Origin of Elements Associated With Uranium in the Cave Hills Area Harding County South Dakota

GEOLOGICAL SURVEY PROFESSIONAL PAPER 476-B

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By GEORGE N. PIPIRINGOS

URANIUM INVESTIGATIONS IN THE CAVE HILLS AREA, HARDING COUNTY, SOUTH DAKOTA

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An investigation of the geological and geochemical history of the elements associated with uranium in coal, carbonaceous siltstone, and phosphatic claystone in the Fort Union Formation of northwest South Dakota

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By George N. Pipiringos

ABSTRACT

This report is based principally on the study of chemical, radiometric, and semiquantitative analyses of 354 samples of coal, carbonaceous siltstone, and phosphatic claystone collected during geologic investigations of the uranium deposits in the Cave Hills area, Harding County, S. Dak.

Eight stratigraphic units of the Paleocene Fort Union Formation were chosen for study of the distribution of uranium and 32 other trace elements and for study of radioactivity equilibrium relations. The stratigraphic units include six coal zones, a carbonaceous siltstone facies of one of the coal beds locally called the Carbonate ore zone, and a phosphatic silty claystone bed locally called the Lonesome Pete ore zone. These units contain all the known uranium occurrences in the area. From youngest to oldest the units are: coal beds F and E, Carbonate coal zone (includes the Carbonate ore zone), coal zone C, coal zone B, Lonesome Pete ore zone, Lonesome Pete coal zone, and lower coal beds. In general, the uranium content decreases from the stratigraphically highest unit downward. All the higher grade uranium occurrences are adjacent or nearly adjacent to aquifers. The lower coal beds, which are the farthest removed from the aquifers, contain the least uranium. The amount of radioactivity disequilibrium (U> or <eU) in the stratigraphic units likewise is greatest near the aquifers. The unit that overlies and three units that most closely underlie the principal aquifer are the only ones containing an excess of eU over U; samples from the others contain an excess of U over eU. These field relations suggest strongly that the initial deposition of uranium, as well as the subsequent leaching and redeposition of uranium, was accomplished by circulating ground water. Presumably a sample having excess eU was leached of some of its uranium, a sample having excess U had uranium added at some time during the last 300,000–500,000 years, and a sample in radioactivity balance was mineralized at some time before about 500,000 years ago.

The syngenetic and epigenetic origin and subsequent history of the trace elements other than uranium in the host rocks of this area were studied by use of three semi-independent methods of investigation. All three methods were based on the assumption that trace elements in these rocks were emplaced in one or more of the following ways: (1) As plant constituents, (2) as constituents of the original inorganic fraction of the rock, and (3) as constitutents added to the rock by circulating ground water. Probable origin and history of the elements were determined by (1) comparison of the range, average, and maximum abundance of elements in coal with those in the noncoals; (2) comparison of the average abundance of elements in coal and noncoals low in uranium content with the abundance of elements in the earth's crust; and (3) determination (partly by analyses, partly by inference) of the inherent composition of the organic fraction of coal.

During Paleocene time the elements Ca?, Mn, B, and Co apparently were concentrated in coal by plant action. After coalification, during post-Paleocene to late Pleistocene time, the elements Fe, P, As, Ba?, Be, Cu?, Ge, La, Mo, Nd, Ni?, Pb?, Sc?, Sn, Sr?, V, Y, Yb, and Zr were absorbed by the coal from circulating ground water, which at the same time leached much of the syngenetic Ca?, K?, and B from the coal. The other elements detected in the coal samples—Si, Al, Mg?, Na, K, Ti, Ag, Cr, and Ga—seem principally to have been original constituents of the inorganic rock.

The elements Ca, P, La, Mo, V, Y, and Yb were added with uranium to the noncoal Carbonate and Lonesome Pete ore zones, after lithification, by circulating ground water. With the possible exception of Nd, concentrations of other elements in noncoal samples are about the same as would be expected in the original inorganic constitutents of these samples.

Further inferences as to whether the elements occurred originally in lean, normal, or rich concentrations in the inorganic constituents of both the coal and in the noncoal ore zones are described in the text.

Radioactivity data suggest that the effect of ground water on coal during about the last 500,000 years (late Pleistocene to Recent time) was much greater than during post-Paleocene through early Pleistocene time.

INTRODUCTION

This report is based principally on the study of chemical, radiometric, and semiquantitative analyses of 354 samples of coal, carbonaceous clayey siltstone, and phosphatic silty claystone (tables 15–19) collected during geologic investigations of the uranium deposits in the Cave Hills area, Harding County, S. Dak. The geology and uranium deposits were described in chapter A of this professional paper (Pipiringos and others, 1965). The carbonaceous clayey siltstone and the phosphatic silty claystone samples are from stratigraphic units locally referred to as the Carbonate and the Lonesome Pete ore zones, respectively. These zone names are used in this report with a stratigraphic rather than an economic connotation. In addition to the foregoing analyses, 70 samples of ordinary sandstone, siltstone, and shale were collected and analyzed chemically, radiometrically, and semiquantitatively (tables 15–21). A study of the results of the analyses of these samples shed no light on the geologic and geochemical history of the trace elements in the uranium-bearing rocks of this area, but these analyses were useful in showing the radioactivity equilibrium status of certain stratigraphic units (chap. A, fig. 27) and in reaching the conclusions discussed in the section titled "Reliability of semiquantitative spectrographic analyses."

The geologic and geochemical history of the trace elements in the uranium-bearing rocks is inferred by a comparison of the elemental composition of samples of the coaly rocks with that of samples of the noncoaly rocks, of samples of the host rocks with that of the average for the earth's crust, of the mainly organic coal fractions with that of the mainly inorganic coal fractions, of the samples high in uranium content with that of the samples low in uranium content, and of the samples in radioactivity disequilibrium with that of the samples in radioactivity equilibrium. These studies aid in identification of elements that (1) were concentrated by plants whose remains formed coal, (2) originated as inorganic sedimentary constituents of the rock, and (3) were added or removed by ground water after coalification or lithification.

This investigation is a separate phase of, but closely dependent upon the results of, the investigations reported on in chapter A. Conclusions reached in chapter A that are pertinent to the present study are given in the following paragraphs.

Uranium mineralization was accomplished by circulating ground water after the Paleocene host rocks were coalified or lithified; subsequent leaching of the host rocks and redeposition of uranium likewise were accomplished by circulating ground water. The principal reasons for these beliefs are summarized as follows:

1. Uranium content of host rocks generally decreases downward; this relation suggests descending mineralizing solutions.
2. Uranium content generally is greatest in host rocks adjacent to aquifers and is least in host rocks farthest from the aquifers.
3. Uranium commonly is sharply localized areally and stratigraphically.
4. Localization of uranium and degree of radioactivity disequilibrium are controlled partly by structure but mostly by proximity to aquifers.
5. Stratigraphically high host rocks adjacent to aquifers show both excess uranium and excess equivalent uranium (enriched and leached); those adjacent to stratigraphically low aquifers show only excess uranium (enriched).

Analcitization and uranium mineralization probably occurred at about the same time. A coincidence in stratigraphic distribution of analcite and uranium and the probability that Miocene Arikaree Formation was the principal source of analcite suggest that most of the uranium in the host rocks also came from that formation in Miocene or post-Miocene time.

Uranium deposited or removed under conditions approximating those under which the Cave Hills coal beds and other host rocks were mineralized or leached would normally attain radioactivity equilibrium in about 500,000 years. Samples containing an excess of uranium ($U>eU$) probably have had uranium added rather than daughter products removed; samples showing an excess of equivalent uranium ($eU>U$) probably have had uranium removed rather than daughter products added, except for radioactive barite deposits noted locally in the Cave Hills area. Consequently, samples in which $U=eU$ were mineralized more than about 500,000 years ago and have not been subjected to either leaching or enrichment of uranium content since; samples in which $U>eU$ either were mineralized more than about 500,000 years ago and have been enriched in uranium since, or the uranium was deposited since about 500,000 years ago and has not reached equilibrium; samples in which $eU>U$ have been leached of uranium within about the last 500,000 years.

The probable geologic history of geologic and geochemical events in the Cave Hills area is summarized as follows:

1. Deposition of potential host rocks and acquifers of the Fort Union Formation in Paleocene time.
2. Deposition of rocks of Eocene age.
3. Folding, jointing, regional uplift, and erosion near the end of Eocene time. Exposed and near-surface parts of the Fort Union Formation probably were oxidized at this time.
4. Deposition of source rocks of the Chadron Formation of Oligocene age, which buried and preserved topographic features resulting from the late Eocene erosion.
5. Some uranium leached from the Chadron Formation by ground water and deposited in underlying host rocks. Mineralization ceased with, or was retarded by, the formation of impervious bentonite and bentonitic claystone beds.
6. Deposition of Brule Formation of Oligocene age.
7. Regional uplift and erosion; landsliding in late Oligocene or early Miocene time (post-Brule, pre-Arikaree). Most of the Brule and much of the Chadron Formations were stripped from the

area. Some uranium mineralization occurred locally.

8. Deposition of the Arikaree Formation of Miocene age. More intense mineralization of underlying Fort Union host rocks began and continued throughout Miocene time, wherever the Arikaree Formation rested directly on the host rocks.
9. Regional uplift and erosion. All the Miocene sequence was stripped from the Cave Hills area, and the principal period of mineralization in this area was concluded.
10. Deposition of slightly uraniferous rocks of Pliocene age. Uranium mineralization of host rocks may have continued but at a much diminished rate.
11. Regional uplift and erosion, the latter resulting in the exhumation of topographic features buried by deposition of the Chadron.
12. Minor deposition alternated with major erosion throughout Pleistocene time.

The water table fluctuated, but it generally moved downward. Little, if any, uranium was transferred from source rocks still remaining in the area. Certainly at about the beginning of the middle of Pleistocene time and probably as early as Pliocene time, the host rocks were exposed to weathering and erosion. The host rocks locally were leached of part of their uranium, which was redeposited structurally lower in the same bed or in other stratigraphically lower host rocks. Leaching resulted in uranium deficiency in host rocks, and redeposition resulted in uranium excess. Visible uranium minerals were the result of redeposition of uranium. Highly radioactive but uranium-deficient deposits, such as radioactive barite, were formed during this time as the result of extreme leaching of weathered host rocks and redeposition of the residual uranium daughter products.

The foregoing conclusions are justified by the data and geologic reasoning in chapter A of this professional paper; likewise, unavoidably, references are made to maps and tables included in chapter A.

In the present study, conclusions with respect to uranium, listed above, are assumed to apply to other elements detected in the samples. Elements whose stratigraphic distribution is similar to that of uranium probably had a similar geologic history. That is, elements more highly concentrated in the stratigraphically higher beds and (or) in the vicinity of aquifers were, like uranium, probably emplaced by ground-water action and probably came from the same source as uranium. Elements whose stratigraphic distribution is independent of, or the inverse of, that of uranium are assumed to have had a different geologic history, and in the discussions that follow the degree and kind of differences are utilized to determine their probable source and subsequent history.

EARLIER INVESTIGATIONS

Since 1950, commencing with the work of Denson, Bachman, and Zeller (1959), geologic investigations of the Cave Hills and other areas in and adjacent to Harding County, S. Dak., principally have been concerned with the uranium deposits that occur in the Fort Union Formation. As many semiquantitative spectrographic analyses of uranium-bearing samples were accumulated, the relations of certain elements to uranium were noted and reported.

The conclusions reached by earlier investigators about the relations to uranium of certain elements in coal from the Cave Hills and adjacent areas are summarized in the following table. Only those elements that were considered by more than one of the earlier investigations are listed. The results of this report are included for comparison.

Investigator and reference	Area	Element															
		Si	Al	Mg	Ca	Na	K	Mn	As	Co	La	Mo	Ni	Pb	Sc	V	Zr
Gill, 1955, p. 153	(1)	----	----	----	----	----	----	----	+	----	----	+	----	----	----	----	----
Deul and Annell, 1956, p. 168	(2)	----	----	----	----	----	----	----	----	----	----	+	----	----	----	----	----
Gill and Denson, 1956, p. 237	(3)	0	0	−	−	−	−	----	+	+	----	+	+	0	0	0	----
Kepferle and Chisholm, 1956, p. 243–251	(4)	----	----	----	----	----	----	----	+	----	----	+	----	----	+	----	+
Vine and Merewether, 1956, p. 356, 357	(1)	----	----	----	----	----	----	−	+	----	+	+	----	----	+	----	+
Denson and Gill, 1965, p. 53–54	(1, 3, 5)	0	0	−	−	0?	−	−	+	+	+	+	+	+	+	0?	+
This report (coal only)	(4)	0	0?	0	−?	0	−?	−	+	0?	+	+	+?	+	0	+	+

+, positively related to uranium; −, negatively related to uranium; 0, not related to uranium; and ----, not determined.

[1] North Cave Hills, Harding County, S. Dak.

[2] Cave Hills and adjacent areas, Harding County, S. Dak.

[3] Slim Buttes, Harding County, S. Dak.

[4] North and South Cave Hills, Harding County, S. Dak.

[5] Little Missouri River escarpment, Billings County, N. Dak.

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Radioactivity analyses were made by B. A. McCall, of the U.S. Geological Survey, Washington, D.C., and by C. G. Angelo, of the U.S. Geological Survey, Denver, Colo.

Semiquantitative spectrographic analyses were made by Charles Annell, Mona Frank, K. V. Hazel, and H. W. Worthing, of the U.S. Geological Survey, Washington, D.C., and by N. M. Conklin and J. C. Hamilton, of the U.S. Geological Survey, Denver, Colo.

RELIABILITY OF SEMIQUANTITATIVE SPECTROGRAPHIC ANALYSIS

A total of 424 samples, 396 from the Cave Hills area and 28 from adjacent areas (Denson and Gill, 1965 a, b), were analyzed by the semiquantitative spectrographic method. The minimum amount of each element detectable by this method is shown in table 1.

The results of the spectrographic analyses are reported as approximate logarithmic midpoints of ranges (table 2), each order of magnitude being divided into three ranges. The reports received from the laboratories indicated that approximately 50–60 percent of the results might be expected to be accurately bracketed within the range.

Chemical analyses of phosphorus and uranium were compared with spectrographic analyses of those elements (tables 15–21, p. B52–B72). Of the 476 analyses compared (424 for U, 52 for P), 86 percent were in agreement. This is considerably greater accuracy than that claimed by the spectrographic laboratories. The chemical analyses showed that 246 samples contain U or P in quantities not spectrographically detectable, and that in 98 percent of this group, U and P were not spectrographically detected. Of the 230 samples that contain more than the minimum amount needed for spectrographic detection, 75 percent were correctly bracketed in the spectrographic analyses.

Of the 230 samples that contained more than the minimum amounts of U and P required for spectrographic detection, 194 were compared for agreement in U content and 49 for P content. Seventy-eight percent of the U analyses were accurately bracketed, and 59 percent of the P analyses were accurately bracketed.

TABLE 1.—*Sensitivities for the elements determined by the semiquantitative spectrographic method used for the analyses given in this report*

Element	Percent	Element	Percent	Element	Percent	Element	Percent
U.S. Geological Survey laboratory, Washington, D.C.							
Si	0.005	Cd	0.005	Ir	0.03	Sb	0.01
Al	.0001	Ce	.03	La	.003	Sc	.0005
Fe	.0008	Co	.001	Li	.01	Sn	.001
Mg	.00003	Cr	.0006	Lu	.005	Sr	.001
Ca	.01	Cs	.08	Mo	.0005	Sm	.008
Na	.01	Cu	.00005	Nb	.001	Ta	.1
K	.1	Dy	.006	Nd	.006	Tb	.01
Ti	.0005	Er	.003	Ni	.001	Te	.08
P	.07	Eu	.003	Os	.1	Th	.05
Mn	.0007	F	.08	Pb	.001	Tl	.04
Ag	.00001	Ga	.001	Pd	.003	Tm	.001
As	.01	Gd	.006	Pr	.01	U	.08
Au	.001	Ge	.001	Pt	.003	V	.001
B	.005	Hf	.007	Rb	7	W	.05
Ba	.0005	Hg	.08	Re	.04	Y	.001
Be	.00005	Ho	.001	Rh	.004	Yb	.0001
Bi	.005	In	.0004	Ru	.008	Zn	.008
						Zr	.0008
U.S. Geological Survey laboratory, Denver, Colo.							
Si	0.002	Cd	0.005	La	0.002	Sc	0.0005
Al	.001	Ce	.02	Li	.02	Sn	.001
Fe	.0008	Co	.0005	Lu	.01	Sr	.0002
Mg	.0005	Cr	.0001	Mo	.0005	Sm	.01
Ca	.005	Cs	2	Nb	.001	Ta	.02
Na	.05	Cu	.0001	Nd	.01	Tb	.1
K	.7	Dy	.005	Ni	.0003	Te	.1
Ti	.0002	Er	.005	Os	.01	Th	.02
P	.2	Eu	.05	Pb	.001	Tl	.01
Mn	.0002	Ga	.0002	Pd	.0003	Tm	.01
Ag	.0001	Gd	.005	Pr	.05	U	.05
As	.1	Ge	.001	Pt	.003	V	.001
Au	.002	Hf	.01	Rb	10	W	.01
B	.002	Hg	1	Re	.005	Y	.001
Ba	.0002	Ho	.01	Rh	.005	Yb	.0005
Be	.0001	In	.001	Ru	.01	Zn	.02
Bi	.001	Ir	.01	Sb	.01	Zr	.001

TABLE 2.—*Explanation of symbols used in presenting results of semiquantitative spectrographic analyses*

Symbols used in tables 15–21	Range (percent) [1]	Logarithmic midpoint reported as [1]
1	[2] More than 10	[2] M
2+	4.64 –10	7
2	2.15 – 4.64	3
2–	1 – 2.15	1.5
3+	.464 – 1	.7
3	.215 – .464	.3
3–	.1 – .215	.15
4+	.0464 – .1	.07
4	.0215 – .0464	.03
4–	.01 – .0215	.015
5+	.00464 – .01	.007
5	.00215 – .00464	.003
5–	.001 – .00215	.0015
6+	.000464 – .001	.0007
6	.000215 – .000464	.0003
6–	.0001 – .000215	.00015
7+	.0000464– .0001	.00007
7	.0000215– .0000464	.00003
7–	.00001 – .0000215	.000015

[1] In laboratory reports.
[2] M values are assumed to be in the 10–20 percent range whose logarithmic midpoint is about 15 percent.

The degree of agreement between chemical and spectrographic analyses probably differs with each of the other elements detected; but it should for the most part be as good or better than that for U because most of the other elements detected in samples from the Cave Hills area are as easy, or easier, to detect and measure than U. Although only 50–60 percent of the spectographic results are claimed by the laboratory to be accurately bracketed, the accuracy of the analyses of the samples discussed in this report is probably about 75 percent.

The calculation of the average concentration of any element in samples analyzed semiquantitatively poses certain problems because (1) there is a threshold value below which the element may be present but undetected, and (2) individual analyses are reported as the midpoint of a range of possible values. Averages calculated from semiquantitative analyses in this report were obtained by multiplying the number of samples in each range by the midpoint value of the range and then by dividing the sum of the products by the total number of samples. In samples in which the element was undetected the concentration was assumed to be one-half the minimum amount normally detectable. This method was tested for U and P by use of groups of samples for which both chemical and semiquantitative spectrographic analyses were available. Good correspondence (of the same order of magnitude) was found in the average values calculated for the two sets of analyses if the element looked for was detected in the spectrographic analyses of more than one-third the samples in the suite.

ORIGIN OF ELEMENTS

The three types of host rocks studied are coal, carbonaceous clayey siltstone (Carbonate ore zone), and phosphatic silty claystone (Lonesome Pete ore zone).

The frequency distribution and average concentration of uranium determined from chemical analyses of samples and sample ash from the stratigraphic units studied are shown in figures 1 and 2, in which units are arranged in descending stratigraphic order. The stratigraphic position and lithology of these units are summarized in the next table and are described more fully in chapter A of this professional paper.

In figures 1 and 2, the Carbonate coal zone is represented by samples from both the Carbonate No. 1 and the Carbonate No. 2 coal beds, whereas the Carbonate ore zone is represented exclusively by samples of carbonaceous siltstone equivalent to the Carbonate No. 1 coal bed and collected from two prospect pits at the Carbonate prospect. (See chap. A, pl. 3 and fig. 16.)

Results of semiquantitative spectrographic analyses of those samples from which figure 2 was compiled are listed in tables 15–19 in the same order and by the same sample or map locality numbers used in tables 6–10, chapter A.

Of the 69 elements detectable by the semiquantitative spectrographic methods of the U.S. Geological Survey laboratories (table 1), Si, Al, Fe, Ca, Na, Mg, Ti, Ba, Zr, Mn, and Cu were detected in all samples; 30 other elements were detected in one or more samples (table 3). The rest of the elements were not detected in any of the samples.

Stratigraphic zone	Average—		Remarks
	Thickness (feet)	Interval to next higher zone (feet)	
Youngest:			
Coal bed F	1.7		Locally splits into 3 coal beds that constitute coal zone F.
Coal bed E	.9	30	
Carbonate coal zone:			
No. 2 coal bed	1	110	
No. 1 coal bed	1.3	14	The Carbonate ore zone is the carbonaceous siltstone equivalent of the Carbonate No. 1 coal bed.
Coal zone C:			
No. 2 coal bed	2	11	
No. 1 coal bed	4	20	
Coal zone B	3.5	20	Zone includes a lower unnamed coal bed not considered here.
Lonesome Pete ore zone.	.4	25	Phosphatic silty claystone.
Lonesome Pete coal zone.	21	1	Consists of 3 coal beds that locally merge to form the Lonesome Pete coal bed.
Oldest:			
Lower coal beds	3	12	Includes all coal beds in the lower 300 ft of the Fort Union Formation.

TABLE 3.—*Elements detected in one or more samples, but not all samples, from the Cave Hills*

[Semiquantitative spectrographic analyses of 424 samples]

Element	Detected in		Element	Detected in	
	Number of samples	Percent of samples		Number of samples	Percent of samples
Cr	423	>99	Ag	216	51
V	420	99	U[1]	196	46
Ga	419	99	As	179	42
Sr	418	99	Ge	134	32
Ni	416	98	Sn	89	21
B	415	98	P	65	15
Sc	411	97	Nd	50	12
Pb	409	96	Ce	[2] 17	4
Y	409	96	Nb	9	2
Yb	407	96	Li	6	1
Be	399	94	Zn	4	<1
Co	384	91	Cd	2	<1
K	371	87	Dy	1	<1
Mo	369	87	Sm	1	<1
La	263	62	Bi	1	<1

[1] Semiquantitative spectrographic analyses of uranium used only for comparisons with chemical analyses as discussed in section on reliability of analytical data.
[2] Elements detected in fewer than 50 samples were not studied further. Er, Eu, and Gd were detected in one of the specially processed samples shown in table 13.

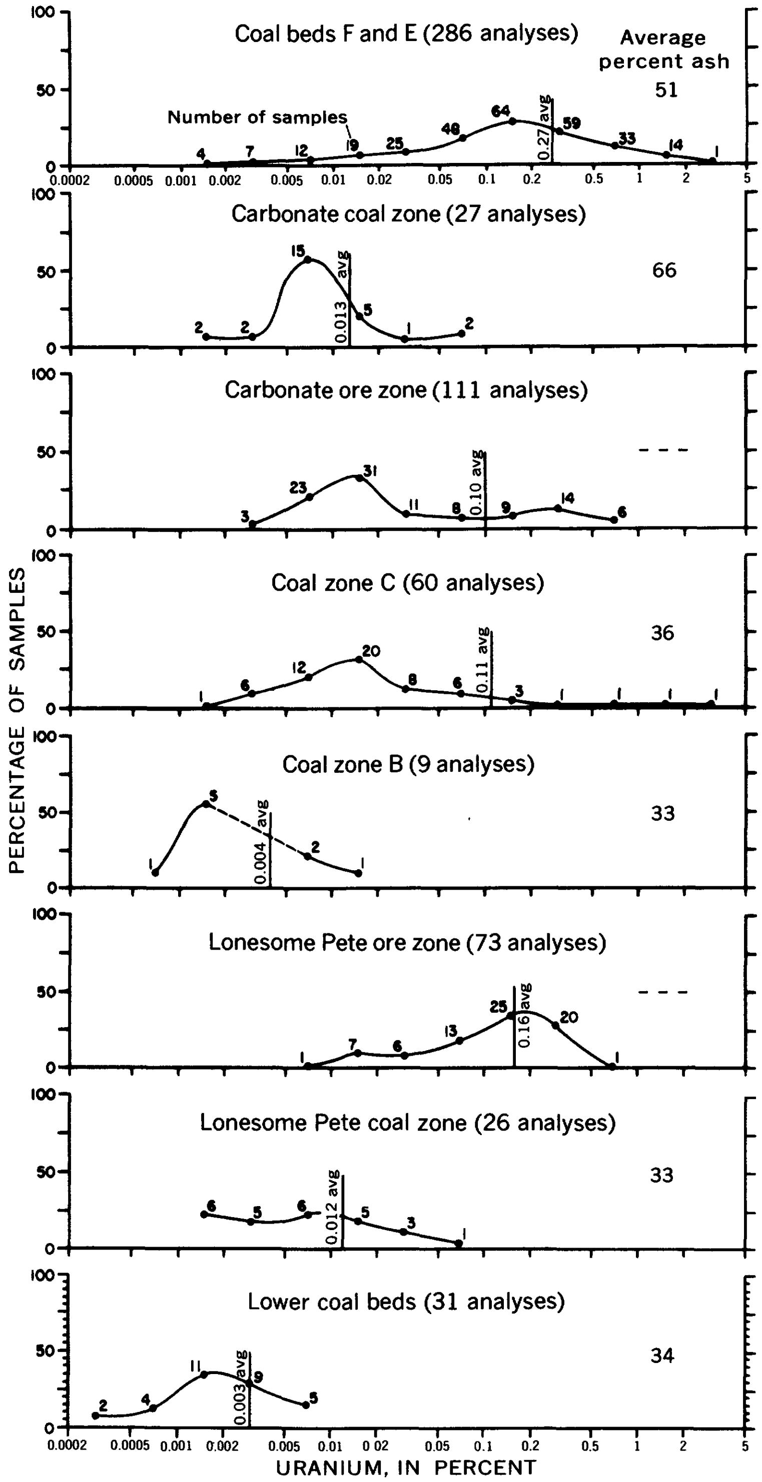


FIGURE 1.—Uranium in samples from stratigraphic units of the Fort Union Formation. Points are averages from ungrouped chemical data.

The possibility that unusual silica-, aluminum-, and iron-accumulator plants might have been among those whose remains are found in rocks from the Cave Hills area was investigated and the results were negative. According to Estella Leopold (written commun. 1959) and J. M. Schopf (written commun. 1959), pollen, spore, and petrographic studies of coal and phosphatic claystone samples from coal beds E and C the Lonesome Pete coal bed and the Lonesome Pete ore zone suggest that the plant material in these rocks was derived primarily from Taxodiaceae (sequoia family) and to a smaller extent from members of the birch, elm, heath, and boxwood families. Also present is a variety of lower forms of plant life such as polypod ferns. Members of the Taxodiaceae are not among the accumulators mentioned by Lovering (1959), nor is any special chemical significance to be attached to any of the other plants identified in these samples. The major-element composition of the coaly and carbonaceous rocks of the Cave Hills area probably was not influenced by accumulator plants such as those described by Lovering (1959).

The averages and frequency distributions of 32 elements compiled from the semiquantitative spectographic analyses listed in tables 15–19 are shown in figures 3–18.

When the geologic possibilities that would explain differing concentrations of elements are considered, the following generalizations seem reasonable and are assumed to apply:

1. Elements concentrated by plants and (or) Eocene (non-uranium-bearing) ground water are those that have a broader range, a higher average concentration or higher maxima in coal relative to the noncoal units, or are more highly concentrated in the organic fraction than in the inorganic fraction of coal, and whose concentrations are independent of, or inversely related to, uranium.
2. Elements deposited with the original inorganic sediment or by Eocene ground water are those that show no relation to either coal or uranium.
3. Elements introduced or leached subsequent to lithification are those whose abundance increases or decreases with increase of uranium. Elements introduced with uranium are assumed to have had the same source and to have been introduced along with the uranium into the host rocks by post-Eocene (uranium-bearing) ground water; elements whose abundance decreases with decrease of uranium are assumed likewise to have been leached at the same time that the uranium was being leached; and, finally elements whose abundance decreases as that of uranium increases are assumed to have been leached at the same time that uranium was being deposited.

In the remaining part of this report, information from the semiquantitative and chemical analyses is organized in various ways so that questions about the geochemical history of elements detected in the analyses may be resolved. Three principal methods of investigation are followed. All three examine the concentration of elements in coal and in noncoaly rocks and the relations of elements to uranium. In addition, the first method of investigation examines the relations

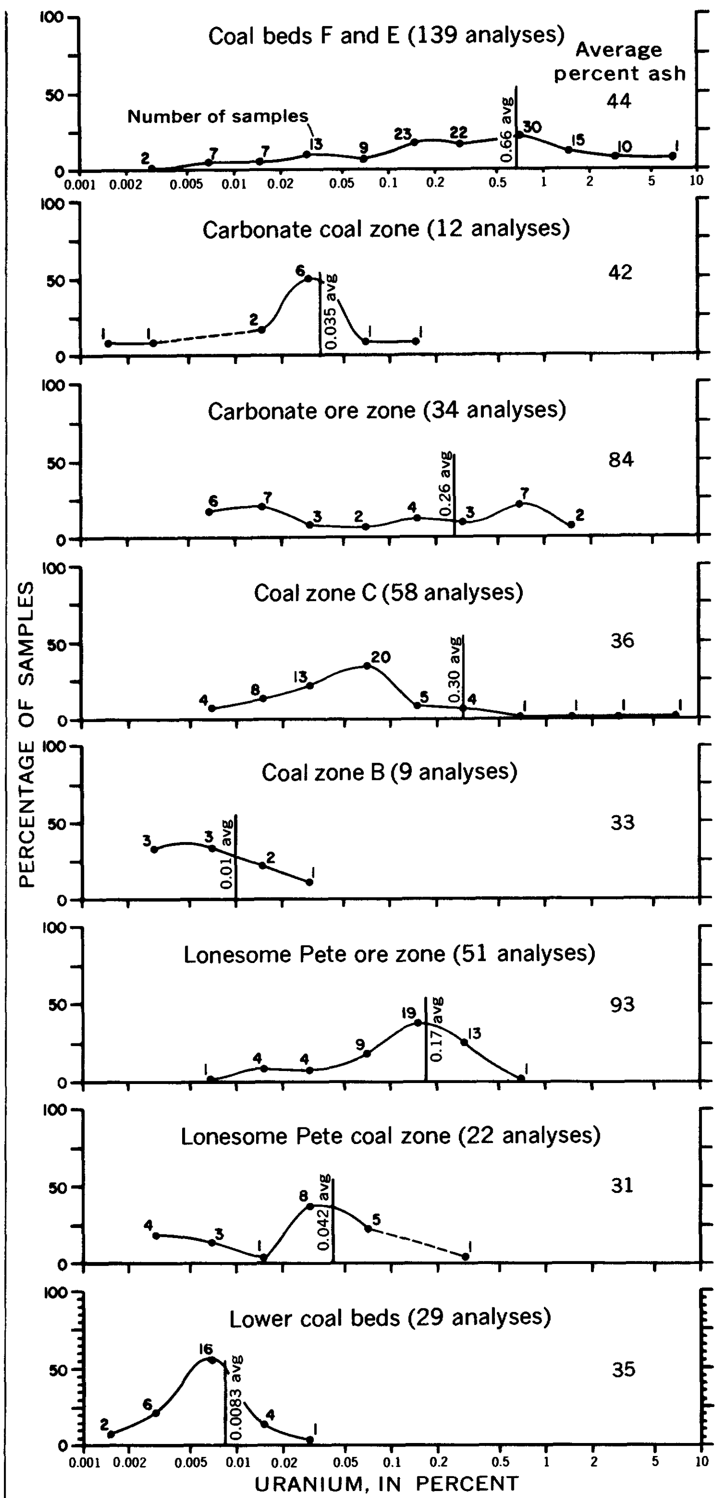


FIGURE 2.—Uranium in ashed samples from stratigraphic units of the Fort Union Formation. Points are averages from ungrouped chemical data.

of elements to equivalent uranium, and the second method of investigation examines the average abundance of elements in samples low in uranium content from the Cave Hills area relative to the average abun-

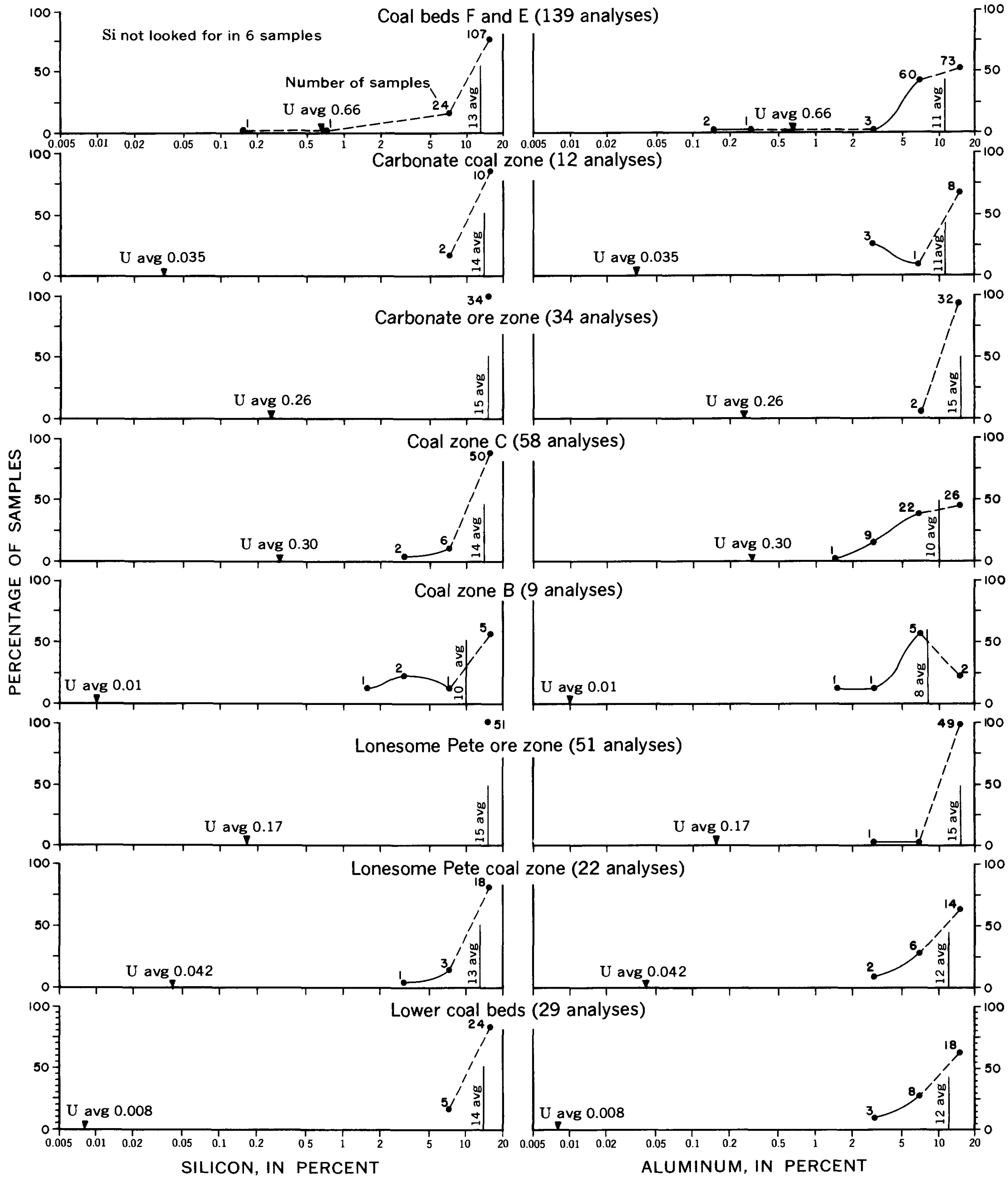


FIGURE 3.—Silicon (Si) and aluminum (Al) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses.

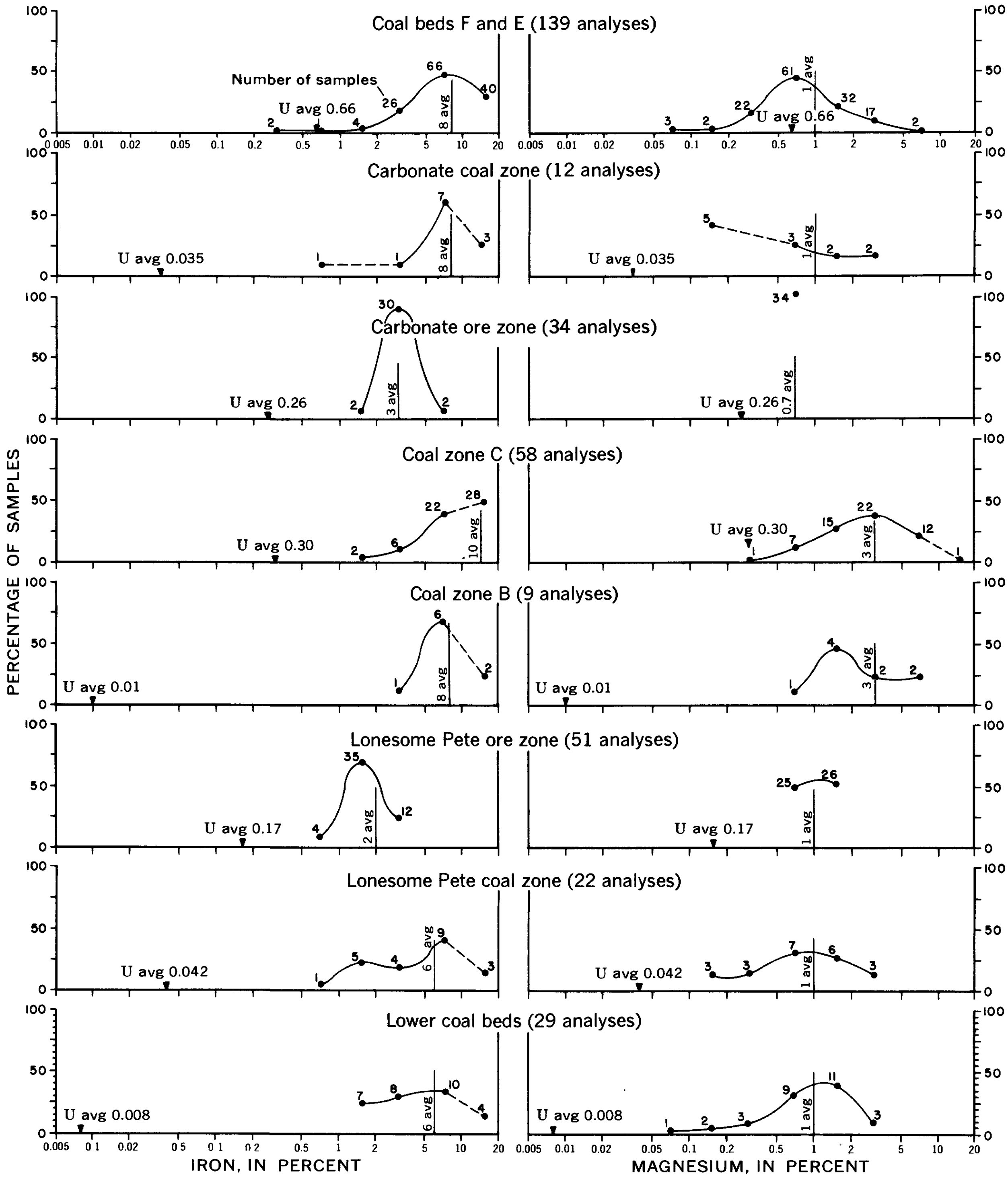


FIGURE 4.—Iron (Fe) and magnesium (Mg) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses.

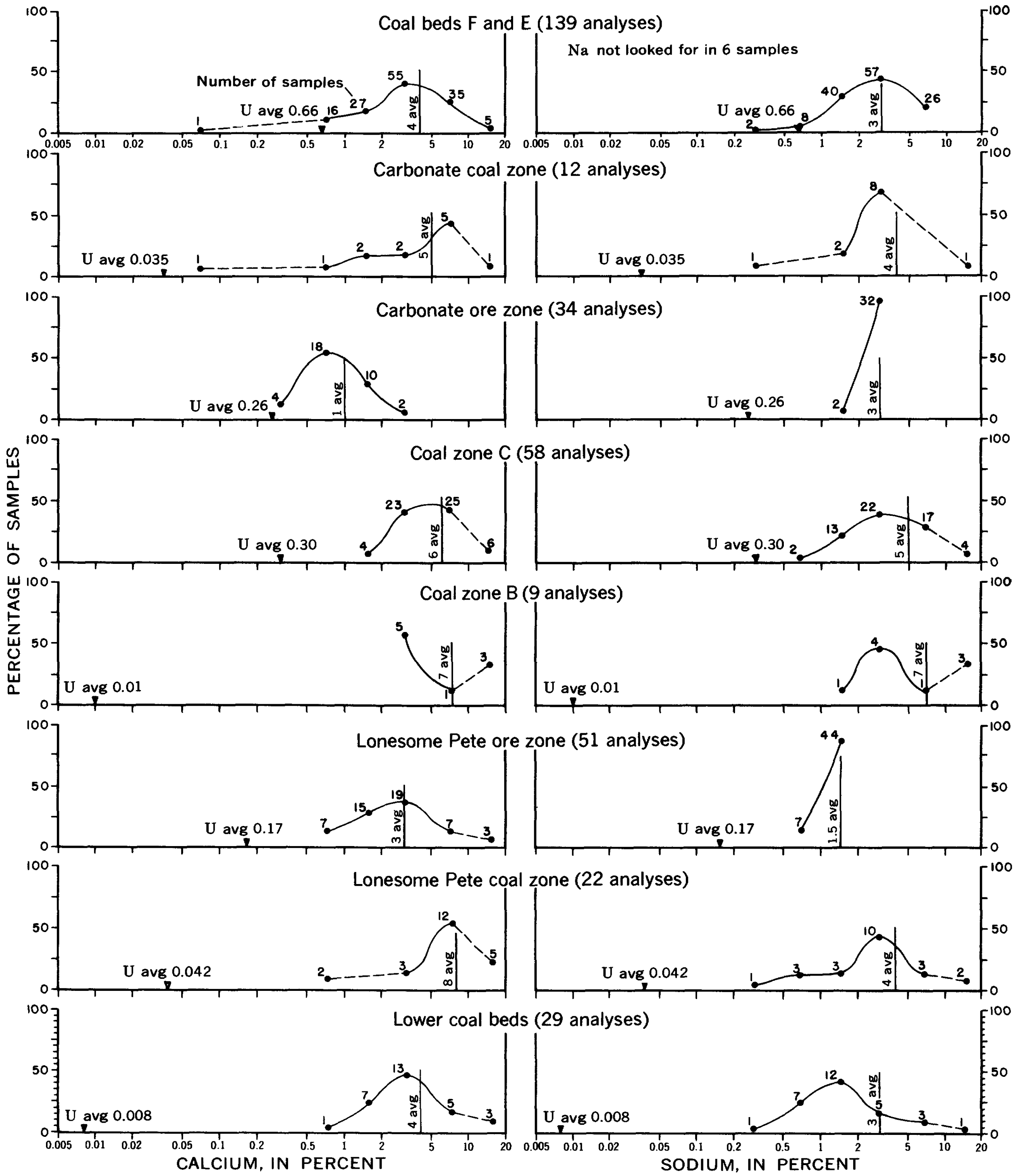


FIGURE 5.—Calcium (Ca) and sodium (Na) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses.

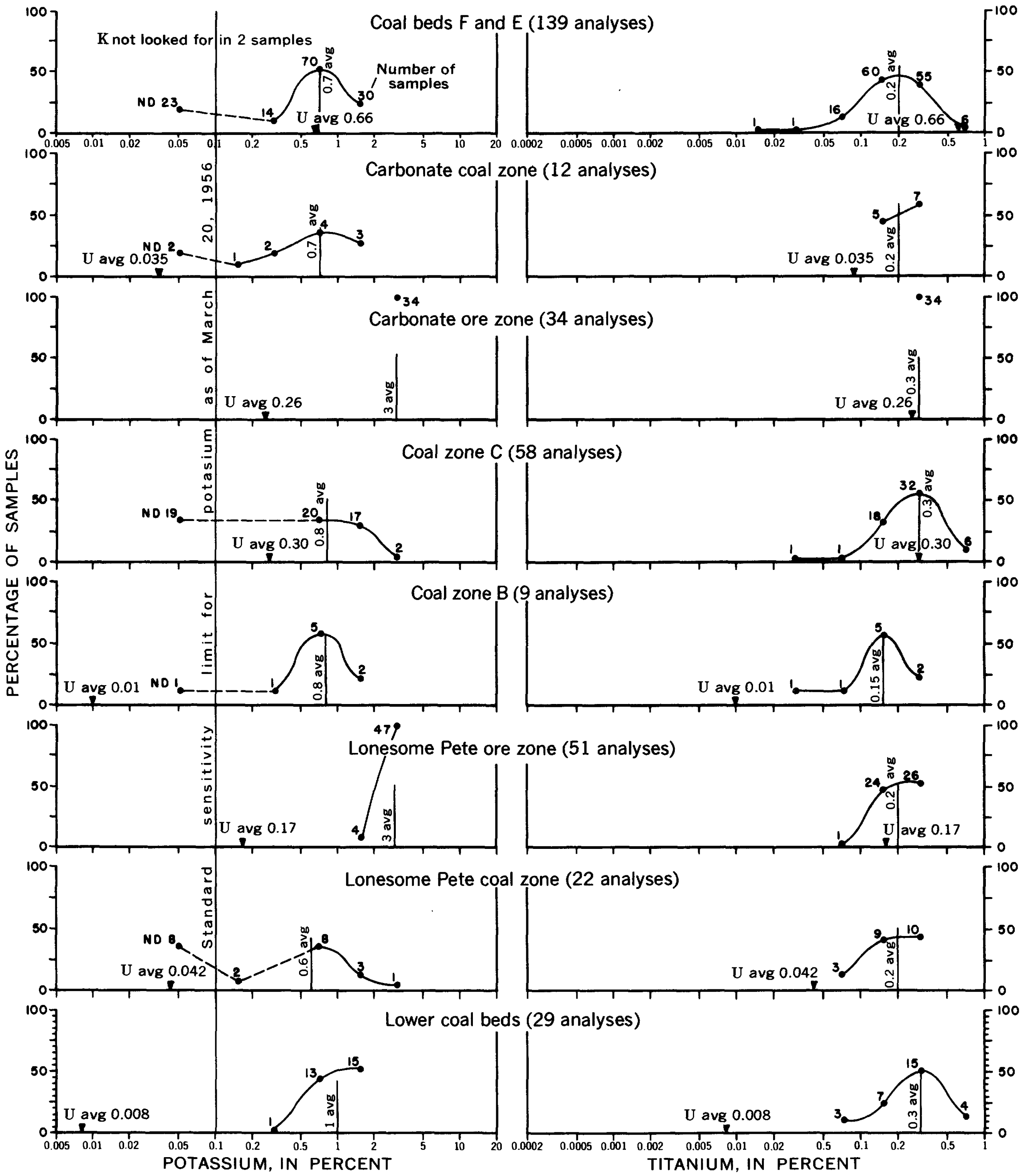


FIGURE 6.—Potassium (K) and titanium (Ti) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 23 means not detected in 23 samples.

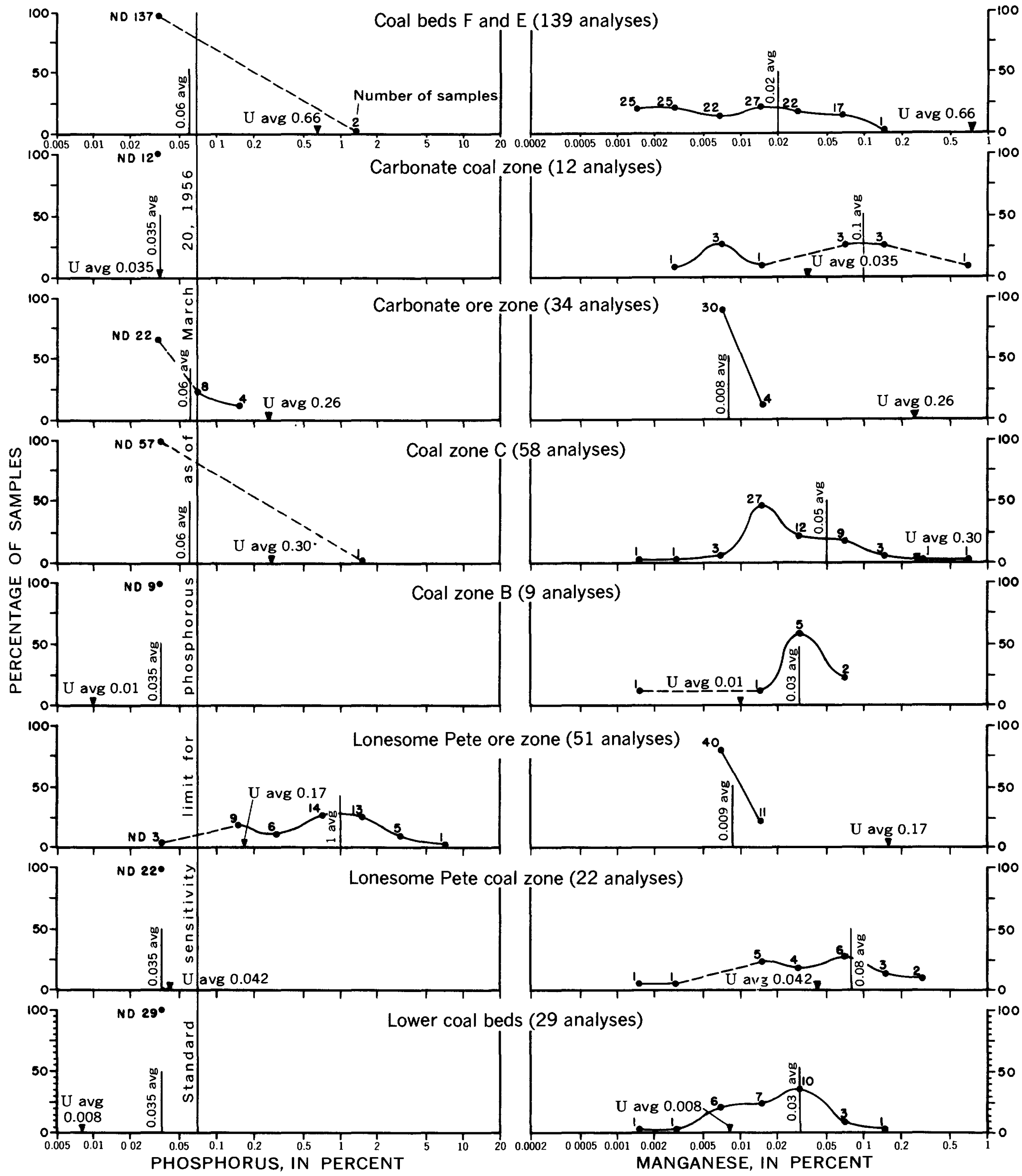


FIGURE 7.—Phosphorus (P) and manganese (Mn) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 137 means not detected in 137 samples.

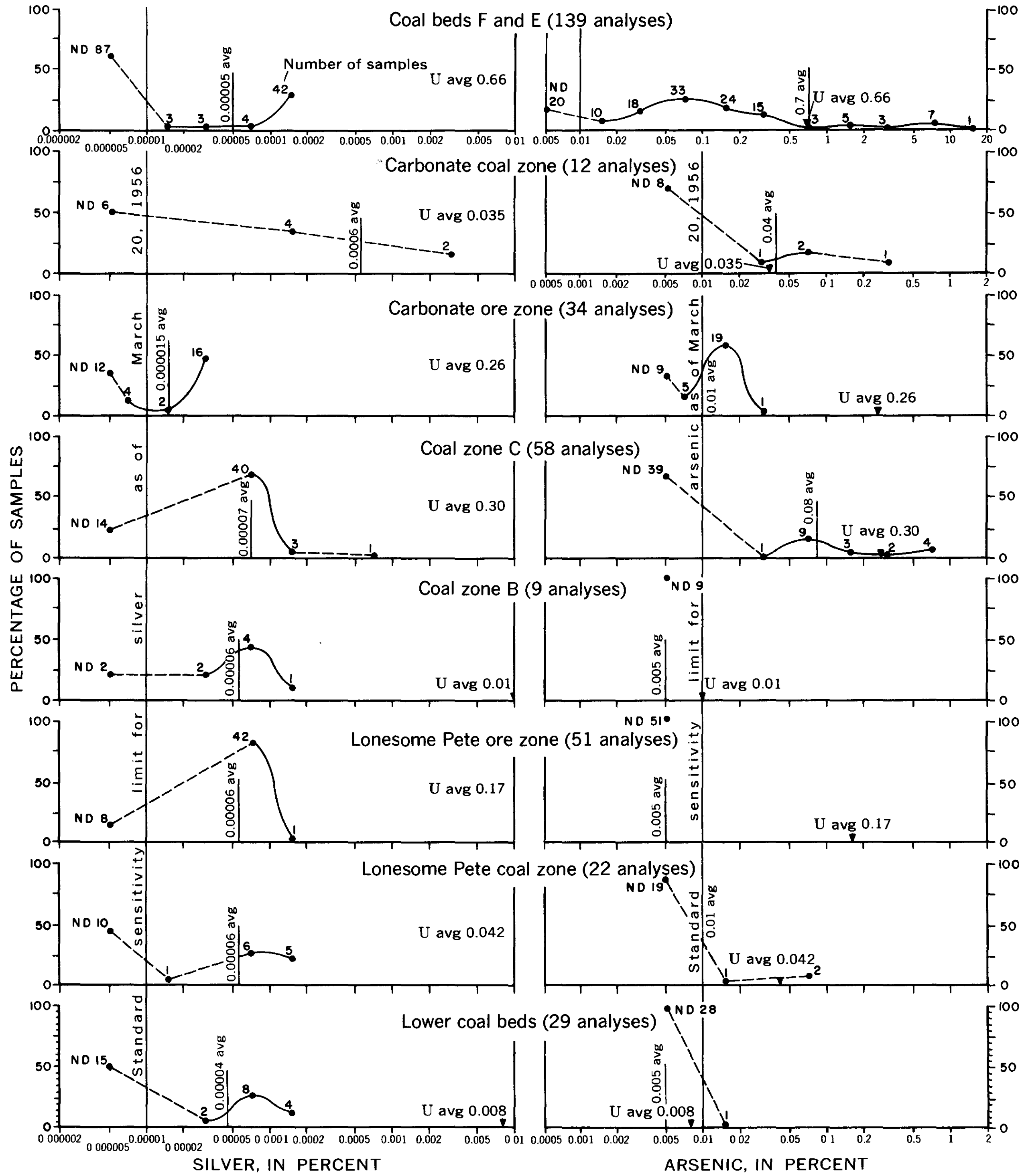


FIGURE 8.—Silver (Ag) and arsenic (As) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 87 means not detected in 87 samples.

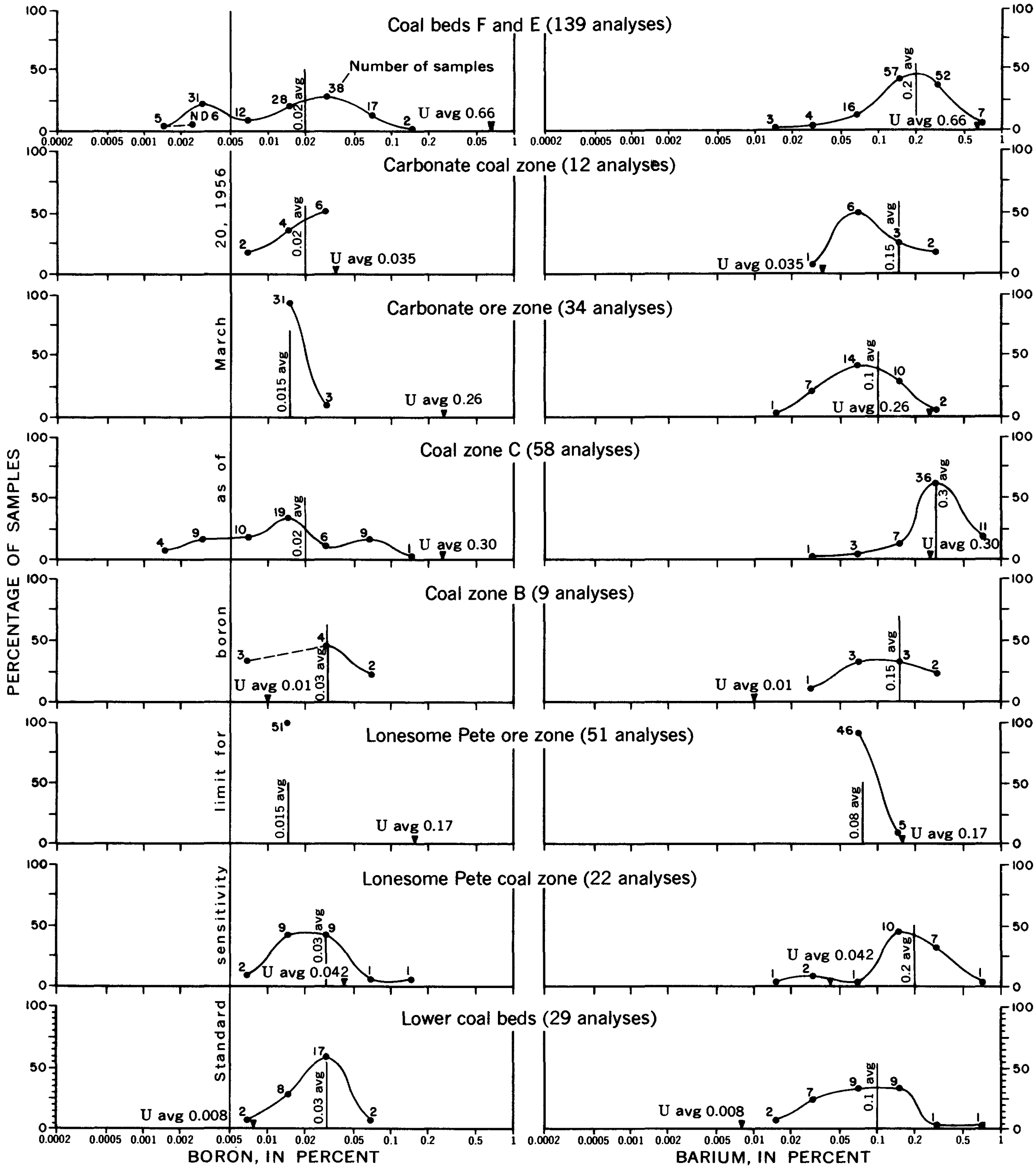


Figure 9.—Boron (B) and barium (Ba) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 6 means not detected in six samples.

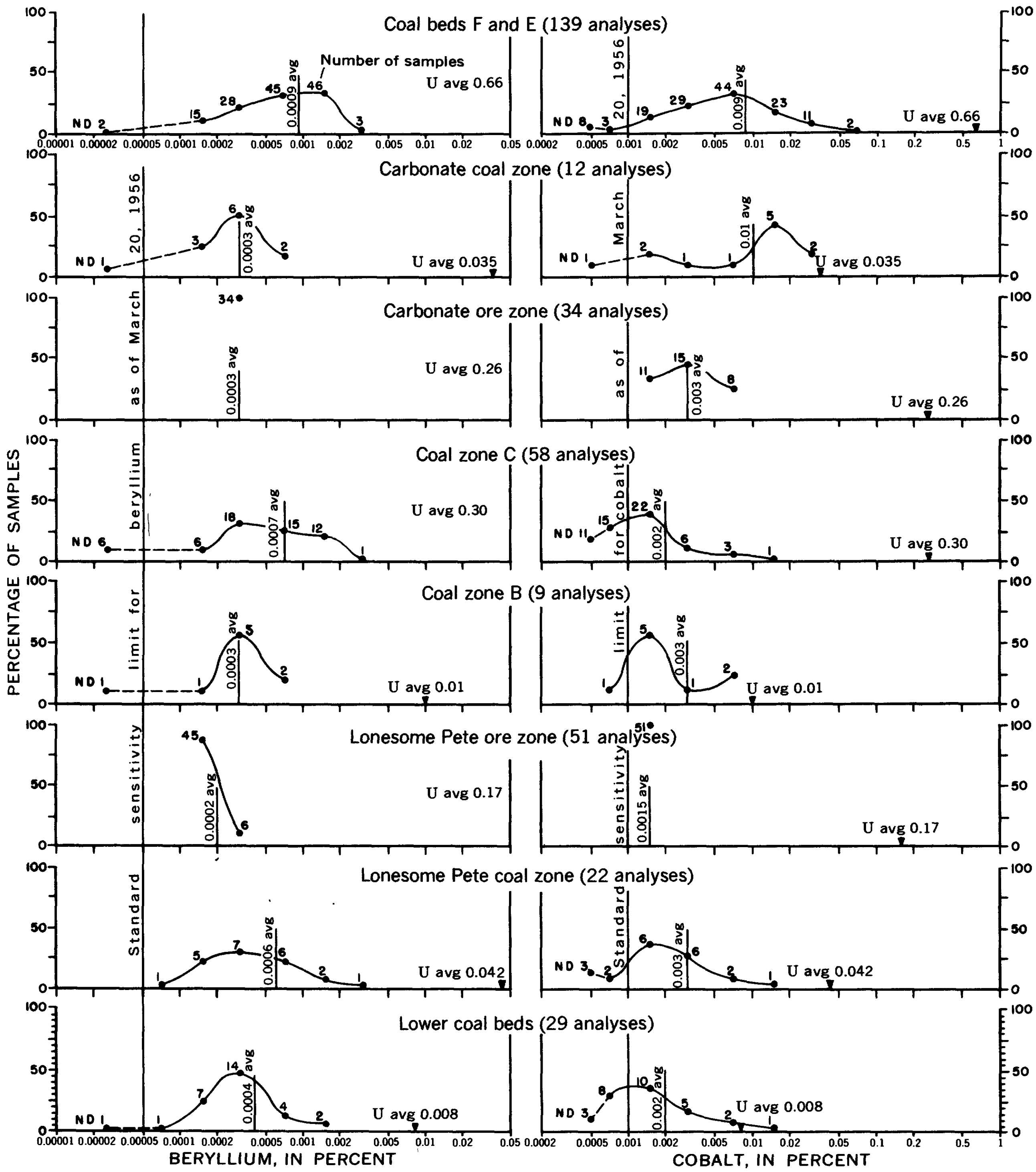


Figure 10.—Beryllium (Be) and cobalt (Co) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 2 means not detected in two samples.

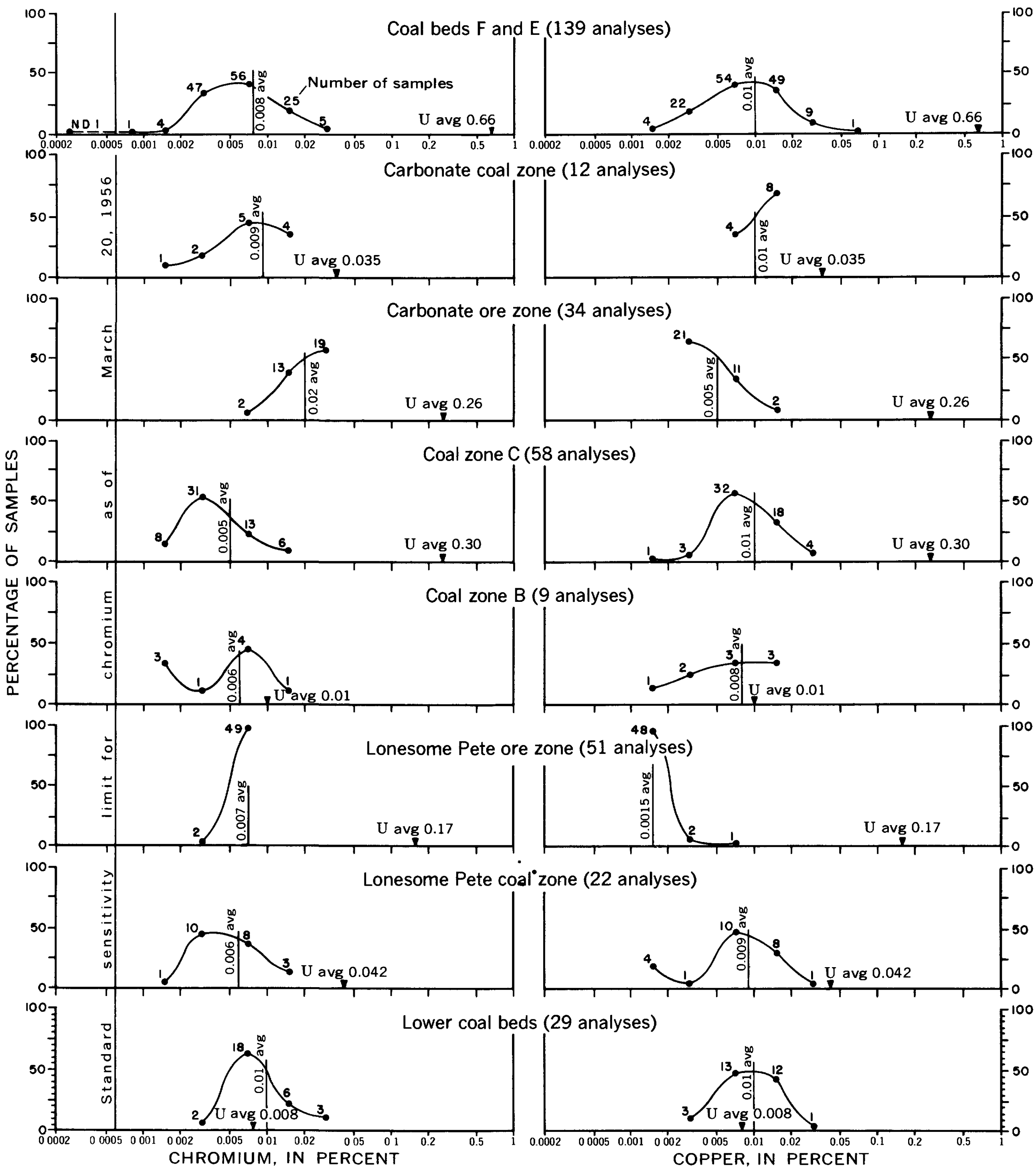


FIGURE 11.—Chromium (Cr) and copper (Cu) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 1 means not detected in one sample.

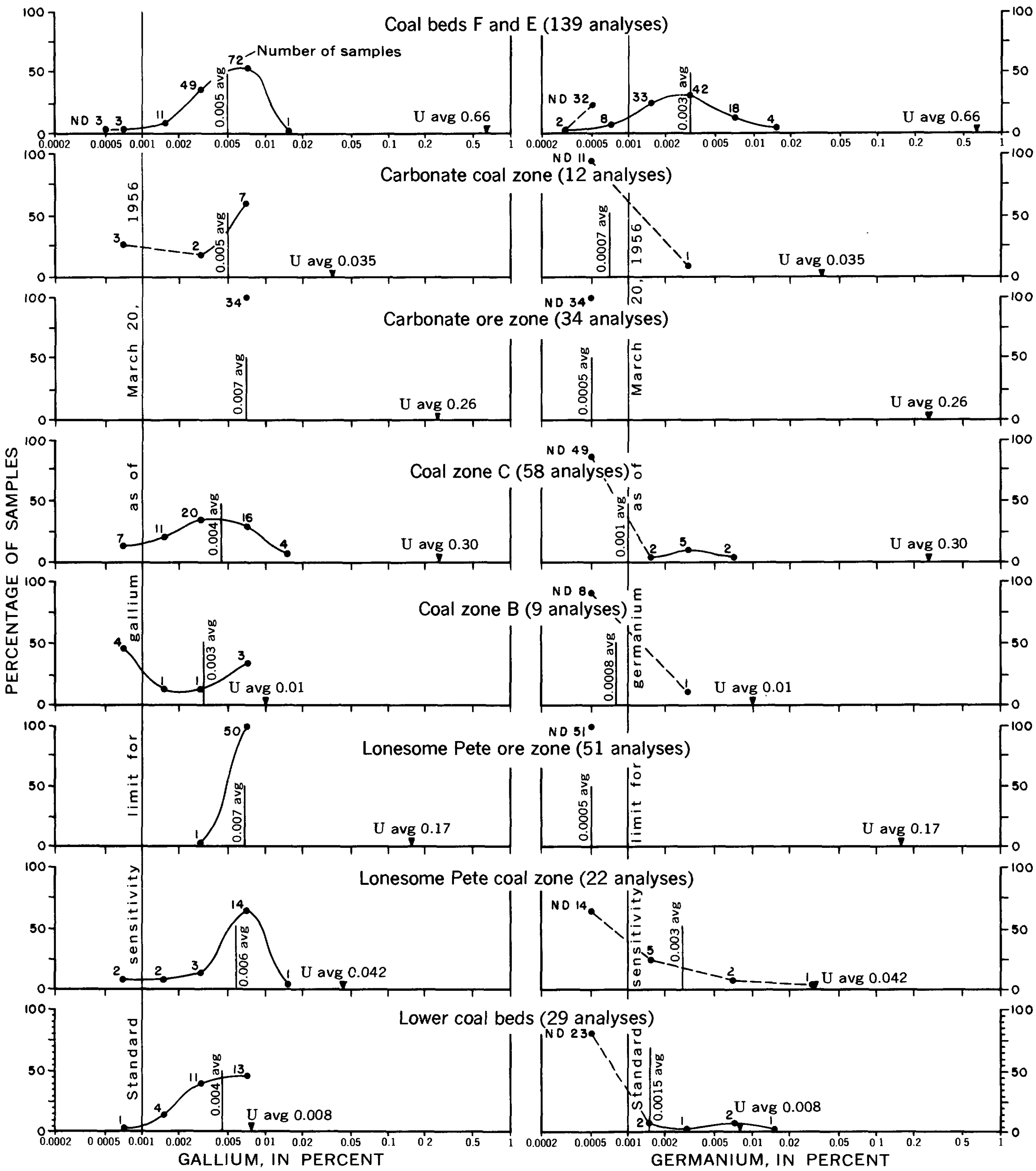


FIGURE 12.—Gallium (Ga) and germanium (Ge) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 3 means not detected in three samples.

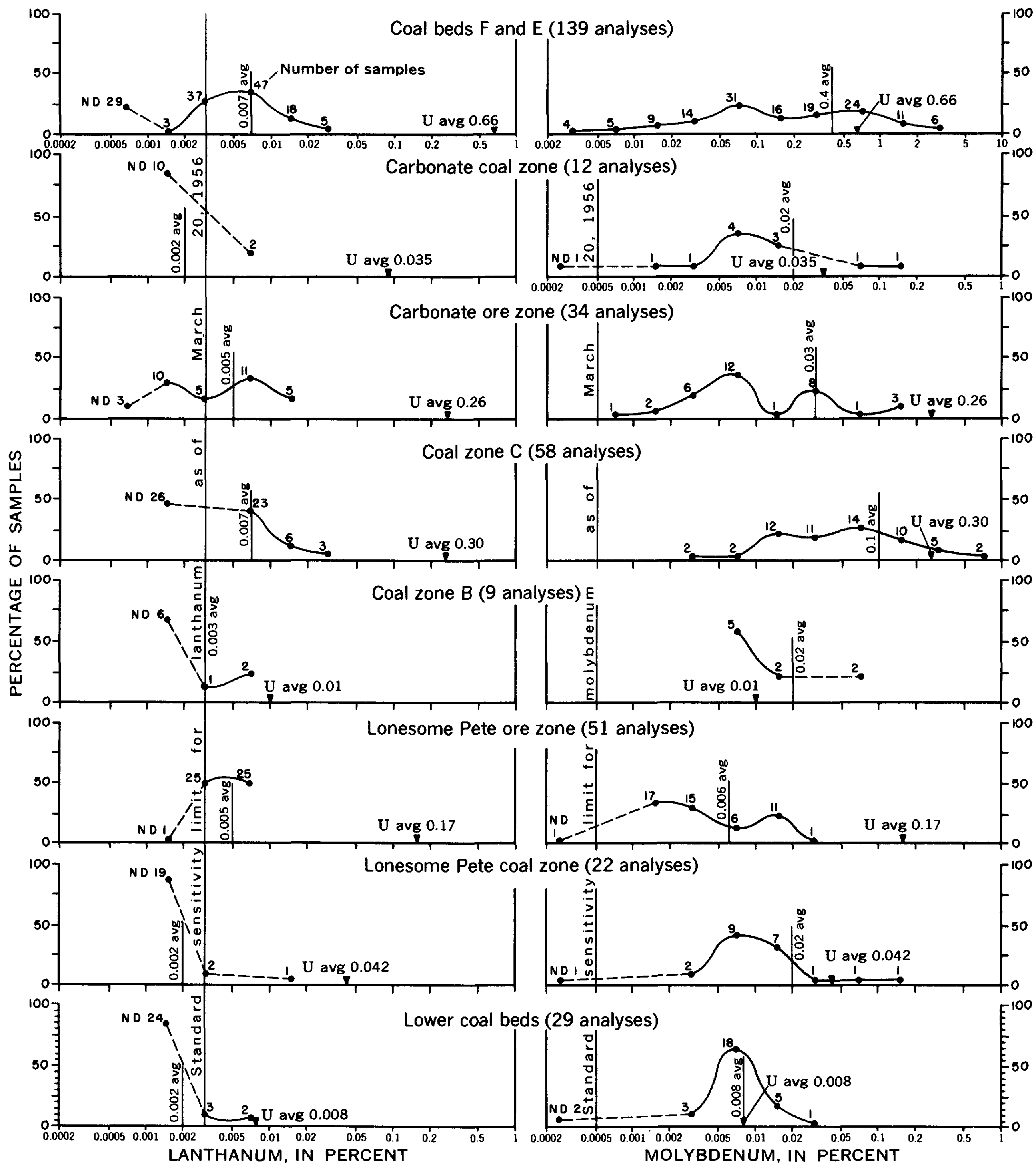


FIGURE 13.—Lanthanum (La) and molybdenum (Mo) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 29 means not detected in 29 samples.

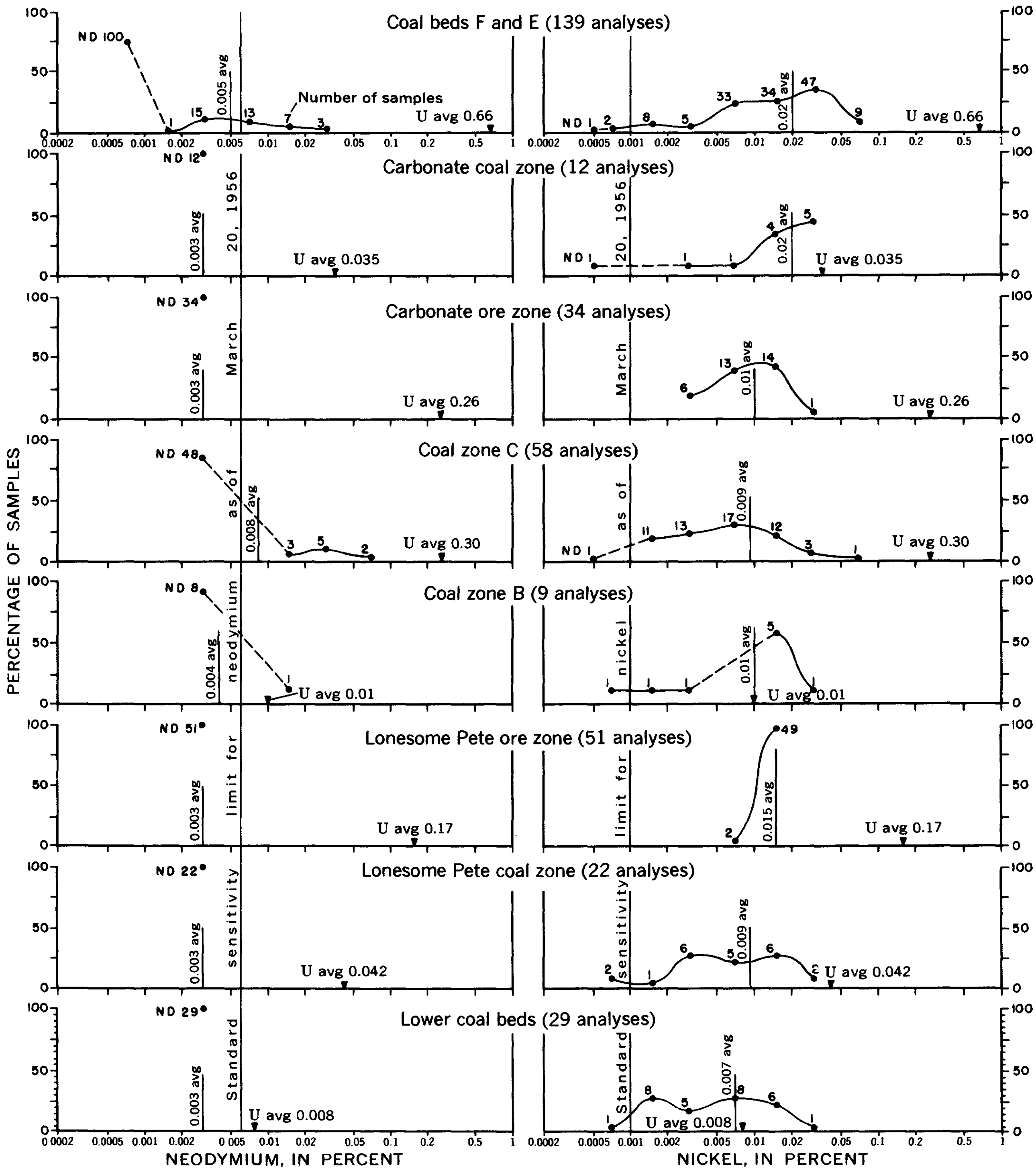


FIGURE 14.—Neodymium (Nd) and nickel (Ni) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 100 means not detected in 100 samples.

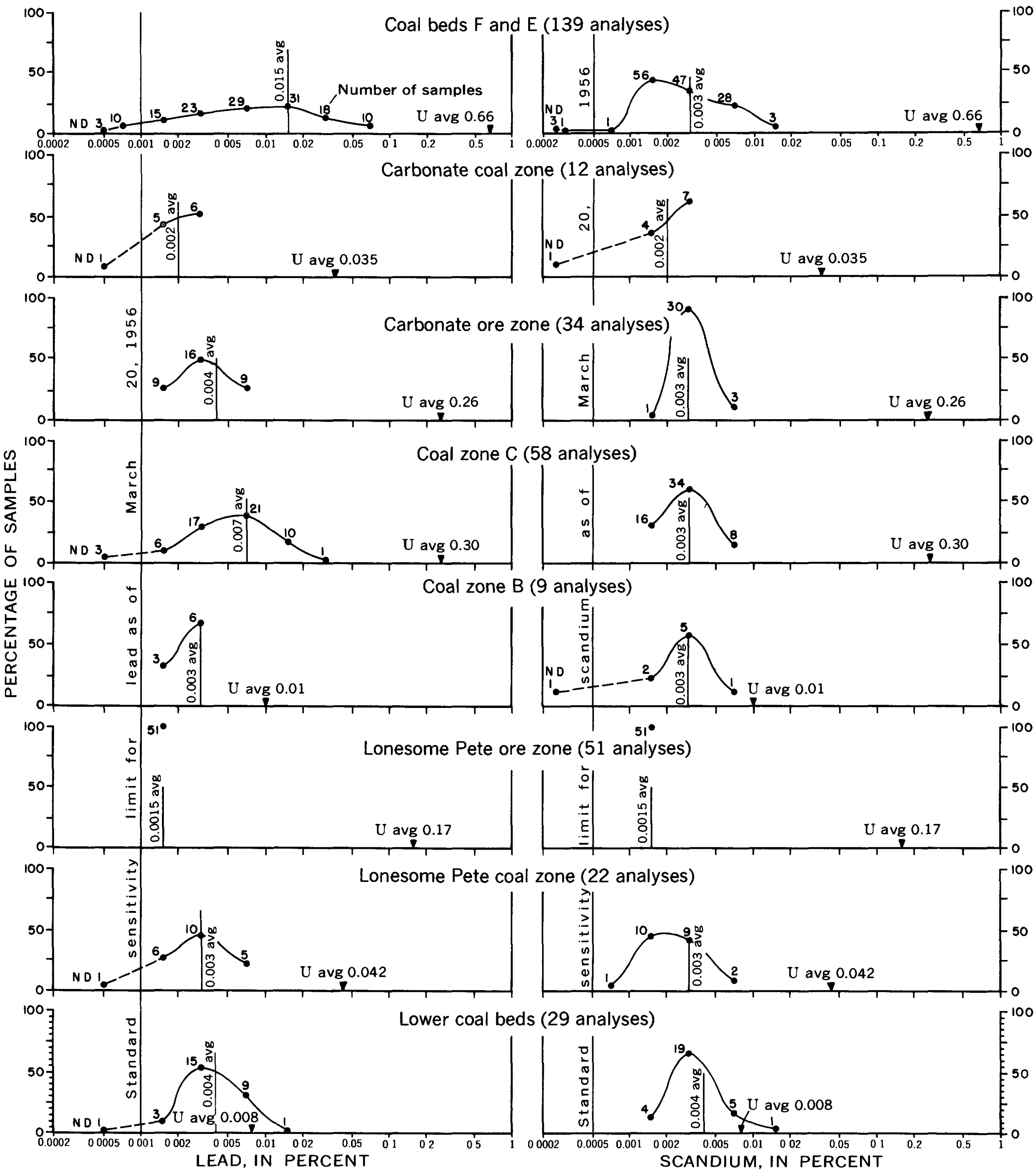


FIGURE 15.—Lead (Pb) and scandium (Sc) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 3 means not detected in three samples.

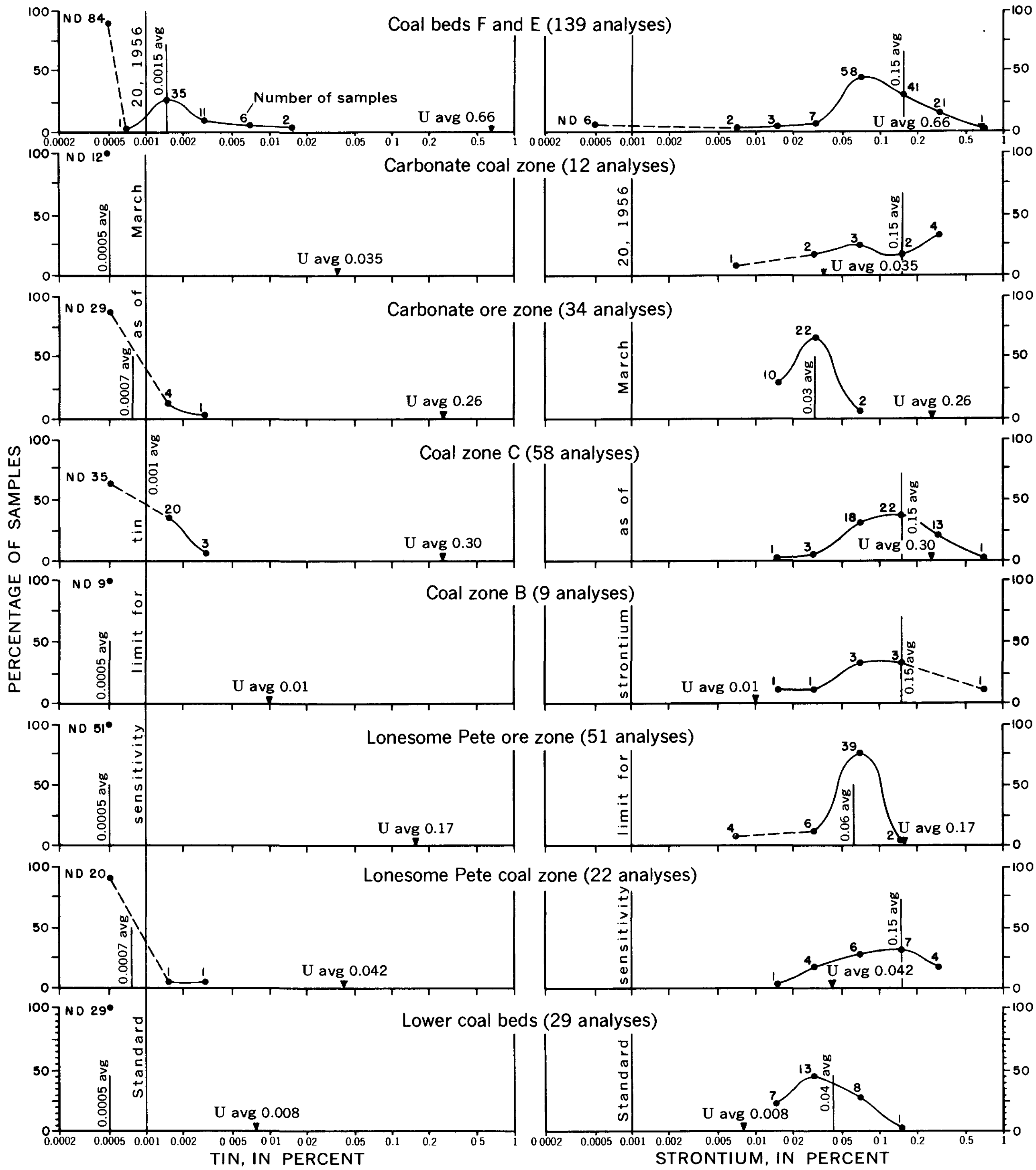


FIGURE 16.—Tin (Sn) and strontium (Sr) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 84 means not detected in 84 samples.

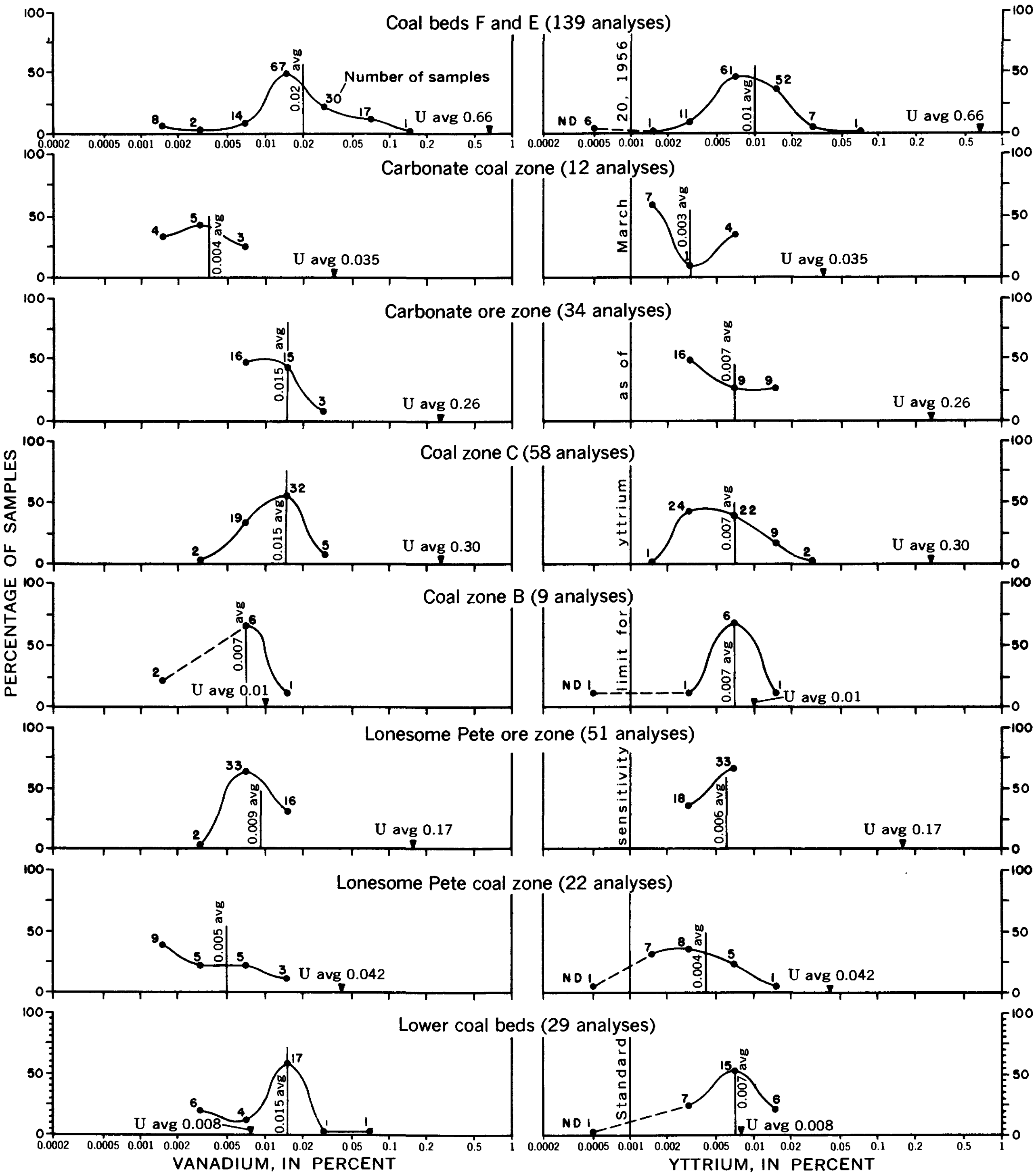


FIGURE 17.—Vanadium (V) and yttrium (Y) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 6 means not detected in six samples.

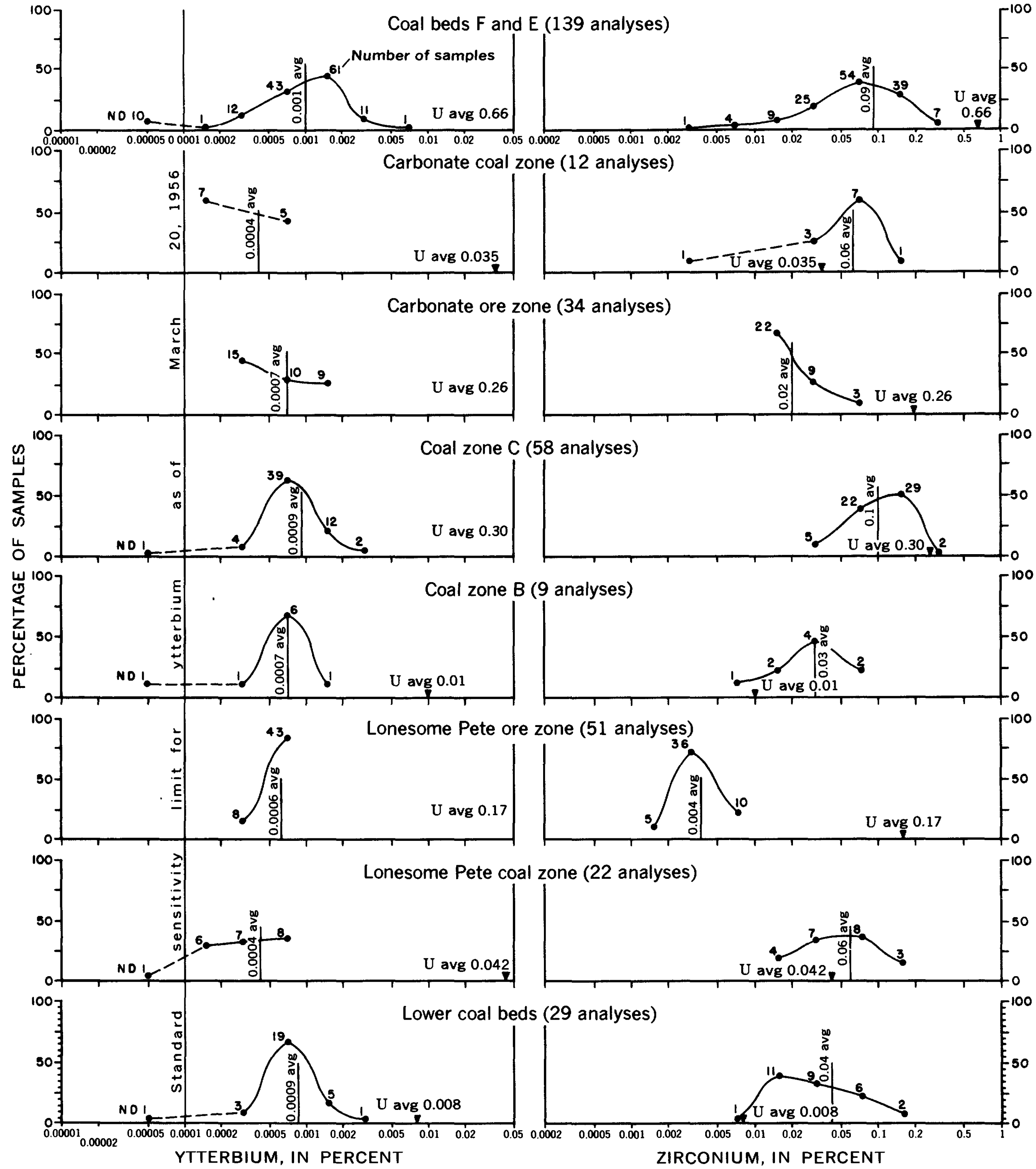


FIGURE 18.—Ytterbium (Yb) and zirconium (Zr) in stratigraphic units of the Fort Union Formation. Uranium averages are based on chemical analyses (fig. 2). All other averages are based on semiquantitative spectrographic analyses. ND 10 means not detected in 10 samples.

dance of elements in the earth's crust and in the average coal.

A geochemical history for each element that explains the differences in concentrations brought out by these comparisons is proposed.

FIRST METHOD OF INVESTIGATION

Certain relations are apparent if the ranges, average concentrations, and maximum concentrations of elements are compared for the eight stratigraphic units chosen for study. These comparisons are made in table 4 in which the stratigraphic units are assigned numbers 1 through 8, in descending stratigraphic order. The data in table 4 are reorganized and summarized in table 5, so that the numbers representing the stratigraphic units are arranged in order of decreasing abundance of elements in each of three categories of data. It should be noted (table 4) that units 3 and 6 are noncoaly rocks, whereas the others are coal beds.

RELATIONS OF ELEMENTS TO LITHOLOGY

The elements may be sorted into three groups on the basis of the sequences of the units listed in table 5:

1. *Elements more concentrated in coal* (noncoaly units 3 and 6 generally occur near the end of the sequence):
   Fe, Mg, Ca, Na, Mn, B, Ba, Be, Co, Cu, Ge, Sr, and Zr.
2. *Elements more concentrated in noncoaly rocks* (noncoaly units 3 and 6 generally occur near the beginning of the sequence):
   K, P, and Ga.
3. *Elements whose concentrations in coal and in noncoaly rocks seem about the same:*
   Si, Al, Ti, Ag, As, Cr, La, Mo, Nd, Ni, Pb, Sc, Sn, V, Y, and Yb.

The inferred modes of origin of the elements in these groups are as follows:

1. Unusual concentrations of elements in coal are attributed to the principal difference between coal and noncoaly rocks—the contained plant material—and (or) to the action of circulating ground water. Their concentration in the inorganic constitutents of the coal probably was lean relative to other elements present in the inorganic part of the coal.

TABLE 4.—*Range, average, and maximum concentrations, in percent, of 33*

[Query (?), element was detected in less than one-third of the samples; figure in parentheses (.035), not detected; average is assumed to be one-half the minimum

Element	1 Coal beds F and E (139 samples)			2 Carbonate coal zone (12 samples)			3 Carbonate ore zone (carbonaceous clayey siltstone, 34 samples)			4 Coal zone C (58 samples)		
	Range	Average	Maximum	Range	Average	Maximum	Range	Average	Maximum	Range	Average	Maximum
U	5.4	0.66	5.4	0.15	0.035	0.15	1.4	0.26	1.4	6.4	0.3	6.4
Si	19.9	13	20	15	14	20	10.0	15	20	18.0	14	20
Al	19.9	11	20	18	11	20	15.0	15	20	19.0	10	20
Fe	19.8	8	20	19.5	8	20	9.0	3	10	19.0	10	20
Mg	9.95	1	10	4.9	1	5	.5	.7	1	19.8	3	20
Ca	19.95	4	20	19.95	5	20	4.8	1	5	19.0	6	20
Na	9.8	3	10	19.8	4	20	4.0	3	5	19.5	5	20
K	2	.7	2	2	.7	2	3.0	3	5	5.0	.8	5
Ti	0.99	.2	1	.4	.2	.5	.3	.3	.5	.98	.3	1
P	2	.06?	2	.07	(.035)	.07	.2	.06	.2	2.0	.06?	2
Mn	.199	.02	.2	.998	.1	1.0	.015	.008	.02	.999	.05	1
Ag	0002	.00005	.0002	.005	.0006	.005	.00005	.000015	.00005	.001	.00007	.001
As	20	.7	20	.5	.04	.5	.05	.01	.05	1.0	.08	1
B	.2	.02	.2	.045	.02	.05	.04	.015	.05	.199	.02	.2
Ba	.99	.2	1	.48	.15	.5	.49	.1	.5	.98	.3	1
Be	.005	.0009	.005	.001	.0003	.001	.0003	.0003	.0005	.005	.0007	.005
Co	.1	.009	.1	.05	.01	.05	.009	.003	.01	.02	.002	.02
Cr	.05	.008	.05	.019	.009	.02	.045	.02	.05	.019	.005	.02
Cu	.099	.01	.1	.015	.01	.02	.018	.005	.02	.049	.01	.05
Ga	.02	.005	.02	.0095	.005	.01	.005	.007	.01	.019	.004	.02
Ge	.02	.003	.02	.005	.0007?	.005	.001	(.0005)	.001	.01	.001?	.01
La	.05	.007	.05	.01	.002?	.01	.02	.005	.02	.05	.007	.05
Mo	4.998	.4	5	.2	.02	.2	.2	.03	.2	.998	.1	.1
Nd	.05	.005?	.05	.006	(.003)	.006	.006	(.003)	.006	.1	.008?	.1
Ni	.1	.02	.1	.05	.02	.05	.048	.01	.05	.1	.009	.1
Pb	.1	.015	.1	.005	.002	.005	.009	.004	.01	.05	.007	.05
Sc	.02	.003	.02	.005	.002	.005	.009	.003	.01	.009	.003	.01
Sn	.02	.0015	.02	.001	(.0005)	.001	.005	.0007?	.005	.005	.001	.005
Sr	1	.15	1	.495	.15	.5	.09	.03	.1	.99	.15	1
V	.199	.02	.2	.009	.004	.01	.045	.015	.05	.048	.015	.05
Y	.1	.01	.1	.009	.003	.01	.018	.007	.02	.049	.007	.05
Yb	.01	.001	.01	.0009	.0004	.001	.0018	.0007	.002	.005	.0009	.005
Zr	.498	.09	.5	.198	.06	.2	.09	.02	.1	.48	.1	.5

2. Unusual concentrations of elements in noncoaly rocks cannot be attributed to plant action; they must be attributed to inorganic sedimentation and (or) to ground-water action. Concentrations of these elements are rich relative to other elements in noncoaly rocks.
3. Elements in the third group were not selectively concentrated by plant action or by inorganic sedimentation. The contents of these elements probably are normal concentrations in inorganic sedimentary constituents and (or) were deposited by ground water.

Uranium was concentrated by ground water principally during erosion of Miocene rocks before the deposition of Pliocene rocks, and subsequently uranium was leached from and redistributed in the host rocks by ground water principally during Pleistocene time. (See p. B2–B3.) It seems reasonable to assume that elements more highly concentrated in the stratigraphically higher beds and (or) in the vicinity of aquifers were also emplaced, simultaneously with uranium, by ground water and also came from the same source. Similarly, inasmuch as samples leached of uranium (eU>U) and samples enriched in uranium (U>eU) are related to stratigraphic position and proximity to aquifers (chap. A, fig. 27), elements whose abundance increases or decreases with excess U or excess eU likewise probably were affected by ground water.

Consequently, elements in the foregoing groups whose concentrations presumably were enriched to some extent by ground water after lithification can be distinguished from elements not enriched by ground water after lithification by comparison of the stratigraphic distribution of uranium with that of the other elements in the samples. The relations to uranium are determined by noting in table 5 the degree of similarity between sequences of stratigraphic units for uranium compared to those for the other elements. Elements that were subsequently leached and redistributed are determined by noting their relation to excess uranium and excess equivalent uranium (tables 8–10) in samples selected for their extreme radioactive unbalance.

elements in stratigraphic units of the Fort Union Formation, Cave Hills area

amount normally detectable (table 1). Uranium data from chemical analyses (fig. 2). Other data from semiquantitative spectrographic analyses (figs. 3–18)]

5			6			7			8		
Coal zone B (9 samples)			Lonesome Pete ore zone (phosphatic silty claystone, 51 samples)			Lonesome Pete coal zone (22 samples)			Lower coal beds (29 samples)		
Range	Average	Maximum	Range	Average	Maximum	Range	Average	Maximum	Range	Average	Maximum
0.025	0.01	0.027	0.66	0.17	0.66	0.25	0.042	0.25	0.041	0.008	0.042
19.0	10	20	10.0	15	20	18.0	10	20	15.0	14	20
19.0	8	20	18.0	15	20	18.0	12	20	18.0	12	20
18.0	8	20	4.5	2	5	19.5	6	20	19.0	6	20
9.5	3	10	1.5	1	2	4.9	1	5	4.5	1	5
18.0	7	20	19.5	3	20	19.5	8	20	19.5	4	20
19.0	7	20	1.5	1.5	2	19.8	4	20	19.8	3	20
2.0	.8	2	4.0	3	5	5.0	.6	5	1.8	1	2
.48	.15	.5	.45	.2	.5	.45	.2	.5	.95	.3	1
.07	(.035)	.07	10.0	1	10	.07	(.035)	.07	.07	(.035)	.07
.099	.03	.1	.015	.009	.02	.499	.08	.5	.199	.03	.2
.0002	.00006	.0002	.0002	.00006	.0002	.0002	.00006	.0002	.0002	.00004	.0002
.01	(.005)	.01	.01	(.005)	.01	.1	.01	.1	.02	.005	.02
.095	.03	.1	.01	.015	.02	.195	.03	.2	.095	.03	.1
.48	.15	.5	.15	.08	.2	.99	.2	1	.99	.1	1
.001	.0003	.001	.0004	.0002	.0005	.00495	.0006	.005	.002	.0004	.002
.0095	.003	.01	.001	.0015	.002	.02	.003	.02	.02	.002	.02
.019	.006	.02	.008	.007	.01	.019	.006	.02	.048	.01	.05
.019	.008	.02	.009	.0015	.01	.049	.009	.05	.048	.01	.05
.0095	.003	.01	.008	.007	.01	.0195	.006	.02	.0095	.004	.01
.005	.0008?	.005	.001	(.0005)	.001	.05	.003	.05	.02	.0015?	.02
.01	.003	.01	.01	.005	.01	.02	.002?	.02	.01	.002?	.01
.095	.02	.1	.05	.006	.05	.2	.02	.2	.05	.08	.05
.02	.004?	.02	.006	(.003)	.006	.006	(.003)	.006	.006	(.003)	.006
.0495	.01	.05	.015	.015	.02	.0495	.009	.05	.0495	.007	.05
.004	.003	.005	.001	.0015	.002	.01	.003	.01	.02	.004	.02
.01	.003	.01	.001	.0015	.002	.0095	.003	.01	.019	.004	.02
.001	(.0005)	.001	.001	(.0005)	.001	.005	.0007?	.005	.001	(.0005)	.001
.99	.15	1.0	.195	.06	.2	.49	.15	.5	.19	.04	.2
.019	.007	.02	.018	.009	.02	.019	.005	.02	.098	.015	.1
.02	.007	.02	.008	.006	.01	.02	.004	.02	.02	.007	.02
.002	.0007	.002	.0008	.0006	.001	.001	.0004	.001	.005	.0009	.005
.095	.03	.10	.009	.004	.01	.19	.06	.2	.195	.04	.2

TABLE 5.—*Sequences of stratigraphic units obtained when ranges, averages, and maxima shown in table 4 are arranged in order of decreasing magnitude for each element listed*

[Numbers are those assigned to the stratigraphic units in table 4. Numbers connected by dashes (2–4) are reversible in sequence; numbers in bold type (**3 6**) are those of the noncoal units]

Element	Decreasing ranges	Decreasing averages	Decreasing maxima
U	4 1 3 6 7 2 8 5	1 4 3 6 7 2 5 8	4 1 3 6 7 2 8 5
Si	1 5 4–7 2–8 3–6	1–2–3–4–6–7–8 5	>10 in all
Al	1 2–4–5–6–7–8 3	1–2–3–6–7–8 4 5	>10 in all
Fe	1 2–7 4–8 5 3 6	4 1–2–5 7–8 3 6	1–2–4–5–7–8 3 6
Mg	4 1 5 2–7 8 6 3	4–5 1–2–6–7–8 3	4 1–5 2–7–8 6 3
Ca	1–2 6–7–8 4 5 3	7 5 4 2 1–8 6 3	1–2–4–5–6–7–8 3
Na	2–7–8 4 5 1 3 6	5 4 2–7 1–3–8 6	2–4–5–7–8 1 3 6
K	4–7 6 3 1–2–5–8	3–6 8 4–5 1–2 7	3–4–6–7 1–2–5–8
Ti	1 4 8 5 6–7 2 3	3–4–8 1–2–6–7 5	1–4–8 2–3–5–6–7
P	6 1–4 3 2–5–7–8	6 3 1–4 2–5–7–8	6 4 1 3 2–5–7–8
Mn	4 2 7 1–8 5 3–6	2 7 4 5–8 1 6 3	2–4 7 1–8 5 3–6
Ag	2 4 1–5–6–7 8 3	2 4 5–6–7 1 8 3	2 4 1–5–6–7–8 3
As	1 4 2 7 3 8 5–6	1 4 2 3–7 8 5–6	1 4 2 7 3 8 5 6
B	1 4 7 5–8 2 3 6	5–7–8 1–2–4 3–6	7 1 4 5 8 2 3 6
Ba	1–7–8 4 3 2–5 6	4 1–7 2–5 3–8 6	7 1 4 5 8 2 3 6
Be	1–4 7 8 2–5 6 3	1 4 7 8 2–3–5 6	1–4–7 8 2–5 3–6
Co	1 2 4–7–8 5 3 6	2 1 3–5–7 4–8 6	1 2 4–7–8 3–5 6
Cr	1 8 3 2–4–5–7 6	3 8 2 1 6 5+7 4	1–3–8 2–4–5–7 6
Cu	1–4–7 8 5 3 2 6	1–2–4–8 7 5 3 6	1 4–7–8 2–3–5 6
Ga	1 7 4 2–5–8 6 3	3–6 7 1–2 4–8 5	1–4–7 2–3–5–6–8
Ge	1–7–8 4 2–5 3–6	1–7 8 4 5 2 3–6	7 1–8 4 2–5 3–6
La	1–4 3–7 2–5–6–8	1–4 3–6 5 2–7–8	1–4 3–7 2–5–6–8
Mo	1 4 2–3–7 5 6–8	1 4 3 2–5–7 8 6	1 4 2–3–7 5 6–8
Nd	4 1 5 2–3–6–7–8	4 1 5 2–3–6–7–8	4 1 5 2–3–6–7–8
Ni	1–4 2 5–7–8 3 6	1–2 6 3–5 4–7 8	1 2–3–5–6 4–7 8
Pb	1 4 8 7 3 2 5 6	1 4 8 3 5–7 2 6	1 4 8 3–7 2–5 6
Sc	1 8 5 7 3–4 2 6	8 1 3–4 5 7 2 6	1–8 3–4–5–7 2 6
Sn	1 3–4–7 2–5–6–8	1 4 3–7 2–5–6 8	1 3–4–7 2–5–6–8
Sr	1 4–5 2 7 6 8 3	1–2–4–5–7 6 8 3	1–4–5 2–7 6–8 3
V	1 8 4 3 5–7 6 2	1 3–4–8 6 5 7 2	1 8 3–4 5–6–7 2
Y	1 4 5–7–8 3 6 2	1 3–4–5–8 6 7 2	1 4 3–5–7–8 2–6
Yb	1–4–8 5 3 7 2 6	1 4–8 3–5 6 2–7	1 4–8 3–5 2–6–7
Zr	1 4 2 8 7 5 3 6	4 1 2–7 8 5 3 6	1–4 2–7–8 3–5 6

The procedures used in further sorting the elements as outlined in the foregoing and in determination of subsequent changes in concentration of elements are discussed in the next two subsections.

RELATIONS OF ELEMENTS TO URANIUM

The probability of the sequences of numbers in table 5 being the same for any one element as for uranium, based on a purely random arrangement of numbers, is 1 in 8 for the first number in the sequence, 1 in 56 for the first two, 1 in 336 for the first three, and so on. It follows that, if elements have the first number in any column on table 5 in the same sequence as uranium, there is an 8 to 1 chance in favor of their occurrence probably being directly related to the occurrence of uranium and the more numbers in the same order, the greater the probability.

The probability that 3 6 or 6 3 will appear at the end of the sequence is 2 in 56, so that the probability that the elements whose sequences end in these combinations (table 5) are related to the coal beds is about 96 percent.

For elements whose sequences in table 5 indicate direct relation to both coal and uranium, such as the elements Be and Zr, it may be possible to infer that the abundance of the element is more directly related to either coal or uranium according to whether the probability is greater for one relation than for the other.

If the probabilities of the random occurrence of sequences in all three colums are compared and evaluated, the following relations can be determined.

A. *Elements directly related to uranium:*
   In coal—Fe?, Mg?, P, As, Ba, Be, Cu?, Ge?, La, Mo, Nd, Ni?, Pb, Sn, Sr?, V, Y, Yb, and Zr.
   In carbonaceous clayey siltstone (unit 3)—P, As, Be?, La, Mo, Nd, Pb, Sn, V, Y, and Yb.
   In phosphatic silty claystone (unit 6)—P, La, Nd, Sn?, V. Y?, and Yb.

B. *Elements independent of uranium:*
   In coal—Si, Al, Ti, Ag, Co, Cr, Ga, and Sc.
   In carbonaceous clayey siltstone (unit 3)—Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn, Ag. B, Ba, Co, Cr, Cu, Ga, Ge, Ni, Sc, Sr, and Zr.
   In phosphatic silty claystone (unit 6)—Si, Al, Fe, Mg, Ca, Na, K, Ti, Mn, Ag, As, B, Ba, Be, Co, Cr, Cu, Ga, Ge, Mo, Ni, Pb, Sc, Sr and Zr.

C. *Elements inversely related to uranium:*
   In coal—Ca?, Na?, K?, Mn?, and B?.
   In noncoals—None?

In groups A and C, elements are queried if the indicated relation is uncertain. In group A, the probability that Nd, V, Y, and Yb are related to uranium ranges from 90 to 98 percent. For the other elements, probabilities are greater than 98 percent. Note that elements in group A (directly related to uranium) probably were concentrated (like uranium) principally by ground water, and that consequently their original concentation in the inorganic sedimentary constituents of the samples probably was low (lean).

RELATIONS OF ELEMENTS TO EQUIVALENT URANIUM

Samples containing more eU than U probably have had some U leached, and samples with U in excess of eU probably have had some U added; such changes must have occurred within about the last 500,000 years—the time it takes for a sample out of balance to achieve radioactive equilibrium.

Samples collected from the Cave Hills can be grouped according to the amount that they are out of radioactive balance, and the concentrations of elements can then be compared to the groups of samples for determination of elements showing a systematic change in concentration with change in the amount of imbalance. This procedure should help in identification of elements that have been leached or concentrated by Recent or late Pleistocene ground water.

To accentuate the U–eU relation, the amount of eU and U in the ash has been calculated and is used in classifying the sample, and only those samples whose eU concentration in the ash (eUA) exceeds by two times the U content in the ash (UA) are considered out of balance. A primary grouping of samples is made according to the level of eUA (table 6). The limits of the group accord with the system for reporting semiquantitative analyses; that is, all samples falling within ranges whose midpoints are 0.7, 0.3, 0.15, and so forth are averaged together for each range. Within each of these radioactivity levels, subgroupings are made according to whether U exceeds eU, U is in balance with eU, or eU exceeds U.

Most of the samples for which the necessary analyses are available are from coal beds E and C; thus, the analysis is limited largely to the relation of elements in these coal beds (table 7).

TABLE 6.—*Average concentration, in percent, of elements in coal samples grouped*

The averages shown in the subcolumns under each eUA group are based on semiquantitative spectrographic analyses and were used in compilation of tables 8–10; localities of samples are shown in table 7.
eUA, equivalent uranium in ash, calculated from percentage of eU in sample and percentage of ash in sample. UA, uranium in ash. Bal., samples in radioactivity balance (eUA = UA); eUA>, samples containing an excess of eUA over UA; UA>, samples containing an excess of UA over eUA. ND, not detected; average concentration of elements so reported is assumed to be one-half the sensitivity limit of the element.

	eUA group, in percent								
	1.5			0.7			0.3		
Number of samples analyzed	0	1	1	3	0	4	2	2	7
Radioactivity equilibrium status	Bal.	eUA>	UA>	Bal.	eUA>	UA>	Bal.	eUA>	UA>
Si	----------	15	7	15	----------	11	15	11	13
Al	----------	15	7	15	----------	11	15	7	8
Fe	----------	7	15	4	----------	9	5	11	13
Mg	----------	3	1.5	1	----------	1.5	.8	.7	1.5
Ca	----------	7	7	2	----------	4	4	7	5
Na	----------	3	3	3	----------	5	2	5	2
K	----------	1.5	.7	1.5	----------	.5	.4	.7	.4
Ti	----------	.3	.3	.2	----------	.15	.3	.15	.15
Mn	----------	.03	.015	.03	----------	.008	.008	.005	.007
Ag	----------	.00007	ND	.000015	----------	.00008	.00005	.00008	.00007
As	----------	ND	.3	.2	----------	.2	.04	.01	.3
B	----------	.015	.03	.004	----------	.05	.005	.03	.02
Ba	----------	.7	.3	.15	----------	.3	.2	.4	.3
Be	----------	.0003	.0015	.0008	----------	.0008	.0009	.001	.001
Co	----------	.0015	.03	.007	----------	.015	.002	.05	.015
Cr	----------	.003	.003	.01	----------	.008	.02	.0015	.007
Cu	----------	.015	.007	.01	----------	.015	.01	.01	.01
Ga	----------	.0015	.007	.004	----------	.007	.007	.007	.005
Ge	----------	ND	.007	ND	----------	.006	ND	.003	.003
La	----------	.007	.007	ND	----------	.006	.004	.007	.009
Mo	----------	.015	.07	.5	----------	.4	.15	.03	.3
Nd	----------	ND	ND	ND	----------	ND	ND	.003	.004
Ni	----------	.015	.03	.015	----------	.03	.015	.05	.02
Pb	----------	.015	.03	.005	----------	.03	.004	.04	.02
Sc	----------	.003	.007	.006	----------	.004	.003	.002	.003
Sn	----------	ND	ND	ND	----------	.001	ND	ND	.0015
Sr	----------	.3	.15	.1	----------	.15	.07	.2	.15
V	----------	.015	.07	.005	----------	.04	.004	.04	.03
Y	----------	.003	.015	.01	----------	.015	.01	.015	.015
Yb	----------	.0007	.0015	.001	----------	.002	.001	.001	.001
Zr	----------	.15	.07	.15	----------	.06	.15	.07	.1

according to average eUA content and according to radioactivity equilibrium status

Samples in the 1.5 eUA group contain 1–2 percent equivalent uranium; samples in the 0.7 eUA group contain 0.5–1 percent equivalent uranium, and so forth. See table 2 for limits of other ranges. Concentrations of elements reported in analyses as >10 percent are assumed to be in the 15 percent range whose limits are 10 and 20 percent. Phosphorus was not detected in any of these samples.

eUA group, in percent—Continued											
0.15			0.07			0.03			0.015		
8	2	8	8	0	4	10	6	7	2	1	0
Bal.	eUA>	UA>	Bal.	eUA>	UA>	Bal.	eUA>	UA>	Bal.	eUA>	UA>
14	15	14	14	------	15	13	14	15	15	15	------
8	15	13	10	------	13	13	10	14	11	7	------
12	7	9	11	------	9	7	8	7	15	3	------
2	1	1	2	------	.9	2	3	4	2	.7	------
5	5	5	5	------	3	4	8	6	11	1.5	------
3	4	2	3	------	3	4	2	4	2	1.5	------
.5	1	.9	.7	------	.7	1	.4	.2	1	1.5	------
.2	.2	.2	.3	------	.2	.3	.3	.2	.3	.15	------
.04	.04	.05	.02	------	.01	.04	.02	.05	.4	.07	------
.00006	.0001	.00007	.00005	------	.00008	.00004	.00004	.00007	.00007	ND	------
.3	.04	.04	.15	------	.05	.05	.06	.03	.07	.07	------
.02	.04	.02	.015	------	.03	.02	.03	.03	.015	.003	------
.1	.4	.3	.3	------	.2	.2	.2	.2	.3	.15	------
.0009	.004	.001	.0007	------	.001	.0009	.0009	.0007	.00009	.0003	------
.006	.015	.01	.002	------	.009	.004	.005	.002	.001	.0015	------
.004	.005	.007	.004	------	.007	.004	.008	.009	.004	.015	------
.01	.015	.009	.01	------	.01	.007	.008	.01	.007	.007	------
.007	.005	.005	.005	------	.006	.004	.004	.004	.0015	.0007	------
.004	.002	.002	.0008	------	.002	.003	.002	.001	ND	ND	------
.008	.007	.008	.005	------	.007	.002	.006	.009	ND	ND	------
.09	.04	.3	.3	------	.06	.15	.03	.08	.04	.07	------
.006	ND	.004	ND	------	.004	ND	.003	.003	ND	ND	------
.02	.04	.02	.01	------	.02	.007	.015	.007	.0015	.007	------
.01	.02	.006	.008	------	.006	.003	.008	.005	.007	.007	------
.004	.005	.002	.002	------	.002	.003	.002	.003	.0015	.0015	------
.0008	ND	.001	.001	------	.0007	.0006	.0008	.0015	ND	ND	------
.15	.15	.15	.15	------	.09	.1	.15	.15	.2	.015	------
.015	.03	.02	.01	------	.015	.01	.02	.02	.02	.015	------
.008	.015	.009	.008	------	.009	.005	.01	.006	.003	.003	------
.0015	.001	.0009	.0009	------	.001	.0007	.0009	.0004	.0007	.0003	------
.1	.07	.1	.1	------	.08	.08	.1	.08	.07	.03	------

TABLE 7.—*Coal samples used in compilation of table 6*

[Equivalent uranium in ash, grouped by midpoints of ranges (eUA group); samples in the 1.5 eUA group contain 1–2 percent equivalent uranium in ash: and so forth. See table 2 for limits of other ranges]

eUA group (percent)	Samples in balance (eUA=UA)			Samples containing excess eUA (eUA>)			Samples containing excess UA (UA>)		
	No.	Bed	Area	No.	Bed	Area	No.	Bed	Area
1.5				[1] 8B	Coal bed C	Traverse Ranch	[2] 32	Coal bed E	North Riley Pass.
.7	[2] 7TM	Coal bed E	Traverse Ranch				[1] 5	do	Western part of South Riley Pass.
	[1] 50	do	Central part of South Riley Pass.				[2] 21	do	North Riley Pass.
	[1] 52	do	do				[2] 29B	do	Do.
							[2] 36	do	Do.
.3	[2] 7T	Coal bed E	Traverse Ranch	[2] 38B	Coal bed E	North Riley Pass.	[1] 24	do	Western part of South Riley Pass.
	[1] 18	Coal bed C	do	[2] 60	do	do	[2] 16	do	North Riley Pass.
							[2] 16B	do	Do.
							[2] 25M	do	Do.
							[2] 31	do	Do.
							[2] 37B	do	Do.
							[2] 40	do	Do.
.15	[1] 73	Coal bed E	Western part of South Riley Pass.	[2] 49	Coal bed E	North Riley Pass.	[1] 62	do	Western part of South Riley Pass.
	[1] 21	do	Eastern part of South Riley Pass.	[1] 7T	Coal bed C	Traverse Ranch.	[2] 22	do	North Riley Pass.
	[1] 25B	do	do				[2] 24	do	Do.
	[2] 18	do	North Riley Pass.				[2] 25	do	Do.
	[2] 47	do	do				[2] 54	do	Do.
	[1] 16	Coal bed C	Traverse Ranch.				[2] 58	do	Do.
	[2] 85T	do	Miscellaneous locality.				[1] 14	Coal bed C	Traverse Ranch.
	[3] 57	Carbonate coal zone.	Vicinity of Lonesome Pete mine.				[4] 9T	Lonesome Pete coal zone.	Lonesome Pete mine.
.07	[1] 65	Coal bed E	Western part of South Riley Pass.				[1] 56	Coal bed E	Western part of South Riley Pass.
	[2] 63	do	North Riley Pass.				[1] 63	do	Do.
	[1] 13	Coal bed C	Traverse Ranch				[2] 14	do	North Riley Pass.
	[1] 17	do	do				[2] 39	do	Do.
	[2] 77	do	Miscellaneous locality.						
	[2] 82	do	do						
	[2] 90T	do	do						
	[2] 91T	do	do						
.03	[1] 51	Coal bed E	Central part of South Riley Pass.	[2] 5	Coal bed E	Traverse Ranch	[2] 11	Coal bed E	North Riley Pass.
	[1] 3	do	Eastern part of South Riley Pass.	[2] 6T	do	do	[2] 12	do	Do.
	[1] 18	do	do	[2] 13	do	North Riley Pass.	[2] 17	do	Do.
	[2] 7D	do	Traverse Ranch	[2] 48	do	do	[1] 5TM	Coal bed C	Traverse Ranch.
	[2] 26T	do	North Riley Pass.	[2] 57	do	do	[1] 5BM	do	Do.
	[2] 41	do	do	[1] 5T	Coal bed C	Traverse Ranch	[4] 17T	Lonesome Pete coal zone.	Lonesome Pete mine.
	[1] 11B	Coal bed C	Traverse Ranch				[3] 15	do	Vicinity of Lonesome Pete mine.
	[2] 80	do	Miscellaneous locality.						

See footnotes at end of table.

TABLE 7.—*Coal samples used in compilation of table 6*—Continued

eUA group (percent)	Samples in balance (eUA=UA)			Samples containing excess eUA (eUA>)			Samples containing excess UA (UA>)		
	No.	Bed	Area	No.	Bed	Area	No.	Bed	Area
0.03	[4] 39T	Lonesome Pete coal zone.	Lonesome Pete mine.	------	------------	----------------	------	------------	----------------
	[3] 54	---do-------	Vicinity of Lonesome Pete mine.	------	------------	----------------	------	------------	----------------
.015	[1] 1	Coal bed C	Traverse Ranch	[1] 64	Coal bed E	Western part of South Riley Pass.	------	------------	----------------
	9	---do-------	-----do---------	------	------------	----------------	------	------------	----------------

[1] See table 15.
[2] See table 16.
[3] See table 19.
[4] See table 18.

The average concentration of elements is given for each subgroup in table 6. The results of comparing various sets of sample data are shown in tables 8–10:

TABLE 8.—*Relations of elements to excess equivalent uranium in ash of coal samples*

Relations determined by comparison of samples in balance to samples containing excess eU (Bal. vs. eUA>). The relation positive (+), negative (−), or not related (0) of an element to excess eUA is based on the comparison of the averages shown in the first and second subcolumns under each eUA group as shown in table 6.

An estimate of whether the averages for a given element are significantly different (and that the element therefore is related to excess eUA) was obtained through use of table 22 (and extrapolation and is indicated by the following symbols: query (?), inconclusive; 0, not related to excess eUA; 0+, positively related, difference in averages less than 50 percent significant; +, positively related, difference in averages 50–70 percent significant; ++, positively related, difference in averages 70–90 per cent significant; ⊕, positively related, difference in averages more than 90 percent significant. Analogous, but negative, symbols express significance of negative relations. ND means not detected.

Basic data shown in tables 6 and 7. Symbols used in headings are explained in table 6.

Element	Relation of samples in balance to samples containing excess eU in indicated eUA group				Consensus [1]
	0.3	0.15	0.03	0.015	
	2 to 2	8 to 2	10 to 6	2 to 1	
Si	−	0+	+	0	(?)
Al	− −	+ +	− −	−	−
Fe	+	− −	⊕	− −	−
Mg	0−	− −	+ +	−	−
Ca	+	0	+ +	− −	(?)
Na	+	0+	⊕	0−	(?)
K	+	+	⊕	+	+

See footnote at end of table.

TABLE 8.—*Relations of elements to excess equivalent uranium in ash of coal samples*—Continued

Element	Relation of samples in balance to samples containing excess eU in indicated eUA group				Consensus [1]
	0.3	0.15	0.03	0.015	
	2 to 2	8 to 2	10 to 6	2 to 1	
Ti	− −	0	0	− −	−
Mn	0−	0	⊖	−	−
Ag	0+	+	0	− −	(?)
As	−	− −	+	0	−
B	+ +	+	+	− −	+
Ba	+	+	0	−	+
Be	0+	+	0	+ +	+
Co	+ +	+	+	+	+
Cr	− −	0+	+ +	+ +	+
Cu	0	+ +	+	0	+
Ga	0	−	−	− −	−
Ge	+ +	−	− −	ND	(?)
La	+	−	+ + ?	ND	+
Mo	− −	− −	⊖	+	−
Nd	0+ ?	− −	0	ND	(?)
Ni	+ +	+	+ +	0	+
Pb	+ +	+	+ +	0	+
Sc	−	0+	− −	0	−
Sn	ND	− ?	+	ND	(?)
Sr	+	0	+ +	−	+
V	+ +	+ +	+ +	0−	+
Y	+	+	+ +	0	+
Yb	0	−	+ +	− −	(?)
Zr	− −	− −	+ +	− −	−

[1] The probabilities that the relations shown in this column are not fortuitous were not determined. Probabilities range from inconclusive, as for Si, to more than 98 percent, as for Co.

TABLE 9.—*Relations of elements to excess uranium in ash of coal samples*

Relations determined by comparison of samples in balance to samples containing excess U (Bal. vs. UA>). The relation positive (+), negative (−), or not related (0) of an element to excess UA is based on the comparison of the averages shown in the first and third subcolumns under each eUA group as shown in table 6.
An estimate of whether the averages for a given element are significantly different (and that the element therefore is related to excess UA) was obtained through use of table 22 (and extrapolation) and is indicated by the following symbols: 0, not related to excess UA; other symbols used are similar to those for table 8.
Basic data shown in tables 6 and 7. Symbols used in headings are explained in table 6.

Element	Relation of samples in balance to samples containing excess U in indicated eUA group					Consensus [1]
	0.7	0.3	0.15	0.07	0.03	
	3 to 4	2 to 7	8 to 8	8 to 4	10 to 7	
Si	− −	−	0	+	+ +	(?)
Al	− −	− −	+ +	+ +	+	(?)
Fe	+ +	+ +	− −	−	0	(?)
Mg	+ +	+	− −	⊖	+ +	(?)
Ca	+ +	0+	0	− −	+ +	+
Na	+ +	0	− −	0	0	0
K	⊖	0	+ +	0	⊖	−
Ti	−	− −	0	− −	− −	−
Mn	− −	0−	0+	− −	+	−
Ag	⊕	+	+	+	+ +	+
As	0	+ +	− −	⊖	− −	−
B	⊕	+ +	0	+	+ +	+
Ba	⊕	0+	+ +	− −	0	+
Be	0	0+	0+	+	− −	+
Co	+ +	⊕	+ +	+ +	− −	+
Cr	−	−	+ +	+	⊕	+
Cu	+	0	−	0	+	(?)
Ga	+ +	−	− −	+	0	(?)
Ge	⊕	+ +	− −	+ +	⊖	+
La	⊕	+	0	+	⊕	+
Mo	−	+ +	+ +	⊖	− −	−
Nd	ND	+	−?	+?	0	(?)
Ni	+ +	+	0	+ +	0	+
Pb	+	+ +	−	−	+ +	+
Sc	−	0	− −	0	0	(?)
Sn	+ +	+ +	+	− −	+ +	+
Sr	+ +	+ +	0	− −	+ +	+
V	⊕	+ +	+	+ +	+ +	+
Y	+ +	+	+	0+	+	+
Yb	+ +	0	− −	0+	⊖	(?)
Zr	⊖	−	0	−	0	−

[1] The probabilities that the relations shown in this column are not fortuitous were not determined. Probabilities range from inconclusive, as for Si, to more than 99 percent, as for Ag.

It is impracticable to determine the statistical significance of the results shown in the "consensus" columns of tables 8–10. As indicated in the table footnotes, however, the probability that these results are significant, apparently is high enough for our purpose. From the results obtained ("consensus" cols., tables 8–10), the elements may be sorted into five groups according to their apparent relations to excess equivalent uranium or to excess uranium as follows:

d. *Elements negatively related to excess eU in coal:* Al, Fe, Mg, Ti, Mn*, As*, Ga, Mo*, Sc, and Zr*.

e. *Elements negatively related to excess U in coal:* K, Ti, Mn, As, Mo, and Zr.

f. *Elements positively related to excess eU in coal:* K*, B, Ba*, Be, Co*, Cr, Cu, La, Ni*, Pb*, Sr, V, and Y.

g. *Elements positively related to excess U in coal:* Ca, Ag, B, Ba, Be, Co, Cr*, Ge, La, Ni, Pb, Sn, Sr, V, and Y.

TABLE 10.—*Relations of elements to excess equivalent uranium and to excess uranium in ash of coal samples*

Relations determined by comparison of samples containing excess eU to samples containing excess U (eUA>vs. UA>). The relation positive (+), negative (−), or not related (0) of an element to excess UA is based on the comparison of the averages shown in the second and third subcolumns under each eUA group as shown in table 6.
An estimate of whether the averages for a given element are significantly different (and that the element therefore is related to excess UA) was obtained through use of table 22 (and extrapolation) and is indicated by the following symbols: 0, not related to excess UA, other symbols used are simular to those for table 8.
Basic data shown in tables 6 and 7. Symbols used in headings are explained in table 6.

Element	Relation of samples in balance to samples containing excess U in indicated eUA group				Consensus [1]
	1.5 [1]	0.3	0.15	0.03	
	1 to 1	2 to 7	2 to 8	6 to 7	
Si	− −	0+	0−	+	(?)
Al	−	+	−	+ +	(?)
Fe	+	0+	+	−	+
Mg	−	+ +	0	+ +	+
Ca	0	−	0	− −	−
Na	0	−	−	⊕	(?)
K	−	− −	0−	− −	−
Ti	0	0	0	−	0
Mn	−	+	0+	⊕	+
Ag	⊖	0−	−	+ +	−
As	⊕	⊕	0−	− −	+
B	+	−	−	0	(?)
Ba	−	0−	0−	0	−
Be	+ +	0	−	−	(?)
Co	⊕	−	0−	⊖	−
Cr	0	+ +	+	+	+
Cu	−	0	− −	+	(?)
Ga	+ +	−	0	0	(?)
Ge	⊕	0	0	− −	+
La	0	+	+	+ +	+
Mo	+ +	⊕	+ +	⊕	+
Nd	ND	+	+?	0	+
Ni	+	−	−	− −	−
Pb	+	−	−	−	−
Sc	+	+	−	+ +	+
Sn	ND	+ +	+ +	+ +	+
Sr	−	0−	0	0	0
V	+ +	0−	−	0	(?)
Y	+ +	0	0−	− −	(?)
Yb	+	0	0−	− −	(?)
Zr	−	+ +	+ +	−	+

[1] The probabilities that the relations shown in this column are not fortuitous were not determined. Probabilities range from inconclusive, as for Si, to more than 99 percent, as for Mo.

h. *Elements whose relations to excess eU and to excess U are indeterminate in coal:* Si, Na, Nd, and Yb.

Some of the elements appear in two of the foregoing groups; that is, they show evidence of having been affected by more than one agent. For such elements, the results shown in the "consensus" column of table 10 were used in determination of which agent apparently was principally effective during late epigenetic groundwater activity. Accordingly, in the foregoing groups (d–g) an element is starred in the group to which it is more closely related.

For example, molybdenum (Mo) is negatively related to excess eU as shown in table 8, and it is negatively related also to excess U as shown in table 9. Thus, there is less Mo in the samples containing excess eU (leached of U) and in the samples containing excess

U (enriched in U) than there is in the group of samples in balance (U content undisturbed by ground-water action), to which they are compared. But inasmuch as table 10 shows a positive relation of Mo to excess U (relative to the excess eU samples)—that there is more Mo in the excess U samples—it follows that Mo was more subject to leaching when uranium was being leached than it was when uranium was being added.

Samples containing excess eU represent rocks whose uranium has been leached by ground water, and samples containing excess U represent rocks whose original U content has been augmented by ground water; therefore, it is probable that group d elements showing a negative relation to excess eU (decrease as eU increases) were leached when uranium was being leached, group e elements showing a negative relation to excess U (decrease as U increases) were leached when uranium was being deposited, group f elements showing a positive relation to excess eU (increase as eU increases) were deposited when uranium was being leached, and group g elements showing a positive relation to excess U (increase as uranium increases) were deposited when uranium was being deposited. The relation of elements listed in group h to excess eU or to excess U could not be determined; presumably they were not significantly affected by ground-water action.

Another negative use of table 10 was in ensuring that in the process of arriving at a consensus of whether a relation was positive or negative an impossible relation was not reached. For example, if the content of a given element was higher in the samples containing excess eUA (eUA>) than in the samples in balance, and lower in the samples containing excess UA (UA>) than in the samples in balance, it would be impossible for the average of the UA> samples to be greater than the average in the eUA> samples. None of the relations between the results shown in tables 8 and 9 are incompatible with the relations shown in table 10. This fact suggests that the direction of difference between averages was in general real, despite the inherent inaccuracy of the semiquantitative spectrographic method of analyses.

Comparison of the average content of a given element in samples containing excess eUA with the average content in samples containing excess UA cannot be used as a basis for statements concerning leaching or enrichment of that element with regard to leaching or enrichment of uranium in the same samples. For example, the relations of neodymium (Nd) to excess eUA and to excess UA could not be determined (tables 8, 9). But comparison of the eUA> suite with the UA> suite (table 10) shows a positive relation of Nd to excess UA (there is more Nd in the UA> group than in the eUA> group). No further inference can be made from this relation because, relative to balanced samples in the same eUA group, the eUA> and the UA> subgroups can have these relations: + +, − −, − +, −O, and O+, none of which are incompatible with a + relation between the eUA> and the UA> groups. That is to say, both suites of samples could have been enriched, or both could have been leached—one leached while the other was enriched, one leached while the other was unaffected, or one enriched while the other was unaffected; any of these methods would cause a + relation between eUA> and UA> samples with no clue as to which method brought about the relation.

SUMMARY OF FIRST METHOD OF INVESTIGATION

To summarize the results of the first method of investigation, it has been determined tentatively which elements were principally concentrated in coal by plants (lean in the sedimentary constituents, group 1), which were rich inorganic sedimentary constituents (group 2), and which seem to have originated as normal inorganic sedimentary constituents in both coal and the ores (group 3).

It has also been determined tentatively which elements were deposited with uranium by ground water (group A), which are independent of uranium (group B), and which were leached when uranium was deposited (group C), all with reference to early epigenetic uranium mineralization of the area.

And finally, it has been determined tentatively which elements were later affected by ground water and in what way (groups d–g), and which elements seem to have been unaffected by ground water (group h), all with reference to late epigenetic leaching and redeposition of uranium.

Because some elements occur in several of these groups—they were concentrated in several ways—whereas others occur in but one or two, the interpretations of how, when, and to what extent the elements were concentrated in the coal beds and ores of the Cave Hills area can be combined and redefined.

For convenience of further discussion, the occurrences of elements in the various groups that have been discussed and the interpretation of each group are tabulated as follows.

Occurrences of elements in various groups

[Number or lettered groups explained on pages B24, B25, B26, B32. Asterisk (*) indicates principal effect of ground water where determinable from table 10]

Element	Relation to lithology			Relation to uranium									Relation to equivalent uranium				
				Coal			Noncoaly rocks						Coal				
							Carbonate ore zone			Lonesome Pete ore zone							
	Coal	Noncoal	Unrelated														
	1	2	3	A	B	C	A	B	C	A	B	C	d	e	f	g	h
Si			×		×			×			×						×
Al			×		×			×			×		×				
Fe	×			×?				×			×		×				
Mg	×			×?				×			×		×				
Ca	×					×?		×			×					×	
Na	×					×?		×			×						×
K		×				×?		×			×			×	×*		
Ti			×		×			×			×		×	×			
P		×		×			×			×							
Mn	×					×?		×			×		×*	×			
Ag			×		×			×			×					×	
As			×	×			×				×		×*	×			
B	×					×?		×			×				×	×	
Ba	×			×				×			×				×*	×	
Be	×			×			×?				×				×	×	
Co	×				×			×			×				×*	×	
Cr			×		×			×			×				×	×*	
Cu	×			×?				×			×				×		
Ga		×			×			×			×		×				
Ge	×			×?				×			×					×	
La			×	×			×			×					×	×	
Mo			×	×			×				×		×*	×			
Nd			×	×			×			×							×
Ni			×	×?				×			×				×*	×	
Pb			×	×			×				×				×*	×	
Sc			×		×			×			×		×				
Sn			×	×			×			×?						×	
Sr	×			×?				×			×				×	×	
V			×	×			×			×					×	×	
Y			×	×			×			×?					×	×	
Yb			×	×			×			×							×
Zr	×			×				×			×		×*	×			

Interpretation of each group

Syngenetic

1. Concentrated by plants (lean in inorganic sedimentary constitutents) and (or) concentrated by ground water after lithification.
2. Originated as rich inorganic sedimentary constituents, and (or) concentrated by ground water after lithification.
3. Originated as normal inorganic sedimentary constitutents, and (or) deposited by ground water after lithification.

Early epigenetic

A. Deposited by ground water when uranium was deposited.
B. Unaffected by ground water when uranium was deposited.
C. Leached by ground water when uranium was deposited.

Late epigenetic

d. Leached when uranium was being leached.
e. Deposited when uranium was being leached.
f. Leached when uranium was being deposited.
g. Deposited when uranium was being deposited.
h. Indeterminate—probably unaffected by ground water.

Elements in group 1 are related to coal, and if they also appear in group A, they are inferred to have been concentrated by plants and further enriched to some extent by ground-water action after lithification. Elements in groups 1 and B were not affected by ground water in any way; those in groups 1 and C were leached by ground water. Consequently, elements in group 1 that also appear in groups B or C were not enriched by ground water; they must have been concentrated principally by plants.

The inorganic constituents of both coaly and noncoaly rocks consist of nearly equal parts of silt and clay. Consequently, concentrations of elements in the inorganic constituents of coal (group 1) are assumed to be lean; otherwise, these elements appear in group 2 (rich) or in group 3 (normal).

Similarly, elements in group 2 that also occur in group A are assumed to have been richly concentrated in the inorganic sedimentary constituents and to have been further enriched by ground water. Elements in groups 2 and B were unaffected by ground water, those in groups 1 and C were leached by ground water. Thus, elements that appear in groups 2 and B and in 2 and C could not have been concentrated by ground water; they must have originated principally as rich concentrations in the inorganic sedimentary constituents.

Elements in group 3 are unrelated to lithology. They presumably originated as normal concentrations in inorganic sedimentary constituents. Those in groups 3 and A were enriched by ground water, those in groups 3 and B were unaffected by ground water, those in groups 3 and C were leached by ground water.

Determination of the syngenetic and (or) early epigenetic origin of elements necessitates consideration of groups 1, 2, and 3 relative to groups A, B, and C; but the late epigenetic history of these elements can be determined directly from their occurrence in groups d, e, f, g, and h, without regard to their occurrence in the previously considered groups.

Data in the columns headed by the numeral 1 in table 14 (p. B48) were compiled by the foregoing methods and summarize conclusions of the first method of investigation concerning the origin and subsequent geochemical history of elements in the rocks of this area. The following examples illustrate how the origin and history of the elements can be read directly from the table.

The ×'s that follow molybdenum (Mo) in the number 1 columns in table 14 indicate that the concentration of Mo was normal in the inorganic sedimentary constituents of the coal and of the noncoaly rocks that were deposited in Paleocene time. In post-Paleocene to late Pleistocene time, Mo was added by circulating ground water to the coal and the carbonaceous clayey siltstone but not to the phosphatic silty claystone. In late Pleistocene to Recent time, circulating ground water that leached uranium from the samples also leached Mo from some samples but added Mo to others. Leaching of Mo was greater than enrichment of Mo.

The 0's in the various columns of table 14 signify "was not" with reference to origin or effect described in the column headings. Mo was not enriched by coal-forming plants, it was not a lean concentration in the organic sedimentary constituents of either coal or noncoaly rocks, and so forth.

Zirconium (Zr) was concentrated in the coal by plant action; its concentration was lean in the inorganic constituents of the coal and in the noncoaly rocks that were deposited in Paleocene time. In post-Paleocene to late Pleistocene time, Zr was added by circulating ground water to the coal but not to the noncoaly rocks. In late Pleistocene to Recent time, circulating ground water that leached U from the samples also leached Zr from some samples but added Zr to others. Leaching of Zr was greater than addition of Zr.

Iron (Fe) and magnesium (Mg) were concentrated by plant action in the sediments that became coal; their concentrations were lean in the inorganic constituents of the coal and in the noncoaly rocks that were deposited in Paleocene time. In post-Paleocene to late Pleistocene time, some Fe and Mg was added by circulating ground water to the coal but not to the noncoaly rocks. In late Pleistocene to Recent time, circulating ground water that leached U from the samples also leached Fe and Mg.

SECOND METHOD OF INVESTIGATION

In the second method of investigation relation of elements to lithology is inferred by comparing the average abundance of elements in the host rocks with the average abundance in the earth's crust and with the abundance in the average coal. Relation to uranium is inferred by comparing abundance of elements in the average of all the samples from a given host rock to the abundance of elements in samples of host rock selected for their low uranium content—the least mineralized samples. The radioactivity status of the samples is not considered; consequently, the results of the second method give information only about original (syngenetic) concentration and about the early epigenetic (post-Paleocene to late Pleistocene) concentration and impoverishment of elements.

Ideally, the average composition of samples from the Cave Hills area should be compared with the average composition of continental Paleocene shale and siltstone in equal parts. However, data for the average composition of Paleocene rocks are unavailable. Comparison with average crustal abundances presumably gives results suitable for the investigation.

The average abundance of elements in samples of coal, carbonaceous siltstone, and phosphatic claystone from the Cave Hills area is shown in table 11 whose data are based on semiquantitative spectrographic analyses except for those of uranium (U) and of phosphorus (P), in columns 8 and 9, which are based on chemical analyses.

RELATIONS OF ELEMENTS TO LITHOLOGY

The relative abundance of elements in the samples low in uranium content in the Cave Hills area compared to crustal abundance of the elements was determined from table 11 as follows:

(1) *Elements in greater than crustal abundance:*
In coal—Al, Ca, Ag, As, B, Ba, Be, Cu, Ga, Ge, Mo, Sc, Sn, Sr, Y, Yb, and Zr.
In carbonaceous siltstone (Carbonate ore zone)—Al, As, B, Be, Co, Ga, Mo, Ni, and Sc.
In phosphatic claystone (Lonesome Pete ore zone)—Ag, B, Ba, Ga, and Mo.

(2) *Elements in approximate crustal abundance:*
In coal—Fe, Na, Mn, Co, La, Nd, Ni, Pb, and V.
In carbonaceous siltstone (Carbonate ore zone)—Na, K, Ag, Ba, Cr, Cu, Ge, La, Nd, Pb, Sn, Y, Yb, and Zr.
In phosphatic claystone (Lonesome Pete ore zone)—Al, Na, K, Ti, As, Be, Cu, Ge, La, Nd, Ni, Pb, Sc, Sn, and Yb.

(3) *Elements in less than crustal abundance:*
In coal—Si, Mg, K, Ti, P, and Cr.
In carbonaceous siltstone (Carbonate ore zone)—Si, Fe, Mg, Ca, Ti, P, Mn, Sr, and V.
In phosphatic claystone (Lonesome Pete ore zone)—Si, Fe, Mg, Ca, P, Mn, Co, Cr, Sr, V, Y, and Zr.

Where the difference in averages is not great, the range of the samples low in uranium content was the basis for deciding whether a given difference was statistically significant or whether the two averages were about the same in a manner analogous to that used in the third method of investigation and discussed later in reference to table 22.

The abundance of elements in the samples low in uranium content (cols. 5, 7, and 9, table 11) was compared, and the elements arranged in three groups according to whether there was a statistically significant difference between these abundances as follows:

1. *Elements more highly concentrated in the coal:*
Al[1], Fe, Ca, Mn, Ag[2], As, B, Ba, Be[1], Co[1], Cr[1], Cu, Ge, Mo, Ni[1], Pb[1], Sc[1], Sn, Sr, V, Y, Yb, and Zr.
2. *Elements equally concentrated in the coal and in the noncoals:*
Si, Mg[1], Na, P, Ag[1], Be[2], La, Nd, and Pb[2].
3. *Elements more highly concentrated in the noncoals:*
Al[2], Mg[2], K, Ti, Co[2], Cr[2], Ga, Ni[2], and Sc[2].

[1] Relative to the Lonesome Pete ore zone only.
[2] Relative to the Carbonate ore zone only.

TABLE 11.—*Average abundance, in percent, of elements in samples of coal ash, carbonaceous siltstone, and phosphatic claystone from the Cave Hills area compared to crustal abundance and to abundance in average coal*

[Cave Hills sample data compiled from figures 3–18 and tables 15–19. Query (?), element was detected in less than one-third of the samples; figure in parentheses (.035), not detected; average is assumed to be one-half the minimum amount normally detectable (table 1)]

Element	Crustal abundance [1]	Abundance in average coal ash [2]	Average abundance of elements in Fort Union Formation [3] at Cave Hills					
			Coal ash		Carbonate ore zone (carbonaceous clayey siltstone)		Lonesome Pete ore zone (phosphatic silty claystone)	
			All samples (269)	Low U samples (20)	All samples (34)	Low U samples (6)	All samples (51)	Low U samples (7)
U	0.0002		[4] 0.41	[4] 0.008	[4] 0.26	[4] 0.007	[4] 0.17	[4] 0.003
Si	28		13	13	15	15	15	15
Al	8.1		11	11	15	15	15	8
Fe	5.0		8	6	3	3	2	1.5
Mg	2.1		1.5	1	.7	.7	1	1
Ca	3.6		5	7	1	.6	3	1.5
Na	2.8		4	3	3	3	1.5	2
K	2.6		.8	.8	3	3	3	3
Ti	.44		.2	.2	.3	.3	.2	.4
P	.12		.05?	(.035)	.06?	.04?	[4] 1	[4] .046
Mn	.10		.04	.07	.008	.01	.009	.015
Ag	.000001	0.0001–0.0005	.00008	.00005	.000015	.00001?	.00006	.00006
As	.0002	.01 – .05?	.4	.03	.01	.009	(.005)	.015?
B	.0003	.06	.02	.02	.015	.015	.015	.015
Ba	.04	.03 – .09	.2	.2	.1	.08	.08	.07
Be	.0002	.0001– .001	.0007	.0004	.0003	.0003	.0002	.0001
Co	.0023	.03	.006	.003	.003	.005	.0015	.0015
Cr	.02	.01 – .04	.007	.009	.02	.03	.007	.004
Cu	.0045	.002 – .02	.01	.009	.005	.008	.0015	.003
Ga	.0015	.01?	.005	.003	.007	.007	.007	.006
Ge	.0002	.005 – .05	.002	.001	(.0005)	(.0005)	(.0005)	(.0005)
La	.0018		.005	.003	.005	.003	.005	.003
Mo	.0001	.01 – .02	.3	.02	.03	.004	.006	.002
Nd	.0024		.005?	.003?	(.003)	(.003)	(.003)	(.003)
Ni	.008	.005 – .08	.015	.009	.01	.015	.015	.006
Pb	.0015	.0005– .005?	.01	.005	.004	.004	.0015	.0015
Sc	.0005	.006?	.003	.002	.003	.003	.0015	.0015
Sn	.0003	.0016– .02?	.001	.001?	.0007	.0009?	(.0005)	(.0005)
Sr	.045	.008 – .017?	.15	.1	.03	.03	.06	.03
V	.011	.01 – .1	.02	.015	.015	.007	.009	.004
Y	.004	.01	.009	.006	.007	.004	.006	.003
Yb	.0003		.001	.0006	.0007	.0004	.0006	.0004
Zr	.016	.01 – .05	.08	.04	.02	.02	.004	.008

[1] From Mason (1958, p. 44), converted from parts per million and rounded.
[2] From Krauskopf (1955, p. 418) except for boron (B) and yttrium (Y) which are from Rankama and Sahama (1950, p. 332); all are converted from parts per million.
[3] From semiquantitative spectrographic analyses except as noted in [4].
[4] From chemical analysis.

RELATIONS OF ELEMENTS TO URANIUM

The average uranium content of all the samples of each rock type (cols. 4, 6, and 8, table 11) is 37 to 57 times greater than that for the samples low in uranium content (cols. 5, 7, and 9, table 11); thus, by a comparison of the appropriate columns the elements may be sorted into three groups according to their relations to uranium.

A. *Elements directly related to uranium*:

In coal—Fe, P, Ag?, As, Be, Co, Ga, Ge, La, Mo, Nd, Ni, Pb, V, Y, Yb, and Zr.

In carbonaceous clayey siltstone—Ca, Mo, V, Y, and Yb.

In phosphatic silty claystone—Al, Ca, P, Cr, Mo, Ni, Sr, V, Y, and Yb.

B. *Elements independent of uranium*:

In coal—Si, Al, Mg, Na, K, Ti, B, Ba, Cr, Cu, Sc, Sn, and Sr.

In carbonaceous clayey siltstone—Si, Al, Fe, Mg, Na, K, Ti, P, Mn, Ag, As, B, Ba, Be, Co, Cr, Cu, Ga, Ge, La, Nd, Pb, Sc, Sn, Sr, and Zr.

In phosphatic silty claystone—Si, Fe, Mg, Na, K, Ag, As, B, Ba, Be, Co, Cu, Ga, Ge, La, Nd, Pb, Sc, and Sn.

C. *Elements inversely related to uranium*:

In coal—Ca and Mn.

In carbonaceaus clayey siltstone—Ni.

In phosphatic silty claystone—Ti, Mn, and Zr.

One further assumption is needed for interpretation of the preceding groupings of elements. It is that originally the proportions and kinds of inorganic sedimentary constituents of the coal and of the Carbonate ore zone were about the same as that of the low-uranium (relatively unmineralized) rock of the Lonesome Pete ore (right-hand column, table 11).

This assumption is plausible inasmuch as the coal and the ore zones were all deposited in virtually the same environment—in, or marginal to, a swamp. The principal detrital impurities in coal are silt and clay, and these two size fractions make up in almost equal parts nearly all the inorganic material in samples of the Carbonate and the Lonesome Pete ore zones. The low-uranium content of the seven samples of the Lonesome Pete ore zone indicates that these particular samples have not been invaded by uranium-bearing ground water, and the radioactivity equilibrium status of the Lonesome Pete ore zone as a whole (chap. A, fig. 27) indicates that the zone has not been affected by later ground water during the last 500,000 years; the seven Lonesome Pete ore zone samples used for comparisons are all in radioactive balance.

Thus, elements in the inorganic sedimentary constituents of coal or in the Carbonate ore zone presumably originated as lean, normal, or rich concentrations in the inorganic sedimentary constituents, depending on whether the elements in the low-uranium suite of Lonesome Pete ore zone samples occur in quantities statistically significantly less than crustal abundance (group (3)), and equal to crustal abundance (group (2)), or greater than crustal abundance (group (1)).

As determined in the first method of investigation, if an element shows a direct relation to uranium (group A) it probably was concentrated principally or partially by uranium-bearing ground water. If an element is independent of uranium (group B), and more highly concentrated in coal than in the ore zones (group 1), it probably was concentrated principally by plants.

The examples that follow illustrate the interpretive procedure.

Silicon.—Silicon originated as a lean concentration in inorganic sedimentary constituents because it occurs in group (3) in samples with low-uranium content from Lonesome Pete ore zone. For all the samples it is classified in group (3) (less than crustal abundance), in group 2 (equally concentrated in the coal and in the noncoals), and in group B (independent of uranium). It was not concentrated by the coal-forming plants. It was not affected by non-uranium-bearing ground water (Eocene), or by uranium-bearing ground water (Oligocene through early Pleistocene) in any of the samples.

Aluminum.—Aluminum originated as a normal concentration in inorganic sedimentary constituents (classified in group (2) in the low-uranium samples from Lonesome Pete ore zone). It is classified in groups (1), 1, and B and in groups (1), 3, and B in the coal, in groups (1), 3, and B in the Carbonate ore zone, and in groups (2), 1, and A in the Lonesome Pete ore zone. It was concentrated in coal by plants. Aluminum is independent of uranium in the Carbonate ore zone; thus, the increase in aluminum content from originally being equal to crustal abundance to presently being greater than crustal abundance is probably due to Eocene ground-water action. The direct relation of aluminum to uranium in the Lonesome Pete ore zone suggests that it was deposited by uranium-bearing ground water. The aluminum in this zone may be contained in the analcite spherulites that contain significant amounts of uranium (see chap. A, p. A48).

Iron.—Iron originated as a lean concentration in inorganic sedimentary constituents. It is classified in groups (2), 1, and A in the coal, and in groups (3), 1, and B in the noncoals. It was enriched in coal by plant action (it is more highly concentrated in the coal than in the noncoals), but it was further enriched by uranium-bearing ground water (it is directly related to uranium). Iron in the noncoals was not appreciably affected by ground-water action.

Potassium.—Potassium originated as a normal concentration in inorganic sedimentary constituents. It occurs in groups (3), 3, and B in the coal, and in groups (2), 3, and B in the noncoals. It may have been impoverished by plant action and (or) leached by non-uranium-bearing ground water in the coal. The possibility that potassium was extracted from the swamp sediments, was converted into a more soluble form by plants, and was lost by solution after the death and decay of the plants is suggested by the lack of evidence that the potassium was leached from the coal by ground water. Potassium is not related to uranium in any of the sample suites, and it is not reasonable to suppose that non-uranium-bearing ground water would leach potassium from the coal beds but not from the Carbonate ore zone, which by its stratigraphic position must have been equally exposed to ground-water action.

Gallium.—Gallium originated as a rich concentration in inorganic sedimentary constituents. It is classified in groups (1), 3, and A in the coal and in groups (1), 3, and B in the noncoals. It was further enriched by uranium-bearing ground water in the coal and by non-uranium-bearing ground water in the noncoals. It was not affected by uranium-bearing ground water in either of the noncoals.

Germanium.—Germanium originated as a lean concentration in inorganic sedimentary constituents. It is classified in groups (1), 1, and A in the coal and in groups (2), 1, and B in the noncoals. It was concentrated by plants and was further enriched by uranium-bearing ground water in the coal. It was enriched by non-uranium-bearing ground water in the noncoals. It was unaffected by uranium-bearing ground water in either of the noncoals.

Lanthanum, and neodymium.—These elements originated as normal concentrations in inorganic sedimentary constituents. They are classified in groups (2), 2, and A in coal and in groups (2), 2, and B in the noncoals. They were enriched by uranium-bearing ground water in the coal, but they were unaffected by any ground water in the noncoals.

SUMMARY OF SECOND METHOD OF INVESTIGATION

The results of the second method of investigation are summarized in table 14 (p. B48) in those columns headed by the numeral 2.

THIRD METHOD OF INVESTIGATION

In the third method of investigation the trace-element content was compared for the organic and inorganic separates of four selected coal samples. This comparison gives information about the relation of the concentrations of elements to lithology.

The abundances of elements were compared for two sample groups—one group having the minimum uranium content, the other having the maximum uranium content. This comparison gives information about the relations of various concentrations of elements to uranium.

RELATIONS OF ELEMENTS TO LITHOLOGY

Sprunk and O'Donnell (1942, p. 2) stated that coal "contains elements that have been assimilated by the living plant, such as iron, phosphorus, sulphur, calcium, potassium, and magnesium." On page 3 they further stated that, "The quantity of inherent mineral matter in coal is comparatively small. If a coal contained only inherent mineral matter it would have about 2 percent or less ash; in some instances the ash would be less than 1 percent." Francis (1954, p. 484) stated, "The quantity of inorganic matter in plants is usually small, on the average less than 2% * * *." Likewise, Marshall (1955, p. 815) stated, "Inherent mineral matter of plants (plant ash) as represented in analyses of vitrain free of mechanically or chemically deposited mineral ranges from less than 2 percent to as little as 0.1 percent."

The large average percentages of Si, Al, Fe, Mg, Ca, and Na in coal ash shown in figures 3–5, as compared to the average amount (2 percent) attributable to inherent inorganic matter in coal, suggest that the bulk of these elements originated as concentrations in the inorganic sedimentary constituents of the coal and (or) were deposited by ground water after coalification. If the maximum concentrations are considered, the elements K, As, Mo, and U (figs. 2, 6, 8, 13) also could have originated as sedimentary constituents and (or) enrichment from ground water in at least some of the samples.

The data on coal samples in their float separates and sink separates shown in table 13 can be used in further investigation of this line of thought. The increase in average abundance of certain elements in the low-uranium content float samples relative to their abundance in the low-uranium content unseparated samples is directly related to the efficiency of the separation. It is inversely related to ash content (42.5 percent ash in the unseparated low-uranium samples to 17.5 percent ash in the low-uranium float separates). If this proportional increase is extrapolated to a hypothetical low-uranium content float separate containing only inherent ash (completely free of minerals), the resulting estimated amounts of these elements contained in the inherent ash still are much smaller than the amounts of these elements in the ash of the unseparated samples low in uranium content. Therefore, all the elements detected in the coal samples presumably must have been concentrated in the coal, at least in part, by inorganic sedimentation while the plant debris that later formed coal was accumulating, and (or) by circulating ground water after the coal was formed.

From chemical analyses of the float and sink separates of a coal sample containing a moderate amount of U from the Mendenhall coal zone in the Slim Buttes area, Breger, Deul, and Rubinstein (1955, p. 210) showed, among other things, that most of the uranium is held in the organic fraction of the coal. Semiquantitative spectrographic analyses of the float and sink separates (p. 213) indicated that the elements Al, Fe, Na, Mg, Ti, Mn, As, B, Be, Co, Cr, Mo, Ni, Sc, and Zr were more highly concentrated in the float (mainly organic) fraction of the coal sample.

Similar, but less complete, specific-gravity separations of four coal samples from the Cave Hills area were made in the present study. Two samples of contrasting uranium content from the coal bed F and two similar samples from coal zone C were treated. After obvious visible mineral impurities were removed by hand, each sample was sieved to the -18 $+60$ sieve-size fraction. A split of each sieved sample was then separated into a >1.7 specific-gravity sink fraction and a <1.7 specific-gravity float fraction. Determinations of the amount of ash indicate that the float fractions consist principally of organic material and the sink fractions of inorganic material. The amount and partial composition of the ash from chemical and radioactivity analyses are shown in table 12. Table 13 shows the average abundance of elements in the four sieved samples, in their float-sink separates, and in the high-uranium and low-uranium samples within each sample group on the basis of semiquantitative spectrographic analyses.

TABLE 12.—*Chemical and radioactivity analyses, in percent, of four coal samples and of their specific gravity separates*

Percentage of uranium in ash calculated from percentage of ash and percentage of uranium in sample. See table 16 for other data.

[Analyses by J. J. Warr, Grafton Daniels, and F. S. Grimaldi, U.S. Geol. Survey lab., Washington, D.C.]

Sample No. (table 16)	Laboratory No.	Coal zone	Ash	U in ash	U in sample	eU in sample
Sieved coal samples [−18 +60 sieve fraction]						
1	145297A	F	42	0.46	0.195	0.20
4a	148819A	F	50	.008	.0038	.0032
83	149354A	C	37	.54	.20	.091
69b	148790A	C	35	.005	.0019	.0018
Float separates <1.7 specific gravity [Mainly organic material]						
1	145297B	F	21	1.1	0.23	0.22
4a	148819B	F	15	.04	.006	.0028
83	149354B	C	24	1.8	.43	.20
69b	148790B	C	20	.013	.0025	.0016
Sink separates >1.7 specific gravity [Mainly inorganic material]						
1	145297C	F	87	0.044	0.038	0.30
4a	148819C	F	79	.002	.0014	.0028
83	149354C	C	67	.04	.026	.099
69b	148790C	C	71	.002	.0012	.0014

The elements detected in coal can be divided into three groups by comparison of the averages shown in the low-uranium float and sink separates in table 13:

1. *Elements more highly concentrated in the float (mainly organic) separate:*
   Fe, Mg, Mn(?), B, Ba, Be, Co, Cu, La, Ni, Pb, Sn, Y, Yb, and Zr.
2. *Element more highly concentrated in the sink (mainly inorganic) separate:*
   K.
3. *Elements whose concentrations in both separates seem about equal:*
   Si, Al, Ca, Na, Ti, Ag, As, Cr, Ga, Mo, Nd, Sc, Sr, and V.

The list of elements in group 1 is similar to that cited previously from Breger, Deul, and Rubinstein and very similar to the list of elements in coal that was concentrated in whole or in part by plant action as determined from the first method of investigation, group 1, p. B24. Potassium is more highly concentrated in the sink separate; this relation is in agreement with the conclusion reached in the first method of investigation that K originated in whole or in part as a rich inorganic sedimentary constituent of coal.

Only the float and sink separates of the samples low in uranium content were compared in the foregoing groups, inasmuch as the effect of uranium-bearing ground water on the composition of these samples was minimal. Therefore, these elements can be interpreted and characterized with regard to their origin in coal in a manner similar to that used in the first method of investigation as follows:

1. Elements that originated as lean concentrations in the inorganic sedimentary constituents of coal and were concentrated in coal by plant action and (or) by circulating ground water:
   Fe, Mg, Mn?, B, Ba, Be, Co, Cu, La, Ni, Pb, Sn, Y, Yb, and Zr.
2. Elements that originated as rich concentrations in inorganic sedimentary constituents and (or) were concentrated by circulating ground water.
   K.
3. Elements that originated as normal concentrations in inorganic sedimentary constituents:
   Si, Al, Ca, Na, Ti, Ag, As, Cr, Ga, Mo, Nd, Sc, Sr, and V.

RELATIONS OF ELEMENTS TO URANIUM

In the first two methods of investigation comparisons were made between groups comprised of large but unequal numbers of samples whose uranium contents differed by factors ranging from 37 in the Carbonate ore zone to 57 in the Lonesome Pete ore zone. In this method sample groups of equal size (although much smaller) are compared, and the uranium contents of these samples differ by factors ranging from 130 in the Lonesome Pete ore zone (fig. 22) to as much as 700 in certain of the coal beds (fig. 20).

Figures 19–22 show the difference in range and average concentration of elements in the samples that are high in uranium content and in those that are low. Differences and similarities in ranges and averages between the samples high in uranium content (top line) and those of the samples low in uranium content are readily apparent. For comparison these differences are expressed as enrichment factors and are shown in a column at the right of each diagram.

These factors are obtained by dividing the larger average by the smaller; where the average of the samples low in uranium content is larger than that of the samples high in uranium content, the enrichment factor is considered negative. The meaning of positive and negative enrichment factors may be expressed another way—as the uranium content increases, the element considered also increases (direct); or as the uranium content increases, the element considered decreases (inverse).

Krauskopf (1955, p. 418), in discussing enrichment of the minor elements in coal ash with respect to crustal abundance, considered that enrichment factors less than 3 probably had little significance.

The test used here to ascertain the significance of the difference between averages of the sample groups being compared is that of Lord (1947, p. 66), shown in slightly modified form in table 22 (p. B74). The test measures the probability of relations both in the second and third methods of investigations. It makes direct use of the ranges of the samples involved and is

TABLE 13.—*Average abundance of elements, in percent, in four sieved coal samples, in their float*

[Analyses by H. W. Worthing, U.S. Geol. Survey lab., Washington, D.C. 0, not detected. Query (?), not detected in some samples. Figure in parentheses (.05), not de- ages from semiquantitative spectrographic analyses. Elements in table 1 not listed here were looked for, but not

Sample No.	Lab. No.	U	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag	As	B	Ba
Sieved coal samples [−18 +60 sieve fraction]															
1	145297A	0.3	>10	>10	3	3	>10	7	0	0.3	0.015	0.00015	3	0.03	1.5
83	149354A	.7	>10	7	>10	1.5	3	3	0	.15	.015	.00015	1.5	.007	.15
Average		.5	15	11	9	2	9	5	(.05)	.2	.015	.00015	2	.02	.8
4a	148819A	0	>10	>10	3	1.5	3	7	0.7	.7	.07	.00015	.07	.015	.07
69b	148790A	0	7	7	7	1.5	>10	3	1.5	.15	.03	.00015	.15	.015	.7
Average		.007	11	11	5	1.5	9	5	1.1?	.4	.05	.00015	.1	.015	.4
Average of all samples		.3	13	11	7	2	9	5	.6?	.3	.03	.00015	1	.015	.6
Float separates < 1.7 specific gravity [Mainly organic material]															
1	145297B	0.7	7	>10	7	7	>10	7	0.7	0.3	0.015	0.0003	3	0.15	0.15
83	149354B	1.5	>10	>10	>10	3	1.5	3	0	.3	.03	.0003	1.5	.03	.015
Average		1.5	11	15	11	5	8	5	.4?	.3	.02	.0003	2	.09	.08
4a	148819B	.03	>10	>10	3	7	>10	7	0	.7	.15	.0003	0	.07	.3
69b	148790B	.03	3	>10	>10	3	1.5	7	.7	.3	.07	.0015	.07	.03	.3
Average		.03	9	15	9	5	8	7	.4?	.5	.1	.0009	.04	.05	.3
Average of all samples		.7	10	15	10	5	8	6	.075?	.4	.07	.0006	1	.07	.2
Sink separates > 1.7 specific gravity [Mainly inorganic material]															
1	145297C	0.03	>10	>10	1.5	0.7	0.7	7	0	0.15	0.007	0.00003	0.3	0.007	3
83	149354C	.03	7	1.5	>10	.3	>10	3	3	.15	.03	.00003	1.5	.007	.7
Average		.04	11	8	8	.5	8	5	1.5?	.15	.02	.00003	.9	.007	2
4a	148819C	0	>10	>10	1.5	.7	.7	7	0.7	.3	.07	.0007	.07	.015	.07
69b	148790C	0	7	1.5	3	.3	>10	.7	1.5	.15	.007	.0003	.07	.007	.15
Average		.002	11	8	2	.5	8	4	1	.2	.04	.0005	.07	.01	.1
Average of all samples		.02	11	8	5	.5	8	4	1.5	.2	.03	.0003	.5	.009	1

much simpler than other methods usually employed in ascertaining the statistical significance of the difference between two sample means. Although Lord's test is less precise than some of the more elaborate statistical tests of significance, it is quite adequate for, and admirably suited to, the present study. It was designed for the testing of small groups of samples (it becomes relatively inefficient when more than 20 samples comprise the group being tested), and the calculations are few, simple, and quickly performed. A brief explanation of the test and its application in the present study is given under "Test for significance," p. B74.

It is clear from the calculations used in Lord's test that, other things being equal, the range (denominator in the formula) is critical in determining the significance of the observed difference between averages of two sample groups. Thus, although the enrichment factors of two elements might be the same, the factor may be significant for one but not for the other, the significance depending on the range of the samples.

Because of the uncertainties of averages and ranges undoubtedly present in any computations based on a relatively small number of semiquantitative spectrographic analyses, the results shown in the following table derived from data in figures 19–22 were tempered by adopting, in addition, Krauskopf's estimate that enrichment factors less than 3 are of doubtful significance. Thus, in the table on page B46 if the difference between averages is significant according to Lord's test, and if one average exceeds the other by a factor of 3 or more, the relation to uranium is indicated as ⊕ (positively related) or ⊖ (negatively related.) If the relation meets one criterion but not the other, it is indicated by an uncircled + or −. If neither of the *separates and sink separates, and in the high-uranium and low-uranium pairs of samples in each group*

tected; average is assumed to be one-half the minimum amount normally detectable (table 1). Uranium and ash averages from chemical analyses (table 12). Other averfound, except F, which was not looked for. See table 16 for other data]

Be	Co	Cr	Cu	Ga	La	Mo	Nd	Ni	Pb	Sc	Sn	Sr	V	Y	Yb	Zr	Ash
Sieved coal samples—Continued [−18+60 sieve fraction]																	
0. 0015 . 0003	0. 015 . 003	0. 007 . 003	0. 03 . 015	0. 003 . 003	0. 015 0	0. 007 . 07	0. 03 0	0. 07 . 015	0. 03 . 007	0. 007 . 0015	0 0. 0015	0. 7 . 07	0. 015 . 015	0. 03 . 003	0. 003 . 0003	0. 03 . 07	42 37
. 0009	. 009	. 005	. 02	. 003	. 008?	. 04	. 015?	. 04	. 02	. 004	. 0009?	. 4	. 015	. 015	. 0015	. 05	39. 5
. 0003 . 0003	. 03 . 003	. 007 . 003	. 007 . 015	. 003 . 0015	. 003 0	. 007 . 015	. 015 0	. 03 . 015	. 015 . 007	. 0015 . 0015	0 . 0007	. 07 . 03	. 015 . 007	. 007 . 007	. 0007 . 0007	. 03 . 03	50 35
. 0003	. 015	. 005	. 01	. 002	. 002?	. 01	. 009?	. 02	. 01	. 0015	. 0005?	. 05	. 009	. 007	. 0007	. 03	42. 5
. 0006	. 015	. 005	. 015	. 003	. 005?	. 02	. 015?	. 03	. 015	. 003	. 0007?	. 2	. 015	. 01	. 001	. 04	41
Float separates < 1.7 specific gravity—Continued [Mainly organic material]																	
0. 003 . 0015	0. 03 . 003	0. 015 . 007	0. 07 . 07	0. 003 . 003	0. 015 . 003	0. 007 . 3	0. 03 . 015	0. 3 . 015	0. 07 . 003	0. 007 . 0015	0. 0007 . 003	1. 5 . 03	0. 015 . 007	0. 03 . 007	0. 003 . 0007	0. 15 . 15	21 24
. 002	. 015	. 01	. 07	. 003	. 009	. 15	. 02	. 15	. 04	. 004	. 002	. 8	. 01	. 02	. 002	. 15	22. 5
. 0015 . 0007	. 07 . 007	. 015 . 007	. 03 . 015	. 007 . 0015	. 007 . 007	. 015 . 03	. 015 . 03	. 15 . 03	. 03 . 007	. 003 . 0015	. 0007 . 003	. 7 . 07	. 007 . 003	. 015 . 015	. 0015 . 0015	. 15 . 15	15 20
. 001	. 04	. 01	. 02	. 004	. 007	. 02	. 02	. 09	. 02	. 002	. 002	. 4	. 005	. 015	. 0015	. 15	17. 5
. 0015	. 03	. 01	. 07	. 004	. 008	. 09	. 02	. 1	. 03	. 003	. 002	. 6	. 008	. 015	. 0015	. 15	20
Sink separates < 1.7 specific gravity—Continued [Mainly inorganic material]																	
0. 0003 . 00015	0. 003 0	0. 003 . 003	0. 0015 . 0015	0. 0015 . 003	0. 007 . 003	0. 007 . 07	0 0. 015	0. 015 . 007	0. 007 . 015	0. 0015 . 0003	0 0. 003	0. 15 . 15	0. 007 . 015	0. 003 . 0015	0. 0003 . 00015	0. 015 . 015	87 67
. 0002	. 002?	. 003	. 0015	. 002	. 005	. 04	. 009?	. 01	. 01	. 0009	. 002?	. 15	. 01	. 002	. 0002	. 015	77
. 00015 . 00015	. 015 0	. 007 . 0015	. 0015 . 003	. 003 . 0015	0 . 003	. 007 . 015	0 . 015	. 015 . 003	. 007 . 0015	. 0015 . 0003	0 0	. 03 . 015	. 007 . 007	. 0015 . 0015	. 00015 . 00015	. 015 . 007	79 71
. 00015	. 008?	. 004	. 002	. 002	. 002?	. 01	. 009?	. 009	. 004	. 0009	(. 0005)	. 02	. 007	. 0015	. 00015	. 01	75
. 0002	. 005?	. 004	. 002	. 002	. 004?	. 02	. 009?	. 01	. 008	. 0009	. 001?	. 09	. 009	. 002	. 0002	. 015	76

criteria is met and the averages are the same, the element in question is assumed to be independent of uranium and the relation is indicated by the symbol 0. If neither of the criteria is met, but there is nevertheless a difference in the averages, the direction of this difference is indicated by the symbols 0+ or 0−. ND means not detected.

For some elements (such as P, Mn, Ba, La, Sr, and Yb) individual results are weakly suggestive of a possible relation to uranium; however, all show a consistent relation to uranium, and collectively, the significance has a minimum probabilty of 93–94 percent even if the individual indicated relations had only a 50–50 chance of being significant.

The relations of the following elements to uranium are based on the results of the third method of investigation and seem to be as follows:

A. *Elements directly related to uranium:*

In coal—Fe?, P, As, Ba?, Be?, Cu?, Ge?, La, Mo, Nd?, Pb, Sc?, Sn, Sr, V?, Y?, Yb, and Zr.

In noncoals—Ca, P, Ba?, La, Mo, Sr, V, Y, Yb, and Zr. (Al?, Cr, and Ni? are positive in the Lonesome Pete ore zone only.)

B. *Elements independent of uranium:*

In coal—Si, Mg?, Ca, Na, Ti, Co?, Ga, and Ni.

In noncoals—Si, Fe, Mg, Na, K, Ag, B, Be, Co, Ga, Pb, and Sc.

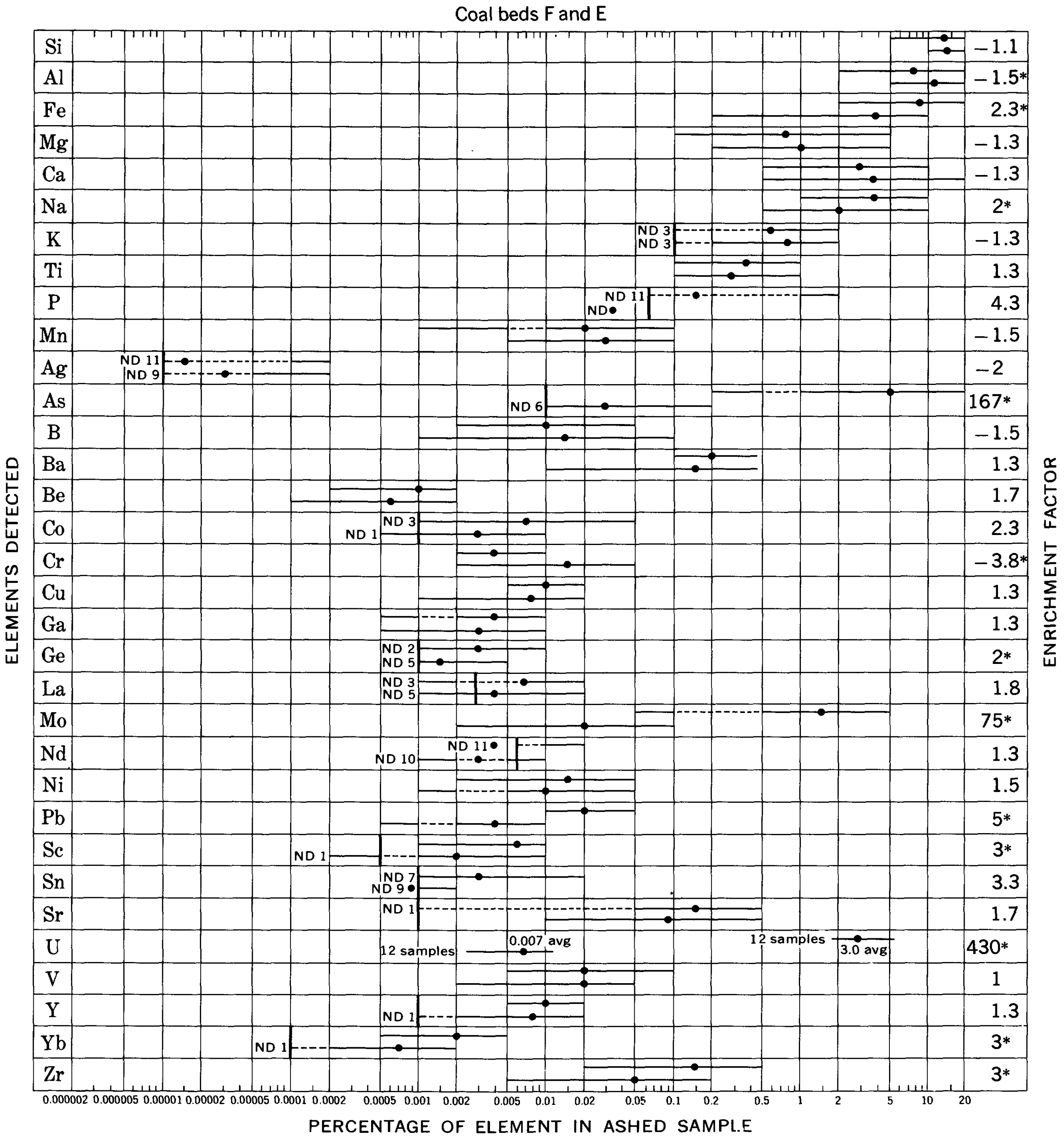
(Al, Ti, As, Cr, and Sn are independent of uranium in the Carbonate ore zone only.)

C. *Elements inversely related to uranium:*

In coal—Al?, K?, Mn, Ag, B, and Cr.

In noncoals—Mn and Cu.

(Ti and As are negative in the Lonesome Pete ore zone only, and Ni is negative in the Carbonate ore zone only.)



EXPLANATION

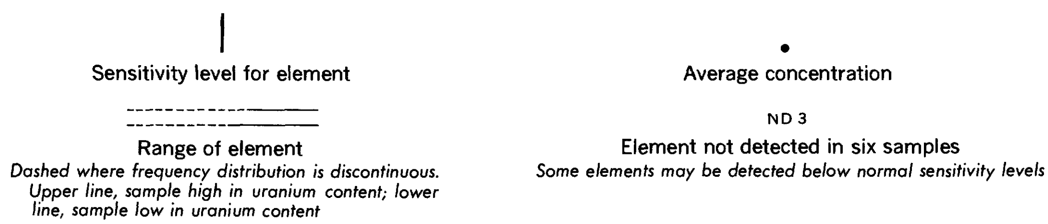


FIGURE 19.—Concentration of elements in 24 ashed coal samples of contrasting uranium content from coal beds F and E of the Tongue River Member of the Fort Union Formation. Semiquantitative spectrographic analyses, except uranium, determined by wet chemical methods. Enrichment factor is number of times one average exceeds the other; if low-uranium average is greater, factor is negative. Asterisk (*) indicates that the difference between averages is 90 percent or more significant. Elements not detected are assumed to be one-half the minimum amount normally detectable. Samples high in uranium content: Nos. 5T, 12, 13, 14, 17T, 25T, 29, 31, 32, 61T (table 15); 32, 62 (table 16). Samples low in uranium content: Nos. 3T–6T, 13, 16TT, 57, 61 (table 16); 64, 79 (table 15).

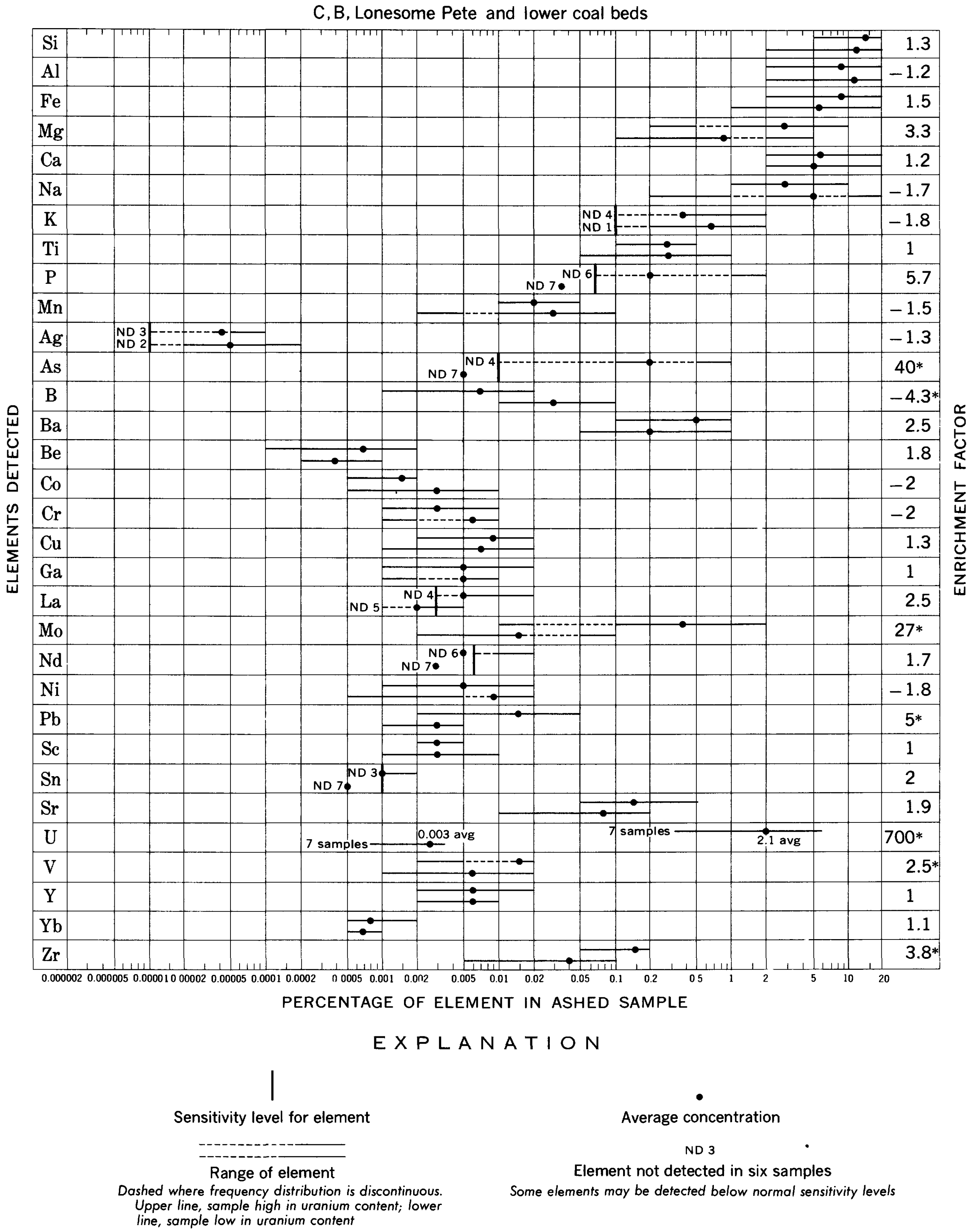


FIGURE 20.—Concentration of elements in 14 ashed coal samples of contrasting uranium content from coal beds C and B, the Lonesome Pete coal zone, and the lower coal beds of the Ludlow Member of the Fort Union Formation. Semiquantitative spectrographic analyses, except uranium, determined by wet chemical methods. Enrichment factor is number of times one average exceeds the other; if low-uranium average is greater, factor is negative. Asterisk (*) indicates that the difference between averages is 90 percent or more significant. Elements not detected are assumed to be one-half the minimum amount normally detectable. Samples high in uranium content: Nos. 8B, 14 15, 18T (table 15); 82a, 83, 85B (table 16). Samples low in uranium content: Nos. 92B, 95B, 96a, 97B, 114, 117, 118T (table 16).

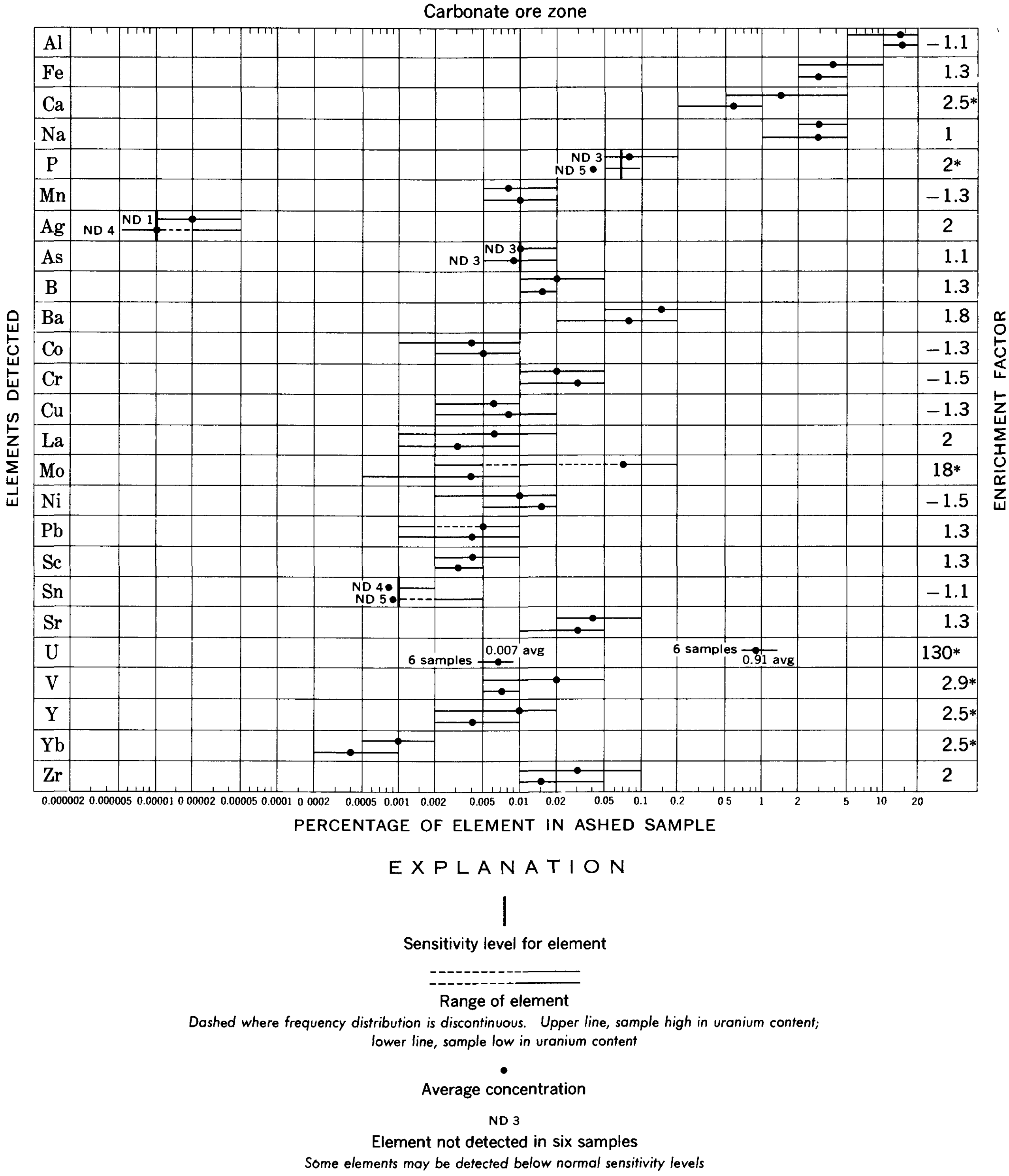
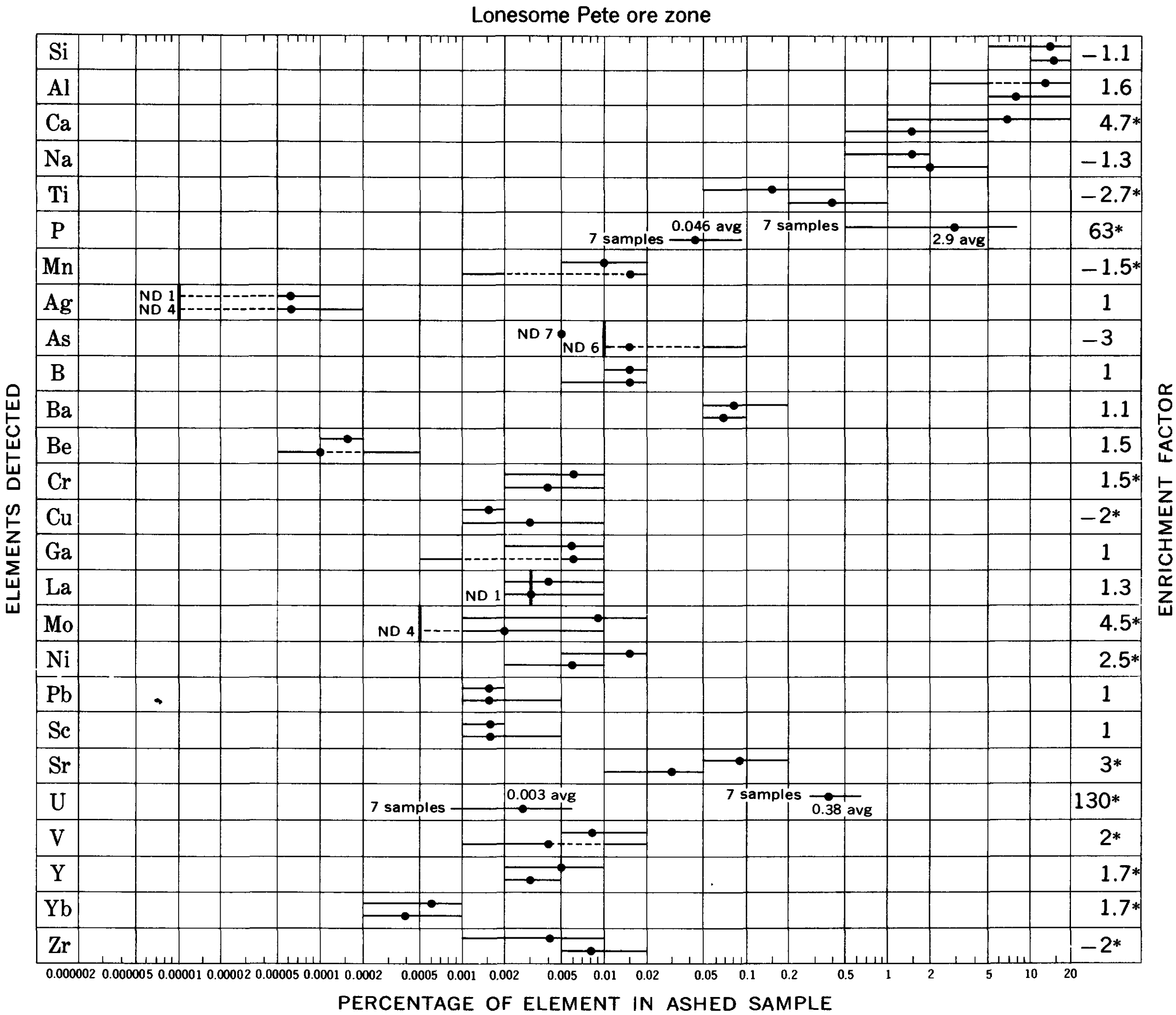


FIGURE 21.—Concentration of elements in 12 ashed samples of carbonaceous siltstone of contrasting uranium content from the Carbonate ore zone in the Ludlow Member of the Fort Union Formation. Semiquantitative spectrographic analyses, except uranium, determined by wet chemical methods: Si, Mg, K, Ti, Be, and Ga were detected, but they are not shown here because they show no differences in range or in average concentration. Enrichment factor is number of times one average exceeds the other; if low-uranium average is greater, factor is negative. Asterisk (*) indicates that the difference between averages is 90 percent or more significant. Elements not detected are assumed to be one-half the minimum amount normally detectable. Samples high in uranium content: Nos. 13, 19, 21, C6, C8, C11 (table 17). Samples low in uranium content: Nos. 8, 33, 35, C1, C2, C3 (table 17).



EXPLANATION

Sensitivity level for element

Range of element

Dashed where frequency distribution is discontinuous. Upper line, sample high in uranium content; lower line, sample low in uranium content

Average concentration

ND 3

Element not detected in six samples

Some elements may be detected below normal sensitivity levels

FIGURE 22.—Comparison of range and average concentration of elements in 14 ashed samples of phosphatic silty claystone of contrasting uranium content from the Lonesome Pete ore zone in the Ludlow Member of the Fort Union Formation. Semiquantitative spectrographic analyses, except phosphorus and uranium, determined by wet chemical methods. Fe, Mg, K, and Co were detected, but they are not shown here because they show no differences in range or in average concentration. Enrichment factor is number of times one average exceeds the other; if low-uranium average is greater, the factor is shown as negative. Asterisk (*) indicates that the difference between averages is 90 percent or more significant. Elements not detected are assumed to be one-half the minimum amount normally detectable. Samples high in uranium content: Nos. 4, 7, 19, 24, 31, 34, 47 (table 18). Samples low in uranium content: Nos. 10, 14, 22, 24, 26, 28, 64 (table 19).

Element	Coal beds F and E	Coal beds C and B, Lonesome Pete coal zone, and lower coal beds	Carbonate ore zone	Lonesome Pete ore zone	Separates (table 13)	
					Float	Sink
Si	O−	O+	O	O−	O+	O
Al	−	O−	O−	+	O	O
Fe	+	O+	O+	O	O+	+
Mg	O−	⊕	O	O	O	O
Ca	O−	O+	+	⊕	O	O
Na	+	O−	O	O−	O−	O+
K	O−	O−	O	O	O	O−
Ti	O+	O	O	−	O−	O−
P	+	+	+	⊕	ND	ND
Mn	O−	O−	O−	−	−	O−
Ag	O−	O−	O+	O	O−	⊖
As	⊕	⊕	O+	−	⊕	+
B	O−	⊖	O+	O	O+	O−
Ba	O+	+	O+	O+	⊖	+
Be	+	O+	O	O+	O+	O+
Co	O+	O−	O−	O	O−	−
Cr	⊖	−	O−	+	O	O−
Cu	O+	O+	O−	−	⊕	O−
Ga	O+	O	O	O	O−	O
Ge	+	ND	ND	ND	ND	ND
La	O+	+	O+	O+	O+	O+
Mo	⊕	⊕	⊕	⊕	+	+
Nd	O+	O+	ND	ND	ND	ND
Ni	O+	O−	−	+	O+	O+
Pb	⊕	⊕	O+	O	O+	O+
Sc	⊕	O	O+	O	O+	O
Sn	+	+	O−	ND	O	+
Sr	O+	O+	O+	⊕	O+	⊕
V	O	+	+	+	O+	O+
Y	O+	O	+	+	O+	O+
Yb	⊕	O+	+	+	O+	O+
Zr	⊕	⊕	+	+	O	O+

In the ore zone samples Ge and Nd were not detected. These elements may have an affinity principally for coal inasmuch as they do not seem to be concentrated in the ores even in the samples high in uranium content. The relation of Sn to U in the Lonesome Pete ore zone could not be determined; Sn was not detected in either of the sample suites chosen for comparison (fig. 22).

SUMMARY OF THIRD METHOD OF INVESTIGATION

The origin of the elements that appear in both the numbered groups (p. B39) and the capital-lettered groups (p. B41) tentatively can be interpreted as follows:

1A. *Lean in inorganic sedimentary constituents, concentrated in coal by plants, enriched by ground water in all samples*:
   In coal—Fe?, Ba?, Be?, Cu?, La, Pb, Sn, Y?, Yb, and Zr. In carbonaceous siltstone (Carbonate ore zone)—Ba?, La, Y, Yb, and Zr.
   In phosphatic siltstone (Lonesome Pete ore zone)—Ba?, La, Ni?, Y, Yb, and Zr.

1B. *Lean in inorgaic sedimentary constituents, concentrated in coal by plants, unaffected by ground water in any samples*:
   In coal—Mg?, Co?, and Ni.
   In carbonaceous siltstone (Carbonate ore zone)—Fe, Mg, B, Be, Co, Pb, and Sn.
   In phosphatic siltstone (Lonesome Pete ore zone)—Fe, Mg, B, Be, Co, and Pb.

1C. *Lean in inorganic sedimentary constituents, concentrated in coal by plants, leached by ground water in all samples*:
   In coal—Mn?, and B.
   In carbonaceous siltstone (Carbonate ore zone)—Mn?, Cu, and Ni.
   In phosphatic siltstone (Lonesome Pete ore zone)—Mn? and Cu.

2A. *Rich in sedimentary constituents, further enriched by ground water*:
   None.

2B. *Rich in sedimentary constituents, unaffected by ground water*:
   In coal—None.
   In carbonaceous siltstone (Carbonate ore zone)—K.
   In phosphatic siltstone (Lonesome Pete ore zone)—K.

2C. *Rich in inorganic sedimentary constituents, leached by ground water*:
   In coal—K?.
   In carbonaceous siltstone (Carbonate ore zone)—None.
   In phosphatic siltstone (Lonesome Pete ore zone)—None.

3A. *Normal in inorganic sedimentary constituents, enriched by ground water*:
   In coal—As, Mo, Nd?, Sc?, Sr, and V?.
   In carbonaceous siltstone (Carbonate ore zone)—Ca, Mo, Sr, and V.
   In phosphatic siltstone (Lonesome Pete ore zone)—Al?, Ca, Cr, Mo, Sr, and V.

3B. *Normal in inorganic sedimentary constituents, unaffected by ground water*:
   In coal—Si, Ca, Na, Ti, and Ga.
   In carbonaceous siltstone (Carbonate ore zone)—Si, Al, Na, Ti, Ag, As, Cr, Ga, and Sc.
   In phosphatic siltstone (Lonesome Pete ore zone)—Si, Na, Ag, Ga, and Sc.

3C. *Normal in inorganic sedimentary constituents, leached by ground water*:
   In coal—Al?, Ag, and Cr.
   In carbonaceous siltstone (Carbonate ore zone)—None.
   In phosphatic siltstone (Lonesome Pete ore zone)—Ti and As.

Phosphorus was not detected in the float and sink coal separates (table 13). However, because it is positively related to uranium in the other coal sample suites (see table, col. 1, and group A, p. B41), it presumably was enriched by uranium-bearing ground water and was in low (lean) concentration in the inorganic sedimentary constitutents of the coal.

The results of the third method of investigation are summarized in table 14 (p. B48), in those columns headed by the numeral 3.

CONCLUSIONS

In table 14 below, the results of all three methods of investigation are listed and interpreted. Where more than one interpretation was made concerning the origin and later history of the concentration of an element, a consensus column was added that is a reasonable evaluation of the immediately preceding pertinent columns.

Conclusions as to how and when elements were concentrated in the samples studied are obtained for each element listed in table 14 by reading, from left to right, the pertinent individual or consensus columns. For example, boron (B) was concentrated by coal-forming plants rather than by sedimentation during Paleocene time; its concentration in the inorganic sedimentary constituents was lean. It was leached from the coal to some extent by uranium-bearing circulating ground water during post-Paleocene to late Pleistocene time, but it was enriched in coal by circulating ground water during late Pleistocene to Recent time regardless of whether the ground water was depositing or was leaching uranium. The boron content of the noncoaly samples was not affected by uranium-bearing ground water in post-Paleocene to late Pleistocene time.

As another example, arsenic (As) and molybdenum (Mo) have nearly identical histories in coal. There is little indication that either of them was concentrated by plants; rather, the evidence strongly indicates that both were enriched in coal by uranium-bearing ground water circulating during post-Paleocene to late Pleistocene time. Both were leached to some extent from the coal by ground water during late Pleistocene to Recent time, particularly by ground water that was also leaching uranium.

A feature of interest that should be noted in the behavior of elements in columns shown under the heading "Late Pleistocene to Recent" (last 5 cols., table 14; cols. d–g, table p. B34) is that although many elements were leached with uranium (col. 5 from the right, table 14) none of them was redeposited with uranium (col. 2 from the right, table 14). This feature suggests that ground-water conditions favoring deposition of iron (Fe), arsenic (As), molybdenum (Mo), and zirconium (Zr) along with uranium during the early epigenetic (post-Paleocene through early Pleistocene) history of the area changed, so that beginning with late Pleistocene time these elements when leached with uranium were not redeposited with uranium. Most of these elements either have been redeposited and are being redeposited in stratigraphic units not considered here or, more probably, gradually are being lost permanently to this area.

It is reasonable to suppose in general that syngenetic elements were concentrated in coal and other host rocks under reducing conditions, that rocks exposed, or near the surface, during late Eocene erosion were leached of certain elements under oxidizing conditions, and that at least a part of the elements so leached were redeposited in more deeply buried rocks under reducing conditions. It is probable that the Paleocene host rocks generally remained buried during most of Oligocene, Miocene, and possibly Pliocene and early Pleistocene time, and that erosional periods during this time resulted in leaching of uranium and other related elements from the younger rocks under oxidizing conditions and redeposition in older rocks under reducing conditions. The last 500,000 years, judged from the presence and stratigraphic distribution of radioactivity equilibrium in samples (chap. A, fig. 27), was characterized by continual erosion and progressive lowering of the water table. At least some of the elements that were leached from host rocks under oxidizing conditions were redeposited in stratigraphically lower host rocks.

With regard to geochemical environments that may have existed at one time in rocks of the Cave Hills area, Dr. G. O. W. Kremp (then palynologist of the Coal Research laboratory, Pennsylvania State Univ.) concluded from the high solubility of much of the organic matter and from the destruction of the very resistant pollen and spore material in coal bed E (especially evident in samples from the Riley Pass area of the North Cave Hills) that the coal must have been exposed to alkaline, oxidizing solutions (White, 1958, p. 65). Logically, these effects on the coal probably occurred penecontemporaneously with the formation of analcite in rocks of this area, principally during Miocene time.

The extent of leaching or enrichment by ground water should be considered in choosing samples to be used in any compilation of data for obtaining an average elemental abundance in a given rock type in the earth's crust. The importance of this consequence can be understood by considering the effects of ground water on the elemental composition of samples studied here. This consideration seems especially important for Tertiary coals overlain by younger Tertiary tuffaceous rocks. High concentrations of the elements Fe, P, As, La, Mo, Nd, Pb, V, and U in particular seem to have an epigenetic origin.

A comparison of the average late diagenetic abundance of elements in coal (based on samples unaffected by ground water) with the composition of the modern descendants of coal-forming plants would indicate what changes in elemental composition occur after the death and decay of plants and before coalification.

Average abundance of elements in the earth's crust, or in a particular rock type in the earth's crust, based on subsurface samples collected from zones not near erosional unconformities undoubtedly would be more reliable than abundance of elements based on surface samples.

TABLE 14.—*Geochemical history of elements in*

[*, very strong direct correlation; ×, strong direct correlation; ×?, weak

	Paleocene																Post-Paleocene to late Pleistocene							
	Syngenetic																Early epigenetic agent							
	Plant processes				Sedimentation												Circulating ground water							
	Organic constituents				Inorganic sedimentary constituents												Leached							
Effect	Enriched [1]				Lean [2]				Normal				Rich											
Host	Coal				Coal and noncoals				Coal and noncoals				Coal and noncoals				Coal				Noncoals			
Method of investigation	1	2	3	Concensus	1	2[3]	3	Concensus	1	2[3]	3	Concensus	1	2[3]	3	Concensus	1	2	3	Concensus	1	2	3	Concensus
Si	0	0	0	0	0	×	0	0	×	0	×	×	0	0	0	0	0	0	0	0	0	0	0	0
Al	0	×	0	0	0	0	0	0	×	×	×	×	0	0	0	0	0	0	×?	0	0	0	0	0
Fe	×	×	×	×	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mg	×	0	×	×	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca	×	×	0	×	×	×	0	×	0	0	×	0	0	0	0	0	×?	×	0	×?	0	0	0	0
Na	×	0	0	0	×	0	0	0	0	×	×	×	0	0	0	0	×?	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	×	0	0	×	0	×	×	×?	E?	×?	×?	0	0	0	0
Ti	0	0	0	0	0	0	0	0	×	×	×	×	0	0	0	0	0	E	0	0	0	E[4] ×[5]	×[5]	×[5]
P	0	0	ND	0	0	×	×	×?	0	0	0	0	×	0	0	0	0	0	0	0	0	0	0	0
Mn	×	×	×?	×	×	×	×?	×	0	0	0	0	0	0	0	0	×?	×	×	×	0	×[5]	×	×[5]
Ag	0	×	0	0	0	0	0	0	×	0	×	×	0	×	0	0	0	0	×	0	0	E[4]	0	0
As	0	×	0	0	0	0	0	0	×	×	×	×	0	0	0	0	0	0	0	0	0	0	×[5]	0
B	×	×	×	×	×	0	×	×	0	0	0	0	0	×	0	0	×?	0	×	×?	0	0	0	0
Ba	×	×	×	×	×	0	×	×	0	0	0	0	0	×	0	0	0	0	0	0	0	E[4]	0	0
Be	×	×	×	×	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Co	×	×	×	×	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr	0	×	0	0	0	×	0	0	×	0	×	×	0	0	0	0	0	0	×	0	0	0	0	0
Cu	×	×	×	×	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	0	0	0	×	0
Ga	0	0	0	0	0	0	0	0	0	0	×	0	×	×	0	×	0	0	0	0	0	0	0	0
Ge	×	×	ND	×	×	×	ND	×	0	0	ND	0	0	0	ND	0	0	0	0	0	0	0	ND	0
La	0	0	×	0	0	0	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	0	0	0
Mo	0	×	0	0	0	0	0	0	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	0
Nd	0	0	ND	0	0	0	ND	0	×	×	ND	×	0	0	0	0	0	0	0	0	0	0	ND	0
Ni	0	×	×	×	0	0	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	×[4]	×[4]	×[4]
Pb	0	0	×	0	0	0	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	0	0	0
Sc	0	×	0	0	0	0	0	0	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0
Sn	0	×	×	×	0	0	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	0	0	0
Sr	×	×	0	×	×	×	0	×	0	0	×	0	0	0	0	0	0	0	0	0	0	0	0	0
V	0	×	0	0	0	×	0	0	×	0	×	×	0	0	0	0	0	0	0	0	0	0	0	0
Y	0	×	×	×	0	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Yb	0	×	×	×	0	0	×	0	×	×	0	×	0	0	0	0	0	0	0	0	0	0	0	0
Zr	×	×	×	×	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	0	×[5]	0	0

[1] In the mainly organic relative to the mainly mineral fraction of coal.

[2] Relative to other elements in the inorganic sedimentary constituents (in the first and third methods of investigation).

uranium-bearing rocks in the Cave Hills area

direct correlation; 0, no correlation; E, Eocene; ND, not detected]

Post-Paleocene to late Pleistocene—Continued																Late Pleistocene to Recent				
Early epigenetic agent—Continued																Late epigenetic agent				
Circulating ground water—Continued																Circulating ground water				
Unaffected								Enriched								Leached when U was—		Enriched when U was—		Not determinable
																Leached	Enriched	Leached	Enriched	
Coal				Noncoals				Coal				Noncoals				Coal				
1	2	3	Concensus	1	2	3	Concensus	1	2	3	Concensus	1	2	3	Concensus	1	1	1	1	1
×	×	×	×	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	×
×	×	0	×	×	×[4]	×[4]	×[4]	0	E	0	0	0	×[5] E[4]	×?[5]	×?[5]	×	0	0	0	0
0	0	0	0	×	×	×	×	×?	×	×?	×	0	0	0	0	×	0	0	0	0
0	×	×?	×?	×	×	×	×	×?	0	0	0	0	E[4]	0	0	×	0	0	0	0
0	0	×	0	×	0	0	0	0	0	0	0	0	×	×	×	0	0	0	×	0
0	×	×	×	×	×	×	×	0	0	0	0	0	0	0	0	0	0	0	0	×
0	×	0	0	×	×	×	×	0	0	0	0	0	0	0	0	0	×	×*	0	0
×	×	×	×	×	×[4]	×[4]	×[4]	0	0	0	0	0	0	0	0	×	×	0	0	0
0	0	0	0	0	×[4]	0	0	×	×	×	×	×	×[5]	×	×	0	0	0	0	0
0	0	0	0	×	×[4]	0	×[4]	0	0	0	0	0	0	0	0	×*	×	0	0	0
×	0	0	0	×	×	×	×	0	×?	0	0	0	0	0	0	0	0	0	×	0
0	0	0	0	×[5]	×	×[4]	×	×	×	×	×	×[4]	E[4]	0	0	×*	×	0	0	0
0	×	0	0	×	×	×	×	0	0	0	0	0	0	0	0	0	0	×	×	0
0	×	0	0	×	×	0	×	×	0	×?	×?	0	0	×?	0	0	0	×*	×	0
0	0	0	0	×[5]	×	×	×	×	×	×?	×	×?[4]	E[4]	0	0	0	0	×	×	0
×	0	×?	×?	×	×	×	×	0	×	0	0	0	E[4]	0	0	0	0	×*	×	0
×	×	0	×	×	×[4]	×[4]	×[4]	0	0	0	0	0	×[5] E[4]	×[5]	×[5]	0	0	×	×*	0
0	×	0	0	×	×	0	×	×?	0	×?	×?	0	0	0	0	0	0	×	0	0
×	0	×	×	×	×	×	×	0	×	0	0	0	E	0	0	×	0	0	0	0
0	0	0	0	×	×	ND	×	×?	×	×?	×	0	E	ND	0	0	0	0	×	0
0	0	0	0	0	×	0	0	×	×	×	×	×	0	×	×	0	0	×	×	0
0	0	0	0	×[5]	0	0	0	×	×	×	×	×[4]	×	×	×	×*	×	0	0	0
0	0	0	0	0	×	ND	0	×	×	×?	×	×	0	ND	0	0	0	0	0	×
0	0	×	0	×	0	0	0	×?	×	0	×?	0	×[5] E[4]	×?[5]	×?[5]	0	0	×*	×	0
0	0	0	0	×[5]	×[5]	×	×	×	×	×	×	×[4]	E[4]	0	0	0	0	×*	×	0
×	×	0	×	×	×	×	×	0	0	×?	0	0	E[4]	0	0	×	0	0	0	0
0	×	0	0	0	×	×[4]	×[4]	×	0	×	×	×	0	0	0	0	0	0	×	0
0	×	0	0	×	×[4]	0	×[4]	×?	0	×	×?	0	×[5]	×	×[5]	0	0	×	×	0
0	0	0	0	0	0	0	0	×	×	×?	×	×	×	×	×	0	0	×	×	0
0	0	0	0	0	0	0	0	×	×	×?	×	×	×	×	×	0	0	×	×	0
0	0	0	0	0	0	0	0	×	×	×	×	×	×	×	×	0	0	0	0	×
0	0	0	0	×	×[4]	0	×[4]	×	×	×	×	0	E[4]	×	0	×*	×	0	0	0

[3] Relative to crustal abundance (see discussion, p. B35–B37).
[4] In the Carbonate ore zone only.
[5] In the Lonesome Pete ore zone only.

ANALYTICAL DATA

TABLE 15.—*Chemical, radioactivity, and semiquantitative spectrographic analyses*

Analyses: Percentage of uranium in sample calculated from percentage of ash and percentage of uranium in ash. Tr., trace; 0, element not detected; ---, element not looked B, bottom; TM, top

[Chemical analyses (U in ash) by Glen Edgington, Joseph Budinsky, Grafton Daniels, and Roosevelt Moore; radioactivity analyses (eU in sample) by B. A. McCall: and and 61T–61TM, which were analyzed by J. C. Hamilton

Loc. No.	Laboratory No.	Thickness (feet)	Chemical analyses (percent)			Radioactivity analyses	Semiquantitative spectrographic analyses (see table 2 for code)									
			Ash	U in ash	U in sample	eU in sample (percent)	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag
COAL BED E																
Western Part of the South Riley Pass district [Chap. A, fig. 12]																
5B	145777	0. 4	59	1. 9	1. 1	0. 55	1	1	2+	3+	2	2+	3+	3	5	0
7	145785	. 6	77	. 016	0. 012, . 011	0. 022, . 026	1	1	2	3+	2	2−	2−	3	5+	0
14	145776	1. 0	46	2. 4	1. 1, 1. 1	. 46	1	1	2+	3	2−	2	3+	3−	5−	0
16	145783	. 9	55	1. 4	. 78	. 41	1	1	2	3+	2	2−	3+	3	5	0
17	145794	. 7	57	1. 2	. 70	. 35	1	1	2+	3+	2	2−	3+	3	5+	0
18	145784	. 9	63	. 50	. 31	. 24	1	1	2	3	3+	2	3+	3	5	0
19	146014	1. 0	59	1. 2	. 70	. 39	1	2+	2	3+	2	2	2−	3−	4−	7+
23T	146042	. 4	53	1. 8	. 96	. 59	1	2+	2+	3−	2−	2−	2−	3−	4−	7+
24	145775	1. 3	38	. 72	. 27	. 11	1	2+	2+	3	2−	2−	3+	3−	5−	0
26	145782	. 7	51	1. 9	. 94	. 44	1	1	2	3+	2	2−	3+	3	5	0
29	145790	1. 1	51	. 37	. 19	. 14	1	1	2+	3	3+	2	3+	3	5−	0
30	145774	1. 4	45	. 91	. 41	. 25	1	1	2+	3+	2−	2	2−	3	5−	0
31	145781	. 5	70	. 14	. 098, . 098	. 059	1	1	2+	3+	2	2−	2−	3	4−	0
37	145789	. 8	53	. 88	. 47	. 26	1	1	2+	3	3+	2	3+	3	5−	0
39	145773	1. 0	63	. 46	. 29	. 18	1	1	2+	3+	2−	2−	2−	3	5	0
41	145780	. 4	73	. 13	. 094	. 053	1	1	2+	3+	2−	2−	3+	3−	4	0
50	145788	. 5	73	. 59	. 43	. 20	1	1	2+	3+	2−	2−	3+	3	4	0
52	145772	. 9	48	. 63	. 30	. 20	1	2+	2+	3+	2	2	3+	3−	5−	0
54	145779	. 7	54	. 72	. 39	. 20	1	1	2+	3+	2	2−	3+	3	5	0
56	145787	1. 0	53	. 17	. 090	. 045	1	1	2+	3+	2	2−	3+	3	5−	0
62	145778	1. 2	39	. 46	. 18	. 072	1	1	2+	3	2−	2−	3+	3	5	0
63	145786	. 9	38	. 17	. 064, . 064	. 028	1	1	2+	3+	2	2−	3+	3−	5+	0
64	145992	. 4	85	. 007	. 005	. 014	1	2+	2	3+	2−	2−	2−	3−	4+	0
65	145793	. 4	70	. 068	. 048	. 048	1	1	2+	3+	2−	2−	2−	3−	4−	0
73	145792	. 5	65	0. 13, . 14	. 087, . 093	. 095, . 089	1	1	2+	3+	2	2−	3+	3−	5+	0
77	146032	. 6	69	. 024	. 016	. 024	1	2+	2+	2−	2	2	2−	3	4+	7+
79	145791	. 5	77	. 005	. 004	. 006	1	1	2+	3+	2−	2−	2−	3	4	0
Central part of the South Riley Pass district [Chap. A, fig. 13]																
17T	237052	0. 6	43	2. 7	1. 17	0. 99	----	2	1	3+	2	----	0	3	5	0
17B	237053	. 8	45	. 95	. 43	. 24	----	2+	1	3+	2+	----	2−	3	4+	0
50	146823	. 8	53	. 57	. 30	. 27	1	1	2	2−	2	2	2−	3−	4	0
51	146822	. 4	86	. 044	. 038	. 036	1	1	2	2−	2−	2	2−	3−	4+	0
52	146821	. 9	71	. 70	. 50	. 45	1	1	2	2−	2−	2	2−	3−	4+	0
61T	237048	. 3	52	5. 3	2. 76	1. 8	----	2	2+	3	2−	----	0	3+	4−	0
61TM	237049	. 3	35	1. 9	. 67	. 54	----	2	2+	3	2−	----	0	3	5	0
61BM	237050	. 25	32	. 69	. 22	. 12	----	1	1	3	2−	----	0	3−	5+	0
61B	237051	. 25	37	. 12	. 046	. 037	----	2+	1	3+	2−	----	0	3	4+	0

of coal samples from the South Riley Pass and Traverse Ranch districts, Cave Hills

for. Two results listed where duplicate analyses were made. Samples are of complete coal bed except as indicated by letters included in locality number (T, top; M, middle; of middle; and so forth).
spectrographic analyses by Mona Frank, Charles Annell, K. V. Hazel, and H. W. Worthing, U.S. Geol. Survey, Washington, D.C., except for samples from localities 17T–17B and N. M. Conklin, U.S. Geol. Survey, Denver, Colo.]

Semiquantitative spectrographic analyses (see table 2 for code)—Continued

COAL BED E—Continued

Western Part of the South Riley Pass district—Continued

[Chap. A, fig. 12]

As	B	Ba	Be	Cd	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Nb	Nd	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zr
3−	4−	3	6	0	0	4−	4−	4−	5+	5+	5+	3−	0	0	4	0	4−	5	5−	0	2−	4	4−	5−	4+
0	4	3−	6−	0	0	5	5+	4−	5+	5−	5	4−	0	0	4−	0	4	5−	5	4+	0	5+	5+	6+	5+
3	4−	3−	6	0	0	5+	5+	4−	5+	5−	5+	3+	0	0	4	0	4−	5	5−	0	2	4−	4−	5−	4+
3	4	3−	6	0	0	5	5+	5+	5+	5−	5	3	0	0	4−	0	5	5−	5−	4+	2−	4−	5+	6+	4
3−	4	3−	6−	0	0	5	5+	4−	5+	5−	5	3+	0	0	4−	0	4−	5−	5−	4+	2−	4−	5+	6+	4+
4	4	3	6	0	0	5	5+	4−	5+	5	5	4+	0	0	4−	0	5+	5−	5+	4+	3+	5+	5+	6+	4
3	5	4+	6	0	0	5	4−	5+	5−	0	0	2−	0	0	4−	0	5+	5	5+	4	3+	4−	5+	5−	3−
2−	5−	3−	6	0	0	5	4−	5+	5−	5	0	2−	0	0	5+	0	5+	5	5+	4	2−	4−	5+	5−	3−
3−	4−	3−	6	0	0	5+	5+	4−	5+	5	5	3	0	0	4−	0	5	5−	5−	0	3+	4−	5+	6+	4+
3	4−	3−	6	0	0	5	5+	5+	5+	5−	5	3−	0	0	4−	0	5+	5−	5−	4+	2−	5+	5+	6+	4
3−	4−	3	6	0	0	5	5	4−	5+	5+	5	3	0	0	4−	0	5+	5−	5−	4+	3	4−	0	6+	4
3−	4−	3	6−	0	0	5+	4−	5+	5+	5−	5	3−	0	0	4−	0	5	5−	5−	0	3+	4−	5+	6+	4+
3−	4−	3	6	0	0	5+	5+	5+	5+	5−	5	4+	0	0	4	0	5+	5−	5−	4+	3−	4−	5+	6+	4−
3−	4−	3	6	0	0	5	5	4−	5+	5+	5	3	0	0	4−	0	5+	5−	0	4+	3+	4−	0	6+	4
3−	4−	3−	6−	0	0	5	4−	5+	5+	5−	5	3+	0	0	5+	0	5	5−	5−	0	3	4−	5+	6+	4+
4+	4−	3−	6	0	0	5+	5+	4−	5+	5	5	4+	0	0	4−	0	5	5−	5+	4+	3−	4−	5+	6+	5+
4+	4	3−	6	0	0	5	5	4−	5+	5	5	3−	0	0	4−	0	5+	5−	5−	4+	3+	4−	0	6+	4−
3−	4−	3	6	0	0	4−	4−	4−	5+	5	5	3−	0	0	4	0	5+	5−	4−	0	3+	4−	5+	6+	4+
3−	4−	3−	6+	0	0	5+	5+	4−	5+	5+	5	3−	0	0	4−	0	5+	5−	5	4+	3+	4−	5+	6+	4
4+	4−	3−	6	0	0	5+	5+	5+	5+	5−	5	4+	0	0	4−	0	5	5−	0	4+	3−	4−	5+	6+	4+
4+	4−	4+	6+	0	0	5+	5+	4−	5+	5−	5	3−	0	0	4−	0	5	5−	5−	4+	3+	4−	5+	6+	4+
4+	4−	3−	5−	0	0	5+	5	4	5+	5	5	4	0	0	4	0	5	5	0	4+	3−	4−	5+	6+	4
4+	5	3−	6	0	0	5−	4−	5+	6+	0	0	4+	0	0	5+	0	5+	5−	0	4−	0	4−	5	6	4
4+	4	3−	6−	0	0	5	5	4−	5+	5−	5	4−	0	0	4−	0	5+	5−	5−	4+	0	4−	5+	6+	5+
3−	4	3−	6	0	0	5+	5	4−	5+	5	5	4	0	0	4	0	4−	5−	5−	4+	3−	4	5+	6+	4−
4+	5	3−	6	0	0	5+	4−	4−	5−	5	0	4+	0	0	4−	0	5+	5	0	4+	0	4−	5+	6+	4
0	4−	3−	6	0	0	5+	5+	5+	5	5−	5	5+	0	0	4−	0	5	5−	5−	4+	0	4−	0	6+	5+

Central part of the South Riley Pass district—Continued

[Chap. A, fig. 13]

As	B	Ba	Be	Cd	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Nb	Nd	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zr
2	Tr.	3	6+	4	0	5−	5	4−	Tr.	5	Tr.	3+	0	0	5+	0	4−	5+	4−	3	2−	5+	5+	5−	3
3+	Tr.	3	5−	0	4	5−	5+	4	5	4−	4−	3+	0	4−	4−	0	4	5+	0	3−	2−	4+	4−	5	3−
3	5	3−	6+	0	0	5	4−	5	5	0	0	3+	0	0	5+	0	5+	5+	0	3−	3+	5+	4−	5−	3−
0	5+	3	6−	0	0	5−	4−	5	6+	0	0	3+	0	0	5	0	5	5	0	4	0	5+	5	6	4
3	5	3−	6	0	0	5−	4−	5	5	0	0	3+	0	0	5	0	5+	5+	0	4+	3+	5+	5+	6+	3−
2+	Tr.	3−	6+	4	4	5−	5+	4−	5	5	4−	3+	0	4−	5+	2−	4−	5+	5+	3−	2+	4−	4−	5	3−
2−	Tr.	3+	5−	0	4	5−	5	4−	5	5	4−	3+	0	4−	4	0	4−	5+	5	4+	2−	4	4−	5	3
0	Tr.	3−	5	0	4	5+	5	5+	5	5+	4−	3+	0	4−	4−	0	4	4−	0	3−	3+	4+	4	5	3−
3	Tr.	3	5	0	4	5+	5	4	5	5+	4	4+	Tr.	4	4	0	4+	4−	0	3−	3−	4+	4+	5+	4+

TABLE 15.—*Chemical, radioactivity, and semiquantitative spectrographic analyses*

Loc. No.	Laboratory No.	Thickness (feet)	Chemical analyses (percent)			Radioactivity analyses	Semiquantitative spectrographic analyses (see table 2 for code)									
			Ash	U in ash	U in sample	eU in sample (percent)	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag
COAL BED E—Continued																
Eastern part of the South Riley Pass																
[Chap. A, fig. 14]																
3	237176	0. 8	31	0. 040	0. 012	0. 010	1	1	2+	2	2+	2+	2−	3	4+	0
5T	237178	. 5	44	3. 4	1. 5	1. 3	1	2+	2	3	3+	2+	3+	3+	4	0
5B	237180	. 5	36	. 36	. 13	. 10	2+	2+	1	3+	2	2+	3+	3−	4+	0
12	237187	1. 4	42	2. 7	1. 13	. 94	1	2+	1	3+	2	2−	3+	3−	4−	0
13	237188	1. 4	38	2. 4	. 91	. 76	1	2+	1	3+	2	2	3+	3−	4−	0
15	237190	. 6	63	. 12	. 075	. 086	1	2+	1	2	2+	2	2−	3	4+	0
16	237191	1. 3	58	1. 6	. 93	. 73	1	2+	1	2−	2	2	2−	3+	4	0
18	237193	. 4	54	0. 033, . 028	. 017	0. 019, . 021	1	1	2+	2+	2	2+	2−	3+	4	0
19	237194	. 6	59	. 13	. 076	. 094	1	2+	1	2	2+	2+	2−	3	4+	0
21	237196	1. 1	47	. 18	. 084	. 087	1	2+	1	2−	2	2+	3+	3	4	0
25T	237202	. 4	58	2. 8	1. 6	1. 8	1	2+	2	3	2−	2+	----	3+	4−	0
25B	237204	. 5	42	. 13	. 054	. 056	1	2+	1	2−	2	2+	3+	3	4+	0
26	237205	1. 0	59	. 088	. 052	. 055	1	2+	1	2−	2+	2+	2−	3	4+	0
29	237208	1. 0	50	3. 0	1. 5	1. 2	1	2+	1	2	2+	2+	2−	3	4+	0
31	237210	1. 2	51	2. 0	1. 0	. 78	1	2+	2+	3	2	2	3+	3	4	0
32	237212	1. 4	29	4. 6	1. 3	1. 2	1	1	2	3−	2	2	0	3	4−	0
32T	237211	. 3	42	2. 4	1. 0	. 95	1	2+	2+	3	2	2	----	3−	4−	0
COAL BED C NO. 1																
TRAVERSE RANCH																
[Chap. A, fig. 15]																
1	149438	1. 0	38	0. 021	0. 008	0. 007	1	2+	1	3+	2+	3+	2−	3	4+	7+
2T	149439	. 7	57	. 009	. 005	0. 006, . 008	1	2+	1	2+	2+	2	2−	3	4	7+
2B	149440	2. 0	43	. 028	. 012	. 010, . 009	1	1	2+	2+	2+	2	0	3+	4+	7+
3	149441	2. 0	30	. 095	0. 030, . 027	. 020, . 015	1	1	2+	2	2	2+	3+	3+	5+	7+
4	149442	3. 3	20	. 021	. 004	. 003	1	1	2	2−	2+	2+	3+	3	4	7+
5T	149443	. 4	59	. 008	. 004, . 005	. 012, . 010	1	2	1	2	2	2	0	3+	4−	7+
5TM	149444	. 4	54	. 04	. 022, . 020	. 011, . 013	1	1	2+	2+	2+	2	0	3	4	7+
5BM	149445	1. 0	34	. 065	. 022, . 021	. 011, . 009	1	1	2+	2+	2	2+	3+	3	4	7+
5B	149446	2. 0	14	. 029	. 003, . 005	. 002	1	1	2+	2+	2	1	0	3−	4	7+
6T	149344	2. 0	22	. 095	. 021	. 020, . 018	1	1	2+	3+	2+	2+	0	3	4+	0
6B	149345	2. 0	26	. 05	. 014	. 012	1	1	1	3+	2	2	2−	3	4+	7+
7T	149436	1. 5	48	. 01	. 002	. 072	1	1	2+	2−	2+	2−	2−	3	4+	7+
7B	149437	1. 5	34	. 015	. 005	. 007	1	1	2+	2	2+	2−	3+	3	3−	7+
8T	149434	1. 5	37	. 024	. 009, . 009	. 012, . 012	1	1	2	2	2+	2	3+	3−	3	0
8B	149435	1. 5	49	. 51	. 26, . 24	. 56, . 53	1	1	2+	2	2+	2	2−	3	4	7+
9	149433	2. 7	42	. 017	. 007	. 008	1	1	1	2	1	2	3+	3	3+	7+
10	149432	1. 7	55	. 11	. 060	. 057	1	2+	2+	2	2+	2	0	3	4−	0
11T	149430	1. 4	43	. 09	. 037	. 021	1	1	2+	2−	2	2	2−	3	4	0
11B	149431	1. 4	26	. 046	. 012	. 011	1	1	1	2	2+	2	3+	3	4+	7+
12	149429	2. 0	49	. 08	. 040	. 036	1	2	1	3+	2	2−	2−	3	4−	7+
13	149428	2. 0	37	. 06	. 022	. 023	1	2+	1	2−	2	2−	0	3+	4−	7+
14	149427	2. 0	38	. 36	. 12, . 15	. 071, . 069	1	2+	2+	3	2	2−	3+	3	4−	7+
15	149426	. 7	44	. 36	. 16, . 15	. 11, . 10	2+	2	1	2−	2+	2−	0	3−	4	7+
16	149350	. 8	43	. 19	. 080	. 076	1	2+	2	2−	2+	2−	0	3−	4−	0
17	149349	3. 6	33	. 09	. 029	. 029, . 026	1	2+	1	2	2	2	0	3	4−	7+
18T	149347	. 6	54	4. 63	2. 5	2. 0	1	2+	2	2	2	2−	0	3	4	0
18	149348	3. 6	31	. 23	. 070	. 063	1	1	2+	2−	2+	2−	0	3	4−	7+
19	149346	3. 5	41	. 03	. 013	. 013	1	1	2+	2−	2	2	2−	3	3−	7+

of coal samples from the South Riley Pass and Traverse Ranch districts, Cave Hills—Continued

Semiquantitative spectrographic analyses (see table 2 for code)—Continued

COAL BED E—Continued
Eastern part of the South Riley Pass—Continued
[Chap. A, fig. 14]

As	B	Ba	Be	Cd	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Nb	Nd	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zr
0	4	3	5−	0	0	5−	5	5	4−	5+	0	4	0	0	5−	0	5+	5−	0	4+	0	4−	5	6+	4+
2+	4−	3−	6+	0	0	5	5+	5+	5+	0	0	2−	0	0	5+	0	4−	5+	5	4+	2	4−	5+	6+	3−
3−	4−	3−	5−	0	0	5+	5−	4+	5	4−	4−	2−	0	4−	4	0	4	5+	0	3	3	4	4−	5	4+
2+	5	3−	5−	0	0	0	5	4−	5	5+	5+	2	0	0	5+	0	4−	5+	0	3−	2	4−	5+	5−	3−
2	5	3	5−	0	0	0	5	5+	5	5	5+	2	0	0	5+	0	4−	5+	0	3	2−	4−	5+	5−	3−
3	6	3	5−	0	0	5	5	5+	5	5+	5+	3	0	0	5+	0	4−	5+	0	3−	0	4−	5+	5−	4+
2	5	3	6+	0	0	0	5+	5+	5	5+	5+	2	0	0	5+	0	4−	5+	0	3−	2−	4−	5+	5−	3−
3	4−	4+	5−	0	0	5+	5	4−	5−	5+	0	4+	0	0	4−	0	5+	5+	0	3−	0	4−	4−	5−	4+
3	5+	4+	5−	0	0	5+	5	5+	5	5+	5+	4+	0	0	5+	0	4−	5+	0	3	3−	4−	4−	5	4
3−	5	4	5−	0	0	5	5	5+	5	5+	5+	3	0	0	5+	0	4−	5+	0	3−	3	4−	5+	5	3−
1	4−	3	6+	0	0	0	5+	5+	5	5	0	2	0	0	5	0	4−	5+	0	3−	2	4−	5+	----	4+
2−	5	4−	5	0	0	4−	5	4−	5	4−	4	4+	0	4	4−	0	4	4−	0	3	3−	4	4−	5	4
4+	5	4+	5−	0	0	5+	5	5+	5	5+	5+	3−	0	0	5+	0	4−	5+	0	3−	3−	4	4−	5−	4+
2+	5	3	5−	0	0	5+	5	5+	5	5+	4−	2−	0	0	5+	0	4−	5+	0	3	2	4	4−	5	3−
2+	5	3	6+	0	0	----	5	5+	5	5	5+	2−	0	0	5+	0	4−	5+	0	3−	2	4−	4−	5−	4+
2+	5+	3−	5−	0	0	5+	5	5+	5	0	0	2−	0	0	4−	0	4−	5+	5	3	2	4−	4−	5	3−
2+	5	3	6+	0	0	----	5+	5+	5	0	0	2	0	0	----	2−	4−	5+	0	3	2+	4−	4−	----	3−

COAL BED C NO. 1—Continued
TRAVERSE RANCH—Continued
[Chap. A, fig. 15]

As	B	Ba	Be	Cd	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Nb	Nd	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zr
4+	4−	3	0	0	0	6+	5+	5+	5−	0	0	4+	0	0	5−	0	5+	5−	0	4+	0	5+	5	6+	4+
0	4−	3	0	0	0	0	5	4−	6+	5	0	4	0	0	5−	0	5+	5−	0	3−	0	4−	5−	6	4+
0	4	3	6	0	0	5−	5+	5	5	0	5+	4−	0	0	5+	0	5+	5	0	3	0	4−	5+	5−	4+
0	4−	3	0	0	4+	6+	4−	4−	5	0	4	4+	0	4	5	0	5	5+	0	3−	0	4−	4−	5−	3−
0	4	3	6−	0	0	5−	5	4−	6+	0	0	5+	0	0	5+	0	5−	5−	0	3+	0	5+	5	6+	4
4+	4	3	0	0	0	0	5+	5+	6+	0	5+	4−	0	0	0	0	5+	5−	5−	3	0	5+	5	6+	4+
0	4+	3	0	0	4	0	4−	4−	5−	0	4−	4−	0	4	5+	0	5+	5	0	3	0	5+	5+	6+	4+
0	4+	3	0	0	0	6+	5+	4	5	0	5+	4	0	0	5+	0	4−	5	0	3	0	4−	5	6+	4+
0	4	3	6+	0	0	5	5	5+	5−	0	5+	4−	0	0	5+	0	5	5−	0	3−	0	5+	5+	6+	4
0	4+	3	6	0	4	5−	4−	5+	5+	0	4−	4+	0	4	5+	0	5+	5+	0	3	3−	4−	5+	5−	3−
0	4+	3	6	0	0	5−	5	4−	5	0	5+	4−	0	0	5+	0	4−	5−	0	3−	0	4−	5+	6+	4+
4+	5+	3+	6	0	0	5−	5	4−	5	0	5+	4−	0	0	5+	0	5+	5	0	3−	0	4	5	6+	4+
0	5+	3	6−	0	0	6+	5	4−	5−	0	0	5	0	0	5+	0	5	5−	0	3	0	4−	5	6	4
0	5+	3	6−	0	0	6+	5−	4−	6+	0	0	5+	0	0	5−	0	5−	5−	0	3	0	4−	5	6	4+
0	4−	3+	6	0	0	5−	5	4−	5−	0	5+	4−	0	0	4−	0	4−	5	0	3	3	4−	5	6+	3−
4+	4−	3	6−	0	0	5−	5−	5+	5−	0	0	4−	0	0	5−	0	5+	5−	0	3	0	4	5	6+	4+
0	5+	3	6	0	0	0	5	5+	5	0	5+	3−	0	0	5−	0	5+	5	0	3−	3−	4−	5	6+	3−
0	4−	3	6+	0	0	5−	5+	5+	5−	0	5+	4−	0	0	5+	0	5	5	0	3−	0	4−	5+	6+	4+
0	5+	3+	6+	0	0	5	5	4−	5−	0	5+	4	0	0	4−	0	5	5	0	3	0	4−	5+	6+	4+
4+	5+	3	6	0	0	6+	5+	5+	5+	0	0	4+	0	0	5+	0	4−	5	5−	4+	0	4	5	6+	3−
4+	5+	3	6+	0	0	6+	5	4−	5+	0	5+	3−	0	0	5+	0	5+	5	5−	3−	0	4−	5	6+	3
0	5	3	6	0	0	6+	5	4−	5	0	0	3−	0	0	5−	0	5+	5	0	4+	3	4−	5	6+	3−
0	5	3−	6−	0	0	5−	5−	5+	5	0	4−	3−	0	4−	5+	0	5	5	5−	3−	3	4−	5+	6+	3−
0	5	4+	6	0	0	6+	5−	5+	4−	0	5+	4	0	0	5	0	5+	5	0	4+	3	5+	5+	6+	4+
0	4−	3	6	0	0	6+	5−	5+	5−	0	5+	3−	0	0	5−	0	5+	5−	5−	3−	3−	5+	5	6+	4+
0	5+	3+	6	0	3−	----	5	5	5	0	0	3	0	0	5−	2−	4	5	5−	3−	2	5	5	6+	4+
0	5	3	6	0	0	5−	5	5+	5+	0	5+	3−	0	0	4−	0	5+	5	0	4+	3	5+	5+	6+	3−
0	4−	3	6+	0	0	5	5	4−	5	0	5+	4+	0	0	4−	0	5+	5−	0	4+	0	4−	5+	6+	4+

TABLE 16.—*Chemical, radioactivity, and semiquantitative spectrographic*

Analyses: Percentage of uranium in sample calculated from percentage of ash and percentage of uranium in ash. 0, element not detected; ND, not determined; Tr., trace. B, bottom; TM, top of middle,

[Analyses for samples 8 and 9: Chemical by R. P. Cox, J. S. Wahlberg, E. C. Mallory, Jr., and Mary Finch; radioactivity by C. G. Angelo; and spectroscopic by J. C. Delevaux, and Carmen Johnson; other radioactivity analyses by B. A. McCall; other spectrographic analyses

Sample No.	Laboratory No.	Location			Thickness (feet)	Chemical analyses, in percent			Radioactivity analyses eU in sample (percent)	Semiquantitative spectrographic analyses (see table 2 for code)					
		Sec.	T.N.	R.E.		Ash	U in ash	U in sample		Si	Al	Fe	Mg	Ca	Na
							COAL ZONE F								
							Riley Pass district and vicinity								
1	145297	NW¼NE¼SE¼ 22	22	5	0.3	39	0.56, 0.54	0.22, 0.21	0.18	1	1	2	2−	2+	2+
2	237240	SW¼SW¼NE¼ 22	22	5	.2	85	.032	.027	0.030, .034	1	1	2−	3+	3+	2
3T	148787	SW¼NE¼NE¼ 35	22	5	1.0	66	.006	.004	.001	1	1	2−	2−	2	2
3B	148788	SW¼NE¼NE¼ 35	22	5	1.2	76	.003	.002	.002	1	1	3+	2−	3+	2
4T	148819	NW¼NW¼NW¼ 36	22	5	3.0	36	.007	.002	.002	1	2+	2	2−	2	2−
4B	148820	NW¼NW¼NW¼ 36	22	5	1.0	55	.009	.005	.003	1	1	2	2−	2−	2
							COAL BED E								
							Traverse Ranch district and vicinity								
5	145574	SW¼NE¼ 15	22	5	0.6	61	0.006	0.004	0.009	1	1	2+	3+	2	3+
6T	237407	SW¼NW¼NW¼ 21	22	5	.6	67	.010	.007	.016	1	1	2+	3+	2+	2−
6TM	237408	SW¼NW¼NW¼ 21	22	5	1.0	13	.15	.019	.015	2+	1	2	2	1	2
6BM	237409	SW¼NW¼NW¼ 21	22	5	1.0	11	.045	.005	.004	2+	1	2	2−	2+	2+
6B	237410	SW¼NW¼NW¼ 21	22	5	1.0	12	.034	.004	.005	2+	1	2	2−	2+	2+
7T	237414	SW¼NW¼NW¼ 21	22	5	1.0	37	.24	.089	.088	1	1	2	4+	3+	2
7M	237415	SW¼NW¼NW¼ 21	22	5	1.0	36	.33	.12	.15	1	2+	2+	4+	3+	2−
7TM	237416	SW¼NW¼NW¼ 21	22	5	.1	26	.92	.24	.22	1	1	2+	3	2−	2−
7B	237417	SW¼NW¼NW¼ 21	22	5	1.0	66	.038	.025	.021	1	1	2	4+	4+	2
8	242427	SW¼NW¼NW¼ 21	22	5	------	ND	ND	.011	.006	3+	3−	3	3−	3+	3
9	242428	SW¼NW¼NW¼ 21	22	5	------	ND	ND	.41	.21	3−	3−	2	3−	3+	3
							North Riley Pass district and vicinity								
10	145287	SW¼SW¼NE¼ 22	22	5	1.6	40	0.025	0.010	0.007	1	1	2+	2	2+	2−
11	145288	SW¼SW¼NE¼ 22	22	5	1.2	43	0.051, .053	0.022, .023	0.012, .008	1	1	1	2	2+	2−
12	145289	SW¼SW¼NE¼ 22	22	5	1.7	27	.12, .12	.030, .028	.008, .011	1	1	2+	2−	2+	2−
13	145290	SE¼SW¼NE¼ 22	22	5	1.5	30	.010, .010	.003, .003	.008, .007	1	1	2+	2	1	2
14	145291	NE¼NW¼SE¼ 22	22	5	1.0	56	.15, .14	.083, .080	.039, .034	1	1	2+	2−	2	2−
15	145292	NW¼NE¼SE¼ 22	22	5	.9	64	.022	.014	.019	1	1	2+	3+	2	2
16 [1]	145295	NW¼NE¼SE¼ 22	22	5	.1	26	.91, .87	.24, .23	.076, .084	1	2+	1	2	2+	2
16T	145293	NW¼NE¼SE¼ 22	22	5	.8	28	.67, .60	.19, .017	.062, .071	1	2+	1	2	2+	2
16TT	145296	NW¼NE¼SE¼ 22	22	5	.3	79	.006	.005	.003	1	2+	2	3+	2	2−
16B	145294	NW¼NE¼SE¼ 22	22	5	.8	16	.84, .84	.13, .13	.050, .055	2+	1	2−	2	2+	2
17 [2]	145301	NE¼NE¼SE¼ 22	22	5	.1	83	.056, .058	.046, .048	.018, .016	1	2+	2+	3	2−	2−
17TT	145300	NE¼NE¼SE¼ 22	22	5	.6	55	.29, .33	.16, .18	.12, .10	1	1	2	3−	2−	2
17T	145298	NE¼NE¼SE¼ 22	22	5	1.0	33	.58, .55	.19, .18	.10, .11	1	1	1	3+	2−	2
17B	145299	NE¼NE¼SE¼ 22	22	5	1.0	19	.88, .83	.17, .16	.094, .087	2+	1	1	3−	2	2
18	145575	NW¼SE¼SE¼ 22	22	5	.9	45	.12	.056	.053	2+	2+	1	2+	1	2
19	145569	SE¼SE¼ 22	22	5	1.0	41	.38	.15	.091	1	1	2+	3+	3+	2−
20	145570	SE¼SE¼ 22	22	5	1.0	22	.21	.047	.029	1	1	2+	3+	2	2
21	145571	SE¼SE¼ 22	22	5	1.8	21	1.6	.34	.15	2+	1	2+	3+	2	2
22	145572	SE¼SE¼ 22	22	5	1.7	36	.32	.12	.039	1	1	2+	2	2	2−
23	145573	SE¼SE¼ 22	22	5	1.6	31	.46	.14	.076	1	1	2+	3+	2	2
24	145302	NW¼NW¼SW¼ 23	22	5	1.9	44	.34, .32	.15, .14	.068, .067	1	1	2+	3	2	2
24M	145303	NW¼NW¼SW¼ 23	22	5	.3	27	.72, .72	.19, .19	.089, .086	1	1	2+	3+	2+	2
25	145304	NW¼NW¼SW¼ 23	22	5	2.2	23	.35, .35	.081, .082	.040, .032	1	1	2+	3	2+	2
25M	145305	NW¼NW¼SW¼ 23	22	5	.8	20	.91, .81	.17, .15	.073, .058	1	1	2+	3+	2	2−
26T	145306	NW¼NW¼SW¼ 23	22	5	.5	62	.029	.018	.018	1	1	2	3+	2	2
26B	145307	NW¼NW¼SW¼ 23	22	5	.7	49	.20, .20	.10, .10	.057, .044	1	1	2+	2−	2+	3+
27T	145310	NW¼NW¼SW¼ 23	22	5	.6	60	.019, .015	.011, .009	.006, .007	1	1	2	3	3+	2−
27B	145308	NW¼NW¼SW¼ 23	22	5	1.7	22	.51, .56	.11, .11	.066, .056	1	1	2+	3+	2+	2−
27MB	145309	NW¼NW¼SW¼ 23	22	5	.7	20	.44, .47	.093, .096	.043, .054	1	1	2+	3+	2+	2
28	145311	SW¼NW¼SW¼ 23	22	5	1.7	30	.33, .33	.10, .10	.055, .066	1	1	2	3+	2+	2+

See footnotes at end of table.

analyses of coal samples from miscellaneous localities in the Cave Hills area

Two results listed where duplicate analyses were made. Samples are of complete coal bed except as indicated by letters included in locality number (T, top; M, middle; and so forth) or by footnotes.
Hamilton and N. M. Conklin, U.S. Geol. Survey, Denver, Colo. Other chemical analyses by Grafton Daniels, Roosevelt Moore, A. R. Sweeney, Irving May, Maryse by Mona Frank, Charles Annell, K. V. Hazel, and H. W. Worthing, U.S. Geol. Survey, Washington, D.C.]

Semiquantitative spectrographic analyses (see table 2 for code)—Continued

COAL ZONE F—Continued

Riley Pass district and vicinity—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
0	3	5+	6−	3	4	3+	5−	0	0	4−	4−	5+	0	5	0	4	0	4−	0	4−	4	5−	5+	0	0	3	3+	4−	4	5	0	4+
3+	3	5+	0	4+	4	3−	6−	0	0	5−	5+	5+	0	5+	0	5	0	4−	0	0	4−	5	5−	0	0	4−	0	4	5	6	0	5
2−	3	4−	0	0	5+	4	6	0	0	5−	4	4−	0	5	0	0	0	5+	0	0	5+	5	5+	0	0	3−	0	4−	4−	5−	0	4−
2−	3	5+	0	0	4−	4−	6−	0	0	5	4	5+	0	5	5	0	0	5	0	0	5+	5+	5	0	0	4	0	4−	5	6	4	4
3+	3−	4+	7+	0	4	3	6−	0	0	6+	5+	5+	0	5−	0	0	0	5	0	0	5−	5	0	0	0	4−	0	5+	5+	6	0	4−
3+	3+	4	0	0	4	3−	6−	0	0	5	4	5+	0	5+	0	5+	0	5+	0	0	4−	5+	5+	0	0	4+	0	4	4−	5−	0	4+

COAL BED E—Continued

Traverse Ranch district and vicinity—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
3+	3	4	0	4	4+	3	5−	0	0	5+	4−	4−	0	5+	5	5	0	4+	0	0	4	5+	5−	0	0	4+	0	4	4−	5−	0	4+
3+	3	4	0	3−	5+	4+	6−	0	0	5−	5+	5−	0	5−	5	0	0	4−	0	0	5+	5	5−	0	0	4+	0	5	5	6	0	4−
2−	3	3−	7−	0	4−	3−	6	0	0	4−	5+	4−	0	5	5−	0	0	4	0	0	4	5−	5	0	0	3+	3−	5−	5+	6+	0	3−
3	3	4+	7−	4+	3−	3−	6−	0	0	5−	5+	4	0	5	0	0	0	4	0	0	5+	5−	5	0	0	3	0	5−	5	6	0	3
3	3	4+	7−	0	3−	3−	6−	0	0	5−	5+	4	0	5	0	0	0	4	0	0	5+	5−	5−	0	0	3	0	5−	5	6	0	3
3+	3	5−	7	4+	5+	4+	5−	0	4	5	4−	4−	0	5+	0	0	0	3−	0	0	4−	5−	5	0	0	4+	3	5−	4−	5−	0	3−
3+	2	5	7	3−	5+	4+	6−	0	0	5	5+	4−	0	5	0	0	0	3−	0	0	4−	5−	5	0	0	4+	3+	5−	5+	6	0	3−
2−	3	5	7	4+	5+	3−	5−	0	0	4−	5+	4	0	5+	0	0	0	3−	0	0	4	5−	5	0	0	3−	2−	5−	4−	6+	0	3−
3	3	5−	0	0	5+	4+	6−	0	0	5−	5+	5	0	5−	0	0	0	4+	0	0	5	5−	5−	0	0	4	0	5	5−	6−	0	4−
0	4	5−	0	0	4−	4	0	0	0	0	5−	5	0	0	0	0	0	5+	5−	0	6+	0	0	0	0	5+	0	5−	0	0	0	4−
0	5+	5−	0	0	5+	4−	0	5	0	6+	6+	4−	0	0	0	0	0	5+	0	0	6+	0	0	0	0	5+	3−	5−	Tr.	Tr.	0	4

North Riley Pass district and vicinity—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
3+	3	4	6−	4+	4−	3−	5−	0	0	5+	4−	5+	0	5	5−	5+	0	3−	0	5	4	5	5	0	5	3−	0	4	5+	6+	0	3
3+	3	4	6−	4+	4−	3	5−	0	0	5+	4−	5+	0	5	5−	5+	0	3−	0	5	4−	5−	5	0	5−	3−	4+	4	5+	6+	0	3−
0	4+	5	0	4	5−	3−	6+	0	0	5	5	5	0	5	5−	4−	0	3	5	5−	5−	5	5	0	5	3−	3−	4−	5+	0	0	3−
3	3−	4	6−	4	5	3−	5−	0	0	5+	4−	5+	0	5	5−	4−	0	4	0	5+	4−	6+	5	0	5−	3	0	5+	4−	5−	0	3−
3+	3	4	6−	4+	5	3−	5−	0	0	5+	4−	5	0	5	5−	4−	0	4+	0	5+	5+	5	5	0	5−	3−	3−	4−	5+	6+	0	3−
3+	3	4−	6−	3	5	3	6+	0	0	5−	4−	5	0	5	5−	4−	0	3−	0	5+	5+	5	5	0	5−	3−	4	4	5+	6+	0	3−
0	3−	4−	6−	3	4	3−	5−	0	0	5	5+	5+	0	5	0	4−	0	3	0	5+	5+	6+	5	0	5−	3	3+	5+	4−	5−	0	3−
0	4+	4−	6−	2−	5	3−	6	0	0	5	5+	5+	0	5	0	5+	0	3+	0	0	5	5−	5	0	5+	3	3+	5+	5+	6+	0	3−
0	3	4−	6−	4−	5	3−	6+	0	0	5−	4−	5	0	5−	5−	5−	0	5+	0	0	5+	6+	6	0	0	3−	0	4	5	6	0	4
3	4+	5−	0	0	5	3	6+	0	0	5+	4−	5	0	5	0	4	4	2+	5−	5	5	5+	5	0	5	3	3+	4−	4−	0	0	3−
0	3	5	0	4+	5	4+	5−	0	0	5−	4−	5	0	5	5−	4−	0	4+	5	5−	5−	5−	5−	0	5	4+	4+	4+	4−	0	0	4+
3+	3	5	6−	4	5−	3−	6	0	0	5−	4−	5	0	5	6+	5+	0	3	0	5+	5+	5	5−	0	5−	3−	3	4−	5+	6+	0	4+
0	3−	4−	6−	4+	5	3	5−	0	0	5+	5+	5	0	5	5−	4−	0	2−	0	5+	4−	5−	5	0	0	3	3+	4	5+	6+	0	3−
3	4+	4−	6−	4−	5+	3	5−	0	0	5+	4−	5	0	5	6+	5+	0	3+	0	5+	4	6+	5	0	5	3	3+	4	4−	5−	0	4+
3	3−	5	6−	3	4+	3	6−	0	0	5	5+	4−	0	5+	5	5	0	4	0	0	4−	4−	5−	0	0	4+	3−	4−	5+	6+	0	3−
2−	3−	5	0	4+	4+	3−	6+	0	0	5+	5+	4−	0	5+	5−	5	0	3	0	0	4	4−	5	0	0	4+	3	4−	6+	6+	0	4+
3+	3−	4−	6−	4+	4+	3	6+	0	0	4−	5+	4−	0	5+	5	5+	0	3	0	0	4	4+	5	0	0	4+	3−	4	4−	5−	0	3−
3+	3−	4−	6−	3−	4+	3	6+	0	0	4−	5+	4−	0	5+	5	5	0	3+	0	0	4	4	5	0	0	4+	2−	4−	4−	5−	0	4+
2−	3−	5+	0	4+	4+	3+	6+	0	0	5+	4−	4−	0	5+	0	5	0	3+	0	0	4−	5−	5−	0	0	4+	3	4	4−	5−	0	4+
3+	3−	5+	0	3−	4+	3	6+	0	0	5+	5+	4−	0	5+	5−	5	0	3	0	0	4−	5+	5−	0	5−	4+	3	4−	5+	6+	0	4+
2−	4+	4	6−	4−	5	3−	5−	0	0	5	5+	5	0	5	6+	5+	0	3	0	5+	5+	6+	5−	0	5−	3−	3	4−	5+	6+	0	4+
3+	4+	4−	6−	4	5	3−	5−	0	0	5+	5	5−	0	5	5−	4−	4−	3+	0	5+	4−	6+	5	0	5−	3−	3+	4	4−	5−	0	4+
0	3−	4	6−	4−	5+	3−	5−	0	0	5+	5+	5	0	5	6	4−	0	3+	0	5+	5+	6+	5	0	5−	3	3	4−	4−	5−	0	3
0	4+	5	0	4−	5	3−	5−	0	0	5+	5	5	0	5	5−	4−	4−	3+	0	0	5+	5	5	0	0	3−	3+	4−	4−	0	0	3−
3+	3	4	6−	4−	5	4+	6+	0	0	6+	5	5−	0	6+	0	5−	0	3	0	0	5−	6+	6+	0	6+	4	4	5+	5	6	0	3−
2−	3−	4	6−	4−	5	3−	5−	0	0	5−	5	5−	0	5−	6	5	0	3	0	5	5−	6+	5−	0	5−	4+	3−	4−	5+	6+	0	3−
3+	3	5	0	4−	5	3−	5−	0	0	5	5+	5	0	5	0	5+	0	3	0	5	5−	5	5−	0	5−	3−	0	4	5+	0	0	4
0	4+	4−	0	4−	5	3−	6+	0	0	5	5	5	0	5	5	5+	3−	3+	0	5	5+	5−	5−	0	5−	3−	3+	4−	4−	0	0	3−
0	4+	4	6−	4	5	4+	5	0	0	5+	5−	5	0	5−	6+	4−	0	3+	0	5+	5+	6+	5	0	5	4+	3	5+	4−	5−	0	3
3	3−	4	6−	4	5−	4+	5	0	0	5	5	5		5	0	4−	0	3+	0	5+	5+	5−	5−	0	5−	3−	3	4−	4−	5−	0	3−

TABLE 16.—*Chemical, radioactivity, and semiquantitative spectrographic*

Sample No.	Laboratory No.	Location			Thickness (feet)	Chemical analyses, in percent			Radioactivity analyses eU in sample (percent)	Semiquantitative spectrographic analyses (see table 2 for code)					
		Sec.	T.N.	R.E.		Ash	U in ash	U in sample		Si	Al	Fe	Mg	Ca	Na
COAL BED E—Continued															
North Riley Pass district and vicinity—Continued															
29T	145566	SW¼NW¼SW¼ 23	22	5	0. 5	24	0. 62	0. 15	0. 086	1	1	2+	3+	2	2+
29B	145567	SW¼NW¼SW¼ 23	22	5	. 85	23	1. 6	. 36	. 13	1	2+	2+	2−	2+	2+
29M [3]	145568	SW¼NW¼SW¼ 23	22	5	. 6	19	1. 2	. 24	. 15	1	2+	2+	3+	2	2+
30	145565	SE¼NE¼SE¼ 23	22	5	1. 3	24	. 44	. 11	. 057	1	1	2+	2	2	2−
31	145594	NW¼SW¼NW¼ 26	22	5	1. 2	36	0. 88, . 88	0. 26, . 26	. 15	2+	2+	1	3+	2	2
32	145593	NW¼SW¼NW¼ 26	22	5	1. 0	36	2. 33, 2. 38	. 86, . 84	. 41	2+	2+	1	2−	2+	2
33	145695	NW¼SW¼NW¼ 26	22	5	1. 0	40	. 45	. 18	. 10	1	2+	1	3+	2	2−
34	145592	NE¼SE¼NE¼ 27	22	5	1. 4	36	. 20, . 20	. 074, . 072	. 062	1	2+	1	3	3+	2
35	145591	NE¼SE¼NE¼ 27	22	5	1. 4	34	. 92, . 89	. 30, . 31	. 18	1	1	2+	3	3+	2
36	145590	NE¼SE¼NE¼ 27	22	5	1. 1	28	1. 44, 1. 41	. 40, . 41	. 19	2+	2+	1	2	2	2
37T	145588	NE¼SE¼NE¼ 27	22	5	. 8	35	. 34	. 12, . 12	0. 12, . 16	2+	2	1	3+	2−	2
37B	145589	NE¼SE¼NE¼ 27	22	5	. 8	22	. 56	. 12, . 12	. 059	2+	2+	1	2	2+	2
38T	145586	SE¼NE¼NE¼ 27	22	5	. 75	34	. 076	. 026	. 019	2+	2+	1	3+	2	2
38B	145587	SF¼NE¼NE¼ 27	22	5	. 75	20	. 17	. 035	. 089	2+	2+	1	3+	2+	2
39	145696	SE¼NE¼NE¼ 27	22	5	1. 0	36	. 15	. 053	. 026	1	2+	1	3+	2−	2+
40	145697	SE¼NE¼NE¼ 27	22	5	. 5	45	. 66	. 30	. 11	1	2+	1	2−	2+	3+
41	145698	SE¼NE¼NE¼ 27	22	5	. 9	60	. 02	. 012	. 010	2+	2+	1	3+	2−	0
42	145699	SE¼NE¼NE¼ 27	22	5	1. 5	21	. 33	. 070	. 051	1	2+	1	3+	3+	2+
43	145700	SE¼NE¼NE¼ 27	22	5	1. 2	32	. 50	. 16	. 10	1	2+	2+	2−	2+	3+
44	145701	SE¼NE¼NE¼ 27	22	5	1. 4	23	. 39	. 092	. 047	1	2+	2+	3+	2	2+
45	145702	SE¼NE¼NE¼ 27	22	5	. 6	37	. 48	. 18	. 10	1	1	2+	2−	2+	3+
46	145703	NW¼NE¼NE¼ 27	22	5	. 7	44	. 091	. 040	. 054	1	2+	2+	2−	2+	3+
47	145704	NW¼NE¼NE¼ 27	22	5	1. 0	37	. 17	. 064	. 062	1	2+	2+	2−	2+	2
48	145577	SW¼NE¼NE¼ 27	22	5	1. 2	36	. 021	. 008	. 016	2+	2+	2+	2	1	2−
49	145578	SW¼NE¼NE¼ 27	22	5	1. 2	24	. 062	. 015	. 038	1	1	2+	3+	2	2+
50	145579	SW¼NE¼NE¼ 27	22	5	1. 1	24	. 15	. 036	. 023	2+	2+	2+	2+	1	3+
51	145580	SW¼NE¼NE¼ 27	22	5	1. 2	29	. 38	. 11, . 11	. 053	2+	2+	1	2	2	2+
52	145581	SW¼NE¼NE¼ 27	22	5	1. 4	21	. 48	. 10, . 10	. 061	2+	2+	1	3+	2	2
53	145582	SW¼NE¼NE¼ 27	22	5	. 3	27	. 22	. 060	. 035	2+	2+	1	3+	2	2
54	145583	NW¼SE¼NE¼ 27	22	5	1. 0	33	. 48, . 51	. 17, . 16	. 064	2+	2+	1	2−	2+	2−
55	145584	NW¼SE¼NE¼ 27	22	5	1. 4	26	. 15	. 040	. 025	2+	2+	1	3	2	2−
56	145585	NE¼SW¼NE¼ 27	22	5	1. 1	40	. 095	. 038	. 022	2+	2+	1	3+	2−	2
57	145705	NE¼SW¼NE¼ 27	22	5	1. 3	49	. 011	. 005	. 017	1	2+	2+	3+	2	3+
58	145706	NE¼SW¼NE¼ 27	22	5	1. 4	27	. 27	. 064	. 038	1	1	2+	2−	2+	2
59	145707	NE¼SW¼NE¼ 27	22	5	1. 2	28	. 043	. 016	. 012	1	2+	2+	3+	2+	2+
60	145708	NW¼SW¼NE¼ 27	22	5	1. 1	36	. 14	. 049	. 11	1	2+	2+	3+	2+	2+
61	148784	NW¼NW¼SW¼ 28	22	5	. 1	94	. 003	. 003	. 001	1	2+	3	3	3+	2+
62	145710	SE¼NE¼NW¼ 35	22	5	1. 2	42	1. 9	. 80	. 97	1	2+	2	3+	2	2
63	148821	NW¼NW¼NW¼ 36	22	5	. 9	37	. 076	. 028	. 033	1	2+	2+	3+	2	2
CARBONATE COAL ZONE															
64T	148782	NW¼NW¼SW¼ 28	22	5	0. 9	33	0. 063	0. 021	0. 013	1	2	2+	2	1	2
64B	148783	NW¼NW¼SW¼ 28	22	5	. 8	24	. 022	. 005	. 003	2+	2	1	2	2	1
66B	237155	NE¼NE¼NW¼ 32	22	5	. 5	54	. 035	. 019	. 016	1	1	2+	3+	2−	2−
67T	237156	NW¼NE¼NW¼ 32	21	5	. 7	70	. 004	. 003	. 002	1	1	2+	3+	2−	2
68	149366	SW¼SW¼SE¼ 21	20	4	------	92	. 002	. 002	. 002	1	2	3+	3−	4+	3
COAL ZONE C															
69T [5]	148789	SE¼SE¼SW¼ 12	21	5	1. 1	16	0. 019	0. 003	<0. 001	2	2	1	2	2−	1
69B [5]	148790	SE¼SE¼SW¼ 12	21	5	1. 1	30	. 005	. 001	<. 001	2	2−	1	2−	1	2
70	149343	NE¼NW¼NW¼ 14	22	5	------	22	0. 063, . 068	0. 014, . 015	. 011	1	1	1	1	1	2−
71T	149340	NE¼NW¼NW¼ 20	22	5	1. 1	15	. 14	. 020	. 018	2+	2+	1	2+	1	1
71M	149341	NE¼NW¼NW¼ 20	22	5	1. 4	21	. 02	. 004	. 003	1	1	2	2	2	2+
71B	149342	NE¼NW¼NW¼ 20	22	5	. 8	25	. 03	. 007, . 006	. 003	1	1	2−	2+	2	2+
72	149451	NW¼SE¼SE¼ 29	22	5	. 4	21	. 028	. 006	. 005	1	1	2+	2	2−	1
73	149452	NW¼SE¼SE¼ 29	22	5	. 8	37	. 048, . 049	. 018, . 019	0. 011, . 012	1	2	1	2+	2+	2+

See footnotes at end of table.

analyses of coal samples from miscellaneous localities in the Cave Hills area—Continued

Semiquantitative spectrographic analyses (see table 2 for code)—Continued

COAL BED E—Continued
North Riley Pass district and vicinity—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
3+	3-	5-	6-	0	4-	3-	6	0	0	5+	5+	4	0	5+	0	5	0	3+	0	0	4	4-	5-	0	5-	3-	3+	4-	5+	6+	0	4+
3+	3-	5+	6-	3-	4+	3	6+	0	0	4-	5+	4-	0	5+	5+	5+	0	3+	0	0	4	4-	5	0	5-	3	2-	4	4-	5	0	4+
3	4+	5-	6-	4	4	3-	6+	0	0	5+	5	4-	0	5+	0	5	0	3+	0	0	4	5+	5	0	5-	3-	2-	4-	5+	6+	0	4+
0	3-	5+	6-	4+	4+	3+	6+	0	0	5+	5+	4	0	5+	5	5	0	3	0	0	4	4-	5	0	5-	3	3	4	5+	5-	0	4+
3+	3-	5+	0	4+	4	3+	5-	0	0	4-	5	4	0	5+	5+	5+	0	3	0	5	4	4+	5	0	0	4+	3+	4+	4-	5-	0	4
3+	3	4-	0	3	4	3	5-	0	0	4	5	5+	0	5+	5+	5+	0	4+	0	0	4	4	5+	0	0	3-	2	4+	4-	5-	0	4+
3+	3-	5+	6-	4+	4+	3+	6+	0	0	4-	5+	5+	0	5+	5	5+	0	3+	0	0	4	5+	5-	0	0	4+	3	4-	5+	5-	0	4+
3	3-	5-	0	4-	4	3	6+	0	0	4	5	5+	0	5+	5	5+	0	4+	0	5	4	4-	5-	0	0	4+	3-	4+	4-	5-	0	4+
3+	4+	5-	0	3	4	3-	6+	0	0	5+	5	5+	0	5+	0	5+	0	4+	0	0	4	5+	5-	0	0	4+	3+	4	5+	5-	0	4
0	4+	5+	0	3	4	3	5-	0	0	4-	5	5+	0	5+	5+	5+	0	4+	0	5	4	4+	5+	0	0	3-	2-	4+	4-	5-	0	4
0	3-	5-	0	3-	4	3-	6	0	0	5+	5-	5+	0	5+	5	0	0	3-	0	0	4	5+	5-	0	0	4+	3	4	5+	5-	0	4+
3+	3-	5+	0	4	4	3	5-	0	0	4+	4-	4-	0	5+	5	4-	0	4	0	5	4+	4+	5+	0	0	3-	3+	4+	4	5-	0	4+
3+	3-	5	0	4	4	4+	6+	0	0	4-	5	5+	0	5+	5-	5	0	4	0	0	4	5+	5	0	0	3-	0	4	5+	5-	0	4+
3+	3-	5+	0	4-	4	3-	5-	0	0	4+	0	4-	0	5+	5	5+	0	4	0	5	4+	4+	5	0	0	3	3-	4+	4-	5-	0	4+
3+	3-	5-	6-	0	4+	3	6+	0	0	4-	5	5+	0	5+	5-	5+	0	4+	0	0	4	4-	5-	0	0	4+	3-	4-	4-	5-	0	4+
3+	3-	5	6-	4+	4	3	6+	0	0	5+	5+	5+	0	5+	5	5	0	4+	0	0	4-	4-	5-	0	0	3-	3+	4-	5+	5-	0	4+
3+	3-	4	6-	4	4+	3-	6	0	0	4-	5	5+	0	5+	5+	5	0	4-	0	0	4-	5-	5-	0	0	4+	0	4-	5+	5-	0	4
3+	3-	5-	6-	4+	4+	3	6+	0	0	4-	5+	4-	0	5+	5+	5+	0	3	0	0	4	4+	5	0	0	4+	3	4+	4-	5-	0	4+
3+	3-	5+	6-	3-	4	3	6+	0	0	4-	5+	5+	0	5+	5-	5+	0	3-	0	0	4	5	5-	0	0	4+	3+	4-	4-	5-	0	4+
3+	3-	5-	6-	4	4	3	6+	0	0	4-	5	4-	0	5+	5-	5+	0	4+	0	0	4	4+	5-	0	0	4+	3	4-	5+	5-	0	4+
3+	3-	5	6-	3+	4	3	6+	0	0	4-	5+	5+	0	5+	5-	5+	0	3-	0	0	4	4-	5-	0	0	4+	3+	4-	5+	5-	0	4+
3+	3-	5-	6-	3+	4	3	6+	0	0	5+	5+	4-	0	5+	5-	5+	0	4+	0	0	4	4	5-	0	0	4+	4+	4	4-	5-	0	3-
3+	3-	5-	6-	3-	4	3	6+	0	0	5+	5+	4-	0	5+	5	5+	0	4+	0	0	4	4	5-	0	0	4+	3	4-	4-	5-	0	4+
3	4+	5+	0	4+	4	3	5-	0	0	5+	5	4-	0	5+	5	5+	0	4	0	0	4	4	5	0	0	4+	0	4	4-	5-	0	3-
3+	3-	5-	6-	0	4+	3-	6+	0	0	4	5+	4-	0	5+	5	5+	0	4+	0	0	4+	4	5+	0	0	3-	3-	4	4	5-	0	4+
3	3-	4-	0	3-	4+	3	5-	0	0	4-	5+	4-	0	5+	5	5+	0	4	0	0	4+	4	5	0	0	4+	3-	4	4	5-	0	4+
3	4+	4-	0	4+	4	3	5-	0	0	4	5	5+	0	5+	5	5+	0	4+	0	5	4	4+	5	0	0	3-	3	4+	4-	5-	0	4
3	4+	4-	0	4+	4	3	5-	0	0	4	5	5+	0	5+	5+	5+	0	3+	0	5	4	4	5	0	4	4+	3+	4+	4-	5-	0	4+
3+	4+	4	0	4+	4+	3	5-	0	0	4	5+	4-	0	5+	5	4-	0	4+	0	5	4+	4+	5	0	0	3-	3-	4+	4-	5-	0	4
3+	3-	4-	0	4	4	3	5-	0	0	4	5+	5+	0	5+	5	5	0	4+	0	0	4+	4	5	0	0	4+	3+	4+	5+	5-	0	4
0	3-	5+	0	4+	4	3-	6+	0	0	4-	5	5+	0	5+	5	5	0	4+	0	0	4	4	5-	0	0	4+	3-	4+	5+	5-	0	4+
3+	3-	5	0	4	4	3-	6+	0	0	4	5+	5+	0	5+	5	5+	0	4-	0	5	4	4-	5	0	0	3-	4+	4	4-	5-	0	4+
0	3-	4-	0	4	4-	3-	6+	0	0	5+	5	5-	0	5	5	5	0	4-	5-	5-	4-	5	5-	0	5-	3-	0	4	4-	0	0	3-
2-	3-	5	0	4+	5	3-	6+	0	0	4-	5	5	0	5	5	4	0	4	5-	5	4-	5+	5-	0	5-	3	3	4	4-	0	0	3-
3+	3-	5+	6-	4	4	3	5-	0	0	4	5	5+	0	5+	4-	5+	0	4-	0	0	4+	4	5	0	0	3-	0	3-	4-	5-	4-	4+
3+	3-	5	6-	0	4	3+	6+	0	0	4	5	5+	0	5+	5	5+	0	4	0	0	4	4-	5-	0	0	4+	4+	4-	4-	6+	4-	4+
0	3	5+	0	0	5-	4	6-	0	0	0	4	4-	0	5-	0	5+	0	5	0	0	5-	5	5-	0	0	4-	0	4-	5+	6	0	4-
3+	3-	5	6-	2-	4	3	6+	0	0	4-	5	4-	0	5+	5	5+	0	3+	0	0	4	4	5-	0	0	4+	2-	4-	5+	5-	0	4
3+	3	4-	0	4+	4-	3-	6+	0	0	5	5+	5+	0	5	0	0	0	3+	0	0	5+	5+	5	0	0	3-	0	4-	5+	6+	0	3-

CARBONATE COAL ZONE—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
0	3	5+	0	0	4-	3-	6	0	0	5-	5+	5+	0	6+	0	5+	0	3-	0	0	5-	5-	5	0	0	3	0	5+	5+	6+	0	4+
2-	3-	4-	6	0	5+	3	6	0	0	5-	5+	5+	0	6+	0	0	0	4+	0	0	5+	5-	5-	0	0	4+	0	5+	5+	6+	0	4+
2-	3	5	6-	4	4-	3	6-	0	4	4-	4-	4-	0	5+	0	5+	0	5+	0	0	4-	5	5-	0	0	4	0	5+	5+	6+	0	4+
2-	3-	5+	0	0	4-	4+	6	0	0	5	5	5+	0	5+	0	0	0	5-	0	0	4-	5	5-	0	0	4	0	5	5+	6+	0	5
3+	3	5+	0	4+	4-	4	0	0	0	0	5-	4-	0	6+	0	0	0	0	0	0	0	0	0	0	0	5+	0	5	5	6+	0	4+

COAL ZONE C—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
3+	4+	5+	7+	0	5	3	6	0	0	5	5+	5+	0	5-	0	5+	0	4+	0	0	5	5-	5	0	0	4+	0	5+	4-	5-	0	4+
3+	4	4-	7+	0	5	3-	6-	0	0	5-	5+	5+	0	6+	0	0	0	4+	0	0	5-	5-	5	0	5	4	0	5+	5	6+	0	4
0	3-	3-	7+	4+	4-	3	6+	0	0	5-	5-	5+	0	6+	0	5+	0	4	0	0	4-	5	5	0	5-	3-	3-	5	5+	5-	0	3-
3+	3-	4-	7+	0	3-	3+	5-	0	4+	5+	5	5+	5+	5-	0	4	0	4+	0	4	5	4-	5+	4-	0	3	3	5+	4	5	0	3
2-	3	4-	7+	0	4+	3	5-	0	0	6+	5+	4-	0	5	0	5+	0	4-	0	0	5	5+	5+	0	0	4+	0	4-	5+	6+	0	3-
2	3	4+	6+	0	4+	3-	5-	0	0	5	4-	4-	0	5+	5	0	0	4	0	0	5+	5	5+	0	0	4+	0	4	5+	6+	0	3-
2-	3	4	7+	0	4-	3	5	0	4+	4-	4-	5+	0	4-	5	4	0	4	0	4	4+	4-	5+	0	0	3-	0	4	4	5	0	3-
0	3+	4-	7+	0	4-	3	5-	0	0	5-	5	5+	0	5	0	0	0	4+	0	0	5+	5	5+	0	5-	3-	0	5+	4-	5-	0	3-

TABLE 16.—*Chemical, radioactivity, and semiquantitative spectrographic*

Sample No.	Laboratory No.	Location			Thickness (feet)	Chemical analyses, in percent			Radioactivity analyses eU in sample (percent)	Semiquantitative spectrographic analyses (see table 2 for code)					
		Sec.	T.N.	R.E.		Ash	U in ash	U in sample		Si	Al	Fe	Mg	Ca	Na
COAL ZONE C—Continued															
74	149448	SE¼SE¼SE¼ 29	22	5	1.0	23	0.09	0.021	0.013	1	2+	1	2	2+	2
75	149449	SE¼SE¼SE¼ 29	22	5	1.0	32	0.025, .016	0.008, .005	.009	1	1	2	2	2	2
76	149450	SE¼SE¼SE¼ 29	22	5	1.0	28	.025	.007	.007	2+	2+	1	2−	2	2+
77	149447	SE¼NE¼NE¼ 32	22	5	1.0	39	.09	.035	.033	1	2+	1	2−	2+	2−
78 [6]	145771	NE¼NE¼NW¼ 35	22	5	2.3	18	.060, .082	.011, .015	.008	1	2+	2+	2−	2−	2+
79	149358	SW¼NW¼SE¼ 2	21	5	1.3	35	.06	.021, .020	0.017, .017	1	2+	1	2	2+	2+
80	149359	SW¼NW¼SE¼ 2	21	5	1.4	26	.05	.013	.011	1	2+	1	2	2	2+
81	149351	SE¼NW¼SE¼ 2	21	5	1.6	35	.05	.019	.017	1	2+	1	2	2+	2+
82	149353	SE¼NW¼SE¼ 2	21	5	1.2	32	.10	.032	.030	1	1	2+	2+	1	2+
82a [7]	149352	SE¼NW¼SE¼ 2	21	5	------	32	2.0	.63	.68	1	1	2+	2+	1	2+
83	149354	SE¼NW¼SE¼ 2	21	5	1.5	36	.36	.13	.11	1	2+	1	2	2+	2
84	149355	NE¼SW¼SE¼ 21	21	5	1.4	37	.04	.015	.013	1	2	1	2−	2+	2
85T	149356	NE¼SW¼SE¼ 21	21	5	1.0	34	.21	.070	.065	1	2	1	2−	2	2
85B	149357	NE¼SW¼SE¼ 21	21	5	.4	30	6.3	1.9	1.7	1	2+	2+	2	2	2
86	149360	NE¼NE¼NE¼ 11	21	5	2.0	26	.026	.007	.006, .005	2+	2+	1	2+	2+	2+
87	149361	NE¼NW¼NW¼ 12	21	5	3.0	35	.04	.014, .015	.011, .011	2+	2	1	2	2	2+
87T	149362	NE¼NW¼NW¼ 12	21	5	.8	40	.05	.021, .020	.014, .017	1	2	1	2−	2	2
88T [8]	149363	NW¼NE¼NW¼ 12	21	5	3.0	25	.03	.008	.006	1	1	2−	2+	2+	2+
89	237160	SE¼SE¼SW¼ 29	21	5	.8	70	.006	.004	.006	1	2+	2+	3+	2	3+
90T	237157	NE¼NE¼NW¼ 32	21	5	1.1	30	.069	.019	.018	1	1	2+	2	2+	2−
91T [9]	237063	SW¼SW¼SW¼ 4	20	5	.4	70	.088	.060	.060	2+	2+	1	3+	2−	2
91B [9]	237064	SW¼SW¼SW¼ 4	20	5	.7	54	.085	.046	.033	1	1	2+	3+	2	2−
COAL ZONE B															
92T [5]	148791	SE¼SE¼SW¼ 12	21	5	1.9	15	0.004	0.001	<0.001	1	2+	2	2	2	1
92M [5]	148792	SE¼SE¼SW¼ 12	21	5	1.9	26	.005	.001	<.001	2−	2−	2+	2−	1	2
92B [5]	148793	SE¼SE¼SW¼ 12	21	5	2.0	11	.003	<.001	<.001	2	2+	2+	2	2	1
92a [5]	148794	SE¼SE¼SW¼ 12	21	5	1.1	28	.005	.001	.001	2	2	1	2−	2	2
93T	148785	SE¼NW¼SW¼ 28	22	5	.8	34	.014	.005	.001	1	2+	2+	2+	1	2+
93B	148786	SE¼NW¼SW¼ 28	22	5	.8	25	.006	.002	.002	2+	2+	1	2+	1	1
94	237161	NE¼NE¼NW¼ 32	21	5	1.6	34	.020	.007	.004	1	2+	2+	2−	2+	2−
95T [9]	237065	SW¼SW¼SW¼ 4	20	5	1.1	47	.026	.012	.013	1	1	2+	3−	2	2
95B [9]	237066	SW¼SW¼SW¼ 4	20	5	1.1	75	.003	.002	.002	1	1	2+	3+	2	2
LONESOME PETE COAL ZONE															
96T [5]	148795	SE¼SE¼SW¼ 12	21	5	1.0	71	0.004	0.003	0.002	1	1	2−	2−	3+	3+
96B [5]	148796	SE¼SE¼SW¼ 12	21	5	.1	11	.011	.001	<.001	1	2	2−	2	3+	1
96a [5]	148797	SE¼SE¼SW¼ 12	21	5	.5	38	.003	.001	.002	1	2	1	3+	2	2
97T [5]	148798	SE¼SE¼SW¼ 12	21	5	1.0	23	.003	.001	<.001	2	2+	1	3+	2+	2
97B [5]	148799	SE¼SE¼SW¼ 12	21	5	1.0	17	.003	.001	<.001	2+	2+	2	3+	1	1
98T [10]	237162	NE¼NE¼NW¼ 32	21	5	.4	29	.050	.014	.011	1	2+	2+	2−	2+	2−
98B [10]	237163	NE¼NE¼NW¼ 32	21	5	1.2	36	.007	.003	.003	1	1	2+	3+	1	3+
LOWER COAL BEDS															
99 [5]	148800	SE¼SE¼SW¼ 12	21	5	1.0	42	0.004	0.002	0.002	1	1	2+	3	2	2−
100 [5]	148801	SE¼SE¼SW¼ 12	21	5	1.2	29	.008	.002	.001	1	2+	2+	2−	2+	2
101 [5]	148802	SE¼SE¼SW¼ 12	21	5	.9	35	.014	.005	.002	2+	2	2+	2	2−	1
102T [5]	148803	SE¼SE¼SW¼ 12	21	5	1.8	22	.004	.001	.001	2+	2	2+	3	1	2−
102B [5]	148804	SE¼SE¼SW¼ 12	21	5	2.0	15	.005	.001	.001	2+	2+	2	3+	1	2−
103T [5]	148805	SE¼SE¼SW¼ 12	21	5	1.5	40	.008	.003	<.001	1	1	2+	2−	2	2−
103B [5]	148806	SE¼SE¼SW¼ 12	21	5	1.5	24	.007	.002	<.001	1	2+	2−	3+	2	2−
104T [5]	148807	SE¼SE¼SW¼ 12	21	5	3.0	58	.009	.005	<.001	1	1	2−	2−	2−	3+
104B [5]	148808	SE¼SE¼SW¼ 12	21	5	1.0	22	.006	.001	.001	1	1	2	2−	2+	2−
105 [5]	148809	SE¼SE¼SW¼ 12	21	5	.5	64	.008	.005	.001	1	1	2+	3+	2−	2−

See footnotes at end of table.

analyses of coal samples from miscellaneous localities in the Cave Hills area—Continued

Semiquantitative spectrographic analyses (see table 2 for code)—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
COAL ZONE C—Continued																																
0	3	4−	6−	0	4−	3	6+	0	4	5−	5+	4	0	5+	0	4−	0	3	0	4−	4−	5+	5+	0	5−	3	0	4−	4−	5−	0	3−
2−	3+	4−	7+	0	4−	3	6+	0	0	5−	5+	5+	0	5	5+	0	0	3−	0	0	5+	5	5	0	0	3	0	4−	5+	6+	0	3−
2−	3	4	7+	3	4−	3	6+	0	0	5−	5	5+	0	5+	5+	4−	0	3	0	4−	4−	5+	5	0	5	3−	0	4−	4−	5−	0	3−
2−	3	4−	7+	0	5	4+	5−	0	0	5−	5+	4−	0	5	0	5+	0	3−	0	0	4−	5	5	0	5−	3−	0	4−	4−	5−	0	3−
2−	3−	5−	6−	0	4+	3+	6	0	0	5	4−	4	0	5+	5−	5+	0	4+	0	0	4−	5+	5−	0	0	3−	4+	5+	5+	6+	0	4+
3+	3−	4−	0	0	5+	3	5−	0	0	0	5−	5+	0	4−	5	0	0	4+	0	0	5	5+	5−	0	5−	4+	0	4−	5	6+	0	4+
3+	3−	4−	0	0	5+	3	5−	0	0	6+	5	5+	0	5+	0	0	0	4+	0	0	5	0	5	0	5−	4+	0	4−	5	6+	0	3−
2−	3−	4	7+	4+	4−	3	6+	0	0	6+	5−	5+	0	5	0	0	0	4	0	0	5	5	5	0	5−	3−	0	5+	5	6+	0	3−
0	3	4−	7+	3+	4−	3	5−	0	0	---	5	5+	0	5+	0	5+	0	3+	0	0	5+	4−	5	0	5−	3−	3+	4−	4−	5−	0	3−
0	3	4−	7+	3+	4−	3+	5−	0	0	---	5	5+	0	5+	0	5+	0	3+	0	0	5+	4	5	0	5−	3−	3+	4−	4−	5−	0	3−
3+	3	4−	0	3−	5−	3−	5−	0	0	---	5+	5+	0	4−	0	0	0	3	0	0	5	5+	5	0	5−	4+	3	4−	5	6+	0	3−
3+	3−	4−	0	4+	5−	3	6	0	0	6+	5	5+	0	5+	0	0	0	4	0	0	5	5−	5	0	5−	4+	0	4−	5	6+	0	3−
0	3−	4−	0	3−	5−	4+	6+	0	0	6+	5	5+	0	5	0	0	0	3−	0	0	5−	5	5	0	5−	4	3	4−	5	6+	0	3−
0	3−	4−	0	3+	5+	3+	6+	0	0	---	5	5+	0	5	0	0	0	2−	0	0	5	4−	5	0	0	4+	2+	4−	5+	---	0	3−
3+	3−	4−	0	0	5	3+	6+	0	0	5−	5	5	0	6+	0	0	0	4+	0	0	5	5−	5−	0	0	3−	0	4−	5+	6+	0	3−
2−	3−	4−	7+	3+	5	3	6+	0	0	5−	5	5	0	5	5	5+	0	4−	0	0	5+	5	5	0	5	4+	0	4−	5+	6+	0	3−
2+	3	4−	7+	3	5−	3+	6+	0	0	0	5	5+	0	5	0	0	0	4	0	0	5−	5	5	0	5−	4+	0	4−	5+	6+	0	3−
2−	3	4+	7+	0	4+	3	5−	0	4	5+	5	5+	0	5	0	4−	0	4	0	4	4	4−	5	0	5−	4+	0	4−	4−	5−	0	3−
2	3−	5	6−	0	4	3−	6	0	0	5−	5	5−	0	5+	0	0	0	5+	0	0	4−	5	5−	0	0	4	0	5+	5	6+	0	4
3+	3	5+	0	4	4	3+	6	0	0	5+	5	4−	0	5+	5−	0	0	4−	0	0	4−	4−	5−	0	0	4+	0	5+	5+	6+	0	4+
3+	3−	4+	7+	3−	4−	3−	6−	0	0	5−	5	5−	0	5+	0	0	0	3	0	0	4	5	5	0	0	3−	3−	5+	5	6+	0	4+
3+	3−	4−	7+	0	4−	3−	6	0	0	5−	5	5+	0	5+	0	0	0	4+	0	0	5	5	5	0	0	4−	4+	5+	5+	6+	0	4+
COAL ZONE B—Continued																																
3+	3	4+	7+	0	4+	3	6	0	0	5+	4−	4−	0	5	5	5+	0	4+	0	4−	4	5	5+	0	0	4	0	4−	4−	5−	0	4
3+	4	4	7+	0	4	4+	0	0	0	6+	5−	5	0	6+	0	0	0	5+	0	0	6+	5−	0	0	0	3−	0	5+	0	0	0	5+
0	3−	4+	7+	0	4+	3−	6	0	0	5	5+	4−	0	5−	0	0	0	4+	0	0	4−	5	5	0	0	3−	0	5+	5+	6+	0	4
2−	4+	4	0	0	4−	4+	6	0	0	5−	5+	5+	0	6+	0	0	0	5+	0	0	4−	5	5	0	0	4+	0	5+	5+	6+	0	4−
2−	3−	4	7+	0	4	4+	6	0	0	5−	5+	5+	0	6+	0	0	0	5+	0	0	5	5−	5−	0	0	3−	0	5+	5+	6+	0	4
3+	3−	4	0	0	4	3−	6+	0	0	5−	5+	5+	0	6+	0	5+	0	5+	0	0	5−	5−	5	0	0	3+	0	5+	5+	6+	0	4
3+	3−	5−	6−	0	4	3−	6	0	0	5−	5−	4−	0	5+	0	0	0	5+	0	0	4−	5	5−	0	0	4+	0	5−	5+	6+	0	4−
3+	3−	4−	7	0	4−	4−	6−	0	0	5−	5	5	0	5+	0	0	0	4−	0	0	4−	5	5	0	0	4−	0	5+	5−	6	0	4+
3	3	4	7	0	4−	3	6+	0	0	5+	5−	5−	0	5+	0	5	0	4−	0	0	4	5	5	0	0	4+	0	5−	5+	6+	0	4+
LONESOME PETE COAL ZONE—Continued																																
2	3	4	0	0	4−	4	6	0	0	5	4−	5+	0	6+	0	0	0	0	0	0	5	5+	5	0	5	4	0	4−	5	6	0	4−
2−	3−	4−	7+	0	4+	4−	6+	0	0	5−	5+	4−	0	4−	4	0	0	4−	0	0	5	5+	5	0	0	4−	0	4−	5	6+	0	3−
2−	3−	4−	0	0	4−	3−	6	0	0	5−	5+	5+	0	5−	0	0	0	5+	0	0	5	5	5	0	0	4+	0	4−	5+	6+	0	4−
3+	4+	4−	0	0	4	3−	6	0	0	6+	5	5+	0	6+	0	0	0	4−	0	0	6+	5+	5−	0	0	4+	0	5+	5	6	0	4
3+	4+	4−	0	0	4	3+	6	0	0	6+	5+	5+	0	5−	0	0	0	5+	0	0	6+	5−	5	0	0	3−	0	5+	5	6+	0	4
3+	4+	5−	6−	0	4−	3	6	0	0	5−	5	4−	0	5+	5−	5	0	5	0	0	4−	5	5−	0	0	4+	0	5+	5+	6+	0	4−
3+	3	5	6−	0	4	3−	6	0	0	5−	5	5+	0	5+	5−	5	0	5	0	0	4−	5	5−	0	0	4+	0	5	5+	6+	0	4−
LOWER COAL BEDS—Continued																																
2−	3	5+	0	0	4−	3−	6	0	0	6+	5+	5+	0	5	0	5+	0	5+	0	0	5−	5	5	0	0	4+	0	4−	5	6+	0	4
2−	3−	5+	7+	0	4−	4+	6−	0	0	0	5+	5+	0	5	0	0	0	5+	0	0	5−	5	5	0	0	4+	0	4−	5	6+	0	4
2−	3−	5+	7+	0	4−	4+	6−	0	0	6+	5+	4−	0	5	5+	0	0	5+	0	0	5	5−	5	0	0	4	0	4−	5+	6+	0	3−
3+	4+	4−	0	0	4	3+	0	0	0	0	5	5+	0	6+	0	0	0	5+	0	0	6+	0	5−	0	0	4+	0	5+	0	0	0	4−
3+	3−	4	6−	0	4+	3−	6+	0	0	5−	5+	4−	0	5	0	0	0	5+	0	0	5+	5+	5	0	0	4+	0	5+	5+	6+	0	4−
2−	3	4−	0	0	4	4	6−	0	0	5−	4−	4−	0	5−	0	0	0	5+	0	0	5	5	5	0	0	4	0	4−	5	6	0	4−
3+	3−	4	0	0	4	4	6	0	0	6+	5+	4−	0	5−	0	0	0	5+	0	0	5−	5+	5	0	0	4	0	4−	5+	6+	0	4−
2−	3+	4	0	0	4	4	6	0	0	6+	4−	5+	0	5	0	0	0	5+	0	0	5−	5+	5	0	0	4−	0	4−	5+	6+	0	4−
2−	3	4	0	0	4	4−	6+	0	0	5	4−	4−	0	5	0	0	0	4	0	0	5+	5+	5	0	0	4	0	4−	4−	6+	0	4−
2−	3	5+	0	0	4−	4	6−	0	0	6+	4−	4−	0	5−	0	0	0	5	0	0	5−	5	5	0	0	4−	0	4−	5	6+	0	4−

TABLE 16.—*Chemical, radioactivity, and semiquantitative spectrographic*

Sample No.	Laboratory No.	Location			Thickness (feet)	Chemical analyses, in percent			Radioactivity analyses eU in sample (percent)	Semiquantitative spectrographic analyses (see table 2 for code)					
		Sec.	T.N.	R.E.		Ash	U in ash	U in sample		Si	Al	Fe	Mg	Ca	Na
							LOWER COAL BEDS—Continued								
106 [5]	148810	SE¼SE¼SW¼ 12	21	5	1.0	23	0.008	0.002	<0.001	1	2+	2	2−	2	2+
106a	148811	SE¼SE¼SW¼ 12	21	5	1.0	23	.040	.009	0.008, .006	1	1	2	2−	2+	3+
107 [5]	148812	SE¼SE¼SW¼ 12	21	5	1.0	31	.009	.003	.001	1	2+	2−	2	2	2
108 [5]	148813	SE¼SE¼SW¼ 12	21	5	.6	27	.010	.003	<.001	1	2	2	3+	2	2
109 [5]	148814	SE¼SE¼SW¼ 12	21	5	.5	39	.009	.004	.001	1	2+	1	3+	2−	2−
110 [5]	148815	SE¼SE¼SW¼ 12	21	5	.8	70	.008	.006	.001	1	1	2−	2−	2−	3+
111 [5]	148816	SE¼SE¼SW¼ 12	21	5	.2	76	.007	.005	<.001	1	1	2−	2−	2−	2−
112T [5]	148817	SE¼SE¼SW¼ 12	21	5	1.9	32	.009	.003	.002	1	1	2	2−	2	2−
112B [5]	148818	SE¼SE¼SW¼ 12	21	5	1.9	54	.005	.003	.001	1	1	2−	2−	2−	2
113 [10]	237164	NE¼NE¼NW¼ 32	21	5	1.1	46	.005	.002	.002	1	1	2+	3+	2	3+
114 [10]	237165	NE¼NE¼NW¼ 32	21	5	.9	35	.002	.0007	<.001	1	1	2+	3+	2+	3+
115 [9]	237067	SW¼SW¼SW¼ 4	20	5	.9	27	.015	.004	.004	1	1	2+	3+	2	2−
116T [9]	237068	SW¼SW¼SW¼ 4	20	5	.8	20	.018	.004	.003	1	1	2	2−	3+	2
117 [9]	237070	SW¼SW¼SW¼ 4	20	5	1.4	41	.003	.001	.001	1	1	2−	3	2	3
118T [9]	237071	SW¼SW¼SW¼ 4	20	5	.8	26	.001	.0003	<.001	1	1	2	3−	2	3+
119T [9]	237073	SW¼SW¼SW¼ 4	20	5	1.7	27	.003	.0008	<.001	1	1	1	3−	2	3+
119B [9]	237074	SW¼SW¼SW¼ 4	20	5	1.2	19	.004	.0008	<.001	2+	2+	1	4+	2+	2−
119a [9]	237074	SW¼SW¼SW¼ 4	20	5	1.2	18	.003	.0005	<.001	2+	2+	1	3+	1	2+
120 [9]	237075	SW¼SW¼SW¼ 4	20	5	.2	38	.009	.003	.002	1	1	2+	2	2	2+

[1] Rider 10 ft above sample 16T.
[2] Rider 10 ft above sample 17T.
[3] Middle, overlaps samples 29T and 29B.
[4] Top of 1.2-ft bed.
[5] Shown on columnar section 8, pl. 2, chap. A.
[6] Shown on columnar section 6, pl. 2, chap. A.
[7] Grab sample from sample 82.
[8] Top of 4-ft bed.
[9] Shown on columnar section 15, pl. 2, chap. A; sample 119a is a split of sample 119B.
[10] Shown on columnar section 11, pl. 2, chap. A.

analyses of coal samples from miscellaneous localities in the Cave Hills area—Continued

Semiquantitative spectrographic analyses (see table 2 for code)—Continued

K	Ti	Mn	Ag	As	B	Ba	Be	Bi	Ce	Co	Cr	Cu	Dy	Ga	Ge	La	Li	Mo	Nb	Nd	Ni	Pb	Sc	Sm	Sn	Sr	U	V	Y	Yb	Zn	Zr
LOWER COAL BEDS—Continued																																
2−	3	4−	7+	0	4	4	6+	0	0	5	5+	4−	0	5	0	0	0	5+	0	0	5+	5	5	0	0	4	0	4−	4−	6+	0	4−
2−	3	4	0	0	4	4	5−	0	0	5	5+	4−	0	5	0	0	0	5+	0	0	4−	5	5	0	0	4	0	4−	4−	5−	0	4
3+	3	4	7+	0	4	4	6+	0	0	5−	5+	4−	0	5+	5	0	0	4−	0	0	5+	4−	5	0	0	4+	0	4−	4−	5−	0	4
3+	3	4−	0	0	5+	4+	6	0	0	5−	4	5+	0	5+	5+	0	0	5+	0	0	5+	5	5	0	0	4	0	4+	5+	6+	0	4
2−	3−	4−	0	0	4	4+	6−	0	0	6+	5+	5+	0	5	5−	0	0	5+	0	0	5	5	5−	0	0	4−	0	4−	5	6	0	4−
2−	3	5+	0	0	4−	4+	6	0	0	6+	5+	5+	0	5	0	0	0	0	0	0	5	5	5	0	0	4	0	4−	5+	6+	0	4
3+	3	5+	0	0	5+	3−	6	0	0	6+	4	5+	0	5−	0	0	0	0	0	0	5−	5	5	0	0	4−	0	4−	5+	6+	0	4
2−	3	4+	0	0	4+	3	6	0	0	5−	4−	4−	0	5	0	0	0	5+	0	0	5+	5	5	0	0	4	0	4−	5+	6+	0	4−
3+	3+	4−	7+	0	4	3−	5−	0	0	5	4	4−	0	5+	0	5+	0	5+	0	0	4−	5+	5+	0	0	4+	0	4	4−	5−	0	4+
2−	3	5−	0	0	4	3−	6	0	0	5−	5	5+	0	5+	5−	5	0	5	0	0	4−	5+	5	0	0	4+	0	5	5+	6+	0	4−
3+	3	5	6−	0	4	3−	6	0	0	5−	5+	4−	0	5+	0	5	0	5+	0	0	4−	5	5−	0	0	4+	0	5+	5+	6+	0	5+
3+	3	4+	7+	0	4	3−	6	0	0	5+	5+	5	0	5+	0	5	0	5−	0	0	4−	5+	5+	0	0	4	0	5	5+	6+	0	4+
3	3+	3−	6−	0	4	4−	6	0	0	4−	5+	5+	0	5+	0	0	0	5−	0	0	4	5+	5	0	0	4	0	5	5+	6+	0	4+
3+	3+	4	7	0	4−	3−	6	0	0	5+	5+	5	0	5+	0	0	0	5+	0	0	4−	5	5	0	0	4−	0	5	5+	6+	0	4+
3+	3−	4	7	0	4	4+	6	0	0	5−	5+	5	0	5+	0	0	0	5	0	0	5−	5	5+	0	0	4	0	5	5+	6+	0	4
3+	3−	4+	7+	0	4	4+	6−	0	0	5	5+	5+	0	5+	0	0	0	5+	0	0	4−	5−	5	0	0	4−	0	5+	5	6	0	4
3+	4+	4	7+	4−	4−	4+	7+	0	0	0	5+	5+	0	5+	0	0	0	4−	0	0	5+	5−	5+	0	0	4	0	5	5	6	0	4+
2−	4+	4−	0	0	4	3−	6−	0	0	5−	5+	4	0	5+	0	Tr	0	4−	0	0	5+	5+	5+	0	0	3−	0	4−	5+	5−	0	4+
2−	3	4	6−	0	4−	4+	6	0	0	5−	4−	5+	0	5+	4−	0	0	5+	5−	0	5	5	4−	0	0	4−	0	4−	4−	5−	0	3−

TABLE 17.—*Chemical, radioactivity, and semiquantitative spectrographic*

Analyses: Percentage of uranium in sample calculated from percentage of ash and percentage

[Chemical analyses (U in ash) by Roosevelt Moore, Grafton Daniels, and Joseph Budinsky; radioactivity analyses (eU in sample) by

Loc. No. on pl. 3, chap. A	Laboratory No.	Thickness (feet)	Chemical analyses, in percent			Radioactivity analyses	Semiquantitative spectrographic analyses (see table 2 for code)									
			Ash	U in ash	U in sample	eU in sample (percent)	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag
					NORTH PIT											
					Grab samples											
10	237105	--------	82	0. 025	0. 020	0. 015, 0. 017	1	1	2	3+	2−	2	2	3	5+	0
12 [1]	237106	--------	92	. 023	. 021	. 023	1	2	2+	3−	3−	3+	2−	3−	4−	0
13	237107	--------	78	0. 59, . 64	0. 46, . 50	. 37, . 39	1	2+	2+	3+	2−	2	2	3	5+	7−
15	237108	--------	79	. 56, . 56	. 44, . 44	. 33, . 35	1	1	2	3+	2−	2	2	3	5+	7−
17 [1]	237109	--------	94	. 011, . 010	. 010, . 009	. 022, . 018	1	2	2+	3−	3−	3+	2−	3−	4−	7−
19	237110	--------	66	1. 4, 1. 3	. 92, . 86	. 63, . 64	1	1	2	3+	3+	2	2	3	5+	7
21	237111	--------	78	. 61, . 66	. 48, . 51	. 36, . 39	1	1	2	3+	2−	2	2	3	5+	0
23	237112	--------	80	. 27	. 22	. 17, . 18	1	1	2	3+	3+	2	2	3	5+	0
25	237113	--------	81	. 19, . 20	. 15, . 17	. 10, . 11	1	1	2	3+	3+	2	2	3	5+	0
27	237114	--------	82	. 11, . 12	. 092, . 098	. 065, . 064	1	1	2	3+	3+	2	2	3	5+	0
29	237115	--------	82	. 023	. 019	. 016, . 016	1	1	2	3+	3+	2	2	3	5+	0
31	237116	--------	83	. 011	. 009	. 010	1	1	2	3+	3+	2	2	3	5+	8+
33	237117	--------	82	. 008	. 007	. 007	1	1	2	3+	3+	2	2	3	5+	8+
35	237118	--------	82	. 005	. 004	. 008	1	1	2	3+	3+	2	2	3	5+	0
					Channel samples											
C6	237095	1. 0	75	0. 82	0. 62	0. 53	1	1	2	3+	2−	2	2	3	5+	7
C10	237098	. 4	85	0. 50, . 50	0. 42, . 42	0. 34, . 31	1	1	2	3+	3+	2	2	3	5+	7
C11	237099	. 5	69	1. 4, 1. 3	. 95, . 86	. 65, . 59	1	1	2	3+	2−	2	2	3	5+	7
C12	237100	. 65	87	. 15, . 14	. 13, . 12	. 083, . 088	1	1	2	3+	3+	2	2	3	5+	7
C15	237101	. 7	91	. 011	. 009	. 009	1	1	2	3+	3	2	2	3	5+	8+
C16	237102	. 5	87	. 011	. 010	. 009	1	1	2	3+	3+	2	2	3	5+	0
C17	237103	. 5	81	. 011	. 009	. 008	1	1	2	3+	2−	2	2	3	5+	8+
C18	237104	. 5	86	. 016	. 014	. 009, . 010	1	1	2	3+	3+	2−	2	3	5+	0
					SOUTH PIT											
					Grab samples											
8	237136	--------	91	0. 008	0. 007	0. 036	1	1	2	3+	3+	2	2	3	4−	7
19	237141	--------	75	. 50	. 37	1. 1	1	1	2	3+	2	2	2	3	5+	7
24	237143	--------	92	0. 24, . 28	0. 22, . 26	0. 80, . 85	1	1	2−	3+	2−	2	2	3	5+	7
26	237144	--------	90	. 050	. 045	. 18	1	1	2+	3+	3+	2	2	3	4−	7
					Channel samples											
C1	237119	1. 2	92	0. 006	0. 006	0. 013	1	1	2	3+	3	2	2	3	5+	0
C2	237120	. 6	89	. 008	. 007	. 023	1	1	2	3+	3+	2	2	3	4−	0
C3	237121	. 4	92	. 006	. 006	. 011	1	1	2	3+	3	2−	2	3	5+	0
C6	237123	. 4	92	0. 017, . 016	0. 016, . 014	0. 066, . 055	1	1	2	3+	2+	2	2	3	5+	7
C8	237125	. 5	78	. 70	. 55	1. 2	1	1	2	3+	2	2	2	3	4−	7
C9	237126	. 35	85	. 16, . 16	. 14, . 14	. 42, . 44	1	1	2	3+	2−	2	2	3	5+	7
C10	237127	. 35	92	. 020, . 021	. 018, . 019	. 056, . 046	1	2+	2	3+	3+	2	2	3	5+	7
C15	237132	. 5	88	. 28, . 28	. 23, . 23	1. 5, . 88	1	1	2−	3+	2	2	2	3	5+	7
C16	237133	. 5	87	. 080	. 069	. 26	1	1	2	3+	2−	2	2	3	5+	7
C20	237152	. 6	90	. 031, . 030	. 028, . 027	. 075, . 067	1	1	2	3+	3+	2	2	3	5+	7

[1] Sandstone dike.

analyses of carbonaceous siltstone samples from the Carbonate prospect

of uranium in ash. 0, element not detected. Two results listed where duplicate analyses were made.
B. A. McCall; spectrographic analyses by Mona Frank, Charles Annell, K. V. Hazel, and H. W. Worthing, U.S. Geol. Survey, Washington, D.C.]

Semiquantitative spectrographic analyses (see table 2 for code)—Continued																				
As	B	Ba	Be	Co	Cr	Cu	Ga	La	Mo	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zr
NORTH PIT—Continued																				
Grab samples—Continued																				
5+	4−	4	6	5	4	5+	5+	0	5	4−	0	5	5	0	4−	0	4−	5	6	4−
4	4−	3	6−	5−	5+	5+	5	0	4	5	0	5	5−	0	4+	0	4−	5−	6	4−
0	4−	4+	6	5+	4	5+	5+	5−	4−	4−	0	5+	5	0	4+	3+	4−	5+	6+	4−
4−	4−	4+	6	5+	4	5	5+	5+	5	4	0	5+	5	0	4	3+	4−	5+	6+	4
4	4−	4+	7+	6+	5+	5−	5	0	5+	5	0	5−	6+	0	4	0	5+	5−	6	4−
0	4−	3−	6	5+	4	5+	5+	5	3−	4−	0	5+	5	0	4	2−	4	4−	5−	4−
0	4−	3−	6	5	4	5	5+	5−	4−	4−	0	5+	5	0	4	3+	5+	5	6+	4−
0	4−	3−	6	5	4	5	5+	0	4−	4−	0	5	5	0	4	3	5+	5	6	4−
0	4−	4−	6	5	4	5	5+	5	4−	4−	0	5	5	0	4	3−	5+	5	6	4−
5+	4−	4	6	5	4	5	5+	5−	5+	4−	0	5	5	0	4	3−	5+	5	6	4−
0	4−	4	6	5	4	5	5+	5−	5+	4−	0	5	5	0	4	0	5+	5	6	4−
5+	4−	4	6	5+	4	5	5+	5	5+	4−	0	5	5	0	4	0	5+	5	6	4−
4−	4−	4	6	5+	4	4−	5+	5−	5+	4−	0	5+	5	5	4	0	5+	5	6	4−
5+	4−	4+	6	5+	4	4−	5+	5−	5+	4−	0	5	5	0	4	0	5+	5	6	4−
Channel samples—Continued																				
4−	4−	4+	6	5	4−	5+	5+	5+	5	5+	3−	5−	5	0	4	3+	4−	4−	5−	4−
4−	4−	3−	6	5−	4−	5	5+	5+	5+	5	4+	5−	5	0	4	3+	4−	5+	6+	4−
4−	4	4+	6	5	4−	5	5+	5+	3−	5	4+	5−	5	5−	4	2−	4	4−	5−	4
4−	4−	3	6	5	4−	5+	5+	5+	4	5+	4+	5−	5	0	4−	3−	4	5+	6+	4
4−	4−	3−	6−	5	4	5	5+	5−	5+	5+	0	5	5	0	4	0	4	5	6	4−
4−	4−	3−	6	5	4	5	5+	5−	5+	5+	0	5	5	0	4−	0	4−	5	6	4−
5+	4−	4+	6	5−	4	5	5+	5	4−	5+	0	5	5	0	4−	0	4−	5	6	4−
4−	4−	4	6	5−	4	5	5+	0	4−	5+	0	5	5	0	4−	0	4−	5	6	4−
SOUTH PIT—Continued																				
Grab samples—Continued																				
4−	4−	4+	6	5	4−	5+	5+	5+	5	5+	4+	5−	5	0	4−	4−	5+	5+	6+	4
4−	4	3−	6	5−	4−	5+	5+	4−	4−	5+	3−	5+	5+	0	4	3+	4−	4−	5−	4
4−	4−	3−	6	5−	4−	5+	5+	5+	5+	5+	3−	5	5	0	4	3	5+	4−	5−	4+
4	4−	3−	6	5−	5+	5	5+	5+	3−	5	0	5−	5	5−	4	4+	4−	5+	6+	4
Channel samples—Continued																				
0	4−	3−	6	5	4	5	5+	5	5−	4−	0	5	5	0	4	0	5+	5	6	4−
0	4−	4+	6	5+	4	5	5+	5−	5	4−	0	5+	5	0	4	0	5+	5	6	4−
0	4−	4+	6	5	4	5	5+	5−	6+	4−	0	5	5	0	4	0	5+	5	6	4−
4−	4−	4	6	5−	4−	5	5+	5+	5−	5	0	5−	5	0	4−	4−	5+	5+	6+	4−
4−	4	3	6	5−	4−	5+	5+	4−	4+	5	3−	5+	5+	5−	4	3+	4−	4−	5−	4+
4−	4−	4+	6	5−	4−	5	5+	4−	4	5+	4+	5	5	0	4	3−	4−	4−	5	4
4−	4−	4+	6	5−	4−	5	5+	5+	5+	5	0	5−	5−	5−	4−	4	4−	5+	6+	4
4−	4−	3	6	5	4−	5+	5+	4−	5+	5+	4+	5+	5+	0	4+	3	5+	4−	5−	4
4−	4−	4+	6	5−	4−	5+	5+	4−	5+	5+	4+	5	5	0	4−	4+	4−	4−	5−	4+
4−	4−	4+	6	5+	5+	5	5+	5+	5	5+	4+	5−	5	0	4−	4	5+	5+	6+	4

TABLE 18.—*Chemical, radioactivity, and semiquantitative spectrographic analyses of*

Analyses: Percentages of uranium and phosphorous in ash calculated from percentages of ash and percentages of uranium and phosphate in sample. 0, element not detected; number (T, top; M, middle; B, bottom;

[Chemical analyses (U in sample and P_2O_5 in sample) of noncoal samples by Joseph Budinsky, Roosevelt Moore, and W. P. Tucker, Jr., of coal samples by Maryse Delevaux, Hazel, and H. W. Worthing, U.S.

Loc. No. on pl. 4, chap. A	Laboratory No.	Thickness (feet)	Chemical analyses, in percent					Radioactivity analyses	Semiquantitative spectrographic analyses (see table 2 for code)						
			Ash	P in ash	P_2O_5 in sample	U in ash	U in sample	eU in sample (percent)	Si	Al	Fe	Mg	Ca	Na	K
						Noncoal samples (ore zone)									
1	146680	0.95	94	0.99	2.1	0.17	0.16	0.14	1	1	2−	3+	2−	2−	2
2	146681	.75	94	1.9	4.1	.29	.27	.24	1	1	2−	3+	2	2−	2
3	146682	.4	94	1.2	2.6	.21	.20	.17	1	1	2−	3+	2	2−	2
4	146683	.4	94	2.6	5.6	.32	.30	.29	1	1	2−	3+	2	2−	2
5	146684	1.0	94	.19	.4	.016	0.014, .015	0.012, .020	1	1	2−	3+	3+	2−	2
6	146685	.95	93	.51	1.1	.075	.070	.068	1	1	2−	3+	2−	2−	2
7	146686	.75	94	.51	1.1	.3	.28	.28	1	1	2	3+	2−	2−	2
8	146687	.5	94	1.1	2.4	.16	.15	.15	1	1	2	3+	2−	2−	2
9T	146700	1.1	94	.14	.3	.013	.012	.014	1	1	2−	3+	3+	2−	2
9B	146701	1.0	93	<.047	<.1	.008	.007	.007	1	1	2−	3+	3+	2−	2
10	146688	.85	92	2.2	4.7	.23	.21	.19	1	1	2−	3+	2+	2−	2
11	146689	.75	93	1.2	2.6	.2	.18	.16	1	1	2−	3+	2	2−	2
12	146690	.8	93	1.2	2.6	.19	.18	.15	1	1	2	3+	2	2−	2
13	146691	.85	92	.90	1.9	.19	.17	.16	1	1	2	2−	2	2−	2
14	146692	.7	92	1.2	2.5	.17	.16	.16	1	1	2−	3+	2	2−	2
15	146693	.9	92	.24	.5	.038	.035	.033	1	1	2−	3+	3+	2−	2
16	146697	1.2	93	.23	.5	.032	.030	.032	1	1	2−	2−	3+	2−	2
17T	146695	1.2	92	.33	.7	.043	.040	.039	1	1	2	2−	2−	2−	2
17B	146694	.8	92	.09	.2	.013	.012	.014	1	1	2	3+	3+	2−	2
18	146696	.9	92	.62	1.3	.11	.10	.097	1	1	2−	2−	3+	2−	2
19	146721	.75	92	3.6	7.5	.44	.40	.36	1	1	2	2−	1	2−	2−
20	146698	.6	92	1.7	3.16	.28	.26	.24	1	1	2−	2−	2	3+	2
21	146699	.85	93	.89	1.9	.17	.16	.14	1	1	2−	3+	2−	3+	2
22	146702	.7	92	.048	.1	.087	.080	.078	1	1	2−	2−	2−	2−	2
23	146703	1.0	92	.85	1.8	.16	.15	.14	1	1	3+	2−	2−	2−	2
24	146704	1.1	92	2.0	4.2	.29	.27	.24	1	1	3+	2−	2+	2−	2
25	146705	.9	92	1.2	2.6	.21	.19	.19	1	1	2−	2−	2+	2−	2
26	146706	.9	92	2.9	6.2	.28	.26	.25	1	1	2−	2−	2+	2−	2
27	146707	.55	92	1.1	2.3	.21	.19	.17	1	1	2−	2−	2	2−	2
28	146708	.6	92	1.1	2.4	.20	.18	.17	1	1	2−	2−	2+	2−	2
29	146709	1.0	92	.85	1.8	.13	.12	.12	1	1	2−	2−	2−	3+	2
30	146710	.8	92	.52	1.1	.12	.11	.10	1	1	2−	2−	2	2−	2
31	146711	.25	92	1.5	3.2	.31	.28	.25	1	1	3+	2−	2	2−	2
32	146713	.9	92	.33	.7	.054	.050	.047	1	1	2−	3+	2−	3+	2
33	146714	.85	92	.62	1.3	.098	.090	.084	1	1	2−	3+	2−	2−	2
34	146715	.75	92	2.2	4.7	.35	.32	.3	1	1	2−	3+	2+	3+	2−
35	146716	.7	92	1.6	3.3	.27	.25	.23	1	1	2−	3+	2	3+	2−
36	146717	.4	92	.81	1.7	.14	.13	.11	1	1	2−	3+	2−	2−	2
37	146718	.9	92	.57	1.2	.11	.10	.094	1	1	2−	2−	2	2−	2
38	146719	.8	92	.47	1.0	.098	.090	.088	1	1	2−	2−	2	2−	2
39B	146712	.6	92	.52	1.1	.087	.080	.075	1	1	2−	3+	2−	3+	2
40	146720	1.0	93	.19	.4	.017	.015, .017	.013, .021	1	1	2	2−	2−	2−	2
41	146722	.9	93	.19	.4	.029	.027	.030	1	1	2	2−	2−	2−	2
42	146723	1.0	92	1.4	3.0, 2.6	.20	.18, .20	.17, .17	1	1	2−	2−	2+	2−	2
43	146724	.7	93	.61	1.3	.097	.090	.094	1	1	2−	2−	2	2−	2
44	146725	.8	92	.43	.9	.065	.060	.062	1	1	2	2−	2	2−	2
45	146726	.8	92	1.1	2.3	.16	.15	.15	1	1	2	2−	2	2−	2
46	146727	.8	92	.61	1.3	.087	.080	.076	1	1	2−	3+	2	2−	2
47	146728	.2	93	7.9	16.8	.64	.60	.55	2+	2	3+	2−	1	2−	2−
48	146729	.5	92	1.7	3.5	.27	.25	.22	1	1	2	2−	1	2−	2

phosphatic claystone and associated rock samples from the Lonesome Pete mine

ND, not determined. Two results listed where duplicated analyses were made. Samples are of complete coal bed except as indicated by letters included in locality
TM, top of middle; and so forth).
Carmen Johnson, and Grafton Daniels; radioactivity analyses (eU in sample) by B. A. McCall; spectrographic analyses by Mona Frank, Charles Annell, K. V.
Geol. Survey, Washington, D.C.]

Semiquantitative spectrographic analyses (see table 2 for code)—Continued

Noncoal samples (ore zone)—Continued

Ti	P	Mn	Ag	As	B	Ba	Be	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Ni	Pb	Sc	Sr	U	V	Y	Yb	Zr
3-	3+	4-	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	3-	5+	5	6	5-
3	2-	4-	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	3	5+	5+	6+	5
3	2-	4-	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	3-	5+	5+	6+	5
3-	2	4-	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	3	5+	5+	6+	5+
3-	3-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4	0	5+	5	6	5
3-	3	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	0	5+	5	6	5
3	3	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5+	4-	5-	5-	4+	3-	5+	5+	6+	5
3	3+	4-	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	3	4-	5+	6+	5
3	3-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5+	4-	5-	5-	5+	0	5+	5+	6+	5
3-	0	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5-	4-	5-	5-	5+	0	5+	5+	6	5
3-	2	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5	4-	5-	5-	4+	3	4-	5	6+	5
3-	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5	4-	5-	5-	4+	3-	4-	5	6+	5
3	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5-	4-	5-	5-	4+	3-	4-	5+	6+	5+
3-	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5	5+	0	5+	5	4-	5-	5-	4+	3-	4-	5+	6+	5+
3-	3+	5+	0	0	4-	4+	6-	0	5-	4+	5-	5+	0	5+	5	5-	5-	5-	4+	3-	4-	5+	6+	5-
3-	3-	5+	0	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5	4-	5-	5-	4+	0	5+	5	6	5-
3	3-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5-	4-	5-	5-	4	0	5+	5+	6+	5+
3	3-	4-	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5	4-	5-	5-	4	0	5+	5	6+	5
3-	0	4-	7+	0	4-	4+	6-	0	5-	5+	5	5+	0	5+	5	4-	5-	5-	4+	0	5+	5	6	5
3	3	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5+	4-	5-	5-	4	4+	5+	5+	6+	5
3	2	4-	7+	0	4-	3-	6-	0	5-	5+	5-	5+	0	5+	4-	4-	5-	5-	3-	3	4-	5+	6+	5+
3-	2-	5+	7+	0	4-	3-	6-	0	5-	5+	5-	5+	0	5+	5+	4-	5-	5-	4+	3	5+	5+	6+	5
3	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	3-	5	5+	6+	5
3	0	5+	7+	0	4-	4+	6-	0	5-	5+	5+	5+	0	5+	5	4-	5-	5-	4+	0	4-	5+	6+	5
3-	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5	4-	5-	5-	4+	3-	5+	5	6+	5-
3-	2-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	4-	4-	5-	5-	4+	3	5+	5	6+	5-
3	2-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	4-	4-	5-	5-	4+	3-	5+	5+	6+	5
3-	2	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	4-	4-	5-	5-	4+	3	4-	5	6+	5
3	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	4-	4-	5-	5-	4+	3-	5+	5+	6+	5
3	2-	5+	7+	0	4-	3-	6-	0	5-	5+	5-	5+	0	5+	4-	4-	5-	5-	4+	3-	4-	5+	6+	5
3-	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5+	4-	5-	5-	4+	3-	5+	5+	6+	5
3	3	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5	4-	5-	5-	4+	3-	5+	5+	6+	5
3-	2-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5+	4-	5-	5-	4+	3-	5+	5	6+	5
3	3-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5	4-	5-	5-	4+	0	4-	5+	6+	5
3-	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	4+	4-	5+	6+	5
3-	2-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	4-	4-	5-	5-	4+	3	5+	5+	6+	5
3-	2-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4+	3	5+	5+	6+	5
3	3+	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5	4-	5-	5-	4+	3-	5+	5+	6+	5
3-	3+	5+	0	0	4-	3-	6-	0	5-	5+	5-	5+	0	5+	5	4-	5-	5-	4+	4+	5+	5	6+	5
3	3	5+	0	0	4-	4+	6-	0	5-	5+	5-	5+	0	5+	5-	4-	5-	5-	4+	3+	5+	5+	6+	5
3	3-	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5	4-	5-	5-	4+	0	5+	5+	6+	5
3	4+	5+	0	0	4-	3-	6-	0	5-	5+	5-	5+	0	5+	5-	4-	5-	5-	4	0	5+	5+	6+	5+
3	3-	5+	7+	0	4-	4+	6	0	5-	5+	5-	5+	0	5	5-	4-	5-	5-	4	0	5+	5+	6+	5+
3-	3-	4-	7+	0	4-	4+	6	0	5-	5+	5-	5+	0	5	4-	4-	5-	5-	4+	3-	5+	5	6+	5
3	3+	5+	7+	0	4-	4+	6	0	5-	5+	5-	5+	0	5+	5-	4-	5-	5-	4+	4+	5+	5+	6+	5+
3	3-	5+	7+	0	4-	4+	6	0	5-	5+	5-	5+	0	5+	5-	4-	5-	5-	4+	0	4-	5+	6+	5+
3-	2-	5+	0	0	4-	4+	6	0	5-	5+	5-	5+	0	5+	4-	4-	5-	5-	4+	3-	4-	5	6+	5
3-	3	5+	7+	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	5	4	5-	5-	4+	4+	4-	5	6+	5
4+	2+	4-	0	0	4-	4+	6-	0	5-	5	5-	5	0	5	5	5+	5-	5-	3-	3	5+	5	6	5
3	2-	5+	0	0	4-	4+	6-	0	5-	5+	5-	5+	0	5	4-	4-	5-	5-	4+	3	4-	5+	6+	5+

TABLE 18.—*Chemical, radioactivity, and semiquantitative spectrographic analyses*

Loc. No. on pl. 4, chap. A	Laboratory No.	Thickness (feet)	Chemical analyses, in percent					Radioactivity analyses	Semiquantitative spectrographic analyses (see table 2 for code)						
			Ash	P in ash	P_2O_5 in sample	U in ash	U in sample	eU in sample (percent)	Si	Al	Fe	Mg	Ca	Na	K
Coal samples															
9T	237399	0. 6	34	ND	ND	0. 25, 0. 23	0. 085	0. 042, 0. 036	1	1	1	3−	2+	2−	3+
17T	237401	1. 0	37	ND	ND	. 095, . 093	0. 035, . 034	. 017	1	1	2+	3+	2+	2	0
17B	237402	1. 0	22	ND	ND	. 037, . 037	. 008	. 004	1	1	2	2−	2+	2	0
39T	237403	. 3	40	ND	ND	. 033	. 013	. 014	1	1	2+	3+	2+	2	3+

TABLE 19.—*Chemical, radioactivity, and semiquantitative spectrographic analyses of*

Analyses: 0, element not detected; ND, not determined.

[Chemical analyses (U in sample, U in ash, and P_2O_5 in sample) of noncoal samples by Joseph Budinsky, Roosevelt Moore, and W. P. Tucker, Jr., of coal samples by Maryse K. V. Hazel, and H. W. Worthing, U.S.

Sample	Columnar section (pl. 4, chap. A)	Laboratory No.	Thickness (feet)	Chemical analyses, in percent					Radioactivity analyses
				Ash	P_2O_5 in sample	P in sample	U in ash	U in sample	eU in sample (percent)
NONCOAL SAMPLES									
[Percentage of phosphorus in sample calculated from percentage of phosphate in sample]									
4	2	146759	1. 2	ND	0. 1	0. 04	ND	0. 003	0. 003
5	2	146760	1. 2	ND	. 1	. 04	ND	. 003	. 003
6	2	146761	1. 2	ND	. 1	. 04	ND	. 002	. 003
8 [1]	2	146763	. 25	ND	4. 9	2. 14	ND	. 27	0. 25, . 23
10	2	146765	1. 0	ND	. 1	. 04	ND	. 005	. 005
11	2	146766	1. 0	ND	. 1	. 04	ND	. 005	. 006
14	2	146767	. 25	ND	<. 1	<. 04	ND	. 002	. 002
22	3	146768	. 15	ND	. 1	. 04	ND	. 001	. 002
23	3	146769	. 75	ND	. 1	. 04	ND	. 001	. 002
24	3	146770	. 75	ND	. 1	. 04	ND	. 002	. 003
25	3	146771	1. 0	ND	. 1	. 04	ND	. 002	. 002
26	3	146772	. 25	ND	. 2	. 09	ND	. 003	. 004
27	3	146773	. 35	ND	. 1	. 04	ND	. 003	. 003
28	3	146774	. 4	ND	. 1	. 04	ND	. 004	. 006
29	3	146775	. 3	ND	. 1	. 04	ND	. 005	. 004
32	3	146776	. 3	ND	. 2	. 09	ND	. 022	. 025, . 022
33	3	146777	. 5	ND	. 1	. 04	ND	. 007	. 008, . 009
34	3	146778	. 5	ND	. 1	. 04	ND	. 006	. 006
64 [2]	----------	149364	1. 0	ND	ND	ND	ND	. 002	. 003
COAL SAMPLES									
Lonesome Pete coal bed									
[Percentage of uranium in sample calculated from percentage of ash and percentage of uranium in ash]									
12	2	237054	1. 1	32	ND	ND	0. 095, 0. 084	0. 039, 0. 027	0. 017, 0. 019
13	2	237055	1. 1	26	ND	ND	. 035	. 009	. 010
15	2	237056	1. 1	35	ND	ND	. 069, . 063	. 024, . 022	. 010, . 012
16	2	237057	1. 0	19	ND	ND	. 037	. 007	. 004
18	2	237059	1. 0	19	ND	ND	. 008	. 001	. 001
35	3	237400	. 6	40	ND	ND	. 043	. 017	. 015
47	4	237388	. 6	34	ND	ND	. 045	. 015	. 015
54	5	237389	1. 0	36	ND	ND	. 033	. 012	. 012
55	5	237390	1. 0	34	ND	ND	. 027	. 009	. 009
56	5	237391	1. 0	45	ND	ND	. 006	. 003	. 002
65 [2]	----------	149365	2. 0	14	ND	ND	. 050	. 007	. 005

See footnotes at end of table.

of phosphatic claystone and associated rock samples from the Lonesome Pete mine—Continued

Semiquantitative spectrographic analyses (see table 2 for code)																								
Ti	P	Mn	Ag	As	B	Ba	Be	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Ni	Pb	Sc	Sr	U	V	Y	Yb	Zr
Coal samples—Continued																								
3	0	3	6−	0	4−	3	6+	0	5+	5	5+	5+	5+	0	4−	4	5−	5−	3−	3−	5−	5−	6−	4+
3−	0	3−	6−	0	4−	3−	6+	0	5	5+	5+	5+	5−	0	5+	4−	5−	5−	3−	4+	5	5−	6−	4
3	0	4+	0	0	4	3−	6−	0	5−	5+	5+	5+	0	0	5+	5+	5	5−	3−	0	5−	5−	6−	4+
3	0	4	7−	4+	5+	3−	5−	4	5+	4−	5+	5	0	0	4−	4−	5	5	3−	0	5−	5+	6+	3−

phosphatic claystone and associated rocks from the vicinity of the Lonesome Pete mine

Two results listed where duplicate analyses were made.
Delevaux, Carmen Johnson, and Grafton Daniels; radioactivity analyses (eU in sample) by B. A. McCall; spectrographic analyses by Mona Frank, Charles Annell, Geological Survey, Washington, D.C.]

Semiquantitative spectrographic analyses (see table 2 for code)																																	
Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	As	Ag	B	Ba	Be	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zn	Zr
NONCOAL SAMPLES—Continued [Percentage of phosphorus in sample calculated from percentage of phosphate in sample]																																	
1	2+	2−	2−	2	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	0	0	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	2−	2	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	0	0	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	2−	2	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	0	0	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	3+	2	2−	2	3	4−	0	6−	4−	4+	6−	0	5−	5	5+	5+	0	0	0	5+	2	5−	5−	0	4+	3	5	5	6	0	5+
1	2+	2−	3+	2−	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	0	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	3+	2−	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	5	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	3+	3+	2−	2	2−	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	0	5	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	3+	2−	2−	2	3	4−	0	6−	4−	4+	7+	0	5−	5	5−	5+	0	5	0	5+	0	5−	5−	0	4	0	5−	5	6	0	5+
1	2+	2−	3+	2−	2−	2−	3−	4−	0	6−	4−	4+	7+	0	5−	5	5−	5	0	0	0	5+	0	5−	5−	0	4	0	5−	5	6	0	5+
1	2+	2−	2−	2	2−	2	3	4−	0	6−	4−	4+	7+	0	5−	5	5	5+	0	5	0	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	2−	2−	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	0	5+	0	5−	5−	0	4	0	5−	5	6	0	5+
1	2+	2−	2−	2−	2−	2	3+	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	0	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	2−	2−	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	0	5+	0	5−	5−	0	4	0	5−	5	6	0	5+
1	2+	2−	3+	2−	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	5−	5+	0	5−	5−	0	4−	0	5−	5	6	0	5+
1	2+	2−	2−	2−	2−	2	3−	4−	0	0	4−	4+	7+	0	5−	5−	5	5+	0	0	6+	5+	0	5−	5−	0	4−	0	5	5	6	0	5+
1	2+	2−	2−	2−	2−	2	3	4−	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	4	5+	0	5−	5−	0	4	0	5	5	6	0	5
1	2+	2−	2−	2−	2−	2	3	5+	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	6+	5+	0	5−	5−	0	4	0	5	5	6	0	5+
1	2+	2−	2−	3+	2−	2	3	5+	0	0	4−	4+	7+	0	5−	5	5	5+	0	5	6+	5+	0	5−	5−	0	4	0	5−	5	6	0	5
1	1	2	2−	3+	2	2	3+	4−	4+	7+	5+	4+	6	0	5−	5+	5+	6+	0	5+	5+	5	0	5	5	0	4	0	4−	5	6+	0	3−
COAL SAMPLES—Continued **Lonesome Pete coal bed—Continued** [Percentage of uranium in sample calculated from percentage of ash and percentage of uranium in ash]																																	
1	1	2	2−	2+	2	0	3−	4+	0	7+	4	3−	6+	0	5	5	5−	5+	0	0	4−	4−	0	5	5	0	4	3−	5+	5+	6+	0	4+
1	1	2−	3+	2	2	0	3	4	0	7+	4−	3−	6	0	5	5+	5−	5+	0	0	4+	5+	0	5+	5	0	4	0	5+	5	6	0	4+
1	1	2−	2−	2+	2+	0	3	4+	0	7+	4−	3−	6−	0	5−	5	5−	5+	0	0	5+	5	0	5	5	0	4	4+	5	5−	6	0	4
1	1	3+	2	1	2+	0	3	3	0	7+	4−	3−	6−	0	0	5	5−	5+	0	4−	4	5	0	5−	5−	0	3−	0	5	5	6	0	4
1	1	2−	2−	2+	3+	0	3−	4	4−	0	4	3	6−	0	5−	5	5	5+	0	0	4−	5	0	5	5	0	4+	0	5	5	6	0	4
1	1	2+	3−	2	2	3−	3	4+	0	6−	4−	3	6+	0	4−	4−	4−	5+	0	0	5+	4	0	5+	5+	0	3	0	5−	5	6	0	4+
1	2+	2+	3	2+	2−	3+	3−	3−	0	0	5+	3	5−	0	0	5+	5+	5+	5−	0	5+	5+	0	5	5−	0	3	0	5−	5−	6−	0	4+
2+	2+	2+	3	1	2	3+	3−	4+	0	0	4	4+	6+	0	5−	5+	4−	5+	5−	0	4−	5+	0	5−	5−	0	3	0	5−	5−	6−	0	4+
1	1	2+	3	2+	2	3−	3−	4+	0	0	4	3	6−	0	5	5	4−	5+	0	0	5+	5+	0	5−	5−	0	3	0	5−	5−	6−	0	4+
2+	2+	2+	3−	1	2	0	3	3−	0	0	4	4	7+	0	0	5−	4−	5	0	0	5	5−	0	0	6+	0	3−	0	5−	0	0	0	4
1	1	2	2	2+	2+	2−	2−	4−	4+	7+	3−	3−	5	0	5	5	4	5	5+	0	3−	4−	0	5	5+	5−	4+	0	5+	4−	6+	4+	3−

TABLE 19.—*Chemical, radioactivity, and semiquantitative spectrographic analyses of phosphatic*

Sample	Columnar section (pl. 4, chap. A)	Laboratory No.	Thickness (feet)	Chemical analyses, in percent					Radioactivity analyses
				Ash	P_2O_5 in sample	P in sample	U in ash	U in sample	eU in sample (percent)
Carbonate coal zone									
57[3]	----------	237392	0.8	38	ND	ND	0.14	0.053	0.047
58[3]	----------	237393	1.0	34	ND	ND	.030	.010	.009
59[3]	----------	237394	1.1	32	ND	ND	.019	.006	.005
60[3]	----------	237395	1.1	25	ND	ND	.031	.008	.006
61[3]	----------	237396	1.3	37	ND	ND	.029	.011	.007
62[3]	----------	237397	1.3	33	ND	ND	.019	.006	.008
63[3]	----------	237398	1.3	30	ND	ND	.029	.009	.008

[1] Ore zone.
[2] See stratigraphic section 13, pl. 2, chap. A.
[3] See stratigraphic section 12, pl. 2, chap. A.

TABLE 20.—*Chemical, radioactivity, and semiquantitative spectrographic,*

[Chemical analyses by Roosevelt Moore, radioactivity analyses by B. A. McCall, and spectrographic analyses by

Sample No.	Laboratory No.	Location			Description of sample	Position in formation (feet)	Chemical analyses	Radioactivity analyses
		Sec.	T.N.	R.E.			U in sample (percent)	eU in sample (percent)
CHADRON FORMATION (OLIGOCENE)								
						Above base:		
1	148770	NE¼SW¼NW¼ 28	22	5	Tuffaceous sandstone----	8-------------------	0.001	0.002
2	148769	NE¼SW¼NW¼ 28	22	5	Conglomerate----------	1.5-----------------	.001	<.001
3	148766	SE¼NE¼SW¼ 21	22	5	Tuffaceous sandstone----	1-------------------	.001	.002
4	148763	NW¼NW¼ 5	20	5	-----do---------------	35------------------	.001	.001
5	148761	NW¼NW¼ 5	20	5	-----do---------------	10------------------	.001	.002
6	148762	NW¼NW¼ 5	20	5	-----do---------------	2-------------------	.001	.002
7	148765	SW¼NW¼ 32	21	5	Silicified claystone------	5-------------------	.001	.002
8	148764	SW¼NW¼ 32	21	5	-----do---------------	4-------------------	.001	<.001
FORT UNION FORMATION (PALEOCENE)								
Tongue River Member								
9	148767	SE¼NW¼SW¼ 21	22	5	Sandstone-------------	Directly under Chadron----	0.001	0.002
10	148768	NE¼SW¼NW¼ 28	22	5	-----do---------------	-----do---------------	.001	.002
11	148772	NW¼NW¼NW¼ 36	22	5	-----do---------------	4 ft above coal zone F-----	.001	.001
12	148771	NW¼NW¼SW¼ 28	22	5	-----do---------------	10 ft above coal bed E-----	.001	.002
13	148773	NW¼NW¼NW¼ 36	22	5	-----do---------------	Directly under coal bed E--	.001	.003
14	237239	SE¼NE¼SE¼ 23	22	5	Siltstone--------------	Directly over coal bed E---	.003	.002
15	237411	SE¼SW¼NW¼ 21	22	5	-----do---------------	-----do---------------	.003	.004
16	237246	SE¼SW¼SW¼ 26	22	5	Claystone--------------	-----do---------------	.025	.014
17	237244	SE¼SW¼SW¼ 26	22	5	Analcitic claystone------	-----do---------------	.050	.047
18	237241	NE¼SW¼NE¼ 27	22	5	Silty claystone---------	-----do---------------	.003	.003
19	237234	NE¼SE¼NE¼ 27	22	5	Claystone--------------	-----do---------------	.010	.008
20	237242	SE¼NE¼NW¼ 35	22	5	Analcitic silty claystone-	-----do---------------	.30	.28
Ludlow Member								
21	237236	NW¼NE¼NE¼ 22	22	5	Sandstone-------------	Directly under Tongue River Member.	0.015	0.014
22	237237	NW¼NE¼NE¼ 22	22	5	-----do---------------	Directly under sample 21---	.080	0.075

claystone and associated rocks from the vicinity of the Lonesome Pete mine—Continued

Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	As	Ag	B	Ba	Be	Ce	Co	Cr	Cu	Ga	Ge	La	Mo	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zn	Zr
Semiquantitative spectrographic analyses (see table 2 for code)																																	
Carbonate coal zone—Continued																																	
1	1	1	3−	3+	2−	3+	3	3−	3	6−	5+	4+	6−	0	4−	5+	4−	5+	5	0	4−	4	0	5	5	0	3	3−	5	5−	6−	0	3−
1	2+	1	3−	2	2	3+	3	4+	4+	6−	4	4+	6	0	4	5+	4−	5	0	0	4−	4	0	5−	5	0	3	0	5−	5−	6−	0	4
2+	1	2+	3−	2+	2	3	3	4+	0	0	4	4+	6	0	4−	4−	4−	5+	0	0	5+	4	0	5−	5	0	4+	0	5	5	6−	0	4+
1	1	2	3−	2+	2	3	3−	4+	0	0	4	4+	6+	4	4−	4−	4−	5+	0	0	5	4	0	5	5	0	4+	0	5−	5−	6−	0	4+
1	1	2+	3+	2+	2	3+	3	3−	0	6−	4	4+	6	0	4	4−	4−	5+	0	0	4−	4	0	5	5	0	3−	0	5	5−	6−	0	4
1	1	2+	2−	2+	2	0	3−	3−	0	0	4	3−	6−	0	5+	5	5+	5	0	0	5+	4−	0	5−	5−	0	3−	0	5−	5−	6−	0	4
1	1	2+	2−	2+	2	3−	3−	3+	0	6	4	3−	6+	0	4−	5+	4−	5+	0	0	5+	4−	0	5	5	0	3	0	5−	5−	6−	0	4+

analyses of sandstone, siltstone, and claystone from the Cave Hills area

Mona Frank, Charles Annell, K. V. Hazel, and H. W. Worthing, U.S. Geological Survey, Washington, D.C.]

Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag	As	B	Ba	Be	Co	Cr	Cu	Ga	Ge	La	Mo	Ni	P	Pb	Sc	Sn	Sr	U	V	Y	Yb	Zr
Semiquantitative spectrographic analyses (see table 2 for code)																															
CHADRON FORMATION (OLIGOCENE)—Continued																															
1	2+	2−	4+	3	2−	3+	3	5−	6−	0	5+	4	0	0	5−	5−	5−	0	0	0	5−	0	5−	6+	0	4−	0	0	5−	6−	4−
1	2+	2+	4+	3	2+	3+	3	5−	6−	0	5+	4−	0	5−	5	5−	5−	0	0	0	5−	0	5−	6+	0	4−	0	5−	5−	6−	4−
1	2+	2+	3	3−	2	3+	3	5−	7	0	4−	4−	6−	5−	5	5−	5−	0	0	0	5−	0	5−	5−	0	5+	0	5−	5−	6−	4−
2+	2+	2	3+	1	2−	3+	3−	4−	7−	0	5+	4−	7+	0	6+	5−	5−	0	0	0	5−	0	5−	5−	0	4	0	5−	5−	6−	5+
1	2+	2+	3+	2	2−	2−	3	5	7	0	4−	4−	6−	5−	5−	5−	5−	0	0	5−	5−	0	5−	5	5−	4	0	5	5−	6−	4−
1	2+	2+	3	3	2	3+	3−	6+	7	0	4−	4−	6−	5−	5−	5−	5−	0	0	0	5−	0	5−	5−	0	4−	0	5−	5−	6−	4−
1	2+	2+	3+	2	2−	2−	3	5+	7	0	4−	4	6−	5−	5−	5−	5−	0	0	0	5−	0	5−	5	0	4	0	5	5−	6−	4−
2+	2	2−	3	1	3	3+	4+	4−	0	0	5	5+	7+	0	6+	4−	0	0	0	0	5−	0	0	5−	0	4	0	5−	5−	6−	5
FORT UNION FORMATION (PALEOCENE)—Continued																															
Tongue River Member—Continued																															
1	2+	2	3	3−	2−	2−	3	5−	7	0	4−	4−	6−	5−	5−	5−	5−	0	5+	0	5−	0	5−	5−	0	4−	0	5−	5	6	4−
1	2+	2+	3	3−	2−	2−	3	5	0	0	4−	4−	7+	5−	5−	5−	5−	0	0	0	5−	0	5−	5−	0	4−	0	5−	5−	6−	5+
1	2+	2	4+	3−	2	3+	3−	5−	6−	0	5	4	7	0	5	5−	5−	0	0	0	5−	0	0	5−	0	4−	0	0	5−	6−	4−
1	2	2	4+	3	2−	2−	3−	5−	6−	0	5	4	7	5−	5	5−	5−	0	0	0	5−	0	0	5−	0	4−	0	0	5−	6−	4−
1	2+	2−	3−	3−	2−	3+	3−	5−	7	0	5+	4	7+	5−	6+	5−	5−	0	0	0	5−	0	0	6+	0	4−	0	0	0	0	4−
1	1	3+	3	3	2	2−	3−	5−	0	0	4−	4+	6−	5−	5+	5−	5+	0	5	5−	4−	0	5−	5−	0	4	0	4	5	6	5
1	1	2−	3−	3−	3−	3−	3	4−	0	4+	4−	4+	7+	0	5+	5−	5−	0	0	5−	5+	0	5−	6+	0	4+	0	5−	5−	6−	4−
1	1	2−	3+	2−	2	2	3	5	0	0	4−	4+	7+	5−	5+	5+	5+	0	5	4−	4−	0	5−	5−	0	4	0	4	5	6	5
1	1	2−	3	3	2	2	3−	5	0	4+	4−	4+	7+	5−	5+	5+	5+	0	5	4+	4−	0	5−	5−	0	4	0	4	5	6	5
1	1	2−	3+	3−	2+	2	3	5−	0	0	4−	4+	7+	5−	5+	5+	5+	5	5	5−	4−	0	5−	5−	0	4	0	4	5	6	5
1	1	2−	3+	3−	2	2	3	5−	0	0	4−	4+	6−	5−	5+	5+	5+	0	5	5+	5+	0	5−	5−	0	4	0	4−	5	6	5−
1	2+	3+	3	3+	2	2−	3	5−	0	3	4−	3−	7+	5−	5+	5+	5	5−	5	4+	4−	0	5−	5−	0	4	3+	4	5	6	5
Ludlow Member—Continued																															
1	2+	2	3+	2+	3+	3+	3−	3	0	4	4−	3−	6−	5−	5	6+	5	0	5+	5−	4−	2	5−	5−	0	4+	3−	4	5	6+	5+
1	2+	2+	3+	2	3+	2−	3	4+	0	4+	4−	3−	6−	5−	5	6+	5	0	5+	5−	4−	2−	5−	5−	0	4+	4+	4	5+	0	5+

TABLE 21.—*Chemical, radioactivity, and semiquantitative spectrographic analyses*

Analyses: 0, element not detected; ND, not determined; Tr., trace. Areas from which samples were taken are shown on fig. 1, chap. A, [All chemical and radioactivity data and spectroscopic data for samples 26–28 from N. M. Denson and J. R.

Sample	Laboratory No.	Location: Sec.		Location: T.	Location: R.	Location: Area	Location: County	Location: State	Description of sample	Position in formation (feet)
									ARIKAREE FORMATION (MIOCENE)	
										Above base:
1	147765	SE¼NW¼	28	1 S.	57 E.	Chalk Buttes	Carter	Mont	Tuffaceous sandstone	265
2	147773	SW¼NW¼	8	3 S.	62 E.	Long Pine Hills	do	do	do	300
									Sandstone from core hole 24 at—	
3	144495	NW¼NW¼	31	18 N.	8 E.	Slim Buttes	Harding	S. Dak	24 ft depth	185
4	144496	NW¼NW¼	31	18 N.	8 E.	do	do	do	42.5 ft depth	170
5	144497	NW¼NW¼	31	18 N.	8 E.	do	do	do	51.8 ft depth	160
6	144498	NW¼NW¼	31	18 N.	8 E.	do	do	do	72.6 ft depth	140
7	144499	NW¼NW¼	31	18 N.	8 E.	do	do	do	92.4 ft depth	120
8	144500	NW¼NW¼	31	18 N.	8 E.	do	do	do	112.0 ft depth	100
9	144501	NW¼NW¼	31	18 N.	8 E.	do	do	do	140.0 ft depth	70
10	144502	NW¼NW¼	31	18 N.	8 E.	do	do	do	161.0 ft depth	50
11	144504	NW¼NW¼	31	18 N.	8 E.	do	do	do	202.0 ft depth	10
12	248487	NW¼NW¼	32	5 S.	60 E.	Finger Buttes	Carter	Mont	Siltstone	Basal 5
13	223431	SW¼SW¼	6	17 N.	8 E.	Slim Buttes	Harding	S. Dak	Quartzitic siltstone from core hole 17 at 53 ft depth.	Near top
14	223430	SE¼NE¼	12	17 N.	7 E.	do	do	do	Tuffaceous siltstone from core hole 16A at 120 ft depth.	Near base
15	144503	NW¼NW¼	31	18 N.	8 E.	do	do	do	Claystone from core hole 24 at 181 ft depth.	Above base: 30
									BRULE FORMATION (OLIGOCENE)	
16	248476	SW¼NE¼1	7	18 N.	8 E.	Slim Buttes	Harding	S. Dak	Tuffaceous claystone	Above base: 145
17	248475	SW¼NE¼	17	18 N.	8 E.	do	do	do	do	65
									CHADRON FORMATION (OLIGOCENE)	
18	223437	NE¼NE¼	8	16 N.	8 E.	Cedar Canyon, Slim Buttes.	Harding	S. Dak	Tuffaceous sandstone	Near top
19	147770	SE¼NE¼	12	17 N.	7 E.	Slim Buttes	do	do	Arkosic sandstone from core hole 16A.	At base (18-ft bed)
20	223434	NE¼SE	1	17 N.	7 E.	Slim Buttes, Mendenhall area.	do	do	do	Above base: 15
21	223432	NE¼SE¼	16	17 N.	8 E.	Slim Buttes: J. B. Hill	Harding	S. Dak	Arkosic sandstone from core hole 16A.	25
22	223433	NE¼NE¼	26	17 N.	7 E.	J. B. Pass	do	do	do	40
										Below top:
23	144505	NW¼NW¼	31	18 N.	8 E.	Slim Buttes	do	do	Claystone from core hole 24 at—222.5 ft depth.	12
24	144506	NW¼NW¼	31	18 N.	8 E.	do	do	do	230.7 ft depth	20
25	223429	SE¼NE¼	12	17 N.	7 E.	do	do	do	Tuffaceous claystone from core hole 16A, at 137 ft depth.	Near top
									FORT UNION FORMATION (PALEOCENE) **Ludlow Member**	
										Below top:
26	144507	NW¼NW¼	31	18 N.	8 E.	Slim Buttes	Harding	S. Dak	Sandstone from core hole 24 at—240 ft depth.	5
27	144508	NW¼NW¼	31	18 N.	8 E.	do	do	do	252 ft depth	17
28	144509	NW¼NW¼	31	18 N.	8 E.	do	do	do	262 ft depth	27

of sandstone, siltstone, and claystone from areas adjacent to the Cave Hills

except Chalk Buttes and Finger Buttes, which are 25 miles west and 15 miles southwest, respectively, of the Long Pine Hills (area 6). Gill (written commun., 1959). Other spectroscopic data from Denson and Gill (1965a, table 22; 1965b, table 23)]

Chemical analyses	Radioactivity analyses	Semiquantitative spectrographic analyses (see table 2 for code)																														
U in sample (percent)	eU in sample (percent)	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Ag	As	B	Ba	Be	Co	Cr	Cu	Ga	La	Li	Mo	Nb	Ni	Pb	Sc	Sn	Sr	V	Y	Yb	Zr
ARIKAREE FORMATION (MIOCENE)—Continued																																
0.0007	ND	1	2+	3+	3+	1	2	2−	3−	4	0	0	0	4+	0	6+	5+	5	6+	0	0	0	0	5−	5−	5−	0	4+	4	5	6	5+
.0003	ND	1	2+	2−	2−	2	2	2	3	4	0	0	5	3−	6−	0	5−	5−	6+	5+	0	0	0	0	5−	0	5−	4+	4−	5+	6+	4
.0003	ND	1	2+	2−	2−	2+	2−	2	3	4	0	0	5	3−	0	6+	5	5−	6+	0	0	0	0	6+	0	5−	0	3−	5+	5	6	4−
.0003	ND	1	2+	2−	2−	2	2−	2	3	4	0	0	5	4	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5−	0	4	5+	5	6	4−
.0002	ND	1	2+	2−	2−	2	2−	2	3	4−	0	0	5	3−	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5−	0	3−	5+	5	6	4−
.0002	ND	1	2+	2−	2−	2	2	2	3	4−	0	0	5	3−	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5−	0	4+	5+	5	6+	4−
.0002	ND	1	2+	2−	2−	2	2	2	3	4−	0	0	5	3−	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5−	0	4+	5+	5	6	4−
.0003	ND	1	2+	2−	2−	2+	2	2	3	4−	0	0	5	4+	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5−	0	4+	5	5+	6+	4−
.0003	ND	1	2+	2−	2−	2	2	2	3	4+	0	0	5	4+	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5−	0	4+	5+	5	6	4−
.0002	ND	1	2+	2−	2−	2+	2+	2	3	4	0	0	5	4+	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5−	0	3−	5	5+	6+	4−
.0002	ND	1	2+	2−	2−	2	2	2	3	4−	0	0	5	3	0	6+	5	5−	6+	5+	0	0	0	6+	5−	5−	0	4+	5+	5+	6+	4−
.0002	<0.001	1	1	2	2	2	2	2	3	4+	0	0	5+	3−	6−	5−	5	5	5−	5	4−	0	5−	5−	5−	5−	0	4	4−	5	6	4
ND	<.001	1	1	2−	3+	2+	2−	2−	3−	4+	0	0	5	4+	0	0	5	5	5	0	0	0	0	0	5−	Tr.	0	4+	5+	5	6+	5+
ND	.004	1	1	2−	3+	2−	2	2−	3−	3	0	0	5	3−	0	0	5	5	5	0	0	0	0	0	5−	Tr.	0	4+	5+	5	6+	5+
.0002	ND	1	2+	2−	2−	2+	2	2	3	4+	0	0	5	4+	0	6+	5−	5−	6+	0	0	0	0	6+	5−	5	0	4+	5	5+	6+	4−
BRULE FORMATION (OLIGOCENE)—Continued																																
0.0001	<0.001	1	2+	2−	2−	1	2	2	3−	4+	0	0	5	4+	0	6+	5−	5	6+	5	4−	0	0	6+	5−	5−	0	4	4−	5	6	4−
.0003	.001	1	2+	2	2−	1	2	2	3−	3−	0	0	5	4+	6−	6+	5	5	6+	5	0	0	0	5−	5−	5−	0	4	5+	5	6	4−
CHADRON FORMATION (OLIGOCENE)—Continued																																
ND	0.004	1	2−	3+	3−	3+	3+	3+	3−	4−	0	0	5	4+	0	0	5	5+	Tr.	0	0	0	0	6+	5−	0	0	5+	5	5	6+	4−
.0002	ND	1	2+	3	2−	3+	2−	2	3−	4−	0	0	0	4+	0	0	5−	6−	6+	0	0	0	0	0	5−	0	0	4−	5−	0	0	5
ND	.002	1	1	3	3+	3+	2−	2−	3−	4−	0	0	5	3−	0	0	5	5−	5	0	0	0	0	6+	5−	Tr.	0	4	5+	0	6−	5
ND	.002	1	2+	3	2−	3+	2−	2−	3−	4−	0	0	Tr.	4+	0	0	5−	6	5	0	0	0	0	0	5−	0	0	4	5	0	6−	5+
ND	.002	1	1	3	3+	3+	2−	2	4+	4−	0	0	5+	4+	0	0	5−	5−	5	0	0	0	0	6+	5−	0	0	4−	5+	0	6−	5+
.0003	ND	1	2+	2−	2	2	2−	2	3	4+	0	0	5	4	0	5−	5+	5−	6+	0	0	0	0	5−	5−	5−	0	4−	4−	5	6	4−
.0003	ND	1	2+	2	2−	2	2	2	3	4	0	0	5	4	0	5−	5+	5	6+	0	0	0	0	5−	0	5−	0	4	4−	5	6	4−
ND	.001	1	2+	2−	2	2+	2−	2−	2−	4+	0	0	5+	4	0	0	5+	5	5	0	0	0	0	5−	5−	Tr.	0	4+	4−	0	6	5
FORT UNION FORMATION (PALEOCENE)—Continued **Ludlow Member—Continued**																																
0.002	ND	1	2+	2−	3+	3+	2−	2	3	4−	0	0	5	4+	6−	6+	5	5−	6+	0	0	0	0	5−	5−	5−	0	4	5+	5	6	4
.002	ND	1	2+	2−	3+	3	2−	2	3	4−	0	0	5	4+	6−	6+	5	5−	6+	0	0	0	0	5−	5−	5−	0	4−	5+	5	6+	4
.002	ND	1	2+	2−	3+	3	2−	2	3+	4−	0	0	5	4+	0	6+	5	5−	6+	5+	0	0	0	5−	5−	5−	0	4−	5+	5	6+	4−

TEST FOR SIGNIFICANCE

Lord's test requires that the sample groups concerned be selected from a group of samples with almost normal distribution. Consequently, probability paper (the Kolmogorov-Smirnov one-sample test, Siegel, 1956, p. 251) was used for testing the distributions of elements shows in figures 2–18. Some elements showed abnormal distributions as follows: Ag in the coal beds F and E, Mn and Ba in coal zone C, Ga and Ni in coal zone B, and Ga in the Lonesome Pete coal zone. But when the distributions of the elements in all the 269 coal samples (table 11, col. 4) are examined, only that of Ag is abnormal; this fact suggests that the other abnormalities noted are only apparent and are probably due to the relatively small number of samples available from some of the coal zones. Inasmuch as abnormal distributions merely lessen the confidence that can be attached to statistical significances indicated by Lord's test, only the direct relation of Ag to uranium is considered questionable (group A, p. B36).

The data in the left half of table 14 were used in testing the significance of the difference in the averages of the various columns shown in table 6, and the results were shown in tables 8–10. Likewise, the data in the left half of table 14 were used in testing the significance in the difference between averages of the groups of samples having low-uranium content and the corresponding groups of samples having relatively high-uranium content shown in table 11. In comparison of the averages of groups of unequal size, the average of the largest groups of samples (as in tables 8–10) or the average of all the samples in any given group (as in table 11) was used as the pre-assigned value necessary for calculation of the ratio (DA/R) shown in the left half of table 22.

Elements were assigned to groups 1 or 3 and A or C in the second method of investigation only if the difference in the appropriate averages was 90 percent or more probably significant; otherwise, the element was assigned to groups 2 and B.

Data in the right half of table 22 were used for testing the significance in the difference between the averages of two groups of samples of equal size (average and range of sample groups shown in figures 19–22; the results of the test are indicated by an asterisk (*) beside the enrichment factor of those elements whose relation to uranium is 90 percent or more probable (figs. 19–22).

Examples of the use made of data in each half of table 22 will illustrate the procedure.

1. In the 0.03 percent eUA group (table 6), 10 samples whose eUA content equals UA (that is, are in radioactivity equilibrium) contain an average of 1 percent potassium (K). Seven samples in the same eUA group that are out of balance in favor of UA contain an average of 0.2 percent K. The difference between these two averages is 0.8 percent; is this difference meaningful? What are the chances that the observed difference is attributable to the difference in radioactivity status of the 2 sample groups, and what are the chances that the averages of 2 groups of samples selected at random from the total of all samples whose eUA content lies in the 0.03 group will differ by 0.8 percent or more? The average of the 10-sample group is used as the pre-assigned value in the formula $\frac{DA}{R}$ (left half of table 22) where *DA* equals the difference between a pre-assigned value and the average of a sample group. Each sample considered here is identified in table 7, so that from tables 15, 16, 18, and 19 it is determined that the potassium (K) content of the 7-sample UA> group ranges from not detected (0) to 0.7 percent. Inasmuch as a value reported as 0.7 is itself the logarithmic midpoint of a range (approx 0.5-1 percent, table 2) the upper limit of the range in this group of samples is conservatively assumed to be 1 percent and the lower limit zero. The total range then of the 7-sample group is 1 percent. If these values are used in the formula, the ratio $\frac{DA}{R}=\frac{0.8}{1}=0.8$, here termed the "significance factor," is obtained. In this example the significance factor exceeds any of the factors shown for a group of 7 samples in the left half of table 22—thus, the probability that the observed difference in averages is fortuitous is less than 1 in 100; conversely, the chances that the observed difference is attributable to the equilibrium status of the sample groups are more than 99 in 100.

TABLE 22.—*Ratios used for estimation of the significance of the difference between a sample group average and a pre-assigned value, or of the difference between the averages of two sample groups of equal size*

[Modified from Lord, 1947, tables 9 and 10, p. 66]

Average of group of samples vs. a pre-assigned value				Average of one sample group vs. average of another sample group of equal size			
Number of samples in group	Values of $\frac{DA}{R}$ [1]			Number of samples in group	Values of $\frac{DA}{AR}$ [2]		
	Probability (percent)				Probability (percent)		
	90	95	99		90	95	99
2	3.196	6.353	31.828	2	2.322	3.427	7.916
3	.885	1.304	3.008	3	.974	1.272	2.093
4	.529	.717	1.316	4	.644	.813	1.237
5	.388	.507	.843	5	.493	.613	.896
6	.312	.399	.628	6	.405	.499	.714
7	.263	.333	.507	7	.347	.426	.600
8	.230	.288	.429	8	.306	.373	.521
9	.205	.255	.374	9	.275	.334	.464
10	.186	.230	.333	10	.250	.304	.419
11	.170	.210	.302	11	.233	.280	384
12	.158	.194	.277	12	.214	.260	.355
13	.147	.181	.256	13	.201	.243	.331
14	.138	.170	.239	14	.189	.228	.311
15	.131	.160	.224	15	.179	.216	.293
16	.124	.151	.212	16	.170	.205	.278
17	.118	.144	.201	17	.162	.195	.264
18	.113	.137	.191	18	.155	.187	.252
19	.108	.131	.182	19	.149	.179	.242
20	.104	.126	.175	20	.143	.172	.232

[1] Used for estimation of significance of relations shown in tables 8–10. *DA*, difference between average and pre-assigned value: *R*, range of samples in group. See discussion that follows.

[2] Used for estimation of significance of enrichment factors shown in figures 19–22. *DA*, difference in averages; *AR*, average range of sample groups. Where values of *DA*/*AR* exceed the factor in the 90 percent column opposite the appropriate number of samples in group, the corresponding enrichment factor is more than 90 percent probably significant; where the significance factor exceeds the factor shown in the 95 percent column, it is more than 95 percent probably significant, and so forth. See discussion that follows.

2. In table 11 the averages of all the samples (cols. 4, 6, 8) are used as the pre-assigned value in the formula $\frac{DA}{R}$. The average strontium (Sr) content in the Lonesome Pete ore zone (col. 8) is 0.06 percent, in the low-U suite it is 0.03 percent. The difference between averages is 0.03 percent. This particular 7-sample low-U suite was used also in the third method of investigation, so that the range can be determined directly from figure 22 as 0.01–0.05 percent and the difference is 0.04 percent. Substituting in the formula, $\frac{DA}{R}=\frac{0.03}{0.04}=0.75$. In the left half of table 22, for a group of 7 samples, the significance factor of 0.75 exceeds the 99-percent probability level. There is less than 1 chance in 100 that the observed difference in averages is fortuitous.
3. The third example illustrates the use of the right half of table 22. The high-U sample suite in figure 19 averages 0.15 percent zirconium (Zr), the low-U suite averages 0.05 percent Zr. The 2 ranges are 0.02–0.5 percent, having a difference of 0.48 percent, and 0.005–0.2 percent, having a difference of 0.195 percent, respectively:

$$\frac{DA}{AR}=\frac{0.15-0.05}{(0.48+0.195)/2}=\frac{0.1}{0.34}=0.29.$$

From the right half of table 22 we see (for group of 12 samples) that the value 0.29 exceeds the value shown for 95 percent probable. There are fewer than 5 chances in 100 that the observed difference in averages is due to random chance.

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