Distribution of Minor Elements In Some Coals in the Western and Southwestern Regions of the Interior Coal Province

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Distribution of Minor Elements In Some Coals in the Western and Southwestern Regions of the Interior Coal Province

By PETER ZUBOVIC, NOLA B. SHEFFEY, *and* TAISIA STADNICHENKO

MINOR ELEMENTS IN AMERICAN COALS

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A study of 15 minor elements in some of the coals of Arkansas, Iowa, Missouri, Oklahoma, and Texas

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DISTRIBUTION OF MINOR ELEMENTS IN SOME COALS IN THE WESTERN AND SOUTHWESTERN REGIONS OF THE INTERIOR COAL PROVINCE

By Peter Zubovic, Nola B. Sheffey, and Taisia Stadnichenko

ABSTRACT

The average minor-element content was determined in 48 columnar samples of coal of Pennsylvanian age and in 4 samples of lignite from rocks of Eocene age. These samples were collected from Iowa, Missouri, Oklahoma, and Arkansas in the Western region of the Interior coal province, and from Texas in the Southwestern region. The coals of Iowa and Missouri contain more of all the minor elements—except titanium, tin, and lanthanum—than do the coals of Oklahoma and Arkansas. Two samples of lignite of Eocene age from Arkansas contain more of all the minor elements, except boron, than do two samples of similar age from Texas.

Weathered coal contains appreciably more beryllium, titanium, vanadium, chromium, cobalt, nickel, copper, gallium, yttrium, and lanthanum than does unweathered coal. The distribution of elements, particularly the ratio of yttrium to lanthanum, suggests that the Oklahoma-Arkansas coal basin was a main drainageway of the inland sea in Des Moines time.

INTRODUCTION

This study of the Western and Southwestern regions of the Interior coal province (fig. 1) is one of a series dealing with the major coal-producing areas of the United States. These studies were made to evaluate coals as possible sources of some of the minor elements, particularly germanium. Our previous publications in this series are: "Concentration of Germanium in the Ash of American Coals—A Progress Report" (Stadnichenko and others, 1953); "Beryllium Content of American Coals" (Stadnichenko and others, 1961); "Geochemistry of Minor Elements in Coals of the Northern Great Plains Coal Province," which includes a large bibliography on other investigations of minor elements in coals (Zubovic and others, 1961); and "Geochemistry of Minor Elements in Coals of the Eastern Interior Region" (Zubovic and others, 1964).

In the present study, the average minor-element content was determined in 48 columnar samples of coal of Pennsylvanian age

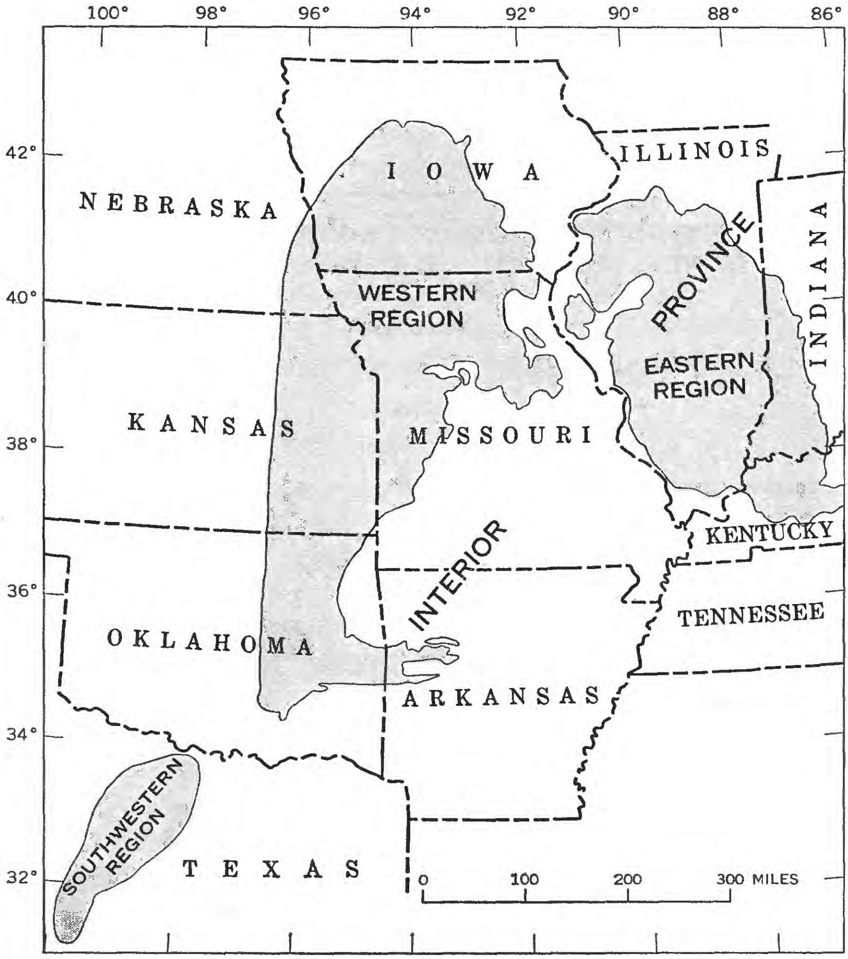

FIGURE 1.—Position of the Western and Southwestern regions relative to the Interior coal province.

(including 46 samples of the Des Moines Series and 2 samples of the Atoka Series) and in 4 samples of lignite from rocks of Eocene age. These samples were collected as follows: 2 from Iowa and 5 from Missouri in 1952; 24 from Oklahoma, 19 from Arkansas, and 2 from Texas in 1955. The general localities from which the columnar samples were taken are shown in figure 2, and the specific localities and their description are given in table 1. No samples were collected from Kansas because Schleicher (1959) reported on the germanium content of many of the coals there.

In our opinion, the coals studied thus far could not be considered an economic source of these minor elements. However, these coals might serve as an emergency source in the event of a national crisis.

FIGURE 2.—Sample localities described in table 1. The following locality symbols on the inset map refer to specific coal bed: ■, McAlester (Stigler) bed; ○, Upper Hartshorne bed; ×, Lower Hartshorne bed; ⊗, Upper and Lower Hartshorne beds. Localities shown by a black dot are not differentiated by bed in this figure. All coal is of Pennsylvanian age.

We thank the mine operators and miners who helped to expedite the sampling. Alex Dinsmore and B. R. Haley of the U.S. Geological Survey accompanied and guided the senior author while he collected samples in Oklahoma and Arkansas. Four samples submitted by Haley were helpful in our interpretations.

TABLE 1.—*Location and description of the coal samples*

Locality (fig. 2)	Coal column	Number of coal block samples	County	Mine and (or) location	Stratigraphic unit	Coal bed		
						Name	Thickness (feet)	Percentage analyzed
Iowa								
1	Ia-P-M	14	Marion	Sinclair Coal Co. Pershing mine, 7 miles east-southeast of Knoxville.	Marmaton Group	Mamouth (No. 1)	2.96	97.6
2	Ia-L-K	17	Wapello	Lanning Coal Co. mine, 2 miles southeast of Kirkville.	do	Kirkville	4.40	46.8
Missouri								
3	Mo-BN-B	18	Macon	Bevier Coal Co. Bevier mine, Bevier	Bevier Formation [1]	Bevier	4.25	74.1
	Mo-BS-B	18	do	South pit	do [1]	do	4.83	30.6
	Mo-B-Mu	5	do	North pit	Mulky Formation [1]	Mulky	1.30	100
4	Mo-P-T	10	Henry	Power Coal Co. mine, 2 miles north of Germantown.	Tebo Formation [1]	Tebo	1.92	80.7
5	Mo-T-M	7	Bates	Sinclair Coal Co. Tiger mine, near Hume.	Bandera Formation [1]	Mulberry	1.86	100
Oklahoma								
6	OK-Pa-Fo	5	Craig	Patch Coal Co. near Welch: No. 2 mine	Senora Formation	(Forsythe above Broken Arrow bed.)	1.00	100
	OK-Pa-BA	6	do	No. 1 mine	do	Broken Arrow (Croweburg).	1.31	100
7	OK-RC-BA	6	Rogers	Rogers County Coal Co., sec. 1, T. 22 N., R. 16 E.	do	do	1.35	100
8	OK-MN-BA	8	do	McNabb Coal Co. mine, 2.6 miles northwest of Catoosa.	do	do	1.39	100
9	OK-BH-H	6	Okmulgee	Ben Hur Coal Co. Blackstone mine, 1 mile north of Henryetta.	do	Henryetta (Croweburg)	3.13	100
10	OK-LC-Se	6	McIntosh	Leavell Coal Co. Bluebonnet mine, sec. 32, T. 12 N., R. 19 E.	Boggy Formation	Secor	2.30	100
11	OK-L-JC	9	Pittsburg	Lee Strip mine, sec. 23, T. 7 N., R. 16 E.	do	Jones Creek (Secor)	2.32	100
12	OK-PC-Ca	4	Le Flore	Pure Coal Co. mine, SW¼SW¼ sec. 4, T. 6 N., R. 25 E.	Savanna Formation	Cavanal	2.20	100
13	OK-SS-St	4	Sequoyah	Salislaw Stripping Co., 1½ miles south of Salislaw.	McAlester Formation	McAlester-Stigler	1.30	100

	OK-SS-StR	1	do	do	do	Rider Coal above McAlester-Stigler.	.46	100
14	OK-Ga-St	5	Haskell	Garland Coal Mining Co., sec. 9, T. 9 N., R. 23 E.	do	McAlester-Stigler	1.70	100
15	OK-Ca-St	3	do	Canadian Mining Co., sec. 12, T. 8 N., R. 20 E.	do	do	1.60	100
16	OK-Sa-Mc	9	Coal	Sandman Coal Co. mine, sec. 7, T. 1 N., R. 11 E.	do	do	3.64	100
17	OK-Du-Mc	11	do	Dunn Strip mine, sec. 25, T. 1 S., R. 10 E.	do	do	3.26	100
18	OK-LS-Mc	6	Pittsburg	Lone Star Steel Co. Carleen No. 5 mine, sec. 5, T. 5 N., R. 16 E.	do	do	3.10	100
19	OK-MA-Mc	7	do	McAlester-Alderson Coal Co., sec. 3, T. 4 N., R. 16 E.	do	do	3.28	100
20	OK-K-UH	12	Latimer	Kinta Stripping Co., sec. 7, T. 5 N., R. 19 E.	Hartshorne Sandstone	Upper Hartshorne	3.69	100
	OK-K-LH	7	do	Kinta Stripping Co., sec. 1, T. 5 N., R. 18 E.	do	do	2.08	100
21	OK-LS-LH	5	Haskell	Lone Star Steel Co. McCurtain mine, sec. 30, T. 8 N., R. 22 E.	do	Lower Hartshorne	3.27	100
22	OK-LS-UH	4	do	do	do	Upper Hartshorne	2.16	100
	OK-EC_2-LH	1	do	Evans Coal Co. mine, sec. 36, T. 9 N., R. 23 E.	do	Lower Hartshorne	.66	100
	OK-EC_1-UH	4	do	Evans Coal Co. mine, sec. 25, T. 9 N., R. 23 E.	do	Upper Hartshorne	1.60	100
	OK-EC_2-UH	4	do	Evans Coal Co. mine, sec. 36, T. 9 N., R. 23 E.	do	do	1.29	100
23	OK-Da-UH	8	Le Flore	Dawes mine, south of Howe	do	do	3.33	100
				Arkansas				
24	Ark-NS-P	4	Logan	Northside Coal Co. mine, sec. 29, T. 8 N., R. 26 W.	Savanna Formation	Paris	2.25	100
25	Ark-Ha_{10}-Ch [2]	2	Johnson	Spillway of Horsehead Dam, SE¼NE¼ sec. 3, T. 10 N., R. 25 W.	do	Unnamed bed 34 ft above Charleston bed.	.48	100
	Ark-Ha_{11}-Ch	4	do	Mine entry 60 ft south of above sample locality.	do	Charleston	1.49	100
26	Ark-Ha_{15}-Ch [2]	3	Franklin	Abandoned strip pit, center east line SW¼ sec. 32, T. 8 N., R. 28 W.	do	do	1.33	100
27	Ark-Sk-Ch	2	Johnson	Skidmore Bros. Coal Co., sec. 6, T. 10 N., R. 23 W.	do	do	1.12	100
28	Ark-QE-UH	5	Sebastian	Quality Excelsior Coal Co. Quality No. 12 mine, 1¼ miles northeast of Hackett.	McAlester Formation	Upper Hartshorne	2.46	100
29	Ark-Ba-LH	27	Scott	Bates Coal Co. strip pit, center sec. 22, T. 3 N., R. 32 W.	do	Lower Hartshorne	8.16	92.8
30	Ark-Hu-LH	20	Sebastian	Abandoned strip mine, sec. 22, T. 5 N., R. 31 W.	do	do	7.12	----------
31	Ark-Ha_{16}-LH [2]	2	Scott	Abandoned strip mine, NW¼SW¼ sec. 9, T. 4 N., R. 30 W.	do	do	1.23	100

See footnotes at end of table.

TABLE 1.—*Location and description of the coal samples*—Continued

Locality (fig. 2)	Coal column	Number of coal block samples	County	Mine and (or) location	Stratigraphic unit	Coal bed		
						Name	Thickness (feet)	Percentage analyzed
				Arkansas—Continued				
32	Ark-OZ-LH	1	Franklin	Roadcut on Highway 22, sec. 14, T. 10 N., R. 27 W.	McAlester Formation	Lower Hartshorne	1.25	100
33	Ark-ACM-LH	5	Johnson	Arkansas Coal Mining Co. mine, sec. 7, T. 9 N., R. 24 W.	do	do	1.63	100
	Ark-ACM-LHR	3	do	do	do	Unnamed bed 10 ft above Lower Hartshorne.	1.08	100
34	Ark-PV-LH	14	Logan	½ mile east of Prairie View, sec. 23, T. 8 N., R. 24 W.	do	Lower Hartshorne	3.31	100
35	Ark-EJ-LH	2	Johnson	E. K. Johnson brick pit, sec. 33, T. 10 N., R. 22 W.	do	do	.88	100
36	Ark-Ru-LH	4	Pope	West side of Highway 64, 1 mile south of Russelville.	do	do	2.75	100
37	Ark-Dr_1-At	1	Logan	Along road near Driggs, sec. 33, T. 7 N., R. 26 W.	Atoka Formation	Unnamed bed 400 ft below Lower Hartshorne.	.67	100
	Ark-Dr_2-At	1	do	Along road near Driggs, sec. 22, T. 7 N., R. 26 W.	do	do	.67	100
38	Ark-M-UE	7	Hot Spring	Malvern Brick Co. clay pit, 1½ miles east of Malvern.	Wilcox Group	Unnamed upper bed	2.02	100
	Ark-M-LE	5	do	do	do	Unnamed lower bed		100
				Texas				
39 [3]	Tex-Mc-UE	19	Harrison	McAlester Fuel Co. strip mine, near Marshall.	Wilcox Group	Unnamed upper bed	7.37	100
	Tex-Mc-LE	15	do	do	Unknown	Unnamed lower bed	4.45	100

[1] Searight (1958).
[2] Sample submitted by Boyd R. Haley, U.S. Geological Survey.
[3] South of area shown in figure 2.

COAL BEDS SAMPLED

The names of the coal beds sampled and the number of samples collected from each bed are shown in table 1; however, identification of some of the beds is uncertain. The two samples of Iowa coal may be from the Mystic bed, but the local names "Mamouth" and "Kirkville" are used in table 1. One sampled coal bed from Oklahoma (OK–Pa–Fo, loc. 6) lies above the Broken Arrow bed and, therefore, could be from the Iron Post bed; however, the mine operator called it the Forsythe bed, and this is the name we have shown in table 1. We assumed that the McAlester and Stigler beds correlate, as suggested by Trumbull (1957), and we have called them the McAlester-Stigler bed in table 1.

The relative stratigraphic position and the correlation of some of the Pennsylvanian coal beds are shown on plate 1.

The Oklahoma-Arkansas basin was the most throughly sampled area, primarily because of our interest in the relation of coal rank to the minor-element content of the coal, but also because more mines were operating and could be sampled. The coals of Iowa, Missouri, and the northern and southwestern parts of the Oklahoma coal fields are high-volatile bituminous in rank (fig. 2). The coals, in the central and eastern parts of the Oklahoma-Arkansas basin are low- to medium-volatile bituminous in rank and those in the extreme eastern part of the basin are semianthracite in rank.

SAMPLE PREPARATION AND PROCESSING

COLLECTION

Samples were collected by cutting out vertical columns from a coal bed. The columns were broken into a series of measured and labeled blocks to facilitate handling, shipping, and reassembling in the laboratory. Thicknesses of the blocks were determined primarily by changes in the macroscopic lithology of the coal. If a column appeared to be largely uniform, it was broken into blocks about 0.5 foot thick. Throughout this paper, "columnar sample" refers to the entire sample of a coal bed, and "block sample" refers to an individual part of a columnar sample. Composite samples were made only from those blocks that were in sequence and whose ash contents were reasonably uniform, so that the principal differences in depositional character throughout the bed would be preserved.

ASHING AND SCREENING

A part of each block sample was ground to pass through a 100-mesh sieve. Ten grams of each ground sample was placed in a cold muffle furnace. The temperature in the furnace was gradually raised to

450°C and was held at that level until all the organic matter was oxidized. A rapid spectrophotometric analytical method, using phenylfluorone as the reagent, was used to determine the approximate amount of germanium in the ash of each block sample. The amount of molybdenum in each sample was determined by the thiocyanite method, which is rapid and produces probable errors of 30 percent or less (Zubovic and others, 1961, p. 20). The ash of individual samples that contained large amounts of these two elements was then analyzed spectrographically. Separate splits of the block coal samples that contained small quantities of these two ellements were combined to form composite samples which were then ashed and spectrographically analyzed for 15 elements.

FLOTATION

Early in the investigation we noticed that many of the elements were undetected in the analyses of ash samples from coals that contained 15 percent or more ash. Also, during sampling we noticed that at almost every mine some method was used to clean the coal. Therefore, we tried to eliminate as much extraneous mineral matter in the coal samples as possible so that the composition of the samples would approximate that of coal produced by most of the mines and used by the principal consumers, as any possible large-scale recovery of elements would be from the ash of such coal.

In this study, 27 percent of the samples were floated. Table 2 lists the block samples that were floated and the percentage of the original block that floated. During the initial breaking of the samples, all removable pyritic, calcitic, and clayey parts were picked out by hand. In addition, coals that contained more than about 8 percent ash were centrifuged in a flotation medium of carbon tetrachloride and ethyl alcohol. The specific gravity of the flotation medium used for each sample depended upon the ash content of the coal. Coals that contained less than 10 percent original ash were floated on liquids having specific gravities of 1.32 or less. Coals that contained more than 10 percent original ash were floated on progressively denser liquids as the ash content increased.

Flotation mediums of different densities were used to get the maximum amount of coal into the floated fraction. In many flotation runs, however, the use of fairly high density liquids on high-ash microbanded coal still resulted in low recoveries. The effect of flotation on the minor-element distribution is discussed in detail in a later section.

TABLE 2.—*List of floated samples*

Locality (fig. 2)	Coal column	Coal block sample	Specific gravity of floating medium	Floated fraction (percent)	Ash (percent)
5	Mo-T-M	1	1.32	----------	5.10
6	OK-Pa-BA	6	1.36	75.1	6.54
7	OK-RC-BA	5	1.36	73.8	5.65
8	OK-MN-BA	5	1.36	68.1	3.88
9	OK-BH-H	3	1.32	73.6	3.60
		4	1.32	87.6	1.72
		5	1.32	90	.99
		6	1.32	83.7	2.42
10	OK-LC-Se	2-4	1.32	51.8	3.36
		5-6	1.30	50.6	2.98
11	OK-L-JC	1	1.36	23.6	5.87
		3-4	1.32	29.3	3.02
		6-8	1.30	53.6	2.07
12	OK-PC-Ca	1	1.34	10	4.70
		2-3	1.32	40.6	3.16
		4	1.32	58.1	2.61
13	OK-SS-St	1-2	1.32	53.8	2.13
		3-4	1.30	63.6	1.28
14	OK-GA-St	1-2	1.34	62.5	2.74
		5	1.32	41.3	3.25
15	OK-Ca-St	2	1.32	88.1	1.69
16	OK-Sa-Mc	1-2	1.32	10.7	3.91
		3-5	1.32	28.6	3.16
		6-7	1.32	35.2	2.22
		9	1.32	32.8	2.23
17	OK-Du-Mc	1	1.32	75.8	3.40
		2-3	1.32	15	3.25
		4	1.32	52.3	3.90
		5-9	1.32	16	3.73
		10	1.32	43.8	3.50
		11	1.36	32.5	5.80
18	OK-LS-MC	1-2	1.32	82.7	2.95
		3-5	1.30	87.4	1.36
19	OK-MA-MC	1	1.34	16.2	6.71
		2-6	1.32	78.5	1.72
		7	1.34	55.3	3.96
20	OK-LS-UH	1	1.32	54.5	3.58
		3-4	1.30	64.5	1.27
	OK-K-LH	1-2	1.32	83.5	2.69
		3-5	1.30	50.9	4.60
		6-7	1.32	18.9	1.58
21	OK-LS-LH	1	1.32	64.5	2.39
		3-4	1.30	47.2	1.48
		5	1.34	13.2	2.96
22	OK-EC$_2$-LH	1	1.34	15.1	3.59
	OK-EC$_1$-UH	1-2	1.32	47.7	2.04
		3-4	1.32	59.1	1.33
	OK-EC$_2$-UH	1-2	1.32	35.3	1.86
		3-4	1.32	45.9	1.87
23	OK-Da-UH	1-2	1.32	32	3.31
		3-5	1.32	56.5	2.46
		7-8	1.32	51	2.66
24	Ark-NS-P	1	1.40	----------	12.41
		2-3	1.40	----------	13.61
28	Ark-QE-UH	1	1.42	----------	4.93
29	Ark-Ba-LH	1-4	1.58	----------	16.60
		9-12	1.58	----------	6.47
		27	1.40	44.7	4.16
30	Ark-Hu-LH	12-14	1.58	----------	12.81
32	Ark-OZ-LH	1	1.58	----------	12.23
33	Ark-ACM-LHR	1	1.40	----------	4.33
35	Ark-EJ-LH	1-2	1.40	----------	12.19

QUANTITATIVE SPECTROGRAPHIC ANALYSIS

The quantitative spectrographic procedure used in the analysis of the coal-ash samples has been described in detail (Zubovic and others, 1961, p. 18–20); therefore, the method is only briefly outlined here.

The total-energy method, employing direct-current arc excitation of samples and synthetic standards, was used. The spectra of samples and standards were recorded on photographic plates that cover the wavelength interval 2300 A–4700 A with a dispersion of 5 A per millimeter. The transmittances of the analytical lines were measured with a microphotometer, and the photographic plates were calibrated by use of a set of homologous iron lines for which relative intensities were known (Dieke and Crosswhite, 1943). Synthetic standards were used to construct analytical curves relating the logarithm of intensity of analytical lines to the logarithm of concentration. Concentrations of the various elements were determined from these curves.

The different limits of detection of the elements listed in table 3 resulted from the use of different instruments and laboratories.

TABLE 3.—*Limits of detection of the elements*

Element	Limit of detection (weight percent of ash)	
	Early analyses [1]	Later analyses [2]
Be	0.0001	0.0002
B	.001	.002
Ti	.005	.0005
V	.001	.0007
Cr	.0001	.0002
Co	.0005	.0003
Ni	.0005	.0003
Cu	.0001	.0002
Zn	.01	.02
		.04
		.05
		.06
Ga	.001	.0007
Ge	.001	.002
		.003
Mo	.0005	.0003
Sn	.001	.002
Y	.001	.001
La	.003	.007
Cd	.005	.02

[1] Limits of detection for the samples from Iowa, Missouri, northern Oklahoma, and some samples from the Oklahoma-Arkansas basin.
[2] Limits of detection for most of the samples of the Oklahoma-Arkansas basin.

The analytical results are generally the average of two single determinations. The coefficient of variation for the mean of such duplicate determinations for all the elements averages about 15 percent and ranges from 10 to 20 percent, depending upon the nature of the ash, the element, and the concentration of the element.

PRESENTATION OF THE DATA

Analyses for 15 elements in the ash of 225 samples, in 2 coalified logs, and in 1 shaly coal are presented in table 4.

The average minor-element content in ash of each columnar sample is listed in table 5; the average minor-element content, in parts per million, for each columnar sample of coal is listed in table 6. The contents for 49 of the columnar samples are weighted averages based on the thickness of each analyzed block or composite sample. For three columnar samples (Ia–L–K, Mo–BS–B, Ark–M–Le), arithmetic averages of the analyzed blocks are given.

EVALUATION OF THE DATA

In the following discussion it must be kept in mind that most samples of high-ash coal were cleaned by flotation and that analytical data from these samples have been mixed with data from low-ash or naturally clean coal. Furthermore, first examination of the data showed marked differences in minor-element content of samples from the Oklahoma-Arkansas basin area and from the Missouri–northern Oklahoma area. A comparison of minor-element content in cleaned (floated) and uncleaned (not floated) samples from these two areas is shown in table 7, and a comparison between minor-element content of coals from the Western and Eastern regions of the Interior province is shown in table 8.

Only eight block samples from the northern Oklahoma-Missouri area were floated. The average compositions of these samples were compared with those of 28 samples of unfloated coal from the same columnar samples. In the floated samples, the average contents of boron, titanium, and yttrium were significantly greater than in the unfloated samples; the average content of zinc was considerably smaller, and the average contents of most of the other elements were somewhat smaller. In the floated and unfloated samples, the beryllium content was almost identical.

Comparison of the floated and unfloated samples from the Oklahoma-Arkansas basin shows that in the floated samples the average contents of cobalt and nickel were considerably smaller; the average contents of beryllium, copper, zinc, gallium, and lanthanum were slightly smaller, whereas the average contents of vanadium and tin were much greater and the average contents of the other elements were slightly greater. In the floated coals from both the northern Oklahoma-Missouri area and the Oklahoma-Arkansas basin, the average contents of cobalt, nickel, zinc, copper, lanthanum, and perhaps gallium were smaller, and the average contents of boron, titanium, and yttrium were greater.

TABLE 4.—*Spectrochemical analyses of 15 minor elements in the ash of block coal samples from the Western region*

[Figures indicate percent by weight; asterisk, visual estimate; leaders, sample not analyzed; a, b, separates of a single block. Location and description of samples given in table 1]

Locality (fig. 2)	Coal column	Coal block sample No.	Thickness (feet)	Ash	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
1	Ia-P-M	1	0.24	6.08	0.004	0.38	0.6	0.031	0.0088	0.013	0.07	0.12	<0.01	0.001	0.02	<0.0005	<0.001	0.009	<0.003
		2	.24	10.66	.002	*.1	.12	<.001	.025	.008	.07	.021	<.01	.004	.034	<.0005	<.001	.008	<.003
		3	.14	9.68	.0006	*.2	.03	<.001	.0004	.006	.04	.12	<.01	.001	.02	<.0005	<.001	.009	<.003
		4	.40	9.14	.003	*.3	.048	<.001	.013	.0042	.045	.014	<.01	.002	.03	<.0005	<.001	.006	<.003
		5	.07																
		6	.24	9.36	.0009	*.09	.1	.009	.004	.006	.05	.006	.2	.004	.01	<.0005	<.001	.01	<.003
		7	.18	12.30	.001	*.1	.1	.006	.004	.015	.056	.007	.36	.002	.015	<.0005	<.001	.007	<.003
		8	.24	12.28	.002	.12	.24	.008	.004	.016	.10	.01	1.4	.003	.022	.001	<.001	.01	<.003
		9	.25	13.02	.0006	.17	.1	.021	.0072	.01	.06	.095	.85	.003	.02	<.0005	<.001	.01	<.003
		10	.15	14.22	.002	*.06	.16	.0088	.0048	.014	.05	.0076	.14	.001	.013	.001	<.001	.007	<.003
		11	.23	22.28	.0004	*.04	.1	.004	.004	.02	.05	*.02	<.01	.001	.01	<.0005	<.001	.008	<.003
		12	.16	14.72	.003	*.05	.2	.009	.005	.02	.04	.005	<.01	.003	.01	<.0005	<.001	.009	.004
		13	.22	14.62	.001	*.06	.28	.017	.018	.004	.06	.0096	<.01	.003	.017	.003	<.001	.008	<.003
		14	.20	15.54	.0008	.04	.4	.03	.02	.003	.008	.005	<.01	.002	.01	<.0005	<.001	.01	.007
2	Ia-L-K	1	.14	12.28	.0006	*.2	.18	.019	.009	.002	.009	.003	<.01	.006	.032	<.0005	<.001	.009	<.003
		2	.70	11.58	.003	*.2	.16	.006	.0054	.002	.0072	.006	<.01	.005	.06	<.0005	<.001	.009	<.003
		3	.10	11.62	.002	*.09	.16	.0063	.0051	.0026	.0042	.004	<.01	.001	.025	<.0005	<.001	.008	<.003
		4	.13																
		5	.09	10.62	.0004	*.1	.08	.0052	.0004	.002	.007	.002	<.01	<.0005	.022	<.0005	<.001	<.001	<.003
		6	.12	6.76	.02	*.4	.1	.005	.002	.003	.008	.005	.04	.002	.02	<.0005	<.001	.02	<.003
		7	.20	11.58	.006	*.4	.16	.0072	.003	.004	.003	.004	.2	.006	.037	<.0005	<.001	.02	
		8-14	2.09																
		15	.32	9.88	.005	*.05	.3	.02	.01	.01	.02	.02	.04	.005	.01	<.0005	<.001	.02	.04
		16	.23	8.66	.004	*.3	.38	.016	.072	.011	.018	.017	<.01	.007	.11	<.0005	<.001	.01	<.003
		17	.16	7.88	.004	*.3	.54	.054	.036	.011	.027	.011	.03	.007	.14	<.0005	<.001	.01	.078
		18	.12																
3	Mo-BN-B	1	.25	15.60	.001	*.05	.3	.01	.005	.002	.02	.008	<.01	.004	.005	<.0005	<.001	.008	<.003
		2	.45	16.04	.001	*.05	.3	.01	.005	.002	.01	.006	<.01	.004	.004	<.0005	<.001	.009	<.003
		3-4	.51																
		5	.23	4.24	.01	.1	.4	.03	.02	.01	.02	.02	.03	.006	.01	.004	.0004	.04	.04
		6	.31	3.26	.02	.2	.2	.02	.01	.008	.02	.01	.03	.006	.01	.003	.0004	.04	<.003
		7	.09	3.40	.01	.2	.2	.02	.01	.01	.02	.01	.03	.006	.01	.003	.0004	.05	<.003
		8	.18	3.48	.01	.3	.3	.02	.01	.009	.02	.01	.03	.007	.02	.003	.0004	.05	<.003
		9	.16	4.12	.01	.2	.4	.02	.01	.008	.02	.01	.03	.006	.01	.003	<.001	.04	<.003
		10	.25	3.60	.01	.2	.4	.03	.01	.008	.02	.02	.03	.008	.02	.004	.0004	.04	<.003
		11	.28	7.28	.003	.2	.5	.02	.01	.003	.01	.01	.03	.006	.01	.002	.0006	.02	<.003
		12-14	.59																
		15	.39	7.84	.004	.1	.6	.05	.03	.01	.03	.02	.04	.006	.015	.007	.0006	.02	.002
		16	.29	8.40	.003	*.05	.3	.01	.007	.004	.02	*.03	.02	.004	.02	.004	<.001	.02	.008

		17	.12	5.94	.005	.1	.3	.02	.01	.009	.03	.02	.04	.006	.03	.009	.0004	.03	<.003
		18	.15	9.20	.0008	*.05	.3	.03	.04	.003	.02	.01	<.01	.003	.01	.009	<.001	.01	.01
	Mo-BS-B	1–5	1.51																
		6	.26	3.82	.01	.2	.3	.02	.009	.01	.02	.01	.03	.006	.03	.004	<.001	.03	<.003
		7	.28	3.46	.004	.25	.15	.021	.03	.0044	.014	.021	<.01	.01	.058	.006	<.001	.01	<.003
		8	.44	7.66	.003	.2	.7	.03	.02	.006	.02	.04	.02	.006	.02	.005	.001	.02	<.003
		9–11	.77																
		12	.16	7.46	.004	.12	.34	.02	.018	.004	.026	.016	<.01	.008	.032	.01	<.001	.007	<.003
		13–14	.29																
		15	.34	4.64	.005	.19	.34	.03	.05	.004	.035	.032	<.01	.01	.11	.009	<.001	.006	.003
		16–18	.78																
	Mo-B-Mu	1	.28	12.80	.002	*.1	.3	.2	.2	.005	.03	*.03	<.01	.002	.008	.04	<.001	.007	<.003
		2	.21	3.64	.01	.2	.6	.03	.02	.005	.02	.04	.02	.005	.04	.02	.0004	.03	<.003
		3	.35	3.32	.01	.3	.7	.03	.02	.008	.02	.03	.03	.007	.03	.02	.0006	.03	<.003
		4	.33	5.94	.007	.2	.6	.02	.01	.01	.03	.02	.03	.006	.02	.01	<.001	.03	<.003
		5	.13	13.50	.002	*.1	.3	.06	.008	.02	.05	*.04	<.01	.002	.008	.004	<.001	.009	<.003
4.	Mo-P-T	1	.19	14.58	.0002	.03	.2	.06	.03	.002	.02	.009	<.01	.003	.01	.02	<.001	.006	<.003
		2	.20	13.38	.0006	*.05	.2	.01	.01	.001	.01	.002	<.01	.003	.009	.009	<.001	.006	<.003
		3	.11	22.98	.0001	.02	.08	.006	.001	.001	.02	.005	<.01	.001	.006	.003	<.001	.006	<.003
		4	.24	13.58	.0006	.03	.2	.01	.01	.001	.02	.007	<.01	.003	.006	.006	<.001	.007	<.003
		5	.12	16.00	.0002	*.04	.1	.01	.01	.001	.01	.002	<.01	.002	.008	.006	<.001	.007	<.003
		6	.35	18.76	.0002	*.05	.08	.008	.009	.002	.02	.003	<.01	<.001	.006	.004	<.001	.005	<.003
		7	.22																
		8	.18	17.18	.0002	.022	.21	.01	.02	.0044	.034	.008	.2	.002	.009	.008	<.001	.007	<.003
		9	.15																
		10	.16	19.38	.0005	.034	.2	.082	.02	.001	.056	.024	>10.	.01	.008	.004	<.001	.007	<.003
5.	Mo-T-M	1	.31	5.10	.006	*.02	.5	.018	.037	.02	.037	.03	.02	.0052	.043	.008	<.001	.05	.02
		2	.30	20.84	.0001								<.01		.008	<.0005	<.001		
		3	.32	15.88	.0003	.02	.4	.02	.03	.002	.005	.01	<.01	.007	.01	.003	<.001	<.001	<.003
		4	.25	11.08	.002	.034	.39	.02	.02	.002	.0094	.013	4.8	.008	.033	.001	<.001	.005	.004
		5	.26	16.38	.0006	.016	.3	.02	.02	.002	.006	.007	.1	.005	.01	.001	<.001	.006	.005
		6a	.28	7.08	.0009	.028	.39	.038	.03	.003	.017	.025	4.4	.0042	.054	.002	<.001	.008	.003
		6b	.14	27.08	.0002	.01	.2	.02	.02	.003	.02	.01	<.01	<.0005	<.001	<.0005	<.001	.005	.005
		2s		50.06	.0001	.01	.3	.01	.02	.002	.009	.006	<.01	.001	<.001	<.0005	<.001	<.001	.004
6.	OK-Pa-Fo	1	.23	3.64	.009	*.05	.3	.041	.046	.003	.017	.04	.06	.014	.18	.035	<.001	.009	<.003
		2	.25	2.66	.01	*.1	.2	.01	.02	.003	.006	.04	.08	.014	.07	.01	<.001	.01	<.003
		3	.16	5.96	.008	*.05	.5	.018	.02	.002	.006	.03	.06	.009	.011	.006	<.001	.01	<.003
		4	.13	3.70	.008	*.1	.4	.016	.033	.003	.008	.03	.08	.016	.027	.013	.02	.01	<.003
		5	.23	4.46	.008	.05	.4	.09	.035	.006	.015	.03	.07	.016	.027	.014	<.001	.02	<.003
	OK-Pa-BA	1	.23	3.36	.002	*.05	.3	.08	.02	.018	.14	.018	<.01	.0097	.096	<.0005	<.001	.01	<.003
		2	.19	2.57	.004	*.05	.4	.022	.01	.024	.14	.024	<.01	.012	.12	<.0005	<.001	.01	<.003
		3	.16	4.08	.003	*.02	.4	.026	.01	.02	.086	.03	<.01	.007	.071	<.0005	<.001	.01	<.003
		4	.36	2.54	.004	*.05	.5	.027	.02	.02	.13	.026	<.01	.012	.11	<.0005	<.001	.01	<.003
		5	.22	4.70	.003	*.03	.8	.027	.02	.02	.12	.026	.04	.006	.078	<.0005	<.001	.01	.004
		6	.15	6.54	.003	*.07	.78	.062	.026	.014	.08	.02	<.01	.004	.031	<.0005	<.001	.01	<.003

See footnotes at end of table.

TABLE 4.—*Spectrochemical analyses of 15 minor elements in the ash of block coal samples from the Western region*—Continued

Locality (fig. 2)	Coal column	Coal block sample No.	Thickness (feet)	Ash	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
7	OK-Rc-BA	1	0.25	1.22	0.02	*0.05	0.4	0.027	0.01	0.039	0.12	0.03	0.25	0.02	0.19	0.002	<0.001	0.01	<0.003
		2	.13	1.77	.01	*.05	.8	.028	.02	.026	.076	.03	.19	.0097	.10	.003	<.001	.02	.02
		3	.25	1.43	.02	*.09	.5	.027	.02	.023	.10	.03	.24	.012	.14	.003	<.001	.01	.02
		4	.26	3.14	.005	*.03	.6	.035	.02	.01	.038	.03	.07	.007	.052	<.0005	.004	.009	.005
		5	.20	5.65	.005	*.07	1.2	.029	.028	.0072	.042	.02	<.01	.007	.027	<.0005	<.001	.009	<.003
		6	.26	3.12	.006	*.05	.5	.059	.03	.024	.16	.04	.25	.0097	.086	.001	<.001	.01	<.003
8	OK-MN-BA	1	.11	2.76	.01	*.07	.5	.12	.04	.039	.16	.017	.41	.016	.14	.02	<.001	.02	<.003
		2	.18	2.40	.007	*.07	.5	.02	.02	.039	.16	.016	.20	.014	.14	.02	<.001	.01	.01
		3	.13	4.16	.004	*.03	.4	.025	.01	.02	.038	.017	.05	.005	.046	.007	<.001	.01	<.003
		4	.23	3.56	.004	*.05	.7	.026	.02	.02	.038	.024	.06	.005	.049	.007	<.001	.01	.009
		5	.30	3.88	.007	*.3	2.0	.032	.037	.019	.046	.019	<.01	.0072	.038	.002	<.001	.009	<.003
		6	.22	3.21	.003	*.02	.6	.022	.01	.01	.03	.02	.03	.005	.036	.002	<.001	.008	.005
		7	.10	2.28	.008	*.05	.6	.03	.02	.04	.13	.05	.08	.01	.18	.005	<.001	.009	.003
		8	.12	3.23	.01	*.09	.6	.059	.03	.039	.10	.04	.08	.006	.12	.01	.02	.01	.009
9	OK-BH-H	1	.42	4.06	.008	*.02	.3	.053	.035	.042	.08	.032	.07	.0096	.09	.08	<.001	.01	<.003
		2	.75	3.28	.003	*.03	.4	.02	.02	.01	.022	.016	.07	.0066	.049	.004	<.001	.01	<.003
		3	.33	3.60	.004	*.2	1.4	.032	.032	.006	.023	.0092	<.01	.0055	.023	.001	<.001	.009	.008
		4	.63	1.72	.006	*.3	1.2	.029	.033	.006	.018	.011	.09	.0065	.033	.003	<.001	.02	.009
		5	.50	.99	.01	*.8	.84	.034	.046	.0075	.031	.04	.16	.011	.14	.004	.005	.02	.01
		6	.50	2.42	.01	*.2	.50	.086	.054	.0075	.052	.05	.05	.012	.097	.007	<.001	.02	.01
10	OK-LC-Se	1	.36	9.70	.003	.032	.2	.01	.042	.001	.006	.012	<.02	.001	.001	.014	<.001	<.001	<.003
		2-4	1.14	3.36	.0025	.058	1.2	.066	.035	.0026	.022	.03	<.04	.003	<.002	.014	.01	.026	.028
		5-6	.80	2.98	.0046	*.05	.66	.09	.032	.0024	.0081	*.01	<.04	.0038	.007	.0054	<.002	.036	.027
11	OK-L-JC	1	.20	5.87	.0006	.03	.52	.024	.011	.0048	.056	.03	.10	.0016	<.002	.009	.016	.0018	.009
		2	.27	3.58	.0002	*.03	.4	.02	.01	.002	.02	*.02	.02	.001	<.001	.01	<.001	.004	<.003
		3-4	.37	3.02	.0006	*.05	.75	.04	.02	.0018	.014	*.05	<.04	.0027	<.002	.02	.006	.009	.01
		5	.30	2.18	.0005	*.2	.4	.02	.01	.002	.02	*.02	<.03	.001	<.002	.01	<.001	.007	<.003
		6-8	.99	2.07	.0014	*.2	1.2	.066	.037	.0025	.0098	.03	<.04	.0039	.002	.017	<.002	.027	.024
		9	.19	6.56	.005	*.07	.5	.03	.03	.008	.02	*.02	<.02	.003	.007	.004	<.001	.03	.01
12	OK-PC-Ca	1	.34	4.70	.0008	.022	.39	.10	.024	.0014	.012	.016	<.04	.0014	<.002	.022	<.002	.014	.007
		2-3	1.36	3.16	.0003	*.03	.22	.013	.013	.0028	.0035	.0049	<.04	.0008	<.002	.0045	.008	.007	.008
		4	.50	4.70	.009	*.02	.17	.072	.023	.0068	.016	*.02	.05	.0008	.002	.014	.005	.015	.005
13	OK-SS-St	1-2	.32	2.13	.0004	.008	.66	.056	.03	.017	.022	*.02	<.04	.0063	.002	.013	.006	.008	.011
		3-4	.98	1.28	.0022	.022	1.3	.048	.038	.068	.08	.066	.05	.0052	.002	.013	.006	.036	.011
	OK-SS-Str	1	.46	15.73	.0006	.014	.68	.028	.018	.0010	.005	*.01	<.06	.0023	<.003	.0027	<.002	.008	.02
14	OK-Ga-St	1-2	.55	2.74	.0007	.015	.32	.06	.022	.0046	.022	*.008	.05	.0024	<.002	.027	.004	.008	<.007

		3	.65	5.06	.0003	.007	.1	.008	.002	.003	.007	.005	<.02	.001	<.001	.004	<.001	.005	<.003
		4	.30	4.86	.002	.0082	.2	.055	.028	.0068	.020	.03	.02	.0038	<.001	.028	<.001	.02	.02
		5	.20	3.25	.0011	.02	1.8	.37	.094	.0046	.1	.07	.06	.011	<.002	.046	.004	.07	.028
15	OK-Ca-St	1	.16	11.98	.0001	.001	.2	.007	.004	.004	.02	.004	<.02	.001	<.001	.006	<.001	.005	<.003
		2	1.06	1.69	.0006	.018	.47	.025	.019	.014	.03	*.02	.09	.0015	<.002	.018	.022	.009	.01
		3	.38	3.12	.004	.024	.3	.025	.045	.038	.078	.08	.18	.0072	<.001	.022	<.001	.02	.01
16	OK-Sa-Mc	1-2	.89	3.91	.0003	*.09	.42	.048	.018	.0015	.0054	*.009	<.04	.003	<.002	.0087	.005	.005	.008
		3-5	1.16	3.16	.0004	*.2	.56	.036	.014	.001	.0056	*.01	.06	.0022	.002	.0075	.009	.008	.008
		6-7	.58	2.22	.0004	*.6	.51	.023	.013	.002	.0056	*.01	.08	.0016	.003	.009	.014	.008	.008
		8	.44	5.90	<.0001	*.2	.06	.007	.002	.0008	.002	.006	<.02	.0008	<.001	.004	<.001	.002	<.003
		9	.57	2.23	.001	*.3	.24	.022	.02	.0018	.01	.02	.08	.0015	.022	.06	.02	.013	.007
17	OK-Du-Mc	1	.28	3.40	.002	*.2	.4	.02	.03	.02	.006	.005	.02	.003	.004	.01	.01	.02	.003
		2-3	.95	3.25	.0004	*.2	.45	.036	.02	.0017	.0087	*.01	.09	.0026	<.002	.014	.014	.008	.009
		4	.15	3.90	.0002	*.2	.32	.018	.026	.0033	.0082	.009	<.02	.0044	<.001	.014	.01	.009	<.003
		5-9	1.35	3.73	.0003	*.1	.37	.026	.017	.0014	.0068	*.01	.08	.0017	<.002	.005	.014	.008	.008
		10	.34	3.50	.0002	*.3	.23	.014	.023	.002	.008	.01	.02	.0032	<.001	.004	.02	.01	<.003
		11	.19	5.80	.002	*.2	.32	.038	.032	.0041	.012	.01	.02	.0062	.02	.005	.01	.02	.009
18	OK-LS-Mc	1-2	.77	2.95	.0008	*.04	.46	.08	.036	.012	.034	*.02	.10	.0075	.003	.024	.007	.01	.009
		3-5	1.83	1.36	.0003	*.05	.40	.042	.026	.019	.057	*.02	.06	.0038	.003	.017	.006	.008	.01
		6	.50	4.94	.0003	*.02	.04	.005	.008	.01	.02	*.02	.05	.001	<.002	.006	<.001	.004	<.003
19	OK-MA-Mc	1	.45	6.71	.0004	*.1	.63	.07	.041	.0038	.012	.012	.05	.0054	.005	.0048	.003	.005	.009
		2-6	2.51	1.72	.0005	*.2	.57	.042	.02	.0034	.014	*.02	.07	.0027	.003	.0075	.012	.011	.011
		7	.32	3.96	.0022	*.05	.16	.093	.048	.0052	.048	*.02	<.04	.0012	.007	.012	.004	.03	.008
20	OK-K-UH	1-3	.97	4.04	.0005	*.2	.20	.009	.027	.016	.047	.01	<.05	.0009	<.003	.0007	.002	.005	<.007
		4-9	1.78	4.53	.0002	.092	.11	.0036	.015	.012	.020	.02	<.05	.0005	<.003	.0003	.003	.003	.007
		10-11	.54	2.73	.0006	*.1	.28	.033	.064	.018	.026	.04	.07	.0020	<.003	.0056	<.002	.009	.011
		12	.40	5.02	.003	*.07	.2	.03	.037	.043	.088	.027	<.02	.0062	.002	.004	.005	.02	<.003
	OK-K-LH	1-2	.51	2.69	.0003	*.09	.39	.028	.021	.0045	.025	*.03	<.04	.0016	.003	<.0008	.009	.007	.005
		3-5	.94	4.60	.0003	*.06	.52	.04	.02	.0024	.0066	*.01	<.04	.004	.002	.0008	.004	.007	.01
		6-7	.63	18.85	.0004	.036	.57	.046	.032	.0030	.015	.03	<.05	.0039	<.001	.0009	<.002	.009	.016
21	OK-LS-LH	1	.70	2.39	.0005	.03	.40	.093	.036	.01	.02	*.02	.11	.0042	.002	.0096	.006	.012	.016
		2	.73	4.40	.0001	.03	.2	.008	.004	.009	.01	*.02	.02	.001	<.002	.002	<.002	.003	<.003
		3-4	1.36	1.48	.0008	.046	2.1	.051	.047	.015	.02	*.03	<.04	.006	<.002	.069	.004	.015	.022
		5	.48	2.96	.0028	.017	1.1	.22	.10	.0052	.02	*.04	.06	.011	.003	.0033	.006	.051	.02
	OK-LS-UH	1	.25	3.58	.0024	.018	.90	.092	.052	.013	.040	.012	.05	.0057	<.002	.0076	.004	.023	.006
		2	.41	7.60	.0002	.01	.09	.003	.002	.001	.003	.003	<.01	.0007	.001	<.0005	<.001	<.001	<.003
		3-4	1.50	1.27	.0008	*.03	.40	.093	.036	.01	.026	*.03	.05	.0033	.009	.0056	.005	.022	.022
22	OK-EC_2-LH	1	.66	3.59	.0022	.022	2.2	.14	.10	.017	.04	.08	.05	.01	.003	.0027	.006	.096	.017
	OK-EC_1-UH	1-2	.71	2.04	.0007	*.02	.40	.034	.025	.0047	.011	*.01	.07	.0022	.004	.0012	.012	.01	.006
		3-4	.89	1.33	.0006	.015	.34	.075	.038	.0086	.0099	*.03	.07	.003	.007	.0069	.011	.016	.02

See footnotes at end of table.

TABLE 4.—*Spectrochemical analyses of 15 minor elements in the ash of block coal samples from the Western region*—Continued

Locality (fig. 2)	Coal column	Coal block sample No.	Thickness (feet)	Ash	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
	OK-EC$_2$-UH	1–2	0.63	1.86	0.0005	*0.02	0.34	0.044	0.023	0.0039	0.0052	*0.01	0.06	0.0026	0.004	0.0016	0.008	0.008	0.007
		3–4	.66	1.87	.0004	.017	.32	.050	.027	.0052	.0066	*.02	.05	.0023	.003	.0055	.015	.014	.023
23	OK-Da-UH	1–2	1.07	3.31	.0008	.011	.78	.048	.02	.011	.027	*.01	<.04	.0034	<.002	.0016	<.002	.011	.01
		3–5	1.12	2.46	.001	.022	.85	.046	.026	.015	.052	*.02	<.04	.0038	<.002	.0054	.006	.009	.01
		6	.32	4.56	.0006	.01	.1	.0085	.004	.039	.02	.02	.03	.0009	<.001	.002	<.001	.006	<.003
		7–8	.82	2.66	.0025	.029	.58	.092	.035	.0081	.033	.04	<.04	.0024	<.002	.01	.015	.034	.01
24	Ark-NS-P	1	.45	12.41	.0004	.013	.32	.066	.020	.0063	.018	.02	.07	.0028	<.003	.009	<.002	.006	.01
		2–3	1.25	3.61	.0002	.039	.27	.014	.016	.0064	.0058	.03	<.05	.0021	<.003	.0043	.01	.008	.011
		4	.55	6.20	.0007	.007	.2	.02	.02	.008	.02	*.02	<.01	.001	<.001	.003	<.001	.01	<.003
25	Ark-Ha$_{10}$-Ch	1	.33	12.72	.0007	.004	.15	.021	.0069	.0069	.015	*.02	<.06	.0028	.004	.0035	<.002	.014	.016
		2	.15	10.05	.0007	.010	.16	.015	.0069	.0072	.0075	*.02	<.06	.0020	.003	<.002	.0078	.009	.007
	Ark-Ha$_{11}$-Ch	1–2	.65	3.22	.003	.028	.50	.064	.040	.048	.056	*.02	<.06	.0048	<.003	.0053	<.002	.053	.12
		3–4	.82	4.15	.0004	.028	.64	.019	.019	.028	.037	*.02	<.06	.0034	<.003	.0030	<.002	.008	.012
26	Ark-Ha$_{15}$-Ch	1	1.17	4.26	.0003	.005	.12	.0062	.0038	.0059	.012	.01	.22	.0007	<.003	.0044	<.002	.004	<.007
		2	.08	12.64	.0002	.005	.6	.07	.034	.005	.032	.007	<.01	.0055	<.001	.001	<.001	.01	.04
		3	.08	19.42	.0002	.007	.5	.04	.03	.006	.04	.009	<.01	.005	<.001	.008	<.001	.01	.02
27	Ark-Sk-Ch	1	.33	5.12	.0007	.01	.4	.03	.02	.01	.02	.008	<.01	.002	<.001	.003	<.001	.01	.03
		2	.79	4.49	.002	.02	.5	.031	.031	.045	.055	*.02	.1	.0045	<.001	.0065	<.001	.035	.04
28	Ark-QE-UH	1	.53	4.93	.0004	.015	.34	.015	.021	.0026	.012	*.01	<.06	.0021	<.003	.0056	.009	.009	.008
		2–4	1.45	7.10	<.0002	.028	.37	.014	.015	.0028	.012	*.01	<.06	.0018	<.003	.0027	<.002	.003	.009
		5	.48	7.22	<.0002	.027	.21	.0092	.011	.0014	.0075	*.01	<.06	.0015	<.003	.0020	<.002	.003	<.007
29	Ark-Ba-LH	1–4	.93	16.60	.0004	.014	.66	.028	.023	.0014	.011	*.01	<.06	.0030	<.003	.0026	<.002	.01	.012
		5–6	1.11	7.71	.0005	.020	.50	.016	.016	.0022	.0093	*.01	<.06	.0028	<.003	.0016	<.002	.008	.012
		7	.15																
		8–9a	1.11	12.20	.0005	.020	.48	.035	.024	.0023	.013	*.01	<.06	.0038	<.003	.0028	<.002	.008	.009
		9c–12	1.10	6.47	.0009	.016	.37	.054	.042	.0058	.037	*.01	.10	.004	<.003	.0033	<.002	.016	.008
		12a–13	.44																
		14–19	1.58	4.47	.0005	.016	.28	.014	.014	.0072	.019	*.007	<.06	.0017	<.003	.0014	<.002	.005	.012
		20–26	1.37	3.36	.0004	.032	.52	.023	.021	.0092	.040	*.03	.14	.0033	<.003	.0015	.002	.006	.016
		27	.37	4.16	.0023	.026	.60	.050	.031	.013	.062	*.04	.15	.0038	<.003	.0033	.002	.039	.021
		27a	------	5.30	.0003	.01	.50	.02	.02	.001	.008	.007	<.02	.004	<.002	.001	<.001	.006	.01
30	Ark-Hu-LH	1–2	1.10	6.63	.001	.022	.49	.033	.022	.0054	.066	*.02	.16	.0032	<.003	.0009	<.002	.02	.018
		3	.40	4.22	.0003	.07	.65	.016	.02	.0088	.065	.01	.14	.0041	<.001	.001	<.001	.005	.009
		4–5	.36	5.69	.0003	.027	.39	.024	.018	.0033	.017	*.01	.08	.0025	<.003	.0016	<.002	.009	.016

		6	.27	4.20	.0003	.05	.6	.02	.02	.006	.03	.009	.06	.003	<.001	.002	<.001	.006	.009
		7	.47	2.74	.0001	.04	.1	.004	.01	.003	.01	.008	.05	.001	<.001	.001	<.001	.002	<.003
		8	.20	3.29	.0002	.04	.3	.02	.02	.006	.02	*.007	.05	.002	<.001	.003	<.001	.004	.009
		9	.33	2.70	.0002	.04	.5	.02	.02	.01	.03	*.01	.07	.002	<.001	.005	<.001	.01	.009
		10-14	.65	12.81	.0004	.016	.51	.058	.043	.0018	.0093	*.03	.05	.0046	<.003	.0022	<.002	.010	.016
		15	.35	7.88	.0006	.028	.27	.041	.028	.003	.022	*.02	.05	.003	<.003	.0045	<.002	.011	.017
		16	.32	3.30	.0005	.02	.35	.029	.026	.014	.072	.02	.12	.0041	<.001	.005	<.001	.015	.02
		17	.36	3.08	.002	.03	.46	.029	.025	.020	.055	.02	.05	.0036	<.001	.0052	<.001	.016	.03
		18	.38	3.39	.0003	.02	.5	.026	.03	.003	.02	*.02	.04	.002	<.001	.005	<.001	.012	.01
		19-20	.48	10.09	.0007	.028	.30	.056	.044	.0021	.0084	.04	.05	.0044	<.003	.0063	<.002	.010	.012
31....	Ark-Ha_{16}-LH.	1	.44	3.64	.0004	.038	.44	.033	.031	.0092	.031	*.03	<.06	.0027	<.003	.0078	<.002	.004	.007
		2	.79	3.29	.0007	.046	.42	.023	.023	.015	.053	*.04	.22	.0026	<.003	.018	<.002	.009	.012
32.....	Ark-OZ-LH..	1	1.25	12.23	.0037	.005	.24	.010	.013	.0030	.028	*.03	<.05	.0009	<.003	.0004	<.002	.016	.020
33....	Ark-ACM-LH.	1	.38	6.26	.0010	.080	.92	.028	.022	.0074	.022	.03	<.05	.0033	<.003	.0023	<.002	.009	.019
		2	.20	4.03	.0005	.03	.6	.02	.02	.02	.02	.008	<.01	.003	<.001	.003	<.001	.008	.01
		3	.42	2.70	.0003	.076	.62	.013	.018	.027	.046	.03	<.05	.0022	<.003	.0027	<.002	.006	.01
		4	.33	2.41	.0003	.009	.2	.006	.01	.03	.02	*.02	<.01	.001	<.001	.002	<.001	.009	.01
		5	.30	3.90	.002	.01	.34	.029	.024	.028	.022	*.02	<.01	.0055	<.001	.0043	<.001	.033	.04
	Ark-ACM-LHR.	1	.30	4.33	.0012	.035	.46	.017	.014	.0028	.0051	.01	<.05	.0027	<.003	.0016	.006	.007	<.007
		2	.25	5.93	.0002	.04	.3	.02	.03	.006	.008	.009	<.01	.002	<.001	.002	<.001	.006	<.003
		3	.53	6.55	.0006	.011	.16	.010	.0069	.0057	.012	.07	<.05	.0028	<.003	.0028	.003	.007	<.007
34....	Ark-PV-LH..	1-2	.55	16.67	.0084	.010	.78	.018	.016	.006	.031	.03	<.05	.0022	<.003	.0012	<.002	.035	.040
		3-6	1.01	12.44	.0009	.058	.80	.022	.020	.010	.044	.02	<.05	.0032	<.003	.0022	<.002	.010	.020
		7-11	.91	8.11	.0004	.020	.46	.014	.016	.024	.050	.02	<.05	.0016	<.003	.0017	<.002	.004	.010
		12	.21	5.84	.0007	.016	.2	.008	.01	.031	.045	.02	<.01	.0037	<.001	.002	<.001	.004	<.003
		13-14	.63	7.87	.0027	.022	.38	.0082	.012	.018	.062	.03	<.05	.0008	<.003	.0010	<.002	.005	<.007
35...	Ark-EJ-LH..	1-2	.88	12.19	.0045	.009	.29	.019	.025	.0032	.018	*.02	<.05	.0010	<.003	.0006	.002	.022	.03
36....	Ark-Ru-LH..	1-2	1.35	50.34	.0033	.029	.56	.035	.019	.0078	.046	.02	<.05	.0039	<.003	.0013	<.002	.012	.021
		3	.82	26.28	.0033	.025	.52	.027	.020	.018	.096	.02	<.05	.0032	<.003	.0015	<.002	.004	.019
		4	.58	43.38	.0006	.026	.78	.027	.018	.012	.067	.02	<.05	.0040	<.003	.0008	<.002	.005	.013
37....	Ark-Dr_1-At...	1	.67	24.50	.0051	.008	.48	.018	.017	.0029	.028	*.03	<.05	.0022	<.003	.0008	<.002	.038	.022
	Ark-Dr_2-At...	1	.67	47.30	.0045	.009	.60	.02	.026	.0013	.0058	*.02	<.05	.0030	<.003	.0013	<.002	.062	.044
38....	Ark-M-UE...	1	.30	12.77	.008	.043	2.9	.027	.02	.005	.013	.016	<.01	.007	.002	<.0005	<.001	.10	.14
		2-5	1.25	10.53	.0058	.055	2.3	.016	.011	.0052	.013	*.02	<.06	.0045	.004	.001	<.002	.037	.069
		6-7	.47	19.60	.0040	.050	2.6	.034	.016	.0026	.0068	*.02	<.06	.0066	<.003	.0007	.002	.011	.027
	Ark-M-LE...	1	-------	7.18	.008	.1	2.3	.054	.032	.01	.032	.02	.29	.02	.047	.001	<.001	.02	.02
		2	-------	16.28	.0039	.054	1.2	.082	.036	.0048	.021	*.01	<.06	.0058	.003	.0008	<.002	.012	.024
		3	-------	7.45	.008	.1	1.4	.062	.032	.009	.027	.02	.031	.03	.05	.001	<.001	.02	.02
		4-5	-------	30.16	.0008	.028	2.6	.019	.016	.002	.0032	*.01	<.06	.01	.034	.0009	.002	.010	.022

See footnotes at end of table.

TABLE 4.—*Spectrochemical analyses of 15 minor elements in the ash of block coal samples from the Western region*—Continued

Locality (fig. 2)	Coal column	Coal block sample No.	Thickness (feet)	Ash	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
	Ark-M-LE [1]	1	-------	2.75	0.004	0.14	1.6	0.82	0.28	0.02	0.038	0.072	1.2	0.16	2.0	0.009	0.008	0.02	0.01
		3	-------	4.50	.005	.12	1.1	.50	.22	.058	.064	.024	<.01	.09	.8	.004	.02	.02	.01
39 [2]	Tex-Mc-UE	1-6	2.35	9.66	.0002	*.2	1.0	.021	.0094	.0019	.0052	*.02	<.06	.0045	<.003	.0011	<.002	.006	<.007
		7-15	3.81	8.36	<.0002	*.2	.90	.018	.0075	.0010	.0038	*.01	<.06	.0022	<.003	.0009	<.002	.004	<.007
		16-19	1.21	14.63	.0005	.15	1.0	.021	.012	.0016	.0048	*.03	<.06	.0042	<.003	.0010	<.002	.011	<.007
	Tex-Mc-LE	1	.13	8.93	.0007	*.1	.6	.02	.01	.002	.008	.01	<.01	.003	<.001	.001	<.001	.01	<.003
		2-5	1.02	5.96	.0004	*.3	.70	.018	.0083	.0019	.0098	*.02	<.06	.0027	<.003	.0013	<.002	.011	.007
		6-11	2.24	7.18	<.0002	*.2	.93	.017	.0075	.0013	.0056	*.02	<.06	.0032	<.003	.0012	<.002	.004	<.007
		12-15	1.06	15.21	.0007	.12	.75	.010	.0063	.0018	.0050	*.01	<.06	.0030	<.003	.0004	<.002	.005	<.007

[1] Sample of coalified wood above bed.
[2] South of area shown in figure 2.

TABLE 5.—*Average minor-element content of the ash of columnar samples from the Western and Southwestern regions*

[All figures are percent by weight. Averages calculated by using zero for element contents below limit of detection, except that averages in parentheses were calculated by using one-half the detection limit of each element not detected. Location and description of samples given in table 1]

Locality (fig. 2)	Coal column	Ash	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
1	Ia-P-M	12.32	0.0017	0.15	0.19	0.011	0.0097	0.01	0.055	0.033	0.24	0.0049	0.019	0.0004 (.0006)	0 (.0005)	0.0084	0.0007 (.002)
2	Ia-L-K	10.10	.005	.23	.23	.015	.016	.0053	.011	.008	.034 (.037)	.0043 (.0044)	.051	0 (.0003)	0 (.0005)	.012	.013 (.014)
3	Mo-BN-B	8.01	.0063	.13	.36	.023	.013	.0061	.018	.013	.023 (.024)	.0054	.012	.036	.0003 (.0005)	.026	.0044 (.0054)
	Mo-BS-B	5.41	.0052	.19	.37	.024	.025	.0057	.023	.024	.01 (.013)	.008	.05	.0068	.0003 (.0006)	.015	.0006 (.0018)
	Mo-B-Mu	7.09	.0067	.20	.53	.067	.055	.0086	.028	.030	.019 (.021)	.0048	.022	.020	.0002 (.0005)	.023	0 (.0015)
4	Mo-P-T	16.72	.0003	.037	.16	.023	.014	.0017	.023	.007	1.3	.0027 (.0028)	.0076	.0075	0 (.0005)	.0062	0 (.0005)
5	Mo-T-M	13.50	.0019	.022	.38	.023	.027	.0059	.016	.017	.58	.0054	.027	.0029	0 (.0005)	.014	.0064 (.0068)
6	OK-Pa-Fo	4	.0087	.069	.34	.038	.031	.0035	.011	.035	.07	.014	.07	.016	.0026 (.003)	.012	0 (.0015)

	OK-Pa-BA	3.70	.0033	.045	.52	.04	.018	.02	.12	.024	.007 (.011)	.0091	.09	0 (.0003)	0 (.0005)	.01	.0007 (.0019)
7	OK-RC-BA	2.70	.011	.057	.63	.035	.021	.022	.092	.030	.17	.011	.10	.0014 (.0015)	.0008 (.0012)	.011	.0066 (.0074)
8	OK-MN-BA	3.29	.0061	.10	.88	.036	.024	.025	.076	.023	.090 (.091)	.0079	.079	.0079	.0017 (.0022)	.010	.0046 (.0051)
9	OK-BH-H	2.60	.0066	.25	.74	.040	.035	.012	.035	.026	.077 (.078)	.0084	.071	.014	.0008 (.0012)	.015	.0058 (.0064)
10	OK-LC-Se	4.23	.0033	.051	.86	.066	.035	.0023	.015	.020	0 (.019)	.003	.0026 (.0031)	.011	.005 (.0054)	.025 (.026)	.023
11	OK-L-JC	3.15	.0012	.13	.81	.044	.025	.0029	.018	.03	.011 (.025)	.0029	.0015 (.0019)	.014	.0011 (.0018)	.017	.013 (.014)
12	OK-PC-Ca	3.75	.0005	.026	.24	.040	.017	.0035	.0077	.010	.036 (.039)	.0009	.0017 (.0018)	.0094	.006 (.0062)	.01	.0072
13	OK-SS-St	1.49	.0018	.019	1.1	.050	.036	.055	.066	.055	.038	.0054	.002	.013	.006	.029	.011
	OK-SS-StR	15.73	.0006	.014	.68	.028	.018	.010	.005	.01	0 (.03)	.0023	0 (.0015)	.0027	0 (.001)	.008	.02
14	OK-Ga-St	4.06	.0008	.011	.39	.076	.024	.0044	.025	.018	.027 (.031)	.0031	0 (.0007)	.021	.0018 (.0021)	.016	.0091 (.0097)
15	OK-Ca-St	3.06	.0014	.018	.43	.023	.024	.019	.040	.033	.10	.0028	0 (.0008)	.018	.015	.011	.0090 (.0092)
16	OK-Sa-Mc	3.38	.0004	.25	.41	.031	.014	.0014	.0058	.011	.044 (.051)	.002	.0046 (.0049)	.016	.0095	.0073	.0069 (.0071)
17	OK-Du-Mc	3.66	.0006	.17	.38	.027	.021	.0034	.0078	.0095	.064 (.065)	.0026	.0015 (.0023)	.0084	.014	.010	.0067 (.0069)
18	OK-LS-Mc	2.32	.0004	.043	.36	.045	.026	.016	.045	.020	.068	.0043	.0025 (.0026)	.017	.0054	.0079	.0081 (.0084)
19	OK-MA-Mc	2.62	.0007	.17	.54	.051	.026	.0036	.017	.019	.060 (.062)	.0029	.0037	.0076	.010	.012	.010
20	OK-K-LH	8.45	.0003	.060	.50	.039	.024	.0031	.014	.021	0 (.022)	.0034	.0016 (.0018)	.0006 (.0007)	.0040 (.0043)	.0076	.011
	OK-K-UH	4.19	.0006	.12	.17	.012	.028	.017	.035	.021	.01 (.03)	.0014	.0002 (.0015)	.0055	.0025 (.0027)	.0062	.0016 (.0044)
21	OK-LS-LH	2.54	.0009	.035	1.2	.075	.043	.011	.018	.027	.037 (.045)	.0052	.0009 (.0015)	.032	.0038 (.0041)	.017	.016
	OK-LS-UH	2.70	.0009	.025	.40	.076	.031	.0086	.023	.023	.041	.0031	.0032	.0048	.0039 (.0040)	.018	.016
22	OK-EC$_2$-LH	3.59	.0022	.022	2.2	.14	.10	.017	.04	.08	.05	.01	.003	.0027	.006	.096	.017
	OK-EC$_1$-UH	1.64	.0007	.017	.37	.057	.032	.0069	.010	.021	.070	.0026	.0057	.0044	.011	.013	.014
	OK-EC$_2$-UH	1.87	.0005	.018	.33	.047	.025	.0046	.0059	.015	.055	.0024	.0035	.0036	.012	.011	.015
23	OK-Da-UH	2.98	.0013	.019	.69	.054	.024	.014	.036	.022	.0029 (.021)	.003	0 (.001)	.005	.0057 (.0061)	.015	.0090 (.0092)
24	Ark-NS-P	6	.0004	.026	.26	.026	.018	.0068	.012	.026	.014 (.029)	.002	0 (.0013)	.0049	.0056 (.0059)	.0081	.0081 (.0085)
25	Ark-Ha$_{10}$-Ch	11.89	.0007	.0059	.15	.019	.0069	.007	.013	.02	0 (.03)	.0025	.0037	.0024 (.0027)	.0024 (.0031)	.012	.013
	Ark-Ha$_{11}$-Ch	3.74	.0015	.028	.58	.039	.028	.037	.045	.02	0 (.03)	.004	0 (.0015)	.004	0 (.001)	.028	.06

See footnote at end of table.

TABLE 5.—*Average minor-element content of the ash of columnar samples from the Western and Southwestern regions*—Continued

Locality (fig. 2)	Coal column	Ash	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
26	Ark-Ha$_{15}$-Ch	5.67	0.0003	0.0051	0.17	0.012	0.0072	0.0058	0.015	0.0098	0.19	0.0012	0 (.0014)	0.0044	0 (.001)	0.0047	0.0036 (.0067)
27	Ark-SK-Ch	4.67	.0016	.017	.47	.03	.028	.035	.045	.016	.07 (.072)	.0038	0 (.0005)	.0055	0 (.0005)	.028	.037
28	Ark-QE-UH	6.64	.0001 (.0002)	.025	.33	.013	.015	.0025	.011	.01	.013 (.036)	.0018	.0006 (.0018)	.0032	.0019 (.0027)	.0043	.007 (.0077)
29	Ark-Ba-LH	7.65	.0006	.02	.46	.028	.023	.0055	.024	.014	.047 (.066)	.0031	0 (.0015)	.0022	.0007 (.0013)	.01	.012
30	Ark-Hu-LH	6.07	.0006	.031	.43	.031	.026	.006	.035	.019	.085	.0032	0 (.001)	.0029	0 (.0008)	.011	.014
31	Ark-Ha$_{16}$-LH	3.42	.0006	.043	.43	.027	.026	.013	.045	.036	.14 (.15)	.0026	0 (.0015)	.014	0 (.001)	.0072	.01
32	Ark-OZ-LH	12.23	.0037	.005	.24	.010	.013	.003	.028	.03	0 (.025)	.0009	0 (.0015)	.0004	0 (.001)	.016	.02
33	Ark-ACM-LH	3.95	.0008	.046	.55	.019	.019	.022	.028	.023	0 (.015)	.0029	0 (.001)	.0028	0 (.0008)	.013	.018
	Ark-ACM-LHR	5.79	.0007	.024	.28	.014	.014	.005	.0092	.039	0 (.02)	.0016	0 (.0013)	.0023	.0031 (.0033)	.0068	0 (.0031)
34	Ark-PV-LH	10.51	.0024	.028	.57	.015	.016	.017	.047	.024	0 (.024)	.0021	0 (.0007)	.0016	0 (.0009)	.011	.016
35	Ark-EJ-LH	12.19	.0045	.009	.29	.019	.025	.0032	.018	.02	0 (.025)	.001	0 (.0015)	.0006	.002	.022	.03
36	Ark-Ru-LH	41.70	.0027	.027	.59	.031	.019	.012	.065	.02	0 (.025)	.0037	0 (.0015)	.0013	0 (.001)	.0081	.019
37	Ark-Dr$_1$-At	24.50	.0051	.008	.48	.018	.017	.0029	.028	.03	0 (.025)	.0022	0 (.0015)	.008	0 (.001)	.038	.022
	Ark-Dr$_2$-At	47.30	.0045	.009	.6	.02	.026	.0013	.0058	.02	0 (.025)	.003	0 (.0015)	.0013	0 (.001)	.062	.044
38	Ark-M-UE	12.99	.0057	.052	2.5	.022	.014	.0046	.012	.019	0 (.027)	.0054	.0028 (.0032)	.0008	.0005 (.0012)	.04	.07
	Ark-M-LE	15.27	.0052	.071	1.9	.054	.029	.006	.021	.015	.08 (.095)	.016	.034	.0009	.0005 (.001)	.016	.022
39[1]	Tex-Mc-UE	9.80	.0002	.19	.95	.019	.0088	.0014	.0044	.016	0 (.03)	.0033	0 (.0015)	.001	0 (.001)	.0058	0 (.0035)
	Tex-Mc-LE	8.86	.0003 (.0004)	.2	.82	.016	.0075	.0016	.0065	.017	0 (.029)	.003	0 (.0015)	.001	0 (.001)	.006	.0016 (.0035)

[1] South of area shown in figure 2.

TABLE 6.—*Average minor-element content of the coal of the columnar samples*

[All averages in parts per million. Averages calculated by using zero for element contents below limit of detection; averages in parentheses were calculated by using one-half of the detection limit of each element not detected. Location and description of samples given in table 1]

Locality (fig. 2)	Coal column	Ash (percent)	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
1	Ia-P-M	12.32	1.9	150	220	13	12	14	66	34	290 (300)	2.9	22	0.51 (.74)	0 (.52)	10	1.1 (2.6)
2	Ia-L-K	10.10	4.3	220	220	15	14	5	11	7.6	36 (39)	4.3 (4.4)	48	0 (.26)	0 (.5)	12	11 (12)
3	Mo-BN-B	8.01	3.1	76	290	16	9.6	3.8	14	10	13 (15)	3.9	8.2	2.2 (2.3)	.78	15	2.5 (3.3)
	Mo-BS-B	5.41	2.6	100	220	13	13	3	13	14	5.4 (6.9)	4.2	24	3.8	0 (.37)	7.7	0 (1)
	Mo-B-Mu	7.09	3.4	110	310	71	61	6.6	23	22	8.4 (10)	2.6	11	16	0 (.36)	12	0 (1.1)
4	Mo-P-T	16.72	.53	61	250	39	22	3	40	12	2,100	4.3 (4.4)	13	12	0 (.84)	10	0 (2.5)
5	Mo-T-M	13.50	1.4	25	430	27	31	4.7	16	16	1,400	6 (6.1)	23	2.5	0 (.62)	10	5.7 (6.2)
6	OK-Pa-Fo	4	3.4	26	150	16	12	1.4	4.3	13	27	5.4	25	6.2	1 (1.1)	4.9	0 (.6)
	OK-Pa-BA	3.70	1.2	17	210	16	7	6.5	42	8.8	3.2 (4.6)	3	30	0 (.09)	.11 (.24)	3.7	.32 (.78)
7	OK-RC-BA	2.70	2.2	15	200	10	6.5	4.6	23	7.9	35	2.5	20	.24 (.27)	.24 (.35)	2.7	1.4 (1.5)
8	OK-MN-BA	3.29	2	37	310	12	7.8	7.9	22	7.5	26 (27)	2.5	23	2.4	.56 (.79)	3.3	1.4 (1.6)
9	OK-BH-H	2.60	1.6	42	180	11	8.7	3.9	10	6.3	17	2.1	17	5.1	.08 (.21)	3.4	1.2 (1.4)
10	OK-LC-Se	4.23	1.4	20	300	22	16	.84	5.3	7.9	0 (8.5)	1	.88 (1)	5	1.7 (1.9)	8.1	7.5 (7.7)
11	OK-L-JC	3.15	.47	32	220	12	7.1	1.1	6.8	9	5.8 (10.3)	.82	.55 (.72)	3.8	1 (1.2)	5.2	3.6 (3.7)
12	OK-PC-Ca	3.75	.21	9.6	90	17	6.7	1.4	3.3	4.2	5.3 (11)	.25 (.3)	.21 (.48)	4	2.1 (2.2)	4	2.6
13	OK-SS-St	1.49	.22	2.5	160	7.7	5.3	6.4	8.9	7.4	4.8 (5.9)	.84	.30	1.9	.90	3.9	1.6
	OK-SS-StR	15.73	.94	22	1,100	44	28	1.6	7.9	16	0 (47)	3.6	0 (2.4)	4.2	0 (1.6)	13	31
14	OK-Gar-St	4.06	.33	4.1	140	26	8.4	1.8	8.9	7	8.5 (12)	1.2	0 (.40)	7.3	.51 (.75)	6.1	3.4 (3.7)
15	OK-Ca-St	3.06	.37	3.9	100	5.5	6.1	4.9	12	8.7	23 (26)	.82	0 (.31)	4.3	2.5 (2.6)	3.1	1.9 (2)

TABLE 6.—*Average minor-element content of the coal of the columnar samples*—Continued

Locality (fig. 2)	Coal column	Ash (percent)	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
16	OK-Sa-Mc	3.38	0.13	75	130	10	4.4	0.4	1.8	3.4	12 (15)	0.67	1.1 (1.3)	4.3	2.6	2.2	2.1 (2.2)
17	OK-Du-Mc	3.66	.22	61	140	10	7.8	1.2	2.9	3.5	20	1	.79 (1.1)	3	5	3.8	2.5 (2.6)
18	OK-LS-Mc	2.32	.11	8.5	70	9.6	5.3	3.2	8.7	4.6	16	.92	.62	3.6	1	1.7	1.5 (1.6)
19	OK-MA-Mc	2.62	.19	37	140	16	8.2	1	4.8	4.5	14 (16)	.92	1.1	1.9	2	3.1	2.6
20	OK-K-UH	4.19	.28	50	67	4.7	11	9.3	15	8.5	2.8 (12)	.62	.11 (.30)	.58	1.1 (1.2)	2.6	.44 (1.7)
	OK-K-LH	8.45	.31	39	460	36	24	5.2	12	21	0 (20)	3.2	.60 (.90)	.70 (.72)	1.4 (2)	7.1	12
21	OK-LS-UH	2.70	.19	4.8	82	12	5.5	1.6	4.2	3.5	6.3 (7.1)	.59	.57	.86	.56 (.64)	2.8 (2.9)	2.2 (2.4)
	OK-LS-LH	2.54	.21	8	220	18	9.5	2.5	4.1	6.6	10 (11)	1.2	.23 (.35)	5.1	.81 (.86)	4	2.6 (2.8)
22	OK-EC$_2$-LH	3.59	.79	7.9	790	50	36	6.1	14	29	18	3.6	1.1	.97	2.2	35	6.1
	OK-EC$_1$-UH	1.64	.11	2.9	61	8.6	5.1	1.1	1.7	3.1	12	.42	.88	.60	1.9	2.1	2
	OK-EC$_2$-UH	1.87	.08	3.5	61	8.8	4.7	.85	1.1	2.9	10	.45	.65	.67	2.2	2.1	2.8
23	OK-Da-UH	2.98	.36	5.3	200	15	6.7	5.7	10	6.2	5.6 (8.5)	.84	0 (.30)	1.4	1.4 (1.6)	4.4	2.6
24	Ark-NS-P	6	.24	12	160	22	11	4.1	8.7	14	17 (23)	1.3	0 (.75)	3.6	2 (2.4)	4.6	4.7 (4.9)
25	Ark-Ha$_{10}$-Ch	11.89	.83	6.7	180	23	8.2	8.3	16	24	0 (36)	3.1	4.5	3.1 (3.4)	2.5 (3.3)	15	16
	Ark-Ha$_{11}$-Ch	3.74	.52	10	220	14	10	13	17	7.5	0 (11)	1.5	0 (.57)	1.5	0 (.37)	9.4	20
26	Ark-Ha$_{15}$-Ch	5.67	.15	3.1	150	12	7.5	3.3	12	5.4	83 (84)	1.3	0 (67)	2.7	0 (.48)	3.4	5.4 (6.7)
27	Ark-Sk-Ch	4.67	.74	7.8	220	14	13	16	20	7.5	32	1.7	0 (.24)	2.5	0 (.24)	13	17
28	Ark-QE-UH	6.64	.04 (.10)	17	220	8.7	10	1.7	7.4	6.7	0 (20)	1.2	0 (1)	2	1 (1.5)	2.6	4.6 (5.1)
29	Ark-Ba-LH	7.65	.43	14	380	23	18	3	15	9.2	21 (39)	2.4	0 (1.2)	1.8	.16 (.85)	7.5	8.7
30	Ark-Hu-LH	6.07	.38	16	260	24	18	2.8	19	14	50	2.2	0 (.75)	1.8	0 (.55)	7.2	9

31	Ark-Ha$_{16}$-LH	3.42	.20	15	150	9.2	8.9	4.4	15	12	47 (50)	.90	0 (.52)	4.8	0 (.34)	2.4	3.5
32	Ark-OZ-LH	12.23	4.5	6.1	290	12	16	3.7	34	37	0 (31)	1.1	0 (.61)	.49	0 (1.2)	20	25
33	Ark-ACM-LH	3.95	.34	20	240	8.3	7.7	7.4	10	9.3	0 (9.7)	1.2	0 (.19)	1.1	0 (.39)	4.9	7.3
	Ark-ACM-LHR	5.79	.36	13	150	8.1	8	3	5.6	25	0 (12)	.86	0 (.74)	1.4	1.7 (1.8)	3.9	9 (1.8)
34	Ark-PV-LH	10.51	3.4	30	660	17	17	15	47	26	0 (26)	2.3	0 (.55)	1.7	0 (1.1)	16	22
35	Ark-EJ-LH	12.19	5.5	11	350	23	31	3.9	22	24	0 (30)	1.2	0 (.61)	.73	2.4	27	37
36	Ark-Ru-LH	41.70	11.3	120	2,500	130	80	44	250	83	0 (104)	16	0 (2.1)	5.1	0 (4.2)	37	79
37	Ark-Dr$_1$-At	24.5	13	20	1,200	44	42	7.1	69	74	0 (61)	5.4	0 (1.2)	2	0 (2.4)	93	59
	Ark-Dr$_2$-At	47.3	22	43	2,800	95	120	6.2	27	95	0 (120)	14	0 (2.4)	6.2	0 (4.7)	290	210
38	Ark-M-UE	12.99	7.1	67	3,200	31	18	5.5	14	25	0 (34)	7.3	3 (3.7)	1	.91 (1.7)	48	84
	Ark-M-LE	15.27	5.1	80	3,100	69	38	6.9	22	19	230 (370)	19	45	1.4	2.3 (2.5)	20	34
39[1]	Tex-Mc-UE	8.86	.18 (.22)	180	940	19	9	1.4	4.4	18	0 (29)	3.3	0 (1.5)	.97	0 (.95)	6.2	0 (3.5)
	Tex-Mc-LE	9.80	.32 (.36)	160	720	13	6.4	1.4	5.4	14	0 (26)	2.7	0 (1.3)	.79	0 (.87)	5	9.6 (3.5)

[1] South of area shown in figure 2.

TABLE 7.—*Comparison of minor-element content in floated and unfloated coal*

[In parts per million]

Element	Missouri and Northern Oklahoma		Oklahoma-Arkansas basin	
	Unfloated (28 samples)	Floated (8 samples)	Unfloated (59 samples)	Floated (54 samples)
Be	2.0	2.1	0.71	0.53
B	21	58	19	26
Ti	271	392	230	240
V	18	15	14	23
Cr	16	13	12	13
Co	6.2	4.6	6.1	2.4
Ni	25	17	17	9.0
Cu	12	8.6	11	10
Zn	33.0	9.2	23	19
Ga	4.1	2.4	1.6	1.5
Ge	27	16	.73	1.1
Mo	3.6	1.0	2.6	3.4
Sn	1.2	<.43	.70	2.3
Y	4.5	6.8	6.4	6.9
La	4.5	3.0	8.6	5.7

TABLE 8.—*Comparison of the average minor-element content of coal from the Western and Eastern regions of the Interior coal province*

[In parts per million]

Element	Western region			Eastern region
	Oklahoma-Arkansas basin (32 samples)	Iowa, Missouri, North Oklahoma (12 samples)	Total Western region (44 samples)	(47 samples)
Be	0.64	2.3	1.1	2.5
B	18	73	33	96
Ti	250	250	250	450
V	17	22	18	35
Cr	12	17	13	20
Co	4.4	5.4	4.6	3.8
Ni	11	24	14	15
Cu	11	13	11	11
Zn	22	[1] 52	[1] 28	44
Ga	1.4	3.7	2.0	4.1
Ge	1.0	22	6.8	13
Mo	2.6	4.3	3.1	4.3
Sn	1.6	.6	1.3	1.5
Y	7.2	7.9	7.4	7.7
La	7.2	2.9	6.5	5.1
Ash	[2] 5.11	[2] 7.45	[2] 5.75	

[1] High zinc samples Mo–T–M (loc. 5, fig. 2) and Mo–P–T (loc. 4, fig. 2) not included in average.
[2] Ash content, in weight percent.

METHODS OF COMPUTING AVERAGE ELEMENT CONTENT

Two methods were used to compute the average element content of the samples: (1) the use of zero for each sample in which the element content was below the limit of detection, and (2) the use of one-half the detection limit if element content was below limit of detection.

The number of analyses that were made for each of the elements and the percentage of samples in which the elements were detected are shown in table 9. Six elements were found in all the samples, and four additional elements were found in more than 97 percent of the samples. For the elements which were detected in the fewest samples—tin, zinc, germanium, lanthanum, and molybdenum—two averages are shown. The lower values are those calculated by using zero for each sample in which the element content was below the limit of detection, and the higher values (in parentheses) are those calculated by using one-half the detection limit for each element. The largest difference between the averages as calculated by the two methods is that for tin, the element that was detected in the fewest samples.

COMPARISON OF WEATHERED AND UNWEATHERED COAL

Among the 48 samples of coal of Pennsylvanian age listed in table 9, 44 are of unweathered coal and 4 (locs. 32, 36, 37 in table 1 and fig. 2) are of weathered coal. The four weathered samples contain abnormally high concentrations of some of the elements, but they do not contain detectable zinc, germanium, or tin. Their molybdenum content is comparable to that of the 44 unweathered samples, their boron content is only slightly higher, and their average contents of the other 10 elements are much higher, ranging from 3.3 times higher for cobalt to 14.9 times higher for yttrium.

We believe that the large amounts of these elements in the four samples of weathered coal do not represent the minor-element content

TABLE 9.—*Average contents of minor elements in 44 unweathered and 4 weathered coal samples*

[All averages were calculated by both methods (1) using zero for each sample in which element content was below limit of detection, and (2) using one-half detection limit if element content was below limit of detection. If averages were same (rounded) by both methods, only one figure is listed; if different, averages obtained by method 2 are shown in parentheses beneath those obtained by method 1]

Element	Number of analyses	Percentage of samples in which element detected	Average element content (ppm)		Factors of enrichment (ppm)
			44 unweathered samples	4 weathered samples	
Be	228	97.8	1.1	13	11.8
B	227	100	33	47	1.4
Ti	227	100	250	1,700	6.8
V	227	98.7	18	70	3.9
Cr	227	100	13	64	4.9
Co	227	100	4.6	15	3.3
Ni	227	100	14	95	6.8
Cu	227	100	11	72	6.5
Zn	228	48.2	100 (108)	0 (76)	-------------
Ga	227	98.2	2.0	9.1	4.6
Ge	228	57	5.8 (5.9)	0 (1.6)	-------------
Mo	228	84.2	3.0 (3.1)	3.4	1.1
Sn	228	30.3	1.0 (1.3)	0 (3.1)	-------------
Y	227	97.8	7.4	110	14.9
La	227	59.5	6.2 (6.5)	93	14.3 (15.0)
Ash	228	-------------	[1] 5.79	[1] 31.43	-------------

[1] Average ash content, in weight percent.

of this same coal when unweathered. Most of these elements probably were introduced into the coal during weathering and are being held in the weathered coal by ion exchange or as simple complexes rather than as chelates. Therefore, until more is known about the effects of weathering, one should not rely on samples from weathered outcrops to indicate the minor-element content of a coal bed.

VARIATIONS IN MINOR-ELEMENT CONTENT OF COAL

VARIATIONS IN RELATION TO RANK DIFFERENCES

In the Oklahoma-Arkansas basin, the rank of coal increases eastward from low-volatile bituminous to semianthracite. The seven McAlester (Stigler) and five Upper Hartshorne samples range in rank from low- to high-volatile bitumiuous. The nine samples of Lower Hartshorne coal range in rank from low-volatile bituminous to semianthracite. Weathered samples are not considered in this discussion.

Among samples of the McAlester (Stigler) bed (fig. 2; table 10), the largest amounts of boron and germanium and the smallest amounts of nickel and copper are in the four samples (locs. 16–19) from the southwestern part of the basin. The other elements do not show evidence of systematic distribution in this bed.

The Upper Hartshorne samples show a similar paucity of trends. The largest amounts of cobalt, nickel, and copper are in the two samples (locs. 20, 23) from the southern part of the basin. The largest amount of boron is in the sample from the southwesternmost part of the basin.

Among the Lower Hartshorne samples, the two from the easternmost part of the semianthracite region contain the most beryllium and lanthanum. Boron content is highest in the southwestern sample. The distribution of the other elements does not show any relation to rank differences.

In summary, the areal trends of beryllium, boron, cobalt, nickel, copper, germanium, and lanthanum appear to be related to rank differences in a single bed. These trends do not appear in all beds, except that the boron content is consistently higher in the lower-rank coals. Differences in rank of coal do not appear to affect the distribution of any element except boron, at least in the Oklahoma-Arkansas basin.

STRATIGRAPHIC VARIATIONS AMONG BEDS

The average minor-element content of five different beds, arranged in stratigraphic sequence, is given in table 11. Analyses of four or more samples were averaged for each of the beds. The largest amounts of beryllium, boron, nickel, gallium, and germanium are in the upper-

TABLE 10.—*Average content of 15 minor elements in columnar samples of 3 coal beds in the Western region*

[In parts per million. Location and description of samples given in table 1]

Locality (fig. 2)	Coal sample	Be	B	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
McAlester coal bed																
13	OK-SS-St	0.22	2.5	160	7.7	5.3	6.4	8.9	7.4	5.9	0.84	0.30	1.9	0.90	3.9	1.6
14	OK-Ga-St	.33	4.1	140	26	8.4	1.8	8.9	7	12	1.2	.40	7.3	.75	6.1	3.7
15	OK-Ca-St	.37	3.9	99	5.5	6.1	4.9	12	8.7	26	.82	.31	4.3	2.6	3.1	2
16	OK-Sa-Mc	.13	75	130	10	4.4	.44	1.8	3.4	15	.67	1.3	4.3	2.6	2.2	2.2
17	OK-Du-Mc	.22	61	140	10	7.8	1.2	2.9	3.5	20	1	1.1	3	5	3.8	2.6
18	OK-LS-Mc	.11	8.5	69	9.6	5.3	3.2	8.7	4.6	16	.92	.62	3.6	1.1	1.7	1.6
19	OK-MA-Mc	.19	37	140	16	8.2	1	4.8	4.5	16	.92	1.1	1.9	2	3.1	2.6
Upper Hartshorne coal bed																
20	OK-K-UH	0.28	49	67	4.7	11	7.3	15	8.5	12	0.62	0.30	0.58	1.2	2.6	2.9
21	OK-LS-UH	.19	4.8	82	12	5.5	1.6	4.2	<3.5	7.1	.59	.57	.86	.64	2.9	2.4
22	OK-EC_1-UH	.11	2.9	61	8.6	5.1	1.1	1.7	3.1	12	.42	.88	.60	1.9	2.1	2
	OK-EC_2-UH	.08	3.5	61	8.8	4.7	.85	1.1	2.9	10	.45	.65	.67	2.2	2.1	2.8
23	OK-Da-UH	.36	5.3	195	15	6.2	5.7	10	6.2	8.5	.84	.30	1.4	1.6	4.4	2.6
28	Ark-QE-UH	.10	17	220	8.7	10	1.7	7.4	6.7	20	1.2	1	2	1.5	2.6	5.1
Lower Hartshorne coal bed																
20	OK-K-LH	0.31	39	460	36	24	5.2	12	21	20	3.2	0.90	0.72	2	7.1	12
21	OK-LS-LH	.21	8	220	18	9.5	2.5	4.1	6.6	11	1.2	.35	5.1	.86	4	2.8
22	OK-EC_2-LH	.79	7.9	790	50	36	6.1	14	29	18	3.6	1.1	.97	2.2	35	6.1
29	Ark-Ba-LH	.43	14	380	23	18	3	15	9.2	39	2.4	1.2	1.8	.85	7.5	8.7
30	Ark-Hu-LH	.38	16	260	24	18	2.8	19	14	50	2.2	.75	1.8	.55	7.2	9
31	Ark-Ha_{16}-LH	.20	15	150	9.2	8.9	4.4	15	12	50	.9	.52	4.8	.39	2.4	3.5
33	Ark-ACM-LH	.34	20	240	8.3	7.7	7.4	10	9.3	9.7	1.2	.19	1.1	.39	4.9	7.3
34	Ark-PV-LH	3.4	30	660	17	17	15	47	26	26	2.3	.55	1.7	1.1	16	22
35	Ark-EJ-LH	5.5	11	350	23	30	3.9	22	24	30	1.2	.61	.73	2.4	27	37

most (Broken Arrow) bed. The largest amounts of titanium, vanadium, chromium, copper, and yttrium are in the lowermost (Lower Hartshorne) bed. The highest concentrations of the other five elements are in the Upper Hartshorne bed. Yttrium and lanthanum are also concentrated in the Charleston and Lower Hartshorne beds, which are composed mostly of higher rank low volatile-bituminous coal.

TABLE 11.—*Average minor-element content of some coal beds sampled*

[In parts per million. Beds are in stratigraphic sequence]

Coal bed	Number of samples	Ash (percent)	Be	B	Ti	V	Cr	Co	Ni
Broken Arrow	4	3.07	1.75	28	230	12	8.5	5.7	24
Charleston	4	6.49	.56	6.9	190	16	9.7	10	16
McAlester-Stigler	7	2.94	.22	27	125	12	6.5	2.7	6.9
Upper Hartshorne	6	3.34	.19	14	115	10	7.2	3	6.6
Lower Hartshorne	9	6.49	1.3	18	390	23	19	5.6	18

Coal bed	Cu	Zn	Ga	Ge	Mo	Sn	Y	La
Broken Arrow	7.6	21	2.5	23	2.0	0.4	3.3	1.3
Charleston	11	41	1.9	1.5	2.5	1.1	10	15
McAlester-Stigler	5.6	16	.91	1.6	3.8	2.1	3.4	2.3
Upper Hartshorne	5.2	12	.69	.62	1	1.5	2.8	3
Lower Hartshorne	17	28	2	.69	2	1.2	12	12

The four samples of Eocene lignite (table 5, locs 38, 39) show a large disparity in their minor-element content. The two samples from Arkansas contain a greater quantity of the minor elements than do either of the two from Texas. Only boron is present in larger amounts in the Texas samples. The reason for such an enrichment of the Arkansas samples is not known.

REGIONAL DISTRIBUTION OF THE MINOR ELEMENTS IN COAL

Of the 15 minor elements for which analyses were made, only tin and lanthanum are more abundant in the coals of the Oklahoma-Arkansas basin than in coals of the central and northern parts of the region, and the average titanium contents are identical for the two areas (table 8). Beryllium, boron, nickel, zinc, gallium, germanium, and molybdenum are much more abundant in the coals of the central and northern areas; vanadium, chromium, cobalt, copper, and yttrium are slightly to appreciably more abundant.

The most enriched element in the coals of the central and northern areas is germanium, which, in the 12 columnar samples analyzed, ranged in content from 8.5 to 48 ppm, and in 8 of the 12 was 20 ppm or more. In comparison, the germanium content of Kansas coals, as reported by Schleischer (1959), ranged from 5 to 116 ppm, and in 55 of his 117 samples it was 20 ppm or more.

Several factors could contribute to the differences between the minor-element contents of the coals of the central and northern areas and those of the Oklahoma-Arkansas basin. Three possible factors are considered in this study: (1) large differences in the source rocks that contributed sediments to the different areas; (2) differences in the degree of tectonism; and (3) the influence of drainage patterns in Pennsylvanian time.

The source rocks factor, in our opinion, did not affect the minor-element content of the coals, because preexisting sedimentary rocks were the principal source rocks for the Oklahoma-Arkansas basin (Laudon, 1961, p. 72) as well as for the northern area (Siever and Potter, 1956). In the central area, some minor elements may have come from igneous rocks of the uplifted Nemaha ridge.

The tectonic factor, which involves the different rates of uplift in the positive areas and of subsidence in the depositional basins, could account for some of the differences in the minor-element content in coals of the region. In the Oklahoma-Arkansas basin, coals were deposited on the northern shelf of a rapidly subsiding eugeosynclinal trough, and the positive area south of the trough must have undergone comparably rapid uplift. Because of the rapidity of erosion and deposition, it is possible that soluble-ion concentrations were very low in solutions that entered the coal-forming swamp from the south. In the central and northern parts of the region, however, the depositional basins and positive source areas were less active. Consequently, the solutions that entered the coal swamps could have been in the weathering rocks longer and thus become relatively more concentrated with soluble ions.

The inferred drainage system of the inland Pennsylvanian sea in Des Moines time, as shown in figure 3, could account for the differences in the minor-element content of the coals in the Western region. This possibility is suggested by the distribution of yttrium: lanthanum ratios in samples from the region, as shown in figure 4. In the samples from the Eastern region of the Interior coal province, the yttrium:lanthanum ratios decrease as the distance from a source increases (Zubovic and others, 1964). In the Western region, the ratios are highest in samples from the central and northern parts, indicating a nearby source area. The ratios are very low in most samples from the Oklahoma-Arkansas basin, indicating a distance source area.

In areas where organic matter was being deposited, solutions that flowed in existing drainage patterns probably supplied most of the minor elements. During deposition of coals in the Oklahoma-Arkansas basin in Des Moines time, the entire Pennsylvanian sea is said to have drained southwestward (Schuchert, 1955, fig. 51). The drainage of

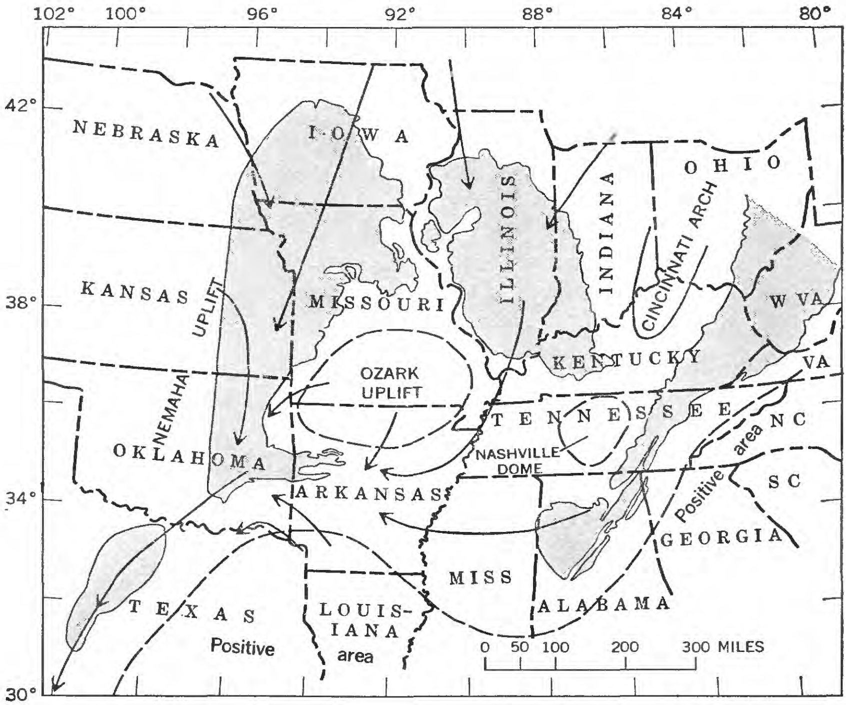

FIGURE 3.—Inferred drainage pattern and extent of the Pennsylvanian sea during Des Moines time. Major drainage directions are indicated by arrows. Coal-bearing regions are stippled.

the Eastern and Appalachian regions was westward through the Oklahoma-Arkansas basin. The transport direction of the Hartshorne Sandstone sediment was west-southwest, according to McDaniel (1961, p. 68). Most of the solutions that entered and flowed through the Oklahoma-Arkansas basin would have come from the Eastern and Appalachian regions, and the solutions probably deposited a large part of their minor-element content with the organic matter in those regions. Consequently, the solutions were depleted in soluble ions by the time they emptied into the Oklahoma-Arkansas basin. We believe that solutions from the rapidly emerging source area across the eugeosynclinal trough south of the basin were deflected westward and probably never reached the parts of the basin now underlain by coal. If organic matter was deposited south of the existing coal, it subsequently was removed by erosion of the intensely uplifted and thrusted eugeosynclinal trough. In the northern and central areas of coal formation in the Western region, however, solutions entered directly from the positive source areas and probably contained higher concentration of soluble ions, as suggested above.

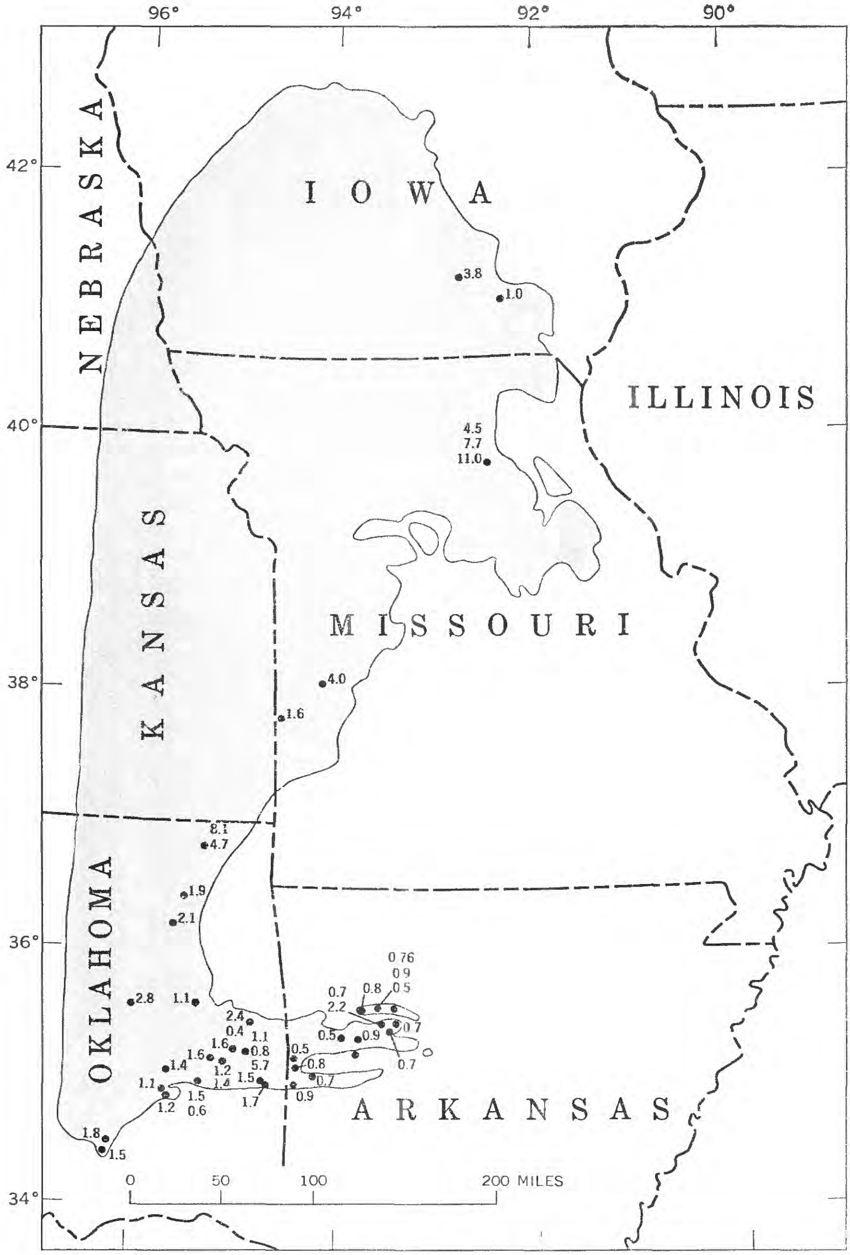

FIGURE 4.—Distribution of the yttrium : lanthanum ratios.

The coals of the Eastern region of the Interior coal province are more similar in minor-element content to coals of the northern and central areas of the Western region than to coals of the Oklahoma-Arkansas basin (table 8). This is to be expected if the solutions that entered the northern and central areas were more nearly saturated than those that entered the Oklahoma-Arkansas basin.

SUMMARY AND CONCLUSIONS

The following table shows the average minor-element content of coal of Pennsylvanian age in the Western region.

Element	*Ppm*	*Element*	*Ppm*	*Element*	*Ppm*	*Element*	*Ppm*
Be	1.1	Cr	13	Zn	108	Sn	1.3
B	33	Co	4.6	Ga	2.0	Y	7.4
Ti	250	Ni	14	Ge	5.9	La	6.5
V	18	Cu	11	Mo	3.1		

Weathered coal seems to be richer in minor elements than unweathered coal.

Except for boron, the minor-element content of coal does not vary with the rank of coal in the range from high-volatile bituminous to semianthracite.

Coals from the northern and central areas contain larger amounts of minor elements except for titanium, tin, and lanthanum, than do coals from the Oklahoma-Arkansas basin. Titanium was found in equal amounts in the two areas.

The yttrium: lanthanum ratios and the general low content of minor elements in the coals of the Oklahoma-Arkansas basin suggest that this area was far from a possible source area of these minor elements. The evidence also suggests that during the time of deposition, the Oklahoma-Arkansas coal basin was the main drainageway for the Pennsylvanian inland sea.

SELECTED REFERENCES

Dieke, G. H., and Crosswhite, H. M., 1943, The use of iron lines as intensity standards: Optical Soc. America Jour., v. 33, p. 425–434.

Haley, B. R., 1960, Coal resources of Arkansas: U.S. Geol. Survey Bull. 1072–P, p. 795–831.

Laudon, R. B., 1961, Carboniferous stratigraphy of the Ouachita Mountains, *in* Tulsa and Fort Smith Geol. Socs. Guidebook, Arkoma basin and north-central Ouachita Mountains: p. 72–75.

Lee, Wallace, 1943, Stratigraphy and structural development of the Forest City basin in Kansas: Kansas Geol. Survey Bull. 51, 142 p.

McDaniel, Gary, 1961, Surface stratigraphy of the Hartshorne formation, Leflore, Latimer, and Pittsburg Counties, *in* Tulsa and Fort Smith Geol. Socs. Guidebook, Arkoma basin and north-central Ouachita Mountains: p. 66–71.

Schleicher, J. A., 1959, Germanium in Kansas coals: Kansas Geol. Survey Bull. 134, pt. 4, p. 161–179.

Schuchert, Charles, 1955, Atlas of paleogeographic maps of North America: New York, John Wiley & Sons, 177 p.

Searight, W. V., 1958, Pennsylvanian (Des Moinesian) of Missouri, *in* Geol. Soc. America Guidebook, field trip 5: p. 65–110. Reprinted (1959) in Missouri Geol. Survey and Water Resources Rept. Inv. 25, 46 p.

Siever, Raymond, and Potter, P. E., 1956, Sedimentary petrology, pt. 2 *of* Sources of basal Pennsylvanian sediments in the Eastern Interior basin: Jour. Geology, v. 64, no. 4, p. 317–335.

Stadnichenko, Taisia, Murata, K. J., Zubovic, Peter, and Hufschmidt, E. L., 1953, Concentration of germanium in the ash of American coals—a progress report: U.S. Geol. Survey Circ. 272, 34 p.

Stadnichenko, Taisia, Zubovic, Peter, and Sheffey, N. B., 1961, Beryllium content of American coals: U.S. Geol. Survey Bull. 1084–K, p. 253–295.

Trumbull, J. V. A., 1957, Coal resources of Oklahoma: U.S. Geol. Survey Bull. 1042–J, p. 307–382.

Weller, J. M., Wanless, H. R., Cline, L. M., and Stookey, D. G., 1942, Interbasin Pennsylvanian correlations, Illinois and Iowa: Am. Assoc. Petroleum Geologists Bull., v. 26, no. 10, p. 1585–1593.

Zubovic, Peter, Stadnichenko, Taisia, and Sheffey, N. B., 1961, Geochemistry of minor elements in coals of the Northern Great Plains coal province: U.S. Geol. Survey Bull. 1117–A, 58 p.

——— 1964, Distribution of minor elements in coal beds of the Eastern Interior region: U.S. Geol. Survey Bull. 1117–B, 41 p.

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