THE NATURE AND OCCURRENCE OF ASH FORMING MINERALS IN ANTHRACITE

by

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and

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STATEMENT OF TRANSMITTAL

Special Report SR-22 transmitted herewith has been prepared by the Coal Research Section of the Mineral Industries Experiment Station. Each of the Special Reports presents the results of a phase of one of the research projects supported by the Pennsylvania Coal Research Board or a technical discussion of related research. It is intended to present all of the important results of the Coal Board research in Special Reports, although some of the results may already have been presented in progress reports. The following is a list of Special Research Reports issued previously.

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SR-4  The Crushing of Anthracite with a Jaw Crusher  November 1, 1958
SR-5  Reactions of a Bituminous Coal with Sulfuric Acid  February 1, 1959
SR-6  Laboratory Studies on the Grindability of Anthracite and Other Coals  April 1, 1959
SR-7  Coal Characteristics and Their Relationship to Combustion Techniques  April 15, 1959
SR-8  The Crushing of Anthracite with an Impactor-Type Crusher  April 25, 1959
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M. E. Bell, Director  
M. I. Experiment Station
SUMMATION OF RESULTS

This Report summarizes progress thus far made in a program of research aimed at providing useful information concerning the nature and distribution of mineral matter in Pennsylvanian anthracite. Specifically, the objectives are focused upon development of:

1. Descriptions of preferential geographic distribution of particular mineral constituents;
2. Descriptions of preferential stratigraphic distribution of particular mineral constituents;
3. Descriptions of preferential concentration of contained minerals at particular levels within the seams under study;
4. Descriptions of the extent to which any of the minerals are preferentially associated with particular macerals or lithotypes;
5. Descriptions of the properties of any distinctive maceral-mineral associations as a basis for development of effective beneficiation practices;
6. Interpretations concerning the relationships between the mineral content of the coal and the chemical composition of the residual ash.

This Report presents some of the qualitative mineralogical data, the preliminary results of maceral analyses, and a discussion of the relationships of certain minerals to seam level and ash content. As such, it constitutes presentation of the results of the initial phase of the investigation.
The most significant result to date has been the development of the petrographic procedure that permits the differentiation of anthracite seams into compositionally different zones. The importance of this lies in the fact that, for the first time, a rational basis for controlled experimentation with different types of anthracite is available. For example, had this knowledge been available at the inception of the research on the blending of anthracite and bituminous coals for metallurgical coke production, more rapid progress could have been made and it is probable that the results would have been even more promising than those achieved. Regardless of this, it is now possible to program this type of research in the best interests of rapidly exploring the potential uses for the various kinds of anthracite. It perhaps should be emphasized that up to this time anthracite has been considered to be a relatively uniform substance. This initial insight into its heterogeneity reveals new avenues of research and could conceivably place certain anthracitic materials in a competitive marketing position in the not too distant future.

Other useful results include recognition of the fact that each anthracite seam is characterized by a distinctive pattern of mineral matter distribution, both vertically and laterally within the seam. Knowledge of this pattern, together with information on the nature of the transitions from high-ash to low-ash zones, should be of use in prescribing efficient cleaning practices, thus increasing yields and reducing production costs as a means of increasing the marketing potential. Also of interest is the fact that the various seams differ in
their mineral content, not only quantitatively, but in terms of kinds of minerals present. From this it is evident that the chemistry of the ash of different seams will vary and knowledge of this may be of value in marketing coals for special uses that require controlled ash chemistry.
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ABSTRACT

This report presents the results thus far obtained in the initial phase of a study of the mode of occurrence of mineral matter in anthracite. The mineral content of 156 strata from 12 coal columns was determined. Ash yield data for the strata from 11 of the columns were also procured. In addition, one column was studied to determine the relative concentration of maceral material in each inch interval through the entire seam thickness. Each four-inch interval of this column was analyzed to determine the concentration of sulfur present. Geologic age and geographic location appear to be correlated, to some extent, with the types of minerals encountered in the seams. The Allegheny coals yielded, on the average, the highest ash residue and contained the greatest variety of minerals. Seam samples collected in the Southern Anthracite Field contained the greatest concentrations of metamorphic minerals.

A petrographic procedure permitting the differentiation of anthracite seams into compositionally different zones has been provided, through creation of a provisional classification of vitrinitic macerals common in anthracite coal. Quantification of the reflectance exhibited by various anthrinoid macerals has made evident that anthracitic coal seams are stratified rock bodies consisting of layers or lenses that are, in themselves, distinctive mixtures of maceral and mineral materials. The compositional heterogeneity encountered appears to be far greater than that previously ascribed to anthracite.
INTRODUCTION

Coal seams are stratified rock bodies consisting of a mixture of organic and inorganic material. The practical importance of the inorganic or mineral fraction has been emphasized upon numerous occasions during the last few decades (Ball, 1935, Sprunk and O'Donnell, 1942, Nelson, 1953, Mackowsky, 1956) and it has become more and more evident that the mineral matter in coal affects almost every aspect of coal mining, preparation and utilization. In terms of the metallurgical coal market, the ash and sulfur content of coking coal products are of primary concern and both are proportional to the nature and distribution of mineral materials in the source seams. Mineral material in the coke oven feed influences the expansion and contraction exhibited by the coal during carbonization. It also affects the structure, strength and reactivity of the resultant coke. In connection with the combustion of coal in modern power plants, increased significance is placed on the nature and quantity of mineral matter in the coal feed because of their relation to clinkering and to the development of flue gas deposits that reduce operating efficiency. Perhaps the best evidence of the importance of mineral matter in coal is to be found in the fact that the practice of cleaning and beneficiating coals has rapidly become more widespread during the last decade. These cleaning and beneficiating procedures are focused primarily upon reducing the quantity and altering the quality of the mineral material in the coal being processed. The methods employed are usually dependent upon the friability, size, shape and specific gravity of the coal particles being processed. These properties,
themselves, are related to the type and quantity of inorganic material in the particle. In mechanized mining, problems are created by irregular occurrences of concentrations of mineral material, and the health of the miners is sometimes endangered by breathing excesses of silica dusts.

Although its importance appears beyond question, comparatively little effort has been directed at furthering our knowledge of the nature and mode of occurrence of the mineral materials in coal seams. A great deal of information exists on quantity of ash yielded by particular coal seams and occasionally information has been developed on the chemical composition of the ash. Such data are useful but it was pointed out as early as 1934 that the oxides contained in the ash residue are totally different from the minerals contained in the original coal (Gauger, Barrett, and Williams, 1934). Some progress has been made in identifying the minerals that commonly occur in coals and it is suggested that, for convenience, it is useful to classify these as follows: (modified from Nelson, 1953)

**The Shale Group** (Group M)

- muscovite
- hydromuscovite
- illite
- bravaisite
- montmorillonite

**The Kaolin Group** (Group K)

- kaolinite
- levisite
- metahalloysite

**The Sulfide Group** (Group S)

- pyrite
- marcasite
- 3 -

The Carbonate Group (Group C)
- ankerite
- calcite
- siderite

The Chloride Group (Group H)
- sylvite
- halite

The Oxide Group (Group O)
- quartz
- hematite
- magnetite

The Accessory Minerals Group (Group A)
- sphalerite
- feldspar
- garnet
- hornblende
- gypsum
- apatite
- zircon
- epidote
- biotite
- augite
- prochlorite
- chlorite
- diaspore
- lepidocrocite
- barite
- kyanite
- staurolite
- topaz
- tourmaline
- topaz
- pyrophyllite
- penninite

A variety of additional minerals could be added to Nelson's Accessory Mineral Group as the result of work completed since the date of his publication. It remains true, however, that the overwhelming bulk of mineral matter that is contained within mineable coal seams consists of minerals belonging to the first four of the above mentioned groups.
This type of a classification is probably more useful in connection with problems of coal utilization than is the genetic classification of coal seam minerals which differentiates between phytogenic (sometimes called "inherent") and non-phytogenic (called "extraneous" or "adventitious") minerals. The latter, in a genetic classification, are usually divided into syngenetic and epigenetic sub-classes. Recently Mackowsky (1956) has proposed a scheme of classification that tends to combine the genetic with the compositional classification and some elaboration of this is probably the most satisfactory means of grouping the mineral constituents of coal seams when such a procedure is dictated by an investigation's objectives. For geologic purposes both genesis and composition are profitably used in a classificatory system and the same is probably true, but to a lesser extent, in connection with the problems encountered in the mining, preparation and utilization of coal.

Although the common coal seam minerals have been identified and tentatively classified, very little effort has been directed toward investigating their mode of occurrence in coal seams and the degree to which they might be preferentially associated with other minerals and particular macerals. It appears logical to expect preferential maceral-mineral association and knowledge of these relationships should be of use to the preparation engineer concerned with controlling ash quality and quantity. Such information should also be of interest to the geologist concerned with understanding the ecological significance of various lithotypes.
OBJECTIVES OF THIS INVESTIGATION

This investigation has been undertaken in an attempt to provide useful information concerning the nature and distribution of mineral matter in certain seams of Pennsylvanian anthracite. More specifically, the objectives are focused upon development of:

1. Descriptions of preferential geographic distribution of particular mineral constituents;
2. Descriptions of preferential stratigraphic distribution of particular mineral constituents;
3. Descriptions of preferential concentration of contained minerals at particular levels within the seams under study;
4. Descriptions of the extent to which any of the minerals are preferentially associated with particular macerals or lithotypes;
5. Descriptions of the properties of any distinctive maceral-mineral associations as a basis for development of effective beneficiation practices;
6. Interpretations concerning the relationships between the mineral content of the coal and the chemical composition of the residual ash.

This report presents some of the qualitative mineralogical data, the preliminary results of maceral analyses, and a discussion of the relationships of certain minerals to seam level and ash content. As such, it constitutes presentation of the results of the initial phase of the investigation.
DESCRIPTION OF METHODS

Twelve column samples, each representing a particular anthracite seam, were procured for study. All columns were obtained in the Anthracite Coal Fields of Pennsylvania, six being derived from the Western Middle Field and six from the Southern Field. The locations of the several sampling areas are shown on the map presented as Figure 1.

The petrographic study of anthracite has received little attention in the past and, as a result, no information was available at the program's inception concerning the manner in which compositionally distinct seam strata could be recognized. Accordingly, each column was arbitrarily divided into a series of samples each representing a 4 inch layer of the seam in question. Each sample was analyzed to determine the particular minerals present in greater than trace amounts. Ash yield data were obtained on samples derived from all but the Primrose coal column. Ash values were obtained following standard A.S.T.M. procedures slightly modified to utilize the equipment available. Approximately two grams were riffled out of representative material from each four inch interval of each seam as measured perpendicular to the bedding planes. This material, whenever possible, was cut from the column sample thereby assuring equal coverage of each one inch interval.

The two gram sample was ground to pass a 60 mesh screen, weighed out into duplicate one gram samples, and ashed at 950°C. in a small muffle furnace for a minimum of five hours. Upon removal, the samples were placed in a dessicator and weighed after a ten minute
LOCATIONS OF SAMPLING AREAS

WESTERN MIDDLE ANTHRACITE FIELD

Area I: Stevens Strip Mine
  #8 1/2 Seam - Middle Split of Mammoth Seam

Area II: Glenburn Colliery
  #9 1/2 Seam - Four Foot Seam
  #11 Seam - Primrose Seam

Steiner Strip Mine
  #19 Seam

Glosek Bros. Mine
  #20 Seam

Area III: Junedale Coal Co.
  #12 Seam - Orchard Seam

SOUTHERN ANTHRACITE FIELD

Area IV: Dando - Confer Mine
  #6 Seam - Seven Foot Seam
  #5 Seam - Buck Mountain

Area V: B. G. and S. Mine
  Lykens Valley #3 Seam
  Neumeister Coal Co.
  Lykens Valley #4 Seam
  Deitrick and Ebert Mine
  Lykens Valley #5 Seam
  F. and W. Coal Co.
  #16 Seam - Peach Mountain Seam
cooling period. Weight difference was then calculated on a percentage basis. Intentional variation of heating period and sample quantity showed insignificant deviations in the results. Further corroboration of the validity of employing this technique was obtained from proximate analyses on some of the seams, carried out by a commercial testing laboratory.

Mineral content was determined by the use of an x-ray diffractometer using standard techniques (Brindley, 1951, Grim, 1953). The samples were representative of each four inch interval, obtained in the same manner as those above to allow correlation with the ash data. The samples were then subjected to a float-sink process using Certigrav heavy liquid with a 1.60 specific gravity. The sink fraction as well as material at the interface between the float and the sink material were collected for the x-ray analysis. This floatation was performed and the samples collected as described in order to remove the masking influence of the carbon as well as to retain the fine clays and sheet silicates suspended in the heavy media interface. A representative sample of this material was then crushed to pass a 325 mesh screen and mounted on a glass slide using a parlodion-amyl acetate mounting medium. A low viscosity was maintained in the mounting medium to allow a preferential orientation of the fine sheet silicates for better qualitative determination of the minerals present.

A copper target was used with a nickel filter. Representative mineral "d" spacings were recorded covering a range from 0 to 60° two theta angles and interpreted from the A.S.T.M. card index. Most
of the pyrite reflections were destroyed by secondary fluorescence resulting from the use of the copper target but the presence of this mineral was ascertained by an examination of the preparation using microscopic techniques. A point count was also conducted on the pyrite particles, affording a general quantitative estimate of the pyrite in the anthracites. In most cases the basal reflections from the minerals were sufficient for an identification thereof, but the wide variety and the mixed layering of the sheet silicates associated with the anthracites allowed little more than a separation into mineral groups rather than identification as specific mineral species. For the purpose of this initial study, the differentiation of mineral groups was sufficient.

The Buck Mountain seam samples were subjected to a more intensive study in which an attempt was made to describe the distribution of vitrinitic macerals and to compare this distribution with the mineral matter distribution.

The reflectance values for these maceral materials in the Buck Mountain seam were taken from briquettes covering each inch of the seam in small block form. A Leitz UAM Ortholux microscope with a special restricting orifice at the ocular site was used with a filtered monochromatic light source powered by a constant voltage transformer. An 8 micron diameter peephole focused the reflections from the various anthrinoids (as located by a 60x oil immersion objective and 10x ocular) on a sensitive filter tube which transmitted these impulses to a recorder to get a relative reflectance reading for that maceral. A spinel standard was used to check the equipment after each 10 consecutive readings and
a scale variance of more than 0.3 from the real value caused rejection of the preceding data. On each reading the stage was rotated through 360° with the maximum scale value being recorded.

Computation of observed scale readings to obtain a reflectance value from the coal was obtained by using a constant relative to the index of refraction of the spinel standard. These values were tabulated and preferential groupings became evident.

The pellets used in the reflectance technique were made by embedding blocks (approximately 2 cm. on a side) of coal in a lucite medium and polishing one face perpendicular to the bedding planes. Readings on the opaque coal block prevented extraneous light from filtering through the mounting medium and giving false values for the particular macerals being read. The readings were taken on a traverse made perpendicular to the bedding, with the reflectance of a minimum of 40 anthrinoid particles being determined for each one-inch interval.

**DESCRIPTION AND DISCUSSION OF INITIAL RESULTS**

A total of 156 samples were examined, each anthracite seam being represented by at least 11 samples. Figures 2 and 3 present the results of the qualitative mineralogical analyses and the quantitative ash determinations for each of the seam strata studied. Inspection of these figures will show that all seams possess pyrite, quartz, kaolin group and shale group minerals at some, and usually at many, stratigraphic levels. Four seams (#9 1/2, #16, #19 and #20) appear very similar, insofar as their mineral contents are concerned, in that they
MINERAL CONTENT
AND
ASH YIELDS ASSOCIATED WITH
CERTAIN PENNSYLVANIA
ANTHRACITE SEAMS

Figure 2
MINERAL CONTENT AND ASH YIELDS ASSOCIATED WITH CERTAIN PENNSYLVANIA ANTHRACITE SEAMS

Figure 3

KEY
- PYRITES
- KAOLIN MINERALS
- QUARTZ
- ILLITIC MINERALS
- PYROPHYLLITE
- CHLORITES
- CARBONATE MINERALS
contain only the four minerals mentioned above, and these minerals were encountered at almost every level within the respective seams. Two of the seams are distinctive because of their pyrophyllite content. This material is present in relatively large concentrations in the Buck Mountain or #5 seam and in the Seven Foot or #6 seam. Both of these beds also contain chlorite in addition to the four basic minerals mentioned above. Another pair of seams contains chlorite (Lykens Valley #3 seam and Lykens Valley #5 seam) but lacks pyrophyllite and contains no carbonate minerals. The remaining four seams (Lykens Valley #4, Primrose #11, Orchard #12 and Middle split of the Mammoth #8 1/2) all possess carbonate minerals and are devoid of pyrophyllite and chlorite, except for minor quantities of chlorite encountered in the Lykens Valley #4 and the Primrose #11 seams. Table 1 summarizes a portion of the data presented in Figures 2 and 3 makes the above described relationships more apparent.

The mineral associations encountered in the various seams suggest that metamorphic processes have not only converted the coal to anthracite but, as might be expected, they have altered the mineral content in a readily recognized manner. The presence of pyrophyllite and chlorite in the Buck Mountain and Seven Foot seams suggests that these have undergone the greatest amount of change. The fact that the partings in these seams (see the high ash zones in Figure 3) no longer contain kaolin minerals appears to be further evidence of the relative intensity of the metamorphic forces.

As might be inferred from a knowledge of the geologic history of the region, the seam samples exhibiting the greatest alteration were
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<th>The Muscovite Group</th>
<th>The Kaolin Group</th>
<th>The Sulfide Group</th>
<th>The Carbonate Group</th>
<th>The Accessory Group</th>
<th>The Chlorite Group</th>
<th>The Oxide Group</th>
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procured from an area that lies to the south of the other collecting sites. In Figure 4A these pyrophyllite-bearing sites are shown in relation to the other sampling areas. The compressional forces responsible for the major folding observable in Appalachian Paleozoic strata were directed toward the northwest and their greatest intensity is thought to have been felt to the south and east of the Anthracite Coal Field. It follows that it is reasonable to find the most altered mineral assemblage in Areas IV and V. The presence of chlorite in all columns procured from these areas (see Figure 4B) and its absence (with one minor and questionable exception) from the sampling areas to the north is consistent with the foregoing facts and inferences concerning the distribution and significance of pyrophyllite.

The geographic distribution of carbonate minerals is also presented in Figure 4, without regard for stratigraphic relationships. Additional quantitative data are required before any interpretation is made of the occurrence of carbonates. In general, distributional patterns are more informative and meaningful if prepared for individual stratigraphic horizons and as this manuscript reports on but a single column from each coal seam, discussion of the matter is minimized.

Figure 5 places the twelve seams studied in proper order with respect to age. As shown, all are coals formed during the Pennsylvanian Period. The Lykens Valley seams belong to the Pottsville series, the Buck Mountain, Seven Foot, Mammoth and Four Foot are Allegheny coals and the five succeeding coals (#11, #12, #16, #19, and #20) belong to the Conemaugh series.
LEGEND

- PYROPHYLITE
- CHLORITE
- CARBONATE MINERALS

DISTRIBUTION OF PYROPHYLITE, CHLORITE, AND CARBONATE MINERALS IN SEAMS AT VARIOUS SAMPLING AREAS

Figure 4
### Figure 5

#### Relationship Between Mineral Content and Stratigraphic Level

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<th>PENNSYLVANIAN SYSTEM</th>
<th>KAOLIN</th>
<th>QUARTZ</th>
<th>ILLITIC MINERALS</th>
<th>PYRITE</th>
<th>CHLORITE</th>
<th>CARBONATE MINERALS</th>
<th>PYROPHYLLITE</th>
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<tr>
<td>BEAR MOUNTAIN #6 SEAM</td>
<td></td>
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<tr>
<td>SEVEN FOOT #6 SEAM</td>
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<td></td>
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<tr>
<td>MIDDLE MAMMOTH #8 1/2 SEAM</td>
<td></td>
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<td></td>
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<tr>
<td>FOUR FOOT #9 1/2 SEAM</td>
<td></td>
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<tr>
<td>PRIMROSE #11 SEAM</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>ORCHARD #12 SEAM</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>PEACH MOUNTAIN #16 SEAM</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>#19 SEAM</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#20 SEAM</td>
<td></td>
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</tbody>
</table>
As is evident from the figure, the samples of Allegheny coals contained the largest variety of minerals. This may be a function of the geographic relation of the sampling sites as opposed to a real difference in mineral assemblages at different stratigraphic levels. The columns of Pottsville coal all contained chlorite at some level in the seam. As in the case of pyrophyllite and as previously mentioned, this mineral may be an alteration product developed as the result of the effects of metamorphic processes. It is of interest that the three Pottsville columns were obtained from the Southern Anthracite Field as were the chlorite-bearing columns from the Buck Mountain and Seven Foot seams. A small amount of chlorite was detected at one level in the Primrose seam, and except for this it was not encountered in the 83 samples analyzed from the more northerly sampling sites.

The three youngest seams (16, 19 and 20) contained no carbonate minerals and neither chlorite nor pyrophyllite was detected in them in spite of the fact that the Peach Mountain seam column came from Sampling Area V in the Southern Anthracite Field. This suggests that stratigraphic level and mineral content are related in connection with the occurrence of epigenetic as well as syngenic minerals. Further evidence of a correlation between stratigraphic level and the occurrence of particular minerals is seen in the fact that only the coals of the Allegheny series contained pyrophyllite. In the samples studied, this mineral was restricted to the two basal coals of the Allegheny sequence. It seems unlikely, however, that distribution of this mineral is so restricted and additional data should be sought before this is
considered to be more than a tentative suggestion. Regardless of the validity of this and any previously made suggestions, the mineral content as recorded is undoubtedly representative of the inorganic materials present in the respective seams in the areas from which the column samples were procured.

Figures 2 and 3 presented data on the quantity of ash derived from each layer of each of the twelve columns that were studied. These are summarized by seam in Table 2. The data are presented in two forms; one including any partings or "divider rock" that may be included

| TABLE 2 |
| Quantities of Ash Derived From Pennsylvanian Anthracite Seams |

<table>
<thead>
<tr>
<th>Age</th>
<th>Seam Designation</th>
<th>Ash Content (Wt. %) (Including Partings)</th>
<th>Ash Content (Wt. %) (Excluding Partings)</th>
<th>Ash Content by Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONEMAUGH</td>
<td>#20 Seam</td>
<td>12.9</td>
<td>10.9</td>
<td>with partings 15.0%</td>
</tr>
<tr>
<td></td>
<td>#19 Seam</td>
<td>14.8</td>
<td>13.6</td>
<td>without partings 12.2%</td>
</tr>
<tr>
<td></td>
<td>#16 Seam (Peach Mountain)</td>
<td>14.9</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>#12 Seam (Orchard)</td>
<td>17.3</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>PENNSYLVANIAN</td>
<td>#9 1/2 Seam (Four Foot)</td>
<td>18.2</td>
<td>13.7</td>
<td>with partings 20.2%</td>
</tr>
<tr>
<td></td>
<td>#8 1/2 Seam (Middle Mammoth)</td>
<td>15.1</td>
<td>12.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>#6 Seam (Seven Foot)</td>
<td>25.6</td>
<td>13.0</td>
<td>without partings 12.8%</td>
</tr>
<tr>
<td></td>
<td>#5 Seam (Buck Mountain)</td>
<td>22.8</td>
<td>11.9</td>
<td></td>
</tr>
<tr>
<td>POTTSVILLE ALLEGHENY</td>
<td>Lykens Valley #3</td>
<td>11.1</td>
<td>8.6</td>
<td>with partings 10.7%</td>
</tr>
<tr>
<td></td>
<td>Lykens Valley #4</td>
<td>5.2</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lykens Valley #5</td>
<td>15.8</td>
<td>15.8</td>
<td>without partings 9.9%</td>
</tr>
</tbody>
</table>
in the seam proper, and the other excluding consideration of these. The data are also summarized in terms of the mean ash values for Conemaugh versus Allegheny versus Pottsville coals. These three values are plotted in simple bar graph form as Figure 6. It is interesting to note that the Allegheny coals yielded a significantly greater amount of ash than the coals of the underlying or overlying strata. Comparison of the ash values computed with the inclusion of ash derived from partings suggests that the major differences referred to above are largely a function of the number and thickness of the partings present in the seams. The implication is, of course, that a comparatively simple cleaning procedure would bring these coals to approximate equivalence as far as their ash residue is concerned.

Of greater interest than this gross comparison of ashing characteristics is the distribution of concentrations of ash-forming constituents within individual seams. Figure 7 presents graphically the variations in ash yield encountered in each of the seams examined. Examination of this figure reveals that there is no single, consistent pattern of mineral matter concentration characterizing the coal columns examined.

Because the basal layers of a coal seam represent the initial phases in the transition from a sedimentary environment in which organic material was not accumulating to an environment in which peat was formed, one might expect a gradual decrease in mineral matter content through the basal layers of the seam. It might be thought that it would be even more reasonable to expect a gradual increase in mineral matter
QUANTITIES OF ASH DERIVED FROM COALS OF DIFFERING GEOLOGIC AGE

Figure 6
content in the uppermost layers of the seam. If it is assumed that these trends in mineral matter concentration are going to be perceivable by means of analyses of samples from two levels, one in the basal and the other in the upper six to eight inches of the seam, then these theoretical conditions are met in nine of the eleven columns with respect to the upper layers of the seam, and in eight of the eleven insofar as the basal transition is concerned. Sampling at one-half inch or one-quarter inch intervals might show that the theoretical conditions are present in all cases. Regardless of the results that such a study might yield one would have to conclude that gradual, intermediate and abrupt transitions occur between coal seams and their juxtaposed strata. Within the coal seam itself, these same conditions attend the boundaries between partings and the adjacent coal. This is evident in Figure 7 if one compares the coal-parting relationships characterizing the Buck Mountain seam (#5).

An example of one of the more abrupt transitions is shown in Plate I (B). The degree of abruptness of these gradations from one type of material to another obviously affects the ease and extent to which the layer of high mineral concentration will break free in a coal cleaning operation. This variation in the nature of the transition zone also characterizes the boundaries between "high mineral" and "low mineral" lenses or lithobodies within that portion of a coal seam that is considered to be devoid of partings and "divider rock". Each lithobody, because of its particular maceral-mineral content, should possess a particular set of physical properties that might prove useful in manipulating the material in beneficiation procedures. Knowledge of the size of the
lithobodies being mined (even though continuous mechanical mining is involved) coupled with information on the physical characteristics of the lithotypes (types of maceral-mineral associations) should improve one's ability to separate the bulk of a particular lithobody from the bulk of the associated lithobodies and transition materials. At the moment almost nothing is known concerning the coal lithotypes that form anthracite seam lithobodies and even less is known about their physical and chemical properties. From this it appears to follow that costly, trial and error practices will have to be employed in prescribing cleaning procedures until the requisite basic information is accumulated.

From a geological point of view the data presented in Figure 7 lead to the conclusion that no two coal seams have had identical sedimentary histories. This is to be expected but the degree to which each appears to differ suggests that local environmental conditions have played a more important role in determining the distribution of the mineral matter in these seams than have regional geologic factors. Studies of modern swamps (Spackman, 1958) suggest that these local conditions prevail over areas that commonly are to be measured in terms of square miles, thus the data from single columns such as those described in the present manuscript are likely to be representative of a reasonable area in the vicinity of the column site.

In addition to inspecting the concentrations of ash-forming mineral matter at various levels within the seams, it is of interest to inquire as to whether there is any relationship between the ash yields and the types of minerals encountered. As may be seen from data
presented in Figure 8, the illitic minerals in the Lykens Valley #4 column are found only in the high ash strata at the top and bottom of the seam. The great bulk of the seam at this location is low in mineral content and devoid of illitic minerals in concentrations sufficient to be detected by the methods employed. This pattern of occurrence suggests that the illitic minerals are components of the larger and heavier rock fragments that were carried into the initial sedimentary environment when fluvial transport was most effective. As marginal swamp environments migrated from the area and the effectiveness of fluvial transport was minimized, only very fine-grained, clastic mineral matter was deposited with the organic debris. During the major portion of the seam's history, the environment either remained stable, or at least, failed to shift in a direction that increased the influx of detrital mineral material. This resulted in the development of the middle, low ash, lithobody of the seam in which the clastic mineral matter is in the form of fine-grained kaolin minerals and quartz, and a large part of the mineral content is in the form of autochthonous pyrite and carbonate minerals.

Although this relationship between ash yield and mineral species exists in the above described instance and is probably characteristic of the Lykens Valley #4 seam in the vicinity of the column, it does not follow that these relationships will hold for all seams at all sites. In the case of the Seven Foot (#6) seam, illitic minerals are again present in the basal and uppermost strata of the seam as well as in a high ash middle stratum. However, as shown in Figure 9, the basal
ILLITIC MINERALS PRESENT

ILLITIC MINERALS PRESENT

OCCURRENCE OF ILLITIC MINERALS IN THE LYKENS VALLEY #4 SEAM

Figure 8
ILLITIC MINERALS PRESENT

ILLITIC MINERALS PRESENT

ILLITIC MINERALS PRESENT

OCCURRENCE OF ILLITIC MINERALS IN THE SEVEN FOOT #6 SEAM

Figure 9
strata of the seam contain the smallest concentrations of ash-forming minerals. Thus, low ash zones are not necessarily devoid of illitic minerals.

If the occurrence of the mineral chlorite is examined in the same way, the following is the result. In the column of the Buck Mountain (5) seam, chlorite occurs in a basal lithobody and in a stratum that occurs just above the middle of the seam. It is absent in the uppermost strata of the seam and the impression given by Figure 10 is that this mineral is restricted from zones producing a high ash yield. Comparison of Figures 10 and 11, however, shows that, although such a relationship may hold for the Buck Mountain seam, it does not describe the associations encountered in Seven Foot (6) seam, even though both columns were procured from the same geographic area. In the column of the Seven Foot seam, chlorite was encountered in both high and low ash strata. Moreover, it was present in the uppermost stratum and absent from the basal stratum, this being the converse of the relationships described for the Buck Mountain seam.

From the above it should be concluded that seam strata containing high concentrations of mineral material should not be thought of as merely containing more of each of the minerals present in the low ash zones. Instead, it would appear that there are patterns of mineral distribution characterizing each coal seam and that these patterns are controlled by the environmental succession responsible for the development of the seam. Epigenetic modifications of mineral content take
OCCURRENCE OF CHLORITE IN BUCK MOUNTAIN #5 SEAM

Figure 10
OCCURRENCE OF CHLORITE IN SEVEN FOOT #6 SEAM

Figure 11
MACERAL, MINERAL, AND SULFUR CONTENT OF PETROGRAPHICALLY DISTINCT ZONES IN THE BUCK MOUNTAIN ANTHRACITE SEAM

Figure 12
place within seam strata systems established as the result of metamorphosis of the initial lithotypes and in most instances, the impact of the original environmental succession is felt all through the history of the seam.

From the preceding, it is evident that in addition to varying in concentration at various levels in anthracite seams, inorganic materials also vary from stratum to stratum in terms of the types of minerals present. The same conclusion can be drawn concerning the organic materials, as shown in Figure 12. Neither the constituent macerals nor the constituent minerals are uniformly distributed through the thickness of any given coal seam, instead they are differentially segregated by various syngenetic and epigenetic processes. The figure depicts diagrammatically the concentration of each of the vitrinitic macerals encountered. These materials are metamorphosed vitrinitoid substances, the latter being the common viritinitic macerals in coals of high volatile bituminous rank. They differ from the vitrinoids in that they are opaque in sections of standard (5 - 10\(\mu\)) thickness and in polished section they reflect in excess of 3.00 percent of vertically incident light. Under normal carbonizing conditions they do not become fluid or plastic. They are similar to macerals of the vitrinitoid group in that particles of megascopic dimensions have the appearance of a black, textureless mass, possessing a vitreous lustre (Plate I, Figure A).

It has previously been suggested that macerals of this type be classed as members of the Vitrinite Suite but distinguished from the Vitrinoids and xylinoids because of their marked differences in basic chemical and
physical properties, as well as in their reactions to carbonization and combustion (Spackman, 1958). It was suggested (op. cit.) that this particular group of vitrinitic macerals be designated the "anthrinoids" in view of their common occurrence in coals of anthracitic rank. Accordingly, the diagram in Figure 12 depicts the relative concentration of the various anthrinoid macerals in the Buck Mountain seam column sample. Until more information can be amassed on the properties of individual anthrinoids, all have been classified as belonging to some particular anthrinoid "type". The types have been arbitrarily established on the basis of light reflectance percentages as follows:

<table>
<thead>
<tr>
<th>Anthrinoid Type</th>
<th>Reflectance Range</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>3.00 - 3.49% reflectance</td>
</tr>
<tr>
<td>2</td>
<td>3.50 - 3.99% reflectance</td>
</tr>
<tr>
<td>3</td>
<td>4.00 - 4.49% reflectance</td>
</tr>
<tr>
<td>4</td>
<td>4.50 - 4.99% reflectance</td>
</tr>
<tr>
<td>5</td>
<td>5.00 - 5.49% reflectance</td>
</tr>
<tr>
<td>6</td>
<td>5.50 - 5.99% reflectance</td>
</tr>
</tbody>
</table>

It is acknowledged that this differentiates the vitrinitic substances in only a gross fashion but it is interesting to observe that it is sufficiently definitive to permit recognition of petrographically distinct zones within the seam. It is immediately apparent that the several zones differ not only in relative concentration of the constituent anthrinoid types but also in the number present. Zones IV and V are the simplest, possessing only Types 2, 3 and 4. Zones II, VI and IX are similar in terms of constituent types and in the concentration of those types present. Zones I and XIII have the same complement of types as Zones II, VI and IX but differ in the relative concentrations of anthrinoid 3 and anthrinoid 4.
Zones VIII, XI and XII differ from all others in possessing five anthrinoid types in varying concentrations.

Although this represents only a preliminary attempt to petrographically zone an anthracite seam, there appears to be some significance to the zonation proposed. As may be seen through inspection of the sulfur profile presented to the right of the petrographic diagram in Figure 12, an excessive concentration of sulfur occurs in Zone I. In contrast to what might be expected, Zones III, VII and X consist largely of inorganic materials but contain the lowest sulfur concentrations of any of the petrographically distinct zones. It is of further interest to find kaolinite totally absent in the partings, apparently converted to pyrophyllite in the course of the metamorphosis of the seam. Chlorite occurs only in Zones VI and XIII and for some reason no pyrophyllite was detected in Zones II and V. Zone IV is much more friable than the other zones, in fact, so friable that a lump sample could not be collected. The relatively high concentration of sulfur in Zone IX is noteworthy in view of the difference in its anthrinoid content when contrasted with adjacent zones. By adding information on the relative concentration of other macerals (e.g. fusinite and micrinite) to the data herein presented and by using quantitative mineralogical data it should be possible to develop rational reconstructions of the lithobody and lithotype composition of anthracite seams in a manner quite comparable to that now profitably employed in the description of coal seams of bituminous rank.
SUMMARY AND CONCLUSIONS

Twelve coal columns each representing one Pennsylvanian anthracitic coal seam were studied. The mineral content of 156 strata from these columns was determined and ash yield data for the strata of eleven columns obtained. In addition, one column was studied to determine the relative concentration of anthrinoid macerals in each inch throughout the entire seam thickness. The Buck Mountain (#5) seam was chosen for this study and for an investigation of the concentration of sulfur at all seam levels.

Geologic age and geographic location appear to be correlated to some extent with the types of minerals encountered in the seams. The Allegheny coals yielded, on the average, the highest ash residue and contained the greatest variety of minerals. Those columns collected from the Southern Anthracite Field showed the greatest development of "metamorphic minerals". No consistent, general correlation between ash yield from individual seam strata and the occurrence of particular minerals was observed but each seam appeared to exhibit a pattern of mineral occurrence and concentration that might well be related to the superposition of different swamp environments during the accumulation of the original organic debris. A variety of lithotypes apparently form anthracitic seams just as they form seams of bituminous coal. Both abrupt and gradual transitions between juxtaposed lithobodies were observed. This, together with the knowledge that coal cleaning procedures depend mainly upon differences in the physical properties of lithotypes, led to the conclusion that beneficiation practices would
have to continue on a trial and error basis until the common lithotypes in anthracite seams were described and their properties defined.

A petrographic procedure permitting the differentiation of anthracite seams into compositionally different zones has herein been described. In addition to being of fundamental value in lithotype definition, this should provide the basis for a better controlled experimentation with different types of anthracite in evaluating the usefulness of these materials in coke production and in other aspects of utilization. This latter benefit accrues because a basis is provided for the description of test samples in terms of reacting entities, thus rendering comparison of data more valid and achieving a means of predicting the behavior of untested but compositionally known samples. A provisional classification of anthrinoid macerals has been used to demonstrate the manner in which zones of differing maceral composition can be recognized. To the extent possible, the maceral and mineral composition of the various zones is discussed. Without additional quantitative mineralogical data the only noteworthy facts are that in the column studied intensively, the inorganic-rich lithotypes (partings) contained no kaolinite in spite of its presence in the other lithobodies composing the seam. In the partings all of the kaolinite had apparently been converted to pyrophyllite. Also, the partings contained lesser concentrations of sulfur-bearing minerals than did the coal lithotypes.

On the basis of the above it is concluded that anthracitic coal seams are heterogeneous mixtures of maceral and mineral materials. These maceral and mineral materials are preferentially segregated in
lenses, or lithobodies, each compositionally distinct from adjacent lithobodies. In these respects they are comparable with seams of bituminous coals but they differ markedly in terms of the types and quantities of particular macerals and minerals that compose the common lithotypes. From this it seems reasonable to infer that petrographic descriptions of anthracite seams should evolve into compositional summaries that will be useful in defining the effect of an anthracitic product in a coke blend or in interpreting the paleoecological significance of various seam strata.
LIST OF REFERENCES


