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A DATA BASE FOR THE ANALYSIS OF COMPOSITIONAL
CHARACTERISTICS OF COAL SEAMS AND MACERALS

Final Report. Part 7

Petrographic Variation Due to Depositional Setting of the Lower
Kittanning Seam, Western Pennsylvania

By
Sharon D. Allshouse
Alan Davis

January 1984
Date Published

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Coal Research Section
The Pennsylvania State University
University Park, Pennsylvania

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A DATA BASE FOR THE ANALYSIS OF COMPOSITIONAL CHARACTERISTICS OF COAL SEAMS AND MACERALS

Alan Davis, Principal Investigator

Final Report - Part 7

PETROGRAPHIC VARIATION DUE TO DEPOSITIONAL SETTING OF THE LOWER KITTANNING SEAM, WESTERN PENNSYLVANIA

by

Sharon D. Allshouse and Alan Davis

Date Published - January 1984

**Coal Research Section
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PREFACE

The major objective of this program, "A Data Base for the Analysis of Compositional Characteristics of Coal Seams and Macerals", has been to use the Penn State Coal Data Base to gain better understanding of the systematic relationships between properties of U.S. coals. The following studies are incorporated within the program:

- a) A statistical study of the interrelationships between the properties of the organic fraction of coals. The extent to which natural groupings of U.S. coals might exist are being investigated by cluster analysis. Cause for the groupings are being sought in such factors as age of coal, source material and thermal/burial history.
- b) A statistical study of the interrelationships between the properties of the inorganic fraction of coals. Correlations are being sought between the major, minor, trace element and mineralogical analyses of coals in the data base.
- c) Studies of the lateral and vertical variability of properties within a single coal seam in response to changes in depositional environments and post-depositional metamorphic changes. The Lower Kittanning seam has been selected because of its broad extent and the range of environments by which it is thought to have been affected. Properties which are being studied include the petrographic characteristics, mineralogy, thermoplastic characteristics and liquefaction behavior.
- d) The basic physical and chemical properties of pure coal macerals. Detailed analyses of vitrinite concentrates are being made to determine what significant differences in functional group content, aromaticity, density, porosity, and optical properties arise from variation in the environmental conditions during peat deposition and in the thermal histories of coals.

This report is the seventh of a series on the research undertaken in the course of the program. It describes the relationships between paleoenvironments of the Lower Kittanning coal swamp and the vertical and lateral variability of lithotypes, maceral composition and vitrinite types in this western Pennsylvania coal seam. The study contrasts the characteristics of freshwater-influenced coal in the eastern part of the bituminous field with coal from an area of marine influence in the central part of the basin.

The following are previous reports published in this series:

- DOE-30013-F1 Relationships Between Coal Constitution, Thermoplastic Properties and Liquefaction Behavior of Coals and Vitrinite Concentrates from the Lower Kittanning Seam.
--Joseph T. Senftle and Alan Davis
- DOE-30013-F2 A Multivariate Study of the Interrelationships Among Selected Variables of the Organic Fraction of Samples of United States' Coals.
--Joseph J. Gerencher, Jr.
- DOE-30013-F3 Some Procedures for the Chemical and Mineralogical Analysis of Coals.
--Norman H. Suhr and Henry Gong
- DOE-30013-F4 Characterization of the Organic Structure of the Lower Kittanning Coal Seam Using Fourier Transform Infrared Spectroscopy and Optical Properties.
--D.W. Kuehn, A. Davis and P.C. Painter
- DOE-30013-F5 Recent FT-IR and ^{13}C NMR Studies of Coal Structure.
--P.C. Painter, A. Davis, M. Starsinic, J.L. Koenig, J.R. Havens, D.W. Kuehn, R.W. Snyder, J.T. Senftle, C. Rhoads, E. Riesser and E. Squires.
- DOE-30013-F6 Petrography and Depositional Environment of the Herrin (No. 6) Seam in Central, Eastern and Northwestern Illinois.
--Suzanne J. Russell

ABSTRACT

Detailed megascopic and microscopic petrographic analyses were conducted on samples of the Lower Kittanning seam from western Pennsylvania. Relationships were sought between the paleoenvironmental setting of the coal swamp and the vertical and lateral variability of lithotypes, maceral composition and vitrinite types.

Megascopically, the four samples collected from the freshwater facies of the seam are similar in appearance and relative lithotype composition, and display no distinct vertical zonations. The sample from the marine-influenced central portion of the basin (PSOC-1340) possesses a marked vertical zonation into a bright lower zone and a dull upper zone. The lower zone is similar in appearance to the freshwater samples.

Detailed microscopic analyses revealed that the vertical zonation of PSOC-1340 is apparent in both the maceral and vitrinite type composition. No similar zonation is apparent in the microscopic analysis of the four freshwater facies samples. Similarities between the lower zone of PSOC-1340 and the whole seam of the freshwater samples are most apparent in the vitrinite-type analysis.

The lower zone of PSOC-1340 and the whole seam from the freshwater facies are considered to be laterally equivalent coal types. The dull upper zone of PSOC-1340 is considered to have formed in response to a major change in the paleoenvironment of the swamp, probably a marine transgression.

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CHAPTER I

INTRODUCTION

The primary objective of this research project has been to delineate vertical and lateral petrographic changes within the Lower Kittanning seam, in selected areas of western Pennsylvania, and to interpret these changes in terms of the varying environmental settings of the original coal swamp. Megascopic and microscopic petrographic analyses were conducted to develop a detailed description and classification of the coal types which occur in selected samples of the Lower Kittanning seam. These data have been used to investigate potential correlations between the paleoenvironmental settings of the Lower Kittanning coal swamp, as inferred from work by E.G. Williams (1960), and the following variables:

- 1) megascopic appearance - vertical and lateral variability of coal types,
- 2) microscopic appearance - vertical and lateral variability of the maceral composition, and
- 3) occurrence and distribution of distinct types of vitrinite macerals.

A secondary goal has been to determine the relationship between the megascopic appearance of a coal type and the nature of its microscopic components. A final objective has been a determination of the effectiveness of alternative analytical techniques in the petrographic analysis of higher rank (medium to low volatile bituminous) coals.

This project was one phase of a regional study of the variability that exists within a single coal seam and of how the variation in

properties relates to changes in the depositional environments and subsequent metamorphic history of the seam. The Lower Kittanning seam was selected for this study because of its broad regional extent, economic importance and the known variability of its depositional environments.

CHAPTER II

GEOLOGIC SETTING OF THE LOWER KITTANNING SEAM

Structural Setting

In western Pennsylvania, the major bituminous coal-bearing strata occur in the Allegheny Plateau physiographic province. The Allegheny Plateau is an upland region separated from the folded Valley and Ridge province to the east by the Allegheny structural front. The area is a structural depression, with the western Pennsylvania coalfield occupying the northern portion of the Pittsburgh-Huntington Synclinorium (see Figure 1). On the Allegheny Plateau the rocks are essentially horizontal, dipping gently at one to six degrees to the northwest and southeast. Broad, low-amplitude, irregular, sinuous folds generally strike northeast-southwest, with the axes of the folds plunging to the southwest. Folding becomes more intense towards the Allegheny Front.

General Stratigraphy

The major bituminous coal-bearing strata in western Pennsylvania occur in the Pennsylvanian System. This system has been subdivided into four series in the northern Appalachian coalfield. In ascending order they are, the Pottsville Group, Allegheny Group, Conemaugh Group and Monongahela Group (Ashley, 1926; Graeber and Foose, 1942).

Formerly, the Allegheny Group was called the Lower Productive Measures because of the extensive and economically important coals contained within the sequence. The name Allegheny is derived from typical exposures along the Allegheny River north of Pittsburgh, Pennsylvania. The Allegheny Group is described as a 300-350 ft (90-105 m) thick succession of shales, sandstones and coal beds. It also contains units

Figure 1. OUTCROP OF THE KITTANNING FORMATION IN THE NORTHERN APPALACHIAN BASIN (after Ferm, 1957)

of marine and freshwater limestones, and some mineable underclays. It extends from the base of the clay under the Brookville coal upwards to the top of the Upper Freeport seam (Butts, 1906; Graeber and Foose, 1942). The lower part of the group contains marine, brackish and freshwater units, but no freshwater limestone. The upper part is entirely non-marine and contains freshwater limestone (Edmunds et al., 1979; Williams, 1960).

Ashley (1926) divided the Allegheny Group into three formations, the Clarion, Kittanning and the Freeport, in ascending order. A generalized stratigraphic column of the Allegheny Group is shown in Figure 2.

It should be noted that a revision of the lithostratigraphic nomenclature for the Pottsville and Allegheny Groups has been published (Edmunds, 1969), and is in use by the Pennsylvania Topographic and Geological Survey. However, because all publications referenced in this report employ the classification described by Ashley (1926), that nomenclature will be followed in this paper.

The Kittanning Formation is defined as the sequence occurring from the base of the clay under the Lower Kittanning seam up to the top of the Upper Kittanning seam (Ashley, 1926). The stratigraphic interval relevant to this study is the lower portion of the Kittanning Formation, consisting of the Lower Kittanning seam and approximately 50 ft (15 m) of clastic rocks overlying the coal, up to the base of the Middle Kittanning seam. Based on faunal evidence, the rocks overlying the Lower Kittanning seam represent two main facies; a marine-brackish facies and a fluvial-lacustrine facies. The marine-brackish facies is overlain by and laterally intertongues with the non-marine facies (Williams, 1960; Ferm and Williams, 1965). The marine facies has been designated the Columbiana

Figure 2. GENERALIZED STRATIGRAPHIC COLUMN OF THE ALLEGHENY GROUP

shale in western Pennsylvania, and is equivalent to the Columbiana shale underlying the Hamden limestone in eastern Ohio (Groth, 1966). The Columbiana shale represents a transgressive-regressive sequence. The middle member, containing an abundant marine fauna, represents a period of marine stillstand and deepest water (Williams et al., 1964). The Columbiana shale is equivalent to the Lower Kittanning shale referred to by other workers. The marine facies, consisting mainly of shale, clay shale and siltstone with some nodular ironstone, limestone and sandstone, directly overlies the Lower Kittanning coal seam in a northeast-southwest trending belt approximately 60 miles (100 km) wide across the Kittanning outcrop area. It thins rapidly to the southeast and northwest where it is laterally replaced by the fluvial-lacustrine facies overlying the coal (Ferm and Williams, 1965).

The fluvial-lacustrine facies consists of complexly related siltstone and sandstone units, coal beds, underclays, and freshwater limestone in the upper portions. Sandstone cut-and-fill channel deposits are common (Groth, 1966; Ferm and Williams, 1965).

No formal stratigraphic name has been assigned to the fluvial-lacustrine facies of the rocks between the Lower and Middle Kittanning seams. For this reason, and for clarity, the two facies of the rock unit overlying the Lower Kittanning seam will be referred to as the marine-brackish and non-marine (or fluvial-lacustrine) facies or rocks.

Figure 3 is an outcrop map of the Kittanning Formation in western Pennsylvania showing the distribution of marine and non-marine facies of the rocks between the Lower Kittanning seam and the marine Washingtonville shale which overlies the Middle Kittanning seam.

Figure 3. OUTCROP MAP OF THE KITTANNING FORMATION IN WESTERN PENNSYLVANIA SHOWING DISTRIBUTION OF MARINE AND NON-MARINE FACIES OF THE ROCKS BETWEEN THE LOWER KITTANNING SEAM AND THE MARINE WASHINGTONVILLE SHALE ABOVE THE MIDDLE KITTANNING SEAM (after Fern and Williams, 1965)

The Lower Kittanning Seam

The Lower Kittanning seam, a member of the Kittanning Formation, is one of the most widespread coal seams in the western Pennsylvania coalfield. It extends almost continuously throughout the Appalachian coalfield in Pennsylvania, West Virginia, Ohio and Maryland (Arndt et al., 1968). Figure 4 shows the extent of the Lower Kittanning seam in the western Pennsylvania region.

In western Pennsylvania the thickness of the coal ranges from less than 20 in (50 cm) to more than five ft (150 cm) (Ashley, 1928). Figure 5 is a generalized thickness map of the Lower Kittanning seam in western Pennsylvania. In the areas sampled for this study the thickness averages 28 in (70 cm) at both the Jefferson and Cambria County sites, and ranges from 24 to 72 in (60-183 cm) at the Somerset County locations. In the thicker areas the coal often splits into as many as five coal horizons separated by clay or shale partings of variable thickness (Keystone Coal Industry Manual, 1980).

The Lower Kittanning seam is recognized stratigraphically by its position as the first major coal seam occurring above the Vanport Limestone of the underlying Clarion Formation (Butts, 1906). The interval between the two units ranges from 15 to 50 ft (4.5 - 15 m) in the western part of Pennsylvania, with an extreme interval range of 15 to 120 ft (4.5 - 37 m) reported by Bergenback (1964).

As Figure 6 shows, the rank of the Lower Kittanning increases eastward from high volatile bituminous ($R_{O(max)}$: 0.9%) in the western part of the state, to medium volatile bituminous ($R_{O(max)}$: 1.2%) along the Allegheny Front. High rank values ($R_{O(max)}$: 1.7%, low volatile

Figure 4. EXTENT OF THE LOWER KITTANNING SEAM IN WESTERN PENNSYLVANIA
(after Deasy and Griess, 1959)

**Figure 5. GENERALIZED ISOPACH MAP OF THE LOWER KITTANNING SEAM
IN WESTERN PENNSYLVANIA
(after Senftle and Davis, 1981)**

Figure 6. RANK VARIATION MAP OF THE LOWER KITTANNING SEAM
IN WESTERN PENNSYLVANIA
(after Senftle and Davis, 1981)

bituminous) occur in the southeastern corner of the coalfield, in the vicinity of Somerset County. Hower and Davis (1981) concluded that an elevated geothermal gradient, rather than greater depth of burial, was responsible for the observed eastward increase in rank in western Pennsylvania.

The coal itself has been stratigraphically zoned on the basis of spore and pollen assemblages and petrographic variation of coal types. Basically, the Lower Kittanning seam has been described as a transgressive coal sequence deposited in a subsiding basin. The rate of subsidence is thought to have increased during the final stages of peat deposition, resulting in the marine transgression responsible for deposition of the overlying clastic sediments which naturally terminated peat deposition (Habib, 1966; Ting, 1967).

CHAPTER III

PREVIOUS STUDIES

Coal Depositional Environments

In recent years increasing emphasis has been placed on the utilization of coal petrology in the interpretation of coal-forming environments. One approach has been the investigation of relationships between depositional and/or tectonic settings and the geometry and distribution of coal seams. Ferm and Horne (1979) and Britten et al. (1975) are among geologists who have related characteristics such as regional geometry, pattern and frequency of seam splitting, number of coal seams, seam thickness and lateral extent to depositional environments and tectonic activity.

Extensive studies on the petrographic variation of coal seams in relation to environments of formation have been published by Shibaoka and Smyth (1975), Shibaoka and Bennett (1975), and Britten et al. (1975) for coal seams in Australian basins. Their work showed a relationship between rate of subsidence and the extent of seam splitting, seam thickness, and relative abundances of bright and dull coal. In general, with rapid rates of subsidence the seams are commonly split and are thicker and richer in vitrinite. Seams which were deposited in stable shelf areas show little or no splitting and are thinner and poorer in vitrinite.

Smith (1968) has classified petrographic and spore assemblages for British coal seams into distinct phases which he has related to the position of the seam within the depositional basin and the degree of subsidence occurring during deposition of the peat.

M. Teichmüller (1975) has recognized four facies in the Miocene brown coals of Germany which resulted from differing vegetation and environmental settings. These facies were reconstructed on the basis of linked paleobotanical and coal petrographic research.

Cameron (1971) conducted a detailed study on the megascopic variations of the Harbour coal seam, Nova Scotia and on the microscopic petrography of dull layers within the seam. He was able to distinguish significant vertical and lateral petrographic changes within the seam. On the basis of these data he was able to interpret the depositional setting of the Harbour seam.

Of particular relevance to this study is the research conducted by Hacquebard et al. (1967) in which the depositional settings of coals within paralic or limnic basins were related to their megascopic appearances, maceral compositions, and relative amounts of vitrinite types (collinite vs. telinite). They reported that in paralic basins the vertical profiles of coal seams are more variable in petrographic composition than coals deposited in limnic basins. In addition, within the paralic basins, they showed a relationship between the degree of petrographic variation and geographic position of the seam within the basin. The greatest variations occur in the seams deposited in the quiet central part of a flood plain and in a coastal lagoon, areas which are both sensitive to changes in sea-level. A coal deposited in the marginal area of the swamp where terrestrial conditions controlled the groundwater level exhibited less extensive petrographic variations.

Paleoenvironments of the Lower Kittanning Seam

E.G. Williams (1957, 1960) studied the distribution of invertebrate fossils contained in the shale unit directly overlying the Lower Kittanning seam. This unit was found to contain "the most complete faunal transition, from deepest marine to freshwater fossils" of the units studied within the Pottsville and Allegheny Groups. Figure 7 shows the distribution of faunas in the shale above the Lower Kittanning as published by Williams (1960). The center of the basin contains the calcareous brachiopods and molluscs which represent a marine habitat. Towards the margins of the basin these fossils are replaced by restricted marine or brackish-water fossils such as phosphatic brachiopods and pectenids. Along the southeastern margin a freshwater environment is inferred from the presence of estherids.

Williams and Keith (1963) demonstrated a relationship between the facies of the overlying shale and the pyritic sulfur content of the Lower Kittanning seam. They found the pyritic sulfur content to be higher in coal underlying the marine facies of the shale and lower in coal below the freshwater facies.

Guber (1972) studied the relationship between total sulfur content in the Lower Kittanning rocks (including the Lower Kittanning coal and superjacent strata), and the presence of *Lingula* in the brackish-water facies. He concluded that "all available data support the division of the Lower Kittanning rocks into fresh, brackish, and marine water facies, and the brackish facies was characterized by *Lingula* and high sulfur."

A palynological study of the Lower Kittanning shale (Columbiana Shale) was conducted by Groth (1966). The sequence and distribution

Figure 7. DISTRIBUTION OF FAUNAS IN SHALE ABOVE THE LOWER KITTANNING SEAM (after Williams, 1960)

of the fossil pollen and spore assemblages he described supports the paleoenvironmental facies outlined by Williams (1960).

Holbrook (1973), in studying the underclay beneath the Lower Kittanning seam found a correlation between kaolinite/mica ratios and paleotopography. A high kaolinite/mica ratio (> 1.5) was related to paleotopographic highs. His results showed a low kaolinite/mica ratio in the Tyrone-Altoona area of Cambria County, in the area where sample PSOC-1335 was collected for this study. The adjacent regions to the northeast and southwest of the Tyrone-Altoona area show high kaolinite/mica ratios. These data indicate that the Tyrone-Altoona area was a paleotopographic low relative to the adjacent areas in the northeast and in Somerset County to the southwest.

Petrography and Palynology of the Lower Kittanning Seam

Work on the Lower Kittanning seam includes that by Habib (1966), Ting (1967), Reyes-Navarro and Davis (1976), Bailey (1981), and Senftle and Davis (1982). Bailey delineated chemical and mineralogical differences in the marine and non-marine facies of the Lower Kittanning seam in Ohio, Pennsylvania and West Virginia. Reyes-Navarro and Davis reported on the vertical distribution of pyrite forms but included petrographic analyses of subsections of two Lower Kittanning column samples, one from the marine facies in Lawrence County, Pennsylvania and one from the non-marine facies in Cambria County, Pennsylvania. The non-marine sample was collected near the Cambria County - Somerset County border and is petrographically similar to the Somerset County samples included in this study.

Habib studied the distribution of spore and pollen assemblages in the Lower Kittanning seam along an east-west transect from central Clearfield County west to the Pennsylvania-Ohio border. His work revealed an orderly vertical and geographical distribution of spore and pollen assemblages. The greatest vertical variation of assemblages occurs at locations where the seam is directly overlain by the marine faunal facies of the Lower Kittanning shale. Where the seam is directly overlain by the freshwater facies of the shale, it is dominated by Lycospora-rich assemblages and displays less vertical variation in the spore and pollen assemblages. He concluded that "the spatial arrangement of spore and pollen assemblages in the Lower Kittanning coal suggests a genetic relationship with the environmental conditions within which the overlying sediments were deposited... The salinity factor resulting from proximity to the sea seems plausible in explaining the distribution of the assemblage zones." He also stated that "The geographic segregation of spore and pollen assemblage zones compares closely with the variation in the facies of the overlying juxtaposed rocks."

Like Habib, Ting (1967) sampled an east-west transect across the strike of the basin running from Jefferson County in the east to Lawrence County along the Pennsylvania-Ohio border. The majority of Ting's samples were from the marine-influenced central portion of the basin, with a few samples from the northwestern margin of the coal basin. He described the Lower Kittanning in terms of one or more "phytostromes" which he defined as distinctive associations of lithotypes. The phytostromes were classified based on microscopic analysis of thin sections prepared from subsections of the seam at the various

localities. He described five "phytostromes which occur in a definite sequence, the variation of which "relates rationally to the nature of the overburden as observed by the author (Ting) ... and to the paleotopography and tectonic history as interpreted by others" (Ting, 1967). The greatest vertical variation, in terms of the number of "phytostromes", as with Habib's floral assemblages, occurs in the central, marine-influenced part of the basin. Ting's one sample from the northwest margin of the basin, underlying the freshwater facies of the shale, consisted of a single phytostrome. He interpreted the Lower Kittanning seam to have been deposited in a rapidly subsiding basin with transgressing marine waters.

Senftle and Davis (1982) conducted a study of the lateral variability of the chemical and maceral composition of the Lower Kittanning seam throughout western Pennsylvania and into Ohio. The observed areal variability led them to conclude that seam thickness, ash and sulfur levels, the petrographic composition, and certain rank-related characteristics were influenced by geologic controls on sedimentation in the basin. The strongest controls are thought to have operated along the eastern margin of the basin. They distinguished two distinct sedimentation and coalification regimes, one in the southeast in Somerset County and the other in the Tyrone-Altoona area of Cambria County. Their summary of the data collected for these two areas is reproduced as Table 1. Four models were considered in order to explain the variations observed in these areas. The first model interprets the Tyrone-Altoona area of Cambria County as a paleotopographic high during Lower Kittanning deposition, with a corresponding paleotopographic low existing in the adjacent Somerset County area.

Table 1. Comparison of Lateral Composition and Constitution of Lower Kittanning Samples from the Tyrone-Altoona Area and Somerset County (after Senftle and Davis, 1982)

		Tyrone-Altoona Area	Somerset County
Petrographic Data	Total Vitrinite	<	>
	Total Inertinite	>	<
	Fusinite	>	<
	Semifusinite	>	<
	Macrinite	>	<
	Micrinite	>	<
Physical Data	Reflectance	<	>
	Thickness of Seam	<	>
Chemical Data	Ash Yield	<	>
	Volatile Matter	>	<
	Carbon	<	>
	Hydrogen	>	<
	Oxygen	>	<
Kaolinite/Mica Ratios (from Holbrook, 1973)		< 1.0	> 1.5

> Relative increase

< Relative decrease

Evidence to support this model include the ash values, relative inertinite contents and seam thickness. In the second model the Tyrone-Altoona area is considered as a topographic low. This is in agreement with the interpretation by Holbrook (1973). In this model the thinning of the coal in the area is related to a deepening of the water in the swamp with the relatively high levels of inertinite resulting from reworking of organic material. A possible marine incursion is postulated for the Tyrone-Altoona area under this model. While the first and second models relied on tectonic and sedimentological processes, the third model considers the chemistry of the peat swamp to be the determining factor in controlling compositional variations in the coal. With this model the swamp in the Tyrone-Altoona area is thought to have undergone a higher degree of degradation resulting in a relative thinning of the coal and increase in inertinite macerals. The swamp is interpreted to have had a higher pH and to have been more "marine" in character than the adjacent area to the south. The final model is a combination of paleotopographic and chemical controls on the peat swamp. The relative thinning of the coal, the relative increase in inertinite macerals and the low ash yield of the Tyrone-Altoona area are explained by the existence of a paleotopographic high during deposition of the peat. The depletion of kaolinite in the underclay of this area as described by Holbrook (1973) is considered to be a result of the influence of a more alkaline environment. This increase in pH could have resulted from "an influx of marine waters,... an influx of carbonate-rich ground or surface waters, or evaporation" (Senftle and Davis, 1982).

The petrographic analysis of PSOC-1335 from this study provides additional insight into the nature of the depositional environment of the Lower Kittanning seam in the Tyrone-Altoona area.

CHAPTER IV

FIELD AND LABORATORY PROCEDURES

Study Area and Sample Locations

Samples analyzed for this study were collected from the eastern portion of the western Pennsylvania bituminous coalfield. This area was selected for several reasons. First, the paleoenvironments of the roof rocks associated with the coal have been well delineated in the eastern part of the coal basin (Williams, 1960). Second, detailed petrographic research has not previously been done on the Lower Kittanning seam in this area. A prior petrographic study (Ting, 1967), concentrated on the Lower Kittanning seam in the central and northwestern region of the coalfield. Finally, samples from the eastern margin of the field provide an opportunity to study coal of a higher rank than occurs elsewhere in the basin.

For this study a total of five samples of the Lower Kittanning seam were collected and prepared for analysis. Sampling sites were selected based on the availability of active surface mines within designated areas. Selection of designated sampling areas was based on the geological reconstruction by E.G. Williams (1957, 1960), of the paleoenvironments existing during deposition of the Lower Kittanning shale. A map of the study area with the paleoenvironmental boundaries and the locations of samples collected is shown in Figure 8.

Of the five sample locations, four are located within the area of fluvial-lacustrine (non-marine) influence, and the fifth sample is from the marine-influenced area. The vertical and lateral variabilities of the seam in the central marine-influenced portion of the basin have been documented by Ting (1967) and Reyes-Navarro and Davis (1976). Consequently,

Figure 8. SAMPLE LOCATION MAP AND RECONSTRUCTED PALEO-ENVIRONMENTS OF THE SHALE ABOVE THE LOWER KITTANNING SEAM (after Williams, 1960)

only one column from this area was collected and analyzed for the present study; this sample had a similar macroscopic appearance to columns described by the previous authors. Table 2 indicates the sample number location by county, Williams' paleoenvironments, and the rank and seam thickness of each sample collected.

PSOC-1340 was collected in the southern portion of Jefferson County, Pa. The marine influence on the Lower Kittanning seam in this area is documented by the faunal evidence in the shale overlying the coal in several localities near the actual sampling site.

One of the four non-marine samples, PSOC-1335 was collected in Cambria County, Pa. This location was selected in order to obtain a non-marine sample with a rank level as close as possible to that of PSOC-1340, the marine sample.

The three remaining samples are from Somerset County, Pa., the area where the Lower Kittanning seam attains its highest rank. These samples were collected to determine if the petrographic trends and relationships, as indicated by analysis of the coal from lower rank areas, are still discernable in coals of low volatile bituminous rank.

Sampling Procedures

Two types of samples, channel and column samples, were collected at each sampling site. Prior to actual collection of the sample a fresh face of the coal was prepared normal to the bedding and as clean as possible. The coal was then described in terms of the thickness of lithotypes present and any special characteristics such as partings or pyrite lenses were noted. The overburden, and roof and floor rocks immediately above and beneath the coal were described and their thicknesses noted

Table 2. Sample Information

Sample No.		Paleo-environment*	Thickness	$\bar{R}_O(\max)\%$ -Rank
PSOC-1197	Somerset County	Non-marine	146 cm	1.7
PSOC-1325	Somerset County	Non-marine	99 cm	1.6
PSOC-1330	Somerset County	Non-marine	186 cm	1.7
PSOC-1335	Cambria County	Non-marine	69 cm	1.2
PSOC-1340	Jefferson County	Marine	70 cm	1.0

*Based on work by E.G. Williams (1960).

where possible. The overall appearance of the coal in the mine was recorded, noting features like continuity of partings and seam thickness, occurrence of rolls or splits, changes in overburden lithologies, and the presence of any weathered zones.

Once the descriptions were completed, a channel sample of the whole seam was collected according to the procedure described in Schopf (1960). Separate channel samples were obtained for any distinct lithotypes or benches observed in the seam. The occurrence of persistent partings, greater than 3/8 in (1 cm) in thickness, would commonly serve as boundaries for dividing the seam into a series of benches.

The technique of column sampling consists of removing from the mine face an entire column of the coal seam from roof to floor, in a series of intact blocks which cover the entire thickness of the seam. Each block of coal was carefully removed and labelled at the sampling site to record the orientation and sequential position of the block within the seam. Adjacent overlapping blocks were collected so that any

material lost from the top or bottom of one block could be matched in the adjacent block. In this manner a sample of the entire coal seam was collected intact. In places, extremely friable zones in the coal were encountered so that obtaining blocks large enough to work with was impossible. Where this occurred, the zone was described (usually a bright, friable clarain), and fragments of the coal from that layer were collected for preparation as particulate samples which were later made into polished pellets.

Sample Preparation

The channel samples were crushed in the laboratory and representative splits taken for routine chemical analysis, preparation of pressed pellets, and duplicate (storage) samples. The pressed pellets were used for reflectance analysis and routine maceral analysis (ASTM, 1982).

The blocks comprising each column sample were unwrapped in the laboratory and, wherever necessary, were coated with an epoxy resin to prevent disintegration of the coal. Each block of coal was cut on a water-cooled diamond edge saw into a series of slabs approximately 2-1/2 in (6 cm) wide, 1/2 in (1 cm) thick, and up to 4 in (10 cm) long (normal to the bedding). As in the collection procedure adjacent slabs were cut so as to provide overlap in case any coal was lost when the horizontal (along bedding) cuts were made with the rock saw. The slabs were "squared up" and the faces and edges made even by rough grinding on a belt sander with coarse grit paper. Each coal slab was then labelled, placed in a metal tray, and covered with Paraplex P-43 cold-setting plastic, activated with cumene hydroperoxide hardener. The plastic was left to harden for up to 48 hours at room temperature. After removing the slabs

from the mold, they were trimmed with the diamond saw to roughly uniform dimensions and ground on the belt sander to expose the approximately 2 x 4 in (5 x 10 cm) coal surface, perpendicular to bedding, for polishing. The plastic-encased blocks of coal were polished on a rotating lap with progressively finer grits. A small amount of water was fed to the grinding surface throughout all steps of the polishing procedure. The final polishing steps utilized 0.3 μm alumina followed by 0.05 μm alumina. After polishing, each block was immersed in distilled water in an ultrasonic tank to remove any remaining polishing compound, then carefully dried with a stream of compressed air. The blocks were stored, polished surface down, on a soft cloth during megascopic examination and prior to microscopic analysis. The final polishing steps were repeated on the blocks not more than 24 hours before the microscopic analysis was performed.

The collection of column samples and the preparation of polished blocks is a very time-consuming method of obtaining coal samples for analysis and requires painstaking attention and care. However, with the exception of the even more difficult thin-section method, the preparation of columnar samples is the only technique which permits the analysis of the coal constituents in their natural sequence, textures and associations. Such information is invaluable to the study of the origin of coal seams and often is worth the extra effort required.

Analytical Techniques

Megascopic Petrographic Terminology and Techniques

In 1919 Marie Stopes introduced the terms vitrain, clarain, durain and fusain to designate the "four visible ingredients in banded bituminous coals". C.A. Seyler, in 1954, proposed the use of the term lithotype

to specify the megascopically recognizable bands in humic coals (ICCP, 1963). The proposal was accepted by the International Committee for Coal Petrology (ICCP), and Stopes' "four visible ingredients" are now referred to as lithotypes. At the present time vitrain, clarain, durain and fusain are the only hard-coal lithotypes which have been defined by the ICCP, although other terms are often included to provide a more complete description of the coal, as is the case in this study.

It should be emphasized that the four recognized lithotypes of bituminous coals, as defined, are purely for megascopic descriptions and carry no genetic implications. Further, no compositional inferences should be made by the use of any lithotype term, although a tendency to do this has arisen in part from the modification of lithotype names for use in microlithotype analysis. A microlithotype is a particular assemblage of macerals and can only be determined through quantitative microscopic analysis. For example, the microlithotype term "clarite" is derived from the lithotype term "clarain". The similarity of terms is unfortunate and it must be remembered that lithotypes and microlithotypes are different classification systems, employed at quite different levels of coal composition; a clarain is not necessarily composed of clarite.

An additional problem with the Stopes-Heerlen lithotype nomenclature needs to be recognized. The four recognized lithotypes are usually considered to be analogous to sedimentary rock types. While this analogy may hold for the lithotypes clarain and durain, it is certainly not valid for vitrain and fusain. Vitrain and fusain most frequently occur as discontinuous lenses within attrital coal types (clarains and durains), so a more appropriate analogy would be the individual grains

within a rock type (e.g., a large quartz grain within a poorly sorted sandstone). The lithotypes identified in this study were differentiated solely for the purpose of providing a detailed description of the megascopic appearance of the Lower Kittanning seam, and not to draw inferences regarding the origins of the coal types.

As a result of confusion surrounding the use of the Stopes lithotype terminology, and the fact that the four recognized lithotypes often do not adequately describe non-Carboniferous or Gondwanaland coals, several alternative megascopic classifications have been developed by coal petrologists. A majority of these classifications are based on the relative bright or dull appearance of the coal and the nature of the observed banding. A summary of the problems associated with the megascopic description of coal and of alternative classifications is presented by Davis (1978).

In spite of the shortcomings discussed above, megascopic descriptions of the Lower Kittanning seam sampled for this project were compiled using the lithotype terminology of Stopes, as defined in the International Handbook of Coal Petrology (ICCP, 1963). This is because the terms were considered suitable for use in obtaining a detailed description of the organic appearance of the seam, without drawing inferences on the origins of the coal types. However, in order to adequately describe the Lower Kittanning samples, two additional classes, clarodurain and boney coal were added, and descriptive modifiers such as bright, dull, or pyrite-rich were applied where necessary. The term clarodurain, introduced by Cady in 1942 (ICCP, 1963), was added to describe a coal type intermediate between clarain and durain. Boney coal is a term often used to describe impure, clay-rich coal layers, which are commonly found at the top of a seam.

Figure 9. SCHEMATIC REPRESENTATION OF POINT-COUNTING TECHNIQUE

In order for a layer or zone within the coal to be classed as a discrete lithotype, a minimum thickness, normal to bedding, of 3 mm was designated. For example, a bright lustrous band of greater than 3 mm would be labelled as vitrain; if less than 3 mm, it would be included within a larger unit such as clarain. Definitions of the four Stopes lithotypes and the two additional types recognized in the Lower Kittanning samples are given in Table 3. All six terms will be referred to as lithotypes in this report.

The technique used for conducting megascopic descriptions was fairly simple. The polished surfaces of the coal blocks were examined under a bright light with the aid of a magnifying glass or hand lens. Each band or zone was measured and identified according to the definitions of the lithotypes, using the 3 mm minimum threshold. Any distinguishing characteristics such as pyrite forms and occurrence of fusain lenses were noted.

The megascopic data were plotted as a 1:1 stratigraphic log. These logs were used to study vertical and lateral variation in lithotype occurrences within the Lower Kittanning seam. The megascopic descriptions also served as the basis for selecting units for microscopic analyses.

Microscopic Petrographic Terminology and Techniques

The most widely used system of nomenclature in coal petrography is known as the Stopes-Heerlen system. The fundamental microscopic unit in this system is the maceral. The term maceral was introduced by Marie Stopes in 1935 to designate the elementary microscopic constituents of coals (ICCP, 1963). Macerals "are the descriptive equivalent of the inorganic units comprising most rock masses and universally called minerals..." (Stopes, 1935).

Table 3. Definitions of Lithotype Terminology

Lithotype	Description
Vitrain	"Very bright bands or lenses, usually 3 to 5 mm thick: thick bands are rare. Clean to the touch. In many coals the vitrain is permeated with numerous fine cracks at right angles to stratification and consequently breaks cubically,-- with conchoidal surfaces" (ICCP, 1963).
Clarain	"Finely striated bands of variable thickness having a lustre between that of vitrain and durain. Conventionally the thickness of the fine, bright and dull striations must be less than 3 mm" (ICCP, 1963).
Durain	"Gray to brownish black color and rough surface with dull or faintly greasy lustre: reflection is diffuse:...markedly less fissured than bands of vitrain, and generally show granular fracture" (ICCP, 1963).
Fusain	"Black or gray color, silky lustre, fibrous structure, extreme friability. The only constituent of coal which marks and blackens objects with which it comes in contact" (ICCP, 1963).
Clarodurain	Intermediate between clarain and durain, banding not as even as in clarain; predominantly dull matrix with bright discontinuous vitrain stringers, and lenses of fusain.
Boney Coal	Grey to brown-black, dull, often with a non-bedded shale-like appearance, hard.

The identification of a particular maceral is determined by its morphology and appearance when viewed microscopically in either reflected or transmitted light. Characteristics which are used to distinguish the individual macerals include: shape, color, reflectance, relief or polishing hardness, and anisotropy. Some of these characteristics are dependent upon the type of microscope illumination system used, i.e. reflected as opposed to transmitted light. In reflected white light the macerals appear in varying shades of gray, black and white with occasional yellowish tinges or internal reflection colors. With thin sections viewed in transmitted light the macerals range in color from bright yellow through red to black. The reflectance characteristics obviously can only be determined in reflected light.

In the Stopes-Heerlen system the individual macerals have been classified into three major groups, namely the vitrinite, liptinite (exinite), and inertinite. The macerals within each group have similar reflectance or color characteristics when viewed under the microscope, but differ from each other in morphology and structure. Table 4 lists most of the individual macerals within the three maceral groups, and offers brief comments on their description and appearance in reflected and transmitted light.

The majority of microscopic coal analyses are conducted in reflected light using oil-immersion objectives. The use of oil immersion provides greater contrast between the various levels of reflectance (shades of gray) displayed by the different macerals. The primary definitions of the macerals in the Stopes-Heerlen system are based on their morphology and appearance in reflected light using oil-immersion objectives. Detailed descriptions and discussions on the origins and properties of the various macerals are given in the International Handbook of Coal

Table 4. Maceral Classification - Stopes-Heerlen System

Maceral Group	Maceral Name	Maceral Description	Appearance	
			Transmitted	Reflected
Vitrinite	Telinite Collinite	altered cell walls, altered cell fillings structureless vitri- nite	red-brown	intermediate gray
	Vitrodetrinite	detrital vitrinite particles		
Liptinitic (or exinite)	Sporinite	altered flattened oval spore exines	yellow	dark gray
	Resinite	round, oval, or rod-like		
	Cutinite	altered waxy leaf cuticles, often with serrate edges		
	Alginite Liptodetrinite	cauliflower like detrital liptinitic particles		
Inertinite	Fusinite Semifusinite	cell structure cell structure, partly gelified	opaque	white, yellowish, light gray
	Macrinite	rounded outline, no cell structure		
	Micrinite	fine granular particles		
	Sclerotinite	roundish chambered bodies		
	Inertodetrinite	detrital inertinite particles		

Petrography (ICCP, 1963, 1971), and in Stach's Textbook of Coal Petrology (Stach et al., 1975).

With the exception of the vitrinite-group macerals, the Stopes-Heerlen system of nomenclature and classification was utilized in this study. The vitrinite maceral group was modified and expanded in order to accommodate the range of vitrinitic materials encountered during microscopic examination of the Lower Kittanning samples.

The microscopic analyses were conducted on both the polished pellets prepared from the channel samples and the polished blocks from the column samples. Standard maceral analyses were performed on the pellets using a Zeiss Universal reflected-light microscope, in plane polarized light, with an oil immersion 40x objective. For each sample 500 points were counted on each of two pellets for a total of 1000 points. The maceral analyses from the pellets was obtained for each of the five channel samples collected for this study.

Detailed microscopic analyses were conducted on the polished blocks of coal using a Zeiss Universal reflected-light microscope, in plane polarized light, with methylene iodide as an immersion medium. Methylene iodide was used in place of the standard oil medium because of the greater degree of contrast it provides.

Two of the five column samples were selected for detailed microscopic analysis, namely PSOC-1340, from the area of marine influence, and PSOC-1335, from the area of freshwater influence. PSOC-1340 was chosen because it was the only sample from the marine facies area. PSOC-1335 was selected from the four "freshwater" samples because it was closest in rank and geographical location to PSOC-1340.

Two separate sets of point-count analyses were performed on each of the two columns. The first set consisted of a standard maceral analysis, the second a vitrinite-type analysis. The standard maceral analysis was conducted to determine overall compositional values for each column sample and for the various lithotypes within each sample. The analysis was done on a mineral-matter-containing basis. The actual macerals and mineral types counted during the analysis are listed in Table 5. During this first analysis the vitrinite types were grouped together. The inertinite and liptinite group macerals were identified as defined by the ICCP (1963). The mineral-matter categories were chosen to cover the range of inorganic occurrences observed in the Lower Kittanning samples. The massive clay usually occurred as lenses, spore infillings, or cell fillings within the fusinite. The disseminated clays were found as whisps, stringers, or finely disseminated particles incorporated in coal macerals, mainly vitrinite. Pyrite was not differentiated as to type, shape, or occurrence. The "other" category was used to record the presence of, most commonly, quartz grains, and occasionally occurrences of siderite.

The vitrinite-type analysis was conducted to determine the relationships between 1) types of vitrinite and the megascopic appearance of lithotypes, and 2) types of vitrinite and the paleoenvironments during deposition of the Lower Kittanning peat. The classes of vitrinite types employed were given letter designations to avoid confusion with previously established nomenclature. Several of the types, however, correspond directly with names established by the ICCP and were so designated in this analysis. Table 6 lists the ten vitrinite categories and describes

Table 5. Categories Used in Maceral Analysis.

Vitrinite Group	Vitrinite (undifferentiated)		Sporinite
			Resinite
	Fusinite	Liptinite Group	Cutinite
	Semifusinite		Alginite
Inertinite Group	Macrinite		Liptodetrinite
	Micrinite		
	Sclerotinite		Clay (massive)
	Inertodetrinite	Mineral Matter	Clay (disseminated)
			Pyrite
			Other

the appearance of each in reflected light with methylene iodide immersion. Several of the categories could not be differentiated under oil immersion. During the vitrinite-type point count the other coal constituents were combined into three groups, inertinite, liptinite, and mineral matter. This permitted comparisons to be made between the results obtained from the two types of analyses.

The lithotypes determined during the megascopic descriptions served as the basis for conducting the microscopic analysis. Point-count analyses, both maceral and vitrinite-type, were conducted on each lithotype. This provides a natural framework for obtaining and analyzing the data. The alternative method would have been to point-count within predetermined intervals, such as every 5 cm; however, this would present the

Table 6. Description of Vitrinite Types in the
Lower Kittanning Seam

Vitrinite Types	Description
A	Corresponds to desmocollinite as described by Stach (1975); lower reflecting, structureless material; most frequently occurs as matrix material but occasionally as pure vitrinite layers; most common vitrinite type observed. See Plate Ia.
A'	Lower reflecting, somewhat structured material with mottled appearance; most often found in discrete layers enclosed by cuticles; may show internal reflections; usually pure but may contain small amounts of micrinite; corresponds most closely to phyllovitrinite as described in Stach (1975). See Plate Ib.
B	Corresponds to telinite as defined by ICCP (1963); cell wall material, may be partially gelified (swollen appearance).
C	Corresponds to telocollinite as described in Stach (1975); higher reflecting, structureless, homogeneous material; usually found as discrete layers; occasionally cuticles are present along the upper and lower boundaries of the layer.
C'	Higher reflecting material with visible cell structure ("wood grain" appearance); occurs in discrete homogeneous layers; frequently grades into type C. Most closely corresponds to telinite with cell filling of collinite or resinite but because of its distinctive appearance was classified separately. See Plate Ic.
D	Corresponds to corpocollinite as defined by ICCP (1963). See Plate II a and b.
E	Corresponds to gelocollinite as defined by ICCP (1963).
F	Fragments of vitrinite, often angular, surrounded by coal macerals; corresponds to vitrodetrinite as defined by ICCP (1963). See Plate IIIa.
G	Argillaceous vitrinite; vitrinite (most commonly Type A) with fine grained clay dispersed throughout, or clay may be confined to a discrete layer. See Plate IIIb.
H	Fragments of vitrinite in a clay matrix, corresponds to vitrodetrinite.

possibility of splitting clearly-defined lithotypes. Subdivision based on lithotypes also permitted investigation into the relationship between megascopic appearance of a coal type and its microscopic composition.

The actual mechanics of point counting the column samples were as follows. The blocks were mounted on a flat 2 X 3 in base with modeling clay, leveled by means of a small press, and placed on a modified Swift automatic point counting stage that was activated by a 12-button counter. Each time a button was pressed the stage automatically advanced 1/3 mm in the x direction (left-right motion). The Swift stage allows a maximum automatic movement of 2.5 cm in the x direction and can be moved manually in the y direction (front-back motion) a maximum of 3 cm. In order to increase the amount of x-direction movement, the Swift stage was fitted to a Leitz graduated mechanical stage which provided up to 11 cm of movement in the x-direction. This arrangement permitted a total area of coal surface of 11 X 3 cm to be analyzed under the microscope. Since the largest dimension of any block was 10 cm, each block could be point counted without any repositioning during analysis. Each block was positioned initially by use of the two knobs on the Leitz mechanical stage. Once a starting position was selected the automatic stepping of the Swift stage provided independent incremental movement in the x direction. The blocks were placed on the stage with the bedding oriented normally to the x direction of movement.

A minimum counting interval of 5 mm, normal to bedding, was selected because this was the size of the smallest megascopically determined lithotype. Within each 5 mm interval seven normal-to-bedding (x direction) traverses of 15 points (1/3 mm spacing) were made for a total of 105 points

in each interval. The seven traverses were spaced 5 mm apart to cover the 30 mm area permitted by the stage arrangement. Therefore, a total of 105 points were counted on each 5 x 30 mm area. At the end of each 105 points the stage was repositioned so that the starting point for the next interval was positioned 1/3 mm away from the end point of the previous interval. The analysis proceeded in this manner until the entire lithotype was covered. For example, a 6 cm thick lithotype consisted of twelve 5 mm counting intervals for a total of 1260 points for that lithotype. In this manner the entire column was analyzed, block-by-block. This resulted in counts of 14,490 points for PSOC-1335 and 14,700 points for PSOC-1340 for both the maceral and vitrinite-type analyses. Figure 9 is a schematic representation of the point-counting technique used.

After both sets (maceral and vitrinite-type) of analyses were completed for each column, a comparison was made between the values obtained for each set. The vitrinite values from the maceral analysis were compared with the sum of the individual vitrinite types from the vitrinite analysis. The sum of the individual maceral and mineral values within each of the inertinite, liptinite and mineral-matter groups obtained from the maceral analysis were compared with the grouped data obtained for these three groups from the vitrinite analysis. If the two compared values were not within the allowable point-counting error, both analyses were repeated.

The allowable error at the 95.4% confidence interval was calculated using the following equation:

$$E_{95.4} = 2 \frac{P(100-P)}{N}$$

where E = probable error in percent

N = total number of points counted

P = percent of component.

Figure 10. MEGASCOPIC DESCRIPTION: PSOC-1197 LOWER KITTANNING SEAM, SOMERSET COUNTY, PA.

The actual comparison was made between maceral and mineral group values obtained for each lithotype from both analyses. For example, for a particular lithotype value the total percent of inertinite obtained from both the maceral and vitrinite analyses were compared. First the calculations would be done using P = percent inertinite obtained from the maceral analysis. The allowable error would be calculated and checked to see if the allowable error included the value obtained for inertinites from the vitrinite analysis. The calculations were then repeated using P = percent total inertinite obtained from the vitrinite analysis and the allowable error compared with the inertinite value from the maceral analysis. The total number of points counted (N) for a lithotype was dependent upon the thickness of that lithotype; the thicker the lithotype the more points that were counted. As the number of total points increased the allowable error decreased. For example, given a component representing 9% of the total lithotype, the allowable error at the 95.4% confidence interval is ± 15.6 when a total of 105 points was counted for a 5 mm lithotype. For a 12 cm thick lithotype the total number of points counted is 2520 with an allowable error of 0.65 for a component representing 9% of the whole.

All data from the two sets of analyses were within the allowable error, so that any major differences in composition as determined by the point-count analysis are not due to counting error.

CHAPTER V

RESULTS OF PETROGRAPHIC ANALYSES

Megascopic Petrography

Megascopic seam profiles showing the vertical sequence of lithotypes in each of the five column samples studied are given in Figures 10 through 14. PSOC-1197, PSOC-1325 and PSOC-1330 (Figures 10, 11, 12, respectively) are predominantly bright coals with scattered, thin, dull layers. PSOC-1335, from Cambria County, has a thicker dull zone near the top of the seam but is also predominantly a bright coal. PSOC-1340, from Jefferson County, has a relatively thick dull zone comprising most of the top 21 cm of the seam. The shale partings present in PSOC-1325, PSOC-1330 and PSOC-1340 are laterally discontinuous. They are interpreted as having formed in response to localized phenomena such as overbank flooding.

The megascopic characteristics of the five Lower Kittanning samples are summarized in Table 7 which displays the relative percentage of each lithotype present in the five columns. In the three Somerset County samples measured portions of the seam were not collected as blocks owing to the extremely friable nature of the coal in certain zones. However, in all of these cases the missing portions were identified in the field as either clarain or vitrain and therefore were included in the percent clarain or vitrain values.

One method of detecting major similarities or differences in the megascopic composition of a series of column samples is to calculate and compare the relative abundances of bright and dull coal. The various lithotypes are assigned to either a bright or dull category. For this study the lithotypes vitrain and clarain were designated as bright coal.

Figure 11. MEGASCOPIC DESCRIPTION: PSOC-1325 LOWER KITTANNING SEAM, SOMERSET COUNTY, PA.

Figure 12. MEGASCOPIC DESCRIPTION: PSOC-1330 LOWER KITTANNING SEAM, SOMERSET COUNTY, PA.

Figure 13. MEGASCOPIC DESCRIPTION: PSOC-1335 LOWER KITTANNING SEAM, CAMBRIA COUNTY, PA.

Figure 14. MEGASCOPIC DESCRIPTION: PSOC-1340 LOWER KITTANNING SEAM, JEFFERSON COUNTY, PA.

Table 7. Lithotype Percentages for Five Column Samples of Lower Kittanning Coal.

Lithotype	Somerset Co. PSOC-1197	Somerset Co. PSOC-1325	Somerset Co. PSOC-1330	Cambria Co. PSOC-1335	Jefferson Co. PSOC-1340
Vitrain	7	3	10	3	7
Clarain	90	95	85	90	63
Durain	0	1	3	7	4
Fusain	0	0	0	0	0
Clarodurain	2	1	0	0	26
Boney Coal	<u>1</u>	<u>0</u>	<u>2</u>	<u>0</u>	<u>0</u>
Total	100%	100%	100%	100%	100%

Table 8. Percentages of Bright and Dull Coal in Five Lower Kittanning Coal Samples.

	Somerset Co. PSOC-1197	Somerset Co. PSOC-1325	Somerset Co. PSOC-1330	Cambria Co. PSOC-1335	Jefferson Co. PSOC-1340
% Bright	97	98	95	93	70
% Dull	<u>3</u>	<u>2</u>	<u>5</u>	<u>7</u>	<u>30</u>
Total	100%	100%	100%	100%	100%

Bright Coal = % vitrain + % clarain.

Dull Coal = % durain + % fusain + % clarodurain + % boney coal.

and the dull coal category included durain, fusain, clarodurain and boney coal. Table 8 shows the percentages of bright and dull coal for each sample. Inorganic partings greater than 5 mm (1/4 in) in thickness were excluded from the total seam thickness for these calculations.

The data in Tables 7 and 8 indicate that a megascopically recognizable and quantifiable difference exists between PSOC-1340 and the other four column samples. This might indicate a different environment of formation on a regional scale, or it may be the result of a local phenomenon such as proximity to a stream channel or local topographic relief.

Microscopic Petrography

Microscopic analyses were conducted in order to:

- 1) determine if the differences observed megascopically occur on a microscopic level;
- 2) investigate the relationship between the megascopic appearance of coal types and the nature of the corresponding microscopic components;
- 3) determine the distribution and abundance of distinctive types of vitrinite macerals; and
- 4) consider any vertical and lateral variations in maceral composition in terms of the range and types of swamp paleoenvironments.

The microscopic analyses consisted of three parts; standard maceral analysis on polished pellets representing all five samples, detailed maceral analysis on polished blocks of columns PSOC-1335 and PSOC-1340, and vitrinite-type analysis on polished blocks of columns PSOC-1335 and PSOC-1340.

Maceral Analysis - Polished Pellets

At the beginning of the study, maceral analyses were performed on pellets prepared from the complete channel samples collected at each of the five sample locations. This was done to determine if major differences or similarities could be detected with a standard maceral analysis. Oil immersion was used and 1000 points were counted for each sample. The results are shown in Table 9.

No liptinite was observed in PSOC-1197, PSOC-1325 or PSOC-1330 because of the high rank (low volatile bituminous) of the coal in these areas. PSOC-1340 is the lowest rank sample collected, accounting for the higher liptinite value obtained during the analysis. Although some differences in the liptinite contents of the two areas could have existed in the original peats, that difference is now masked because liptinite is not discernible under the microscope in the higher rank Somerset County coal. The slightly lower vitrinite percentage reported for this coal probably is a function of the apparent increase in liptinite.

The data from this set of analyses indicate a similarity in overall composition of the five samples. Previous paleoenvironmental reconstructions and related studies (Williams, 1960; Ting, 1967; Habib, 1966), have indicated that at least one of the samples, PSOC-1340, should be from an area of marine influence. The remaining samples were collected from areas of no marine influence. At this point there seem to be three alternatives regarding the five Lower Kittanning samples under investigation.

- 1) Different environmental conditions such as marine or non-marine have no effect on the maceral composition of the coal.

Table 9. Maceral Analysis - Pellets - Oil Immersion.

	PSOC-1197	Somerset County PSOC-1325	PSOC-1330	Cambria Co. PSOC-1335	Jefferson Co. PSOC-1340
Vitrinite	89	90	84	81	77
Fusinite	1	tr	tr	1	1
Semifusinite	2	2	3	7	2
Macrinite	tr	1	1	1	1
Micrinite	2	1	1	3	3
Inertodetrinite	1	tr	2	1	3
Liptinite	0	0	0	1	8
Pyrite	tr	1	1	1	1
Clay	5	4	8	4	4
Other Mineral Matter	0	1	0	0	0

Percentage values rounded to nearest whole number.

tr = trace, i.e. < 1%

- 2) All five samples collected are from similar environments of deposition.
- 3) Compositional differences can occur as a result of paleo-environmental changes or differences but may not be detectable through routine maceral analyses.

Previous petrographic research on the Lower Kittanning coal (Ting, 1967; Reyes-Navarro and Davis, 1976), indicate alternative #1 is unlikely. The paleoenvironmental model on which this study is based indicates that alternative #2 should not be the case. Since the first 2 possibilities seem unlikely and because a difference was observed in the megascopic analyses, alternative #3 was tested.

Maceral Analyses - Polished Blocks

The next step consisted of conducting detailed maceral analyses on the entire seam using the sequences of vertically contiguous polished blocks. One of the major problems with microscopic analysis of the coals collected for this study was the relatively high rank of the Lower Kittanning seam along the eastern and southeastern portions of the coalfield. The higher contrast provided by the use of methylene iodide as an immersion medium permitted the differentiation of macerals and maceral types that would not have been possible with the use of standard oil immersion objectives. For example, the rank of PSOC-1335, 1.2% R_o (medium volatile bituminous), is at approximately the point where the reflectance of the sporinite merges with that of the vitrinite. This would mask the presence of sporinite under ordinary oil immersion. With the use of a methylene iodide objective the spores are still discernable, even past the point where they have effectively disappeared if observed with oil

immersion. In addition, the use of methylene iodide enables the observer to notice subtle differences in reflectance levels and even structures of different types of the same maceral, such as vitrinite.

Only two of the column samples were selected for this phase of the study, PSOC-1335 (Cambria Co.) and PSOC-1340 (Jefferson Co.). The high rank ($R_0 = 1.7\%$, low volatile bituminous) of the other three samples excluded them from the detailed microscopic analysis. Even with the methylene iodide immersion medium, their overall microscopic appearance was too homogeneous to provide the necessary amount of useful information.

The raw data assembled during these detailed maceral analyses are given in Tables 10 and 11. Petrographic logs displaying a graphic representation of the maceral analyses are shown in Figures 15 through 18. For the maceral analyses a total of 14,490 points was counted for PSOC-1335 and 14,700 points for PSOC-1340. Figures 15 and 17 show the results of the actual maceral analysis for each column by lithotype. Figures 16 and 18 show the grouped vitrinite, inertinite and liptinite values calculated to a mineral-matter-free basis.

PSOC-1335 (Cambria County)

The overall microscopic composition of PSOC-1335 appears to be fairly uniform. Noticable differences in maceral composition occur in the three durain bands at 10-10.5 cm, 11-14.5 cm and 65-66 cm; the few scattered vitrain bands; and the massive pyrite layer at 62.5-63.5 cm.

The lithotype clarain comprises 90% of the seam at this locality, and as Figure 15 shows the maceral composition of the clarains is fairly similar. Megascopically the clarains exhibit banding in the form of alternating bright and dull layers. Microscopically this banding is apparent as bands of very pure vitrinite alternating with heterogeneous

Table 10. Maceral Analysis Data from Polished Blocks of PSOC-1335

Interval Thickness cms		Litho- type	Vitri- nite	Fusi- nite	Semi- fusinite	Macri- nite	Micri- nite	Inert- detrinite	Spori- nite	Cuti- nite	Resi- nite	Lipto- detrinite	Clay (massive)	Clay (disseminated)	Pyrite	Other Mineral Matter
0- 1.5	cts %	C	241 77	- -	15 5	1 Tr	9 3	4 1	7 2	- -	- -	- -	1 Tr	21 7	11 3	5 2
1.5- 2.5	cts %	V	204 97	- -	2 1	- -	- -	- -	- -	- -	- -	- -	- -	2 1	2 1	- -
2.5- 3.5	cts %	C	135 64	5 2	22 0	2 1	7 3	14 7	11 5	- -	- -	6 3	- -	5 2	3 1	- -
3.5- 8.5	cts %	C	647 62	21 2	75 7	2 Tr	58 6	48 5	66 6	2 Tr	- -	3 Tr	6 1	97 9	10 1	15 1
8.5- 9.0	cts %	V	95 90	- -	1 1	- -	- -	- 1	2 2	- -	- -	- -	- -	4 4	2 2	- -
9.0-10.0	cts %	C	135 64	2 -	16 8	- -	2 1	14 7	12 6	- -	- -	- -	- -	14 7	2 1	13 6
10.0-10.5	cts %	D	59 56	- 1	14 13	2 2	- -	9 9	13 12	- -	1 1	- -	- -	4 4	- -	2 2
10.5-11.0	cts %	C	68 65	- -	5 5	- -	1 1	5 5	13 12	- -	- -	- -	- -	12 11	1 1	- -
11.0-14.5	cts %	D	203 28	16 2	74 10	2 Tr	6 1	103 15	101 14	- -	- -	1 Tr	- -	151 20	1 Tr	72 10
14.5-48.5	cts %	C	5104 71	130 2	471 7	32 Tr	289 4	347 5	345 5	4 Tr	2 Tr	17 Tr	34 Tr	197 3	44 1	124 2

(Continued)

Table 10 (Continued)

48.5-49.0	cts	V	105	-	-	-	-	-	-	-	-	-	-	-	-	-
	%		100	-	-	-	-	-	-	-	-	-	-	-	-	-
49.0-52.5	cts	C	2192	105	163	8	66	83	92	1	3	4	6	41	30	41
	%		77	4	6	Tr	2	3	3	Tr	Tr	Tr	Tr	1	1	1
62.5-63.5	cts	Pyr	25	-	-	1	-	-	-	-	-	-	-	-	184	-
	%		12	-	-	Tr	-	-	-	-	-	-	-	-	88	-
63.5-65.0	cts	C	254	1	5	-	6	10	10	-	-	-	-	11	9	9
	%		81	Tr	2	-	2	3	3	-	-	-	-	3	3	3
65.0-65.0	cts	D	41	-	39	6	6	39	27	-	-	-	1	27	3	21
	%		20	-	19	3	3	19	13	-	-	-	Tr	13	1	10
66.0-69.0	cts	C	448	9	31	1	8	22	16	-	-	-	9	22	45	19
	%		71	1	5	Tr	1	3	3	-	-	-	1	3	7	3
0-69 cm			69	2	6	Tr	3	5	5	Tr	Tr	Tr	Tr	4	2	2

V = vitrain; C = clarain; D = durain, Pyr = pyrite band; Tr = trace, i.e. < 1%.

cts = actual counts.

% = percent values.

Table 11. Maceral Analysis Data from Polished Blocks of FSDC-1340

Interval Thickness cms		Litho- type	Vitri- nite	Fusi- nite	Semi- fusinite	Macri- nite	Micri- nite	Inerto- detrinite	Spori- nite	Cuti- nite	Resi- nite	Liptc- detrinite	Clay (massive)	Clay (disseminated)	Pyrite	Other Mineral Matter
0- 5.0	cts %	CD	489 47	36 3	50 5	1 Tr	4 Tr	79 8	55 5	3 Tr	2 Tr	13 1	62 6	157 15	22 2	77 7
5.0- 5.5	cts %	V	105 100	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
5.5-10.0	cts %	CD	393 42	12 1	41 4	2 Tr	39 4	197 21	104 11	- -	- -	13 1	17 2	95 10	8 1	24 3
10.0-10.5	cts %	V	102 97	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	3 3	- -
10.5-12.5	cts %	D	268 64	2 Tr	6 1	2 Tr	- -	54 13	80 19	- -	- -	6 1	- -	1 Tr	1 Tr	- -
12.5-21.0	cts %	CD	988 55	4 Tr	69 4	12 1	90 5	287 16	272 15	1 Tr	3 Tr	7 Tr	4 Tr	17 1	23 1	8 Tr
21.0-27.0	cts %	C	992 79	9 1	19 2	4 Tr	69 5	34 3	75 6	5 Tr	4 Tr	12 1	5 Tr	18 1	4 Tr	10 1
27.0-32.5								SHALE PARTINGS								
32.5-44.5	cts %	C	2092 83	14 1	35 1	12 Tr	44 2	46 2	105 4	18 1	3 Tr	33 1	36 1	75 3	6 Tr	1 Tr
44.5-45.0	cts %	V	98 93	- -	2 2	- -	1 1	2 2	1 1	- -	- -	1 1	- -	- -	- -	- -

(Continued)

Table 11 (Continued)

45.0-47.0	cts %	C	335 85	1 Tr	3 1	- -	17 4	4 1	16 4	8 2	- -	12 3	3 1	1 Tr	- -	- -
47.0-47.5	cts %	V	102 97	- -	- -	- -	- -	- -	3 3	- -	- -	- -	- -	- -	- -	- -
47.5-48.5	cts %	C	182 87	- -	- -	- -	8 4	3 1	9 4	3 1	- -	4 2	- -	1 Tr	- -	- -
48.5-49.0	cts %	V	102 97	- -	1 1	- -	1 1	1 1	- -	- -	- -	- -	- -	- -	- -	- -
49.0-49.5	cts %	C	88 84	1 1	2 2	1 1	5 5	3 3	4 4	- -	- -	- -	- -	1 1	- -	- -
49.5-50.0	cts %	V	104 99	- -	- -	- -	- -	1 1	- -	- -	- -	- -	- -	- -	- -	- -
50.0-52.5	cts %	C	391 74	3 1	26 5	6 1	24 5	29 6	38 7	2 Tr	- -	2 Tr	2 Tr	2 Tr	- -	- -
52.5-53.0	cts %	V	101 96	- -	1 1	- -	- -	1 1	2 2	- -	- -	- -	- -	- -	- -	- -
53.0-57.0	cts %	C	626 75	4 Tr	44 5	3 Tr	29 3	50 6	55 7	1 Tr	- -	10 1	- -	6 1	- -	12 1
57.0-57.5	cts %	V	103 98	- -	- -	- -	1 1	- -	1 1	- -	- -	- -	- -	- -	- -	- -
57.5-70.0	cts %	C	2205 84	26 1	134 5	21 1	62 2	56 2	80 3	5 Tr	- -	21 1	8 Tr	5 Tr	2 Tr	- -
0-21 cm			53	1	4	Tr	3	14	12	Tr	Tr	1	2	6	1	2
21-70 cm			83	1	3	1	3	2	4	1	Tr	1	1	1	Tr	Tr
0-70 cm			73	1	3	1	3	6	7	Tr	Tr	1	1	3	1	1

V = vitrain; C = claraïn; D = durain; CD = clarodurain; Tr = trace, i.e. < 1%.

cts = actual counts.

% = percent values.

Figure 15. PETROGRAPHIC PROFILE OF PSOC-1335 – MACERALS, MINERAL CONTAINING BASIS; LOWER KITTANNING SEAM, CAMBRIA COUNTY, PA.

Figure 16. PETROGRAPHIC PROFILE OF PSOC-1335 - MACERAL GROUPS, MINERAL-FREE BASIS; LOWER KITTANNING SEAM, CAMBRIA COUNTY, PA.

Figure 17. PETROGRAPHIC PROFILE OF PSOC-1340 - MACERALS, MINERAL CONTAINING BASIS; LOWER KITTANNING SEAM, JEFFERSON COUNTY, PA.

Figure 18. PETROGRAPHIC PROFILE OF PSOC-1340 - MACERAL GROUPS, MINERAL-FREE BASIS; LOWER KITTANNING SEAM, JEFFERSON COUNTY, PA.

duller layers. Vitrinite is the most common component of the clarains, present in both the pure vitrinite bands and as the matrix of the heterogeneous layers. The various types of vitrinite present are discussed in the section on vitrinite-type analyses. The inertinite, liptinite and mineral matter in the clarains are concentrated in the heterogeneous duller layers. While the absolute abundance of inertinite macerals ranges from 7 to 24% (Table 13) within the clarain, the relative abundance of the individual inertinite macerals remains fairly consistent. The fusinite and semifusinite are scattered throughout the dull heterogeneous layers and macrinite is rare. Inertodetrinite is not as prevalent as in the durains but ranges from 1 to 7% of the total composition of the clarains. The liptinite consists mainly of spores with very minor amounts of cutinite, resinite and liptodetrinite. Although maceration and spore analyses were not performed, no identifiable pattern of the occurrence and distribution of spore types was observed during the course of the petrographic study. The relative abundance of thick-to-thin-walled spores did not show a distinct vertical variation. This is consistent with the lack of vertical variation in spore types in coals underlying the freshwater facies of the Lower Kittanning shale (Habib, 1966). The mineral matter consists predominantly of fine clays disseminated throughout the vitrinite matrix of the dull layers, similar to the occurrence of micrinite. Clay also occurs as cell fillings in fusinite and semifusinite, and occasionally fills spore cavities. Quartz grains are also fairly common in the dull layers. Some pyrite occurs as cell fillings in fusinite, and small crystals and framboids were observed, most often associated with the purer vitrain bands.

The most distinctive feature of the durains is their higher inertinite content, in particular inertodetrinite is up to three times as abundant as in the clarains and makes up from 9 to 19% of the total composition of the durains. Inertodetrinite particles counted during analysis of polished blocks in which the seam is studied intact are a result of in situ degradation processes and therefore can provide information concerning conditions and processes operating in the swamp during peat accumulation. Semifusinite also is common, occurring as compressed lenses and often exhibiting "bogenstruktur". In some instances, it appears to have been partially gelified. Fusinite is scarce and occurs as small lenses one to two cells thick. The liptinite macerals in the durains consist of thick- and thin-walled microspores, megaspores and megaspore fragments. In the thick durain layer at 11-14.5 cm the microspores often are filled with clay and therefore have not been compressed. The vitrinite types present within the durains are discussed under the results of the vitrinite-type analysis; however, the slight banding these durains exhibit megascopically is a result of the presence of discontinuous stringers of impure vitrinite. The durain bands contain a higher proportion of mineral matter than the other lithotypes. Most of this is in the form of finely disseminated clays. Rounded quartz grains also are common in these durains. Pyrite is rare, occurring as small framboids and euhedra. The durains in PSOC-1335 are interpreted as having formed in response to localized and temporary environmental changes, such as a local rise or fall in the water table.

The vitrain bands are scarce; only three occur in PSOC-1335 and all three are very pure. The actual vitrinite types contained in these bands are described in the section on vitrinite-type analyses.

The massive pyrite zone at 62.5 cm is 1 cm thick and extends across the entire sample block. In the mine this pyrite zone was a lens-shaped mass of pyrite approximately 15 to 20 cm in its longest observed dimension. - Under the microscope it consisted of large intergrown framboids with pyrite overgrowths. Vitrinite fragments were present at the upper and lower boundaries of the zone. Many of the vitrinite bands throughout the column contained small pyrite framboids, so perhaps this massive pyrite zone was the result of complete replacement of a former vitrain band.

In summary, the overall microscopic composition of PSOC-1335 is fairly uniform and shows no distinct trends or zonations in vertical variability. Noticable differences in composition occur in the durain and vitrain lithotypes; however, these constitute only a minor portion (durain = 7%, vitrain = 3%) of the entire seam.

PSOC-1340 (Jefferson County)

PSOC-1340 has a marked zonation between the upper 21 cm and the lower 49 cm of the seam. The lower 49 cm (except the parting at 27 to 32.5 cm) is moderately bright clarain with six vitrain bands concentrated between 44 and 58 cm. The upper 21 cm is considerably duller than the lower portion of the seam. The upper zone is composed predominantly of claro-durain with two 5 mm vitrain bands and one 2 cm durain (at 10.5-12.5 cm). Figures 17 and 18 show the petrographic profiles constructed for PSOC-1340.

The clarodurains in the upper portion of the seam display the greatest variety in composition and maceral association. Vitrinite content ranges from 42-55% of the total volume of this lithotype and is described in the section on vitrinite analysis. They contain appreciably larger

amounts of inertinite and liptinite than the rest of the seam, particularly inertodetrinite which comprises up to 21% of the total volume of the lithotype. The liptinite (predominantly sporinite) content of these clarodurains actually decreases towards the top of the seam. The two clarodurains at the top (0-5.0 cm and 5.5-10.0 cm) contain large megaspores and megaspore fragments with scattered thick- and thin-walled microspores. The microspores appear degraded in many cases. The clarodurain at 12.5 to 21 cm contains the greatest proportion of sporinite (15%), with several of the layers of this clarodurain containing abundant densospores in a vitrinite matrix. These spores also appear somewhat degraded and are associated with inertodetrinite particles, small pyrite grains and clay particles.

As Figure 17 shows, the mineral matter content increases towards the top of the seam. The uppermost layer, a clarodurain at 0 to 5 cm, contains 30% mineral matter. Most of this is in the form of disseminated clays, but appreciable amounts of massive clay lenses and quartz grains also occur. The cavities of large megaspores are often filled with detrital material, usually clay, but occasionally include fragments of inertinite and liptinite in a vitrinite matrix.

Some interesting structures and maceral associations occur in the three clarodurains which can best be described as organic clasts (Plate IIIa). They are small (2-3 mm) lens-shaped aggregates consisting predominantly of inertodetrinite, with some spore fragments and subangular vitrinite fragments (vitrodetrinite). They occur as discrete entities, and are elongated parallel to the bedding. The enclosing coal macerals are compacted around these bodies which probably originated as transported clasts of previously deposited and partially consolidated peat. Modern

analogs may be seen along the barrier islands off the coast of Virginia and North Carolina. In these areas fragments of Pleistocene peat deposits are continually being eroded and redeposited along tidal channels and inlets along the coast (personal observation).

The only durain identified occurs at 10.5-12.5 cm. Study of this lithotype provided insight into the relationship between megascopic appearance and microscopic composition of coal types. Vitrinite content of this durain is 64%, which is somewhat higher than that of the clarodurains and less than that determined for the clarains in the lower portion of the seam. It has the highest concentration of liptinite within the seam (20%), and resembles the clarodurains in terms of inertinite content (14%). The layer has very little mineral matter, consisting of trace amounts (< 1%) of clay and pyrite.

The megascopically visible banding exhibited by the clarain and, in a less regular manner, by the clarodurain lithotypes is readily discernible on a microscopic level. In these lithotypes heterogeneous layers alternate with layers of relatively pure vitrinite, creating a banded appearance. In the durain at 10.5 to 12.5 cm the inertinite and liptinite is dispersed throughout a vitrinite matrix, rather than concentrated in discrete bands. This textural difference accounts for its duller, non-banded megascopic appearance.

The clarains in PSOC-1340 are similar in composition, both above and below the shale parting. As in PSOC-1335 they are composed of pure vitrinite layers alternating with heterogeneous layers where inertinite, liptinite and mineral matter is concentrated. Semifusinite, micrinite and inertodetrinite are the most abundant inertinite macerals. The liptinite is predominantly sporinite, but with significant amounts of

cutinite and liptodetrinite. The actual percentage values are listed in Table 11.

The mineral-matter content of the clarains in PSOC-1340 is substantially lower than in PSOC-1335. Quartz grains are extremely rare and clays are present in very minor amounts. Pyrite is scarce to absent in these clarains; it was observed only in those clarains above and below the parting and at the base of the seam.

As Figure 17 shows, the two clarains at 50 to 52.5 cm and 53 to 57 cm have higher inertinite contents than the other clarains in the seam. These two clarains most clearly resemble the clarains of PSOC-1335.

The vitrains are more numerous in PSOC-1340 than in PSOC-1335, eight in all.

In summary, the vertical zonation visible megascopically in PSOC-1340 is also obvious in the microscopic composition. The duller upper 21 cm contains larger amounts of inertinite, liptinite and mineral matter. The observed occurrence of abundant densospores concentrated in the clarodurains and durain of the upper zone is consistent with the findings of Habib (1966) and Ting (1967). Habib found greater vertical variability in spore assemblages with a densospore-dominated assemblage occurring at the top of the coal wherever it was directly overlain by the marine facies of the Lower Kittanning shale. Ting (1967) also observed greater variability and vertical zonations in the petrography of the coal, with the uppermost zone ("phytostrome") of the coal containing abundant densospores in areas underlying the marine facies of the shale. The clarains comprising the lower portion of the seam consist predominantly of vitrinite, with inertinite and liptinite components concentrated in layers. The alternation of vitrinite and heterogeneous layers produces the stratified appearance recognized megascopically as banding.

Comparison of PSOC-1335 and PSOC-1340

The lateral variability between the two samples is shown in Table 12 which provides a summary of the microscopic analysis in the form of mean values for each of the maceral groups, on a mineral-matter-containing and a mineral-matter-free basis. Because PSOC-1335 possessed no marked vertical zonation the means are given for the whole seam only. The data for PSOC-1340, however, have been calculated for two zones, namely 0 to 21 cm and 21 to 70 cm (excluding the parting at 27 to 32.5 cm); mean values are also given for the whole seam.

The mean values for the whole seam obtained for the two columns, show an overall similarity, as did the maceral data from the pellet analyses (given in Table 9). However, the composition of the upper 21 cms of PSOC-1340 is notably different from that of the lower subsection, reflecting the vertical zonation noted in the megascopic description. A comparison of the means for PSOC-1335 to each of the subsections in PSOC-1340 reveals no distinct similarities. The apparent discrepancy in maceral composition of the coals, particularly PSOC-1335, reported in Tables 9 and 12 is a function of the different analytical techniques employed in the analyses. Table 9 reports the data obtained from analysis of polished pellets of crushed coal using the standard oil immersion techniques. The data in Table 12 were obtained from analysis of the polished blocks using methylene iodide immersion. An increased ability to recognize liptinite macerals using methylene iodide immersion is apparent in a comparison of the values obtained from the two different types of analysis.

Clarain comprises 90% of PSOC-1335 and 93% of the lower zone of PSOC-1340. Because of this similarity a comparison was made of the maceral data

Table 12. Composition of PSOC-1335 and PSOC-1340 by Maceral Group - Mean Values

	Mineral-Matter Containing Basis				Mineral-Matter- Free Basis		
	V	I	L	M	V	I	L
<u>PSOC-1335 (Cambria County)</u>							
0-69 cm	69	17	5	9	75	19	6
<u>PSOC-1340 (Jefferson County)</u>							
0-21 cm	53	22	13	12	60	26	14
21-70 cm	82	10	6	2	84	10	6
0-70 cm	73	14	8	5	77	15	9

V = vitrinite; I = inertinite, L = liptinite, M = mineral matter.

for these two groups of clarains. Table 13 summarizes the compositional data obtained for the clarains in the two samples. A comparison of the means for each of the maceral groups and mineral matter shows that the clarains of PSOC-1340 average higher vitrinite and lower inertinite and mineral matter contents than those of PSOC-1335. The major difference appears to be in mineral matter content. When the maceral data are recalculated to a mineral-matter-free basis, the compositions of the two seams become more similar. Clarains of PSOC-1335, however, still have a higher inertinite content.

The lateral variability of the two samples is most evident in the presence of a distinct vertical zonation in PSOC-1340 and a lack of any in PSOC-1335. The similarity observed in megascopic appearance between PSOC-1335 and the lower zone of PSOC-1340 is not as noticable in terms of microscopic composition. However, the following factors should be taken into consideration, namely:

Table 13. Maceral Group Composition of Clarains from PSOC-1335 and PSOC-1340

PSOC-1335 (Cambria Cc.)					PSOC-1340 (Jefferson Cc.)				
cm/%	V	I	L	M	cm/%	V	I	L	M
0-1.5	77	9	2	12	21.0-27.0	79	11	8	3
2.5-3.5	64	24	8	4	32.5-44.5	83	5	6	5
3.5-8.5	62	19	7	12	45.0-47.0	84	5	9	1
9.0-10.0	64	16	6	14	47.5-48.5	87	5	8	Tr
10.5-11.0	65	11	12	12	49.0-49.5	84	11	4	1
14.5-48.5	71	18	5	6	50.0-52.5	74	17	3	1
49.0-62.5	77	15	4	4	53.0-57.0	74	15	3	2
63.5-65.0	81	7	3	9	57.5-70.0	84	11	4	1
66.0-69.0	71	11	3	15					
$\bar{x}$	70	14	6	10	$\bar{x}$	81	10	7	2
s	± 6.8	± 5.4	± 3.3	± 4.3	s	± 4.7	± 4.4	± 1.9	± 1.5

MINERAL-MATTER-FREE BASIS

cm/%	V	I	L	cm/%	V	I	L
0-1.5	87	11	2	21.0-27.0	81	11	8
2.5-3.5	67	25	8	32.5-44.5	87	6	7
3.5-8.5	70	22	8	45.0-47.0	85	6	9
9.0-10.0	75	19	7	47.5-48.5	87	5	8
10.5-11.0	74	12	14	49.0-49.5	85	11	4
14.5-48.5	76	19	5	50.0-52.5	75	17	8
49.0-62.5	81	16	4	53.0-57.0	76	15	8
63.5-65.0	89	8	3	57.5-70.0	84	12	4
66.0-69.0	84	13	3				
$\bar{x}$	78	16	6	$\bar{x}$	83	10	7
s	± 7.5	± 5.6	± 3.7	s	± 4.7	± 3.9	± 1.9

- 1) the heterogeneous and variable nature of coal,
- 2) the fact that the two sample sites are separated by a distance of 45 miles, and
- 3) the variability of paleoenvironments existing within the basin (E.G. Williams, 1960).

When these factors are considered, coupled with the obvious differences of the upper zone of PSOC-1340, the similarities between PSOC-1335 and the lower zone of PSOC-1340 appear more striking.

Vitrinite-Type Analyses

Vitrinite is the major microscopic component of the Lower Kittanning coal. Analysis of the various vitrinite types was conducted to determine if recognizable trends exist in the vertical and lateral distribution and relative abundance of the individual vitrinite types, and to relate any identifiable trends to variations in paleoenvironments of the Lower Kittanning swamp. The relationship between megascopic appearance of the lithotypes and component vitrinite-types was also investigated.

Vitrinite types within the Lower Kittanning samples were differentiated on the basis of reflectance levels and morphology. Some of the types have been differentiated on the basis of their plant anatomical characteristics; quite possibly these might be better described as phytoliths (Cady, 1942) rather than macerals. Descriptions of the ten vitrinite types distinguished are given in Table 6, with accompanying photomicrographs in Plates I through III. The results obtained during the analysis, reported on a percent basis, are shown in Tables 14 and 15 for PSOC-1335 and PSOC-1340, respectively. Mean values for each vitrinite type are given at the bottom of the table for the whole seam and for zones within PSOC-1340.

Plate I. (a) Desmocollinite forming matrix material enclosing sporinite and inertodetrinite. Methylene iodide immersion (x625). (b) Vitrinite Type A' - lower reflecting vitrinite with mottled appearance (Phyllovitrinite), bounded by cutinite. Methylene iodide immersion (x625). (c) Vitrinite Type C' - telinite with cell fillings and "wood grain" appearance. Methylene iodide immersion (x625).

a

b

c

PLATE I

Plate II. (a) Vitrinite Type D - Corpocollinite. Methylene iodide immersion (x625). (b) Same field view as (a) but under oil immersion (x625).

a

b

Plate III. (a) Vitrinite Type F - Vitrodetrinite, vitrinite fragment in center of organic clast. Methylene iodide immersion (x625). (b) Vitrinite type G - Agrillaceous vitrinite, clay particles incorporated in vitrinite, oil immersion (x625).

a

b

Table 14. Results of Vitrinite-Type Analysis - PSOC-1335
(Cambria Co.) Percent Values

cm	Litho- type	Vitrinite Types									
		A	A'	B	C	C'	D	E	F	G	H
0.0- 1.5	C	42	2	-	53	1	1	-	Tr	Tr	Tr
1.1- 2.5	V	4	1	-	80	15	-	-	-	-	-
2.5- 3.5	C	71	6	-	19	3	-	-	-	2	-
3.5- 8.5	C	38	1	Tr	49	2	1	-	-	9	Tr
8.5- 9.0	V	3	-	-	96	1	-	-	-	-	-
9.0-10.0	C	43	1	-	39	-	1	-	1	15	-
10.0-10.5	D	87	-	-	12	-	-	-	-	2	-
10.5-11.0	C	41	-	-	55	-	-	-	-	3	-
11.0-14.5	D	46	-	-	22	-	-	-	-	33	-
14.5-48.5	C	64	2	-	30	Tr	2	-	Tr	1	-
48.5-49.0	V	-	-	-	100	-	-	-	-	-	-
49.0-62.5	C	65	2	-	26	3	3	-	-	1	-
62.5-63.5	Pyr	36	-	-	64	-	-	-	-	-	-
63.5-65.0	C	73	2	-	19	-	2	-	-	4	-
65.0-66.0	D	57	-	-	4	-	7	-	4	28	-
66.0-69.0	C	88	1	-	8	-	Tr	-	-	3	-
U-69		60	2	Tr	32	1	2		Tr	3	Tr

C = clarain; V = vitrain; D = durain; Pyr = pyrite; Tr = trace amount (> 1%). All percent values are rounded off to nearest whole number.

Table 15. Results of Vitrinite-Type Analysis - PSOC-1340
(Jefferson Co.) Percent Values

cm	Litho- type	Vitrinite Types									
		A	A'	B	C	C'	D	E	F	G	H
0.0- 5.0	CD	39	-	Tr	14	11	2	-	3	16	14
5.0- 5.5	V	-	-	-	100	-	-	-	-	-	-
5.5-10.0	CD	31	1	Tr	5	2	4	-	2	55	Tr
10.0-10.5	V	-	-	-	92	8	-	-	-	-	-
10.5-12.5	D	74	1	-	22	-	2	Tr	Tr	1	-
12.5-21.0	CD	77	7	-	5	7	3	-	1	-	-
21.0-27.0	C	68	6	-	20	2	4	-	Tr	1	-
32.5-44.5	C	55	13	-	24	3	3	-	Tr	1	-
44.5-45.0	V	4	-	-	95	1	-	-	-	-	-
45.0-47.0	C	58	4	-	36	Tr	1	-	-	1	-
47.0-47.5	V	8	-	-	89	3	-	-	-	-	-
47.5-48.5	C	53	1	-	45	1	1	-	-	-	-
48.5-49.0	V	3	-	-	94	-	3	-	-	-	-
49.0-49.5	C	23	-	-	70	3	2	-	2	-	-
49.5-50.0	V	-	-	-	99	-	1	-	-	-	-
50.0-52.5	C	47	5	-	41	Tr	6	-	1	-	-
52.5-53.0	V	3	2	-	88	6	1	-	-	-	-
53.0-57.0	C	69	9	-	13	3	6	-	Tr	1	-
57.0-57.5	V	-	-	-	99	1	-	-	-	-	-
57.5-70.0	C	57	4	-	36	1	2	-	Tr	1	-
0-21		54	3	Tr	17	6	2	Tr	1	13	3
21-70		53	7	0	34	2	3	0	Tr	1	0
0-70		53	6	Tr	30	3	3	Tr	1	4	1

C = clarain; V = vitrain; CD = clarodurain; D = durain; Tr = trace amount (< 1%). All percent values are rounded off to the nearest whole number.

The major vitrinite type present in PSOC-1335 and PSOC-1340 is type A. This material may occur as discrete homogeneous bands, but most frequently appears as the matrix material of layers containing other macerals or mineral matter. Type A, which corresponds to desmocollinite in the Stopes-Heerlen classification, is the dominant form of vitrinite found in the dull layers of the seam, the durains and clarodurains. It is also the major constituent in most of the clarains, but occasionally is less abundant than type C (telocollinite).

Type A' is a minor vitrinite component. It exhibits a mottled appearance and is most often found in discrete pure layers, enclosed by cutinite. This vitrinite type corresponds most closely to phyllovitrinite as described and pictured by Stach (1975). The cutinite enclosing this vitrinite type is thicker than any observed elsewhere in the sample, and frequently display stomatal openings. A probable origin of this vitrinite is parenchymatous mesophyll, or perhaps humic substances which entered through the stomatal openings during early stages of peat diagenesis. Type A' is most abundant in the lower zone of PSOC-1340, most commonly associated with clarain. However, the clarodurain occurring at the base of the upper zone in PSOC-1340 contains 7% of its vitrinite as type A'.

Vitrinite Type B is composed purely of cell-wall material, either preserved intact and filled with non-vitrinite material, or partially swollen and/or compressed. The Stopes-Heerlen term for this vitrinite type is telinite. As the data show, it is a very rare component of these coals.

The higher reflecting, homogeneous, band vitrinite is classed as type C, and is the second most abundant form of vitrinite in the Lower

Kittanning samples studied. Vitrinite type C, which is termed telocollinite in the Stopes-Heerlen system, is present in varying amounts in all lithotypes throughout the seam. It normally occurs as discrete layers of varying thickness, up to 5 mm in the case of vitrain bands. The vitrains in the Lower Kittanning columns are composed almost entirely of vitrinite type C. Within the clarains, type C is the dominant vitrinite comprising the homogeneous, bright bands, while type A (desmocolinite) forms the matrix of the heterogeneous layers. Occasionally, within the clarains, thin cuticles in varying degrees of preservation form the upper and lower boundaries of the telocollinite bands. These bands which are rimmed by cuticles are thought to be derived from leaves or green twigs (M. Teichmüller in Stach, 1975). Type C is a relatively minor component of the vitrinite within the clarodurains of PSOC-1340, occurring as the megascopically visible thin (< 1 mm), discontinuous vitrinite stringers. The seemingly high percentage of type C contained in some of the durains, in both samples, is a result of the presence of isolated, thin (< 1 mm) vitrinite lenses or discontinuous stringers.

If the higher reflecting band vitrinite contained apparent cell structure, it was designated type C'. This material actually appears to consist of telinite with cell fillings of collinite or resinite. Because it is not a pure maceral substance, but incorporates the cell-filling material (including some which is not even vitrinitic) it might be preferable to think of type C' as a phytol rather than a maceral. It was classified separately because of its distinctive appearance and common physical associations with type C. Type C' occurs only in the homogeneous bands of vitrinite type C and the two types, C and C', most often grade into one another. As Tables 14 and 15 indicate, type C'

shows no particular vertical distribution within the seam, nor does it show any affinity for a particular lithotype.

Vitrinite type D is corpocollinite as defined by the ICCP (1971, 1975). It is slightly more common in PSOC-1340 than in PSOC-1335, but shows no marked affinity for lithotypes or subsections within either column sample.

Type E, gelocollinite as defined by the ICCP (1971, 1975), is extremely rare. Only one instance of its occurrence was noted out of over 29,000 points counted.

The most frequent occurrence of type F, vitrodetrinite as defined by the ICCP (1971, 1975), is in the organic clasts described previously. Its greatest abundance is in the upper 21 cm of PSOC-1340, where these clasts are concentrated.

Type G, the argillaceous vitrinite, is vitrinite material which contains fine-grained clays dispersed throughout the material. It is generally a lower reflecting vitrinite type and, if the clays had not been present, would have been classed as type A in most instances. This argillaceous vitrinite is predominantly concentrated in the duller coal types, the durains and clarodurains. However, the clarain at 9 to 10 cm of PSOC-1335, which overlies a durain contains a significant amount of type G.

Vitrinite type H also consisted of fragments of vitrinite (vitrodetrinite), but unlike type F these particles were surrounded by an inorganic matrix, predominantly clay. These particles of vitrinite are found almost exclusively at the top of PSOC-1340.

A comparison between the mean values for each vitrinite type within the two column samples shows a similarity in the overall vitrinite-type composition. Again, as with the megascopic and detailed maceral analyses, a difference is apparent between the two zones in PSOC-1340.

Summary of the Petrography of the Lower Kittanning Seam in PSOC-1335 and PSOC-1340

PSOC-1335 is a 69 cm thick, moderately bright coal that displays no distinct lithotype zonation. It contains three thin (less than 1 cm) vitrains and three durains (from 0.5 to 3.5 cm thick), with clarain comprising the major portion of the seam. There is very little visible pyrite, with the exception of a massive, 1 cm thick, pyrite lens near the base of the seam. Maceral analyses reveals that vitrinite is the major petrographic constituent of the coal (69%), with inertinite comprising 17%, liptinite 5%, and mineral matter 9%. The relative abundances of inertinite and liptinite increases in the dull lithotypes (durains) and in the duller bands within the clarains. The major vitrinite types within the column are types A (desmocollinite) and C (telocollinite), which are present throughout the seam in all lithotypes. Type G (argillaceous vitrinite) is a major component of the two thicker durain layers.

PSOC-1340 is a 70 cm thick coal that displays a definite zonation. The upper 21 cm consists mainly of dull, somewhat banded clarodurains, and also contains two 5 mm thick vitrains and one 2 cm thick durain. The lower zone, at 21 to 70 cm, is bright and consists of clarains and vitrains. A locally persistent (within the mine) parting of non-banded shale is present at 27 to 32.5 cm. The upper portion of the seam contains appreciable amounts of visible pyrite in the form of small blebs (1 to 2 mm) and lenses of pyrite (often mixed with fusinite) up to 3 cm long and 5 to 6 mm thick. The lower zone of the column contains very little visible pyrite. Maceral analyses show that vitrinite is the major petrographic constituent. The clarodurains contain substantially more inertinite and liptinite than the clarains. The major vitrinite types in the upper zone of PSOC-1340 are types A (desmocollinite), C (telocollinite)

and G (argillaceous vitrinite). Types A and C constitute the major portion of vitrinite macerals in the lower zone of the seam; type C is twice as abundant here as in the upper zone. Telinite (types B and C') is slightly more abundant in the upper zone.

Comparison of the data from the petrographic analyses indicate similarities (of varying degrees) between the megascopic appearance, maceral composition, and vitrinite composition, of PSOC-1335 and the lower zone of PSOC-1340. The upper portion of PSOC-1340 is distinctly different from the lower zone of PSOC-1340 and the entire seam of PSOC-1335. This difference is apparent in the megascopic appearance, pyrite content, maceral composition, vitrinite-type composition and microscopic textures.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Megascope and microscope analysis of the Lower Kittanning seam were used to determine vertical and lateral petrographic variations within the seam, with the objective of interpreting the depositional settings which existed within the ancestral peat swamp. Relationships were sought between previously determined paleoenvironments (E.G. Williams, 1960) and the following variables:

- 1) megascopic appearance - vertical and lateral variability of lithotypes,
- 2) microscopic appearance - vertical and lateral variability of the maceral composition, and
- 3) occurrence and distribution of distinct types of vitrinite macerals.

Results of the megascopic analysis show a similarity in appearance and relative abundance of lithotypes among PSOC-1335 (Cambria Co.) and the three Somerset County samples. In addition, none of these four samples possess any recognizable trends in vertical variability or distinct zonations. PSOC-1340 (Jefferson Co.), however, does possess a distinct vertical zonation into an upper (dull) and lower (bright) zone. The coal type represented by the upper zone is not present in any of the samples studied from the eastern margin of the basin, in Cambria and Somerset Counties. However, the lower zone of PSOC-1340 does exhibit a megascopic appearance similar to that of the other four samples.

Detailed microscopic analyses reveal that the vertical zonation of PSOC-1340 is equally apparent in both the maceral and vitrinite-type

composition. No similar vertical zonation is apparent in either of these sets of analysis for PSOC-1335.

In a comparison of the analytical results for PSOC-1340 and PSOC-1335 similarities between the lower zone of PSOC-1340 and the whole seam of PSOC-1335 are apparent. These similarities are most pronounced in the megascopic appearance and the vitrinite-type composition.

The following conclusions are drawn from this data. 1) The lower zone of PSOC-1340 and the whole seam of PSOC-1335 are laterally equivalent coal types. They were deposited under relatively constant environmental conditions. 2) The upper zone of PSOC-1340 is megascopically and compositionally distinct from the bottom zone of PSOC-1340 and the whole seam of PSOC-1335. It represents a significant change in the environmental conditions of the swamp in that area. Similar environmental changes are not evident along the eastern margin of the basin.

The petrographic composition of the coals studied reflect the depositional setting of the peat swamp and the changes which occurred during the course of deposition. Interpretations of the environments for the coals studied are as follows.

PSOC-1335 is interpreted as having formed in a freshwater swamp. A relatively rapid rate of subsidence is inferred from the high vitrinite content of the seam (Shibaoka and Smyth, 1975). The abundance of vitrinite-type C (telocollinite) and the presence of leaf and twig-like vitrinite material rimmed by cuticles (types A' and C) also indicate rapid burial and little degradation. The increase in occurrence and relative abundance of vitrinite types A', C, and C' towards the top of the seam indicate the rate of subsidence increased during the latter stages of peat deposition. The lack of any distinct vertical zonation

in the megascopic appearance and maceral composition of the seam in this area indicate no major environmental changes, such as a marine incursion, took place. The presence of appreciable amounts of inertodetrinite, clays, and quartz grains in certain layers are evidence that the area experienced an occasional influx of detrital material.

The lower zone of PSOC-1340 is considered to be laterally equivalent to PSOC-1335, and a similar environment is postulated. Abundant vitrinite types C and C' (telocollinite and telinite) indicate conditions existed for excellent preservation of woody material, probably derived from the bark, trunks, stems and roots of arborescent vegetation (Stach, 1975). The cuticle-rimmed vitrinite types A' and C, derived from leaves and twigs are even more abundant in this lower zone than in PSOC-1335. A freshwater environment is depicted for this portion of the seam; however, a more rapid rate of subsidence than that of PSOC-1335 is inferred from the increased amounts of well-preserved vitrinite and the increased concentration of vitrain bands. The low abundances of mineral matter and inertodetrinite indicate a lack of detrital material.

As with PSOC-1335 the rate of subsidence increased during the later stages of peat deposition. This increase resulted in a major environmental change in this area of the coal basin and is reflected in the upper zone of PSOC-1340. This zone contains a high mineral-matter content, with a greater amount of pyrite, rounded detrital quartz grains, together with abundant inertodetrinite, degraded sporinite, organic clasts, and a larger proportion of degraded vitrinite types than in the bottom zone. The relatively high amounts of the well-preserved vitrinite types C and C' (telocollinite) reported for this zone are actually concentrated in the vitrain bands and discrete springers of homogeneous vitrinite which exist in the clarodurain. These probably represent larger pieces of

woody material, such as trunks, branches or roots, which were deposited and quickly buried prior to degradation. All of these features enable the zone to be interpreted as reflecting the effect of encroaching marine conditions upon the swamp, as a result of a transgression within the basin. The occurrence of abundant densospores in this upper zone might support this interpretation (Habib and Groth, 1967). The petrographic composition of this zone is similar to that reported by Ting (1967) for the upper layers of the Lower Kittanning seam in other areas in the central portion of the basin. He reported a close association between this coal type and the marine facies of the roof rocks and considered it to represent the last phase of a coal-forming swamp in a rapidly subsiding region prior to termination of the swamp by open marine conditions.

The interpretations mentioned above are consistent with the paleo-environmental model developed for this region and stratigraphic interval by Williams (1960), and are in agreement with the depositional settings and history of the Lower Kittanning seam as interpreted by Habib (1966) and Ting (1967). The conclusion reached here regarding the subaqueous origin of densospore-rich dull coal at the top of PSQC-1340 supports Habib's (1966) interpretation rather than that of Smith (1968), which required an elevated peat-bog environment.

The results of the analyses on PSQC-1335 are not consistent with two of the four models suggested by Senftle and Davis (1982) for the deposition of coal in the Tyrone-Altoona area. These authors presented a series of alternative models which considered how paleotopographic and chemical controls during peat deposition would explain the lateral variability observed in the coal. One of the models which invoke chemical control supposed that the relative thinning and higher

inertinite content of the coal in the Tyrone-Altoona area resulted from a higher degree of degradation of the peat. According to this model, the peat swamp in the area might have had a higher pH than the adjacent areas. This higher pH could have resulted from a slight influx of marine waters, an availability of carbonate-rich waters, or evaporation. The results of the present study, which show that well-preserved vitrinite macerals (type A', C and C') occur throughout the seam, and actually increase towards the top, do not support the chemical degradation aspect of the models presented by Senftle and Davis (1982).

A secondary objective of this study was to investigate the relationships between the megascopic appearance of coal lithotypes and their microscopic composition. Results show that the megascopic appearance of a coal is determined not only by the maceral composition, but also by the grain size and textures of the microscopic constituents.

An additional objective of this study was a determination of the effectiveness of alternative techniques in the petrographic analysis of higher rank coals. In this study methylene iodide was used as an immersion medium and although it proved very useful in the medium volatile ($R_0 = 1.0 - 1.3\%$) rank range it would be of more limited aid in the higher rank low volatile coals, like those of Somerset County. Perhaps the use of etching techniques coupled with methylene iodide as an immersion medium would provide more observable detail and information from high rank coals.

In summary, the petrographic nature of the Lower Kittanning seam samples studied generally support the environmental models and interpretations developed by previous workers. PSOC-1340 demonstrates an environmental change which corresponds to an incursion of marine waters

in the central portion of the basin. PSOC-1335 and the Somerset County samples are freshwater facies of the seam and show no evidence of marine influence.

The most valuable result of this study is the demonstrated effectiveness of analyzing different types of vitrinite macerals. The analysis of the vitrinite types provided useful information for the interpretation of environmental conditions.

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