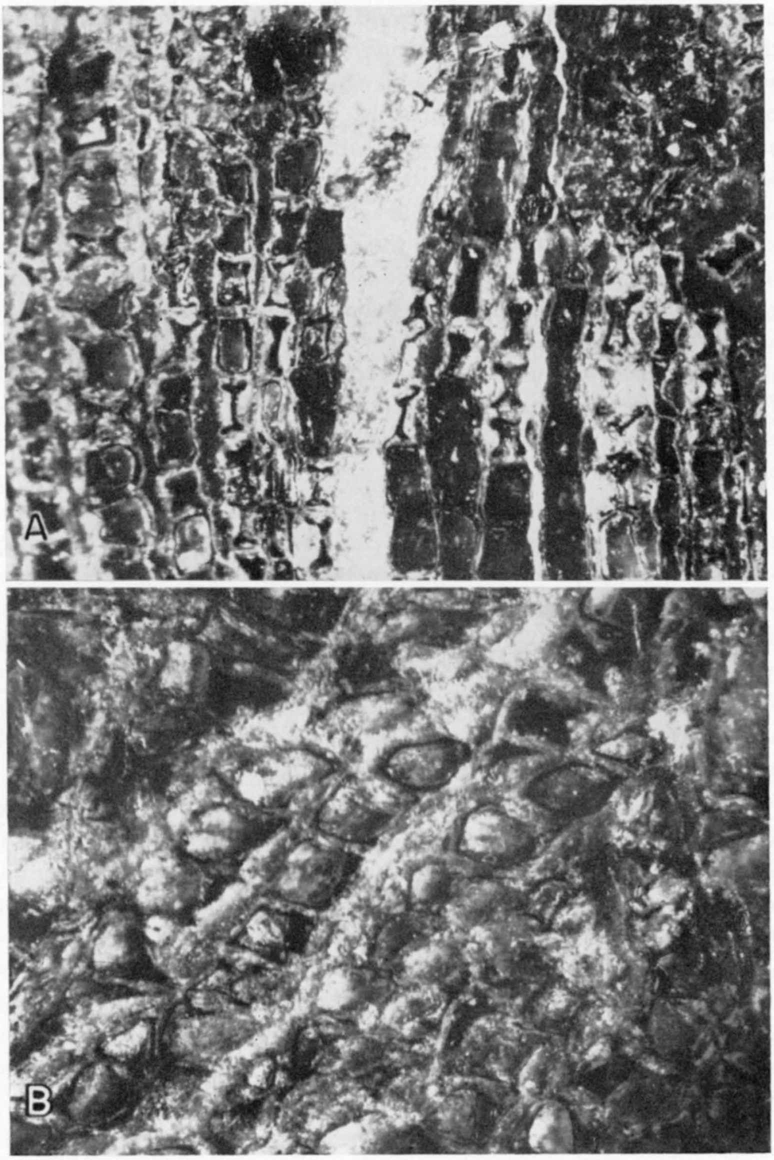


Plate 9. Calcite in "coal balls." **A**, Photomicrograph of a coal ball taken with a reflecting microscope using obliquely incident light. The material in the center of the boxlike cells is calcite; the original woody plant material is preserved in the cell walls (X 80). **B**, Same, showing different section of plant cells (X 85).

patterns as shown in Plate 8 A and B. Aragonite was identified in the crushed samples by its orange color, fibrous appearance, and refractive index. In thin sections, the aragonite resembles calcite but usually can be distinguished by its biaxial interference figure and fibrous structure. It may grade into coarsely crystalline calcite which shows undulatory extinction, indicating that at least some of the calcite has resulted from an aragonite-calcite transition. Little is known of the stability range or the conditions favoring the precipitation of aragonite. Rankama and Sahama (1950, p. 470) state that ground water often precipitates calcium carbonate either as calcite or aragonite. The stability of aragonite is probably a sensitive function of the partial pressure of carbon dioxide, temperature, and pH. The fracture-filling type of carbonate probably was deposited after coalification since it is unlikely that such fractures could develop in plastic peat.

Calcite also occurs in the open spaces of fusain (Pls. 6 and 7) and as the impregnating material of "coal balls." This calcite probably was deposited prior to coalification since it provides structural support for the cells which could not have maintained their form unless they were filled before compaction of the surrounding coal. This type of calcite is easily identified in both the crushed samples and the thin sections. In the crushed samples, the cell walls are often broken away from the calcite so that it emerges as a cast of the cell interior and looks like a small, milled cylinder.

The "coal balls," which are found only in the Mineral coal, are of particular interest. They are nodules or laterally persistent bands of calcite-impregnated plant material. Since the original woody parts of the plant are preserved in the calcite, they have been an important source of information concerning the structure of coal-forming plants. Plate 9 shows two photomicrographs of polished "coal balls" taken with the aid of a reflecting microscope using obliquely incident light. Plate 10 is a projection print of a peel of the same material. In both cases, the original cell walls can be seen clearly.

Pyrite.—Pyrite is widely distributed throughout the coal beds and is occasionally associated with marcasite. It occurs principally as disseminations in the attrital parts of the coal as shown in Plate 8C. Well-developed cubes like the one in the upper right corner of the photograph can be seen in some thin sections. The small opaque particles in the photograph are also pyrite.

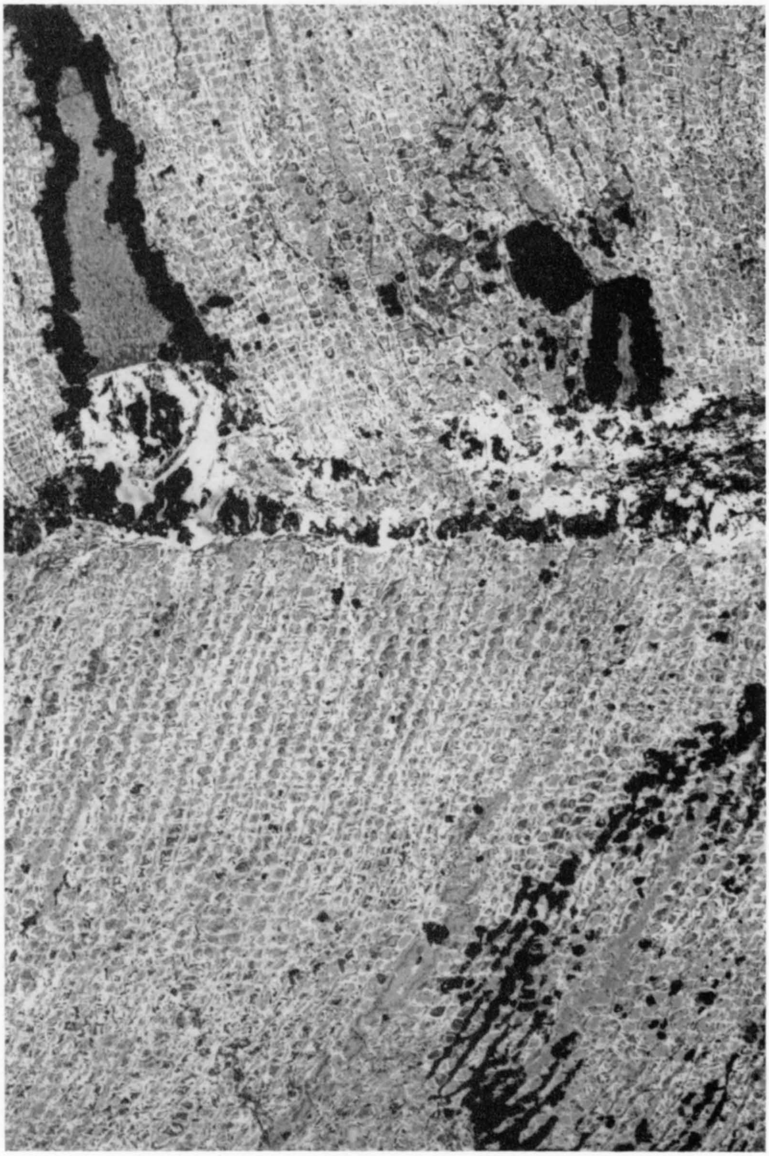


PLATE 10. "Coal ball" peel. The woody plant material is preserved in calcite and can be seen distinctly. Black material is coal (Mineral coal, X 16).

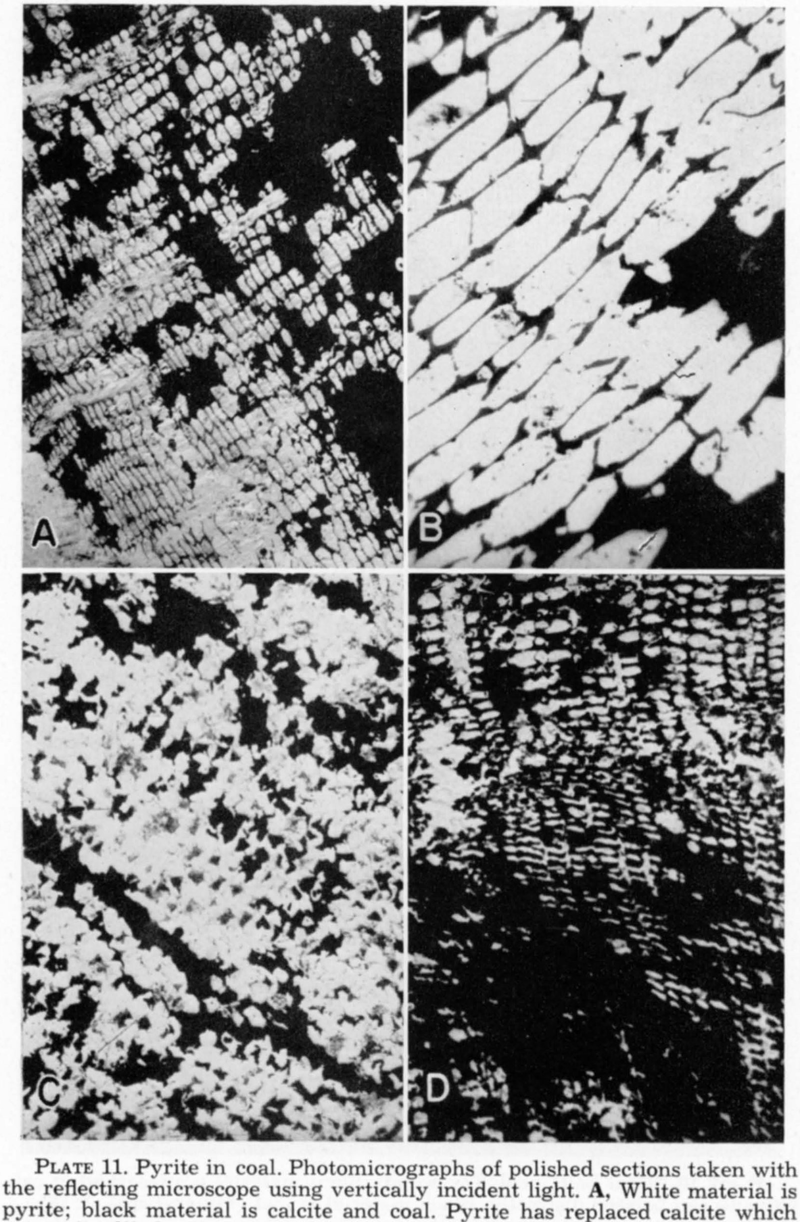


Plate 11. Pyrite in coal. Photomicrographs of polished sections taken with the reflecting microscope using vertically incident light. **A**, White material is pyrite; black material is calcite and coal. Pyrite has replaced calcite which originally filled cell cavities and has partially replaced coal (Mineral coal, X 95). **B**, Pyritic replacement of calcite at higher magnification (Mineral coal, X 375). **C**, Coalescence of pyrite where it replaces calcite and coal (Mineral coal, X 95). **D**, Pyritic replacement of calcite and coal. Plant cells have been somewhat deformed (Mineral coal, X 95).

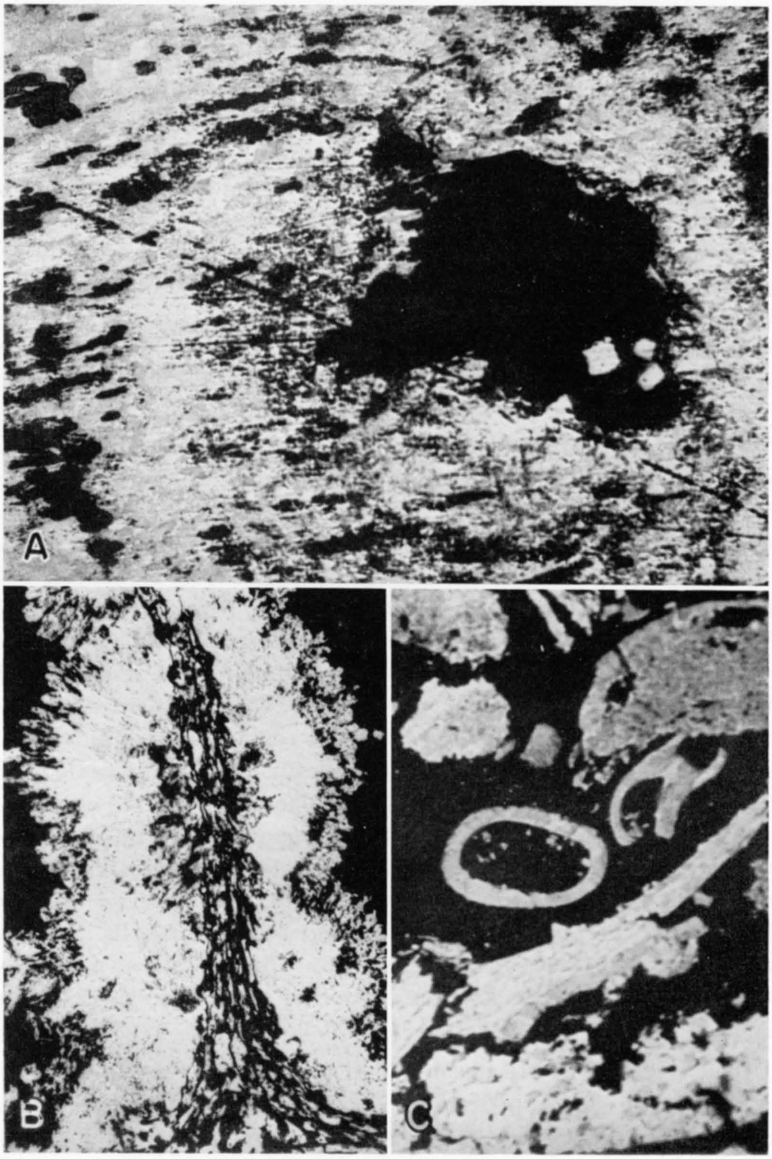


PLATE 12. Pyrite in coal. Photomicrographs of polished sections taken with the reflecting microscope using vertically incident light. **A**, Transverse section of a plant stem replaced by pyrite. White material is pyrite. The stem is almost completely replaced at its periphery but is only partially replaced at the center (Mineral coal, X 95). **B**, Longitudinal section showing same relation as above (Mineral coal, X 95). **C**, Pyritized plant debris. Note transverse section in center (Mineral coal, X 95).

Although quantitatively less important, the most interesting occurrence of pyrite is in nodules and bands. The distribution of these forms was shown earlier in the profile diagrams of the column samples. The nodules and bands of the Kansas coals are never simple, concretionary forms deposited along bedding planes, but are intimately associated with the plant material. In most cases, the pyrite replaces calcite which had either filled fusain open spaces or impregnated "coal balls." In other cases, the pyrite completely replaces the entire plant or coal material so that evidences of earlier calcite are entirely lacking. In some places, transitions from partially replaced calcite and plant material to massive pyrite are found. Relations of this kind were observed in polished sections. Plate 11 shows pyrite replacing the calcite filling of plant cells. In Plate 11A and B, the cell structure is preserved intact, for the most part, so that each cell is individually outlined in pyrite. Toward the lower left corner of Plate 11A, there are areas of more complete replacement. The white material in the photographs is pyrite, the dark partitions between the blebs of pyrite are preserved cell walls, and the remainder of the dark material is principally calcite. Plate 11C shows replacement of both calcite and coal. The areas of pyrite have begun to coalesce where calcite and coal are replaced. Plate 11D shows partial replacement and also illustrates minor deformation of the plant structure. Pyritic replacement of individual plant parts is illustrated in Plate 12. A transverse section of a stem in Plate 12A shows almost complete replacement of the peripheral part and only partial replacement of the central portion. Plate 12B is a longitudinal section of a stem which again shows only partial replacement in the pithy part of the plant. The difference in the character of the pith cells and the wood and cortex cells is rather well illustrated. Plate 12C shows a mixture of replaced plant debris. In one place, a transverse section of a replaced stem can be seen.

The origin of pyrite is somewhat problematic. However, most authors agree (see Rankama and Sahama, 1950, p. 668) that iron sulfide is precipitated in stagnant water in the presence of hydrogen sulfide. The processes which produce hydrogen sulfide are bacterial reduction of sulfoproteins, bacterial reduction of sulfates, and bacterial action on free sulfur. Dissolved iron compounds such as ferrous sulfate, as well as colloidal and precipitated ferric hydroxide, react with the hydrogen sulfide to form iron sulfide. Marcasite was identified in a few places. The presence of marcasite is not too surprising in the light of Buerger's (1934) studies of the pyrite-marcasite relation. Buerger points out that pyrite and marcasite can precipitate together—the proportion of marcasite being a function of the hydrogen ion concentration (e.g., the lower the pH, the greater the amount of marcasite).

Sphalerite.—Sphalerite is a minor constituent of the coals. Traces of it were found in the sink fractions of all but a few of the samples. No sphalerite was positively identified in the thin sections. This could easily be due to the loss of such a constituent in cutting to a thickness of 10 microns since much of the calcite could not even be saved. The sphalerite distribution can only be inferred from the angularity of the fragments in the crushed samples. In all probability it was deposited in the calcite-filled cleats and fractures.

The distribution of the mineral matter in the coal has historical significance in that it has served to indicate something of the origin of fusain. It might also be inferred from the extremely low content of detrital minerals in Kansas coals that extremely stable conditions prevailed during the time of coal accumulation.

COAL PETROGRAPHY AS RELATED TO COAL UTILIZATION

As early as 1923, Stopes and Wheeler had observed differences in the banded components of coal with respect to distillation and coking qualities. It is now recognized that the petrographic components of coal have differing chemical and physical properties and that these properties are of importance in effective coal utilization. Some of the physical and chemical properties of the petrographic components are summarized in the following discussion. Since a practical concern of coal petrography is to determine the significance of petrographic differences with regard to various utilization practices, some fields of application are suggested and the significance of mineral matter in coal is evaluated.

Physical Properties

SPECIFIC GRAVITY

Variations in specific gravity inherently due to type differences have been little explored according to McCabe (1945, p. 313). Anthraxylon is usually found to have the lowest apparent specific gravity whereas fusain has the highest. These differences largely reflect the ash content although pure fusain has a distinctly higher specific gravity than the other components. Some application of the property may be found in dust removal since a large part of the dust is composed of fusain. It is also possible that specific gravity differences could be utilized to prepare pure ingredients from Kansas coal should the need arise for a coal with particular properties.

RESISTIVITY

McCabe (1937, p. 277) reports that moisture-free vitrain (anthraxylon) and clarain (translucent attritus) are nonconductors. Fusain, in contrast, exhibited a low restivity. Davis and Younkins (1929) were thus able to separate fusain electrostatically from associated bone and mineral matter in the high specific gravity fraction. No efforts have been made to determine the feasibility of cleaning Kansas coal refuse by this method.

FRIABILITY

One measure of the strength of coal is its ability to withstand disintegration during handling. This is called friability and depends on toughness, elasticity, and fracture characteristics as well as on strength. However, the friability test is the measure of strength most frequently used. The work of McCabe (1936) on Illinois coals has shown that the petrographic components differ markedly in friability: fusain is structurally the weakest; vitrain (anthraxylon) is brittle but stronger than fusain; clarain (translucent attritus) is relatively strong and nonfriable; and durain (opaque attritus) is the strongest of the group. The counterparts of Thiessen's (1920) classification possess the same relative friability.

This information is of immediate significance in the mining process. For example, a coal bed high in fusain and anthraxylon responds more readily to cutting than does one high in opaque and translucent attritus. One the other hand, mines in splint coals are not as dusty, the proportion of lump is higher, not as much is lost in cleaning, but a larger charge is required in shooting. These factors influence total cost, ultimate recovery, and mine safety.

Another concern is in the operation of washing plants. A coal high in anthraxylon and fusain will produce an excess of fines which have little market value and may cause a plant to operate below capacity.

The most important significance of variable friability lies in the field of coal preparation. McCabe (1936) has shown, from a petrographic study of screenings of the Illinois Herrin (No. 6) Seam coal, that the concentration of certain constituents can be brought about by mechanical processing, thus producing a type of coal concentrate having vastly different characteristics from the bed coal. He reported that, although the vitrain (anthraxylon) content was only 20 percent in the bed coal, in the 1.25-0.75 inch screen size it had increased to 42 percent and reached 79 percent in the minus 48 mesh size. Extended studies have also shown that, in the natural fine sizes of Illinois coals, the vitrain content increases as indicated above but that, in the minus 48 mesh size, the fusain content increases and finally exceeds the vitrain in the minus 100 mesh size.

This distribution of vitrain and fusain in the fine sizes of Illinois coals suggested that it might be possible to show the reverse relationship in Kansas coals—e.g., the distribution of fine sizes should be some function of the distribution of anthraxylon and fusain in the bed sample. Therefore, the ratio of opaque attritus plus translucent attritus to anthraxylon plus fusain was calculated as the independent variable for each of the column samples and designated the "nonfriability ratio." These data are tabulated in Table 10. It would have been more desirable to use the inverse relation and designate it the"friability ratio." However, within the

TABLE 10.—*Friability data*

Sample no.	Anthraxylon, percent	Fusain, percent	Nonfriability ratio*	Minus 18 mesh, percent	Sieve ratio**
Bn-2-B	54.4	5.4	0.67	17.8	4.6
Bn-3-B	45.5	6.1	0.94	18.2	4.5
Ck-4-M	41.1	5.9	1.1	18.2	4.5
Cr-13-B	49.8	10.5	1.2	16.8	5.0
Cr-9-B	38.3	3.5	1.4	13.1	6.3
Cr-6-B	33.7	5.1	1.6	15.1	5.6
Cr-1-C	21.0	13.1	1.9	12.3	7.1
Cr-4-M	21.3	8.2	2.4	11.1	8.0

*Ratio of opaque attritus plus translucent attritus to anthraxylon plus fusain.
**Ratio of percent of sample plus 18 mesh to percent minus 18 mesh.

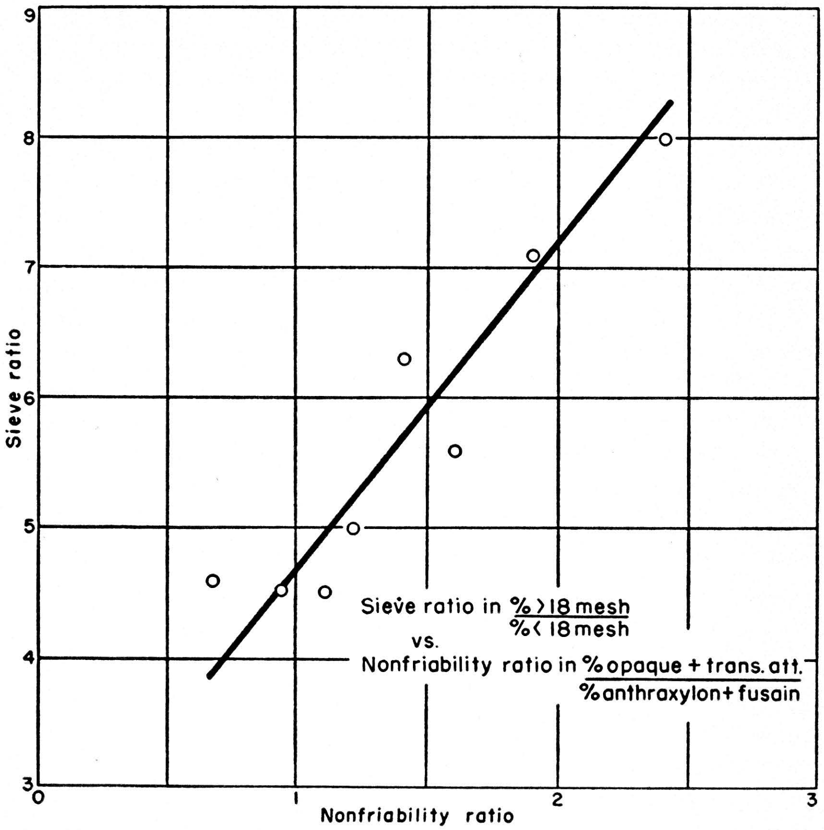


FIG. 5.—Distribution of fines as a function of petrographic composition.

range of Kansas coals the distribution of values is too narrow for convenient manipulation.

From the range of ratios, eight samples were selected which were representative of the possible values. The samples were crushed to one-half inch size in a Blake jaw crusher, cut to about 200 grams in Jones splitter, and sieved through an 18-mesh screen (1 mm). The minus 18 mesh size was weighed and the percent by weight determined. In order to narrow the spread of points in plotting the data, a ratio of plus 18-mesh size to minus 18-mesh size was calculated as the dependent variable and designated the "sieve ratio." These ratios are tabulated with the nonfriability ratios in Table 10. Figure 5 is the plot of nonfriability ratio versus sieve ratio and shows that there is a linear relation between the two. It is somewhat surprising that the relationship is shown so well since there are variables which have not been considered. For example, it might be expected that fusain would actually contribute more to the fine sizes than anthraxylon. Another difficult factor to evaluate is the mineral content of the coal. In the larger sizes it is probable that the mineral matter would act as a binder and reduce the percentage of fines whereas with finer crushing it might contribute appreciably to the fines. Since the ash content of the samples does not have a range of greater than 5 percent and since all the samples were subjected to standard treatment, it may be that the mineral matter contributed equally to all the samples.

Because the petrographic components differ in chemical behavior, their segregation according to relative friability imparts different properties to the various sizes of commercial coal. The ash content, ash-fusing temperature, volatile content, and coking qualities may differ. An understanding of such variations is important to the producer who is interested in maintaining a uniform product and to the consumer who is interested in a coal with particular characteristics. The petrographic composition is thus an important element of coal preparation since different coals can be blended and different sizes of the same coal can be mixed to obtain the desired characteristics.

As an example of practical importance, McCabe, Konzo, and Rees (1942) investigated the possibility of adapting banded ingredients for combustion in underfed domestic stokers since a high anthraxylon content results in excessive caking. Cady (1945, pp. 124-130) reports that other fields of application lie in coking or briquetting since fusain is noncoking and in excess of 15-20 percent acts to weaken the structure of the coke and briquettes.

CHEMICAL PROPERTIES

There is much evidence that differences in chemical composition or behavior may be correlated with differing petrographic components. However, the results of such studies are sometimes regarded with reservation due to the inadequacy of chemical methods to determine completely the complex chemical structures. In addition, the petrographic purity of the material studied is not always beyond question.

The general chemical nature of the components of coal is known largely through the research of Thiessen (1947) and his coworkers who have been able to relate coal structures to the structures of modern plants. Pollen, spores, cuticle, and algae are of a waxy and fatty character and hence are resistant to alteration. The waste products or resins of plant materials also fall in this general category. Probably the principal plant materials are lignin or cellulose since they predominate in the cell walls of the higher plants. Cellulose is a relatively unstable compound but it is at least represented by residues. The lignins alter to humic acid or humins.

PROXIMATE AND ULTIMATE ANALYSIS

Sprunk and others (1940, pp. 28-36) report that the average analyses of a number of associated bright and splint coals reveal significant differences if compared on an ash- and moisture-free basis. Splint coals are higher in fixed carbon, generally high in ash and ash-fusion temperature, and have a higher calorific value. Bright coals are lower in sulfur and higher in moisture, hydrogen, nitrogen, and oxygen and may thus have a higher total volatile content. However splints often contain abundant spores and resin so that the low volatile content due to the opaque constituents is increased and may be similar to that of anthraxylon. The higher sulfur and ash of splint coals may be attributed to the influx of clay, pyrite, and other mineral matter. The ash content of fusain is often unusually high because of mineral infiltration into open spaces and high adsorption capacity. Fusain is also lowest in volatiles and highest in fixed carbon. Since the Kansas coals are rather uniform in petrographic composition, it might be expected that their chemical composition would be fairly uniform as shown earlier.

CARBONIZATION

According to Sprunk and others (1940, pp. 37-49), splint coals yield smaller amounts of water of decomposition than associated bright coals and usually a smaller amount of gas. The coal tar and oil products seem to vary in either direction; doubtlessly a reflection of the spore and resin content since these constituents are high in waxes and oil. The relative coking qualities of the different types of coal are not certain. However, the coke yield seems to increase regularly with an increase in fixed carbon in both bright and splint coals. It is known that fusain does not coke and that its presence in large quantities prevents coking of the other ingredients. Hoffmann (1930) has shown that, although there are varieties of vitrain (anthraxylon) which will not coke, generally speaking it forms a better coke than durain (opaque attritus). On the basis of petrographic analysis, it seems that the coke yield of the Mineral, Croweburg, and Bevier coals should be good. However, the high ash and sulfur contents are responsible for an unsatisfactory product.

CHEMICAL REACTIVITY

Chemically, coals are natural polymers which may be investigated by studies of thermal decomposition in the presence or absence of solvents, oxidation, and reduction reactions. Lowrey (1942, p. 384), in a summary of such studies, shows that chemical reactivity usually decreases from brights to dulls to fusain and that there is no indication of the presence of essentially distinct types of chemical compounds peculiar to any of the ingredients of banded coal. They usually show a gradation of properties from one to the next.

HYDROGENATION

Hydrogenation is a reduction reaction which would be discussed under "Chemical Reactivity" except that it merits special attention. In areas of dwindling oil reserves, the conversion of coal to liquid fuel by hydrogenation has long been a subject of intensive investigation. Realizing that such a process might, at some future date, become essential to the power requirements of the United States, the Bureau of Mines has investigated the amenability of various types of coal to hydrogenation. Storch and others (1941) have described the process, the experimental plant, and assays of typical coals.

The essential differences between bituminous coal and petroleum are the higher ratio of the number of carbon atoms to hydrogen atoms in coal; the lower oxygen, nitrogen, and sulfur content of petroleum; and the lower molecular weight of the petroleum molecules. In order to produce petroleum-like material from coal, it is necessary to double the number of hydrogen atoms; to remove most of the oxygen, nitrogen, and sulfur; and to crack the coal molecules until their weight equals that of the petroleum molecules. In 1913, Bergius (1926) discovered how to add hydrogen to coal at a temperature of 450°C. and at 200 atmospheres hydrogen pressure. Under such conditions, most of the oxygen was eliminated as water, the nitrogen as ammonia, and the sulfur as hydrogen sulfide. A petroleum-like liquid resulted. Suitable contact catalysts subsequently were developed to increase the speed of hydrogen addition to the cracked coal.

Fisher and other (1942) have shown, on the basis of small-scale bomb tests of 129 samples, that bright coals are more suitable than splint coals for conversion to liquid products. The petrographic components may be classed into two groups with respect to yield. The first group is easily liquefied and includes anthraxylon and all the organic constituents of translucent attritus, such as woody degradation matter, leaves, spores, pollens, cuticle, and algae. This applies to coal containing less than 89 percent carbon on the moisture-free and ash-free basis. The second group is more difficult to liquefy and includes opaque attritus and fusain. The average yield of opaque attritus from splints is about 60 percent at 430° C. for 3 hours in the presence of stannous chloride with an initial hydrogen pressure of 1,000 psi. Individual samples of opaque attritus, however, show a range in yield from 39 to 79 percent. This was attributed to variation in opacity since the less opaque matter would be expected to hydrogenate more readily. Seven samples of fusain gave a yield ranging from 15 to 27 percent, indicating that it is the most resistant of all the petrographic components.

Considerable success has been attained in selecting the best coals for large-scale tests. Further, with the aid of microscopic analysis, it has been possible to predict the yield of acetone insoluble residue with a fair degree of accuracy. Predictions of this kind are made on the following basis, provided proximate analysis indicates less than 89 percent fixed carbon on a moisture-free and ash-free basis:

Ash and fusain	Should yield 100 percent residue
Opaque attritus	Should yield 38 percent residue
All other constituents	Should yield no residue

The extent to which liquefaction yield from hydrogenation can be correlated with and predicted from petrographic analysis depends upon the accuracy and completeness of the analysis. Better correlations should be obtained when the opacity of the petrographic components is more completely defined by physical criteria. Although the method is not completely accurate, it is adequate for rejecting unsuitable coals. In addition, the concentration of high liquid-yield components by mechanical processing based on petrographic analysis seems to be an imminent possibility.

No experimental hydrogenation yield data are currently available for Kansas coals but the probable yield has been calculated according to the method described above. The calculated probable residue yield for each column sample and the average calculated probable yield for the bed are tabulated in Table 11.

Since the predicted liquefaction yield is largely a function of translucency, the ratio of anthraxylon plus translucent attritus to opaque attritus plus fusain has been calculated and designated the

TABLE 11.—*Predicted hydrogenation residues*

Locality no.	Sample no.	Translucency ratio	Predicted yield, percent*
		Bevier coal	
19	Bn-3-B	6.1	9.3
20	Bn-2-B	8.8	7.3
21	Bn-1-B	4.7	16.6
22	Cr-9-B	11.7	5.3
25	Cr-5-B	4.4	16.1
26	Cr-6-B	8.2	7.4
27	Cr-7-B	11.1	5.6
30	Cr-12-B	7.9	8.6
31	Cr-14-B	6.0	8.6
32	Cr-11-B	8.9	7.0
33	Cr-13-B	5.8	12.2
34	Cr-10-B	6.9	8.5
35	Ck-1-B	6.4	8.6
37	Lt-1-B	4.7	10.6
Average		7.2	9.4
		Mineral coal	
1	Cr-2-M	13.3	5.4
2	Cr-4-M	9.4	8.8
3	Cr-3-M	7.7	8.9
9	Cr-8-M	4.4	13.9
15	Ck-5-M	9.7	7.7
16	Ck-4-M	12.7	6.5
18	Ck-2-M	13.3	6.1
Average		10.1	8.2
		Croweburg coal	
8	Cr-1-C	2.8	16.2

*Hydrogenation residue determined as follows: opaque attritus, 38 percent; fusain, 100 percent; all other constituents, none .

"translucency ratio." An opacity ratio might have been used except that such values would have a narrow distribution for Kansas coals. This devise provides a simple method for characterizing the translucency or opacity of a coal in terms of a single value and could be used as a basis for describing regional variation.

No attempt has been made to plot regional variation in the Mineral and Bevier coals because the values seem to be erratic on the basis of relatively few data. Certain general observations can be made nevertheless. (1) The Bevier coal has a lower average translucency ratio than the Mineral coal and could thus be expected to produce a lower liquefaction yield. (2) The Mineral coal data are suggestive of a trend which could be substantiated only with additional information. Just north of Frontenac, the coal has a low translucency ratio and hence probably a low liquefaction yield. Both north and south of this low, the ratios increase although there is a considerable interval between this point and the nearest point to the south. (3) The coals are probably amenable to hydrogenation and should produce good yields except for the high ash content which contributes to the total residue. Beneficiation would undoubtedly make them more desirable for this purpose.

SIGNIFICANCE OF MINERAL MATTER

The distribution of the mineral matter in the coal is important from the standpoint of beneficiation. It has been shown that the principal minerals are pyrite and calcite which are intimately associated with the coal. The larger quantity of pyrite is finely disseminated and much of the calcite occurs either in fusain or in the finely branching parts of the fractures and cleats. Such a distribution means that the coal must be crushed to a fine size if most of the mineral matter is to be released or that a substantial part of the coal must be rejected as refuse if it is cleaned in a low specific gravity zinc chloride solution. However, some of the pyrite and calcite can be removed in the nodular form. It thus seems that the coals can be improved to a certain extent but that preparation of a low-ash coal concentrate is not economically feasible. In an effort to test this contention, ash determinations were run on two of the minus 60 mesh samples which were the float fractions from the 1.70 specific gravity separation. Ash determinations had also been made on the original samples. In one sample the ash content decreased from

12.0 to 6.6 percent and in the other it decreased from 10.0 to 7.4 percent (decreases of 45 and 26 percent, respectively). In ordinary cleaning it would be impractical to grind the coal so finely or to use such a high-gravity solution.

No effort has been made to determine the effect of the mineral matter content on the chemical and physical properties of the coal. However, Gauger (1936) has been able to show the effect of mineral composition of the slagging characteristics of coal in carbonization studies.

SUMMARY AND CONCLUSIONS

The petrographic as well as the chemical and physical properties of the Mineral and Bevier coals of southeastern Kansas have been described in detail. Correlations which have been established are significant in the more effective utilization of the coals. The results of the study are summarized below.

(1) The average proximate chemical analysis (moisture- and ash-free basis) of the Mineral coal is 14,980 B.t.u., 5.1 percent sulfur, and 58.7 percent fixed carbon. The average ash content is 13.4 percent (moisture-free basis). The coal is remarkably uniform in composition. It is a high volatile A bituminous coal (A.S.T.M. rank designation) and should make a fair coke except for the high sulfur content. The average analysis of the Bevier coal is 14,690 B.t.u., 3.9 percent sulfur, 57.1 percent fixed carbon, and 17.7 percent ash. The rank and coking qualities are similar to those of the Mineral coal.

(2) The coals exhiibt a small, systematic regional variation in fixed carbon content which may be related to geologic structure. Fixed carbon increases from southwest to northeast.

(3) The coals were analyzed petrographically. They are finely banded attrital coals in which the anthraxylon bands do not exceed 5 mm in width, fusain is conspicuous, and opaque attritus is a relatively minor constituent. The types of coal and the percentage of components have been shown graphically for 22 column samples. The coals are bright coals which may contain thin bands of splint or semisplint coal near the top or bottom of the bed. The Mineral coal contains an average of 30.2 percent anthraxylon, 60.1 percent translucent attritus, 3.2 percent opaque attritus, and 6.9 percent fusain. The Bevier contains 37.9 percent anthraxylon, 49.2 percent translucent attritus, 5.9 percent opaque attritus, and 13.1 percent fusain.

(4) The opaque constituents of the coal are difficult to identify due to a gradational relation with other constituents. The process which produces opacity in bituminous coals is uncertain. However, study of Kansas coals indicates that (a) the process (here called fusinization) which produces fusain may act upon any of the plant materials and the resulting degree of opacity is dependent upon the intensity and duration of the process, and (b) fusinization is operative in the early stages of coalification and may be local in nature.

(5) The ribbon transect method of analysis can be used for the comparison of column samples of coal. There are, however, a number of serious disadvantages. (a) The differences between anthraxylon and attritus, as well as between opaque attritus and fusain, are based on arbitrary critical size limits. Since the differences are of a more fundamental nature, they should be defined by significant chemical or physical criteria. (b) Another basis for differentiation is opacity. There are no critical limits for distinguishing opacity which is a function of the degree of fusinization, the thickness of the section, and the kind of illumination. Although it is difficult to cut coal sections to uniform thickness, standard illumination should be defined. (c) The term "opaque attritus" is misleading in those places where its gradation to anthraxylon is obvious. (d) Fusain is classified largely on the basis of its open cell structure. In those cases where the open spaces have not been supported by mineral matter, the crushed fusain resembles opaque attritus. Much fusain has undoubtedly been classified as opaque attritus. (e) The type classifications in current usage are not completely adequate. The results of petrographic analysis will be more reliable when a satisfactory classification has been devised.

(6) The essential mineral constituents of Kansas coals are calcite and pyrite. Aragonite, marcasite, sphalerite, quartz, apatite, and clay minerals are lesser constituents. Calcite occurs in cleats and fractures in the coal as well as in the open spaces of fusain. It is also the impregnating agent of "coal balls." Pyrite is found disseminated in the attrital material and replacing calcite and plant material.

(7) The relation of petrographic composition to coal utilization shows that there is a linear relation between the sum of anthraxylon plus fusain and the friability of the coal. On the basis of the percentage of opaque constituents, it is possible to predict the probable amenability of the coals to hydrogenation. Except for the

high ash content, the coals should hydrogenate readily. Since most of the mineral matter in the coals is finely disseminated and intimately associated with the coal, it is doubtful that a low-ash concentrate is economically feasible. Ash determinations on two of the float fractions from 1.70 specific gravity separation show reductions in ash of 45 and 26 percent respectively.

REFERENCES

ABERNATHY, G. E. (1937) The Cherokee group of southeastern Kansas: Kansas Geol. Soc., Guidebook 11th Ann. Field Conf., pp. 18-23.

——— (1938) Cyclic sedimentation of the Cherokee: Kansas Acad. Sci. Trans., vol. 41, pp. 193-197.

——— (1944) Mined areas of the Weir-Pittsburg coal bed: Kansas Geol. Survey, Bull. 52, pt. 5, pp. 213-228.

——— (1946) Strip-mined areas in the Southeastern Kansas coal field: Kansas Geol. Survey, Bull. 64, pt. 4, pp. 125-144.

ABERNATHY, G. E., JEWETT, J. M., AND SCHOEWE, W. H. (1947) Coal reserves in Kansas: Kansas Geol. Survey, Bull. 70, pt. 1, pp. 1-20.

AMERICAN SOCIETY FOR TESTING MATERIALS (1938) American standard specifications for classification of coals by rank: Am. Soc. for Testing Materials, Philadelphia, Pa., pt. 3, pp. 1-6.

BERGIUS, F. (1926) The transformation of coal into oil by means of hydrogenation: Proc. 1st. Internatl. Conf. Bituminous Coal, Carnegie Inst. Technol., pp. 102-131

BOWSHER, A. L., AND JEWETT, J.M. (1943) Coal resources of the Douglas group in east-central Kansas: Kansas Geol. Survey, Bull. 46, pp. 1-94.

BUERGER, M. J. (1934) The pyrite-marcasite relation: Am. Mineralogist, vol. 19, pp. 37-61.

CADY, G. H. (1942) Modern concepts of the physical constitution of coal: Jour. Geology, vol. 50, no. 4, pp. 337-356.

——— (1945) Coal petrography: Chemistry of Coal Utilization, John Wiley & Sons, New York, vol. 1, pp. 86-131.

Davis, J. D., and Younkins, J. A. (1929) Electrostatic method for determining fusain in bituminous coal: Fuel in Sci. and Practice, vol. 8, pp. 438-440.

Dawson, J. W. (1859) On the vegetable structures in coal: Quart. Jour. Geol. Soc. London, vol. 15, pp. 626-641.

Dreyer, R. M. (1947) Magnetic survey of southeastern Crawford County, Kansas: Kansas Geol. Survey, Bull. 70, pt. 5, pp. 107-115.

Duparque, A. (1933) Structure microscopic des charbons du bassin houiller du Nord et du Pas de Calais: Mem. Soc. Geol. Nord, vol. 11, pt. 1, pp. 35-51.

Fieldner, A. C., and Schmidt, L. D. (1941) Annual report of research and technologic work on coal: U.S. Bur. Mines, Information Circ. 7190, pp. 1-60.

Fisher, C. H., and others (1942) Hydrogenation and liquefaction of coal, part 2: U. S. Bur. Mines, Tech. Paper 642, pp. 1-162.

Gauger, A. W. (1936) Coal and its mineral matter with reference to carbonization: Pennsylvania State College Min. Industries Exper. Sta., Tech. Paper 28, pp. 3-11.

Gibbs, H. L., and Evans, L. G. (1950) Improvements in methods for preparing thin sections of rock U. S. Bur. Mines, Rept. Investi. 4711, pp. 1-6.

Haworth, Erasmus, and Crane, W. R. (1898) Special report on coal: Univ. Geol. Survey of Kansas, vol. 3, pp. 1-347.

Head, R. E., and others (1932) Statistical microscopic analysis of mill products of the Copper Queen concentrator of the Phelps-Dodge Corporation: U. S. Bur. Mines, Tech. Paper 533, pp. 1-48.

Hendricks, T. A. (1945) The origin of coal: Chemistry of Coal Utilization, John Wiley & Sons, New York, vol. 1, pp. 1-24.

Hoffmann, E. (1930) Aufberietungstechnische Trennung der petrographischen Kohlenbestandteile: Glückauf 46, pp. 529-540.

Hutton, W. (1833) Observations on coal: London and Edinburgh Philos. Mag. and Jour. Sci., vol. 2, pp. 302-304.

Jewett, J. M., and Schoewe, W. H. (1942) Kansas mineral resources for wartime industries: Kansas Geol. Survey, Bull. 41, pt. 3, pp. 69-180.

Lowrey, H. H. (1942) Relation of the physical constitution of coal to its chemical characteristics: Jour. Geology, vol. 50, no. 4, pp. 357-384.

McCabe, L. C. (1936) Concentration of the banded ingredients of Illinois coals by screen sizing and washing: Am. Institute Mining and Metal. Engineers Trans., vol. 119, pp. 321-329.

——— (1937) Some physical evidences of development of rank in vitrain: Fuel in Sci. and Practice, vol. 16, no. 9, pp. 267-286.

——— (1945) Physical properties of coal: Chemistry of Coal Utilization, John Wiley & Sons, New York, vol. 1, pp. 310-336.

McCabe, L. C., Konzo, S., and Rees, O. W. (1942) Correlation of domestic stoker combustion with laboratory tests and types of fuels, I, Preliminary studies: Illinois Geol. Survey, Rept. Investi. 78, pp. 1-20.

McCartney, J. T. (1949) Electron microscopy of coal: Econ. Geology, vol. 44, no. 7, pp. 617-620.

Moore, R. C. (1936) Stratigraphic classification of Pennsylvanian rocks in Kansas: Kansas Geol. Survey, Bull. 22, pp. 1-256.

Moore, R. C., and Landes, K. K. (1913), Underground resources of Kansas: Kansas Geol. Survey, Bull. 13, pp. 1-154.

Moore, R. C., and others (1951) The Kansas rock column: Kansas Geol. Survey, Bull. 89, pp. 1-132.

Muck, F. (1881) Grundzuge und Zeile der Steinkohlen-Chemie: Bonn, Strauss, pp. 1-170.

Parks, B. C., and O'Donnell, H. J. (1948) Determination of petrographic components of coal by examination of thin sections: Am. Institute Mining and Metal. Engineers, Coal Div. Trans., vol. 177, pp. 535-551.

PARR, S. W. (1928) The classification of coal: Univ. Illinois Engr. Exper. Sta., Bull. 180, pp. 1-59.

PIERCE, W. G., AND COURTIER, W. H. (1938) Geology and coal resources of the Southeastern Kansas coal field in Crawford, Cherokee, and Labette Counties: Kansas Geol. Survey, Bull. 24, pp. 1-91.

RAISTRICK, A., AND MARSHALL, C. E. (1939) The nature and origin of coal seams; English Universities Press, Ltd., London, pp. 1-287.

RANKAMA, K., AND SAHAMA, T. G. (1950) Geochemistry: Univ. Chicago Press, pp. 1-912.

ROOS, G. (1937) Comparative researches on the variation of the constituents of coal of one seam from South Limberg (The Netherlands): Comp. rend. deuxieme congr. l'avance. etudes strat. Carbonifere, Heerlen, 1935 (Maastricht), II, p. 1100.

SCHOEWE, W. H. (1944) Coal resources of the Kansas City group, Thayer bed, in eastern Kansas: Kansas Geol. Survey, Bull. 52, pt. 3, pp. 81-136.

——— (1946) Coal resources of the Wabaunsee group in eastern Kansas: Kansas Geol. Survey, Bull. 63, pp. 1-144.

——— (1951) Coal resources of the Permian System in Kansas: Kansas Geol. Survey, Bull 90, pt. 3, pp. 53-68.

——— (1952) Coal resources of the Cretaceous System (Dakota formation) in central Kansas: Kansas Geol. Survey, Bull. 96, pt. 2, pp. 69-156.

SCHOPF, J. M. (1938) Spores from the Herrin (no. 6) coal bed in Illinois: Illinois Geol. Survey, Rept. Investi. 50, pp. 1-73.

——— (1948) Discussion of "Determination of the petrographic components of coal by examination of thin sections": Am. Institute Mining and Metal. Engineers, Coal Div. Trans., vol. 177, pp. 551-555.

——— (1948a) Variable coalification; the process involved in coal formation: Econ. Geology, vol. 43, pp. 207-225.

SCHULZE, F. (1855) Uber des Verkommenwohlerhaltenes Cellulose im Braunkohle und Steinkohle: Ber. kgl., Berlin, pp. 676-678.

SPRUNK, G. C., AND OTHERS (1940) Splint coals of the Appalachian region, their occurrence, petrography, and comparison of chemical and physical properties with associated bright coals: U.S. Bur. Mines, Tech. Paper 615, pp. 1-59.

STACH, E. (1928) Kohlenpetrographisches Praktikum: Samml. naturw. Prakita, Bd. 14, pp. 1-196, Berlin, Gebr. Borntraeger.

STANTON, F. M., FIELDNER, A. C., AND SELVIG, W. A. (1939) Methods of analyzing coal and coke: U.S. Bur. Mines, Tech. Paper 8, rev. ed., pp. 1-59.

STOPES, M. C. (1919) On the four visible ingredients in banded bituminous coals, Studies in the composition of coals, no. 1: Proc. Roy. Soc. London, vol. 90, pp. 470-487.

——— (1935) On the petrology of banded bituminous coals: Fuels in Sci. and Practice, vol. 14, no. 1, pp. 4-13.

STOPES, M. C., AND WHEELER, R. V. (1923) Spontaneous combustion of coal in relation to its composition and structure: Fuels in Sci. and Practice, vol. 2, pp. 83-92.

STORCH, H. H., AND OTHERS (1941) Hydrogenation and liquefaction of coal, Part 1: U.S. Bur. Mines, Tech. Paper, 622, pp. 1-110.

THIESSEN, REINHARDT (1920) Compilation and composition of bituminous coals: Jour. Geology, vol. 28, pp. 185-209.

——— (1947) What is coal?: U.S. Bur. Mines, Information Circ. 7397, pp. 1-53.

THIESSEN, REINHARDT, AND SPRUNK, G. C., (1936) The origin of the finely divided or granular opaque matter in splint coals: Fuel, vol. 15, pp. 304-315.

THIESSEN, REINHARDT, SPRUNK, G. C., AND O'DONNELL, H. J. (1938) Preparation of thin sections of coal: U.S. Bur. Mines, Information Circ. 7021, pp. 1-8.

VON GUMBLE, C. W. (1883) Beitrage zur Kenntnis der Textureverhaltnisse der Mineralkohlen: Sitzungsber. kgl. bayr. Acad. Wissensch. (München), vol. 13, pp. 111-216.

WHITE, DAVID, AND THIESSEN, REINHARDT (1914) The origin of coal: U. S. Bur. Mines, Bull. 38, pp. 1-378.

WINTER, H. (1923) The examination of coal in reflected light: Fuels in Sci. and Practice, vol. 2, pp. 78-82.

WITHAM, H. T. M. (1833) On the internal structure of fossil vegetables found in the Carboniferous and oolitic deposits of Great Britain: Black, Edinburgh, pp. 1-84.

YOUNG, C. M., AND ALLEN, H. C. (1925) Kansas coal: Kansas Univ. Bull. 26, no. 5, Engr. Bull. 13, pp. 1-202.

State Geological Survey
of Kansas

Bulletin 102, Part 1
Plate 1

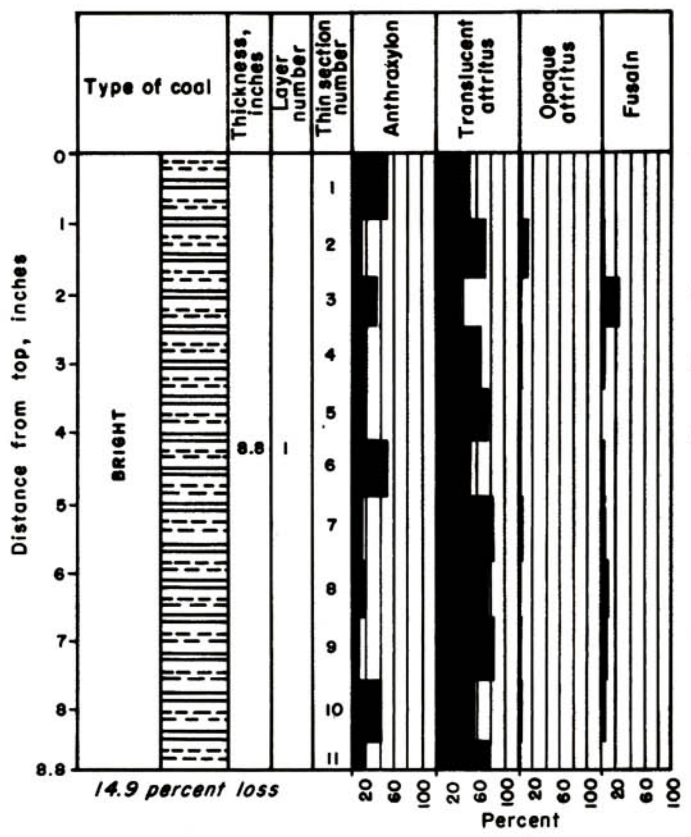
Profiles
of
Southeastern Kansas
Coal Beds

showing types of coal and percentage of components found in column samples of the Mineral, Bevier, and Croweburg beds

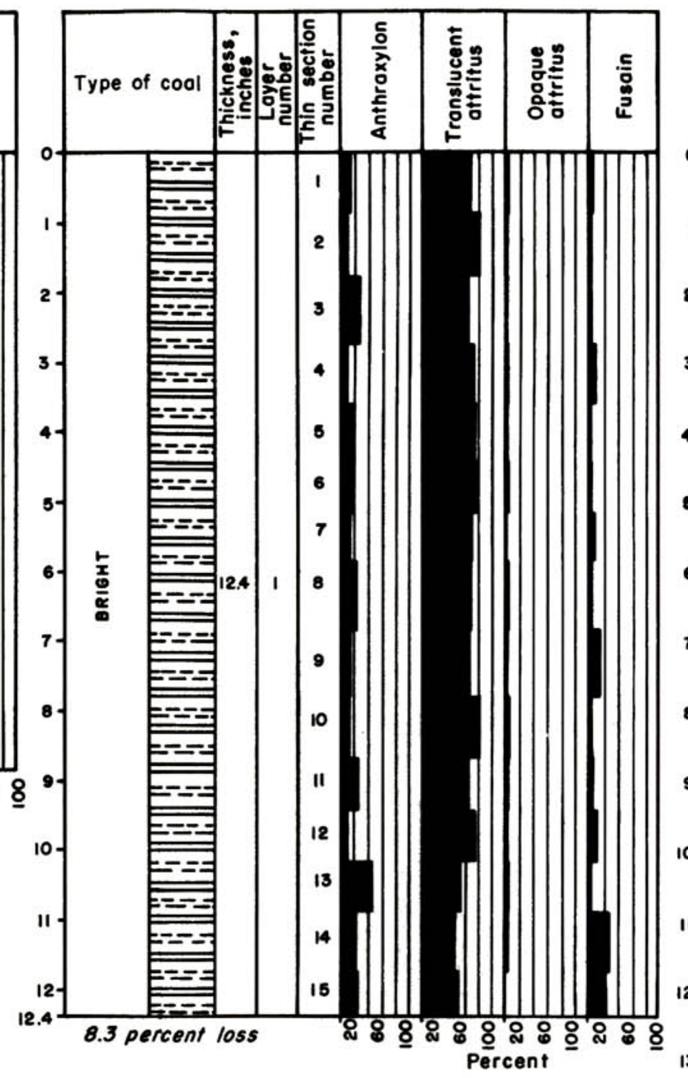
by William W. Hambleton

1953

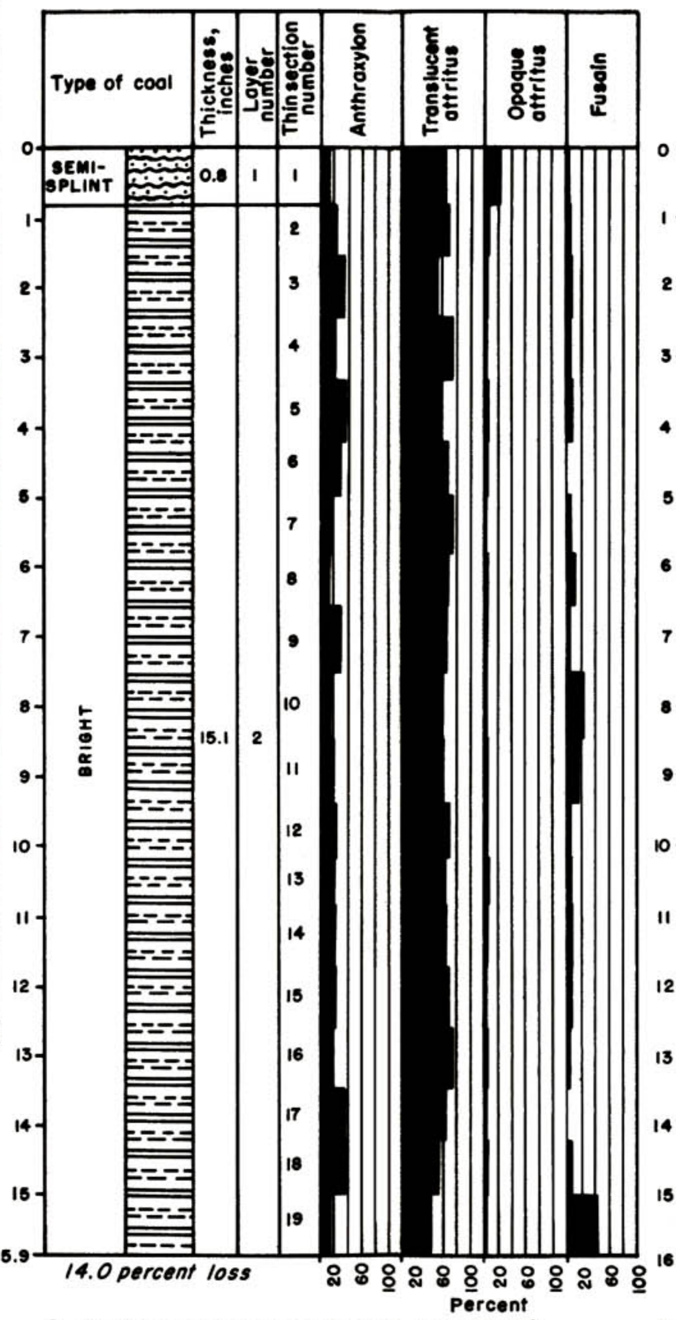
Sample localities are shown in Figure 1 and are described in Table 5.



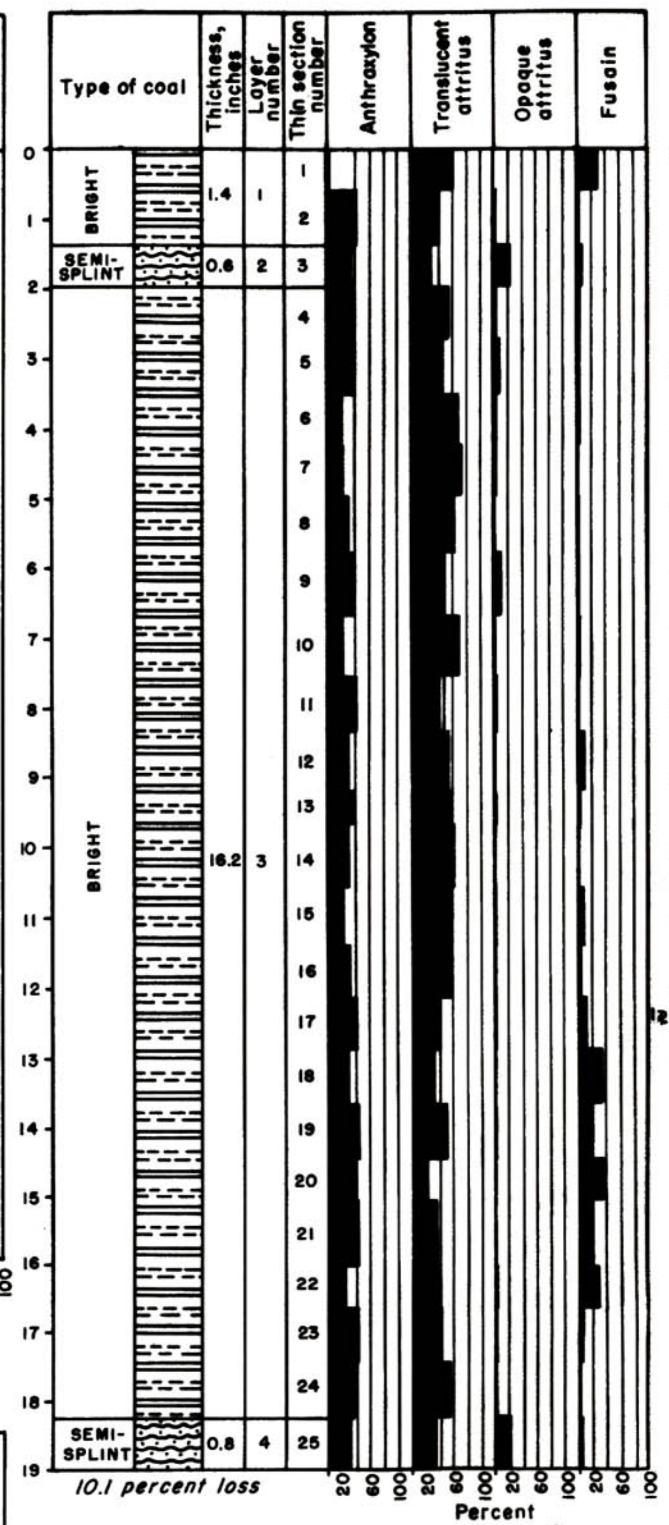
A...Mineral coal (Sample CR-2-M, Locality 1)



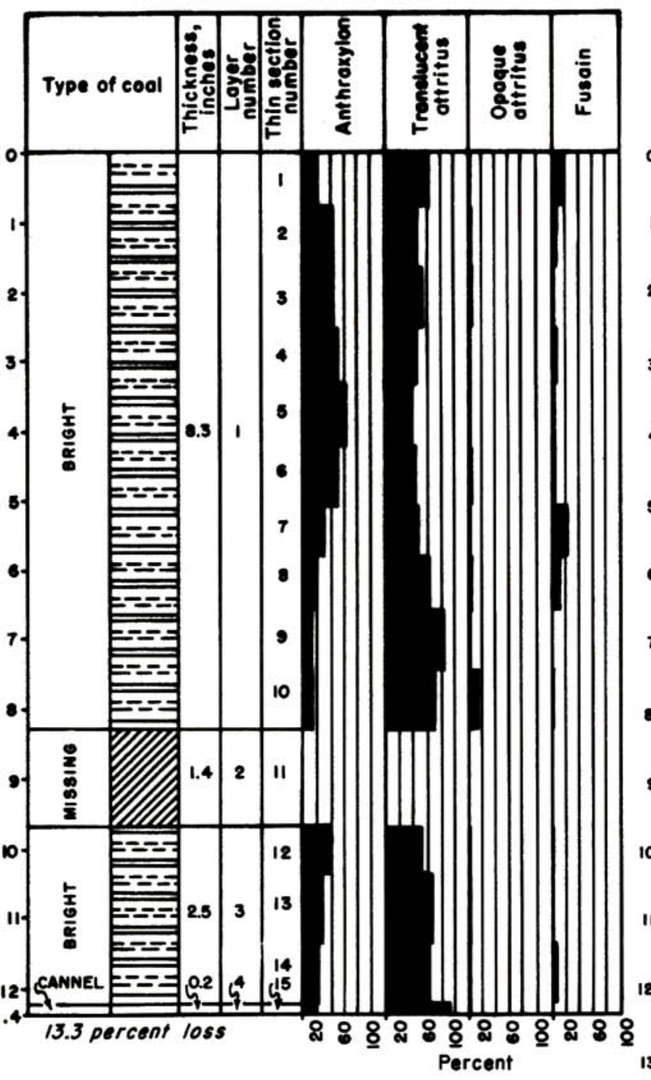
B...Mineral coal (Sample CR-4-M, Locality 2)



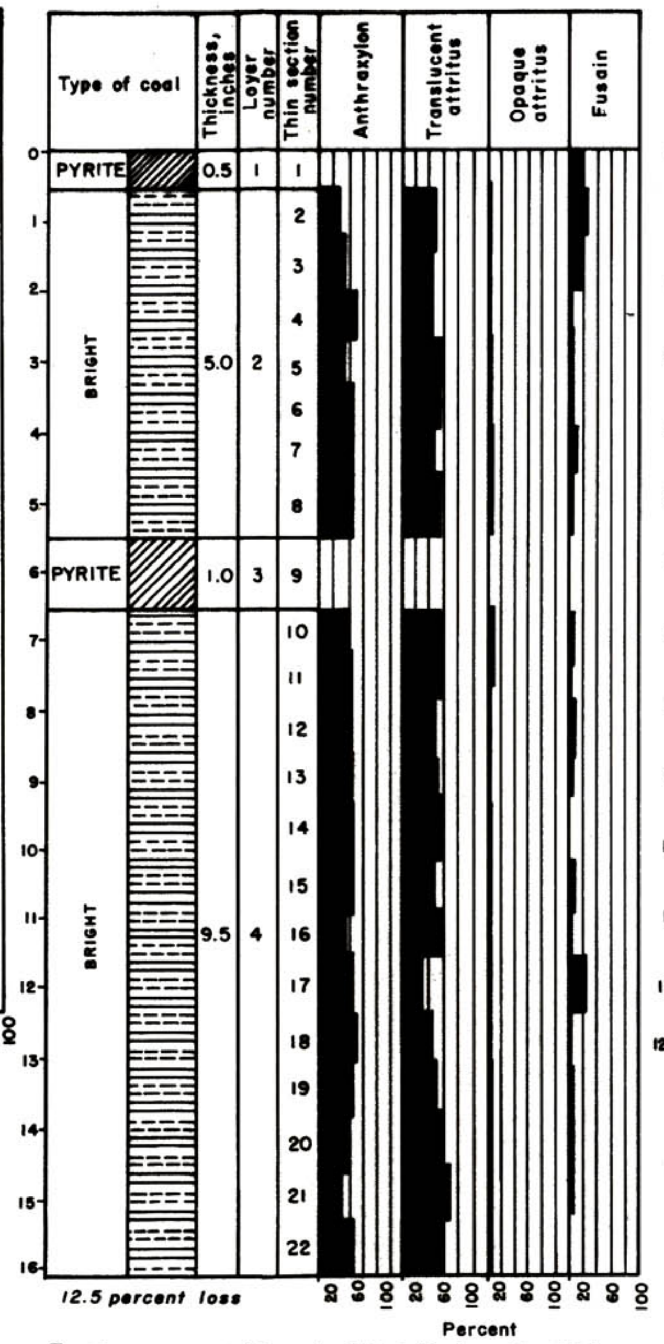
C...Mineral coal (Sample CR-3-M, Locality 3)



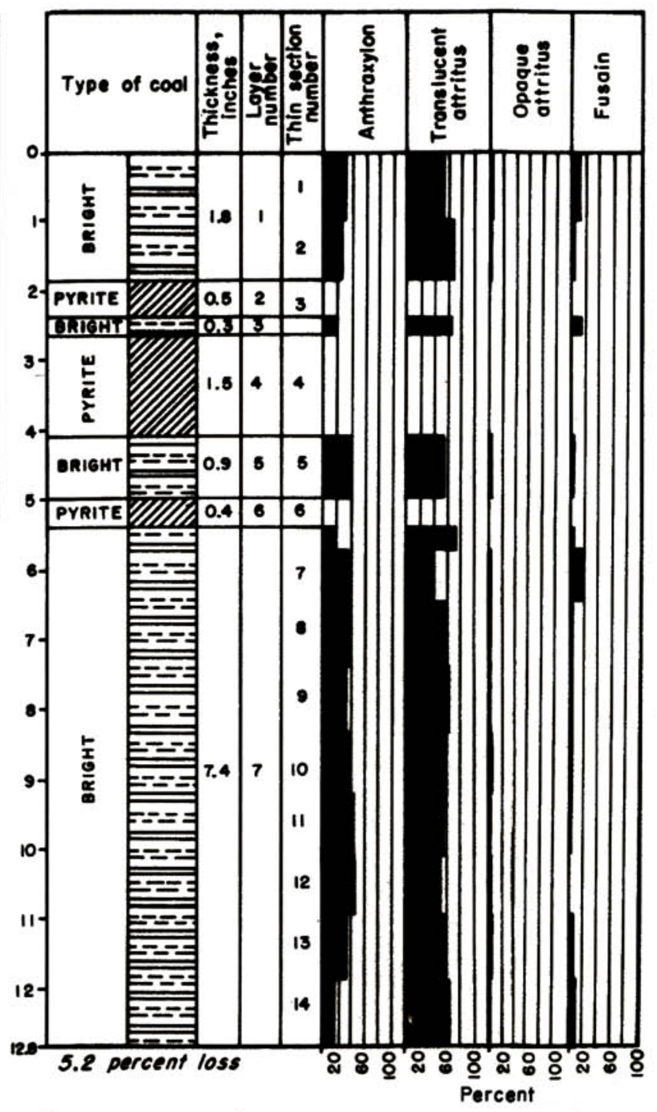
D...Mineral coal (Sample CR-8-M, Locality 9)



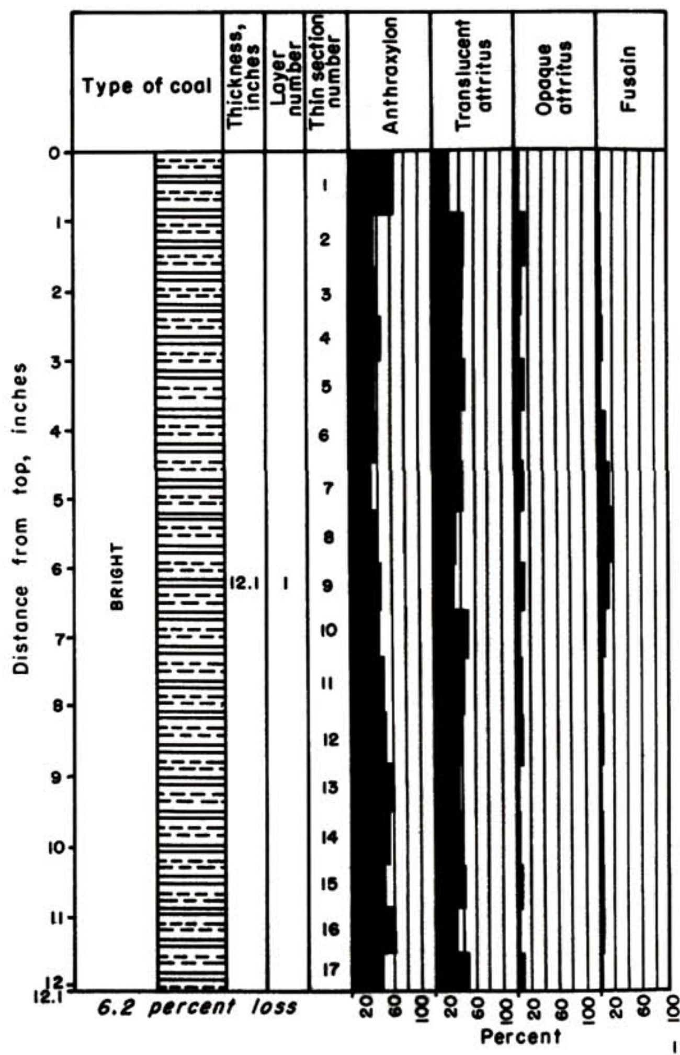
E...Mineral coal (Sample CK-5-M, Locality 15)



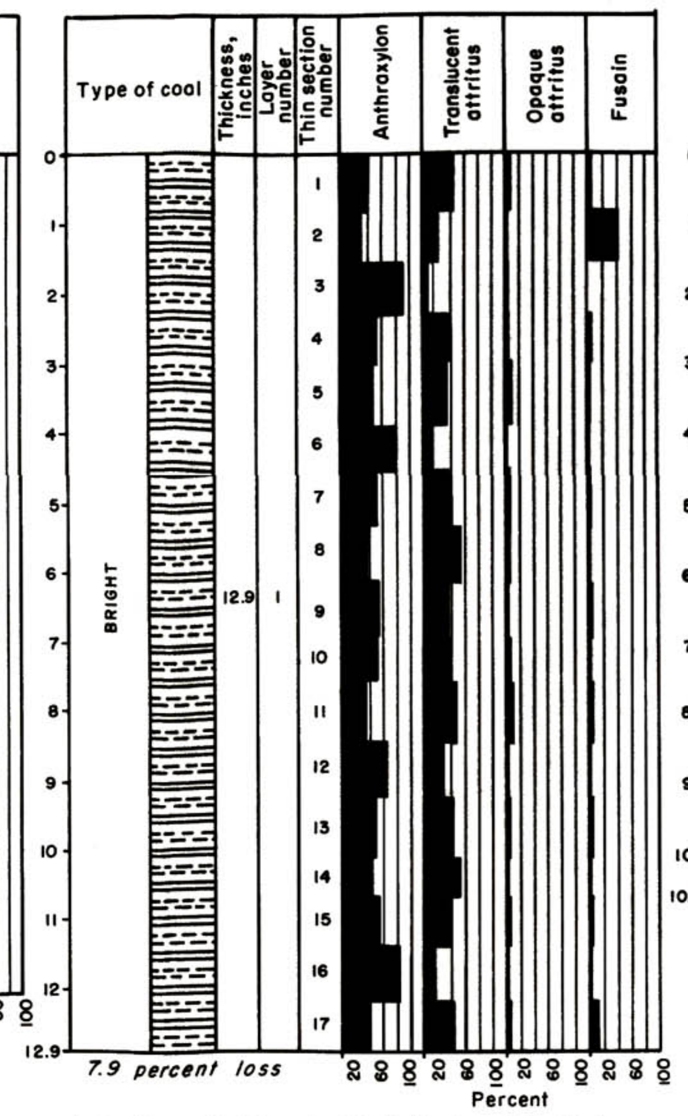
F...Mineral coal (Sample CK-4-M, Locality 16)



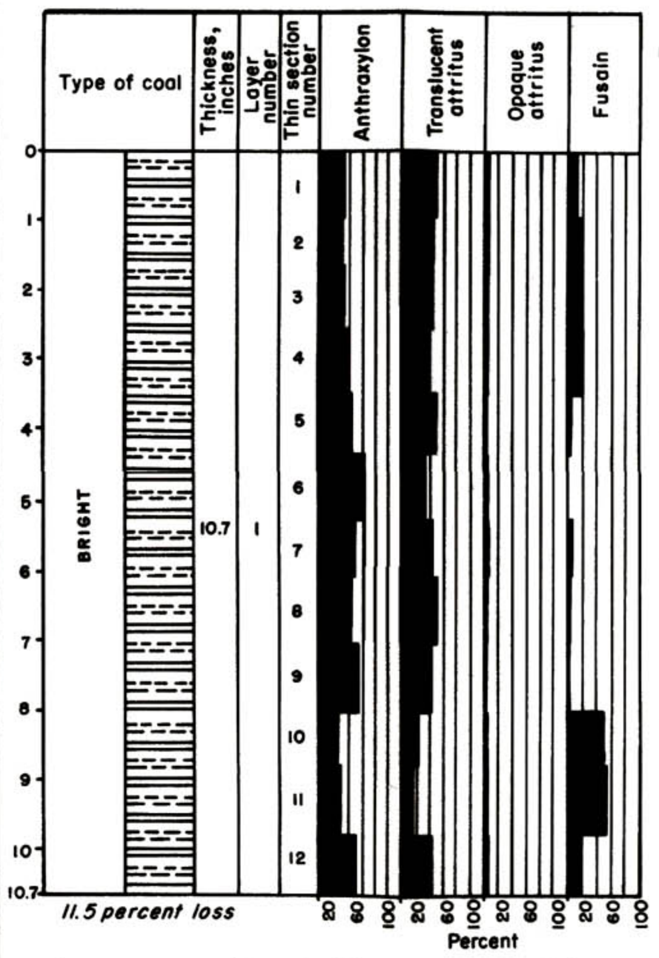
G...Mineral coal (Sample CK-2-M, Locality 18)



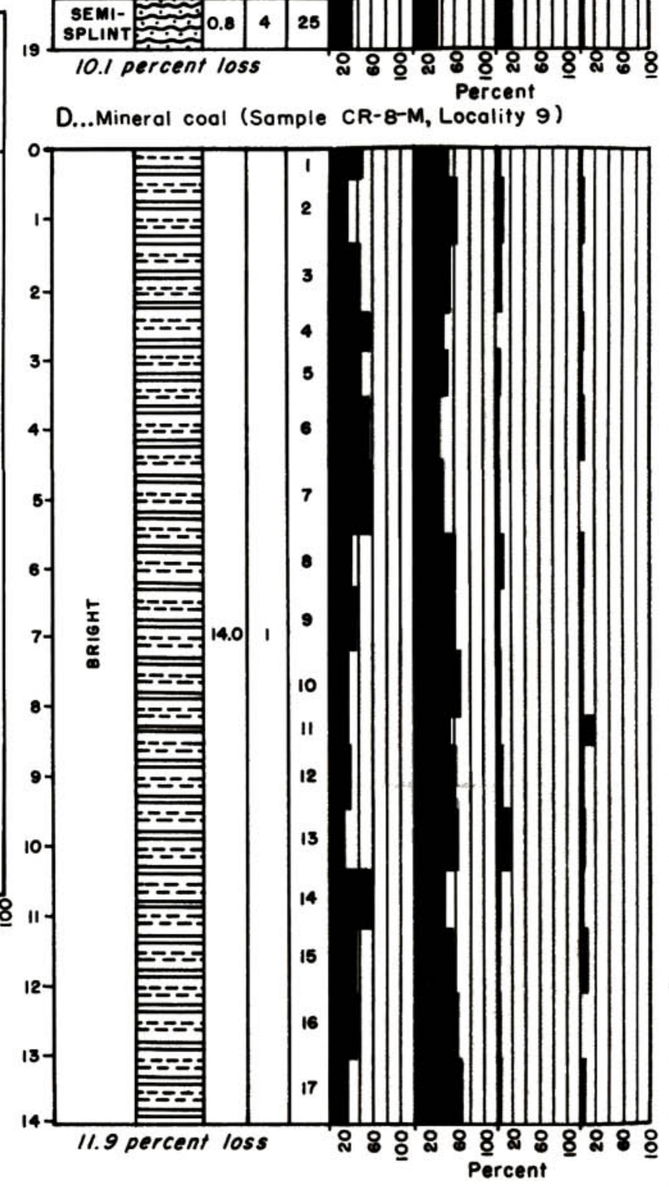
H...Bevier coal (Sample BN-3-B, Locality 19)



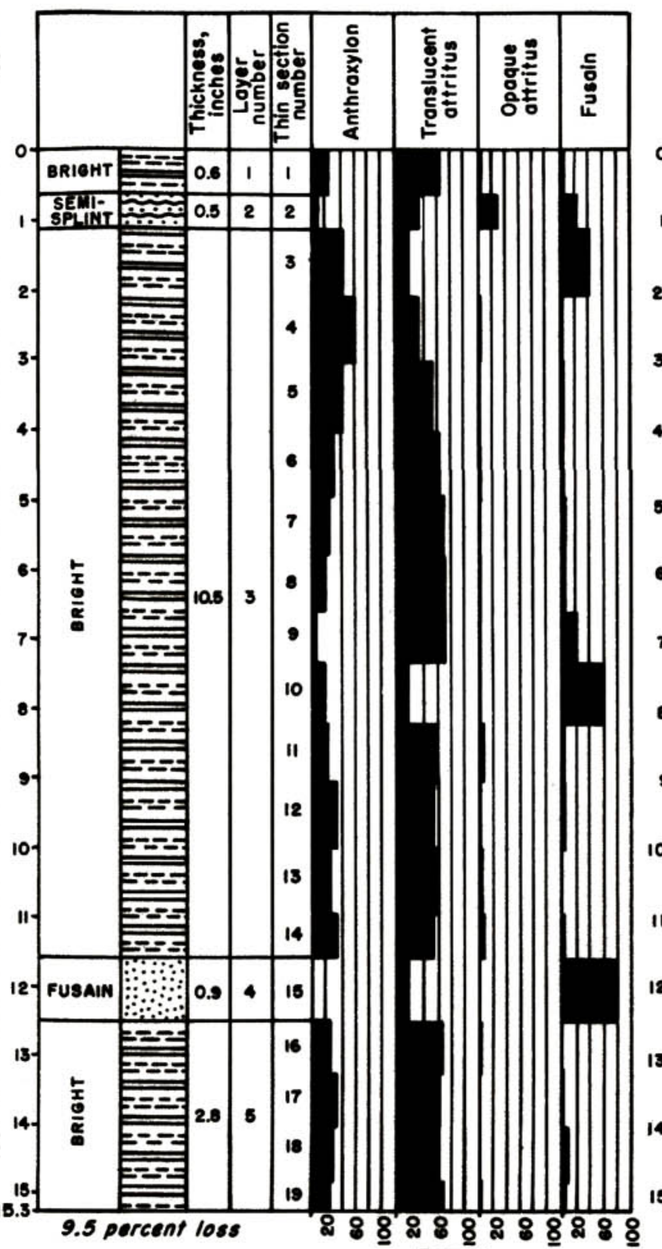
I...Bevier coal (Sample BN-2-B, Locality 20)



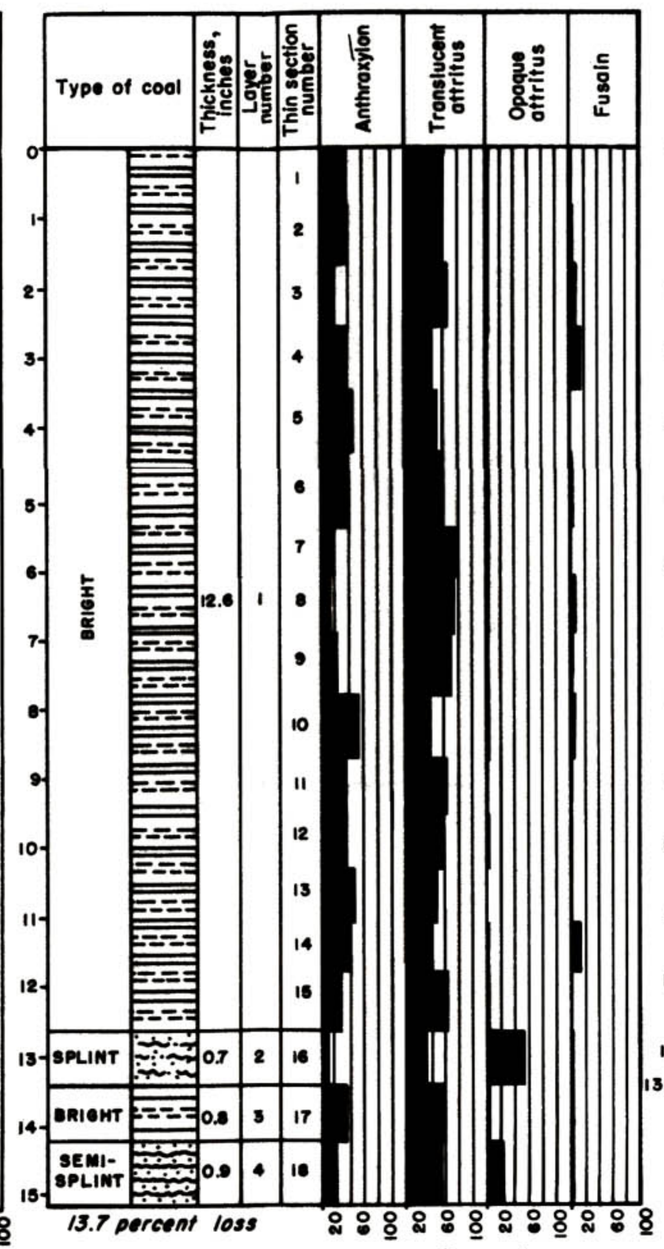
J...Bevier coal (Sample BN-1-B, Locality 21)



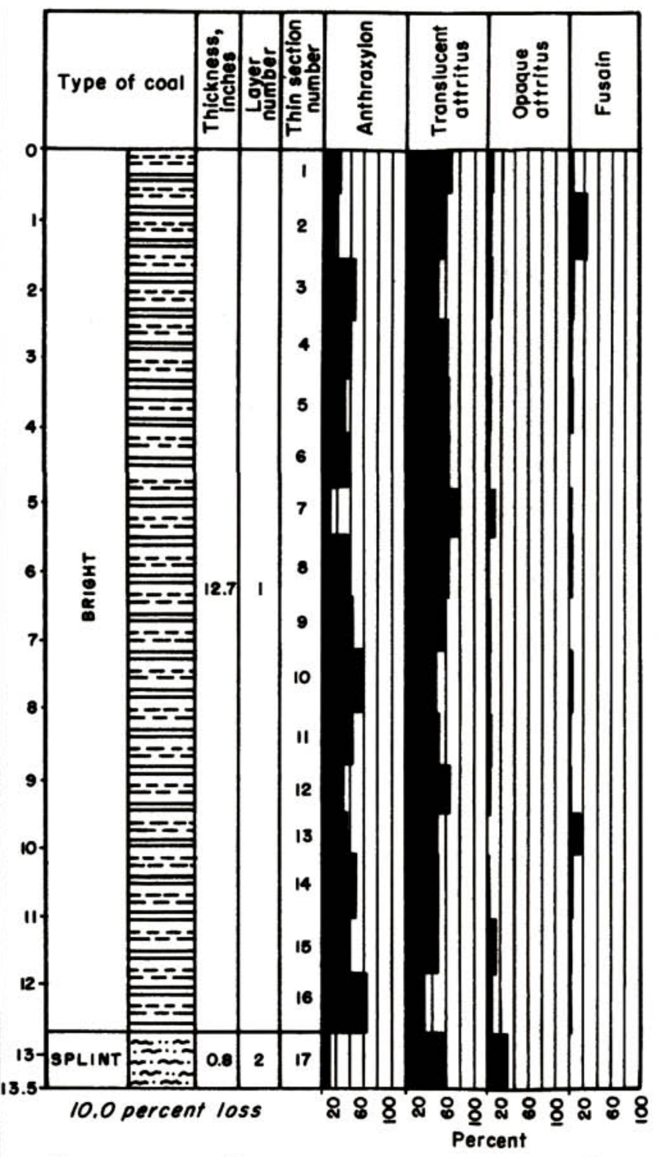
K...Bevier coal (Sample CR-9-B, Locality 22)



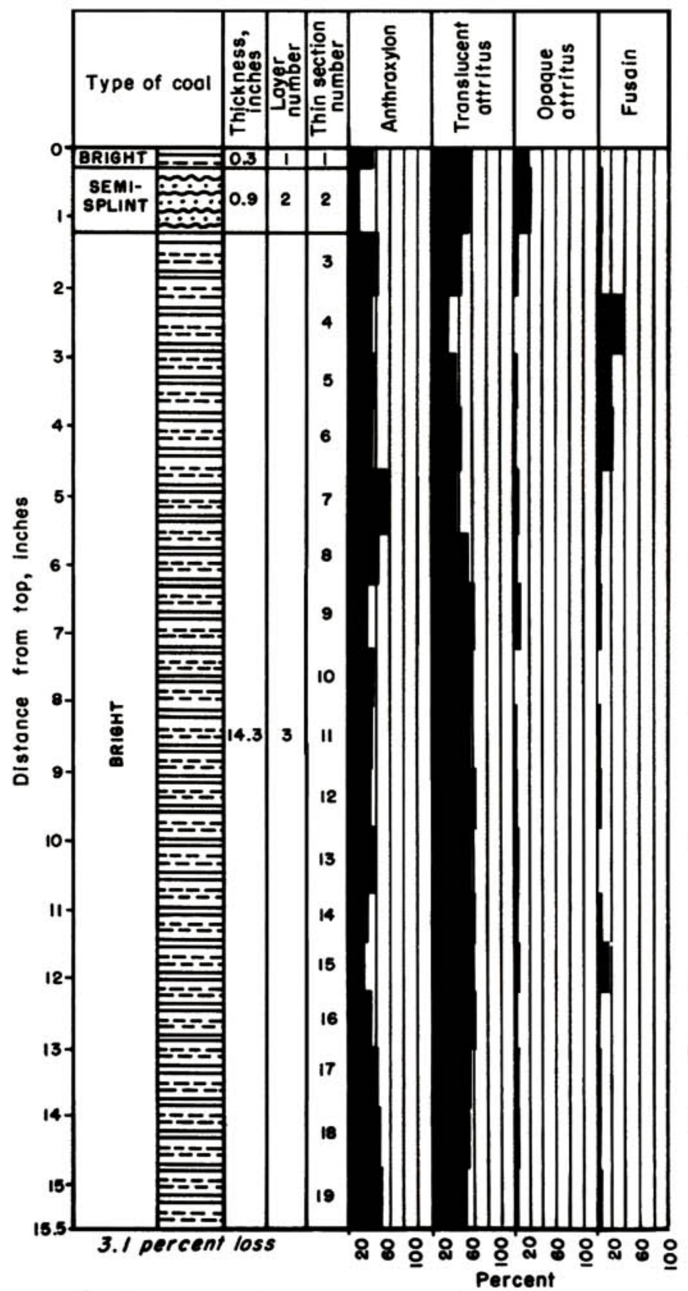
L...Bevier coal (Sample CR-5-B, Locality 25)



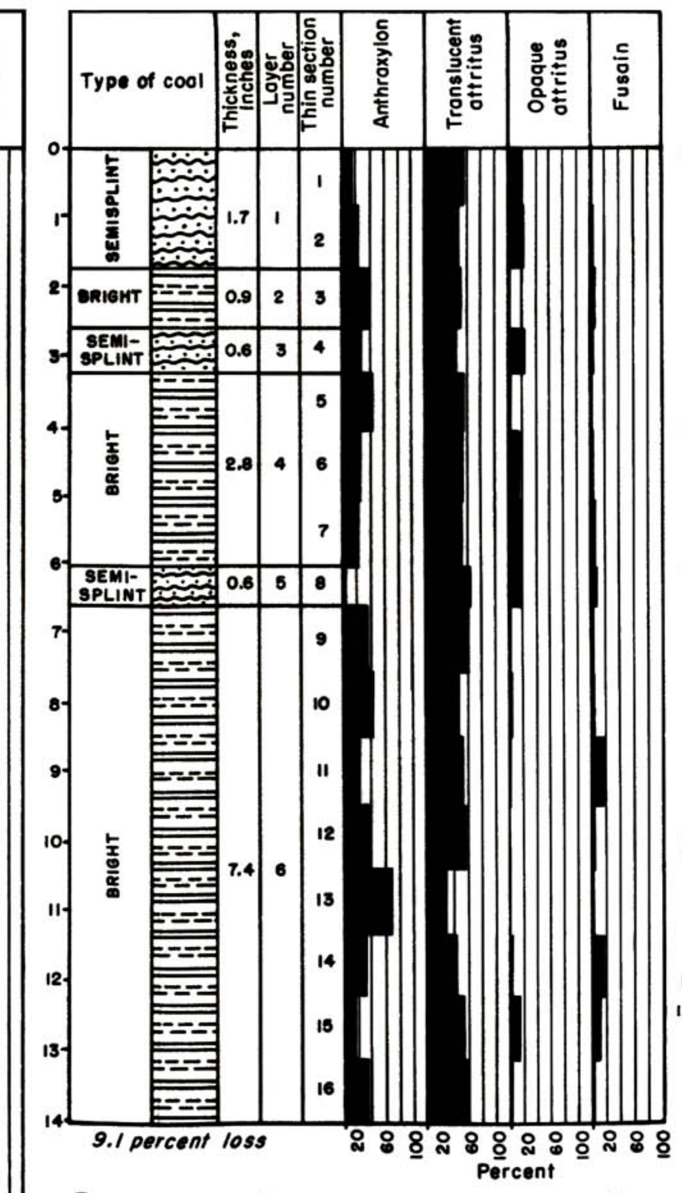
M...Bevier coal (Sample CR-6-B, Locality 26)



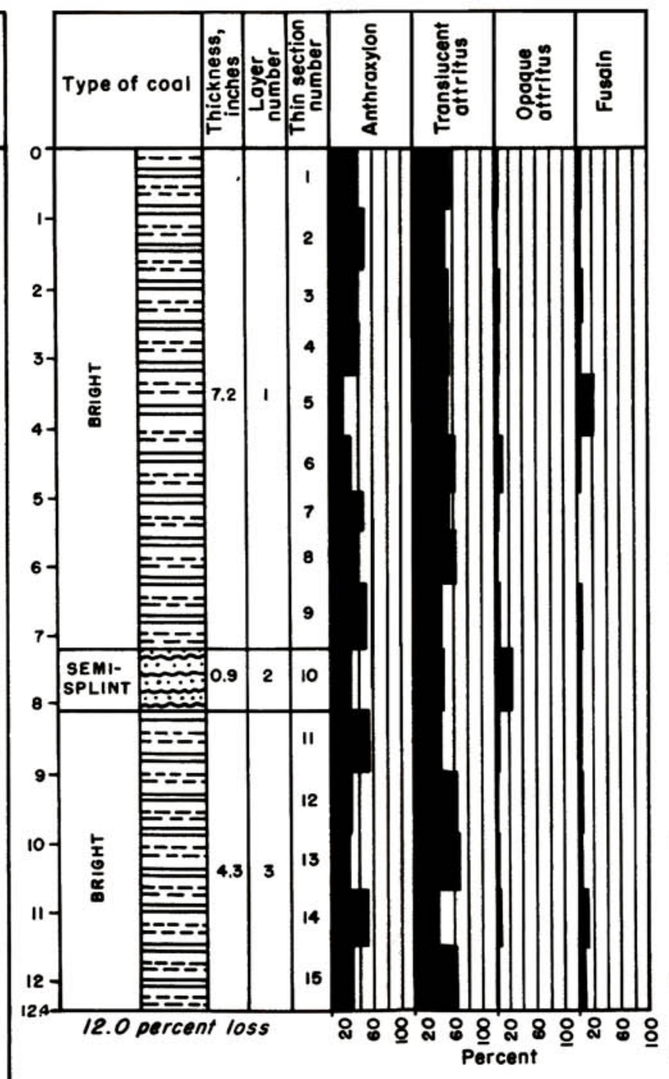
N...Bevier coal (Sample CR-7-B, Locality 27)



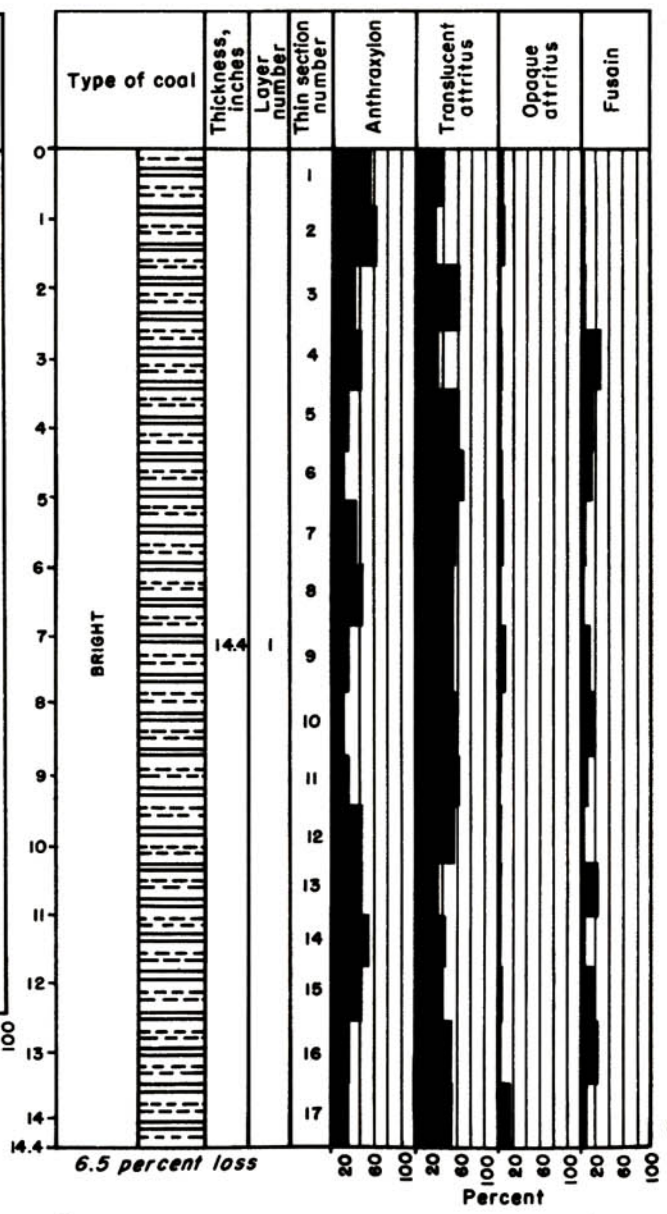
O...Bevier coal (Sample CR-12-B, Locality 30)



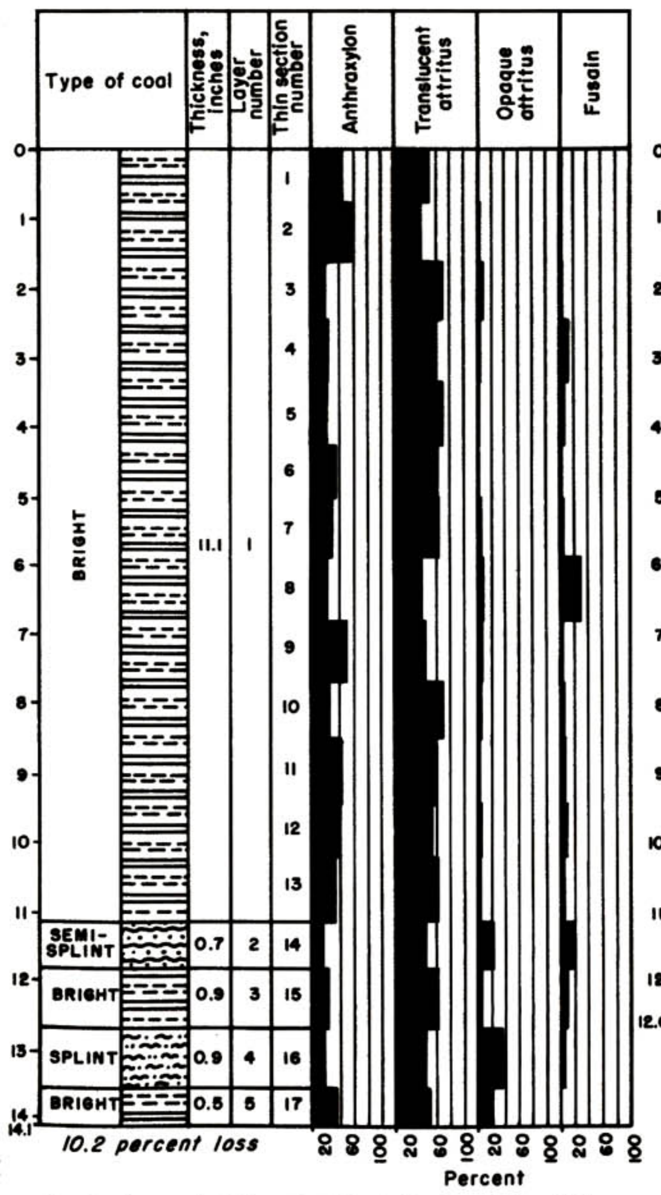
P...Bevier coal (Sample CR-14-B, Locality 31)



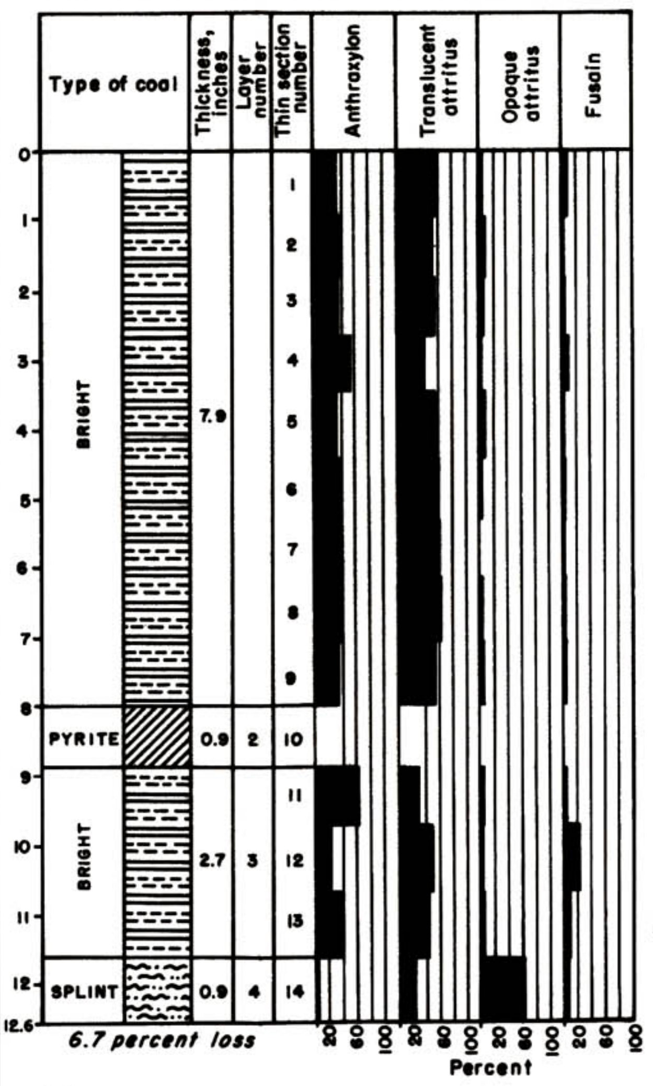
Q...Bevier coal (Sample CR-11-B, Locality 32)



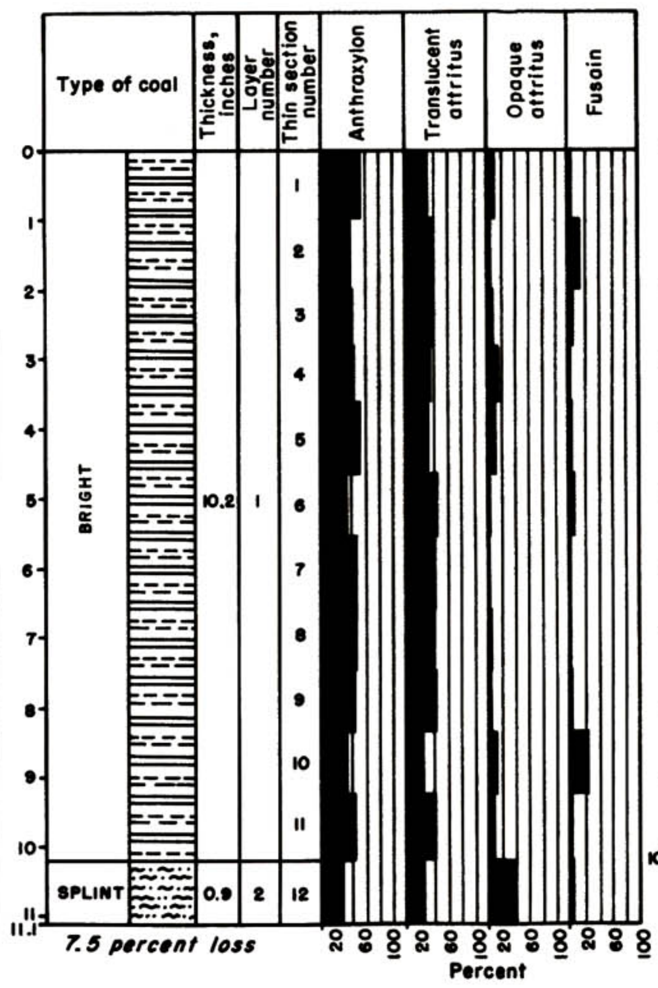
R...Bevier coal (Sample CR-13-B, Locality 33)



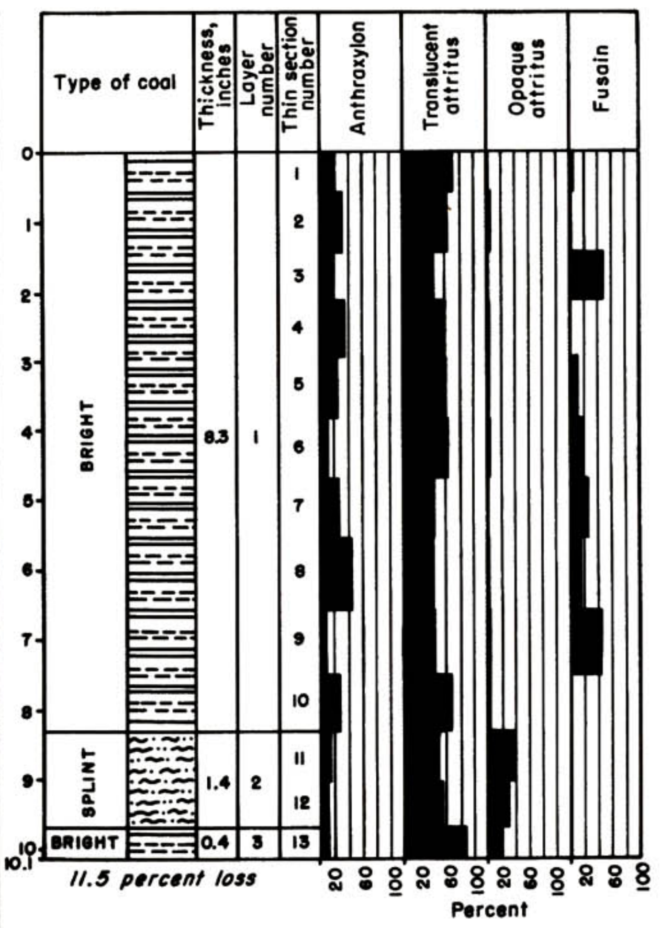
S...Bevier coal (Sample CR-10-B, Locality 33)



T...Bevier coal (Sample CK-1-B, Locality 35)



U...Bevier coal (Sample LT-1-B, Locality 37)



V...Croweburg coal (Sample CR-1-C, Locality 8)

STATE GEOLOGICAL SURVEY OF KANSAS

Recent Publications

BULLETIN 78. Oil and Gas Developments in Kansas During 1948, by W. A. Ver Wiebe, J. M. Jewett, and Earl K. Nixon, 186 pages, 1949. Mailing charge, 25 cents.

BULLETIN 79. Geology and Ground-Water Resources of a Part of South-Central Kansas with special reference to the Wichita municipal water supply, by Charles C. Williams and Stanley W. Lohman, 455 pages, 1949. Mailing charge, 40 cents.

BULLETIN 80. Geology and Ground-Water Resources of Pawnee and Edwards Counties, Kansas, by Thad G. McLaughlin, 189 pages, 1949. Mailing charge, 25 cents.

BULLETIN 81. Geology and Ground-Water Resources of Norton County and Northwestern Phillips County, Kansas, by John C. Frye and Alvin R. Leonard, 144 pages, 1949. Mailing charge, 25 cents.

BULLETIN 82. 1949 Reports of Studies (Three parts issued separately). Mailing charge, 10 cents each part.

BULLETIN 83. Divisions of the Pennsylvanian System in Kansas, by Raymond C. Moore, 203 pages, 1949. Mailing charge, 25 cents.

BULLETIN 84. Ground-Water Conditions in the Smoky Hill Valley in Saline, Dickinson, and Geary Counties, Kansas, by Bruce F. Latta, 152 pages, 1949. Mailing charge, 25 cents.

BULLETIN 85. Geology and Ground-Water Resources of Rice County, Kansas, by O. S. Fent, 142 pages, 1950. Mailing charge, 25 cents.

BULLETIN 86. 1950 Reports of Studies (Six parts issued separately). Mailing charge, 10 cents each part.

BULLETIN 88. Geology and Ground-Water Resources of Barton and Stafford Counties, Kansas, by Bruce F. Latta, 228 pages, 1950. Mailing charge, 25 cents.

BULLETIN 89. The Kansas Rock Column, by Raymond C. Moore, John C. Frye, J. M. Jewett, Wallace Lee, and Howard G. O'Connor, 132 pages, 1951. Mailing charge, 25 cents.

BULLETIN 90, 1951 Report of Studies (Eight parts issued separately). Mailing charge, 10 cents each part.

BULLETIN 91. The Manufacture of Lightweight Concrete Aggregate from Kansas Clays and Shales, by Norman Plummer and William B. Hladik, 100 pages, 1951. Mailing charge, 25 cents.

BULLETIN 92. Oil and Gas Developments in Kansas During 1950, by W. A. Ver Wiebe, J. M. Jewett, E. K. Nixon, R. K. Smith, and A.L.Hornbaker, 187 pages, 1951. Mailing charge, 25 cents.

BULLETIN 93. Geology and Ground-Water Resources of Lane County, Kansas, by Glenn C. Prescott, Jr., 126 pages, 1951. Mailing charge, 25 cents.

BULLETIN 94. Ground-Water Resources of Pawnee Valley, Kansas, by V. C. Fishel, 144 pages, 1952. Mailing charge, 25 cents.

BULLETIN 95. Geology and Ground-Water Resources of Lincoln County, Kansas, by Delmar W. Berry, 96 pages, 1952. Mailing charge, 25 cents.

BULLETIN 97. Oil and Gas Developments in Kansas During 1951, by W. A. Ver Wiebe, J. M. Jewett, E. D. Goebel, and A. L. Hornbaker, 188 pages, 1952. Mailing charge, 25 cents.

BULLETIN 98. Geology and Ground-Water Resources of the North Fork Solomon River in Mitchell, Osborne, Smith, and Phillips Counties, Kansas, by Alvin R. Leonard, 150 pages, 1952. Mailing charge, 25 cents.

BULLETIN 99. Pleistocene Geology of Kansas, by John C. Frye and A. Byron Leonard, 230 pages. Mailing charge, 25 cents.

VOLUME 11. Geology, Mineral Resources, and Ground-Water Resources of Chase County, Kansas, by Raymond C. Moore, John Mark Jewett, Howard G. O'Connor, and R. Kenneth Smith, 49 pages, 1951. Mailing charge, 40 cents.

VOLUME 12. Geology, Mineral Resources, and Ground-Water Resources of Lyon County, Kansas, by Howard G. O'Connor, Edwin D. Goebel, and Norman Plummer, 59 pages, 1953. Mailing charge, 40 cents.

KANSAS ROCKS AND MINERALS, by Laura Lu Tolsted and Ada Swineford, 56 pages, 1948. Mailing charge, 5 cents.

GROUND WATER IN SOUTHWESTERN KANSAS, by John C. Frye and V. C. Fishel, 24 pages, 1949. Mailing charge, 5 cents.

THE KANSAS SCENE, by Grace Muilenburg, 48 pages, 1953. Free of charge.

STATE GEOLOGICAL SURVEY OF KANSAS

BULLETIN 96

1952 REPORTS OF STUDIES

PART 1. KANSAS VOLCANIC ASH RESOURCES, by J. Sheldon Carey, John C. Frye, Norman Plummer, and Ada Swineford, pp. 1-68, figs. 1-4, pls. 1-7, February 15, 1952.

PART 2. COAL RESOURCES OF THE CRETACEOUS SYSTEM (DAKOTA FORMATION) IN KANSAS, by Walter H. Schoewe, pp. 69-156, figs. 1-23, pls. 1-6, February 29, 1952.

PART 3. OIL SHALE IN KANSAS, by Russell T. Runnels, Robert O. Kulstad, Clinton McDuffee, and John A. Schleicher, pp. 157-184, figs. 1-2, pls. 1-3, March 15, 1952.

PART 4. MINOR ELEMENTS IN KANSAS SALT, by Russell T. Runnels, Albert C. Reed, and John A. Schleicher, pp. 185-200, pl. 1, April 15, 1952.

PART 5. GEOLOGY AND GROUND-WATER RESOURCES OF THE KANSAS RIVER VALLEY BETWEEN LAWRENCE AND TOPEKA, KANSAS, by Stanley N. Davis and William A. Carlson, pp. 201-276, figs. 1-8, pls. 1-7, June 1, 1952.

PART 6. EXPERIMENTAL PRODUCTION OF FELDSPAR AND SILICA FROM SEVERAL RIVER SANDS IN KANSAS, by Frank W. Bowdish and Russell T. Runnels, pp. 277-300, figs. 1-3, June 1, 1952.

PART 7. AMENABILITY OF CERTAIN KANSAS CLAYS TO ALUMINA EXTRACTION BY THE LIME-SINTER PROCESS, by E. D. Kinney, pp. 301-328, figs. 1-3, October 15, 1952.

PART 8. THE RED EAGLE FORMATION IN KANSAS, by Howard G. O'Connor and John Mark Jewett, pp. 329-362, fig. 1, pl. 1, December 31, 1952.

PART 9. ORTHOGRAPHY AS A FACTOR IN STABILITY OF STRATIGRAPHICAL NOMENCLATURE, by Raymond C. Moore, pp. 363-372, December 31, 1952.

BULLETIN 102

1953 REPORTS OF STUDIES

PART 1. PETROGRAPHIC STUDY OF SOUTHEASTERN KANSAS COALS, by William W. Hambleton, pp. 1-76, figs. 1-5, pls. 1-12, May 15, 1953.