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PETROGRAPHIC CHARACTERIZATION OF KENTUCKY COALS

Final Report, Part VI: The Nature of Pseudovitrinites in Kentucky Coals

By
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University of Kentucky
Lexington, Kentucky

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PETROGRAPHIC CHARACTERIZATION OF
KENTUCKY COALS
FINAL REPORT: PART VI:

THE NATURE OF PSEUDOVITRINITES
IN KENTUCKY COALS

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ABSTRACT

Overall average pseudovitrinite content for 1055 eastern Kentucky coal samples is nearly 9% while average percentage of pseudovitrinite for 551 western Kentucky coals is approximately 4%. Examination of variation in pseudovitrinite content relative to rank changes shows uniformity in pseudovitrinite percentages within the 4 to 7 V- type interval for eastern Kentucky coals but a gradual increase in pseudovitrinite content for western Kentucky coals over the same rank interval. Coals from both coal fields show similar, distinct increases in pseudovitrinite percentage in the highest V- type categories (V-9 and V-10 for eastern Kentucky coals; V-8 for western Kentucky coals). However, it is suggested here that these supposed increases in pseudovitrinite percentages are not real but rather, indicate distinct increase in the brightness of vitrinite resulting from increased alteration of vitrinite beginning at this stage of coalification and continuing into the higher rank stages. This conclusion is reached when it is found that differences between pseudovitrinite and vitrinite reflectance are least in coals at these high rank intervals of Kentucky and, also, when vitrinite particles are often visually observed having brightness equal to that of pseudovitrinite particles.

More- detailed pseudovitrinite percentage trends are found when data from specific coal beds or zones of each coal field are

analyzed and compared. Coals selected encompass most of the Pennsylvanian coal stratigraphic section and when examined from this perspective, it is found that coals from either coal field having highest pseudovitrinite percentages occur within relative confined stratigraphic intervals rather than being randomly dispersed among coals with lower than average pseudovitrinite contents.

When relating variations in pseudovitrinite percentage to those occurring for other macerals, it is found that pseudovitrinite has no linear relationship to vitrinite, but does have a strong negative correlation to inertinite whether taken as a maceral group or as individual inert submacerals. A positive correlation was presumed for the latter relationship as both macerals groups are related by varying degrees to oxidative processes. A later- discovered very significant inverse relationship between pseudovitrinite and sulfate sulfur possibly suggests that pseudovitrinite was a product of partial or slight oxidative processes and that stronger oxidative events may have altered or destroyed pseudovitrinite in favor of inertinite development. However, this pseudovitrinite/ sulfate sulfur relationship is presently regarded as coincidental as sulfate sulfur formation is thought to be secondary.

Relation of pseudovitrinite to other sulfur forms and total sulfur in general shows no significant trends, although the relatively high pyritic sulfur content in western Kentucky coals,

coupled with relatively low inert percentages suggest the existence of predominantly reducing, or at least non-oxidizing conditions in the Pennsylvanian peat swamps of western Kentucky.

Distinct jumps in the percent difference between pseudovitrinite and vitrinite reflectance (ΔR) in eastern Kentucky coals appear to roughly coincide with reflectance/chemical boundaries dividing the high volatile bituminous rank subcategories. Such abrupt increases may indirectly serve to verify chemical changes occurring in coals during these rank stages as the ΔR increase suggests an increase in pseudovitrinite alteration. Changes in ΔR for western Kentucky coals expose the problems that exist, particularly at higher ranks, when attempting to distinguish pseudovitrinite from vitrinite. Vitrinite particles are often as bright as pseudovitrinite particles at the V-8 interval and, as important identifying features such as slitted structures are usually lacking in western Kentucky pseudovitrinite, distinction between pseudovitrinite and vitrinite becomes subjective.

Initial work involving Vicker's microhardness testing of coals indicates that microhardness values for pseudovitrinite are higher than those for vitrinite within the same sample regardless of coal rank or coal field from which the sample was collected. Also, the degree of difference between pseudovitrinite and vitrinite microhardnesses within the same sample is, on the average, higher in eastern Kentucky coals as opposed to western Kentucky coals.

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INTRODUCTION

During their petrographic studies of Appalachian coals, Thompson and others (1966) found that a certain percentage of the vitrinite maceral group was anomalously poorly- reactive during the coking process. In addition, Benedict and others (1968) observed several microscopic characteristics of the same poorly-reactive material that distinguished it from the reactive variety. These characteristics include: higher reflectance, slitted structures, unusual fracture patterns, remnant cellular structure, and paucity or absence of pyrite inclusions. Consequently, Benedict and others (1968) suggested that the poorly- reactive vitrinite be categorized separately and proposed the term "pseudovitrinite" to represent this new category.

Origin and properties of pseudovitrinite remain uncertain but several workers have provided a better understanding of the nature of pseudovitrinite. Mackowsky, as cited by Smith (1980), mentioned that pseudovitrinite possibly developed as a result of primary oxidation during the biochemical phase of coalification. The relationship of pseudovitrinite to primary oxidative processes was based on controlled oxidation studies by Benedict and Berry (1964) which produced pseudovitrinite microfeatures and showed similar anomalous chemical properties for high pseudovitrinite coals and coals oxidized in the laboratory. However, subsequent results of comparative analyses (for example, from etching tests on coals as initiated by Spackman (1970)) had wide divergence when attempts were made to support optically-

classified pseudovitrinite with physical/ chemical tests.

Smith (1980) indicated the confusion resulting from placement of pseudovitrinite within the vitrinite group, as all other macerals within the vitrinite group are distinguished by differences in source material for each while pseudovitrinite is related to oxidation of similar source material. The latter type of relationship is the basis in the Stopes- Heerlen system for distinguishing maceral groups rather than macerals within a group. Accordingly, Smith (1980) suggested that pseudovitrinite would be more appropriately classified as a separate maceral group as opposed to being a submaceral of the vitrinite group.

Although not all laboratories have accepted this maceral group, this laboratory has found that the microscopic traits distinguishing pseudovitrinite from vitrinite are quite observable in eastern Kentucky (Appalachian) coals and, therefore, uses the term pseudovitrinite in our maceral analyses. In our studies of western Kentucky (Illinois Basin) coals, we find pseudovitrinite more difficult to recognize and occasionally question whether or not pseudovitrinite by its "Appalachian coal" definition actually exists in western Kentucky coals. A major conclusion of Benedict and others (1968) was that pseudovitrinite is present in coals of all ranks and, therefore is considered to be an inherent maceral in all coal seams. However, their study dealt only with Appalachian Basin coals and did not examine the

nature or existence of pseudovitrinite in Illinois Basin or other coals. This study will examine Illinois Basin, specifically western Kentucky, coals, and compare data from this region with classic pseudovitrinite characteristics observed in eastern Kentucky coals. The fact that coals from eastern Kentucky and western Kentucky have considerable overlap in geologic age (primarily middle Pennsylvanian) and in rank range (high volatile C bituminous to high volatile A bituminous) enhances this already good opportunity to study and compare the nature of pseudovitrinite from two separate yet equally- accessible coal fields.

PROCEDURE

Three areas were examined in attempting to understand the nature of pseudovitrinite in eastern Kentucky and western Kentucky coals: percentage of pseudovitrinite occurring in coals of each coal field; differences in reflectance of pseudovitrinite versus that of vitrinite within a coal sample; and, variation in the Vickers' microhardness of pseudovitrinite versus that of vitrinite within a coal sample. Initially, each of the three sections will be examined on a separate basis. Within each section more specific related subcategories of data from the two coal fields will be compared. It is hoped that exposing trends within each category will allow for easier deciphering later of relationships existing among the three major categories.

Percentage of pseudovitrinite within a specific coal sample was obtained by point-counting individual macerals on a polished coal pellet surface. One thousand total point counts were performed on two pellets representing one particular sample. Maceral composition analysis is a routine procedure in our laboratory and as a result, maceral data (and, therefore pseudovitrinite percentages) for more than 1500 Kentucky coals were available. For this study, pseudovitrinite percentage variations were examined in great detail and from several perspectives. For example, pseudovitrinite percentage was initially averaged for all coals sampled within each of the two coal fields. Secondly, seam-by-seam variations in pseudovitrinite percentages were determined and, by selecting a sequence of coal seams which encompass nearly the entire Pennsylvanian coal stratigraphic interval for each study area, potential changes in pseudovitrinite content through geologic time were noted. Lastly, the relationship of pseudovitrinite to other maceral types and to sulfur content was examined. Specifically, pseudovitrinite variation was compared with changes in inertinite percentages owing to the supposition that both maceral types originated by oxidative processes. As sulfur, specifically pyritic sulfur, is generally thought to form under reducing conditions, the idea of observing potential relationships between sulfur content and pseudovitrinite formation is informative.

Greater brightness (and, therefore, higher reflectance) for pseudovitrinite as compared with vitrinite is the most important property used to identify pseudovitrinite and this study accordingly examined this property in great detail. Variation between vitrinite and pseudovitrinite reflectance was calculated for approximately 240 coal samples (about 120 samples from each coal field) and data was compared on an overall coal field basis. Comparison of reflectance variations between vitrinite and pseudovitrinite for eastern Kentucky and western Kentucky coals was then made within the specific rank (V- type) categories found in both coal fields.

Microscopically, pseudovitrinite is often found to exhibit higher relief than vitrinite on a polished pellet surface and as such indicates that it may have greater hardness. With this observation in mind, a final step in comparing the nature of pseudovitrinite in eastern Kentucky and western Kentucky coals involved performing Vickers' microhardness tests on pseudovitrinite and vitrinite. Microhardness is determined by measuring the size of small indentations made by impressing a diamond- shaped cone into a large, polished surface of a maceral particle. Because of the above- mentioned observation of relief differences between the two maceral varieties, it is expected that the Vickers' microhardness values for pseudovitrinite will be greater than those for vitrinite.

In previous coal science applications, Schuyer and others(1956) showed the relationship of Vicker's microhardness to coal rank, and Das (1971) and Das and Hucka (1977) demonstrated that Vicker's microhardness values and variation in the actual physical appearance of the microhardness impression could be used to determine coking properties of a given coal. Honda and Sonada (1956) mention that hardness of a given material is essentially an expression of the plastic, and to a lesser extent, elastic nature of that material. Specifically, a permanent impression with smooth surfaces and edges indicates plastic- ductile coal material, while an impermanent impression would indicate elastic coal material (Nandi and others, 1976). Data obtained in this study is only preliminary and insufficient to compare with specific trends that were established in the above microhardness studies. For the present, the point of interest will be to compare the numerical degree of difference between pseudovitrinite and vitrinite microhardnesses for eastern Kentucky and western Kentucky coals.

PSEUDOVITRINITE CONTENT IN KENTUCKY COALS

Entire Coal Field Analysis

One thousand and fifty- five coal samples from the Eastern Kentucky Coal Field and 551 samples from the Western Kentucky Coal Field have been analyzed for maceral content. This study deals specifically with pseudovitrinite and to lesser extents, for comparative purposes, vitrinite and inertinite maceral contents of the coals. All maceral determinations are made on a dry, mineral- matter- free basis. Complete maceral compositions for all coal seams studied are summarized in Hower and others (1983).

Table 1 presents an overall indication of the percentage of pseudovitrinite occurring in Kentucky coals by comparing the means and ranges of pseudovitrinite content for all samples analyzed from the eastern Kentucky and western Kentucky coal fields. While our lab has found total vitrinite content ("normal" vitrinite plus pseudovitrinite) consistently much higher in western Kentucky coals than in eastern Kentucky coals (average of 83.6 % total vitrinite for the former as opposed to 72.9 % for the latter), Table 1 shows that the overall average of the submaceral pseudovitrinite is much higher in eastern Kentucky coals. Taking into consideration the above averages of total vitrinite content for coals from the two coal fields, the higher

Table 1. Comparison of pseudovitrinite content for all coals studied from the Eastern Kentucky and Western Kentucky Coal Fields.

COAL FIELD	No. of Samples	% Pseudovitrinite (s.d.)	Range
Eastern Kentucky	1055	8.88 (4.88)	0.00- 32.60
Western Kentucky	555	4.10 (3.33)	0.00- 18.82

Table 2. Comparison of mean pseudovitrinite contents of specific V- types for eastern Kentucky versus western Kentucky coals.

V- type	% Pseudovitrinite (s.d.)		No. of Samples	
	E. KY.	W. KY.	E. KY.	W. KY.
4	8.34 (4.04)	2.78 (2.54)	12	129
5	8.74 (5.15)	3.83 (3.04)	74	268
6	8.77 (5.07)	4.88 (3.07)	273	102
7	8.15 (4.43)	6.41 (3.94)	395	44
8	9.36 (4.93)	10.22 (5.27)	212	12
9	11.27 (5.15)	-	68	-
10	12.05 (5.56)	-	21	-

comparative percentage of pseudovitrinite within the total vitrinite group is even more pronounced for eastern Kentucky coals (12.2 % for eastern Kentucky versus 4.9 % for western Kentucky).

Benedict and others (1968) stated that pseudovitrinite is found in Pennsylvanian coals of all ranks. Accordingly, the presence or absence of pseudovitrinite in coals through the entire Kentucky rank sequence is examined and, as coals from the eastern Kentucky and western Kentucky coal fields have considerable rank overlap, direct comparison of data from the two coal fields can be made. Coal rank is determined here by vitrinite maximum reflectance (% R_{max}), with approximate relation between R_{max} and actual rank categories for Kentucky coals as follows: R_{max} of 0.45 to 0.60%: high volatile C bituminous; R_{max} of 0.60 to 0.70 %: high volatile B bituminous; R_{max} of 0.75 to 1.05%: high volatile A bituminous. The range of vitrinite reflectance values for eastern Kentucky coals is roughly 0.45 to 1.05 % and for western Kentucky coals, approximately 0.40 to 0.85%, thereby indicating that the entire high volatile bituminous rank sequence exists in both coal fields. For the sake of more detailed comparison, this study examines variation in pseudovitrinite percentage with rank in terms of V- types representing 0.1% increments in vitrinite reflectance. (For example, a V- type of "4" represents all reflectance values ranging from 0.40 to 0.49%.)

Table 2 shows that pseudovitrinite does occur in coals of all ranks in Kentucky but also that significant differences in pseudovitrinite percentage variation across V- types are found when comparing coals from the two coal fields. For eastern Kentucky coals pseudovitrinite percentage variation within the 4 to 7 V- type interval is very slight and probably only indicates insignificant pellet-to-pellet maceral percentage deviations and/or minor operator-to-operator discrepancies in maceral determinations. In contrast to this uniformity in pseudovitrinite content for eastern Kentucky coals, pseudovitrinite percentages for western Kentucky coals continuously increase by $> 0.1\%$ for each V- type increase within the 4 to 7 V- type interval. The discrepancy within this V- type interval suggests that rank apparently influenced pseudovitrinite content (or at least the recognition of it) in western Kentucky coals but has no relationship to pseudovitrinite percentages in eastern Kentucky coals. This will be discussed later when vitrinite/pseudovitrinite reflectance comparisons are made.

Examination of pseudovitrinite variation from the V-7 to V-8 (and higher) interval finds a notable jump in pseudovitrinite content for coals of both coal fields (Table 2). For eastern Kentucky coals, pseudovitrinite increases by $> 0.1\%$ from the V-7 to V-8 category and then increases by nearly 2% for coals in the V-9 rank range. In western Kentucky, the increase in

pseudovitrinite percentage across the V-7 to V-8 interval is even more pronounced, as average pseudovitrinite content increases from 6.4 to > 10%. Recall that the reflectance boundary between high volatile B bituminous and high volatile A bituminous rank coals is approximately 0.70%. The sharp increase in pseudovitrinite content near and above this boundary possibly indicates some change in the rate of alteration of pseudovitrinite or vitrinite at this stage of coalification. Later discussion of reflectance differences between vitrinite and pseudovitrinite across V- types will deal further with this possibility.

Specific Coal Seam Analysis

Pseudovitrinite percentage trends are further and better discerned when examined and compared on an individual coal bed or zone basis. The specific coal beds or zones studied here were chosen because they represent economically important Kentucky coals; have a reasonable number of sample analyses available for examination and, when examined together, encompass nearly the entire Pennsylvanian stratigraphic section of their respective coal field. Average pseudovitrinite percentages were determined separately for 19 coal beds or zones from eastern Kentucky and 11 coal beds or zones from western Kentucky and data are shown in Table 3. Table 3 clearly illustrates not only consistently higher

Table 3. Average pseudovitrinite percentages for specific coal beds or zones of eastern and western Kentucky. Coals are listed in stratigraphic sequence. Refer to Figure 1 for specific location of each coal within the Pennsylvanian system of each coal field.

EASTERN KENTUCKY			WESTERN KENTUCKY		
Coal Bed	N	% Pvit (s.d.)	Coal Bed	N	% Pvit (s.d.)
Princess # 7	14	12.53 (5.86)	No. 14	16	4.91 (2.93)
Richardson*	51	6.30 (3.27)	No. 13	18	4.54 (2.84)
Broas*	54	7.06 (3.53)	No. 12	25	4.30 (2.62)
Peach Orchard*	171	8.30 (4.05)	No. 11	51	4.37 (3.47)
Hazard*	71	7.56 (4.37)	No. 9	130	3.43 (2.28)
Haddix*	14	11.56 (6.53)	No. 6	24	3.66 (3.58)
Taylor*	39	5.63 (3.43)	Elm Lick*	14	3.60 (1.73)
Fire Clay Rid.	19	7.06 (3.84)	No. 4*	49	3.04 (3.41)
Fire Clay	51	7.35 (3.33)	Dunbar*	34	3.71 (2.85)
Whitesburg*	20	8.42 (3.99)	Foster	16	3.48 (1.85)
Amburgy*	28	10.74 (4.80)	Amos	19	7.40 (3.48)
U. Elkhorn # 3*	53	11.71 (4.92)			
Jellico*	85	11.78 (5.03)			
Lower Elkhorn	18	13.82 (5.38)			
Blue Gem	17	10.93 (4.79)			
Manchester	31	6.83 (3.58)			
Grayhawk	10	8.28 (2.85)			
Barren Fork	11	7.04 (2.64)			
Stearns # 2	21	6.19 (3.16)			

* Coal zone: two or more coal seams
N= Number of samples analyzed

percentages of pseudovitrinite found in individual eastern Kentucky versus western Kentucky coal seams, but also the relatively greater range of pseudovitrinite values in eastern Kentucky coals.

Additionally, coals in Table 3 are listed in descending stratigraphic sequence to enable any general trends in pseudovitrinite variation over geologic time to be noted. As an example, recalling from Table 1 that overall average pseudovitrinite percentage for eastern Kentucky coals is 8.9%, one can observe in Table 3 that a majority of coal beds or zones having higher than average pseudovitrinite contents occur in a cluster covering an interval extending from the Amburgy coal zone to the Blue Gem coal bed. Similar clustering, as opposed to randomness, of higher pseudovitrinite values is also seen for coals in the western Kentucky stratigraphic interval. Again recalling from Table 1 that overall average pseudovitrinite content in western Kentucky coals is 4.1%, one notices in Table 3 that all coal beds within the No. 14(Coiltown) to No. 11(Herrin) stratigraphic interval have higher than average pseudovitrinite percentages.

The above basic stratigraphically-related trends for pseudovitrinite content become more tightly defined when more specific stratigraphic positions of the trend-related coals are pointed out as in Figure 1. Figure 1 shows that the five coals in eastern Kentucky which comprise the "high pseudovitrinite

cluster" are stratigraphically situated within the same formation (lower Breathitt) as well as European series (lower Westphalian B). Similarly, the group of four coal beds from western Kentucky having higher than average pseudovitrinite content are confined to a limited stratigraphic range, with three coals occurring near the base of the Sturgis formation, and the fourth coal representing the top boundary of the Carbondale formation, immediately below the Sturgis. In addition, all four coals occur in the upper Des Moinesian of the Midcontinent series and in the European Westphalian D series. The point to be made is that both of these coal groups having higher than average pseudovitrinite content indeed represent clusters that occur in a definite, limited stratigraphic interval (as opposed to being interspersed among or proximal to coals having relatively lower pseudovitrinite percentages).

It is also interesting to note that coals from one coal field that occur at roughly the same stratigraphic interval as coals from the other coal field usually have correspondingly higher or lower pseudovitrinite percentages. For example, the Princess #7 coal bed of eastern Kentucky occurs within the same stratigraphic interval as the No. 14 to No. 11 coals of western Kentucky and, like its western Kentucky stratigraphic counterparts, has higher than average pseudovitrinite content. The same situation is evident when comparing relative pseudovitrinite content and stratigraphic position of the Amos

coal bed of western Kentucky with the high pseudovitrinite/stratigraphic cluster of eastern Kentucky. (However, it is realized that such inter-coal field comparisons of pseudovitrinite variation in regards to relative stratigraphic positions are mentioned with caution as inter-coal field coal seam correlations are tenuous to begin with.)

Keeping in mind that pseudovitrinite is presumed to be a partial oxidation product (Benedict and others, 1968), an indirect insinuation can be made that the apparent clustering of high (or low) pseudovitrinite percentages in coals at specific intervals of the Pennsylvanian possibly indicates occasional but distinct fluctuations in the oxidation-reduction balance over the time span encompassing the many Pennsylvanian peat swamps of Kentucky. Furthermore, change in this balance often serves as an indicator of subtle environmental and/or climatic change occurring over a given time interval. Predicting environmental/climatic changes is beyond the purpose of this study, and variation of a minor constituent of coal by itself is not suggested here as a primary or decisive indicator of such changes. However, the impression derived from the relatively clear trends shown by pseudovitrinite is that such trends shown by any macerals may serve to be complementary to trends of other environmental indicators.

Relation of pseudovitrinite content to other macerals. In an

attempt to determine why seam-to-seam pseudovitrinite variations occur, pseudovitrinite content is related here to variations in vitrinite percentage, total inertinite content, and percentages of the submacerals of total inertinite. Vitrinite percentage variations are considered because vitrinite and pseudovitrinite are very similar morphologically and both are thought to originate from the same woody material in peat (although possibly, in some instances, from different wood sources). Vitrinite is also used for the purpose of later statistical analyses to lend attention to the problem of closure that potentially plagues correlation coefficient significance. Total inertinite as a whole maceral group is examined as it, like pseudovitrinite, originated by oxidative processes. In addition, Benedict and others (1968) found that coals with abundant pseudovitrinite often also contain larger percentages of inerts. Submacerals of the total inertinite group are examined and compared separately to pseudovitrinite because each submaceral was formed in response to varying rates of oxidation, and the relative position of pseudovitrinite within the context of degree of oxidation is worth considering.

The same coal beds or zones presented in Table 3 were analyzed for average maceral percentages and the data is shown in Table 4. However, coals are listed here in order of increasing pseudovitrinite percentage so that maceral variation within and among the individual coal beds or zones are more readily examined

Table 4. Comparison of maceral contents within and among individual coal seams of (A) Eastern Kentucky and (B) Western Kentucky. Plus (+), minus (-) and equal (=) signs beside maceral percentages indicate relative position of that value to the overall mean value listed at bottom of each maceral category.

A. Eastern Kentucky Coal Field							
COAL SEAM	PVIT	VIT	T. IN.	FUS	SFUS	MAC	MIC
Taylor*	5.63 -	57.36 -	25.35 +	5.99 +	11.79 +	0.51 +	7.06 +
Stearns #2	6.19 -	68.51 +	15.97 -	5.54 +	6.84 +	0.28 -	3.31 -
Richardson*	6.30 -	60.74 -	22.22 +	7.75 +	7.94 +	0.71 +	5.82 +
Manchester	6.83 -	70.97 +	14.63 -	3.78 -	3.85 -	0.25 -	6.75 +
Barren Fork	7.04 -	70.25 +	13.56 -	3.91 -	5.25 -	0.17 -	4.23 -
Broas*	7.06 -	61.17 -	22.21 +	8.19 +	7.44 +	0.64 +	5.94 +
Fire Clay Rid.	7.06 -	63.71 -	20.15 +	5.01 -	7.13 +	0.57 +	7.44 +
Fire Clay	7.35 -	61.76 -	21.69 +	5.79 +	7.22 +	0.68 +	8.00 +
Hazard*	7.68 -	59.64 -	21.62 +	5.93 +	8.98 +	0.60 +	6.11 +
Grayhawk	8.28 -	68.75 +	14.39 -	4.65 -	4.51 -	0.32 -	4.91 -
Peach Orchard*	8.30 -	61.04 -	20.38 +	6.89 +	7.68 +	0.82 +	4.99 -
Whitesburg*	8.42 -	63.84 -	18.42 +	4.52 -	7.98 +	0.54 +	5.38 -
Amburgy*	10.19 +	62.79 -	17.13 -	5.47 +	5.28 -	0.31 -	6.07 +
Blue Gem	10.93 +	68.55 +	11.79 -	4.02 -	1.85 -	0.22 -	5.70 +
Haddix*	11.56 +	60.53 -	18.55 +	5.15 -	7.26 +	0.56 +	5.58 -
U. Elkhorn #3*	11.71 +	61.85 -	17.91 +	5.71 +	4.95 -	0.27 -	6.98 +
Jellico*	11.78 +	64.08 +	14.93 -	5.14 =	4.07 -	0.39 -	5.33 -
Princess # 7	12.53 +	66.51 +	12.72 -	3.87 -	4.83 -	0.45 =	3.56 -
Lower Elkhorn	13.82 +	62.45 -	16.38 -	5.40 =	5.77 -	0.23 -	4.98 -
MEAN	8.88	63.97	17.89	5.40	6.35	0.45	5.69

Table 4., continued

B. Western Kentucky Coal Field							
COAL SEAM	PVIT	VIT	T. IN.	FUS	SFUS	MAC	MIC
No. 4*	3.04 -	76.80 -	14.86 +	7.32 +	4.06 +	0.21 =	3.27 +
No. 9	3.43 -	80.69 +	12.31 +	5.37 +	4.05 +	0.26 +	2.63 -
Foster	3.48 -	76.07 -	13.55 +	5.18 +	2.99 -	0.26 +	5.12 +
Elm Lick*	3.60 -	79.06 -	11.22 +	4.66 -	3.09 -	0.16 -	3.31 +
No. 6	3.66 -	78.22 -	11.10 -	5.88 +	3.36 +	0.16 -	1.70 -
Dunbar *	3.71 -	75.78 -	13.19 +	6.44 +	3.37 +	0.19 -	3.19 +
No. 12	4.30 +	83.72 +	8.85 -	3.94 -	3.25 +	0.26 +	1.40 -
No. 11	4.37 +	81.24 +	9.64 -	4.50 -	2.49 -	0.26 +	2.39 -
No. 13	4.54 +	82.07 +	8.81 -	3.67 -	3.04 -	0.32 +	1.78 -
No. 14	4.91 +	79.52 +	10.68 -	4.68 -	3.80 +	0.18 -	2.02 -
Amos	7.40 +	78.42 -	8.51 -	2.79 -	1.43 -	0.10 -	4.19 +
MEAN	4.22	79.23	11.16	4.95	3.18	0.21	2.82

* = Coal zone - two or more coal seams represented

PVIT- Pseudovitrinite VIT- Vitrinite T. IN.- Total Inertinites F- Fusinite

SFUS- Semifusinite MAC- Macrinite MIC- Micrinite

from the perspective of pseudovitrinite variation. Qualitative comparison of maceral variations is built into Table 4 by usage of mathematic symbols to indicate if a specific maceral value is higher (+), lower (-) or equal (=) to the overall mean percentage calculated for that maceral. To quantify the general trends observed in Table 4, correlation matrices showing correlation coefficients for all maceral pairings of eastern Kentucky and western Kentucky coal beds or zones are displayed in Table 5.

For coal seams of eastern Kentucky, Table 4 shows vitrinite values having a weak overall positive correlation with pseudovitrinite, but no clear correlation where pseudovitrinite is higher than average. Consequently, the correlation coefficient (r) for vitrinite/ pseudovitrinite shown in Table 5 is nearly zero and thereby indicates that virtually no linear relationship exists between the two macerals in terms of maceral variation. To show this relationship more clearly, comparing mean vitrinite contents for coals with lower than average pseudovitrinite percentages to those with higher than average pseudovitrinite percentages shows vitrinite percentages of 64.0 and 63.8, respectively. This vitrinite/ pseudovitrinite relationship, or rather, nonrelationship is purposely emphasized to suggest that, because of this poor association, problems of closure involving vitrinite and inertinite should not carry over to statistical variations involving pseudovitrinite and inertinite.

Table 5. Correlation coefficients (r values) for maceral pairings from (A) eastern Kentucky and (B) western Kentucky coal beds or zones listed in Table 4. R- values listed at the 5% and 1% confidence limits are from Arkin and Colton (1963, p. 155).

A. Eastern Kentucky							
	PVIT	VIT	T. IN.	FUS	SFUS	MAC	MIC
Pseudovitrinite	1.0000						
Vitrinite	-0.0032	1.0000					
Total Inerts	-0.5011	-0.8487	1.0000				
Fusinite	-0.3062	-0.7006	0.7635	1.000			
Semifusinite	-0.5180	-0.7396	0.8898	0.5590	1.0000		
Macrinite	-0.3342	-0.6742	0.7480	0.6602	0.6495	1.0000	
Micrinite	-0.2349	-0.4471	0.5627	0.2185	0.2481	0.2921	1.0000

D.F.	Confidence Limit	
	5%	1%
17	0.456	0.575

B. Western Kentucky							
	PVIT	VIT	T. IN.	FUS	SFUS	MAC	MIC
Pseudovitrinite	1.000						
Vitrinite	0.1881	1.0000					
Total Inerts	-0.7091	-0.7416	1.000				
Fusinite	-0.7809	-0.5922	0.8981	1.0000			
Semifusinite	-0.7852	-0.0509	0.6114	0.7175	1.0000		
Macrinite	-0.4373	0.4738	-0.0056	0.0033	0.3233	1.0000	
Micrinite	0.0990	-0.7086	0.4509	0.0749	-0.3445	-0.2822	1.0000

D.F.	Confidence Limit	
	5%	1%
9	0.602	0.735

Degrees of freedom (D.F.) = $N - n_r$, where N equals the number of groups of observations (for example, for E. KY., $N = 19$) and n_r equals the number of variables (in all cases, 2).

In regards to total inertinite, Table 4 shows negative correlation between pseudovitrinite and total inertinite in 13 of 19 eastern Kentucky coal beds or zones. This relationship was not expected in light of the work by Benedict and others (1968) which suggested a positive relationship between these two variables. The certainty of the negative relationship between pseudovitrinite and total inertinite in eastern Kentucky coals cannot be doubted as the corresponding r value in Table 5 indicates very strong statistical correlation. This negative relationship is further substantiated in that it is also found occurring between pseudovitrinite and any of the four individual inertinite submacerals. Table 4 shows 11 of 19 coals with negative pseudovitrinite/ fusinite and pseudovitrinite/ micrinite relationships, 13 of 19 with a negative pseudovitrinite/ macrinite correlation and 15 of 19 having a negative pseudovitrinite/ semifusinite relationship. Corresponding r values in Table 5 agree with and statistically clarify the qualitative relationships observed in Table 4.

Important to this study is the relative degree of negative correlation between pseudovitrinite and the individual inertinite macerals. Table 5 shows relatively high r values for each pseudovitrinite/ inertinite submaceral pairing, although only the pseudovitrinite/ semifusinite r value is significant at the 95% confidence level. The general implication of pseudovitrinite/ inertinite correlations for eastern Kentucky coals is that

pseudovitrinite formation is somehow adversely affected by oxidative processes (or the degree or extent of these processes) responsible for the formation of the inert macerals and, in particular, oxidative processes associated with semifusinite development.

Comparing the above maceral relationships for eastern Kentucky coals with those for western Kentucky coals, Table 4 shows an apparently strong positive pseudovitrinite/ vitrinite correlation that was not observed in eastern Kentucky coals. Nine of the 11 coal beds or zones show this positive relationship, and comparison of mean vitrinite percentage of coals with lower than average pseudovitrinite percentage to those with higher than average pseudovitrinite values gives figures of 77.8 and 81.0%, respectively. The corresponding r value in Table 5 quantifies this positive correlation although the calculated value is not statistically significant at the given confidence limits. Nonetheless, perhaps any hint of a positive correlation of pseudovitrinite with the most dominant maceral in western Kentucky coals, vitrinite, might indicate that the following correlations between pseudovitrinite and inertinite might be susceptible to closure problems that affect similar comparative analyses involving vitrinite and inertinite. Accordingly, one suspects a possible problem related to closure when comparing the relationship of pseudovitrinite to total inertinite versus that

of vitrinite to total inertinite in Tables 4 and 5 and finding very similar strongly negative correlations for both pairings. However, upon further comparison of pseudovitrinite and vitrinite relationships to the specific submacerals of inertinite, one finds several differences between the two pairings that merit consideration even within the limitations imposed by a possible closure situation.

Table 4 shows pseudovitrinite content negatively related to all inert submacerals, and fusinite in particular. Corresponding r values in Table 5 show the pseudovitrinite/ fusinite relationship being significant at the 99% confidence level but also show an equally strong pseudovitrinite/ semifusinite correlation. Additionally, despite 8 out of 11 coal seams giving the impression of a negative correlation between pseudovitrinite and micrinite in Table 4, the related r value indicates no significant correlation at all. In contrast, the strongest correlation among vitrinite/ inertinite pairings is the vitrinite/ micrinite comparison, in which 10 of 11 coals show negative correlation and the corresponding r value supporting the qualitative observation with a statistically significant figure at the 95% confidence level. Also, the vitrinite/ fusinite r value is nearly significant at the same confidence level. However, in great contrast to the very significant pseudovitrinite/ semifusinite correlation, vitrinite and semifusinite show virtually no qualitative or statistical

relationship to each other. It is hoped that the very significant difference found when comparing the vitrinite- versus- pseudovitrinite relationship to the inert macerals suggest little effect of vitrinite related closure on pseudovitrinite/ inertinite correlations and hence, that consideration of the latter relationships be allowable.

In summary, pseudovitrinite/ inert maceral relationships found among western Kentucky coals agree, in general, with trends established for these relationships from analyses of eastern Kentucky coals. The primary trend established is that average pseudovitrinite percentage variations observed in coal seam-to-seam analyses are inversely related to increase or decrease in total inertinite content. Such a trend is initially surprising as some degree of positive correlation was expected owing to the supposed origin of these macerals being related by varying degrees to oxidation. This negative relationship is further perplexing when relating pseudovitrinite to the inert submacerals which individually owe their origin to the varying degrees of oxidation. Pseudovitrinite shows similar significant or very significant negative correlation with fusinite and semifusinite, usually the products of rapid, high temperature and slower, low temperature oxidation, respectively. This observation at first glance might suggest that pseudovitrinite formation is negatively affected by oxidation and, therefore, is not really a product of oxidative processes. In actuality, the above relationship

probably only indicates that pseudovitrinite formation is inversely affected by the higher degrees of oxidation related to inertinite formation, and not necessarily by lesser (partial) degrees of oxidation. The fact that pseudovitrinite variation is statistically unrelated to vitrinite percentage deviations indirectly supports the necessity of some degree of oxidation for pseudovitrinite formation, as vitrinite precursors supposedly would remain relatively unaltered in non-oxidizing peat swamp environments. Lower pseudovitrinite percentages and much higher vitrinite percentages in western Kentucky versus eastern Kentucky coals and, as will be shown later, the presence of higher sulfur content, specifically, pyritic sulfur, in western Kentucky coals supports the above contention of a pseudovitrinite/oxidation relationship.

Hypothetical scenarios involving pseudovitrinite/inertinite variations can be constructed that demonstrate possible effects of changing Eh on formation of these macerals. For example, oxidizing conditions may have existed which were initially favorable towards the formation of inertinite or pseudovitrinite, but if such conditions were to become too extreme (in terms of time) or too harsh (in terms of temperature), material formed during early stages of oxidation (such as pseudovitrinite) supposedly could not keep pace with formation of more highly oxidized products. Conversely, a peat body subjected to relatively lower or shorter intervals of aeration would develop

partially oxidized material that would otherwise have been preserved as vitrinite. If oxidation remained relatively brief or mild, further alteration of pseudovitrinite into the inert products would be less likely to occur and, therefore, greater amounts of partially oxidized material such as pseudovitrinite would remain available for preservation. (As a side note, however, total inertinite percentages are always greater than pseudovitrinite percentages (see Table 4), thus suggesting that subjection of peat to primarily slight oxidizing conditions does not guarantee a final product of pseudovitrinite. The odds of repeated occurrence of oxidative events seem to be great. Hence, inertinites could form as alteration products of pseudovitrinite even under slightly oxidizing conditions if the effects of such conditions became cumulative. At the other extreme, a peat fire caused by a bolt of lightning rapidly fusinitizes a large, relatively dry surface of the peat body on which, up to the very moment of disaster, large portions of this surface were only partially oxidizing into what would have been pseudovitrinite!)

Relationship of pseudovitrinite to sulfur content. An important piece of evidence used by Benedict and others (1968) to support formation of pseudovitrinite by partial oxidation is the paucity or absence of pyrite inclusions in pseudovitrinite particles, even if pyrite happened to occur abundantly in vitrinite particles of the same coal sample. Iron sulfides are considered to be a product formed in a reducing environment and

hence, their absence in pseudovitrinite would suggest non-reducing conditions. Additionally, Clark and others (in review) examined the relationship of organic sulfur to pseudovitrinite and vitrinite particles in Illinois Basin coals. Their results showed higher organic sulfur levels in vitrinite than in pseudovitrinite. This study does not attempt to establish such detailed particle- to- particle sulfur/ maceral relationships, but rather examines the make up and percent of sulfur content in entire coal samples and compares seam- by- seam variation in sulfur with pseudovitrinite variation just presented for the same coals. Table 6 compares pseudovitrinite content and sulfur content applying the same format used for maceral comparisons in Table 4. Table 7 provides the statistical quantification of the general trends shown in Table 6 by cross- correlating pseudovitrinite, total sulfur and forms of sulfur.

Table 6 shows no clear overall relationship between pseudovitrinite and total sulfur in eastern Kentucky coals, but coal beds or zones with higher than average pseudovitrinite contents usually show lower total sulfur values. Probably because of this latter relationship, the corresponding r value in Table 7 indicates negative correlation between pseudovitrinite and total sulfur that is high although not at the listed confidence levels. The percentages of sulfur forms comprising total sulfur (Table 6) show no clear relationship between either pyritic sulfur and pseudovitrinite or organic sulfur and pseudovitrinite. R values

Table 6. Comparison of pseudovitrinite content and sulfur content for (A.) eastern Kentucky and (B.) western Kentucky coal beds or zones (*). Sulfur form values represent percentage of the form making up the associated total sulfur value.

A. EASTERN KENTUCKY					
COAL BED	% PVIT	% TOTAL SULFUR	FORMS OF SULFUR		
			PYR/TOTS	SULF/TOTS	ORG/TOTS
Taylor*	5.63 -	3.38 +	49.2 +	2.8 +	48.0 -
Stearns # 2	6.19 -	2.90 +	37.0 -	3.0 +	60.0 -
Richardson*	6.30 -	1.30 -	27.1 -	2.6 +	70.3 +
Manchester	6.83 -	1.53 -	32.0 -	3.1 +	67.0 +
Barren Fork	7.04 -	1.94 +	30.0 -	3.3 +	66.7 +
Broas*	7.06 -	1.96 +	35.9 -	2.2 +	62.1 +
Fire Clay Rider	7.06 -	1.57 -	41.0 +	2.1 =	57.0 -
Fire Clay	7.35 -	1.25 -	29.0 -	1.9 -	69.0 +
Hazard*	7.68 -	1.73 -	38.0 +	2.1 =	60.0 -
Grayhawk	8.28 -	1.24 -	37.9 +	2.4 +	59.7 -
Peach Orchard*	8.30 -	1.54 -	34.0 -	2.9 +	63.0 +
Whitesburg*	8.42 -	2.55 +	51.8 +	1.2 -	47.0 -
Amburgy*	10.19 +	2.01 +	44.0 +	1.2 -	54.8 -
Blue Gem	10.93 +	1.52 -	33.1 -	1.7 -	65.2 +
Haddix*	11.56 +	1.03 -	26.0 -	1.2 -	72.8 +
U. Elkhorn # 3	11.71 +	1.77 -	42.2 +	1.7 -	56.2 -
Jellico*	11.78 +	1.65 -	43.4 +	1.6 -	55.0 -
Princess # 7	12.53 +	2.29 +	47.5 +	1.7 -	50.7 -
Lower Elkhorn	13.82 +	0.86 -	29.2 -	1.1 -	69.8 +
MEAN	8.88	1.79	37.3	2.1	60.8

Table 6, continued

B. WESTERN KENTUCKY

COAL BED	% PVIT	% TOTAL SULFUR	PYR/TOTS	FORMS OF SULFUR	
				SULF/TOTS	ORG/TOTS
No. 4*	3.04 -	3.47 -	51.1 +	3.8 +	45.2 -
No. 9	3.43 -	4.19 +	45.7 -	3.5 +	50.8 +
Foster	2.69 -	2.69 -	44.4 -	2.9 -	52.8 +
Elm Lick*	3.60 -	2.65 -	44.0 -	2.8 -	53.2 +
No. 6	3.66 -	3.61 +	54.3 +	5.6 +	40.1 -
Dunbar*	3.71 -	3.79 +	—	—	—
No. 12	4.30 +	3.82 +	50.6 +	1.9 -	47.5 -
No. 11	4.37 +	4.53 +	48.3 -	2.2 -	49.5 +
No. 13	4.54 +	4.26 +	47.2 -	3.5 +	48.9 +
No. 14	4.91 +	4.36 +	52.6 +	3.2 -	43.8 -
Amos	7.40 +	1.30 -	—	—	—
MEAN	4.22	3.52	48.8	3.3	48.0

PYR= Pyritic sulfur; SULF= Sulfate sulfur; ORG= Organic sulfur

Table 7. Correlation coefficients (r values) for pseudovitrinite and sulfur pairings for (A) eastern Kentucky and (B) western Kentucky coal beds or zones listed in Table 6. R- values listed at the 5% and 1% confidence limits are from Arkin and Colton (1963, p. 155).

A. Eastern Kentucky

	PVIT	TOTS	PYR	SULF	ORG
Pseudovitrinite	1.0000				
Total Sulfur	-0.3906	1.000			
Pyritic Sulfur	0.0363	0.7072	1.0000		
Sulfate Sulfur	-0.7555	0.2817	-0.2058	1.0000	
Organic Sulfur	0.0177	-0.7424	-0.9957	0.1363	1.0000
	<u>D.F.</u>	<u>Confidence Limits</u>			
		<u>5%</u>	<u>1%</u>		
	17	0.456	0.575		

B. Western Kentucky

	PVIT	TOTS	PYR	SULF	ORG
Pseudovitrinite	1.0000				
Total Sulfur	-0.1225	1.000			
Pyritic Sulfur	0.2639	0.4115	1.0000		
Sulfate Sulfur	-0.3467	-0.0534	0.4571	1.0000	
Organic Sulfur	-0.1668	-0.3555	-0.9718	-0.6422	1.0000
	<u>D.F.</u>	<u>Confidence Limits</u>			
		<u>5%</u>	<u>1%</u>		
For Pvit/ Tots:	9	0.602	0.735		
All other pairings :	7	0.666	0.798		

Degrees of freedom (D.F.) = $N - n_T$, where N equals the number of groups of observations (for example, for E. KY., N= 19) and n_T equals the number of variables (in all cases, 2).

for both pairings further emphasize the non-relationship of either sulfur form to pseudovitrinite.

In contrast to the lack of any relationship of pyritic or organic sulfur forms to pseudovitrinite is the strong negative correlation found between sulfate sulfur and pseudovitrinite. Table 6 shows 10 of the 12 coal beds or zones with lower than average pseudovitrinite percentage having related sulfate sulfur percentages equal to or greater than the overall sulfate sulfur average. All seven coal beds or zones with higher than average pseudovitrinite content have correspondingly lower than average sulfate sulfur values. The r values in Table 7 pertaining to the pseudovitrinite/ sulfate sulfur pairing is -0.76 and easily represents a very significant value at the 99% confidence level. This pseudovitrinite/ sulfate sulfur relationship could be helpful in clarifying pseudovitrinite/ inert maceral trends and oxidation rates related to these trends, but there is a serious problem concerning the validity of sulfate sulfur percentages when used in the context of original peat swamp conditions.

Coal seams and related samples exposed to air undergo relatively rapid weathering and it is known that under such conditions, sulfate sulfur can increase rapidly as pyrite breaks down (oxidizes) into ferric and ferrous sulfates. Consequently, sulfate sulfur values determined in laboratories can be too high and may actually only indicate the relative degrees to which coal samples have been weathered. Therefore, until more detailed

analysis is performed in regards to sulfate sulfur percentages and their relationship to pseudovitrinite content, the presently shown relationship must be regarded as coincidental.

Proceeding to the western Kentucky portion of Tables 6 and 7, comparison of pseudovitrinite and total sulfur indicates a predominant positive correlation between the two variables in Table 6. This correlation, as shown in Table 7, did not prove to be significant. Sufficient sulfur form data was unavailable for two coal beds but correlations are nonetheless attempted using data from the remaining nine coal coal beds or zones. Table 6 shows pyritic sulfur and organic sulfur forms having no clear relationship to pseudovitrinite. Corresponding r values in Table 7 verify the lack of any clear correlations, although the pseudovitrinite/ pyritic sulfur pairing may have a slightly positive correlation. An inverse, though statistically insignificant relationship between pseudovitrinite and sulfate sulfur is observed in Table 6 for six of the nine coals, but the previously discussed problem with this relationship also holds for this case. Overall, no trends appear certain when comparing pseudovitrinite to sulfur but an attempt is made to find indirect trends by comparing western Kentucky sulfur data to that determined for eastern Kentucky coals.

The obvious difference in sulfur content between the coal fields is that mean total sulfur percentage is nearly twice as high in western Kentucky coals. The predominant form of sulfur

comprising the total sulfur in eastern Kentucky is organic sulfur whereas pyritic sulfur is the major sulfur form in western Kentucky coals. Pyritic sulfur is generally an indicator of reducing environmental conditions and, therefore, one might assume that pseudovitrinite content is lower in western Kentucky coals because of reducing conditions as indicated by high pyritic sulfur percentages. However, as Benedict and others (1968) reported on Appalachian coals and this study showed in the eastern Kentucky portions of Tables 6 and 7, pyrite content can be relatively abundant in a coal yet have no apparent influence on pseudovitrinite percentage variation. However, those pseudovitrinite/ pyritic sulfur relationships, like the recognition and definition of pseudovitrinite, are based on studies of Appalachian coals, and hence, a point is again reached where western Kentucky data must be closely examined and compared to the "classic" data accumulated in the former coal basin. The average pyritic sulfur percentages comprising total sulfur in western Kentucky and eastern Kentucky coals are 48.8 and 37.3%, respectively. The 11% difference between the two in itself appears significant, but perhaps a more compelling comparison is revealed when the pyritic sulfur percentages are translated into actual numerical percentages comprising coals of their respective coal field. Average pyritic sulfur content in western Kentucky coals is 1.72%, while in eastern Kentucky coals it is 0.67%. These figures reveal that, while total sulfur in western Kentucky

coals is already shown to be nearly twice as high as that in eastern Kentucky coals, pyritic sulfur in western Kentucky coals is more than two and one-half times greater than pyrite occurring in eastern Kentucky coals. Additionally, the 1.72% figure for western Kentucky pyritic sulfur almost equals the 1.79% figure representing the entire average sulfur content for eastern Kentucky coals. Such significantly different total sulfur and pyritic sulfur values provide evidence for the original assumption that reducing conditions are responsible for only a relatively small amount of pseudovitrinite in western Kentucky coals. Other information aside from pyritic sulfur points to the existence of predominantly reducing, or at least, non-oxidative conditions in Pennsylvanian peat swamps of western Kentucky. Examination of maceral percentages for coals of each coal field yields some evidence. For example, the great disparity in vitrinite percentage between the two coal fields was already discussed but is repeated for the present argument: average vitrinite content of western Kentucky coals is more than 15% higher than that of eastern Kentucky coals. Higher vitrinite content in a coal supposedly indicates relatively fewer disturbances or alterations by, for example, oxidative processes, of peat material. Additionally, the fact that total inertinite percentages in eastern Kentucky coals average nearly 8% higher than related values for western Kentucky coals is by itself a

revealing indication of apparently differing Eh conditions existing between the two coal fields. But, if one adds the pseudovitrinite percentage for each coal field to the total inertinite content (as all are products of oxidation) the difference between coal fields becomes more pronounced. Average percentage of macerals related to oxidative processes is almost 27% in eastern Kentucky coals, but roughly only 15.5% in western Kentucky coals.

Comparison of the percentages of inert submacerals comprising total inertinites of each coal field is also revealing. Fusinite, semifusinite and micrinite are represented in fairly even amounts within the total inertinite group in eastern Kentucky coals, having comprising percentages of 30, 35.5 and 32%, respectively. By comparison, comprising percentages of fusinite, semifusinite and micrinite within the total inertinite makeup of western Kentucky coals are 44, 28.5 and 25%, respectively. A possible implication from the western Kentucky inert figures is that nearly half of the oxidative processes responsible for inertinite formation in the western Kentucky peat swamps were related to combustion. Such high temperature oxidative events are suggestive of natural disasters that would represent brief periods of a swamp's life span.

In summary, the presence of relatively high percentages of pyritic sulfur in western Kentucky coals, coupled with the large supportive amount of maceral data, suggests overall persistent

existence of reducing conditions within the Pennsylvanian peat swamp environment of western Kentucky. Such conditions served to limit formation of pseudovitrinite as well as inertinite macerals, as higher Eh's favorable for such maceral development apparently occurred relatively infrequently in the western Kentucky peat swamps. The above example of rapid, high temperature oxidative events resulting in fusinization of peat would be a relatively catastrophic event that would represent a brief surge in the Eh of the swamp environment. Less dramatic oxidative events would tend to be related more to pseudovitrinite or semifusinite formation. For example, incursion of brackish or marine waters into a peat swamp would provide, among other things, aqueous sulfate which could serve as an oxidizing agent capable of altering peat material. However, this action would be short-lived in an organic rich peat swamp, as hydrogen sulfides would be generated by bacterial reduction of sulfate ions (Goldhaber and Kaplan, 1974).

Dry swamp conditions would produce "classic" oxidation settings, but apparently such events were not as frequent as in the eastern Kentucky peat environment, as evidenced by lower pseudovitrinite and semifusinite maceral percentages in western Kentucky coals. Combustion could also be a factor in the production of pseudovitrinite and/ or semifusinite. Relatively driest peat directly contacted by fire would obviously become fusinitized but relatively more moist or non-contacted peat such

as that found beneath a (burning) peat surface would be subjected to less intense heat/ oxidation. The significant positive correlation between fusinite and semifusinite found in both coal fields might be an indicator of this situation. This example can be likened to a contact metamorphism situation that is recognized when studying the relationship of igneous intrusions to the surrounding country rock. Rock directly contacted by the intrusion might undergo severe metamorphism while areas proximal to but not directly contacted are slightly but not totally altered.

COMPARISON OF PSEUDOVITRINITE REFLECTANCE TO VITRINITE REFLECTANCE OF KENTUCKY COALS

The previous section examining pseudovitrinite content in coals dealt with the nature of pseudovitrinite as it existed before or during the actual peat stage. This section examines the nature of pseudovitrinite as it undergoes changes related to post-depositional coalification processes that converted peat into its present bituminous coal state. The main property used to distinguish pseudovitrinite from vitrinite is the relatively brighter appearance and hence, greater reflectance of pseudovitrinite versus vitrinite. The purpose here is to quantitatively examine the difference between pseudovitrinite and vitrinite reflectance and compare the degree of difference occurring over the V- type intervals related to both eastern Kentucky and western Kentucky coals.

Mean vitrinite and pseudovitrinite reflectance were determined for 128 eastern Kentucky coals and 110 western Kentucky coals and the difference between these reflectances (ΔR) are summarized within the related V- type intervals in Table 8. Overall mean ΔR for eastern Kentucky and western Kentucky coals are very close, with the ΔR value for eastern Kentucky coals being 0.053% as compared to 0.047% for western Kentucky coals. However, similarity between ΔR percentages for coals of each coal field ends when variations of ΔR within and across the specific V- types are compared. For eastern Kentucky coals, a steady increase in ΔR is observed within the 4 to 8 V- type interval, beginning with a 0.029 ΔR value at V-4 and ending with a maximum difference of nearly 0.08% in the V-8 category. However, this increasing ΔR trend does not continue into the higher V- type categories for eastern Kentucky, as ΔR values are shown decreasing for coals in the V-9 and V-10 rank categories.

Comparative ΔR trends across similar V- type intervals for western Kentucky coals is quite the opposite to the above trend shown by eastern Kentucky coals. For western Kentucky coals, the highest ΔR value (0.063%) occurs for coals in the lowest V- type category (V-4), then gradually decreases through the 5, 6 and 7 V- type intervals before reaching a minimum value of 0.012% at the final, V-8 category. Calculated variations in ΔR within and between each coal field can be at least partly explained by examining the relative actual appearance of pseudovitrinite and

Table 8. Comparison across v- types of the percent difference (ΔR) between pseudovitrinite and vitrinite maximum reflectance measurements for eastern Kentucky versus western Kentucky coals.

V- TYPE	ΔR (s.d.)		No. of Samples	
	Eastern Kentucky	Western Kentucky	E. KY.	W. KY.
4	0.029 (0.011)	0.063 (0.037)	9	9
5	0.038 (0.016)	0.057 (0.031)	28	34
6	0.053 (0.033)	0.043 (0.026)	34	42
7	0.068 (0.029)	0.040 (0.015)	17	18
8	0.078 (0.042)	0.012 (0.006)	17	7
9	0.056 (0.026)	-	16	-
10	0.036 (0.025)	-	7	-
MEAN	0.053 (0.032)	0.047 (0.029)		

vitronite particles through the rank intervals.

Figures 2 through 6 present typical appearances of pseudovitrinite and vitronite in eastern Kentucky coals in order of increasing rank. Figure 2 illustrates the relatively dull gray appearance of a pseudovitrinite particle in a coal at the lower end of the high volatile C bituminous rank stage. Portions of vitronite particles are seen above and below the pseudovitrinite particle of Figure 2 and one observes very little brightness difference between the vitronite particles and pseudovitrinite at this rank. When compared to the following figures showing higher-ranked eastern Kentucky coals, it becomes evident why coals in this lower rank range have the lowest ΔR among eastern Kentucky coals. In Figure 3, pseudovitrinite and vitronite particles are also relatively dull gray but somewhat easier to distinguish by brightness than the example in Figure 2. Figure 3 is taken from a coal at the V-5 - V-6 (high volatile C bituminous- high volatile B bituminous) rank boundary and it is at this approximate position that Table 8 shows a fair jump in ΔR . Figures 4 and 5 illustrate the increasing brightness differences developing between pseudovitrinite and vitronite as coals approach the V-7 and V-8 categories, respectively. Highest ΔR values for eastern Kentucky coals are found over this rank interval which, as mentioned earlier, represents the boundary zone between high volatile B bituminous and high volatile A bituminous coals. Coal rank categories were established on the basis of distinct changes

Figure 2. Pseudovitrinite and vitrinite particles in a high volatile C bituminous coal from eastern Kentucky. Note distinctive slitted structures in pseudovitrinite. (Unknown coal below the Fire Clay zone, Greenup Co.; $R_{max} = 0.44\%$; $275\times$.)

Figure 3. Pseudovitrinite and vitrinite particles for a coal at the high volatile C/high volatile B bituminous rank boundary. (Hazard Coal bed, Knott Co.; $R_{max} = 0.59\%$; $350\times$)

Figure 4. Pseudovitrinite/vitrinite particle showing distinct difference in brightness between the two macerals occurring in high volatile B bituminous coals in eastern Kentucky. Also note more angular, stepped edges for the pseudovitrinite particle (Upper Elkhorn No. 2 coal bed, Morgan Co.; $R_{max} = 0.68\%$; $275\times$.)

Figure 5. Pseudovitrinite and vitrinite particles in a high volatile B/high volatile A bituminous rank coal. Note clear disparity in brightness typical for coals of this rank. Also note remnant cellular structure often found in pseudovitrinites. (Peach Orchard coal bed, Lawrence Co.; $R_{max} = 0.75\%$; 275 $\times$.)

occurring for important chemical properties (for example, volatile matter) inherent in coals. The discontinuity occurring for ΔR at the two high volatile bituminous rank boundaries may represent an indirect additional indication of the chemical changes occurring in coals at the given rank boundaries. Specifically, the increase in the difference between pseudovitrinite reflectance and vitrinite reflectance in the vicinity of high volatile bituminous rank boundaries suggests variation in the degree of alteration of pseudovitrinite versus that of vitrinite. Benedict and others (1968) also reported variations between pseudovitrinite and vitrinite reflectances with rank and related them to changes in the degree of pseudovitrinite alteration, but their analyses dealt with a much broader and mostly higher rank range that did not specifically note or recognize ΔR changes within the high volatile bituminous rank category.

Examining the remaining two V- type categories for eastern Kentucky coals, one notices a sharp decrease in ΔR from the V-8 to V-10 interval (Table 8). The sequence of photographs of a V-9 coal in Figure 6 exposes potential reasons for this decrease. Figure 6a shows pseudovitrinite and vitrinite particles that are clearly distinguishable in terms of brightness but which represents an infrequent relationship between the two macerals at this upper end of the high volatile A bituminous rank stage. More typical are the pseudovitrinite/ vitrinite relationships

Figure 6. Sequence of photographs illustrating difficulties which are encountered when examining pseudovitrinite and vitrinite particles in coals at the upper end of the high volatile A bituminous rank stage. In (a), pseudovitrinite is relatively easy to distinguish from vitrinite as the former is clearly brighter and exhibits several identifying features for pseudovitrinite; (b) pseudovitrinites are still relatively discernable from vitrinites but not by brightness alone, as vitrinite brightness is comparable to that for pseudovitrinite; (c) pseudovitrinites in this example are actually duller than the vitrinite particle at right; (d) the particle at left is clearly vitrinite but the maceral identities for most of the remaining particles is uncertain. (Upper Elkhorn No. 3 coal bed, Pike Co.; $R_{max} = 0.98\%$; 350 $\times$.)

illustrated in Figures 6b- 6d in which clearly banded vitrinite is shown to be as bright as nearby "classic" pseudovitrinite particles (Figure 6b); pseudovitrinite (?) particles of varying brightness are interspersed with vitrinite (?) particles which are actually brighter than the duller pseudovitrinite particles (Figure 6c); or broken particles of varying brightness which could represent portions of either pseudovitrinite or vitrinite occur in the same field of view (Figure 6d). In essence, a situation similar to the pseudovitrinite/ vitrinite relationship at the V-4, V-5 intervals (Figure 2) exists at this higher rank interval, but at the other extreme of the relative brightness scale. Both examples expose a two- fold problem dealing with the validity of reflectance and maceral content calculations involving pseudovitrinite and vitrinite at these rank stages.

The problem of questionable reflectance measurements on eastern Kentucky coals can probably be eliminated immediately as, as a matter of procedure, pseudovitrinite reflectance measurements are performed only on particles that are undeniably pseudovitrinite (that is, besides having relatively higher brightness, the particles also have most or all additional parameters used to identify pseudovitrinite). Of these other parameters, the slitted structures are usually the most decisive factor in choosing a pseudovitrinite particle for reflectance. In addition, vitrinite reflectances are performed only on the telocollinitic (banded) variety of vitrinite, thus eliminating

the problem of a solitary particle of vitrinite possibly being a pseudovitrinite. Hence, validity of pseudovitrinite and vitrinite reflectances for eastern Kentucky coals of all ranks is virtually unquestioned and associated ΔR trends should be considered as "real". Consequently, decrease in ΔR from the 8- to- 10 V- type interval is accurate and suggests that vitrinite alteration has increased at this coalification stage relative to that for pseudovitrinite. Benedict and others (1968) support this contention for higher rank coals as they show a narrowing gap between pseudovitrinite and vitrinite reflectances for medium volatile to high volatile bituminous coals.

The problem concerning validity of pseudovitrinite and vitrinite maceral percentages is not as easily answered. Recall from Table 2 that mean pseudovitrinite contents for the specific V- types show relative uniformity in percentages across the V-4 to V-7 interval but relatively large increase in pseudovitrinite percentage from the 8 to 10 V- type interval. It is shown in this section that a problem with coals in this latter, higher rank interval is the greater abundance of brighter maceral particles and, unless a distinctive pseudovitrinite parameter such as slitted structures is found on these particles, it is often very difficult to differentiate between pseudovitrinite and vitrinite. A homogenous, bright particle might be a pseudovitrinite fragment broken or oriented in particulate pellets in such a way that slitted structures are missing, or it could represent a fragment

separated from a bright, banded layer of vitrinite. As brightness is considered a primary determinant of pseudovitrinite, one can readily deduce that the tendency of a petrographer will be to categorize most bright, clean particles as pseudovitrinite. Unfortunately, at this (and subsequent higher) rank, many bright particles are technically, if not actually, vitrinite, as shown in Figure 6. Therefore, it is suggested here that the supposed increase shown in Table 2 for pseudovitrinite contents in the higher ranked coals of eastern Kentucky is not real, but rather an indirect indication of the increased alteration and, therefore, brightness change undergone by vitrinite. This change apparently begins at this rank stage and, according to Benedict and others (1968), continues to do so into the higher coalification stages.

There is no clear solution to the problem of differentiating between pseudovitrinite and vitrinite in the case of questionable particles. An initial procedure might involve point counting definite vitrinites, definite pseudovitrinites and the problematical particles as three separate categories. At the completion of point counting, the problematical particle percentage would be added into the pseudovitrinite and vitrinite categories according to the relative percentages of the latter two macerals.

Problems involving pseudovitrinite and vitrinite reflectances must also be addressed in the case of western

Kentucky coals as the above mentioned problems may exist to a greater extent for western Kentucky coals. Figures 7 through 9 show pseudovitrinite and vitrinite as they appear at the three high volatile bituminous rank stages in western Kentucky coals. Figure 7a clearly indicates why the highest ΔR values exist for western Kentucky coals in the V-4 to V-5 rank interval.

Vitrinites in coals of this rank are usually dark gray and often exhibit a mottled, granular- like texture (coals at this low end of the high volatile C bituminous rank stage exhibit vitrinites that are somewhat transitional in appearance from lower rank huminite macerals). Hence, when a much brighter, cleaner particle as shown in the center of Figure 7a is found, it can easily be classified as pseudovitrinite. In contrast, a question arises as to whether the relatively brighter and clearer portion of the particle shown in Figure 7b is actually pseudovitrinite or if it is merely a bright, smooth variation of the duller gray vitrinite surrounding it. An isolated, bright particle such as that shown in Figure 7a may be pseudovitrinite, but it is very uncommon for any pseudovitrinite particles at this rank to exhibit other important identifying features of pseudovitrinite. Recall from Table 2 that pseudovitrinite percentages are lowest in western Kentucky coals of high volatile C bituminous rank and, consequently, it is usually difficult to locate sufficient pseudovitrinite particles on which to perform

Figure 7. (a) Example of the great brightness distinction found between pseudovitrinite and vitrinite for lowest rank coals in western Kentucky; (b) particle of similar ranked coal showing a bright, smooth area within more typical dull gray vitrinite mass. (a. No. 9 coal bed, Muhlenberg Co.; $R_{max} = 0.51\%$; b. No. 9 coal bed, Union Co.; $R_{max} = 0.43\%$; $275\times$.)

statistically valid reflectance measurements. Hence, temptation may exist to point count or measure reflectances on any smoother or brighter material, including that shown in Figure 7b, under the pseudovitrinite category when, in actuality such material may be a different variety of, or differently preserved vitrinite.

This problem exists, although perhaps to a lesser extent for high volatile B bituminous coals of western Kentucky as large, relatively brighter and angular particles are more common and thus are more easily distinguished from duller, banded vitrinites. Figure 8 is an example of the clearly different physical appearance that can be found between pseudovitrinite and vitrinite particles at this rank. However, Figure 8 is an ideal example and does not demonstrate that reflectance differences at this rank can be minimal. Doubt in pseudovitrinite identification stems again from the fact that many important parameters used to identify pseudovitrinite are absent from western Kentucky coals of this rank. To stress this point, if similar brightnesses exist among pseudovitrinite and vitrinite particles in coals of this or any rank in eastern Kentucky, one could at least be further aided in distinguishing the two by searching and finding the many other parameters used to identify pseudovitrinite. Most important among these parameters are the slitted structures that are clearly evident in Figures 2, 3, 5 and 6, but rarely evident in western Kentucky coals. In western Kentucky coals, degree of brightness, smoothness and angularity of particles are the three main

Figure 8. Easily distinguishable pseudovitrinite and vitrinite particles from a high volatile B bituminous coal. Bright spots are pyrite particles (No. 5 coal bed, Muhlenberg Co.; $R_{max} = 0.62\%$; 275x.)

parameters used to identify pseudovitrinite. However, recall that vitrinite content in western Kentucky coals averages 80% and it becomes obvious that large, homogenous, angular particles could very easily represent portions of thick vitrain or bright clarain bands. Such thick layers of vitrinite would tend to lose their actual "banded" identity at a microscopic scale where they are viewed as crushed -20 mesh (840 micron) particles which are usually too small to show the relatively thicker banded vitrinites occurring in western Kentucky coals.

The question here is not whether or not pseudovitrinite exists in western Kentucky coals. Benedict and others (1968) suggested that the slitted structures so often crucial in identifying Appalachian pseudovitrinites were a result of partial devolatilization occurring during the early stages of coalification. Perhaps such devolatilization did not occur under the same conditions for western Kentucky coals as it did for eastern Kentucky coals and therefore, an important identifying feature for pseudovitrinite was never strongly developed in western Kentucky coals. The question, rather, is whether large, bright, angular particles found in the vitrinite-dominated coals of western Kentucky are all actually pseudovitrinite or are they simply, in some cases, brighter vitrinites? This problem is magnified for higher rank (high volatile A bituminous) coals in western Kentucky. As with eastern Kentucky coals at this rank, vitrinite alteration apparently was accelerated; the result being

the appearance of many vitrinite particles with brightnesses similar to that of pseudovitrinite. As a consequence of this discontinuity in vitrinite alteration, the main parameter heretofore used to identify pseudovitrinite in lower rank western Kentucky coals is effectively masked at this rank. Figure 9 illustrates the potential seriousness of this situation. Under these conditions, one is able to understand the very slight ΔR value calculated for western Kentucky coals at the high volatile A bituminous rank (see Table 8). And, recalling the problems encountered when attempting to accurately determine pseudovitrinite and vitrinite percentages for coals of this rank in eastern Kentucky, one can relate the supposed great increase in pseudovitrinite shown in Table 8 for the V-8 category of western Kentucky to the same circumstances discussed for the eastern Kentucky situation. However, the lack of any clear identifying feature for pseudovitrinite in western Kentucky coals at this rank expands the problem of pseudovitrinite/ vitrinite differentiation into the area of rank (reflectance) determination. Ultimately, it becomes clear that selection of pseudovitrinite during point counting or reflectance measurement becomes a matter of subjectivity on the part of the petrographer, and such subjectivity inevitably varies from operator to operator. A potential solution to this problem would be to compare vitrinite and pseudovitrinite macerals from a different perspective. The following section attempts to do this by using the Vicker's microhardness test.

Figure 9. Pseudovitrinite and vitrinite particles of equal brightness in a high volatile A coal. Macerals are distinguishable in this example as vitrinites have many organic and inorganic inclusions and are clearly banded as opposed to celan, angular pseudovitrinite particle. However, this distinction can not be made when thick banded vitrinites are broken to these sizes and take on very similar appearance to pseudovitrinite. (Sulphur Springs coal bed, Webster Co.; $R_{max} = 0.87\%$; 350x.)

COMPARISON OF PSEUDOVITRINITE AND VITRINITE MICROHARDNESS FOR EASTERN KENTUCKY AND WESTERN KENTUCKY COALS

Results of Vicker's microhardness tests presented in this study are among the first attempts at such testing on coals in this laboratory. Consequently, data and associated trends found from these tests are not of the magnitude or relative certainty as that attained from maceral and reflectance analyses. Accordingly, the primary purposes are basic at this early stage and are, simply, to calculate microhardness values for pseudovitrinite and vitrinite; examine the calculated difference between pseudovitrinite and vitrinite microhardness values ($\Delta(MH)_v$) through Kentucky rank intervals; and compare the $\Delta(MH)_v$'s of eastern Kentucky coals with those found for western Kentucky coals.

As previously mentioned Vicker's microhardness is related to the size of the impression left by a diamond indenter on a particle surface. The two diagonals of the impression are what is specifically measured and subsequently used in calculating Vicker's microhardness from the formula:

$$(MH)_v = 1854.4 \times P / d^2,$$

where $(MH)_v$ is Vicker's microhardness, P is the weight load applied to the diamond point onto the particle surface, and d is the length of the diagonals in microns. The weight load (P) used

in this study was 32 grams and it was applied onto a maceral surface for 15 seconds.

Vicker's microhardness testing was performed on 23 eastern Kentucky and 11 western Kentucky coals and Table 9 summarizes the data for these coals as it pertains to the stated objectives. The most consistent variation found concerns the relationship between pseudovitrinite and vitrinite microhardnesses. On an individual coal sample basis, average Vicker's microhardness values for pseudovitrinite are always higher than related values for vitrinite regardless of coal field, seam or rank. Raione (in press) also found this relationship in his study of the Upper Elkhorn No. 2 coal zone of eastern Kentucky. As mentioned earlier, this relationship was expected owing to microscopically observed higher relief for pseudovitrinite particles.

Pseudovitrinite content, morphology and reflectance have been shown to vary between eastern Kentucky and western Kentucky coals. Comparison of the respective $\Delta(MH)v$'s for coals of each coal field could also be a primary consideration, and Table 9 shows that variation also exists in regards to this parameter. The overall average $\Delta(MH)v$ for the 23 eastern Kentucky coal samples is 2.06, while the average for the 11 western Kentucky coals is less than half the eastern Kentucky value: 0.90. One reason for this large variation between coal fields may again be the greater ease in identifying pseudovitrinite in eastern

Table 9. Comparison of Vickers' microhardness ((MH)v) values for pseudo-vitrinite and vitrinite macerals in eastern Kentucky and western Kentucky coal samples. Coals are listed in order of increasing rank (% Rmax) within each coal field to observe microhardness differences (Δ (MH)v) between pseudovitrinite and vitrinite through rank.

A. Eastern Kentucky		VICKERS' MICROHARDNESS ((MH)v)		
COAL	% Rmax	Pseudovitrinite	Vitrinite	Δ (MH)v
Williamson	.52	35.10	33.73	1.37
Fire Clay	.59	33.46	32.01	1.45
Lower Elkhorn	.62	39.76	37.89	1.87
Fire Clay	.67	30.84	29.00	1.84
U. Elkhorn #3	.68	37.55	35.29	2.26
Richardson	.72	34.26	32.95	1.31
Richardson	.73	37.46	33.55	3.91
U. Elkhorn #2	.75	38.46	36.40	2.06
U. Elkhorn #3	.76	37.49	35.32	2.17
U. Elkhorn #1	.76	38.25	35.88	2.37
Richardson	.78	33.64	31.14	2.50
U. Elkhorn #2	.85	37.40	35.89	1.51
U. Elkhorn #2	.90	39.01	37.33	1.68
U. Elkhorn #2	.91	39.65	37.04	2.61
U. Elkhorn #2	.91	38.58	36.71	1.87
U. Elkhorn #3	.92	38.99	36.63	2.36
U. Elkhorn #2	.94	38.60	36.50	2.10
U. Elkhorn #3	.94	35.42	33.81	1.61
Upper Alma	.97	36.93	35.44	1.49
Lower Elkhorn	.98	36.69	35.50	1.19
U. Elkhorn #3	1.01	40.54	38.02	2.52
L. Cedar Grove	1.01	38.71	36.48	2.23
Lower Elkhorn	1.09	40.02	36.82	3.20

Table 9., continued

B. Western Kentucky COAL	% Rmax	VICKERS' MICROHARDNESS ((MH)v)		
		Pseudovitrinite	Vitrinite	(MH)v
No. 4	.49	*	25.54	-
No. 11	.67	35.01	33.42	1.59
No. 11	.67	34.15	33.40	0.75
Wheatcroft	.70	33.60	33.12	0.48
No. 11	.70	35.90	35.60	0.30
No. 13	.76	32.41	30.93	1.48
No. 6	.76	34.16	33.66	0.50
NO. 6	.78	35.96	34.09	1.87
Amos	.81	22.68	22.29	0.39
Amos	.86	23.97	23.24	0.73
Unknown	.89	*	29.96	-

*- Pseudovitrinite too rare or too difficult to distinguish from vitrinite.

Kentucky coals. Vicker's microhardness for pseudovitrinites in eastern Kentucky coals, as with reflectance determination, is determined only on bona fide pseudovitrinite particles, which again entails the presence of slitted structures on a particle. Likewise, vitrinites chosen for microhardness measurements are only of the banded variety. Such distinction between pseudovitrinite and vitrinite is not usually possible in western Kentucky coals as explained in the previous section.

Another reason for lower $\Delta(MH)v$'s in western Kentucky samples may involve the significant differences in pseudovitrinite content found between coals from the two coal fields. One has a better chance while scanning a coal pellet of finding "prime" particles of pseudovitrinite in eastern Kentucky coals not only because of more clearly identifiable pseudovitrinite, but also because there is, as shown in Table 1, more than twice as much pseudovitrinite from which to choose. In other words, one cannot be as selective in choosing the extremes in morphological differences between the pseudovitrinite and vitrinite maceral types when working with western Kentucky coals.

However, for argumentive purposes, it must be noted that the Amos coal seam samples used in this study represent one of those rare western Kentucky coals in which slitted structures are observed in pseudovitrinite particle. As many of the Amos samples are high volatile A bituminous rank, they are also partly responsible for the apparent significant increase in average

pseudovitrinite percentage at the V-8 rank interval shown in Table 2. Therefore, if less distinctive and fewer available ideal pseudovitrinite particles explain why western Kentucky coals have lower $\Delta(\text{MH})_v$'s, one would expect values related to this western Kentucky "anomaly", the Amos coal, to be higher than average. Table 9 shows that this is not the case, as $\Delta(\text{MH})_v$ values for the Amos samples are actually among the lowest found. It is apparent, then, that relative appearance or quantity of pseudovitrinite are not the sole reasons for the strong discrepancies in $\Delta(\text{MH})_v$ values for eastern Kentucky versus western Kentucky coals. Further analyses on many more samples are needed before more definite trends concerning Vicker's microhardness can be recognized. For the present, at least two basic trends have been established: pseudovitrinite microhardnesses are greater than those for vitrinite, and the numerical difference between these hardnesses are greater in eastern Kentucky coals.

SUMMARY

This study has examined the nature of pseudovitrinite from a limited viewpoint in that the coals studied fell within specific rank and age ranges. Consequently, several questions relating to a specific origin of pseudovitrinite are unanswered. For example, is pseudovitrinite an alteration product of all vitrinite precursors, or only to certain vegetative forms? Also, is pseudovitrinite found only in Pennsylvanian-aged coals? An ideal situation for possibly uncovering the answer to the first question would be to find and study a particular coal(s) that occurs over a very broad rank range (for example, from lignite into the bituminous rank stage) so that changes or alteration in specific vegetation across rank could literally be observed. The second question could obviously be answered if different aged bituminous coals could be studied and compared with Pennsylvanian coals. It is well known, for example, that Mesozoic and younger floras are quite different from those found in Pennsylvanian aged rocks. These are questions that need to be answered if pseudovitrinite is to be understood on a broader scale, but for now, the results presented here deal with the coals which were most abundant and available to this laboratory.

Comparing the nature of pseudovitrinite in eastern Kentucky coals to that of western Kentucky coals is considered a viable project because coals from each of these coal fields are very

similar in rank and geologic age and, owing to equal accessibility to each, many samples were available for analysis. Analytical parameters used to clarify the nature of pseudovitrinite indicate some similarities but also exposed many differences between pseudovitrinites of the two coal fields.

Average pseudovitrinite content for all eastern Kentucky coals is almost 9% while percentage of pseudovitrinite for western Kentucky coals is only slightly greater than 4%. Pseudovitrinite is found in coals of all ranks for each coal field and thereby further substantiates the conclusion of Benedict and others (1968) regarding the inherent nature of pseudovitrinite in coals. When pseudovitrinite variations are examined across the specific V- type rank intervals, a major difference in trends is found between eastern Kentucky and western Kentucky coals. Pseudovitrinite percentage in eastern Kentucky coals remains quite constant across the 4 to 7 V- type interval but increases fairly sharply within the higher (V-9 and V-10) rank categories. By contrast, pseudovitrinites in western Kentucky coals increase progressively with each V- type increase. However, similarity is also found between the two coal fields regarding this aspect in that the greatest jump in pseudovitrinite percentage occur in the highest V- type intervals of coals from both coal fields. Subsequent examination of reflectance differences (ΔR) occurring between pseudovitrinite and vitrinite of coals in these highest rank categories shows

relatively lower amounts of reflectance difference occurring at these rank intervals. Accompanying figures illustrate changes in the relative physical appearance of the two macerals types with rank and clearly show increased difficulty in discerning pseudovitrinite and vitrinite in coals at the highest rank intervals. A suggestion is given based on this low ΔR / high pseudovitrinite relationship that the supposed discontinuity in pseudovitrinite at these high rank intervals is not related to an actual increase in pseudovitrinite but rather indicates the significant increase in brightness of the vitrinite macerals. This increase in vitrinite brightness presumably coincides with a stepped- up alteration of vitrinite that apparently begins at this rank stage and, according to Benedict and others (1968), continues into the higher coalification stages reached by other Appalachian coals.

More- detailed pseudovitrinite percentage trends are discerned when data for specific coal beds or zones from each coal field is examined and compared. Taken together, these coal beds encompass a large portion of the Pennsylvanian coal stratigraphic interval. Within this orderly stratigraphic context, it is found for both eastern Kentucky and western Kentucky coals that coals with highest pseudovitrinite percentages tend to be clustered within the same, limited

stratigraphic interval. As pseudovitrinite is supposedly a partial oxidation product, it is cautiously suggested that the clear separation of coals with higher than average pseudovitrinite contents from those with lower than average pseudovitrinite percentages might be a subtle indicator of variations in Eh conditions that may have occurred in peat swamps during the Pennsylvanian.

Relating pseudovitrinite variation to the inertinite macerals provides an indication of where pseudovitrinite fits within the context of degree of oxidation. A major observation during these maceral comparisons is that pseudovitrinite content is inversely related to inertinite percentages. This relationship is found in the case of both coal fields and was not expected as both macerals groups are related by varying degrees to oxidative processes and hence, one would rather expect a positive correlation existing between the two groups. Additionally, Benedict and others (1968) did report a positive relationship between pseudovitrinite and inerts for the Appalachian coals which they studied. Pseudovitrinite is subsequently compared to the individual inert submacerals to find possible affinity of pseudovitrinite to a particular submaceral and thereby, indirectly to a particular type or degree of oxidation. It is

found that pseudovitrinite is inversely related to both highly oxidized and slightly oxidized macerals. The resulting notion that pseudovitrinite perhaps is not related to oxidative processes at all is dispelled first by its strong non-relationship to vitrinite, whose existence in itself stems from relatively non-alterative, or at least non-oxidative conditions, and perhaps also by sulfur trends which helped clarify pseudovitrinite's position in relation to Eh conditions.

Initially, the primary purpose of comparing pseudovitrinite to sulfur was to specifically observe pseudovitrinite relation to pyritic sulfur, as this sulfur form develops under reducing conditions. In eastern Kentucky, no relationship at all is found between pseudovitrinite and pyritic sulfur but, upon further analysis, a significant negative relationship between pseudovitrinite and sulfate sulfur is discovered. However, until more data is obtained, this relationship is treated as being coincidental, as sulfate sulfur formation is related to recent weathering of pyrites in coals.

Relatively lower pseudovitrinite percentages in western Kentucky coals are thought to be a result of overriding reducing conditions existing in the precursor peat swamps. Predominance of vitrinite and concomitant lower percentages of the inert macerals points to the relative infrequency of oxidative events, but the prevailing evidence for the existence of predominantly low Eh

conditions is the high percentage of pyritic sulfur found in western Kentucky relative to eastern Kentucky coals.

Studies of the variation in ΔR values with rank change in eastern Kentucky coals show distinct jumps in ΔR at or near the reflectance boundaries separating the high volatile bituminous subcategories. These abrupt increases suggest changes in the rate of alteration of pseudovitrinite and may prove to be a supplemental indicator of chemical changes occurring in coals at these coalification stages. Analysis of the differences between pseudovitrinite and vitrinite reflectance for western Kentucky coals exposes the difficulty that often exists in discerning pseudovitrinite from vitrinite owing to lack of important features such as slitted structures that are useful for confident pseudovitrinite identification. The burden of subjectivity is consequently placed on the petrographer. This problem is especially a factor when examining higher rank western Kentucky coals, during which one must constantly determine which particles are sufficiently bright, homogenous and/ or angular to be classified as pseudovitrinite.

Determination of Vicker's microhardness for coals is only at preliminary stages but some basic trends are already evident when

comparing hardness values of pseudovitrinite to those for vitrinite. The main observation is that pseudovitrinite microhardness is greater than vitrinite microhardness for coals of all ranks and from either coal field. A second general trend indicates that the difference in these pseudovitrinite versus vitrinite microhardnesses is significantly greater for eastern Kentucky coals as opposed to western Kentucky coals (average $\Delta(MH)v$'s of 2.06 and 0.90, respectively).

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