Geology and Mineralogy

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Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

LABORATORY STUDY OF URANIUM-BEARING LIGNITE FROM WESTERN NORTH DAKOTA AND SOUTH DAKOTA*

By

James M. Schopf, Ralph J. Gray and Charles J. Felix

October 1955

Trace Elements Investigations Report 572

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

USGS - TEI-572

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	51

CONTENTS

ILLUSTRATIONS

Page

TABLES

LABORATORY STUDY OF URANIUM-BEARING LIGNITE FROM WESTERN NORTH DAKOTA AND SOUTH DAKOTA

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ABSTRACT

Laboratory studies of uraniferous coal were started in connection with explorational core drilling in 1951. The cores were described and used for coal analyses, for determinations of uranium and other mineral elements, and for microscopical investigations. Results of microscopical studies are featured in this report.

The coal is generally similar to woody lignite commercially mined in North Dakota. Many of the coal beds show a top preferential distribution of uranium. Fine-textured (attrital) coal layers sometimes contain more uranium than woody layers, but numerous exceptions show that plant composition is less important than position relative to tuffaceous deposits that are a potential uranium source. This agrees with results of other studies which indicate ground water effects the transfer of uranium into the coal beds. The Dakota coal beds that are not in a favorable position for uranium enrichment are similar to most coal deposits in having a very low uranium content. The slight control of uranium concentration by different kinds of coaly material agrees with other evidence which suggests that uranium was introduced after the coal had reached its present state of consolidation.

INTRODUCTION

This report gives the results of studies, carried on since 1951, of uraniferous lignite deposits in Harding and Perkins Counties, S. Dak., and Bowman County, N. Dak. These studies have been in connection with programs of explorational core drilling conducted by the U. S. Geological Survey in 1951 and 1952, and in cooperation between the Survey and the U. S. Bureau of Mines in late 1952 and 1953. Results of drilling programs have been reported by Zeller (in preparation) and Gill (in preparation).

Laboratory studies were undertaken to show what relationship existed between the kinds of lignitic plant material and its uranium content. A further consideration was the nature of the coal, its mode of formation, and characteristics related to potential utilization. The ease with which uranium may be concentrated in coal ash and the possibility of recovering heat or byproducts while coal is being processed for recovery of uranium, suggest that relatively low grade uraniferous coal deposits may hold economic promise.

Initial studies were largely concerned with sampling of cores shipped from the field to obtain coordinated coal analytic, uranium and spectrographic data, and a detailed laboratory description of the material. Initial radioactivity determinations also were obtained during this work of "core processing." A reserve of core material was taken at the time cores were originally sampled, for use in the studies now being reported. Material was studied from 27 drill holes, one auger hole and one column from a former mine opening. This amounted to nearly 500 feet of core, about half of it coal.

Methods of core processing and determination of radioactivity have been discussed in progress reports previously issued (Schopf, Gray and Warman, 1953, p. 125-138; idem, 1953, p. 146-156; Schopf and Gray, 1953, p. 156-159; Schopf, Gray and others, 1954, p. 124-129; Schopf, Warman and others, 1954, p. 129-131; Schopf, Gray and Felix, 1954, p. 175-180). Coal petrologic methods developed by Thiessen and his colleagues at the U. S. Bureau of Mines (Thiessen, 1931; Thiessen and Sprunk, 1935; Thiessen, 1937; and Parks and O'Donnell, 1949) have been followed and to some extent expanded upon as indicated in a previous report (Schopf and Gray, 1954). Correlation of different kinds of analytic results with microscopical studies has provided an unusually complete characterization of these lignite deposits.

The studies conducted for this report have been carried out by the Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

Geologic setting

The Dakota uraniferous coal deposits occur in the Ludlow member of the Fort Union formation of Paleocene age. The beds appear to be largely flat lying, but Gill's studies (report in preparation) have shown that structural irregularities occur. Fort Union beds were truncated by erosion during the mid-Tertiary, and sandy and tuffaceous beds of the White River group and Arikaree sandstone were deposited above this erosional unconformity. The region was elevated during the later Tertiary and at present the deposits are being dissected. Rocks of the areas studied form stratigraphic outliers located in the drainage basins of the Grand, Moreau and Little Missouri Rivers. The White River beds and overlying Arikaree sandstone characteristically form cliffs, buttes and mesas above the rolling terrain of this plains country.

Bentonitic beds, which occur in the lower part of the White River group and the Ludlow shales, are not resistant to erosion. Consequently, the margins of the buttes are subject to slumping, and it is difficult to interpret bed rock geology from outcrops. Drilling has shown that at least six minable beds are present in the Mendenhall area of the Slim Buttes. A greater number of beds are present in the northern part of the Slim Buttes in the Bar H area and at least one bed, in addition to the Harmon, is present in the Lodgepole area of Perkins County. These areas and others, in which uraniferous lignite has been studied during recent investigations by the U. S. Geological Survey, are shown in figure 1. The deposits reported on here are in the Mendenhall and Bar H areas of southeastern Harding County, S. Dak., the Medicine Pole Hills of central Bowman County, N. Dak., and the Lodgepole Hills of Perkins County, S. Dak.

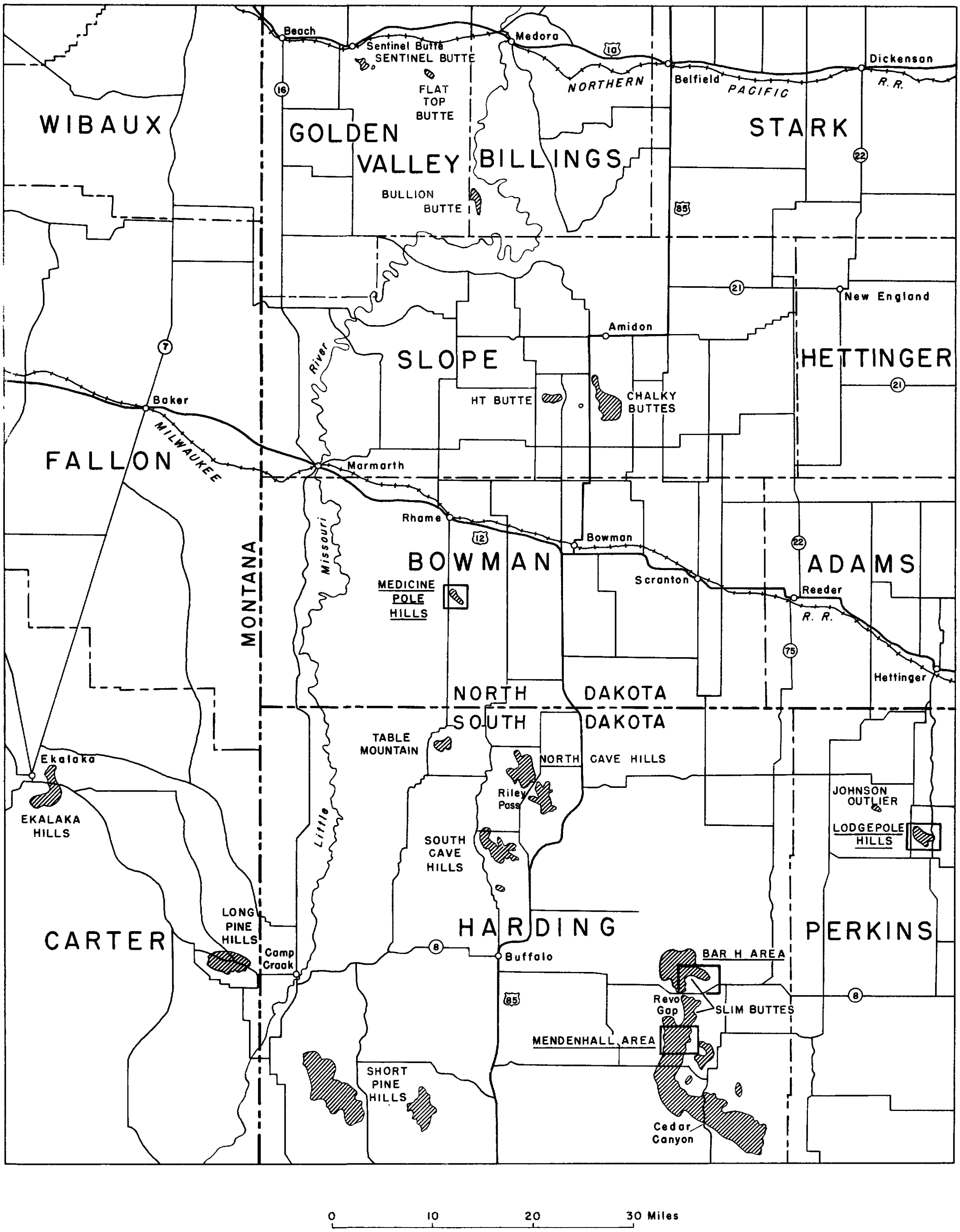


Figure 1.— Index map showing areas of uranium-bearing lignite.

A more detailed account of the geology of Dakota uraniferous coal is given by Denson, Bachman and Zeller (in preparation), by Zeller (in preparation) and by Gill (in preparation). Geologic mapping of Harding and Perkins Counties, S. Dak. was done by Winchester and others (1916), and Hares (1928) mapped the lignite resources of the Marmarth field in southwestern North Dakota. Breger, Deul, and Rubinstein (1955) studied the chemistry of uranium association in the Mendenhall coal. They determined that the uranium exists as an organo-uranium complex or compound and that little of the uranium is held by adsorption in the coal.

Acknowledgments

Uranium, ash and spectrographic determinations have been carried out at the Washington laboratory of the U. S. Geological Survey. Chemical coal analyses have been made by the Coal Analysis Section of the U. S. Bureau of Mines under supervision of Roy F. Abernethy. James R. Gill, Charles Sterling, James Warman, Chester Blattert, Chester Frye, Vinton Garbesi, Peter Popenoe, Robert Caren, Bruce Middleton and Henry Hildreth helped at various times with core processing, radioactivity determination and thin section preparation of coal. Mr. Warman also assisted in analytic calculations and Mr. Hildreth assisted in making microscopical determinations.

COAL IN THE MENDENHALL AREA

The Mendenhall area, about 9 square miles in extent in the central part of the Slim Buttes of southeastern Harding County, S. Dak., has been explored the most extensively by drilling. Figure 2 shows the location of drill holes, drainage and the edge of the White River-Arikaree escarpment. The escarpment approximately corresponds with the extent of the overlying Arikaree formation in this area. The White River group crops out in a marginal zone around the escarpment and the drill holes penetrate to the coal-bearing Ludlow member of the Fort Union formation beneath the White River unconformity.

Three pairs of minable coal beds have been sampled by this series of drill holes. All are somewhat variable in thickness and partings. They have been designated as follows for purposes of this report:

Coal Beds	Thickness
1. Upper Mendenhall Rider	Up to 5.25' in hole SD-8
2. Lower Mendenhall Rider	Up to 8.04' in hole 16
3. Upper Mendenhall	Up to 5.29' in hole SD-19
4. Lower Mendenhall	Up to 7.78' in hole 3
5. Upper Olesrud	Up to 6.93' in hole SD-19
6. Lower Olesrud	Up to 5.69' in hole SD-8

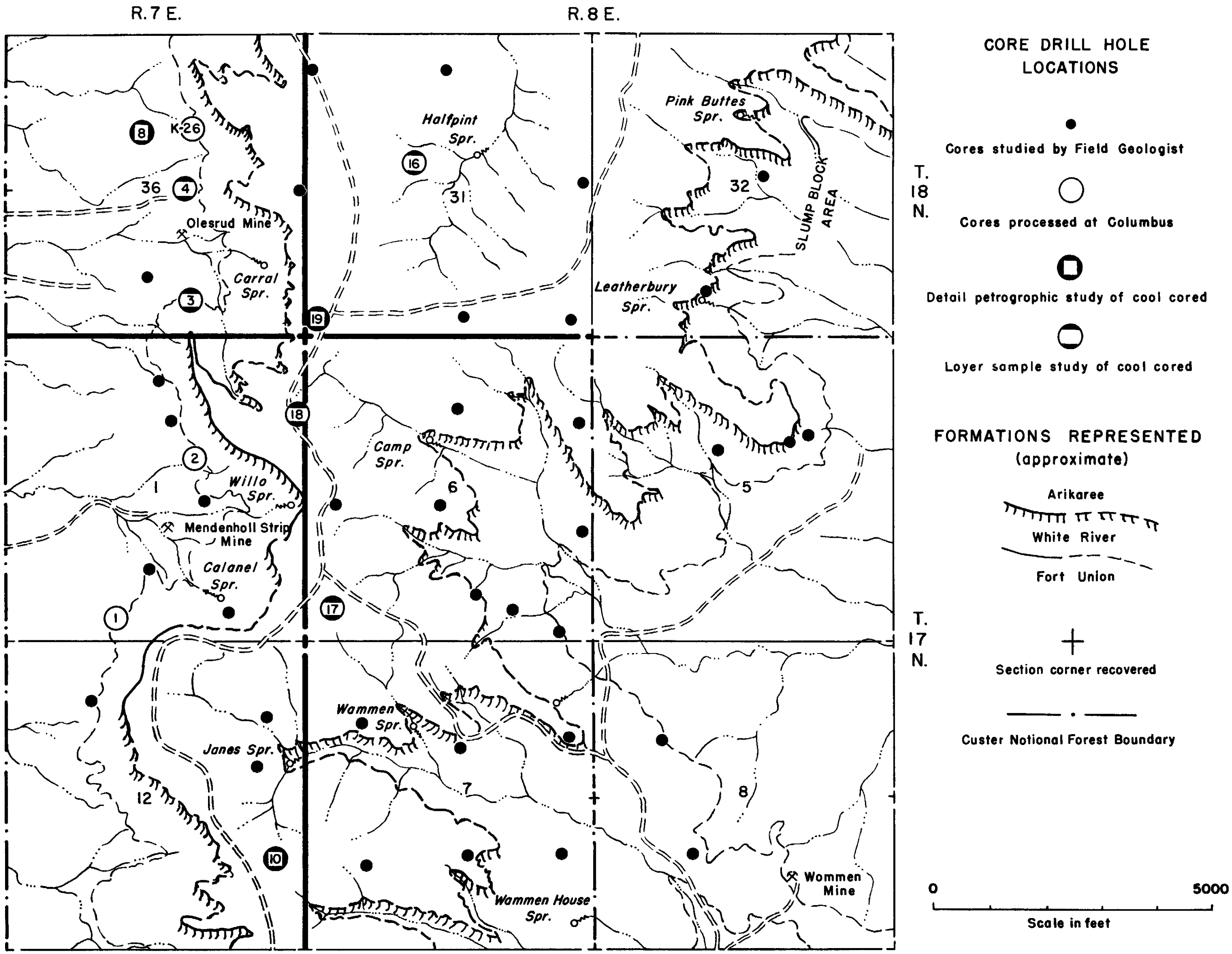


Figure 2. — Index map of the Mendenhall area, Slim Buttes, Harding County, South Dakota, showing locations of core drill holes. (after J. R. Gill)

A summary of chemical analyses of these coal beds in the Mendenhall area is given in table 1. All the beds are of lignitic rank (moist, mineral-matter-free Btu < 8,300) and probably have a bed moisture content of 42 or 43 percent. Ash varies from 8 to 10 percent. All values are based on material obtained from unweathered drill cores that had been protected from drying. However, none of the samples were equilibrated for moisture, so it may not be safe to use the moist analytic results for purposes of very precise comparison. Many of the analyses not used in preparing these averages showed less moisture and most of these samples evidently had dried before analyses could be made. In a number of instances coal analyses have been obtained from samples in which substantial partings or other extraneous material was present. None of these faulty analyses were used in preparing table 1 so that the results given seem to represent fairly the best available information on the minable coal in the Mendenhall area. Source of all of the samples averaged is indicated. Individual analyses are given by Zeller (report in preparation, in Appendix B) and by Gill (report in preparation, in Appendix B). Core descriptions have been given for coals of the plain numbered drill holes 1 - 9 in Appendix C, by Zeller (in preparation), and for the "SD" cores studied at Columbus in Appendix A, by Gill (in preparation).

TABLE 1. - Averages of selected chemical analyses of coal beds in the Mendenhall area.

Basis of reporting 1/	Proximate, percent				Ultimate, percent								Calorific value
	Moisture	Volatile matter	Fixed carbon	Ash	Total sulfur	Sulfate sulfur	Pyritic sulfur	Organic sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	B.t.u.
UPPER MENDENHALL RIDER COAL BED													
AR	39.0	25.5	29.5	6.0	1.0	0.03	0.40	0.59	6.9	39.2	0.5	46.4	6,510
MF		41.8	48.4	9.8	1.7	0.05	0.65	0.73	4.2	64.3	0.7	19.3	10,670
M&AF		46.4	53.6		1.9	0.59	0.97	1.07	4.7	71.3	0.8	21.3	11,840
MMinF	41.9	26.5	31.6										6,950
M&MinF		45.6	54.4										11,970
Includes only one analysis representing the lower part of the coal bed from hole SD-8. Sample may contain a little less than normal bed moisture. Real specific gravity 1.55.													
LOWER MENDENHALL RIDER COAL BED													
AR	43.4	22.0	26.8	7.8	0.8	0.02	0.03	0.66	7.1	35.0	0.4	49.0	5,820
MF		38.9	47.4	14.7	1.4	0.03	0.06	1.20	4.0	62.0	0.8	18.3	10,300
M&AF		45.1	55.0		1.6	0.04	0.07	1.33	4.6	71.8	0.9	21.3	11,930
MMinF	47.6	23.1	29.4										6,350
M&MinF		44.1	56.0										12,120
Based on two proximate & ultimate analyses, holes SD-8 & 16; forms of sulfur from hole SD-8. Real specific gravity 1.57.													
UPPER MENDENHALL COAL BED													
AR	42.3	23.1	25.4	9.2	1.3	0.03	0.85	.63	6.9	33.8	0.5	47.1	5,690
MF		40.0	44.1	16.0	2.3	0.04	1.48	1.11	3.8	59.2	0.8	15.6	10,140
M&AF		47.6	52.4		2.8	0.06	1.80	1.36	4.7	72.3	1.0	18.8	12,060
MMinF	47.4	24.5	28.3										6,480
M&MinF		46.4	53.7										12,310
Based on four proximate analyses from holes 3, 4, 18 & SD-19; two ultimate analyses & forms of sulfur from holes 18 & SD-19. Real specific gravity 1.65.													
LOWER MENDENHALL COAL BED													
AR	43.2	22.7	26.0	8.1	1.3	0.01	0.13	0.63	7.2	34.1	0.4	49.8	5,830
MF		39.9	45.7	14.3	2.2	0.01	0.23	1.14	4.0	61.8	0.8	17.9	10,250
M&AF		46.6	53.4		2.6	0.01	0.27	1.32	4.6	71.9	0.9	21.0	11,960
MMinF	47.7	23.8	28.5										6,370
M&MinF		45.5	54.5										12,170
Based on five proximate analyses from holes 3, 4, 17, 18 & SD-19; one ultimate analysis & forms of sulfur from hole SD-19. Real specific gravity 1.61.													
UPPER OLESRUD COAL BED													
AR	43.4	22.5	25.9	8.1	0.9	0.01	0.23	0.56	7.2	34.3	0.4	49.8	5,790
MF		39.7	46.0	14.3	1.6	0.02	0.35	1.01	4.0	61.9	0.8	18.3	10,220
M&AF		46.4	53.6		1.9	0.02	0.40	1.15	4.6	71.7	0.9	21.2	11,930
MMinF	47.8	23.7	28.5										6,340
M&MinF		45.4	54.6										12,140
Based on five proximate analyses from holes 3, SD-8, SD-10, 18 & SD-19; four ultimate analyses from SD-8, SD-10, 18 & SD-19 & three forms of sulfur from holes SD-8, SD-10 & SD-19. Real specific gravity 1.60.													
LOWER OLESRUD COAL BED													
AR	43.1	22.4	25.8	8.8	1.0	0.01	0.25	0.78	7.2	34.0	0.4	49.1	5,820
MF		39.4	45.3	15.4	1.8	0.02	0.45	1.13	4.1	60.6	0.8	17.8	10,220
M&AF		46.5	53.5		2.1	0.03	0.51	1.33	4.8	71.3	0.9	21.0	12,080
MMinF	47.9	23.7	28.5										6,410
M&MinF		45.4	54.6										12,290
Based on four proximate analyses from holes 3, SD-8, SD-10 & SD-19; three ultimate analyses & forms of sulfur from holes SD-8, SD-10 & SD-19. Real specific gravity 1.59.													

1/ AR, as received; MF, moisture free; M&AF, moisture and ash free; MMinF, moist, mineral-matter free; M&MinF, moisture and mineral-matter free.

Table 2 shows the average temperatures of ash fusion for the six Mendenhall coal beds. These data are of interest in connection with recovery of uranium after ashing the coal, inasmuch as the solubility of uranium may be affected by its intermediate combination in ash components. Generally speaking, the fusion temperatures of the Mendenhall area coal beds are in the low to intermediate fusion range.

TABLE 2. - Temperatures of average fusibility of ash (degrees Fahrenheit), Mendenhall area coal beds.

	Initial deformation	Softening	Fluid
Upper Mendenhall Rider (One analysis, hole SD-8)	2170	2260	2370
Lower Mendenhall Rider (One analysis, hole SD-8)	2100	2250	2340
Upper Mendenhall (Analyses of holes 3, 4, 18 & SD-19)	1980	2070	2140
Lower Mendenhall (Analyses of holes 3, 4, 17, 18 & SD-19)	1960	2100	2160
Upper Olesrud (Analyses of holes 3, 8, SD-10, 18 & SD-19)	2060	2120	2180
Lower Olesrud (Analyses of holes 3, SD-8, SD-10 & SD-19)	2063	2108	2268

Table 3 gives the average petrologic composition of the six coal beds in the Mendenhall area. Average values for woody lignite from commercial mines in North Dakota and for attrital lignite from Arkansas, Texas and California also are given for purposes of comparison. Maximum and minimum values are shown in parentheses where more than one analysis can be reported. All the Mendenhall coal beds are within the range of composition of woody lignite. Coal of the Mendenhall area appears to have a higher than average fusain content.

TABLE 3. - Average petrologic composition, in percent, of coal beds in the Mendenhall area, and average composition of other woody and attrital types of lignitic coal; maximum and minimum values shown in parentheses.

	Relatively Reactive Constituents		Relatively Inert Constituents	
	Anthraxylon	Translucent Attritus	Opaque Attritus	Fusain
Upper Mend. Rider (One analysis, hole SD-8)	60.6	29.8	1.7	7.9
Lower Mend. Rider (One analysis, hole SD-8)	56.6	27.8	6.0	9.6
Upper Mendenhall (Average of four analyses, holes 3, 4, 18 & SD-19)	47.9 (53.7-38.8)	43.7 (50.1-40.1)	3.8 (6.2-1.9)	4.7 (5.7-2.6)
Lower Mendenhall (Average of four analyses, holes 3, 17, 18, & SD-19)	54.1 (58.1-49.2)	36.2 (39.8-32.4)	4.1 (6.6-1.4)	5.6 (7.4-3.8)
Upper Olesrud (Average of five analyses, holes SD-8, SD-10, 17, 18, SD-19)	53.0 (57.7-43.6)	37.0 (47.1-29.3)	4.2 (5.6-2.7)	5.8 (8.6-2.1)
Lower Olesrud (Average of three analyses, holes SD-8, SD-10, SD-19)	56.1 (57.3-55.1)	35.2 (37.6-31.4)	3.6 (5.5-2.3)	5.1 (7.1-3.8)
N. Dakota woody lignite 1/ (Average of five analyses)	57.6 (63.0-53.4)	29.6 (33.4-25.1)	9.1 (15.4-3.8)	3.8 (6.6-1.0)
Three attrital lignites 1/ (Ark., Texas, Cal.)	18.3 (39.7-10.3)	79.1 (89.1-64.4)	2.3 (4.9-0.6)	0.3 (1.0-0.0)

1/ Averages for woody and attrital types of lignitic coal are based on column analyses given in U. S. Bureau of Mines Info. Circ. 7691, Table 10, p. 66, 1954.

Distribution of uranium

The radioactivity profiles of the six beds and their general lithologic characteristics in different drill holes are shown in figures 3, 4 and 5. All radioactivity determinations are given in pulses per minute per gram (P/M/G) which makes allowance for the differing densities of field rock and coal and in application has been found to correspond fairly well with actual determinations of uranium obtained from many of these same samples. 1/ The locations for each set of drill holes are shown on the small index maps on figures 3, 4 and 5 and may be compared with locations of other drill holes in the Mendenhall area shown on figure 2.

1/ Radioactivity determinations have been illustrated because they were obtained for all samples, many of which did not warrant chemical determinations of uranium. One P/M/G unit usually corresponds to 25 to 30 parts per million (.0025-.003%) uranium as determined by fluorimetric procedures.

Radioactivity profiles of coal beds usually indicate top-preferential distribution of uranium unless a higher coal bed intervenes below the White River tuffaceous deposits. The coal beds that show top-preferential radioactivity are those that appear to have had the higher coals removed by mid-Tertiary erosion before White River beds were deposited. In general the White River unconformity transgresses from a position 50 or 60 feet above the younger Rider beds in the northern part of the area, to places where the older Olesrud beds have been "cut out" in the southern part of the area. These relations have been discussed

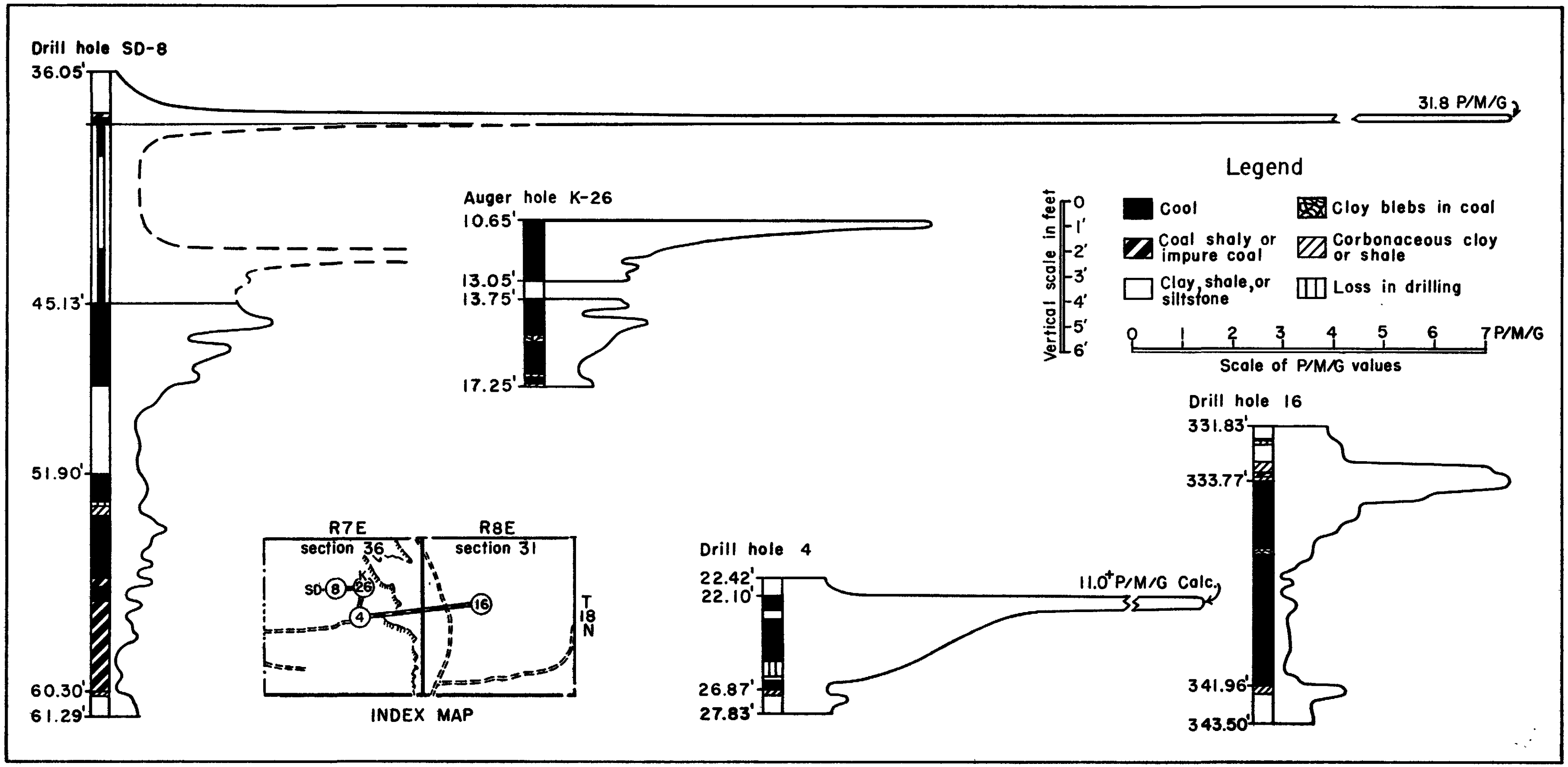


Figure 3.-Radioactivity profiles of Upper and Lower Mendenhall rider beds in the Mendenhall area, Harding Co., South Dakota.

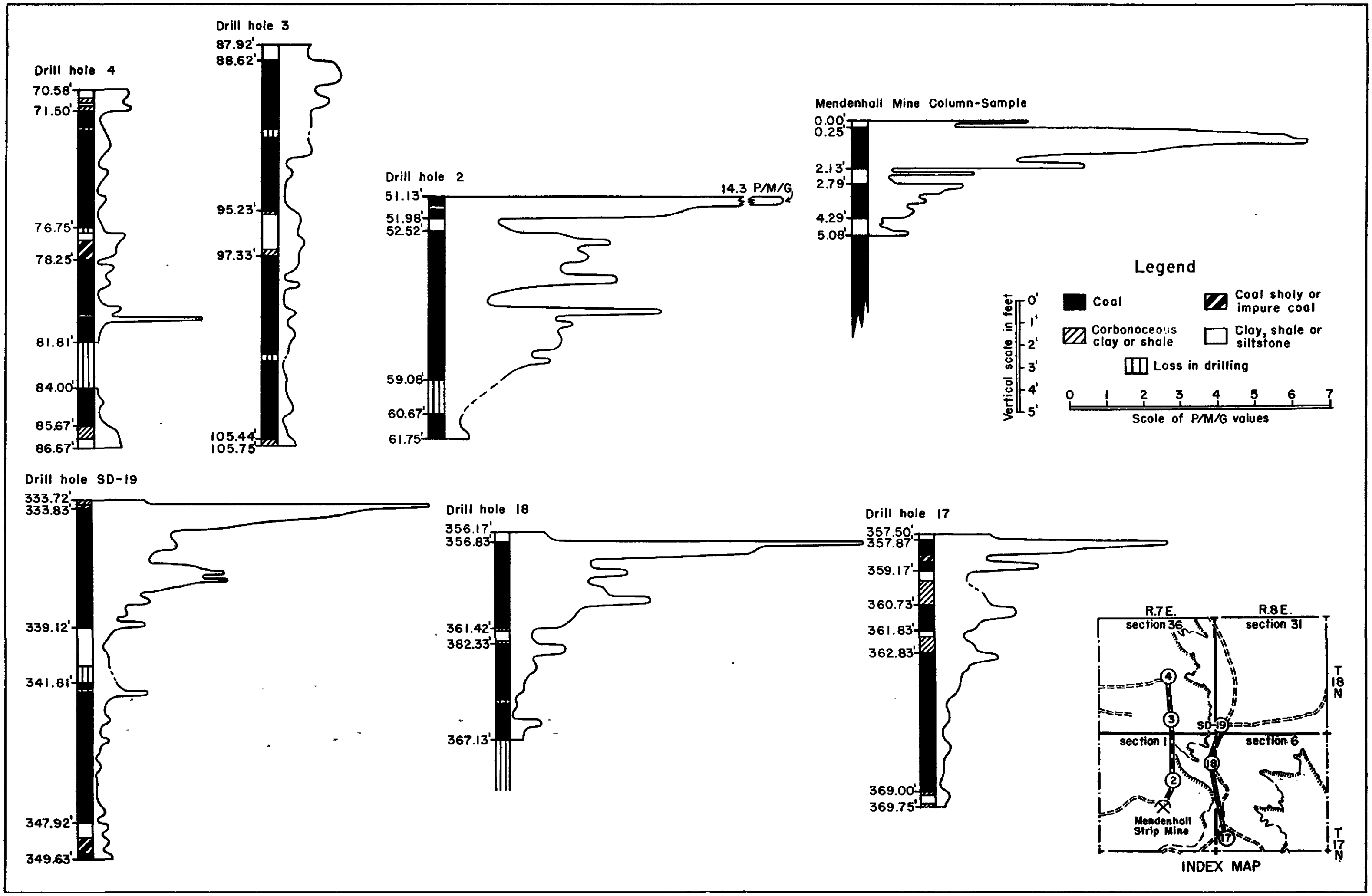


Figure 4.-Radioactivity profiles of Upper and Lower Mendenhall beds in the Mendenhall area, Harding County, South Dakota.

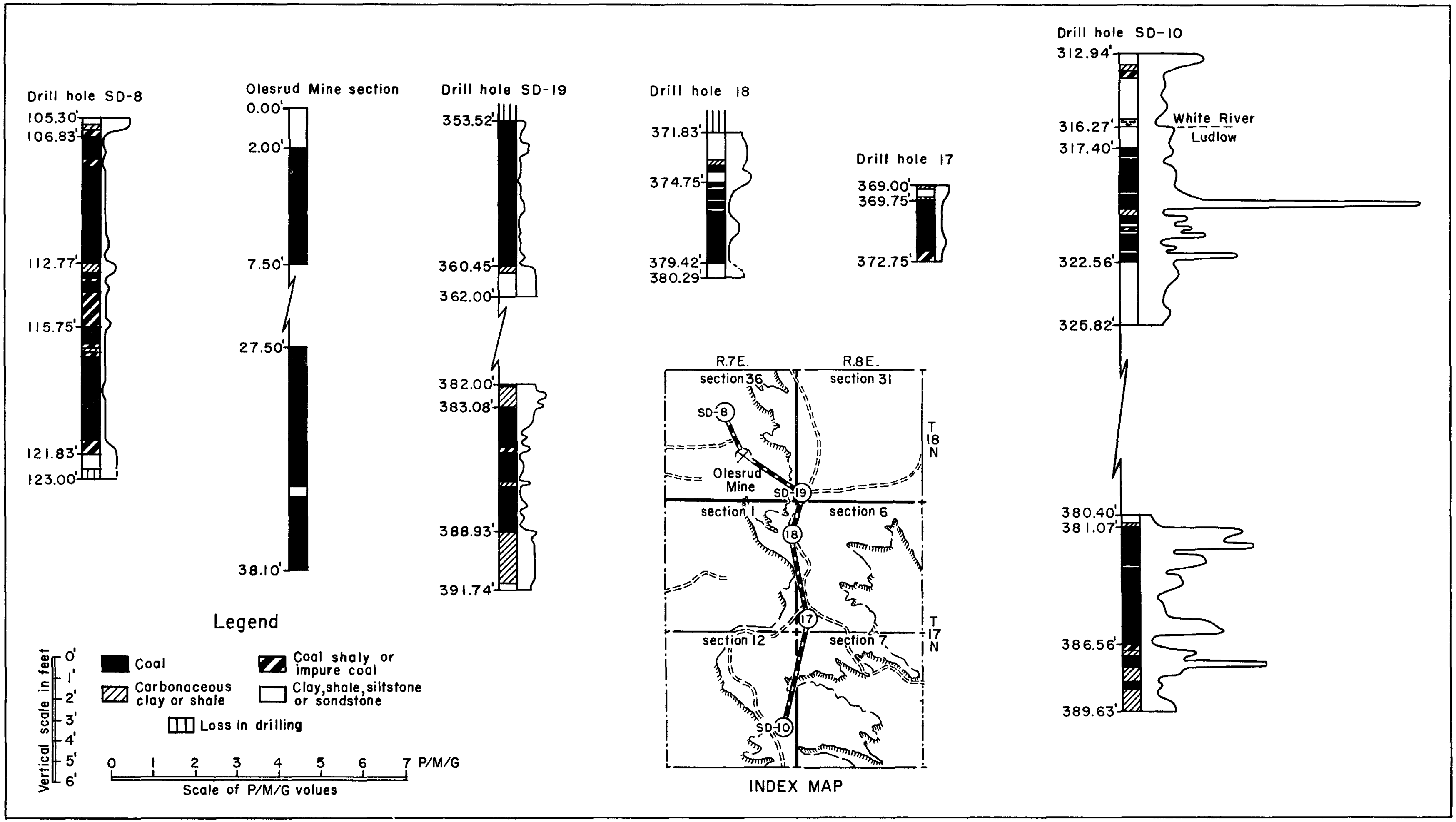


Figure 5.-Radioactivity profiles of Upper and Lower Olesrud beds in the Mendenhall area, Harding County, South Dakota.

in greater detail by Gill (in preparation). The only real exception to top-preferential distribution is shown by the two Olesrud beds in hole SD-10 (fig. 5). No convincing explanation is available for distribution of uranium in hole SD-10 although, in view of the importance of ground water movement that has been suggested by Denson, Bachman and Zeller (in preparation), it would seem that ground water circulation has not been normal at this locality. The White River unconformity is little more that a foot above the Upper Olesrud bed at hole SD-10 and irregularities probably can be expected close to this erosional contact with the coal.

These data show that there is a relationship between the overlying tuffaceous deposits from which uranium can be leached and the distribution of uranium in the coal beds. Nearly 200 chemical determinations of uranium in coal and associated rocks are available to us from coal deposits of the Mendenhall area. The uranium content of 150 of these samples (excluding those from hole SD-10) has been plotted in figure 6 in relation to the top of the <u>first</u> coal bed below the White River unconformity, to illustrate the degree to which position within the uppermost coal bed is related to uranium content. Practically all the samples of high uranium content are within 1-1/2 feet of the top of the upper coal bed; at a distance greater than 10 feet below the top of the coal bed, uranium values are low and correspond with those normal for most coal deposits, i.e., they are well below 10 parts per million (.001%). Secondary maxima, which are rather prominent in the Mendenhall coal beds (fig. 4), tend to be averaged out when the samples from many drill holes are plotted together. There is no indication of a "saturation threshold" for uranium in the coal within the range of concentration existing in these deposits; the rather uniform decrease in average

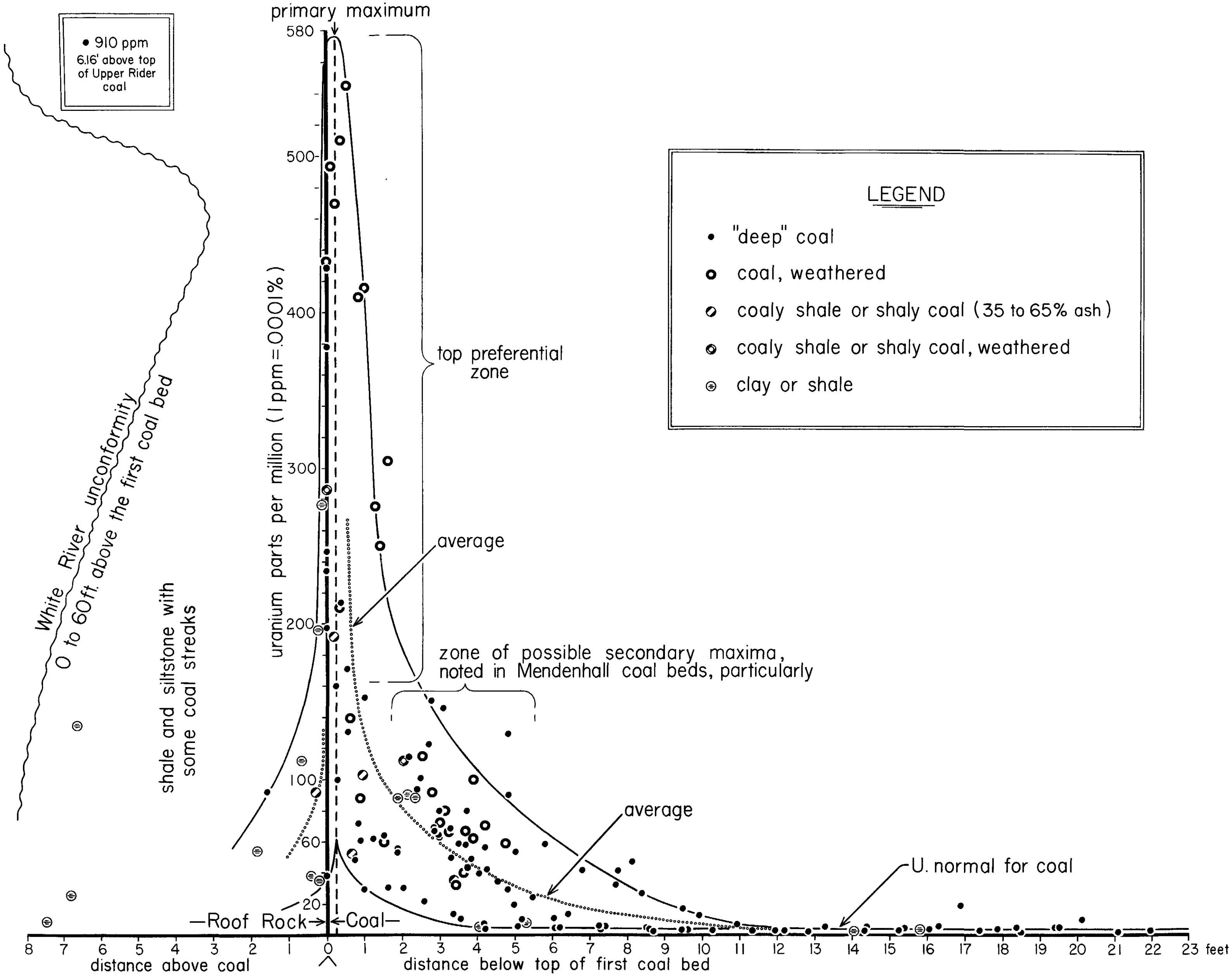


Figure 6. The uranium anomaly in coal beds below the White River unconformity in the Mendenhall area of South Dakota

uranium content below the top of the coal bed, as shown in figure 6, is suggestive of a diffusion front beneath a perched water table.

Characteristics of the coal

Following is a brief discussion of the distribution and petrologic composition for each of the six coal beds in the Mendenhall area. Petrologic characteristics are emphasized as this has been the principal objective of the laboratory study.

Upper Mendenhall Rider coal bed

The Upper Mendenhall Rider is the stratigraphically highest coal bed in the Mendenhall area, but, owing to the White River unconformity, it has the smallest areal extent. The material available for study was relatively scant and detailed petrologic studies are limited to the 3.12 feet of coal recovered from the middle and lower part of the bed in hole SD-8. Thus the information presented may not be characteristic of the bed in its entirety.

The coal studied is more woody in composition than any other beds of comparable thickness in the Mendenhall area and compares favorably in petrologic composition with woody lignite commercially mined in central North Dakota. Over 40 percent of the coal is composed of woody bands greater than 5 mm in thickness; about 7-1/2 percent of the coal consists of woody streaks 1/2 to 5 mm thick and about 12-1/2 percent consists of fibrous anthraxylon. About 8 percent of the bed is fusain, but less than 2 percent consists of opaque attritus. This is a relatively large amount of fusain for lignitic coal, but other coal beds of the Mendenhall area have nearly as much.

Only one chemical analysis of coal from the Upper Rider coal (hole SD-8) appears significant for purposes of comparison, and this has been given in table 1. The average uranium content of this coal sample is 0.008 percent (80 ppm) and is variable from layer to layer. A thin coaly layer about 5 feet above the top of the bed contained 0.09 percent uranium (900 ppm) which is the greatest of any samples reported in this study.

Thin sections have been studied for all the coal recovered from hole SD-8 and the results, in comparison with uranium and ash content, are shown in figure 7. The anthraxylon is very resinous and nearly all of it shows structures that identify its origin from gymnospermous wood. Translucent attritus contains a heterogeneous group of components that have been analyzed in detail. The data presented in table 5 show that humic matter degraded below a particle size of 2 or 3 microns makes up 80 to 90 percent of the translucent attritus in this coal. Opaque attritus is intimately mixed with translucent attritus in minor amounts. Figure 7 shows that the concentration of opaque attritus follows that of fusain. Not very much mineral matter is visible and ash determinations show this is not a high ash coal. Visible mineral matter (determined on the basis of area-volume) shows a parallelism with ash content (determined on the basis of weight). Pyritic mineral matter, some of it finely disseminated and some associated with fusain partings, is most abundant. Occasionally some of the clayey mineral matter (probably kaolinite) has infiltrated and petrified plant tissues during the peat stage before they were compressed.

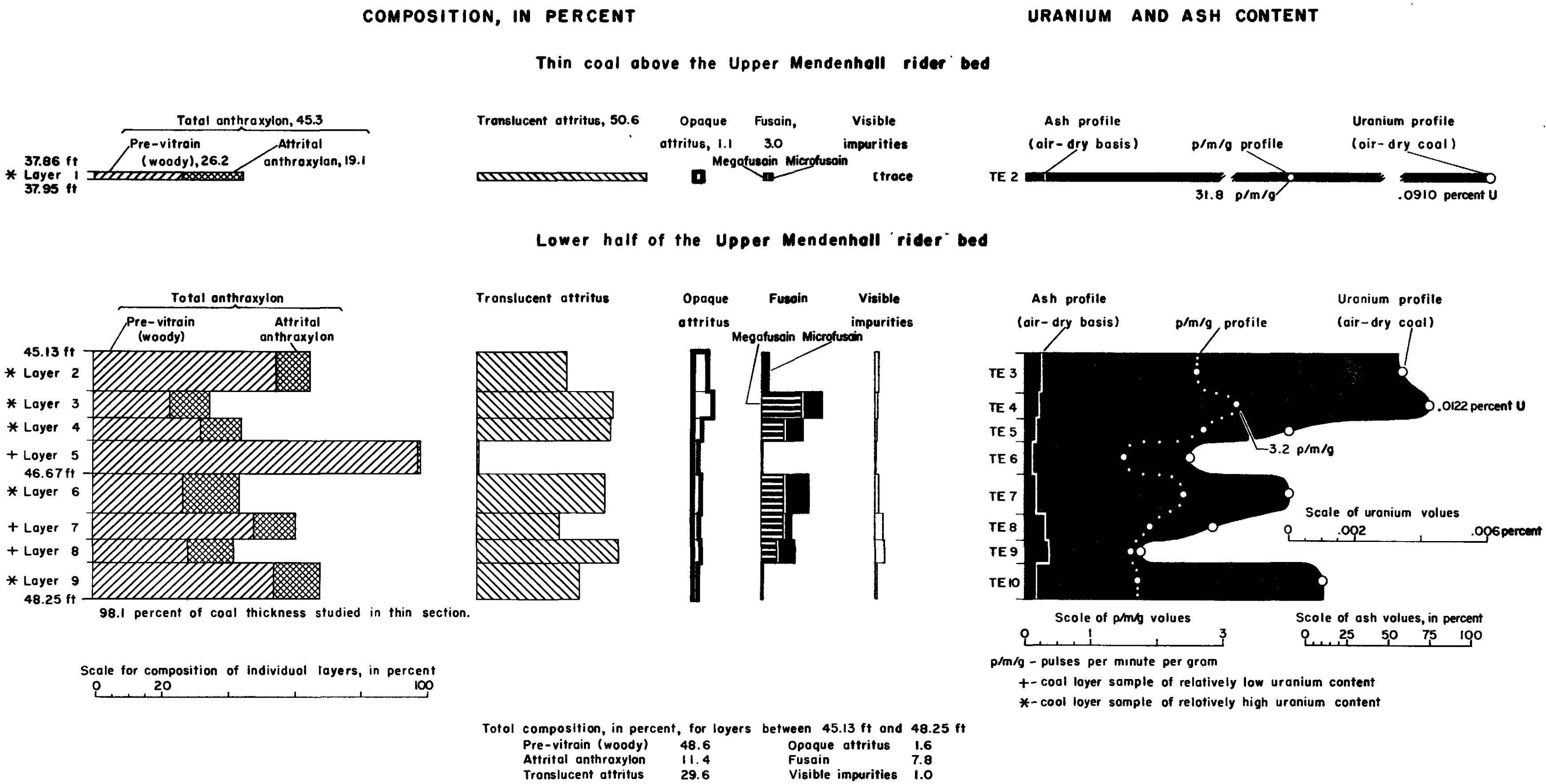


Figure 7. - Composition of lignite in lower half of the Upper Mendenhall rider bed and thin coal above, drill hole SD-8, Mendenhall area, Harding County, South Dakota.

A detailed analysis was made of all the coal in order to determine whether any microscopic components could be correlated directly with the concentration of uranium. Layers of the bed are arranged in table 4 in the order of their uranium content. The number of samples is insufficient for specific conclusions, but it is evident that the high uranium content of layer 1 must be attributed to its favorable position, rather than to differences in organic composition. The nearly pure woody coal composing layer 5 contains relatively little (50 ppm) uranium. Coal both above and below the woody layer is remarkably similar in both uranium content (80 ppm) and in organic composition. This suggests that organic composition may be important in determining uranium concentration within the central part of the bed. The higher uranium content of upper layers seems most easily explained by initial exposure to percolating, uranium-bearing waters. The higher concentration (90 ppm) of uranium in layer 9 at the base of the bed seems anomalous and may reflect the emplacement of uranium by a somewhat differing mechanism. Except for layer 5, the anthraxylon content is greatest in layer 9 at the base of the bed.

TABLE 4. - Composition (area percent) of uraniferous coal layers in the Upper Mendenhall Rider coal bed (hole SD-8), arranged in order of decreasing uranium content.

Constituents or Components	Layer 1 (TE-2)	Layer 3 (TE-4)	Layer 2 (TE-3)	Layer 9 (TE-10)	Layer 4 (TE-5)	Layer 6 (TE-7)	Layer 7 (TE-8)	Layer 5 (TE-6)	Layer 8 (TE-9)
Anthraxylon:									
Coarse	26.16	23.40	55.29	54.34	32.23	27.50	48.36	98.20	28.86
Attrital	19.07	12.14	10.19	13.99	12.47	16.65	13.42	0.58	13.46
Total	45.23	35.54	65.48	68.33	44.70	44.15	61.78	98.78	42.32
TRANSLUCENT ATTRITUS									
Subanthraxylon	0.16	1.01	0.45	1.21	1.49	1.35	0.74	-	0.78
Humic Matter	44.89	34.34	26.38	27.49	32.77	31.87	21.47	0.85	34.82
Total	45.05	35.35	26.83	28.70	34.26	33.22	22.21	0.85	35.60
Red Att. Resins	0.48	0.21	0.08	0.31	0.15	0.04	0.15	-	0.06
Cuticle	-	0.01	0.02	0.07	-	-	0.02	-	0.03
Spores	0.13	0.03	0.10	0.15	0.01	0.03	0.01	-	0.08
Yellow Att. Resins	0.19	-	0.02	0.07	-	-	0.03	-	-
Waxy Amorphous	2.51	0.11	0.10	0.24	0.04	0.07	0.05	-	0.27
Total	2.83	0.15	0.24	0.53	0.05	0.10	0.11	-	0.38
Fungal Phyterals	0.03	-	-	-	0.05	-	-	-	-
Brown Matter	2.0	5.38	0.54	1.41	5.79	5.24	2.81	-	6.92
Total Trans. Attritus	50.65	41.09	27.69	30.95	40.30	38.60	25.28	0.85	42.96
Opaque Attritus	1.08	4.41	3.40	0.03	1.91	1.53	0.89	0.04	1.88
Microfusain	1.5	5.87	2.19	0.44	4.87	6.89	2.76	0.32	5.42
Megafusain	1.5	12.30	-	-	7.56	7.62	7.05	-	4.89
Total	3.0	18.17	2.19	0.44	12.43	14.51	9.81	0.32	10.31
Disseminated Pyrites	-	0.34	0.98	0.07	0.22	0.94	2.13	-	2.20
Transparent Minerals	-	0.36	0.08	0.15	0.13	0.18	0.08	0.01	0.20
Clayey Minerals	-	0.09	0.19	0.04	0.32	0.08	0.05	-	0.13
Total	-	0.79	1.25	0.26	0.67	1.20	2.26	0.01	2.53
Total	99.96	100.00	100.01	100.01	100.01	99.99	100.02	100.01	100.00
Percent Uranium	.0910	.0122	.0114	.0090	.0080	.0080	.0057	.0050	.0035

TABLE 5. - Composition (area percent) of translucent attritus in uraniferous coal layers in the Upper Mendenhall Rider coal bed (hole SD-8), arranged in order of decreasing uranium content.

Components	Layer 1 (TE-2)	Layer 3 (TE-4)	Layer 2 (TE-3)	Layer 9 (TE-10)	Layer 4 (TE-5)	Layer 6 (TE-7)	Layer 7 (TE-8)	Layer 5 (TE-6)	Layer 8 (TE-9)
Subanthraxylon	0.32	2.46	1.62	3.92	3.71	3.51	2.93	This sample is 98% woody and lacks a significant amount of translucent attritus.	1.81
Humic Matter	88.63	83.56	95.28	88.83	81.32	82.55	84.96		81.05
Total	88.95	86.02	96.90	92.75	85.03	86.06	87.89		82.86
Red Attrital Resins	0.95	0.51	0.29	0.99	0.37	0.10	0.57		0.15
Cuticles	-	0.03	0.09	0.21	-	-	0.07		0.07
Spores	0.25	0.08	0.37	0.48	0.02	0.08	0.05		0.19
Yellow Attrital Resins	0.38	-	0.06	0.21	-	-	0.14		-
Waxy Amorphous	4.96	0.27	0.34	0.78	0.11	0.18	0.18		0.63
Total	5.59	0.38	0.86	1.68	0.13	0.26	0.44		0.89
Total Fungal Phyterals	0.57	-	-	-	0.12	-	-		-
Brown Matter	3.94	13.09	1.95	4.57	14.36	13.58	11.11		16.10
Total	100.00	100.00	100.00	99.99	100.01	100.00	100.01		100.00
Total Translucent Attritus in Layer	50.65	41.09	27.69	30.95	40.30	38.60	25.27	0.856	42.97
Percent Uranium	.0910	.0122	.0114	.0090	.0080	.0080	.0057	.0050	.0035

Lower Mendenhall Rider coal bed

The Lower Rider bed underlies the Upper Mendenhall Rider and is separated from it by a variable succession of clay, shale and siltstone, ranging from 4 inches to 11 feet thick. Siltstone is most evident where the interval is thickest. The Lower Rider coal bed has its greatest proved thickness in the northern part of the area and both thins and is removed by pre-White River erosion in the central and southern part. Its further extension northward is unknown.

Two coal cores suitable for study were available from the Lower Mendenhall Rider coal bed. Most of the petrologic information to be presented is from the 4.3 feet of coal in hole SD-8. The greater thickness of Lower Rider coal in hole 16 reported on previously (Schopf and Gray, 1954, p. 5) was based on a less adequate sampling for microscopic study than now appears desirable. Unfortunately the core reserve material from hole 16 was exhausted by early initial studies and no additional information can be obtained. Study of the complete series of their sections obtained from the Lower Rider bed in hole SD-8 indicates a considerably lower concentration of opaque matter than was reported in the coal at hole 16. However, samples from both holes evidently have much brown matter contributing to translucent attritus so that the distinction between opaque and translucent attritus is less definite than it usually is.

The Lower Rider coal bed has less coarse woody material in it than the Upper Rider bed previously discussed. About 22-25 percent is composed of woody bands more than 5 mm thick and about 10 percent of the coal consists of woody streaks 1/2 to 5 mm thick. About the same amount of fusain (8%) is present in the Upper and Lower Rider beds, but the Lower Rider contains more than twice as much opaque attritus (over 5%).

Two adequate analyses of the Lower Rider coal are included in the average values in table 1 (B. of M. Lab. Numbers E-19299 from SD-8 and D-71570 from hole 16). An average value for uranium content would lack much significance because this evidently greatly depends on the local presence or absence of the Upper Rider coal. Regular top preferential distribution of uranium is shown by the coal in hole 16 where the Upper Rider is absent (Schopf and Gray, 1954, fig. 3) but the bed evidently has a low uranium content in hole SD-8 (fig. 8) as shown by radioactivity determinations.

Thin sections have been studied for nearly all the coal recovered from the 4.3 feet of the Lower Rider bed in hole SD-8. These results are summarized and given in comparison with radioactivity measurements in figure 8. Anthraxylon in the coal closely resembles that in the Upper Rider bed in being derived from highly resinous gymnospermous wood; a considerable amount of anthraxylon also is derived from gymnospermous bark. Fibrous flattened rootlets, which may not be of gymnospermous origin, are abundant in the more finely textured attrital coal. Translucent attritus is very fine textured and often is intimately associated with disseminated granules of brown and opaque matter so that it has a "speckled" appearance under the microscope.

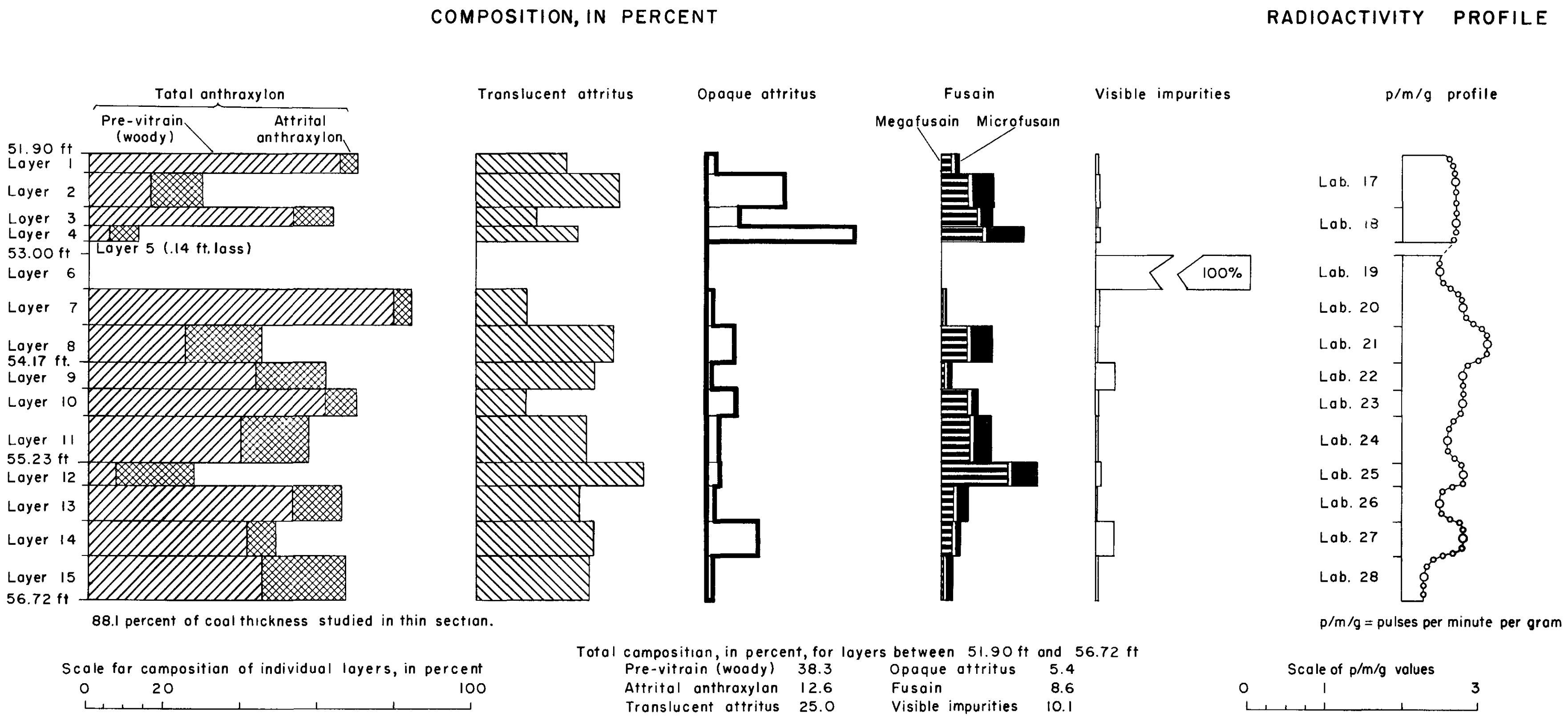


Figure 8.– Composition of lignite in Lower Mendenhall rider bed, drill hole SD-8, Mendenhall area, Harding County, South Dakota.

Very little cuticular matter is present, but some small spores and pollen grains are generally present in the attrital areas. Much of the fusain is evidently derived from the same type of gymnospermous wood that is so commonly preserved as anthraxylon.

A moderate amount of visible impurity is present. In a few instances kaolinite has been observed filling delicate uncompressed cellular tissue. Disseminated pyrite is observable in many sections and some fusain lenses are more highly pyritized. However, chemical analyses show less than 1 percent sulfur on an as-received basis.

Owing to the low uranium content of the Lower Rider coal in hole SD-8, no detailed component analyses of particular layers have been made.

Upper Mendenhall coal bed

The Upper Mendenhall coal bed is separated from the Lower Rider bed that overlies it, by an interval of variable clastics 11 to 46 feet thick. Clay is most common directly below the Lower Rider. Gray shale, carbonaceous shale, siltstone and sandstone are present between the two coal beds. Local coaly streaks usually represent drift logs, but a thin layer of attrital coal also occurs 3 feet above the Upper Mendenhall bed in hole SD-8. Sandy or silty deposits are commonly present directly above the Upper Mendenhall coal bed. The Upper Mendenhall coal bed extends over a larger area than the Lower Rider and is less extensive than the Lower Mendenhall bed beneath it (Gill, report in preparation). The Upper Mendenhall bed has more local partings than other beds of the area.

Four cores were available for study of the Upper Mendenhall coal bed from holes 3, 4, 18 and SD-19. Good megascopic information was obtained from all of these cores, but not enough material was saved from holes 3 and 4 to provide accurate microscopic results. About 17 percent of the Upper Mendenhall coal bed from these cores consists of woody bands more than 5 mm thick; about 10 percent is in thinner bands ranging from 1/2 to 5 mm in thickness. Thus the thin woody streaks are present in about the same proportion as in the two Rider beds above, but less coarse woody material is present. Nearly 5 percent of the coal consists of fusain and about 4 percent can be identified as opaque attritus. Somewhat lesser amounts of inert organic constituents are present than in the Lower Rider bed (table 3).

A column specimen of weathered coal, representing the two benches of the Upper Mendenhall coal bed (fig. 4), was collected at the abandoned Mendenhall strip mine (fig. 2) in July 1952 by Messrs. N. M. Denson, H. D. Zeller and A. Erickson of the Geological Survey, and T. F. Bates and W. Spackman, Jr. of Pennsylvania State University. An equal division of the column specimen was made for separate studies by the Geological Survey and by Pennsylvania State University. The collection site and method of sampling have been reported by Bates and his associates (1953). The difficulties in petrologic study of weathered lignites have been described in their report. The weathered lignite from the Mendenhall strip mine corresponds with material studied by Breger, Deul and Rubinstein (1955) that showed how closely uranium is associated with organic matter in coal.

Table 6 shows the contrast in composition between coal from drill holes 18 and SD-19 and weathered coal from the Mendenhall mine. The coal from the mine is materially different from that of the drill holes correlated with it. Probably the apparent increase in opaque attritus is partly induced by oxidation in weathering. This cannot account for the greater amount of fusain or the extreme reduction in amount of anthraxylon. It appears that this coal was originally much more highly attrital than the other samples studied. Comparison of the results of petrologic study of weathered and unweathered lignite is of interest because similar studies have not been made.

TABLE 6. - Comparison of petrologic composition of coal from Mendenhall strip mine and from the Upper Mendenhall coal bed of drill cores (percent area=volume).

	Anthra-xylon	Transl. Attritus	Opaque Attritus	Petrog. Fusain	Visible Impurity
Hole SD-19	48.6	39.7	5.0	5.6	1.0
(Over 90% of fine textured coal sampled microscopically.)					
Hole 18	38.2	49.3	6.1	4.8	1.5
(About 20% of fine textured coal sampled microscopically.)					
Strip mine	5.7	64.8	13.1	13.4	3.0
(About 50% of fine textured coal sampled microscopically.)					

An indication of the degree of weathering of the strip mine coal is shown by comparison of as-received calorific values, 3800 Btu for the upper bench of coal from the strip mine and about 5690 Btu for unweathered coal of the Upper Mendenhall bed (table 1). Coal from the strip mine had less than .1 percent pyritic sulfur and none of the pyrite was visible; sulfates are abundant. Analysis of the weathered coal showed 31.6 percent oxygen (M&AF basis), but the unweathered coal contained 18.8 percent oxygen.

Four proximate and two ultimate analyses were selected as representative of the unweathered coal in the Upper Mendenhall coal bed (B. of M. Lab. numbers D-68853, D-68864, D-73909, E-12615). The average results have been presented in table 1. The uranium content of the coal varies greatly as indicated by radioactivity profiles from six drill holes and the mine column specimen shown in figure 4. Presumably, pronounced top preferential distribution of uranium is not found in coal from hole 4 because the Lower Rider coal is above it at this location (fig. 3). No coal bed was found above the Upper Mendenhall in hole 3, but the low uranium content suggests that it has been affected by an overlying coal bed that may be present within a short distance from this location. Secondary maxima in uranium content frequently occur in the Upper Mendenhall bed, associated with impurities in the coal or clay or shaly partings. These seem to be of local significance as the partings are variable and the uranium values tend to average out as shown in figure 6. Gill (report in preparation) has estimated that the combined Upper and Lower Mendenhall beds in this area have an average uranium content exceeding 0.005 percent.

Thin sections have been studied for all the coal recovered from hole SD-19. These results are summarized according to layers and in comparison with uranium and ash content in figure 9. Similar results based on study of the weathered coal from the strip mine column specimen are given in figure 10. The highly attrital character of the strip mine coal is evident, and this may be generally reflected by its much higher uranium content. It seems clear, however, that the relation of uranium to petrologic constituents is not very specific and that position in the bed and the presence of partings is more important.

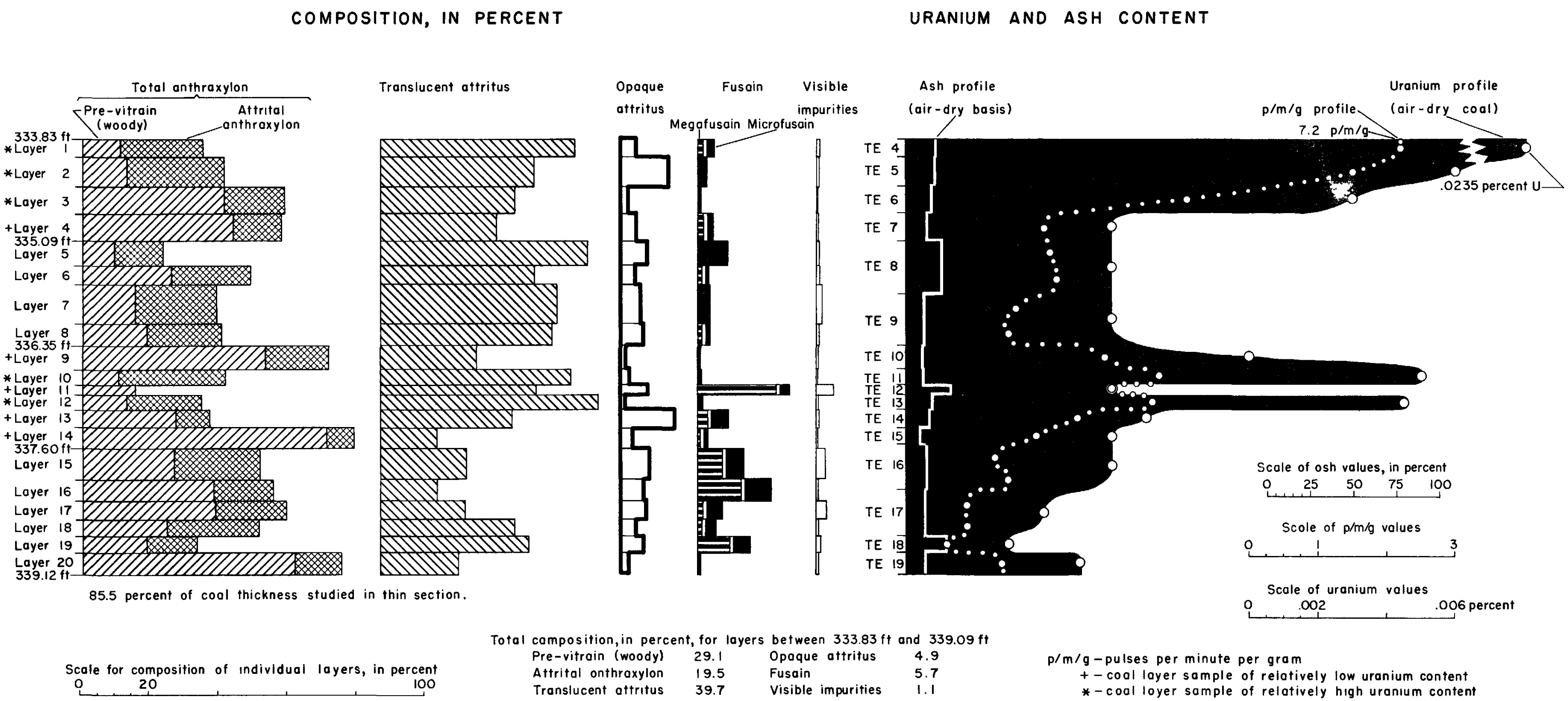


Figure 9.—Composition of lignite in Upper Mendenhall bed, drill hole SD-19, Mendenhall area, Harding County, South Dakota.

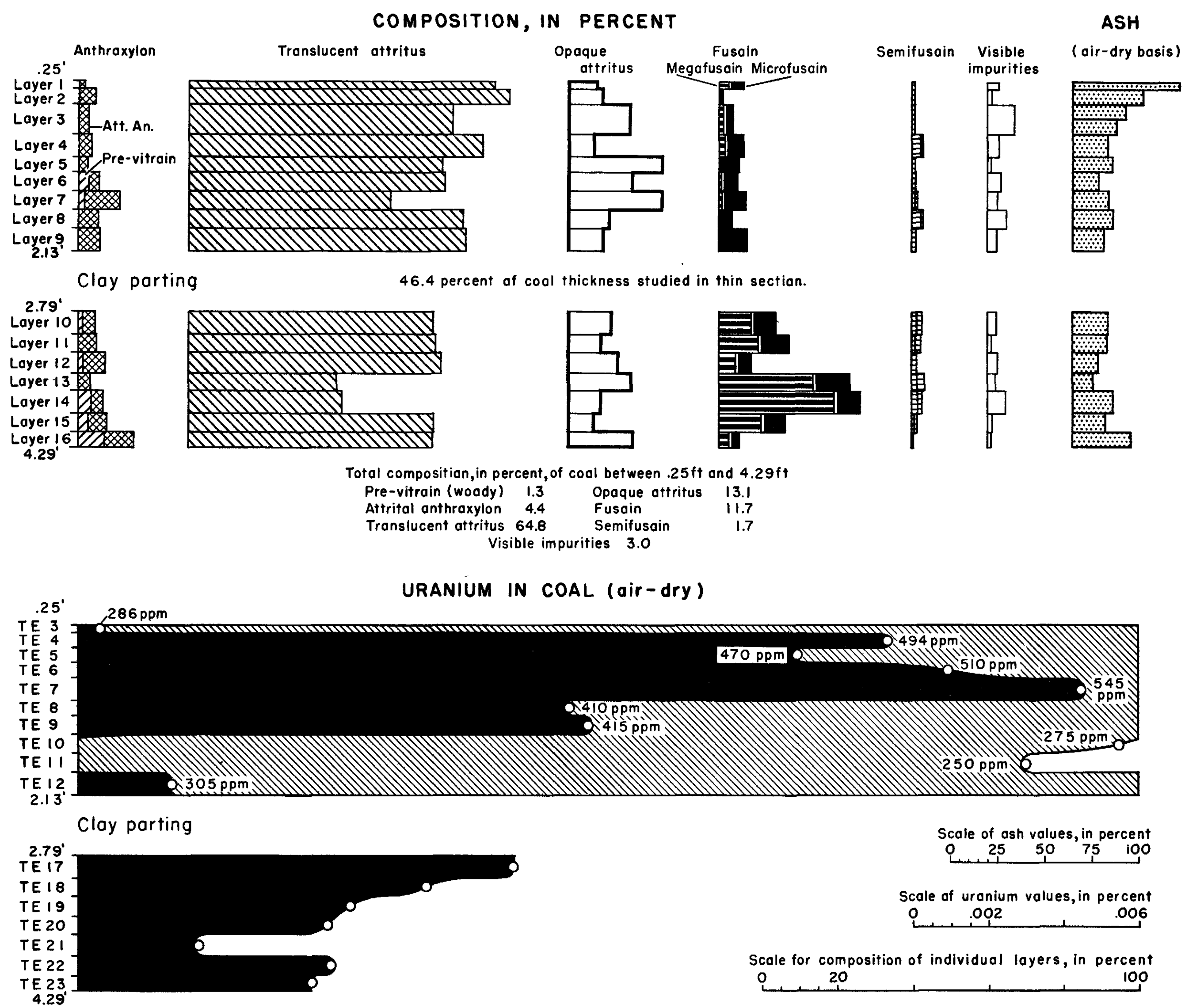


Figure 10.-Composition of lignite in Upper Mendenhall bed, Mendenhall mine, Harding County, South Dakota.

The high fusain content of the lower part of the bed generally shows a negative relationship with uranium.

Anthraxylon in the unweathered coal is generally resinous and very similar to that of the Upper and Lower Rider beds. No thick anthraxylon is present in the strip mine coal and, in all but the lower portion of the bed, cellular structure of anthraxylon is very obscure. This evidently is a result of weathering. Inasmuch as the weathered coal was broken by many horizontal fissures, some of which were filled by secondary mineral matter, sections for microscopical study were obtained only with the aid of embedding procedure. Translucent attritus seems more susceptible to oxidation darkening than anthraxylon in the weathered coal. One suspects that the higher content of opaque attritus is partially owing to this effect. Yellow resins and larger terpene resin blebs have been observed in the attritus of the strip mine coal, that were less common in the unweathered cores. The general distribution of fusain is similar, but the higher concentration of fusain in coal at the strip mine suggests that a somewhat different mode of accumulation was responsible for coal at that location. Much of the visible mineral matter in the strip mine coal is of secondary origin and probably introduced during weathering.

A detailed study has been made of the components entering into ten of the layers of the Upper Mendenhall coal bed in hole SD-19. Layers selected because of their relatively high uranium content are marked with an asterisk at the left margin of figure 9; those with a contrasting low uranium content are marked by a cross. The detailed composition of each of these layers, arranged in order of their uranium content, is given in table 7. In table 8 the data are recalculated to

TABLE 7. - Composition (area percent), of uraniferous coal layers in the Upper Mendenhall coal bed (hole SD-19), arranged in order of decreasing uranium content.

Constituents or Components	Layer 1 (TE-4)	Layer 2 (TE-5)	Layer 10 (TE-11)	Layer 12 (TE-13)	Layer 3 (TE-6)	Layer 9 (TE-10)	Layer 13 (TE-14)	Layer 4 (TE-7)	Layer 11 (TE-12)	Layer 14 (TE-15)
Anthraxylon:										
Coarse	11.10	12.90	10.27	13.66	40.45	52.58	26.66	43.84	-	70.84
Attrital	23.61	27.13	31.37	20.62	18.42	18.59	10.21	14.10	15.49	7.58
Total	34.71	40.03	41.64	34.28	58.87	71.17	36.87	57.94	15.49	78.42
TRANSLUCENT ATTRITUS										
Subanthraxylon	1.90	2.02	3.22	2.66	2.42	1.30	1.25	1.54	0.95	1.42
Humic Matter	46.93	38.86	49.20	58.77	35.56	25.09	30.77	30.13	42.20	11.79
Total	48.83	40.88	52.41	61.43	37.98	26.39	32.02	31.67	43.15	13.21
Red Att. Resins	0.24	0.22	0.69	0.52	0.19	0.41	0.61	0.10	1.45	0.13
Cuticle	0.02	0.01	0.14	0.10	0.01	0.11	0.03	-	-	-
Spores	0.20	0.11	0.47	0.17	0.05	0.17	0.11	0.06	0.09	0.02
Yellow Att. Resins	0.02	0.10	0.01	0.01	-	0.11	0.01	0.07	0.04	-
Waxy Amorphous	0.27	0.49	0.26	0.31	0.12	0.14	0.07	0.18	0.14	0.02
Total	0.51	0.71	0.88	0.59	0.18	0.53	0.22	0.31	0.27	0.04
Fungal Phyterals	0.03	-	0.20	0.01	-	0.01	0.06	-	-	-
Brown Matter	6.67	2.62	1.52	0.60	0.95	0.69	5.73	1.86	0.86	3.38
Total Trans. Attritus	56.28	44.43	55.71	63.15	39.30	28.03	38.64	33.94	45.73	16.76
Opaque Attritus	3.44	12.77	1.80	0.95	1.23	0.14	14.68	3.65	6.79	2.22
Microfusain	2.58	2.19	0.83	1.27	0.40	0.26	5.95	2.33	22.82	1.93
Megafusain	1.64	-	-	-	-	-	2.90	1.71	3.65	0.41
Total	4.22	2.19	0.83	1.27	0.40	0.26	8.85	4.04	26.47	2.34
Disseminated Pyrites	0.24	0.15	0.03	-	-	-	0.47	0.12	4.50	0.05
Transparent Minerals	0.15	0.21	-	0.19	-	-	0.10	0.21	0.11	0.06
Clayey Minerals	0.96	0.23	-	0.17	0.21	0.39	0.39	0.11	0.91	0.16
Total	1.35	0.59	0.03	0.36	0.21	0.39	0.96	0.44	5.52	0.27
Total	100.00	100.01	100.00	100.01	100.01	99.99	100.00	100.01	100.00	100.01
Percent Uranium	.0235	.0160	.0150	.0145	.0130	.0100	.0070	.0060	.0060	.0060

TABLE 8. - Composition (area percent), of translucent attritus in uraniferous coal layers in the Upper Mendenhall coal bed (hole SD-19), arranged in order of decreasing uranium content.

Components	Layer 1 (TE-4)	Layer 2 (TE-5)	Layer 10 (TE-11)	Layer 12 (TE-13)	Layer 3 (TE-6)	Layer 9 (TE-10)	Layer 13 (TE-14)	Layer 4 (TE-7)	Layer 11 (TE-12)	Layer 14 (TE-15)
Subanthraxylon	3.38	4.55	5.78	4.22	6.16	4.65	3.24	4.53	2.08	8.46
Humic Matter	83.39	87.48	88.30	93.06	90.48	89.50	79.65	88.80	92.28	70.33
Total	86.77	92.03	94.08	97.28	96.64	94.15	82.89	93.33	94.36	78.79
Red Attrital Resins	0.43	0.49	1.25	0.82	0.49	1.47	1.58	0.29	3.17	0.77
Cuticle	0.04	0.02	0.24	0.16	0.02	0.38	0.08	-	-	-
Spores	0.35	0.24	0.84	0.27	0.13	0.59	0.28	0.17	0.20	0.14
Yellow Attrital Resins	0.04	0.23	0.02	0.02	-	0.38	0.03	0.20	0.10	-
Waxy Amorphous	0.48	1.10	0.47	0.49	0.31	0.50	0.18	0.52	0.30	0.14
Total	0.91	1.59	1.57	0.94	.46	1.85	0.57	0.89	0.60	0.28
Total Fungal Phyterals	0.05	-	0.36	0.02	-	0.05	0.15	-	-	-
Brown Matter	11.85	5.90	2.74	0.94	2.41	2.47	14.82	5.50	1.88	20.17
Total	100.01	100.01	100.00	100.00	100.00	99.99	100.01	100.01	100.01	100.01
Total Translucent Attritus in Layer	56.28	44.42	55.71	63.15	39.30	28.03	38.64	33.93	45.73	16.76
Percent Uranium	.0235	.0160	.0150	.0145	.0130	.0100	.0070	.0060	.0060	.0060

show only the materials included in translucent attritus. Amounts of uranium in each layer are shown at the bottom of both tables. No correlation with particular components is evident, but there is a general tendency for more uranium to be associated with layers with the greater amounts of translucent attritus. Most of the translucent attritus is composed of humic matter that occurs as red-translucent, more or less discrete lenticles, particles or granules, each less than 3 microns in vertical thickness. Small amounts of dispersed opaque matter lend a characteristic "speckled" appearance to the translucent attritus in this coal.

Lower Mendenhall coal bed

The Upper and Lower Mendenhall coal beds often are separated by a clay or shaly parting less than a foot thick that serves as a convenient means of division. In some holes the parting swells to more than 3 feet and is sandy (holes 3, 7 and SD-8). The Lower Mendenhall bed is 2 to 9 feet thick and, in the southeastern part of the area, apparently merges with the underlying Upper Olesrud bed.

Four coal cores suitable for study were available from the Lower Mendenhall coal bed. Much of the petrologic information is based on coal 6.3 feet thick from hole SD-19 that was sectioned completely. Some sections also were prepared from cores of Lower Mendenhall coal from holes 3, 17 and 18. About 24 percent of the attrital or fine-textured coal was included in thin sections from this bed in hole 17 and, when results based on these sections are carefully weighted according to respective thickness of layers, the total results approximate those obtained by complete sectioning procedure. About

20 percent of the Lower Mendenhall coal is composed of woody bands exceeding 5 mm in thickness; about 15 percent of the coal consists of thin woody bands 1/2 to 5 mm in thickness. Fusain is fairly abundant and may account for 4 to 7 percent of the coal. Two and a half percent opaque attritus was present in the core that was completely sectioned. Table 9 shows the general results obtained for the two most reliable analyses of cores from the Lower Mendenhall coal bed.

TABLE 9. - Petrologic composition of the Lower Mendenhall coal bed (percent area=volume).

	Anthraxylon	Trans. Attritus	Opaque Attritus	Petrog. Fusain	Visible Impurity
Hole SD-19	57.3	32.0	2.5	6.9	0.3
(Over 90% of fine textured coal sampled microscopically.)					
Hole 17	53.4	35.6	1.3	7.2	2.5
(About 24% of fine textured coal sampled microscopically.)					

Five proximate and one ultimate analyses are the basis for average coal analytic values given in table 1. Bureau of Mines laboratory numbers for the individual analyses are as follows: D-68854, hole 3; D-68863, hole 4; D-73498, hole 17; D-73910, hole 18; E-12616, hole SD-19 (incl. ult. and forms of S). Owing to the small interval between Lower and Upper Mendenhall coal beds, both usually are present at locations tested. Much of the uranium tends to be concentrated in the upper rather than the lower bed, and the Lower Mendenhall bed has a consistently lower uranium content (fig. 4). The outcrop belt, where the lower bed is uppermost below the White River unconformity, probably is narrow and, for this reason, the lower bed is not as important a potential source of uranium. However, it constitutes a substantial fuel reserve and might be readily accessible if the upper bed were mined for uranium. Only three samples at the top of the Lower Mendenhall bed in hole SD-19 were radioactive enough to warrant analysis (fig. 11).

Results of microscopic study of the Lower Mendenhall coal bed are presented according to layers, in comparison with radioactivity measurements in figure 11. For the most part the thick woody anthraxylon is of the red resin-filled gymnospermous type, common in the coals previously discussed. Each wood parenchyma cell contains a dense red resinous globule, and sometimes the resins amount to 40 or 50 percent of the compressed coalified wood. A few terpene-filled (yellow) resin canals are present in this thick woody anthraxylon and some larger blebs are rarely present in the attrital coal. The amount of yellow resins, however, is negligible. Most of the fibrous anthraxylon is derived from root or rootlet material. Some of the larger roots are evidently similar in origin to the thick red-resinous wood, but the prevalent type shows little resinous material and has a thin sclerotic exodermis. These rootlets may be derived from a type of plant that did not contribute secondary wood. For the most part the distinction between opaque and translucent attritus is better defined in this coal, and less of the intimately mixed "speckled" attritus is present. Much of the fusain is in small lenticular flecks in the attrital coal, and some of this material is so small that it must be identified as fusinized opaque matter. Much of the visible mineral matter is of the clayey type that probably represents kaolinite. Fusain is commonly mineralized and sometimes vitrinized plant remains are semipetrified by mineral matter emplaced before delicate tissues had been flattened. Little pyrite is present.

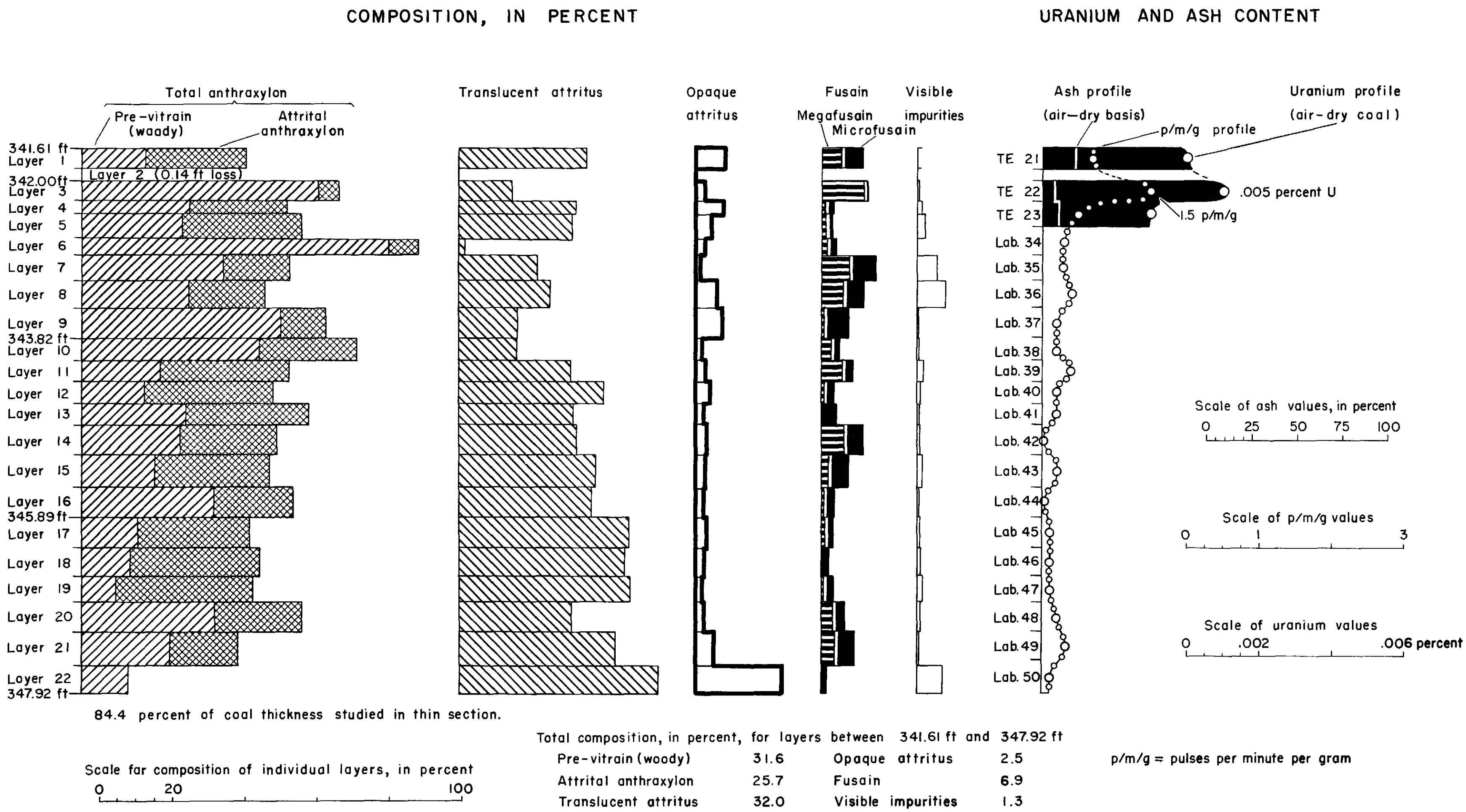


Figure 11. – Composition of lignite in Lower Mendenhall bed, drill hole SD-19, Mendenhall area, Harding County, South Dakota.

An interesting relationship may be observed by comparison of profiles of Upper and Lower Mendenhall coal beds (figs. 9 and 11). Translucent attritus is notably more abundant toward the top of the Upper Mendenhall bed and declines toward the bottom; anthraxylon shows a reciprocal trend (fig. 9). The trend is present, but somewhat less evident, in the Upper Mendenhall bed at the strip mine location because the amount of anthraxylon is so small (fig. 10). In the Lower Mendenhall coal bed (fig. 11) the relations are reversed, with a greater concentration of translucent attritus toward the bottom of the bed. It appears that the initial accumulation of plant material for the Lower Mendenhall bed favored plants having little woody tissue, but the incidence of woody plants increased as the accumulation became thicker. Abundant woody vegetation dominated the lower part of the Upper Mendenhall bed at some localities and was less evident at others (the strip mine) but subsequently declined, with non-woody forms again becoming generally ascendant in the upper layers. The abundance of translucent attritus in the upper part of the Upper Mendenhall coal bed may be a secondary factor that favors the emplacement of uranium in the top of this coal bed.

Upper Olesrud coal bed

The Upper Olesrud coal bed is separated from the Lower Mendenhall by a maximum interval of about 13 feet (hole 3), but the interval is commonly less than half that much; in the southeastern part of the area the Lower Mendenhall and Upper Olesrud beds come together. As in the intervals between higher beds, silty and sandy deposits appear where the coal beds are farther apart, and clay and shale are present where the coal beds are closer together. Sometimes a few inches of attrital coal is present within the interval and commonly the shaly and silty beds are more or less carbonaceous. The Upper Olesrud is more extensive than the coal beds above it and is present over the entire area.

Five coal cores suitable for petrologic study were available from the Upper Olesrud bed. Three of these, drilled last, were sectioned completely so that virtually the entire thickness of the bed could be studied microscopically. Woody bands more than 5 mm thick compose about 24 percent of the coal; thinner woody streaks down to 1/2 mm thickness compose about 12 percent. The amount of fibrous anthraxylon is variable, according to these studies, and composes from about 12 to 20 percent of the coal. Thus the average total anthraxylon content is about 53 percent. A rather similar size distribution of anthraxylon is shown by the Lower Rider coal bed. About 35 percent of the coal is classed as translucent attritus. About 4 percent is opaque attritus and 6 or 7 percent is fusain. The visible mineral matter is variable from 1.2 to 6.8 percent by area; the larger amount was determined in hole SD-10 where the bed is interrupted by partings.

Nearly forty analyses have been made of coal from the Upper Olesrud bed, but a great many of these show less than normal amounts of bed moisture or include partings, impure coal, sections of roof or floor rock, etc., so that an extremely variable and misleading impression of the coal deposit can be obtained from all of this analytic data. The five analyses (B. of M. Lab. numbers D-68855, hole 3; E-19300, hole SD-8; E-9832, SD-10; D-73912, hole 18; E-12617, hole SD-19) included in the average values given in table 1, have been selected because they appear to represent the coal as it exists in the bed. In all of these samples we have excluded only the impurities normally rejected from face samples of coal (Holmes, 1911, p. 8). Where precautions have been taken to preserve bed moisture in the cores, analyses of samples show about 44 percent moisture. However, one sample included in the bed average (hole 3) was partly dry when submitted and showed a moisture content of only 38.2 percent.

Only one of the cores suitable for thorough microscopical study (SD-10) had a high uranium content. At the location of holes SD-8 and SD-19 the higher coal beds included significant concentrations of uranium and the Upper Olesrud bed was not enriched. The petrologic data presented here probably have equal pertinence for the southern extension of the bed where it does contain uranium in substantial amounts.

Results of microscopical study of the Upper Olesrud coal in holes SD-8, SD-19 and SD-10 are shown according to layers in figures 12, 13 and 14. Figure 14 shows the Upper Olesrud coal bed broken by shale partings and thinner than normal. The uranium distribution is unusual, and a previous study was made of this core section in which the two

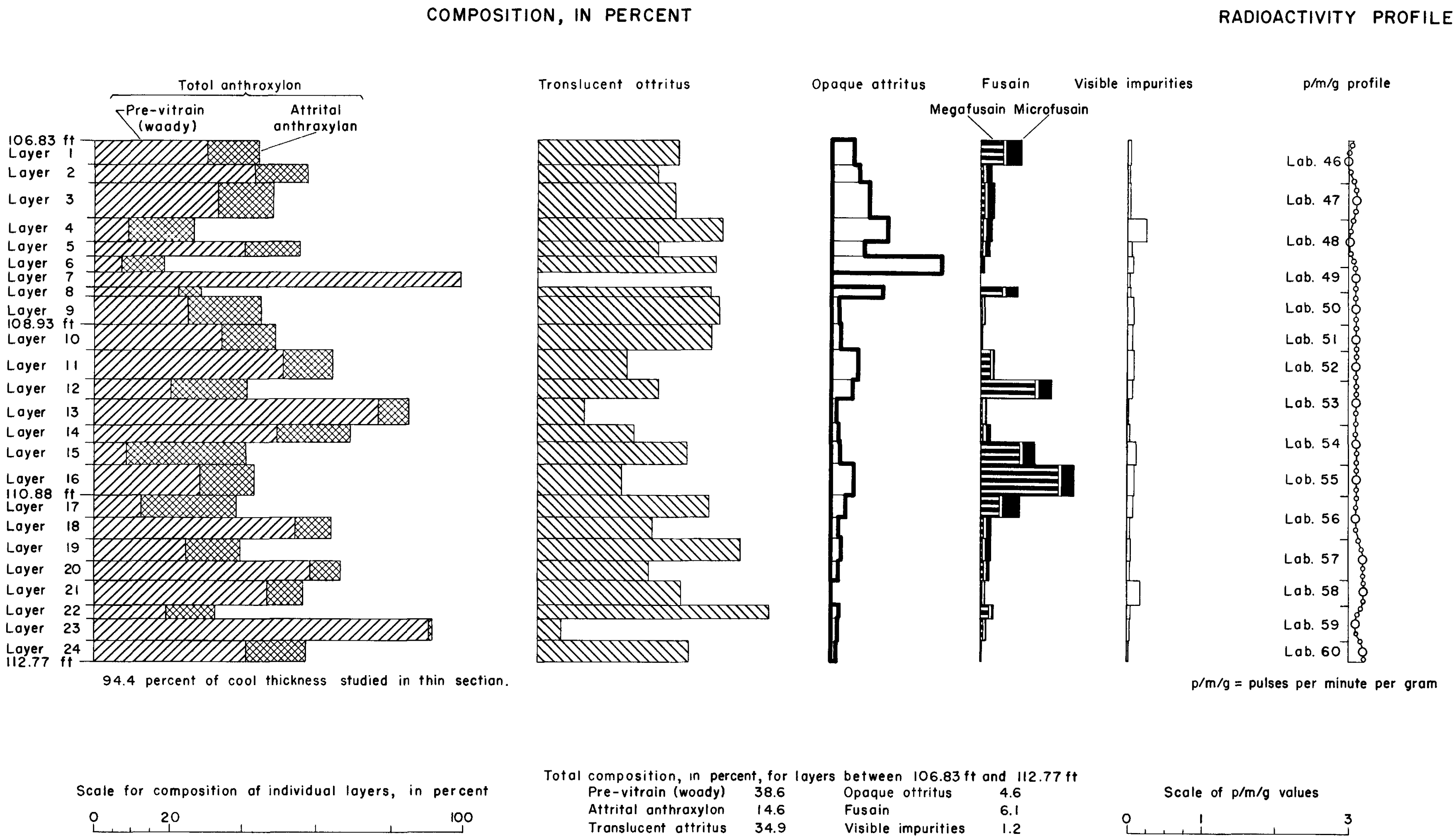


Figure **12**.—Composition of lignite in Upper Olesrud bed, drill hole SD-8, Mendenhall area, Harding County, South Dakota.

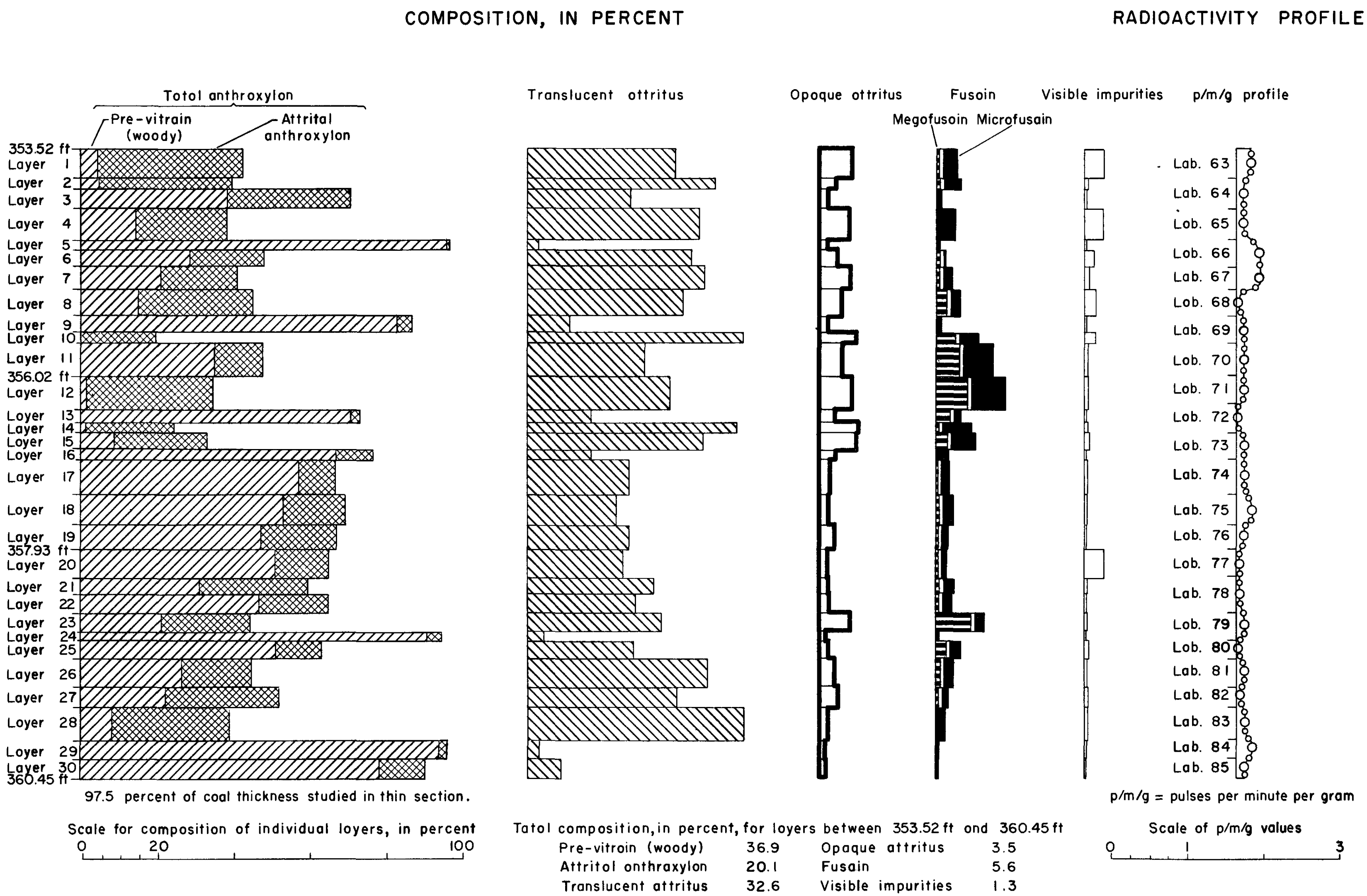


Figure 13.—Composition of lignite in Upper Olesrud bed, drill hole SD-19, Mendenhall area, Harding County, South Dakota.

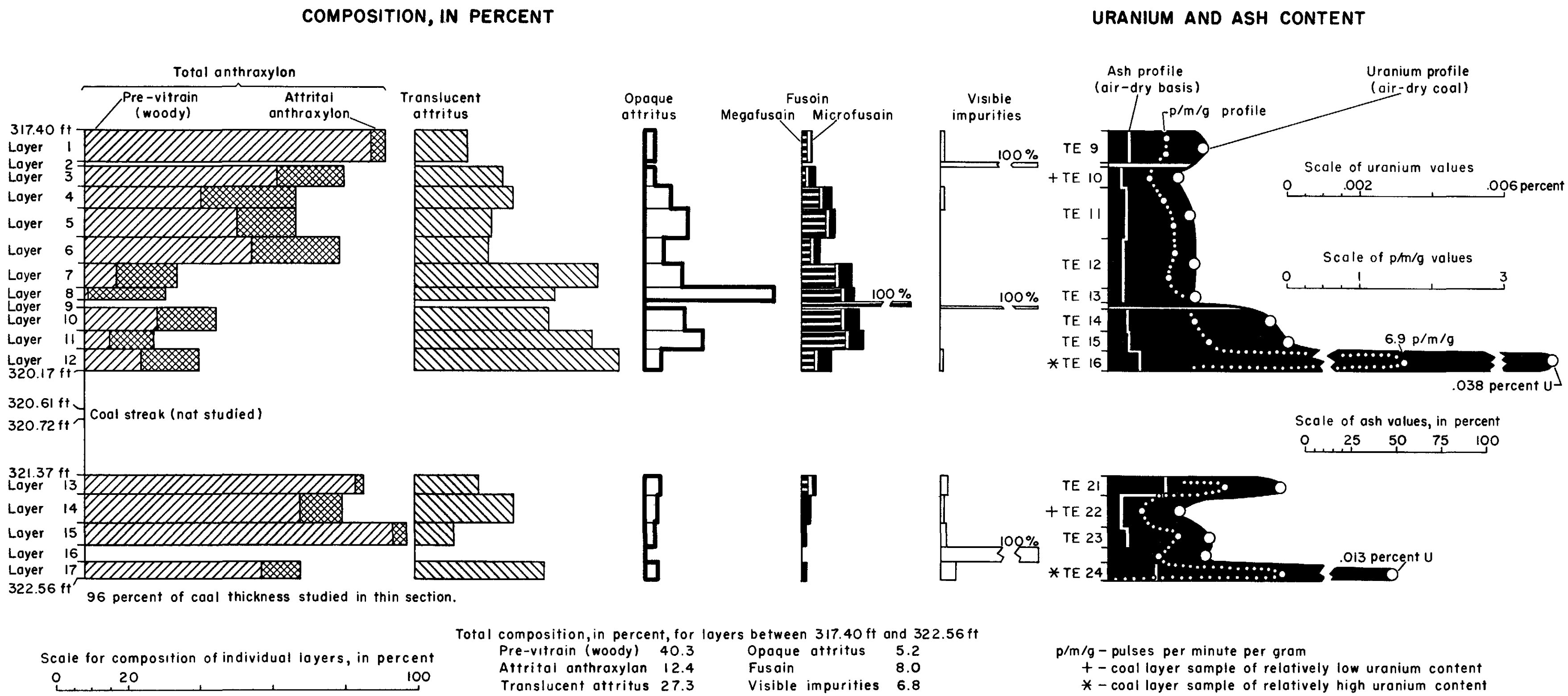


Figure 14.—Composition of lignite in Upper Olesrud bed, drill hole SD-10, Mendenhall area, Harding County, South Dakota.

coal benches were treated as separate thin beds (Schopf and Gray, 1954). New calculations are given here to present the data on a comparable basis for all three of the coal-bed studies. The detailed composition of four layers of higher uranium content and five layers with 0.002 percent uranium or less from the Upper Olesrud coal in hole SD-10 also has been presented by Schopf and Gray (1954, p. 8) in tables 3 and 4. These tables are comparable with those given for selected layers of the Upper Mendenhall and Upper Rider coal beds in the present report (tables 4 and 5; 7 and 8).

The thick anthraxylon (pre-vitrain) of the Upper Olesrud bed is dominated by red-resinous gymnospermic wood but a somewhat greater variety of types, some of which show much less wood parenchyma and correspondingly less of the red-resinous cell contents, are represented. Anthraxylon of the slightly resinous types is more common in the lower portion of the bed. A very small amount of yellow terpene resin is present as resin canal fillings in the wood or as blebs of various sizes isolated in the attrital coal. Fibrous anthraxylon is fairly constant in quantity and consists nearly entirely of root material. Larger roots of the red-resinous and slightly-resinous types correspond with the prevalent types of thick woody anthraxylon. A different type of small fibrous rootlet with a prominent exodermal layer is extremely characteristic of the attrital coal. In a few instances, the rootlet tissues have been petrified by a clayey mineral, probably kaolinite, before compression. Though the petrifaction is imperfect and single sections in random planes are not ideal for identification, it appears that these rootlets may belong to herbaceous monocotyledons. Translucent attritus is very similar to that of higher coal beds. Opaque attritus is sometimes abundant and includes a considerable proportion of finely particulate fusinized cell wall fragments. In some layers an abundance of fusain appears as microscopic lenticular flecks in attrital coal.

Distribution of the coal constituents shown in figures 12, 13 and 14 suggests correlation of certain coal-layer groups. Holes SD-8 and SD-19 are a little less than a mile apart (fig. 2) and hole SD-10 is nearly two miles farther south. At these localities a group of layers with high fusain content occurs more or less centrally in the bed. The lower part of the bed is dominated by thick woody anthraxylon or previtrain in holes SD-10 and SD-19, but this is not so apparent in SD-8. In hole SD-8 (fig. 12) the maximum fusain concentration is somewhat below the middle of the bed, and it may be that the basal layers at that location are equivalent to only the top of the woody concentration shown in the coal bed at the SD-19 and SD-10 locations. The upper part of the coal bed seems condensed in hole SD-10, and the partings evidently displace coal that is present at the other localities.

Translucent attritus apparently shows a greater capacity for enrichment by uranium than the other coal constituents. Some support for this is derived from the distribution of translucent attritus and uranium in the upper bench of the Upper Olesrud bed in hole SD-10. However, the presence of uranium evidently is not dependent on any single coal constituent, and the distribution of uranium in hole SD-10 may be unusual for other reasons. Apparently the low uranium content of this bed at the SD-19 and SD-8 locations is due to the presence of uraniferous coal beds higher in the same drill holes (figs. 3 and 4). Gill (report in preparation) has reported a substantial and characteristic uranium enrichment of the Upper Olesrud bed where the Rider and Mendenhall beds are absent.

Lower Olesrud coal bed

The Upper and Lower Olesrud beds are essentially one bed in the northwestern part of the area (hole SD-8, fig. 5), but the interval between them increases westward and southward. At hole SD-10 the interval consists of about 60 feet of predominantly sandy and silty beds. The intervening beds are more shaly where the interval is less. The Lower Olesrud coal bed probably underlies the entire area but has not been so fully tested in the northern part of the area where it is deepest. This coal bed has proved to be uraniferous at only one drill location (SD-10), and no reserves estimates are available for it. One would judge that, if the bed is sufficiently persistent, it might be more consistently uranium-bearing farther to the south.

In the course of thin section study plant megaspores were observed in the lower Olesrud bed and in the thin "Y" and "Z" beds that occur beneath it (Gill, in preparation). These forms appeared so distinctive that an effort was made to identify them and to trace their lateral persistence for use in correlation. The spores were first identified in maceration residues from the "Y" bed in hole SD-10 and in the Lower Olesrud above it and a further study was made of samples from the Lower Olesrud cores in holes SD-7, SD-8 and SD-19. Three types of megaspores commonly are present. An estimate of their relative abundance in these drill cores is given in figure 15. Two of the spore forms evidently represent species of floating water ferns allied with Azolla. The other bears a strong resemblance to spores of the quillwort, Isoetes, a

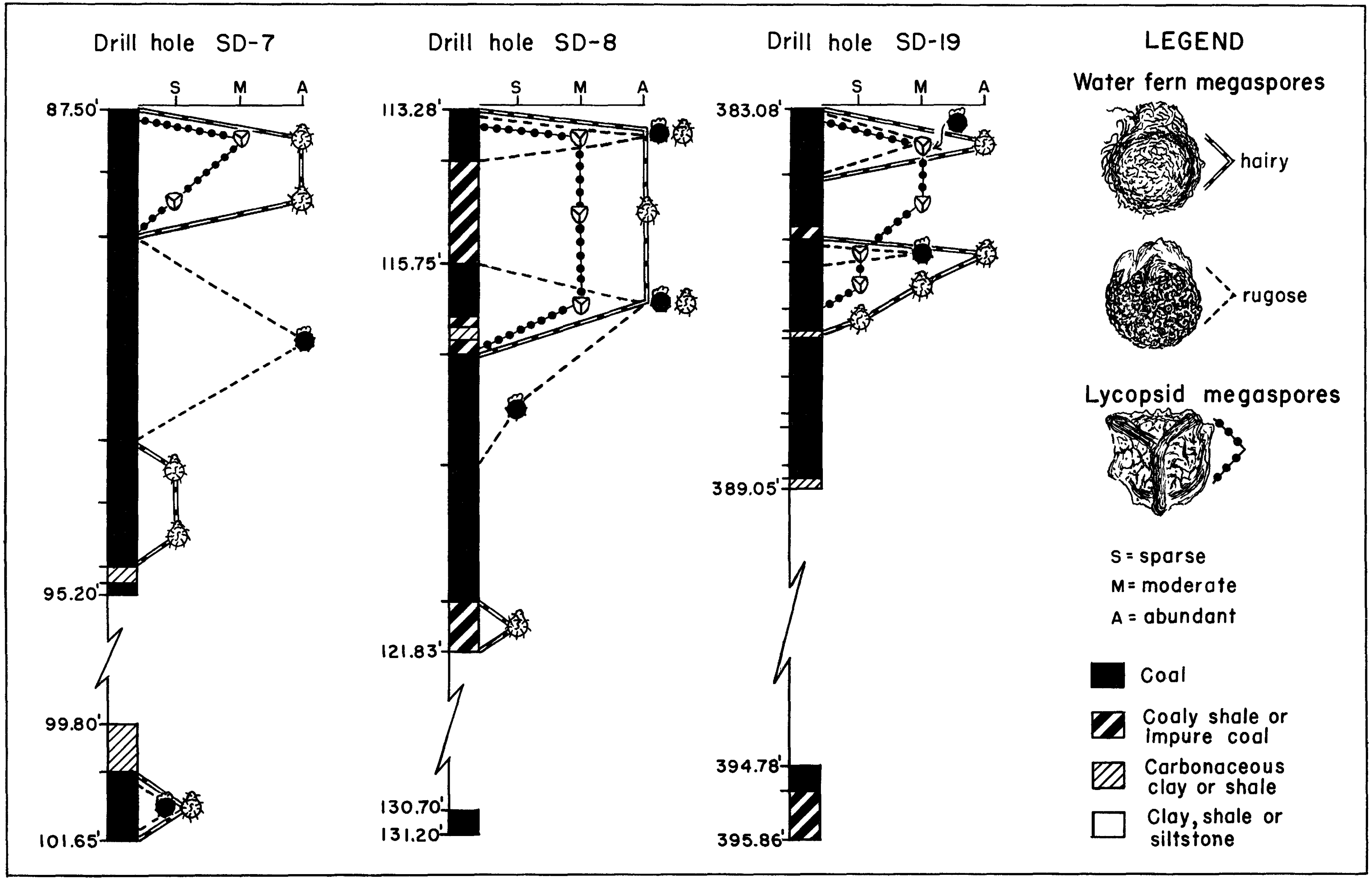


Figure 15.-Occurrence of certain plant spores in Lower Olesrud coal bed.

shallow water plant. It also is allied with (but probably specifically distinct from) the form Miner (1935) described as Selaginellites mirabilis from coal of Fort Union age on Bear Creek in Carbon County, Mont. Examination of the finer residues showed a few small boat-shaped microspores, 15 x 22 microns in diameter. These further suggest the presence of Isoetes. Isolated examples of water fern megaspores occasionally have been found as high as the Upper Mendenhall coal bed, but they do not seem to occur generally in coal beds above the Upper Olesrud. They have been found in all the coal beds presumed to represent the Lower Olesrud bed that have been examined, and this occurrence supports the correlations of Gill.

Three cores of the Lower Olesrud bed were suitable for petrologic study. These are at the same locations as those studied for the Upper Olesrud; in the order of location from north to south, holes SD-8, SD-19 and SD-10 (fig. 2). Nearly 30 percent of the coal consists of thick woody bands over 5 mm thick in holes SD-8 and SD-10, but about 10 percent less than this is present at the SD-19 location. However, about the same amount of total anthraxylon is present in all (about 53%); the difference is made up by smaller bands of anthraxylon in hole SD-19. About 30 to 35 percent of the coal consists of translucent attritus. About 5 percent opaque attritus is present in this bed at hole SD-10 but only half as much is present at SD-8. Fusain is similarly varied with nearly 7 percent present in the southern hole and about 3-1/2 percent present at the north. Amounts of opaque attritus and fusain in the coal at hole SD-19 are intermediate, but values are closer to that of hole SD-8 which is not as far away. Shaly and clayey impurities are more common in the Lower Olesrud than in higher beds. Values given above are on the whole-coal basis (including visible impurities). The average composition given in table 3 (p. 17) is on a visually pure basis calculated with exclusion of all impurities observable by petrologic study.

Nearly 30 coal analyses are available from the Lower Olesrud bed which, like most of the analyses of the Upper Olesrud, show great variability, particularly in moisture and ash. The average analytic values given in table 1 are based on four samples (B. of M. Lab. numbers E-19301, hole SD-8; D-68856, hole 3; E-13500, hole SD-19; E-9833, hole SD-10), all of which are from cores processed at the U. S. Geological Survey Coal Geology Laboratory. These four analyses show greater consistency and probably are the best basis available for evaluating the chemical properties of coal in the bed. About 44 percent moisture is normal for this coal before drying; the coal from hole 3 was partly dried when sampled and had only 40.8 percent moisture as-received. Normal standards for rejection of impurities have been adhered to in core processing procedure (Holmes, 1911, p. 8). According to this sampling practice, the coal has a little less than 9 percent ash.

Of the three cores of this coal that were studied, only the one from hole SD-10 showed enrichment in uranium. The presence of uranium in this core seems extraordinary in view of its stratigraphic position nearly 60 feet below a coal bed that is similarly enriched. Some unusual features of ground water circulation may be responsible because coal from the Lower Olesrud bed in hole SD-10 is very similar to the non-uraniferous coal found elsewhere in the same bed.

This comparison is clearly brought out by results of microscopical study. The composition of the three cores from holes SD-8, SD-19 and SD-10, is shown according to layers and in comparison with radioactivity and uranium profiles in figures 16, 17 and 18. The uranium content of the core from hole SD-10 contrasts strongly with that of other coal samples from the same bed; it also shows a much less regular distribution of uranium than do the other uraniferous beds of the Mendenhall area (figs. 3 and 4).

The Lower Olesrud bed seems to include all types of anthraxylon found in the stratigraphically higher coals, with the exception of one scarce angiospermous type. Fibrous rootlet anthraxylon contributes consistently to the attrital coal. Many of the thick woody bands are less highly resinous than in the coal beds above. One anthraxylon fragment with pronounced sclerotic caps and diffuse vascular bundles of the Palmoxylon type was found near the base of the coal bed in hole SD-10. Commonly translucent attritus is almost lacking in admixture with opaque particles; in other layers the "speckled" appearance dominates. Opaque attritus is characteristic in appearance, when present, and the intercalation of fibrous anthraxylon (rootlets) often produces an appearance very similar to durain as described from Paleozoic coal. Megaspores, remarked in a paragraph above, are not commonly associated with opaque attritus. Their greatest abundance in thin sections was observed in a translucent matrix near the base of the coal in hole SD-10. Both fusinized wood and cortical tissues are present. Clayey mineral matter is most common. Kaolinitic blebs occur sporadically, sometimes petrifying vegetative tissues to indicate introduction in solution prior to compression of the top peat. In other instances

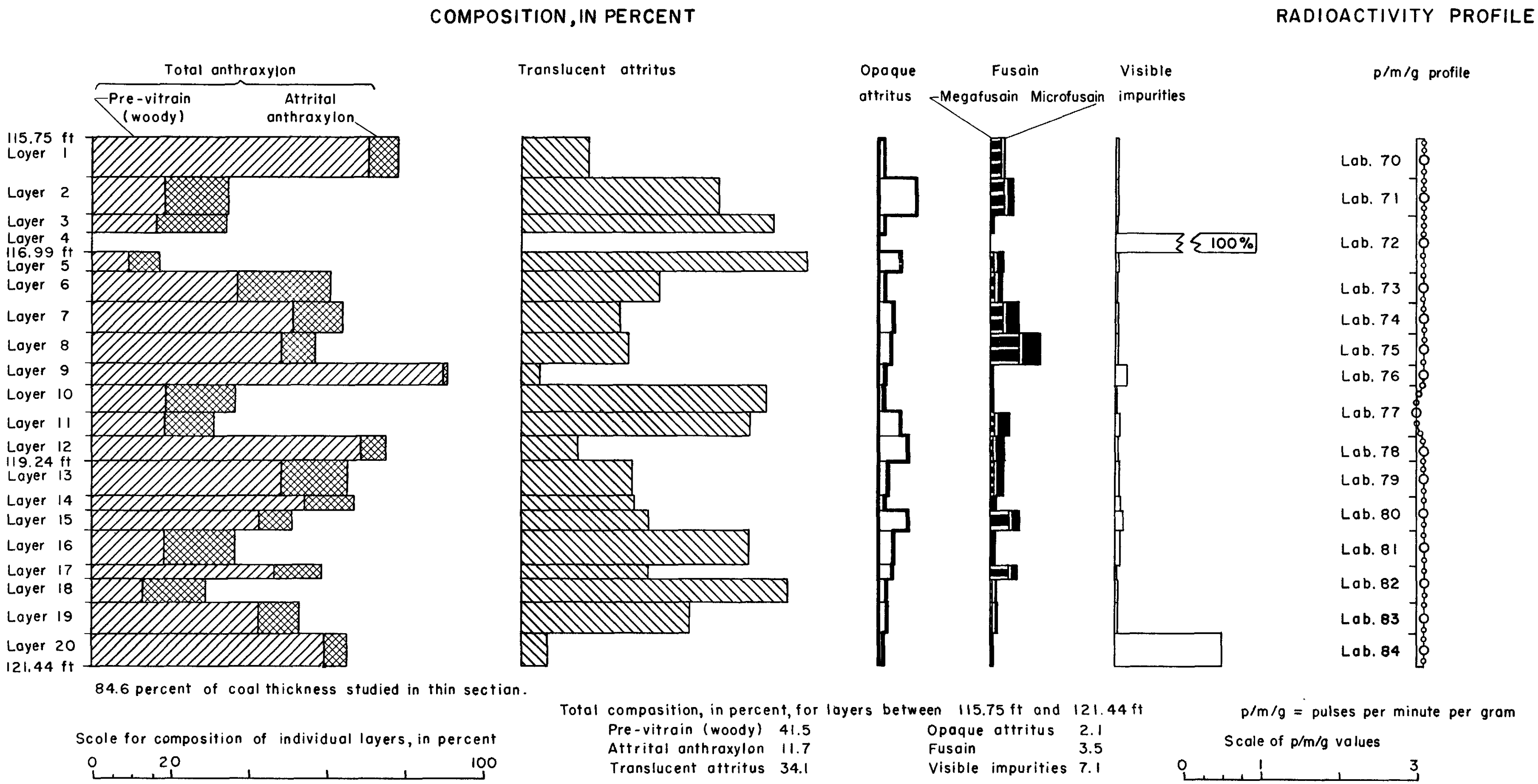


Figure 16.- Composition of lignite in Lower Olesrud bed, drill hole SD-8, Mendenhall area, Harding County, South Dakota.

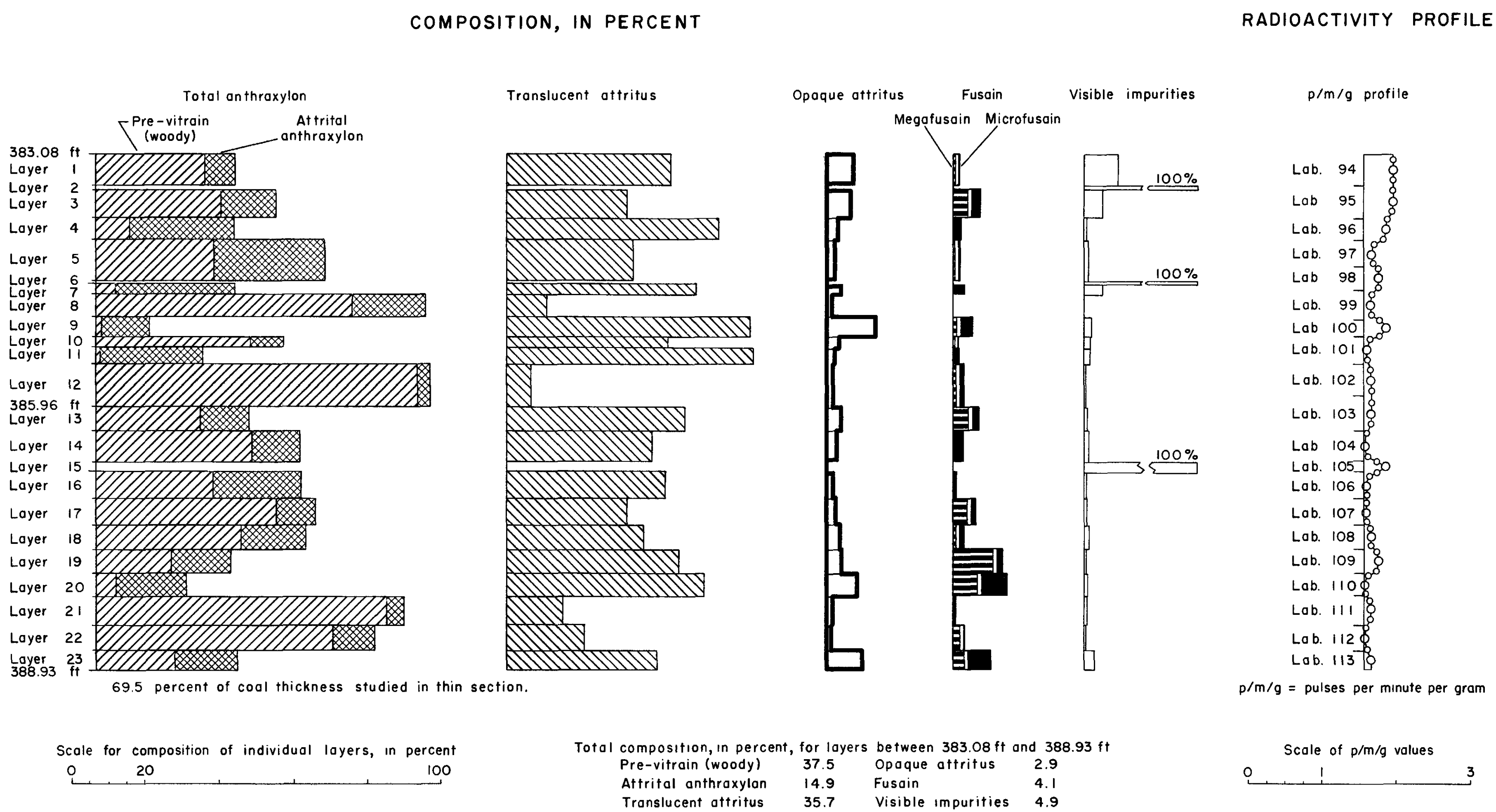


Figure **17.** – Composition of lignite in Lower Olesrud bed, drill hole SD-19, Mendenhall area, Harding County, South Dakota.

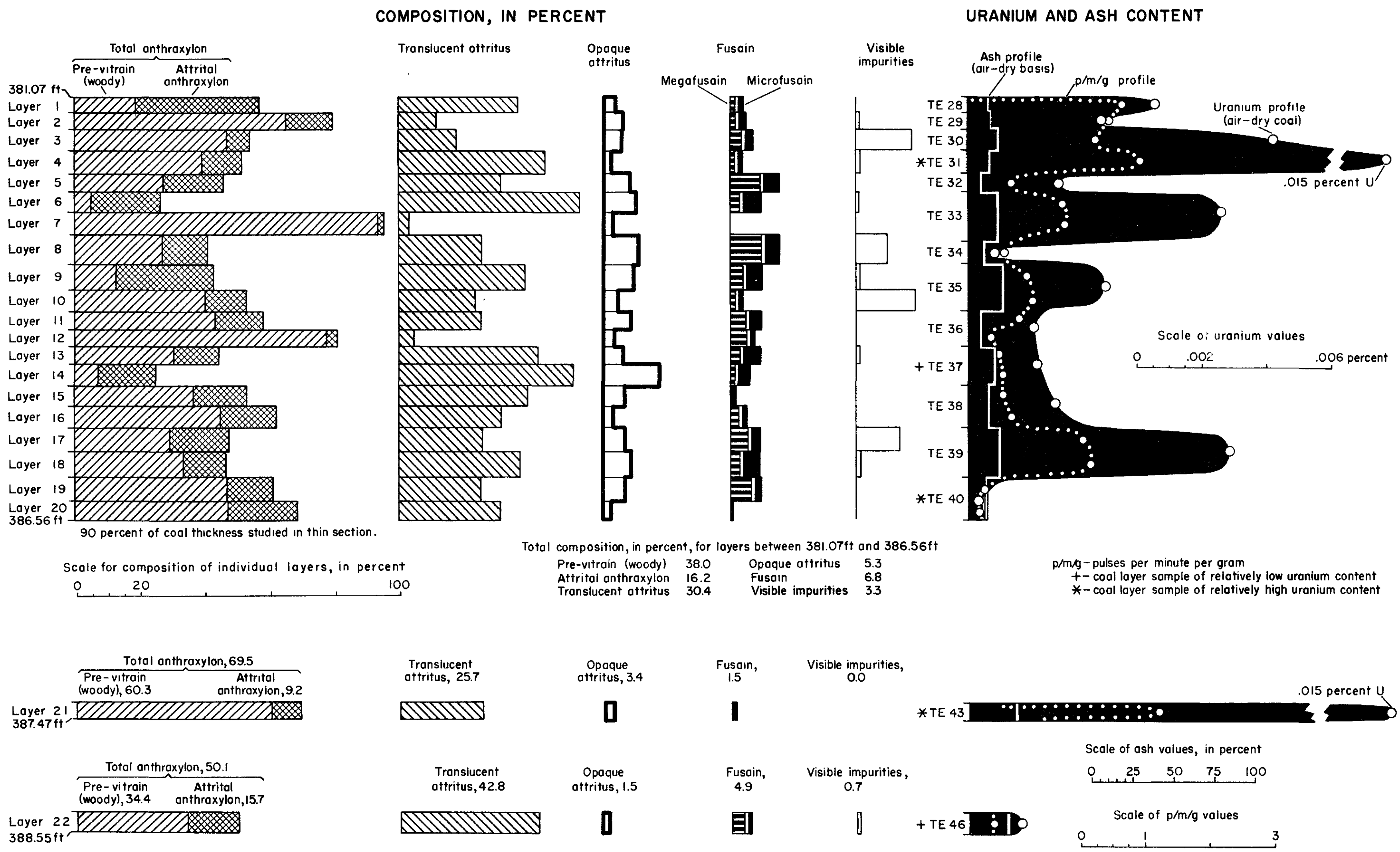


Figure 18.—Composition of lignite in Lower Olesrud bed, drill hole SD-10, Mendenhall area, Harding County, South Dakota.

clayey and other transparent mineral grains are evidently of detrital origin. Pyrites are usually finely dispersed and only one local concentration, partly secondary, was noted in the core from hole SD-10.

Distribution of constituents in the layers of coal in figures 16, 17 and 18 offers several suggestions about bench equivalence within the coal bed. The thick group of layers high in pre-vitrain at the base of the coal in figure 18 (SD-10) may correspond with the basal two or three layers of figures 16 and 17. The layer high in pre-vitrain at the top in figure 16 (SD-8) seems lacking in figure 17 (SD-19); otherwise the upper parts of these beds seem comparable. The thin partings shown as 100 percent impurity in figure 17 may correspond with three of the four layers of high impurity in figure 18.

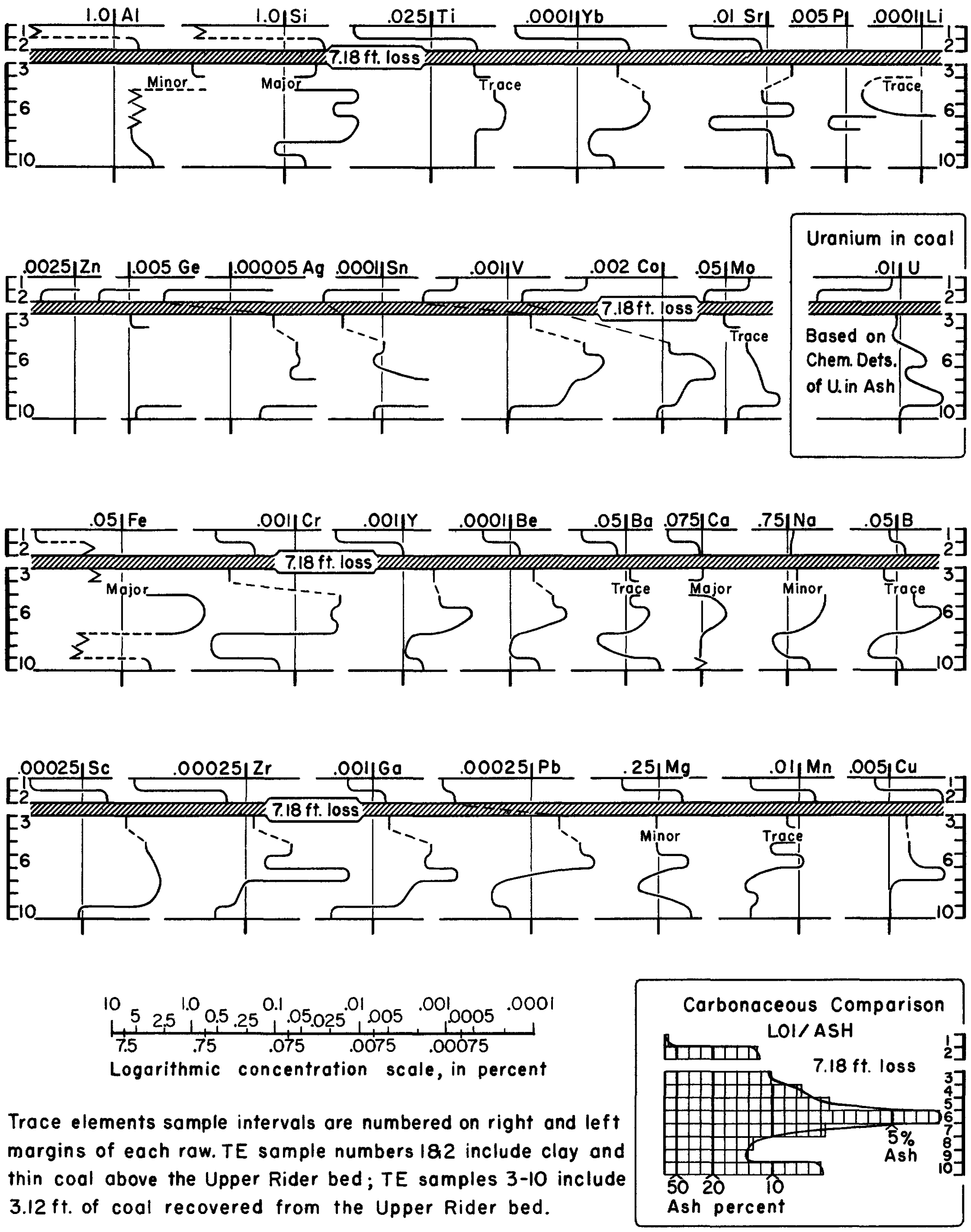
An approximate correlation of translucent attritus and uranium content is apparent in figure 18 (SD-10) with the exception of the uranium concentration in TE39 toward the base of the bed. The asterisks and crosses opposite sample intervals TE31, 37, 40, 43 and 46, mark layers for which detailed component analyses have been previously reported (Schopf and Gray, 1954, p. 8).

This work does not appear to provide a more satisfactory explanation for the unusual concentration of uranium in various layers of the core from hole SD-10. The occurrence of secondary pyrites, lining some vertical cracks in pre-vitrain, suggests movement of ground water in the coal subsequent to coalification. Probably the incidence of uranium itself is more compelling evidence that late movement of uraniferous ground water has occurred.

Mineral elements associated with uranium in coal of the Mendenhall area

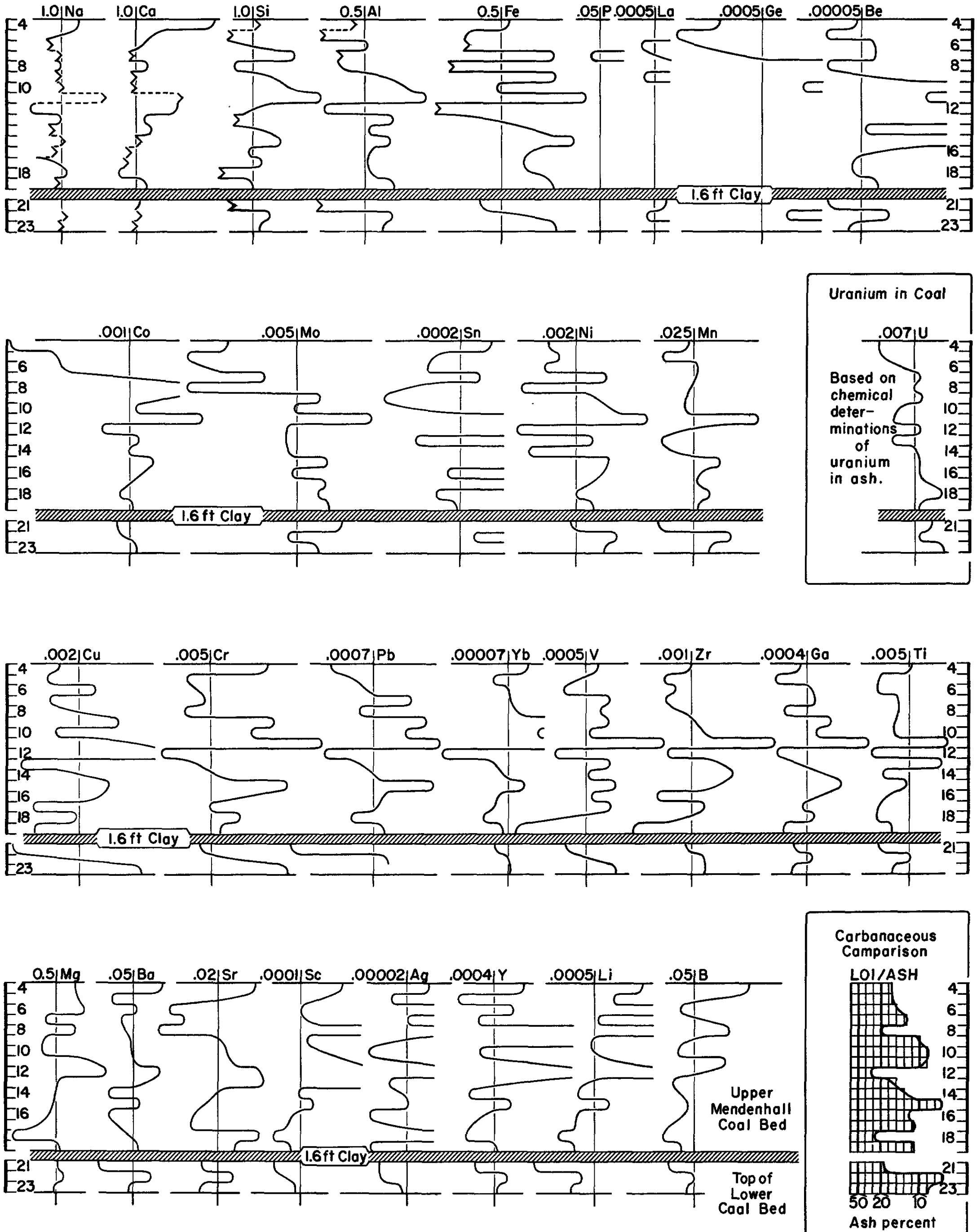
Many semiquantitative spectrographic analyses of the ash from uraniferous coal samples have been reported by Zeller (report in preparation, Appendix A) and by Gill (report in preparation, Appendix C). Spectrographic analyses from three of the drill cores we have studied petrographically are presented graphically in figures 19, 20 and 21, drawn to show the relative concentrations of various elements detected, as they occur in the samples before ashing. The curves are drawn to a logarithmic scale so that inequalities resulting from the semiquantitative nature of analysis are minimized, but the significant variations in concentration still are apparent. Uranium concentrations based on chemical analyses are shown at the same scale on each chart. The concentration of carbonaceous material also is presented for comparison with each suite of samples. Trace elements sample numbers are given at the margins of each row and further information about any sample may be obtained from earlier sections of this report by reference to the uranium and ash curves given on respective charts presenting petrologic composition.

The arrangement of curves for different spectrographically detected elements has been based principally on apparent similarity of curves. Some elements appear to have a more or less similar relative concentration in successive samples, but these groupings are not always the same in different coal beds.

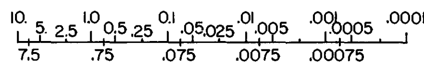


Trace elements sample intervals are numbered on right and left margins of each raw. TE sample numbers 1&2 include clay and thin coal above the Upper Rider bed; TE samples 3-10 include 3.12 ft. of coal recovered from the Upper Rider bed.

Figure 19.—Profiles of chemical elements detected in the Upper Mendenhall Rider bed and thin coal above, drill hole SD-8, Mendenhall area, South Dakota.



Trace element sample intervals are numbered on right and left margins of each row, TE sample numbers 4 – 19 include Upper Mendenhall Coal bed 5.3 ft. thick; TE samples 21 – 23 include 0.6 ft. of coal recovered from top 1.6 ft. of Lower Mendenhall Coal bed.



Logarithmic concentration scale, in percent

Figure 20.— Profiles of chemical elements detected in Mendenhall Coal beds, drill hole SD-19, Mendenhall area, Harding County, South Dakota.

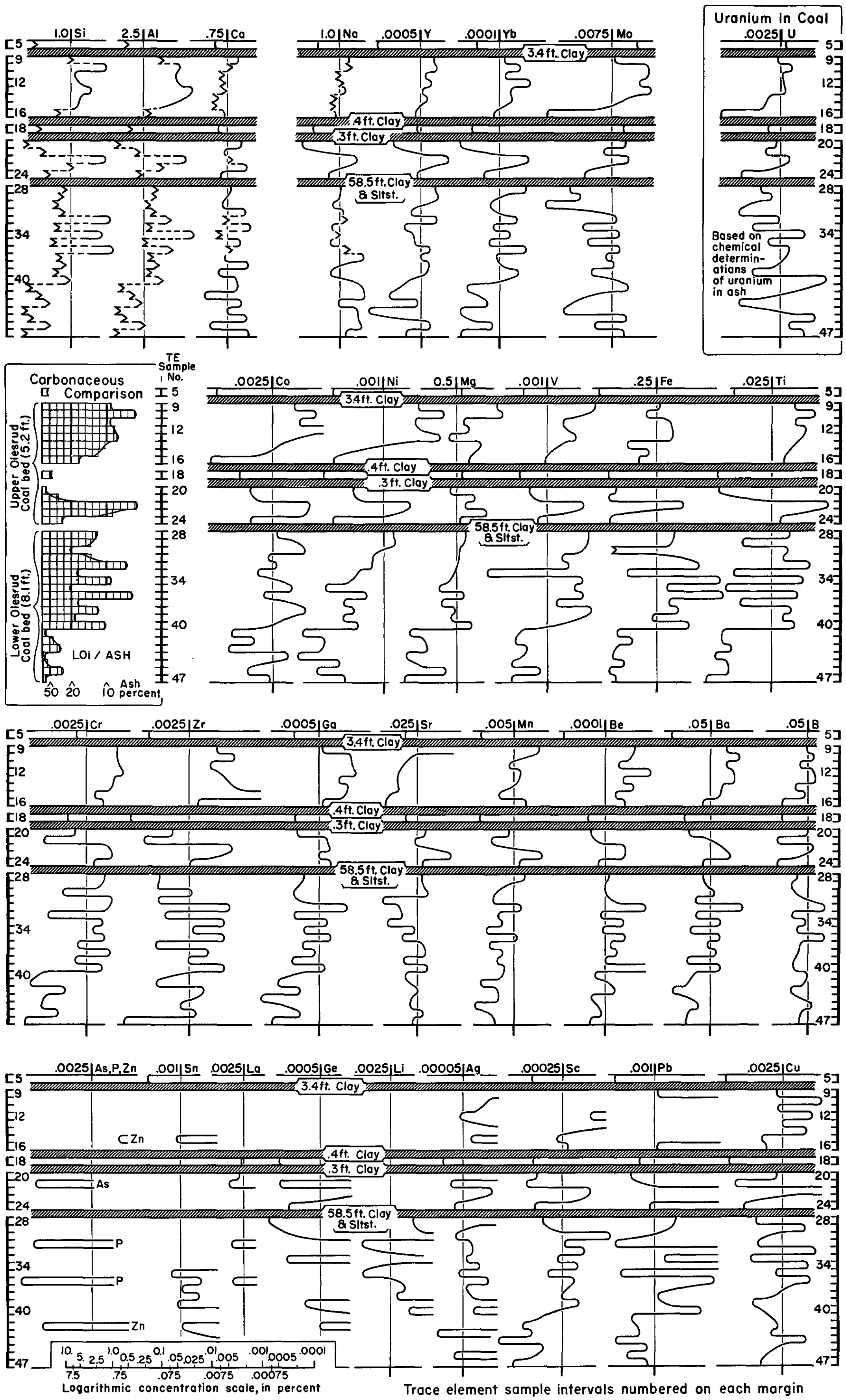


Figure 21.—Profiles of chemical elements detected in Olesrud Coal beds, drill hole SD-10

The distribution curves of molybdenum and, to a lesser extent cobalt, appear similar to uranium in the coals of the Mendenhall area. This is most apparent in figure 19, showing samples from the Upper Rider bed, and from the Olesrud coal beds in hole SD-10 (fig. 21). The relationship is less evident in the Mendenhall coal beds of hole SD-19 (fig. 20) because there the top-preferential distribution of cobalt and molybdenum is much more extreme than it is for uranium. Germanium also shows a marked top-preferential occurrence in the Upper Mendenhall coal bed at hole SD-19. Germanium likewise shows top preferential occurrence in the Lower Olesrud bed of Hole SD-10, but uranium does not seem particularly to correspond with it. Vanadium is shown to be somewhat similar to cobalt in the Rider beds (fig. 19), but its distribution is more like ytterbium and zirconium in the Mendenhall, and shows a still different distribution in the Olesrud beds.

It is very difficult to distinguish indigenous and adventive elements in coal when they are present in such slight concentrations that no characteristic mineral is recognized. The fact that molybdenum and cobalt show some similarity with uranium in their pattern of distribution in the coal but have little else in common may be taken as a further indication that all probably are largely adventive and introduced since the coal became consolidated to about its present condition.

COAL IN THE BAR H AREA

The Bar H area is located about six miles north of the Mendenhall area in the northern part of the Slim Buttes, as shown on the general index map (fig. 1, p. 6). An index map of the Bar H area, showing locations of drill holes, is given in figure 22. Eight exploratory holes were drilled in this area by the Geological Survey; one in late 1951 and the others in 1952. Field studies have not been fully completed and the several coal beds in different drill holes are not assuredly correlated. Water fern megaspores of the type found in the Lower Olesrud and "Y" beds at the Mendenhall area have been observed in the coals at a depth of 379.37 feet in hole 19, 76.17 feet in hole 23 and in a coaly layer 1.5 feet below the coal at a depth of 70.71 feet in hole 25 of the Bar H area. Observations are too few at the present time to suggest correlation. For purposes of this report the coal beds studied have been arbitrarily numbered as shown in figure 23.

Coal analyses that appear to provide reliable indications of the chemical properties of the coal beds in the Bar H area are presented in table 10. The petrologic composition of the coal beds is summarized in table 11. Ash and uranium determinations are given for samples of coal in table 12.

Two of the coal beds studied petrologically are shown in figure 24 according to approximate composition of layers utilizing the layer sampling method of study. The middle part of coal No. 1 from hole 19 had a relatively high uranium content (0.037%). The dry sample contained only 14 percent ash (table 12) and the ash contained 0.12 percent uranium. The relatively high concentration of uranium in the

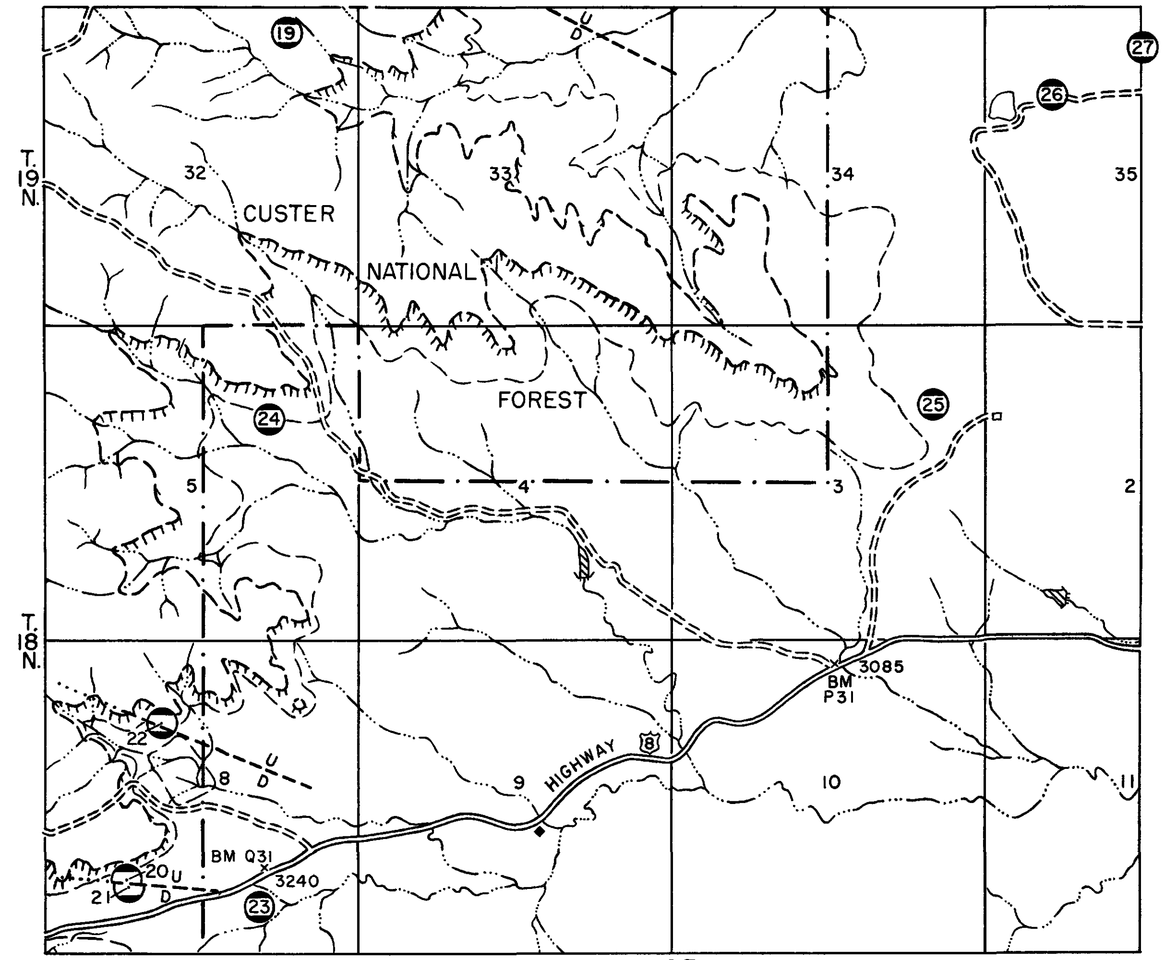


Figure 22.-Index map of the Bar H area, Harding County, South Dakota, showing locations of core drill holes (adapted after H.D. Zeller)

Core drill hole locations

Formations represented
Arikaree (escarpment)
White River
Fort Union

Custer National Forest Boundary

0 5000
Scale in feet

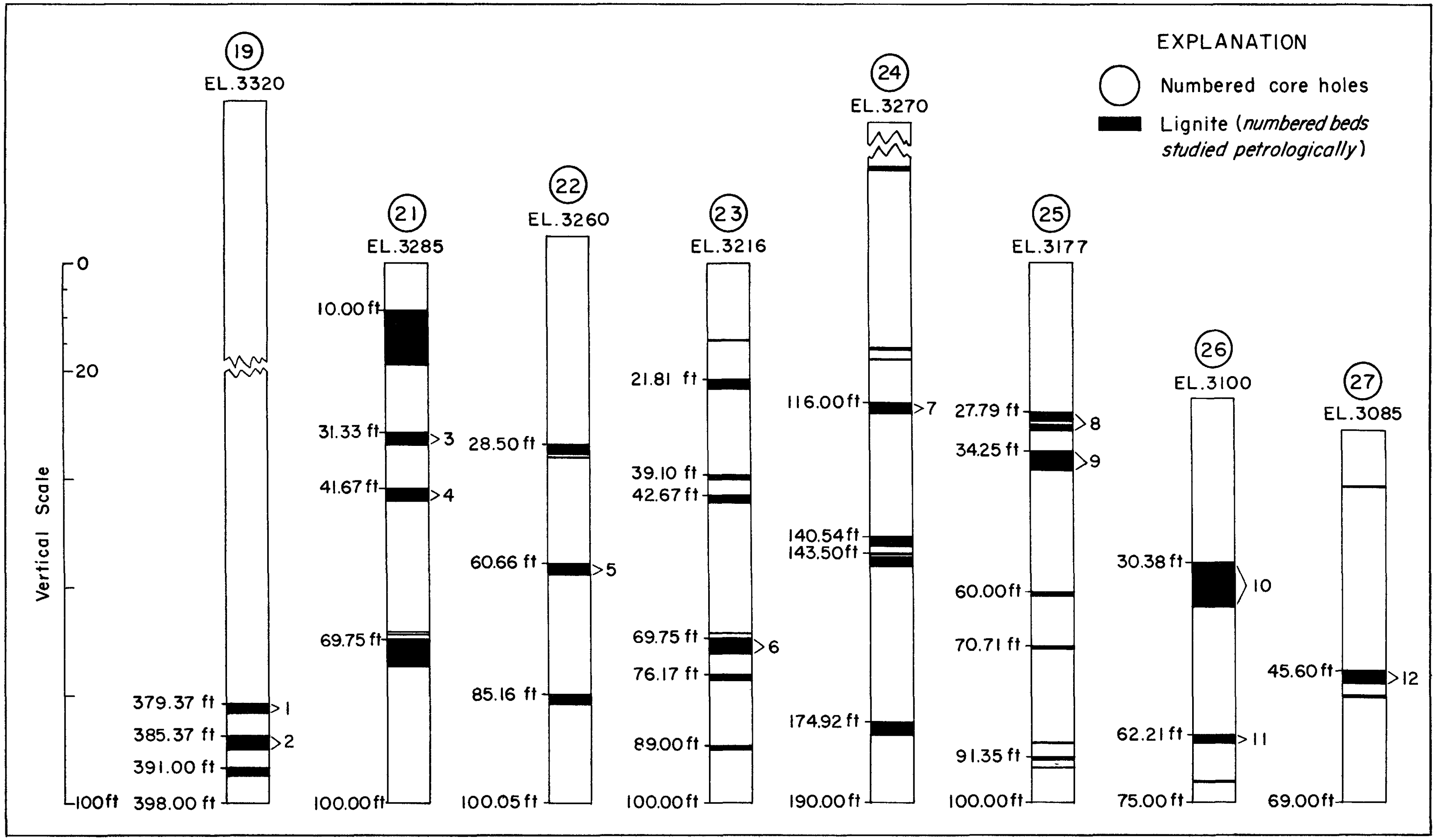


Figure **23**.—Stratigraphic position of uncorrelated lignite beds in Bar H area core holes, Harding County, South Dakota.

TABLE 10. - Chemical analyses of coal beds in the Bar H area.

Bed, Drill Hole, and B. of M. Lab. No.	Basis of reporting 1/	Proximate, percent				Ultimate, percent					Calorific value
		Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	B.t.u.
Bed 4	AR	43.7	20.9	24.4	11.0	0.8	7.0	32.6	0.4	48.2	5490
Hole 21	MF		37.2	43.3	19.5	1.4	3.8	57.9	0.7	16.7	9750
D-89671	M&AF		46.2	53.8		1.7	4.7	71.8	0.9	20.9	12110
	MMinF	50.9	22.0	27.1							6080
	M&MinF		42.9	57.1							11860
Interval:	41'8-1/2" - 44'0"; Loss 1-1/4"; Rej. 0"; Coal in sample 26-1/4".										
	AR	43.3	20.5	25.3	10.9	2.5	6.8	32.7	0.4	46.7	5500
Hole 21	MF		36.2	44.5	19.3	4.4	3.6	57.7	0.7	14.3	9700
D-89672	M&AF		44.8	55.2		5.5	4.4	71.4	0.9	17.8	12020
	MMinF	49.9	21.4	28.7							6190
	M&MinF		42.8	57.2							12340
Interval:	69'9" - 74'8-1/4"; Loss 0"; Rej. 0"; Coal in sample 59-1/4".										
Bed 5	AR	46.9	19.8	22.8	10.5	0.7	7.4	29.8	0.5	51.1	5070
Hole 22	MF		37.3	42.9	19.8	1.4	4.0	56.2	0.9	17.7	9560
D-89996	M&AF		46.5	53.5		1.8	5.0	70.0	1.1	22.1	11920
	MMinF	53.1	21.2	25.7							5700
	M&MinF		45.1	54.9							12170
Interval:	60'7-7/8" - 62'5-1/2"; Loss 0"; Rej. 0"; Coal in sample 21-5/8".										
Bed 6	AR	43.5	20.7	25.5	10.3	0.6	6.8	32.9	0.5	48.9	5460
Hole 23	MF		36.7	45.1	18.2	1.1	3.6	58.1	0.9	18.1	9660
D-90067	M&AF		44.8	55.2		1.4	4.3	71.0	1.1	22.2	11800
	MMinF	49.1	22.2	28.7							6130
	M&MinF		43.6	56.4							13210
Interval:	69'9" - 72'7"; Loss 3-3/4"; Rej. 0"; Coal in sample 30-1/4".										
Bed 7	AR	44.2	20.4	25.8	9.6	0.3	6.9	33.0	0.3	49.9	5370
Hole 24	MF		36.6	46.3	12.1	0.5	3.6	59.1	0.5	19.2	9620
D-90297	M&AF		44.1	55.9		0.6	4.4	71.3	0.6	23.1	11610
	MMinF	49.4	21.8	28.8							5990
	M&MinF		43.1	56.9							11830
Interval:	116'0" - 118'0"; Loss 0"; Rej. 0"; Coal in sample 24".										
Bed 8	AR	40.2	22.9	26.8	10.1	1.0	6.8	34.9	0.4	46.8	5890
Hole 25	MF		38.2	44.9	16.9	1.6	4.0	58.4	0.6	18.5	9850
D-90758	M&AF		46.0	54.0		1.9	4.8	70.3	0.8	22.2	11850
	MMinF	45.4	24.5	30.1							6600
	M&MinF		44.9	55.1							12080
Interval:	27'9-1/2" - 31'3"; Loss 2-1/2"; Rej. 0"; Coal in sample 31".										
Bed 10	AR	40.3	23.6	27.5	8.6	1.2	6.8	36.7	0.2	46.5	6120
Hole 26	MF		39.6	46.0	14.4	2.0	3.9	61.4	0.3	18.0	10250
D-90760	M&AF		46.2	53.8		2.4	4.5	71.8	0.3	21.0	11980
	MMinF	44.8	24.9	30.3							6730
	M&MinF		45.1	54.9							12180
Interval:	30'4-5/8" - 38'5"; Loss 1"; Rej. 0"; Coal in sample 95-3/8".										

1/ AR, as received; MF, moisture free; M&AF, moisture and ash free; MMinF, moist, mineral-matter free; M&MinF, moisture and mineral-matter free.

TABLE 11. – Petrologic composition of coal beds in the Bar H area.

Bed Number (drill hole)	Bed Thickness (feet)	Anthraxylon	Transl. Attritus	Opaque Attritus	Petrog. Fusain	Visible Impurity
Bed 1 (Hole 19)	2.09	51.4	39.4	6.1	2.8	0.3
Bed 2 (Hole 19)	2.38	55.7	39.0	2.2	1.9	1.2
Bed 3 (Hole 21)	2.40	58.0	29.8	9.2	2.4	0.6
Bed 4 (Hole 21)	2.18	39.4	48.7	7.2	3.4	1.3
Bed 5 (Hole 22)	1.81	47.0	49.2	1.4	0.9	1.5
Bed 6 (Hole 23)	2.56	49.9	40.9	4.9	4.0	0.3
Bed 7 1/ (Hole 24)	2.0	51.9 (54.1)	39.2 (41.0)	2.7 (2.9)	1.9 (2.0)	4.3
Bed 8 1/ (Hole 25)	3.25	39.9 (53.5)	29.1 (39.0)	3.0 (4.0)	2.6 (3.5)	25.4
Bed 9 (Hole 25)	4.25	55.6	34.5	3.5	5.4	1.0
Bed 10 (Hole 26)	8.04	49.2	36.4	9.5	3.3	1.6
Bed 11 (Hole 26)	1.73	51.9	26.9	13.0	6.4	1.8
Bed 12 1/ (Hole 27)	2.23	47.5 (49.7)	42.4 (44.5)	3.6 (3.8)	1.9 (2.0)	4.6

1/ Calculations on visually pure basis are given in parentheses.

TABLE 12. - Uranium and ash determinations (air-dry) from Bar H area, Harding County, South Dakota.

Sample Depths	Sample Material	Percent Ash	Parts Per Million 1/ U in Ash	Parts Per Million 1/ U in Sample
Hole 19; NW, NE, NE, Sec. 32, T19N, R8E				
340' 8" – 342' 1"	Sh. carb.	91.5	20	18
342' 1" – 342' 3-1/2"	Shale	93.5	10	11
342' 3-1/2" – 342' 6"	Coal & sh.	65.5	10	15
342' 6" – 342' 9"	Sh. coaly	68.7	20	13
379' 0" – 379' 4-1/2"	Coal imp.	36.7	170	62
379' 4-1/2" – 380' 1/2"	Coal	14.0	1200	168
380' 1/2" – 380' 11-3/4"	Coal	20.9	1750	365
380' 11-3/4" – 381' 5-1/2"	Coal	41.4	360	149
381' 5-1/2" – 381' 9-3/4"	Sh. carb.	55.2	210	115
385' 4-1/2" – 386' 2-1/2"	Coal	24.0	335	80
386' 2-1/2" – 387' 1-1/2"	Coal	18.8	100	18
387' 1-1/2" – 387' 9"	Coal	19.9	190	38
390' 10" – 391' 0"	Coal imp.	46.7	80	37
391' 0" – 391' 11"	Coal	26.7	80	21
391' 11" – 392' 8-1/2"	Coal	20.7	250	52
Hole 21; C of SW 1/4 of Sec. 8, T18N, R8E				
31' 4" – 31' 9"	Coal	21.8	10	2
31' 9" – 32' 3-1/4"	Coal	8.8	10	1
32' 3-1/4" – 32' 10-3/8"	Coal	10.7	20	2
32' 10-3/8" – 33' 9"	Coal	13.4	10	1
41' 8-1/2" – 42' 4-5/8"	Coal	19.3	10	2
42' 4-5/8" – 43' 1-3/4"	Coal	17.7	10	2
43' 1-3/4" – 43' 10-3/4"	Coal	22.2	10	2
69' 9" – 74' 8-1/4"	Coal, 7 samples < 12 ppm			
Hole 22; SW 1/4 of NW 1/4 of Sec. 8, T18N, R8E				
28' 6" – 30' 3/4"	Coal, 3 samples < 10 ppm			
60' 7-7/8" – 61' 0"	Coal	13.7	70	9
61' 0" – 61' 5-3/4"	Coal	7.0	70	5
61' 5-3/4" – 61' 11-3/4"	Coal	12.6	70	9
61' 11-3/4" – 62' 5-1/2"	Coal	29.1	60	17
85' 2" – 85' 7-3/4"	Coal	17.5	40	7
85' 7-3/4" – 86' 1-3/4"	Coal	8.8	110	97
86' 1-3/4" – 86' 7"	Coal	29.5	30	89
Hole 23; SW 1/4, SE 1/4, Sec. 8, T18N, R8E 2/				
21' 9-3/4" – 22' 2-1/8"	Coal imp. W	37.4	270	101
22' 2-1/8" – 22' 4-1/8"	Coal imp. W	44.6	130	58
22' 4-1/8" – 22' 6-1/4"	Coal imp. W	32.3	90	29
22' 6-1/4" – 22' 8-1/4"	Coal imp. W	43.0	60	26
22' 8-1/4" – 22' 10-1/4"	Coal imp. W	45.7	70	32
22' 10-1/4" – 23' 0"	Coal imp. W	47.4	130	62
23' 0" – 23' 1-1/4"	Coal & sh. W	52.4	150	78
39' 1-1/4" – 39' 11"	Coal, 2 samples < 12 ppm			
Hole 23 continued				
42' 8" – 44' 1-1/2"	Coal, 3 samples < 10 ppm			
69' 9" – 70' 4-1/2"	Coal	24.6	20	5
70' 4-1/2" – 70' 8-3/4"	Coal	16.9	20	3
70' 8-3/4" – 71' 5-1/4"	Coal	9.1	60	5
71' 5-1/4" – 71' 9-3/4"	Coal	8.4	20	2
71' 9-3/4" – 72' 3-3/4"	Coal	17.5	40	7
76' 2" – 76' 10-1/4"	Coal, 2 samples < 17 ppm			
Hole 24; C of NE 1/4 of Sec. 5, T18N, R8E				
105' 8" – 105' 10-1/4"	Coal	26.8	340	91
105' 10-1/4" – 106' 1-1/4"	Coal imp.	59.6	160	95
107' 6" – 107' 8"	Coal imp.	48.1	70	34
116' 0" – 116' 5"	Coal	8.25	200	16
116' 5" – 116' 11-3/4"	Coal	11.0	130	14
116' 11-3/4" – 117' 7-1/4"	Coal	21.8	50	11
117' 7-1/4" – 118' 0"	Coal	19.2	50	10
140' 6-1/2" – 142' 4"	Coal, 3 samples < 10 ppm			
144' 5-3/4" – 146' 5-1/4"	Coal, 3 samples < 10 ppm			
174' 11" – 176' 4-1/4"	Coal, 2 samples < 10 ppm			
Hole 25; NE 1/4, NE 1/4, Sec. 3, T18N, R8E				
27' 9-1/2" – 28' 4-3/4"	Coal	26.7	310	83
28' 4-3/4" – 29' 3"	Coal	8.1	660	53
29' 11" – 30' 7-3/4"	Coal	18.8	400	75
30' 7-3/4" – 31' 1/2"	Coal	8.4	560	52
34' 3" – 34' 10-3/8"	Coal	15.2	110	17
34' 10-3/8" – 35' 7"	Coal	8.7	130	11
35' 7" – 36' 3-1/2"	Coal	7.4	160	12
36' 3-1/2" – 37' 1-1/4"	Coal	5.2	240	12
37' 1-1/4" – 37' 10"	Coal	14.3	70	10
37' 10" – 38' 6"	Coal	10.6	120	13
Hole 26; C of NW 1/4, Sec. 35, T19N, R8E				
30' 4-5/8" – 38' 5"	Coal (ash; see Fig. 24) U<10ppm			
62' 2-1/2" – 62' 10-3/4"	Coal	20.6	< 5	< 1
62' 10-3/4" – 63' 7-1/2"	Coal	10.8	10	1
63' 7-1/2" – 63' 11-1/4"	Coal	9.8	30	3
Hole 27; NW 1/4, NE 1/4, Sec. 35, T19N, R8E				
45' 7-1/4" – 46' 5"	Coal	13.2	< 5	< 1
46' 5" – 47' 2"	Coal	14.5	10	1
47' 2" – 47' 10"	Coal	42.3	< 5	< 2

1/ 1 part per million (1 ppm) = 0.0001%; 100 ppm = 0.01%.

2/ All samples of Hole 23 marked W (21' 9-3/4 - 23' 1-1/4") are weathered.

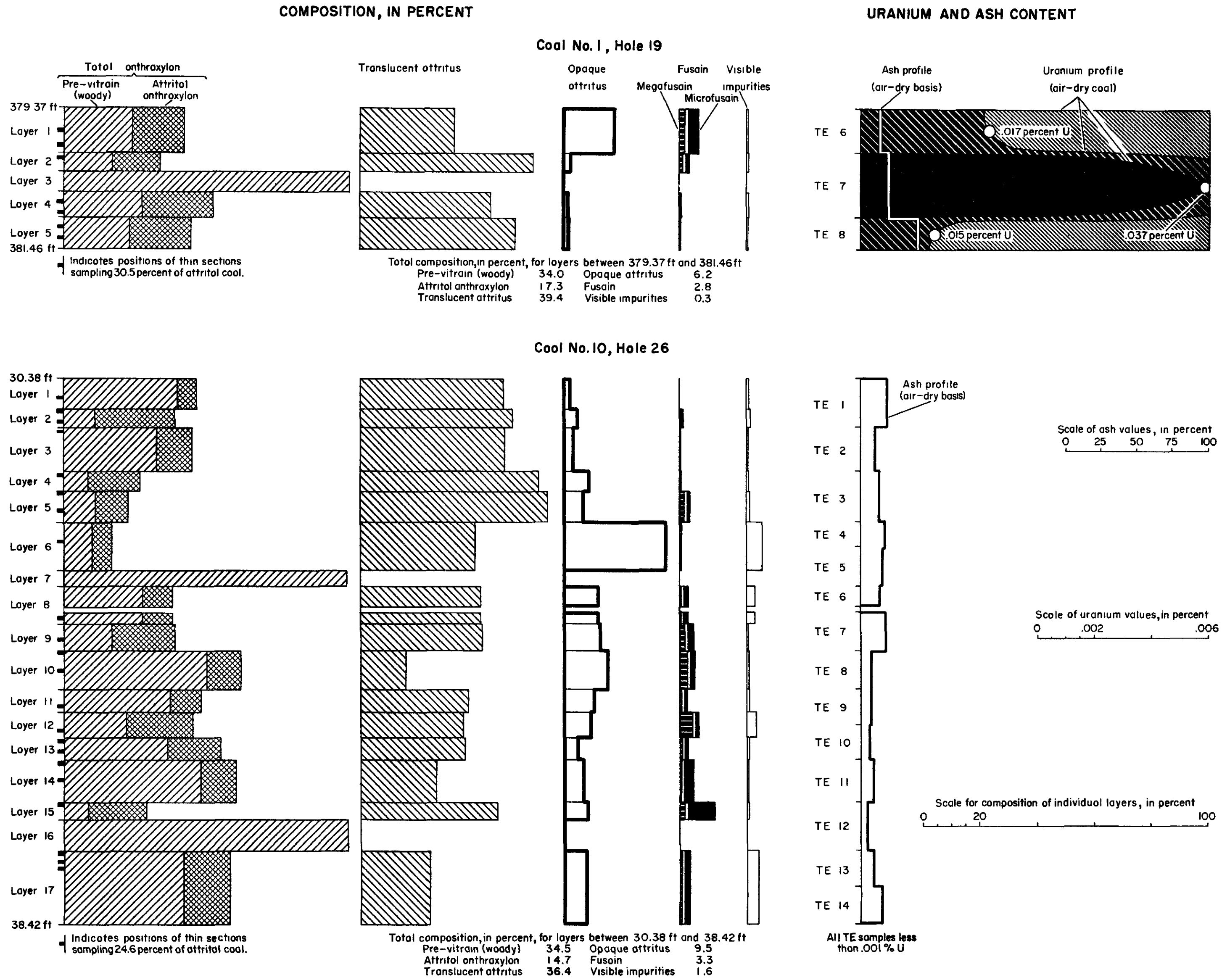


Figure 24.—Composition of lignite in two unnamed coal beds, drill holes 19 and 26, Bar H area, Harding County, South Dakota.

central sample is not readily explicable by peculiarities of the composition of the coal. A thick woody band (determined megascopically) occurs in this sample and the average concentration of translucent attritus would be less than that of the coal above or below it.

The composition of coal No. 10 from hole 26 also is shown in figure 24 and tables 10, 11, and 12. A greater concentration of translucent attritus occurs in layers toward the top of the bed and decreases downward. The anthraxylon shows a generally reciprocal distribution with respect to translucent attritus. Opaque attritus appears to be more concentrated in the central part of the bed. Only ash determinations are given in the column to the right. All samples from this coal bed had less than 0.001 percent uranium.

COAL IN THE MEDICINE POLE HILLS AREA

The Medicine Pole Hills are about 45 miles northwest of the Slim Buttes in central Bowman County, N. Dak., as shown on the general index map (fig. 1, p. 6). The area is small and the location of holes drilled in 1951 are shown on the large scale index map (fig. 25). The Harmon coal bed, originally mapped by Hares (1928), is present in the Medicine Pole Hills over an area of about 360 acres according to Zeller (report in preparation).

Zeller (report in preparation, Appendix B) has given analyses of the coal. It appears to be a little lower rank than that of the Slim Buttes with a normal bed content of about 46 percent moisture. The bed averages a little less than 10 percent ash. Zeller has commented on the rather unusual distribution of uranium in the Harmon coal bed.

Results of the petrologic examination of the Harmon bed are given in comparison with uranium and ash determinations in figure 26. The Harmon bed is very extensive beyond the small area of the Medicine Pole Hills, and for this reason it seems desirable to present available data on its petrologic composition. An incomplete suite of sections was prepared from selected blocks from three of the drill cores. These probably are adequate for purposes of approximation but may be less accurate than results given for coals of the Mendenhall area. Spacing of sections has limited the number of layers for which data could be obtained so that the layer profiles are somewhat generalized.

The average petrologic composition of the Harmon bed is 43 percent anthraxylon, 51.5 percent translucent attritus, 2.8 percent opaque attritus, 1.4 percent fusain and about 1.3 percent visible impurities.

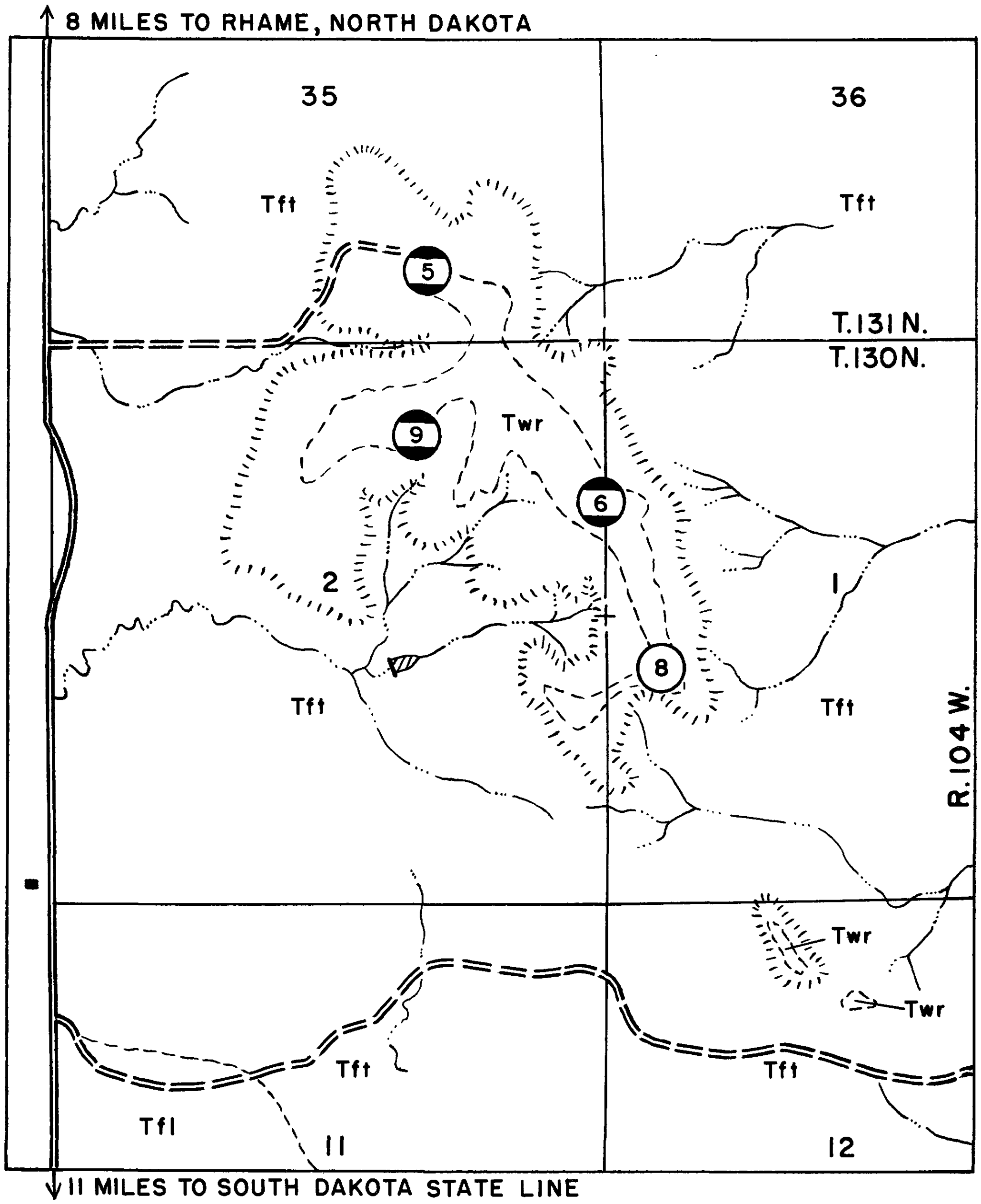
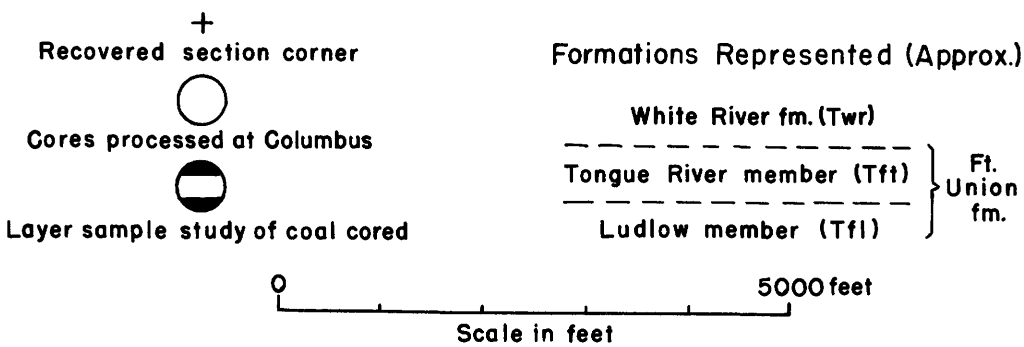


Figure 25.—Index map of the Medicine Pole Hills area, Bowman County, North Dakota, showing core hole locations. (after H.D. Zeller)



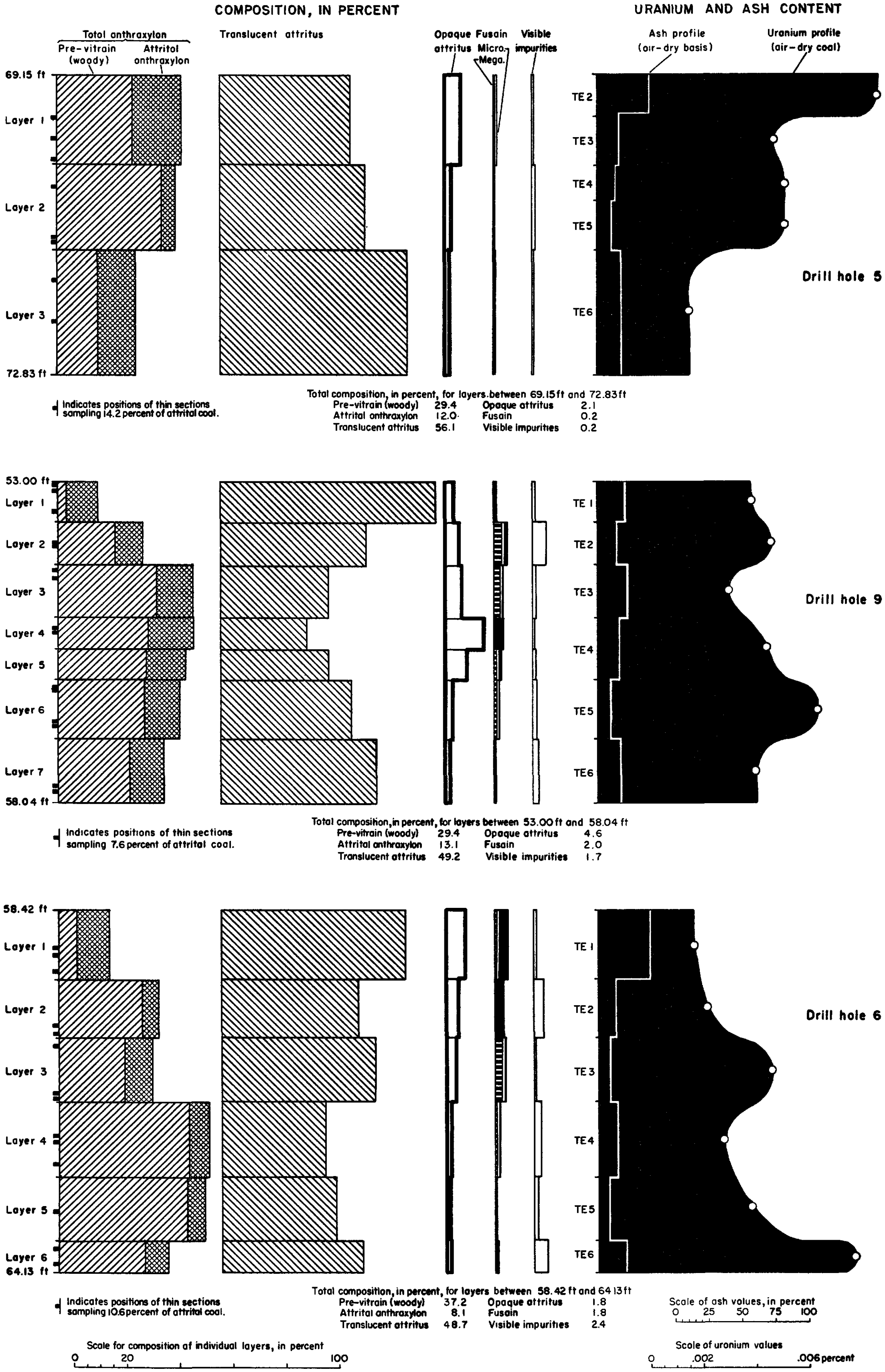


Figure 26.—Composition of lignite in Harmon Coal bed, Medicine Pole Hills, Bowman County, North Dakota.

From figure 26 it appears that the uranium is in normal top-preferential concentration in hole 5 (top) and that anthraxylon and opaque attritus likewise decline toward the bottom of the bed. In hole 9 (center) increasing anthraxylon and opaque attritus is shown in the central part of the bed. Although uranium concentration in this core is more nearly uniform, it does not correspond with distribution of petrologic constituents. The greatest concentration of uranium is in the bottom layer of the coal bed in hole 6. Anthraxylon also is in greater concentration in the lower part of the bed, but correlation with uranium concentration is not apparent. These results do not support any interpretation of consistent relationship between petrologic composition of the coal and its uranium content. This lends weight to Zeller's interpretation that mineralized ground water, moving laterally at the bottom and through the coal bed, may have resulted in enrichment of uranium in the coal.

COAL IN THE LODGEPOLE AREA

The Lodgepole area is about 25 miles northeast of the Slim Buttes in central Perkins County, S. Dak., about two miles south of Lodgepole Post Office as shown on the general index map (fig. 1, p. 6). The Lodgepole area is approximately 50 miles southeast of the Medicine Pole Hills previously discussed. A large scale map showing location of drill holes, roads and drainage of the immediate area is given in figure 27. The geology has been mapped and discussed by Zeller (report in preparation). The Lodgepole area was included by Winchester and others (1916) in their study of the lignite field in northwestern South Dakota.

Two coal beds are present, identified tentatively as the Harmon and the Harmon "Rider." Studies of both coal beds have been made, similar in quality to the studies of the Harmon bed in the Medicine Pole Hills of North Dakota. Chemical analyses of the Lodgepole drill cores have been given by Zeller (report in preparation, Appendix B). Probably in both the Lodgepole and Medicine Pole areas the coal is of about the same rank (46 percent bed moisture).

The results of petrologic examination are shown in figure 28. Ash profiles are given in comparison, but all layers of both of these coal beds at the localities studied contained a negligible amount of uranium.

The petrologic composition of the Harmon coal bed at the Medicine Pole Hills and of the Harmon and Harmon "Rider" in the Lodgepole area is summarized in table 13. It is apparent that the general composition of these beds is similar, but opaque attritus is significantly higher

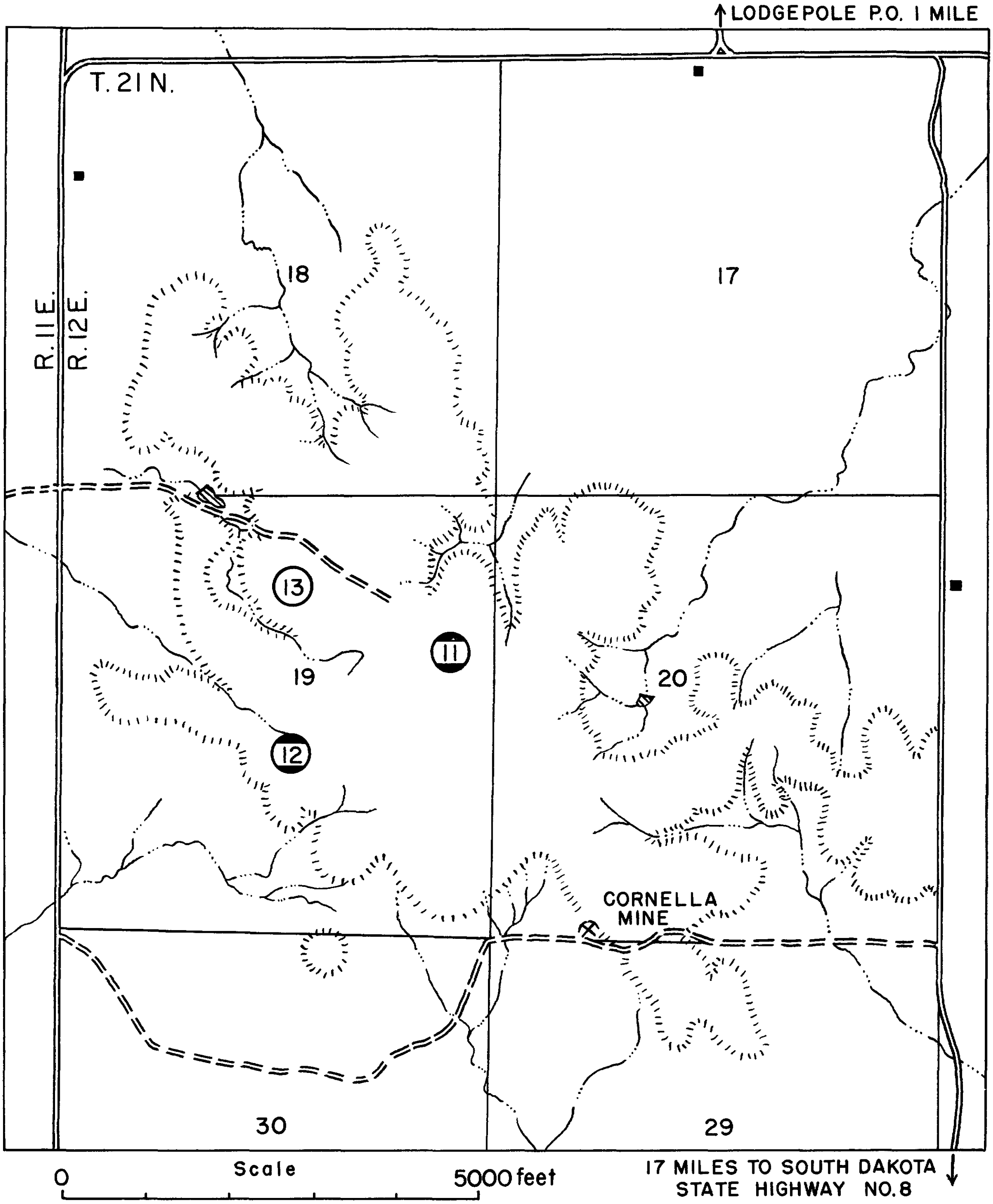
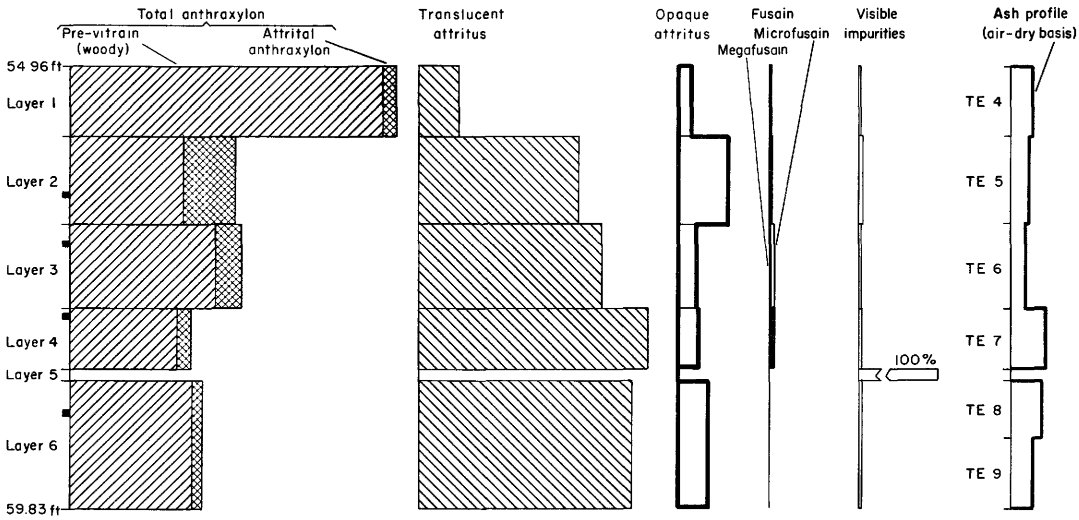


Figure **27**.— Index map of the Lodgepole area, Perkins County, South Dakota, showing core hole locations. (adapted after H. D. Zeller)

Cores processed at Columbus

Layer sample study of coal cored

Harmon Rider Bed, Hole 11



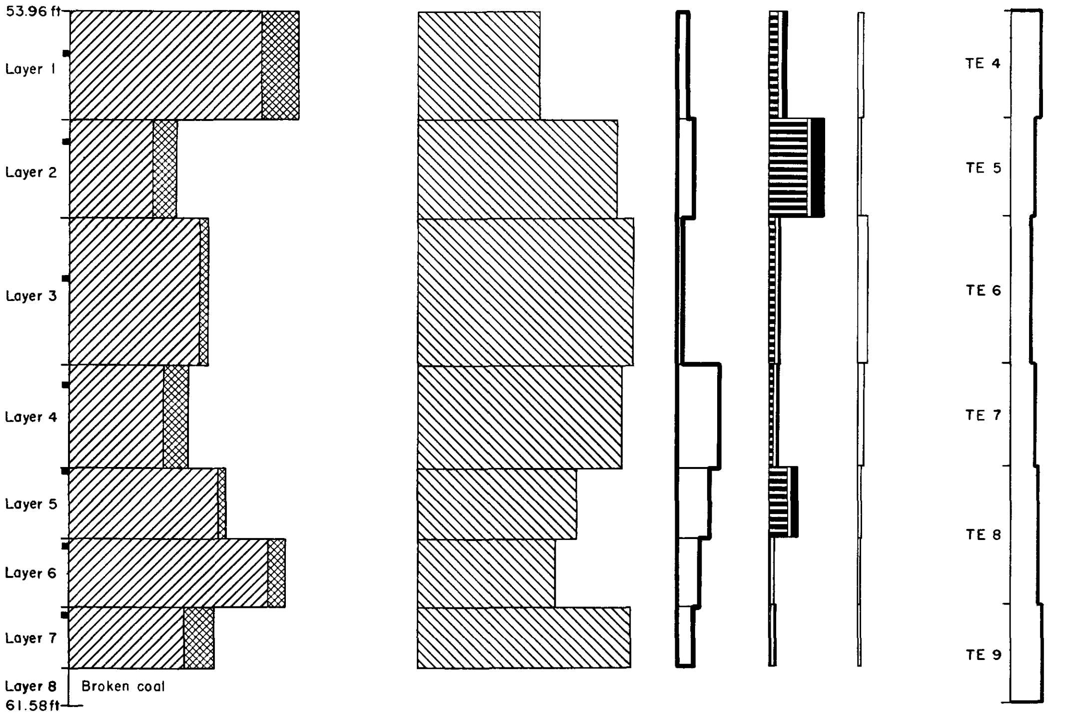
▪ Indicates positions of thin sections sampling 8.5 percent of attrital coal.

Total composition, in percent, for layers between 54.96 ft and 59.83 ft

Pre-vitrain (woody)	39.6	Opaque attritus	7.3
Attrital anthraxylon	5.9	Fusain	0.5
Translucent attritus	43.6	Visible impurities	3.1

All TE samples less than .0005 % U

Harmon Coal Bed, Hole 12



▪ Indicates positions of thin sections sampling 10.1 percent of attrital coal.

Total composition, in percent, for layers between 53.96 ft and 61.58 ft

Pre-vitrain (woody)	35.9	Opaque attritus	4.6
Attrital anthraxylon	5.4	Fusain	5.0
Translucent attritus	47.7	Visible impurities	1.4

All TE samples less than .001 % U

Scale for composition of individual layers, in percent: 0 20 100

Scale of ash values, in percent: 0 25 50 75 100

Figure 28.–Composition of lignite in Harmon "Rider" and Harmon Coal beds, drill holes 11 and 12, Lodgepole area, Perkins County, South Dakota

in the Harmon "Rider," and fusain is less abundant. It is also apparent that the Harmon "Rider" at this location is the more impure bed; chemical analysis (B. of M. Lab. No. D-69688) of the coal showed 28.4 percent ash on a moisture-free basis. The Harmon bed at the Lodgepole location contains substantially more opaque attritus and fusain than it does in the Medicine Pole Hills. Such differences are to be expected over distances much less than those separating these localities.

TABLE 13. - Composition of Harmon coal bed, Medicine Pole Hills (N. Dak.), and of Harmon and Harmon "Rider" beds, Lodgepole Hills (S. Dak.).

	Anthraxylon	Trans. Attritus	Opaque Attritus	Petrog. Fusain	Visible Impurity
Harmon bed at Medicine Pole Hills	43.0	51.5	2.8	1.4	1.3
(Average of three determinations: Holes 5, 6 and 9.)					
Harmon bed at Lodgepole Hills	41.3	47.7	4.7	5.0	1.4
(One determination: Hole 12.)					
Harmon "Rider" bed at Lodgepole Hills	45.5 (47.0)	43.6 (45.0)	7.2 (7.5)	0.5 (0.5)	3.1
(One determination: Hole 11; visually pure values in parentheses.)					

The Harmon bed appears to include somewhat less anthraxylon than coals of the Mendenhall area and considerably less than the usual woody lignites of North Dakota (table 3). According to the tendency indicated by coals in the Mendenhall area, the larger amount of translucent attritus should make this bed a good receptor for uranium. Elsewhere, in the Johnson outlier a few miles from the Lodgepole area (e.g., hole 14; Zeller, report in preparation, fig. 8), this seems to be borne out. The local availability of uranium-bearing solutions seems in any case to be of greater importance than the petrologic composition of the coal.

CONCLUSION

Denson, Bachman and Zeller (report in preparation) have contrasted the evidence supporting the syngenetic theory of origin for uranium in the Dakota lignites, with that supporting an epigenetic origin. The syngenetic hypothesis of origin has much theoretical appeal. When this investigation of the Dakota coals began, there seemed a considerable likelihood that some of the organic constituents or components in the coal would prove to have a much greater affinity for uranium than others. It also seemed likely that such a relationship would throw considerable light on the time at which the uranium was emplaced in the coal deposits. It now seems evident that the petrologic constituents of low rank coals in western North and South Dakota do not exert a very specific influence on the occurrence of uranium. Our laboratory studies have confirmed the top-preferential distribution of uranium in the Dakota coals in greater detail. This type of uranium occurrence contrasts with the less regular distribution of uranium in other western uraniferous coals (Schopf and Gray, 1954, and report in preparation).

The strong positional relationship shown by uranium in Dakota coals implies that the uranium was introduced late in the history of the coal beds. If the uranium had been emplaced in the early diagenetic or peat stage, a more specific relationship to the kinds of plant components would be likely because differences in composition and physical condition of the organic material are greatest before coalification. The lack of a very evident distinction in the affinity of organic components for uranium seems good supporting evidence in favor of emplacement after coalification had attained the present stage. The Dakota uraniferous lignites present a single distinctive and well-defined type of uranium occurrence and only a single theory seems adequate to explain origin of the uranium. No information developed in the course of the present study appears to be in conflict with the theory of uranium emplacement advanced by Denson, Bachman and Zeller (in preparation).

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