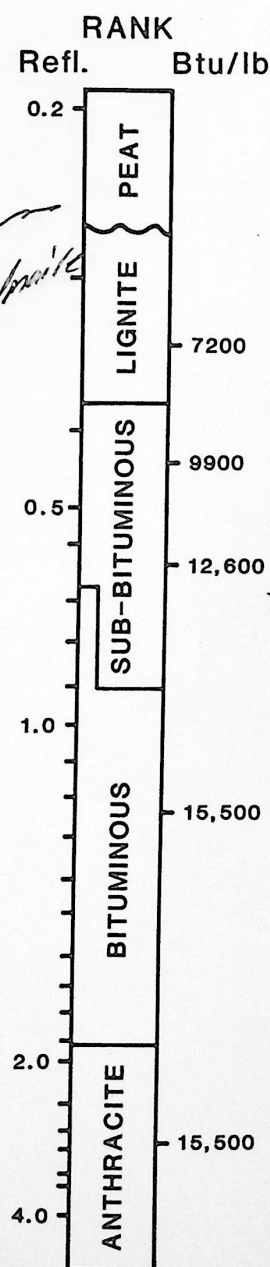
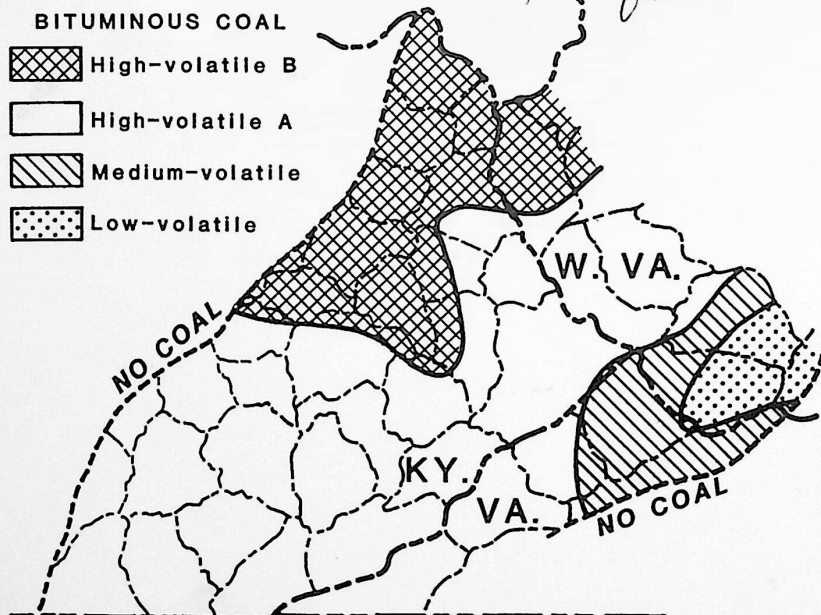




KENTUCKY GEOLOGICAL SURVEY
 Donald C. Haney, Director and State Geologist
 UNIVERSITY OF KENTUCKY, LEXINGTON

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PUBLISHER'S NOTE

This report on coal reflectance and rank in the Eastern Kentucky Coal Field is a slightly modified version of a thesis which was submitted in partial fulfillment of requirements for the degree of Master of Science at Eastern Kentucky University in 1979.

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ABSTRACT

A general isoreflectance map of the Eastern Kentucky Coal Field was prepared, using 72 reflectance readings collected in conjunction with this study and eight samples collected by Hower (1978). Additional data from West Virginia and Virginia (Cole and Smith, 1979) were incorporated into the study to enhance reflectance trends. The reflectance trends show that coalification increases to the southeast through eastern Kentucky and reaches a maximum in McDowell County, West Virginia. The fixed-carbon (dry, ash free [daf]) content of the coals confirms this coalification trend.

The general increase in coalification to the southeast is attributed to an increase in the depth of burial of the coal to the southeast. A local reflectance high in the southwestern part of the study area is attributed to a possible deep-seated heat source that raised the local temperature gradient.

INTRODUCTION

The rank of a coal is the degree of metamorphism to which the coal has progressed in response to geological and geochemical processes. The early stages of coalification are considered diagenetic but in later stages the physical and chemical changes are so profound that the processes must be termed metamorphic.

Rank Parameters

The rank of coal can be determined chemically by the amounts of fixed carbon, volatile matter, hydrogen, and moisture it contains; it can be determined physically by properties such as reflectance, calorific value, porosity,

and Vicker's hardness. For a more complete review of coal characterization and its usefulness, see Davis (1978).

A good rank parameter is one that changes regularly with the degree of coalification. Certain parameters are more accurate for rank determination than others and have specific ranges of coalification for which they are best suited. For example, volatile content and mean maximum reflectance of vitrinite macerals are best suited for rank determinations in the medium- and low-volatile bituminous stages because these parameters show rapid changes with variation, as opposed to fixed carbon content, which shows little change in these rank stages. Figure 1 shows the various rank parameters and their applicability to different coalification stages (Stach and others, 1975).

The two parameters used in this study to determine the rank of the coals studied are fixed-carbon content and average-maximum reflectance of the vitrinite. The fixed-carbon content of a coal is defined as the percentage of remaining combustible matter in a coal after removal of the moisture, ash, and volatile-matter contents. Reflectance is defined as the percentage of incident light that is reflected off a polished surface of a vitrinite maceral (Davis, 1978).

The procedure used to determine fixed-carbon content is from the American Society for Testing and Materials (ASTM)

Rank		Refl. $R_{m_{oil}}$	Vol. M. d. a. f. %	Carbon d. a. f. Vitrinite	Bed Moisture	Cal. Value Btu/lb (kcal/kg)	Applicability of Different Rank Parameters		
German	USA								
Torf	Peat	0.2	68						
			64	ca. 60	ca. 75				
Weich-	Lignite	0.3	60						
			56		ca. 35	7200 (4000)			
Matt-	Sub-Bit.	0.4	52						
			48	ca. 71	ca. 25	9900 (5500)			
Glanz-	C	0.5	44						
			40	ca. 77	ca. 8-10	12600 (7000)			
Flamm-	B	0.7	36						
			32						
Gasflamm-	A	0.8	28						
			24						
Gas-	Medium Volatile Bituminous	1.0	20						
			16						
Fett-	Low Volatile Bituminous	1.2	12						
			8						
Ess-	Semi-Anthracite	1.4	4						
Mager-	Anthracite	1.6							
Anthrazit	Meta-Anthr.	1.8							
Meta-Anthr.		2.0							

Figure 1. The different stages of coalification according to the German (DIN) and North American (ASTM) classifications and their applicability to different physical and chemical rank parameters. (From Stach and others, 1975.)

(1976). The procedure for determining the mean-maximum reflectance is discussed in Stach and others (1975), Davis (1978), and ASTM (1976), and will be briefly discussed later in this study.

Most fixed-carbon values used in this study were derived from a literature search (Harnsberger, 1919; Giles, 1921; Fohs, 1912; Crandall and Sullivan, 1912; Hodge, 1912; Miller, 1910; Hunt and others, 1936; Hinds, 1918; Babu and others, 1973; and Barlow, 1974). Some fixed-carbon analyses were determined in conjunction with this study.

Brief History of Coal Petrography

In 1830, Lindley began modern coal petrography by inspecting coal fragments under a microscope, and offered the hypothesis that coal was derived from plant material. In 1833, Hutton and others worked with thin sections of coal and were able to prove Lindley's idea (Kaegi, 1976). Coal petrography techniques had lagged behind the techniques of inorganic petrography, so many of the techniques used in coal petrography were borrowed from the inorganic field. In 1913, Winter and others used reflection techniques derived from inorganic petrography to study block slices of coal. Thiessen, meanwhile, was doing intensive work with thin sections (Stach, 1975). In 1925, Stach developed the technique of using the oil immersion lens, which enhances the reflection contrasts of the coal constituents (Stach,

1975). Stach is also responsible for using particulate blocks of crushed coal in a mounting medium for petrographic analysis (Stach, 1975). The development of the Berek microphotometer made possible the modern-day technique of reflected light petrography for rank determination. In the early days, polished metallic standards were used to subjectively describe coal reflectance. Using this technique, Hoffman and Jenker (1932) determined that coal reflectance increased continuously with rank. In 1943, Seyler, using a similar technique but with a monochromatic filter on the light source, further enhanced the reflection contrasts, and developed a discontinuous model for reflectance changes.

With the development of the photoelectric cell, the human subjectivity was finally eliminated, providing more precise direct readings of reflectivity. Broadbent and Shaw (1955), using statistical methods, argued against Seyler's (1943) discontinuous model, and by 1956 the continuous model for reflectance changes was accepted by most coal petrologists.

In 1935 the Third International Stratigraphic Congress adopted the nomenclature for coal constituents in reflected light as proposed by Marie Stopes. An alternate system was developed by Thiessen for work with thin sections (ICCP, 1976).

There have been over 240 publications on coal petrography since 1924 (Stach and others, 1975). Today, vitrinite reflectance is a readily accepted procedure for rank determinations and for many other uses such as the comparison of coke blends.

Coalification and Coal Rank

Coalification is the result of chemical and physical changes in original plant material, beginning with peat and ending with the anthracite stages. The earliest transformations are biochemical and are the result of microorganisms feeding on the easily digestible contents of the peat. With increased depth of burial, the biologic activity is eliminated, and geochemical processes become the most important coalification factor. The most striking physical change occurs with the gelification (vitrinization) of the humic substances to form the bright, lustrous, sub-bituminous coals. As the rank of coal increases, coalification becomes a process of geochemical changes in the coal, resulting in a loss of moisture, an increase in calorific value, an increase in fixed-carbon content, and an increase in reflectance. These geochemical changes are caused by the splitting off of functional groups from organic compounds, resulting in increased aromatization.

The advancement in coal rank (or coalification) was first described by Van Grumbel as being the process that converts

peats to coal by way of lignite and the various stages of bituminous coals to anthracites (Teichmuller and Teichmuller, 1968). The processes by which coal increases in rank are considered to be diagenetic up to sub-bituminous rank; the change is attributed mostly to a loss of water content with few chemical changes. The physical and chemical changes occurring after sub-bituminous rank are so radical that the processes are termed metamorphic.

In general, the rank of a coal increases with depth of burial and is not strongly dependent on composition (Teichmuller and Teichmuller, 1968). The increasing rank is most strongly related to the increasing temperature encountered with depth (geothermal gradient). Other factors relating to rank are overburden pressure and tectonic pressure, the lithology of surrounding rocks, and time. The increasing rank of a coal may actually be impeded by high static pressure (Stach and others, 1975) and may be accelerated by abnormally high geothermal gradients associated with igneous activity.

As the rank of a coal changes, the character of the coal changes, both chemically and physically. The most significant change in the physical appearance occurs between the peat and the sub-bituminous stages of coalification. During this period the peat is transformed from a woody substance that can be cut with a knife to a hard, brittle,

lustrous substance that can only be recognized as plant-derived under a microscope.

Geologic Factors in Coalification

Coalification is most significantly advanced by heat (either by heat flow from an igneous intrusion or by the natural geothermal gradient by which temperature increases with greater depth of burial). Time is only significant in relation to temperature increase. Time by itself will not promote coalification. Pressure is most important only in the earliest stages of coalification (peat to sub-bituminous), when compression is important in reducing the porosity of the peat and thus the moisture content. Pressure is also important in forming optical anisotropy and in the increased graphitization of the anthracite ranks. Static pressure may actually retard coalification. The lithology of the surrounding rocks may affect coalification in relation to the geothermal gradient. If the thermal conductivity of the surrounding rocks is high, heat may be conducted away too rapidly to have much effect on the coal.

The effect of time is only important in relation to temperature. The longer a heat source (igneous intrusion or geothermal gradient) is allowed to act on a coal, the higher the rank attained. Likewise, the higher the temperature, the greater the influence of time. Time by itself has little effect, as shown by the Carboniferous lignites of the

Moscow Basin. These lignites have never been buried very deeply and have never attained temperatures greater than 20 to 25°C (Stach and others, 1975).

For a more complete discussion of the relationship of coalification to geologic factors such as temperature, time, and pressure, see Teichmuller and Teichmuller (1968), Chandra (1963, 1965), Damberger (1971), Hacquebard and Donaldson (1970), Heck (1943), and Hower (1978).

The Use of Vitrinite Reflectance for Rank Determination

Vitrinite reflectance is an optical technique used to determine the rank of coal. It is particularly reliable for coals with less than 30 percent volatile matter (daf) (McCartney and Teichmuller, 1972). The maceral vitrinite is the main microscopic constituent of most coals. It is especially useful for optical techniques such as reflectance measurements because it occurs in large, homogenous, relatively structureless particles (McCartney and Teichmuller, 1972).

To determine the rank of a coal by vitrinite reflectance, one of two methods may be used: mean-maximum reflectance in polarized light, used by most United States laboratories, and mean-average reflectance in nonpolarized light, used in many European laboratories (McCartney and Teichmuller, 1972). In this study the mean-maximum reflectance was used. For the specific procedure, see ASTM (1976).

Previous Work

Huddle and others (1963) were the first to make a general statement about the rank of eastern Kentucky coals, classifying them as high-volatile A and B bituminous with possible occurrences of high-volatile C. Hower (1978) reported reflectance values for eight eastern Kentucky samples. Several papers concerning the petrography of eastern Kentucky coals have been published (Hower and Wild, 1980, 1981; Hower and others, 1981a, 1981b, 1981c; Hower and others, 1982; Trinkle and others, 1981).

STUDY AREA

The area of this study is the part of the Eastern Kentucky Coal Field that is delineated by the Ohio, West Virginia, Virginia, and Tennessee state borders and by the line of no coal on the west, and by the Pine Mountain Fault scarp on the southeast (Fig. 2).

STRATIGRAPHY

The rocks of Pennsylvanian age in the study area are subdivided into three formations. Beginning with the lowest, they are the Lee, Breathitt, and Conemaugh Formations. The Monongahela may be present in the Allegheny Synclinorium south of Ashland, Kentucky (Rice and others, 1979). The Pennsylvanian rocks of eastern Kentucky lie in a wedge that thickens from west to east toward the axis of the Appalachian Basin (Fig. 3). Table 1 shows abbreviations

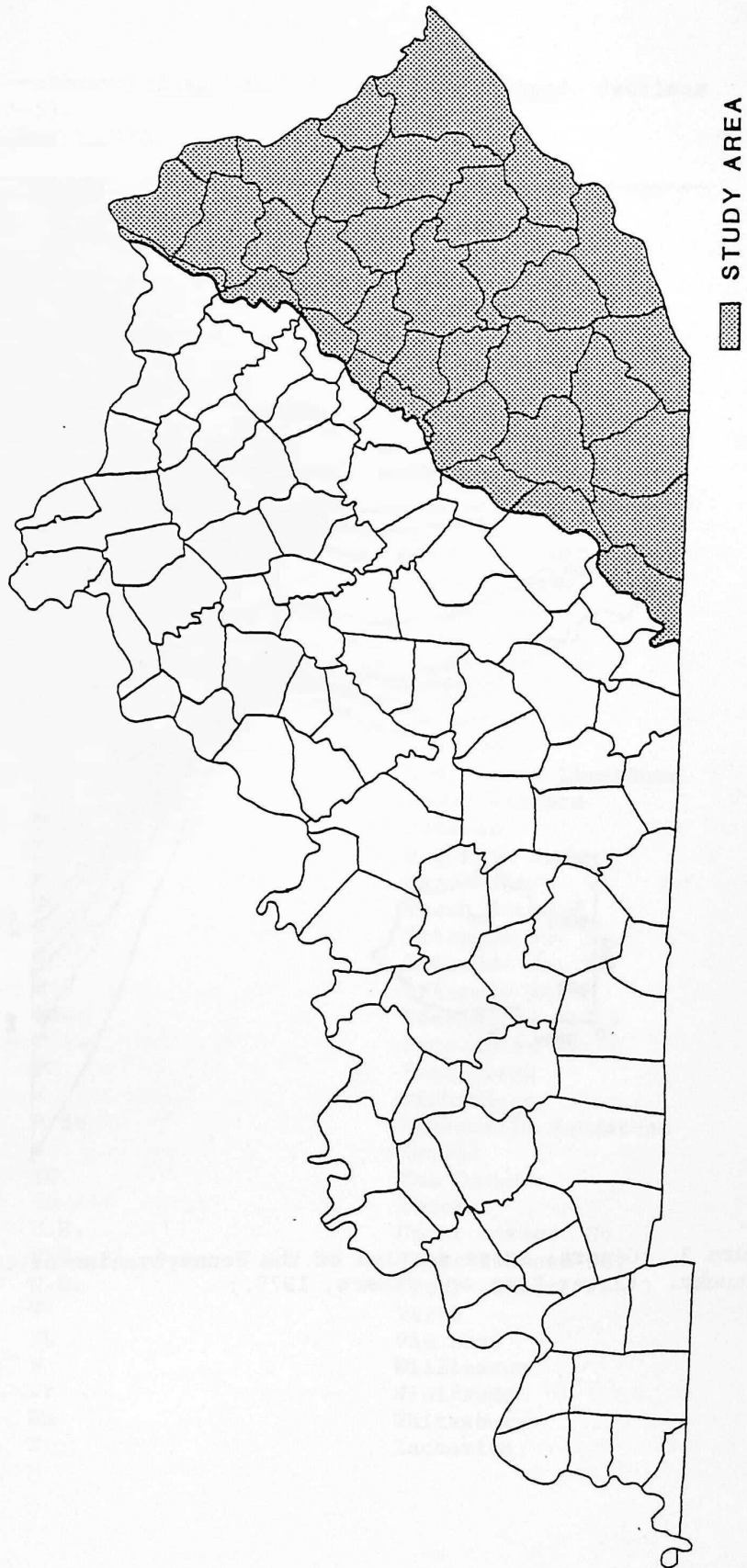


Figure 2. Map showing location of study area.

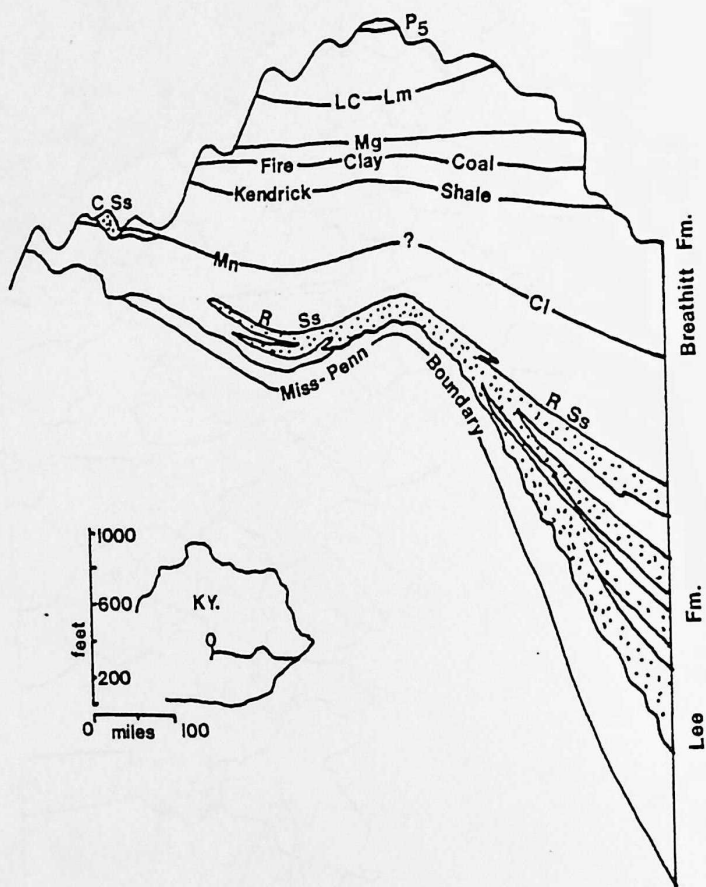


Figure 3. General cross section of the Pennsylvanian of eastern Kentucky. (After Rice and others, 1979.)

Table 1.--Abbreviations Used in the Generalized Sections
(Figures 3-5).

ABBREVIATION	NAME
Alma	Alma
Am	Amburgy
B	Broas
BC	Buffalo Creek
Be	Beattyville
BG	Blue Gem
CC	Cannel City
Cl	Clintwood
C Ss	Corbin Sandstone
FC	Fire Creek
G	Grassy
GC	Gun Creek
GH	Gray Hawk
GL	Gilbert
H	Hazard
H	Hazard No. 4
H	Hazard No. 7
H	Hazard No. 9
Hx	Haddix
I	Iaeger
J	Jellico
LC Lm	Lost Creek Limestone
LE	Lower Elkhorn
Ma	Matewan
Mg	Magoffin Beds
Mn	Manchester
PO	Peach Orchard
P	Princess No. 3
P	Princess No. 5
P	Princess No. 7
Poco	Pocohontas No. 3
Poco	Pocohontas No. 4
PC	Pond Creek
R	Richardson
R Ss	Rockcastle Sandstone
S	Sewell
TC	Tom Cooper
Th	Thacker
U.E.	Upper Elkhorn No. 1
U.E.	Upper Elkhorn No. 2
U.E.	Upper Elkhorn No. 3
V	Vires
VL	Van Lear
W	Williamson
Wf	Winifrede
Wh	Whitesburg
Z	Zachariah

used in Figure 3 and other related figures. The rocks are composed principally of clastic deltaic sediments of sandstone, siltstone, shale, and coal, and minor amounts of limestone.

The deposition of Pennsylvanian sediments was strongly influenced by the subsidence of the southeast-trending Appalachian Trough (Rice and others, 1979). In the southeastern part of the basin, the Pennsylvanian sequence may be a part of a continuous series of deposition with the Mississippian sequence. In the northwestern part of the basin, the Pennsylvanian sequence lies unconformably on eroded Mississippian rocks. Individual cumulative thicknesses for the three formations are estimated by Rice and others (1979) to be: Lee, 500 meters; Breathitt, 950+ meters; and Conemaugh-Monongahela, 175 meters. Rice and others (1979) and Huddle and others (1963) stated that the Lee Formation ranges from 204 meters at the Tennessee line to 30.5 meters at the Ohio River. The interval between the Upper Elkhorn No. 3 and the Hazard coal beds increases from 46 meters at the Ohio River, to 91.5 meters in southern Lawrence County, to 183 meters in central Pike and Clay Counties, to 396 meters south of the Pine Mountain Fault scarp.

Figure 4 is a west-east generalized cross section across eastern Kentucky and Figure 5 is a north-south generalized

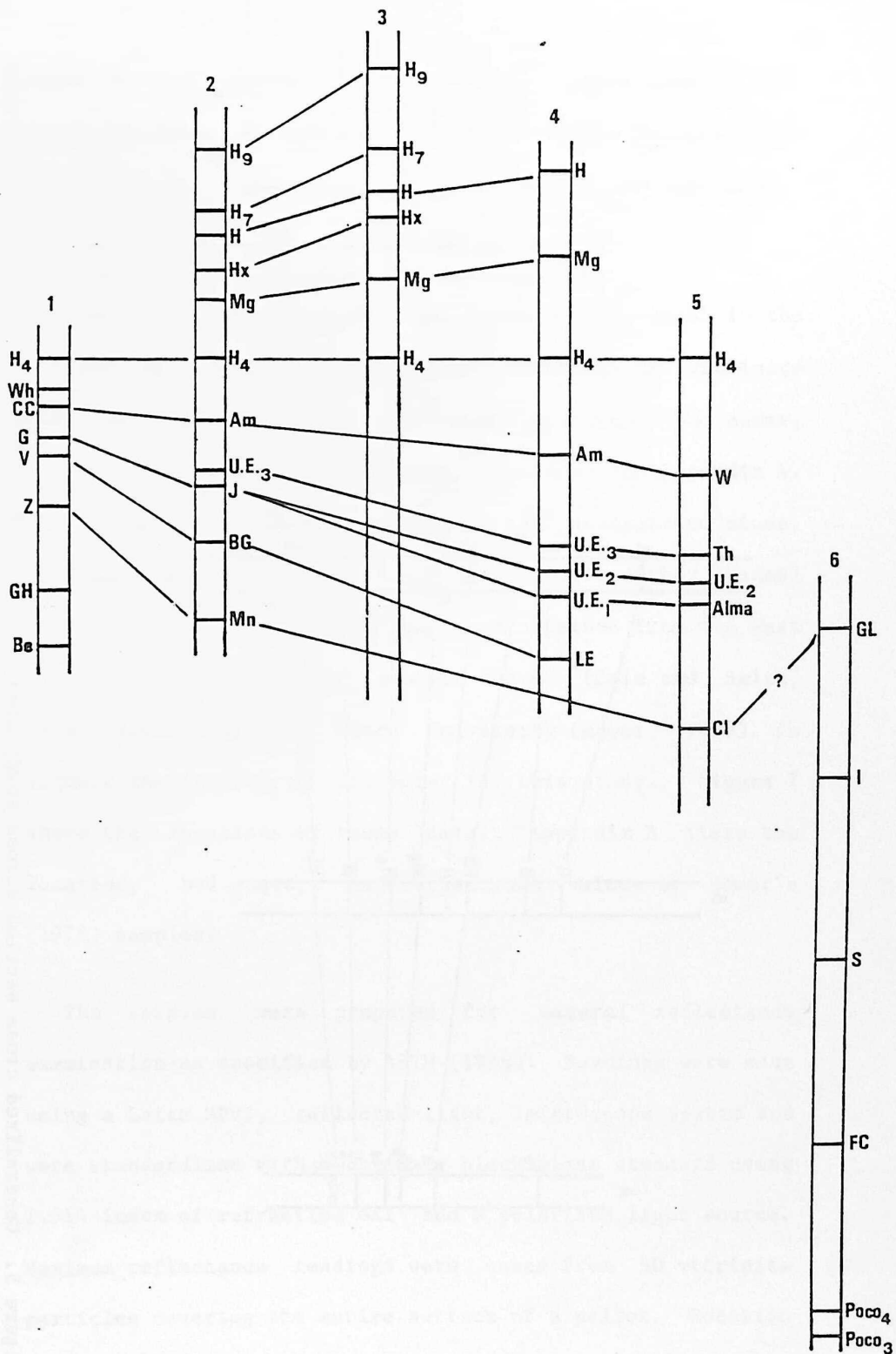


Figure 4. Generalized cross section across study area, west to east. Vertical scale 1 inch equals 300 feet.

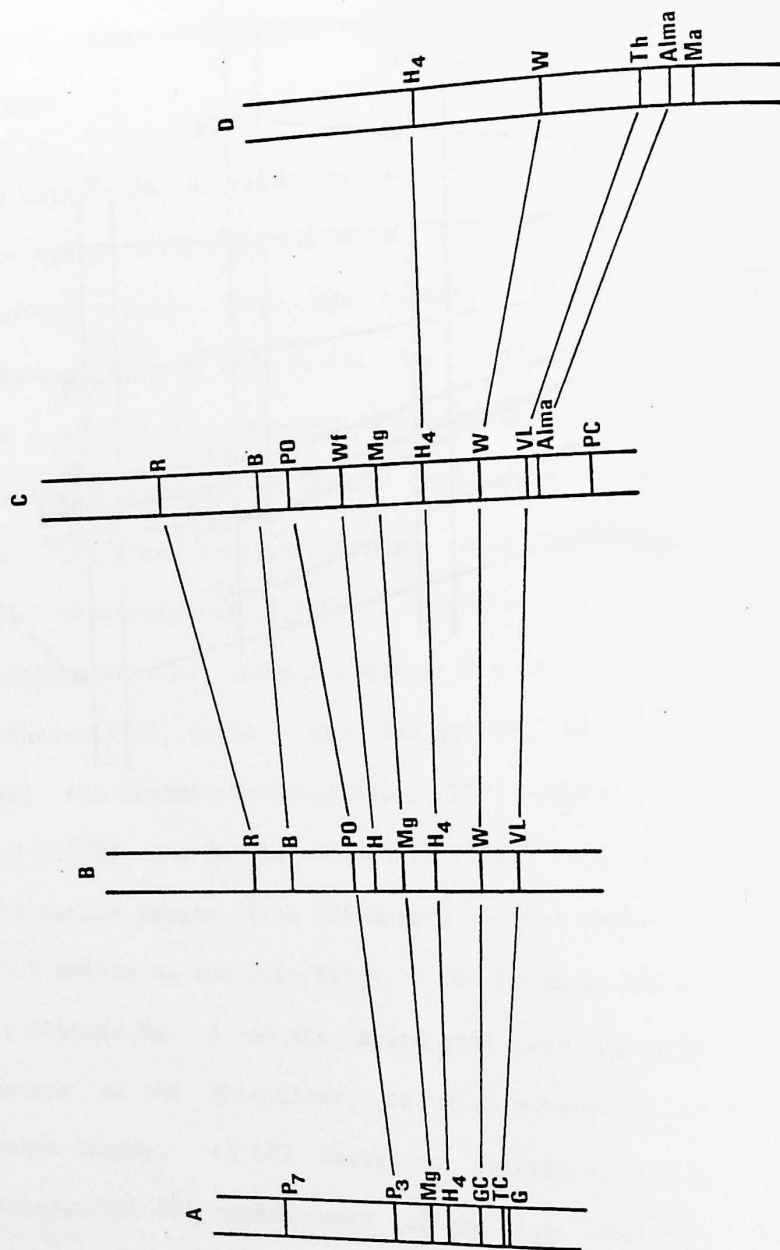


Figure 5. Generalized cross section across study area, northwest to southeast. Vertical scale 1 inch equals 300 feet.

cross section across eastern Kentucky. Locations of both cross sections are shown in Figure 6. The cross sections illustrate the thickening strata to the east and southeast.

PROCEDURE

Seventy-two coal samples from numerous coal beds in the Eastern Kentucky Coal Field were collected for vitrinite reflectance studies (Fig. 7). Their locations, bed names, and vitrinite reflectance values are listed in Appendix A. The samples were taken from surface and underground mines, roadcuts, and drill cores. All samples were either channel or run-of-mine. Additional data were obtained from the West Virginia Geological and Economic Survey (Cole and Smith, 1979) and Pennsylvania State University (Hower, 1978) to augment the information collected in this study. Figure 7 shows the locations of these data. Appendix B lists the location, bed names, and reflectance values of Hower's (1978) samples.

The samples were prepared for maceral reflectance examination as specified by ASTM (1976). Readings were made using a Leitz MPV2, reflected-light, microscope system and were standardized with a primary black-glass standard using 1.514 index of refraction oil and a polarized light source. Maximum reflectance readings were taken from 50 vitrinite particles covering the entire surface of a pellet. Rotation of the stage for reflectance readings was done by hand. The

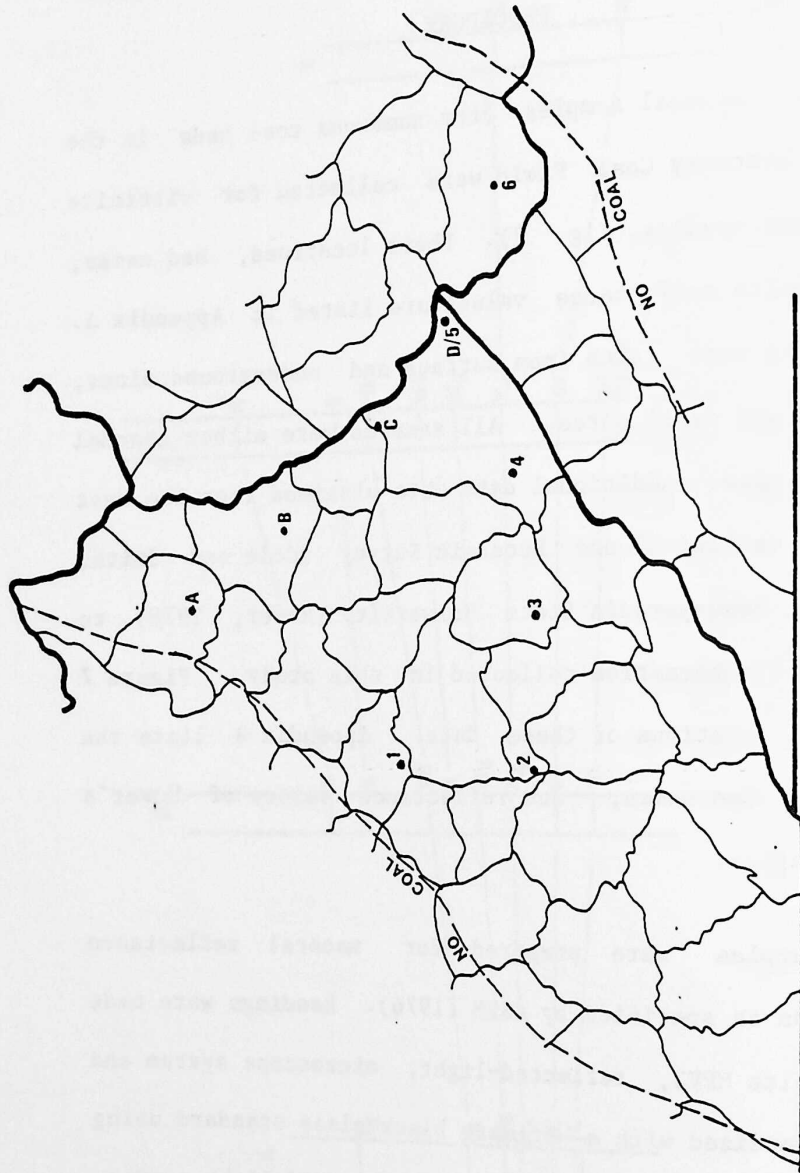


Figure 6. Map showing locations of cross sections (Figs. 4 and 5).

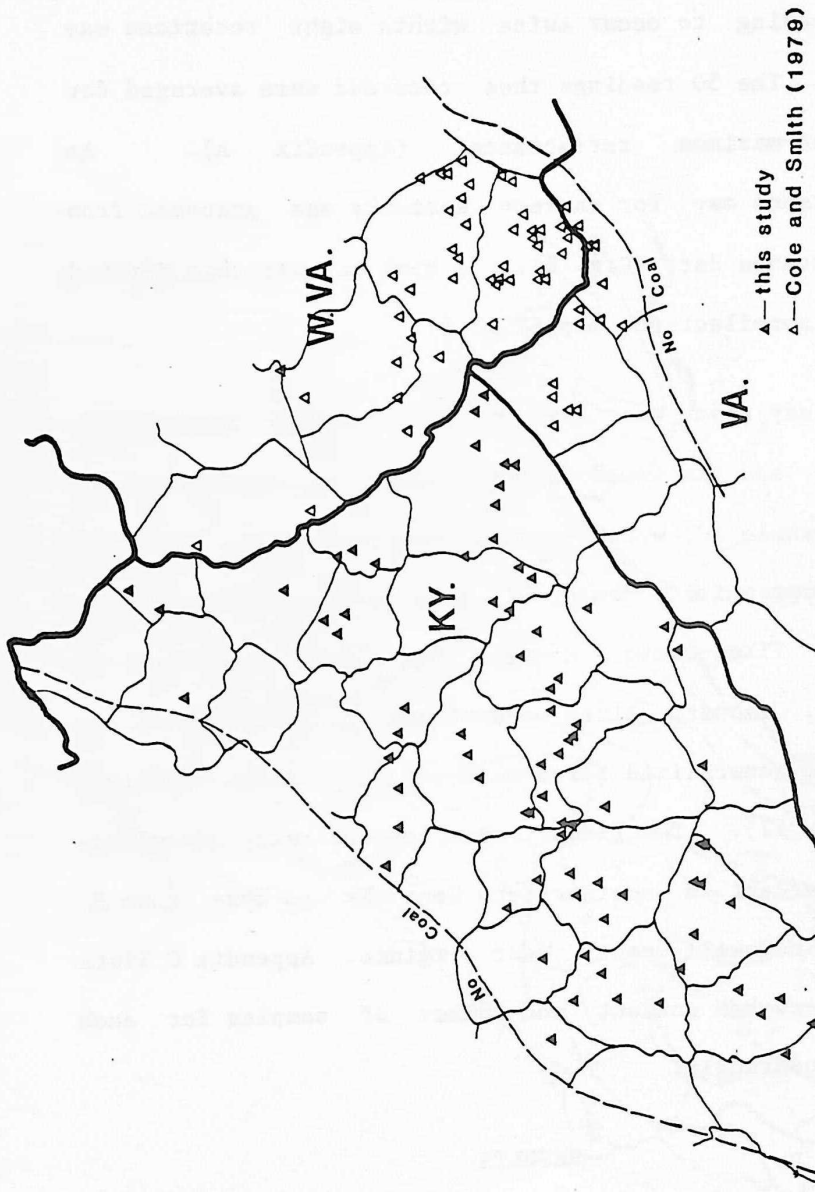


Figure 7. Map showing locations of samples in study area.

highest reading to occur twice within eight rotations was recorded. The 50 readings thus recorded were averaged for the mean-maximum reflectance (Appendix A). An isorefectance map for eastern Kentucky was prepared from the reflectance data (Fig. 8). A rank map was then derived from the isorefectance map (Fig. 9).

The study area was divided into 5-minute quadrangles (Fig. 10) and the fixed-carbon content was determined for each quadrangle for which samples were available. Figure 11 shows the approximate number of samples in each quadrangle. After the fixed-carbon content had been determined by quadrangle, isocarb lines were drawn to construct a map showing the generalized fixed-carbon trend across the study area (Fig. 12). The fixed-carbon content ranges from less than 60 percent in northeastern Kentucky to more than 85 percent in McDowell County, West Virginia. Appendix C lists the fixed-carbon content and number of samples for each 5-minute quadrangle.

RESULTS

The mean-maximum reflectance for eastern Kentucky ranges from 0.559 percent reflectance of the Upper Freeport coal in Boyd County to 1.118 percent reflectance for the Splash Dam coal in Pike County. The maximum reflectance is greater than 1.7 percent in West Virginia (Cole and Smith, 1979) (Fig. 8). The general low- to high-reflectance trend is to

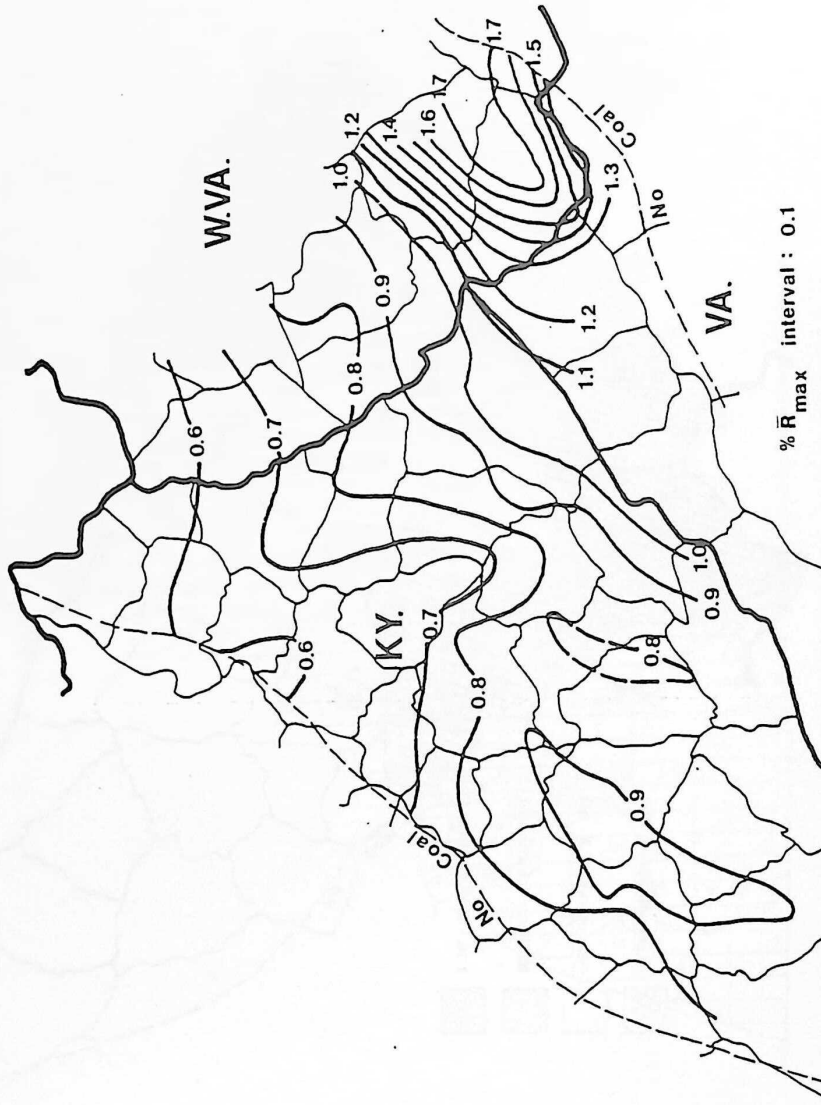


Figure 8. Map showing generalized reflectance trends across Kentucky, Virginia, and West Virginia.

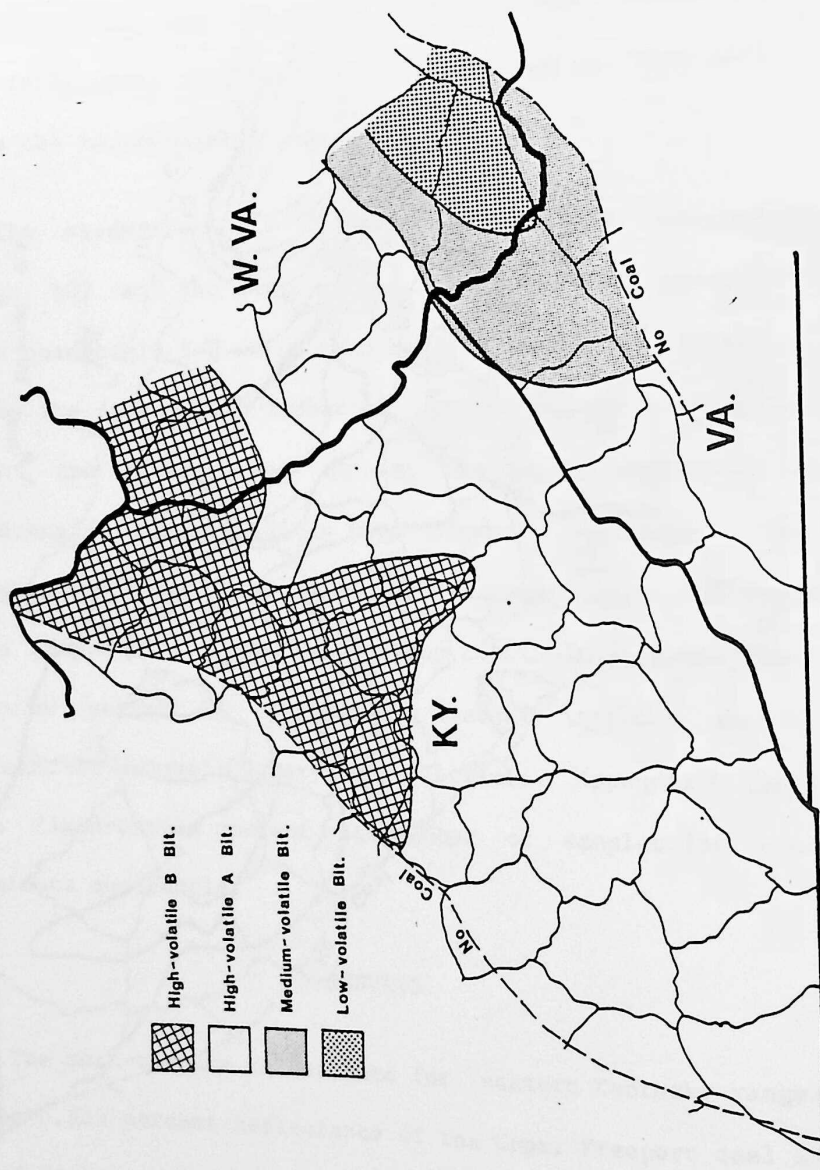


Figure 9. Map showing rank classes and their extent in the study area. Based on average-maximum reflectance.

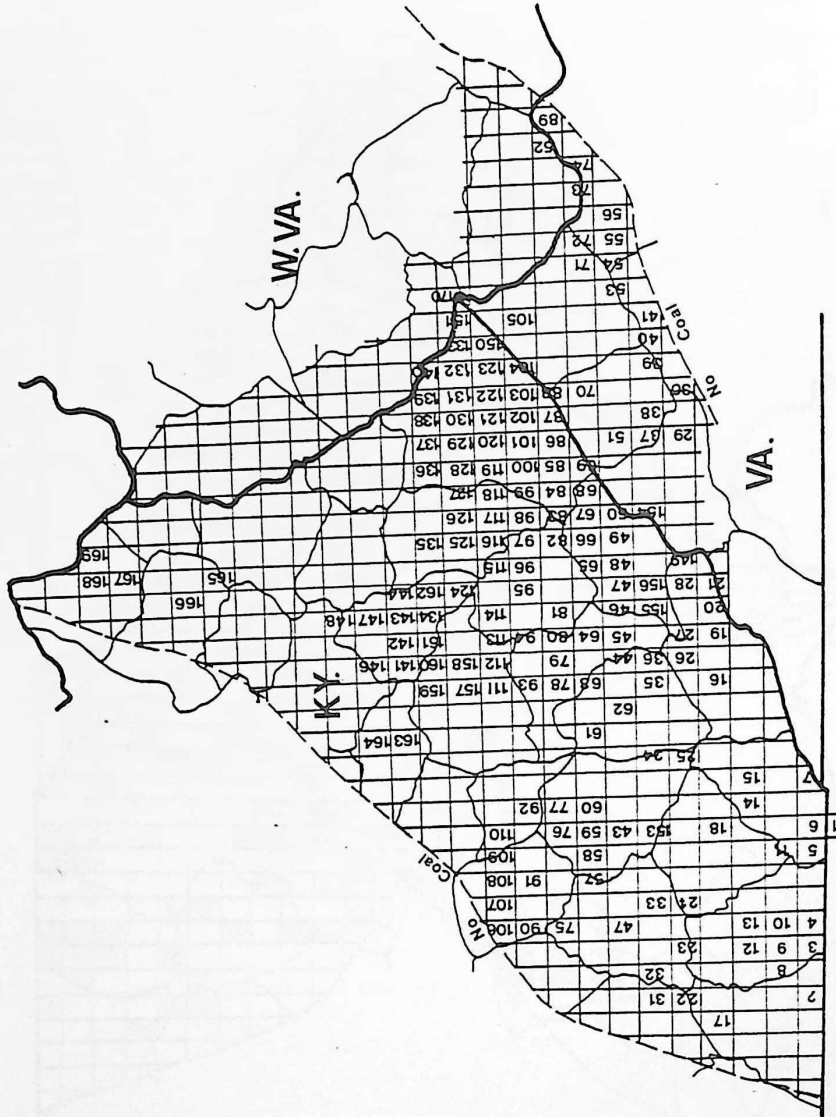


Figure 10. Map showing 5-minute quadrangles used for fixed-carbon determination. See Appendix A for values.

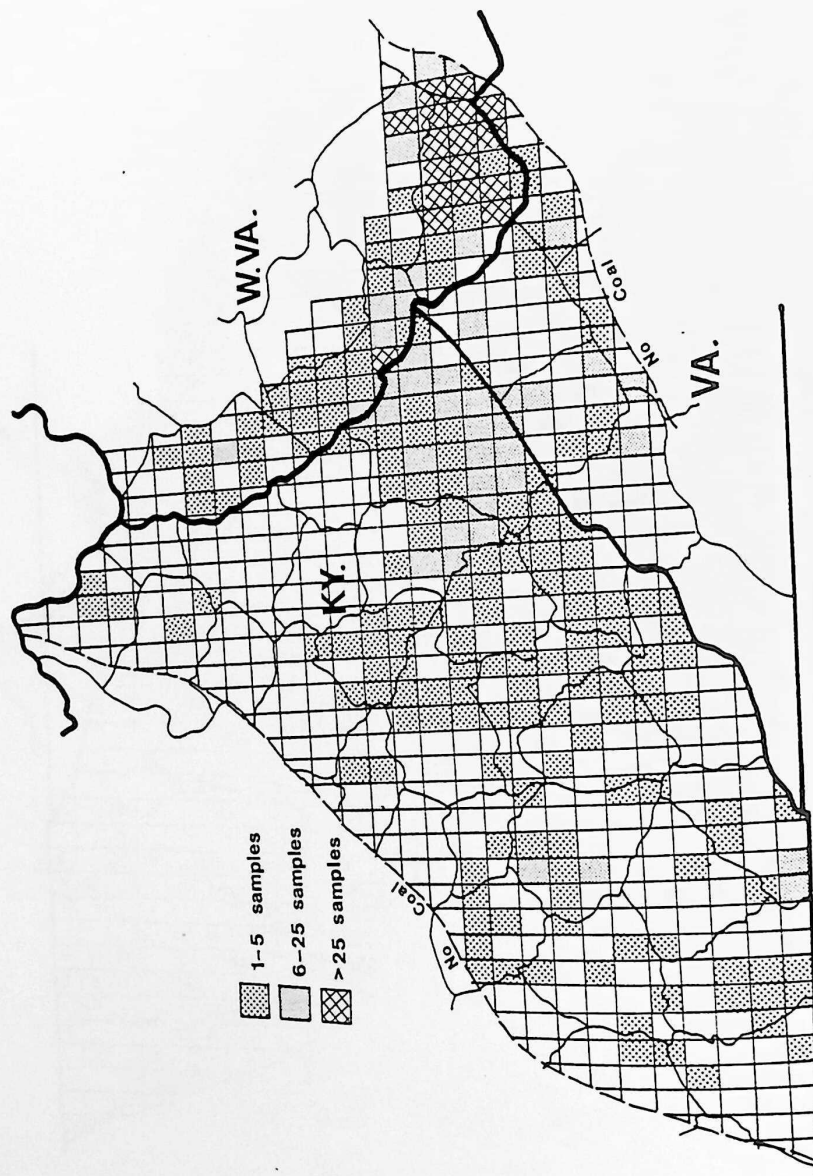


Figure 11. Map showing number of samples in each 5-minute quadrangle used for fixed-carbon determination.

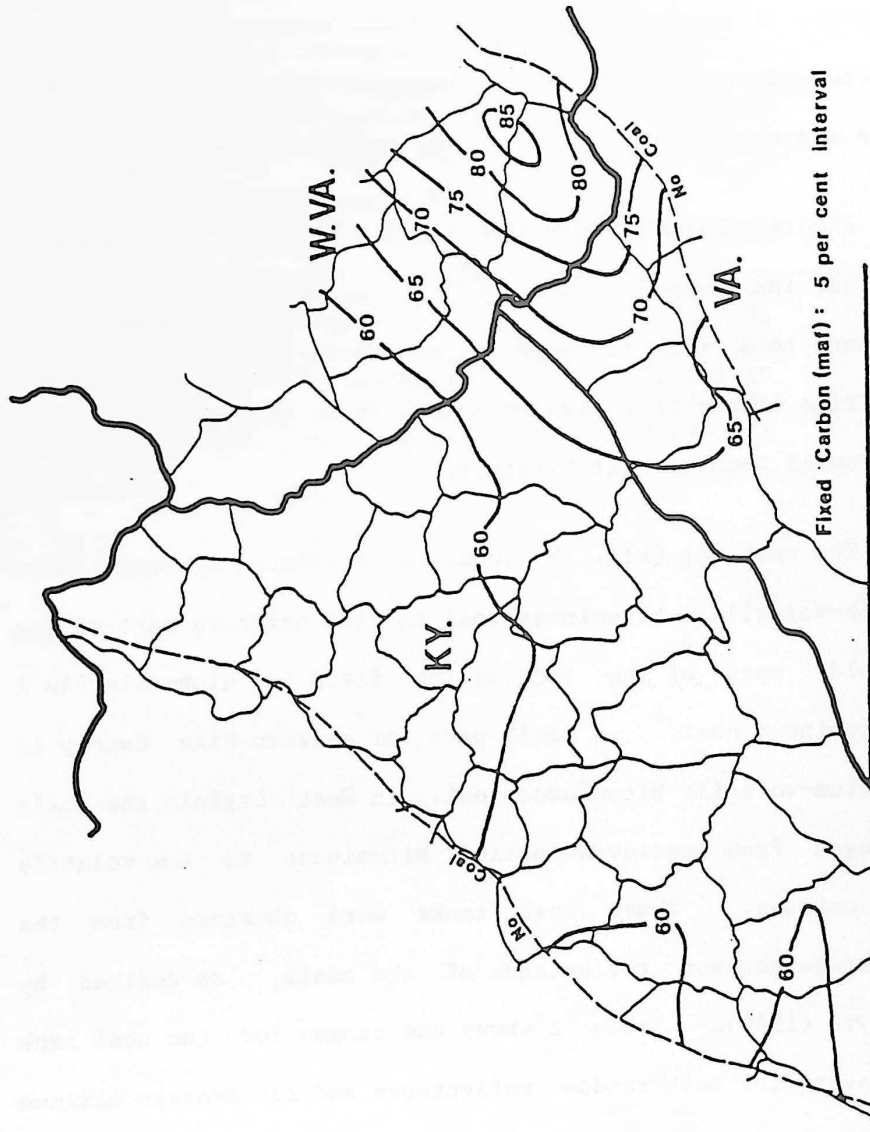


Figure 12. Map showing generalized fixed-carbon content trend across Kentucky, Virginia, and West Virginia.

the southeast. There are three deviations from this trend: a high area across Whitley, Knox, Clay, Laurel, and Owsley Counties; a low area in Perry and Leslie Counties; and a trough striking northwestward from Morgan County to Knott County. The reflectance data show that the reflectance trend culminates in McDowell County, West Virginia, where the average-maximum of 1.7 percent range tends to close.

Figure 12 shows that the isocarbs have the same general trend, and range from a low of 52.4 percent (daf) in Jackson County to a high in eastern Kentucky of 65.6 percent (daf) in Pike County to a high of greater than 85 percent (daf) in McDowell County, West Virginia.

The rank map (Fig. 9) shows eastern Kentucky coals to be high-volatile B bituminous coal in the northern part of the field; most of the rest of the field is high-volatile A bituminous coal. A small part of eastern Pike County is medium-volatile bituminous coal. In West Virginia the coals ranged from medium-volatile bituminous to low-volatile bituminous. These coal ranks were obtained from the average-maximum reflectance of the coals, as defined by Davis (1978). Table 2 shows the ranges for the coal rank classes for both random reflectance and for average-maximum reflectance.

The rank trends derived from the reflectance data agree with those derived from the fixed-carbon data. Both

Table 2.--Rank Classification According to Average Random (from Stach and Others, 1975) and Average Maximum (from Davis, 1978) Reflectances.

AVERAGE RANDOM REFLECTANCE	
RANK	REFLECTANCE
Semi-anthracite	1.92-2.50
Low-volatile bituminous	1.51-1.92
Medium-volatile bituminous	1.12-1.51
High-volatile A bituminous	0.78-1.12
High-volatile B bituminous	0.65-0.78
High-volatile C bituminous	0.48-0.65
AVERAGE MAXIMUM REFLECTANCE	
RANK	REFLECTANCE
Semi-anthracite	2.05-3.00
Low-volatile bituminous	1.50-2.05
Medium-volatile bituminous	1.10-1.50
High-volatile A bituminous	0.71-1.10
High-volatile B bituminous	0.57-0.71
High-volatile C bituminous	0.47-0.71

parameters indicate that rank increases to the southeast in the Eastern Kentucky Coal Field and that coals in eastern Kentucky are high-volatile A and B bituminous. Although the contour interval used for the isocarb map is not as sensitive to changes in rank as the contour interval used for the reflectance map, both maps show the general rank to be high in the southeastern part of the study area.

The increase to the southeast in reflectance, carbon content, and thus rank, may be controlled by the thickening of the Pennsylvanian strata (see Stratigraphy). The high-rank region in West Virginia is probably caused by the increase of the strata thickness resulting from greater subsidence in contrast to the relatively stable platform to the north, and a higher geothermal gradient caused by possible thermal activity related to the Allegheny Orogeny (Arkle, 1971; Hower, 1978; Cole and Smith, 1979). The local deviations in the general reflectance trend in Kentucky may be related to one thermal event (see below). The reflectance high in the southwestern part of the study area is defined by the closure on the 0.9 percent isorefectance contour in Whitley, Laurel, Clay, and Knox Counties. The high is also demonstrated by the deflection to the west of the 0.8 percent and 0.7 percent isorefectance contours. The deflection of this isograde forms the Morgan-Knott County trough. The third deviation in the trend is the small low defined by the closure of the 0.8 percent

isoreflectance contour in Leslie and Perry Counties. If the high defined by the 0.9 percent contour were removed and the other contours redrawn to compensate for its absence, both the Morgan-Knott County trough and the 0.8 percent low would disappear. This would mean that the three isoreflectance deviations are interrelated and the reflectance high in the southwestern part of the study area resulted from a deep-seated heat source that raised the local geothermal gradient.

Another explanation for the 0.9 percent reflectance high is that the majority of the measurements in this area were made from samples of the Manchester coal. The Manchester coal is lower in the stratigraphic section than coals immediately to the east. The higher coal beds to the east had reflectances ranging from 0.82 to 0.86 percent, while the Manchester ranged from 0.90 to 0.94 percent. Reflectance values for the Manchester outside the immediate area of the 0.90 percent closure ranged from 0.71 to 0.94 percent reflectance, but averaged approximately 0.84 percent. Some, if not all, of the rank change for the area in question is attributable to the Manchester coal being lower in the stratigraphic section, and therefore attaining a higher rank (Hilt's Law); thus, there may be no argument for an unusual geothermal gradient. Still, there may be some justification because there is closure, and values for the Manchester outside this closure are significantly lower.

A third explanation for the 0.9 percent reflectance high would be that the area of the high subsided more than surrounding areas, allowing for a deeper burial and consequent higher rank coal.

Because this study is a general investigation of coal rank and reflectance, several coals from various positions in the stratigraphic section were used. The variation in reflectance may be due to anomalies in the coals or their parent materials, or to the relative position of the coals in the section. In other words, if coals lower in the section were sampled in the east, a false reflectance increase in that direction would be indicated. It is true that the reflectance of the vitrinite in a coal is most strongly related to the rank of the coal (Teichmuller and Teichmuller, 1968; Stach and others, 1975; McCartney and Teichmuller, 1972). However, the higher the bitumen content of the vitrinite, the lower the percent reflectance; this is a factor in marine coals and could be a factor elsewhere (Stach and others, 1975).

In Kentucky, the coal bed sampled most in the west was the Manchester. In the east, where the higher reflectivities were attained, coals above the stratigraphic level of the Manchester were mostly sampled. The coal beds sampled in Virginia and West Virginia were stratigraphically lower than the Kentucky beds. This stratigraphic difference

would have some effect on the general trend. If the same stratigraphic level could have been sampled in West Virginia, the reflectance high in McDowell County, West Virginia, would not have been as pronounced. Regardless of stratigraphic influences, the general trend from Kentucky is substantiated by the general trend for coals of a similar stratigraphic level to the north and east in West Virginia. This general trend supports the hypothesis that the coals in the eastern part of the study area attained a higher rank by means of a greater depth of burial within the Appalachian Trough. Hower (1978) determined that the paleogeothermal gradient for McDowell County was 50 to 55°C/kilometer and that the approximate depth of burial was 3 kilometers.

THE GEOTHERMAL GRADIENT

It is beyond the scope of this study to discuss the possible events that might account for the local geothermal gradient of eastern Kentucky, but, with respect to the inferred 0.9 percent reflectance high, it is necessary to at least review some possibilities.

There are several mechanisms for increasing the geothermal gradient such as igneous intrusions, hydrothermal activity, or a concentration of radioactive material in the basement rocks.

The only known igneous intrusion of Permian age in Kentucky is in Elliott County (McFarlan, 1943). There are

no exposures of igneous rocks in the immediate vicinity of the 0.9 percent high, but this does not rule out an intrusion at depth. Hydrothermal perturbations are possible, especially along such structures as the 38th Parallel Lineament (Heyl, 1972). A concentration of radioactive material in the basement rocks is unlikely in light of the geophysical evidence that indicates basaltic rocks at depth (Ammerman and Keller, 1979).

Ammerman and Keller (1979) presented evidence that eastern Kentucky has been tectonically active in the past with deep basement faults and rift zones. Although there is no specific geophysical evidence for Late Paleozoic igneous intrusions in the vicinity of the 0.9 percent reflectance high, these rift zones or basement faults could have served as channels for convection of heat by hydrothermal activity.

For further geophysical information on eastern Kentucky, see Ammerman and Keller (1979), Zeitz and others (1968), Heyl (1972), and Lidiak and Zeitz (1976).

THE INFLUENCE OF STRUCTURE ON REFLECTANCE

In the study area there are three major structural features: the Allegheny Synclinorium, the Irvine-Paint Creek Uplift, and the Eastern Kentucky Syncline. The study area is bordered on the southeast by a fourth prominent feature, the Cumberland Overthrust block (Fig. 13). The Allegheny Synclinorium is a southwest-northeast-trending

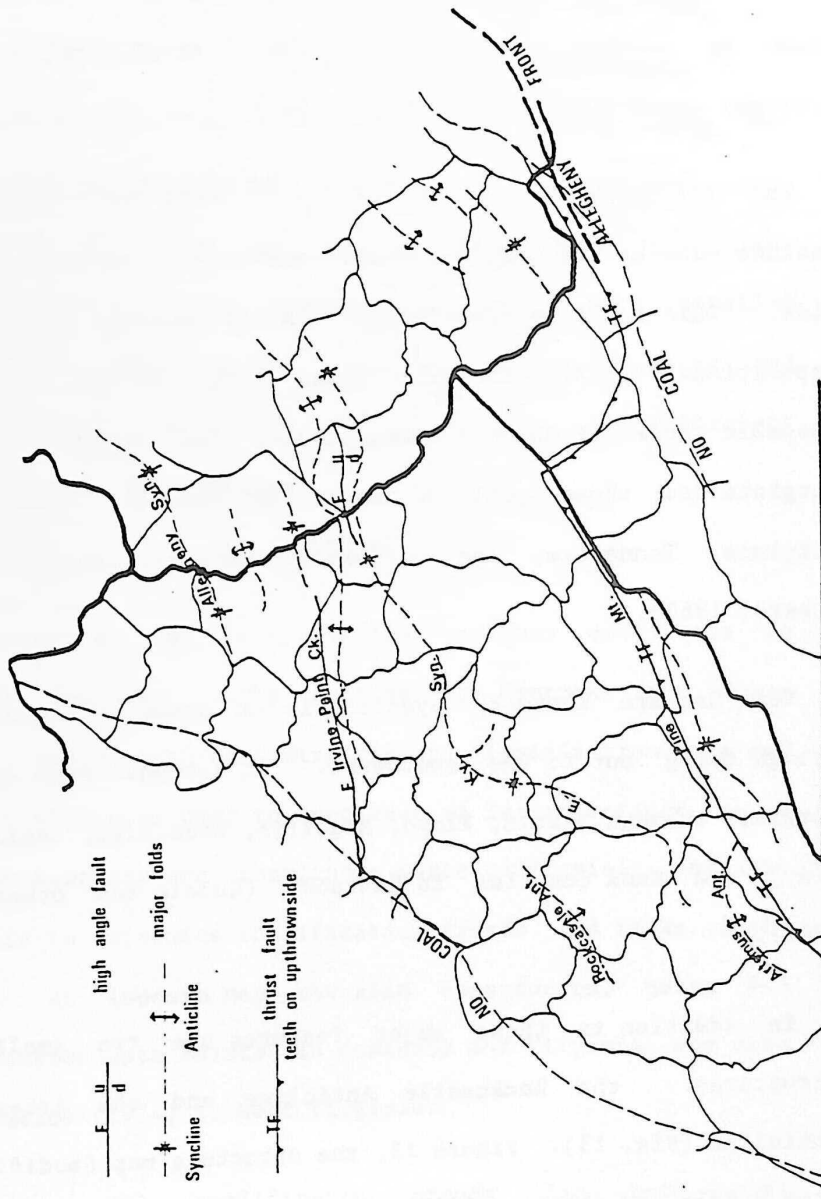


Figure 13. Map showing major structural features in study area.

feature coming out of West Virginia into northeastern Kentucky north of the Irvine-Paint Creek Uplift. Here is where the youngest rocks in the Pennsylvanian section of Kentucky occur (Huddle and others, 1963).

The Irvine-Paint Creek Uplift is a west-east-trending feature made up of multiple faults downthrown on the south side. This fault system divides eastern Kentucky into two depositional provinces. The rocks north of the uplift resemble those of Ohio, Pennsylvania, and northern West Virginia and those south of the uplift resemble rocks of Virginia, Tennessee, and southwestern Virginia (Huddle and others, 1963).

The Eastern Kentucky Syncline is a broad structural trough dying out to the southwest. It extends from West Virginia through Martin, Floyd, Magoffin, Breathitt, Leslie, Clay, and Knox Counties in Kentucky (Huddle and others, 1963).

In addition to these major features are two smaller structures: the Rockcastle Anticline and the Artemus Anticline (Fig. 13). Figure 13, the structure map (modified from Huddle and others, 1963), shows the major structural features in the study area. According to the structure map, there seem to be few relationships between the prominent structural features and the reflectivity of the coals. The general rank trends cross the major structural features with

no apparent deviation, with one exception: the reflectance high in the southwestern part of the study area (Fig. 8). This reflectance high corresponds with a structural high (Rockcastle Anticline). If this anomaly in the reflectance is caused by an igneous intrusion at depth, then this intrusion might also be reflected by a structural high. Verification of this hypothesis awaits a more detailed geophysical investigation, because the data density and stratigraphic verification of this study is not sufficient for an unqualified conclusion.

SUMMARY

Seventy-two coal samples from various coal beds in eastern Kentucky, eight samples in Kentucky from Hower (1978), and data in West Virginia and Virginia from Cole and Smith (1978) were used to construct an isoreflectance map of eastern Kentucky and contiguous parts of Virginia and West Virginia to determine coalification trends and ranks of the coals. An isocarb map was also constructed, using 645 fixed-carbon data points in Kentucky and Virginia and data from Barlow (1974) in West Virginia.

The general coalification trends for both coal reflectance and fixed carbon showed a gradual increase in rank from northwest to southeast in Kentucky and a sharp increase that defines an intense coalification high in West Virginia. The coal ranks based on reflectance in eastern

Kentucky were determined to be high-volatile B bituminous in the north and high-volatile A bituminous in the south. A small area of medium-volatile bituminous coal occurs in extreme eastern Pike County. Three deviations in the general coalification trend as shown by reflectance analyses may be related to a possible deep-seated heat source that caused a rise in the local geothermal gradient.

There is no indication of any structural control on the coalification pattern, although the Rockcastle Anticline might be related to a heat source that may have caused the coalification high in the same locality.

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ACKNOWLEDGMENTS

The author wishes to thank Drs. Harry P. Hoge, Perry B. Wigley, and Charles T. Helfrich of Eastern Kentucky University, who reviewed the manuscript. Mr. Gary A. Cole of the West Virginia Geological and Economic Survey gave guidance and allowed the author to use the West Virginia Geological and Economic Survey's preparation laboratory and reflectance microscope. Dr. James Hower of the University of Kentucky Institute for Mining and Minerals Research also gave guidance.

APPENDIX A

A list of 72 coal samples collected for this study for vitrinite reflectance analyses. Shown are the county and Carter coordinate sections, the name of the coal, and the average-maximum reflectance values.

COUNTY	CARTER COOR.	COAL	AVG.MAX. %R
Carter	5-V-78	Tom Cooper	0.617
Boyd	11-W-81	Princess No. 7	0.564
Lawrence	13-S-82	Peach Orchard	0.780
	10-Q-83	Broas	0.757
Johnson	13-Q-81	Hazard No. 5A	0.730
	24-R-81	Peach Orchard	0.686
	9-Q-80	Van Lear	0.754
Martin	19-P-83	Broas	0.806
	25-Q-84	Peach Orchard	0.818
Wolfe	15-P-71	Beattyville	0.629
	2-O-72	Grassy	0.691
	5-O-74	Whitesburg	0.624
Morgan	23-P-75	Hazard	0.675
Magoffin	2-O-76	Fireclay	0.567
	9-O-77	Fireclay	0.657
Jackson	24-K-67	Manchester	0.813
Owsley	14-L-69	Manchester	0.880
	16-K-70	Jellico	0.893
	14-J-72	Hazard	0.906
	19-J-72	Hazard	0.856
Breathitt	15-K-73	Hazard	0.813
	15-K-73	Haddix	0.922
	19-M-74	Grassy	0.763
	7-M-76	Hazard No. 9	0.819
	7-M-76	Hazard No. 7	0.830
	11-M-75	Skyline	0.785

COUNTY	CARTER COOR.	COAL	AVG.MAX.%R
Floyd	19-L-81	Amburgy	0.751
	11-K-82	U. Elkhorn No. 3	0.944
	6-K-83	U. Elkhorn No. 1	0.956
	10-L-81	U. Elkhorn No. 1	0.866
Knott	4-J-78	Hazard No. 7	0.882
	9-J-78	Hazard No. 7	0.857
	2-K-79	Hazard No. 7	0.720
	19-K-80	U. Elkhorn No. 3	0.804
Pike	12-M-83	U. Elkhorn No. 3	0.825
	8-L-84	L. Elkhorn	0.898
	10-L-85	L. Elkhorn	1.035
	12-L-86	Williamson	0.903
	17-L-88	Clintwood	1.079
	24-M-88	Williamson	0.937
	22-M-89	Alma	1.015
	4-L-90	Splash Dam	1.118
Laurel	17-J-65	Manchester	0.790
	18-I-66	Manchester	0.904
	4-I-67	Manchester	0.897
	3-H-65	Manchester	0.711
	15-G-65	Manchester	0.897
Clay	10-H-69	Manchester	0.916
	20-I-68	Manchester	0.924
	21-J-69	Manchester	0.928
	20-J-70	Manchester	0.988
	16-I-70	Manchester	0.988
Leslie	24-I-73	Fireclay	0.866
Perry	13-J-72	Hazard No. 5A	0.856
	21-K-73	Hazard No. 5A	0.819
	25-K-75	Hazard No. 5A	0.817
	9-J-75	Hazard No. 9	0.811
	19-J-76	Hazard No. 7	0.734
	22-K-77	Hazard No. 8	0.870
Knox	2-F-66	Manchester	0.904
	23-E-69	Manchester	0.825
	21-F-71	Haddix	0.830
	21-F-71	Hazard No. 7	0.906
	24-F-70	Whitesburg	0.756
	24-F-70	U. Elkhorn No. 3	0.805
	10-F-67	Jellico	0.909
McCreary	15-C-63	Manchester	0.881

COUNTY	CARTER COOR.	COAL	AVG. MAX. %R
Whitley	21-D-64	Manchester	0.829
	16-B-64	Manchester	0.858
	7-C-65	Manchester	0.936
	10-D-65	Jellico	0.911
Rockcastle	12-J-63	Lee No. 1	0.760

APPENDIX B

A list of eight vitrinite reflectance values from Hower (1978). The format is the same as for Appendix A.

COUNTY	CARTER. COORD.	COAL	AVG. MAX. %R
Boyd	12-X-82	U. Freeport	0.559
Perry	13-J-76	Hazard No. 7	0.757
	13-J-76	Hazard No. 5A	0.754
Pike	23-L-88	L. Elkhorn	1.000
Letcher	8-I-81	U. Elkhorn No. 3	0.844
	20-G-80	Imboden	1.012
Harlan	4-F-79	Kentucky C	0.911
	25-F-75	Hazard No. 9	0.792

APPENDIX C

A list of the average fixed-carbon values used for the isocarb map (Fig. 9). The "Quad." column refers to Figure 10. The "Samples" column gives the number of individual fixed-carbon values used to compute the average fixed-carbon values shown in the "F. Carbon %" column.

QUAD.	F. CARBON %	SAMPLES	QUAD.	F. CARBON %	SAMPLES
1	64.0	3	41	64.7	3
2	62.3	1	42	52.9	1
3	63.1	3	43	60.6	9
4	62.5	1	44	62.1	3
5	64.0	6	45	58.7	1
6	64.5	10	46	58.2	1
7	60.4	1	47	60.7	1
8	64.6	1	48	61.2	4
9	62.0	1	49	61.7	1
10	64.1	4	50	62.4	2
11	63.8	2	51	65.9	2
12	58.0	2	52	75.9	6
13	57.4	3	53	64.8	2
14	64.4	4	54	65.0	2
15	62.3	3	55	68.1	10
16	61.3	3	56	69.1	2
17	57.9	1	57	60.7	1
18	63.6	1	58	63.0	2
19	63.1	5	59	60.7	2
20	61.7	2	60	60.4	1
21	61.5	4	61	62.9	1
22	60.3	2	62	61.4	1
23	63.1	1	63	59.7	5
24	61.7	2	64	64.5	1
25	66.5	4	65	57.8	3
26	61.1	3	66	59.4	3
27	63.2	1	67	61.4	3
28	62.7	2	68	61.4	3
29	64.5	11	69	61.9	2
30	61.5	20	70	66.5	4
31	61.3	1	71	76.8	1
32	60.6	1	72	71.4	3
33	61.6	1	73	79.6	1
34	63.7	5	74	76.5	1
35	60.9	1	75	59.8	3
36	62.2	1	76	61.3	6
37	67.9	1	77	59.6	2
38	70.5	3	78	60.6	3
39	62.0	6	79	61.3	3
40	65.0	3	80	58.8	1

QUAD.	F. CARBON %	SAMPLES	QUAD.	F. CARBON %	SAMPLES
81	59.4	2	126	61.1	1
82	62.3	3	127	60.0	1
83	62.4	4	128	60.4	5
84	63.3	1	129	60.5	6
85	63.2	10	130	58.8	2
86	64.7	12	131	63.4	4
87	66.6	6	132	64.9	12
88	66.1	6	133	65.2	7
89	77.4	15	134	63.1	2
90	52.4	1	135	60.0	2
91	62.5	1	136	59.7	1
92	60.9	1	137	59.7	4
93	58.4	2	138	61.3	2
94	59.8	1	139	62.0	9
95	55.6	1	140	62.6	13
96	61.1	3	141	57.8	1
97	62.2	5	142	58.1	1
98	62.0	16	143	58.8	1
99	61.5	7	144	60.8	1
100	62.4	17	145	57.8	2
101	61.9	10	146	55.8	2
102	65.3	6	147	59.2	2
103	66.2	7	148	57.4	2
104	68.3	2	149	62.6	2
105	65.9	1	150	65.6	2
106	62.5	1	151	65.3	2
107	65.5	2	152	58.5	3
108	63.9	1	153	63.7	2
109	60.4	1	154	61.4	3
110	62.8	2	155	64.0	3
111	61.2	2	156	59.1	3
112	61.3	1	157	59.7	2
113	57.3	1	158	59.0	3
114	54.2	1	159	54.5	1
115	61.3	4	160	58.0	2
116	61.4	12	161	58.2	3
117	60.5	12	162	57.1	5
118	58.5	1	163	61.7	1
119	60.3	2	164	59.7	1
120	61.9	5	165	61.0	1
121	62.8	4	166	57.6	1
122	65.0	6	167	58.8	3
123	65.4	6	168	58.3	1
124	63.2	3	169	57.6	4
125	61.3	9	170	65.9	3