Department of the Interior
U.S. Geological Survey
Open File Report 90-697

Coal Quality and Compositional Characteristics of the Upper Freeport Coal Bed, Pennsylvania, Source of the Argonne #1 Premium Sample

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ABSTRACT

The Upper Freeport coal bed, a high volatile (A) bituminous coal in Indiana County, Pennsylvania, was the first in a series of eight samples comprising the Argonne Premium Coal Sample Bank. The Upper Freeport coal bed occurs at the stratigraphic boundary of the Allegheny and Conemaugh Formations and is Upper Pennsylvanian in age. This coal is economically important in Pennsylvania and is a dedicated reserve used to generate steam for a mine mouth electric power plant. The composition of the Upper Freeport coal bed is variable throughout its occurrence, and reflects the assemblage and composition of the coal bed subunits or facies present. The facies were defined on the basis of megascopic characteristics and petrographic and chemical variability. Identifying and studying the Upper Freeport coal bed by facies facilitated in the definition and quantification of the coal quality parameters. The coal bed facies represent development phases within the original peat mire. The Upper Freeport coal bed is interpreted to have formed from a low-lying, topogenous mire and passed through transitional phases toward oligotrophic, domed peat formation.

BACKGROUND

The Upper Freeport coal bed was sampled as part of the Argonne National Laboratory's Premium Coal Sample Program and is included as sample #1 of the Premium Coal Sample Bank. The Argonne Premium Coal Sample Program entailed sampling eight coal beds of various ranks and compositions in the United States. The Premium Coal Sample Bank is intended to be a sample resource containing consistent, high quality coal samples available to coal researchers. A general description of the program may be found in Vorres (1989). Detailed analyses of the Upper Freeport coal bed, characterization of the coal from coal bed facies samples, and interpretation of the data are the subject of this paper.

INTRODUCTION

The Upper Freeport coal bed occurs throughout a large area of Pennsylvania, West Virginia, and Ohio. The Argonne Premium Sample was taken from the Lucerne #6 mine, near Homer City, in Indiana County, west-central Pennsylvania (fig. 1). The Lucerne #6 mine is owned and operated by the Rochester and Pittsburgh Coal Company and is a dedicated reserve used to fuel a mine mouth electric power plant run by the Pennsylvania Electric and New York State Electric Gas Companies. As a fuel for steam, the Upper Freeport is one of the most important coal beds in this part of the country.

The Upper Freeport coal bed is Upper Pennsylvanian in age and marks the stratigraphic boundary of the Allegheny and Conemaugh Formations (fig. 2). The Upper Freeport coal bed is associated with other mineable coal beds within the Allegheny Formation. This contrasts with the overlying Conemaugh Formation in which economically important coal beds are scarce.

DEPOSITIONAL ENVIRONMENT

The ancestral Upper Freeport peat developed within a fluvial-lacustrine environment. Associated limestones and shales were deposited within freshwater lakes and contain freshwater fossils, namely estherids, ostracods, and gastropods (Williams, 1960). The Upper Freeport limestone extends across the same geographic area as the Upper Freeport coal bed and ranges from a brecciated limestone to a silty brecciated claystone which sometimes exhibits irregular microkarstic surfaces. The Upper Freeport limestone is interpreted as having formed subaqueously (Weedman, 1988) or as a result of extensive subaerial exposure (Cecil and others, 1981). The Upper Freeport coal bed occasionally rests directly on this limestone, however, in most places the coal overlies intervening claystones and underclays.

Overlying the Upper Freeport coal are black, well laminated shales commonly referred to as the Uffington Shale. These shales were derived from lacustrine clays deposited in freshwater lakes which terminated the peat formation of the Upper Freeport. Progradation of a stream system into the lacustrine environment resulted in deposition of the sands which formed the precursor to the Mahoning Sandstone. In some cases, this sandstone rests directly on top of the Upper Freeport coal bed. Thin, discontinuous peat developed adjacent to these stream channels and formed the Mahoning coal. Above the Mahoning sequence, freshwater lacustrine clays and silts again dominated. The Brush Creek coal formed as thin, discontinuous, low quality (high ash, high sulfur) peat bodies. This freshwater interval was terminated by the incursion of a transgressive phase beginning with the deposition of the marine Brush Creek shale.

SAMPLING SCHEME FOR THE UPPER FREEPORT COAL BED

To minimize contamination from mining equipment, the one ton (908 kg) Argonne Premium sample was collected from a freshly mined coal face using hand picks. The block of coal was cut from roof to floor excluding the thin durain parting which is located approximately 23 cm (9 in) above the base of the coal (fig. 3). The block of coal was caught on a canvas tarpaulin and placed in heavy plastic bags which were carried to the surface where they were loaded into stainless steel drums. Following the Argonne Premium Coal Sample procedure, the drums were sealed and then purged with argon gas to prevent oxidation of the coal sample.

After collecting the gross channel sample for the Argonne Premium sample, the coal bed was described, using a modified method of Schopf (1961), and subunit or facies boundaries were determined. Using Schopf's (1961) modified method, the coal bed was described megascopically, based on thickness of vitrain and attrital layers, vitrain abundance, relative hardness of the coal and fracture type, mineral matter occurrence (especially pyrite and calcite), fusain thickness, cleat spacing, and presence of partings greater than 0.25 in (6 mm) thick. The description of the coal bed taken in the mine is shown in Figure 3. The subunits or facies of the Upper Freeport coal bed had been channel sampled prior to the Argonne sampling during a joint U.S. Geological Survey/Environmental Protection Agency study (Cecil and others, 1981; Stanton and others, 1986). Data from samples obtained at several of the previous study's sites near the Argonne sample are presented in this report. These data include petrographic and chemical data from three localities, washability data from two localities, and paleobotanical data from one locality. The localities of these samples and the Argonne Premium sample are shown in Figure 4.

SAMPLE PREPARATION

Sample preparation consisted of (1) the Argonne Premium Coal Sample Method for the gross channel sample (Vorres, 1989) and (2) facies channel sample preparation at U.S. Geological Survey laboratories. Facies channel samples were ground to pass a No. 20 U.S. Standard Sieve (less than 850 µm) and split for a variety of analyses. A commercial laboratory performed washability analyses (on facies samples and whole-bed channel samples) and determined ash yield and sulfur forms. All procedures of sampling and analyses conformed to the methods and practices of the American Society of Testing and Materials (ASTM) guidelines (ASTM, 1985).

Subsplits of facies samples were used to make pellets for petrographic analyses. The coal was mixed with a binding agent of epoxy resin, allowed to cure, and then ground and polished to obtain a scratch-free surface (ASTM, 1985). These pellets were then analyzed petrographically using reflected, white-light, bright-field illumination microscopy. Two pellets per sample (facies) were point counted, 500 points per pellet. The pellets were first point-counted in order to identify and count the macerals of the liptinite group. Although macerals of the liptinite group are usually counted using fluorescence microscopy (blue irradiation), the rank of the Upper Freeport in the study area is too high for the liptinite-group macerals to fluoresce. Therefore, the liptinites were identified on polished pellets under white light. After the liptinites were counted, the pellets were etched in a solution of acidified potassium permanganate (Stach and other, 1982; Moore and Stanton, 1985) to enhance the textural details of the vitrinite submacerals (crypto-macerals) that would otherwise be obscured (ICCP, 1971; Pierce and others, in press). Because the macerals of the vitrinite group were identified using etched pellets, the prefix "crypto" is understood and not used in the following discussion. After etching the coal pellets, they were again point-counted to identify and count the macerals of the inertinite and vitrinite groups. For each sample, the point count data from the two pellets were compared to each other to ensure that the results were within two percent mean variation (ASTM, 1985). The reflectance of vitrinite was measured in accordance with ASTM test method D2798 (ASTM, 1989).

CHEMISTRY AND COAL QUALITY

The ash yield and sulfur data for samples nearest the Argonne Premium Sample are found in Table 1. The chemical data of samples within a facies are very similar but distinct from those of samples from other facies. The lower parting, facies LP, yields by far the highest ash (average 35 percent), classifying this facies as an impure coal. The ash yields are relatively high at the base of the bed in facies E (average 13.6 percent) and decrease in samples from the upper part of the bed (facies D averages 12 percent and facies C averages 5.5 percent).

The sulfur values are also variable, with total sulfur ranging from an average of 0.66 percent in facies LP to an average of 2.82 percent in facies E (Table 1). The highest pyritic sulfur contents are found at the top and bottom of the coal bed, in facies C (0.96 percent) and facies E (1.52 percent). A similar pattern of distribution can be observed for organic sulfur (Table 1).

The washability data used in this study were taken from the 1/8 in by 100 mesh (2.36 mm by 150 µm) fraction of each sample which represented greater than 90 percent of the total weight percent of each sample (Table 2). Washability curves illustrate the relationship among coal composition, yield (weight percent recovery), and apparent bulk density. The cumulative washability curves for the whole-bed channel samples and four facies samples from two localities (for a total of 10 curves per graph) are shown in Figures 5 through 7. Curves of samples within facies are similar to each other but are significantly different from curves of samples of other facies. It is important to note that each facies has a unique set of characteristics. Facies C has by far the lowest ash contents and highest recoveries (Figures 5, 6, and 7). Alternatively, facies LP has by far the highest ash contents and lowest recoveries (Figures 5, 6, and 7). It is apparent that the curves of the whole-bed channel samples are quite different from curves of the individual facies samples. As would be expected, in each graph the whole-bed curves fall in an area between the extremes of the individual facies curves.

PETROGRAPHY

The vitrinite reflectances performed on the Upper Freeport coal bed (R_o = 1.12) indicate that this coal's rank is between a high volatile A and medium volatile bituminous coal. The fixed carbon content is 67.12 percent and the calorific value is 15980 Btu (both on a dry, mineral-matter-free basis), indicating that the Upper Freeport coal in this area is high volatile A in rank.

The results of the petrographic analyses are found in Table 3 and Figure 8. Each facies is unique in its petrographic composition, and the samples from a single facies are similar to each other.

The liptinite percentage values (Table 3) are probably under-represented. Because of the rank of the Upper Freeport coal bed, coalification and the chemical changes related to coalification change the liptinites so that microscopically they are difficult to distinguish from the vitrinite macerals.

Facies E contains the highest total vitrinite and lowest inertinite contents of the coal bed, and relatively low amounts of total and individual liptinite macerals. The lower parting, facies LP, is composed of extremely high and low percentages of inertinite macerals and vitrinite macerals, respectively. Facies LP also contains the highest percentages of liptodetrinite and inertodetrinite macerals. Facies D has moderately high percentages of inertinites and vitrinites and moderately low percentages of liptinites. The uppermost facies, facies C, contains the highest liptinite content, with an average of 17 percent (Table 3), the majority of which is sporinite. In addition, facies C has a relatively low vitrinite content.

Paleobotanical analyses of the Upper Freeport also illustrate the uniqueness of each facies (Figure 9) and provide additional data concerning the development of the Upper Freeport mire. A mixed floral assemblage, consisting mainly of lycopods and pteridosperms, is found at the base of the coal bed in facies E. Lycopods are the dominant palynoflora throughout the coal bed, with lycopod tissues being especially abundant in the high-ash lower parting (LP). The lower parting also contains the largest amount of degraded vegetal matter of the four facies. Facies D contains a mixed floral assemblage as well as the highest amount of ferns found in the coal bed. The percentage of rootlets increases considerably at the top of the coal bed, in facies C.

DISCUSSION

Distinct subunits (facies) within the Upper Freeport coal bed were first recognized by Thiessen and Voorhees (1922). They studied the coal bed and found marked megascopic, microscopic, and chemical variations throughout the coal bed which were laterally persistent. Koppe (1963) also noted the presence of megascopically and compositionally unique "layers" or "zones" (facies) in the Upper Freeport.

The Upper Freeport coal bed is composed of as many as ten coal bed facies, four of which (facies C, D, LP, and E) are continuous over approximately 300 km^2 in the study area (Stanton and others, 1986). Within the present study area, these three coal facies (C, D, E) and one parting facies (facies LP) (Figure 3) are present. Coal bed facies have distinctive lithologic and stratigraphic characteristics that can be traced laterally. Each facies is distinct in its megascopic, petrographic, and chemical composition, and in washability characteristics. These systematic changes, represented by the facies within the bed, are the result of developmental phases in the paleomire. The changes in composition throughout the bed controls the changes in the coal quality characteristics which are also systematic. Coal quality assessment and prediction are more reliable when using facies analysis because better control may be obtained over the whole coal bed. Washability curves also provide additional insights regarding the depositional environment in which the Upper Freeport coal bed developed.

The peat which formed the Upper Freeport coal bed began accumulating on a substrate of subaerially-exposed limestone or flint clay (Cecil and others, 1981). The lowermost facies (E) is interpreted to have formed from a peat that was topogenous, influenced by both ground and surface water. The nutrient availability would be relatively very high in such an environment, perhaps fostering plant growth that yielded the high percentage of vitrinite (woody material) found in this facies (Figure 8 and Table 3). Relatively, facies E contains few inertinite (oxidized) macerals. This would support the interpretation that at facies E's time of formation, the peat was topogenous, influenced by both ground and surface water. The equal amounts of preserved cellular material (telinite) and degraded cellular material (gelocollinite) (Figure 8 and Table 3) found in this facies may be the combined result of mire flora and environment of formation. The mixed floral assemblage, consisting mainly of lycopods and pteridosperms (Figure 9), were relatively resistant to decay in comparison to other major floral components, tree ferns, which contained more easily degradable plant parts. This abundance of resistant tissue may account for the relatively high amount of telinite found in facies E. The near-neutral pH found in a topogenous environment (Gorham, 1957; Ingram, 1983) can promote bacterial activity and plant-tissue decomposition. Under these conditions, biochemical gelification is enhanced and may convert plant tissues into colloidal humic gels (Stach and others, 1982; Stanton and others, 1987), which results in the precursor of the maceral gelocollinite. Therefore, the combination of resistant floral assemblage and a degradative near-neutral pH, topogenous environment could have produced the equal amounts of telinite and gelocollinite within facies E.

The combination of factors within the paleopeat mire also controlled the coal quality characteristics within this facies. The intermittent detrital influx from adjacent stream channels resulted in the discrete high ash attrital layers within facies E, thereby yielding a relatively high-ash coal on a bulk sample facies basis (Table 1). This facies contains the highest ash yield of the Upper Freeport's "low ash" facies (i.e. facies C, D, and E).

The formation of the lower parting, facies LP, is attributed to influx of detritus caused by a rise in the water level, which is believed to have covered the entire peat body at one point and resulted in the degradation of the top of the peat. As evidenced from the very high ash yield of facies LP (Table 1), the mire was very susceptible to detrital influx at this stage of development. The ubiquitous nature and consistent thickness of the lower parting (facies LP), support the interpretation that the mire continued to be low-lying and topogenic in nature.

Lycopods, the dominant palynoflora in this high-ash facies (Figure 9), required relatively wet, low-lying conditions for their specialized reproductive habits (Phillips, 1979). Therefore, an abundance of their preserved tissues would support the interpretation of a low-lying, topogenous environment at this stage of development of the Upper Freeport paleomire. The lower parting also contains the largest amount of degraded vegetal matter of the four facies. This might be related to the fact that facies LP contains the highest amount of detrital liptinite and detrital inertinite material (Figure 8), which might have been concentrated relative to vitrinite precursors. The abundance of these two detrital macerals would support the interpretation of a topogenous, perhaps physically degradational, environment. In addition, the lower parting has an extremely high overall inertinite content and relatively very little vitrinite material. This is attributed to a fluctuating water table that led to the oxidation of the woody material forming the precursors to the inertinite macerals.

Facies LP has very distinct and unique washability curves in comparison to the other facies (Figures 5, 6, and 7). These curves indicate very poor quality as evidenced by extremely high ash contents (Figures 6 and 7) and exceptionally poor recovery (Figures 5 and 7). This poor quality is interpreted to be the direct result of the environment in which the lower parting was allowed to form; that is, it reflects a topogenous, low-lying environment, which was susceptible to sediment influx which resulted in high ash yields.

After formation of the parting, peat accumulation resumed and produced two more (facies D and C, Figure 3) in the area where the Argonne sample was obtained. Facies D is interpreted to have been a transitional phase of peat development between a low-lying, topogenous peat and the initiation of domed peat formation. The ash yield values support this interpretation. Facies D yields an ash percentage of 11.9 percent (Table 1) indicating a supply of ash material, yet not as much as in previous facies, E and particularly LP. This is reflected in the petrography of facies D which contains relatively high vitrinite and inertinite contents compared to the other coal facies (Table 3 and Figure 8). The abundance of previtrinite material in facies D was probably fostered by the presence of the lower parting which could have provided necessary nutrients. The initiation of doming probably exposed the surface of the peat to a greater degree of aeration, thus accounting for the moderately high amounts of inertinite macerals in facies D and C.

The environmental conditions are reflected in the paleobotanical analyses as well (Figure 9). The greatest percentage of ferns is found in facies D. The lycopods show a slight decrease toward the top of the bed. These trends may have resulted from the drier conditions of a domed peat relative to a planar peat. The evolving drier conditions may have provided too rigorous an environment for the lycopods to thrive as they did earlier in the mire.

Facies C is interpreted to have been a continuation of the domed conditions initiated in facies D. The changes in petrography (Table 3, Figure 8) and paleobotany (Figure 9) are minor, perhaps indicating only very subtle changes in the environment. The continuation of doming may be reflected in the petrography of facies C. The majority of the liptinites are composed of spores, which are very resistant to decay, and may be indicative of a change in paleobotanical contributions to the peat. The low vitrinite contents may reflect a stunting of the vegetation as the mire plants became relatively nutrient-starved. Because a domed peat depends mainly on rainfall for its nutrients, the nutrient level becomes very low compared to that of a topogenous mire (Romanov, 1968; Korchunov and others, 1980; Anderson, 1983). The percentage of rootlets increases considerably at the top of the coal bed (figure 9). This may be due in part to the preferential preservation of rootlets compared to other vegetation, because of the relatively stressful physical environment within a domed peat. The extremely low ash yields (Table 1) and distinct washability curves (Figures 6 and 7) for facies C also reflect this domed environment. Because a domed peat is raised above the surrounding environments, it is not as susceptible to detrital influence from adjacent streams and therefore produces peat/coal of very good quality, with extremely low ash yield and high weight percent recovery.

After formation of facies C, freshwater lakes formed over most of the mire, terminating the peat development of the lower bench of the Upper Freeport peat.

The average pyritic sulfur values in the Upper Freeport coal bed range from 0.25 percent in the middle facies (facies D) to 0.96 and 1.52 percent in the upper (C) and lower (E) facies, respectively (Table 1). Because considerably higher pyritic sulfur values occur at the top and bottom of the coal bed, it is believed that some of the pyritic sulfur may have been secondary. In addition, preliminary microscopic analyses of the pyritic sulfur in the Upper Freeport coal bed facies indicates that the lowermost facies, E, contains a mixed assemblage of pyritic sulfur, namely framboidal, crystalline, and some massive varieties. In contrast, there are many more massive varieties of pyrite in the upper facies, facies C. In addition, cleat pyrite was observed megascopically when sampling facies C. The more massive varieties are most likely the secondary pyritic sulfur forms. The smaller framboidal and crystalline pyritic sulfur is believed to be primary because of its intimate association and occurrence within the coal macerals. Therefore, the environment at the time of facies E's formation was probably more conducive to the formation of pyritic sulfur, as compared to facies C. This would support the previous interpretation and discussion of facies E having formed within a topogenous environment and facies C having formed within a domed environment. A domed peat, inhibitive to clastic input and sulfate-bearing groundwater, would be iron-limited due to the lack of clays and sulfur-limited due to lack of source. This lack of iron, and perhaps sulfate, would limit the formation of pyritic sulfur. In addition, the acidic (Gorham, 1957; Stach and others, 1982; Ingram, 1983) and oxidizing environment of a domed peat would not be as conducive to the formation of pyritic sulfur which requires reducing conditions.

Organic sulfur shows the same trend as pyritic sulfur, with average values being high at the bottom, in facies E (1.23 percent), and moderately high at the top, in facies C (0.78 percent). This trend may have resulted from some diagenetic influence. The trend may also reflect a distribution of finely divided pyrite that is not leached during analysis for organic sulfur because ASTM calculation of organic sulfur is dependent upon complete analysis of the pyritic sulfur. However, Spiker and others (in preparation) tested this on very finely ground and exhaustively leached samples; the sulfur isotopes showed secondary organic sulfur. Therefore, we believe that there is a diagenetic overprint of organic sulfur.

CONCLUSIONS

The Upper Freeport ancestral peat formed in an extensive mire within a fluvial-lacustrine environment. Changing chemical and physical conditions throughout the development of the paleomire produced as many as ten coal bed facies, four of which are present within the Argonne study area. These facies are compositionally unique, having different megascopic, petrographic, chemical, and quality characteristics.

The Upper Freeport peat is interpreted to have formed through a phase development sequence from a low-lying, eutrophic, topogenous peat to an oligotrophic, domed peat. The early, low-lying, topogenous peat was nutrient-rich and susceptible to detrital influx. These environmental conditions resulted in facies that yield relatively high to very high ash percentages and are of low quality. These conditions also fostered a mixed floral assemblage that thrived under wet, low-lying conditions, namely lycopods and pteridosperms.

Environmental conditions within the peat changed and yielded coal with considerably less ash, more oxidized macerals, and a floral assemblage that contained more ferns and rootlets. In addition, this environment produced coal facies with much better quality than facies formed earlier in the peat mire. These characteristics are interpreted to be the result of the initial stages of doming of the peat body.

This progression in mire development from an initially low-lying peat to a domed, oligotrophic peat may be representative of peat formation of other upper Middle and Upper Pennsylvanian coal beds. In addition to the Lower Freeport coal bed which Pierce and others (in press) studied, these authors showed that other coal beds within this stratigraphic sequence such as the Upper, Middle, and Lower Kittanning, Redstone, Waynesburg, and Pittsburg coal beds, contain very similar sequences and may have formed in a manner similar to that described in the present study. In other words, many peats of upper Middle and Upper Pennsylvanian age may have formed through facies successions from initially planar, topogenous environments through a transitional phase toward oligotrophic, domed conditions.

ACKNOWLEDGMENTS

We would like to thank William Bragonier and the Rochester and Pittsburgh Coal Company for logistical help and access to the Upper Freeport coal bed. Personnel of the Lucerne #6 coal mine, Helvetia Coal Company, provided valuable help while sampling underground. Grateful acknowledgment is made to Richard Winston presently of the Alabama Geological Survey for his paleobotanical analyses as an NRC Postdoctoral Research Associate with the USGS. James Pontolillo, of the U.S. Geological Survey, performed the vitrinite reflectance measurements on the whole coal samples.

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Table 1. Ash yield and sulfur data from facies of the Upper Freeport coal bed, where ash=ash yield, ts=total sulfur, os=organic sulfur, and ps=pyritic sulfur.

facies/sample	ash	ts	os	ps
FACIES C				
2502-1.1	4.5	0.86	0.64	0.18
2506-1.1	5.0	2.71	0.90	1.75
2518-1.1	6.9	1.46	0.79	0.96
average	5.5	1.68	0.78	0.96
FACIES D				
2502-1.2	10.5	0.7	0.69	0.05
2506-1.2	13.2	1.23	0.70	0.51
2518-1.2	12.1	0.7	0.48	0.18
average	11.9	0.88	0.62	0.25
FACIES LP				
2502-1.3	23.1	0.7	0.61	0.05
2506-1.3	45.0	0.89	0.31	0.57
2518-1.3	37.3	0.4	0.29	0.05
average	35.13	0.66	0.40	0.22
FACIES E				
2502-1.4	10.6	3.0	1.68	1.24
2506-1.4	14.7	2.87	1.12	1.65
2518-1.4	15.6	2.6	0.88	1.66
average	13.63	2.82	1.23	1.52

Table 2. Weight percent coal recovered at the 1/8 in by 100 mesh (2.36 mm by 150 micron) fraction of the washability analyses.

locality/ facies	percent weight of total
603 whole bed	95.50
603 C	97.03
603 D	93.68
603 LP	95.98
603 E	97.46
609 whole bed	92.78
609 C	95.05
609 D	94.43
609 LP	97.13
609 E	92.45

Table 3. Petrographic composition of the Upper Freeport coal bed. Sample localities found in Fig. 4. Maceral analyses are rounded to the nearest whole number and are on a mineral-matter-free basis. V=total vitrinite, T=telinite, CT=corpocollinite in telinite, G=gelocollinite, CG=corpocollinite in gelocollinite, Dt=vitrodetrinite, I=total inertinite, F=fusinite, Sf=semifusinite, Id=inertodetrinite, L=total liptinite, S=sporinite, C=cutinite, B=bituminite, E=exsudatinite, Ld=liptodetrinite.

facies/ sample number	V	T	CT	G	CG	Dt	I	F	Sf	Id	L	S	C	R	B	E	Ld
FACIES C																	
2502 - 1.1	62	33	6	21	1	1	19	7	10	2	18	10	1	2	0	2	3
2506 - 1.1	71	30	6	32	2	1	14	4	8	2	16	12	0	1	0	1	2
2518 - 1.1	71	30	8	30	3	0	12	3	7	2	16	12	0	3	0	0	1
average	68	31	7	28	2	1	15	5	8	2	17	11	0	2	0	1	2
FACIES D																	
2502 - 1.2	71	28	8	33	2	0	17	8	7	2	13	5	1	1	0	2	4
2506 - 1.2	76	27	12	34	2	1	16	5	8	3	9	3	0	1	1	1	3
2518 - 1.2	72	31	11	27	2	1	19	5	9	5	10	2	1	0	0	1	6
average	73	29	10	31	2	1	17	6	8	3	11	3	1	1	0	1	4
FACIES LP																	
2502 - 1.3	59	25	7	24	2	1	26	10	12	4	16	5	0	2	2	1	6
2506 - 1.3	39	18	3	15	1	2	49	21	21	7	14	4	0	1	3	1	5
2518 - 1.3	45	20	7	17	1	0	40	14	19	7	15	3	0	1	2	1	8
average	48	21	6	19	1	1	38	15	17	6	15	4	0	1	2	1	6
FACIES E																	
2502 - 1.4	81	35	13	30	3	0	7	1	4	2	10	4	0	2	0	2	2
2506 - 1.4	78	31	12	32	2	1	12	7	4	1	9	4	0	1	1	2	1
2518 - 1.4	78	31	11	33	2	1	11	6	4	1	10	5	0	1	1	2	1
average	79	32	12	32	2	1	10	5	4	1	10	4	0	1	1	2	1
Whole Coal Argonne Site	70	26	8	34	1	1	15	7	6	2	16	6	0	2	1	1	6

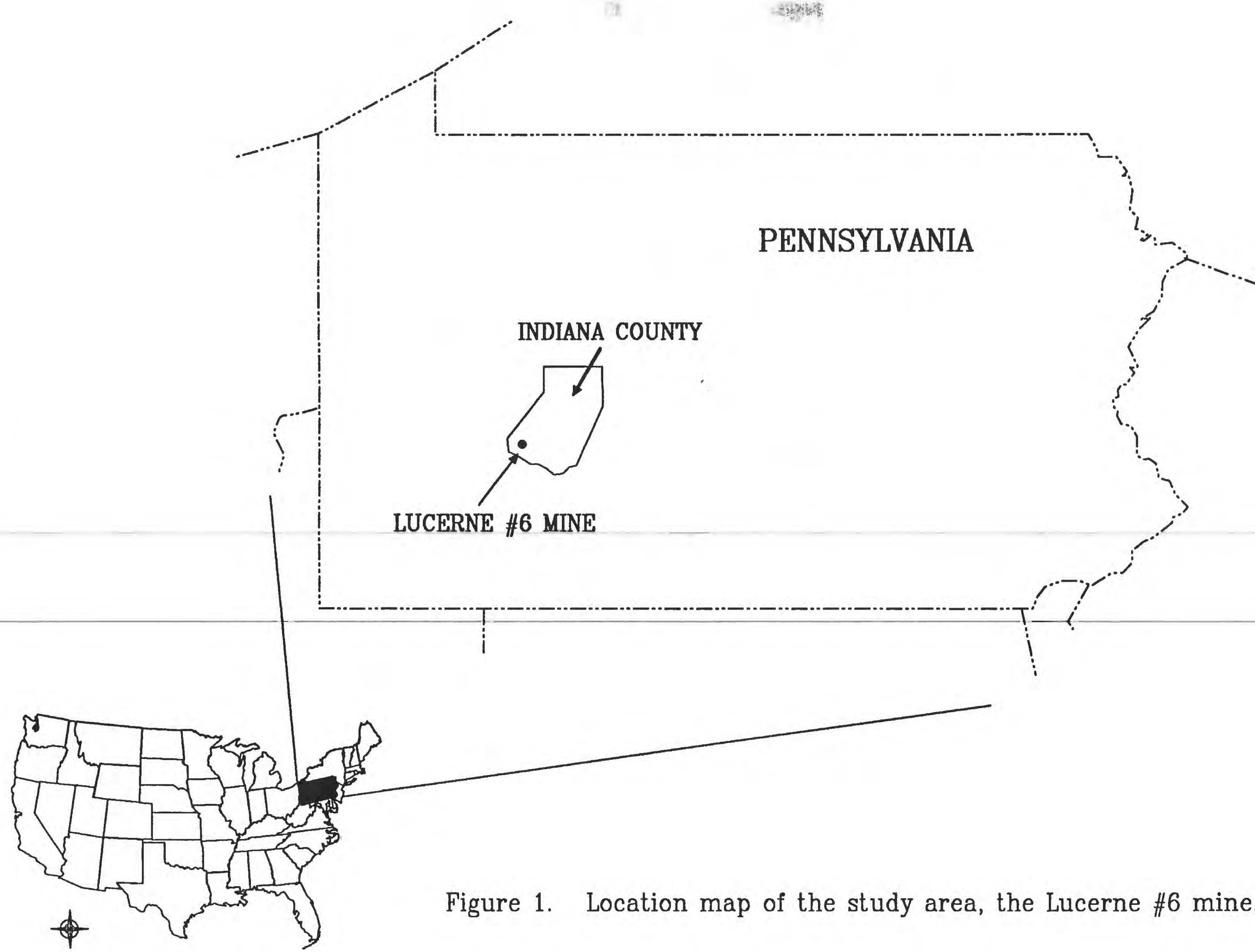

Figure 1. Location map of the study area, the Lucerne #6 mine.

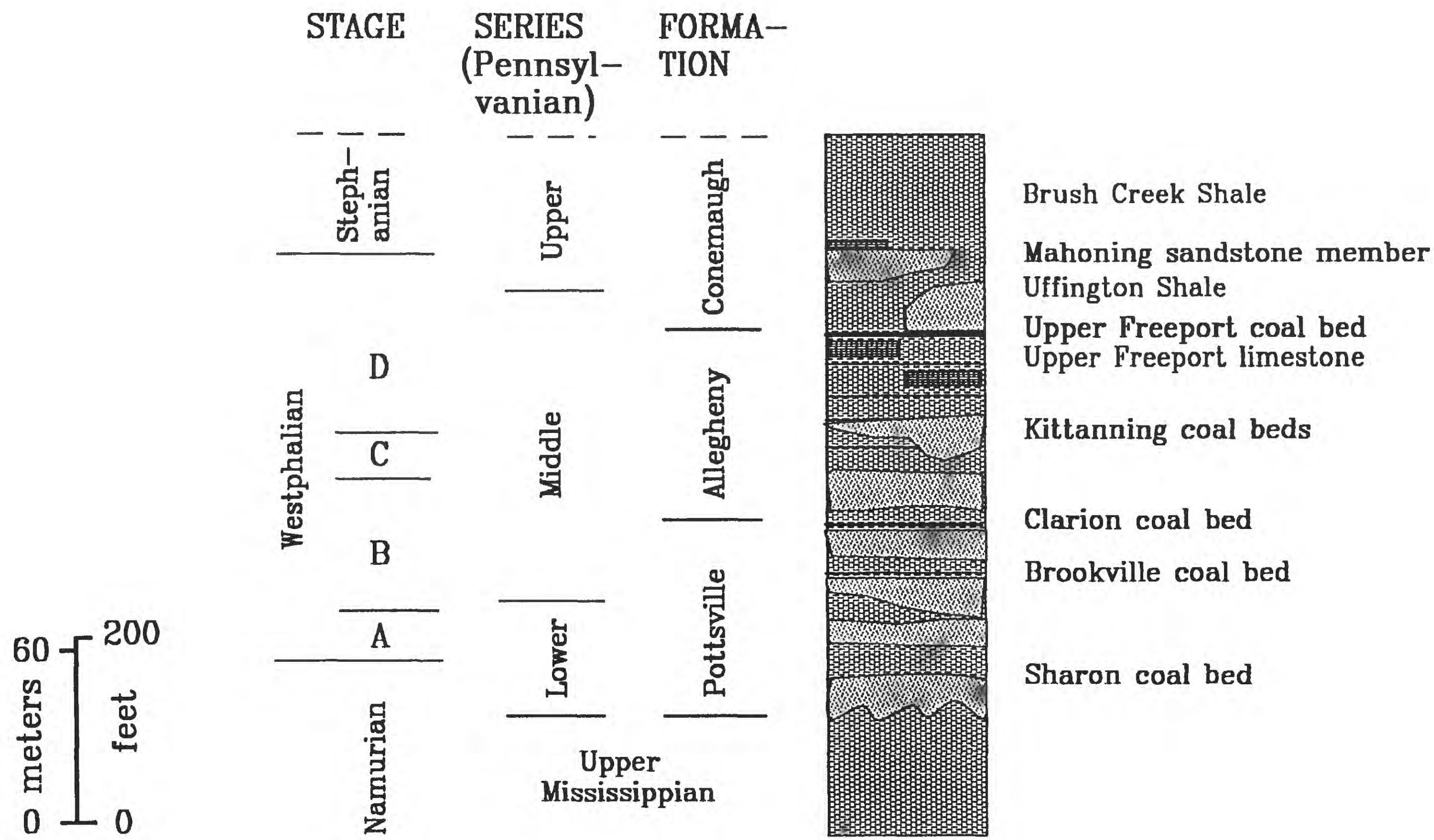

Figure 2. Stratigraphic column of rocks in and around the study area (modified from Puglio and Iannacchione, 1979 and Cecil and others, 1985).

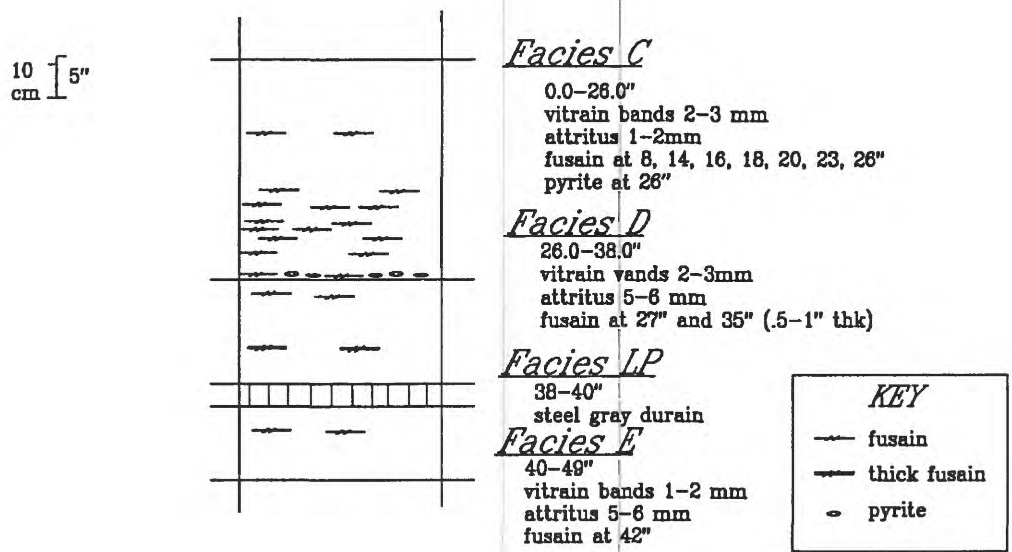

Figure 3. Coal bed facies description of the Upper Freeport coal bed in the Lucerne #6 mine at the Argonne sampling site.

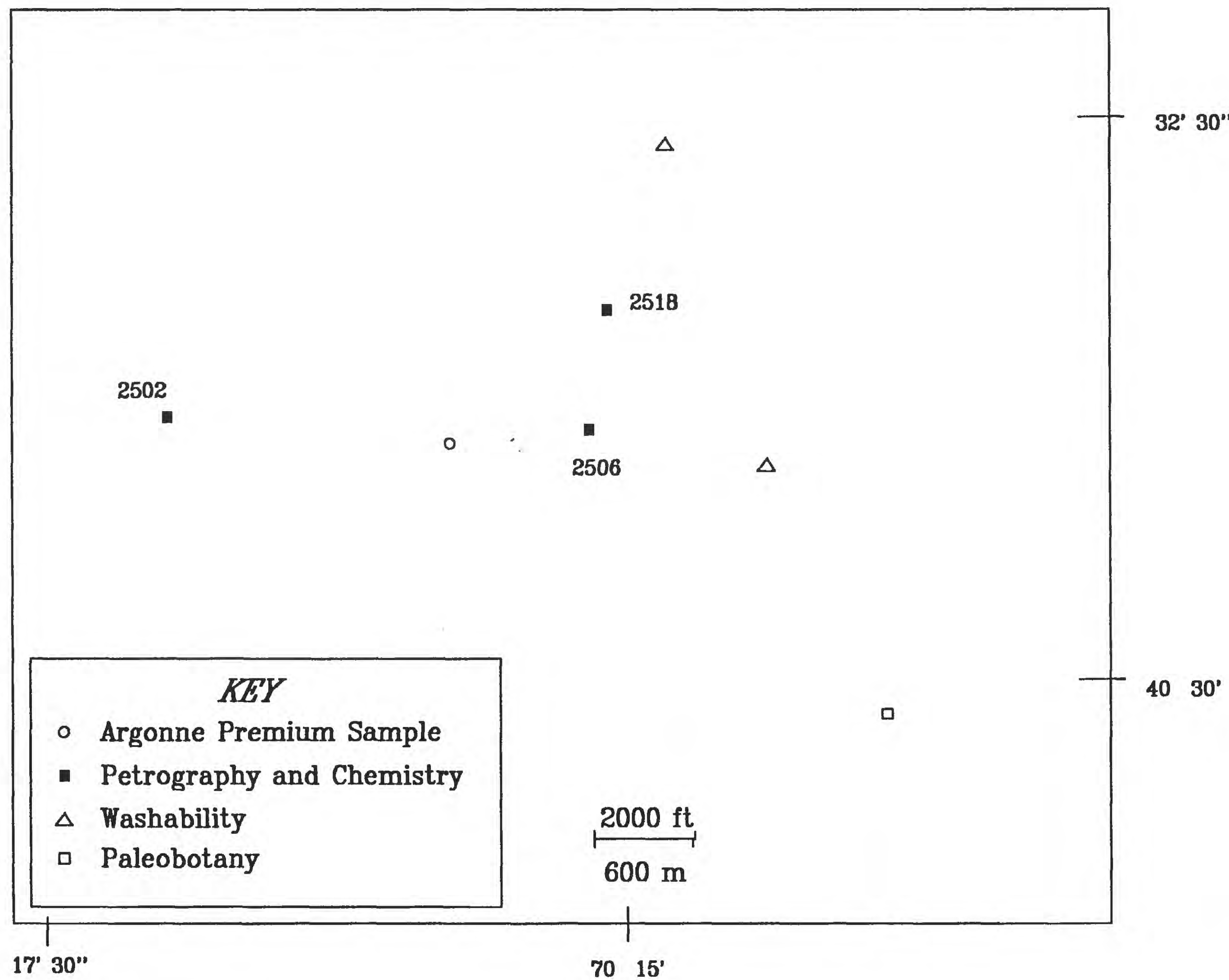

Figure 4. Relative sample localities of various analyses used in this study of the Upper Freeport coal bed.

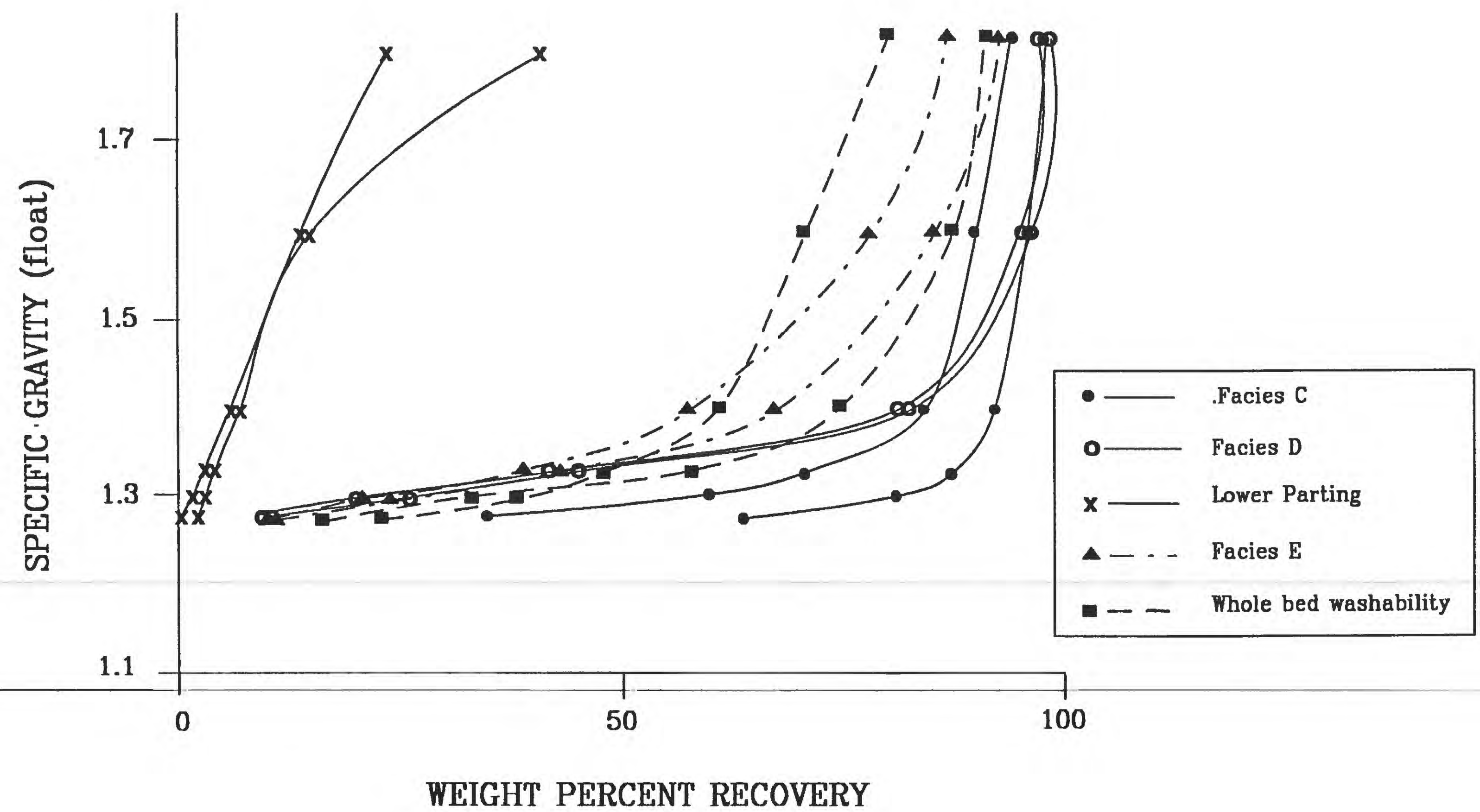

Figure 5. Washability curves of Specific Gravity vs Yield for the Upper Freeport coal bed.

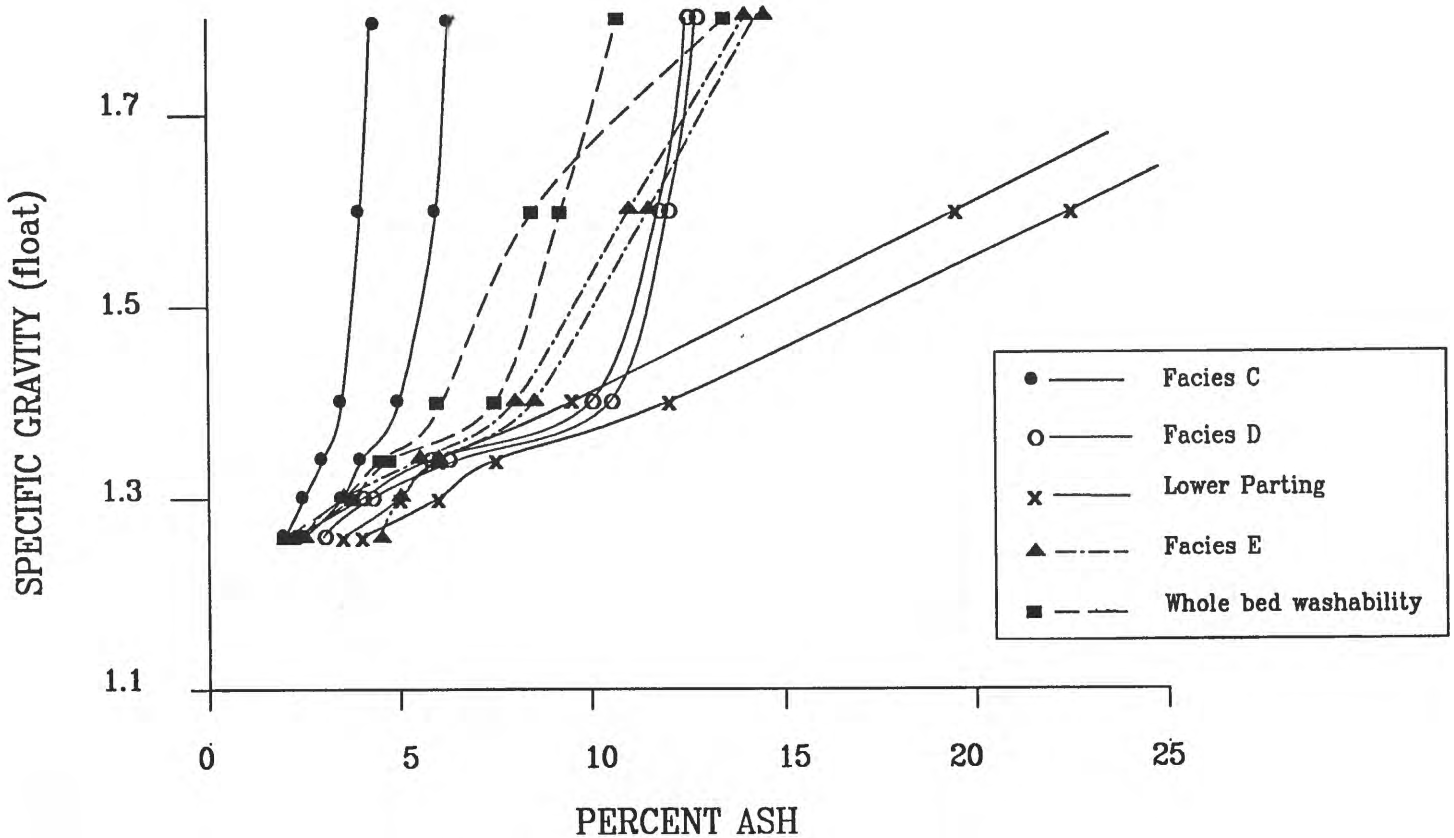

Figure 6. Washability curves of Specific Gravity vs Percent Ash for the Upper Freeport coal bed.

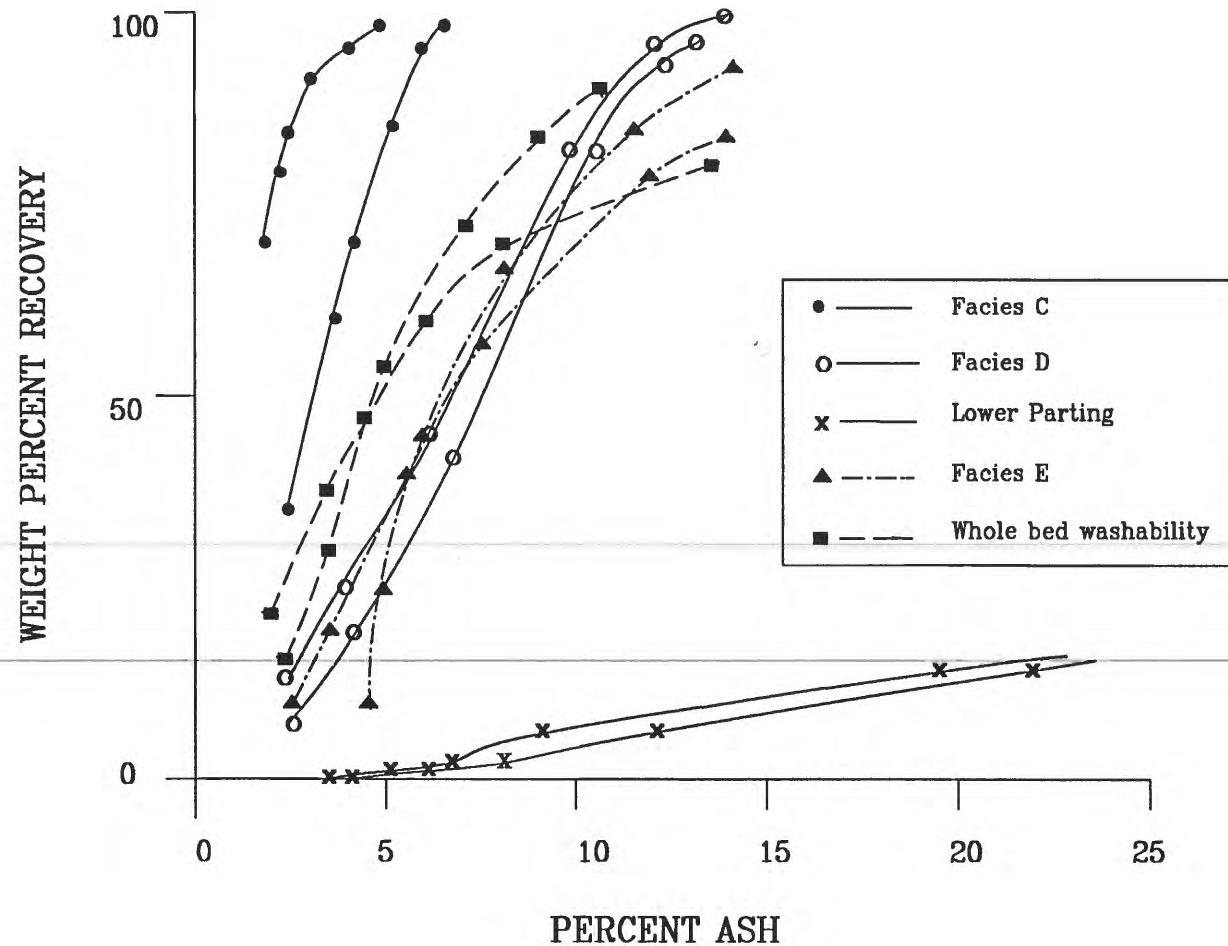

Figure 7. Washability curves of Yield vs Percent Ash for the Upper Freeport coal bed.

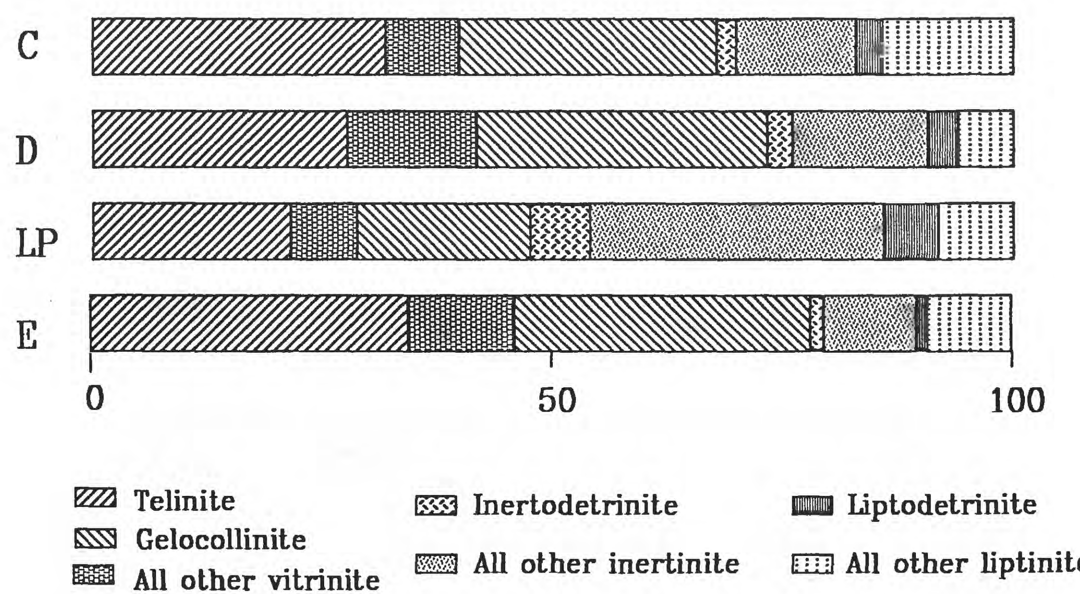

Figure 8. Petrographic composition of the Upper Freeport coal bed.

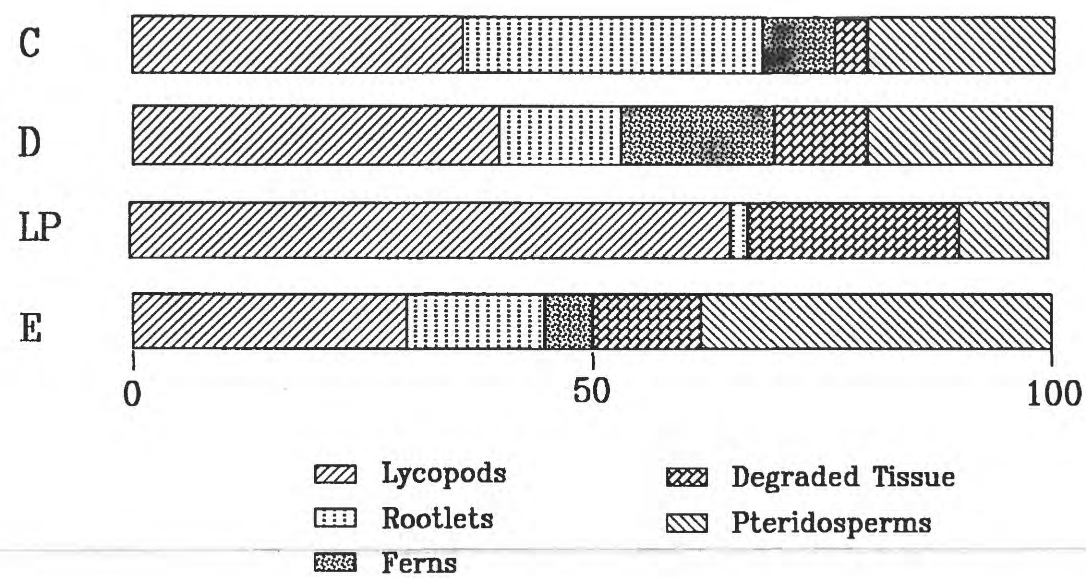

Figure 9. Paleobotanical composition of the Upper Freeport coal bed (data from Winston, in press).