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Volume III

**Characterization
of
Selected
Ohio Coals
to Predict
Their
Conversion
Behavior
Relative to
104
North American
Coals**

Work Performed by

**The University of Toledo
Organic Carbon Facility**

Under Contract To

Air Products and Chemicals, Inc.

February 1982

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Department of Energy
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Volume III

Characterization of Selected Ohio Coals to Predict
Their Conversion Behavior Relative to
104 North American Coals

By

Timothy P. Whitacre
Timothy J. Hunt
and
Dr. William A. Kneller

MASTER

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An Abstract of

CHARACTERIZATION OF SELECTED OHIO COALS TO PREDICT
THEIR CONVERSION BEHAVIOR RELATIVE TO 104 NORTH
AMERICAN COALS

by

Timothy P. Whitacre,

Timothy J. Hunt

and

Dr. William A. Kneller

Twenty-six coal samples from Ohio were collected as washed and seam samples, and lithobodies within the seams that included varying amounts of pyrite and other mineral matter. Characterization of these samples included determination of % maceral, % R_{max} , LTA, chlorine content and proximate/ultimate and qualitative mineral analyses. These data were compared to data from a similar project by Yarzab, R. F., et al., 1980 completed at Pennsylvania State University using tetralin as the hydrogen donor solvent. The characteristics of these coals were correlated with liquefaction conversion and other data accrued on 104 North American coals by statistical analyses. Utilizing percent carbon, sulfur, volatile matter, reflectance, vitrinite and total reactive macerals, Q-mode cluster analysis demonstrated that Ohio coals are more similar to the coals of the Interior province than to those of the Appalachian province, Bivariate plots of these variables, however, suggest that these coals could be transitional between Appalachian and Interior coals. Linear multiple regression analysis for the 104 North American coals provided a prediction equation for conversion ($R=.96$). The predicted conversion values for the samples range from 58.8 to 79.6%, with the Lower Kittanning (No. 5) and the Middle Kittanning (No. 6) coal seams showing the highest predicted percent conver-

sion (respectively, 73.4 and 72.2%). The moderately low FSI values for the No. 5 and No. 6 coals (respectively, 2.5 and 3) and their moderately high alkaline earth content (respectively, 0.69 and 0.74%) suggest that these coals possess the best overall properties for conversion. Stepwise regression has indicated that the most important coal characteristics affecting conversion are, in decreasing order of importance: % volatile matter, % vitrinite and % total sulfur. Conversion processes can be expected to produce higher yields in Ohio coals due to the presence of such mineral catalysts as pyrite and kaolinite. It is believed that the presence of these disposable catalysts increases the marketability of Ohio coals.

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INTRODUCTION

General Statement

Since 1974, the OPEC nations have increased indiscriminately the price of oil and have the capability of interrupting oil supplies. In addition, present petroleum reserves in the U.S. are on the decrease, whereas the future demand will double over the next twenty years. Another problem of energy production is the 1979 Clean Air Act under which strict guidelines for SO_2 emission during combustion are outlined. Recent developments in technology, however, have made coal, the most abundant energy resource, a viable answer to present and future energy demands of the United States. Even though coal makes up 90 percent of the conventional U.S. energy reserves, only 17 percent of the energy demand is met by this fuel (Braunstein, 1977, p. 1-1). Coal is a heterogeneous carbonaceous rock that in the past was not well understood. As research techniques in coal characterization improve, the potential for greater industrial use of coal will increase. Coal conversion offers a solution to the major energy problems facing the United States. Conversion of coal results in a clean-burning product. For example, in the Solvent-Refined Coal Process (SRC-I) a glossy pitch-like solid is produced with an ash content of less than 0.1% and a sulfur content of less than 0.8% (Flask and Pryor, 1979, p. 11). Furthermore, regardless of the original quality of the coal feedstock, the SRC-I end product exhibits a heat content of about 16,000 BTU/lb (Braunstein, 1977, p. 3-75).

Coal conversion can be separated into three major groups: gasification, liquefaction, and solid solvent refined coal (SRC-I). In the three systems, the major problem that must be dealt with is hydrogen-deficient hetero-

geneous organic substances (Granoff, 1980). Conversion of coal to a usable gas, liquid, or solid product requires the structural breakdown of organic molecules and the addition of hydrogen atoms. Most of the unwanted constituents, such as ash and sulfur, are removed by these processes. Further characterization of coal, however, is needed to determine what specific coal properties control or affect the conversion processes.

Normal coal utilization (direct combustion) presents many problems that must be overcome. When burned under normal conditions, many toxic gases and particulates are given off. Environmental regulations limit the amounts of SO_2 , NO_x and particulate matter emitted. Mineral matter lowers the BTU output of coal and may cause industrial problems, especially if there is a large ash content. Sulfur, whether organic, sulfatic or pyritic, can cause the production of SO_2 during the combustion of coal. Recent studies indicate that acid rainfall may be attributed to SO_2 as well as NO_x emission. In addition, the emission of harmful elements into the ecosystem and the proper disposal of wastewater are problems that accompany direct combustion of coal. Coal conversion offers a means by which these problems may be diminished or more easily controlled.

The possibilities of producing a variety of gas, liquid and solid products from coal offer relief to the other factions in the energy picture. The gases and liquids can be promptly distilled or added to petroleum products as blendstock and then converted to a wide range of substances. Even the solid fraction may be heated and distilled to liquids. Electrical utilities and other industries offer a market for the chars and solid SRC products.

At the present time, the projected demand will exceed the supply of the coal conversion products, especially SRC. In the year 2000, for example, if four full-scale SRC plants were in operation, less than 5% of the market demand could be met. The economics of the different projects indicate that the energy produced would be at a cost less than the costs involved with imported petroleum (Gupta, 1979, p. 1).

The initiation of the coal conversion industry would result in many new coal products. Coal derived chemicals (phytochemicals) would offer an alternative to those produced from petroleum today. Filter cake by-products from coals rich in rare metals may become "ore bodies" by process enrichment. In Ohio, some seams contain an unusually high amount of germanium. This element is vital to the computer industry for microchips, and with further research the germanium could be processed from the filter cake (personal communication, Kneller, 1980). Nitrogen gas produced may be recycled into ammonia for fertilizer (Anon., Coal Age, 1979, p. 89, 170). These products refined from coal would relieve part of the demand for petrochemicals.

The new coal conversion plants now under study, design, and construction are the most energy efficient systems yet to be developed. Any excess thermal energy in one area of a plant will be transferred to locations where it may best be used. A completely closed system is impossible to achieve, but energy saving designs are being implemented. The more energy efficient an operation is, the more economically feasible the process becomes. Through the support of industrial, state and federal programs, fully operational coal conversion plants can be expected by 1990 (Gupta, 1979, p. 1).

In conversion processes, metallic catalysts such as Ni, Cr, and Mo

have long been used. These catalysts are, however, very expensive and are susceptible to deterioration and are difficult to recover. Recent investigations show that minerals exhibit catalytic properties. Gangwer and Prasad (1979, p. 577-584) discussed the hydrogen-transfer catalytic activity of minerals common to coal in a tetralin/1,2-dihydronaphthalene/naphthalene transfer system. They indicated that iron-bearing minerals appear to exhibit the greatest catalytic effect during coal conversion. They stated that in order of decreasing site catalytic activity, based upon unit area, the more active minerals are pyrite, magnetite, diaspore and limonite. These findings changed the perspective by which mineral matter in coal is evaluated.

For decades, the minerals, especially the pyrite content in coal, were considered very undesirable. However, today this same mineral matter may prove to be our greatest and least expensive ally in the reformation of the coal industry. These recent technological developments in coal conversion offer new hope for Ohio's coal mining industry. Plagued by federal regulations, production from coal mines has been on a steady decline. Environmental restrictions dealing with sulfur limit the number of mineable seams. Investigations have shown, however, that pyrite acts as a catalyst, and a number of Ohio coal seams are rich in pyrite. This type of coal may be used individually or blended with lower sulfur coals to obtain the optimum reactivity conditions during coal conversion. This increased interest in pyrite as a catalyst in coal could lead to an increased use of Ohio coals.

Coal conversion plants are of economic interest, because their operation would eliminate pre-treatment of coal. Proposed scrubber programs, which are costly, inefficient, and have waste disposal problems,

could be deleted.

Characterization of Ohio coals should include the study of the following properties: submolecular and molecular, physicochemical, phyteral, maceral, trace element, major and minor mineral composition, lithotype and lithobody content of coals. Data gleaned from these studies will improve the understanding of coal conversion processes. More intensive research about Ohio coals should prove these coals to be a valuable energy resource for the present and the future.

Purpose and Scope

The purpose of this study is to characterize coal samples, collected as seams and parts within the seams (lithobodies), that included varying amounts of pyrite and other mineral matter. Certain lithobodies within the seams were selected to represent different types of feedstock for the SRC-I process. Standard collection procedures of coal state that partings of shale and bone coal greater than 3/8 inches are not to be included in the sample. The reason for my sampling method is recent evidence which has linked minerals found in coal with catalytic activity during coal conversion; therefore, the minerals found coexisting with coal are of engineering interest (Tarrer, et al., 1977).

The samples vary from washed and unwashed seam to selected feedstock samples. The most interesting samples collected are the variable feedstock coals. Seams were selectively divided into parts with and without pyrite, claystone, and bone coal partings. These feedstock samples should help to determine the operating limits of the reactor used in the conversion process. This knowledge is of enormous importance in evaluating the economics of the process used, because it will indicate whether one or several sources of coal can be utilized.

In addition, detailed petrographic samples of easily recognized lithotypes within each seam were collected. These detailed samples were carefully stored for future reference and study.

Originally, percent conversions of Ohio coals used in a SRC-I process were to be made available by a chemical company; however, these data have not yet arrived at the Organic Carbon Facility of The University of Toledo (UTOC). The SRC-I conversion data were to be compared with coal parameters characterized in our laboratories. It was necessary, therefore, to utilize data from another similar project (Yarzab, et al., 1980, p. 81-92). Coal characteristics determined in this study were then statistically correlated with the coal conversion data of Yarzab, et al., (1980).

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GEOLOGIC SETTING

Stratigraphy

The Central Appalachian sedimentary deposits of southeastern Ohio consist of Upper Pennsylvanian and Lower Permian sequences. These sedimentary rocks, which are primarily nonmarine shales and sandstones, lie disconformably upon rocks of Mississippian age. The regional structure exhibits a north-south strike with a very slight eastern dip of 30 feet per mile.

Coals deposited in southeastern Ohio represent organic debris that originated in a warm temperate to hot, humid climate as indicated by paleontological evidence. The environment of deposition was a swampy coastal plain. Slowly changing transgressive/regressive conditions provided a favorable setting for the primary stages of coalification.

The strata of the Pennsylvanian and Permian were deposited in a distinct rhythmic order. These repetitious bedding sequences were first noted by Weller in 1930 and named cyclothems. Cyclothems consist of both marine and nonmarine derived sediments. In southeastern Ohio, the nonmarine sequences are prevalent. The cyclothems may show lateral differences in lithology due to different environments of deposition. Continual migration of stream channels over the deltaic environment is indicated by the heterogenous nature of the sediments. Early mapping of southeastern Ohio geology was hampered by such local unconformities.

In Ohio, fifty cyclothems make up the Pennsylvanian system. Most of the cyclothems contain a layer of coal which varies in thickness from a thin carbonaceous film to seams several feet in thickness. Whereas numerous layers of coal exist in the Pennsylvanian, only about ten percent of the seams are commercially mineable. Variations in the thicknesses of the

coal seams were the first parameters used by early geologists and miners in the grouping of the Pennsylvanian rocks. Today, four divisions of the Pennsylvanian system in Ohio are recognized as the Pottsville, Allegheny, Conemaugh and Monongahela series (See Figure 1.).

The oldest of the divisions is the Pottsville series, which lies disconformably upon the Mississippian Maxville limestone. The Pottsville series includes the Sharon (No. 1), Quakertown (No. 2) and the Lower Mercer (No. 3) coal seams and extends from the basal Sharon conglomerate to the base of the Brookville (No. 4) coal. Averaging 250 feet in thickness, the Pottsville contains massive nonmarine conglomerates, sandstones, shales, and thin coal beds. There are also some thin members of marine shale, limestone, ironstone and flint. The exposed Pottsville in Ohio represents the upper portion of the entire series and can be divided into ten different cyclothemic events.

The Allegheny series extends from the base of the Brookville (No. 4) coal to the top of the Upper Freeport (No. 7) coal. Between these units lie the Clarion (No. 4A), Lower Kittanning (No. 5), Middle Kittanning (No. 6) and Lower Freeport (No. 6A) coals. These rock units are predominately fine-grained sandstones, siltstones, and shales. The Allegheny's average thickness of 200 feet is divided into two sections. The lower division consists of seven cyclothems, all of which contain only marine limestone. Overlying the Lower Freeport (No. 6A) coal is the first nonmarine carbonate, the Hamden limestone (Sturgeon, et al., 1958, p. 47). In the upper division six cyclothems occur and are represented by nonmarine and marine limestones.

The Conemaugh series represents an average of 400 feet of Pennsylvanian sedimentary rocks from the top of the Upper Freeport (No. 7) coal seam to the base of the Pittsburgh (No. 8) coal seam. The fifteen cyclothems,

FIGURE 1. Generalized Section of the Permo-Carboniferous Rocks of Ohio (Modified from: Generalized Section of Rocks of Ohio, Ohio Geological Survey, 1967).

recognized in the Conemaugh series, consist primarily of poorly sorted sandstones, siltstones, and sandy shales. Variations in thickness and color exist throughout the formation. Nonmarine and marine limestones may or may not be present in this formation. These limestones are located primarily in the lower strata. An exception to this is the coarsely crystalline, fossiliferous Ames limestone member (Branson, 1962, p. 104). This marine limestone is the most continuous horizon of the Conemaugh series throughout southeastern Ohio, but it too has local unconformities.

The Monongahela series is the uppermost unit of the Pennsylvanian system. This series includes the Pittsburgh (No. 8), Redstone (No. 8A), Sewickley/Meigs Creek (No. 9), Uniontown (No. 10), and Waynesburg (No. 11) coal seams. Limestones within the twelve cyclothems are finely crystalline with thin partings present. Silt and clay impurities are found in the limestones. Calcareous redbeds and freshwater limestones locally grade into one and other. The micaceous sandstones in the Monongahela series are poorly sorted. Organic plant debris is occasionally found in the lower portions of the sandstone beds overlying coal seams. In Ohio, the Monongahela averages a thickness of 250 feet.

The Dunkard group represents the Pennsylvanian-Permian boundary in southeastern Ohio. The Dunkard in some regions grades vertically upward from the Pennsylvanian Monongahela series and in other regions a distinct unconformity exists between the two. At some locations, the Upper Waynesburg (11A) coal occurs within the lower Dunkard. The unconformity is the recognized marker which is used to differentiate the Pennsylvanian and the Permian in neighboring states. Plant and amphibian fossils identify the Dunkard as Permian in age.

The Dunkard group represents the youngest Paleozoic formations in Ohio.

The base of the Dunkard begins at the top of the Waynesburg (No. 11) coal and exceeds a thickness of 600 feet in the state. The Dunkard group has been divided into the Washington and Greene formations. The former formation includes the Washington (No. 12) coal seam. According to Stauffer and Schroyer (1920), these two formations are very diverse. There are sandstones, shales, beds of limestone and coal; in fact, it includes nearly all the different varieties of sediments from coarse sandstone and conglomerate to the finest grained shale. These changes rather rapidly from one to the other, so that it is often impossible to trace a horizon for any great distance.

FIELD METHODS

Seam Selection

Little research data on Ohio coals covering all the necessary properties which characterize these coals are available or have been published. Some coal statistics, however, are available and they include percent carbon, hydrogen, sulfur, oxygen, and annual tonnage production. These statistics were used initially to select the coals for study.

Percentages of these elements (C, H, O and S) were of particular interest because of their relationship to known reactive macerals and minerals. For example, Reggel, et al., (1970), studied the catalytic dehydrogenation of coal by comparing exinite, micrinite, and fusinite with vitrinite. They observed that the macerals of the exinite group exhibited the highest H/C ratios, whereas the macerals of the intertinite group exhibit the lowest H/C ratios. In the case of oxygen content, the relationship is less distinct, because most O₂ analyses are calculated by a difference method and do not reflect true oxygen functional groups within the organic constituents of a given coal. However, Stach, et al., (1975, p. 55), states that in isometamorphic maceral groups of the same rank, vitrinite contains relatively more oxygen. Many recent investigations have recognized the positive catalytic effect of pyrite during conversion. It was stated in a note in a recent issue of "Coal Age" that the presence of three to five percent pyrite can increase the liquefaction yield as much as fifteen percent (Anon., 1979, p. 170). It was assumed that the total sulfur content of Ohio coals would reflect the pyrite composition and that the content range for this element would reflect the compositional range of Ohio coals.

In addition, different seams were also selected for study to determine which seams prove to be the most productive in coal conversion processes. Mines of interest had to have a production of approximately 500,000 tons per year. This requirement was needed because many on stream conversion plants consume between 5000-6000 tons daily. Seams from mines which had smaller production figures were also considered if the seam exhibited anomalously high or low oxygen, hydrogen, carbon or sulfur percentages.

Once a variety of coal seams had been isolated, their location was determined from Ohio Geological Survey identification numbers. The county, township, and state inventory of mining companies was used to locate as closely as possible the mining operations. Figure 2 illustrates the locations of the coals sampled for this study.

Sample Methods

Four seams were sampled in accord with ASTM STP 661 (Dutcher, 1976, p. 58-63) entitled: Field Description of Coal. Large quantities of coal were gathered as needed for laboratory experimentation. The sample site was first cleared of any loose coal or rock debris, and a flat surface was developed on the seam face. The seam was measured, sketched and described noting the different lithobodies.

A vertical channel approximately one foot wide and one foot deep from the roof to the floor was removed. All the coal was caught on a vinyl drop cloth that had been spread beneath the channeled zone. After the drop cloth was filled, the coal was placed in canvas bags and marked on site in the underground mines to allow for easier transport out of the mine. This procedure was repeated until the amount of coal mined would fill a 55-gallon drum with a clamp type lid.

FIGURE 2. Location Map of the Collection Sites of Some Selected Ohio Coals.

In the open pit mines, coal from the seam was channelled from the seam onto a vinyl drop cloth, placed in a bucket and then immediately put into the 55-gallon drum. The drums were promptly marked and identified. In addition to the seam samples, variable feedstock samples were obtained. The different lithobodies and lithotypes were marked by an orange colored chalk and the sections measured (See Appendix A). A rock hammer and chisel were used to prevent unwanted coal from bordering divisions to mix with desired samples on the drop cloth. Enough coal was bagged and marked in the underground mine to fill a five-gallon container with lid. In an open pit, mine samples were placed directly into the metal containers. When the marked bench contained a shale or bone zone, these non-coal horizons were included in some of the feedstock samples.

These feedstock samples were biased to provide the widest possible variation in maceral and mineral matter content for use in a SRC-I pilot plant to determine the compositional/operational limits of the process.

Detailed petrographic samples were also taken. The lithobodies and major lithotypes were carefully marked with chalk and measured. Coal from each recognized division was carefully collected. Approximately 750 cubic centimeters of coal from within each recognized zone were obtained. Wherever possible, individual specimens of the claystone and bone partings were sampled separately. The samples were placed into plastic freezer containers, sealed, marked and stored for future reference.

The two washed samples were collected from the Clarion (No. 4A) and Pittsburgh (No. 8) coal seams. The coal was collected in accordance with ASTM D 2234-74, entitled: Standard Methods for Collection of a Gross Sample of Coal, and stored in sealed, marked 55-gallon drums. The Clarion (No. 4A) wash sample represents a mixture from two different 4A-coal

mines, which share the same washing facility.

LABORATORY METHODS

Initial Preparation of the Sample

The initial crushing was carried out at Ohio University, where the bulk coal samples were processed through a Sturtevant Automatic Coal Crusher and Sampler (SACCS). The large crusher reduced the size of the raw lump coal to approximately minus 10 mesh. The first samples to be processed were the variable feedstock coals.

A representative sample for laboratory study was taken from an automatic side split device. Every feedstock sample was run through the crusher twice to achieve a side-split sample which weighed approximately five pounds. These side-splits were placed into labeled canvas bags and the other part of the crushed coal was sealed in a metal container. The SACCS was then opened and cleaned to avoid contamination of the next sample to be run. The SACCS was then run for a short time period to allow debris not removed by the hand brush to advance out of the machine. This was the final step before the next sample was processed.

The seam and washed samples collected were crushed in the same fashion. However, prior to the crushing, the samples in the drums were split three times using the large Jones splitter.

Side-splits of the variable feedstock, seam and washed samples were then taken to The University of Toledo for further preparation. Samples weighing about 250 grams were split from the ground coal. The splits were completely crushed, until they passed through a minus 20 mesh sieve. It was with these samples that all other analyses were made.

Maceral Analysis

Briquette Preparation

The coal briquettes (pellets) were prepared in accordance with ASTM Method D 2797, entitled: Standard Method of Preparing Coal Samples for Microscopical Analysis by Reflected Light. Using a micro-splitter, approximately 30 cc. of coal was split from the minus 20 mesh fraction. After a pellet was made, a series of grinding and polishing steps were followed until a well-polished surface was developed. As soon as the pellet surface was free of all scratches, it was ready for microscopic examination.

Analytical Procedure

The macerals were studied following the ASTM Method D 2779-72, entitled: Standard Method for Microscopical Determination of Volume Percent of Physical Components of Coal. A Zeiss Universal Microscope System MPM-01K was used in tandem with a power regulated high pressure halogen lamp. The ocular lenses used were 8x and 12.5x, whereas the objectives used were at magnifications of 16x, 25x and 40x. The oil immersion objective lenses utilized a Zeiss immersion oil that has an index of refraction (n) of 1.518 at 20° c.

A Brinkman Instruments Automatic Point Counter was used for the mechanical advancement of the pellets. Following the International Committee of Coal Petrologists (ICCP) procedures, an interpoint and interline distance of 0.5 mm was employed. Five hundred counts were made on each pellet. Since two polished pellets were made for each of the 26 samples, volume maceral percentages were based upon approximately 1,000 point counts.

The analytical accuracy of any maceral analysis study is dependent upon the number of point counts made. When 1,000 counts are made on a pellet, as in this study, the accuracy for each maceral or maceral group is at the 95% confidence level, (ICCP, 1963; Stach, et al., 1975, p. 255; Chandra, 1963, p. 457-465). Results of the maceral analyses are recorded in Tables 2-7, pages 32-37 of this report.

Reflectance Analysis

The mean maximum reflectance ($\bar{R}_m$) of the polished pellets was obtained by following ASTM D 2798-72, entitled: The Standard Method for Microscopical Determination of the Organic Components in a Polished Specimen of Coal. Measurements were made on the vitrinite component in immersion oil ($n_e = 1.518 @ 23^\circ \text{C}$) using a Zeiss Universal Microscope System MPM-01K. A high pressure halogen lamp, powered by a regulated power supply, was utilized as an illuminator. The light was transformed into monochromatic light after passing through a filter with a peak transmittance in the range $546 \pm 5 \text{ nm}$ and a half-peak transmittance band width that is less than 30 nm.

The reflected light was detected by a photomultiplier tube and subsequently the signal strength increased by a Model PMI-1 photomultiplier indicator. The stage was then rotated through 360 degrees and the maximum reflectance was recorded from the digital display on the PMI indicator.

The calibration of the photometer was accomplished by using optical glasses prepared by the Bausch and Lomb Company. The four high-index glass standards used bracketed the reflectance of the coal components measured in this study. Immediately after the calibration, measurements were made on a sample. The photometer was then checked after every

twenty-fifth reading.

After at least 100 readings had been made, the double standard deviation (2s) of the mean maximum reflectance values was determined. For the calculation of the double standard deviation 2s, the following equation was used:

$$2s = 2 \sqrt{\frac{n}{100(n-1)} \cdot \left[\sum (R_i^2 \cdot x_i) - 100 \cdot \bar{R}_m^2 \right]}$$

Where:

n = number of measurements

R_i = mean value of the maximum reflectance of the half V-steps in %

x_i = percent frequency of the measured values in the half V-steps in %

$\bar{R}_m$ = mean value of the maximum reflectance of all measured values in %

Histograms which summarize the results of these reflectance studies can be found in Figure 7 on page 63. A complete set of raw reflectance values obtained for each of the seam samples are located in Appendix B.

Mineral Analysis

High Temperature Ashing (HTA)

The determination of a coal's noncombustible constituents is accomplished by high-temperature ashing. High-temperature ash percentages were determined in accordance with ASTM Standard Test Method D 3174-73, entitled: Ash in the Analysis Sample of Coal and Coke.

A three-gram sample from the 20 mesh ground split was removed for the high-temperature ashing experiments. The coal was ground so that the entire

amount passed a 60 mesh sieve. One gram was then dried in an oven, at a temperature of 100°C , for 24 hours. The crucibles used in the experiments were also placed in the oven to remove any residual moisture.

After the designated time period, the coal and crucible were placed in a desiccator and allowed to cool to an ambient room temperature. The exact weights of the crucibles empty and the crucibles with the oven-dried coal were recorded. A muffle furnace was used to heat the samples to 500°C in one hour and to 750°C in two hours. After maintaining the 750°C temperature for several hours, the crucibles were removed and placed in a desiccator to cool and weighed when they reached ambient temperatures. The results of the high temperature ashing are found in Table 1.

Low Temperature Ashing (LTA)

The low-temperature ashing of coals enables the determination of unaltered mineral matter, by removing the organic constituents of a coal at a temperature of approximately 150°C (Gluskoter, 1965). This is accomplished by passing a controlled amount of gaseous oxygen through a high-energy electromagnetic field. The activated gas ". . . is a mixture of atomic and ionic species as well as electronically and vibrationally excited states. . ." (Gleit, 1963).

The preparation and operational procedure of Gluskoter (1965) was followed in these experiments. The only variation was particle size reduction from 20 mesh to 80 mesh (Miller, Yarzab and Given, 1978). The coals were ground by mortar and pestle. They were then placed in an oven at 100°C , along with the pyrex boats used for ashing, to remove any moisture.

After twenty-four hours, the coal and the Pyrex boats were removed

TABLE 1. HIGH TEMPERATURE ASH (HTA) AND LOW TEMPERATURE ASH (LTA)
PERCENTAGES OF SELECTED OHIO COALS.

UTOC SAMPLE NO.			SEAM NO.	% HTA	% LTA
264	Seam	CPDU-134	4A	26.53	31.40
	Wash	CPDU 130-A		15.99	19.38
FZ	I	CPDU 130-B		28.82	31.85
	II	CPDU 130-C		22.64	21.82
	III	CPDU-132		11.48	13.14
262	Seam	CPDU-136	5	12.02	16.92
FZ	I	CPDU 129-A		4.67	7.43
	II	CPDU 129-B		3.55	4.42
	III	CPDU 129-C		13.80	18.62
263	Seam	CPDU-133	6	10.52	10.23
FZ	I	CPDU 126-A		5.11	9.74
	II	CPDU 126-B		4.63	6.30
	III	CPDU 126-C		3.19	4.25
	IV	CPDU 126-D		30.24	40.49
259	Seam	CPDU-131	8	12.03	13.87
	Wash	CPDU 131-A		15.72	21.09
260	Seam	CPDU-137	8	19.01	20.19
FZ	I	CPDU 127-A		19.04	27.02
	II	CPDU 127-B		16.63	19.04
	III	CPDU 127-C		7.77	11.46
	IV	CPDU 127-D		14.13	16.56
265	Seam	CPDU-135	8	14.37	17.01
FZ	I	CPDU 128-A		7.19	10.57
	II	CPDU 128-B		29.55	36.49
	III	CPDU 128-C		6.98	8.71
	IV	CPDU 128-D		10.95	14.06

FZ = Feedstock Zone

from the oven. The empty pyrex containers to be used were carefully weighed. Then between 1.5 and 2.0 grams of coal were placed into an individual boat and carefully re-weighed.

The low-temperature asher (LTA) used in this investigation was an International Plasma Corporation model PM 148 single chamber reactor and model PM 104B generator control console, with a frequency output of 13.56 MHz and a power output of 0-150 watts.

The samples were then placed into the fused quartz chamber of the LTA and the air evacuated. A vacuum of between 1.0 and 1.5 torr was then established. Since the coal is fine-grained, this vacuum was developed slowly because a rapid evacuation of the chamber resulted in the sample being blown out of the Pyrex boat.

The radio-frequency (r.f.) oscillator power was then turned on and adjusted to achieve a plasma. The r.f. power level was adjusted to between 60 and 70 watts and a constant oxygen flow of 100 cc per minute was maintained. After every three hours of ashing, the boats were removed and the samples stirred with a platinum wire. This procedure was repeated continuously until the stirred ash began to achieve a homogeneous shade of gray. When this occurred, the samples were placed in a desiccator, allowed to cool, and then weighed. The sample was completely ashed when the weight of the ash did not decrease by more than one percent. The ash values determined by LTA are found in Table 1.

The mineralogy of the coals after LTA show no discernable change except in some pure minerals where dehydration may occur (Gluskoter, 1965).

X-Ray Diffraction

The mineralogy of the coals was determined from the low temperature ash by x-ray diffraction (XRD) methods. Ashed samples were split and

ground using a mortar and pestle until the entire split passed a 200 mesh sieve. The ash was then firmly packed into an aluminum cavity mount.

The sample was then placed in the Norelco X-ray unit and run from 4° to 64° (2θ) at a speed of 2° per minute and a range of 250. The chart speed was set at 60 inches per hour. The d-spacings of the different peaks were measured and the minerals identified following standard procedures. Results of this analytical phase are found in Table 12 on pages 47-48. The index of the patterns for the diffractograms is found in Appendix C.

Statistical Analysis

An IBM 4341 computer was utilized in evaluating most of the data acquired in this study. A prediction equation for percent conversion was derived using the data of Yarzab, et al., (1980). In their paper, Dependence of Coal Liquefaction Behaviour on Coal Characteristics.

4.Cluster Analyses for Characteristics of 104 Coals, they determined what appear to be the most important variables controlling the conversion of coal to liquid fuels. These variables are total sulfur (dry), carbon (dmmf), volatile matter (dmmf), percent reflectance, vitrinite and total reactive macerals in volume percent (dmmf). A conversion equation was derived by these authors based upon percent conversion values determined in the laboratory. These values were obtained experimentally by determining the weight of the insoluble residue from coals treated by tetralin. This treatment used an ethyl acetate soxhelt extraction to obtain the reaction products. This process produces a benzene insoluble residue, whereas in the SRC process a creosol oil solvent is used that produces a pyridine insoluble residue. The SRC process is more effective, yielding relative conversions from 15 to 20 percent higher than the tetralin process

(Personal communication, Garg, 1980). This suggestion by Garg is based upon only a few samples of Ohio coals; therefore, the conversion values from Yarzab, et al., (1980) were used in this study.

A cluster analysis was made of the combination of data from this study and the work of Yarzab, et al., (1980). The BMDP P2M program (Dixon and Brown, 1979) was utilized to cluster the coal data and a description of the Biomedical Data Processing Manual follows:

"P2M forms clusters of cases (observations) based on one of four distance measures. The distance measures are the Euclidean distance (L_2 , the square root of the sum of squares of the differences between the values of the variables for two cases); the L_p distance (the sum of the p th power of the absolute difference); or the chi-square statistic or phi-square (both measure the difference of frequencies in two cases and are used when the data are counts).

Initially, each case is considered to be in a cluster of its own. At each step, the two clusters with the shortest distance between them are combined (amalgamated) and treated as one cluster. This process of combining clusters continues until all the cases are combined into one cluster. This algorithm is called average distance or average linkage.

P2M prints either a vertical or horizontal tree diagram to describe the sequence of clusters formed. The means of the variables for the cluster formed at each step are also printed."

In this study, only one distance measure (L_2) was used. The amalgamated distance, (See Plates 1-4) is the distance between the centroids of two clusters being fused at a given stage during the clustering process. In addition, values are initially standardized to give each variable equal weight in the cluster analysis, thus avoiding any bias due to the wide value range of the data (10^4 to 10^{-1}). The results of these analyses appear in Plates 1-4 (in pocket). Groupings which bracketed the samples were isolated from the entire set of data to form smaller data sets upon which regression analyses were made.

The GLM procedure from the SAS manual (Barr, et al., 1976) utilizes the principle of least squares to fit linear models. This procedure performs a multiple linear regression including as independent variables percent volatile matter, reflectance, carbon, total sulfur, vitrinite and total reactive macerals. The dependent variable in this regression is the percent conversion. The multiple linear regression provided prediction equations based on the data of Yarzab et al., (1980) from which the percent conversion can be calculated.

The STEPWISE procedure, also from SAS (Barr, et al., 1976), was utilized with the same dependent and independent variables as used in the SAS GLM procedure. Two separate STEPWISE procedures were applied to the Yarzab, et al., (1980) data. A description for the two techniques from the SAS Manual follows:

- "1. Forward Selection. This technique finds first the single-variable model which produces the largest R^2 statistic. R^2 is the square of the multiple correlation coefficient; it can also be expressed as the ratio of the regression sum of squares to the (corrected) total sum of squares. For each of the other independent variables, STEPWISE calculates an F-statistic reflecting that variable's contribution to the model were it to be included. If the F-statistic for one or more variables has a significance probability greater than the specified 'significance level for entry,' then the variable with the largest F-statistic is again calculated for the variables still remaining outside the model, and the evaluation process is repeated. Variables are thus added one by one to the model until no variable produces a significant F-statistic.
4. Maximum R^2 Improvement. This technique was developed by James H. Goodnight; he considers it superior to the stepwise technique and almost as good as calculating regressions on all possible subsets of the independent variables. Unlike the three techniques above, this technique does not settle on a single model. Instead, it looks for the 'best' one-variable model, the 'best' two-variable model, and so forth. It finds first the one-variable model producing the highest R^2 statistic. Then another variable, the one which would yield the greatest increase in R^2 , is added. Once this two-variable model is obtained, each of the variables in the model is compared to each variable not in the model. For each comparison, the procedure determines if removing the

variable in the model and replacing it with the presently excluded variable would increase R^2 . After all the possible comparisons have been made, the switch which produces the largest increase in R^2 is made. Comparisons are made again, and the process continues until the procedure finds that no switch could increase R^2 . The two-variable model thus settled on is considered the 'best' two-variable model the technique can find. The technique then adds a third variable to the model, according to the criteria used in adding the second variable. The comparing-and-switching process is repeated, the 'best' three-variable model is discovered, and so forth. This technique differs from the STEPWISE technique in that here all switches are evaluated before any switch is made. In the STEPWISE technique, removal of the 'worst' variable may be accomplished without consideration of what adding the 'best' remaining variable would accomplish."

The STEPWISE procedure is useful in determining which independent variables have the strongest relationship with regards to the dependent variable. In both the "Forward Selection" and "Maximum R^2 Improvement" techniques involving the six independent variables, volatile matter is the variable most highly correlated with percent conversion.

The final computer analyses provided bivariate scatter plots using the BMDP P6D program. All possible pairs of variables are plotted against each other. Any trends between variables are delineated. The scatter plots offer a valuable visual tool for comparing the data of several groups. The significant bivariate plots of this study can be observed on pages 73-75.

PETROLOGY OF SOME OHIO COALS

General Statement

The petrologic study of coal enables the interpretation of depositional environments and subsequent maturation processes of the organic sediments. The newest applications of coal petrology and petrography are in the synthetic fuel industry. To engineer and design coal conversion facilities, it is essential to understand the heterogeneous properties of coal. Only through detailed characterization can important factors influencing coal conversion be determined. The characterization of coal and the practical application of the data demands the integrated use of a variety of physical and chemical tools and methods.

Coal microscopy is a major subdivision of coal petrology. Coal is made up of a variety of organic and inorganic particles and these constituents have physical properties that are recognizable using a microscope. Reflectance studies of coal allow rapid and effective means to predict yields of coal conversion and carbonization products, coal strength, free-swelling index, B.T.U. content, geothermal gradients and to monitor oxidation tendencies of coal (Stach, 1975, p. 2). Geochemical data is accrued from not only whole coal, but also from ash derived from low temperature ashing techniques. The ash can be used to determine quantitative/qualitative mineral, major/minor oxides, and the trace element content of the coal.

By utilizing the combined data accumulated from the different parameters, a variety of geological and industrial problems can be solved. The success of synfuel programs will hinge upon the complete characterization of the coal prior to modification. Any variance of a parameter outside limits

specified for a process may result in an inferior product or cause the fouling of the synfuel system. Also, the determination of environment of deposition, which is essential to coal exploration, is possible with coal petrology. Mineral and petroleum exploration can be assisted by the characterization of coal. The application of data derived from coal characterization has been and will continue to aid a variety of scientific interests.

Maceral Content

The term "maceral" was first used by Stopes in 1935 to describe the fragmentary organic remains of plants which constitute coal. Microscopic identification is based on the varying reflective and morphological differences. Three major groups of macerals have been established: vitrinite, exinite and inertinite. The following descriptions are paraphrased from the ICCP Handbook, (1963, 1971).

Vitrinite Group

The vitrinite group is the most reactive during carbonization. In reflected light, macerals of the vitrinite group have a grey appearance and a medium reflectance compared to the other two groups. This humic part of the coal is comprised of three macerals: telinite, collinite and vitrodetrinite.

Remnant plant cell-wall material is termed telenite. Collinite, a structureless gel, commonly fills the voids between the telinite cell walls. Vitrodetrinite is the detrital form of vitrinite (less than 10 microns in diameter) originating from plants or humic peat particles which were degraded at a very early stage.

Exinite (Liptinite) Group

Exinite macerals are derived from waxy secretions such as plant cuticles and spore and pollen exines. The macerals of this group are typified by a low reflectance, high relief, and a higher hydrogen content than the vitrinites. Macerals of the exinite group include sporinite, cutinite, alginite, resinite and liptodetrinite. Sporinite is the preserved remnants of spores, cutinite of plant cutin, alginite from algae, resinite from plant resin and liptodetrinite represents macerated liptin particles of less than 10 microns in diameter.

Inertinite Group

The inertinite group is composed of macerals which are the most reflective and are the least reactive. Inertinite macerals have a high carbon and a low hydrogen content. These macerals, although similar in origin to vitrinites, have been strongly oxidized prior or consequent to burial and coalification. In reflected light, these macerals appear white and have a higher relief than other macerals. Macerals of the inertinite group include fusinite, semifusinite, micrinite, macrinite, sclerotinite and inertodetrinite.

Fusinite always shows cell structure and commonly originates from forest fires. Semi-fusinite which may or may not show cell structure represents an intermediate maceral between fusinite and vitrinite. Micrinite is composed of attritus, less than 10 microns in diameter, from cell walls which has been coalified. Macrinite is described as a more or less amorphous, non-granular ground mass showing no or little structure with a size greater than 10 microns in diameter (Stach, 1975, p. 100).

A summary of the volumetric content of the coals examined in this study is found in Tables 2-7. The values of each of the maceral groups are on a mineral matter containing basis (mmcb) and mineral matter free basis (mmfb).

TABLE 2.

VOLUME PERCENT MACERAL CONTENT AS RECEIVED
FOR SELECTED SAMPLES OF OHIO COALS
CLARION (NO. 4A) COAL
UTOC 264

SAMPLE NO.	CPDU-134		CPDU 130-A		CPDU 130-B		CPDU 130-C		CPDU-132	
	Seam		I		II		III		Wash	
	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb
TELINITE	1.9	2.5	2.6	3.2	4.4	5.3	3.7	4.1	3.2	3.6
COLLINITE	65.6	83.1	63.1	80.1	60.7	73.4	75.4	84.3	68.9	78.9
VITRODETRINITE	0.9	1.1	0.1	0.1	1.5	1.8	0.8	0.9	1.2	1.3
TOTAL VITRINITE	68.4	88.7	65.8	83.5	66.6	80.5	79.9	89.3	73.3	83.8
SPORINITE	2.5	3.2	2.0	2.5	2.0	2.5	0.9	1.0	3.4	3.9
RESINITE	1.2	1.5	3.5	4.4	3.0	3.6	2.3	2.5	2.0	2.3
CUTINITE	0	0	0.1	0.1	0	0	0	0	0	0
LIPTODETRINITE	0.9	1.1	0.3	0.4	1.0	1.2	1.2	1.3	1.3	1.4
TOTAL EXINITE	4.6	5.8	5.9	7.4	6.0	7.3	4.4	4.8	6.7	7.6
FUSINITE	2.3	3.0	1.2	1.6	2.7	3.2	1.9	2.1	2.9	3.3
SEMIFUSINITE	2.7	3.4	4.4	5.7	5.8	7.0	2.4	2.6	3.7	4.2
SCLEROTINITE	0.2	0.2	0.3	0.4	0.2	0.2	0	0	0.4	0.4
MICRINITE	0.7	0.9	1.1	1.4	1.4	1.7	1.0	1.1	0.5	0.6
MACRINITE	0	0	0	0	0.1	0.1	0	0	0	0
INERTODETRINITE	0	0	0	0	0	0	0.1	0.1	0.1	0.1
TOTAL INERTINITE	5.9	7.5	7.0	9.1	10.2	12.2	5.4	5.9	7.6	8.6
CARBARGILLITE	2.3		1.5		1.9		1.2		1.1	
CARBOPYRITE	0.3		0.3		0.2		0.2		0	
SUBTOTAL										
CARBOMINERITE	2.6		1.8		2.1		1.4		1.1	
PYRITE	2.1		7.7		3.9		3.5		2.3	
OTHER MINERALS	16.4		11.8		11.2		5.4		9.0	
SUBTOTAL										
MINERAL MATTER	18.5		19.5		15.1		8.9		11.3	
GRAND TOTAL										
MINERAL MATTER	21.1		21.3		17.2		9.3		12.4	
COUNTS PER PELLET	1031		1055		1129		1105		1034	

mmcb-mineral matter containing basis
mmfb-mineral matter free basis

TABLE 3. VOLUME PERCENT MACERAL CONTENT AS RECEIVED
FOR SELECTED SAMPLES OF OHIO COALS
LOWER KITTANNING (NO. 5) COAL
UTOC 262

SAMPLE NO.	CPDU-136		CPDU 129-A		CPDU 129-B		CPDU 129-C	
	Seam		I		II		III	
	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb
TELINITE	0.1	0.1	0	0	0	0	0.1	0.1
COLLINITE	76.5	89.5	81.6	88.3	86.6	94.4	81.3	92.9
VITRODETRINITE	0.1	0.1	0	0	0	0	0	0
TOTAL VITRINITE	76.7	89.7	81.6	88.3	86.6	94.4	81.4	93.0
SPORINITE	0.5	0.6	1.1	1.2	1.4	1.5	0.7	0.8
RESINITE	0.4	0.5	0.2	0.2	0	0	0.1	0.1
CUTINITE	0	0	0	0	0	0	0	0
LIPTODETRINITE	1.2	1.4	0.4	0.4	0.6	0.6	0.3	0.4
TOTAL EXINITE	2.1	2.5	1.7	1.8	2.0	2.1	1.1	1.3
FUSINITE	2.1	2.4	2.7	3.0	0.7	0.7	1.9	2.2
SEMIFUSINITE	3.0	3.5	4.7	5.1	1.7	1.8	1.3	1.5
SCLEROTINITE	0	0	0	0	0	0	0	0
MICRINITE	1.1	1.3	1.2	1.3	0.7	0.7	1.1	1.3
MACRINITE	0	0	0	0	0	0	0	0
INERTODETRINITE	0.5	0.6	0.5	0.5	0.3	0.3	0.6	0.7
TOTAL INERTINITE	6.7	7.8	9.1	9.9	3.4	3.5	4.9	5.7
CARBARGILLITE	4.6		3.4		2.5		5.9	
CARBOPYRITE	0.8		0.9		2.0		3.2	
SUBTOTAL								
CARBOMINERITE	5.4		4.3		4.5		9.1	
PYRITE	5.7		2.6		2.6		3.1	
OTHER MINERALS	3.4		0.7		0.9		0.4	
SUBTOTAL								
MINERAL MATTER	9.1		3.3		3.5		3.5	
GRAND TOTAL	14.5		7.6		8.0		12.6	
MINERAL MATTER								
COUNTS PER PELLET	1008		1058		1024		977	

mmcb-mineral matter containing basis
mmfb-mineral matter free basis

TABLE 4.

VOLUME PERCENT MACERAL CONTENT AS RECEIVED
FOR SELECTED SAMPLES OF OHIO COALS
MIDDLE KITTANNING (NO. 6) COAL

UTOC 263

	CPDU-133		CPDU 126-A		CPDU 126-B		CPDU 126-C		CPDU 126-D	
SAMPLE NO.	Seam		I		II		III		IV	
	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb
TELINITE	0.8	0.9	0.1	0.1	0	0	0	0	0.2	0.3
COLLINITE	77.8	90.1	85.8	90.7	84.2	89.2	88.7	91.0	63.8	83.9
VITRODETRINITE	0	0	0	0	0	0	0	0	0	0
TOTAL VITRINITE	78.6	91.0	85.9	90.8	84.2	89.2	88.7	91.0	64.0	84.2
SPORINITE	1.7	1.9	1.6	1.7	1.7	1.8	2.3	2.3	1.0	1.3
RESINITE	0.8	0.9	0.6	0.7	0.5	0.5	0.8	0.8	1.1	1.4
CUTINITE	0	0	0	0	0	0	0	0	0	0
LIPTODETRINITE	0.6	0.7	0.6	0.7	1.5	1.6	0.8	0.8	0.6	0.8
TOTAL EXINITE	3.1	3.5	2.8	3.1	3.7	3.9	3.9	3.9	2.7	3.5
FUSINITE	1.5	1.7	2.0	2.1	2.4	2.5	2.0	2.0	2.9	3.5
SEMIFUSINITE	1.8	2.1	2.0	2.1	2.1	2.2	2.6	2.6	3.9	5.2
SCLEROTINITE	0	0	0	0	0	0	0	0	0	0
MICRINITE	0.9	1.0	0.9	1.0	0.8	0.8	0.2	0.2	1.3	1.7
MACRINITE	0	0	0	0	0	0	0	0	0.1	0.1
INERTODETRINITE	0.6	0.7	0.8	0.9	1.3	1.4	0.3	0.3	1.1	1.4
TOTAL INERTINITE	4.8	5.5	5.7	6.1	6.6	6.9	5.1	5.1	9.3	12.3
CARBARGILLITE	2.0		0.4		0.2		0		0.9	
CARBOPYRITE	0.5		0.1		0.4		0		0.7	
SUBTOTAL										
CARBOMINERITE	2.5		0.5		0.6		0		1.6	
PYRITE	3.9		1.5		2.5		1.6		13.4	
OTHER MINERALS	7.1		3.6		2.4		0.7		9.0	
SUBTOTAL										
MINERAL MATTER	11.0		5.1		4.9		2.3		22.4	
GRAND TOTAL										
MINERAL MATTER	13.5		5.6		5.5		2.3		24.0	
COUNTS PER PELLET	1028		973		1062		1011		1017	

mmcb-mineral matter containing basis
mmfb-mineral matter free basis

TABLE 5. VOLUME PERCENT MACERAL CONTENT AS RECEIVED
FOR SELECTED SAMPLES OF OHIO COALS
PITTSBURGH (NO. 8) COAL
UTOC 259

SAMPLE NO.	CPDU-131		CPDU 131-A	
	Seam mmcb	mmfb	Wash mmcb	mmfb
TELINITE	2.2	2.5	2.0	2.3
COLLINITE	72.5	82.6	74.3	84.5
VITRODETRINITE	1.6	1.8	0.5	0.5
TOTAL VITRINITE	76.3	86.9	76.8	87.3
SPORINITE	1.2	1.4	1.8	2.0
RESINITE	0.8	0.9	1.7	1.9
CUTINITE	0	0	0	0
LIPTODETRINITE	1.1	1.3	0.7	0.8
TOTAL EXINITE	3.1	3.6	4.2	4.7
FUSINITE	3.2	3.7	1.0	1.1
SEMIFUSINITE	4.1	4.7	5.3	6.1
SCLEROTINITE	0.7	0.8	0.3	0.3
MICRINITE	0.3	0.3	0.5	0.5
MACRINITE	0	0	0	0
INERTODETRINITE	0	0	0	0
TOTAL INERTINITE	8.3	9.5	7.1	8.0
CARBARGILLITE	1.0		0.9	
CARBOPYRITE	0.1		0	
SUBTOTAL CARBOMINERITE	1.1		0.9	
PYRITE	3.0		3.7	
OTHER MINERALS	8.2		7.3	
SUBTOTAL MINERAL MATTER	11.2		11.0	
GRAND TOTAL MINERAL MATTER	12.3		11.9	
COUNTS PER PELLET	1061		1050	

mmcb-mineral matter containing basis
mmfb-mineral matter free basis

TABLE 6. VOLUME PERCENT MACERAL CONTENT AS RECEIVED
FOR SELECTED SAMPLES OF OHIO COALS
PITTSBURGH (NO. 8) COAL

UTOC 260

SAMPLE NO.	CPDU-137		CPDU 127-A		CPDU 127-B		CPDU 127-C		CPDU 127-D	
	Seam		I		II		III		IV	
	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb
TELINITE	4.0	4.6	2.9	3.5	2.5	2.8	1.8	1.9	2.6	3.0
COLLINITE	70.4	81.9	69.8	82.7	66.1	74.5	81.1	86.0	71.7	81.7
VITRODETRINITE	0.2	0.2	1.4	1.6	0.8	0.9	0.6	0.6	0.6	0.6
TOTAL VITRINITE	74.6	86.7	74.1	87.7	69.4	78.2	83.5	88.5	74.9	85.3
SPORINITE	1.8	2.1	2.5	2.9	3.9	4.4	1.2	1.3	1.7	1.9
RESINITE	2.6	3.0	2.1	2.4	2.1	2.4	1.8	2.0	2.4	2.8
CUTINITE	0	0	0	0	0	0	0	0	0	0
LIPTODETRINITE	0.4	0.4	1.5	1.7	0.7	0.8	0.2	0.2	0.3	0.3
TOTAL EXINITE	4.8	5.5	6.1	7.0	6.7	7.6	3.2	3.5	4.4	5.0
FUSINITE	0.9	1.0	0.9	1.0	6.0	6.7	3.0	3.2	2.7	3.1
SEMIFUSINITE	4.1	4.7	2.8	3.4	4.8	5.4	3.4	3.6	5.2	5.9
SCLEROTINITE	0.5	0.6	0.2	0.2	0.4	0.4	0.4	0.4	0.2	0.2
MICRINITE	1.3	1.5	0.6	0.7	1.4	1.6	0.6	0.7	0.5	0.5
MACRINITE			0	0	0	0	0	0	0	0
INERTODETRINITE			0	0	0.1	0.1	0.1	0.1	0	0
TOTAL INERTINITE	6.8	7.8	4.5	5.3	12.7	14.2	7.4	8.0	8.6	9.7
CARBARGILLITE	0.9		1.3		1.1		0.1		0.8	
CARBOPYRITE	0.2		0.1		0.1		0.1		0.1	
SUBTOTAL										
CARBOMINERITE	1.1		1.4		1.2		0.2		0.9	
PYRITE	7.8		8.5		1.4		3.4		4.9	
OTHER MINERALS	4.9		5.4		8.6		2.3		6.3	
SUBTOTAL										
MINERAL MATTER	12.7		13.9		10.0		5.7		11.2	
GRAND TOTAL										
MINERAL MATTER	13.8		15.3		11.2		5.9		12.1	
COUNTS PER PELLET	1128		1019		1071		1080		1075	

mmcb-mineral matter containing basis
mmfb-mineral matter free basis

TABLE 7. VOLUME PERCENT MACERAL CONTENT AS RECEIVED
FOR SELECTED SAMPLES OF OHIO COALS
PITTSBURGH (NO. 8) COAL

UTOC 265

SAMPLE NO.	CPDU-135		CPDU 128-A		CPDU 128-B		CPDU 128-C		CPDU 128-D	
	Seam		I		II		III		IV	
	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb	mmcb	mmfb
TELINITE	2.9	3.2	3.6	3.7	1.9	2.4	2.8	2.9	2.0	2.1
COLLINITE	70.1	78.1	80.6	83.3	55.1	69.4	79.4	82.3	72.0	78.0
VITRODETRINITE	0.2	0.2	0.8	0.8	0.9	1.2	1.1	1.1	0.8	0.8
TOTAL VITRINITE	73.2	81.5	85.0	87.8	57.9	73.0	83.3	86.3	74.8	80.9
SPORINITE	2.9	3.3	1.4	1.5	3.6	4.5	1.9	2.0	3.1	3.4
RESINITE	5.2	5.8	1.1	1.2	3.1	3.9	1.4	1.4	2.2	2.3
CUTINITE	0	0	0	0	0	0	0	0	0	0
LIPTODETRINITE	0.3	0.3	0.6	0.6	2.0	2.5	0.4	0.4	0.9	1.0
TOTAL EXINITE	8.4	9.4	3.1	3.3	8.7	10.9	3.7	3.8	6.2	6.7
FUSINITE	3.2	3.6	3.6	3.7	5.4	6.9	4.8	4.9	6.6	7.1
SEMIFUSINITE	3.8	4.3	3.7	3.8	6.1	7.7	3.9	4.0	3.9	4.2
SCLEROTINITE	0	0	0.4	0.4	0.6	0.7	0.1	0.1	0.1	0.1
MICRINITE	1.1	1.1	0.9	0.9	0.6	0.7	0.7	0.8	0.8	0.8
MACRINITE	0	0	0	0	0	0	0	0	0	0
INERTODETRINITE	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2
TOTAL INERTINITE	8.1	9.1	8.7	8.9	12.8	16.1	9.6	9.9	11.6	12.4
CARBARGILLITE	1.2		0.1		3.9		0.1		0.6	
CARBOPYRITE	0.1		0		0.1		0		0	
SUBTOTAL										
CARBOMINERITE	1.3		0.1		4.0		0.1		0.6	
PYRITE	2.9		1.7		3.8		1.5		2.7	
OTHER MINERALS	6.1		1.4		12.8		1.8		4.1	
SUBTOTAL										
MINERAL MATTER	9.0		3.1		16.6		3.3		6.8	
GRAND TOTAL										
MINERAL MATTER	10.3		3.2		20.5		3.4		7.4	
COUNTS PER PELLET	1124		1046		1064		1029		1061	

mmcb-mineral matter containing basis
mmfb-mineral matter free basis

Geochemistry

Trace and Minor Elements

Trace elements are defined as elements present in the earth's crust in concentrations of 0.1% (1000 ppm) or less (Hall, et al., 1974, p. 35). A wide variety of trace elements are found in coal. Minor elements are defined as elements present in the coal in concentrations ranging from 0.1 to about 5 percent. Recent analyses of trace elements by atomic absorption spectroscopy have aided in the characterization of coal. At one time, experimental techniques provided analyses that were at best approximate. Today, trace element determination procedures accurately detect particulates which are parts per billion of a sample. Quantitative studies of trace elements, are being applied to many problems which were previously unsolved.

Coal-derived trace and minor elements have created a concern which is twofold. The first problem is the threat to the environment by known toxic elements, i.e., cadmium, mercury, lead, and selenium. Even though coal contains only minor amounts of poisonous elements, they become concentrated in the bottom and fly ash following combustion. An estimated 75 million tons of ash will be produced in 1980 alone (Morrison, 1978, p. 24). The potential of serious ecologic damage over an extended time period is very possible. Toxicologists are only now just beginning to study the effects of long-term, low level trace element exposures on the environment.

The other concern posed by trace and minor elements deals with the utilization of coal. Industrial problems are caused by certain elements during normal combustion and conversion processes. Severe metal corrosion in boilers and turbines is caused by vanadium, sulfur, and chlorine.

In coal conversion, specially derived catalysts are very effective, but very expensive. Certain elements (titanium, iron, calcium and sodium) are detrimental to these catalysts and cause deactivation (Kang and Johanson, 1977, p. 89). Therefore, the amounts of these trace and minor elements from different coals should be determined prior to the selection of seams for coal conversion.

Recent investigations into mineral catalysis indicate certain trace and minor elements which are poisonous to artificially produced catalysts may, in fact, be catalysts themselves. Iron, sulfur, and titanium content in coal has been shown to have a direct relationship to coal conversion (Mukhejee and Chowdhury, 1976). Further investigations may prove the natural inorganics as advantageous to coal conversion as manufactured catalysts.

Trace and minor elements in coal originate in two different ways. The first mode of occurrence includes those elements which are inherent and occur in the plants which formed the coal. Trace and minor elements in coal may also be introduced from an outside source. These adventitious elements may originate syngenetically or epigenetically with other mineral matter.

Knowledge of the interdependence of trace and minor elements and their origin can aid in the characterization investigations for the industrial use of coal. For example, boron is used to determine paleosalinity, whereas manganese is used as an Eh and pH indicator. The compilation of elemental data relevant to depositional environments assists in the development of paleogeographic maps. Detailed regional mapping of marine and nonmarine domains has industrial applications. Different industrial uses of coal require different qualities of coal. By outlining

individual zones for specific utilization, a coal seam in one area may be used for coking while the same seam in another area may be best applied in liquefaction. One point must always be considered when attempting to interpret depositional environments; trace elements are only a part of the necessary information required for depositional environment determination.

The trace and minor elements for the specific coal samples in this study have yet to be determined, however, trace element analyses on the same seams from the immediate area of our samples were conducted by the U.S.G.S. and recorded by Botoman and Stith in 1978. These values are used initially for comparison with other data and can be found in Tables 10 and 11.

Major/Minor Elements and Oxides

The major and minor element composition of the whole coal samples (See Table 10) are from coals located close to those examined in this study. The elements are representative of the most abundant elements in the earth's crust. The organic elements carbon, oxygen, hydrogen and nitrogen are not included in the percentages. These organic elements are a major portion of the whole coal and make up the difference of the total percentage. Variations of the elements exist not only from seam to seam, but also between the different horizons within a single seam. These differences may be related to different environments of deposition.

The major and minor oxides content of the laboratory ash is determined from the analyses of the elements in the ash as an oxide equivalent. Oxides (See Table 11) rarely occur in coals because the oxygen is combined with elements to form different compounds such as silicates, carbonates,

TABLE 8. TRACE ELEMENT COMPOSITION OF THE WHOLE COAL FROM SEAMS IN CLOSE PROXIMITY TO THE SAMPLES STUDIED
(From G. Botoman and D. A. Scith, 1978).

Seam	Clarion (No. 4A)					Low, Kittanning (No. 5)					Mid. Kittanning (No. 6)					Pittsburgh (No. 8)					Pittsburgh (No. 8)								
County	Vinton					Coshocton					Muskogum					Monroe					Harrison								
Township	Wilkesville					Virginia					Adams					Switzerland					Cadiz								
OCS File #	807					745					743					726					796								
Type	bed sample					bed sample					bed sample					bed sample					bed sample								
Assoc. UTOC	264					262					263					259					260/265								
Ag	0.05L	Hf	28L	Ru	0.9L	Ag	0.03L	Hf	10L	Ru	0.4L	Ag	0.412	Hf	25L	Ru	0.9L	Ag	N	Hf	N	Ru	B	Ag	0.08	Hf	9.9L	Ru	0.1L
As	2.2	Hg	0.1	Sb	0.2	As	.3	Hg	0.2	Sb	0.2	As	1.4	Hg	0.2	Sb	0.3	As	4	Hg	0.0	Sb	0.2	As	9	Hg	0.2	Sb	0.24
Au	2.8L	Mo	1.9L	Sc	7	Au	1.0L	Mo	0.8L	Sc	2.2	Au	2.5L	Mo	1.7L	Sc	3.3	Au	N	Mo	B	Sc	2.1	Au	0.1L	Mo	0.3L	Sc	1.9
B	146G	In	2.8L	Se	6W	B	104G	In	0.8L	Se	1.1	B	52	In	1.7L	Se	3.0	B	52	In	N	Se	3.3X	B	46G	In	0.5L	Se	1.7
Ba	95	Ir	12L	Sm	13L	Ba	23	Ir	23L	Sm	5.0L	Ba	62	Ir	17L	Sm	12L	Ba	31	Ir	B	Sm	N	Ba	21.6	Ir	0.7L	Sm	0.7L
Be	1.8	La	13	Sn	2L	Be	2.3	La	3	Sn	0.9L	Be	1.12	La	6	Sn	1.8L	Be	0.73	La	10LE	Sn	N	Be	1.3	La	5	Sn	1.5L
Bi	6.3L	Li	16	Sr	111	Bi	2.4L	Li	4.7	Sr	24	Bi	5.7L	Li	50	Sr	45	Bi	N	Li	16	Sr	52	Bi	0.5L	Li	8.9	Sr	19
Br	12.2	Lu	6.3L	Ta	91L	Br	0.5	Lu	2.4L	Ta	34L	Br	15	Lu	5.7L	Ta	81L	Br	N	Lu	N	Ta	N	Br	16	Lu	0.7L	Ta	46L
Cd	0.21	Mn	49W	Tb	8.2L	Cd	0.1	Mn	28W	Tb	3.4L	Cd	0.11L	Mn	30W	Tb	8L	Cd	0.10LE	Mn	16	Tb	N	Cd	0.1	Mn	14	Tb	5.7L
Ce	21	Mo	2.9L	Te	B	Ce	6	Mo	3.6	Te	B	Ce	8	Mo	3L	Te	B	Ce	52LE	Mo	1.0	Te	N	Ce	11	Mo	1.1	Te	46L
Co	4.1	Nb	5.5	Th	4.4L	Co	2.0	Nb	1.8	Th	3L	Co	1.7	Nb	2L	Th	3L	Co	2.1E	Nb	2.1	Th	3L	Co	2.3	Nb	1.5L	Th	3L
Cr	26	Nd	19	Ti	2.8L	Cr	8	Nd	5.9L	Ti	0.1L	Cr	9.2	Nd	12L	Ti	2.4L	Cr	7.3E	Nd	N	Ti	N	Cr	11	Nd	6.7L	Ti	0.5L
Cs	2.7	Ni	11	Tm	1.3	Cs	.3	Ni	5.7	Tm	0.5L	Cs	1.3L	Ni	5	Tm	1.1L	Cs	N	Ni	7.3	Tm	B	Cs	0.7	Ni	7.3	Tm	0.3L
Cu	13.5	Os	2.8L	U	1.4	Cu	7.7	Os	0.1L	U	1.5L	Cu	6.7	Os	2.5L	U	0.4L	Cu	5.4	Os	B	U	0.2L	Cu	5.9	Os	2.2L	U	0.6
Dy	9.1L	Pb	5	V	36L	Dy	3.6L	Pb	2.7	V	10	Dy	8.1L	Pb	2.7L	V	14	Dy	N	Pb	3.6	V	17	Dy	1.5L	Pb	3.2	V	13
Er	2.9L	Pd	0.5L	W	2.8	Er	1.4L	Pd	0.2L	W	0.1L	Er	2.5L	Pd	0.4L	W	2.9L	Er	N	Pd	N	W	N	Er	0.5L	Pd	0.1L	W	1.0L
Eu	0.6L	Pr	19L	Y	12	Eu	0.23L	Pr	8L	Y	9.4	Eu	0.43L	Pr	17L	Y	2.6	Eu	N	Pr	N	Y	3.4	Eu	0.20	Pr	1.4	Y	3.3
F	192	Pt	6.8L	Yb	1.1	F	68	Pt	0.8L	Yb	0.7	F	119L	Pt	1.7L	Yb	0.6	F	60	Pt	N	Yb	B	F	58	Pt	0.7L	Yb	0.4
Ga	10	Rb	29	Zn	19	Ga	2.9	Rb	6L	Zn	41	Ga	5.0L	Rb	28L	Zn	19	Ga	3.1	Rb	B	Zn	9.0	Ga	4.2L	Rb	21L	Zn	9.9
Gd	3.5L	Re	2.8L	Zr	83	Gd	1.7L	Re	0.1L	Zr	23	Gd	1.7L	Re	2.5L	Zr	22	Gd	N	Re	N	Zr	N	Gd	2.2L	Re	1.0L	Zr	11
Ge	1.8L	Rh	0.3L			Ge	6.8L	Rh	0.1L			Ge	2.3L	Rh	0.3L			Ge	N	Rh	B			Ge	0.89	Rh	0.1L		

Key to symbols -

Method: DNA - by delayed neutron activation
E - by emission spectrography
NA - by neutron activation
W - by wet chemistry

B - no data available
E - calculated from emission spectrographic data on ash
L - less than value shown

N - not detected
X - by X-ray fluorescence on whole coal

TABLE 9. TRACE ELEMENT COMPOSITION OF THE LABORATORY ASH FROM SEAMS IN CLOSE PROXIMITY TO THE SAMPLES STUDIED
(From G. Botoman and D. A. Stith, 1978).

Seam	Clarion (No. 4A)				L. Kittanning (No. 5)				M. Kittanning (No. 6)				Pittsburgh (No. 8)				Pittsburgh (No. 8)			
County	Vinton				Coshocton				Muskingum				Monroe				Harrison			
Township	Wilkesville				Virginal				Adams				Switzerland				Judith			
QCS File #	807				745				743				726				796			
Type	bed sample				bed sample				bed sample				bed sample				bed sample			
Assoc. ITOC	264				262				263				259				260/265			
	Ag E	0.3L	Nb E	86	Ag E	0.1L	Nb E	19	Ag E	0.3L	Nb E	6L	Ag E	N	Nb E	20	Ag E	0.8	Nb E	15L
	Au E	10.8L	Nd E	53	Au E	11L	Nd E	69	Au E	12L	Nd E	59L	Au E	N	Nd E	N	Au E	10L	Nd E	68L
	B E	919G	Ni E	11L	B E	1100G	Ni E	65	B E	498	Ni E	34	B E	500	Ni E	70	B E	460G	Ni E	74
	Ba E	347	Os E	21	Ba E	244	Os E	11L	Ba E	349	Os E	12L	Ba E	300	Os E	B	Ba E	218	Os E	22L
	Be E	11	Pb W	2.1L	Be E	24	Pb W	30	Be E	12	Pb W	13L	Be E	7	Pb W	35	Be E	13	Pb W	32
	Bi E	24L	Pd E	73L	Bi E	25L	Pd E	2L	Bi E	27L	Pd E	2L	Bi E	N	Pd E	N	Bi E	5L	Pd E	1L
	Cd W	1.3	Pr E	7.5L	Cd W	1.2	Pr E	84L	Cd W	2.5L	Pr E	83L	Cd W	1L	Pr E	N	Cd W	1.0	Pr E	14
	Ce E	B	Pt E	11L	Ce E	B	Pt E	8L	Ce E	B	Pt E	9L	Ce E	500L	Pt E	N	Ce E	B	Pt E	7L
	Co E	B	Re E	1L	Co E	B	Re E	11L	Co E	B	Re E	12L	Co E	20	Re E	N	Co E	B	Re E	10L
	Cr E	B	Rh E	1L	Cr E	B	Rh E	1L	Cr E	B	Rh E	1L	Cr E	70	Rh E	B	Cr E	B	Rh E	1L
	Cu W	72	Ru E	3L	Cu W	87	Ru E	4L	Cu W	55	Ru E	6L	Cu W	62	Ru E	B	Cu W	60	Ru E	1L
	Dy E	35L	Sc E	32	Dy E	39L	Sc E	23	Dy E	39L	Sc E	16	Dy E	B	Sc E	20	Dy E	15L	Sc E	19
	Er E	12L	Sm E	50L	Er E	16L	Sm E	52L	Er E	12L	Sm E	56L	Er E	B	Sm E	N	Er E	5L	Sm E	7L
	Eu E	2.4L	Sn E	7.5L	Eu E	2L	Sn E	10L	Eu E	2L	Sn E	9L	Eu E	N	Sn E	N	Eu E	2	Sn E	15L
	Ga E	53	Sr E	637	Ga E	32	Sr E	256	Ga E	34	Sr E	760	Ga E	30	Sr E	500	Ga E	43	Sr E	190
	Gd E	20L	Ta E	346L	Gd E	18	Ta E	360L	Gd E	9L	Ta E	388L	Gd E	B	Ta E	N	Gd E	22L	Ta E	460L
	Ge E	8L	Tb E	35L	Ge E	78	Tb E	36L	Ge E	12L	Tb E	39L	Ge E	N	Tb E	B	Ge E	9	Tb E	68L
	Hf E	100L	Te E	B	Hf E	110L	Te E	B	Hf E	119L	Te E	B	Hf E	N	Te E	N	Hf E	100L	Te E	460L
	Ho E	8L	Tl E	11L	Ho E	8L	Tl E	11L	Ho E	9L	Tl E	12L	Ho E	B	Tl E	N	Ho E	36	Tl E	5L
	In E	8L	Tm E	5L	In E	8L	Tm E	5L	In E	9L	Tm E	6L	In E	N	Tm E	B	In E	5L	Tm E	3L
	Ir E	B	V E	184	Ir E	255L	V E	106	Ir E	106L	V E	58	Ir E	B	V E	150	Ir E	7L	V E	130
	La E	89	W E	11L	La E	B	W E	11L	La E	B	W E	12L	La E	100L	W E	N	La E	B	W E	10L
	Li W	24L	Y E	73	Li W	51	Y E	102	Li W	132	Y E	26	Li W	150	Y E	30	Li W	90	Y E	33
	Lu E	303W	Zb E	6	Lu E	25L	Zb E	8	Lu E	27L	Zb E	4	Lu E	B	Zb E	B	Lu E	7L	Zb E	4
	Mn E	18L	Zn E	98	Mn E	287W	Zn E	465	Mn E	152W	Zn E	381	Mn E	150	Zn E	98	Mn E	140	Zn E	100
	Mo E	29	Zr E	440	Mo E	39	Zr E	255	Mo E	28L	Zr E	68	Mo E	10	Zr E	N	Mo E	11	Zr E	110

Key to symbols

Method: E - by omission spectrography
W - by wet chemistry
* - averaged seam value

B - no data available
L - less than value shown
N - not detected

TABLE 10. MAJOR AND MINOR ELEMENT COMPOSITION ON A WHOLE COAL BASIS FROM SEAMS IN CLOSE PROXIMITY TO THE SAMPLES STUDIED (From G. Botoman and D. A. Stith, 1978).

County	Township	Seam	OGS File No.	UTOC No.	Si (%)	Al (%)	Ca (%)	Mg (%)	Na (%)	K (%)	Fe (%)	Ti (%)	P (ppm)	S (%)	Cl (%)
Vinton	Wilkesville	No. 4A	807	264	5.0	2.9	0.37	0.174	0.162	0.31	1.8	0.155	94	0.25	B
Coshocton	Virginia	No. 5	745	262	1.7	0.7	0.54	0.018	0.050	0.08	1.9	0.045	53	0.19	B
Muskingum	Adams	No. 6	743	263	3.4	1.6	0.23	0.140	0.090	0.28	3.1	0.110	63	0.22	B
Monroe	Switzerland	No. 8	726	259	1.7	1.2	0.22	0.035	0.047	0.12	2.0	0.056	450L	0.12	0.02L
Harrison	Cadiz	No. 8	796	260 265	2.0	0.9	0.05	0.039	0.026	0.14	2.2	0.046	430L	0.06	0.02L

Sulfur content calculated from SO_3 content of 525°C ash. Values for S should be taken from the proximate-ultimate analyses.

B - no data available.

L - less than value shown.

TABLE 11. MAJOR AND MINOR OXIDE COMPOSITION OF THE LABORATORY ASH, BY BED FROM SEAMS IN CLOSE PROXIMITY TO THE SAMPLES STUDIED (From G. Botoman and D. A. Stith, 1978).

County	Township	Seam	OGS File No.	UTOC No.	Ash (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	CaO (%)	MgO (%)	Na ₂ O (%)	K ₂ O (%)	Fe ₂ O ₃ (%)	TiO ₂ (%)	P ₂ O ₅ (%)	SO ₃ (%)	Cl (%)
Vinton	Wilkesville	No. 4A	807	264	23.8	40	22	4.3	1.07	1.02	2.0	23	1.10	0.1	3.5	B
Coshocton	Virginia	No. 5	745	262	9.3	38	14	7.4	0.33	0.72	1.0	30	0.80	0.1	5.0	B
Muskingum	Adams	No. 6	743	263	16.8	22	12	4.4	0.69	0.87	0.7	50	0.77	0.1	6.6	B
Monroe	Switzerland	No. 8	726	259	10.4	35	22	3.0	0.56	0.61	1.4	27	0.89	1L	2.8	0.2L
Harrison	Cadiz	No. 8	796	260 265	9.9	43	17	0.7	0.65	0.35	1.7	32	0.78	1L	1.6	0.2L

Ash figure is percentage of total coal; major and minor oxide and chlorine figures are percentages of ash figures.

B - no data available.

L - less than value shown.

hydroxides and sulfates.

Mineralogy

Recently, mineral matter in coal has come under closer scrutiny because of its potential as an environmental hazard and because it can be used as a disposable catalyst in coal conversion. The term mineral matter is applied to all inorganic materials occurring in coal and includes elements usually considered to be inorganic, even if they are combined in organic complexes. That is, all elements in coal except carbon, hydrogen, oxygen, nitrogen and sulfur are considered to be part of the mineral matter and four of these organic elements also occur in inorganic combination in coals (Rao and Gluskoter, 1973, p. 2). The minerals which are the most common occur as silicates, sulfides and carbonates.

The silicate minerals average some 60 to 80% of the total mineral matter in coal (Stach, 1975, p. 122). Of the silicates, the most prominent are the clay minerals and quartz. Different proportions of the clays kaolinite, illite, and montmorillonite exist in various seams. Of these clays, kaolinite and illite have been found to be the most abundant. A high kaolinite content results in an increase in the ash fusion point (Stach, 1975, p. 122) and in some instances acts as a catalyst in conversion processes (Mukherjee and Chowdhury, 1976, p. 7).

The other major silicate mineral associated with coal is quartz. Two phases are commonly found and both phases relate to two different modes of deposition. Granular quartz indicates an allochthonous origin and was deposited with other sediments in the subsiding swamp. The other type of quartz is finely crystalline. Precipitation of this silicate fraction may have occurred at any stage of coalification (Stach, 1975,

p. 129).

The sulfides associated with coals are dominately iron or zinc sulfide minerals. Pyrite and its dimorph marcasite, are the dominant sulfide minerals of Ohio coals. The origin of these minerals can be syngenetic or epigenetic. The syngenetic sulfides are finely crystalline, and in some instances form layered concretions. Epigenitic forms of the sulfides crystallize along the cleats and fractures of the coal (Stach, 1975, 128). The presence of sulfides in large amounts has caused deleterious effects in many industries which rely upon coal as boiler fuel. Environmental problems have also been related to emissions from power plants utilizing high sulfur coals. The demeanor of pyrite is not entirely negative. The occurrence of pyrite in coal has shown very promising results in coal conversion. Pyrite may be used as a disposable catalyst as an alternative to costly manmade catalysts (Moroni and Fischer, 1980, p. 1).

A variety of carbonate minerals have been recognized in different coals worldwide. Calcite, dolomite, siderite and ankerite are the more abundant carbonate minerals. Their presence in coal may be attributed to syngenetic or epigenetic origins. The carbonates may precipitate out as nodules (coal balls) or as fissure and cleat infillings (Stach, 1975, p. 127).

The mineralogy of the Ohio coals sampled in this study has been determined by x-ray techniques using the LTA ash derived from these coals. Table 12 lists the minerals identified. The minerals indicated as "not detected" may, in fact, be present but occur in too small a quantity (less than 4-5 percent) to be detected by x-ray diffraction. Other analytical methods such as x-ray fluorescence, atomic absorption and scanning

Table 12. SUMMARY OF X-RAY ANALYSES (NRD) OF THE LOW-TEMPERATURE ASHES FROM SEAM AND VARIABLE FEEDSTOCK SAMPLES OF SELECTED OHIO COALS

SAMPLE IDENTIFICATION	Clay Minerals				Iron Sulphides										Carbonates			Sulphates		Oxides & Hydroxides											
	ILLITE	MONTMORILLONITE	KAOLINITE	SERICITE	CHLORITE	PYRITE	NARCASITE	MELNIKOVITE	PYRRHOTITE	CHALCOPHOSITE	GREIGITE	TRILOITE	COQUIMBITE	SZOMOLONKITE	JAROSITE	ROZENITE	MELANERITE	ROMERITE	CAICITP	DOLOMITE	SIDERITE	ANKERITE	GYPSUM	ANHYDRITE	BASSANITE	HEMATITE	QUARTZ	LIMONITE	DIASPORE	GEOTHITE	
UTOC 265 Variable Feed Stock Samples																															
I (CPDU-128-A)	D	nd	D	nd	rd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
II (CPDU-128-B)	D	nd	D	nd	rd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
III (CPDU-128-C)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
IV (CPDU-128-D)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	P	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
Seam (CPDU-135) Sample	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
UTOC 260 Variable Feed Stock Samples																															
I (CPDU-127-A)	P	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
II (CPDU-127-B)	D	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
III (CPDU-127-C)	P	nd	D	nd	nd	D	P	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
IV (CPDU-127-D)	D	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
Seam (CPDU-127-D) Sample	D	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
UTOC 259 Seam (CPDU-131-A) Sample	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	P	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
Wash (CPDU-131) Sample	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd

D - Dominant
P - Present
T - Trace
nd - Not Detected

Table 12. (CONTINUED) SUMMARY OF X-RAY ANALYSES (XRD) OF THE LOW-TEMPERATURE
ASHES FROM SEAM AND VARIABLE FEEDSTOCK SAMPLES OF SELECTED OHIO COALS

SAMPLE IDENTIFICATION	Clay Minerals					Iron Sulphides												Carbonates			Sulphates			Oxides & Hydroxides							
	ILLITE	MONTMORILLONITE	KAOLINITE	CHLORITE	SERICITE	PYRITE	MARCASITE	MELNIKOVIITE	PYRRHOTITE	CHALCOPHRITE	GREIGITE	TRILOITE	COQUINITE	SZONOLONKITE	JAROSITE	BOZENITE	MELANERITE	ROMERITE	CALCITE	DOLomite	SIDERITE	ANKERITE	CYPSUM	ANHYDRITE	BASSANITE	HEMATITE	QUARTZ	LIMONITE	DIASPORE	COETHITE	
UTOC 264 Variable Feed Stock Samples																															
I (CPDU-130-A)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
II (CPDU-130-B)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
III (CPDU-130-C)	nd	nd	D	nd	nd	D	P	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
Seam Sample (CPDU-134)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
Wash Sample (CPDU-132)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	T	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
UTOC 263 Variable Feed Stock Samples																															
I (CPDU-126-A)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
II (CPDU-126-B)	T	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	P	nd	nd	nd	nd
III (CPDU-126-C)	D	nd	D	nd	nd	D	P	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	P	nd	nd	nd	nd	nd	nd	P	nd	nd	nd	nd
IV (CPDU-126-D)	T	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
Seam Sample (CPDU-133)	D	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
UTOC 262 Variable Feed Stock Samples																															
I (CPDU-129-A)	D	nd	D	nd	nd	D	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
II (CPDU-129-B)	nd	nd	D	nd	nd	D	T	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
III (CPDU-129-C)	T	nd	D	nd	nd	D	P	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
Seam Sample (CPDU-136)	P	nd	D	nd	nd	D	P	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	D	nd	nd	nd	nd
D - Dominant P - Present					T - Trace nd - Not Detected																										

electron microscopy will be used to identify these minerals. A complete set of the x-ray tables containing d-spacing and intensity data is located in Appendix C.

Proximate/Ultimate Analyses

The proximate/ultimate analyses are tests used to check the quality of coal. A vast amount of information has been collected on coal seams worldwide, therefore, the values represent a large data base with which coals may be compared. The proximate analysis and the ultimate analysis represent different tests.

The proximate analysis is carried out in accordance with the Standard Method of Test for Proximate Analysis of Coal and Coke, D 3172-73. This method determines the moisture, volatile matter, fixed carbon, and ash contents of a coal sample. These values may be used in conjunction with correlation curves to determine the grade, rank and quality of the coal. This type of analysis is by no means a perfect procedure to evaluate coals, however, it does allow a good estimation of the economic value of a coal. Proximate analyses appear in Appendix D.

The values of the ultimate analysis were made as prescribed by ASTM Standard Method of Test for Ultimate Analysis of Coal and Coke, D 3176-76. In these investigations, the chemical components, carbon, hydrogen, sulfur nitrogen and the ash are determined. The carbon and hydrogen are evaluated from the gaseous products from complete combustion. The material as a whole is used to determine the sulfur, nitrogen, and ash, whereas oxygen is determined by the difference method. Usually, the moisture is also determined in this analysis so that the volume percent of the elements can be determined on a moisture-free basis.

A major problem with the ultimate analysis is the determination of

the oxygen content. The oxygen is calculated by subtracting the sum of carbon, sulfur, nitrogen, hydrogen and ash from 100. During ashing, mineral matter in coal undergoes chemical changes which release oxygen in a variety of gasses. This error and other related errors in the determination of oxygen by ultimate analysis are cumulative. It is recommended, therefore, that a number of corrections be made for each of the elements as outlined by Given and Yarzab (1978). See Appendix D for the ultimate analyses.

Chlorine

The chlorine content of coals is usually low, occurring mostly as inorganic salts such as sodium, potassium, calcium, iron and magnesium chlorides. Some of the chlorine may also occur in the organic form. When coals contain more than 0.3% chlorine, they are unsuitable for many applications because the presence of chlorine may cause corrosion (Montgomery, 1978, p. 226). The chlorine content of the Ohio coals were determined in accordance with ASTM Specification D 2301 entitled: Chlorine in Coal. The results of these analyses are found in Appendix D, recorded with the ultimate analyses.

Free-Swelling Index

The free-swelling properties of the coals examined in this study were determined following: ASTM D 720-67 (Reapproved, 1972) The Standard Method of Testing for Free-Swelling Index of Coal. This rapid test aids in predicting the expansion of coal in a fuel bed (Parks, et al., 1957, p. 1). This property may also be applied to the behavior of coal in conversion processes. The free-swelling characteristics of the Ohio coals tested are listed in Table 13.

TABLE 13. FREE-SWELLING INDEX (FSI) VALUES OF SEVERAL OHIO COALS.

UTOC No.		Seam No.	Average FSI
264 Seam	CPDU-134	4A	1
FZ I	CPDU 130-A		2
II	CPDU 130-B		2
III	CPDU 130-C		3
Wash	CPDU-132		2
262 Seam	CPDU-136	5	3
FZ I	CPDU 129-A		3
II	CPDU 129-B		2
III	CPDU 129-C		2
263 Seam	CPDU-133	6	2.5
FZ I	CPDU 126-A		2.5
II	CPDU 126-B		3.5
III	CPDU 126-C		3
IV	CPDU 126-D		2
259 Seam	CPDU-131	8	6
Wash	CPDU 131-A		5
260 Seam	CPDU-137	8	4
FZ I	CPDU 127-A		2.5
II	CPDU 127-B		3.5
III	CPDU 127-C		4.5
IV	CPDU 127-D		5
265 Seam	CPDU-135	8	5
FZ I	CPDU 128-A		3
II	CPDU 128-B		2
III	CPDU 128-C		4
IV	CPDU 128-D		5

FZ = Feedstock Zone

MINERAL CATALYSIS

Catalysts in coal conversion processes are of great importance, because they increase the yields and substantially reduce the sulfur present in final product. Catalysts, when introduced with hydrogen, alter the hydrogen-poor organic molecules in the coal. In the presence of an effective catalyst, organic molecular structures open and become receptive to molecular hydrogen; therefore, the resultant modified hydrocarbons are utilized more efficiently. The ability of sulfur to be removed is related also to the introduction of hydrogen, because these two elements easily combine and leave the system as hydrogen sulfide gas.

Mineral catalysis, as it relates to coal conversion processes, is also a very important area of study. Mineral matter in coal and its reactivity in coal conversion is being explored for a number of reasons. Commercial catalysts, such as nickel or cobalt-molybdenum, tend to produce the highest conversion yields; however, these catalysts are susceptible to deactivation by sintering, carbon deposition and metal deposition (Kang and Johanson, 1977, p. 93). In addition, these commercial catalysts are expensive, and recycling of these spent catalysts is costly and inefficient. Mineral matter provides an inexpensive alternative. In fact, many minerals common to coal enhance the conversion of coal to synfuels.

Pyrite, a mineral which is abundant in Ohio coals, is one of the most important inherent catalytic minerals in coal conversion. The catalytic behavior of pyrite aids in the hydrogenation of solvents used in many of the conversion processes. This is important because the rate-limiting step in liquefaction is the hydrogenation of the solvent. The

hydrogen donating capacity of the solvent increases as the solvent itself becomes enriched with hydrogen. Commercial and mineral catalysts interact with the hydrogen-solvent mixture at varied rates and with different results (See Figure 3). During the SRC process, the initial hydrogen pressure decreases during liquefaction as the hydrogen reacts with the coal derived solvent, creosote. Tarrer, et al., (1977 p. 54) state that using total pressure as a rough indicator of reaction rate, from Figure 3, some of the coal minerals definitely appear to provide catalysis for hydrogenation of the creosote oil.

The ability of pyrite to actively participate in the hydrogen-transfer is also related to particle size. Mineral matter found in coal varies in size from large nodules two feet in diameter to submicroscopic particles. Pyrite, one of the most active catalysts, exists in all sizes. Size is of importance primarily because of the possible site from which conversion may be aided. The smaller particles have a greater surface area per volume than larger particles. Conversion, therefore, is increased as the particle size is decreased. A comparison of the hydrogenation activity rate of pyrite, one particle size equal to -80 to +150 mesh and the other pyrite particles equal to -325 mesh, is shown in Figure 3.

Pyrite, although not as effective as cobalt-molybdenum, is highly regarded as a potential disposable catalyst for coal conversion. During conversion, pyrite changes into the mineral pyrrhotite by losing one sulfur atom (Moroni and Fischer, 1980, p. 6).

where: $0 \leq x \leq 0.125$

FIGURE 3. Catalytic Effect of Coal Minerals as Indicated by Total Hydrogen Pressure (Modified from Tarrer, et al., 1977, p. 50).

The presence of the two iron sulfides results in higher conversion yields. In the studies completed by Moroni and Fischer, pyrrhotite has been shown to be as active in synfuel processes as the more expensive commercial catalysts. Initial investigations indicate that the amount of iron associated with the iron sulfides is inversely proportional to the percent conversion. Continued research in this field could result in isolating which mineral species of pyrrhotite is the most advantageous to coal conversion (Montano and Granoff, 1980, p. 314). The intimate relationship between the different phases of the Fe-S system are shown in Figure 4. A positive side effect also makes the use of pyrite as a disposable catalyst very attractive. The phase change from pyrite to pyrrhotite is also accompanied by a change in physical properties from a weakly paramagnetic mineral to a ferromagnetic mineral (Maxwell, et al., 1980, p. 1). The magnetic properties of pyrrhotite allow the removal of the spent mineral catalyst by magnetic separation.

Other minerals associated with coal are involved in mineral catalysis. Catalytic activity per unit area and per gram of mineral were determined by Gangwer and Prasad in 1979 (p. 577-584). The most active minerals, other than the iron sulfides, are magnetite, diaspore and limonite. Metallic iron and iron oxides also are thought to react with the solvent, resulting in the dehydrosulfurization of the solvent (Tarrer, et al., 1977, p. 57). This reaction was also observed by Mukherjee and Chowdhury (1977, p. 4-8). During their experimentation, conversion percentages increased with increased titanium content. Yield increases were also observed during similar tests using kaolinite. Figure 5 illustrates the catalytic effect of the kaolinite; increasing the specific yield from 31% to 52%.

FIGURE 4. Phase Diagram of Low Temperature Iron Sulfides (From Kissin, 1974).

FIGURE 5. Catalytic Effect of Kaolinite as Illustrated in Volume Percentages (Modified from Murkejee and Chowdhurry, 1977, p. 7).

There are three modes of occurrence of mineral matter in coal.

The first mode occurs along the cleats, which according to Dean, et al., (1980, p. 4) were primarily formed by tectonic forces. In this case, the minerals have precipitated from ground water and are not intergrown with the organic particles. Second, microscopic examination of coal shows that some mineral matter is intimately intergrown with or has replaced organic particles. The third mode of mineral occurrence is as submicroscopic particles. These can be identified only by x-ray diffraction or electron optical techniques. For a better understanding of how the mineral matter reacts during coal conversion, it is important to study each of the phases.

Commercial and mineral catalysts both work, but in many cases the mineral catalyst is detrimental to the commercial catalyst. For example, iron and titanium exhibit positive behavior in coal conversion. These same elements, when present in relatively higher than normal amounts in coal, will poison cobalt-molybdenum catalysts. This interrelationship between the coal and catalyst makes it necessary to characterize the elemental and mineral contents of coals. Once determined, the data may be used to choose which catalysts and processes will allow optimum conversion.

In general, it has been determined that with an increase in mineral matter, there is an increase in conversion. Tarrer, et al., (1977, p. 58) observed that untreated coals have converted at a higher rate than slurried and demineralized coals (See Figure 6). Researchers have explored the catalytic effects of individual mineral and commercial catalysts successfully. A better understanding of how groups of minerals interact and which are best for the different liquefaction and gasification

FIGURE 6. Effect of Demineralized Coal and Slurried Coal (with water) on Conversion (Modified from Tarrer, et al., 1977, p. 55).

processes has yet to be determined. This knowledge will be essential for the development of a mature and economic synfuel industry.

DISCUSSION AND RESULTS

The original intent of this study was to correlate the characteristics of six seam, two washed and 18 feedstock samples of Ohio coal to the conversion results of a solvent refined coal (SRC) process. By relating the different properties of these coals to the percent conversion, prioritizing of these coals for SRC conversion could be made. The data from all the pilot plant runs were not completed or were not made available in time for reasonable completion of this thesis. Without the actual SRC percent conversion data, evaluation could not proceed. It was, therefore, necessary to relate information from this project to the results of other studies. Coal characteristics were correlated to liquefaction behavior outlined by the recent work of several authors (Given et al., 1975, 1975a; Abdel-Baset et al., 1978; Yarzab et al., 1980). They determined that the most reactive macerals were the vitrinites, whereas the exinite macerals are considered only semi-reactive. By combining the vitrinite group with the exinite group percentage, a parametric value is derived and is known as the total reactive maceral (TRM) volume percent. The abundance of TRM macerals was correlated with conversion percentages derived from a new bench reactor system (Given and Spackman, et al., 1976). The researchers mentioned above concluded that the higher the TRM percentage, the more transformable molecular structures present which can be converted into synfuels.

The Ohio coal samples of this study, on a dmmf basis, have a range from 83.9 to 96.5 percent TRM. This range indicates that Ohio coals are excellent for conversion. The petrography of the coals also includes the non-organic constituents i.e., mineral matter. The samples in this

study had a range from a low of 2.3 to a high of 24.0 volume percent mineral matter. Of the total mineral matter the pyrite varied from 1.4 to 13.4 volume percent. The size distribution and morphologies of the pyrite in the coals of this study are currently under investigation. This petrographic information will be useful in the final evaluation of these samples for coal conversion. The individual maceral and mineral matter volumetric percentages are found in Tables 2-7 on pages 32-37.

The percent reflectance of a coal measures the degree of maturity or rank of a coal and can be related to other coal characteristics such as percent carbon, hydrogen, H/C ratios, volatile matter and others. Therefore, the mean maximum reflectance values were measured on the vitrinite in the six seam samples of this study. The variable feed-stock coal samples were not evaluated because the thermal alteration of the organics are known to vary only slightly within the seams. The reflectance values determined in this study are from 0.53 percent for the Clarion (No. 4A) coal from Vinton County to 0.65 percent for the Pittsburgh (No. 8) coal from Monroe County (See Figure 7). The percent reflectance values appear to be lower than normal for coals of the Appalachian province. Trinkle et al., (1978, p. 506) observed higher percentages (0.7 to 0.8%) for coals from Pennsylvania and West Virginia that are located near the Ohio River. Since the UTOC reflectance values were suspect, the microscope was checked for alignment and instrumental problems. None were found. The coal pellets were carefully repolished and the percent reflectance remeasured. The mean maximum reflectance values remained low. In general, the mean maximum reflectance values increase from west to the east. This can be related to the seat of metamorphism which is at a greater distance from Ohio, causing the

FIGURE 7. Reflectograms Illustrating the Distribution of Reflectance Measurements in Half V-Steps at Two Standard Deviations ($2s$).

Ohio coals to be less mature than the coals of Pennsylvania and West Virginia. A similar change in the reflectance of phytoclasts from west to east was also observed by Potter, et al., (1980) in Devonian black shales of the eastern U.S. These phytoclasts exhibit steadily increasing maturity (greater reflectance) towards the east and southeast. In Ohio, these organic particles show reflectance values of the same range as those determined on the coals of this study. This is important because the Devonian phytoclasts, according to the effects of time and temperature, should exhibit higher reflectance values because they are geologically older than the Ohio coals. Another study, Epstein, et al., (1977), relates the color alteration index (CAI) of conodonts to the vitrinite reflectance of Ordovician, Silurian, and Mississippian rocks. In each instance, isograd values of the geothermal alteration increases from west to east. The CAI isograd for the Ohio area correlates well when compared with the coal reflectance values determined in this study.

In the literature, percent volatile matter is frequently compared with the percent mean maximum reflectance of coals. Contrary to this literature, Thompson and Benedict (1974, p. 102-103) indicate that the plot of percent volatile matter versus mean maximum reflectance is not a continuous curve. Their data suggest discontinuities around the 0.7, 1.0, and 1.3 percent reflectance values. They further state that the significance of these discontinuities is that these breaks occur respectively at the boundaries between (1) hvBa and hvBb coals, (2) hvBa and medium volatile coals, and (3) medium volatile and low volatile coals. The reflectance values of the coals in this study fall between lower and upper curves of the hvBa and hvBb boundary.

The non-organic constituents of the coals of this study were

determined by two different procedures. The high-temperature ashing (HTA) technique utilizes temperatures of 750° C to cause the combustion of the organics. In the second technique, low-temperature ashing (LTA), an oxygen plasma causes the reduction of the organics at a temperature of less than 150° C. The temperature difference causes two different resultant ashes. In HTA clay minerals associated with the coal are destroyed and the volatiles are driven off, whereas in LTA the mineral matter remains relatively unaltered. In each instance, the high temperature ash weight percentage is less than the weight percentage of the ash derived by LTA. To compare the mineral matter content of the two techniques it is necessary to calculate the true mineral matter content of the HTA. The most widely used conversion formula is the Parr formula, in which sulfur and ash contents are used to determine the mineral matter (Rao and Gluskoter, 1973, p. 17). The Parr mineral matter was determined using the original Parr formula:

$$\text{Parr mineral matter} = 1.08 \times \text{Ash} + 0.55 \times \text{Sulfur}$$

The correlation between the Parr mineral matter value and the low temperature mineral matter is very good (correlation coefficient $r = 0.99$). This indicates that the weight percent ash values derived by LTA are very close to the calculated Parr mineral matter content of the coals, thus indicating that the LTA determinations are accurate.

The HTA for the seam, washed, and variable feedstock samples ranges from 3.19 to 30.24 weight percent. The wide variation of ash content reflects the sampling technique purposely employed in obtaining the feedstock samples (See Appendix A). However, the high ash percentages for the different feedstock samples did not always correlate with samples

that included a claystone parting. For example, in the Feedstock Zone I of UTOC 264 there are no partings present and yet the HTA ash is 28.82 percent (See Figure 13, Appendix A). The mineral matter of this feedstock sample (UTOC 264-I) is probably interspersed with the organic particles (carbargillite). In comparing the washed and seam samples of Pittsburgh (No. 8) coal, UTOC 259, it was observed that the washed sample exhibited a higher ash content than the seam sample. This relationship usually does not occur unless more than one mine from the same seam is blended during washing, or most of the mineral matter is finely interspersed with the organic component of the coal(s). The seam and washed samples of the Clarion (No. 4A) coal, (UTOC 264), however, exhibited a 40 percent reduction in mineral matter after washing, which indicates that a large portion of the mineral matter is associated with the partings.

The mineralogy of the coal ash (LTA) was determined by X-ray diffraction (XRD) techniques. The minerals identified in all 26 of the samples included pyrite, kaolinite and quartz; illite was present in most of the samples. Some samples contained marcasite, dolomite and calcite. Quartz, pyrite and kaolinite dominate the diffractograms with quartz and pyrite being the prevalent peaks. Relatively large amounts of quartz occur in the Pittsburgh (No. 8) coals, whereas smaller amounts of quartz occur in the Middle Kittanning (No. 6) coals. Pyrite is the dominant mineral in the Middle Kittanning (No. 6) coals. A variety of other clay minerals, iron sulphides, carbonates, sulfates, oxides, and hydroxides were searched for, but were not observed (See Table 12, pages 47-48). These unobserved minerals are indicated as "not detected," however, they may be present in quantities too small to be detected by XRD methods.

The free-swelling indices (FSI) of the Ohio UTOC samples were

determined and are listed in Table 13, page 51. The Clarion (No. 4A) coal was the only coal that exhibited nonagglomerating properties. The exact cause of why coals swell is not fully understood, however, it has been established empirically that the non-swelling coals are generally more desirable for conversion, particularly gasification. During the heating of coals, the swelling properties, if large, hinder the flow of solvent during processing. Whereas other characteristics of a coal may make it very desirable for conversion, a large FSI value could rule out the coal for this type of industrial use.

Proximate/ultimate analyses (See Appendix D) were made on the 26 coal samples of this study. In the proximate analyses the ash percentages exhibit a wide variance as previously discussed. The volatile matter, which was recalculated to a dmmf basis following the guidelines of Given and Yarzab (1978), ranged from 36.95 to 48.90 percent. This characteristic of the coals is very desirable for coal conversion. The percent sulfur (dry basis) varied in the ultimate analyses from 2.31 to 7.49 percent. Other elements in these analyses exhibit smaller variation. A chlorine content of 0.01 to 0.12 was determined on the UTOC coals of this study. The chlorine content of the coals should present no problem for industrial utilization, since the values fall below the threshold level of 0.3 percent (Montgomery, 1978, p. 288).

Major/minor oxide, major/minor element and trace element analyses of the coals of this study have not been completed. Values have been calculated for each of these characteristics by the U.S.G.S. on coals that are in close proximity to each of the coals of this study (See Tables 8-11, pages 41-44). Major differences exist between the Clarion (No. 4A) coal and the Pittsburgh (No. 8) coal with respect to the sum of the

alkaline/alkali earth metals. The No. 4A coal from Vinton County totals to 1.01 percent and the No. 8 coal from Harrison County is 0.26 percent. The presence of the alkaline/alkali earths has been reported to influence the reactivity in coke making (Patrick and Shaw, 1972) and to enhance catalytic gasification (Marsh and Walker, 1978 and Prasher, 1979). The Clarion (No. 4A) coal, therefore, may be desirable as a raw coal for synfuel.

These same elements may be partly responsible for the differences in the free-swelling indices of the UTOC coals. Ting (1975) observed that agglomeration is more evident if a coal is low in ash and ion-exchangeable cations -- primarily sodium, potassium, calcium, and magnesium. The free-swelling indices of the UTOC coals and the corresponding total percent alkali and alkaline earths are as follows:

<u>Seam No.</u>	<u>Alkali/Alkaline Earths (%)</u>	<u>FSI Range</u>
4A	1.01	1.5-2
5	0.69	2.5-3
6	0.74	2-3.5
8	0.26	4-6.5

The Clarion (No. 4A) coal exhibits the lowest free-swelling indices and the highest total alkali and alkaline earth content. The Nos. 5 and 6 coals have low FSI values and intermediate total alkali and alkaline earth content, whereas the No. 8 coal possesses moderate to high FSI values and the lowest alkali/alkaline earth content. These observations are only based on a few samples, however, their trend supports the conclusions of Ting (1975). Assuming these characteristics are valid, the Clarion (4A) coal is non-agglomerating and would promote even feed in the reactor during gasification, especially in a flash pyrolysis reactor.

Coals which vigorously agglutinate (particles which swell and adhere to adjacent particles) during heating tend to plug-up gasifiers; however, they may be desirable for liquefaction. The above data suggest that the Nos. 5 and 6 coals may possess the best overall characteristics for conversion to synfuels.

Preliminary results of the trace elements analyses of UTOC coals indicate that the concentration of these elements closely parallel those obtained by the U.S.G.S. These early results support the initial use of the trace element data of the U.S.G.S. In Botoman and Stith (1978), trace elements of the coals from near the collection sites exhibit only a few major differences. However, the trace elements known to be catalysts in coal conversion, Co, Mo, Ni, Cr, and Fe, and trace elements known to be catalytic poisons, Ti and V (Cusamano, et al., 1978, p. 54-55), are all quite similar from coal to coal. This is also true of many of the environmentally hazardous trace elements, namely, As, Be, Br, Cd, Hg, Pb, Sb, Se, U, and Zn.

The recent article, Dependence of coal liquefaction behaviour of 104 coals, authored by Yarzab, et al., (1980) provided the foundation for this study. Their data establish a basis for comparative analysis with the UTOC coals. The solvent used in their study was tetralin. Their liquefaction process operated at a temperature of 400° C for one hour in a 'tubing bomb'. The reactors were vibrated by an agitator mechanism at 400 vibrations for one to two minutes and then reduced to 100 per minute for the remaining time. After the conclusion of this reaction period, the residue was removed by rinsing with ethyl acetate into a Soxhlet thimble. After 24 hours of continuous treatment with tetralin solvent, the contents were flushed out of the Soxhlet thimble with ethyl acetate,

dried and weighed. The insoluble residue was then used to determine the percent conversion by:

$$\% \text{ conversion} = \frac{\text{wt. coal} - \text{wt. insoluble residue}}{\text{wt. coal}} \times 100$$

Their conversion data were initially related to 14 predictor variables.

The variables are:

- 1) % volatile matter
- 2) wt. % carbon (dmmf)
- 3) % R_m mean maximum reflectance
- 4) calorific value (BTU's)
- 5) hydrogen/carbon ratio
- 6) oxygen/carbon ratio
- 7) % oxygen
- 8) % total sulfur
- 9) % organic sulfur
- 10) % pyritic sulfur
- 11) vitrinite (vol. % dmmf)
- 12) total reactive macerals (vol. % dmmf)
- 13) % mineral matter
- 14) % organic sulfur (dmmf)

After an initial statistical analysis, Yarzab, et al., (1980) determined that the percent volatile matter (dmmf), carbon (dmmf), total sulfur (dry), vitrinite reflectance, total vitrinite and total reactive macerals (vol. % dmmf) were the variables most closely associated with percent conversion. Bivariate scatter plots of these six variables versus percent conversion showed strong trends. They applied multiple regression to the conversion and other data to develop their predictive equations.

The data collected by Yarzab, et al., (excluding the percent conversion) was combined with the corresponding data of this study for statistical analyses. Cluster analyses were initially run to determine what type of interrelationships existed between the coals of the two studies. As can be seen in Plate 1, the Ohio coal seam samples are found primarily within the confines of Interior province coals. Outliers do exist, but they

are limited to the variable feedstock samples, which were purposely biased. The Western province coals in this dendrogram show a distinct grouping. Because of the homogeneity of the Western coals, the cluster analysis was run again without them to examine the relationship of the remaining coals. Plate 2 illustrates a close relationship between the Interior province and the coals of Ohio. Coals which are outliers on the dendrogram of Plate 2 are again the variable feedstock samples. Two additional cluster analyses were performed. In the first, thesis samples were combined with the Interior province coals (Plate 3) and in the second, thesis samples were combined only with Appalachian province coals (Plate 4). In Plate 3, the dendrogram shows the UTOC samples are interspersed throughout the full spread of Interior province coals. Plate 4 indicates that the Ohio coals tend to be segregated from the coals of the Appalachian province. Comparison of Plate 3 with Plate 4 suggests that Ohio coals are more related in character to Interior province coals than Appalachian province coals.

The lower than normal percent mean maximum reflectance at first appears to be the controlling variable which caused the Ohio coals to cluster with the Interior coals. The reflectance values range from 0.65% to 0.53% (These values fall between the high and low reflectance values of 0.78% and 0.47% recorded for Ohio coals by Yarzab, et al., 1980, p. 91). A cluster analysis was made using UTOC % $\bar{R}_m$ values which were increased by 0.125 percent. This was done to determine how the clustering is effected by the larger % $\bar{R}_m$ values. In comparing these results with the original cluster analysis results (Plates 1-4), it was observed that the increased % $\bar{R}_m$ had little impact upon the distribution of the Ohio coals in the dendograms; however, minor shifts did occur.

The Ohio coals continue to remain a separate entity from the Appalachian province coals, which indicates the Ohio coals have characteristics more similar to the Interior basin coals, even when the increased reflectance values were employed in the analysis. When the increased reflectance values were used in predicting the percent conversion, it was observed that only a minor change of less than a two percent decrease in conversion occurred. Further investigations may yield greater reflectance percentages; however, these values will have minimal effect upon the predicted conversion determinations.

To assist in evaluating the relationship between the UTOC coals and the coals of Yarzab, et al., (1980) on a bivariate basis a computer was utilized to provide scatter plots. Each of the predictor variables were plotted against each other. In these bivariate plots (See Figures 8-10), three major geographic coal groupings develop; Western, Interior, and Appalachian provinces. The UTOC coals exhibit a position transitional between the latter two provinces. The relationship of the Ohio coals of this study, to the other coals, is supportive of the cluster analysis results.

The Western coals exhibit moderate reflectance values, low sulfur, low carbon and high volatile matter content. The Interior coals exhibit lower reflectance values, a wide range in sulfur content, moderate carbon content and a medium to high volatile matter content. The Appalachian coals exhibit the highest reflectance values, lower sulfur content, higher carbon and lower volatile matter content. Each of the provinces are somewhat unique because the values differ from characteristic to characteristic. Other bivariate plots, such as S_{total} (wt. % dry) vs. VM (wt. % dmmf); S_{total} (wt. % dry) vs. % TRM; and Carbon (% dmmf) vs. % $\bar{R}_m$, showed

FIGURE 8. Bivariate Scatter Plot of Total Sulfur (wt.%, dry) vs. Carbon (wt.%, dmmf).

FIGURE 9. Bivariate Scatter Plot of Total Sulfur (wt.%, dry) vs. Total Reactive Macerals (vol.%, dmmf).

FIGURE 10. Bivariate Scatter Plot of Mean Vitrinite Reflectance (%) vs. Volatile Matter (wt.%, dmmf).

the same grouping and, therefore, were not included as illustrations in this study.

Regression analyses were made for various combinations of coals from the three provinces in an attempt to establish the best predictive equation. A stepwise regression analysis using 104 North American coals from the study of Yarzab *et al.*, (1980) permitted the establishment of the three best variables (% total sulfur, % TRM and % VM) to characterize the coals for determining percent conversion. The standard error of the estimate, SEE, (i.e., the standard deviation of the actual conversions about the regression line) associated with this analysis is 3.80 percent, whereas the square of the multiple correlation coefficient (i.e., variance explained), R^2 is 0.83. The standard error of the estimate and variance explained were increased to 3.97% and 0.88 in this study using the Yarzab's samples without the Western province coals. An increase in credibility was attained by using six variables, yielding a reduced standard error of the estimate of 3.13% and the variance explained increased to 0.93. The following equations were used to predict percent conversion:

No. of variables

3	Appalachian, Interior and Western Province Coals (104 samples), Con. = $1.61 S_t + 0.20 \text{ TRM} + 1.79 \text{ VM} - 33.7$.
3	Appalachian and Interior Province Coals (65 samples), Con. = $1.81 S_t + 0.16 \text{ TRM} + 1.81 \text{ VM} - 32.6$.
6	Appalachian and Interior Province Coals (65 samples), Con. = $1.59 S_t + 0.79 \text{ VM} - 0.14 \text{ TRM} - 15.3 R_m - 0.79 C - 0.21 V - 96.3$.

Where:

S_t - total sulphur (wt. % dry)

TRM - total reactive macerals (vol. % dmmf)

- VM - volatile matter (wt. % dmmf)
- $\bar{R}_m$ - mean maximum reflectance of vitrinite (%)
- C - carbon (wt. % dmmf)
- V - vitrinite content (vol. % dmmf)

The estimated percent conversions computed from the equations for the UTOC samples are listed in Table 14. The seam, washed and variable feedstock samples all resulted in relatively high conversion percentages with the Lower Kittanning (No. 5) and Middle Kittanning (No. 6) coals exhibiting the highest percent conversion potential. These values rate in the upper half of the coals tested by Yarzab et al., (1980). In Figure 11, the volatile matter of the coal plotted against the conversion values show the good to excellent potential performance during conversion of the UTOC samples.

In an attempt to increase further the reliability of the percent conversion prediction equation, the Interior and Appalachian province samples were analyzed separately by a multiple linear regression program. Apparently, the decreased number of samples affected the reliability of these equations as R^2 decreased and the SEE increased. The conversion values derived from the previously stated equations would, therefore, be better for predicting the conversion of the UTOC samples.

A SAS STEPWISE regression procedure was run to determine which two of the six most important variables, as established by Yarzab et al., (1980) were the best predictor variables. Two different STEPWISE techniques determined the percent volatile matter to have the strongest correlation coefficient, $r = 0.908$. The relationship of conversion to volatile matter is significant because Ohio coals are characteristically

TABLE 14. PERCENT CALCULATED CONVERSION DATA BASED UPON THE WORK OF YARZAB, et al., (1980).

Sample			% Conversion Based upon 104 North American Coals	% Conversion Based upon 65 Coals From the Appalachian and Interior Coal Provinces		
R^2			0.84	0.88	0.93	
UTOC No.	Seam No.	Seam No.	*	*	**	
264	Seam CPDU-134	4A	70.80	70.36	70.72	
	I CPDU 130-A		68.81	68.40	68.15	
	II CPDU 130-B		77.64	78.13	79.60	
	III CPDU 130-C		69.85	69.64	71.28	
	Wash CPDU-132		71.36	71.00	70.75	
262	Seam CPDU-136	5	70.42	70.36	73.38	
	I CPDU 129-A		65.65	65.19	68.89	
	II CPDU 129-B		67.78	71.47	71.47	
	III CPDU 129-C		66.98	66.59	72.16	
263	Seam CPDU-133	6	75.80	75.57	72.22	
	I CPDU 126-A		66.70	66.10	67.28	
	II CPDU 126-B		79.29	79.15	74.58	
	III CPDU 126-C		67.76	67.06	67.67	
	IV CPDU 126-D		76.28	77.15	78.54	
259	Seam CPDU-131	8	74.84	74.66	69.86	
	Wash CPDU 131-A		71.18	70.91	67.27	
260	Seam CPDU-137	8	60.22	59.72	64.90	
	I CPDU 127-A		74.27	74.61	74.24	
	II CPDU 127-B		60.07	58.42	58.80	
	III CPDU 127-C		61.89	61.16	63.39	
	IV CPDU 127-D		63.85	63.71	61.90	
265	Seam CPDU-135	8	61.30	60.80	64.28	
	I CPDU 128-A		63.85	63.37	66.04	
	II CPDU 128-B		56.64	56.20	60.38	
	III CPDU 128-C		54.78	54.08	62.62	
	IV CPDU 128-D		59.62	59.28	63.94	

Note: Coal Parameters Used to Determine Percent Conversion

* The three variables used are:
volatile matter, total sulfur and total reactive macerals

** The six variables used are:
volatile matter, total sulfur, total reactive macerals,
percent carbon, percent reflectance, and vitrinite percentage

R^2 Square of the multiple correlation coefficient (i.e.,
variance explained)

FIGURE 11. Bivariate Scatter Plot of Conversion (wt.%, dmmf) vs. Volatile Matter (wt.%, dmmf) of 104 PSOC and 26 UTOC Samples (Modified after Yarzab, et al., 1980, p. 83).

high in volatile matter. This relationship is shown graphically in Figure 11 (page 79). The next variable related most to conversion, from the results of both STEPWISE techniques, is the volume percent of the maceral vitrinite. These "reactive" macerals provide most of the convertible molecular structures which can be changed into synfuels. Most of the Ohio coals exhibited large percentages of these macerals. Coals which possessed large amounts of the reactive macerals also exhibited the larger predicted conversion percentages. For example, the highest vitrinite percentage, 94.0 percent, corresponds to a predicted conversion of 71.5 percent, whereas the lowest, 73.0 percent vitrinite, corresponds to a 60.2 percent conversion.

The study by Yarzab et al., (1980) provided an invaluable data base from which percent conversion may be predicted. However, coal characteristics determined in this study, other than those employed in the computer analyses, should be used to develop a better understanding of their role in conversion. Mineral matter and its catalytic effect on coal conversion is an aspect of coal characterization that must be considered.

Sulfur in coals and its relationship to conversion is a facet of coal conversion undergoing intensive study. Studies of pyrite, the most common iron sulfide, has led to progress in the development of mineral catalysis. Figure 3, page 54, shows that pyrite is a reactive noncommercial catalyst in the SRC process. Other investigations have supported this finding (i.e., Moroni and Fischer, 1980; Granoff, 1979). Another iron sulfide, pyrrhotite has shown higher catalytic activity than pyrite. Pyrite is easily altered by losing a single sulfur atom to pyrrhotite at about 75° C (See Figure 5, page 57). Since conversion

reactions take place at temperatures above this, the accompanying alteration increases the reactivity. The different phases of pyrrhotite have different morphologies and surface areas. Further investigations of this type (Montano and Granoff, 1980, p. 214; Lambert, et al., p. 687) may indicate which of the phases is most active during conversion. One of the phases, monoclinic pyrrhotite (Fe_7S_8) is strongly ferrimagnetic, until reaction temperatures reach about 300°C upon which the pyrrhotite becomes paramagnetic. This physical property of monoclinic pyrrhotite may permit magnetic recovery of the catalyst during a SRC process run (Jacobs, Levinson, and Hart, 1978, p. 1776). Moroni and Fischer (1980) also determined that the amount of pyrite or any other iron sulfide is reflected by the total sulfur content which shows a strong relationship with the percent conversion of a given coal. They attempted to artificially increase the sulfur/iron sulfide percentages by a special coal cleaning process which eliminated non-catalytic mineral matter at a 95 percent coal beneficiation efficiency (Moroni and Fischer, 1980, p. 9). Figure 5 (page 57) indicates that clay content has been shown to cause an increase of catalytic activity in coals during conversion (Mukherjee and Chowdhury, 1976). Detailed investigations into the effects of combined mineral catalysts have not yet been undertaken and may prove to be of great economic value upon completion.

The positive effect of pyrite in coal conversion is of great importance to the coal industry in Ohio. A major problem that has plagued the mining and burning of Ohio coals has been the high sulfur and pyrite content. During World War I, industrial demands for sulfuric acid were met by converting pyrite into the sulfuric acid. Cleveland's chemical plants were supplied from coal mines located in southeastern Ohio (Tucker, 1919,

p. 200). The most productive regions, pictured in Figure 12, are mining areas which are now under restraint by recent EPA regulations. Federal and state laws have closed many of these mines because their coals produced high SO_2 emissions during direct combustion. The coals of these areas are so rich in "reactive" pyrite that they can become a source for disposable mineral catalysts. The coal reserves represented by Pittsburgh (No. 8), Middle Kittanning (No. 6) and Lower Kittanning (No. 5) coal seams, outlined in Figure 12, are over 5,640 million tons (Nielsen, 1977), and are sufficient to maintain several coal conversion systems. The introduction of any coal conversion plants would revitalize the coal industry of southeastern Ohio.

The presence of carbonate, clay minerals and quartz was detected in the LTA ash of the UTOC samples using X-ray diffraction methods. Although the exact weight percentages have not been determined, relative amounts can be distinguished. Kaolinite and illite are the dominant clay minerals found in the Ohio coals. Figure 5 (page 57) shows the reactivity of kaolinite as a catalyst. Quartz is present in each of the Ohio coal samples tested. Relatively large amounts of quartz occur in the Pittsburgh (No. 8) coals, whereas only traces of quartz occur in the Middle Kittanning (No. 6) coals. According to Tarrer et al., (1977) the amount of quartz present in a coal may hinder the reactivity. In Figure 3 (page 54), quartz shows a very limited effect upon the conversion of coal. Large quantities of quartz, however, may mask or hinder the ability of active catalytic minerals in a conversion process. Selective separation of the inert minerals to increase the relative percentages of the iron sulfides may be a solution which could increase product yields during conversion. Mineral matter favorable to catalytic activity should be

FIGURE 12. Pyrite Occurrence in Southeastern Ohio. The shaded zones represent areas in Southeastern Ohio where large quantities of pyrite occur along with the Nos. 5, 6 and 8 coal seams (Modified after Tucker, 1919, p. 216).

studied microscopically to determine particle size. Figure 3 (page 54) shows that the smaller the particle size, the greater the reactivity; which is true in both mineral as well as commercial catalysts.

The overall evaluation of the 26 coal samples demands the integration of the characteristics of each of the coal parameters. In comparing the different seam, washed and variable feedstock samples, the order of decreasing predicted reactivity is:

- 1) Middle Kittanning (No. 6) coal
- 2) Lower Kittanning (No. 5) coal
- 3) Clarion (No. 4A) coal
- 4) Pittsburgh (No. 8) coal.

The No. 6 coal was selected to be the most desirable for a number of reasons; these are the % vitrinite content, % total reactive macerals, % total alkali and alkaline earths, % volatile matter content, % iron, low free-swelling index and the abundance of reactive pyrite. All of these characteristics rank either first or second when compared to the other coals. Although the seam sample did not have the highest predicted conversion percentage, it was only one percent less than the highest, the No. 5 coal. Following this logic, the other seams were so ordered.

One of the objectives of this study was to obtain samples which exhibited a wide variation in coal characteristics. This mission was accomplished by the sampling techniques utilized and described. Many characteristic differences are exhibited by the bivariate scatter plots (See Figures 8-10, pages 73-75). Much of the diversification in the samples may be attributed to the variable feedstock samples. Because properties widely vary in a coal, it is important for a synfuel industry

to establish their operational parameters for a given conversion system. The feedstock samples provide a wide range of compositions derived from only a few seams. The sampling of coal lithobodies within a seam could prove to be the most efficient and economical method of collecting samples for coal research associated with the development of a given synfuel process.

CONCLUSIONS AND RECOMMENDATIONS

The petrology of coal samples revealed that UTOC coals exhibit a high volume percent (73.0-94.4%) of vitrinite, the most reactive maceral. In addition, values of the percent mean maximum reflectance ($\% \bar{R}_m$) of the vitrinite were measured and were found to be anomalously lower than would be anticipated for coals from the Appalachian basin. Comparative study of the literature that illustrated plots of percent volatile matter versus percent reflectance suggests that the anomalously lower reflectance values are correct. Several other authors reported similarly low ($\% \bar{R}_m$) values, which supports this conclusion. The low reflectance values of the UTOC samples (0.53-0.65%) could reflect a different phyteral composition in the original organic material and/or slightly different coalification history than those coals of the Appalachian province.

Excellent correlation is observed between the LTA content and the calculated Parr mineral value. The linear correlation coefficient (r) of 0.99 between the derived Parr Mineral Value and the LTA values indicates that the ash weight percent obtained by the low temperature method is the actual (true) mineral matter weight percent. It was observed that the higher ash values did not always correlate to a feedstock zone that contained claystone, bone coal, or black shale partings. This suggests that not all the mineral matter is associated with these partings; a portion of the mineral matter must be finely interspersed with the organic matter.

X-ray diffractograms of the LTA indicate that a majority of the Ohio coals are dominated by four minerals -- quartz, pyrite, kaolinite, and

illite. Analysis of the relative peak intensities (heights) indicate that quartz and/or pyrite are the most abundant mineral species. In Ohio coals, other minerals are present only in minor amounts.

Further complete investigations are needed to determine the trace elements in the UTOC coals; however, preliminary results from another thesis indicate that the trace element content reported by the U.S.G.S. on nearby coals are very similar. It is important for industry to develop what threshold concentrations of trace elements are harmful when released into the environment or what concentration in the whole coal could poison catalysts used during conversion. Once these threshold concentrations are determined, coal seams enriched in these harmful elements could be avoided.

The free-swelling indices for the UTOC coals ranged from 1.5 to 6.5. The Nos. 4A, 5, 6, and 8 coals (seams only) respectively, ranged from 1.5-2; 2.5-3; 2-3.5; to 4 through 6.5. Ting (1975) observed that the agglomeration tendency is more evident if a coal sample is low in ash and ion-exchangeable cations -- primarily sodium, potassium, calcium and magnesium. The percent total alkali and alkaline earths for the Nos. 4A, 5, 6, and 8 coals (seams only) are: 1.01; 0.69; 0.74; and 0.26. Note that the Clarion (No. 4A) coal shows an alkali-alkaline earth content four times greater than the Pittsburgh (No. 8) coal. The FSI range from 1.5 to 6.5. This trend is reinforced when the FSI is compared with the total alkali/alkaline earth content of these coals. It is known that the No. 4A coal with its very low FSI is a non-agglomerating coal, whereas the No. 8 coal with its much larger free-swelling indices is considered highly agglomerating. The Nos. 5 and 6 exhibit moderately low free-swelling indices and are probably non- or weakly agglomerating coals. Because

highly agglomerating coals tend to plug-up the reactors in gasifiers; they are less desirable for gasification, especially those of the flash pyrolysis type. However, highly agglomerating coals tend to be very desirable for liquefaction processes. This brief analysis suggests that the No. 5 and 6 coals may possess the best overall characteristics for conversion.

From the statistical analyses (See Plates 1-4) it is concluded that the Ohio coals are different in character from the coals of the Appalachian province -- a province with which Ohio coals historically were associated. These cluster analyses (See Plates 2 and 4) also suggest that the UTOC coals are more related in character to the coals of the Interior province (See Plate 3). However, the bivariate scatter plots suggest a different interpretation (See Figures 8-10, pages 73-75). These plots suggest that the UTOC coals in character are transitional between the coals of the Interior and Appalachian provinces.

The transitional character of the Ohio coals may be related to a different phyteral assemblage(s) or depositional environment(s) which existed in the original swamp; and/or a different coalification tract(s) than experienced by the coals of the Appalachian and Interior provinces.

A derived prediction equation was formulated that shows a multiple correlation coefficient (R) of 0.96. This equation was formulated using six predictor variables (% VM, % S_t, %C, %R_m, %V and %TRM) of the coals from the Interior and Appalachian provinces. The same six characteristics of the Ohio UTOC coals were then used in the prediction equation. The conversion values derived, when plotted against volatile matter, appear in the upper half of the bivariate plot (See Figure 11, page 79). The Lower (No. 5) and Middle (No. 6) Kittanning coal seams exhibited the

highest predicted percent conversions (respectively, 73.4 and 72.2%). Two seam samples (UTOC 260, 265) of the Pittsburgh (No. 8) coal showed the lowest conversion values, but these ranked in the upper half of all the coals studied.

The most important coal characteristic which effects conversion is the percent volatile matter followed in decreasing order by percent vitrinite and percent total sulfur. These observations were verified by the SAS STEPWISE regression using a "Forward Selection" technique. The observations indicate that Ohio coals are excellent raw feeds for conversion to synfuels because these coals exhibit high volatile matter (H_2 - rich); high vitrinite (O_2 - rich), the highest organic reactivity, and higher total sulfur ($S_{py} + S_o$) content when compared with most other coals.

The pyrite and kaolinite present in the UTOC coals are known to be disposable mineral catalysts which increase the synfuel yield during conversion. It is believed that the presence of these disposable catalysts will increase the marketability of Ohio coals and could spark the resurgence in production and use of these coals.

If pyrite is used widely as a mineral catalyst, it will be necessary to locate or extract large quantities of this mineral. Five to seven percent of pyrite is needed during liquefaction of coal. Ohio coals average approximately three to four percent sulfur, about forty percent of which is organic sulfur. It is necessary, therefore, to add catalytic pyrite to coal feedstocks during liquefaction. Ohio is unique because large deposits of pyrite are known to occur with certain coal seams (See Figure 12, page 83). The reserves of coal and pyrite in the areas shown in Figure 12 are sufficient to support several coal conversion plants.

It is recommended that studies of the size and shape distribution of pyrite in Ohio coals be made. Furthermore, it is recommended that the chemical reactivities of these pyrites be determined because reactivity is important in evaluating conversion efficiency.

The feedstock samples obtained for this study provide an excellent continuum of coal characteristics which could be expected in a continuous feed synfuel process. This method of sampling is more efficient and economic because fewer seams are collected. In addition, these samples could be blended to produce greater yields during conversion. Furthermore, the feedstock samples help determine which minerals and their concentrations act as disposable catalysts. These samples should be instrumental in determining the operational limits of the SRC conversion process.

REFERENCES CITED

- Abdel-Baset, M. B., Yarzab, R. F. and Given, P. H., 1978, Dependence of coal liquefaction behaviour on coal characteristics. 3. Statistical correlations of conversion in coal-tetralin interactions: Fuel, v. 57, p. 89-94.
- Annual Book of ASTM Standards, 1977, Part 26, Gaseous Fuels; Coal and Coke, Atmospheric Analysis: American Society for Testing and Materials, 1977.
- Anonymous, 1979, Cheap fool's gold added to coal improved conversion to liquid fuel: Coal Age, v. 84, n. 9, p. 170.
- Barr, A. J., Goodnight, J. H., Sall, J. P., and Helwig, J. T., 1976, A user's guide to statistical analysis systems (SAS)-76: Sparks Press, Raleigh, N. C., 329 p.
- Botoman, G., and Stith, D. A., 1978, Analyses of Ohio coals: Ohio Geol. Survey, Information Cir. No. 47, 148 p.
- Branson, C. C., 1962, Pennsylvanian system of Central Appalachians, in Branson, C. C., ed., Pennsylvanian System in the United States: Collegiate Press, Menasha, Wisc., p. 97-116.
- Braunstein, H. M., 1977, Summary in Environmental, Health, and Control Aspects of Coal Conversion: An Information Overview, v. 1, eds., H. M. Braunstein, Ed Copenhauer, and H. A. Pfuderer: Oak Ridge, National Laboratory, Oak Ridge, Tenn., p. 1-1.
- Chandra, D., 1963, Reproducibility and accuracy of maceral analysis of coal by point counter technique: Fuel, v. 42, p. 457-465.
- Cusumano, James A., Dalla Betta, Ralph A., and Levy, Richardo B., 1978 Catalysis in coal conversion: Academic Press, New York, p. 51-58.
- Dean, S. L., Kulander, B. R., Williams, R. E., and others, 1980, Fracture trends in the Allegheny Plateau of West Virginia: West Virginia Geological Economic Survey, 18 p.
- Dixon, W. J., and Brown, M. B., 1979, BMDP-79, Biomedical computer programs, P.-Series: University of California Press, Berkeley, 880 p.
- Dutcher, R. R., 1976, Field description of coal: ASTM, Special Technical Publication 661, 71 p.
- Epstein, A. G., Epstein, J. B., and Harris, L. D., 1977, Conodont color alteration, an index to organic metamorphism: U.S. Geol. Surv. Prof. Paper 995, 1977.

- Flask, A. P. and Pryor, J. A., 1979, SRC solids -boiler fuel and building block: Paper presented at the 6th Energy Technology Conference, Washington, D.C., February 27, 1979.
- Gangwer, T. E., and Prasad, H., 1979, Hydrogen-transfer catalytic activity of minerals common to coal: Fuel, v. 58, p. 577-584.
- Garg, D., 1980, Personal Communication.
- Given, P. H., Cronauer, D. C., Spackman, W., Lovell, H. L., Davis, A. and Biswas, G., 1975, Dependence of coal liquefaction behaviour on coal characteristics, 1. Vitrinite-rich Samples: Fuel, v. 54, p. 34-39.
- _____, 1975a, Dependence of coal liquefaction behaviour on coal characteristics, 2. Role of Petrographic Composition: Fuel, v. 54, p. 40-49.
- Given, P. H., Spackman, W., Walker, P. L., Davis, A. and Lovell, H. L., 1976, The relation of coal characteristics to liquefaction behavior: Pennsylvania State University, Quarterly Technical Progress Report, October-December, 1976, to U.S. ERDA, FE-2494-2.
- Given, P. H. and Yarzab, R. F., 1978, Analysis of the organic substances of coals: Problems posed by the presence of mineral matter, C. Karr, Jr., ed., in Analytical Methods for Coal and Coal Products v. II, Chapter 20: Academic Press, N. Y., p. 3-39.
- Gleit, C. E., 1963, Electronic apparatus for ashing biological specimens: Journal of Medical Electronics, v. 2, p. 112-118.
- Gluskoter, H. J., 1965, Electronic low-temperature ashing of bituminous coal: Fuel, v. 44, p. 285-291.
- Granoff, B., 1978, Mineral matter effects in coal liquefaction: First Quarterly Report, Sandia Laboratory, October-December, 1978, Sand 79-0306, 43 p.
- Gupta, A. S., 1979, SRC-I coal refinery: Markets and commercial efforts: Paper presented at the Coal Technology 1979 Conference, Houston, Texas, November 6-8, 1979.
- Hall, H. J., Varga, G. M., and Magee, E. M., 1974, Trace elements and potential pollutant effects in fossil fuels: Symposium proceedings: Environmental aspects of fuel conversion technology, May 1974, E.P.A.-R2-73-188, PB-220 376, p. 35-47.
- International Handbook of Coal Petrography, 1963, Intern. Committee for Coal Petrology (ICCP) ed., 2nd ed., Centre National Recherche Scientifique, Paris.
- International Handbook of Coal Petrography, 1971, 1975, Intern. Committee for Coal Petrology (ICC) ed., Supp. to 2nd ed., Centre National Recherche Scientifique, Paris.

- Jacobs, I. S., Levinson, L. M., and Hart, H. R., Jr., 1978, Magnetic and mossbauer spectroscopic characterization of coal: J. Appl. Phys., v. 49, n. 3, p. 1775-1779.
- Kang, C. C., and Johanson, E. C., 1977, Deactivation and attrition of Co-Mo catalyst during H-coal operations, Ellington, R. T., ed., in Liquid Fuels from Coal: Academic Press, New York, p. 89-101.
- Kissin, S. A., 1974, Phase relations in a portion of the Fe-S system: Unpublished Ph.D. Thesis, University of Toronto, Canada.
- Kneller, W. A., 1980, Personal Communication.
- Lambert, J. M., Jr., Simkovich, G., and Walker, P. L., Jr., 1980, Production of pyrrhotites by pyrite reduction: Fuel, v. 59, p. 687-690.
- Marsh, H. and Walker, P. L., 1978, The effects of impregnation of coal with potassium and sodium salts: Technical Report 6, for USDE contract EX-76-C-01-2030, 16 p.
- Maxwell, E., Jacobs, I. S., Kelland, D. R. and Levinson, L. M., 1980. Magnetic separation and thermo-magneto-chemical properties of coal liquefaction mineral particulates: General Electric Tech. Info. Series No. 80, CRD 162, Tech. Info. Exchange Bldg. 81, Rm. A133, Schenectady, N. Y. 12345, 18 p.
- Miller, R. N., Yarzab, R. F., and Given, P. H., 1979, Determination of the mineral-matter contents of coals by low-temperature ashing: Fuel, v. 58, p. 4-10.
- Montano, P. A. and Granoff, B., 1980, Stoichiometry of iron sulphides in liquefaction residues and correlation with conversion: Fuel, v. 59, n. 3, p. 214.
- Montgomery, W. J., 1978, Standard laboratory tests for coal and coke, in C. Karr, Jr., ed., Analytical Methods for Coal and Coal Products, v. I, Chapter 6: Academic Press, N. Y., p. 191-246.
- Moroni, Eneo E., and Fischer, Ronald H., 1980, Disposable catalysts for coal liquefaction: U.S. Department of Energy, Office of Coal Processing, Division of Coal Liquefaction.
- Morrison, R. E., 1976, Power plant ash: A new mineral resource in Torrey S., ed., Coal Ash Utilization, Fly Ash, Bottom Ash and Slag: Noyes Data Corporation, Park Ridge, N. J., p. 23-27.
- Mukherjee, D. K. and Chowdhury, P. B., 1976, Catalytic effect of mineral matter constituents in a North Assam coal on hydrogenation: Fuel, v. 55, p. 4-8.
- Nielsen, G. F., 1977, U.S. Coal Mine Production by Seam 1975: Mining Informational Services, Keystone Coal Industry Manual, McGraw-Hill, New York, N. Y., p. 182-216.

- Ohio Department of Natural Resources, Division of Geol. Survey, 1967, Generalized section of rocks of Ohio: Ohio Geol. Survey, Columbus, Ohio, 1 plate.
- Parks, B. C., O'Donnell, H. J., and Darakos, W. E., 1957, Relation between petrographic composition and free-swelling properties of Chilton coal: United States Department of the Interior, Bureau of Mines, Report of Investigations 5294, 22 p.
- Patrick, J. W. and Shaw, F. H., 1972, Influence of sodium carbonate on coke reactivity: Fuel, v. 51, p. 69-75.
- Potter, P. E., Maynard, J. B., and Pryor, W. A., 1980, Final report of special geological, geochemical and petrological studies of the Devonian shales in the Appalachian basin: USDOE, Eastern Gas Shales Project, Contract DE-AC21-76MC05291, Fisk Laboratory of Sedimentology, Department of Geology, University of Cincinnati, 86 p.
- Prasher, B. D., 1979, An assessment of catalytic gasification: U.S. Department of Energy, METC/SP-79/7, 98 p.
- Rao, C., Prasada, and Gluskoter, Harold J., 1973, Occurrence and distribution of minerals in Illinois coals: Illinois State Geol. Surv., Circular 476, 56 p.
- Reggel, L., Wender, I. and Raymond R., 1970, Catalytic dehydrogenation of coal: Part 4. A comparison of exinite, micrite and fusinite with vitrinite: Fuel, v. 49, p. 281-286.
- Stach, E., Taylor, G. H., Mackowsky, K. T., Chandra, D., Teichmuller, M., and Teichmuller, R., 1975, Stach's textbook of coal petrology: Gebruder Borntraeger, Berlin and Stuttgart, 428 p.
- Stauffer, C. R., and Schroyer, C. R., 1920, The Dunkard Series of Ohio: Geological Survey of Ohio, Bulletin 22, p. 15-23.
- Stopes, M. C., 1935, On the petrology of banded coals: Fuel, v. 14, p. 4-13.
- Sturgeon, M. T., and Associates, 1958, The geology and mineral resources of Athens County, Ohio: Geological Survey of Ohio, Bulletin 22, p. 36-176.
- Tarrer, Arthur R., Guin, James A., and others, 1977, Effects of coal minerals on reaction rates during coal liquefaction, in Ellington, R. T., ed., Liquid Fuels from Coal: Academic Press, New York, p. 45-61.
- Thompson, R. R., and Benedict, L. G., 1973, Vitrinite reflectance as an indicator of coal metamorphism for coke making in Dutcher, R. R., Hacquebard, P. A., Schopf, J. M., and Simon, J. A., (eds.): Carbonaceous Material, as Indicators of Metamorphism. Geol. Soc. America, Spl Paper No. 153, p. 95-108.

- Ting, F. T. C., 1975, Experimental enhancement of agglomerating properties in lignite: Proc. Coal Agglomeration and Conversion Symposium, W. Va. Geol. and Econ. Surv. and Coal Res. Bureau, W. Va. University, Morgantown, W. Va., p. 63-83.
- Trinkle, E. J., Sitler, J. A., Sasso, J. A., Kardosh, W. F., and Ting, F. T. C., 1978, Coalification pattern of West Virginia coals (eds.): Geol. Soc. America, Abstracts with Programs Joint annual meeting, Toronto, Ontario Canada, p. 506.
- Tucker, W. M., 1919, Pyrite deposits in Ohio coal: Economic Geology, v. 14, p. 198-219.
- Weller, J. M., 1930, Cyclical sedimentation of the Pennsylvanian period and its significance: Jour. Geology, v. 38, n. 2, p. 97-135.
- Yarzab, R. F., Given, P. H., Spackman, W., and Davis, A., 1980, Dependence of coal liquefaction behaviour on coal characteristics. 4. Cluster analyses for characteristics of 104 coals: Fuel, v. 59, p. 81-92.

CODING SUPPLEMENT

An Interim Report to Air Products and Chemical, Inc.
Project No. 216, 255, 3658
Whitacre, T. P., Hunt, T. J., and Kneller, W. A., 1981

UNIVERSITY OF TOLEDO (UTO) CODE NUMBER COAL SAMPLES, AND
AIR PRODUCTS AND CHEMICALS, INC. EQUIVALENT NUMBERS

UTO SAMPLE NO.	OHIO SEAM NO.	A/P EQUIVALENT SAMPLE NO.
264 Seam	4A	CPDU - 134
FZ I		CPDU - 130-A
II		CPDU - 130-B
III		CPDU - 130-C
WASH		CPDU - 132
262 Seam	5	CPDU - 136
FZ I		CPDU - 129-A
II		CPDU - 129-B
III		CPDU - 129-C
263 Seam	6	CPDU - 133
FZ I		CPDU - 126-A
II		CPDU - 126-B
III		CPDU - 126-C
IV		CPDU - 126-D
259* Seam	8	CPDU - 131
Wash		CPDU - 131-A
260 Seam	8	CPDU - 137
FZ I		CPDU - 127-A
II		CPDU - 127-B
III		CPDU - 127-C
IV		CPDU - 127-D
265 Seam	8	CPDU - 135
FZ I		CPDU - 128-A
II		CPDU - 128-B
III		CPDU - 128-C
IV		CPDU - 128-D

NOTE: FZ = Feed Stock Zone - See Appendix
A = Seam Profile

APPENDIX A

Seam Profiles

**CLARION (No. 4A) COAL
UTOC 264**

WILKESVILLE, OHIO 7.5' QUAD

VINTON COUNTY
WILKESVILLE TOWNSHIPR16W T8N
SECTION 15
NE 1/4, SW 1/4, NW 1/4

FIGURE 13

LOWER KITTANNING (No. 5) COAL**UTOC 262****SUGARCREEK, OHIO 7.5" QUAD.****HOLMES COUNTY
WALNUT CREEK TOWNSHIP****R5W T9N
SECTION 9
SW 1/4, SW 1/4, NE 1/4**

FIGURE 14.

MIDDLE KITTANNING (No.6) COAL
UTOC 263
PLAINFIELD, OHIO 7.5" QUAD.

MUSKINGUM COUNTY
ADAMS TOWNSHIP

R5W T3N
SECTION 2
NE1/4, NE1/4, SW1/4

FIGURE 15.

PITTSBURGH (No.8) COAL
UTOC 259

CAMERON, OHIO 7.5" QUAD.

MONROE COUNTY
SWITZERLAND TOWNSHIP

R4W T4N
SECTION 12
SW1/4, NW1/4, NE1/4

FIGURE 16.

PITTSBURGH (No. 8) COAL**UTOC 260****FLUSHING, OHIO 7.5" QUAD****HARRISON COUNTY
CADIZ TOWNSHIP****R5W T10N
SECTION 8
NE 1/4, SW 1/4, NW 1/4** **FIGURE 17.**

PITTSBURGH (No. 8) COAL
UTOC 265
FLUSHING, OHIO 7.5" QUAD

HARRISON COUNTY
ATHENS TOWNSHIP

R5W T9N
SECTION 36
SE 1/4, NE 1/4, NW 1/4

FZ = Feedstock Zone

1 in. = 10 in. vertical

FIGURE 18.

APPENDIX B

Percent Reflectance Values

Clarion (No. 4A) Coal

V-Stage	Range of Vitrinite Reflectance %	Mid-Point of Class	Reflectance Measurements from Data Sheets		Totals	% $\bar{R}_m$
			SEAM PELLET			
			A	B		
3	4.0					
4	0.40 - 0.45 0.45 - 0.50	4.25 4.75	8	3	11	11.0
5	0.50 - 0.55 0.55 - 0.60	5.25 5.75	31 9	31 16	62 25	62.0 25.0
6	0.60 - 0.65 0.65 - 0.70	6.25 6.75	2	0	2	2.0
7	0.70 - 0.75 0.75 - 0.80	7.25 7.75				
8	0.80 - 0.85 0.85 - 0.90	8.25 8.75				
9	0.90 - 0.95 0.95 - 1.00	9.25 9.75				
10	1.00 - 1.05 1.05 - 1.10	10.25 10.75				
11	1.10 - 1.15 1.15 - 1.20	11.25 11.75				
12	1.20 - 1.25 1.25 - 1.30	12.25 12.75				
13	1.30 - 1.35 1.35 - 1.40	13.25 13.75				
14	1.40 - 1.45 1.45 - 1.50	14.25 14.75				
15	1.50 - 1.55 1.55 - 1.60	15.25 15.75				
			Total		100	100

Lower Kittanning (No. 5) Coal

Lower Reflectance (R ₀ - 0.40)						
V-Stage	Range of Vitrinite Reflectance %	Mid-Point of Class	Reflectance Measurements from Data Sheets		Totals	% $\bar{R}_m$
			SEMI PELLET			
			A	B		
3	4.0					
4	0.40 - 0.45 0.45 - 0.50	4.25 4.75				
5	0.50 - 0.55 0.55 - 0.60	5.25 5.75	36 38	30 20	66 58	52.8 46.4
6	0.60 - 0.65 0.65 - 0.70	6.25 6.75	1	0	1	0.8
7	0.70 - 0.75 0.75 - 0.80	7.25 7.75				
8	0.80 - 0.85 0.85 - 0.90	8.25 8.75				
9	0.90 - 0.95 0.95 - 1.00	9.25 9.75				
10	1.00 - 1.05 1.05 - 1.10	10.25 10.75				
11	1.10 - 1.15 1.15 - 1.20	11.25 11.75				
12	1.20 - 1.25 1.25 - 1.30	12.25 12.75				
13	1.30 - 1.35 1.35 - 1.40	13.25 13.75				
14	1.40 - 1.45 1.45 - 1.50	14.25 14.75				
15	1.50 - 1.55 1.55 - 1.60	15.25 15.75				
			Total		125	100

Middle Kittanning (No. 6) Coal

V-Stage	Range of Vitrinite Reflectance %	Mid-Point of Class	Reflectance Measurements from Data Sheets		Totals	% $\bar{R}_m$
			SEMI PELLET			
			A	B		
3	4.0					
4	0.40 - 0.45 0.45 - 0.50	4.25 4.75				
5	0.50 - 0.55 0.55 - 0.60	5.25 5.75	48 48	22 28	70 76	46.7 50.7
6	0.60 - 0.65 0.65 - 0.70	6.25 6.75	4	0	4	2.6
7	0.70 - 0.75 0.75 - 0.80	7.25 7.75				
8	0.80 - 0.85 0.85 - 0.90	8.25 8.75				
9	0.90 - 0.95 0.95 - 1.00	9.25 9.75				
10	1.00 - 1.05 1.05 - 1.10	10.25 10.75				
11	1.10 - 1.15 1.15 - 1.20	11.25 11.75				
12	1.20 - 1.25 1.25 - 1.30	12.25 12.75				
13	1.30 - 1.35 1.35 - 1.40	13.25 13.75				
14	1.40 - 1.45 1.45 - 1.50	14.25 14.75				
15	1.50 - 1.55 1.55 - 1.60	15.25 15.75				
			Total		150	100

Pittsburgh (No. 8) Coal

V-Stage	Range of Vitrinite Reflectance %	Mid-Point of Class	Reflectance Measurements from Data Sheets		Totals	% $\bar{R}_m$
			SEMI PELLET			
			A	B		
3	4.0					
4	0.40 - 0.45 0.45 - 0.50	4.25 4.75				
5	0.50 - 0.55 0.55 - 0.60	5.25 5.75	0 9	1 5	1 14	0.8 11.7
6	0.60 - 0.65 0.65 - 0.70	6.25 6.75	23 28	11 25	34 53	28.3 44.2
7	0.70 - 0.75 0.75 - 0.80	7.25 7.75	9 0	8 1	17 1	14.2 0.8
8	0.80 - 0.85 0.85 - 0.90	8.25 8.75				
9	0.90 - 0.95 0.95 - 1.00	9.25 9.75				
10	1.00 - 1.05 1.05 - 1.10	10.25 10.75				
11	1.10 - 1.15 1.15 - 1.20	11.25 11.75				
12	1.20 - 1.25 1.25 - 1.30	12.25 12.75				
13	1.30 - 1.35 1.35 - 1.40	13.25 13.75				
14	1.40 - 1.45 1.45 - 1.50	14.25 14.75				
15	1.50 - 1.55 1.55 - 1.60	15.25 15.75				
			Total		120	100

UTOOC 260

Pittsburgh (No. 8) Coal

V-Stage	Range of Vitrinite Reflectance %	Mid-Point of Class	Reflectance Measurements from Data Sheets		Totals	% $\bar{R}_m$
			SEAM PELLET			
			A	B		
3	4.0					
4	0.40 - 0.45 0.45 - 0.50	4.25 4.75				
5	0.50 - 0.55 0.55 - 0.60	5.25 5.75	28	46	74	59.2
6	0.60 - 0.65 0.65 - 0.70	6.25 6.75	19 3	28 1	47 4	37.6 3.2
7	0.70 - 0.75 0.75 - 0.80	7.25 7.75				
8	0.80 - 0.85 0.85 - 0.90	8.25 8.75				
9	0.90 - 0.95 0.95 - 1.00	9.25 9.75				
10	1.00 - 1.05 1.05 - 1.10	10.25 10.75				
11	1.10 - 1.15 1.15 - 1.20	11.25 11.75				
12	1.20 - 1.25 1.25 - 1.30	12.25 12.75				
13	1.30 - 1.35 1.35 - 1.40	13.25 13.75				
14	1.40 - 1.45 1.45 - 1.50	14.25 14.75				
15	1.50 - 1.55 1.55 - 1.60	15.25 15.75				
			Total		125	100

UTOC 265

Pittsburgh (No. 8) Coal

V-Stage	Range of Vitrinite Reflectance %	Mid-Point of Class	Reflectance Measurements from Data Sheets		Totals	% $\bar{R}_m$
			SEMI PELLET			
			A	B		
3	4.0					
4	0.40 - 0.45 0.45 - 0.50	4.25 4.75				
5	0.50 - 0.55 0.55 - 0.60	5.25 5.75	31 42	23 27	54 69	43.2 55.2
6	0.60 - 0.65 0.65 - 0.70	6.25 6.75	2	0	2	1.6
7	0.70 - 0.75 0.75 - 0.80	7.25 7.75				
8	0.80 - 0.85 0.85 - 0.90	8.25 8.75				
9	0.90 - 0.95 0.95 - 1.00	9.25 9.75				
10	1.00 - 1.05 1.05 - 1.10	10.25 10.75				
11	1.10 - 1.15 1.15 - 1.20	11.25 11.75				
12	1.20 - 1.25 1.25 - 1.30	12.25 12.75				
13	1.30 - 1.35 1.35 - 1.40	13.25 13.75				
14	1.40 - 1.45 1.45 - 1.50	14.25 14.75				
15	1.50 - 1.55 1.55 - 1.60	15.25 15.75				
			Total		125	100

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 264

 $\bar{R}_m = 0.531$

SEAM Clarion (No. 4A)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 9-15-80		Room Temp. Start 24 Finish 24		Date 9-15-80		Room Temp. Start 24 Finish 24	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990	1.650	1.647	1.657	1.990	1.657	1.690	1.647
1.856	1.025	1.004	0.999	1.856	1.025	1.025	1.023
1.757	0.492	0.506	0.587	1.757	0.518	0.481	0.504
1.694				1.694			
1) 0.489 26) 0.600 2) 0.497 27) 0.495 3) 0.556 28) 0.530 4) 0.573 29) 0.515 5) 0.499 30) 0.512 6) 0.514 31) 0.507 7) 0.601 32) 0.501 8) 0.587 33) 0.549 9) 0.537 34) 0.523 10) 0.529 35) 0.534 11) 0.573 36) 0.539 12) 0.501 37) 0.547 13) 0.517 38) 0.531 14) 0.493 39) 0.498 15) 0.514 40) 0.521 16) 0.506 41) 0.507 17) 0.564 42) 0.509 18) 0.559 43) 0.506 19) 0.479 44) 0.529 20) 0.511 45) 0.584 21) 0.485 46) 0.537 22) 0.519 47) 0.569 23) 0.547 48) 0.545 24) 0.504 49) 0.509 25) 0.524 50) 0.553				1) 0.541 26) 0.515 2) 0.575 27) 0.509 3) 0.519 28) 0.512 4) 0.540 29) 0.565 5) 0.564 30) 0.569 6) 0.589 31) 0.559 7) 0.523 32) 0.588 8) 0.531 33) 0.589 9) 0.565 34) 0.512 10) 0.515 35) 0.536 11) 0.515 36) 0.514 12) 0.502 37) 0.560 13) 0.522 38) 0.535 14) 0.516 39) 0.585 15) 0.517 40) 0.506 16) 0.511 41) 0.502 17) 0.502 42) 0.510 18) 0.499 43) 0.517 19) 0.532 44) 0.487 20) 0.528 45) 0.518 21) 0.551 46) 0.554 22) 0.498 47) 0.517 23) 0.559 48) 0.541 24) 0.556 49) 0.585 25) 0.528 50) 0.519			

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 263

 $\bar{R}_m = 0.556$

SEAM Middle Kittanning (No. 6)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 9-9-80		Room Temp. Start 23 Finish 23		Date 9-9-80		Room Temp. Start 23 Finish 23	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990				1.990			
1.856	1.025	0.998	0.999	1.856	1.025	1.002	1.014
1.757	0.505	0.506	0.507	1.757	0.507	0.513	0.512
1.694	0.327	0.326	0.327	1.694	0.330	0.335	0.332
1) 0.533		26) 0.528		1) 0.527		26) 0.519	
2) 0.522		27) 0.581		2) 0.547		27) 0.567	
3) 0.534		28) 0.598		3) 0.578		28) 0.540	
4) 0.537		29) 0.525		4) 0.538		29) 0.589	
5) 0.580		30) 0.597		5) 0.572		30) 0.582	
6) 0.543		31) 0.548		6) 0.576		31) 0.585	
7) 0.530		32) 0.561		7) 0.531		32) 0.527	
8) 0.543		33) 0.523		8) 0.597		33) 0.549	
9) 0.584		34) 0.568		9) 0.582		34) 0.531	
10) 0.575		35) 0.576		10) 0.696		35) 0.535	
11) 0.537		36) 0.573		11) 0.543		36) 0.517	
12) 0.519		37) 0.550		12) 0.573		37) 0.527	
13) 0.568		38) 0.558		13) 0.554		38) 0.524	
14) 0.571		39) 0.556		14) 0.550		39) 0.578	
15) 0.528		40) 0.528		15) 0.531		40) 0.540	
16) 0.548		41) 0.585		16) 0.532		41) 0.569	
17) 0.538		42) 0.597		17) 0.593		42) 0.599	
18) 0.598		43) 0.531		18) 0.558		43) 0.545	
19) 0.597		44) 0.538		19) 0.563		44) 0.592	
20) 0.519		45) 0.571		20) 0.542		45) 0.572	
21) 0.596		46) 0.528		21) 0.563		46) 0.584	
22) 0.563		47) 0.530		22) 0.541		47) 0.573	
23) 0.600		48) 0.559		23) 0.548		48) 0.578	
24) 0.557		49) 0.598		24) 0.596		49) 0.563	
25) 0.538		50) 0.546		25) 0.551		50) 0.521	

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 262

 $\bar{R}_m = 0.548$

SEAM Lower Kittanning (No. 5)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 9-9-80		Room Temp. Start 23 Finish 23		Date 9-9-80		Room Temp. Start 23 Finish 23	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990				1.990			
1.856	1.025	0.997	0.987	1.856	1.025	0.983	0.995
1.757	0.507	0.507	0.503	1.757	0.498	0.512	0.518
1.694	0.299	0.311	0.315	1.694	0.322	0.335	0.338
1) 0.533 26) 0.533 2) 0.574 27) 0.519 3) 0.541 28) 0.565 4) 0.547 29) 0.557 5) 0.558 30) 0.545 6) 0.547 31) 0.530 7) 0.567 32) 0.543 8) 0.559 33) 0.572 9) 0.513 34) 0.521 10) 0.567 35) 0.543 11) 0.552 36) 0.538 12) 0.572 37) 0.530 13) 0.514 38) 0.552 14) 0.538 39) 0.584 15) 0.552 40) 0.530 16) 0.542 41) 0.545 17) 0.521 42) 0.557 18) 0.545 43) 0.592 19) 0.558 44) 0.560 20) 0.594 45) 0.505 21) 0.553 46) 0.521 22) 0.518 47) 0.504 23) 0.534 48) 0.532 24) 0.544 49) 0.527 25) 0.543 50) 0.551				1) 0.597 26) 0.532 2) 0.598 27) 0.536 3) 0.515 28) 0.551 4) 0.545 29) 0.589 5) 0.508 30) 0.516 6) 0.525 31) 0.554 7) 0.531 32) 0.565 8) 0.530 33) 0.524 9) 0.514 34) 0.569 10) 0.597 35) 0.568 11) 0.557 36) 0.577 12) 0.531 37) 0.545 13) 0.562 38) 0.544 14) 0.515 39) 0.557 15) 0.512 40) 0.584 16) 0.568 41) 0.526 17) 0.561 42) 0.561 18) 0.535 43) 0.575 19) 0.575 44) 0.573 20) 0.559 45) 0.546 21) 0.563 46) 0.562 22) 0.602 47) 0.555 23) 0.539 48) 0.549 24) 0.527 49) 0.569 25) 0.544 50) 0.524			

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 262 (Continued)

 $\bar{R}_m = 0.548$

SEAM Lower Kittanning (No. 5)

Oil $n_e = 1.518$ @ 23°C

PELLET A				PELLET B			
Date 10-25-80		Room Temp. Start 23 Finish 23		Date		Room Temp. Start Finish	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990				1.990			
1.856	1.027	0.993	0.993	1.856			
1.757	0.507	0.509	0.509	1.757			
1.694	0.308	0.311	0.311	1.694			
1) 0.533 26) 2) 0.564 27) 3) 0.573 28) 4) 0.538 29) 5) 0.569 30) 6) 0.554 31) 7) 0.519 32) 8) 0.535 33) 9) 0.524 34) 10) 0.522 35) 11) 0.594 36) 12) 0.513 37) 13) 0.566 38) 14) 0.538 39) 15) 0.524 40) 16) 0.569 41) 17) 0.557 42) 18) 0.529 43) 19) 0.579 44) 20) 0.537 45) 21) 0.517 46) 22) 0.561 47) 23) 0.525 48) 24) 0.545 49) 25) 0.567 50)				1) 26) 2) 27) 3) 28) 4) 29) 5) 30) 6) 31) 7) 32) 8) 33) 9) 34) 10) 35) 11) 36) 12) 37) 13) 38) 14) 39) 15) 40) 16) 41) 17) 42) 18) 43) 19) 44) 20) 45) 21) 46) 22) 47) 23) 48) 24) 49) 25) 50)			

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 259

 $\bar{R}_m = 0.650$

SEAM Pittsburgh (No. 8)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 10-24-80		Room Temp.		Date 10-24-80		Room Temp.	
		Start 22				Start 22	
		Finish 22				Finish 22	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990	1.686	1.706	1.692	1.990	1.684	1.747	1.677
1.856	1.025	1.015	1.025	1.856	1.025	1.017	1.050
1.757	0.518	0.509	0.507	1.757	0.540	0.523	0.534
1.694				1.694			
1) 0.627		26) 0.656		1) 0.684		26) 0.650	
2) 0.688		27) 0.532		2) 0.638		27) 0.641	
3) 0.671		28) 0.626		3) 0.712		28) 0.639	
4) 0.682		29) 0.677		4) 0.628		29) 0.642	
5) 0.671		30) 0.595		5) 0.722		30) 0.595	
6) 0.689		31) 0.704		6) 0.625		31) 0.595	
7) 0.678		32) 0.670		7) 0.678		32) 0.656	
8) 0.691		33) 0.636		8) 0.648		33) 0.710	
9) 0.672		34) 0.699		9) 0.677		34) 0.725	
10) 0.586		35) 0.709		10) 0.708		35) 0.658	
11) 0.660		36) 0.654		11) 0.681		36) 0.660	
12) 0.646		37) 0.704		12) 0.690		37) 0.675	
13) 0.719		38) 0.633		13) 0.679		38) 0.595	
14) 0.630		39) 0.680		14) 0.693		39) 0.710	
15) 0.667		40) 0.652		15) 0.695		40) 0.657	
16) 0.640		41) 0.587		16) 0.692		41) 0.651	
17) 0.649		42) 0.706		17) 0.775		42) 0.658	
18) 0.684		43) 0.659		18) 0.667		43) 0.653	
19) 0.645		44) 0.612		19) 0.575		44) 0.667	
20) 0.646		45) 0.646		20) 0.567		45) 0.710	
21) 0.714		46) 0.624		21) 0.725		46) 0.678	
22) 0.658		47) 0.614		22) 0.674		47) 0.608	
23) 0.634		48) 0.679		23) 0.590		48) 0.612	
24) 0.672		49) 0.643		24) 0.630		49) 0.690	
25) 0.697		50) 0.654		25) 0.615		50) 0.678	

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 259 (Continued)

 $\bar{R}_m = 0.650$

SEAM Pittsburgh (No. 8)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 10-24-80		Room Temp. Start 22 Finish 22		Date		Room Temp. Start Finish	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990	1.647	1.645	1.645	1.990			
1.856	1.013	1.025	1.025	1.856			
1.757	0.518	0.523	0.523	1.757			
1.694				1.694			
1) 0.640 26) 2) 0.595 27) 3) 0.657 28) 4) 0.700 29) 5) 0.629 30) 6) 0.664 31) 7) 0.645 32) 8) 0.704 33) 9) 0.640 34) 10) 0.573 35) 11) 0.644 36) 12) 0.586 37) 13) 0.640 38) 14) 0.667 39) 15) 0.558 40) 16) 0.567 41) 17) 0.730 42) 18) 0.650 43) 19) 0.570 44) 20) 0.611 45) 21) 46) 22) 47) 23) 48) 24) 49) 25) 50)				1) 26) 2) 27) 3) 28) 4) 29) 5) 30) 6) 31) 7) 32) 8) 33) 9) 34) 10) 35) 11) 36) 12) 37) 13) 38) 14) 39) 15) 40) 16) 41) 17) 42) 18) 43) 19) 44) 20) 45) 21) 46) 22) 47) 23) 48) 24) 49) 25) 50)			

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 260

 $\bar{R}_m = 0.595$

SEAM Pittsburgh (No. 8)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 9-3-80		Room Temp.		Date 9-3-80		Room Temp.	
		Start	23			Start	23
		Finish	23			Finish	23
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990	1.715	1.681	1.666	1.990	1.660	1.659	1.617
1.856	1.025	1.013	0.970	1.856	1.025	1.037	1.038
1.757	0.520	0.492	0.498	1.757	0.506	0.492	0.509
1.694				1.694			
1) 0.557	26) 0.584	1) 0.553	26) 0.608				
2) 0.563	27) 0.591	2) 0.577	27) 0.591				
3) 0.572	28) 0.626	3) 0.612	28) 0.573				
4) 0.572	29) 0.597	4) 0.608	29) 0.569				
5) 0.582	30) 0.602	5) 0.575	30) 0.615				
6) 0.680	31) 0.592	6) 0.561	31) 0.503				
7) 0.590	32) 0.644	7) 0.580	32) 0.623				
8) 0.631	33) 0.603	8) 0.632	33) 0.593				
9) 0.645	34) 0.660	9) 0.560	34) 0.590				
10) 0.637	35) 0.603	10) 0.647	35) 0.561				
11) 0.594	36) 0.623	11) 0.661	36) 0.586				
12) 0.590	37) 0.640	12) 0.612	37) 0.579				
13) 0.598	38) 0.614	13) 0.602	38) 0.593				
14) 0.603	39) 0.658	14) 0.620	39) 0.587				
15) 0.562	40) 0.593	15) 0.629	40) 0.589				
16) 0.610	41) 0.553	16) 0.551	41) 0.589				
17) 0.606	42) 0.570	17) 0.575	42) 0.568				
18) 0.613	43) 0.566	18) 0.572	43) 0.602				
19) 0.566	44) 0.595	19) 0.573	44) 0.616				
20) 0.567	45) 0.596	20) 0.585	45) 0.556				
21) 0.584	46) 0.582	21) 0.601	46) 0.583				
22) 0.608	47) 0.577	22) 0.586	47) 0.621				
23) 0.594	48) 0.601	23) 0.600	48) 0.554				
24) 0.613	49) 0.590	24) 0.616	49) 0.582				
25) 0.596	50) 0.629	25) 0.579	50) 0.583				

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 260 (Continued)

 $\bar{R}_m = 0.595$

SEAM Pittsburgh (No. 8)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date		Room Temp. Start Finish		Date 10-24-80		Room Temp. Start 23 Finish 23	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990				1.990	1.681	1.666	1.666
1.856				1.856	1.013	0.097	0.970
1.757				1.757	0.492	0.498	0.498
1.694				1.694			
1) 26)				1) 0.583		26)	
2) 27)				2) 0.579		27)	
3) 28)				3) 0.577		28)	
4) 29)				4) 0.572		29)	
5) 30)				5) 0.582		30)	
6) 31)				6) 0.608		31)	
7) 32)				7) 0.596		32)	
8) 33)				8) 0.631		33)	
9) 34)				9) 0.554		34)	
10) 35)				10) 0.561		35)	
11) 36)				11) 0.553		36)	
12) 37)				12) 0.590		37)	
13) 38)				13) 0.583		38)	
14) 39)				14) 0.632		39)	
15) 40)				15) 0.614		40)	
16) 41)				16) 0.567		41)	
17) 42)				17) 0.556		42)	
18) 43)				18) 0.589		43)	
19) 44)				19) 0.645		44)	
20) 45)				20) 0.603		45)	
21) 46)				21) 0.613		46)	
22) 47)				22) 0.616		47)	
23) 48)				23) 0.612		48)	
24) 49)				24) 0.644		49)	
25) 50)				25) 0.572		50)	

REFLECTANCE MEASUREMENTS DATA SHEET

UTO C NO. 265

 $\bar{R}_m = 0.554$

SEAM Pittsburgh (No. 8)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 9-3-80		Room Temp. Start 23 Finish 23		Date 9-3-80		Room Temp. Start 23 Finish 23	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990	1.650	1.647	1.657	1.990	1.657	1.690	1.645
1.856	1.025	1.004	0.999	1.856	1.025	1.013	1.021
1.757	0.492	0.506	0.487	1.757	0.513	0.481	0.504
1.694				1.694			
1) 0.555	26) 0.561	1) 0.554	26) 0.528				
2) 0.590	27) 0.542	2) 0.563	27) 0.567				
3) 0.569	28) 0.547	3) 0.537	28) 0.568				
4) 0.551	29) 0.549	4) 0.571	29) 0.531				
5) 0.546	30) 0.582	5) 0.554	30) 0.526				
6) 0.538	31) 0.553	6) 0.525	31) 0.550				
7) 0.581	32) 0.600	7) 0.573	32) 0.568				
8) 0.528	33) 0.533	8) 0.559	33) 0.572				
9) 0.551	34) 0.542	9) 0.543	34) 0.555				
10) 0.556	35) 0.554	10) 0.529	35) 0.597				
11) 0.557	36) 0.530	11) 0.581	36) 0.527				
12) 0.564	37) 0.535	12) 0.532	37) 0.569				
13) 0.587	38) 0.567	13) 0.586	38) 0.546				
14) 0.547	39) 0.569	14) 0.530	39) 0.525				
15) 0.589	40) 0.533	15) 0.585	40) 0.531				
16) 0.558	41) 0.540	16) 0.540	41) 0.529				
17) 0.558	42) 0.634	17) 0.527	42) 0.525				
18) 0.566	43) 0.573	18) 0.531	43) 0.581				
19) 0.550	44) 0.532	19) 0.551	44) 0.567				
20) 0.558	45) 0.540	20) 0.539	45) 0.582				
21) 0.554	46) 0.576	21) 0.571	46) 0.531				
22) 0.543	47) 0.564	22) 0.544	47) 0.527				
23) 0.563	48) 0.603	23) 0.565	48) 0.556				
24) 0.565	49) 0.574	24) 0.594	49) 0.558				
25) 0.557	50) 0.562	25) 0.561	50) 0.539				

REFLECTANCE MEASUREMENTS DATA SHEET

UTOC NO. 265 (Continued)

 $\bar{R}_m = 0.554$

SEAM Pittsburgh (No. 8)

Oil $n_e = 1.518 @ 23^\circ\text{C}$

PELLET A				PELLET B			
Date 10-24-80		Room Temp. Start 23 Finish 23		Date		Room Temp. Start Finish	
Glass Standard	Start	After 25 Measurements	Finish	Glass Standard	Start	After 25 Measurements	Finish
1.990	1.645	1.647	1.647	1.990			
1.856	1.021	1.026	1.026	1.856			
1.757	0.504	0.511	0.511	1.757			
1.694				1.694			
1) 0.528 26) 2) 0.594 27) 3) 0.547 28) 4) 0.543 29) 5) 0.568 30) 6) 0.531 31) 7) 0.542 32) 8) 0.558 33) 9) 0.597 34) 10) 0.585 35) 11) 0.535 36) 12) 0.587 37) 13) 0.525 38) 14) 0.581 39) 15) 0.540 40) 16) 0.556 41) 17) 0.525 42) 18) 0.589 43) 19) 0.532 44) 20) 0.546 45) 21) 0.527 46) 22) 0.537 47) 23) 0.579 48) 24) 0.555 49) 25) 0.544 50)				1) 26) 2) 27) 3) 28) 4) 29) 5) 30) 6) 31) 7) 32) 8) 33) 9) 34) 10) 35) 11) 36) 12) 37) 13) 38) 14) 39) 15) 40) 16) 41) 17) 42) 18) 43) 19) 44) 20) 45) 21) 46) 22) 47) 23) 48) 24) 49) 25) 50)			

APPENDIX C

X-Ray Diffraction Data

X-RAY DATA

SAMPLE: UTOC 264 Seam

RADIATION = Cu_K
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = $1^\circ(2\theta)/\text{min}$
 START = $4^\circ(2\theta)$
 END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.90	14	9.94	9.90	80	002	illite
2	12.35	30	7.18	7.18	100	001	kaolinite
3	17.80	6	4.98	4.90	60	004	illite
4	19.95	14	4.45	4.48	80	02-	kaolinite/illite
5	20.55	7	4.32	4.29	40	111	illite
6	20.95	18	4.24	4.26	35	100	quartz
7	24.95	16	3.57	3.58	100	002	kaolinite
8	26.70	100	3.34	3.34	100	101	quartz/illite
9	28.60	8	3.12	3.13	35	111	pyrite
10	29.20	6	3.06	3.04	100	104	calcite
11	33.20	28	2.70	2.71	85	200	pyrite
12	35.10	15	2.55	2.57	100	$20\bar{2}$	illite
13	36.10	6	2.49	2.50	80	$13\bar{1}$	kaolinite
14	36.65	6	2.45	2.46	12	110	quartz/illite
15	37.15	15	2.42	2.42	65	210	pyrite
16	38.50	15	2.34	2.34	90	$20\bar{2}$	kaolinite
17	39.50	10	2.28	2.28	12	102	quartz
18	40.40	6	2.23	2.24	6	111	quartz
19	40.85	13	2.21	2.21	50	211	pyrite
20	41.50	3	2.17	2.14	60	$20\bar{6}$	illite
21	42.50	11	2.12	2.12	9	200	quartz
22	45.30	3	2.00	1.99	60	0,0,10	illite
23	45.80	10	1.98	1.98	6	201	quartz/kaolinite
24	47.00	3	1.93	1.94	40	206	illite
25	47.55	15	1.91	1.92	40	220	pyrite

SAMPLE: UTOC 264 Seam (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
26	48.50		1.88	1.88	17	116	calcite
27	50.20	16	1.82	1.82	17	112	quartz
28	52.00	4	1.76	1.76	63	211	marcasite
29	55.10	8	1.66	1.66	3	103	quartz/kaolinite
30	56.35	27	1.63	1.63	100	311	pyrite
31	58.20		1.58	1.59	2	1,0,10	calcite
32	59.20	5	1.56	1.56	14	222	pyrite
33	60.10	10	1.54	1.54	15	211	quartz/kaolinite
34	61.80	10	1.50	1.50	20	230	pyrite
35	62.40	9	1.49	1.50	80	060	illite
36							
37							
38							
39							
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55							

X-RAY DATA

SAMPLE: UTOC 264 I

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	8.90	17	9.936	9.90	80	002	illite
2	12.45	26	7.109	7.18	100	001	kaolinite
3	20.10	15	4.42	4.48	80	02-	kaolinite/illite
4	21.05	18	4.13	4.26	35	100	quartz
5	22.85	15	3.89	3.88	60	11 $\bar{3}$	illite
6	25.10	20	3.54	3.58	100	002	kaolinite
7	25.50	12	3.49				
8	26.80	100	3.32	3.34	100	101	quartz/illite
9	28.70	7	3.11	3.13	35	111	pyrite
10	29.75	3	3.00	3.04	100	104	calcite
11	30.80	14	2.90	2.86	60	115	illite
12	33.20	19	2.70	2.71	85	200	pyrite
13	35.20	19	2.55	2.57	80	20 $\bar{1}$	kaolinite
14	36.10	20	2.49	2.50	80	13 $\bar{1}$	kaolinite
15	36.70	7	2.45	2.46	12	110	quartz
16	37.20	11	2.42	2.42	65	210	pyrite
17	38.50	11	2.34	2.34	90	20 $\bar{2}$	kaolinite
18	39.60	8	2.27	2.28	12	102	quartz
19	40.50	4	2.23	2.24	6	111	quartz/illite
20	40.90	8	2.21	2.21	50	211	pyrite
21	42.50	8	2.12	2.12	9	200	quartz
22	46.90		1.94	1.94	40	206	illite
23	47.60	9	1.91	1.92	40	220	pyrite
24	50.30	14	1.81	1.82	17	112	quartz
25	51.30	10	1.78	1.79	40	004	kaolinite

SAMPLE: UTOC 264 I (cont'd.)

OBSERVED PATTERN				STANDARD DIFFRACTION DATA			
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	56.50	14	1.63	1.63	100	311	pyrite
27	60.10	7	1.54	1.54	15	211	quartz
28	62.00	7	1.50	1.50	20	230	pyrite/illite
29							
30							
31							
32							
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55							

X-RAY DATA

SAMPLE: UTOC 264 II

RADIATION = Cu_k

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	8.85	15	9.93	9.90	80	002	illite
2	12.46	50	7.10	7.18	100	001	kaolinite
3	20.00	14	4.44	4.48	80	02-	illite/kaolinite
4	20.92	14	4.25	4.26	35	100	quartz/illite
5	25.00	41	3.56	3.58	100	101	kaolinite
6	25.97	17	3.43				
7	26.75	100	3.33	3.34	100	101	quartz/illite
8	28.62	32	3.12	3.13	35	111	pyrite
9	29.54	12	3.02	3.04	100	111	calcite
10	29.89	11	2.99				
11	33.19	67	2.70	2.71	85	200	pyrite
12	35.09	20	2.56	2.57	80	20 $\bar{1}$	illite/kaolinite
13	36.10	9	2.49	2.50	80	13 $\bar{1}$	calcite
14	36.74	10	2.44	2.46	12	110	quartz
15	37.24	48	2.41	2.42	65	210	pyrite
16	38.53	21	2.33	2.34	90	20 $\bar{2}$	kaolinite
17	39.56	15	2.28	2.28	12	102	quartz/calcite
18	40.90	46	2.20	2.21	50	211	pyrite
19	43.37	2	2.08	2.10	18	202	calcite
20	45.93	13	1.97	1.98	6	201	quartz/kaolinite
21	47.51	33	1.91	1.92	40	220	pyrite/calcite
22	50.30	18	1.81	1.82	17	112	quartz
23	55.20	9	1.66	1.66	50	133	kaolinite
24	56.36	60	1.63	1.63	100	311	pyrite
25	57.48	2	1.60	1.60	8	212	calcite

SAMPLE: UTOC 264 II (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	58.98	13	1.56	1.56	14	222	quartz
27	59.33	11	1.55				
28	60.07	14	1.54	1.54	15	211	quartz
29	61.94	21	1.50	1.50	20	230	pyrite
30	62.47	14	1.49	1.50	8	060	illite
31							
32							
33							
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X-RAY DATA

SAMPLE: UTOC 264 III

RADIATION = Cu_k
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = $1^\circ(2\theta)/\text{min}$
 START = $4^\circ(2\theta)$
 END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.84	6	10.00	9.90	80	002	illite
2	12.49	38	7.09	7.18	100	001	kaolinite
3	20.65	20	4.30	4.29	40	111	illite
4	21.11	20	4.21	4.26	35	100	quartz
5	23.15	8	3.84	3.86	12	102	calcite
6	25.10	30	3.54	3.58	100	002	kaolinite
7	26.83	41	3.32	3.34	100	101	quartz
8	28.72	40	3.11	3.13	35	111	pyrite
9	29.67	12	3.01	3.04	100	111	calcite
10	30.73	10	2.91	2.86	60	115	illite
11	33.22	100	2.70	2.71	85	200	pyrite/marcasite
12	35.15	15	2.55	2.57	80	$20\bar{1}$	kaolinite
13	36.20	9	2.48	2.50	80	$13\bar{1}$	kaolinite/calcite
14	37.26	56	2.41	2.42	65	210	pyrite/marcasite
15	38.62	23	2.33	2.34	90	$20\bar{2}$	kaolinite
16	40.94	52	2.20	2.21	50	211	pyrite
17	42.85	6	2.11	2.10	18	202	calcite
18	47.60	43	1.91	1.92	40	220	pyrite/calcite/marcasite
19	51.13	8	1.79	1.79	40	004	kaolinite
20	52.16	14	1.75	1.75	63	211	marcasite
21	52.31	14	1.75				
22	54.47	9	1.68	1.69	15	002	marcasite
23	55.44	13	1.66	1.66	50	133	kaolinite
24	56.52	91	1.63	1.63	100	311	pyrite
25	58.29	8	1.58	1.59	20	031	marcasite

SAMPLE: UTOC 264 III (cont'd.)

OBSERVED PATTERN				STANDARD DIFFRACTION DATA			
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	59.27	17	1.56	1.56	14	222	pyrite
27	59.98	8	1.54	1.54	15	211	quartz
28	60.57	10	1.53				
29	61.94	26	1.50	1.50	20	230	pyrite
30	63.52	10	1.46				
31							
32							
33							
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X-RAY DATA

SAMPLE: UTOC 264 Wash

RADIATION = Cu_K
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = 1°(2θ)/min
 START = 4°(2θ)
 END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	d ^o Å	d ^o Å	I/I	hkl	Mineral
1	9.01	9	9.82	9.90	80	002	illite
2	12.52	37	7.07	7.18	100	001	kaolinite
3	18.14	7	4.89	4.90	60	004	illite
4	20.05	12	4.43	4.48	80	02-	illite/kaolinite
5	20.57	11	4.32				
6	21.08	21	4.21	4.26	35	100	quartz
7	23.33	9	3.81				
8	25.16	25	3.54	3.58	100	002	kaolinite
9	26.82	100	3.32	3.34	100	101	quartz/illite
10	28.73	13	3.10	3.13	35	111	pyrite
11	29.65	13	3.01	3.04	100	111	calcite
12	33.21	44	2.70	2.71	85	200	pyrite
13	35.26	15	2.54	2.57	80	20 $\bar{1}$	illite/kaolinite
14	36.11	11	2.49	2.50	80	13 $\bar{1}$	kaolinite/calcite
15	36.68	9	2.45	2.46	12	110	quartz/illite
16	37.25	26	2.41	2.42	65	210	pyrite
17	37.85	7	2.38	2.39	80	003	illite/kaolinite
18	38.54	23	2.33	2.34	90	20 $\bar{2}$	kaolinite
19	39.45	10	2.28	2.28	12	102	quartz
20	40.93	20	2.20	2.21	50	211	pyrite
21	42.56	11	2.12	2.14	60	20 $\bar{6}$	quartz
22	45.76	10	1.98	1.99	60	0,0,10	illite
23	47.56	22	1.91	1.92	40	220	pyrite
24	49.02	8	1.86	1.88	17	116	calcite
25	50.28	11	1.81	1.82	17	112	quartz

SAMPLE: UTOC 264 Wash (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\overset{\circ}{\text{\AA}}$	d $\overset{\circ}{\text{\AA}}$	I/I	hkl	Mineral
26	56.50	37	1.63	1.63	100	311	pyrite
27	59.27	8	1.56	1.56	14	222	pyrite
28	60.10	8	1.54	1.54	15	211	quartz
29	61.89	16	1.50	1.50	20	230	pyrite/illite
30							
31							
32							
33							
34							
35							
36							
37							
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49							
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51							
52							
53							
54							
55							

X-RAY DATA

SAMPLE: UTOC 262 Seam

RADIATION = Cu_k

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	7.37	11	11.98				
2	8.85	9	9.98	9.90	80	002	illite
3	12.47	21	7.09	7.18	100	001	kaolinite
4	20.97	26	4.23	4.26	35	100	quartz
5	24.89	23	3.57	3.58	100	002	kaolinite
6	26.75	77	3.33	3.34	100	101	quartz
7	28.60	47	3.12	3.13	35	111	pyrite
8	33.07	100	2.71	2.71	85	200	pyrite
9	34.98	18	2.56	2.57	80	20 $\bar{1}$	kaolinite
10	37.12	73	2.42	2.42	65	210	pyrite
11	38.45	28	2.34	2.34	90	20 $\bar{2}$	kaolinite
12	39.55	18	2.27	2.28	12	102	quartz
13	40.84	62	2.21	2.21	50	211	pyrite/kaolinite
14	42.87	11	2.11				
15	45.89	17	1.98	1.99	40	20 $\bar{3}$	kaolinite
16	47.49	45	1.91	1.92	40	220	pyrite
17	50.20	23	1.82	1.82	17	112	quartz
18	56.38	89	1.63	1.63	100	311	pyrite
19	57.99	8	1.59	1.59	20	031	marcasite
20	59.11	14	1.56	1.56	14	222	pyrite
21	60.26	9	1.54	1.54	10	203	kaolinite
22	61.84	10	1.50	1.50	8	060	illite
23	62.45	20	1.49	1.50	20	230	pyrite
24							
25							

X-RAY DATA

SAMPLE: UTOC 262I

RADIATION = Cu_k
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = $1^\circ(2\theta)/\text{min}$
 START = $4^\circ(2\theta)$
 END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d^\circ\text{\AA}$	$d^\circ\text{\AA}$	I/I	hkl	Mineral
1	9.00	8	9.82	9.90	80	002	illite
2	12.46	29	7.10	7.18	100	001	kaolinite
3	18.14	11	4.89	4.90	60	004	illite
4	19.94	12	4.45	4.48	80	02-	kaolinite/illite
5	20.86	9	4.26	4.26	35	100	quartz/illite
6	24.99	30	3.56	3.58	100	002	kaolinite
7	26.77	56	3.33	3.34	100	101	quartz/illite
8	28.72	31	3.11	3.13	35	111	pyrite/illite
9	31.21	10	2.86	2.86	60	115	illite
10	33.09	100	2.70	2.71	85	200	pyrite
11	35.08	10	2.56	2.57	80	$20\bar{1}$	kaolinite/illite
12	36.00	9	2.49	2.50	80	$13\bar{1}$	kaolinite
13	37.16	62	2.42	2.42	65	210	pyrite
14	38.50	20	2.34	2.34	90	$20\bar{2}$	kaolinite
15	39.50	11	2.28	2.28	12	102	quartz
16	40.88	52	2.21	2.21	50	211	pyrite/kaolinite
17	45.87	15	1.98	1.99	40	$20\bar{3}$	kaolinite
18	47.54	49	1.91	1.92	40	220	pyrite
19	49.63	12	1.83				
20	50.23	15	1.82	1.82	17	112	quartz
21	51.18	13	1.78	1.79	40	004	kaolinite
22	56.23	86	1.64	1.63	100	311	pyrite
23	59.19	19	1.56	1.56	14	222	pyrite
24	61.87	19	1.50	1.50	20	230	pyrite
25							

X-RAY DATA

SAMPLE: UTOC 262 II

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	12.42	18	7.12	7.18	100	001	kaolinite
2	24.97	14	3.56	3.58	100	002	kaolinite
3	28.69	35	3.11	3.13	35	111	pyrite
4	33.12	100	2.70	2.71	85	200	pyrite/marcasite
5	37.15	71	2.42	2.42	65	210	pyrite
6	38.44	13	2.34	2.34	90	20 $\bar{2}$	kaolinite
7	38.70	13	2.32	2.32	25	120	marcasite
8	39.40	12	2.28	2.28	12	102	quartz
9	40.87	59	2.21	2.21	50	211	pyrite
10	42.55	15	2.12	2.13	9	200	quartz
11	43.38	13	2.08				
12	47.48	54	1.91	1.92	40	220	pyrite
13	52.06	20	1.76	1.76	63	211	marcasite
14	56.43	92	1.63	1.63	100	311	pyrite
15	59.29	18	1.56	1.56	14	222	pyrite
16	61.86	22	1.50	1.50	20	230	pyrite
17	62.37	10	1.49				
18							
19							
20							
21							
22							
23							
24							
25							

X-RAY DATA

SAMPLE: UTOC 262 III

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = $1^\circ(2\theta)/\text{min}$ START = $4^\circ(2\theta)$ END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.97	6	9.85	9.90	80	002	illite
2	12.51	24	7.07	7.18	100	001	kaolinite
3	20.00	9	4.44	4.48	100	110	illite
4	25.02	24	3.56	3.58	100	002	kaolinite
5	25.98	11	3.43	3.44	40	110	marcasite
6	26.79	25	3.32	3.34	100	101	quartz/illite
7	27.43	12	3.25				
8	28.71	30	3.11	3.13	35	111	pyrite
9	33.20	100	2.70	2.71	85	200	pyrite/marcasite
10	37.23	53	2.41	2.42	65	210	pyrite
11	38.49	13	2.34	2.34	90	$20\bar{2}$	kaolinite
12	40.91	75	2.20	2.21	50	211	pyrite
13	47.59	44	1.91	1.92	40	220	pyrite/marcasite
14	52.10	11	1.75	1.76	63	211	marcasite
15	54.41	14	1.68	1.69	15	002	marcasite
16	56.50	93	1.63	1.63	100	311	pyrite
17	58.25	10	1.58				
18	59.22	18	1.56	1.56	14	222	pyrite
19	62.00	16	1.50	1.50	20	230	pyrite
20							
21							
22							
23							
24							
25							

X-RAY DATA

SAMPLE: UTOC 263 Seam

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	9.06	11	9.75	9.90	80	002	illite
2	12.45	31	7.10	7.18	100	001	kaolinite
3	19.93	17	4.45	4.48	80	02-	illite/kaolinite
4	25.02	21	3.56	3.58	100	002	kaolinite
5	26.75	44	3.33	3.34	100	101	quartz/illite
6	28.63	27	3.12	3.13	100	111	pyrite
7	30.02	10	2.97				
8	33.14	100	2.70	2.71	85	200	pyrite/marcasite
9	35.09	15	2.56	2.57	80	20 $\bar{1}$	illite/kaolinite
10	37.24	57	2.41	2.42	65	210	pyrite
11	38.42	19	2.34	2.34	90	20 $\bar{2}$	kaolinite
12	40.86	40	2.21	2.21	50	211	pyrite
13	47.52	51	1.91	1.92	40	220	pyrite
14	50.30	13	1.81	1.82	17	112	quartz
15	52.10	15	1.75	1.76	63	211	marcasite
16	56.41	87	1.63	1.63	100	311	pyrite
17	59.26	14	1.56	1.56	14	222	pyrite
18	61.90	22	1.50	1.50	20	230	pyrite
19							
20							
21							
22							
23							
24							
25							

X-RAY DATA

SAMPLE: UTOC 263 I

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	12.43	16	7.12	7.18	100	001	kaolinite
2	18.05	7	4.91	4.90	60	004	illite
3	19.86	8	4.47	4.48	80	02-	kaolinite/illite
4	20.96	17	4.24	4.26	35	100	quartz/illite
5	22.29	11	3.98				
6	23.38	10	3.80				
7	24.94	21	3.57	3.58	100	002	kaolinite
8	26.71	100	3.36	3.34	100	101	quartz/illite
9	28.58	36	3.12	3.13	100	111	pyrite/illite
10	33.11	95	2.70	2.71	85	200	pyrite/marcasite
11	34.98	11	2.56	2.57	80	20 $\bar{1}$	kaolinite/illite
12	35.99	8	2.49	2.50	80	13 $\bar{1}$	kaolinite
13	37.15	51	2.42	2.42	65	210	pyrite
14	38.58	15	2.33	2.34	90	20 $\bar{2}$	kaolinite
15	40.82	37	2.21	2.21	50	211	pyrite
16	42.58	9	2.12	2.14	60	206	quartz
17	45.45	37	1.99	1.92	40	220	pyrite
18	50.13	13	1.82	1.82	17	112	quartz
19	56.35	77	1.63	1.63	100	311	pyrite
20	59.17	15	1.56	1.56	14	222	pyrite
21	60.10	12	1.54	1.56	14	222	quartz
22	61.84	15	1.50	1.50	20	230	pyrite
23							
24							
25							

X-RAY DATA

SAMPLE: UTOC 263 II

RADIATION = Cu_k
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = 1°(2θ)/min
 START = 4°(2θ)
 END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	12.36	5	7.16	7.18	100	001	kaolinite
2	20.03	6	4.43	4.48	80	02-	kaolinite
3	24.99	7	3.56	3.58	100	002	kaolinite
4	26.89	10	3.31				
5	28.53	33	3.13	3.13	100	111	pyrite
6	33.06	100	2.71	2.71	85	200	pyrite/marcasite
7	36.07	8	2.49	2.50	80	13 $\bar{1}$	kaolinite
8	37.11	57	2.42	2.42	65	210	pyrite
9	38.45	10	2.34	2.34	90	20 $\bar{2}$	kaolinite
10	40.82	41	2.21	2.21	50	211	pyrite
11	47.43	39	1.92	1.92	40	220	pyrite
12	52.00	7	1.76	1.76	63	211	marcasite
13	56.29	78	1.63	1.63	100	311	pyrite
14	59.09	10	1.56	1.56	14	222	pyrite
15	61.83	16	1.50	1.50	20	230	pyrite
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

X-RAY DATA

SAMPLE: UTOC 263 III

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = $1^\circ(2\theta)/\text{min}$ START = $4^\circ(2\theta)$ END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.98	4	9.84	9.90	80	002	illite
2	12.47	23	7.09	7.18	100	001	kaolinite
3	20.94	8	4.24	4.26	35	100	quartz
4	25.03	20	3.56	3.58	100	002	kaolinite
5	25.92	9	3.44	3.44	40	110	marcasite
6	26.70	46	3.34	3.34	100	101	quartz
7	28.65	29	3.11	3.13	100	111	pyrite
8	29.82	12	2.99				
9	31.17	7	2.87	2.88	100	104	dolomite
10	32.05	11	2.79				
11	33.17	100	2.70	2.71	85	200	pyrite/marcasite
12	34.32	12	2.61				
13	37.19	57	2.42	2.42	65	210	pyrite
14	38.45	16	2.34	2.34	90	$20\bar{2}$	kaolinite
15	40.90	47	2.20	2.21	50	211	pyrite
16	47.50	49	1.91	1.92	40	220	pyrite
17	56.33	79	1.63	1.63	100	311	pyrite
18	59.20	15	1.559				
19	60.07	10	1.539	1.54	10	203	kaolinite
20	59.82	21	1.545	1.54	15	211	quartz
21							
22							
23							
24							
25							

X-RAY DATA

SAMPLE: UTOC 263 IV

RADIATION = Cu_k

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	12.47	26	7.09	7.18	100	001	kaolinite
2	19.97	16	4.44	4.48	80	02-	kaolinite
3	24.95	23	3.57	3.58	100	002	kaolinite
4	26.71	49	3.34	3.34	100	101	quartz
5	28.65	24	3.11	3.13	100	111	pyrite
6	29.76	11	3.00				
7	33.18	100	2.70	2.71	85	200	pyrite/marcasite
8	35.10	21	2.55	2.57	80	201	kaolinite
9	37.23	66	2.41	2.42	65	210	pyrite
10	38.48	17	2.34	2.34	90	202	kaolinite
11	40.90	44	2.20	2.21	50	211	pyrite
12	45.94	15	1.97	1.98	6	201	quartz/kaolinite
13	47.65	48	1.91	1.92	40	220	pyrite
14	52.23	14	1.75	1.76	63	211	marcasite
15	56.40	78	1.63	1.63	100	311	pyrite
16	59.19	17	1.56	1.56	14	222	pyrite
17	60.16	11	1.54	1.54	15	211	quartz
18	60.59	11	1.53				
19	60.99	14	1.52	1.52	6	112	marcasite
20	61.72	22	1.50	1.50	20	230	pyrite
21							
22							
23							
24							
25							

X-RAY DATA

SAMPLE: UTOC 259 Seam

RADIATION = Cu_k
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = $1^\circ(2\theta)/\text{min}$
 START = $4^\circ(2\theta)$
 END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.92	6	9.94	9.90	80	002	illite
2	12.45	34	7.11	7.18	100	001	kaolinite
3	18.01	9	4.93	4.90	60	004	illite
4	20.00	14	4.44	4.48	80	02-	kaolinite/illite
5	21.00	19	4.23	4.26	35	100	quartz
6	21.50	10	4.13				
7	24.35	7	3.65	3.65	50	023	illite
8	25.02	33	3.56	3.58	100	002	kaolinite
9	26.80	100	3.32	3.34	100	101	quartz/illite
10	28.75	25	3.10	3.13	35	111	pyrite
11	29.60	39	3.02	3.04	100	111	calcite
12	31.20	4	2.86	2.86	60	115	illite
13	33.20	73	2.70	2.71	85	200	pyrite
14	35.15	18	2.55	2.57	80	$20\bar{1}$	kaolinite
15	36.25	8	2.48	2.50	80	$13\bar{1}$	kaolinite
16	36.65	13	2.45	2.46	12	110	quartz/illite
17	37.25	39	2.41	2.42	65	210	pyrite
18	38.50	13	2.34	2.34	90	$20\bar{2}$	kaolinite
19	39.60	13	2.27	2.28	12	102	quartz/calcite
20	39.70	9	2.27	2.24	50	$22\bar{1}$	illite
21	40.40	6	2.23	2.24	6	111	quartz
22	40.90	34	2.20	2.21	50	211	pyrite
23	42.62	9	2.12	2.14	60	$20\bar{6}$	quartz/illite
24	43.20	5	2.09	2.10	18	202	calcite
25	45.50	10	1.99	1.99	60	0,0,10	illite

SAMPLE: UTOC 259 Seam (cont'd.)

OBSERVED PATTERN				STANDARD DIFFRACTION DATA			
Peak	2 θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
26	45.91	6	1.98	1.98	6	201	quartz
27	47.60	42	1.91	1.92	40	220	pyrite/calcite
28	48.25	7	1.88	1.88	17	116	calcite
29	48.80	9	1.87				
30	50.30	16	1.81	1.82	17	112	quartz
31	50.44	13	1.81				
32	52.20	13	1.75				
33	55.15	13	1.66	1.66	50	133	kaolinite
34	56.45	14	1.63	1.63	100	311	pyrite
35	57.51	5	1.60	1.60	8	212	calcite
36	59.30	15	1.56	1.56	14	222	pyrite
37	60.20	10	1.54	1.54	15	211	quartz/kaolinite
38	61.90	15	1.50	1.50	20	230	pyrite
39	62.60	14	1.48	1.50	8	060	illite
40							
41							
42							
43							
44							
45							
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50							
51							
52							
53							
54							
55							

X-RAY DATA

SAMPLE: UTOC 259 Wash

RADIATION = Cu_k

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	8.95	9.4	9.90	9.90	80	002	illite
2	12.45	21.6	7.11	7.18	100	001	kaolinite
3	19.92	13.4	4.46	4.48	80	02-	kaolinite/illite
4	20.45	8.0	4.34	4.29	40	111	illite
5	20.90	18.8	4.25	4.26	35	100	quartz
6	22.91	4.8	3.88	3.88	60	11 $\bar{3}$	illite
7	25.00	21.2	3.56	3.58	100	002	kaolinite
8	26.75	100	3.33	3.34	100	101	quartz/illite
9	28.65	15.6	3.11	3.13	35	111	pyrite
10	29.60	8.6	3.01	3.04	100	104	calcite
11	31.45	3.8	2.84	2.86	60	115	illite
12	33.20	54.6	2.70	2.71	85	200	pyrite
13	34.92	6.8	2.57	2.57	100	20 $\bar{2}$	illite
14	36.13	7.2	2.49	2.50	80	13 $\bar{1}$	kaolinite
15	36.25	13.4	2.44	2.46	12	110	quartz
16	37.21	33.6	2.42	2.42	65	210	pyrite
17	38.45	13.0	2.34	2.34	90	20 $\bar{2}$	kaolinite
18	39.62	10.2	2.27	2.28	12	102	quartz
19	40.85	27.6	2.21	2.21	50	211	pyrite
20	42.55	9.0	2.12	2.12	9	200	quartz
21	45.60	8.2	1.99	1.98	6	201	quartz
22	46.90	7.0	1.94	1.94	40	206	illite
23	47.55	25.6	1.91	1.92	40	220	pyrite
24	50.25	16.0	1.81	1.82	17	112	quartz
25	54.30	9.8	1.69				

SAMPLE: UTOC 259 Wash (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	55.10	10.6	1.66	1.66	3	103	quartz
27	56.35	52.4	1.63	1.63	100	311	pyrite
28	59.20	10.0	1.56				
29	60.00	13.8	1.54	1.54	15	211	quartz
30	61.75	14.4	1.50	1.50	20	230	pyrite
31							
32							
33							
34							
35							
36							
37							
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49							
50							
51							
52							
53							
54							
55							

X-RAY DATA

SAMPLE: UTOC 260 Seam

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = $1^\circ(2\theta)/\text{min}$ START = $4^\circ(2\theta)$ END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.97	12	9.86	9.90	80	002	illite
2	12.46	17	7.10	7.18	100	001	kaolinite
3	20.01	7	4.43	4.48	80	02-	kaolinite/illite
4	20.53	4	4.33	4.29	40	111	kaolinite
5	20.98	19	4.23	4.26	35	100	quartz
6	24.99	18	3.35	3.34	100	101	kaolinite
7	25.85	5	3.44	3.44	40	110	marcasite
8	26.75	100	3.33	3.34	100	101	quartz
9	28.69	14	3.11	3.13	35	111	pyrite
10	33.20	30	2.70	2.71	85	200	pyrite
11	35.10	8	2.55	2.57	80	20 $\bar{1}$	kaolinite
12	36.66	8	2.45	2.46	12	110	quartz
13	37.19	20	2.42	2.42	65	210	pyrite
14	37.84	3	2.38	2.38	80	13 $\bar{1}$	kaolinite
15	38.54	10	2.33	2.34	90	20 $\bar{2}$	kaolinite
16	39.58	10	2.28	2.28	12	102	quartz
17	40.95	12	2.20	2.21	50	211	pyrite
18	42.53	7	2.12	2.14	60	20 $\bar{6}$	quartz
19	45.87	6	1.98	1.99	60	0,0,10	quartz
20	47.57	17	1.91	1.92	40	220	pyrite
21	50.22	18	1.82	1.82	17	112	quartz
22	51.95	5	1.76	1.76	63	211	marcasite
23	54.43	4	1.68	1.69	15	002	marcasite
24	55.00	8	1.67	1.66	3	103	quartz
25	56.38	26	1.63	1.63	100	311	pyrite

SAMPLE: UTOC 260 Seam (cont'd.)

OBSERVED PATTERN				STANDARD DIFFRACTION DATA			
Peak	2 θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
26	59.12	3	1.56	1.56	14	222	pyrite
27	60.07	9	1.54	1.54	15	211	quartz
28	61.02	3	1.52	1.52	5	214	calcite
29	61.87	7	1.50	1.50	20	230	pyrite
30	62.35	5	1.49	1.50	8	060	illite
31							
32							
33							
34							
35							
36							
37							
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52							
53							
54							
55							

X-RAY DATA

SAMPLE: UTOC 260 I

RADIATION = Cu_k

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN				STANDARD DIFFRACTION DATA			
Peak	2θ	I/I	d ^o Å	d ^o Å	I/I	hkl	Mineral
1	9.18	6	9.63	9.90	80	002	illite
2	12.44	32	7.12	7.18	100	001	kaolinite
3	20.30	8	4.37	4.48	80	02-	kaolinite
4	20.99	16	4.23	4.26	35	100	quartz
5	21.58	9	4.11	4.11	40	111	illite
6	25.02	29	3.56	3.58	100	002	kaolinite
7	25.90	6	3.44	3.44	40	110	marcasite
8	26.73	68	3.33	3.34	100	101	quartz
9	27.35	12	3.26				
10	28.09	10	3.17				
11	28.67	43	3.11	3.13	35	111	pyrite
12	31.05	28	2.88	2.88	100	104	dolomite
13	33.16	100	2.70	2.71	85	200	pyrite
14	35.22	11	2.55	2.57	80	20 $\bar{1}$	kaolinite
15	36.26	15	2.48	2.50	80	13 $\bar{1}$	kaolinite
16	37.19	68	2.42	2.42	65	210	pyrite
17	38.54	20	2.33	2.34	90	20 $\bar{2}$	kaolinite
18	37.63	10	2.39	2.38	80	13 $\bar{1}$	kaolinite
19	40.88	49	2.21	2.21	50	211	pyrite
20	42.57	8	2.12	2.14	60	20 $\bar{6}$	quartz
21	42.98	23	2.10				
22	43.79	10	2.07				
23	45.88	11	1.98	1.99	60	0,0,10	quartz
24	47.55	50	1.91	1.92	40	220	pyrite
25	50.26	16	1.81	1.82	17	112	quartz

SAMPLE: UTOC 260.I (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\overset{\circ}{\text{\AA}}$	d $\overset{\circ}{\text{\AA}}$	I/I	hkl	Mineral
26	52.05	11	1.76	1.76	63	211	marcasite
27	54.50	9	1.68	1.69	15	002	quartz
28	56.25	100	1.63	1.63	100	311	pyrite
29	59.25	15	1.56	1.56	14	222	pyrite
30	60.13	10	1.54	1.54	15	211	quartz
31	61.80	22	1.50	1.50	20	230	pyrite
32	62.40	8	1.49	1.50	8	060	illite
33							
34							
35							
36							
37							
38							
39							
40							
41							
42							
43							
44							
45							
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48							
49							
50							
51							
52							
53							
54							
55							

X-RAY DATA

SAMPLE: UTOC 260 II

RADIATION = Cu_k
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = $1^\circ(2\theta)/\text{min}$
 START = $4^\circ(2\theta)$
 END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.87	6	9.97	9.90	80	002	illite
2	12.45	25	7.11	7.18	100	001	kaolinite
3	18.00	4	4.92	4.90	60	004	illite
4	20.07	12	4.42	4.48	80	02-	kaolinite
5	20.98	23	4.23	4.26	35	100	quartz
6	22.47	14	3.95				
7	22.85	2	3.89	3.88	60	11 $\bar{3}$	illite
8	25.04	25	3.55	3.34	100	101	kaolinite
9	25.93	6	3.43	3.44	40	110	marcasite
10	26.76	100	3.33	3.34	100	101	quartz
11	28.67	9	3.11	3.13	35	111	pyrite
12	29.48	3	3.03	3.04	100	111	calcite
13	31.65	3	2.82	2.86	60	115	illite
14	33.20	21	2.70	2.71	85	200	pyrite
15	35.13	6	2.55	2.57	100	20 $\bar{2}$	illite
16	35.99	5	2.49	2.50	80	13 $\bar{1}$	kaolinite
17	36.70	8	2.45	2.46	12	110	quartz
18	37.27	14	2.41	2.42	65	210	pyrite
19	38.00	2.7	2.37	2.38	80	13 $\bar{1}$	kaolinite
20	38.57	16	2.33	2.34	90	20 $\bar{2}$	kaolinite
21	39.52	8	2.28	2.28	12	102	quartz
22	40.43	5	2.23	2.24	6	111	quartz
23	40.88	10	2.21	2.21	50	211	pyrite
24	42.55	9	2.12	2.14	60	20 $\bar{6}$	quartz
25	45.99	7	1.97	1.99	60	0,0,10	quartz

SAMPLE: UTOC 260 II (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	47.55	10	1.91	1.92	40	220	pyrite
27	48.50	3	1.88	1.88	17	116	calcite
28	50.27	16	1.81	1.82	17	112	quartz
29	51.12	2	1.78	1.79	40	004	kaolinite/dolomite
30	51.28	2	1.78	1.78	30		dolomite
31	52.02	6	1.76	1.76	63	211	marcasite
32	54.35	4	1.69	1.69	15	002	marcasite
33	55.09	5	1.67	1.66	3	103	quartz
34	56.42	16	1.63	1.63	100	311	pyrite
35	59.14	6	1.56	1.56	14	222	pyrite
36	60.09	12	1.54	1.54	15	211	quartz
37	60.98	3	1.52	1.52	5	214	calcite
38	62.00	7	1.50	1.50	20	230	pyrite
39	62.38	6	1.49	1.50	8	060	illite
40							
41							
42							
43							
44							
45							
46							
47							
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X-RAY DATA

SAMPLE: UTOC 260 III

RADIATION = Cu_K
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = $1^\circ(2\theta)/\text{min}$
 START = $4^\circ(2\theta)$
 END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	12.40	24	7.14	7.18	100	001	kaolinite
2	20.30	9	4.37	4.48	80	02-	kaolinite
3	20.90	7	4.25	4.25	35	100	quartz
4	21.80	6	4.07	4.11	40	111	illite
5	23.10	8	3.85	3.86	12	102	calcite
6	25.00	14	3.56	3.58	100	002	kaolinite
7	26.80	57	3.32	3.34	100	101	quartz
8	28.60	29	3.12	3.13	35	111	pyrite
9	29.80	12	3.00				
10	33.20	100	2.70	2.71	85	200	pyrite/marcasite
11	35.20	7	2.55	2.57	80	20 $\bar{1}$	kaolinite
12	36.60	10	2.45	2.46	12	110	quartz
13	37.20	56	2.42	2.42	65	210	pyrite
14	37.90	7	2.37	2.38	80	13 $\bar{1}$	kaolinite
15	38.50	19	2.34	2.34	90	20 $\bar{2}$	kaolinite
16	39.60	11	2.27	2.28	12	102	quartz
17	40.80	43	2.21	2.21	50	211	pyrite
18	42.70	10	2.12	2.14	60	20 $\bar{6}$	quartz
19	47.50	44	1.91	1.92	40	220	pyrite
20	49.20	11	1.85				
21	50.30	18	1.81	1.82	17	112	quartz
22	51.20	10	1.78	1.79	40	004	kaolinite
23	52.10	17	1.75	1.76	63	211	marcasite
24	53.20	8	1.72	1.72	20		illite
25	54.00	10	1.70				

SAMPLE: UTOC 260 III (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
26	54.60	6	1.68	1.69	15	002	marcasite
27	55.10	10	1.66	1.68	15	002	quartz/kaolinite
28	56.40	86	1.63	1.63	100	311	pyrite
29	58.10	18	1.59	1.56	14	222	pyrite
30	60.00	7	1.54	1.54	15	211	quartz
31	61.00	17	1.52	1.52	5	214	calcite
32	61.80	30	1.50	1.50	20	230	pyrite
33	62.40	11	1.49	1.50	8	060	illite
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X-RAY DATA

SAMPLE: UTOC 260 IV

RADIATION = Cu_k

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = $1^\circ(2\theta)/\text{min}$ START = $4^\circ(2\theta)$ END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d^\circ\text{\AA}$	$d^\circ\text{\AA}$	I/I	hkl	Mineral
1	8.91	10	9.92	9.90	80	002	illite
2	12.25	16	7.22	7.18	100	001	kaolinite
3	17.86	6	4.96	4.90	60	004	illite
4	19.92	5	4.45	4.46	100	110	kaolinite
5	20.48	5	4.33	4.29	40	111	kaolinite
6	20.93	14	4.24	4.26	35	100	quartz
7	21.56	6	4.12	4.11	40	022	illite
8	25.00	9	3.56	3.58	100	002	kaolinite
9	25.99	5	3.42	3.44	40	110	marcasite
10	26.73	100	3.33	3.34	100	101	quartz
11	28.57	20	3.12	3.13	35	111	pyrite
12	31.29	5	2.86	2.86	60	115	illite
13	33.16	68	2.70	2.71	85	200	pyrite
14	35.03	6	2.56	2.57	80	$20\bar{1}$	kaolinite
15	35.28	4	2.54	2.57	100	$20\bar{2}$	illite
16	36.25	5	2.48	2.50	80	$13\bar{1}$	kaolinite
17	36.67	8	2.45	2.46	12	110	quartz
18	37.17	42	2.42	2.42	65	210	pyrite
19	37.93	12	2.37	2.38	80	$13\bar{1}$	quartz
20	38.54	4	2.33	2.34	90	$20\bar{2}$	kaolinite
21	39.00	8	2.31	2.32	25	120	marcasite
22	39.57	8	2.28	2.28	12	102	quartz
23	40.39	7	2.23	2.24	6	111	quartz
24	40.88	27	2.21	2.21	50	211	pyrite
25	42.50	8	2.12	2.13	9	200	quartz

SAMPLE: UTOC 260 IV (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\overset{\circ}{\text{\AA}}$	d $\overset{\circ}{\text{\AA}}$	I/I	hkl	Mineral
26	45.60	5	1.99	1.99	60	0,0,10	quartz
27	45.98	7	1.97	1.98	6	201	quartz
28	47.54	28	1.91	1.92	40	220	pyrite
29	50.20	17	1.82	1.82	17	112	quartz
30	52.20	11	1.75				
31	53.27	4	1.72	1.72	20		illite
32	55.03	4	1.67	1.66	3	103	quartz
33	56.36	50	1.63	1.63	100	311	pyrite
34	59.24	10	1.56	1.56	14	222	pyrite
35	59.97	18	1.54	1.54	15	211	quartz
36	60.97	6	1.52	1.52	5	214	calcite
37	61.80	15	1.50	1.50	20	230	pyrite
38	62.22	8	1.49	1.50	8	060	illite
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X-RAY DATA

SAMPLE: UTOC 265 Seam

RADIATION = Cu_k

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = $1^\circ(2\theta)/\text{min}$ START = $4^\circ(2\theta)$ END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d^\circ\text{\AA}$	$d^\circ\text{\AA}$	I/I	hkl	Mineral
1	8.95	10	9.90	9.90	80	002	illite
2	12.45	32	7.11	7.18	100	001	kaolinite
3	17.91	7	4.95	4.90	60	004	illite
4	20.00	9	4.44	4.48	80	02-	kaolinite/illite
5	20.90	16	4.25	4.26	35	100	quartz
6	21.50	5	4.13	4.11	40	022	illite
7	23.01	3	3.86	3.86	12	102	calcite
8	25.02	26	3.56	3.58	100	002	kaolinite
9	26.69	100	3.34	3.34	100	101	quartz/illite
10	28.65	15	3.11	3.13	35	111	pyrite
11	31.48	4	2.84	2.86	60	115	illite
12	33.20	37	2.70	2.71	85	200	pyrite
13	35.20	8	2.55	2.57	100	$20\bar{2}$	illite
14	36.10	7	2.49	2.50	80	$13\bar{1}$	kaolinite/calcite
15	36.80	6	2.44	2.46	12	110	quartz/illite
16	37.20	19	2.42	2.42	65	210	pyrite
17	38.50	15	2.34	2.34	90	$20\bar{2}$	kaolinite
18	39.50	9	2.28	2.28	12	102	quartz
19	40.20	4	2.24	2.24	6	111	quartz/illite
20	40.91	19	2.20	2.21	50	211	pyrite
21	42.60	7	2.12	2.13	9	200	quartz/illite
22	45.80	8	1.98	1.98	6	201	quartz
23	47.50	21	1.91	1.92	40	220	pyrite
24	50.20	15	1.82	1.82	17	112	quartz
25	53.25	4	1.72	1.72	20		illite

SAMPLE: UTOC 265 Seam (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\overset{\circ}{\text{\AA}}$	d $\overset{\circ}{\text{\AA}}$	I/I	hkl	Mineral
26	55.00	5	1.67	1.67	7	202	quartz
27	56.35	37	1.63	1.63	100	311	pyrite
28	59.15	8	1.56	1.56	14	222	pyrite
29	60.00	6	1.54	1.54	15	211	quartz/kaolinite
30	61.75	10	1.50	1.50	20	230	pyrite/illite
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X-RAY DATA

SAMPLE: UTOC 265 I

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
1	9.00	16	9.82	9.90	80	002	illite
2	12.50	45	7.08	7.18	100	001	kaolinite
3	17.90	5	4.95	4.90	60	004	illite
4	19.90	12	4.46	4.48	80	02-	kaolinite
5	20.40	8	4.35	4.29	40	111	illite
6	20.90	12	4.25	4.26	35	100	quartz
7	23.10	11	3.85	3.86	12	102	calcite
8	25.00	37	3.56	3.58	100	002	kaolinite
9	26.80	100	3.32	3.34	100	101	quartz/illite
10	28.60	26	3.12	3.13	35	111	pyrite
11	29.90	10	2.99	3.04	100	104	calcite
12	30.90	7	2.89	2.86	3	006	calcite
13	33.20	75	2.70	2.71	85	200	pyrite
14	34.20	8	2.62	2.60	100	130	illite
15	35.00	18	2.56	2.57	80	20 $\bar{1}$	kaolinite/illite
16	36.10	11	2.49	2.50	80	13 $\bar{1}$	kaolinite
17	36.70	10	2.45	2.46	12	110	quartz
18	37.20	52	2.42	2.42	65	210	pyrite
19	38.60	21	2.33	2.34	90	20 $\bar{2}$	kaolinite
20	39.60	13	2.27	2.28	12	102	quartz
21	40.40	8	2.23	2.24	6	111	quartz
22	40.96	34	2.20	2.21	50	211	pyrite
23	41.40	10	2.18	2.14	60	20 $\bar{6}$	illite
24	45.70	14	1.98	1.98	6	201	quartz/illite
25	47.50	38	1.91	1.92	40	220	pyrite

SAMPLE: UTOC 265 I (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	dÅ	dÅ	I/I	hkl	Mineral
26	50.30	19	1.81	1.82	17	112	quartz
27	55.40	13	1.68	1.67	7	202	quartz
28	56.40	73	1.63	1.63	100	311	pyrite
29	59.10	16	1.56	1.56	14	222	pyrite
30	60.00	12	1.54	1.54	15	211	quartz/kaolinite
31	61.80	17	1.50	1.50	20	230	pyrite
32	62.20	14	1.49	1.50	80	060	illite
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X-RAY DATA

SAMPLE: UTOC 265 II

RADIATION = Cu_k
 FILTER = Ni
 KV = 30
 MA = 12
 RANGE = 250

TIME CONSTANT = 5
 SCAN SPEED = $1^\circ(2\theta)/\text{min}$
 START = $4^\circ(2\theta)$
 END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d^\circ\text{\AA}$	$d^\circ\text{\AA}$	I/I	hkl	Mineral
1	8.90	7	9.90	9.90	80	002	illite
2	12.40	19	7.14	7.18	100	001	kaolinite
3	20.10	13	4.44	4.48	80	02-	kaolinite/illite
4	20.90	22	4.25	4.26	35	100	quartz
5	24.95	16	3.57	3.58	100	002	kaolinite
6	26.60	100	3.35	3.34	100	101	quartz/illite
7	28.61	8	3.12	3.13	35	111	pyrite
8	30.15	4	3.00	3.04	100	104	calcite
9	33.15	13	2.70	2.71	85	200	pyrite
10	35.10	16	2.55	2.57	80	$20\bar{1}$	kaolinite/illite
11	36.70	13	2.45	2.46	12	110	quartz/illite
12	37.20	13	2.42	2.42	65	210	pyrite
13	37.85	10	2.37	2.39	80	003	kaolinite
14	38.50	14	2.34	2.34	90	$20\bar{2}$	kaolinite
15	39.80	11	2.26	2.28	12	102	quartz
16	40.40	7	2.23	2.24	6	111	quartz/illite
17	40.90	11	2.20	2.21	50	211	pyrite
18	42.55	9	2.12	2.13	9	200	quartz/illite
19	43.90	10	1.98	1.98	6	201	quartz
20	46.80	4	1.94	1.94	40	206	illite
21	47.60	6	1.91	1.92	40	220	pyrite
22	50.20	14	1.82	1.82	17	112	quartz
23	55.30	11	1.66	1.67	7	202	quartz/kaolinite
24	56.40	16	1.63	1.63	100	311	pyrite
25	60.50	10	1.53	1.54	15	211	quartz/kaolinite

SAMPLE: UTOC 265 II (cont'd.)

OBSERVED PATTERN				STANDARD DIFFRACTION DATA			
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	61.80	6	1.50	1.50	20	230	pyrite
27	62.20	6	1.49	1.50	80	060	illite
28							
29							
30							
31							
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X-RAY DATA

SAMPLE: UTOC 265 III

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = 1°(2θ)/min

START = 4°(2θ)

END = 65°(2θ)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	d ^o Å	d ^o Å	I/I	hkl	Mineral
1	9.01	13	9.83	9.90	80	002	illite
2	12.45	37	7.11	7.18	100	001	kaolinite
3	18.053	7	4.91	4.90	60	004	illite
4	19.99	15	4.44	4.48	80	02-	kaolinite
5	20.60	8	4.31	4.29	40	111	illite
6	21.01	25	4.23	4.26	45	100	quartz
7	23.25	6	3.82	3.86	12	102	calcite
8	24.98	36	3.56	3.58	100	002	kaolinite
9	26.78	100	3.32	3.34	100	101	quartz/illite
10	28.71	27	3.11	3.13	35	111	pyrite
11	29.42	10	3.04	3.04	100	104	calcite
12	33.19	94	2.70	2.71	85	200	pyrite
13	34.80	4	2.58	2.57	80	20 $\bar{1}$	kaolinite
14	35.09	16	2.55	2.57	100	20 $\bar{2}$	illite
15	36.07	7	2.49	2.50	14	110	calcite
16	36.71	7	2.45	2.46	12	110	quartz
17	37.15	47	2.42	2.42	65	210	pyrite
18	38.60	18	2.33	2.34	90	20 $\bar{2}$	kaolinite
19	39.65	10	2.27	2.28	12	102	quartz
20	40.39	7	2.23	2.24	6	111	quartz
21	40.89	43	2.20	2.21	50	211	pyrite
22	42.71	13	2.12	2.13	9	200	quartz
23	43.49	6	2.08	2.10	18	202	calcite
24	45.85	7	1.98	1.98	6	201	quartz
25	46.71	6	1.94	1.99	40	20 $\bar{3}$	kaolinite

SAMPLE: UTOC 265 III (cont'd.)

OBSERVED PATTERN				STANDARD DIFFRACTION DATA			
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	47.60	47	1.91	1.92	40	220	pyrite
27	50.30	21	1.81	1.82	17	112	quartz
28	56.40	80	1.63	1.63	100	311	pyrite
29	59.20	14	1.56	1.56	14	222	pyrite
30	60.05	11	1.54	1.54	15	211	quartz
31	61.90	19	1.50	1.50	20	230	pyrite
32	62.60	11	1.48	1.50	80	060	illite
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X-RAY DATA

SAMPLE: UTOC 265 IV

RADIATION = Cu_K

FILTER = Ni

KV = 30

MA = 12

RANGE = 250

TIME CONSTANT = 5

SCAN SPEED = $1^\circ(2\theta)/\text{min}$ START = $4^\circ(2\theta)$ END = $65^\circ(2\theta)$

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2θ	I/I	$d\text{\AA}$	$d\text{\AA}$	I/I	hkl	Mineral
1	8.90	9	9.94	9.90	80	002	illite
2	12.65	30	7.00	7.18	100	001	kaolinite
3	17.80	6	4.98	4.90	60	004	illite
4	19.90	9	4.46	4.48	80	02-	kaolinite/illite
5	21.00	15	4.22	4.26	35	100	quartz
6	21.60	5	4.31	4.29	40	111	illite
7	23.10	4	3.85	3.86	12	102	calcite
8	24.50	7	3.63	3.65	50	023	illite
9	25.00	16	3.56	3.58	100	002	kaolinite
10	26.70	100	3.34	3.34	100	101	quartz/illite
11	28.65	32	3.11	3.13	35	111	pyrite
12	30.70	5	2.91	3.04	100	104	calcite
13	33.20	77	2.70	2.71	85	200	pyrite
14	34.70	8	2.58	2.57	80	$20\bar{1}$	kaolinite/illite
15	35.10	11	2.55	2.57	100	$20\bar{2}$	illite
16	36.20	8	2.48	2.50	80	$13\bar{1}$	kaolinite
17	36.70	8	2.45	2.46	12	110	quartz
18	37.20	65	2.42	2.42	65	210	pyrite
19	38.50	13	2.34	2.34	90	$20\bar{2}$	kaolinite
20	38.70	13	2.32				kaolinite
21	39.50	12	2.28	2.28	12	102	quartz
22	40.90	40	2.20	2.21	50	211	pyrite
23	42.60	8	2.12	2.14	60	$20\bar{6}$	illite
24	43.30	11	2.09	2.10	18	202	calcite
25	45.70	8	1.98	1.98	6	201	quartz

SAMPLE: UTOC 265 IV (cont'd.)

OBSERVED PATTERN			STANDARD DIFFRACTION DATA				
Peak	2 θ	I/I	d $\text{\AA}$	d $\text{\AA}$	I/I	hkl	Mineral
26	47.50	30	1.91	1.92	40	220	pyrite/calcite
27	50.20	12	1.82	1.82	17	112	quartz
28	56.40	63	1.63	1.63	100	311	pyrite
29	59.10	17	1.56	1.56	14	222	pyrite
30	60.10	9	1.54	1.54	15	211	quartz/kaolinite
31	61.80	14	1.50	1.50	20	230	illite/pyrite
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APPENDIX D

Proximate/Ultimeate, and Chlorine
Content of Some Ohio Coals

UTOC 264 Seam

Clarion (No. 4A) Coal

CPDU-134

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	5.09	xxxxxx	
% Ash	25.18	26.53	
% Volatile	33.31	35.10	
% Fixed Carbon	<u>36.42</u>	<u>38.37</u>	
	100.00	100.00	
Btu/lb.	9589	10103	13751
% Sulfur	3.48	3.67	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	5.09	xxxxxx
% Carbon	53.44	56.31
% Hydrogen	4.10	4.32
% Nitrogen	0.96	1.01
% Chlorine	0.07	0.07
% Sulfur	3.48	3.67
% Ash	25.18	26.53
% Oxygen (diff.)	7.68	8.09

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n UTOC 264 I

Clarion (No. 4A) Coal
CPDU 130-A

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.61	xxxxx	
% Ash	28.07	28.82	
% Volatile	32.97	33.85	
% Fixed Carbon	<u>36.35</u>	<u>37.33</u>	
	100.00	100.00	
Btu/lb.	9621	9879	13879
% Sulfur	3.20	3.28	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.61	xxxxx
% Carbon	53.18	54.61
% Hydrogen	4.34	4.46
% Nitrogen	1.57	1.61
% Chlorine	0.07	0.07
% Sulfur	3.20	3.28
% Ash	28.07	28.82
% Oxygen (diff.)	6.96	7.15

UTOC 264 II

Clarion (No. 4A) Coal
CPDU 130-B

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.10	xxxxx	
% Ash	22.16	22.64	
% Volatile	35.81	36.58	
% Fixed Carbon	<u>39.93</u>	<u>40.78</u>	
	100.00	100.00	
Btu/lb.	10446	10670	13792
% Sulfur	7.33	7.49	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.10	xxxxx
% Carbon	55.54	56.73
% Hydrogen	4.61	4.71
% Nitrogen	1.07	1.09
% Chlorine	0.07	0.07
% Sulfur	7.33	7.49
% Ash	22.16	22.64
% Oxygen (diff.)	7.12	7.27

UTOC 264 III

Clarion (No. 4A) Coal

CPDU 130-C

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.97	xxxxxx	
% Ash	11.14	11.48	
% Volatile	38.36	39.53	
% Fixed Carbon	<u>47.53</u>	<u>48.99</u>	
	100.00	100.00	
Btu/lb.	10503	10824	12228
% Sulfur	4.95	5.10	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.97	xxxxxx
% Carbon	66.47	68.50
% Hydrogen	4.98	5.13
% Nitrogen	1.43	1.47
% Chlorine	0.10	0.10
% Sulfur	4.95	5.10
% Ash	11.14	11.48
% Oxygen (diff.)	7.96	8.22

UTOC 264 Wash
Clarion (No. 4A) Coal
CPDU-132

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	5.47	xxxxx	
% Ash	15.12	15.99	
% Volatile	37.13	39.28	
% Fixed Carbon	<u>42.28</u>	<u>44.73</u>	
	100.00	100.00	
Btu/lb.	11035	11674	13896
% Sulfur	3.16	3.34	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	5.47	xxxxx
% Carbon	61.51	65.07
% Hydrogen	4.68	4.95
% Nitrogen	1.04	1.10
% Chlorine	0.03	0.03
% Sulfur	3.16	3.34
% Ash	15.12	15.99
% Oxygen (diff.)	8.99	9.52

UTOC 262 Seam
Lower Kittanning (No. 5) Coal
CPDU-136

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	4.96	xxxxx	
% Ash	11.42	12.02	
% Volatile	36.88	38.80	
% Fixed Carbon	<u>46.74</u>	<u>49.18</u>	
	100.00	100.00	
Btu/lb.	11476	12075	13724
% Sulfur	4.80	5.05	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	4.96	xxxxx
% Carbon	63.91	67.25
% Hydrogen	4.82	5.07
% Nitrogen	0.00	0.00
% Chlorine	0.00	0.00
% Sulfur	4.80	5.05
% Ash	11.42	12.02
% Oxygen (diff.)	10.09	10.61

UTOC 262 I

Lower Kittanning (No. 5) Coal
CPDU 129-A

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.63	xxxxxx	
% Ash	4.55	4.67	
% Volatile	40.19	41.28	
% Fixed Carbon	<u>52.63</u>	<u>54.05</u>	
	100.00	100.00	
Btu/lb.	13324	13684	14355
% Sulfur	3.02	3.10	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.63	xxxxxx
% Carbon	73.41	75.39
% Hydrogen	5.43	5.58
% Nitrogen	1.57	1.61
% Chlorine	0.11	0.11
% Sulfur	3.02	3.10
% Ash	4.55	4.67
% Oxygen (diff.)	9.28	9.54

UTOC 262 II
Lower Kittanning (No. 5) Coal
CPDU 129-B

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.77	xxxxx	
% Ash	3.45	3.55	
% Volatile	42.05	43.25	
% Fixed Carbon	<u>51.73</u>	<u>53.20</u>	
	100.00	100.00	
Btu/lb.	13438	13821	14330
% Sulfur	3.57	3.67	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.61	xxxxx
% Carbon	74.60	76.60
% Hydrogen	5.61	5.76
% Nitrogen	1.37	1.41
% Chlorine	0.13	0.13
% Sulfur	3.57	3.67
% Ash	3.46	3.55
% Oxygen (diff.)	8.65	8.88

UTOC 262 III
Lower Kittanning (No. 5) Coal
CPDU 129-C

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.81	xxxxxx	
% Ash	13.41	13.80	
% Volatile	35.31	36.33	
% Fixed Carbon	<u>48.47</u>	<u>49.87</u>	
	100.00	100.00	
Btu/lb.	11578	11912	13819
% Sulfur	4.23	4.35	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.81	xxxxxx
% Carbon	63.09	64.91
% Hydrogen	4.75	4.89
% Nitrogen	0.95	0.98
% Chlorine	0.05	0.05
% Sulfur	4.23	4.35
% Ash	13.41	13.80
% Oxygen (diff.)	10.71	11.02

UTOC 263 Seam
Middle Kittanning (No. 6) Coal
CPDU-133

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	1.83	xxxxxx	
% Ash	10.33	10.52	
% Volatile	41.62	42.40	
% Fixed Carbon	<u>46.22</u>	<u>47.08</u>	
	100.00	100.00	
Btu/lb.	12552	12786	14290
% Sulfur			

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	1.83	xxxxxx
% Carbon	70.26	71.57
% Hydrogen	4.85	4.94
% Nitrogen	1.48	1.51
% Chlorine	0.10	0.10
% Sulfur	4.42	4.50
% Ash	10.33	10.52
% Oxygen (diff.)	6.73	6.86

UTOC 263 I

Middle Kittanning (No. 6) Coal

CPDU 126- A

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.61	xxxxxx	
% Ash	4.98	5.11	
% Volatile	39.62	40.68	
% Fixed Carbon	<u>52.79</u>	<u>54.21</u>	
	100.00	100.00	
Btu/lb.	13374	13733	14473
% Sulfur	2.99	3.07	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.61	xxxxxx
% Carbon	74.44	76.44
% Hydrogen	5.57	5.72
% Nitrogen	1.40	1.44
% Chlorine	0.10	0.10
% Sulfur	2.99	3.07
% Ash	4.98	5.11
% Oxygen (diff.)	7.91	8.12

UTOC 263 II

Middle Kittanning (No. 6) Coal

CPDU 126-B

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.47	xxxxx	
% Ash	4.52	4.63	
% Volatile	45.45	46.60	
% Fixed Carbon	<u>47.56</u>	<u>48.77</u>	
	100.00	100.00	
Btu/lb.	13422	13762	14431
% Sulfur	4.24	4.35	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.47	xxxxx
% Carbon	73.76	75.63
% Hydrogen	5.72	5.86
% Nitrogen	1.29	1.32
% Chlorine	0.11	0.11
% Sulfur	4.24	4.35
% Ash	4.52	4.63
% Oxygen (diff.)	7.89	8.10

UTOC 263 III

Middle Kittanning (No. 6) Coal
CPDU 126-C

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.64	xxxxx	
% Ash	3.11	3.19	
% Volatile	41.86	42.99	
% Fixed Carbon	<u>52.39</u>	<u>53.82</u>	
	100.00	100.00	
Btu/lb.	13695	14066	14530
% Sulfur	2.55	2.62	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.64	xxxxx
% Carbon	76.16	78.23
% Hydrogen	5.46	5.61
% Nitrogen	1.24	1.27
% Chlorine	0.10	0.10
% Sulfur	2.55	2.62
% Ash	3.11	3.19
% Oxygen (diff.)	8.74	8.98

UTOC 263 IV
Middle Kittanning (No. 6) Coal
CPDU-126-D

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.14	xxxxx	
% Ash	29.59	30.24	
% Volatile	32.11	32.81	
% Fixed Carbon	<u>36.16</u>	<u>36.95</u>	
	100.00	100.00	
Btu/lb.	9351	9555	13697
% Sulfur	9.11	9.31	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.14	xxxxx
% Carbon	49.35	50.43
% Hydrogen	4.18	4.27
% Nitrogen	0.25	0.26
% Chlorine	0.08	0.08
% Sulfur	9.11	9.31
% Ash	29.59	30.24
% Oxygen (diff.)	5.30	5.41

UTOC 259 Seam

Pittsburgh (No. 8) Coal

CPDU-131

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	1.77	xxxxxx	
% Ash	11.82	12.03	
% Volatile	40.38	41.11	
% Fixed Carbon	<u>46.03</u>	<u>46.86</u>	
	100.00	100.00	
Btu/lb.	12467	12692	14428
% Sulfur	4.73	4.82	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	1.77	xxxxxx
% Carbon	68.95	70.19
% Hydrogen	5.01	5.10
% Nitrogen	1.06	1.08
% Chlorine	0.06	0.06
% Sulfur	4.73	4.82
% Ash	11.82	12.03
% Oxygen (diff.)	6.60	6.72

UTOC 259 Wash
Pittsburgh (No. 8) Coal
CPDU 131-A

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	1.97	xxxxxx	
% Ash	15.41	15.72	
% Volatile	38.06	38.82	
% Fixed Carbon	<u>44.56</u>	<u>45.46</u>	
	100.00	100.00	
Btu/lb.	12026	12268	14556
% Sulfur	4.23	4.32	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	1.97	xxxxxx
% Carbon	65.80	67.12
% Hydrogen	4.78	4.88
% Nitrogen	1.12	1.14
% Chlorine	0.01	0.01
% Sulfur	4.23	4.32
% Ash	15.41	15.72
% Oxygen (diff.)	6.68	6.81

UTOC 260 Seam
Pittsburgh (No. 8) Coal
CPDU-137

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	3.23	xxxxxx	
% Ash	18.40	19.01	
% Volatile	32.34	33.42	
% Fixed Carbon	<u>46.03</u>	<u>47.57</u>	
	100.00	100.00	
Btu/lb.	10988	11365	14034
% Sulfur	3.75	3.88	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	3.33	xxxxxx
% Carbon	61.23	63.27
% Hydrogen	4.60	4.75
% Nitrogen	1.09	1.13
% Chlorine	0.07	0.07
% Sulfur	3.75	3.88
% Ash	18.40	19.01
% Oxygen (diff.)	7.63	7.89

UTOC 260 I
Pittsburgh (No. 8) Coal
CPDU 127-A

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	1.74	xxxxxx	
% Ash	18.71	19.04	
% Volatile	34.96	35.58	
% Fixed Carbon	<u>44.59</u>	<u>45.38</u>	
	100.00	100.00	
Btu/lb.	11295	11495	14198
% Sulfur	7.98	8.12	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	1.74	xxxxxx
% Carbon	60.44	61.51
% Hydrogen	4.63	4.71
% Nitrogen	1.15	1.17
% Chlorine	0.07	0.07
% Sulfur	7.98	8.12
% Ash	18.71	19.04
% Oxygen (diff.)	5.28	5.38

UTOC 260 II

Pittsburgh (No. 8) Coal

CPDU 127-B

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	1.94	xxxxx	
% Ash	16.31	16.63	
% Volatile	34.07	34.74	
% Fixed Carbon	<u>47.68</u>	<u>48.63</u>	
	100.00	100.00	
Btu/lb.	11991	12109	14523
% Sulfur	2.38	2.41	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	1.94	xxxxx
% Carbon	68.39	69.74
% Hydrogen	4.06	4.14
% Nitrogen	1.74	1.77
% Chlorine	0.05	0.05
% Sulfur	2.36	2.41
% Ash	16.31	16.63
% Oxygen (diff.)	5.15	5.26

UTOC 260 III
Pittsburgh (No. 8) Coal
CPDU 127-C

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	1.94	xxxxxx	
% Ash	7.62	7.77	
% Volatile	37.05	37.78	
% Fixed Carbon	<u>53.39</u>	<u>54.45</u>	
	100.00	100.00	
Btu/lb.	13193	13454	14588
% Sulfur	2.31	2.35	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	1.94	xxxxxx
% Carbon	72.59	74.03
% Hydrogen	5.32	5.43
% Nitrogen	1.34	1.37
% Chlorine	0.10	0.10
% Sulfur	2.31	2.35
% Ash	6.62	7.77
% Oxygen (diff.)	8.78	8.95

UTOC 260 IV

Pittsburgh (No. 8) Coal

CPDU 127-D

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	1.97	xxxxxx	
% Ash	13.85	14.13	
% Volatile	35.62	36.34	
% Fixed Carbon	<u>48.56</u>	<u>49.53</u>	
	100.00	100.00	
Btu/lb.	12199	12445	14492
% Sulfur	4.37	4.46	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	1.97	xxxxxx
% Carbon	71.41	72.84
% Hydrogen	3.44	3.51
% Nitrogen	1.21	1.23
% Chlorine	0.06	0.06
% Sulfur	4.37	4.46
% Ash	13.85	14.13
% Oxygen (diff.)	3.69	3.77

UTOC 265 Seam

Pittsburgh (No. 8) Coal

CPDU-135-A

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	3.43	xxxxxx	
% Ash	13.88	14.37	
% Volatile	33.73	34.93	
% Fixed Carbon	<u>48.96</u>	<u>50.70</u>	
	100.00	100.00	
Btu/lb.	11762	12180	14225
% Sulfur	3.36	3.48	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	3.43	xxxxxx
% Carbon	65.50	67.83
% Hydrogen	4.77	4.94
% Nitrogen	1.28	1.33
% Chlorine	0.06	0.06
% Sulfur	3.36	3.48
% Ash	13.88	14.37
% Oxygen (diff.)	7.72	7.99

NOTE: This Pittsburgh No. 8 coal, UTOC 265, was originally mislabelled consol No. 9.

UTOC 265 I

Pittsburgh (No. 8) Coal
CPDU 128-A

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.18	xxxxx	
% Ash	7.03	7.19	
% Volatile	37.61	38.45	
% Fixed Carbon	<u>53.18</u>	<u>54.36</u>	
	100.00	100.00	
Btu/lb.	13211	13505	14551
% Sulfur	3.31	3.38	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.18	xxxxx
% Carbon	73.21	74.84
% Hydrogen	5.29	5.41
% Nitrogen	1.07	1.09
% Chlorine	0.08	0.08
% Sulfur	3.31	3.38
% Ash	7.03	7.19
% Oxygen (diff.)	7.83	8.10

UTOC 265 II
Pittsburgh (No. 8) Coal
CPDU 128-B

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.03	xxxxx	
% Ash	28.95	29.55	
% Volatile	29.14	29.74	
% Fixed Carbon	<u>39.88</u>	<u>40.71</u>	
	100.00	100.00	
Btu/lb.	9700	9901	14053
% Sulfur	2.57	2.62	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.03	xxxxx
% Carbon	54.49	55.62
% Hydrogen	4.27	4.36
% Nitrogen	0.98	1.00
% Chlorine	0.02	0.02
% Sulfur	2.57	2.62
% Ash	28.95	29.55
% Oxygen (diff.)	6.69	6.83

UTOC 265 III

Pittsburgh (No. 8) Coal
CPDU 128-C

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.31	xxxxxx	
% Ash	6.82	6.98	
% Volatile	35.63	36.47	
% Fixed Carbon	<u>55.24</u>	<u>56.55</u>	
	100.00	100.00	
Btu/lb.	13153	13464	14475
% Sulfur	2.69	2.75	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.31	xxxxxx
% Carbon	72.90	74.62
% Hydrogen	5.21	5.33
% Nitrogen	1.26	1.29
% Chlorine	0.06	0.06
% Sulfur	2.69	2.75
% Ash	6.82	6.98
% Oxygen (diff.)	8.75	8.97

UTOC 265 IV

Pittsburgh (No. 8) Coal

CPDU 128-D

PROXIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>	<u>MAF</u>
% Moisture	2.45	XXXXXX	
% Ash	10.68	10.95	
% Volatile	34.29	35.15	
% Fixed Carbon	<u>52.58</u>	<u>53.90</u>	
	100.00	100.00	
Btu/lb.	12481	12794	14367
% Sulfur	3.72	3.81	

ULTIMATE ANALYSIS

	<u>As Received</u>	<u>Dry Basis</u>
% Moisture	2.45	XXXXXX
% Carbon	69.48	71.23
% Hydrogen	5.00	5.13
% Nitrogen	1.06	1.09
% Chlorine	0.05	0.05
% Sulfur	3.72	3.81
% Ash	10.68	10.95
% Oxygen (diff.)	7.56	7.74

PLATE 2. Cluster Analysis of Selected Ohio Coals, Appalachian Province Coals and Interior Province Coals.

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