IN REPLY REFER TO:

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

AEC-212/6

October 7, 1955

Mr. Robert D. Nininger, Assistant Director
Division of Raw Materials
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Bob:

Transmitted herewith are three copies of TEI-527, "Laboratory study of a core from uranium-bearing coal in the Red Desert, Sweetwater County, Wyoming," by James M. Schopf and Ralph J. Gray, June 1955.

We are asking Mr. Hosted to approve our plan to publish this report as a chapter in a Survey bulletin.

Sincerely yours,

John H. Eric
for W. H. Bradley
Chief Geologist

Geology and Mineralogy

This document consists of 57 pages.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

LABORATORY STUDY OF A CORE FROM URANIUM-BEARING COAL IN THE RED DESERT, SWEETWATER COUNTY, WYOMING*

By

James M. Schopf and Ralph J. Gray

June 1955

Trace Elements Investigations Report 527

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

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

USGS-TEI-527

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LABORATORY STUDY OF A CORE FROM URANIUM-BEARING COAL IN THE RED DESERT, SWEETWATER COUNTY, WYOMING

by James M. Schopf and Ralph J. Gray

ABSTRACT

This report presents the results of a detailed laboratory study of uranium in an 8-inch core of coal and coaly shale from the Luman No. 1 coal bed in the northern part of the Red Desert area, Sweetwater County, Wyoming. Results of microscopic, spectrographic, chemical, and radiometric work are presented for samples from this core. The Luman No. 1 bed at this locality appears to be a characteristic example of the uraniferous coal of the Red Desert area.

Layers of impure coal contain more uranium than purer coal layers. The uranium probably is in intimate association with the carbonaceous material as an organo-uranium complex or compound. Semiquantitative spectrographic analyses were studied for many other elements, but none show a distribution pattern that is sufficiently similar to that of uranium to indicate a similarity in mode of deposit.

Microscopic studies show that the coal is dominantly attrital, and that highly uraniferous layers usually have a considerable amount of amorphous waxy and clayey mineral matter and commonly lie adjacent to a layer of much greater mineral content. The extent of organic degradation, type of organic matter, and the occurrence of mineral impurities all appear to have significance in relation to the natural concentration of uranium in this deposit.

INTRODUCTION

This report gives results of a detailed study of one of the Red Desert coal beds and its associated sediments from a core 8 inches in diameter that was obtained for special study at the close of the 1953 field season.

The coal and uranium occurrences in this 8-inch Red Desert core appear to be generally comparable to the other occurrences in coal in this district insofar as they are known to us. The sample material available from the large core has provided an excellent opportunity for establishing the nature of the coaly materials associated with varying uranium content in the Red Desert area. The investigation was conducted by the Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

Acknowledgments

Uranium, ash, and spectrographic determinations on TE samples have been carried out at the Washington Trace Elements Laboratory of the U. S. Geological Survey. Coal analyses and real specific gravity determinations have been made by the Coal Analysis Section of the U. S. Bureau of Mines under supervision of Roy Abernethy. James Warman, Henry Hildreth, and Bruce Middleton have assisted in preparing the core description, sampling, radioactivity and apparent specific gravity measurement, in preparation and microscopic analysis of thin sections. Charles J. Felix assisted in the calculation of petrologic and analytic results and in maceration of coal samples used for this report.

PREVIOUS INVESTIGATIONS

The source location for the material studied is shown on the index map in figure 1. Hole 72 was drilled in the SE 1/4 NW 1/4 sec. 15, T. 24 N., R. 95 W., about 30 miles north of Wamsutter in the northeastern part of Sweetwater County. The core samples the Luman No. 1 coal bed mapped through the area by Masursky and Pipiringos (in preparation).

The Red Desert coal field is in the northeastern part of the extensive Eocene basin in southwestern Wyoming. This basin was formerly largely occupied by deposits of the Wasatch and Green River formations which still are exposed over large areas including part of the Red Desert. It seems reasonable to suppose that the general conditions of rainfall, temperature, evaporation, relief, and erosion that have been established by Bradley (1930, 1948) in determining the mode of origin for the Green River formation apply equally to this coal-bearing sequence. These conditions evidently had considerable bearing on the type characteristics of the coal.

The organic composition of the oil shale and coal offers points for comparison, particularly in the impure layers associated with the coal. Plant microfossils similar to some of those in the coal also occur in the oil shale (Bradley, 1931), but the matrix is different. Wodehouse (1933) identified an extensive flora based on pollen of the oil shale. Other reports pertinent to the paleobotany, paleoecology and general environment of the Green River Lake areas have been given by Berry (1930), Brown (1929, 1934), and by Chaney (1944). A recent study of petrified woody remains

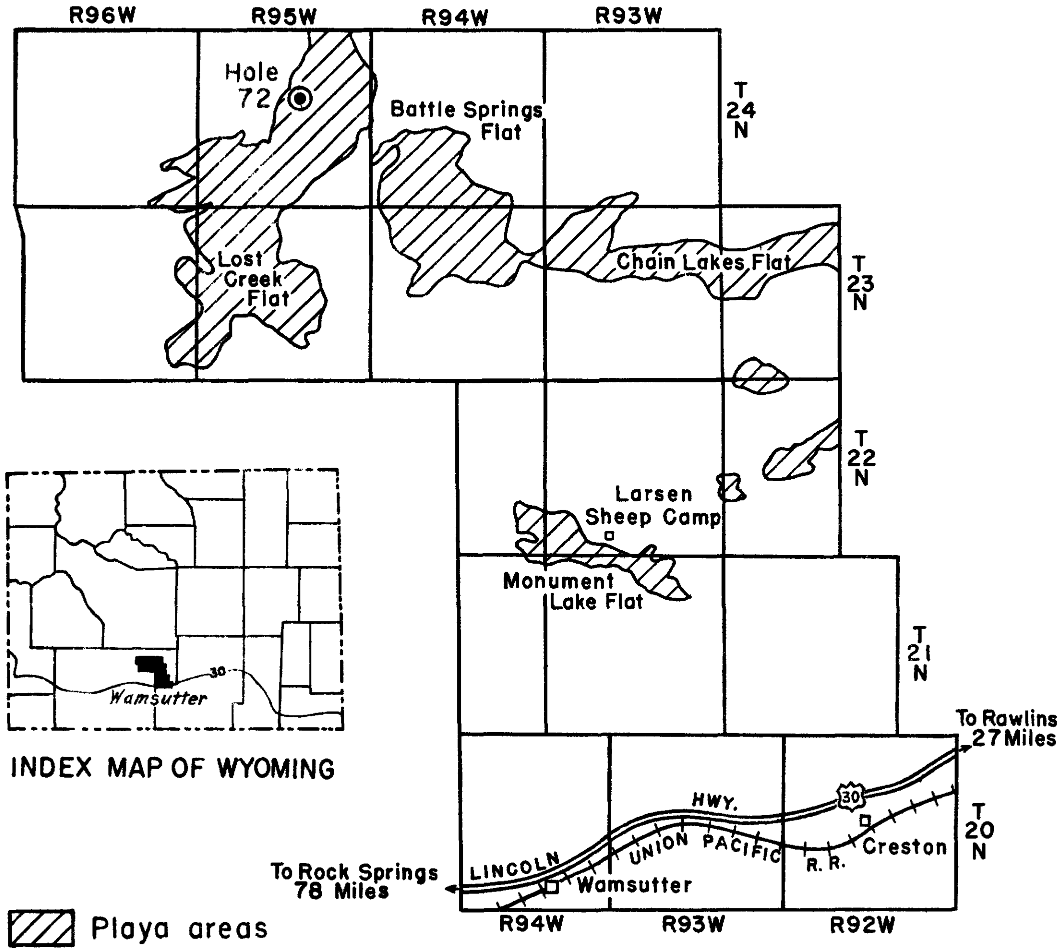

FIGURE 1.- INDEX MAP SHOWING LOCATION OF HOLE 72, SWEETWATER COUNTY, WYOMING

of Green River age by Kruse (1954) re-emphasizes the tropical to sub-tropical character of the flora.

Breger, Deul, Meyrowitz (in press) have described chemical and mineralogical features associated with uranium in a thin and relatively pure layer of the Luman No. 1 bed.

GENERAL DESCRIPTION OF THE MATERIAL STUDIED

Slightly over 9 feet of the 8-inch diameter core was recovered in a 10-foot run, starting at a depth of approximately 96 feet. In the laboratory several longitudinal segments were cut from the core for preparation of thin sections, determination of radioactivity, chemical determination of uranium, spectrographic determination of elements detectable in the ash, and for standard coal analyses.

The core studied includes the following succession of beds:

	Character and thickness	Depths in feet		
1.	silty shale (3.36')	96.00'	to	99.36'
2.	impure and shaly coal (.92')	99.36'	to	100.28'
3.	upper coal bench, relatively pure (.84')	100.28'	to	101.12'
4.	impure and shaly coal (.32')	101.12'	to	101.44'
5.	light gray "middle" shale (.31')	101.44'	to	101.75'
6.	shaly coal and coaly shale (2.23')	101.75'	to	103.98'
7.	lower coal bench, relatively pure (.72')	103.98'	to	104.70'
8.	coaly shale (.12')	104.70'	to	104.82'
9.	plastic clay (.18')	104.82'	to	105.00'

The general features of the section are indicated diagrammatically, with some indication of additional differentiation of layers, in figures 2, 3, and 8 to indicate the correlation of lithology with other data. Microscopic study has assisted in further lithologic differentiation as indicated by the additional thin layers in the "micro" lithologic section of figures 10 and 11

Coal of the two purer benches, noted above, is largely thin- or micro-banded. One vitrain band band 3/4 of an inch thick is an exceptional occurrence near the base. A very small amount of vitrain is present in the lower bench of coal and this occurs in bands less than 2 millimeters thick. Aside from the few vitrain bands, all the coal has a moderately dull to moderately bright luster and is sparingly cleated. The luster is diminished, and cleat is very poorly developed or absent in the impure or shaly layers. The impure layers have a tendency to break into tabular pieces, owing to the "striped" distribution of clayey impurities.

The shaly or clayey layers show no striking features. No identifiable megascopic plant or animal fossil remains and no "root zones" were observed. Small carbonaceous fragments can usually be detected in the shales.

RADIOACTIVITY AND URANIUM CONTENT

The radioactivity of the core from hole 72, expressed in pulses per minute per gram as determined in the coal geology laboratory, the radioactivity expressed as equivalent uranium as determined in the geochemical laboratories, and the chemically determined uranium, are shown graphically in figure 2. The generally good agreement between chemical and radioactive indications suggests that the uranium in most samples is in good equilibrium with its daughter products.

The relationships between radioactivity (pulses per minute and pulses per minute per gram), specific gravity, and ash content of the coal and interbedded rock of the core, are shown in figure 3. The relatively purer, low

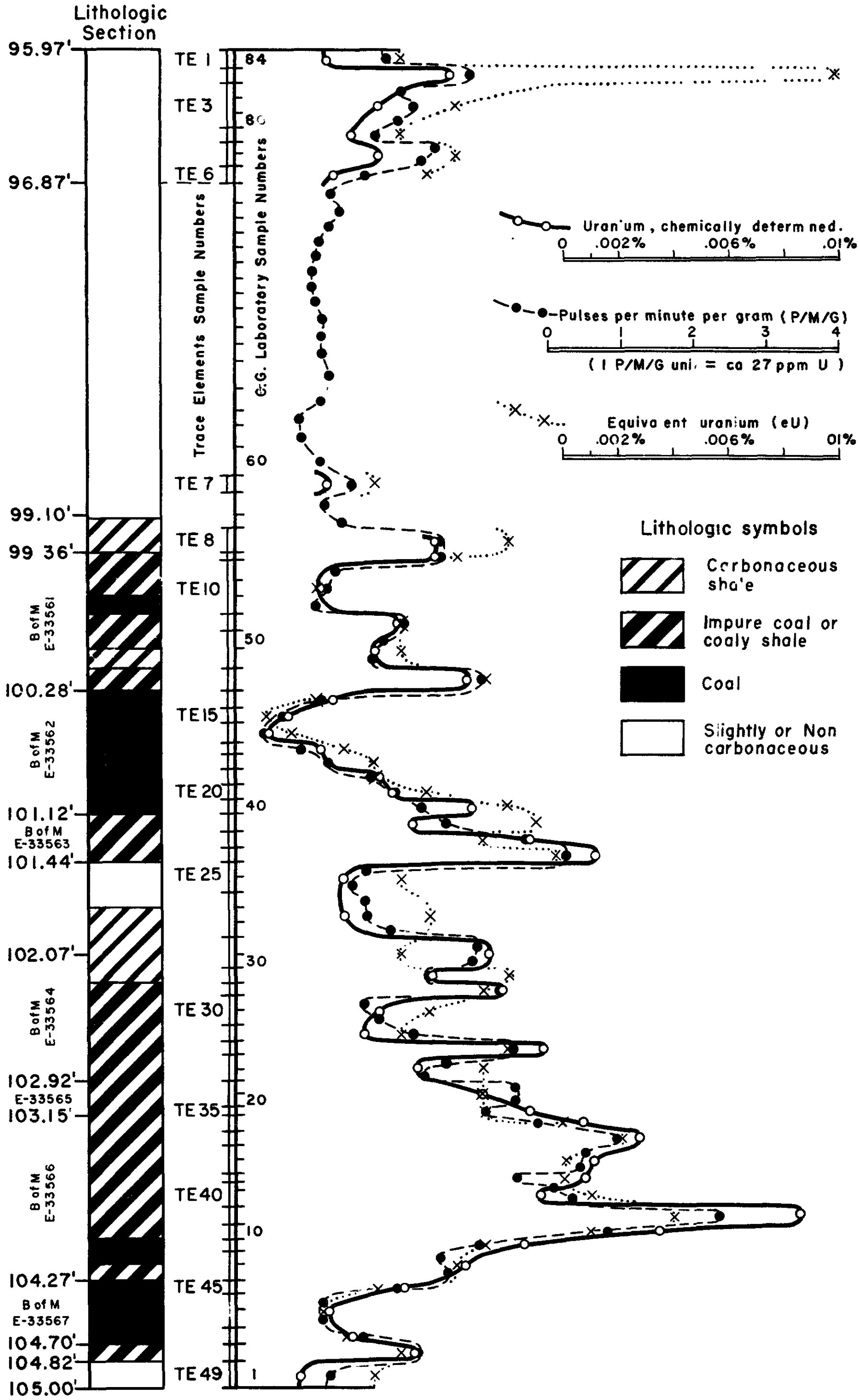

FIGURE 2.-CORRELATION OF URANIUM CONTENT WITH RADIOACTIVITY MEASUREMENTS, HOLE 72.

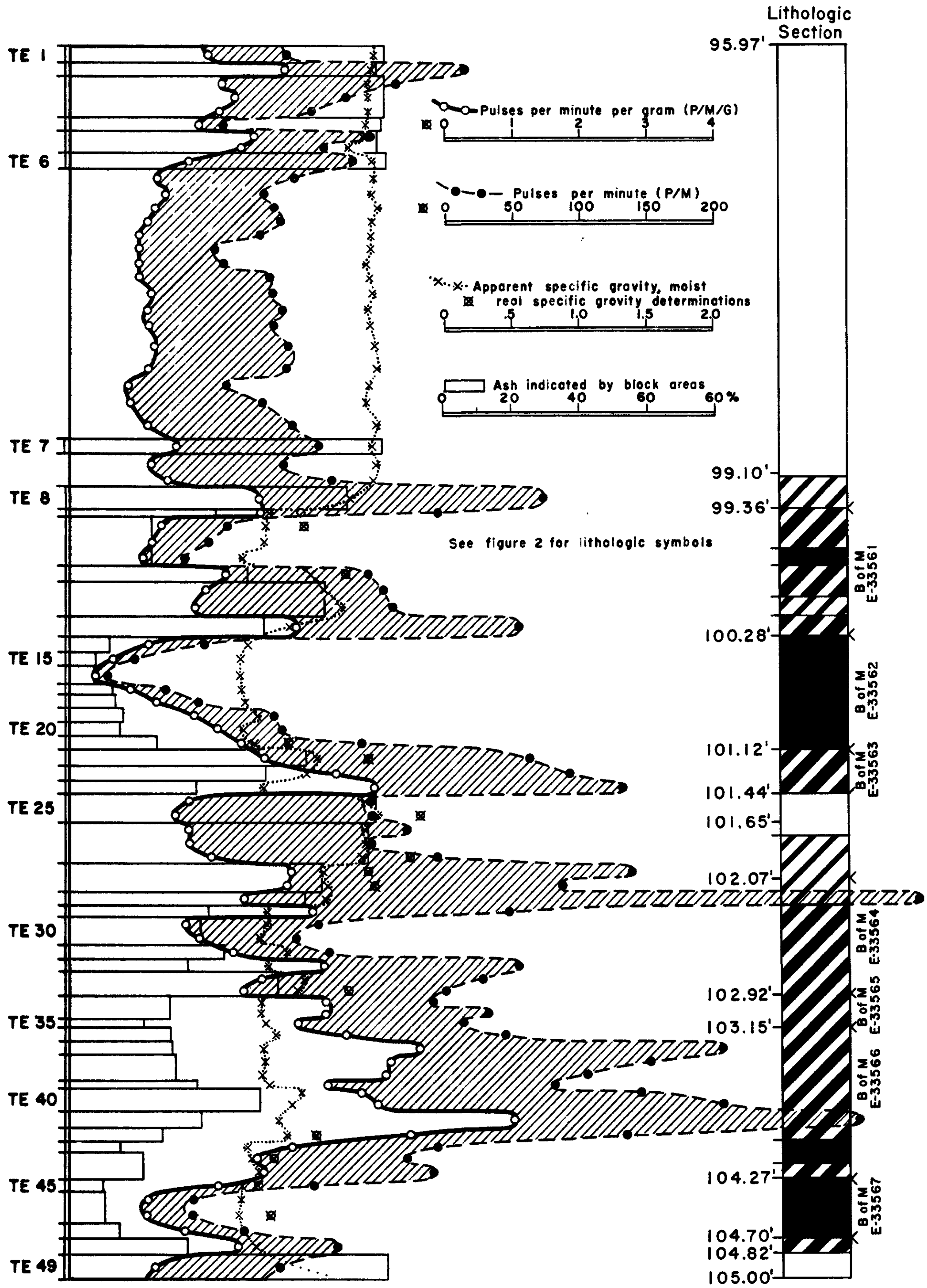

FIGURE 3.-RADIOACTIVITY MEASUREMENTS COMPARED WITH APPARENT SPECIFIC GRAVITY AND ASH CONTENT, HOLE 72.

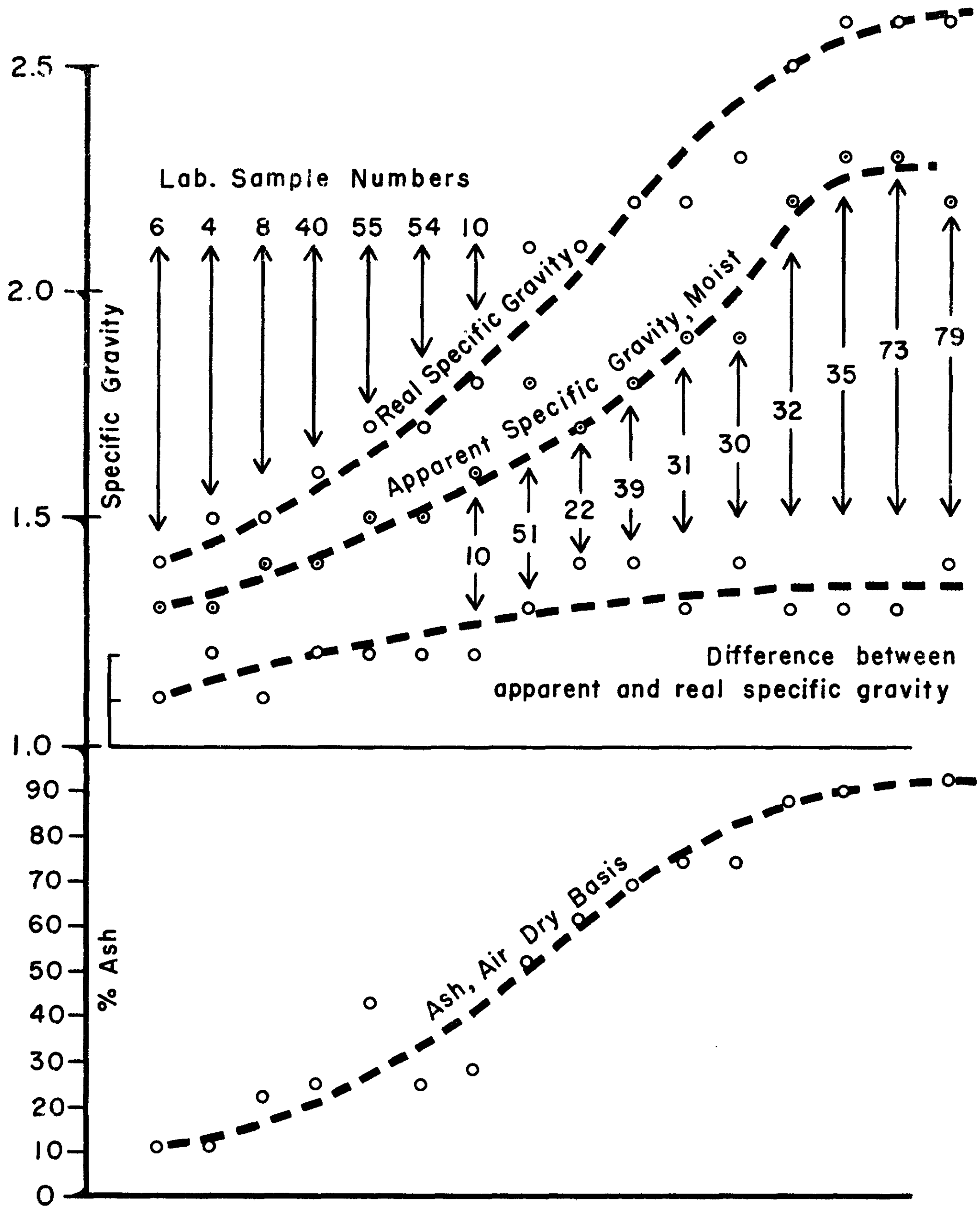

FIGURE 4.-COMPARISON OF SPECIFIC GRAVITY AND ASH CONTENT OF SELECTED SAMPLES.

ash and low specific gravity, coal layers show the least radioactivity and have a low uranium content.

Sixteen of the sample blocks used for determination of the apparent specific gravity were dried, crushed, and submitted to the Bureau of Mines laboratory for real specific gravity determinations. The suite of samples was chosen to range from coal with about 10 percent ash, to shale with over 90 percent ignition residue. The results are given in figure 4, arranged in order of their real specific gravities, and compared with their corresponding apparent specific gravity values and with their ash contents.

OCCURRENCE OF OTHER TRACE ELEMENTS

Semiquantitative spectrographic determinations of chemical elements present in the ash or ignition residues were made by the geochemical laboratories of the U. S. Geological Survey for the 49 TE samples from hole 72. Elements reported in the ash have been assigned within the following determinative brackets in this report: over 10 percent, 5-10 percent, 1-5 percent, .5-1 percent, 0.1-0.5 percent, .05-.1 percent, .01-.05 percent, .005-.01 percent, .001-.005 percent, .0005-.001 percent, and .0001-.0005 percent. The method of analysis and list of 68 elements that can be determined by this procedure has recently been described by C. L. Waring and C. S. Annell (1953). The elements identified, and the minimum amounts of these elements detectable with the analytical method used, is shown in table 1. Table 2 shows a similar listing of elements searched for, but not identified, which presumably are not present in concentrations above their levels of spectrographic sensitivity.

Table 1. --Elements identified by spectrography in trace elements samples from hole 72 (Minimum percentage detectable by method used is shown in parentheses.)

4	Be	(.00005)	24	Cr	(.0006)	40	Zr	(.0008)
5	B	(.005)	25	Mn	(.0007)	42	Mo	(.0005)
11	Na	(.01)	26	Fe	(.0008)	47	Ag	(.00001)
12	Mg	(.00003)	27	Co	(.008)	50	Sn	(.005)
13	Al	(.0001)	28	Ni	(.005)	56	Ba	(.001)
14	Si	(.005)	29	Cu	(.00005)	57	La	(.003)
20	Ca	(.01)	31	Ga	(.004)	58	Ce	(.03)
21	Sc	(.001)	32	Ge	(.001)	60	Nd	(.006)
22	Ti	(.0005)	38	Sr	(.001)	66	Dy	(.006)
23	V	(.001)	39	Y	(.003)	70	Yb	(.0003)
						82	Pb	(.001)

Table 2. --Elements searched for but not identified by spectrography of trace elements samples from hole 72 (Minimum percentage detectable by method used is shown in parentheses.)

3	Li	(.04)	51	Sb	(.01)	72	Hf	(.03)
15	P	(.07)	52	Te	(.08)	73	Ta	(.1)
19	K	(.3)	55	Cs	(.8)	74	W	(.07)
30	Zn	(..008)	59	Pr	(.01)	75	Re	(.04)
33	As	(.01)	62	Sm	(.008)	76	Os	(.1)
37	Rb	(7.0)	63	Eu	(.003)	77	Ir	(.03)
41	Nb	(..001)	64	Gd	(.006)	78	Pt	(.003)
44	Ru	(.008)	65	Tb	(.01)	79	Au	(.001)
45	Rh	(.004)	67	Ho	(.001)	80	Hg	(.08)
46	Pd	(.003)	68	Er	(.003)	81	Ti	(.04)
48	Cd	(.005)	69	Tm	(.001)	83	Bi	(.005)
49	In	(.0004)	71	Lu	(.005)	90	Th	(.08)
						92	U	(.08)

Results of this procedure, giving for the successive samples the relative abundance of elements in the rock, is shown graphically in figures 5, 6, and 7. The amount of carbonaceous material in each sample, plotted as LOI (loss on ignition)/Ash, and the amount of chemically determined uranium in each sample (not as ash) also is shown on each figure. The elements are arranged according to their relative abundance and apparent similarities in distribution.

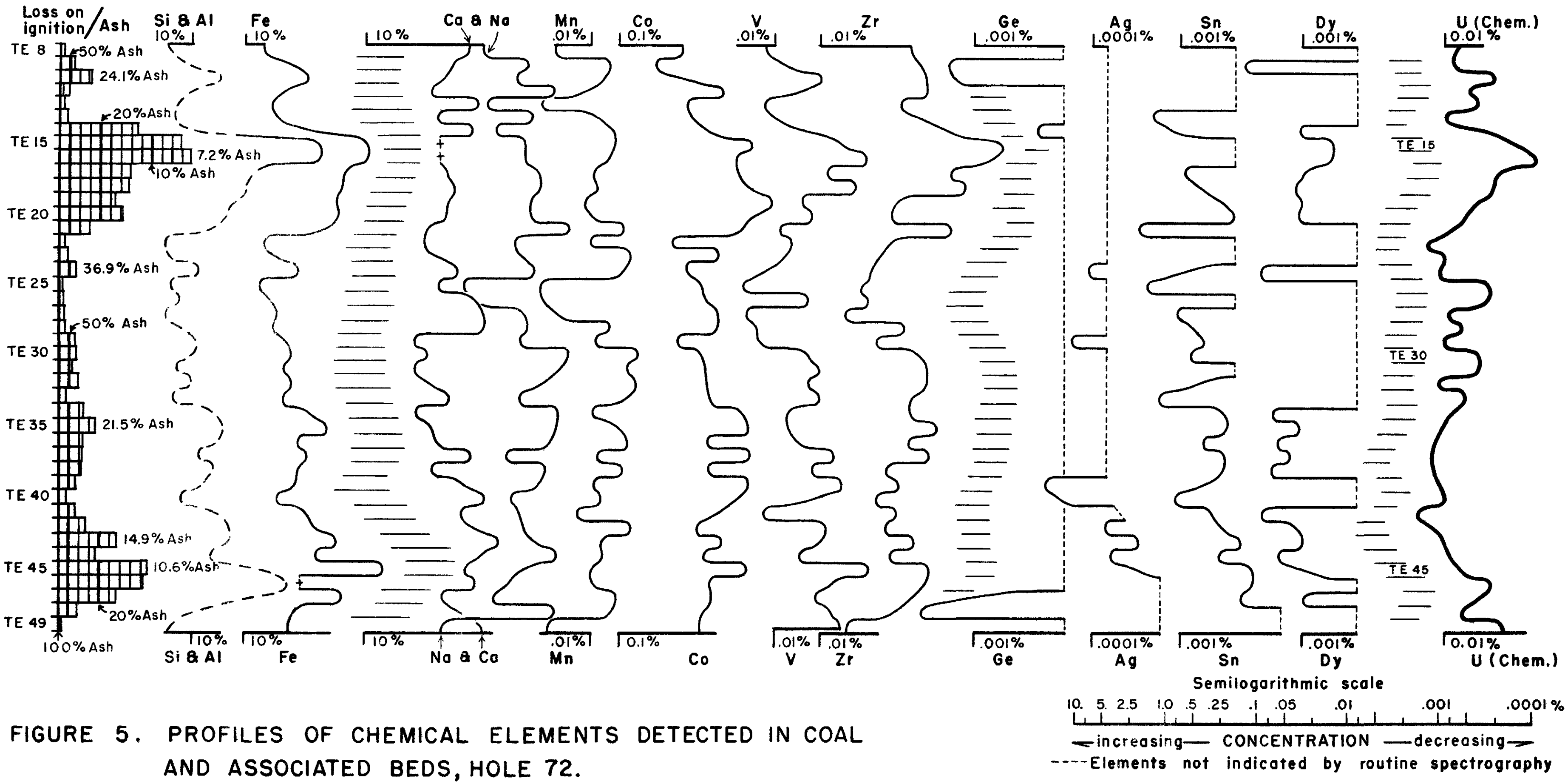

FIGURE 5. PROFILES OF CHEMICAL ELEMENTS DETECTED IN COAL AND ASSOCIATED BEDS, HOLE 72.

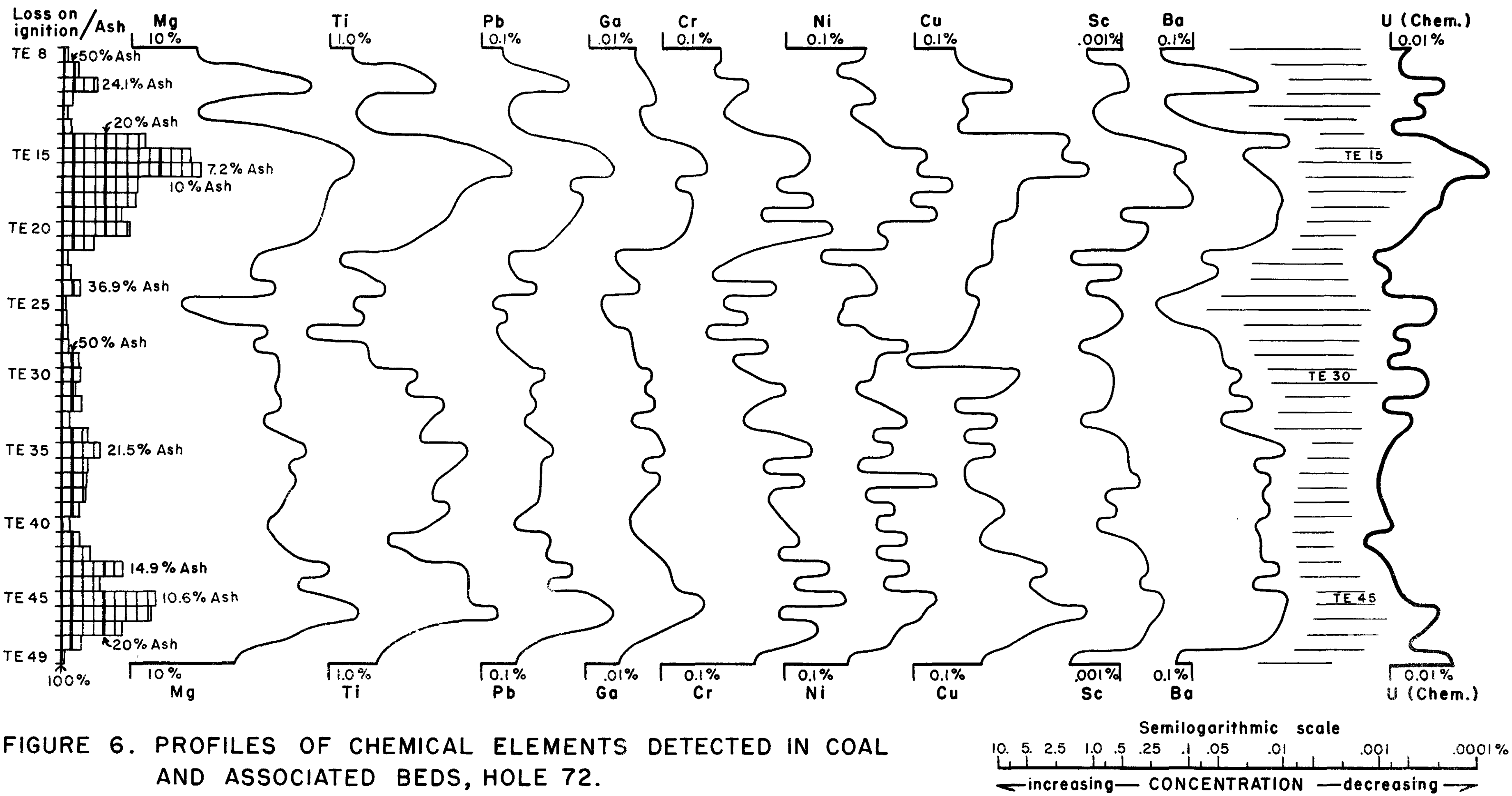

FIGURE 6. PROFILES OF CHEMICAL ELEMENTS DETECTED IN COAL AND ASSOCIATED BEDS, HOLE 72.

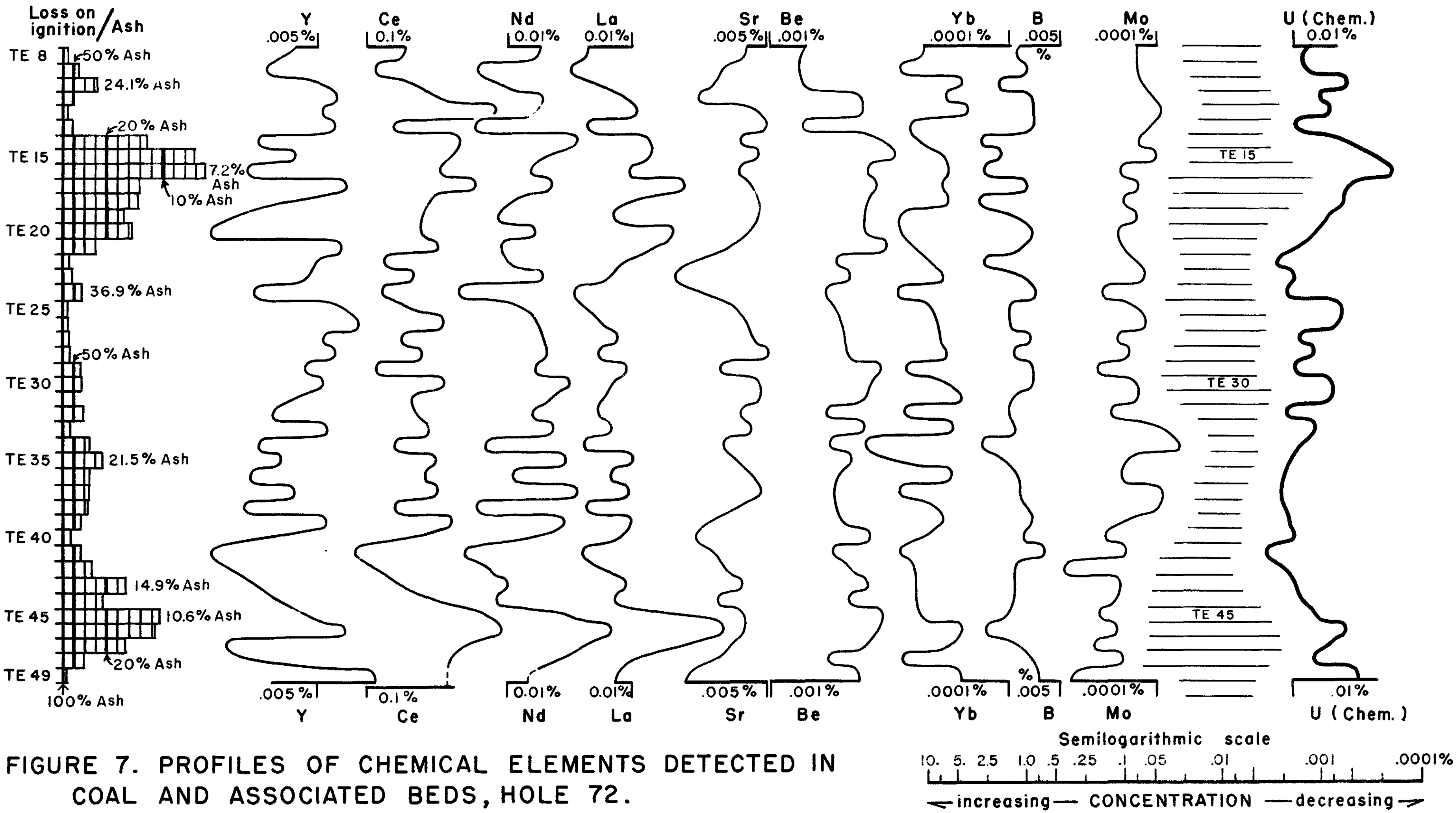

FIGURE 7. PROFILES OF CHEMICAL ELEMENTS DETECTED IN COAL AND ASSOCIATED BEDS, HOLE 72.

As the ash (or ignition residue) varies from 7.2 percent to over 90 percent in different samples of the suite from hole 72, direct comparison of spectrographic analyses of the ash is difficult to interpret in terms of actual geologic occurrence of different elements in the rock. The relative abundance of an element in the rock, as opposed to the occurrence in the ash, may be determined approximately from semi-quantitative analyses by compensating for the concentration that takes place in burning the samples in preparation of ash or ignition residues.

In order to test the possibility of an association of germanium with vitrain in TE-9 and TE-10 a special series of samples was submitted for spectrographic analysis. Results are given in table 3.

COAL ANALYSES

Proximate analyses, calorific, ash fusibility and specific gravity values for composite samples of purer banded coal and of impure (shaly) coal layers of the core are given in table 4. Proximate and ultimate analyses and other values for all the core as divided in seven layers are given in table 5, arranged according to the sequence of samples in the drill core. All standard coal analyses have been made by the U. S. Bureau of Mines. The Bureau laboratory numbers, corresponding to respective intervals as sampled, are shown in relation to the analytic tables and the lithologic sections and trace element sample intervals in figures 2, 3, 8, 10, and 11.

Table 3.--Occurrence of Germanium in Special Samples from Hole 72 1/

Description and Sample no.	Depths and Interval	Ash percent (MF 2/)	Ge in ash (MF)	Ash percent (AR 3/)	Moisture (AR 3/)	Ge in sample (MF 3/	Ge in sample (AR 2/)
Coaly shale 72TE-9-1	99.31 to 99.36' (.05')	62.7	<.0010	58.3	7.0	<.0006	.0006
Attrital coal 72TE-9-2	99.36 to 99.53' (.17')	36.5	.0400	31.9	12.5	.0146	.0128
Attrital coal 72TE-10-3	99.53 to 99.73' (.2')	27.2	.0300	23.0	15.6	.0082	.0069
Attrital coal with vitrain 72TE-10-4	99.53 to 99.73' (.2')	25.2	.0200	21.3	15.5	.0050	.0043
Pure vitrain 72TE-10-5	99.73 to 99.755' (.025')	10.8	.0400	8.5	21.3	.0043	.0034
Pyritic vitrain 72TE-10-6	99.755 to 99.77' (.015')	14.9	.0070	11.9	20.1	.0010	.0008

1/ Analyses by C. Vaughn and M. Frank, U. S. Geological Survey Washington Laboratory.
2/ MF = moisture free basis; dried at 110°C.
3/ AR = as received basis.

Table 4. --Proximate analyses of selected composite samples of shaly coal and banded coal from hole 72.

	Composite of impure (shaly) coal samples (E-33561, E-33563, E-33564 and E-33566)			Composite of purer banded coal samples (E-33562 and E-33567)		
B of M Lab. No.	E-33568			E-33569		
Basis of reporting 1/	A R	M F	M and A F	A R	M F	M and A F
Moisture	17.2	-	-	22.4	-	-
Volatile Matter	23.4	28.3	53.9	30.3	39.1	46.9
Fixed Carbon	20.1	24.3	46.1	34.4	44.2	53.1
Ash	39.3	47.4	-	12.9	16.7	-
Sulfur	1.0	1.1	2.2	1.3	1.7	2.0
Btu	5280	6380	12130	8580	11050	13260
Ash fusibility	Init. Def. 2600°F Softening 2790°F Fluid > 2910°F			Init. Def. 2310°F Softening 2440°F Fluid 2520°F		
Real specific gravity	1.83			1.51		

1/ A R = As received; M F = Moisture free; M and A F = Moisture and ash free.

Table 5.—Coal analyses of core samples from hole 72

Nature of material and depth	Impure and shaly coal 11-1/8"; depth 99'4-1/4" to 100'3-3/8"			Upper coal bench 10-1/8"; depth 100'3-3/8" to 101'1-1/2"			Impure and shaly coal 3-3/4"; depth 101'1-1/2" to 101'5-1/4"			Shaly coal & coaly shale 10-1/4"; depth 102'3/4" to 102'11"			Shaly coal 2-3/4"; depth 102'11" to 103'1-3/4"			Impure and banded coal 13-1/2"; depth 103'1-3/4" to 104'3-1/4"			Lower coal bench (part) 5-1/8"; depth 104'3-1/4" to 104'8-3/8"		
B of M Lab. No.	E-33561			E-33562			E-33563			E-33564			E-33565			E-33566			E-33567		
Rank indication 1/	(51-88)			(56-98) Sub B eq'v.			(48-91)			(49-88)			(53-97)			(52-97)			(52-103) Sub B eq'v.		
Basis of reporting 2/	A R	M F	M&A F	A R	M F	M&A F	A R	M F	M&A F	A R	M F	M&A F	A R	M F	M&A F	A R	M F	M&A F	A R	M F	M&A F
Proximate: Moisture	17.0	-	-	22.2	-	-	15.1	-	-	16.1	-	—	19.9	-	-	18.9	-	-	23.0	-	-
Proximate: Volatile Matter	21.4	25.8	54.2	29.0	37.2	45.8	21.8	25.7	57.1	21.3	25.4	56.1	26.6	33.2	48.9	26.1	32.2	50.8	31.5	41.0	47.1
Proximate: Fixed Carbon	18.1	21.7	45.8	34.2	44.0	54.2	16.4	19.3	42.9	16.7	19.9	43.9	27.9	34.8	51.1	25.3	31.2	49.2	35.4	45.9	52.9
Proximate: Ash	43.5	52.5	-	14.6	18.8	-	46.7	55.0	-	45.9	54.7	-	25.6	32.0	-	29.7	36.6	-	10.1	13.1	-
Ultimate: Sulfur: Sulfate	.04	.04	.09	.02	.02	.03	-	-	-	—	-	-	-	-	-	.01	.02	.02	.00	.00	.00
Ultimate: Sulfur: Pyritic	1.06	1.28	2.69	.62	.80	.98	-	-	-	-	-	-	-	-	-	.20	.24	.38	.42	.55	.63
Ultimate: Sulfur: Organic	.42	.51	1.06	.76	.97	1.20	-	-	-	-	-	-	-	-	-	.57	.70	1.10	.72	.93	1.07
Ultimate: Sulfur: Total	1.5	1.8	3.8	1.4	1.8	2.2	0.5	0.6	1.3	0.6	0.8	1.6	0.6	0.8	1.1	0.8	1.0	1.5	1.1	1.5	1.7
Ultimate: Hydrogen	-	-	-	6.0	4.5	5.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ultimate: Carbon	-	-	-	46.7	60.0	73.9	-	-	-	-	-	—	-	-	-	-	-	-	-	-	-
Ultimate: Nitrogen	-	-	-	1.1	1.4	1.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ultimate: Oxygen	-	-	-	30.2	13.5	16.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Btu	4680	5640	11860	8280	10640	13100	4520	5320	11830	4450	5310	11710	7030	8770	12900	6570	8090	12760	9130	11860	13640
Ash Fusibility	Init.Def.2490°F			Init.Def.2350°F			-			-			-			Init.Def.2810°F			Init.Def.2300°F		
	Softening 2670°F			Softening 2450°F			-			-			-			Softening 2890°F			Softening 2450°F		
	Fluid 2870°F			Fluid 2650°F			-			-			-			Fluid > 2910°F			Fluid 2530°F		
Real specific gravity	1.91			1.54			1.92			1.93			-			1.69			1.46		

1/Rank indication is given by a parenthetic hyphenated number according to the method suggested by ASTM Standards on Coal & Coke (1949, p. 653). The parentheses indicate both included numbers are calculated on a Mineral-Matter-Free basis; the first number represents percent fixed carbon on the dry, or unit coal, basis; the second number represents hundreds of Btu on a moist basis. The rank indication suggests what rank would apply if the samples had been obtained under standard conditions, as specified by ASTM standards.

2/AR=As received; MF=Moisture Free; M & A F=Moisture and Ash Free.

Calorific values are given in table 6 for the seven samples according to the five common bases of expressing them. The coaly material apparently is of slightly lower rank than the well-known Monarch bed near Sheridan in northern Wyoming and a little higher rank than the thick bed at the Wyodak mine, east of Gillette, Wyoming, in the Powder River Basin.

Table 6.--Calorific and ash values from core samples of hole 72.

B of M sample no.	Ash A R 1/	Mineral Matter 2/	CALORIFIC VALUES (Btu) Bases of calculation 1/				
			A R	M F	M&AF	MMinF	M&MinF
E-33561	43.5	47.8	4680	5640	11850	8820	13080
E-33562	14.6	16.5	8280	10640	13100	9840	13400
E-33563	46.7	50.7	4520	5320	11830	9120	13150
E-33564	45.9	49.9	4450	5310	11710	8820	13000
E-33565	25.6	28.0	7030	8770	12900	9720	13430
E-33566	29.7	32.5	6570	8090	12780	9680	13400
E-33567	10.1	11.5	9130	11860	13650	10260	13868

1/ A R = As received; M F = Moisture-free; M and A F = Moisture and ash-free; M Min F = Moist, mineral-matter-free; M and Min F = Moisture and mineral-matter-free.

2/ Mineral matter calculated as 1.08 x ash + .55 x sulfur.

Figure 8 shows diagrammatically the comparison of petrologic ingredients with proximate composition of each of the 7 samples. Variations of uranium and ash within each of the coal sample layers also is shown at the right of the diagram. The illustration indicates that substantial differences exist between the layers with regard to petrologic composition. These differences could

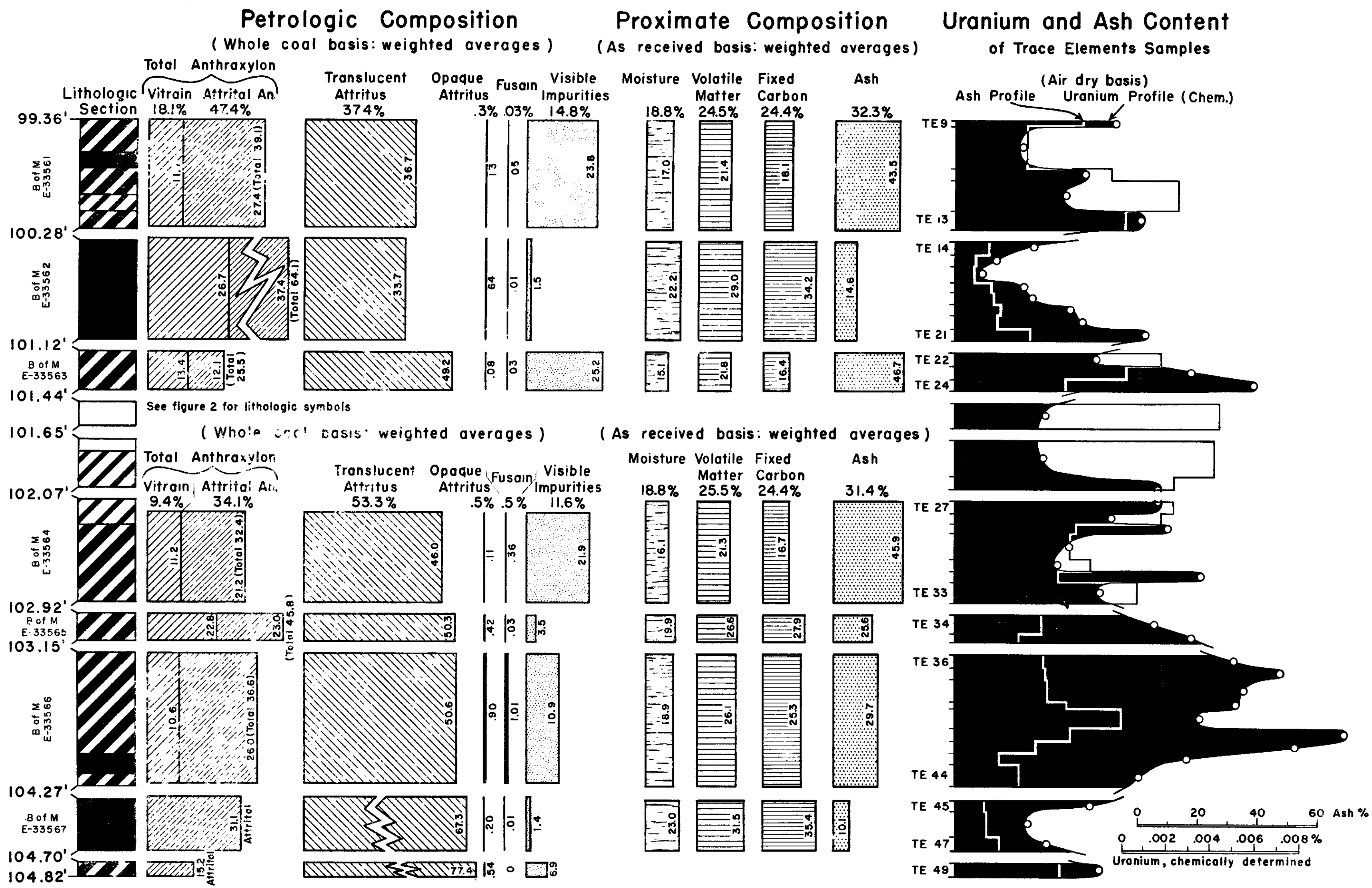

FIGURE 8.-COMPARISON OF PETROLOGIC AND PROXIMATE COMPOSITION OF COAL ANALYTIC SAMPLES WITH URANIUM AND ASH CONTENTS, HOLE 72.

cause at least some of the apparent analytic discrepancy between samples.

COAL PETROLOGY

Except for about 8-1/2 inches of "middle" shale and coaly shale below 101.44 feet depth, all of the coal and coaly shale between depths of 99.36 feet and 104.82 feet has been studied microscopically in thin section. Results of the microscopic study are summarized in table 7.

Table 7.--Summary of petrologic constituents in coal beds from hole 72.

WHOLE COAL BASIS

Visible impurities 13%	Vitrain 13.2%	Attrital coal (clarain and durain fraction; constituent plant fragments less than 0.5 mm thick) 73.6%			Megascopic fusain .2%
Clayey 12.5% Pyritic .3% Other .2%	Anthraxylon 40%	Translucent attritus 46.3%	Opaque attritus .4%	Attrital fusain .1%	
				Petrologic fusain .3%	
	Relatively reactive 86.3%			Relatively inert .7%	

VISUALLY PURE BASIS
87% of bed = 100% "coal"

Anthraxylon	45.8%	Opaque attritus	.5%
Translucent attritus	53.3%	Fusain	.4%
Relatively reactive	99.1%	Relatively inert	.9%

The form in which table 7 is presented is semi-diagrammatic in that it indicates the relationship of texture and quantity of the megascopic coal ingredients (vitrain, attrital coal, and megascopic fusain) with that of microscopic constituents (anthraxylon, translucent attritus, opaque attritus and petrologic fusain). It emphasizes the fact that not all anthraxylon is identifiable megascopically as vitrain and that the quantity of identifiable fusain also depends on the observational facilities that are employed. Most of all, this table emphasizes the very large attrital fraction that characterizes this coal and the small amount of inert organic matter that is present.

Table 8 shows a tabulation of the coal constituents for the upper and lower divisions of the coal bed in hole 72, and for the 7 coal analytic layers. From the tabulation in table 8 the general features of petrologic composition are apparent. All this coal is characterized by small, almost insignificant amounts of opaque attritus and fusain.

It would appear from results shown in table 8 that the basal coal was formed of most highly degraded plant materials but coarser fragments become more abundant and decay probably somewhat less pronounced toward the upper portion of the lower coal division. A slight reversal in this tendency occurred at the top. The same tendency is recapitulated in the upper coal division but with less extreme degradation indicated. In the upper division the maximum concentration of anthraxylon occurs in the layer of purest coal, whereas in the lower division the maximum occurs <u>above</u> the purer layer in the section with 3.5 percent visible mineral matter and 25 percent ash.

The thickness threshold for identification of anthraxylon is about 14 microns and all anthraxylon is identified in lenticles, strands or bands of greater thickness (see "discussion," p. 553, <u>in</u> Parks and O'Donnell, 1949). The threshold for identification of vitrain used in these studies is 500 microns

Table 8.--Percentages of coal constituents in upper and lower divisions of the bed and in coal analytic samples, calculated on visually pure basis

		An1/	TAt2/	OAt3/	Fus4/	Visible impurity omitted from VP5/ calculation
	Upper division 99.36' to 101.44' (= TE9-TE24)	55.6	44.9	.4	<.1	14.8
	Lower division 102.16' to 104.82' (=1/2 TE28-TE48)	38.5	60.3	.6	.9	11.5
Upper division	B of M E-33561 99.36' to 100.27' (=TE9-TE13)	51.3	48.4	.2	.1	23.7
Upper division	B of M E-33562 (bench of purer coal) 100.27' to 101.12' (= TE14-TE21)	65.1	34.3	.6	trace	1.5
Upper division	B of M E-33563 101.12' to 101.44'	34.1	65.7	.1	<.1	25.2
Lower division	B of M E-33564 102.16' to 102.92' (= TE 27 - TE 33)	41.0	58.4	.1	.5	21.3
Lower division	B of M E-33565 102.92' to 103.15' (= TE34-TE35)	47.5	52.1	.4	trace	3.5
Lower division	B of M E-33566 103.15' to 104.27' (= TE36-TE44)	41.1	56.8	1.0	1.1	10.9
Lower division	B of M E-33567 (bench of purer coal) 104.27' to 104.70' (= TE45-TE47)	31.5	68.3	.2	trace	1.4
Lower division	(no coal analysis) 104.70' to 104.82' (= TE48)	16.3	38.1	.6	nil	6.9

1/ An= Anthraxylon
2/ TAt = Translucent Attritus
3/ OAt = Opaque Attritus
4/ Fus = Petrologic Fusain
5/ VP = Visually Pure

or half a millimeter, this being about the limit of practical megascopic observation. Thus the series of vitrain determinations, given in table 9, also can be used as an index of degree of degradation of plant material. It applies, however, at a different (coarser) textural level than that shown by the amounts of anthraxylon. The trend of abundance of vitrain illustrated by table 9 is roughly parallel to the trend of anthraxylon as given in table 8, whether the amount of vitrain is computed on the visually pure basis or not. The absence of anthraxylous material in strands thick enough to be classed as vitrain is indicated for the two lower samples of the lower bench of coal. This serves to re-emphasize the extremely attrital character of this coal at the bottom of the core section studied.

Microscopic appearance

Drawings have been prepared of selected areas from photomicrographs of thin sections to illustrate the habit of occurrence of entities distinguished in these studies. These are presented in figure 9, A to H. The distinctions based on color transmission are, of course, not entirely evident in any illustrations depending on shades of grayness. Thin sections present the characteristic components in brilliant shades of red, yellow, brown, black or grayish ("opaque") and pellucid when normally observed by transmitted light. Anthraxylon, sub-anthraxylon and humic matter are characteristically red translucent, derived from comparable tissue fragments, and distinguished only on the basis of size. For purposes of the present report sub-anthraxylon consists of strands of vitrinized tissue about 3 to 14 microns thick. The

Table 9.--Vitrain in samples of Luman coal.

		Vitrain % (whole coal basis)	Vitrain % (visually pure basis)	Visible impurity % omitted from VP calculation	% Ash as given by coal analysis
Upper division	B of M E-33561 99.36' to 100.27' (= TE9-TE13)	11.6	13.0	23.7	43.5
	B of M E-33562 100.27' to 101.12' (= TE14-TE21)	25.6	25.9	1.5	14.6
	B of M E-33563 101.12' to 101.44' (= TE22-TE24)	13.4	17.9	25.2	46.7
Lower division	B of M E-33564 102.16' to 102.92' (= 1/2 TE27-TE33)	11.2	14.2	21.3	45.9
	B of M E-33565 102.92' to 103.15' (= TE34-TE35)	22.8	23.6	3.5	25.6
	B of M E-33566 103.15' to 104.27' (= TE36-TE44)	10.6	11.9	10.9	29.7
	B of M E-33567 104.27' to 104.70' (= TE45-TE47)	nil	nil	1.4	10.1
	No B of M sample 104.70' to 104.82' (= TE48)	nil	nil	6.9	-

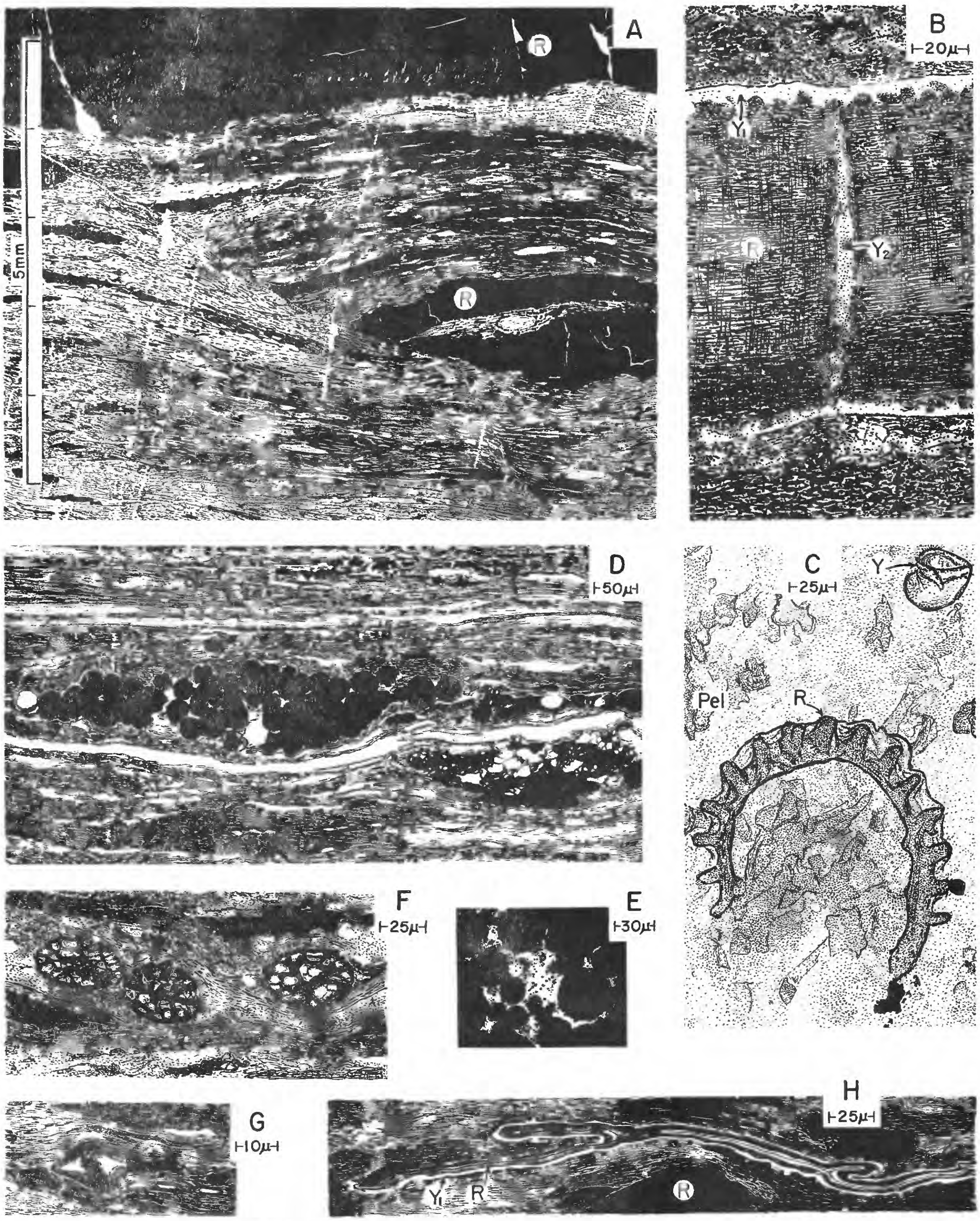

FIGURE 9.- MICROSCOPIC COMPOSITION OF THIN SECTIONS, HOLE 72.

humic or cell wall degradation matter is degraded to finer sizes and anthraxylon is identified as the material in lenticles, strands or bands, exceeding 14 microns in thickness. At least vestiges of the original cellular tissue texture are visible in anthraxylon strands or bands, but the finer materials, mostly derived from cellular fragments and cell contents, usually are too fragmental for identification of their specific origin.

Figure 9A shows the characteristic texture of impure coal from the upper coal zone including one of the minor low angle "compaction" faults. Microscopic shear planes of this type frequently die out in a distance of a few millimeters. The darker areas of this section are nearly all red translucent (R), and the coarser bands are identified as anthraxylon. The light areas here are nearly pellucid, with tinges of yellowish waxy material. It is most difficult to estimate accurately the amount of waxy matter so finely dispersed in a clayey matrix. Apparently the clayey matter is virtually "infiltrated" with yellow waxy organic material and this in highly variable degree. Probably both clay and waxy matter were deposited in semicolloidal dispersion; probably their interrelations were considerably modified during diagenesis. The relative amounts of inspissated waxy matter can be judged by the intensity of coloration, but the quantitative accuracy of these relative estimates cannot be proved. In component analysis of selected layers the amount of "wax in clay" has been estimated at a relatively high magnification and listed in tables 10 and 11 as a separate entity.

Figure 9B illustrates a band of anthraxylon with its enclosing cuticle to provide proof of its origin from a small woody twig. The vitrinized materials are characteristically red translucent (R) and show an obscure horizontal striation resulting from the collapse and compression of vascular and other tissues as they were altered to form coal.

Deeply yellow colored waxy-resinous canals are evident in much of the anthraxylon in this deposit. They commonly show wedge or dagger-shaped extrusions into the adjoining vitrinized tissues, proving that the waxy contents of these secretory canals yielded under pressure. In the particular anthraxylon strand illustrated in figure 9B the canals are infrequent, but a characteristic cleat (shrinkage) fissure appears which is wax-filled. Displaced occurrences of amorphous waxy matter are common in the deposit. The cleat-filling wax has a deeper coloration (Y_2) than that of the outer cuticle (Y_1). The cuticle is a bright lemon yellow and evidently has not been materially displaced, though it is distorted by compression. Some of the remains of epidermal cells are deeply embedded in the waxy cuticle layer.

Visible mineral matter rarely occurs within anthraxylon bands, but the attritus above and below the example illustrated in figure 9B contains irregular microgranular aggregates of clayey minerals that, according to the study by Breger and others (in press), probably is kaolinite. Organic matter of the attritus mostly consists of disordered red-translucent humic matter.

Figure 9C is taken from one of the few horizontal thin sections that were prepared to demonstrate botanical features of some of the characteristic materials. This illustration shows a spore and a fern sporangium in a clayey matrix. The sporangium is similar to that previously illustrated by

Bradley (1930, p. 23, fig. 12) and by Winchester (1923, pl. 7c) from Green River oil shale. Tiny fragments of humic and resinous attrital matter also are present. The distinctive annulus of the fern sporangium suggests that ferns of essentially modern type contributed to the coal deposit.

Figure 9D and figure 9E illustrate occurrences of pyrite that are highly characteristic. Very tiny pyritic crystals, drawn as black specks in the central part of figure 9E, are of common occurrence. Usually whenever any local abundance of pyrite is noted the tiny crystallites are grouped in distinctive spherical aggregates 20 to 40 microns in diameter. These spherical aggregates often are clumped in larger lenticles and more or less grown together. The lamination in some samples is almost undisturbed, suggesting actual organic replacement; in others, it dips steeply around the pyrite suggesting that most of the compaction of organic matter occurred after the pyrite had been deposited. It seems clear that pyrite was deposited contemporaneously with decay, during initial compaction or shortly thereafter, just as Bradley (1930, p. 30-31) has reported for similar pyritic occurrences in the Green River oil shale. No veinlets of secondary pyrite were observed.

Many of the pyritic spherulites are so smooth that question may arise as to their identity when viewed as opaque objects by transmitted light. The high reflectance of these spherulites when observed by vertical illumination and the occurrence with "framboidal" types of aggregates of lower density--the spherulitic form and size being normally developed in these but with the individual tiny cubic crystals separated from one another by organic material so that one becomes convinced of the comparative internal similarity of all--amount to an adequate proof of the pyritic nature of these bodies by whatever means they are observed. There also is no indication that they represent mineralized "fossilization" of any organic structure. Although such primary occurrences of pyrite probably indicate anaerobic decomposition by bacteria that liberated hydrogen sulfide, no visible evidence of actual bacterial remains could be observed. The pyritic spherulites may nevertheless mark the approximate former locations of active bacterial colonies.

Pyrite is not present in any important concentration except in the layer corresponding with TE Sample 9, where it accounts for about 5 percent of the visible mineral matter, in the upper part of TE-10, and in TE-46. Probably these concentrations are responsible for the slight increase in total sulfur in respective coal analytic samples. Tiny crystals and aggregates of pyrite are observable in most of the thin sections, but the sulfur determinations given for coal analytic samples are all relatively low and indicative of the general dispersion of microcrystalline pyrite.

Fungal remains are shown in figures 9F and G. The former shows three sclerotia of a common type as they occur in attrital coal. Several other characteristic varieties are present which are not illustrated. The most abundant form is elongate lenticular, about half a millimeter long, with thinner cell walls which differ from those shown in being much compressed. The structure shown in figure 9G is probably a wind-blown fungus spore, possibly cut in an oblique plane. Fungal materials of this type occur in practically all of the thin sections but are more abundant in some layers than in others.

Very similar types of fungus spores have been illustrated by Bradley (1931, pls. 19 and 20) from microtome sections of Green River shale.

There are three possible sources of fungus remains in this deposit and probably representation from all three. Some, possibly the most abundant varieties including vegetative mycelium, are clearly saprophytic and grew in situ in the deposit. Some of the remains of saprophytic forms also could have been carried from some distance as an organic sediment with other degraded plant remains. Wind blown fungus spores also have no direct bearing on the in situ decomposition of the deposit. In addition, evidences of parasitic fungi have been observed that had their origin with their host plants. The in situ saprophytic fungi are of greatest interest to us as they indicate an environment of aerobic decomposition. Further study of fungus remains is required to distinguish the types indicated above and all have been included as fungal phyterals in tables 10 and 11.

Figure 9H shows a characteristic type of seed that is most abundant in the lower part of the lower coal zone. It has much of the appearance in thin section of the large megaspores found in Paleozoic coal beds but it evidently is more complex. The wall includes a thin red humic layer (R) that represents a thin seed coat, and the outermost waxy layer (Y_1) is cuticular. Only the internal yellow band represents a seed megaspore. The presence of the seed megaspore indicates that these fossils represent one of the groups of gymnosperms. Examination of isolated seed examples obtained by maceration of the coal also suggests the presence of a micropylar tube similar to the "tubulus" present on seeds of Ephedra, the "Mormon Tea," which has a more southerly distribution in the present day flora. All seeds observed are smaller than those of any modern North American species of Ephedra, however, and further study is required to establish the relationship of these fossils. Relationship with Ephedra would be interesting, if true, in indicating an extreme diversity of habitats in this Eocene lake basin because modern species of Ephedra are extreme xerophytes and, as such, would contrast strongly with the general character of the floral assemblage. The common occurrence of gymnospermous elements in the Green River flora is somewhat exceptional.

The bulk of the plant remains in this deposit are in all probability angiospermous in derivation. The cuticles of angiospermous plants seem to dominate the few maceration residues that have been prepared from this coal, and there is an abundance of angiospermous pollen. However, from the evidence presented above, it appears the flora was quite diversified and that gymnosperms, ferns, and a considerable number of saprophytic and parasitic fungi also are represented. Coalified filamentous fossils resembling some of the algae described by Bradley (1931) were noted in one horizontal thin section.

THE RELATION OF PETROLOGIC COMPOSITION TO THE OCCURRENCE OF URANIUM

Large variations in uranium content are present in nearly all of the coal analytic samples, as previously demonstrated by the profile of uranium concentration in figure 8. The coal analytic samples apparently are sufficiently specific to indicate the general range of variations in peat accumulation prerequisite to forming coal and for purposes of type comparison between coal deposits, but there evidently is no direct connection between average concentration of coal constituents in these samples and the amount of uranium that may be present in the coal. The following discussion in relation to occurrence of uranium is based, therefore, on petrologic study of the smaller and more specific laboratory samples that were originally taken for determination of radioactivity. These samples are closely correlated with those used for chemical determinations of uranium.

The chart shown in figure 10 illustrates the inherent petrologic variations in this material, calculated on a visually pure basis. Figure 11 illustrates the composition on a whole-coal basis with visible impurities included in the respective layers. The weighted averages of composition for upper and lower coal zones are presented at the top of table 8 (p. 29). Specific thin layers differ very appreciably from these averages as shown by the varying length bars in figures 10 and 11. Uranium concentration in organic matter, as computed by the methods discussed below, is shown superimposed on the column of translucent attritus in figure 10, and in a separate column in relation to ash content in figure 11. The microscopic

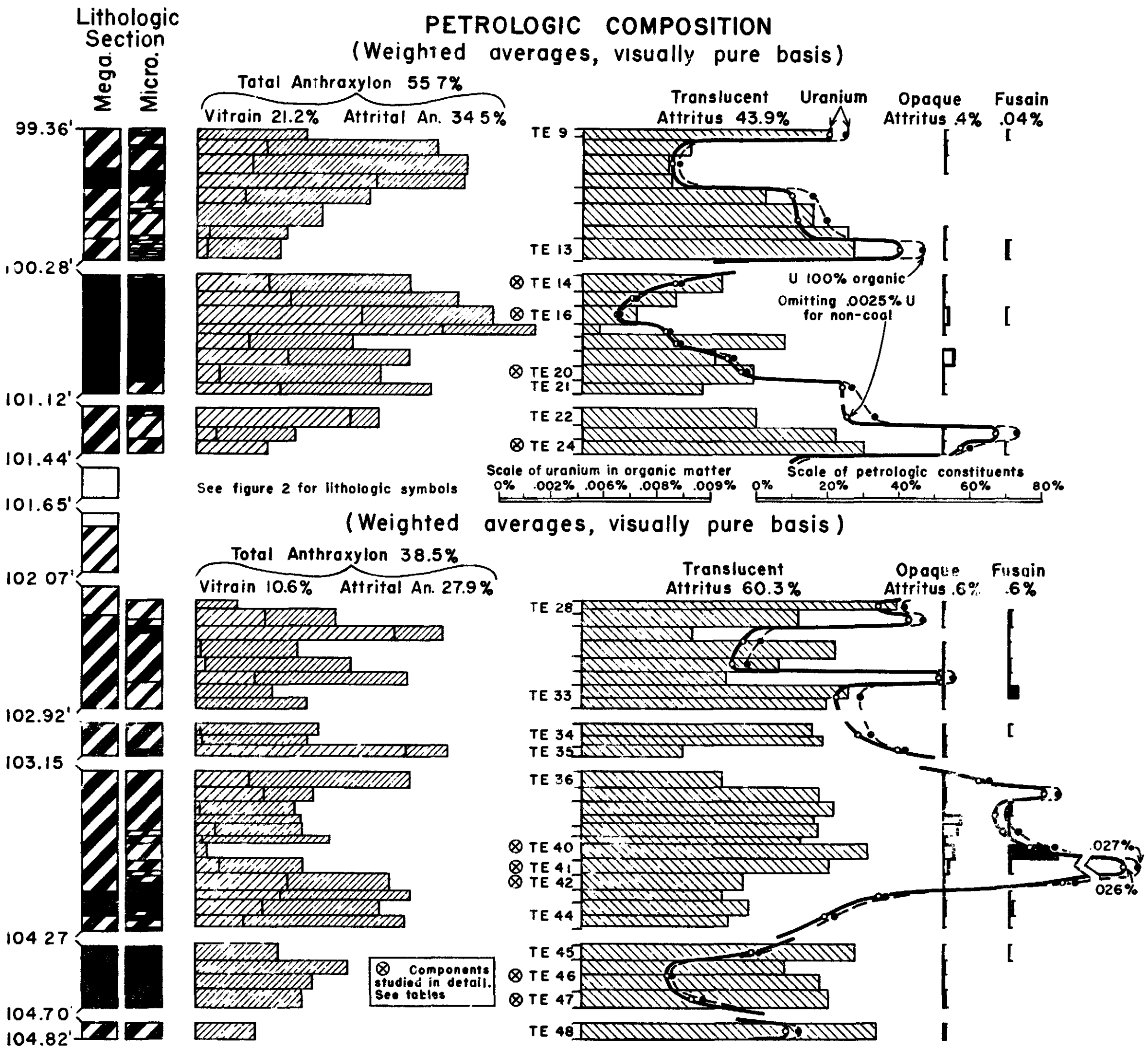

FIGURE 10.-DIAGRAM SHOWING RELATIONSHIP OF ANTHRAXYLON, TRANSLUCENT ATTRITUS AND, URANIUM OF THE LUMAN NO. 1 BED. HOLE 72.

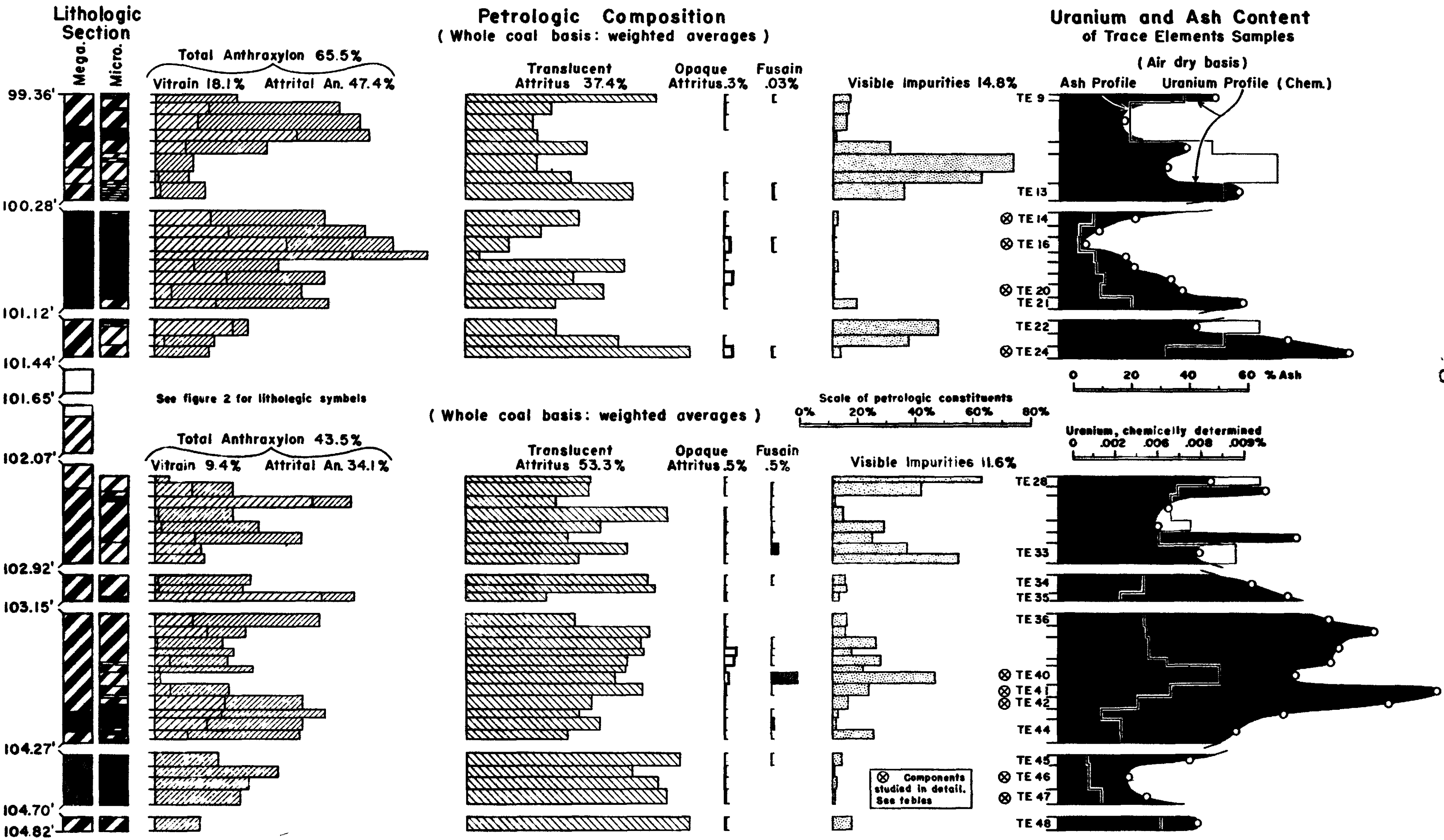

FIGURE 11.-COMPARISON OF PETROLOGIC COMPOSITION, WHOLE COAL BASIS, WITH URANIUM AND ASH CONTENTS, HOLE 72.

studies, upon which the charts are largely based, also have indicated some lithologic refinements that are shown in the separate "micro" column at the left of the figures. All columns have been broken at points corresponding to divisions between coal analytic samples to facilitate a detailed comparison with those results previously discussed.

According to Breger and others (in press), 98 percent of the uranium present in a sample of purer coal from the upper part of the Luman No. 1 coal bed is associated with the organic matter; 2 percent is accounted for in mineral association. Their whole sample assayed about .0022 percent U, so they estimated that the average uranium content of the organic matter in their material amounted to about .0023 percent, and that the mineral matter contained about .0006 percent U. If the same relations hold in our more highly uraniferous and higher ash samples, the smaller proportion of organic matter in these samples must have a relatively high uranium content. The uranium associated with the mineral matter might be practically ignored.

On the other hand, it is conceivable that their estimate of the amount of uranium in the mineral matter associated with the Luman coal bed is somewhat too low. The upper part of the core from hole 72 consisted essentially of noncarbonaceous silty shale that contained about .0033 percent uranium according to the determination based on sample TE-7. Radioactivity values for our laboratory samples as plotted in figures 2 and 3 suggest that perhaps .0020-.0030 percent of uranium is normal for essentially noncarbonaceous core from hole 72.

Uranium data have been calculated on a pure-coal volumetric basis (considering uranium to be mostly associated with organic matter) in two different ways: (1) according to the assumption that essentially all uranium is associated with organic matter, and (2) on the assumption that the mineral matter itself contains about .0025 percent uranium. Both sets of results have been shown, superimposed graphically on the translucent attritus column in figure 10. It is apparent that only a slight relative change in uranium distribution is involved.

The best correlation between uranium concentration and petrologic composition is shown by translucent attritus. The correlation is somewhat better when results are presented on a whole-coal basis (fig. 11) than on the visually-pure basis (fig. 10), even though the uranium evidently is chiefly associated with the organic matter, and the visible impurities (determined on an area basis) correspond closely with trends of concentration shown by ash (determined by weight). The correlation is most striking for samples included in the upper coal division. It also appears that a layer is most likely to be highly uraniferous if it occurs adjacent to a layer having a high mineral content. This relationship is best shown in the lower division where the relation to translucent attritus is less evident.

PETROLOGY OF SELECTED LAYERS

The nature of components included in the translucent attritus of different layers also was investigated for its possible influence on the occurrence of uranium. Nine layers corresponding with trace elements samples were selected for further study and detailed comparison of their microscopic composition.

Table 10. Percent petrologic composition of selected coal layers, Red Desert hole 72.

	CONSTITUENTS OR COMPONENTS	"HIGH" URANIUM CONTENT TE-41	TE-42	TE-24	TE-40	LOW URANIUM CONTENT TE-20	TE-47	TE-14	TE-46	TE-16
	Coarse anthraxylon (=vitrain)	5.62	24.53	0.00	0.65	6.02	0.00	19.75	0.00	45.97
	Attrital anthraxylon	20.28	26.80	19.21	13.17	45.69	29.70	39.32	36.68	37.23
	Total anthraxylon	25.90	51.33	19.21	13.82	51.71	29.70	59.07	36.68	83.20
Translucent attritus	Sub-anthraxylon	11.67	10.81	4.79	2.14	25.74	59.39	20.30	57.34	7.11
Translucent attritus	Translucent humic deg. matter	26.58	17.60	42.18	18.93	18.16	4.05	15.63	0.79	5.70
Translucent attritus	Total humic or cell wall degradation matter	38.25	28.41	46.97	21.07	43.90	63.44	35.93	58.13	12.81
Translucent attritus	Red attrital resins	0.59	1.13	0.21	0.48	0.35	1.88	0.34	1.22	0.34
Translucent attritus	Cuticle	0.00	0.00	0.08	0.01	0.21	0.18	0.10	0.24	0.29
Translucent attritus	Spores	1.33	0.82	1.50	2.91	0.13	0.00	0.06	0.00	0.12
Translucent attritus	Yellow attrital resins	0.42	0.21	0.21	0.54	0.00	0.00	0.00	0.00	0.12
Translucent attritus	Waxy amorphous	7.67	6.64	10.41	10.83	1.39	2.25	1.01	1.22	0.36
Translucent attritus	Estimated wax in clay	12.60	5.57	17.57	16.32	1.21	0.68	1.35	1.00	0.22
Translucent attritus	Total yellow-waxy matter	22.02	13.24	29.77	30.61	2.94	3.11	2.52	2.46	1.11
Translucent attritus	Fungal phyterals	trace	trace	trace	trace	0.44	0.33	0.13	0.33	0.75
Translucent attritus	Brown matter	0.25	0.52	0.75	0.94	0.37	0.65	0.21	0.30	0.07
	Opaque attritus	0.51	0.12	0.21	1.27	0.04	0.35	0.14	0.19	1.50
	Micro-fusain	0.14	0.00	0.14	0.11	0.00	0.00	0.00	0.00	0.08
	Mega-fusain	0.00	0.00	0.00	5.38	0.00	0.00	0.00	0.00	0.00
	Total fusain	0.14	0.00	0.14	5.49	0.00	0.00	0.00	0.00	0.08
	Disseminated pyrites	0.13	0.20	0.14	0.00	0.13	0.11	0.39	0.69	0.08
	Transparent minerals	0.09	0.00	0.14	0.03	0.05	0.00	0.00	0.00	0.04
	Clayey minerals	12.08	5.04	2.47	26.29	0.09	0.42	1.24	0.00	0.00
	Total visible mineral impurities	12.30	5.24	2.75	26.32	0.27	0.53	1.63	0.69	0.12
	TOTAL	99.96	99.99	100.01	100.00	100.02	99.99	99.97	100.00	99.98
	% uranium chemically determined	.0206	.0155	.0117	.0111	.0057	.0042	.0035	.0033	.0012

These included the four highest in uranium content and five of low radioactivity, including layers from the parts having a minimum uranium concentration within the two benches of purer coal. This selection should indicate whether systematic differences in specific organic composition are associated with the presence or absence of significant uranium concentrations in this material. The special layers selected for this study are marked by asterisks along the base line of the translucent attritus column in figure 10 and along the uranium column in figure 11. The quantitative results are given in detail in tables 10 and 11. Both tables are arranged in the order of decreasing uranium content.

Table 10 shows the detailed composition of each of the layers selected for this special study including visible impurities, coal constituents and all their important components. An important component, "estimated wax in clay," has been added to further differentiate materials normally included in translucent attritus. It may be significant that all five samples of relatively high uranium content have a considerable amount of waxy material, and the clayey laminae in some sections appear highly yellow translucent on account of it. However, neither the estimated wax, amorphous wax, nor the amount of clayey minerals show precise quantitative relationship to the uranium content.

The same general relationship is shown in table 11 which presents the composition of translucent attritus in these layers, exclusive of impurities or other constituents. The amount of translucent attritus contained in each of the layers is given near the bottom of the table. The "high" layers average

Table 11 - Percent composition of translucent attritus in selected coal layers, Red Desert hole 72.

COMPONENTS	"HIGH" URANIUM CONTENT				LOW URANIUM CONTENT				
	TE-41	TE-42	TE-24	TE-40	TE-20	TE-47	TE-14	TE-46	TE-16
Sub-anthraxylon	19.09	24.97	6.15	4.03	53.64	85.58	51.87	91.84	47.12
Translucent humic degradation matter	43.48	40.65	54.29	35.65	37.83	5.84	39.94	1.27	37.82
Total humic or cell wall degradation matter	62.57	65.62	60.44	39.68	91.47	91.42	91.81	93.11	84.94
Red attrital resins	0.97	2.60	0.27	0.91	0.74	2.70	0.88	1.95	2.24
Cuticle	0.00	0.00	0.11	0.03	0.43	0.25	0.24	0.38	1.92
Spores	2.18	1.90	1.93	5.47	0.26	0.00	0.15	0.00	0.80
Yellow attrital resins	0.69	0.49	0.27	1.01	0.00	0.00	0.00	0.00	0.80
Waxy amorphous	12.56	15.33	13.40	20.40	2.90	3.24	2.58	1.95	2.40
Estimated wax in clay	20.62	12.87	22.62	30.74	2.51	0.97	3.46	1.60	1.44
Total yellow-waxy matter	36.05	30.59	38.33	57.65	6.10	4.46	6.43	3.93	7.36
Total fungal phyterals	trace	trace	trace	trace	0.91	0.47	0.34	0.53	4.97
Brown matter	0.41	1.19	0.96	1.76	0.78	0.94	0.54	0.48	0.48
TOTAL	100.00	100.00	100.00	100.00	100.00	99.99	100.00	100.00	99.99
Approximate percent of layer represented by the translucent attritus analyzed	61.12	43.29	77.69	53.10	47.98	69.40	39.14	62.43	15.08
% uranium chemically determined	.0206	.0155	.0117	.0111	.0057	.0042	.0035	.0033	.0012

58.8 percent translucent attritus and the low uranium layers 46.8 percent. This tends to support the general relationship previously noted between translucent attritus and uranium content in this coal, but it certainly is not definite enough to serve as more than a tentative guide for investigation.

The total yellow waxy matter would seem to offer a better indication of uranium concentration than the amount of translucent attritus. The "high" layers average about 40 percent waxy, the low uranium layers about 5.6 percent. The dominant waxy matter includes both "amorphous waxy" and "estimated wax in clay." Since the relationship is not an exact one, the waxy material must be regarded as a factor favorable to uranium emplacement, rather than a cause, and, although it would seem that this is the organic component with which uranium is most likely to be associated, no doubt a great deal depends upon the availability of and access to some uranium source.

Source of waxy matter

Presumably the wax in clay is a dispersed form of the amorphous waxy matter which is fairly common as a minor component in many coals. From the geologic relationships, proximity and microscopic appearance, it would seem that the origin of most of the waxy matter of the Luman zone and the Green River shale may be similar.

This amorphous waxy material is largely identified by its lack of morphologically distinguishing features, and its source is not easily determined. It may be presumed that it originates as a vegetable product that has been separated from the plant tissues that were genetically associated with it and secondarily dispersed, or concentrated within the existing deposit. It now is associated with such a diverse assemblage of organic and inorganic micro-materials that its present association is of little assistance in identifying its origin more precisely than the assemblage of plants known as the Green River flora. Most of this assemblage consists of shrubby or arborescent angiosperms, but, as mentioned previously, some gymnosperms, ferns, and a variety of fungi and algae have been recognized.

It is not certain that the waxy matter may all be derived from a plant source. Sections prepared for comparison of types of organic matter from the varved Green River marlstone at the Fossil Fish Cliffs locality west of Kemmerer, Wyoming, have shown a striking association of the amorphous waxy material with carapaces of abundant ostracodes. The ostracode valves evidently initiate formation of a type of microgeode within which crystalline calcite was deposited marginally. The center of such "geodes" is usually more or less fully occupied by amorphous waxy matter in contact with the euhedral terminations of calcite. No obvious connection with waxy amorphous material outside the carapaces is visible; and, if one had not observed the identical type of substance in many other kinds of association, the conclusion that this yellow material represented alteration products, possibly including fatty food reserves, etc., indigenous to the ostracodes, would be rather compelling. It is still far from proved that this microscopically indistinguishable type of waxy matter is all derived from a unique vegetable source. It probably could arise from different sources with the much modified end products of the same microbial and geochemical environment tending to show points of resemblance.

Whatever the original source or sources were, it seems evident that the waxy material has undergone considerable transfiguration in arriving in its present occurrence. As pointed out in previous discussion, wax-filled secretory canals are common in anthraxylon of the Luman zone and these generally show evidence of mobility under coalification pressure. Cleat cracks in vitrain commonly are filled by waxy matter that has migrated to fill them. There is every indication that much of the waxy material in the deposit, not incorporated in spore coats or cuticles, is more or less labile and susceptible to flowage and displacement during consolidation. Prior to consolidation of the deposit a softer, much more plastic, essentially "fluid," condition can be presumed for most of the organic substances. Any waxy matter freed from plant tissues by extrusion or early decay could contribute to the amorphous waxy matter of the deposit, provided these products are chemically sufficiently stable.

It is very likely that most of the organic matter in the deposit was contributed by angiospermous plants resembling those of southern coastal swamps. Remains of all the kinds of tissues that such plants might contribute seem to be reasonably represented in the coal with the exception of periderm. Corky layers of the bark are not as commonly found as in the more prominently banded western coals. The plant waxes known as suberin are generally present in the corky tissues of angiospermous plants to aid retention of moisture in living tissues. Sometimes suberin forms a substantial proportion of the dry weight of the corky layers. Suberin may be mixed with some variety of organic materials and may show differences in chemical composition, but, as a type of substance, suberin is relatively stable (Zetzsche, 1932; Kaufmann, 1932). In general it is similar to the waxes that form the plant cuticle and spore coats except that it is not usually so completely exposed to atmospheric oxygen and does not become fully saturated. Some of these fatty plant products have characteristics of drying oils, of which linseed is an example. Suberin may thus be suggested as a most plausible general source for the amorphous waxy matter in the coaly deposit. If so, it has been generally modified by decay, probably both aerobic and anaerobic, so that direct proof of its origin has been virtually obliterated.

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APPENDIX

CORE DESCRIPTION

Hole 72, 8" Diameter Core, Red Desert Area, Sweetwater County, Wyoming.

DATES: Cored--11/24/53, by the Pennsylvania Drilling Company, Harlan Gallihue, driller.

Shipment received at Columbus--11/30/53
Described and sampled at Coal Geology Laboratory--12/14 through 12/23/53
Samples sent to TE Laboratories 12/22/53 and 12/29/53

LOCATION: SE 1/4 of NW 1/4 of Section 15, T 24 N, R 95 W

ELEVATION: 6,580'

	Sample Number
95.97'	
Shale, light gray with very light silty streaks and a few thin carbonaceous streaks. CGL 84, 2.03 P/M/G, 2.297 ASGM 1/	TE 1
96.08'	
Shale as above. CGL 83, 3.15 P/M/G, 2.272 ASGM	TE 2
96.18'	
Shale as above. CGL 82, 2.23 P/M/G, 2.246 ASGM	
96.29'	
Shale, light gray with black carbonaceous streaks at top. CGL 81, 2.41 P/M/G, 2.254 ASGM	TE 3
96.39'	
Shale, light gray with a few carbonaceous streaks and very light silty streaks at bottom. CGL 80, 2.19 P/M/G, 2.253 ASGM	
96.49'	
Shale, light gray with carbonaceous streaks. CGL 79, 1.89 P/M/G, 2.227 ASGM, 2.64 RSG 2/	TE 4
96.58'	
Shale as above with thin light gray clayey parting in middle. CGL 78, 2.69 P/M/G, 2.209 ASGM	
96.67'	TE 5
Shale, light gray with thin carbonaceous streaks and clayey parting at bottom. CGL 77, 2.51, P/M/G, 2.123 ASGM	

1/ ASGM = apparent specific gravity in moist condition.

2/ RSG = real specific gravity, U. S. Bureau of Mines determination.

96.75'
Shale, silty, light gray with lighter silty streaks and very fine carbonaceous flecks; thin dark gray carbonaceous streaks at top. CGL 76, 1.74 P/M/G, 2.266 ASGM

TE 6

96.87'
Shale, silty, light gray with lighter silty streaks and very fine carbonaceous flecks. CGL 75, 1.28 P/M/G, 2.289 ASGM

97.00'
Shale as above. CGL 74, 1.40 P/M/G, 2.280 ASGM

97.10'
Shale as above. CGL 73, 1.24 P/M/G, 2.316 ASGM, 2.62 RSG

97.20'
Shale as above, less silty. CGL 72, 1.13 P/M/G, 2.275 ASGM

97.30'
Shale as above. CGL 71, 1.08 P/M/G, 2.268 ASGM

97.40'
Shale as above. CGL 70, 1.03 P/M/G, 2.269 ASGM

97.51'
Shale as above. CGL 69, 1.03 P/M/G, 2.240 ASGM

97.61'
Shale, finely silty, light gray, slightly more carbonaceous than above. CGL 68, 1.08 P/M/G, 2.254 ASGM

97.71'
Shale as above. CGL 67, 1.18 P/M/G, 2.278 ASGM

97.83'
Shale, silty, light gray with lighter silty streaks and a few carbonaceous flecks. CGL 66, 1.14 P/M/G, 2.253 ASGM

97.95'
Shale as above. CGL 65, 1.16 P/M/G, 2.268 ASGM

98.07'
Shale, silty, light gray with carbonaceous flecks. CGL 64, 1.23 P/M/G, 2.302 ASGM

98.25'
Shale, silty, light gray with irregular carbonaceous streaks. CGL 63, 1.15 P/M/G, 2.316 ASGM

98.40'
Shale as above. CGL 62, 0.85 P/M/G, 2.255 ASGM

98.49'
Shale, light gray with lighter irregular silty streaks and carbonaceous flecks. CGL 61, 0.89 P/M/G, 2.236 ASGM

98.64'
Shale as above; becomes gray carbonaceous shale in lower half. CGL 60, 1.13 P/M/G, 2.305 ASGM

98.83'
Shale, light gray with carbonaceous streaks. CGL 59, 1.56 P/M/G, 2.276 ASGM

TE 7

98.95'
Shale, light gray with carbonaceous flecks. CGL 58, 1.20 P/M/G, 2.300 ASGM

99.10'
Shale light gray, carbonaceous in lower half with thin clayey partings. CGL 57, 1.43 P/M/G, 2.279 ASGM

99.18'
Shale, light gray with black carbonaceous bands. CGL 56, 2.77 P/M/G, 2.114 ASGM — TE 8

99.36'
Coal; impure coal in upper 1/3 with gray shaly blebs. Finely disseminated pyrite blebs.throughout. CGL 55, 2.79 P/M/G, 1.509 ASGM, 1.70 RSG — TE 9

99.41'
Coal, impure, sparsely thin-banded with .02' band of coal .02' from bottom. Finely disseminated pyrite throughout, with pyrite lenses in bottom half. CGL 54, 1.34 P/M/G, 1.475 ASGM, 1.74 RSG

99.53'
Coal, impure, sparsely thin-banded. Finely disseminated pyrites concentrated in upper .02' and scattered pyrite blebs throughout upper half. CGL 53, 1.21 P/M/G, 1.458 ASGM — TE 10

99.65'
Coal, moderately medium-and coarse-banded. .04' vitrain band at bottom. Impure with small amount of finely disseminated pyrite in upper 1/3. CGL 52, 1.07 P/M/G, 1.312 ASGM

99.77'
Coal, shaly, sparsely thin-banded, becoming more shaly towards bottom. Pyrite blebs scattered through upper 1/3. Micro-fault present. CGL 51, 2.28 P/M/G, 1.814 ASGM, 2.05 RSG — TE 11

99.88'
Shale, gray to black, carbonaceous with impure coal between 99.94' and 99.96'. Numerous clay blebs in lower half. CGL 50, 1.98 P/M/G, 1.911 ASGM

100.00'
Shale, gray to black carbonaceous with numerous gray clayey blebs. CGL 49, 1.83 P/M/G, 2.040 ASGM — TE 12

100.13'
Shale, black, coaly, with some carbonaceous shale, sparsely thin-banded. Gray clay blebs and finely disseminated pyrite throughout. CGL 48, 3.31 P/M/G, 1.658 ASGM — TE 13

100.28'
Coal, sparsely thin-banded. About 0.8' impure coal layer at top. Finely disseminated pyrite throughout. CGL 47, 1.15 P/M/G, 1.338 ASGM — TE 14

100.40'
Coal, moderately thin- and medium-banded. CGL 46, 0.63 P/M/G, 1.286 ASGM — TE 15

100.50'	
Coal, abundantly medium to coarse banded. CGL 45, 0.37 P/M/G, 1.294 ASGM	TE 16
100.63'	
Coal, moderately to abundantly thin- and medium-banded with .06' vitrain at top. CGL 44, 0.88 P/M/G, 1.297 ASGM	TE 17
100.72'	
Coal, moderately thin- and medium-banded. CGL 43, 1.27 P/M/G, 1.322 ASGM	TE 18
100.82'	
Coal, moderately thin-banded. Some pyrite and humic canneloid in bottom 1/3. Pyrite wedge .007' thick in upper 1/3. CGL 42, 1.82 P/M/G, 1.412 ASGM	TE 19
100.92'	
Coal, sparsely thin- and medium-banded, with some humic canneloid layers. CGL 41, 2.16 P/M/G, 1.305 ASGM	TE 20
101.02'	
Coal, impure, moderately thin- to medium-banded. CGL 40, 2.51 P/M/G, 1.382 ASGM 1.63 RSG	TE 21
101.12'	
Shale carbonaceous, sparsely thin-banded, with irregular gray shaly lenses and blebs. .03' vitrain band at top. CGL 39, 2.85 P/M/G, 1.849 ASGM, 2.21 RSG	TE 22
101.23'	
Shale carbonaceous, black at top to impure coal in lower 1/4. Sparsely thin-banded. CGL 38, 3.91 P/M/G, 1.776 ASGM	TE 23
101.34'	
Coal impure, attrital. More mineral matter and finely disseminated pyrite in upper 1/3 CGL 37, 4.47 P/M/G, 1.455 ASGM	TE 24
101.44'	
Shale, light gray with carbonaceous streaks CGL 36, 1.75 P/M/G, 2.223 ASGM	TE 25
101.54'	
Shale as above. CGL 35, 1.55 P/M/G, 2.297 ASGM, 260 RSG	TE 25
101.65'	
Shale as above. CGL 34, 1.73 P/M/G, 2.219 ASGM	
101.75'	
Shale carbonaceous, gray with black streaks. CGL 33, 1.76 P.M.G, 2.218 ASGM	TE 26
101.85'	
Shale as above. CGL 32, 2.07 P/M/G, 2.186 ASGM, 2.54 RSG	
101.95'	
Shale, black with coaly streaks. CGL 31, 3.25 P/M/G, 1.907 ASGM, 2.21 RSG	TE 27

102.07' Shale, dark gray with coaly streaks. CGL 30 3.19 P/M/G, 1.944 ASGM, 2.25 RSG	TE 27
102.16' Shale carbonaceous, with light gray shaly blebs and small amount of finely disseminated pyrite. CGL 29, 2.57 P/M/G, 1.923 ASGM	TE 28
102.26' Coal shaly, upper 1/2 carbonaceous shale; moderately thin-banded with one coarse vitrain band. .01' thick. CGL 28, 3.57 P/M/G, 1.476 ASGM	TE 29
102.34' Coal impure, moderately to abundantly thin-banded. .04' vitrain band at top. CGL 27 1.71 P/M/G, 1.482 ASGM	TE 30
102.44' Coal impure, sparsely thin-banded. Very small amount of finely disseminated pyrite. CGL 26, 1.91 P/M/G, 1.428 ASGM	
102.54' Coal shaly to impure coal, sparsely thin-banded. Small amount of pyrite blebs and streaks. CGL 25, 2.40 P/M/G, 1.617 ASGM	TE 31
102.65' Impure coal, moderately thin-banded. Small amount of finely disseminated pyrite. CGL 24, 3.73 P/M/G, 1.485 ASGM	TE 32
102.74' Shale carbonaceous. CGL 23, 2.82 P/M/G, 1.759 ASGM	TE 33
102.84' Shale carbonaceous. Gray clay blebs scattered throughout. CGL 22, 2.55 P/M/G, 1.711 ASGM, 2.07 RSG	
102.92' Coal impure, shaly. Sparsely thin-banded. CGL 21, 3.76 P/M/G, 1.430 ASGM	TE 34
103.01' Coal impure, sparsely thin-banded. CGL 20, 3.75 P/M/G, 1.426 ASGM	
103.08' Coal and impure coal, moderately thin- to medium-banded. Top 1/3 more shaly; bottom .04' vitrain. CGL 19, 3.36 P/M/G, 1.463 ASGM	TE 35
103.15' Coal impure, sparsely thin- to medium-banded. CGL 18, 4.06 P/M/G, 1.541 ASGM	TE 36
103.26' Coal impure to carbonaceous shale, moderately thin-banded. .015 vitrain band at top. CGL 17, 5.13 P/M/G, 1.454 ASGM	TE 37

103.35'
Shale coaly and carbonaceous shale. CGL 16, 4.71 P/M/G, 1.463 ASGM

103.45' — TE 38
Coal impure, attrital. CGL 15, 4.64 P/M/G, 1.438 ASGM

103.54'
Coal impure with carbonaceous shale in lower 1/3. — TE 39
CGL 14, 3.79 P/M/G, 1.475 ASGM

103.60'
Coal impure to shaly coal, with few scattered clay blebs. CGL 13, 4.28 P/M/G, 1.739 ASGM — TE 40

103.66'
Shale carbonaceous, with a few scattered clay blebs. CGL 12, 4.53 P/M/G, 1.667 ASGM

103.77'
Coal impure; carbonaceous shale in upper and lower 1/5, sparsely thin-banded. Small amount of dissem- — TE 41
inated pyrite through lower 1/3. CGL 11, 6.53 P/M/G, 1.555 ASGM

103.88'
Coal impure, shaly. Moderately thin-banded with — TE 42
one .02' vitrain band at bottom. CGL 10, 5.01 P/M/G, 1.617 ASGM, 1.83 RSG

103.98'
Coal, moderately thin-banded, with .02' vitrain — TE 43
band at top. Finely disseminated pyrite throughout CGL 9, 3.27 P/M/G, 1.334 ASGM

104.07'
Coal, sparsely to moderately thin-banded with .025' impure layer at bottom. Finely dissemi- nated pyrite throughout. CGL 8, 2.75 P/M/G,
1.360 ASGM, 1.51 RSG — TE 44

104.16'
Coal impure, thin carbonaceous band at top, sparsely thin banded. Finely disseminated pyrite throughout. CGL 7, 2.85 P/M/G, 1.407 ASGM

104.27'
Coal attrital, slightly impure in upper 1/2.
Finely disseminated pyrite in upper 1/3. CGL 6, — TE 45
2.18 P/M/G, 1.291 ASGM, 1.40 RSG

104.36'
Coal attrital. Small amount of finely disseminated pyrite throughout. CGL 5, 1.16 P/M/G, 1.282 ASGM

104.47' — TE 46
Coal attrital. Blebs and streaks of pyrite con- centrated .05' from bottom. CGL 4, 1.14 P/M/G, 1.270 ASGM, 1.49 RSG

104.58'
Coal attrital. CGL 3, 1.70 P/M/G, 1.304 ASGM — TE 47

104.70'
Coal impure, attrital. CGL 2, 2.48 P/M/G., 1.377 ASGM — TE 48
104.82'
Clay, light gray, plastic. CGL 1, 1.25 P/M/G — TE 49
105.00' (Bottom of core received at Coal Geology Laboratory)
1' loss in coring recorded at drill site
106.00' (Total depth drilled.)