GEOLOGICAL SURVEY CIRCULAR 343

MICROSCOPIC STUDIES OF URANIFEROUS COAL DEPOSITS

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UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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Washington, D. C., 1954

Free on application to the Geological Survey, Washington 25, D. C.

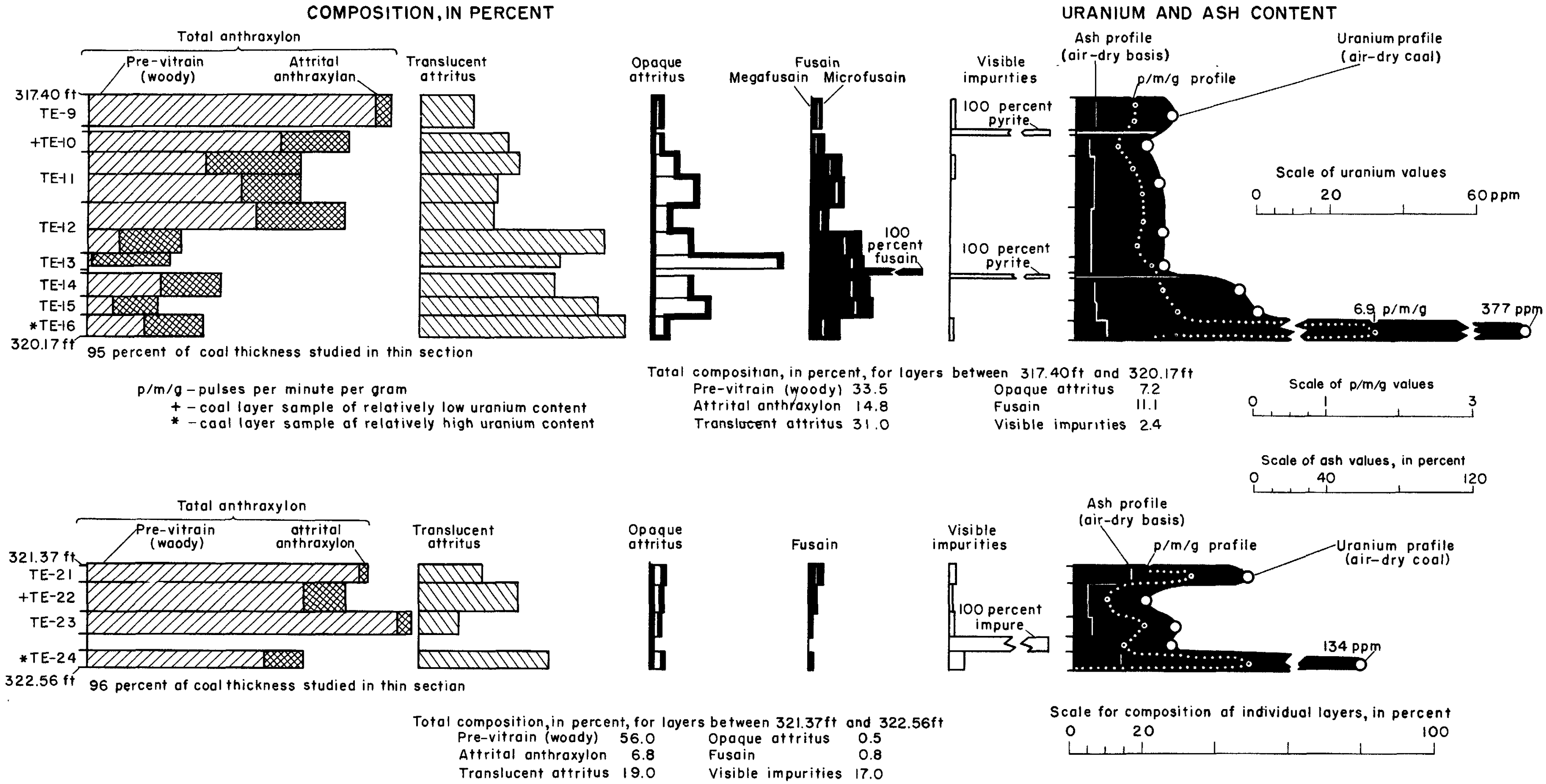

Figure 1.—Composition of lignite in upper bench, Olesrud bed, drill hole SD-10, Slim Buttes area, Harding County, South Dakota.

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ABSTRACT

Quantitative coal petrologic studies have been completed on 4 beds of uranium-bearing lignite from the Slim Buttes area of Harding County, S. Dak. Comparison of analyses of these deposits with analyses of lignite from commercial deposits suggests that the Slim Buttes coal deposits are highly diverse in composition. Relative to most coal deposits, however, all of the Slim Buttes coal that was studied has an unusually high uranium content. The studies show that no quantitative correlation exists between uranium content and the coal petrologic constituents that are normally determined for coal-type classification and for prediction of coal behavior in utilization.

As the coal constituents normally determined are to some extent heterogeneous, 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 11 layers of relatively high uranium content and for 8 associated layers that are much less radioactive and approach values that are about normal for coal. The results of this comparison cast 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 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. The 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 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, as 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 the deposits in these areas and in the Red Desert area are continuing. The work is being 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; and Parks and O'Donnell, 1949) have been followed in the present study and to some extent expanded. These methods of study more definitely indicate similarities or differences in the plant products that have contributed to the coal than standard chemical analyses that are based on empirical procedures. However, the two procedures are complementary, each being used to evaluate different properties. Thiessen's petrologic procedures have been most widely applied in the United States, and thus are preferable for our use in studying the relationship between plant constituents and uranium content. Most coal beds are not uraniferous (see Russell, 1944, 1945; DeMagnée, 1952; and Welch, 1954); therefore, 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 almost all of the uranium in weathered lignite from the nearby Mendenhall mine is chemically held by the organic matter as an organouranium compound or complex, and is not directly associated with mineral matter or with other trace elements. Because radioactivity profiles of weathered and unweathered lignite are similar (Schopf, 1952, unpublished), it is probable that this condition applies generally to radioactive coal of the Slim Buttes area. However, the uneven distribution of uranium within a coal bed requires further explanation.

Acknowledgments

Analytic values for air-dry ash and uranium have been determined in the 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 U. S. Bureau of Mines under supervision of Mr. Roy F. Abernethy.

GEOLOGIC INVESTIGATIONS

The uranium-bearing lignite in the Slim Buttes area was 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 the present report. 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 the present report.

GEOLOGIC SETTING

The uranium-bearing lignite in the Slim Buttes area is 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, at most places mildly radioactive, and recently have 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 are in the Salt Lake formation of probable 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 uranium had been deposited in the lignite and carbonaceous shale by ground water that 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 3 coal beds cored in hole SD-10[1] and 1 bed in hole 16.[2] According to recent studies by J. R. Gill (personal communication, 1954), 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$\frac{1}{4}$ sec. 36, T. 18 N., R. 7 E.

[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.

[2] Core holes designated by numbers without a letter prefix were drilled by the Geological Survey in 1951.

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 in the outcrop along the west side of the Slim Buttes. This bed is located some distance above the Mendenhall bed of the nearby Mendenhall strip mine (NW$\frac{1}{4}$SE$\frac{1}{4}$ 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.

Uranium-bearing lignite in the Slim Buttes area usually shows definite, nearly 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 the uranium is irregularly concentrated in several layers (figs. 1 and 2). Apparently, this irregular distribution is related to a cause other than downward percolation of 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 at this locality a 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 lignite deposits of North and South Dakota that contain little or no uranium. [3] 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 of Slim Buttes coal is the wide range in petrologic composition of the different beds.

An unusually high content of opaque attritus seems to be distinctive for the coal from hole 16 (fig. 3). The high anthraxylon content of the thin second coal bed in hole SD-10 indicates an extremely woody lignite (fig. 1). The 11 percent of fusain found in the upper coal bed in hole SD-10 (fig. 1) is also 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 upper 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 diversity of composition undoubtedly signifies differences in conditions of accumulation having paleoecologic significance —in the varieties of plants, their accumulation and decay in peat formation, and in their influence on diagenetic changes. Although these topics merit further consideration, they are beyond the range of this preliminary report.

Standard coal analyses were obtained for all cores of coal beds that might be of economic interest. Analyses of samples from hole SD-10 and hole 16 are given in table 2. Older analyses are given by Winchester and others (1916, p. 42-3). Analyses of lignite from a few recently operated mines in North Dakota, and one recent analysis of impure coal from Goose Creek, are included in table 2 for comparison. The usual evaluations of coal quality, which are based almost entirely on chemical analyses such as those in table 2, do not indicate the variety of organic materials composing the beds. For example, 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 coal from the Slim Buttes area and only about 2 percent more total carbon.

The similarity of the coal analyses, regardless of marked differences in organic makeup, is not surprising because the materials contributed by different plants may be similar in chemical properties. However, these materials 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 understood in coal of low rank

[3] None of 21 lignite samples from 4 companies producing in North Dakota in 1951 and 1952 showed more than 0.001 percent equivalent uranium, according to TWP reports 1324 and 1590-93, and TWC report 1803 of the Geological Survey laboratory.

Table 1.—Comparison of average composition, in percent, of Slim Buttes coal beds with other coal beds mined in North Dakota

Source	Depth (feet)	Anthraxylon	Translucent attritus	Opaque attritus	Fusain
Uraniferous coal of Slim Buttes					
Hole 16 (Mendenhall "rider")	333.92	53	17	24	3
Hole SD-10 (top split of Olesrud bed, upper bench).	317.4	50	32	7	11
Hole SD-10 (bottom split of Olesrud bed, upper bench).	321.37	75	23	1	1
Hole SD-10 (Olesrud bed, lower bench).	381.07	56	31	6	7
Lignite mined in North Dakota					
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

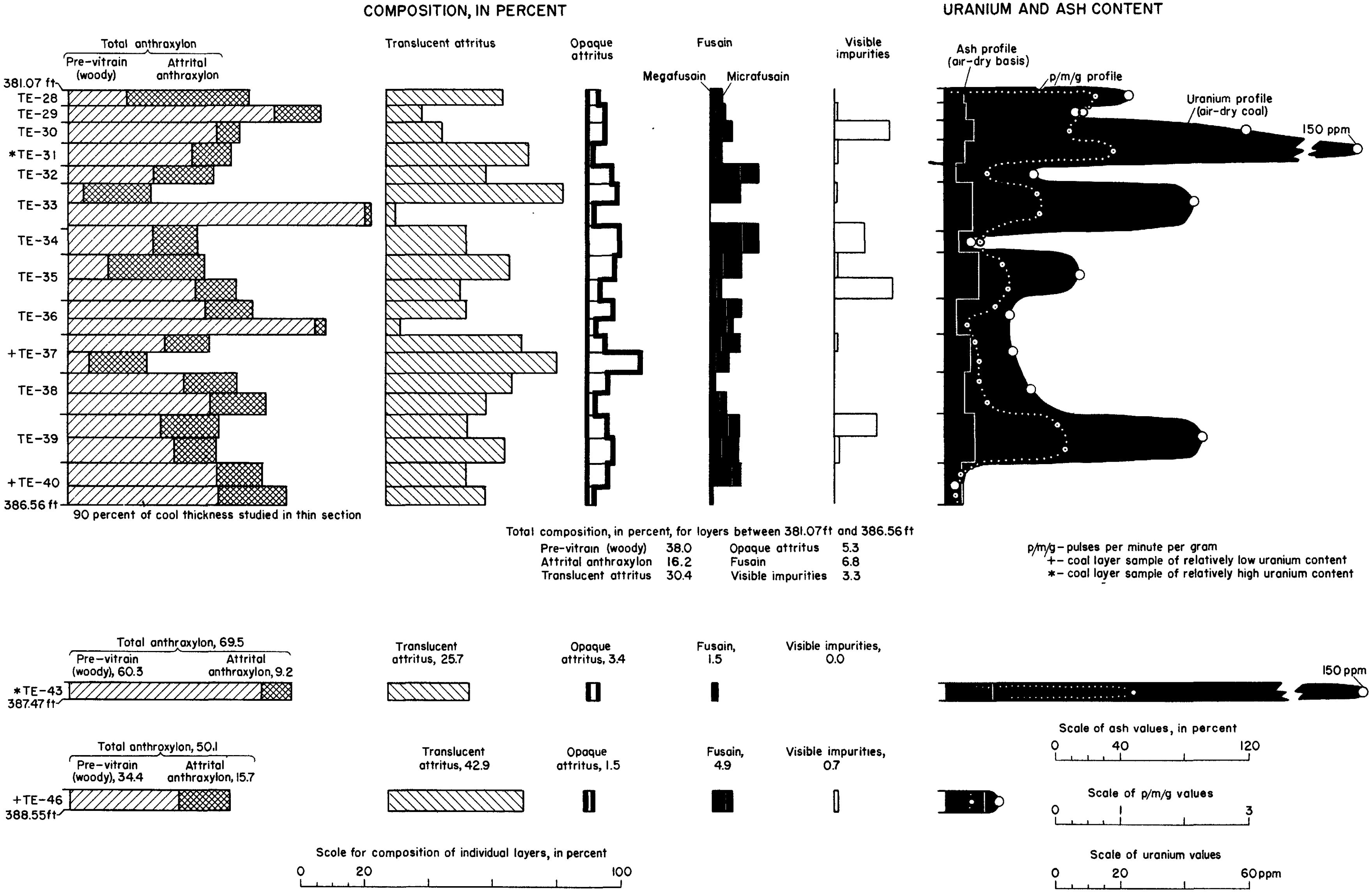

Figure 2. —Composition of lignite in lower bench, Olesrud bed, drill hole SD-10, Slim Buttes area, Harding County, South Dakota.

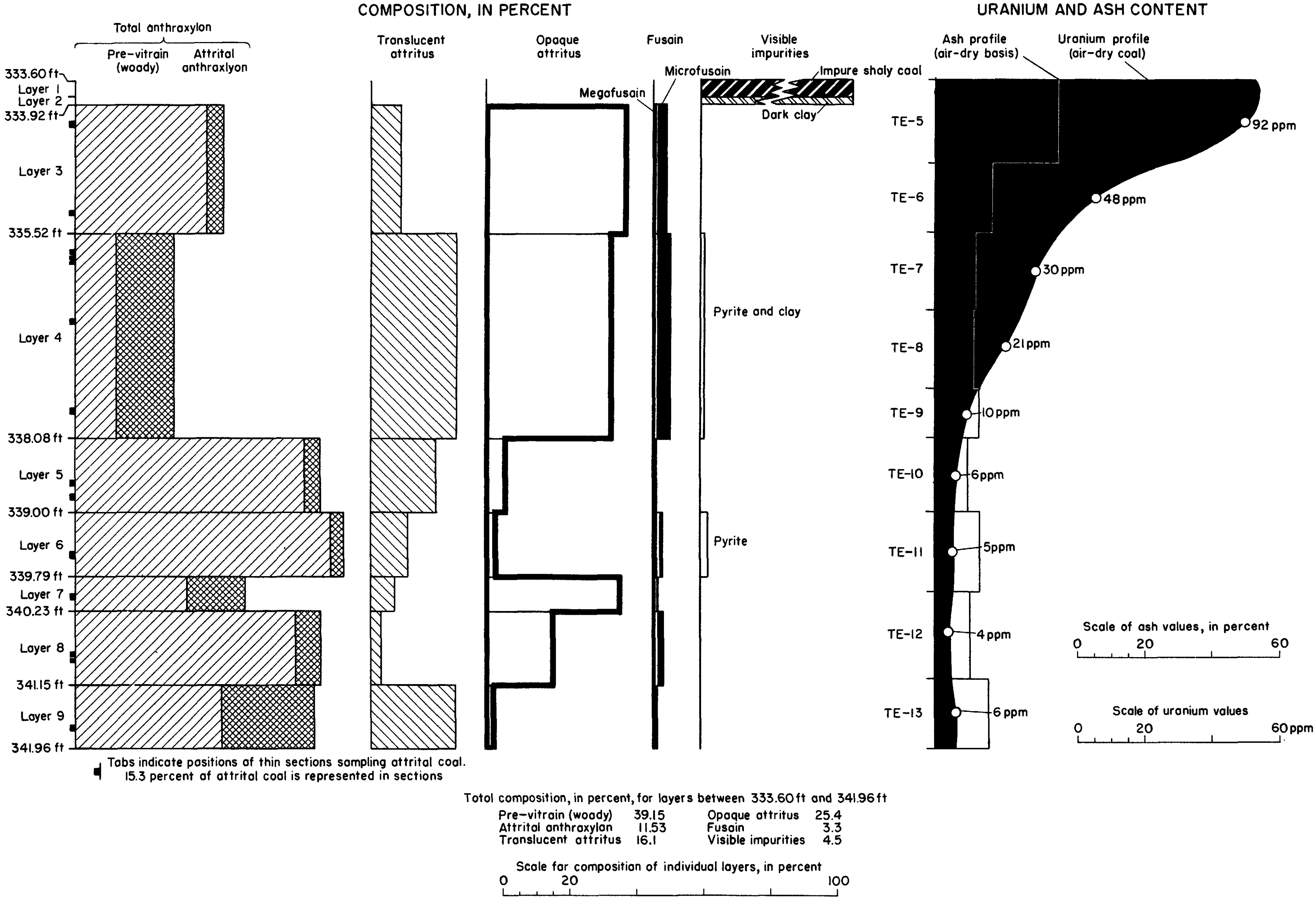

Figure 3.—Composition of lignite in Mendenhall "rider" bed, hole 16, Slim Buttes area, Harding County, South Dakota.

Table 2.—Analyses of coal

[Bureau of Mines lab. nos. Basis of reporting: AR, as received; MF, moisture free; MAF, moisture and ash free]

		E-9832 AR	E-9832 MF	E-9832 MAF	E-9933 AR	E-9933 MF	E-9933 MAF	D-71570 AR	D-71570 MF	D-71570 MAF	C-32442[1] AR	C-32442[1] MF	C-32442[1] MAF
Proximate	Moisture	44.2	------	------	43.9	------	------	41.8	------	------	36.7	------	------
	Volatile matter	20.2	36.3	44.1	21.6	38.4	45.8	22.0	37.9	45.8	29.3	46.3	50.7
	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
	Ash	9.9	17.7	------	9.0	16.1	------	10.1	17.3	------	5.5	8.7	------
Ultimate	Sulfur: Sulfate	.01	.02	.02	.01	.01	.02	------	[2].07	[2].08	------	------	------
	Sulfur: Pyritic	.24	.43	.52	.41	.74	.88	------	[2].29	[2].35	------	------	------
	Sulfur: Organic	.32	.57	.70	.42	.74	.89	------	[2]1.25	[2]1.50	------	------	------
	Sulfur: Total	.6	1.0	1.2	.8	1.5	1.8	[3].8	[4]1.4	[5]1.7	.6	.9	1.0
	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
	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
	Nitrogen	.4	.7	.8	.4	.8	.9	.4	.8	.9	.6	1.0	1.1
	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
Btu		5470	9790	11890	5640	10050	11970	5790	9950	12030	6930	10960	12000
Fusibility of ash, °F	Initial deformation		1980			1970			2050			------	
	Softening		2020			2020			2100			2500	
	Fluid		2130			2060			2180			------	
Specific gravity			1.65			1.63			-----			------	

		C-65444[1] AR	C-65444[1] MF	C-65444[1] MAF	C-46606[1] AR	C-46606[1] MF	C-46606[1] MAF	E-28432 AR	E-28432 MF	E-28432 MAF
Proximate	Moisture	35.5	------	------	38.2	------	------	33.4	------	------
	Volatile matter	26.6	41.3	45.6	26.7	43.2	47.7	11.8	17.7	50.1
	Fixed carbon	31.7	49.1	54.4	29.3	47.5	52.3	11.7	17.6	49.9
	Ash	6.2	9.6	------	5.8	9.3	------	43.1	64.7	------
Ultimate	Sulfur: Sulfate	------	------	------	------	------	------	.05	.08	.23
	Sulfur: Pyritic	------	------	------	------	------	------	.33	.50	1.42
	Sulfur: Organic	------	------	------	------	------	------	.60	.90	2.55
	Sulfur: Total	.5	.7	.8	.3	.5	.5	1.0	1.5	4.2
	Hydrogen	------	------	------	------	------	------	5.0	2.0	5.7
	Carbon	------	------	------	------	------	------	16.6	24.9	70.6
	Nitrogen	------	------	------	------	------	------	0.3	0.5	1.4
	Oxygen	------	------	------	------	------	------	34.0	6.4	18.1
Btu		7250	11240	12430	6750	10920	12050	2925	4390	12450
Fusibility of ash, °F	Initial deformation		------			------			2490	
	Softening		------			------			2670	
	Fluid		------			------			2770	
Specific gravity			------			------			1.92	

[1] Analyses from U. S. Bureau of Mines Bull. 482, p. 23 (Selvig, Ode, Parks, and O'Donnell, 1950).
[2] Forms of sulfur determined from a duplicate dry sample corresponding to D-71570.
[3] Total sulfur of D-71570.
[4] Total sulfur of D-71570. Total of duplicate dry sample is 1.61.
[5] Total sulfur of D-71570. Total of duplicate dry sample is 1.93.

Source of samples:
E-9832. Top and middle Slim Buttes beds, 317 feet 4¾ inches to 322 feet 6¾ inches; hole SD-10.
E-9933. Lower Slim Buttes coal bed, 381 feet ⅞ inch to 386 feet 6¾ inches; hole SD-10.
D-71570. Mendenhall "rider"(?) bed, 333 feet 7¼ inches to 341 feet 11½ inches; hole 16.
C-32442. Burleigh strip mine, Burleigh County, N. Dak.; coal bed face sample.
C-65444. Noonan bed, Baukol-Noonan mine, Divide County, N. Dak.; mine-run composite sample.
C-46606. Coteau bed, Velva mine, Ward County, N. Dak.; mine-run composite sample
E-28432. Goose Creek impure coal, 243 feet 6⅝ inches to 247 feet 8½ inches; hole 2.

that has been only slightly metamorphosed. The analyses of commercial deposits of North and South Dakota appear to indicate coal of somewhat higher rank than the beds of the Slim Buttes.

The petrologic charts (figs. 1, 2, and 3) illustrate the layer-by-layer distribution of all the coal constituents, impurities, ash, and uranium. These results, based as they are on a succession of diverse layers, 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 laboratory radioactivity profiles (p/m/g)[4] and air-dry ash determinations for successive layers are also superimposed on the uranium profiles in figures 1 and 2. The ash profiles suggest a very slight increase of ash in several of the more radioactive layers. Generally, the radioactivity measurements closely parallel chemical determinations of uranium for this type of material. Where chemical analyses were made by combining laboratory radioactivity samples, the results suggest that the uranium is distributed even more irregularly than is indicated by the profiles based on the larger chemically determined samples.

COMPOSITION OF TRANSLUCENT ATTRITUS

In order to test further for a possible correlation between microscopically visible plant materials and degradation products, it is principally necessary to identify and separate the various components of translucent attritus. This finely particulate, nonopaque fraction of coal can vary greatly in amount between different samples and is the most heterogeneous of the constituents. According to the standard coal petrologic procedure (Parks and O'Donnell, 1949), translucent attritus is determined by difference after anthraxylon, fusain, and opaque attritus have been determined by direct transect measurements. It is usually described qualitatively. The refinement of the process of quantitatively analyzing the translucent attritus 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 in the following paragraphs, 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 4 SD-10 coal layers of relatively high uranium content and compared with 5 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 6 layers of high radioactivity from Goose Creek hole 2 and 3 layers of low radioactivity from Goose Creek hole 3A. The results of these studies are given in tables 3 and 4. Each set of samples is arranged in detail 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 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 nonbanded type and contrasts strongly, in appearance and petrologic composition, with the banded lignite of the Slim Buttes area. Highly and slightly radioactive samples 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 nonbanded carbonaceous deposits such as oil shale and cannel coal than in banded coal. As the Goose Creek deposits are essentially nonbanded, 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 predetermined uniform 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.

The data presented in these tables deserves 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 minor elements, such as disseminated pyrite, may signify differences in decomposition processes. Other components, such as spore coats or fungal sclerotia that have a striking appearance under the microscope, are shown to be quantitatively unimportant.

DISCUSSION

It is very doubtful that a direct correlation exists between any single coal component and uranium content. The presence of the greatest amount of yellow waxy matter (14 to 25 percent) in the most radioactive samples (Goose Creek coal, hole 2) seems most suggestive. Virtually all of the waxy matter in this Goose Creek coal is similar to the waxy amorphous matter that predominates in the most highly organic

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[4] 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.

Table 3.—Composition, in percent, of uraniferous coal layers

Components	Banded coal-layer samples, Slim Buttes hole SD-10									Nonbanded or highly attrital coal samples, 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
Anthraxylon:																		
Coarse	16.48	60.25	39.48	48.40	18.66	59.58	53.96	34.37	46.95	-----	-----	-----	-----	-----	-----	-----	-----	-----
Attrital	16.08	9.24	12.43	10.81	16.05	11.95	18.02	15.76	17.77	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total	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:																		
Subanthraxylon	0.83	1.26	2.20	0.62	0.27	0.25	0.55	0.78	0.38	-----	-----	-----	-----	-----	-----	-----	-----	-----
Humic matter	46.99	18.97	38.66	31.10	36.37	23.79	20.92	32.56	23.19	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total	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	0.39	0.27	0.35	0.90	0.74	0.32	0.19	2.16	0.27	0.87	0.62	0.32	0.40	0.39	0.19	2.50	0.45	0.55
Spores, pollen, cuticle	0.24	0.13	0.21	0.07	0.23	0.04	0.05	0.12	0.27	-----	-----	-----	-----	-----	-----	-----	-----	-----
Yellow attrital resins	.13	.07	.03	.06	.0	.02	.07	.20	Tr.	-----	-----	-----	-----	-----	-----	-----	-----	-----
Waxy amorphous matter	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	0.84	5.36	1.29	17.38	24.70	17.58	13.83	22.10	18.04	1.86	3.71	6.74
Transparent organic matter	0.01	0.04	0.10	0.0	0.62	0.02	0.02	0.0	0.04	0.68	2.95	1.65	0.77	1.35	0.58	2.78	3.89	6.74
Fungus spores	0.08	0.05	0.04	0.02	0.01	0.03	0.03	0.0	0.03	0.19	0.30	0.19	0.10	0.13	0.19	0.47	0.95	2.28
Fungal sclerotia	.40	.13	.23	.0	.0	.02	.05	.0	.03	.0	.60	.0	.0	.45	.0	.0	.0	.0
Total	0.48	0.18	0.27	0.02	0.01	0.05	0.08	0.0	0.06	0.19	0.90	0.19	0.10	0.58	0.19	0.47	0.95	2.28
Brown matter with traces of semifusain fragments	5.56	0.98	0.84	0.61	7.18	1.31	1.43	1.96	2.65	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Opaque attritus	2.46	3.35	0.42	1.14	10.02	0.40	0.26	1.51	2.68	0.87	0.30	1.84	0.87	0.29	0.29	0.65	0.08	0.18
Fusain:																		
Microfusain	4.42	0.0	1.43	0.0	5.14	0.0	2.33	1.10	1.66	-----	-----	-----	-----	-----	-----	-----	-----	-----
Megafusain	3.80	1.47	1.36	.14	2.08	1.15	0.83	3.77	3.02	-----	-----	-----	-----	-----	-----	-----	-----	-----
Total	8.22	1.47	2.79	0.14	7.22	1.15	3.16	4.87	4.68	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Visible mineral impurities:																		
Disseminated pyrites	0.10	0.15	0.02	0.50	0.0	0.0	0.0	0.63	Tr.	0.29	0.03	0.0	0.39	0.10	0.68	0.37	0.0	0.0
Transparent minerals	.12	Tr.	.06	.15	.0	.01	.0	.0	Tr.	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	0.22	0.15	0.27	4.11	0.07	0.09	0.0	0.66	Tr.	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 determined or estimated ppm	377	150	150	134	21	20	19	16	3	[1]1103	[1]896	[1]753	[1]676	[1]404	[1]273	[1]23	[1]5	[1]5

[1] Estimated from radioactivity determinations.

Table 4.—Composition, in percent, of translucent attritus in uraniferous coal layers

Components	Banded coal-layer samples, Slim Buttes hole SD-10									Nonbanded or highly attrital coal samples, 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
Subanthraxylon	1.47	4.90	4.93	1.76	0.56	0.92	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	84.59	78.77	91.59	89.60	76.31	89.31	89.13	77.85	84.43	79.50	69.74	78.31	84.05	73.97	79.45	91.47	87.44	81.11
Red attrital resins	0.70	1.05	0.79	2.55	1.55	1.20	0.80	5.05	0.98	0.93	0.64	0.35	0.40	0.40	0.21	2.78	0.63	0.62
Spores, pollen, cuticle	0.43	0.51	0.47	0.19	0.48	0.20	0.21	0.29	0.98	-----	-----	-----	-----	-----	-----	-----	-----	-----
Yellow attrital resins	.24	.28	.08	.17	.0	.08	.28	.46	.01	-----	-----	-----	-----	-----	-----	-----	-----	-----
Waxy amorphous matter	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	18.53	25.59	19.15	14.67	23.55	19.49	2.06	5.17	7.61
Transparent organic matter	0.19	0.17	0.22	0.0	1.30	0.10	0.10	0.0	0.15	0.72	3.10	1.80	0.82	1.44	0.63	3.09	5.42	7.61
Fungus spores	0.15	0.21	0.10	0.06	0.01	0.12	0.24	0.0	0.12	0.21	0.41	0.21	0.10	0.13	0.0	0.51	1.33	2.58
Fungal sclerotia	.72	.50	.40	.0	.0	.08	.23	.0	.09	.0	.60	.0	.0	.46	.21	.0	.0	.0
Total	0.87	0.71	0.60	0.06	0.01	0.20	0.47	0.0	0.22	0.21	1.01	0.21	0.10	0.59	0.21	0.51	1.33	2.58
Brown matter with traces of semifusain fragments	9.84	3.85	1.88	1.79	14.96	4.89	5.90	4.59	9.50	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.	Tr.
Total	99.90	99.99	99.99	100.00	100.01	99.95	99.90	100.00	99.91	99.89	100.08	99.82	100.04	99.96	99.99	99.91	99.99	100.00
Uranium determined or estimated ppm	377	150	150	134	21	20	19	16	3	[1]1103	[1]896	[1]753	[1]676	[1]404	[1]273	[1]23	[1]5	[1]5
Approximate amount of layer represented by the translucent attritus analyzed—percent	56.5	25.7	44.6	35.4	48.0	26.9	24.1	42.8	27.9	94.3	97.5	91.8	94.3	93.7	92.2	91.0	71.7	88.6

[1] Estimated from radioactivity determinations.

laminae of oil shale in the Green River formation. However, no direct correlation with estimated uranium content (based on laboratory radioactivity measurements) is apparent among the several adjacent samples from Goose Creek hole 2; neither does the waxy amorphous matter nor the total of yellow waxy matter and waxy amorphous matter of the "high" and "low" Slim Buttes layers indicate a direct 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 none of the differences in petrologic composition can be taken as an indication of the concentration of uranium.

If it is assumed that the uranium in all the coal components is combined or taken up by the organic matter in the same way, the correlation of petrologic components with the variations in uranium content would appear to be 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 position within the bed.

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 layer, less than 3 inches thick, is the only lignitic material receivea 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 layer from hole SD-8 with samples from hole SD-10 and hole 16 seemed of interest because the sample (TE-2) from hole SD-8 is in normal top-preferential position. A summary of rounded totals from this unusual layer, expressed on the whole-coal basis for comparison with table 3, is as follows: anthraxylon, 35 percent; humic matter, 53 percent; red resins, 0.5 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.

This sample and the richest sample from hole SD-10 (TE-16; 380 ppm U) have the highest amounts of humic matter (53 and 48 percent) and fungus material (0.49 and 0.48 percent) among the Slim Buttes samples. 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. Obviously, this relationship is not likely to lead to an exact basis for the prediction of uranium occurrences, but the data suggest more than a fortuitous coincidence. Further investigation of the relationship will require the collection of more data that reflect on the paleoecology of coal formation and the related processes of aerobic and anaerobic microbial decay.

CONCLUSION

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 can at most only predispose the coal to uranium emplacement.

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INT.-DUP. SEC., WASH., D.C. 68283