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PETROGRAPHIC COMPOSITION AND SULFUR CONTENT OF A COLUMN OF PITTSBURGH SEAM COAL

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ABSTRACT

A column of the Pittsburgh seam measuring 64 inches thick was collected from the Mathies Mine of the Mathies Coal Company in Washington County, Pennsylvania. From this column 16 polished blocks and 142 thin sections were prepared such that the entire seam was covered by both methods. Sixty-four sulfur analyses were also made, each representing an "inch level" of the seam.

It was found from examination of the sulfur analyses that the percentage of total sulfur in the seam is not constant throughout, but varies from 0.26% to 5.44%. The organic sulfur, on the other hand, shows a lesser variation from 0.75% near the top to 1.5% near the bottom of the seam. The sulfate and sulfide sulfur shows a concentration near the top and bottom of the seam, another peak approximately 35 inches from the top of the seam, in a lithotype associated with the "bearing-in-bands", and a fourth peak located at the 41 to 42 inch level.

From a study of the master column and thin sections the seam was divided into 16 lithotype zones. Of particular significance is the fact that each sulfur peak fell within the boundaries of an individual lithotype. It is also interesting to note that the lithotypes which contain the high sulfur peaks were not all of the same type. Certain ones are high in vitrinoids while others are high in their fusinoid content. The principal modes of occurrence of the sulfur are as cleat fillings, both gypsum and pyrite, and as cell fillings in the fusinoids and microcrystalline aggregates of pyrite in the vitrinoids.

INTRODUCTION

A large tonnage of Pennsylvania's coal reserves is excluded from premium markets because of its high sulfur content. Another sizeable tonnage seldom finds its way to these markets because of a lack of information on how such coals can be upgraded and what role they might play as blending coals in the production of metallurgical coke. Additional data must be gathered on the composition of each of the large variety of coal types found in the bituminous fields before quality can be controlled as demanded by today's consumers, and these data are also essential to minimizing production costs which are so important in relation to a highly competitive market. It would appear of paramount importance, therefore, to make rapid progress in describing the composition of our coal resources as the basis of a more profitable handling and selling of the product. The results of such efforts should provide new markets for marginal coals, new markets for coals now restricted to minimum price markets and at the same time provide information basic to the efficient mining, preparation and utilization of Pennsylvania's high, medium, and low volatile fuels.

As a basis of prescribing efficient preparation, marketing and utilization practices, it was proposed that this investigation have as its objective the amassing of data on the petrographic composition of the mineable bituminous coals of Pennsylvania. It is intended that these descriptions will include a specific discussion of the mode of occurrence of the sulfur and an analysis of the practical significance of the association of high sulfur concentrations with particular lithotypes.

If these associations of sulfur and particular lithotypes can be defined adequately, it is then planned to isolate these components and further determine their physical and chemical properties. When this is effectively done, preparation practices may be modified to bring about a more complete "washing" operation through the recycling and recrushing of selected plant products.

ACKNOWLEDGEMENT

The authors wish to express their sincere thanks and appreciation to J.M. Vonfeld, Product Control Manager and D.H. Davis, Vice-President of the Mathies Coal Company for all of their assistance both during the collection operations and during the preparation of this report.

TERMINOLOGY

Coal is an extremely heterogeneous organic sediment. In this country for many years, almost everyone who has had anything to do with coal - producer, consumer, or for the most part even a geologist - considered it to be essentially homogeneous. This is one of the main causes behind the fact that many coals have not been used to their greatest potential.

The English paleobotanist Marie C. Stopes concluded that ordinary bituminous coal is made up of four visible ingredients. In her paper "On the Four Visible Ingredients in Banded Bituminous Coal" (Stopes, 1919) she designated the "four visible ingredients" as "vitrain", "clarain", "durain", and "fusain". The essential characteristics of each as first set down by Stopes may be summarized as follows:

I. Vitrain (from "vitro" meaning glass)

   A. Occurs in bands or lenses

   B. Has a vitreous luster

   C. Usually shows a conchoidal fracture

D. Megascopically, it is homogeneous and structureless

E. Microscopically, it is translucent

II. Clarain (from "clare" meaning clear or bright)

A. Occurs in bands of variable thickness

B. A smooth, glossy, striated surface characterizes breaks formed at right angles to the bedding planes

C. Predominantly translucent in thin section with abundant triturated plant debris

III. Durain (from "dur" meaning hard or tough)

A. Occurs in thick and thin irregular bands

B. Hard and compact

C. Broken face is never smooth but shows a matte surface

D. Appears somewhat granular to the naked eye

IV. Fusain (French word for charcoal)

A. Occurs in lenses, bands, or irregular masses

B. Fibrous or porous in appearance

C. Friable - breaks down easily and soils hands

D. In thin section it is opaque and shows some evidence of cellular structure.

This classification was enlarged by Stopes (1935) and she suggests that these terms were analogous to the rock types of the petrologist. She went on to say (p. 8) that these terms "explicitly applied to visible portions of bituminous coal rock and they are only applicable to hand specimens". This means that these terms should be used for macroscopic description only.

A modified form of this classification is essentially what has been used for this Report. The prefixes bright or dull are sometimes added to the term clarain. There also may be layers of shale or other rocks that run through the coal seam. These are called partings or bone layers.

Both vitrain and fusain are essentially homogeneous while clarain and durain are completely heterogeneous. As the petrologist's rock types are made up of many chemically and optically different entities called minerals, the different bands of coal are composed of chemically and optically dissimilar entities called "macerals". This is another term proposed by Stopes in 1935 in her paper "On the Petrology of Banded Bituminous Coal" (Stopes, 1935). Stopes states in her paper (p. 11), "These organic units, composing the coal mass I propose to call macerals, and they are the descriptive equivalent of the inorganic units composing most rock masses and universally called minerals . . ."

Two separate schools of thought have developed through the years as to the proper method of classifying the microscopic constituents of coal. The Americans, led by the United States Bureau of Mines, have only three main classes of these entities. They are: anthraxylon, which is a very hard vitreous constituent approximately equivalent to vitrain; fusain which has already been described; and attritus which accounts for all the remaining material. This system is much too vague to be of any great value to quantitative coal petrography. The Europeans, on the other hand, have a more detailed system. It is a modified form of the European system that is used in this Report for microscopic petrography (see Spackman, Brisse and Berry, 1957 and Spackman, 1958). The five maceral groups that will be used here are as follows:

1. VITRINOIDS Bands of organic material derived mostly from lignified plant tissues and commonly appearing translucent red to yellowish brown in thin section. They may show relic plant structure or be completely structureless. Some also have a mottled appearance.
2. FUSINOIDS Lenses, bands or irregular masses of opaque material usually exhibiting some evidence of cell structure.
3. MICRINOIDS Granular or amorphous opaque material.
4. EXINOIDS The exines (outer coverings) of pollen grains and spores plus cuticular material, which are translucent bright yellow to deep yellow-orange in thin section.
5. RESINOIDS Variously shaped masses (spheroids, rodlets) derived from resinous material; many times found filling relic cells in the vitrinoids and usually appearing reddish or very light yellow in thin section.

It is also possible to recognize minerals in the routine examination of coals. They are usually grouped together under the heading of "mineral matter". Sometimes, however, it is advantageous to distinguish individual minerals, such as pyrite and marcasite (iron sulfide), which have a definite effect on the coal product, and make special note of them.

As was mentioned before, fusain and vitrain are essentially homogeneous. Fusain, however, may have some mineral matter within it in addition to the fusinoid macerals. Vitrain is composed essentially of vitrinoids but may have a small percentage of micrinoids, fusinoids and resinoids in it. Clarain and durain are usually composed of all the macerals, the main difference being that clarain has a higher percentage of vitrinoids than does durain, which is dominantly made up of the so-called "inert" ingredients plus exinoids and resinoids.

COLLECTION SITE

It was felt that a coal seam which generally yields a good coke product should be examined first so that it could be used as a standard by which to judge other samples collected and studied in conjunction with this program. For this reason the Pittsburgh seam, consistently one of Pennsylvania's best coking coals, was sampled.

The seam was collected from the Mathies Mine of the Mathies Coal Company, located in the northeastern part of Washington County about half way between Pittsburgh and Washington (see Fig. 1). At the point of sampling the seam is 162.5 centimeters (64 inches) thick. The exact mine location is No. 4 breakthru in 19 face entries, 100 feet off No. 1 entry of Main Butts.

A complete column was taken from the roof to the floor of a sufficient size so that thin sections, polished blocks and sulfur analyses could be made. The minimum quantity of coal in any one part of the seam that could adequately supply the material needed for all phases of study was a piece approximately four inches square. Whenever possible a larger sample was taken.

PETROGRAPHY

Megascopic Examination

A complete sample of the seam from the roof to the floor was cut out of the column that was taken at the mine. This was mounted in plaster blocks to form a "master column". This master column was then ground and

INDEX MAP SHOWING SAMPLING SITE

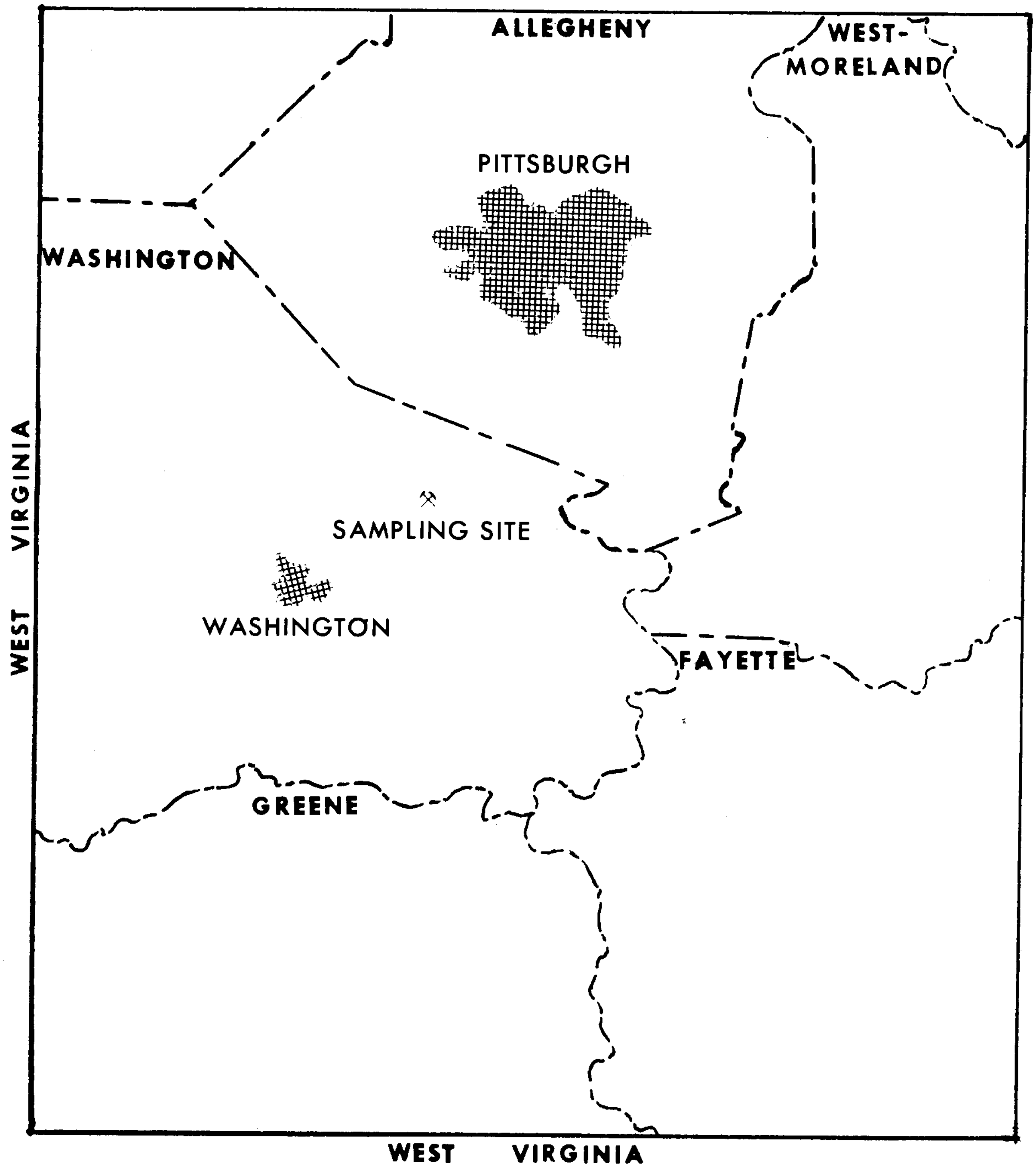


Figure 1

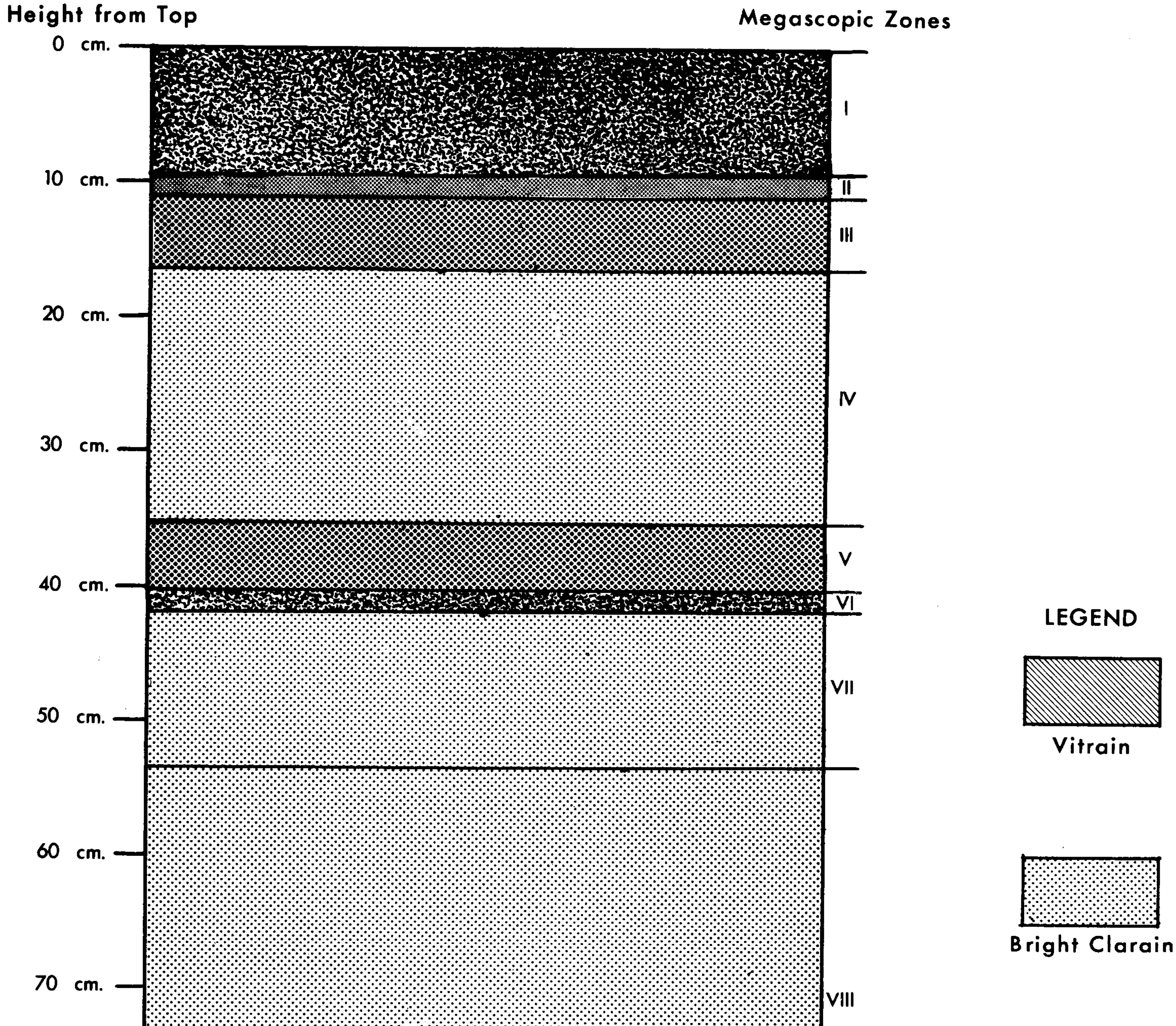
polished to a higher luster so that the surface of the coal could be readily examined with the naked eye and the megascopic petrography determined.

The master column was then examined by two different people without the use of any means of magnification and divided into petrographic units. The compilation of these two results is shown in Figure 2, expressed in words it is as follows:

Distance from top of seam (in centimeters)	Description
0 - 9.5	Durain, finely banded, visible pyrite layers
9.5 - 11	Clarain
11 - 16.5	Dull clarain, some vitrain stringers
16.5 - 35.5	Bright clarain with vitrain bands up to 4mm. thick
35.5 - 40.5	Dull clarain finely banded
40.5 - 42	Durain
42 - 53.5	Bright clarain, coarse banding
53.5 - 88	Bright clarain, coarse banding with virtain up to 5mm. thick
88 - 89	Parting
89 - 95	Clarain, mineralized zone at 90 cm.
95 - 96.5	Parting
96.5 - 103	Durain, finely banded with vitrain bands 2 - 3mm. thick
103 - 105	Fusain
105 - 123.5	Bright clarain with vitrain bands up to 1 cm. thick
123.5 - 127	Durain
127 - 139	Clarain, 1 cm. of durain at 131.5 to 132.5 cm. level
139 - 148.5	Bright clarain
148.5 - 161	Dull clarain
161 - 162.5	Durain with visible mineral matter

Although the seam was divided up into 19 zones on the basis of the

MEGASCOPIC PROFILE OF THE PITTSBURGH SEAM, WASHINGTON CO., PENNA.



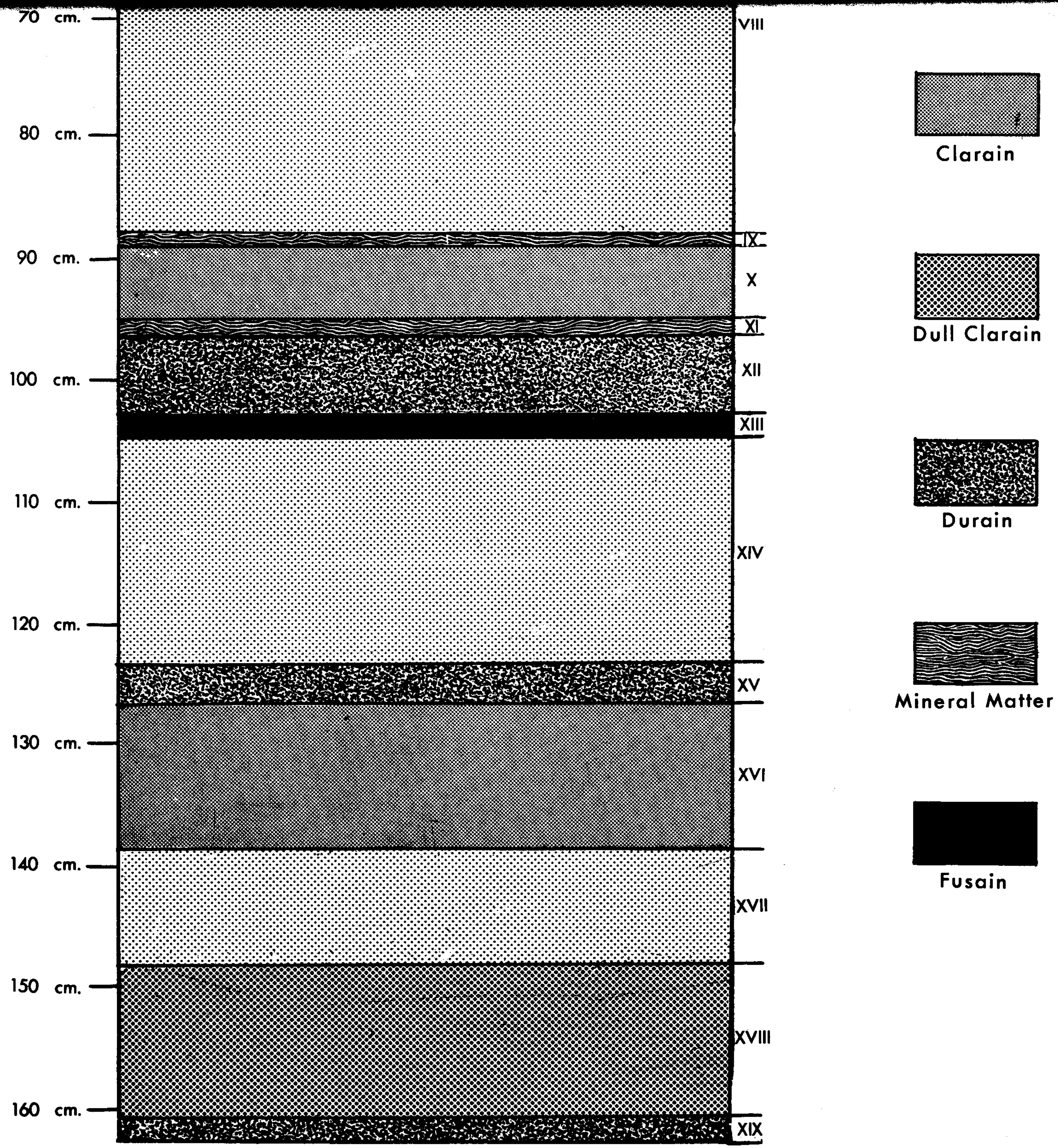

70 cm.
80 cm.
90 cm.
100 cm.
110 cm.
120 cm.
130 cm.
140 cm.
150 cm.
160 cm.
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
XIX
Clarain
Dull Clarain
Durain
Mineral Matter
Fusain

Figure 2

megascopic description, relatively speaking, the seam is quite uniform. For the most part there are no great differences in physical appearance between the several zones. Most of the seam is a clarain which varies only in the amount and size of banding within it. The only major breaks in the uniformity of the seam, at first glance, are the two partings that occur in the middle of the seam. It is only after close examination that the other differences can be recognized. It is to a microscopic study of the seam that one must turn in order to recognize how much variation is really inherent in the coal mass.

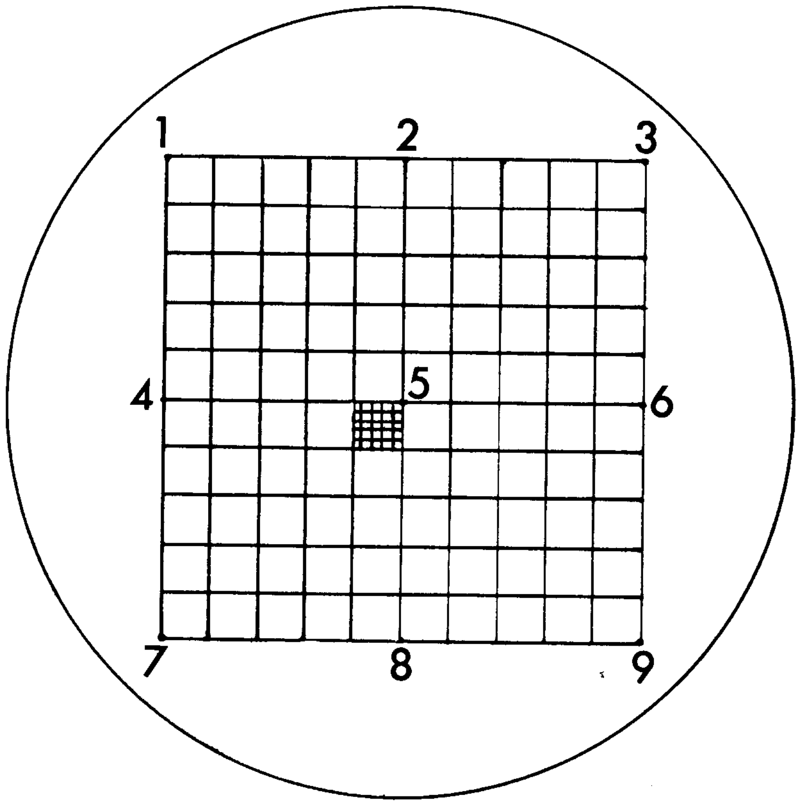
Microscopic Petrography

The microscopic petrography was determined employing transmitted light. Thin sections were made in the normal way so that the complete seam from top to bottom was covered. One hundred and forty-three thin sections, each covering about 1.5 to 2.0 centimeters of the seam were necessary to afford sufficient overlap so that complete and accurate coverage of the seam could be made.

The percentage of each maceral was determined by using a modified point count method with a Bausch and Lomb Model EBN research microscope and a Whipple disc (see Fig. 3). For each centimeter of the seam 300 points were counted, while 9 points were counted for each field of vision. These points are indicated on Figure 3. Data sheets were kept, recording the number of times each maceral was encountered in each centimeter. From these data the percentage of each maceral in each centimeter was calculated and recorded.

After the whole seam had been read and the petrographic composition calculated, the data was examined and areas of gross similarity in the

DIAGRAMMATIC REPRESENTATION OF WHIPPLE DISC



SHOWING 9 POINTS COUNTED

Figure 3

percentages of different macerals were noted. By combining these data with the megascopic description previously noted, the seam was divided up into 16 lithotype zones. This is represented diagrammatically in a bar graph (Fig. 4) and the maceral composition of each zone is given in Table 1 of the Appendix.

Since the seam as a whole is very bright, a clarain, one would expect it to have a high percentage of vitrinoids. Microscopic analysis of the seam proved this supposition to be true for it was found to contain 78% vitrinoids. The fact that there was about 16% fusinoids in the seam seemed at first glance to be out of line with the megascopic description. However, during the microscopic study many small lenses of fusinoids were noted that would easily escape recognition in a macroscopic investigation of the seam. The other macerals occur in relatively small percentages showing up mostly in the dull bands with the exception of the resinoids which were encountered in this seam almost entirely within the vitrinoids, filling relic cells.

The resinoids occur only in six zones, five of which are below the partings. In each of the zones they appear in quantities of less than one percent. The other macerals are present in all of the zones except the partings. Mineral matter is present in all zones but one, however, it is only greater than one percent in four zones.

In each zone when the mineral matter was under one percent the dominant mineral present was pyrite. Although some pyrite was found in the four zones where mineral matter was above one percent, it was of only minor importance. The clay minerals made up the bulk of the mineral matter in these four zones. Individual species were not identified because

Microscopic Petrography of the Pittsburgh Seam, Washington Co., Penna.

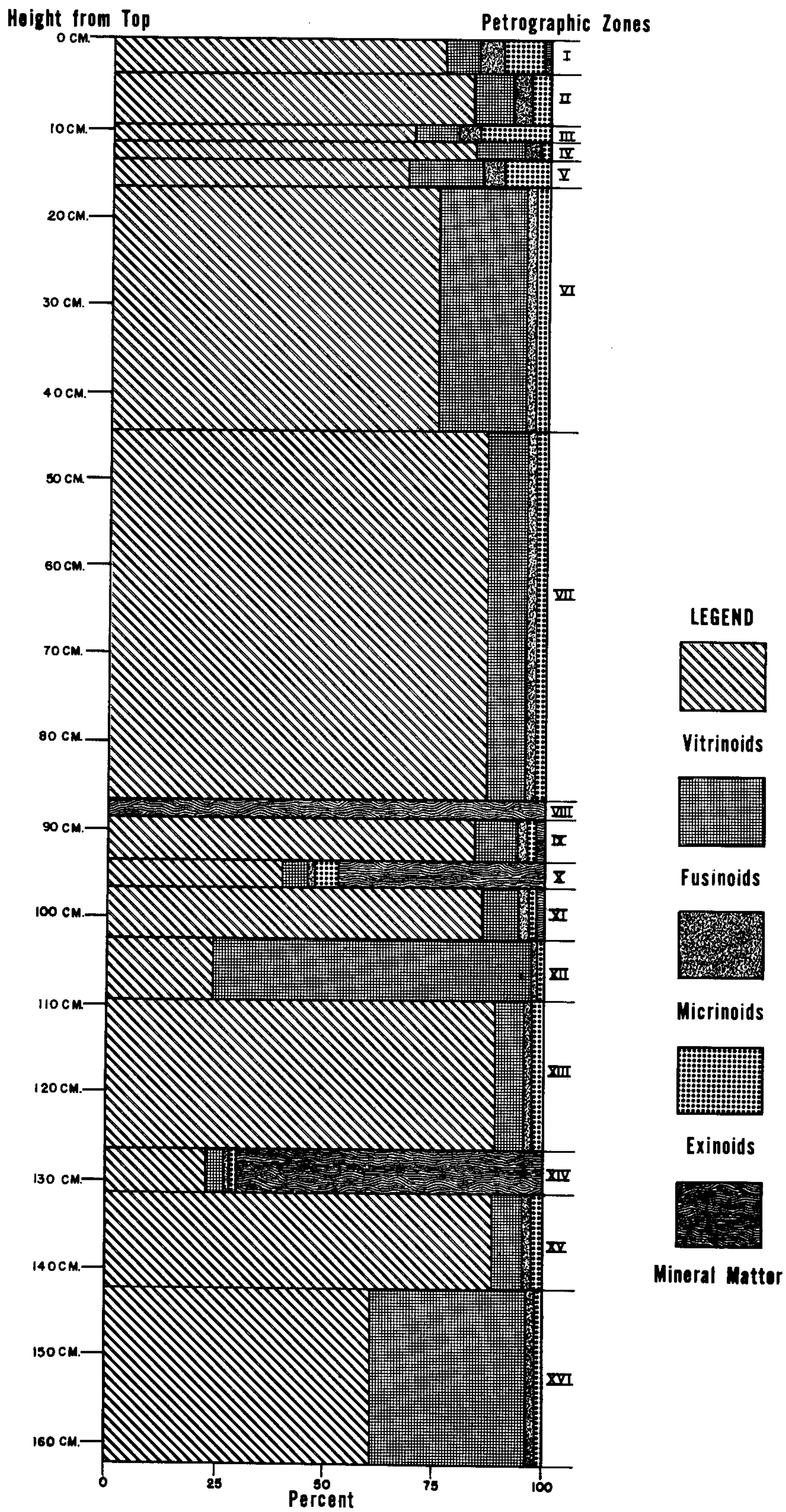


Figure 4

they are not directly influencing the sulfur content of the subject coal. The two partings, themselves, make up two of the four high mineral matter zones while the zone between them constitutes a third area high in mineral content. The fourth zone is below the partings about 30 to 34 centimeters above the floor. This zone is very hard with one centimeter of it being extremely dull - this area might easily be mistaken for a parting.

When this coal is processed through a preparation plant there is a good chance that most of the coal in these four zones ends up in the refuse stream. This is often a very serious consideration in coal preparation plants for along with the mineral matter some of the best coking coal is being lost from these zones. Three of the four zones are relatively high in exinoids and micrinoids, which are necessary components of a good coking coal (see Spackman, Brisse and Berry, 1957). The attendant high concentrations of mineral matter are responsible for cutting this material out of the plant stream and placing it in the refuse category.

As can be seen from the microscopic petrography, each of these 16 zones is different from all of the other zones. This in itself illustrates the heterogeneity of the coal seam. Along with petrographic differences these zones have physical differences which will allow them to be selectively removed from the coal if their characteristics are detrimental to a good coke product. They can be selectively blended with other coals to yield a better coke product if they have an abundance of macerals which are known to improve coke quality when present in the correct proportions. These physical differences include such things as visible differences i.e. bright or dull, differences in specific gravity and differences in hardness or grindability.

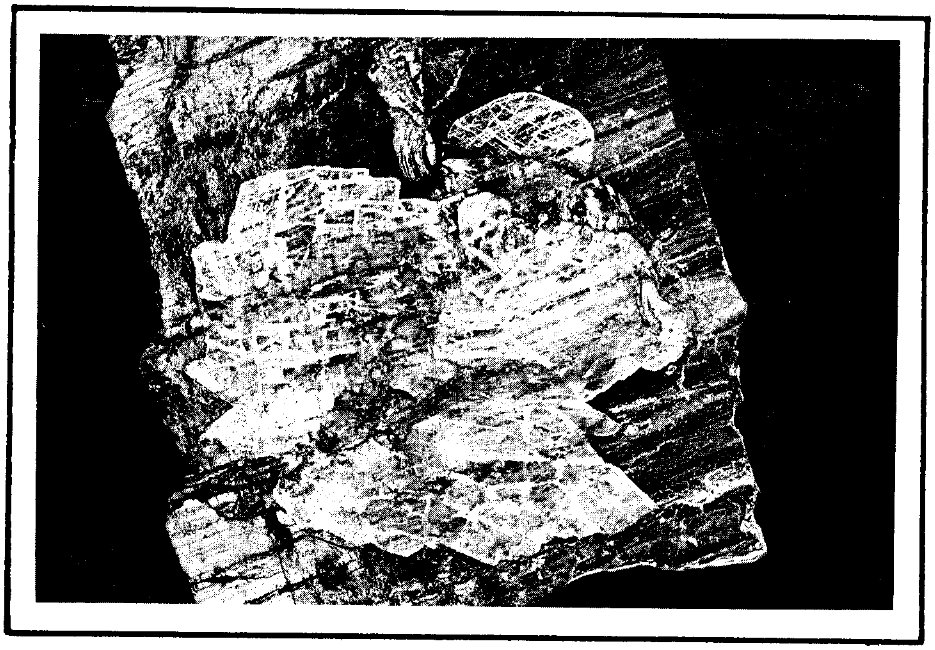
Each zone will be different in the relative ease with which it can be crushed so that the different size fractions of coal will tend to have different petrographic compositions (this has been noted by Dutcher, Berry and Koppe, 1957). The smallest fraction will be highest in fusinoids because the fusinoids are the weakest macerals. The bright bands are the most brittle and will break up into all sizes thus spreading the vitrinoids through the range of fractions. The dull bands are the strongest and will place much of the micrinoid and exinoid material in the larger fractions. For this reason it is important to examine much of the larger size, high specific gravity material with a view toward possible recycling for additional crushing to free valuable coal constituents from the mineral matter present.

Mineral matter such as that shown in Plate I A and B and Plate II A, is more easily removed than other types. Plate I shows mineral material along cleat faces which is readily freed during crushing and washing and the bulk is easily removed. The natural tendency of the coal to fracture along the cleat is of great service in preparation. The pyrite shown in fusain, Plate II A, is also apt to be removed as the contact between fusain, mineralized or not, and the adjacent coal, along bedding surfaces, is weak. Normal preparation practices will account for most of this type of impurity.

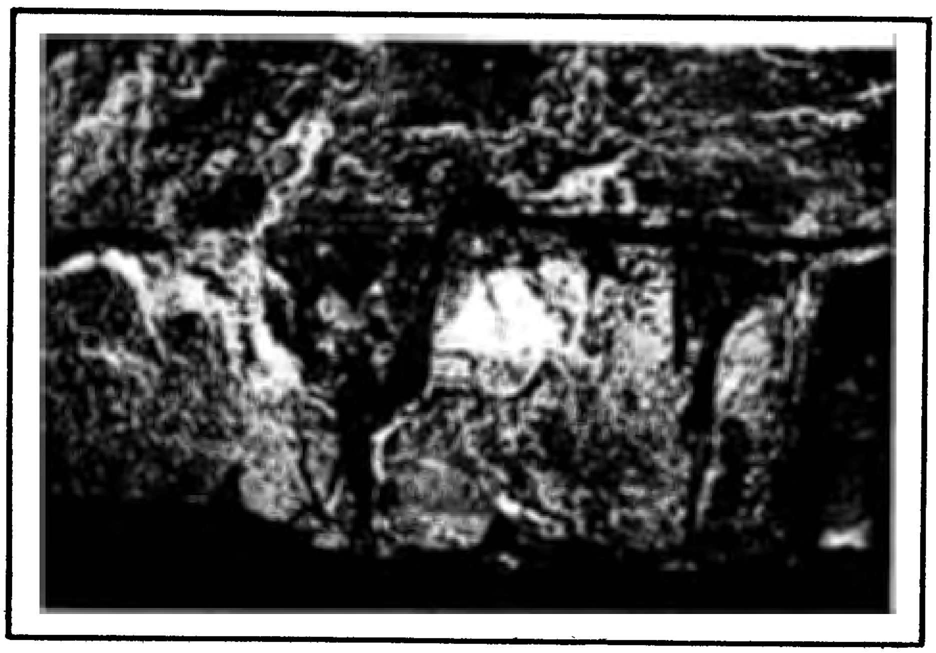
Mineral matter types, more difficult to remove, are shown in Plate II B and Plate III A and B. Here some of the intimate associations of pyrite with maceral groups are presented. All three of these modes of occurrence strongly resist sulfur reduction by normal preparation practices. The microcrystalline nature of the material, the intimate nature of the association and the degree of dispersal all preclude effective removal. The

PLATE I

Figure A	Gypsum as a cleat filling from the Pittsburgh Seam, Washington County, Pennsylvania	(2.5x)
Figure B	Pyrite as a cleat filling from the Pittsburgh Seam, Washington County, Pennsylvania	(2.5x)



A

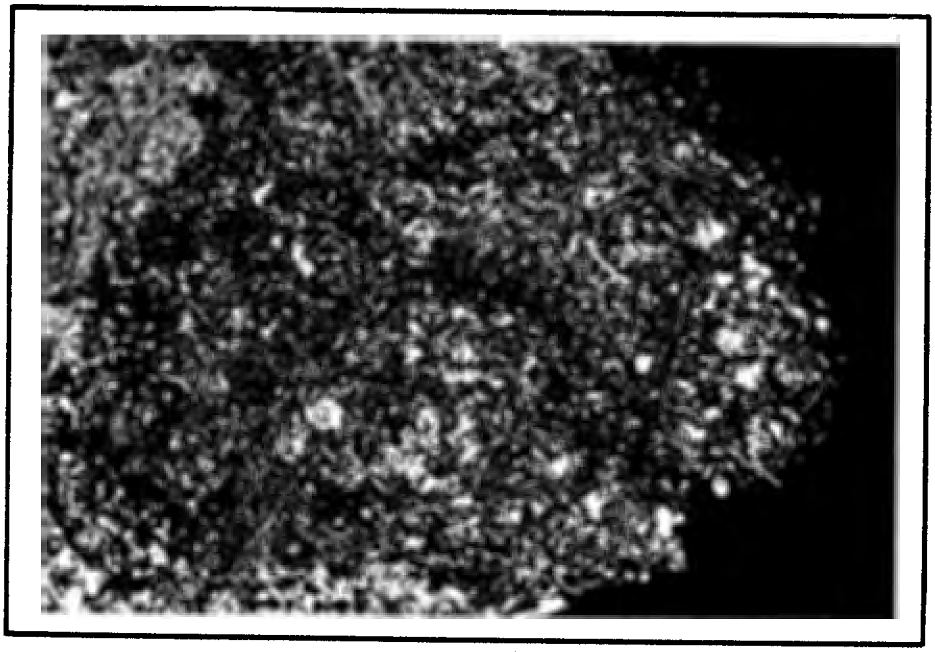


B

PLATE I

PLATE II

Figure A	Pyrite in fusain, from the Pittsburgh Seam, Washington County, Pennsylvania	(4x)
Figure B	Pyrite in a fusinoid, from the Pittsburgh Seam, Washington County, Pennsylvania. 0-1 cm. from top of seam	(104x)



A

B

PLATE II

PLATE III

Figure A	Pyrite in a vitrinoid, from the Pittsburgh Seam, Washington County, Pennsylvania. 9-10 cm. from top of seam	(23x)
Figure B	Pyrite along a bedding plane, from the Pittsburgh Seam, Washington County, Pennsylvania. 8-9 cm. from top of seam	(30x)

A

B

PLATE III

weakest mode of occurrence of the three presented is shown in photograph B of Plate II. Here the high concentration of mineral material (pyrite) in the fusinoid extending across the center of the picture is a zone of weakness. During preparation the grain might easily fracture along this plane and much of the mineralized fusinoid would be washed out and end up in the refuse fraction.

SULFUR STUDIES

Analyses

Another complete sample of the seam was cut from the column that was collected from the sampling site. This sample was cut into blocks, each of which represented an "inch level" of the seam. These blocks were all crushed so that the coal could pass through a hundred mesh U.S. Bureau of Standards sieve, and submitted to the Mineral Constitution Laboratory at The Pennsylvania State University for sulfur analyses.

Pyrite and sulfate sulfur were determined by the method described by Fieldner and Selvig, 1951, in the Bureau of Mines Bulletin 492, "Methods of Analyzing Coal and Coke". The "Eschka" method in "ASTM Standards on Coal and Coke" (Sept. 1951) was followed for determining total sulfur. The organic sulfur was determined by finding the difference between the two above.

When a consumer asks about the amount of sulfur in a seam of coal he is interested primarily in total sulfur. The forms which the sulfur takes are not critical. Organic sulfur is that which is inherent in the coal. It was present as part of the plants which formed the peat deposit that later was turned into coal by geological processes over millions of years. The only way that this sulfur can be isolated is by chemically removing the coal from it in a laboratory. Most sulfate and sulfide sulfur, on the other hand, can be mechanically eliminated. If the coal were crushed fine enough, much of it could probably be removed, however economic limitations preclude the extremely fine crushing of all coal. Pyrite such as that shown in Plate III A, and finer material, is not effectively removed by any presently employed methods. It is therefore necessary to find the optimum for size and sulfur content.

The results of the sulfur analyses are given in Table 2 of the Appendix and they are represented graphically by Figures 5, 6 and 7.

The average total sulfur for the whole seam is only 1.56%, which makes it a fairly low sulfur coal. Of this, 0.80% is organic and cannot intentionally be removed by mechanical processes. The remaining 0.76%, however, is sulfate and sulfide sulfur, the bulk of which can be removed in a preparation plant.

It has been thought at times that the percentage of sulfur is fairly constant throughout the seam. Actually the opposite of this is true. The total sulfur in the seam varies from 0.26% to 5.44%, ranging normally below 2% but there are five peaks above 3%. Figure 5 is a sulfur profile for the column under investigation. The organic sulfur shows the least variation ranging around 0.75% for the top half of the seam after which it makes two dips below 0.5% and then slowly climbs to 1.5% at the bottom of the seam (see Fig. 7). The sulfate and sulfide sulfur show the most variation throughout the seam and vary from a high of 4.34% to a low of 0.02%. The graphic representation of this distribution is presented as Figure 6. These forms of sulfur show concentrations near the top and bottom of the

TOTAL SULFUR OF THE PITTSBURGH SEAM, WASHINGTON CO., PENNA

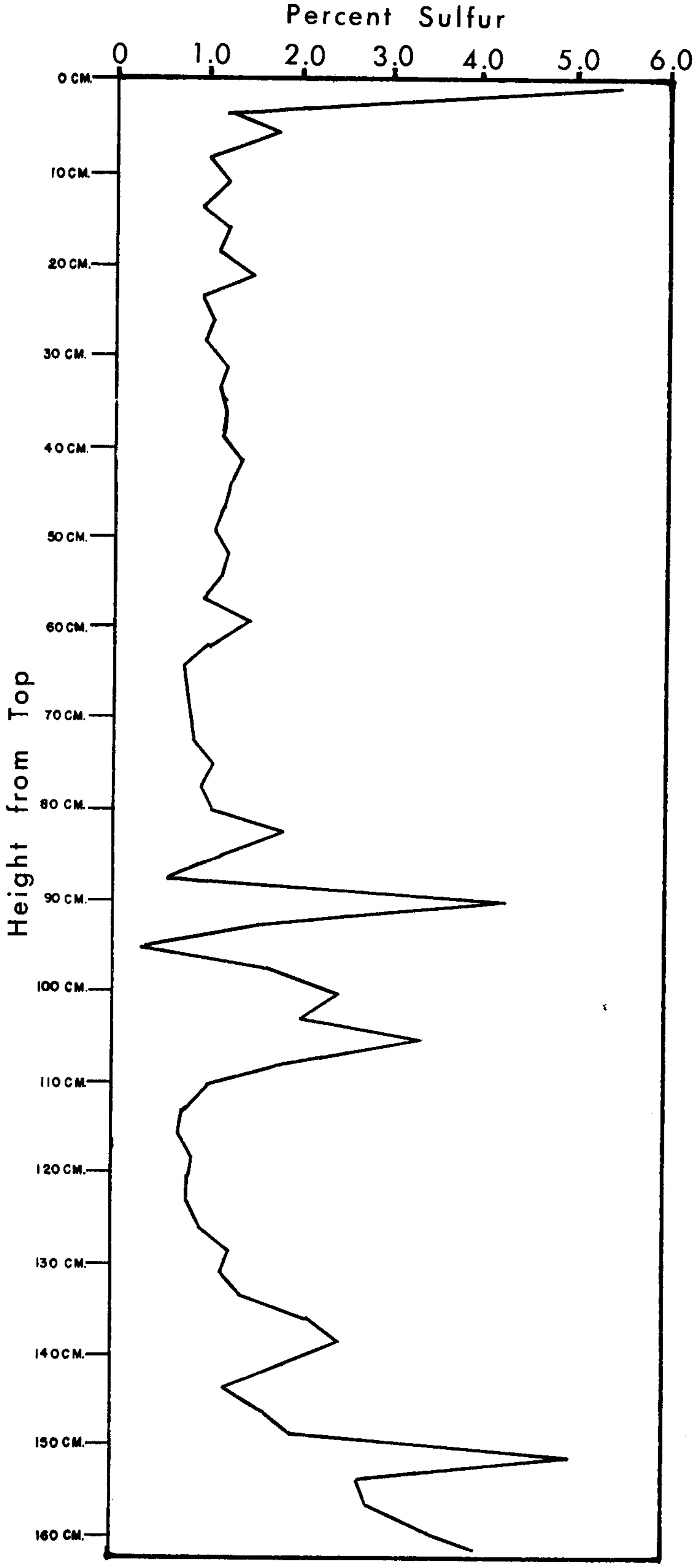


Figure 5

SULFATE AND SULFIDE SULFUR OF THE PITTSBURGH SEAM,
WASHINGTON CO., PENNA.

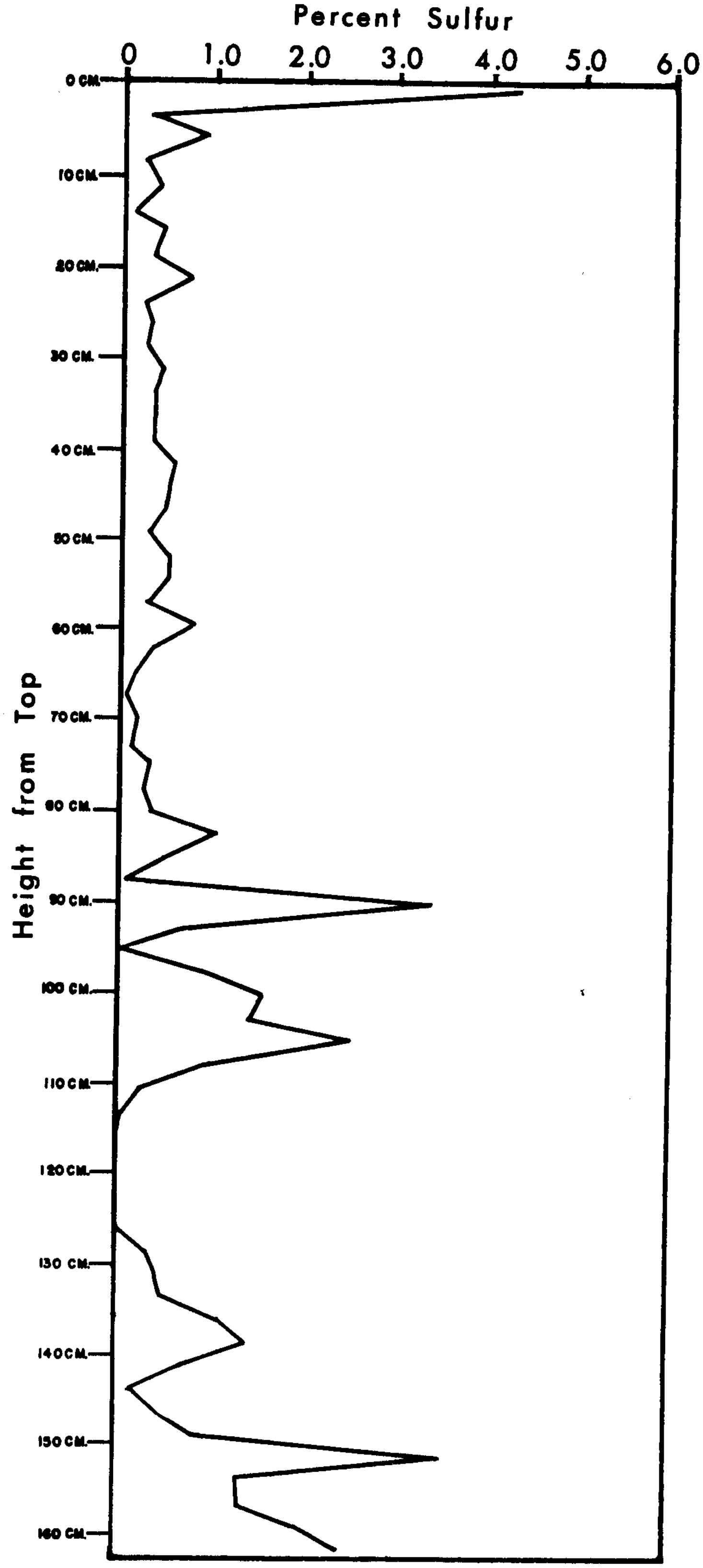


Figure 6

ORGANIC SULFUR OF THE PITTSBURGH SEAM, WASHINGTON CO. PENNA.

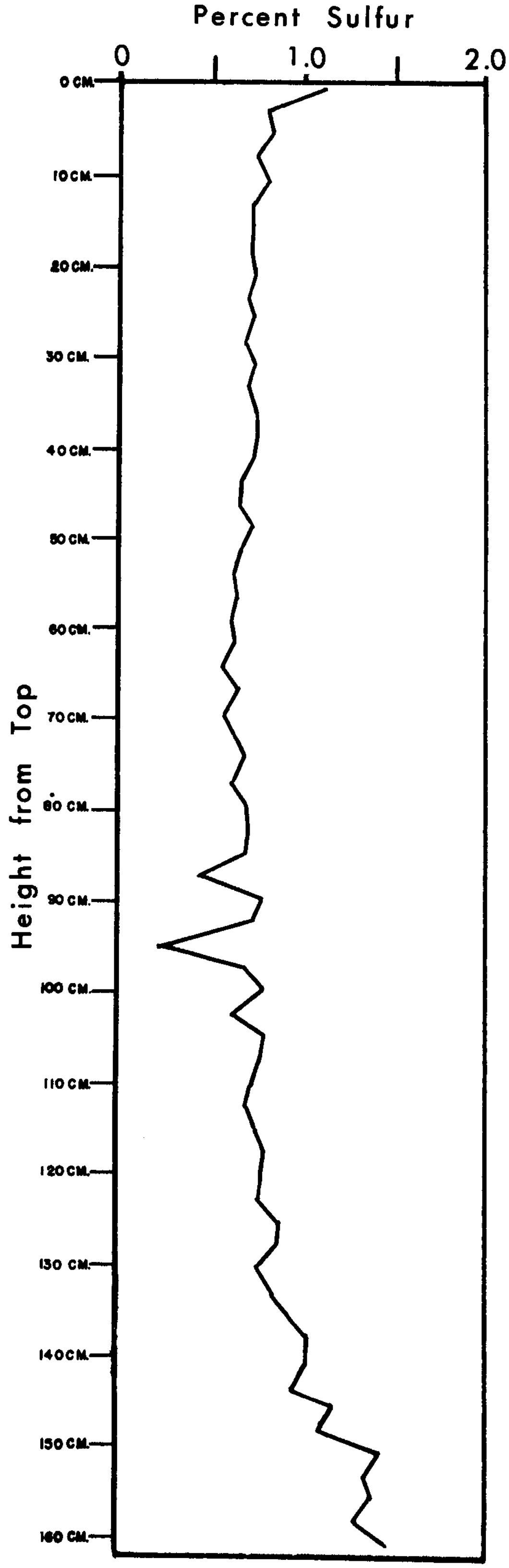


Figure 7

seam and several concentrations associated with the partings. Since most of the removable portions of the sulfur are concentrated within small zones, the amount of work necessary to remove the sulfur is lessened.

Mode of Occurrence

As has been previously stated, organic sulfur is inherent within the coal itself. It is in the form of elemental sulfur atoms within the complex of non-crystalline hydro-carbons that make up the coal. This is completely submicroscopic in size. The sulfate and sulfide sulfur is crystalline and can be seen with a microscope while some of it can even be seen with the unaided eye.

The sulfate sulfur almost always occurs as extraneous material from the coal itself, quite often occurring as part of the suite of minerals that make up the partings. Sulfate sulfur, commonly in the form of gypsum, is sometimes found filling the cleats that run through a seam. These are almost always easily recognized by the unaided eye and can be handled with relative ease. This type of occurrence is illustrated in photograph A of Plate I, however, the mineral matter in this particular case, for illustrative purposes, is gypsum.

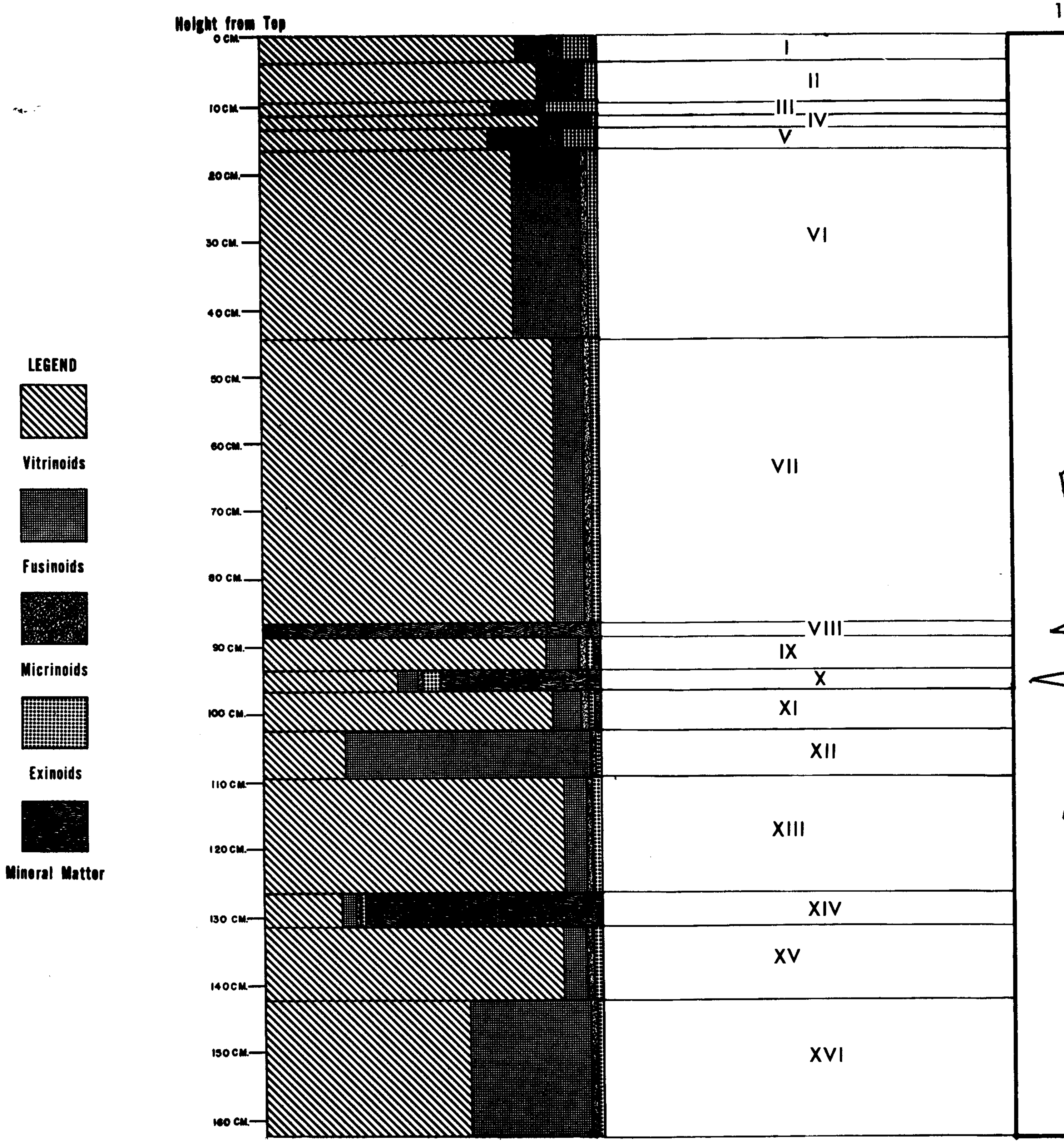
The sulfides, of which pyrite is the major member in coals, (when the term pyrite is used it may mean pyrite and/or marcasite, which are chemically the same) also occur in partings and cleat fillings (see Plate I B). In these forms, pyrite too can be easily recognized in a hand specimen by its bright golden color. Pyrite also occurs, however, as small crystalline aggregates within the coal itself. Quite often it fills the empty cells in the fusinoids and these aggregates are usually under 0.1 mm. in diameter.

There is sometimes so much pyrite in the fusinoids that it too can be recognized in a hand specimen (see Plate II A). Pyrite also occurs within the vitrinoids for no immediately apparent reason. These microcrystalline aggregates are all smaller than 0.1 mm. and usually smaller than 0.05 mm. (see Plate III A). There are sometimes micro-cleats within the vitrinoids which are filled by microcrystalline pyrite aggregates. This type of accumulation was not noted in this study. Pyrite is also found along bedding planes within the coal. Here it is associated with not just one maceral but instead it is in close proximity to almost all of them (see Plate III B).

One of the most interesting observations noted is the fact that each high sulfur peak falls within the boundaries of a single lithotype zone (see Fig. 8). In fact, all of the major changes of percentage of sulfur occur within the boundaries of individual lithotypes. The four major peaks, however, did not all fall within similar lithotypes. The top two peaks both occurred in lithotype zones of relatively high vitrinoid concentration while the two lower peaks occurred in high fusinoid zones.

Since each zone of high sulfur concentration occurs within an individual lithotype zone, these zones can be selectively removed from the coal at the preparation plant. They can then be processed separately so as to remove the high concentration of sulfur. This could probably be best done by further crushing and cleaning of these zones. There is also the possibility that the most economic way of dealing with some of these high sulfur zones would be to completely remove them from the rest of the coal and have them directed to the refuse stream.

TOTAL SULFUR AS RELATED TO PETROGRAPHIC

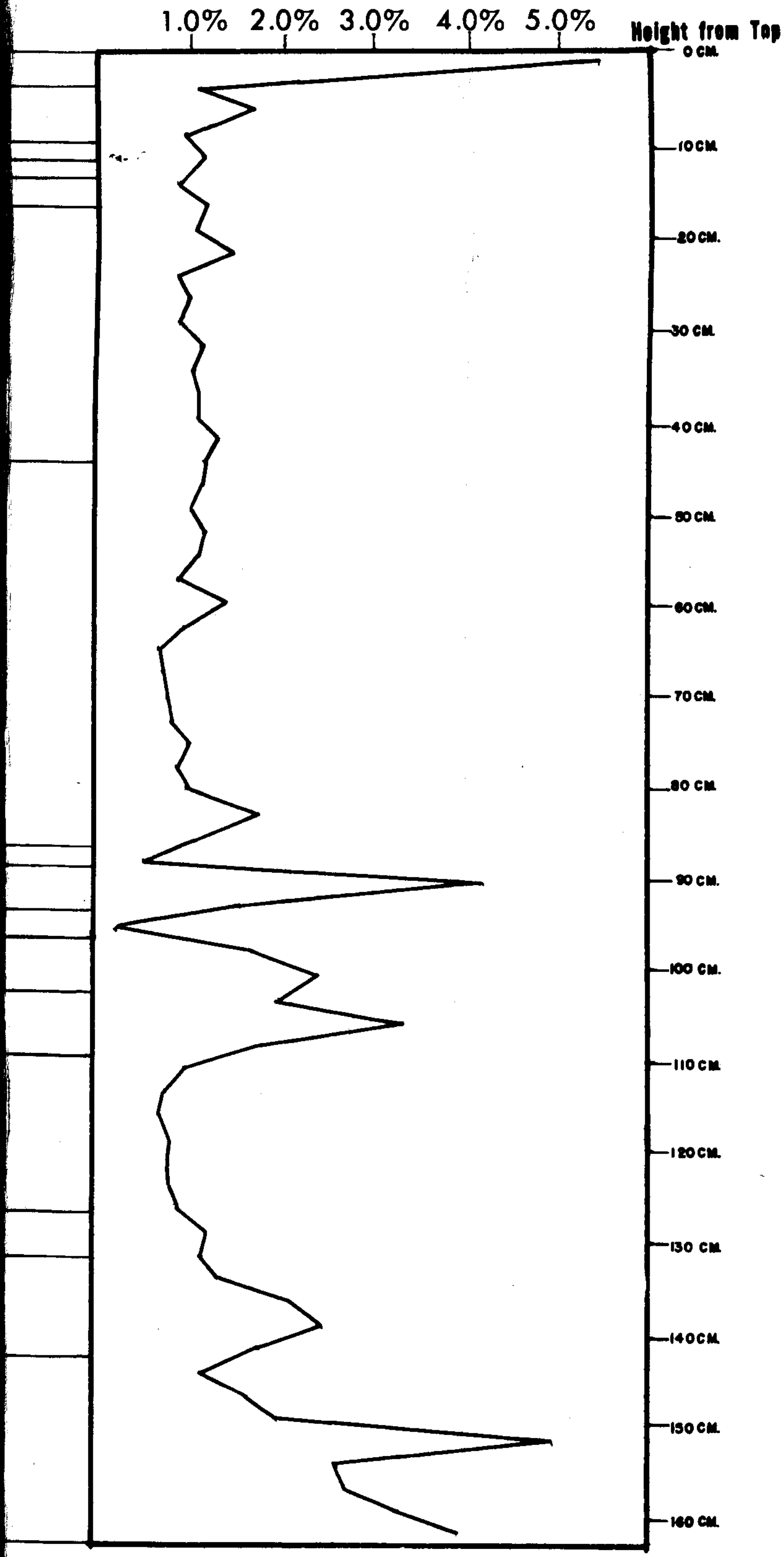


Microscopic Petrography

Lithotype Zones

Figure 8

RAPHIC COMPOSITION



Total Sulfur

CONCLUSIONS

Sulfur occurs within coal seams in three categories: 1) pyritic sulfur, 2) sulfate sulfur and 3) organic sulfur. That which is organic in nature cannot be directly removed by preparation procedures. It will be removed only accidently as other types of materials are diverted to the refuse stream. The pyritic and sulfate sulfur which occurs in coal is for the most part present in discrete particles. This fact allows ready recognition of the bulk of the removable sulfur forms. Microscopic examination is necessary however, to adequately observe much of this material.

The primary mode of occurrence of sulfate sulfur is as calcium sulfate which for the most part is present as cleat fillings or as a powdery residue formed by weathering. This material is easily removed in most preparation practices. The material is often "crumbly" in nature and readily flakes off cleat faces in a "sheet-like" manner.

Pyritic sulfur also occurs as cleat fillings which are readily removed by preparation. A variety of pyritic sulfur more difficult to remove, is that which is intimately associated with one or more of the organic entities which comprise coal. Here the sulfur may be so finely disseminated that it is impossible to remove it using known methods regardless of the size consist of the product.

In this event, if further reduction of the sulfur content is desired, it would be wise to channel this fraction into a market with less strict sulfur tolerances. Adequate characterization of the lithotypes involved will enable this to be carried out.

An additional important consideration is the effect of the organic entities themselves upon product behavior. Certain plant-fractions which have slightly undesirable properties may be improved both with regard to sulfur content and behavioristically by modifications of plant flow-sheets.

It is felt that research such as has been carried out on this column of Pittsburgh Seam coal can benefit the Commonwealth's bituminous coal industry. The mine operators will be better able to understand that which they are mining. Therefore, they may be able to place their coal, by such means as selective preparation of the seam material, on higher price markets. This would enable them to upgrade at least part of their coal by selecting certain fractions of the seam for the premium markets while the rest could be diverted to the steam coal market.

In the preparation plant, changes can be made that will enable the producer to lose less of a valuable coal to the refuse stream. There is ample opportunity for the operators to lower the percentage of sulfur in the final product by applying data gathered through this type of study. Knowledge of the forms that sulfur takes within the coals and of its lithotype distribution is of paramount importance to effective preparation, marketing and utilization.

The location of the high sulfur coal within the seam and an analysis of the lithotype in which it occurs will determine what practices must be modified to increase the plant efficiency. This can be done by carrying this line of investigation to completion with a detailed analysis of prepared coals.

The consumer, too, will benefit by having a better grade of coal more readily available. Premium coals would be in greater supply and cost would be lessened if the marginal coals that surround large consumer areas in the western part of the Commonwealth are upgraded. Refinement of preparation practices would immediately increase the reserves of high grade coals within the Commonwealth of Pennsylvania.

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APPENDIX

TABLE 1

Summary of Petrographic Data

Lithotype Zones	Distance from top of seam (centimeters)	Maceral Composition: Vitrinoids	Fusinoids	Micrinoids	Exinoids	Resinoids	Mineral Matter
I	0 - 4	75.7	7.7	5.6	10.3	0.0	0.6
II	5 - 10	82.8	9.2	3.0	4.7	0.0	0.2
III	11 - 12	69.5	9.8	5.1	15.6	0.0	0.0
IV	13 - 14	83.7	11.2	2.7	1.8	0.0	0.5
V	15 - 17	67.6	16.7	4.7	10.9	0.0	0.2
VI	18 - 45	75.3	20.5	1.6	2.5	0.0	0.2
VII	46 - 87	87.1	8.7	1.8	2.2	0.1	0.1
VIII	88 - 89	0.0	0.0	0.0	0.0	0.0	100.0
IX	90 - 94	84.4	9.5	2.2	1.5	0.0	2.4
X	95 - 97	40.0	5.3	1.7	4.8	0.0	48.2
XI	98 - 103	86.2	7.5	3.3	2.7	0.1	0.7
XII	104 - 110	24.8	74.0	0.4	0.4	0.1	0.1
XIII	111 - 127	89.8	7.1	1.6	1.5	0.1	0.1
XIV	128 - 132	23.3	4.9	0.4	1.4	0.0	70.1
XV	133 - 143	89.4	7.9	1.4	1.1	0.1	0.1
XVI	144 - 162.5	61.2	37.2	0.8	0.7	0.1	0.1

TABLE 2

Sulfur Analyses

Distance from top of seam (inches)	Total Sulfur (percent)	Sulfate + Sulfide Sulfur (percent)	Organic Sulfur (percent)
0 - 1	5.44	4.34	1.10
1 - 2	1.18	0.38	0.80
2 - 3	1.74	0.92	0.82
3 - 4	0.98	0.25	0.73
4 - 5	1.20	0.41	0.79
5 - 6	0.91	0.18	0.73
6 - 7	1.20	0.47	0.73
7 - 8	1.10	0.37	0.73
8 - 9	1.49	0.77	0.72
9 - 10	0.94	0.24	0.70
10 - 11	1.04	0.32	0.72
11 - 12	0.97	0.28	0.69
12 - 13	1.17	0.44	0.73
13 - 14	1.08	0.38	0.70
14 - 15	1.12	0.38	0.74
15 - 16	1.13	0.38	0.75
16 - 17	1.31	0.57	0.74
17 - 18	1.23	0.55	0.68
18 - 19	1.17	0.49	0.68
19 - 20	1.08	0.35	0.73
20 - 21	1.21	0.54	0.67
21 - 22	1.17	0.54	0.68
22 - 23	0.97	0.32	0.65
23 - 24	1.45	0.82	0.63
24 - 25	1.01	0.38	0.63
25 - 26	0.73	0.16	0.57
26 - 27	0.76	0.12	0.64
27 - 28	0.79	0.20	0.59
28 - 29	0.82	0.17	0.65
29 - 30	1.04	0.36	0.68
30 - 31	0.91	0.29	0.62
31 - 32	1.03	0.33	0.70
32 - 33	1.81	1.10	0.70
33 - 34	1.17	0.47	0.70
34 - 35	0.54	0.10	0.44
35 - 36	4.24	3.44	0.80
36 - 37	1.58	0.85	0.73
37 - 38	0.26	0.05	0.21
38 - 39	1.67	0.98	0.69
39 - 40	2.43	1.61	0.81

TABLE 2 (Cont.)

Distance from top of seam (inches)	Total Sulfur (percent)	Sulfate + Sulfide Sulfur (percent)	Organic Sulfur (percent)
40 - 41	2.03	1.48	0.53
41 - 42	3.37	2.57	0.80
42 - 43	1.81	1.02	0.79
43 - 44	1.01	0.26	0.75
44 - 45	0.80	0.09	0.71
45 - 46	0.77	0.01	0.76
46 - 47	0.82	0.02	0.80
47 - 48	0.81	0.02	0.79
48 - 49	0.82	0.03	0.79
49 - 50	0.92	0.02	0.90
50 - 51	1.23	0.35	0.88
51 - 52	1.18	0.47	0.77
52 - 53	1.35	0.49	0.86
53 - 54	2.12	1.16	0.96
54 - 55	2.47	1.44	1.03
55 - 56	1.79	0.74	1.05
56 - 57	1.20	0.21	0.99
57 - 58	1.62	0.43	1.19
58 - 59	1.97	0.84	1.13
59 - 60	4.98	3.56	1.42
60 - 61	2.64	1.31	1.33
61 - 62	2.76	1.37	1.39
62 - 63	3.26	1.94	1.32
63 - 64	3.94	2.44	1.50