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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

MICROSCOPIC STUDIES OF URANIFEROUS COAL DEPOSITS—A PROGRESS REPORT *

By

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USGS Coal Geology Laboratory
Columbus, Ohio

February 1954

Trace Elements Investigations Report 408

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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-408

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MICROSCOPIC STUDIES OF URANIFEROUS COAL DEPOSITS — A PROGRESS REPORT

By James M. Schopf and Ralph J. Gray

ABSTRACT

Quantitative coal petrologic studies have been completed on four beds of uranium-bearing lignite from the Slim Buttes area of Harding County, S. Dak. Comparison with analyses of lignite from commercial deposits suggests that the Slim Buttes coals are highly variable in composition. However, in comparison with most coal deposits, all of the Slim Buttes coals studied have in common an unusually high uranium content. These studies show that no quantitative correlation exists between uranium content and the coal petrologic constituents that are normally determined for coal type classification and prediction of coal behavior in utilization.

As the coal constituents normally determined are to some extent heterogenous, a further study was made of subordinate components. The components of translucent attritus were studied particularly, not only for selected layers of Slim Buttes lignite, but also for layers of coal from the Goose Creek field in southern Idaho. These data are presented for eleven layers of relatively high uranium content and for eight associated layers that are much less radioactive and approach values that are nearly normal for coal. This comparison casts doubt on direct correlation of uranium content with the amount of any single microscopic component of coal. A more complex control of uranium occurrence in coal is indicated.

It may be significant that the samples richest in uranium contain relatively large amounts of humic attrital matter resulting from decomposition and microbial decay. One may tentatively conclude that this type of highly degraded organic material is most favorable to uranium emplacement.

INTRODUCTION

Uranium-bearing coals in South Dakota, Idaho, and Wyoming are being studied by the Geological Survey as possible sources of uranium. Fuel value of the coal should favor economic uranium extraction. Field reconnaissance and detailed geologic studies have been followed by exploratory drilling in the Slim Buttes area, South Dakota, the Goose Creek area, Idaho, and the Red Desert area, Wyoming. Cores from the exploratory drilling have been processed and sampled in the Coal Geology Laboratory of the Geological Survey to provide close correlation of analyses and descriptions of the coal and associated rocks as a basis for further petrologic and geochemical research.

The object of these studies is to determine the nature of these uranium-bearing coals and, so far as possible, to indicate conditions governing the occurrence of uranium in them. Only brief statements, showing general radioactivity profiles (Schopf, 1953) and progress in petrologic investigations (Schopf, Gray and Warman, 1953), have previously been given. Part of the petrologic research, involving quantitative microscopy of coal thin sections from the Slim Buttes area, Harding County, S. Dak. and from the Goose Creek area, Cassia County, Idaho, is presented in this progress report. Studies of these coals and those from the Red Desert area are continuing. The work was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

Coal petrologic methods and microanalytic standards developed by Thiessen and his colleagues at the U. S. Bureau of Mines (Thiessen 1931, Thiessen and Sprunk 1935, Thiessen 1937, Parks and O'Donnell 1949) have been followed in the present study and to some extent expanded upon. This method of study indicates similarities or differences in the plant products that have contributed to coal to a greater extent than standard chemical analyses that are based on empirical procedures. Both methods present kinds of data that are useful for different purposes and for evaluating different properties so that both are essentially complementary. Thiessen's petrologic procedures have been most widely applied in the United States and they afford the best basis for studying the relationship between plant constituents and uranium content. Most coal beds are not uraniferous (among others, see Russell, 1944, 1945; DeMagnée, 1952; and Welch, 1954) so that this comparison should disclose whether coal of unusual plant composition is associated with an unusual content of uranium.

Breger and Deul (1952) have shown that nearly all of the uranium in weathered lignite from the nearby Mendenhall mine is chemically held as an organo-uranium compound or complex by the organic matter, and is not directly associated with mineral matter or with other trace elements. Since radioactivity profiles of the weathered and unweathered lignites are similar (Schopf, 1952), it seems probable that this condition applies generally to radioactive coal of the Slim Buttes area. However, uranium is always distributed very unequally within each bed of coal, and this requires a further explanation.

Acknowledgments

Analytic values for air-dry ash and uranium have been determined in the Washington Trace Elements Laboratory of the U. S. Geological Survey by Alice Padgett, Alice Cammerer, and Thomas Murphy under the direction of Irving May. Standard analyses of coal have been provided by the Coal Analysis Section of the U. S. Bureau of Mines under supervision of Mr. Roy F. Abernethy.

GEOLOGIC INVESTIGATIONS

The uranium-bearing lignites in the Slim Buttes area, Harding County, S. Dak. were studied by Denson, Bachman, and Zeller (1951) and results of exploratory core drilling by the Geological Survey were reported by Zeller (1952). The area was included in the earlier geologic report by Winchester and others (1916). Additional core drilling was undertaken in 1952 by the Atomic Energy Commission in cooperation with the Bureau of Mines and the Geological Survey. J. R. Gill of the Geological Survey is preparing a geologic report on the drilling by the Atomic Energy Commission. Samples from both programs of exploratory drilling are included in this preliminary statement of results of coal petrologic studies. Hail and Gill (1953) made a reconnaissance study of the geology of the Goose Creek area and Mapel and Hail (1953) described the geology of the district in detail. Exploratory core drilling was undertaken there by the Geological Survey in 1953, and samples from two of these holes are included in this progress report.

GEOLOGIC SETTING

The uranium-bearing lignites in the Slim Buttes area of South Dakota are in the Ludlow member of the Fort Union formation of Paleocene age. The lignite-bearing rocks are exposed in the lower part of the Slim Buttes, a prominent topographic feature which is capped by rocks of the White River group (Oligocene) and by the Arikaree formation [Miocene (?)]. Denson, Bachman, and Zeller (1951) and Zeller (1952) believe that uranium was emplaced in the lignite beds by ground water that had leached uranium from the overlying Oligocene and Miocene (?) strata. The White River deposits are thick and tuffaceous, generally mildly radioactive, and recently have also been found to contain carnotite (Gill, 1953). Emplacement of uranium in Slim Buttes coal by ground water movement is suggested by the frequent occurrence of uranium in greatest concentration in the uppermost part of the first bed of lignite below the pre-Oligocene unconformity.

The uranium-bearing lignite and carbonaceous shale in the Goose Creek area is in the Salt Lake formation of Pliocene age, a thick sequence made up chiefly of volcanic ash and welded tuff. The volcanic ash is slightly uraniferous. Mapel and Hail (1953) suggest that the lignite and carbonaceous shale were enriched in uranium by extracting uranium from ground water which had leached the uranium from the volcanic ash and tuffs.

COAL PETROLOGY OF LIGNITE FROM SLIM BUTTES

Coal petrologic studies thus far have been completed for the three coal beds cored in Hole SD-10[1] and one bed in Hole 16[1]. According to recent studies by J. R. Gill (personal communication) the upper two beds of Hole SD-10 are jointly equivalent to the upper bench of the bed formerly worked at the Olesrud mine in the SE 1/4 of sec. 36, T. 18 N., R. 7 E. The third bed is equivalent to the lower bench of coal at the Olesrud mine. The coal bed tested in Hole 16 is equivalent to the thin bed shown in outcrop along the west side of the Slim Buttes that is located some distance above the Mendenhall bed of the nearby Mendenhall strip mine (NW 1/4SE 1/4 sec. 1, T. 17 N., R. 7 E.) and is referred to as the Mendenhall "rider". The results of these studies are illustrated diagrammatically in figures 1-3.

[1] Core holes designated by numbers prefixed with SD were drilled in 1952 and 1953 by the Atomic Energy Commission in cooperation with the Bureau of Mines and the Geological Survey. Core holes designated by numbers without a letter prefix were drilled by the Geological Survey in 1951.

Uranium-bearing lignite in the Slim Buttes area usually shows very definite, more or less regular, concentration of uranium at the top of the bed as is illustrated by the Mendenhall "rider" bed in figure 3. In Hole SD-10 the Olesrud group of beds is exceptional, for at that locality uranium is irregularly concentrated in various layers (figs. 1 and 2). Apparently this irregular distribution is related to a cause other than to downward percolating ground water. For this reason it presents an opportunity to test the relationship of the petrologic composition to uranium content under circumstances that might be unusually revealing. It was hoped that some direct petrologic correlation would be apparent and so indicate which coal constituents or components were most receptive to emplacement of uranium.

The average composition of these Slim Buttes coal beds is presented in table 1 in comparison with some of the available petrologic data on other Dakota lignite deposits that are essentially lacking in uranium.[1]

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[1] None of twenty-one lignite samples from four companies producing in North Dakota in 1951 and 1952 showed more than .001% equivalent uranium, according to TWP reports 1324, 1590 to 1593, and TWC report 1803 of the Washington Trace Elements Laboratory.

If any general feature of petrologic composition is related to the unusual association of uranium in coal, such a comparison should reveal it, but none is apparent. The most striking feature is the high degree of variability in petrologic composition of the different beds of Slim Buttes coal.

Table 1.--Average composition of Slim Buttes coal beds and of beds mined in North Dakota

	Source	Anthraxylon (percent)	Translucent attritus (percent)	Opaque attritus (percent)	Fusain (percent)
Uraniferous coal of Slim Buttes	Hole 16 at 333.92' Mendenhall "rider"	53	17	24	3
	Hole SD-10 at 317.4' Top split of Olesrud Upper bench	50	32	7	11
	Hole SD-10 at 321.37' Bottom split of Olesrud Upper bench	75	23	1	1
	Hole SD-10 at 381.07' Olesrud Bed Lower bench	56	31	6	7
Lignite mined in N. Dak.	Burleigh lignite	63	31	5	1
	Lehigh lignite	59	36	3	2
	Beulah lignite	53	25	15	6
	Baukol-Noonan lignite	56	33	4	7

An unusually high content of opaque attritus seems distinctive for the coal from Hole 16 (fig. 3). The high anthraxylon content of the thin second coal bed in SD-10 indicates an extremely woody lignite (fig. 1). The eleven percent of fusain found in the upper coal bed in SD-10 (fig. 1) also is exceptional, particularly as it is linked with a high, but not extraordinary, occurrence of opaque attritus. There is, however, a considerable amount of pyrite associated with the uppermost coal bed in this drill hole, which suggests at least temporary periods of increased anaerobic bacterial activity (Schopf, 1952) during the period of peat accumulation. The marked variations in composition undoubtedly signify differences in conditions of accumulation having paleo-ecologic significance -- in the varieties of plants, their accumulation and decay in peat formation, and their influence on diagenetic changes, which resulted in coal of this diversity. These topics can scarcely be discussed in this preliminary report but all will require further consideration.

Standard coal analyses were obtained for all coal cores that had potential economic interest. Analyses of samples from Hole SD-10 and Hole 16 are given in table 2. Other older analyses are given by Winchester and others (1916, p. 42-3). Analyses of lignite from recently operated mines in North Dakota are included in table 2 for the present comparison. One recent analysis of Goose Creek impure coal also is included. Usually the quality of coal is evaluated almost entirely by means of such chemical analyses, but the petrologic results presented here show that the variety of organic materials composing these beds is not indicated by these customary methods. For example, chemical analysis of the coal from Hole 16, which is unusually high in opaque attritus shows, on a moisture and ash free basis, fixed carbon almost identical to the other coals from the Slim Buttes area and only about 2 percent more total carbon.

The reasonable agreement of these coal analyses as compared with the marked differences in organic make-up, is not surprising. The materials contributed by quite different kinds of plants may be similar in chemical properties although they react in different ways during coalification. Opaque attritus and fusain generally indicate a greater concentration of carbon but this expected effect can be counterbalanced in a sample by other materials of more volatile composition. The relation between plant composition (type) and advancing incoalation (rank) is least well understood in coals of low rank that have been only slightly metamorphosed. The analyses of Dakota commercial deposits appear to indicate coal of somewhat higher rank than the beds of the Slim Buttes.

Table 2.--Analyses of coal

Bed, location and kind of sample	Top and middle Slim Buttes beds; 317'4-3/4" to 322'6-3/4" depth; Core from Hole SD-10			Lower Slim Buttes coal bed; 381'7/8" to 386'6-3/4" depth; Core from Hole SD-10			Mendenhall Rider (?) bed; 333'7¼" to 341'11½" depth; Core from Hole 16			Burleigh Strip Mine; Burleigh Co., N.Dak.; Coal bed face sample			Noonan bed, Baukol-Noonan Mine; Divide Co., N.Dak.; Mine-run composite sample			Coteau bed, Velva Mine; Ward Co., N.Dak.; Mine-run composite sample			Goose Creek Impure coal; 243'6-5/8" to 247'8½" depth; Core from Hole 2		
B of M Lab. No.	E-9832			E-9933			D-71570			C-32442 2/			C-65444 2/			C-46606 2/			E-28432		
Basis of reporting 1/	AR	MF	MAF	AR	MF	MAF	AR	MF	MAF	AR	MF	MAF	AR	MF	MAF	AR	MF	MAF	AR	MF	MAF
Proximate: Moisture	44.2	-	-	43.9	-	-	41.8	-	-	36.7	-	-	35.5	-	-	38.2	-	-	33.4	-	-
Proximate: Volatile M.	20.2	36.3	44.1	21.6	38.4	45.8	22.0	37.9	45.8	29.3	46.3	50.7	26.6	41.3	45.6	26.7	43.2	47.7	11.8	17.7	50.1
Proximate: Fixed Carbon	25.7	46.0	55.9	25.5	45.5	54.2	26.1	44.8	54.2	28.5	45.0	49.3	31.7	49.1	54.4	29.3	47.5	52.3	11.7	17.6	49.9
Proximate: Ash	9.9	17.7	-	9.0	16.1	-	10.1	17.3	-	5.5	8.7	-	6.2	9.6	-	5.8	9.3	-	43.1	64.7	-
Ultimate: Sulfur: Sulfate	.01	.02	.02	.01	.01	.02	3/	.07	.08	-	-	-	-	-	-	-	-	-	.05	.08	.23
Ultimate: Sulfur: Pyritic	.24	.43	.52	.41	.74	.88		.29	.35	-	-	-	-	-	-	-	-	-	.33	.50	1.42
Ultimate: Sulfur: Organic	.32	.57	.70	.42	.74	.89		1.25	1.50	-	-	-	-	-	-	-	-	-	.60	.90	2.55
Ultimate: Sulfur: Total	.6	1.0	1.2	.8	1.5	1.8	.8	(1.61) 1.4	(1.93) 1.7	.6	.9	1.0	.5	.7	.8	.3	.5	.5	1.0	1.5	4.2
Ultimate: Hydrogen	7.0	3.7	4.5	7.1	3.9	4.6	6.9	3.8	4.6	6.9	4.4	4.8	-	-	-	-	-	-	5.0	2.0	5.7
Ultimate: Carbon	32.8	58.8	71.4	33.4	59.5	70.9	34.7	59.7	72.2	42.0	66.3	72.6	-	-	-	-	-	-	16.6	24.9	70.6
Ultimate: Nitrogen	.4	.7	.8	.4	.8	.9	.4	.8	.9	.6	1.0	1.1	-	-	-	-	-	-	0.3	0.5	1.4
Ultimate: Oxygen	49.3	18.1	22.1	49.3	18.2	21.8	47.1	17.0	20.6	44.4	18.7	20.5	-	-	-	-	-	-	34.0	6.4	18.1
Btu	5470	9790	11890	5640	10050	11970	5790	9950	12030	6930	10960	12000	7250	11240	12430	6750	10920	12050	2925	4390	12450
Fusibility of Ash	Init.Def.1980°F			Init.Def.1970°F			Init.Def.2050°F			-			-			-			Init.Def.2490°F		
	Softening 2020°F			Softening 2020°F			Softening 2100°F			Softening 2500°F			-			-			Softening 2670°F		
	Fluid 2130°F			Fluid 2060°F			Fluid 2180°F			-			-			-			Fluid 2770°F		
Specific Gravity	1.65			1.63			-			-			-			-			1.92		

1/AR=As Received; MF=Moisture Free; MAF=Moisture and Ash Free.
2/Analyses taken from U. S. Bureau of Mines Bull. 482, p 23, 1950.
3/Forms of sulfur determined from a duplicate dry sample corresponding to D-71570.

The petrologic charts presented in figures 1, 2, and 3 illustrate layer by layer distribution of all the coal constituents, impurities, ash, and uranium. These results, based as they are on a diverse suite of coals, do not suggest a direct correlation between uranium content and coal petrographic constituents. The chemical analyses for uranium are the basis for the uranium profiles presented on the right in each of the three figures. The Coal Geology Laboratory radioactivity profile (P/M/G)[1] and air-dry ash

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[1] P/M/G=pulses per minute per gram. For this purpose a coarsely crushed sample is placed in a cup surrounding a thin walled Geiger-Müller tube (Victoreen 1B85) and pulses recorded by a standard 64 scaler. Net pulses per minute per gram are determined in duplicate and averaged, using roughly similar volumes of sample for duplicate determinations. Introduction of the weight factor in calculating results apparently compensates to some extent for natural variations in density as well as for variations in sample volume occasioned by a minimum procedure in sample preparation.

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determinations for successive layers also are superimposed on the uranium profile in figures 1 and 2. The ash profile suggests a very slight increase of ash in several of the more radioactive layers. Coal Geology Laboratory radioactivity measurements generally closely parallel chemical determinations of uranium for this type of material. In some instances, where chemical analyses were made by combining laboratory radioactivity samples, they suggest that the uranium actually is distributed even more irregularly than the profiles based on the larger chemically determined samples would indicate.

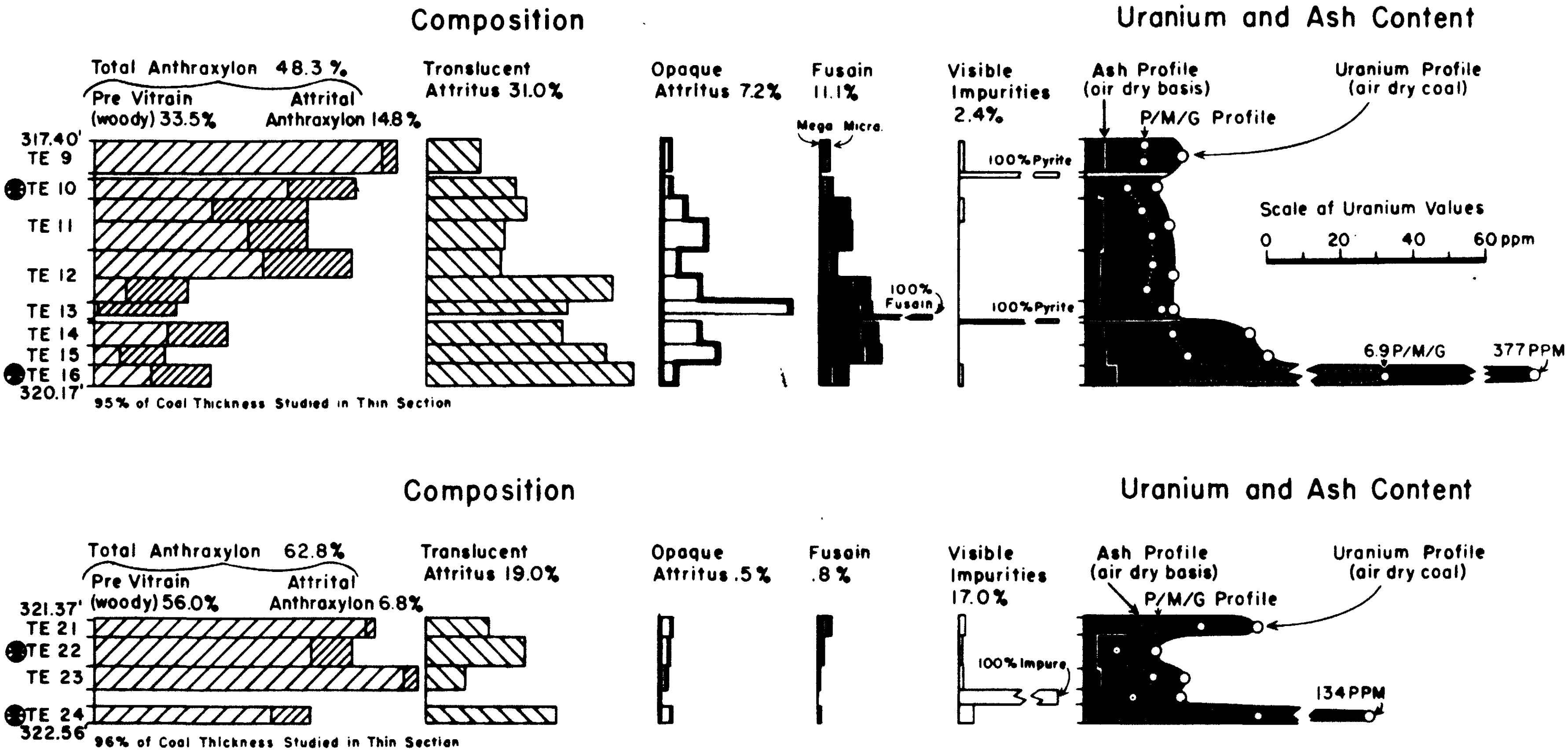


Fig. 1 - COMPOSITION OF LIGNITE IN UPPER BENCH, OLESRUD BED, DRILL HOLE SD-10
Slim Buttes Area, Harding County, South Dakota

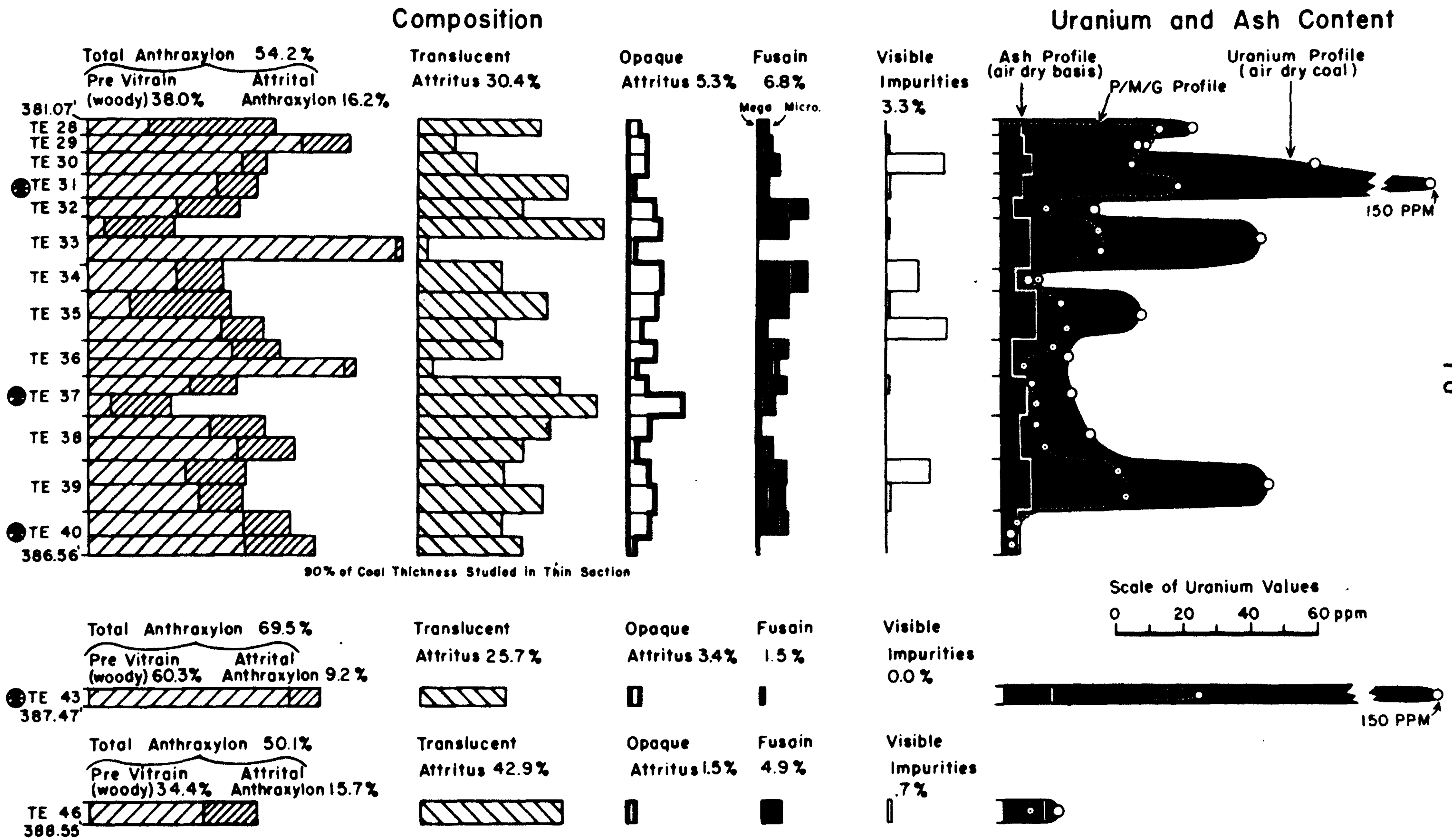
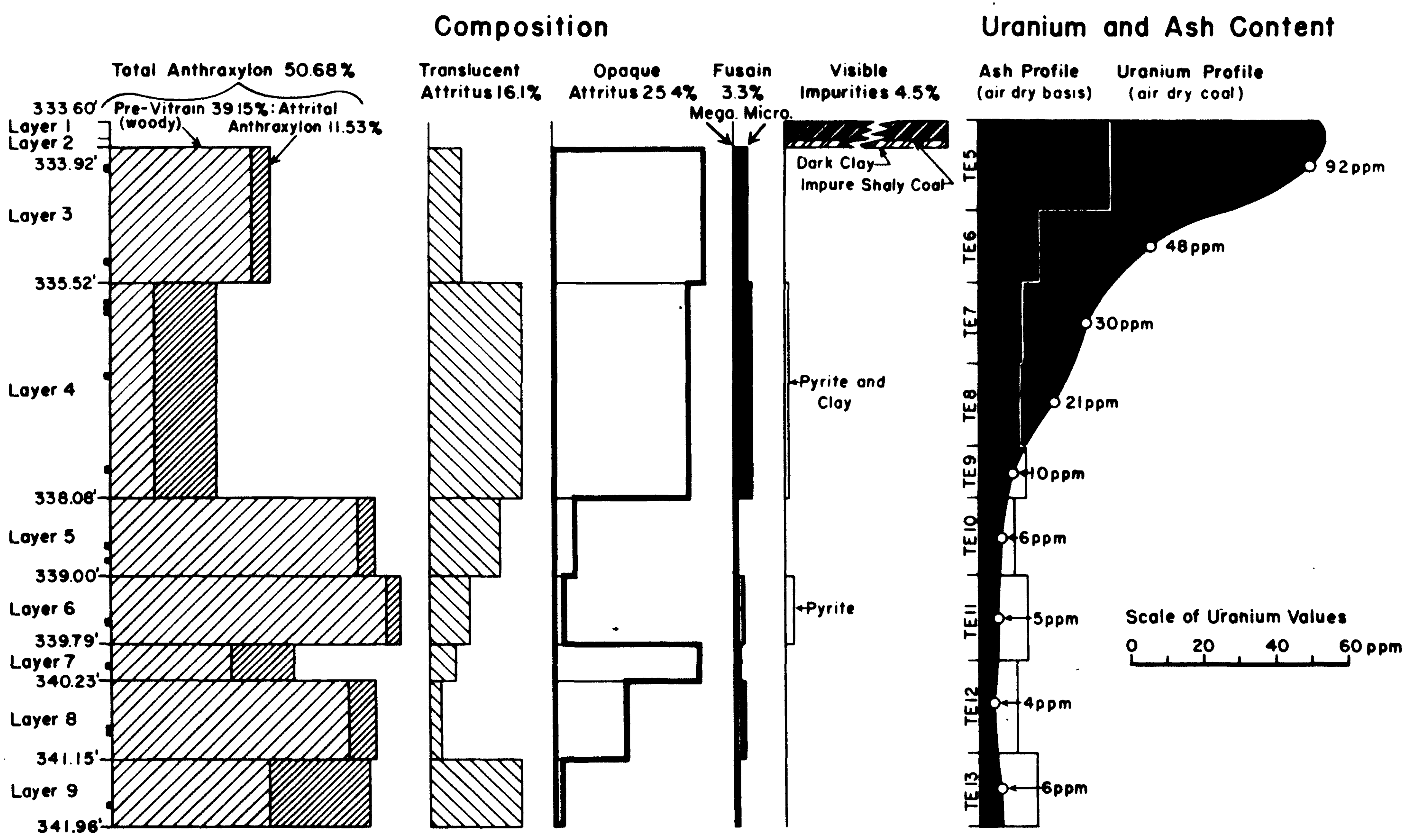


Fig. 2 - COMPOSITION OF LIGNITE IN LOWER BENCH, OLESRUD BED, DRILL HOLE SD-10
Slim Buttes Area, Harding County, South Dakota



Tabs Indicate Positions of Thin Sections Sampling Attrital Coal. 15.3% of Attrital Coal is Represented in Sections

Fig. 3 – COMPOSITION OF LIGNITE IN MENDENHALL "RIDER" BED, HOLE 16
Slim Buttes Area, Harding County, South Dakota

COMPOSITION OF TRANSLUCENT ATTRITUS

In order to test further for a possible correlation between different microscopically visible plant materials and degradation products, it is principally necessary to identify and separate the various components of translucent attritus -- the most heterogeneous of the coal constituents. According to the standard coal petrologic procedure (Parks and O'Donnell, 1949) translucent attritus is determined by difference. In regular practice, after anthraxylon, fusain and opaque attritus are determined by direct transect measurements, this finely particulate, heterogeneous, non-opaque fraction (which can vary greatly in amount) is usually described qualitatively. The refinement of quantitatively analyzing the translucent attritus fraction requires more time and painstaking observation at higher microscopic magnification than normally is practicable for study of an entire coal bed. Data comparable to that presented below, concerning the quantitative occurrence of materials composing translucent attritus, have not been previously presented in coal petrologic literature.

The relation between uranium content and the composition of coal layers was studied in four SD-10 coal layers of relatively high uranium content and compared with five layers of low uranium content. These layers are marked by asterisks at the left margin of figures 1 and 2. A similar but briefer study was made of five layers of high radioactivity from Goose Creek Hole 2 and three layers of low radioactivity from Goose Creek Hole 3A. The results of these studies are given in detail in tables 3 and 4. Each set of samples is arranged in order of decreasing uranium content. Table 3 presents the distribution of all identified constituents or components as percentages of the individual layers; table 4 presents the distribution of the identified constituents or components of the translucent attritus as percentages of the total translucent attritus alone. In interpreting table 4 it should be borne in mind that translucent attritus makes up from about 25 to 55 percent of the layers of the lignite from the Slim Buttes area and over 70 percent of all layers in the Goose Creek deposit. Percentages of total translucent attritus in each layer studied are given at the bottom of each column in table 4.

The Goose Creek coal is of a highly attrital or non-banded type and contrasts strongly, in appearance and petrologic composition, with the banded lignite of the Slim Buttes area. Highly and slightly radioactive portions from different Goose Creek drill holes are indistinguishable in appearance but in radioactivity the contrast is more pronounced than in Slim Buttes material. The most radioactive layers of the bed in Hole 2 are centrally and somewhat irregularly distributed without apparent fixed relation to the top of the coal bed.

The different kinds of organic particles are more uniformly dispersed in non-banded carbonaceous deposits such as oil shales and cannel coals than in banded coal. As the Goose Creek deposits are essentially non-banded, adequate analytic studies require somewhat fewer thin sections. The Goose Creek data are based on studies at high magnification of one or two thin sections from each of the arbitrarily selected layers. The composition was determined in detail from each of 20 to 30 fields that were distributed at uniformly predetermined intervals across the thickness of coal included on each thin section slide. Anthraxylon was determined by normal transect procedure and the results from both transects were combined to yield data comparable to that available for the selected layers of Slim Buttes coal. The method seems suitable for detailed comparison of many of the very fine textured carbonaceous deposits that differ from banded coal.

Table 3.--Composition of uraniferous coal layers

CONSTITUENTS OR COMPONENTS	BANDED COAL LAYER SAMPLES, SLIM BUTTES HOLE SD-10									NON-BANDED OR HIGHLY ATTRITAL COAL, GOOSE CREEK								
	"HIGH" RADIOACTIVITY				LOW RADIOACTIVITY					"VERY HIGH" RADIOACTIVITY: Hole 2						LOW RADIOACTIVITY: Hole 3A		
	TE-16	TE-43	TE-31	TE-24	TE-37	TE-22	TE-10	TE-46	TE-40	L-8	L-6	L-7	L-9	L-11	L-10	L-2	L-3	L-5
Coarse anthraxylon	16.48	60.25	39.48	48.40	18.66	59.58	53.96	34.37	46.95									
Attrital anthraxylon	16.08	9.24	12.43	10.81	16.05	11.95	18.02	15.76	17.77									
Total anthraxylon	32.56	69.49	51.91	59.21	34.71	71.53	71.98	50.13	64.72	2.40	1.60	2.90	3.30	3.50	2.90	7.20	24.80	8.90
TRANSLUCENT ATTRITUS:																		
Sub-anthraxylon	.83	1.26	2.20	.62	.27	.25	.55	.78	.38									
Humic matter	46.99	18.97	38.66	31.10	36.37	23.79	20.92	32.56	23.19									
Total humic or cell wall degradation matter	47.82	20.23	40.86	31.72	36.64	24.04	21.47	33.34	23.57	74.57	67.31	71.85	79.23	69.24	73.21	82.33	62.66	72.25
Red attrital resins	.39	.27	.35	.90	.74	.32	.19	2.16	.27	.87	.62	.32	.40	.39	.19	2.50	.45	.55
Spores, pollen, cuticle	.24	.13	.21	.07	.23	.04	.05	.12	.27									
Yellow attrital resins	.13	.07	.03	.06	.0	.02	.07	.20	T									
Waxy amorphous	1.72	3.76	1.94	2.00	2.59	1.07	.72	5.04	1.02									
Total yellow-waxy matter	2.09	3.96	2.18	2.13	2.82	1.13	.84	5.36	1.29	17.38	24.70	17.58	13.83	22.10	18.04	1.86	3.71	6.74
Transparent organic	.01	.04	.10	.0	.62	.02	.02	.0	.04	.68	2.95	1.65	.77	1.35	.58	2.78	3.89	6.74
Fungus spores	.08	.05	.04	.02	.01	.03	.03	.0	.03	.19	.30	.19	.10	.13	.19	.47	.95	2.28
Fungal sclerotia	.40	.13	.23	.0	.0	.02	.05	.0	.03	.0	.60	.0	.0	.45	.0	.0	.0	.0
Total fungal phyterals	.48	.18	.27	.02	.01	.05	.08	.0	.06	.19	.90	.19	.10	.58	.19	.47	.95	2.28
Brown matter with traces of semi-fusain fragments	5.56	.98	.84	.61	7.18	1.31	1.43	1.96	2.65	T	T	T	T	T	T	T	T	T
Opaque attritus	2.46	3.35	.42	1.14	10.02	.40	.26	1.51	2.68	.87	.30	1.84	.87	.29	.29	.65	.08	.18
Micro-fusain	4.42	.0	1.43	.0	5.14	.0	2.33	1.10	1.66									
Mega-fusain	3.80	1.47	1.36	.14	2.08	1.15	.83	3.77	3.02									
Total fusain	8.22	1.47	2.79	.14	7.22	1.15	3.16	4.87	4.68	.0	.0	.0	.0	.0	.0	.0	.0	.0
Disseminated pyrites	.10	.15	.02	.50	.0	.0	.0	.63	T	.29	.03	.0	.39	.10	.68	.37	.0	.0
Transparent minerals	.12	T	.06	.15	.0	.01	.0	.0	T	2.14	1.57	3.50	1.16	2.41	3.98	1.76	3.44	2.37
Clayey minerals	.0	.15	.19	3.46	.07	.08	.0	.03	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Total visible mineral impurities	.22	.15	.27	4.11	.07	.09	.0	.66	T	2.43	1.60	3.50	1.55	2.51	4.66	2.13	3.44	2.37
TOTAL	99.81	99.81	99.99	99.98	100.03	100.04	99.43	99.99	99.96	99.39	99.98	99.83	100.05	99.96	100.06	99.92	99.98	100.01
Uranium ppm determined or estimated	377	150	150	134	21	20	19	16	3	Est. 1103	Est. 896	Est. 753	Est. 676	Est. 404	Est. 273	Est. 23	Est. 5	Est. 5

Table 4.--Composition of translucent attritus in uraniferous coal layers

CONSTITUENTS OR COMPONENTS	COMPOSITION OF TRANSLUCENT ATTRITUS FROM BANDED COAL LAYER SAMPLES, SLIM BUTTES HOLE SD-10: "HIGH" RADIOACTIVITY				LOW RADIOACTIVITY				
	TE-16	TE-43	TE-31	TE-24	TE-37	TE-22	TE-10	TE-46	TE-40
Sub-anthraxylon	1.47	4.90	4.93	1.76	.56	.92	2.27	1.83	1.36
Humic matter (amorphous)	83.12	73.87	86.66	87.84	75.75	88.39	86.86	76.02	83.07
Total humic or cell wall degradation matter	84.59	78.77	91.59	89.60	76.31	89.31	89.13	77.85	84.43
Red attrital resins	.70	1.05	.79	2.55	1.55	1.20	.80	5.05	.98
Spores, pollen, cuticle	.43	.51	.47	.19	.48	.20	.21	.29	.98
Yellow attrital resins	.24	.28	.08	.17	.0	.08	.28	.46	.01
Waxy amorphous	3.04	14.65	4.36	5.64	5.40	3.97	3.01	11.77	3.64
Total yellow-waxy matter	3.71	15.44	4.91	6.00	5.88	4.25	3.50	12.52	4.63
Transparent organic	.19	.17	.22	.0	1.30	.10	.10	.0	.15
Fungus spores	.15	.21	.10	.06	.01	.12	.24	.0	.12
Fungal sclerotia	.72	.50	.40	.0	.0	.08	.23	.0	.09
Total fungal phyterals	.87	.71	.60	.06	.01	.20	.47	.0	.22
Brown matter with traces of semi-fusain fragments	9.84	3.85	1.88	1.79	14.96	4.89	5.90	4.59	9.50
TOTAL	99.90	99.99	99.99	100.00	100.01	99.95	99.90	100.00	99.91
Uranium ppm determined or estimated	377	150	150	134	21	20	19	16	3
Approximate percent of layer represented by the translucent attritus analyzed	56.5	25.7	44.6	35.4	48.0	26.9	24.1	42.8	27.9

CONSTITUENTS OR COMPONENTS	COMPOSITION OF TRANSLUCENT ATTRITUS FROM NON-BANDED OR HIGHLY ATTRITAL COAL, GOOSE CREEK: "VERY HIGH" RADIOACTIVITY: Hole 2						LOW RADIOACTIVITY: Hole 3A		
	L-8	L-6	L-7	L-9	L-11	L-10	L-2	L-3	L-5
Sub-anthraxylon									
Humic matter (amorphous)									
Total humic or cell wall degradation matter	79.50	69.74	78.31	84.05	73.97	79.45	91.47	87.44	81.11
Red attrital resins	.93	.64	.35	.40	.40	.21	2.78	.63	.62
Spores, pollen, cuticle									
Yellow attrital resins									
Waxy amorphous									
Total yellow-waxy matter	18.53	25.59	19.15	14.67	23.55	19.49	2.06	5.17	7.61
Transparent organic	.72	3.10	1.80	.82	1.44	.63	3.09	5.42	7.61
Fungus spores	.21	.41	.21	.10	.13	.0	.51	1.33	2.58
Fungal sclerotia	.0	.60	.0	.0	.46	.21	.0	.0	.0
Total fungal phyterals	.21	1.01	.21	.10	.59	.21	.51	1.33	2.58
Brown matter with traces of semi-fusain fragments	T	T	T	T	T	T	T	T	T
TOTAL	99.89	100.08	99.82	100.04	99.96	99.99	99.91	99.99	100.00
Uranium ppm determined or estimated	Est. 1103	Est. 896	Est. 753	Est. 676	Est. 404	Est. 273	Est. 23	Est. 5	Est. 5
Approximate percent of layer represented by the translucent attritus analyzed	94.3	97.5	91.8	94.3	93.7	92.2	91.0	71.7	88.6

The data presented in these tables is deserving of a more extensive discussion than can be given here. Calculations have been reported to two places in all instances so that an indication of relative abundance of very minor elements might be reflected. Some of these, such as disseminated pyrite, may signify differences in decomposition processes. Other components, such as spore coats or fungal sclerotia that present a striking appearance under the microscope, are shown to be quantitatively unimportant.

DISCUSSION

It is apparent that a direct correlation between any single coal component and uranium content remains highly doubtful. The presence of the greatest amount of yellow-waxy matter (14 to 25 percent) in the most radioactive samples (Goose Creek coal, Hole 2) may seem to be suggestive. Virtually all of the waxy matter in this Goose Creek coal is similar to the amorphous waxy material that predominates in the most highly organic laminae of Green River oil shale. However, no direct correlation with estimated uranium content (based on radioactivity measurements of the Coal Geology Laboratory) is apparent among the several adjacent samples from Goose Creek Hole 2; neither does the amorphous-waxy nor the total of yellow-waxy matter of the "High" and "Low" Slim Buttes layers provide any support for such a correlation.

Some other more or less systematic differences can also be noted from tables 3 and 4. For example, the low radioactivity samples from Goose Creek Hole 3A all contain more anthraxylon than high radioactivity samples from Goose Creek Hole 2. This is very probably indicative of a difference in decay. The types of fungus spores in these samples also differ. It is clear, however, that no one of the differences in petrologic composition can be taken as an indication of the concentration of uranium.

Although not yet proved, if it is assumed that the uranium in all these materials is combined or taken up by the organic matter in the same way, the correlation of petrologic constituents or components with the variations in uranium content would appear to be not simple, but highly complex and probably also dependent on other factors. The particular significance of this series of samples rests on the fact that none of them appear to owe their high or low uranium content to their relative positions within the beds.

An unusually high uranium content at the top of the Mendenhall "rider" coal in Hole SD-8 has been noticed in the course of processing core from test drilling in the Slim Buttes area. This thin layer, less than three inches thick, is the only lignitic material received from the Slim Buttes area that is as highly radioactive as that from Goose Creek Hole 2. A comparison of translucent attritus components of the thin coal from Hole SD-8 with samples from Hole SD-10 and Hole 16 seemed of interest because this SD-8 sample (TE-2) is in normal top-preferential position. A summary of rounded totals from this unusual layer in Hole SD-8, expressed on the whole-coal basis for comparison with table 3, is as follows: anthraxylon 35 percent; humic matter 53 percent; red resins .5 percent; brown matter 2.3 percent; opaque attritus 1.5 percent; fusain 4 percent; visible impurities negligible. Translucent attritus comprises nearly 60 percent of the layer and the layer contains about 900 ppm uranium on analysis.

Both this sample (SD-8, TE-2; 900 ppm U) and the richest sample from SD-10 (TE-16; 380 ppm U) have highest amounts of humic matter (53 and 48 percent) among the Slim Buttes samples. Both of them also lead in amount of fungus material (.49 and .48 percent). Humic matter is largely the product of extensive decomposition of plant materials. The types of fungi observed are chiefly responsible for processes of aerobic decay. The very rich series of samples from Goose Creek Hole 2 has already been noted as exceptionally rich in products of plant decay, and sclerotium-forming fungi also are present as they are in the Slim Buttes coal. This relationship obviously is not likely to lead to an exact basis for prediction of uranium occurrences but the data presented suggest more than a fortuitous coincidence. In order to investigate these possibilities, further data need be collected that reflect on paleoecology of coal formation and the related processes of aerobic and anaerobic microbial decay.

CONCLUSIONS

It is conceivable that plant material that has been most subjected to decay is the most receptive to uranium emplacement. This working hypothesis would seem consistent with the almost sapropelic condition of Goose Creek material of high radioactivity, as well as the most radioactive Slim Buttes material. It would also seem generally consistent with the usual dominance of humic substances in the organic matter of radioactive marine deposits. The coal of low radioactivity in Goose Creek Hole 3A, however, indicates that extensive decay, in any event, can only be a predisposing factor. The indicated relationship between uranium and products of decay in coal will be tested by further observation.

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