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GEOLOGICAL SURVEY BULLETIN 1084-K

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CONTRIBUTIONS TO GEOCHEMISTRY

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CONTENTS

ILLUSTRATIONS

[All plates in pocket]

TABLES

CONTRIBUTIONS TO GEOCHEMISTRY

BERYLLIUM CONTENT OF AMERICAN COAL

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

ABSTRACT

The results of spectrochemical analyses of 1,385 coal ash samples suggest a significant distribution pattern for beryllium. The highest average beryllium content of coal ash (62 ppm) was found in the Appalachian region. An average content of beryllium in ash of 49 ppm was found in the Interior province. This figure for the Interior province is very close to the average for all the coal samples studied, 46 ppm. The average beryllium content of the samples from the northern Great Plains and Rocky Mountain provinces is about one-half the average for all the coal ash samples examined.

Considerable variation in beryllium concentration exists within each of the provinces. In the Eastern province very high concentrations of beryllium in ash are found in eastern Kentucky (0.067 percent and 0.081 percent). In the Interior province, the Eastern region has a higher beryllium content in the coal beds along the north and southeast edges and a lower content in the central parts; in the Western region, the coal beds of the McAlester Basin (Oklahoma and Arkansas) have a much lower content of the element than do the coal beds of the central and northern parts of the region. In the northern Great Plains province a similar distribution is found; the coal beds of the Great Falls and the Lewistown fields have a much higher beryllium content than do those of the rest of this province.

Large variations are found in concentrations of beryllium in different samples of the same bed. The beryllium content of bed 5 of Illinois ranges from 0.0011 percent (9.52 percent ash) to 0.0050 percent (6.52 percent ash). Similar variations are noted in other beds from which two or more samples were collected and analyzed. The distribution of beryllium in the blocks of columnar coal samples is reasonably uniform. In a few, however, concentrations were found in the top, center, or bottom part of the bed.

A study of the various types of coal indicates that beryllium is primarily concentrated in vitrain. Float-sink experiments clearly show that the concentration of beryllium is in the coal substance.

A study of the data has led to the belief that the accumulation of beryllium by coal was a syngenetic process. Conclusions have been reached that (a) the beryllium content of the coal is primarily dependent on the beryllium content of the rocks that contributed material to the coal-depositional sites, (b) the position in the basin determined the amount of beryllium in the coal samples, (c) rank and age of the coal bed is not related to the beryllium content of the coal, and (d) the chemical properties of beryllium suggest a way by which the element can be released from rocks, can be transported to a coal depositional site, and can become fixed in the coal.

INTRODUCTION

PURPOSE AND SCOPE

This report on beryllium is a part of a much broader study, which includes 15 other minor elements in coal. Work was started on a limited scale in 1948 and has gradually been expanded to cover most of the coal-producing areas of the United States.

Two kinds of reports are being prepared: One is a series dealing with individual elements, the other is a series on the content of all 16 elements as found in the analyses of coal ash from the coal-producing regions and provinces. This report is the second of the series dealing with individual elements. A detailed background of this study is given in the first report, which is on the concentration of germanium in the ash of American coals (Stadnichenko and others, 1953).

The coal samples were collected from 22 States and generally represent the principal beds in the areas. Only unweathered coal samples were collected and, consequently, only those mines that were in operation or had recently been in operation were sampled. Channel, auger, grab, and other types of coal samples, as noted in the tables, were submitted to the authors for analysis.

This report, which gives the data accumulated to January 1958, is based on 1,342 determinations for beryllium; 43 additional analyses are not treated in the text (see p. 284).

ACKNOWLEDGMENTS

The authors express gratitude to the coal miners, the mine superintendents, and the coal-mine operators for their help and for permission to collect samples in the mines; and to A. C. Fieldner, H. P. Greenwald, and R. F. Abernethy of the U.S. Bureau of Mines for their permission to use the laboratory facilities of the Pittsburgh Experimental Station. H. I. Smith and his associates and J. W. Huddle of the U.S. Geological Survey were very cooperative in giving assistance in the field.

Although most of the spectrographic analyses were made by Nola B. Sheffey, analyses in the early stages of the work were made by K. J. Murata, H. J. Rose, Jr., Janet D. Fletcher, and Elizabeth L. Hufschmidt of the U.S. Geological Survey.

PREVIOUS STUDIES OF BERYLLIUM IN COAL

Goldschmidt and Peters (1935) reported on the minor-element content in 17 samples of the ash of brown, bituminous, and anthracite coal from Germany and England. They gave 0.1 percent beryllium in ash as a maximum content and 0.03 percent beryllium in ash as an average. Goldschmidt (1935) found that some elements, including beryllium, are concentrated in forest humus and suggested that the

high values for some of these elements in coal are a result of this type of accumulation.

Zilbermintz and Rusanov (1936) spectrographically determined the beryllium content of 602 coal samples from different fields of the U.S.S.R.; their limit of detectability was 0.001 percent or 5 clarkes. The clarke of an element is its average abundance in the earth's crust; for this report Sandell's (1952) figure of 2 ppm is used. The following tabulation gives the results summarized by Zilbermintz and Rusanov (1936, table 5):

Distribution of beryllium in coal samples from various basins in the U.S.S.R.

Coal basin	Number of coal samples having beryllium in the various spectrographic ranges as indicated				Total number of samples
	0.01–0.1	0.001–0.01	<0.001	0	
Donets	1	18	132	153	304
Humara	1	5	8	3	17
Tkvibuli		4	29	6	39
Tkvardeli		3	14	1	18
Other deposits	1	6	72	145	224
Total	3	36	255	308	602

Headlee and Hunter (1955, p. 45, 55, 100) determined the content of beryllium and 35 other elements, in 594 ash samples of 35 columnar samples of coal beds from West Virginia. Beryllium was found in all but four of the samples. The limit of detectability was 0.0005 percent beryllium. The average beryllium content in the coal averaging 10.1 percent ash was 0.0029 percent. The data of Headlee and Hunter show a higher beryllium content in the coals of the southern part of West Virginia than in those of the northern part.

Duel and Annell (1956) reported on the occurrence of beryllium in 319 samples of lignite and coal from Colorado, North Dakota, South Dakota, and Texas. They found that the beryllium content in ash commonly ranges from 0.0001 to 0.001 percent. Duel and Annell (1956, table 5) give 151 samples from Harding County, S. Dak., which showed a maximum concentration of beryllium ranging from 0.1 to 1.0 percent; however, the number of samples in this range was not stated.

GEOCHEMISTRY OF BERYLLIUM

The first estimate of the abundance of beryllium in the earth's crust (10 ppm) was made by Clarke and Washington (1924, p. 21). Since that time, especially in the past few years, many investigators have used improved methods of analysis on different rock types and minerals and have expanded the knowledge of the geochemical environment of the element. A summary of the estimates of beryllium in different rock types is given in table 1.

One of the first comprehensive geochemical studies of beryllium was made by Goldschmidt and Peters (1932). Many rock types and minerals were examined spectrographically, and the average abundance of the element in the earth's crust was estimated to be less than 3.3 ppm and more likely to be 1.8 ppm. The latter figure is in close agreement with the estimate of 2 ppm by Sandell (1952). Later, Goldschmidt (1937, p. 656) estimated the abundance of beryllium in the earth's crust to be 6 ppm based on the analysis of composite samples of shale. This value has often been quoted by geochemists. Goldschmidt and Peters estimated a value of 3.6 ppm for granite, which is also in close agreement with estimates for the abundance of the element in granite given by Sandell (1952) and Beus (1956b, p. 76–79). Goldschmidt and Peters (1932) concluded that beryllium is a lithophile element, concentrated largely in residual melts and solutions.

TABLE 1.—*Estimates of the beryllium content in different rock types and its abundance in the earth's crust*

Rock type and earth's crust	Beryllium content (ppm.)	Author
Igneous	6	Rankama and Sahama, 1950.
Ultrabasic	.2	Vinogradov, 1956.
Basalt	.3	Beus, 1956b.
Nepheline syenite	.65	Borodin, 1956.
Diorites	1.6	Sandell, 1952.
Diorite and gabbro-diorite	1.8	Beus, 1956b.
Granite	3.6	Goldschmidt and Peters, 1932.
Do	3	Sandell, 1952.
Do	5	Beus, 1956b.
Shales	3.6	Rankama and Sahama, 1950.
Shale and clay	7	Vinogradov, 1956.
Earth's crust	10	Clarke and Washington, 1924.
Do	6	Goldschmidt, 1937.
Do	4	Fersman, 1939.
Upper part of the lithosphere	2	Sandell, 1952.
Do	3.5	Beus, 1956a.

Fersman (1939, p. 46–49) mentioned 32 beryllium-bearing minerals; most are associated with granitic pegmatite, some with nepheline syenite and syenitic pegmatite, and a few are hydrothermal postpegmatitic contact-type minerals. Fersman concluded that beryllium was predominantly concentrated in the middle phase of the residual granitic crystallization of pegmatites and in the analogous phase of pneumatolytic minerals. He regarded the strong ionic polarization of beryllium to be the reason for its relatively poor capacity for migration and its crystallization in the median phases of pegmatitic processes; he believed that this was why beryllium does not reach the supergene phase in the course of its migration. Beryllium is, therefore, unknown in surface deposits in which its strong polarization would lead to very rapid absorption by soils.

Fersman's estimate for the abundance of beryllium in the earth's crust is 4 ppm. He noted beryllium to be a deficient element in the earth's crust and that the bulk of it is in a dispersed state.

Sandell and Goldich (1943, p. 169) reported an average beryllium content of 7 ppm for 9 silicic rocks from North America, 5 of which were from Llano, Tex. Sandell (1952) reported an average beryllium content of 3.2 ppm for 7 composite samples of silicic rocks (64 individual samples, including 5 from Llano, Tex.) containing 68 to 78 percent SiO_2. However, when he excluded the Llano composite sample, the average dropped to 2.8 ppm beryllium. Sandell found that the average beryllium content of basaltic rocks (47 to 50 percent SiO_2) was 1 ppm or less; he estimated that equally weighted amounts of the 2 rock types would have a beryllium content between 1 and 3 ppm. He obtained an average value of 2 ppm for the beryllium content of the upper part of the lithosphere.

Fleischer and Cameron (1946) in their review of the geochemistry of beryllium gave 57 minerals whose beryllium content ranged from 0.004 to 36.0 percent and indicated the type of occurrence of the minerals.

Rankama and Sahama (1950, p. 443–447) in discussing the geochemistry of beryllium followed the suggestion of V. M. Goldschmidt that the silicic igneous rocks contain the bulk of the element. They restated Goldschmidt's observation that many nepheline syenite minerals such as alkalic feldspars, alkalic amphiboles, alkalic pyroxenes, micas, nepheline, sodalite, and tourmaline may contain considerable quantities of beryllium and pointed out that in these minerals beryllium seems to replace silicon in SiO_4^{-4} tetrahedra. Rankama and Sahama also accepted Goldschmidt's view that during the weathering and sedimentation, beryllium, because of the similarity of its ionic potential (5.88) to that of aluminum (5.26), closely follows the course of aluminum and concentrates in clay, bauxite, recent deep-sea deposits, and other hydrolyzate sediments. In a study of Arkansas bauxite deposits and the parent nepheline syenite rocks, Gordon and Murata (1952, p. 174–178) found that the relation of aluminum and beryllium could not be adequately explained by the ionic potential alone.

Borodin (1956) felt that some of the earlier estimates of the beryllium content of nepheline syenite rocks were based on too few analyses; consequently, from 79 average samples he prepared 6 composite samples of the Khibin massif, one of the largest of the nepheline syenite massifs. The samples were analyzed spectrographically for beryllium; his results are given below. From the data Borodin concluded that the nepheline syenite samples analyzed by Goldschmidt and Peters (1932) must have contained beryllium minerals.

584502 O - 61 - 2

Rocks	Surface distribution in the massif (percent)	Number of average samples	Beryllium content of composite sample (ppm)
Trachytoid khibinite	45	22	0.8
Normal khibinite		5	.6
Nepheline syenite, average grain size	7	14	.7
Rischorite	10	12	.6
Foyaite	34	25	.6
Iolite-urtite	4	1	.5

Beus and Fedorchuk (1955) studied the beryllium content of samples of granitic pegmatites and minerals from the pegmatities. Some of the results of their studies are summarized below. Beus and Fedorchuk found that the beryllium content of these samples varied considerably, not only between the different types of rocks, but also between the same types of rocks and minerals collected at different localities. On the basis of their study they estimated the average beryllium content of granitic pegmatites as 2 ppm.

Dispersed beryllium in samples of rocks and their minerals

Number of samples	Description	Beryllium (ppm)
19	Pegmatites free of rare-earth minerals; tourmaline, garnet, microcline, quartz, and muscovite.	1–3
98	Pegmatites containing beryllium minerals; graphic pegmatite, microcline, albite, micas, tourmaline, garnet, spodumene, and apatite.	3–126
10	Pegmatites containing rare-earth minerals and not containing beryllium minerals.	1–36

Beus and Sazhina (1956) reported the beryllium content of 584 samples of granitic rocks collected throughout the European and Asiatic parts of the U.S.S.R. They found that although the major part of the beryllium was in the feldspars, the highest concentrations were in the dark-colored minerals.

In a summary of his work since 1953, Beus (1956a) discussed the crystallization and distribution of beryllium in igneous, pegmatitic, hydrothermal, contact metasomatic, and supergene processes. He pointed out that his estimate of 3.5 ppm for the beryllium content of the upper part of the sial was calculated from the results of the analyses of a large number of rocks collected from a very large part of the earth's surface and thus concluded that his estimate should be accepted as a "real average."

In this report Sandell's (1952) estimate of 2 ppm is used as the average abundance (1 clarke) of beryllium in the earth's crust.

DESCRIPTION OF THE COALS

The coal deposits that have been analyzed for beryllium range from Pennsylvanian to Eocene. The largest number of samples, collected from the Eastern and the Interior provinces, are from the coal of Pennsylvanian age. Coal deposits of the Northern Great Plains province are principally of Paleocene age, and some are from the Jurassic, Cretaceous, and Eocene. Coal deposits of the Rocky Mountain province are mostly of Cretaceous age with some Eocene. The subdivisions used in this report are shown in figure 41 and described below.

EASTERN PROVINCE, APPALACHIAN REGION

Coal samples collected from the Eastern province are of Pennsylvanian age, with the exception of one sample of anthracite of Mississippian age. All the samples are from the Appalachian region, which is divided for the purposes of this report into northern and southern parts.

NORTHERN PART

The coal samples are of the Lower and Middle Kittanning coal beds of the Allegheny formation. Of the 20 columnar samples reported, 17 are from Ohio, 2 from Pennsylvania, and 1 from Maryland. The coal samples are of bituminous rank, with those from the western part of the basin lower in rank than those from the eastern part; the increase in rank from west to east is gradual.

SOUTHERN PART

In this part of the Appalachian region are the coal fields of West Virginia, Virginia, eastern Kentucky, Tennessee, Georgia, and Alabama. The most extensively sampled coal beds were in Alabama, with 23 columnar samples of 14 different beds, and in eastern Kentucky, with 19 columnar samples of 13 different beds. From the coal fields of the other States 9 columnar samples are reported from West Virginia, 7 from Tennessee, 3 from Georgia, and 2 from Virginia. All the coal beds of Alabama, West Virginia, and Virginia correspond in age to the Pottsville formation. In eastern Kentucky the coal corresponds in age to the Pottsville and Allegheny formations.

Generally the coal is similar in rank to those of the northern part of the Appalachian region. Coal of higher rank formed along the east edge of the basin. The coals are mostly of high- and medium-volatile bituminous rank with some of low-volatile bituminous rank in the extreme eastern part.

In Alabama the coal beds range in thickness from 2 to 5 feet; in eastern Kentucky the range is about 2 to 23 feet; in Tennessee,

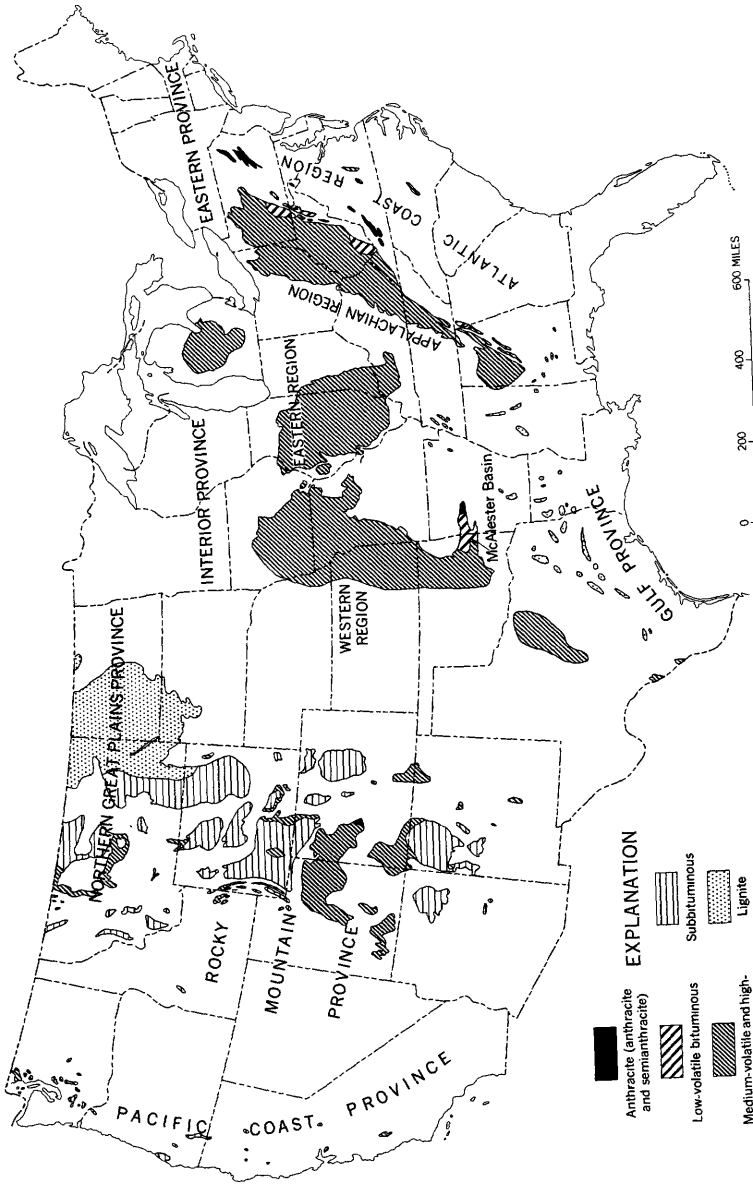

FIGURE 41.—Map showing location of the provinces and regions referred to in the text.

about 3 to 5 feet; and in West Virginia, the Pocahontas No. 3 bed is 12 to 15 feet thick.

INTERIOR PROVINCE

This province includes four regions, Northern (Michigan), Eastern (Illinois, Indiana, and western Kentucky), Western (Iowa, Missouri, Kansas, Oklahoma, and Arkansas), and Southwestern (Texas). Samples from only the Eastern and Western Interior regions have been collected and studied. Four samples of Texas and Arkansas lignite, which are actually in the Gulf province, are included in this province.

EASTERN REGION

The Eastern region is divided into two areas, the Illinois-Indiana and the western Kentucky areas. At the time of deposition these areas were probably continuous, but since that time structures have developed which do not permit them to be treated separately. The principal structures that separate these areas are fault zones and an uplift in southern Illinois. The generalized structural feature of the Illinois-Indiana coal fields is a broad shallow basin with its deepest part in southeastern Illinois. The dip of the formations from the margins of the deepest part is gradual. Many minor structures are present throughout the basin. In the southern part of this area the Shawneetown fault system and uplift cause the coal beds to dip very steeply and even to be overturned in some places.

In western Kentucky the deepest part of the basin of coal-bearing rocks is near the Ohio River opposite the deepest part of the basin in Illinois. As in the Illinois-Indiana part of the region, the dip is very gradual from the margins to the center of the basin. All the coals of the region are found in equivalents of the Pottsville and Allegheny formations of Pennsylvanian age. All the coals are of high-volatile B and C bituminous rank; some are used in the production of coke.

The principal beds that are being mined are No. 5 of Illinois, which is correlated with Bed V of Indiana and No. 9 of western Kentucky; and No. 6 of Illinois, correlated with Bed VI of Indiana and No. 11 of western Kentucky. Other beds which are being mined are the Davis, DeKoven, Murphysboro, and Nos. 2 and 7 in Illinois; Lower Block, Minshall, III and VII of Indiana, and Nos. 6, 12, and 14 of western Kentucky.

Beds No. 5 of Illinois, with its correlatives in Indiana and western Kentucky, and No. 6 of Illinois and its correlatives in the other States were the most thoroughly sampled by the authors.

WESTERN REGION

The coal and lignite samples from the Western region come from Arkansas, Iowa, Missouri, Oklahoma, and Texas. Several samples that were collected in Kansas have not been analyzed. Although the coal from Arkansas and Oklahoma was the most thoroughly sampled, many of the samples are now being processed and the results are not available for this report.

The coal samples from Iowa, Missouri, Oklahoma, and most of Arkansas are bituminous in rank and are of Pennsylvanian age. The samples of lignite of Eocene age from the Gulf province were too few in number to warrant a separate description. For convenience they are included in this region.

Most coal in the Western region is high- or medium-volatile bituminous in rank. The coal of the McAlester basin in eastern Oklahoma and west-central Arkansas shows a progressive increase in rank from west to east. Coal in the southwestern part of the basin is high-volatile bituminous in rank; eastward it grades to medium-volatile bituminous. In the vicinity of the Oklahoma-Arkansas border, the rank has increased to low-volatile bituminous. Along the eastern part of the basin, coal is of semianthracite rank.

NORTHERN GREAT PLAINS PROVINCE

Coal samples from this province were collected in Montana, North Dakota, and Wyoming; most of the samples are from Montana, and the fewest are from Wyoming. In addition, 26 channel and auger samples were submitted to the authors by Survey geologists.

Four of the columnar samples are from coal of Jurassic age from central Montana; one is from coal of Cretaceous age from north-central Montana; six are channel samples from coal of Eocene age from Wyoming; the rest of the samples are coal from the Tongue River member of the Fort Union formation.

The rank of the coal ranges from lignite in the eastern part of the province to subbituminous A to C on the western part; this transition is very gradual and no precise line of demarcation can be drawn.

ROCKY MOUNTAIN PROVINCE

Coal samples of this province were collected in Wyoming, Colorado, Utah, and New Mexico. Colorado is the most thoroughly sampled State. Although this province has been more adequately sampled than some of the others, little of the analytical work has been completed.

The coal samples range in age from Cretaceous to Eocene; most of the samples are from the Upper Cretaceous Mesaverde formation.

Coal samples collected from the Raton formation in southeastern Colorado and New Mexico are of Cretaceous and Paleocene age, and those from the Hanna formation in Wyoming are of Eocene age. Although blocks of coal from only two mines in Utah are reported, other mines were sampled, but analyses have not been made.

SAMPLING AND PREPARATION OF COALS

The sampling and ashing of coal have been adequately explained by Stadnichenko and others (1953, p. 2–3). However, many of the samples used in this report have been cleaned by flotation methods, which were not previously described. Coal with an ash content greater than 5 percent was processed as follows: Forty grams of −100-mesh coal was distributed among four 100-ml centrifuge tubes. A mixture of carbon tetrachloride and ethyl alcohol of the proper specific gravity was added and the mixture thoroughly stirred. The tubes were centrifuged for 20 minutes at 800 rpm. After this, the tubes were removed and the float cakes and liquid decanted on to Whatman No. 42 filter paper placed in a Buchner funnel. The sink fraction was scraped out of the tubes into a porcelain crucible. The float fraction was also placed in a porcelain crucible. Both were then dried in an oven at about 70°C. After the fractions were dried and weighed, 10 grams of the float fraction was ashed in the same manner as described for raw coal.

METHOD OF ANALYSIS

The determination of beryllium in the ash of the coal samples was made by spectrochemical analysis. The method has been described for germanium and other minor elements (Stadnichenko and others, 1953), but beryllium was not present in the standards used in those analyses. A set of standards containing beryllium oxide in the same pegmatite-base material was used for beryllium determinations. In addition to these synthetic standards, two chemically and spectrochemically analyzed samples of beryl containing 0.05 and 0.26 percent BeO were diluted in pegmatite base and used to validate the working curve.

For concentrations near the limit of detectability for beryllium (0.0001 percent) the spectral line Be 2348.61 A was used. The spectral line Be 3131.07 A was used for concentrations above 0.001 percent.

PRESENTATION OF DATA

The data (table 2) are arranged by provinces. States and counties are arranged alphabetically in each province. In addition the bed, mine, and location are used to identify the samples.

The data are averages of the analyzed blocks of coal from each columnar sample of the bed. In the northern Great Plains and the Rocky Mountain provinces a large number of channel and auger samples were analyzed; and, since these are representative of the whole bed the one analysis is an average of the bed. The data shown are given for average ash, average beryllium in ash, maximum beryllium in ash, and average content of beryllium in coal (in parts per million).

In the northern Great Plains province and the Eastern Interior region, whenever more than 75 percent of a bed has been analyzed, the averages are weighted according to the sizes of the blocks. All others, including those from the other provinces, are arithmetic averages.

Additional information and more complete data will be available in the province reports.

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TABLE 2.—*Beryllium content of the coal ash and coal samples of the provinces*

Sample	County	Location and remarks	Bed	Number of samples	Average ash of coal (percent)	Beryllium in ash of coal (percent)		Beryllium average in coal (ppm)
						Average	Maximum	
EASTERN PROVINCE, APPALACHIAN REGION								
NORTHERN PART								
Maryland								
Md-Up-LK	Garrett	Upperman, mine near Deer Park	Lower Kittanning	6	14.55	0.0018	0.0040	2.4
Ohio								
O-Mal-LK	Carroll	Stark Ceramics Co., Cameron pit, near Malvern	Lower Kittanning	8	9.85	0.0016	0.0040	1.6
O-Mal-LK(F)	do	Stark Ceramics Co., Cameron pit, naar Malrvern (float fractions.	do	7	2.60	.0064	.0100	1.7
O-Mal-MK	do	Stark Ceramics Co., Cameron pit, near Malvern	Middle Kittanning	6	7.62	.0023	.0050	1.8
O-L-MK	Columbiana	J. and R. Coal Company mine, at Guilford Lake near Lisbon.	do	8	11.07	.0016	.0030	1.6
O-SB-MK	Coshocton	Abandoned strip mine, Harris Farm, near Sunnybrook	do	5	3.02	.014	.0400	4.2
O-W-MK	Jackson	Broken Aro mine, near Wellston	do	4	14.19	.0042	.0100	4.0
O-P-LK	Perry	Floyd Angle mine, near Junction City	Lower Kittanning	8	12.62	.0025	.0050	2.4
O-SH-LK	do	Sunnyhill No. 8 mine, New Lexington	do	6	11.73	.0034	.0060	3.3
O-SH-LK-(F)	do	Sunnyhill No. 8 mine, New Lexington (float fractions)	do	2	4.01	.0095	.0100	3.8
O-SH-LK-(t)	do	Sunnyhill No. 8 mine, New Lexington (tipple samples)	do	6	11.82	.0043	.0200	5.1
O-SH-MK	do	Sunnyhill No. 8 mine, New Lexington	Middle Kittanning	15	19.20	.002	.0090	2.6
O-M-LK	Stark	Billman Coal Company mine, Miller's Farm, Waynesburg.	Lower Kittanning	12	11.46	.0021	.0100	2.4
O-Mag-LK	do	Magnolia Mining Company mine, near Waynesburg	do	7	11.43	.0027	.0040	2.6
O-Me-LK	do	Metropolitan Clay Company mine, southeast of East Canton.	do	7	15.52	.004	.0050	4.1
O-SC13$_1$-LK	do	Stark Ceramics Co. pit No. 13, East Canton (collected in 1948).	do	3	6.55	.0039	.0100	2.5
O-SC13$_2$-LK	do	Stark Ceramics Co. pit No. 13, East Canton (collected in 1951).	do	6	7.14	.0022	.0050	1.6
O-SC14-LK	do	Stark Ceramics Co. pit No. 14, East Canton	do	4	6.06	.0041	.0070	2.4
O-SC14-MK	do	do	Middle Kittanning	8	8.39	.002	.0060	1.5
O-SC14-MK(f)	do	Stark Ceramics Co. pit No. 14, East Canton (fusain)	do	2	15.85	.0003	.0004	.5
O-SC20-LK	do	Stark Ceramics Co. pit No. 20, East Canton	Lower Kittanning	6	11.70	.0032	.0060	3.2
O-T-LK	Tuscarawas	Copperhead mine, Sugar Creek	do	7	8.50	.0024	.0040	1.8

TABLE 2.—*Beryllium content of the coal ash and coal samples of the provinces*—Continued

Sample	County	Location and remarks	Bed	Number of samples	Average ash of coal (percent)	Beryllium in ash of coal (percent)		Beryllium average in coal (ppm)
						Average	Maximum	
Pennsylvania								
Pa-Pi-LK	Armstrong	Pittshaw No. 15 mine, north of Kittanning	Lower Kittanning	3	11.83	0.0030	0.0040	3.7
Pa-Wa-LK	Indiana	Waterman No. 2 mine, Homer City	do	6	6.51	.0028	.0100	1.8
Pa-Ash-PSU	Not known	Pennsylvania anthracite coal ash. Samples received from Pennsylvania State University.	Not known	4		.0008	.0010	
SOUTHERN PART								
[Ky-Pu, Ky-SX, Ky-EJ, and Ky-IH represent columnar samples collected by J. W. Huddle, U.S. Geological Survey]								
Alabama								
Ala-BD-W	Bibb	Blocton No. 9 mine, West Blocton	Woodstock	2	4.89	0.0017	0.0030	1.1
Ala-E-BC	De Kalb	Sand Mountain Coal Co. mine, Route 5	Black Creek	2	5.69	.0055	.0070	3.0
Ala-FtP	do	Hill's mine, near Fort Payne	Fort Payne	2	4.38	.0070	.0070	3.1
Ala-Da-P	Jefferson	Davidson No. 9 mine, Adamsville, Route No. 1	Pratt	3	3.58	.0030	.0050	1.2
Ala-Z-M_1	St. Clair	Ziegler mine, near Leeds (1st bench)	Mammoth	2	4.42	.0017	.0030	.8
Ala-Z-M_2	do	Ziegler mine, near Leeds (2d bench)	do	4	4.31	.0011	.0030	.5
Ala-Z-M_3	do	Ziegler mine, near Leeds (3d bench)	do	2	5.62	.0027	.0050	1.4
Ala-Mi-B(R)	Tuscaloosa	Mitchell Brothers Construction Co. mine, near Brookwood.	Brookwood (Rider)	1	9.06	.0037	.0037	3.4
Ala-Mi-B	do	do	Brookwood	4	7.93	.0058	.0110	4.6
Ala-Mi-M	do	do	Milldale	2	3.55	.0100	.0170	3.6
Ala-TH-B	do	Toxey Hosmer Coal Co. mine, near Brookwood	Brookwood	3	6.37	.0030	.0050	1.9
Ala-TH-M	do	do	Milldale	4	3.64	.0123	.0290	4.4
Ala-T-M	do	Kellerman mine, Searles	do	3	4.47	.0046	.0100	2.0
Ala-T-B	do	do	Brookwood	3	3.89	.0070	.0160	1.9
Ala-De-BC	Walker	Empire Strip No. 6 mine, Empire	Black Creek	6	1.71	.0150	.0300	2.6
Ala-H-BC	do	Hawk's No. 4 mine, Carbon Hill (1st sample)	Black Creek (Jefferson)	4	3.15	.0040	.0080	1.1
Ala-Ga-BC	do	Hawk's No. 4 mine, Carbon Hill (2d sample)	do	7	3.96	.0077	.0200	3.0
Ala-Ma-J	do	Marigold mine, Jasper (Shovel pit)	Jefferson (Black Creek)	4	7.48	.0045	.0070	3.4
Ala-Ma-J_1	do	Marigold mine, Jasper (Drag line pit)	do	2	3.67	.0020	.0020	.7
Ala-Ga-ML	do	Galloway Coal Mining Co., Inc., No. 29, mine, Carbon Hill.	Mary Lee	2	15.05	.0012	.0020	1.8
Ala-G-A	do	Gorgas mine, Gorgas	American	4	5.78	.0029	.0040	1.8
Ala-G-NP	do	Exposure near Gorgas mine, Gorgas	Nickel Plate	1	6.02	.0030	.0030	1.8
Ala-G-P	do	do	Pratt	1	3.58	.0040	.0040	1.4

Georgia

Ga-W-4	Walker	Waldin mine, Rising Fawn, Route 3	No. 4	2	1.47	0.0035	0.0050	0.8
Ga-B-5	do	Boulevard Coal Co. mine, stripping near abandoned prison.	No. 5	1	3.12	.0070	.0070	2.2
Ga-Bl	do	W. T. Bleben's mine, Rising Fawn	Unknown	3	3.73	.0047	.0060	1.7

Kentucky (eastern)

Ky-Pu	Bell	Pruden Coal and Coke Co. mine, Log Mountain	Hignite	1	4.02	0.0002	0.0002	0.1
Ky-SL	Breathitt	Sky Line mine, Evanston	Tip Top	6	4.31	.0010	.0020	.4
Ky-GV$_1$	Floyd	Glo Valley Coal Corp. mine, Glo Valley	Elkhorn No. 1	10	3.83	.0034	.0200	1.8
Ky-B&S	do	Burchatt and Stambo mine, Hunter	Elkhorn No. 2	2	9.32	.0033	.0036	3.1
Ky-Hop	do	Hopkins Coal Co. mine, Hunter	do	7	4.54	.01	.0200	2.3
Ky-W	do	Wilson Creek Co. mine, Manton	Elkhorn No. 3	2	5.72	.007	.007	4.0
Ky-IH	Harlan	International Harvester No. 2 mine, Benham	Harlan (B)	4	2.85	.11	.2400	31
Ky-Am	Letcher	Amburgy mine, Premium	Amburgy	1	3.72	.0100	.0100	3.7
Ky-Con	do	Consolidation Coal Co. No. 204 mine, near Jenkins	Elkhorn No. 2	2	3.70	.0025	.0040	.9
Ky-EJ	do	Elkhorn-Jellico mine, near Whitesburg	Elkhorn No. 3(?)	5	9.03	.0053	.0110	4.8
Ky-Hend	do	Hendrix mine, Deane	Elkhorn No. 3	2	4.34	.0043	.0080	1.9
Ky-Wh	do	Sand Lick Coal Co. mine, Whitesburg	Whitesburg	1	13.90	.0020	.0020	2.8
Ky-SX	do	Sexton's mine, near Whitesburg	Hazard No. 4 (Fire clay)	5	6.46	.081	.1800	19
Ky-Col$_1$	Perry	Columbus No. 4 mine, Allais	Hazard No. 4	8	2.54	.0037	.0100	.9
Ky-Col$_2$	do	Columbus No. 6 mine, Allais	do	4	1.91	.013	.0300	2.4
Ky-Har	do	Harvey Coal Corp. No. 9 mine, Harveyton	Hazard No. 7(?)	8	4.63	.0010	.0040	.5
Ky-Dia	do	Fourseam Coal Corp. No. 3 mine, Diablock	Hazard No. 9(?)	15	8.88	.0016	.0100	1.3
Ky-Le	do	Leatherwood No. 1 mine, Leatherwood	Leatherwood	3	3.18	.0031	.0036	1.1
Ky-Wo	Whitley	Woodbine mine, near Woodbine	Jellico	1	1.36	.0050	.0050	.7

Tennessee

Tenn-A	Campbell	Blue Rose mine, Morley	Jellico	6	2.39	0.0005	0.0010	0.1
Tenn-V	do	Anthras mine, Coal Valley	Vasper	6	8.91	.0046	.0200	11
Tenn-Va	do	Vasper mine, Coal Valley	do	5	6.28	.0026	.0110	1.6
Tenn-R&P	do	Rochester and Pittsburgh Coal Company mine, Briceville.	Windrock (Lower Dean)	4	3.52	.0011	.0030	.6
Tenn-D	Claiborne	Dippel mines, Clairfield	Clairborne	4	3.13	.0043	.0060	1.6
Tenn-E	do	Eagan mine, Eagan	Jellico	3	10.22	.0042	.0090	2.3
Tenn-Re	Marion	Reel's Cove mine, near Whitewell, Route 108	Sewanee	1	7.58	.0033	.0033	2.5

Virginia

Va-3	Tazewell	Boissevain mine, Boissevain	Pocahontas No. 3	4	10.28	0.0018	0.0040	1.9
Va-340	do	Amonate mine, Amonate	Pocahontas No. 4	1	6.60	.0007	.0007	.5

TABLE 2.—*Beryllium content of the coal ash and coal samples of the provinces*—Continued

Sample	County	Location and remarks	Bed	Number of samples	Average ash of coal (percent)	Beryllium in ash of coal (percent)		Beryllium average in coal (ppm)
						Average	Maximum	
West Virginia								
WVa-210	Fayette	Canyon Top Coal Company mine, Thurmond	Sewell	7	2.53	0.0031	0.0050	0.8
WVa-320	McDowell	Jenkinjones mine, Jenkinjones	Pocahontas No. 3	1	3.27	.0020	.0020	.7
WVa-370	McDowell	Crozer mine, Mayberry	Pocahontas No. 11	2	1.72	.0065	.0100	1.1
WVa-300	Mercer	Springton mine, Springton	Pocahontas No. 3	2	4.55	.0013	.0020	.6
WVa-140/150	Mingo	Ames mine, Thacker	Cedar Grove	5	4.99	.0072	.0200	3.6
WVa-160	do	do	Lower Cedar Grove	1	3.00	.0080	.0080	2.4
WVa-200	do	Red Jacket Coal Corporation mine, Red Jacket	Coalburg	2	17.10	.0007	.0010	1.2
WVa-180	Raleigh	Eccles No. 5 mine, Eccles	Beckley	2	4.90	.0030	.0050	1.5
WVa-220	do	Eccles No. 6 mine, Eccles	Sewell	3	1.27	.0017	.0020	.2

INTERIOR PROVINCE, EASTERN REGION

[Ill-S-Da and Ill-S-Dek represent columnar samples collected by J. A. Simon and M. E. Hopkins, Illinois Geological Survey. Ky-BD-9 and Ky-Oh-9 are channel samples submitted for analysis by the Black Star Coal Corp.]

Illinois

Ill-Pa-6	Christian	Peabody No. 17 mine, Pana	No. 6	8	9.57	0.0018	0.0030	1.8
Ill-Pw-6	do	Peabody No. 10 mine, Pawnee	do	10	4.73	.0034	.0100	1.4
Ill-OB-6	Franklin	Old Ben No. 22 mine, Valier	do	6	3.47	.0049	.0050	1.6
Ill-P-1	Fulton	Putt Creek mine, near Cuba	No. 1	12	5.96	.0072	.0300	3.1
Ill-Tr-5	do	Red Ember mine, near Fiatt	No. 5	12	7.57	.0028	.0080	1.9
Ill-R-5	Fulton and Knox	Rapatee mine, also known as Middle Grove No. 3 mine, Rapatee.	do	9	9.16	.0033	.0090	2.3
Ill-F-6	do	Farmington mine, near Farmington	No. 6	13	4.35	.0043	.0100	1.4
Ill-PH-LW	Gallatin	Blue Blaze mine, near Pounds Hollow Lake	Lower Willis	7	3.96	.0068	.0110	2.7
Ill-B&W-5	do	B. and W. Coal Co. mine, 5 miles west of Junction	No. 5	4	13.69	.0013	.0020	1.7
Ill-G-5	do	Oak Hill mine, near Gibsonia	do	6	4.17	.0029	.0060	.8
Ill-A-1	Henry	Alpha mine, Alpha	No. 1	7	5.99	.0021	.0040	1.3
Ill-A-6	do	Mecco No. 1 mine, near Atkinson	No. 6	17	7.27	.0043	.0080	2.0
Ill-P-Mu	Jackson	Phillips mine, near Carbondale	Murphysboro	6	4.07	.0039	.0060	1.6
Ill-TrB-5	do	Burning Star mine, Elkville	No. 5	6	10.27	.0023	.0040	2.1
Ill-TrB-6	do	do	No. 6	8	5.06	.0041	.0050	1.7
Ill-T-1	Knox	Thermal No. 1 mine, Knoxville	No. 1	11	6.88	.0033	.0050	1.9
Ill-Ma-5	Marion	Glenridge mine, Centralia	No. 5	1	6.10	.0020	.0020	1.2
Ill-Ma-6	do	do	No. 6	3	16.51	.0004	.0007	.5
Ill-C-6	Montgomery	Crown mine, Farmersville	do	11	5.83	.0040	.0090	1.8
Ill-TrP-6	Perry	Pyramid mine, Pinkneyville	do	2	19.92	.0020	.0020	4.0

Ill-BB-5	Saline	Blue Bird mine, 15 miles west of Harrisburg	do	3	11.87	.002	.0040	2.2
Ill-S-5	do	Sahara No. 7 mine, 13 miles west of Harrisburg	do	5	8.39	.0014	.0020	1.1
Ill-S-6	do	Sahara No. 6 mine, 11 miles west of Harrisburg	No. 6	2	8.55	.0030	.0030	2.6
Ill-H-5	do	Peabody No. 43 mine, Harco	No. 5	6	3.22	.0016	.0020	.6
Ill-M-6	do	Majestic No. 14 mine, near DuQuoin	No. 6	3	9.05	.0018	.0025	1.2
Ill-S-Da	do	Saxton No. 2 mine, Carrier Mills	Davis	7	4.35	.017	.030	5.7
Ill-S-Dek	do	do	DeKoven	6	7.67	.0039	.0020	2.2
Ill-F-5	Sangamon	Farrand mine, near Riverton	No. 5	9	6.03	.0018	.0030	1.1
Ill-W-5	do	Wenneborg mine, near Sherman	do	14	7.23	.0035	.0100	1.5
Ill-V-6	Vermilion	V-Day mine, southwest of Danville	No. 6	8	7.60	.0017	.0040	1.3
Ill-D-7	do	Two Rivers Coal Company mine, near Danville	No. 7	10	3.92	.0087	.0200	3.2
Ill-Ha-7	do	Harmattan mine, near Danville	do	8	4.40	.005	.0100	1.9
Ill-B-2	Will and Grundy	Braidwood mine, Braidwood	No. 2	15	5.57	.0086	.0400	4.3
Ill-E-2	Will	Essex mine, southeast of Braidwood	do	11	5.30	.0052	.0080	2.3
Ill-E-5	do	do	No. 5	15	6.08	.0051	.0130	2.6
Indiana								
Ind-Hi-LB	Clay	Old Hickory No. 1 mine, 3 miles west of Carbon	Lower Block	7	8.83	0.0066	0.0180	4.7
Ind-C-III	do	Chinook mine, 2 miles south of Staunton	III	6	13.83	.0048	.0100	6.6
Ind-H-III	Daviess	Hicks mine, 4.3 miles south of Cannelburg	III	10	4.71	.018	.0330	6.8
Ind-L-VII	Pike	Landrey No. 1 mine, 6 miles northwest of Winslow	VII	13	8.12	.013	.1000	5.1
Ind-Ge	Spencer	Roadcut 1 mile south of Gentryville	Unknown	3	9.21	.0090	.0100	7.6
Ind-M-M	do	Mulzer mine, 1.5 miles northeast of Buffaloville	Minshall	9	7.15	.012	.0200	3.7
Ind-S-VI	Vermillion	Sunspot mine, 5 miles west of Clinton	VI	15	7.40	.012	.0290	4.0
Ind-S-V	Warrick	Sunlight No. 11 mine, Boonville	V	11	4.37	.0032	.0072	1.4
Ind-P-V	do	Phillips mine, 2.5 miles north of Boonville	V	5	10.52	.0035	.0100	3.5
Ind-D-VI	do	Ditney Hill mine, 2 miles south of Elberfeld	VI	10	4.52	.0034	.0072	1.4
Kentucky (western)								
Ky-F-9	Daviess	Lick Branch mine, 16 miles south-southwest of Owensboro.	No. 9	5	11.72	0.0019	0.0026	2.0
Ky-G_1-9	do	Panther mine, near Panther (1st sample)	do	9	8.95	.0056	.0070	3.6
Ky-G_2-9	do	Panther mine, near Panther (2d sample)	do	6	6.49	.0039	.0065	2.3
Ky-Sch-9	do	Schaber mine, 2 miles northeast of West Louisville	do	4	10.78	.0043	.0070	4.4
Ky-Wi-9	Henderson	Wilson Risley mine, Hebbardsville	do	7	8.96	.0042	.0080	2.2
Ky-Co-14	do	Community Coal Company mine, Smith Mills	No. 14	5	3.96	.0075	.0090	5.0
Ky-D-6	Hopkins	Daylight No. 6 mine, Dawson Springs	No. 6	12	3.43	.0067	.0110	1.6
Ky-SP-9	do	Stony Point mine, near Providence	No. 9	10	7.51	.0037	.0072	2.5
Ky-Ho-11	do	Homestead mine, Earlington	No. 11	4	8.44	.0022	.0030	1.6
Ky-Ho-12	do	do	No. 12	3	13.05	.0004	.0005	.5
Ky-BD-9	Ohio	Ken mine, Beaver Dam	No. 9	1	6.70	.003	.0030	2.0
Ky-Oh-9	do	Kentucky Winner mine, Hartford	do	1	2.26	.011	.0110	2.5
Ky-PR-9	Union	Poplar Ridge mine, 2 miles southeast of Sturgis	do	6	4.55	.0057	.0100	1.9
Ky-U-9	do	Uniontown mine, Uniontown	do	6	5.47	.0042	.0030	1.3
Ky-U-11	do	do	No. 11	13	3.87	.005	.0100	1.7
Ky-H-11	Webster	Precision mine, Providence	do	4	15.10	.0009	.0020	1.0
Ky-H-14	do	do	No. 14	9	10.91	.0037	.0140	4.2

TABLE 2.—*Beryllium content of the coal ash and coal samples of the provinces*—Continued

Sample	County	Location and remarks	Bed	Number of samples	Average ash of coal (percent)	Beryllium in ash of coal (percent)		Beryllium average in coal (ppm)
						Average	Maximum	
INTERIOR PROVINCE, WESTERN REGION								
[Ark-Ha-15-Ch represents a columnar sample collected by B. R. Haley, U.S. Geological Survey]								
Arkansas								
Ark-Ha-15-Ch	Franklin	Columnar samples	Charleston	2	16.03	0.0002	0.0002	0.3
Ark-M-UE	Hot Spring	Malvern Brick Co. clay pits, Malvern	Unnamed	1	12.77	.0080	.0080	10.2
Ark-M-LE	do	do	do	2	7.32	.0080	.0080	5.9
Ark-M-LE(tr)	do	Malvern Brick Co. clay pits, Malvern (tree)	do	2	3.63	.0045	.0050	1.6
Ark-Sk-Ch	Johnson	Skidmore mine, 5 miles north of Clarksville	Charleston	2	4.81	.0014	.0020	.7
Ark-ACM-LH(R)	do	Hartman mine, 2 miles northeast of Hartman	Lower Hartshorne(Rider)	1	5.93	.0002	.0002	.1
Ark-ACM-LH	do	do	Lower Hartshorne	3	3.45	.0009	.0020	.3
Ark-PV-LH	Logan	Abandoned mine, 0.5 mile east of Prairie View	do	1	5.84	.0007	.0007	.4
Ark-NS-P	do	Northside Coal Co. mine, Paris	Paris	1	6.20	.0007	.0007	.4
Ark-Ba-LH	Scott	Bates Co. mine, Bates	Lower Hartshorne	2	4.21	.0003	.0003	.1
Ark-Hu-LH	Sebastian	Unnamed mine, 3 miles west of Huntington	do	8	3.37	.0005	.0020	.2
Iowa								
Ia-P-M	Marion	Pershing mine, south of Knoxville	Mammoth	9	10.10	0.0050	0.0200	5.1
Ia-L-K	Wapello	Kirkville mine, near Kirkville	Kirkville	13	12.61	.0016	.0040	2.0
Missouri								
Mo-M_1	Bates	Tiger mine, Hume (1st sample)	Mulberry	6	13.80	0.0012	0.0030	1.7
Mo-M_2(-100)	do	Tiger mine, Hume (2d sample, −100 mesh)	do	6	13.92	.0014	.0036	2.0
Mo-M_2 (F)	do	Tiger mine, Hume (2d sample, float fractions)	do	14	6.14	.0170	.1000	10.4
Mo-T	Henry	Power mine, 2 miles north of Germantown	Tebo	8	16.98	.0003	.0006	.5
Mo-BS	Macon	Bevier mine, Binkley (south pit)	Bevier	5	5.41	.0052	.0100	2.8
Mo-BN	do	Bevier mine, Binkley (north pit)	do	13	7.11	.0067	.0200	4.2
Mo-MU	do	do	Mulky	5	7.84	.0062	.0100	4.9

Oklahoma

Ok-Du-Mc(F)	Coal	Dunn's mine, Coalgate (float fractions)	McAlester	5	3.56	0.0021	0.0060	0.8
Ok-Pa-BA	Craig	Patch No. 1 mine, near Welch	Broken Arrow	6	3.97	.0032	.0040	1.3
Ok-Pa-Fo	do	Patch No. 2 mine, 12 miles northwest of junction of Highway Nos. 60 and 66.	Forsythe	5	4.12	.0086	.0100	3.5
Ok-LS-UH	Haskell	McCurtin mine, 0.5 mile west of McCurtin	Upper Hartshorne	1	7.60	.0002	.0002	1.5
Ok-LS-LH	do	do	Lower Hartshorne	1	4.40	.0001	.0001	<.1
Ok-Ca-St	do	Canadian Mining Company mine, Stigler	Stigler	2	7.55	.0021	.0040	1.6
Ok-Gar-St	do	Garland mine, Keota	do	2	4.96	.0011	.0020	.5
Ok-K-UH	Latimer	Kinta Strip Mining Company mine, Wilburton	Upper Hartshorne	1	5.02	.0030	.0030	1.5
Ok-Da-UH	Le Flore	Dawes mine, Howe	do	1	4.56	.0006	.0006	.3
Ok-LC-Se	McIntosh	Bluebonnet mine, Checotah	Secor	1	9.70	.0030	.0030	2.9
Ok-BH-H	Okmulgee	Blackstone mine, Henryetta	Henryetta	6	2.68	.0068	.0100	1.8
Ok-L-JC	Pittsburg	Lee mine, Blocker	Jones Creek	3	4.11	.0019	.0050	.8
Ok-LS-Mc	do	Carleen No. 5 mine, Krebs	McAlester	1	4.93	.0003	.0003	.1
Ok-MN-BA	Rogers	McNabb mine, Catoosa	Broken Arrow	8	3.14	.0066	.0100	2.1
Ok-RC-BA	do	Rogers mine, Claremore	do	6	2.72	.0110	.0200	3.0

Texas

Tex-Mc-LE	Harrison	McAlester Fuel Co. lignite pit, near Marshall	Unnamed	1	8.93	0.0007	0.0007	0.6

NORTHERN GREAT PLAINS PROVINCE

Mont-P-1 through Mont-P-3 represent samples collected by W. T. Pecora, U.S. Geological Survey; Mont-GS-10501 through Mont-GS-10510 represent samples collected by G. E. Prichard, U.S. Geological Survey; ND-F-49874 through ND-F-49880 represent samples collected by W. D. Johnson, U.S. Geological Survey; Wyo-Ch-He-1 through Wyo-Ch-He-6 represent samples collected by W. J. Mapel, Jr., U.S. Geological Survey]

Montana

Mont-S	Blaine	Sargent Brothers mine, near Chinook	Unnamed	6	15.19	0.0029	0.004	4.4
Mont-B	Cascade	East Belt mine, Belt	do	15	18.25	.0015	.004	2.7
Mont-Su	do	Surmi mine, 30 miles south of Great Falls	do	6	5.95	.0094	.016	5.6
Mont-FC-3	Carbon	Foster Creek mine, Red Lodge	Bed No. 3	3	4.44	.0002	.0003	.1
Mont-G-F	Chouteau	Georges mine, 11 miles south southeast of Box Elder	Flatness	4	5.39	.0033	.009	1.8
Mont-RB-F	do	Rocky Boy Mine, 13 miles south southeast of Box Elder	do	3	4.99	.0022	.003	1.1
Mont-P-1	do	Gilbavey Property, Bearpaw Mountains area	Unnamed (upper bed)	1	26.48	.0003	.0003	.8
Mont-P-2	do	do	Flatness	1	13.80	.0004	.0004	.6
Mont-P-3	do	Blue Pony Property, Bearpaw Mountains area	Unnamed (lower bed)	1	29.00	.0005	.0005	1.5
Mont-AT	Fergus	Anton Tuss mine, 17 miles southeast of Lewistown	Unnamed	16	10.01	.0058	.02	5.8
Mont-CMT	do	Cyril M. Tuss mine, 12 miles southeast of Lewistown	do	15	10.57	.0039	.005	4.1
Mont-Gi-BM	Musselshell	Gildroy mine, 19 miles south of Roundup	Bull Mountain	4	4.37	.0025	.004	1.1
Mont-Ke-CC	do	Keene No. 2 mine, Keene	Carpenter Creek	7	5.69	.0019	.01	1.1
Mont-K-Ro	do	Klein No. 2 mine, Roundup	Roundup	11	6.39	.002	.008	1.3
Mont-K-Ro-KB&Tr	do	do	do	7	4.39	.011	.030	4.8
Mont-N-Ro	do	Niess mine, 3 miles southwest of Roundup	do	2	7.01	.013	.02	9.1
Mont-N-Ro-KB	do	do	do	2	2.50	.012	.013	3.0

TABLE 2.—*Beryllium content of the coal ash and coal samples of the provinces*—Continued

Sample	County	Location and remarks	Bed	Number of samples	Average ash of coal (percent)	Beryllium in ash of coal (percent)		Beryllium average in coal (ppm)
						Average	Maximum	
Montana—Continued								
Mont-SW-Ro	Musselshell	Sheridan Wyoming Coal Co., Roundup No. 3 mine, Roundup.	Roundup	2	4.47	0.007	0.009	3.2
Mont-GS-10501	Richland	SE¼SE¼SW¼ sec. 2, T. 26 N., R. 56 E	H	1	56.16	<.0001	<.0001	<.5
Mont-GS-10502	do	NE¼NW¼SE¼ sec. 21, T. 25 N., R. 55 E	F	1	15.92	.004	.004	6.0
Mont-GS-10503	do	NW¼NW¼SE¼ sec. 19, T. 27 N., R. 55 E	E	1	25.32	.001	.001	2.5
Mont-GS-10504	do	NE¼SE¼NE¼ sec. 30, T. 27 N., R. 57 E	G	1	7.80	.002	.002	1.6
Mont-GS-10505	do	SW¼NE¼NW¼ sec. 29, T. 27 N., R. 56 E	G	1	16.16	.002	.002	3.2
Mont-GS-10506	do	SE¼SE¼SE¼ sec. 9, T. 26 N., R. 57 E	H	1	10.02	.001	.001	1.0
Mont-GS-10507	do	SW¼SW¼SW¼ sec. 7, T. 27 N., R. 55 E	D	1	9.80	.0005	.0005	.5
Mont-GS-10508	do	SE¼SW¼SE¼ sec. 20, T. 25 N., R. 55 E	H	1	14.14	<.0001	<.0001	<.2
Mont-GS-10509	do	SE¼NW¼SW¼ sec. 18, T. 27 N., R. 55 E	F	1	14.12	.0006	.0006	.8
Mont-GS-10510	do	SE¼SW¼NW¼ sec. 17, T. 27 N., R. 56 E	F	1	24.20	.0005	.0005	1.2
Mont-Col-R	Rosebud	Northwest Improvement Co., Rosebud mine, Colstrip	Rosebud	2	5.69	.0001	.0002	<.1
North Dakota								
ND-TT-N	Burke	Truax Traer Coal Co. mine, sec. 19, T. 162 N., R. 93 W.	Noonan	7	7.11	0.0003	0.004	0.2
ND-BN-N	Divide	Baukol Noonan Coal Co. mine, Noonan	do	17	7.68	.0006	.004	.5
ND-BN-$\frac{30}{N}$	do	do	Unnamed (30 ft above Noonan).	2	14.93	.0001	.0002	.1
ND-BN-$\frac{50}{N}$	do	do	Unnamed (50 ft above Noonan).	13	9.32	.0011	.006	1.0
ND-Cu-GC	McLean	Traux Traer Coal Co., Custer mine, sec. 19, T. 148 N., R. 83 W.	Garrison Creek	5	5.57	.0025	.003	1.4
ND-KR-Bu	Mercer	Knife River Coal Co., Beulah mine, sec. 18, T. 144 N., R. 87 W.	Benlah-Zap	3	8.54	.0008	.003	.7
ND-TT-DS	do	Truax Traer Coal Co., Dakota Star mine, sec. 21, T. 145 N., R. 86 W.	do	2	3.45	<.0001	<.0001	<.1
ND-F-49874	Oliver	SW¼ sec. 14, T. 142 N., R. 87 W	Otter Creek (lower bed)	1	7.60	.001	.001	.8
ND-F-49875	do	NW¼ sec. 33, T. 143 N., R. 86 W	Red Butte	1	9.70	.0003	.0003	.3
ND-F-49876	do	NE¼ sec. 9, T. 143 N., R. 86 W	Beulah-Zap (upper bed)	1	14.70	.0002	.0002	.3
ND-F-49877	do	NW¼ sec. 35, T. 141 N., R. 86 W	Local, 100 ft above Otter Creek.	1	10.50	.0005	.0005	.5
ND-F-49878	do	SE¼ sec. 3, T. 141 N., R. 86 W	Local, 45 ft above Otter Creek.	1	20.00	.002	.002	4.0
ND-F-49879	do	NE¼ sec. 14, T. 142 N., R. 87 W	Herman	1	9.00	.0005	.0005	.5
ND-F-49880	do	SE¼ sec. 9, T. 142 N., R. 87 W	Otter Creek (lower bed)	1	21.00	.0007	.0007	1.5

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Wyoming

Wyo-Wy-S	Campbell	Wyodak mine, east of Gillette, T. 50, R. 71 W	Smith	3	6.93	0.0001	0.0001	0.7
Wyo-Ch-He-1	Johnson	Lake de Smet area	Healy	1	23.40	.0001	.0001	.2
Wyo-Ch-He-2	do	do	Unnamed (at Dry Creek level).	1	22.90	.0001	.0001	.2
Wyo-Ch-He-3	do	do	Unnamed (24 ft below Healy).	1	17.40	.0005	.0005	.8
Wyo-Ch-He-4	do	do	Unnamed (160 ft below Healy).	1	14.40	.0001	.0001	.1
Wyo-Ch-He-5	do	do	Unnamed (335 ft below Healy).	1	9.50	.0001	.0001	.1
Wyo-Ch-He-6	do	do	Unnamed (110 ft below Healy).	1	25.70	.0002	.0002	.5
Wyo-Mo-Mo	Sheridan	Monarch Coal Co. mine, Monarch	Monarch	6	4.89	.0002	.0007	.1

ROCKY MOUNTAIN PROVINCE

[Colo-500 to Colo-650, grab samples except Colo-570, a channel sample, and Wyo-620 and Wyo-630, grab samples, were collected by Larry Warner, U.S. Geological Survey]

Colorado

Colo-640	Boulder	Black Diamond mine, Lafayette	Laramie	1	6.30	<0.0001	<0.0001	0 <0.1
Colo-600	Fremont	Exposure on Route 50 between Canon City and Florence	Brookside	1	8.20	.0006	.0006	.5
Colo-610	do	Double Dick mine, southeast of Canon City	Unnamed	1	13.60	.0002	.0002	.3
Colo-Sun-A	Garfield	Sunlight mine, Cattle Creek	A	11	8.31	.0004	.0007	.3
Colo-Sun-B	do	do	B	4	5.25	.0010	.0030	.5
Colo-Sun-C	do	do	C	4	4.12	.0006	.0010	.2
Colo-Sun-D	do	do	D	8	3.51	.0015	.0090	.5
Colo-520	do	Exposure 10 miles north of Rifle	Unnamed	1	12.90	.0009	.0009	1.2
Colo-530	do	Exposure 7 miles north northeast of Rifle	do	1	8.60	.0009	.0009	.8
Colo-540	do	Exposure 8 miles north of Silt	do	1	9.80	.0004	.0004	.4
Colo-Som-B	Gunnison	Somerset mine, Somerset	B	5	5.16	.0006	.0009	.3
Colo-Som-C	do	do	C	1	4.21	.0030	.0030	1.3
Colo-HN-D	do	Hawks Nest mine, Somerset	D	4	4.94	.0003	.0003	.1
Colo-Oli-D	do	Oliver No. 2 mine, Oliver	do	1	4.95	.0620	.0620	31
Colo-CB-UMV	do	Crested Butte mine, Crested Butte	Upper Mesaverde	4	3.77	.0015	.0050	.6
Colo-500	do	Mine on east side of Slate Creek, 4 miles north of Crested Butte.	Unnamed	1	16.80	.0004	.0004	.6
Colo-Ke-Wn	Huerfano	Kebler No. 2 mine, Tioga	Walsen	1	20.72	.0020	.0020	4.1
Colo-590	do	Exposure on Route 6, 5 miles west of La Veta	do	1	21.20	.0004	.0004	.8
Colo-Vi-Mv-Ri	La Plata	Victory mine, 5 miles west of Durango	Mesaverde rider	2	14.00	.0013	.0020	1.8
Colo-Vi-Mv	do	do	Mesaverde	4	9.72	.0017	.0060	1.6
Colo-Vi-Mv'	do	do	Unnamed (80 feet above Mesaverde).	1	25.24	.0002	.0002	.5
Colo-550	do	Castle mine, 5 miles northwest of Durango	Unnamed	1	3.90	.0003	.0003	.1
Colo-560	do	O. K. mine, 4 miles northwest of Durango	do	1	4.50	.0006	.0006	.3
Colo-570	do	Exposure 2 miles south of Durango	do	1	36.80	.0001	.0001	<.4

TABLE 2.—*Beryllium content of the coal ash and coal samples of the provinces*—Continued

Sample	County	Location and remarks	Bed	Number of samples	Average ash of coal (percent)	Beryllium in ash of coal (percent)		Beryllium average in coal (ppm)
						Average	Maximum	
Colorado—Continued								
Colo-580	La Plata	Yellow Jack mine, near Bayfield	Unnamed	1	16.50	0.0003	0.0003	0.5
Colo-Fr-Fr	Las Animas	Frederick mine, Valdez	Frederick	2	13.13	.0009	.0010	1.2
Colo-Ca-Ca	Mesa	Cameo mine, Cameo	Cameo	1	1.30	.0040	.0040	.5
Colo-RW-Co	Moffat	Red Wing mine, Axial (Lower part)	Collum	2	1.96	.0003	.0004	<.1
Colo-RW-Co'	do	Red Wing mine, Axial (Upper part)	do	3	4.31	.0002	.0003	<.1
Colo-WH-WH	do	Wise Hill mine, near Craig	Wise Hill	8	5.12	.0004	.0008	.2
Colo-510	Pitkin	Exposure on State Route 327, 4 miles south of Redstone	Unnamed	1	11.70	.0005	.0005	.6
Colo-Ed-Lx	Routt	Edna mine, Oak Creek	Lennox	1	5.20	<.0001	<.0001	<.1
Colo-Key-Pi	do	Keystone mine, Routt	Pinnacle	3	5.48	.0012	.0030	.7
Colo-Ra-Pi	do	Ramsey mine, Hayden	do	9	4.88	.0024	.0080	1.1
Colo-Ha-Wa	Routt	Harris mine, Mount Harris	Wadge	1	4.16	.0020	.0020	.8
Colo-650	Weld	Washington mine, Erie	Laramie	1	7.80	.0003	.0003	.2
Colo-Lin	do	Lincoln mine, Erie	do	4	5.63	.0008	.0030	.4
New Mexico								
NM-MaA-WA	Sante Fe	Albuquerque and Cerrillos Coal Co. mine, Madrid (anthracite coal).	White Ash	2	36.15	<0.0001	<0.0001	<0.4
NM-MaB-WA	do	Albuquerque and Cerrillos Coal Co. mine, Madrid (bituminous coal).	do	2	13.20	.0002	.0002	.3
Utah								
U-Su-Su	Carbon	Sunnyside No. 2 mine, Sunnyside	Lower Sunnyside	5	7.85	0.0004	0.0008	0.3
U-Su-Su(-100)	do	Sunnyside No. 2 mine, Sunnyside (−100 mesh)	do	6	6.07	.0005	.0009	.3
U-Su-Su(F)	do	Sunnyside No. 2 mine, Sunnyside (float fractions)	do	20	2.35	.0024	.0060	.6
U-Ke-Ke	do	Kenilworth mine, Kenilworth	Kenilworth	2	6.73	<.0001	<.0001	<.1

Wyoming

Wyo-Nu-HaP$_1$	Carbon	Nugget mine, Pit No. 1, Hanna	Hanna No. 1	5	2.58	<0.0001	<0.0001	<0.1
Wyo-UP-Ha$_2$	do	Hanna No. 4A mine, Hanna	Hanna No. 2	3	5.30	.0003	.0010	.2
Wyo-Ga-F$_1$	do	Gary mine, 12 miles southeast of Hanna	Finch No. 1	5	4.80	.0002	.0005	.1
Wyo-Ga-F$_2$	do	do	Finch No. 2	2	5.00	.0016	.0030	.8
Wyo-Ga-F$_3$	do	do	Finch No. 3	3	4.97	.0006	.0010	.8
Wyo-Ga-F$_4$	do	do	Finch No. 4	2	1.35	.0005	.0009	<.1
Wyo-Ga-F$_5$	do	do	Finch No. 5	13	7.04	.0001	.0008	<.1
Wyo-630	do	Mine (pit) east of Hanna	Unnamed	1	4.60	.0003	.0003	.1
Wyo-Br-Km	Lincoln	Brilliant mine, Frontier	Kemmerer	4	4.38	.0001	.0002	<.1
Wyo-El-El	do	Elkol mine, Elkol	Elkol	1	2.30	.0007	.0007	.2
Wyo-St-1	Sweetwater	Stansbury mine, Stansbury	Rock Springs No. 1	1	3.38	.0003	.0003	.1
Wyo-St-7½	do	do	Rock Springs No. 7½	7	2.71	.0110	.0200	3.1
Wyo-Re-7	do	Reliance mine, Reliance	Rock Springs No. 7	3	5.09	.0023	.0060	1.2
Wyo-Re-9	do	do	Rock Springs No. 9	2	2.82	.0250	.0300	7.0
Wyo-Re-11	do	do	Rock Springs No. 11	1	4.25	.0300	.0300	12.7
Wyo-Sup-9	do	Superior D. O. Clarke mine, Superior	Rock Springs No. 9	2	1.72	.0380	.0700	6.5
Wyo-620	do	Copenhagen mine, Superior	Unnamed	1	10.20	.0004	.0004	.4

GENERAL REMARKS ON THE DATA

A summary of the maximum and minimum averages of beryllium content in ash and in coal for beds given in table 2 is presented in table 3. In several instances, table 2 gives samples with a higher beryllium content than those given in table 3; such samples usually were selected or floated and, therefore, could not be considered as being representative of a bed. The maximum and minimum averages of the beryllium in ash are not necessarily the same as those for parts per million in coal.

In the northern part of the Appalachian region the Lower Kittanning and the Middle Kittanning were the only two beds sampled. The percentage of beryllium in ash seems to indicate dissimilarity between the beds, but this is explained by the different concentration

TABLE 3.—*Summary of maximum and minimum averages of the beryllium content of beds given in table 2*

	Maximum beryllium in ash	Average ash of coal	Minimum beryllium in ash	Ash average of coal	Beryllium in coal (ppm)		Number of—	
	Percent				Maximum	Minimum	Bed averages	Individual samples
Eastern province, Appalachian region								
Northern part:								
Lower Kittanning bed	0.0041	6.06	0.0016	9.85	4.1	1.6	14	104
Middle Kittanning bed	.014	3.02	.0016	11.07	4.2	1.5	6	46
Southern part:								
Alabama	.015	1.71	.0011	4.31	4.6	.5	23	68
Eastern Kentucky	.11	2.85	.001	4.31	31	.4	19	87
Tennessee	.0046	8.91	.0005	2.39	11	.1	7	29
Virginia and West Virginia	.0072	4.99	.0007	6.60	3.6	.2	11	30
Interior province								
Eastern region:								
Illinois (all samples)	0.011	5.72	0.0004	16.21	6.3	0.7	35	253
Bed 5	.011	3.20	.0011	9.52	3.2	1	12	90
Bed 6	.0044	6.28	.0004	16.21	4	.7	12	74
Indiana (all samples)	.017	5.25	.0032	6.30	12	1.5	10	83
Western Kentucky (all samples)	.0093	10.18	.0004	13.05	9.5	.5	17	96
Bed 9	.0057	5.87	.0013	13.28	4.3	1.7	10	47
Western region:								
McAlester Basin	.003	5.02	.0001	4.40	2.9	<.1	18	44
All other	.011	2.72	.0003	16.98	5.1	.5	12	110
Northern Great Plains province								
Jurassic and Cretaceous	0.0094	5.95	0.0015	18.25	5.8	2.7	5	58
Paleocene and Eocene	.013	7.01	<.0001	3.45	9.1	<.1	43	131
Rocky Mountain province								
Sweetwater County, Wyo.	0.038	1.72	0.0003	3.38	13	0.1	7	17
All other	.062	4.95	<.0001	5.20	31	<.1	53	174

effect of the low-ash content of coals. However, on a parts-per-million basis the beds are quite similar.

In the southern part of the Appalachian region, the greatest variations in the beryllium content of the coal ash are found in eastern Kentucky. The sample with the highest content, 0.24 percent in 1.00 percent ash, is found in block 1–b of columnar sample Ky–IH. The bed with the highest average of beryllium, 0.11 percent in 2.85 percent ash (31 ppm in coal) is also found in the same columnar sample. Columnar sample Ky–SX, has the next highest beryllium content in coal (19 ppm).

In Alabama only 68 of about 200 block samples of coal were analyzed. In this group, as well as in samples from Georgia, no unusual concentrations of beryllium are found. In table 2 the averages of the columnar samples from Alabama range from less than 1 to 4.6 ppm beryllium in coal. These averages show some similarity to the averages of coal from the northern part of the Appalachian region.

In the Interior province, the eastern region shows two persistent trends. On the basis of the percentage of beryllium in ash as well as parts per million in coal, the Indiana coal beds contain noticeably more beryllium than those of western Kentucky and Illinois; and the coal samples collected from the perimeter of the basin contain more beryllium than do the samples of the central part.

Coals from the Western region of this province also show a differentiated distribution pattern. Coal beds of northern Oklahoma, Missouri, and Iowa contain 1.3 to 5 ppm beryllium and have more beryllium than the coal beds of the McAlester basin in Oklahoma and Arkansas. The latter beds range from less than 0.1 to 2.9 ppm in beryllium content, but only four of the bed samples average more than 1 ppm. However, two Eocene lignite beds from Arkansas averaged 10.2 and 5.9 ppm beryllium in coal, and a group of float fractions of sample Mo–M, averaged 10 ppm.

In the northern Great Plains province the Jurassic coal beds of the Lewistown and Great Falls fields have the highest content of beryllium, 2.7 to 5.8 ppm; the sample of Cretaceous coal of the Milk River field is also in this range. With a few exceptions, averages of beds of Paleocene coal are less than 2 ppm. All the samples of this province from Wyoming have less than 1 ppm beryllium.

Most of the coal samples of the Rocky Mountain province have a low beryllium content. Only one group of samples from Sweetwater County, Wyo., has any beryllium enrichment. The maximum amount of beryllium (31 ppm) given in table 3 was found in a block of bone coal from the top of the bed and should not be considered as significant.

DISTRIBUTION OF BERYLLIUM IN COAL

SOME PETROGRAPHIC CONSTITUENTS

During the examination of blocks of coal, selections of samples of vitrain, fusain, and other petrographic constituents of coal were made, and some of these were analyzed for beryllium. The data are presented in table 4.

The data show that the ash of vitrain is enriched in beryllium compared with the ash of the whole coal. The data also show that on a parts-per-million basis the vitrain contains more beryllium than does the whole coal. Because the major petrographic component in banded coal beds is vitrain, it follows that the bulk of the beryllium that is found in coal of this type is associated with vitrain.

TABLE 4.—*Beryllium and ash content of vitrain and fusain samples*

Code	Ash (percent)			Be in ash (percent)			Be in coal (ppm)		
	Whole coal	Vitrain	Fusain	Whole coal	Vitrain	Fusain	Whole coal	Vitrain	Fusain
O–Mal–Mk–4	6.56	3.50	13.04	0.001	0.01	0.0004	0.66	3.5	0.52
O–368 [1]	10.80	---	19.60	.002	---	.0005	2.2	---	1.0
Va–310	3.42	3.00	5.80	.002	.01	.0006	.7	3.0	.4
WVa–215	---	.90	9.60	---	.004	<.0001	---	.4	<.1
Ill–P–1–9	5.26	[2] 2.02	---	.005	[2] .03	---	2.6	6.1	---
Mont–K$_1$–6	---	3.98	7.08	---	.003	.0001	---	1.2	<.07

[1] Fusain sample containing some durain.
[2] Sample rich in vitrain.

Vitrain and fusain are probably derived from similar plant components; however, they have undergone different chemical changes to create these constituents that are now found in coal. A comprehensive report on this subject is given by Francis (1954). In addition to the lower beryllium content of fusain, the contents of the elements oxygen, nitrogen, and hydrogen are also lower and have presumably been lost during the metamorphism of the plant components to fusain. This relationship suggests two possible causes for the lower beryllium content of the fusain samples. Most or all the beryllium now found in the coal may be there as a result of plant accumulation. In the formation of beryllium-organic complexes, beryllium is known to have a tendency to combine with oxygen as the donor element (Martell and Calvin, 1952, p. 169). The loss of beryllium in fusains parallels a similar loss of oxygen, and nitrogen, and could reflect the breakdown of beryllium-organic complexes and other compounds containing nitrogen and oxygen during fusinization. Another possibility is that some of the beryllium found in coal is due to accumulation by plants, but that some, or perhaps even a large part of it, originated in the coal beds as a result of fixation by either adsorption on the colloidal organic particles in the swamp or by the formation of beryl-

lium-organic complexes with the decomposition products of the plant tissues.

The beryllium complexes are very stable; so they probably have a much greater role than does adsorption by colloidal particles. Therefore, it is reasonable to propose that during vitrinization, an addition of beryllium is retained, whereas, if fusinization takes place, very little chance is given for the accumulation of beryllium by adsorption or by formation of organic beryllium complexes. In the vitrinization process numerous organic compounds are released with which beryllium could form complexes, whereas in the more drastic fusinization process, it is possible that these compounds are destroyed.

It has been shown by Hoagland (1952) that beryllium can be very toxic to plants particularly at low pH values. The fact that some coal contains much beryllium raises the question as to why the beryllium did not prove toxic to the plants growing where these amounts of beryllium accumulated, provided, of course, that the accumulation of beryllium was syngenetic with swamp development. As beryllium complexes are very stable, it would be possible to have large amounts of the element enter the swamp and not prove toxic to the plants growing there because of the formation of these beryllium complexes. Under this last proposal larger amounts of beryllium would be expected to be found near the perimeter of basins rather than in the interior parts (p. 286).

FLOAT-SINK FRACTIONS

Of the many samples that were floated, two are used to illustrate the distribution of beryllium in ash of various float and sink fractions of coal. The results for these two samples, Ky–U–9–1 and Ky–PR–9–2, are shown in figure 42. The coals were ground to pass through a 100-mesh sieve. Forty grams of the coal was evenly distributed into four 100-ml centrifuge tubes, and a carbon tetrachloride-alcohol mixture with a specific gravity of 1.28 was added. The samples were centrifuged at 800 rpm for 20 minutes. The float cake and liquid were decanted into a Buchner funnel. The sink fraction was then floated at a specific gravity of 1.32. The procedure was repeated at specific gravities of 1.36 and approximately 1.6.

Two significant features are evident from the graph (fig. 42), the abrupt increase of beryllium in the light float fractions and the asymptotic approach of the curve to the 0 line as the ash content approaches and goes beyond 50 percent of the sample. In the region of low-ash content the coal substance contains almost all the beryllium. This is further indicated by the approach of the curve to the 0 line in the region of high-ash content. It is obvious that the maximum beryllium that can be contributed by the extraneous ash of the coal is less than

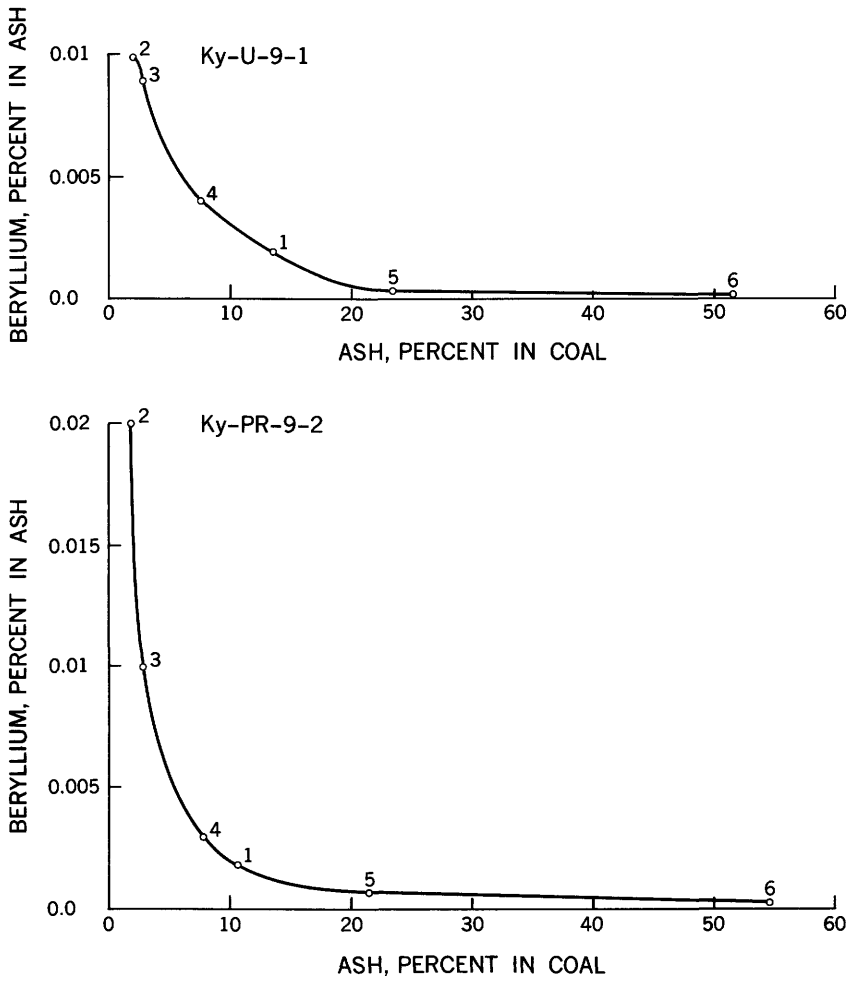

FIGURE 42.—Graphs showing beryllium distribution of the ash of float and sink fractions of coal. Plotted points, 1–6, for both samples are, 1, whole coal; 2, sp gr <1.28; 3, sp gr 1.28–1.32; 4, sp gr 1.32–1.36; 5, sp gr 1.36–1.60; 6, sp gr >1.6.

0.0002 percent, or 2 ppm of the ash present. This is also the percentage estimated as the average abundance of beryllium in the earth's crust.

In order to substantiate that the extraneous ash contains less than 0.0002 percent beryllium, it is necessary to examine the sink fractions (specific gravity >1.6) of the coal. The sink fraction for sample Ky–U–9–1 contains 1 ppm beryllium in coal and that for sample Ky–PR–9–2 contains 1.6 ppm in coal. If the ash contains 2 ppm of beryllium, then the extraneous ash would contain all the beryllium in sample Ky–U–9–1, and about 60 percent in sample Ky–PR–9–2.

Therefore, little or no beryllium may be present in the coal of the sink fractions, which would be contradictory to the finding that most of the beryllium is in the coal substance. An alternative is that the beryllium content of the extraneous ash is well below 0.0002 or even 0.0001 percent; and, therefore, the beryllium content of the ash-free coal of these fractions approaches that of the original sample and its float fractions.

Table 5 gives several additional samples that yielded similar results.

In all these, it is apparent that the beryllium content of the inorganic constituents of coal is extremely low and that most of the beryllium in coal samples is associated with the organic matter of the coal.

Horton and Aubrey (1950, p. s46) also show that all or almost all beryllium in the coal samples they examined is associated with the organic matter.

TABLE 5.—*Float-sink experiments with coal samples showing the trend of beryllium content*

Sample	Specific gravity	Ash (percent)	Be in ash (percent)	Be in coal (ppm)
Ky–SX–13	<1. 32	1. 98	0. 17	35
	>1. 32	7. 00	. 006	4. 2
Ok–Mc–D–1	<1. 32	3. 40	. 002	. 68
	>1. 32	21. 50	. 0001	. 22
O–Mal–LK–7	<1. 26	1. 56	. 01	1. 6
	1. 26–1. 30	2. 28	. 008	1. 8
	1. 30–1. 32	4. 70	. 003	1. 4
	>1. 32	40. 02	. 0002	. 8
U–Su–Su–6A	<1. 24	. 85	. 005	. 43
	1. 24–1. 28	1. 14	. 005	. 57
	1. 28–1. 32	1. 80	. 003	. 54
	>1. 32	15. 17	. 0002	. 30
U–Su–Su–10	<1. 24	1. 17	. 003	. 35
	1. 24–1. 28	1. 54	. 002	. 31
	1. 28–1. 32	3. 90	. 001	. 39
	>1. 32	18. 90	<. 0001	<. 19

COLUMNAR SAMPLES

Plate 1 shows the distribution of beryllium in coal blocks of columnar samples from various coal beds of the Interior province. The effect of dilution of the high-ash content of coal on the beryllium content of the ash is shown by the graphs. Almost invariably the higher the ash figure becomes, the lower is the beryllium content of the ash. As a result of the varying ash content of the coal it is difficult to ascertain the distribution of the beryllium in the coal from the beryllium-in-ash data; consequently, the results were calculated in parts per million in coal and are presented in the third column of the graphs. Several beds show a somewhat higher beryllium content at the top

and bottom of the beds; however, quite often the central parts of the beds are enriched. This is particularly noticeable in the two Indiana beds. It has been suggested that large concentrations of elements in the top and bottom parts of a coal bed were accumulated after burial of the beds. The assumption is that percolating solutions transfer these elements from the enclosing strata into the coal. The authors' data do not suggest that such a process took place for beryllium. There is no pronounced overall large-scale increase of beryllium content toward any part of a bed; rather there is an erratic distribution of the element, and blocks of coal with a large degree of variance in their beryllium content can be found adjacent to one another. Probably no secondary redistribution of beryllium took place. No redistribution of beryllium in vitrains and fusains was observed. It is believed that these observations substantiate the premise that the beryllium now found in the coal and its constituent parts is the result of syngenetic rather than postdepositional processes.

BETWEEN COAL BEDS

Samples of beds from the Rocky Mountain and the northern Great Plains provinces (as well as beds 5 and 6 of Illinois and the Lower and Middle Kittanning beds of Ohio) provide the best example of beryllium in the different coal beds in limited areas. Table 6 has been compiled from data in table 2.

Table 6 shows that the average beryllium content of coal in the Finch beds (samples Wyo–Ga–F_1 to $-F_5$) ranges from 0.1 to 0.8 ppm. No systematic variation is apparent in these samples. In a series of beds in the Rock Springs formation, the upper beds (samples Wyo–Re–9 and –11) contain much more beryllium than do the lower beds; but, as some of these beds are represented by the analysis of only one of several blocks of the columnar sample of the bed, the distribution of the beryllium content in these beds cannot be determined with certainty.

Auger samples of beds in four areas of the northern Great Plains province were analyzed (table 6). However, these samples do not represent the entire sequence of coal beds in these areas because there probably are beds stratigraphically lower and higher than the ones sampled. In three of the four areas the lowermost and the uppermost beds have less beryllium than do some of the intermediate beds. In the other area (Mont–P) there is little difference in the three beds; in fact the Flatness bed has a greater range in the averages of three of its samples than exists between the beds. In area Mont–GS there is also a similarity in the average beryllium content of the following beds: E, 2.5 ppm; F, 2.7 ppm; and G, 2.4 ppm.

TABLE 6.—*Beryllium content of various coal beds in limited areas*

Position of beds	Sample	Bed	Beryllium in coal (ppm)
	Rocky Mountain province		
Upper	Wyo-Ga-F_5	Finch No. 5	<0.1
	Wyo-Ga-F_4	Finch No. 4	<.1
to	Wyo-Ga-F_3	Finch No. 3	.8
	Wyo-Ga-F_2	Finch No. 2	.8
lower	Wyo-Ga-F_1	Finch No. 1	.1
Upper	Wyo-Re-11	No. 11	12.7
	Wyo-Re-9	No. 9	7.0
to	Wyo-Sup-9	No. 9	6.5
	Wyo-St-7½	No. 7½	3.1
	Wyo-Re-7	No. 7	1.2
lower	Wyo-St-1	No. 1	.1
	Northern Great Plains province		
Upper	Mont-P-1	Unnamed	0.8
	Mont-P-2	Flatness	.6
to	Mont-RB-F	do	1.1
	Mont-G-F	do	1.8
lower	Mont-P-3	Unnamed	1.5
Upper	Mont-GS-10501	H	<.5
	Mont-GS-10506	do	1.0
	Mont-GS-10508	do	<.2
	Mont-GS-10504	G	1.6
to	Mont-GS-10505	do	3.2
	Mont-GS-10502	F	6.0
	Mont-GS-10509	do	.8
	Mont-GS-10510	do	1.2
	Mont-GS-10503	E	2.5
lower	Mont-GS-10507	D	.5
Upper	ND-F-49877	Unnamed	.5
to	ND-F-49878	do	4.0
lower	ND-F-49874	Otter Creek (lower bed)	.8
	ND-F-49880	do	1.5
Upper	Wyo-Ch-He-1	Healy	.2
	Wyo-Ch-He-3	Unnamed	.8
to	Wyo-Ch-He-6	do	.5
	Wyo-Ch-He-4	do	.1
lower	Wyo-Ch-He-5	do	.1

The similarity in beryllium content that would probably exist for beds in the same general area if a large number of samples of the same bed were analyzed is best shown by the following table.

Bed	Number of bed samples	Average beryllium in coal (ppm)
Illinois No. 5	12	1.6
Illinois No. 6	12	1.8
Ohio Lower Kittanning	10	2.5
Ohio Middle Kittanning	6	2.6

These comparisons are made of beds that are stratigraphically relatively close together. The similarity in their beryllium content serves as an indicator that source material during the deposition of these different beds changed very little. It is probable that these similarities in succeeding beds are found only in the Paleozoic basins

of the eastern and central United States where coal beds were deposited in large continuous sheets. Perhaps the great differences in the western basins are the result of the nature of the depositional basins. Coal was deposited in small isolated basins that had little or no continuity, and as a result some sites could receive a large influx of material whereas others could be completely cut off from a source.

The examples given in the preceding table indicate that from an analysis of one or only a few samples of an extensive coal bed, no significant prediction can be made as to the average amount of beryllium in a bed nor can any comparison be made between beds. Thus, beds with an unusual beryllium content such as those of eastern Kentucky and Indiana should be studied in more detail.

COAL ASH OF THE PROVINCES

There are 1,385 analyses given in table 2; however, 43 of them were late additions for the Eastern region of the Interior province. Only the results of the earlier 1,342 analyses are discussed in this bulletin. The 43 additional samples analyzed are not discussed because they would not change the results to any large degree. The summary shown in figure 43 indicates that a significant difference exists between the average beryllium content of the coal ash of the different provinces. These differences would also apply to the beryllium content of the coal as the difference between the ash averages are small (table 7). Figure

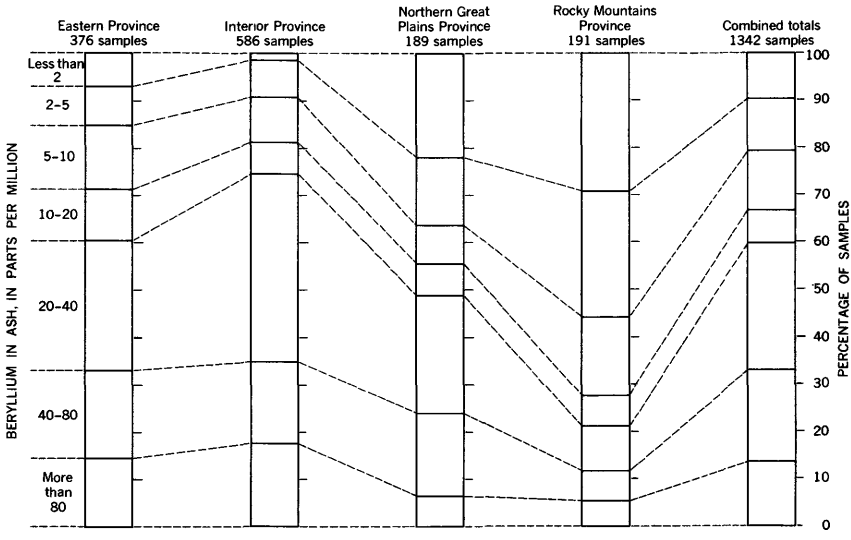

FIGURE 43.—Correlation chart showing distribution of the individual samples by province and by the beryllium content of the ash.

43 shows that the Rocky Mountain province has the largest number of analyses in the lower beryllium ranges (72 percent have less than 10 ppm), whereas the Interior province has only 18.6 percent in the same category. Data on page 255 compiled by Zilbermintz and Rusanov (1936) show a range in this category from 5.6 to 64.7 percent for various deposits in the U.S.S.R. Thus, there seems to be a general similarity between the American coals and those of the U.S.S.R.

The averages by province for beryllium in ash further accentuate these differences (table 7). The Rocky Mountain province has the lowest average content (24 ppm or 12 clarkes), the northern Great Plains province has one slightly higher, the Interior province has double that of the Rocky Mountain province, and the Eastern province has an average content still higher (62 ppm or 32 clarkes). Because the average ash content of the coal is about the same, approximately the same ratios would be maintained if the beryllium content in coal was determined in parts per million.

TABLE 7.—*Beryllium content of the average ash in the coal samples of the provinces*

Province	Number of samples	Average ash (percent)	Average beryllium content of the ash	
			(ppm)	(clarkes)
Eastern	376	7. 59	62	31
Interior	586	7. 71	49	24. 5
Northern Great Plains	189	9. 83	27	13. 5
Rocky Mountain	191	6. 22	24	12
Total or average	1, 342	7. 74	46	23

Table 7 infers that the beryllium content of the coal beds of the provinces depends upon the rank and the age of the coal. The older (Pennsylvanian) and higher rank coal of the Eastern and Interior provinces contains on the average much more beryllium than does the younger (Cretaceous to Eocene) and lower rank coal of the other two provinces. A closer inspection of the data invalidates such a relationship. The Jurassic coal beds of Montana contain approximately the same amount of beryllium as do the Pennsylvanian coal beds. In Sweetwater County, Wyo., coal beds contain much more beryllium than do any of the other coal beds of their age, and more than many Pennsylvanian coal beds. The coal beds of Oklahoma and Arkansas, although all are of Pennsylvanian age, differ greatly in their beryllium content. Although the coal beds of Arkansas are of higher rank, it is particularly noticeable that they contain much less beryllium than do those of northern Oklahoma. The data show extreme differences in the beryllium content of coal beds of the same rank and age, as well as

similarities between differing ranks and ages. It is doubtful, therefore, that the age and to a limited extent, the rank of coal have any influence on its beryllium content. As the authors suggested earlier, the beryllium content is dependent on the quantity of the element introduced into a coal-forming swamp from the surrounding borderland during deposition.

EFFECTS OF POSITION IN THE BASIN AND PROXIMITY TO SOURCE ROCKS

The data show that beryllium may be enriched in the coal samples taken from the marginal areas of a depositional basin; an additional enrichment may result if the eroding source rocks in the vicinity of the areas are high in beryllium. However, a limitation is that the exact original extent of the coal beds is not known, and consequently the position of the samples in the original basin cannot be ascertained.

Figure 44 shows the average beryllium content of columnar samples of bed 5 of Illinois and its correlatives in Indiana and western Kentucky. The 2 northernmost samples of bed 5, which are definitely nearer the edge of the depositional basin that the next 4 samples to the south, contain more beryllium than any of these, or for that matter, of any other sample of bed 5 in Illinois.

In the northern Great Plains province the Paleocene coal beds that contain more beryllium are nearer to the major source of sedimentation. In the Appalachian region where the general direction of the sedimentary source was from the southeast a similar relation is found. In the two samples of the Hazard No. 4 bed in eastern Kentucky (table 2), Ky–SX (19 ppm beryllium in coal) is much closer to a possible southeastern source of sedimentation than is Ky–Col_1 (0.7 ppm beryllium in coal). Headlee and Hunter (1955, p. 100) show that the coal beds of the southern part of the State contain more beryllium than do those of the northern part. The Pocahontas coal beds of Virginia and of southeastern West Virginia have the highest content in beryllium. These observations show that the position in the depositional basin and the proximity to a primary source have an effect on the beryllium content of coal beds.

Some coal samples of eastern Kentucky show the effect of erosion on rocks containing beryllium. Dikes of southwestern Virginia and northwestern North Carolina are possible sources of the beryllium in the coal beds of eastern Kentucky. Kulp and others (1957) give apparent ages of 320 to 370 million years to these rocks. Whether or not these rocks were subject to erosion during Pennsylvanian time is uncertain; however, the accumulation of beryllium in the coal beds nearest to these rocks would seem to indicate that they were. McFarlan (1943, p. 99–110) reported that the basal sandstone and conglom-

erate of the Pennsylvanian formations of the eastern and western basins of Kentucky contain pebbles of vein quartz and suggested that the source of the pebbles was from outside Kentucky. This is a further indication that erosion of the dikes could have been taking place by Pennsylvanian time.

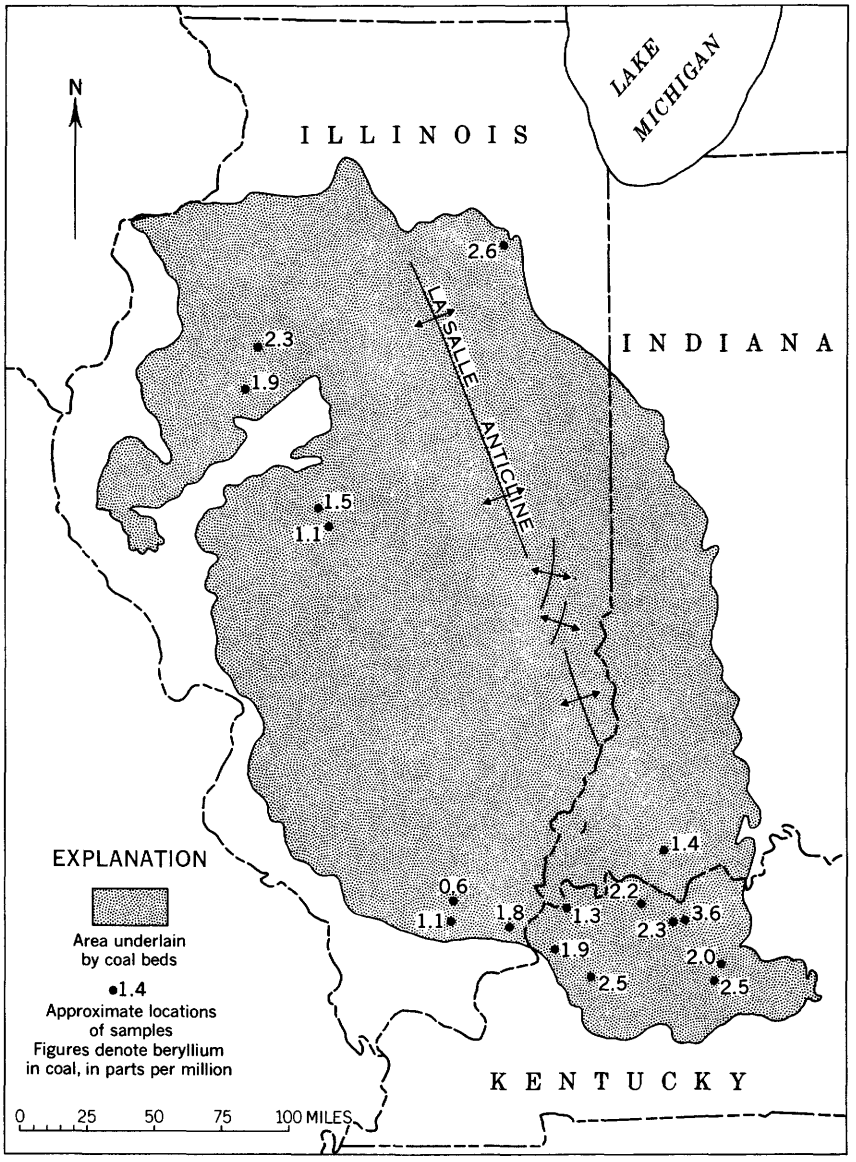

FIGURE 44.—Map showing beryllium distribution in bed 5 of Illinois and its correlatives in Indiana and western Kentucky.

The reason coal beds in the same general areas and having a similar source of weathering products have very different beryllium contents can be attributed to the changing strand lines for the different depositional cycles, and the changing drainage pattern from the erosional site through the depositional site to the sea. These would also differ from formation to formation and bed to bed and thus influence the beryllium contents of succeeding beds of coal in any single locality.

The coal samples from Indiana show unusually high contents of beryllium; these samples are difficult to explain if attempts to correlate the coal beds of the Interior region with those of the Appalachian region are assumed to have some validity. McFarlan (1943, p. 136–137) suggests that the beds were continuous. Any such widespread eastward continuity of bed 5 would place these samples far in the central part of the depositional basin. This is also true of the other beds of this area. Many of the correlation attempts were based on lithologic similarities of the enclosing rocks, but in a basin of repeated cyclic sedimentation these similarities should be easy to find. McFarlan (1943, p. 108–109) reports that the Kyrock conglomerate of the western Kentucky basin can be traced as channel-fill outliers to the Rockcastle conglomerate of the Appalachian basin and suggests a source east of the latter basin. These conglomerates can be equivalent rock units, but not necessarily equivalent time units. The abrupt thinning of the Pottsville and other Pennsylvanian units toward the Cincinnati arch and the thickening westward from the arch suggest that this arch was a topographic high during most of Pennsylvanian time. As such the Cincinnati arch could have acted as a dam that may have prevented the deposition of similar rock units which are equivalent in time. Siever (1951, p. 570–578) suggests that the basal Pennsylvanian sandstones of the Interior province are westward extensions of large alluvial fans in the Appalachian geosyncline. It is entirely possible that when coal beds were being deposited in the Interior basin, clastic material was being deposited in the Appalachian region; it is doubtful that conditions would exist which would be conducive to the simultaneous deposition of coal beds in the Appalachian and the Interior regions.

Potter and Olson (1954, p. 66) in a study of crossbedding in some basal Pennsylvanian sandstone beds of the eastern Interior basin suggest a northeastern source for these sandstone beds. They also suggest that the southwestward trend of sedimentary transport may be the result of southward deflection by the LaSalle anticline of sediments derived from an eastern source.

The higher values for the beryllium content in samples of bed 5 in western Kentucky and Indiana (fig. 44), as well as the very high values of Indiana coal beds in general, seems to indicate that these

coal beds were deposited near the east edge of a depositional area now known as the eastern region of the Interior province. This suggests that the source of the sediments and other weathering and erosional products were somewhere to the east and perhaps related to the high beryllium values found in the coal beds of eastern Kentucky. Plate 2 shows a generalized drainage pattern which is suggested by the beryllium distribution in these two regions.

PROBABLE METHOD OF BERYLLIUM ACCUMULATION IN COAL

The decomposition of rocks by weathering makes possible two ways by which beryllium can be redeposited in a depositional site: As beryllium silicates in clastic remnants of the decomposing rock and as solutions of ions, complexes, or compounds of beryllium which are mobilized from the completely decomposed parts of the rocks.

Upon consideration of the contribution of beryllium to coal by the first of these ways, it should be remembered that in the float-sink separations the data indicated that very little if any of the beryllium found in coal was associated with the extraneous sedimentary material. These separations would also eliminate most of the beryllium which would be associated with the clay minerals deposited in the coal beds. It could be argued that beryllium silicates brought into the swamp in clastic form could be decomposed and that the beryllium would be released and taken up by the peat; however, under the pH conditions found in the peat bogs and swamps (pH=4 to 6) beryllium silicates are very insoluble.

During the formation of coal the transport rate of clastic material can be assumed to be very low and the chemical decomposition rate of the rocks high. Under these conditions a large percentage of the beryllium in the rocks would be put into solution. The problem arises that the pH would vary considerably during the transport of beryllium from the place of weathering to that of depositional. As mentioned previously, the pH of peat and swamp water is about 4 to 6; that of river water commonly ranges from about 6.5 to 8.5 depending upon the degree of carbonate saturation; and that of the weathering site, particularly if granitic or pegmatitic rocks were being weathered, should be much higher. This poses the problem of the reactions that beryllium undergoes in going through these systems.

The following discussion considers only the system beryllium in water. It does not take into account all the factors that would cause a deviation from the simple system, such as adsorption and changing ionic strength in going through the cycle of weathering to deposition. As very little is known about these two factors it would be impossible to make necessary corrections. It is certain that the following dis-

cussion is adequate as a first approximation for the general behavior of beryllium.

The relation of the solubility of beryllium hydroxide as a function of pH (Charlot, 1954, p. 160) is shown on figure 45. The diagram shows that at higher pH values the complex anions predominate whereas at the low pH values the cations Be^{+2} and Be_2O^{+2} are found in solution. Concentrations of 1×10^{-5} mole (approximately 1 ppm) or higher are found below a pH of 7.4 or above 10.5. The average beryllium content of rocks in the earth's crust is 2 ppm; that of the enriched rocks is somewhat more. Upon weathering and solution of beryllium minerals this small quantity is further reduced several times. All the beryllium could easily be put in solution in a complex-ion form at a pH of 12, if such a pH value can be reached in nature. Some $Be(OH)_2$ could precipitate between pH values of 8 to 10. Below a pH of about 8 some of the beryllium if previously precipitated could redissolve. At a pH of about 6.7 approximately 100 ppm of beryllium cations could exist in a saturated solution. Below this pH value it is doubtful that the beryllium content of rock could supply enough of the element to cause a precipitate.

The relative amounts of the cations Be_2O^{+2} and Be^{+2} in the acid region of the diagram (fig. 45) can be determined from the equilibrium constants given by Charlot. The ratio of Be_2O^{+2} to Be^{+2} would range between 10 and 100. These ratios are independent of pH and indicate that beryllium would be present principally as the complex cation.

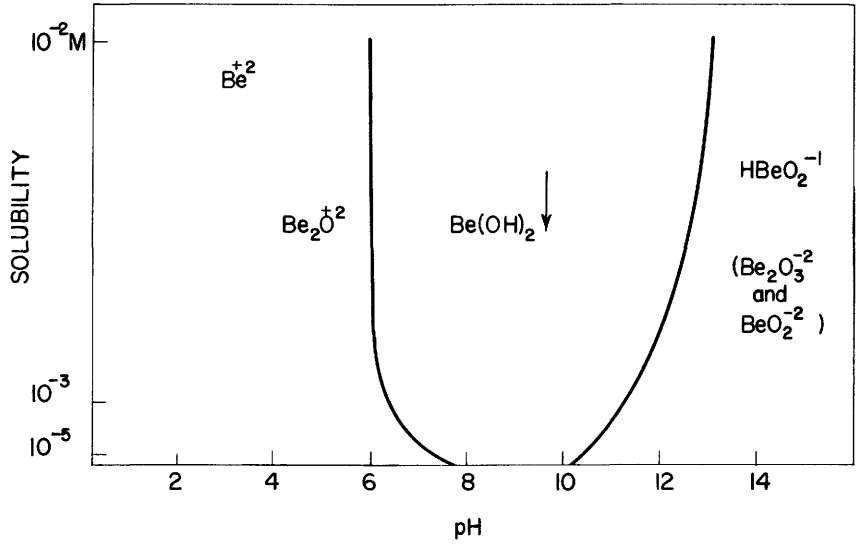

FIGURE 45.—Diagram showing apparent solubility of beryllium hydroxide as a function of pH. (After Charlot, 1954, p. 160.)

Therefore, disregarding the formation of organic complexes during transport, it is easy to follow the course of the beryllium. It is put into solution as complex anions by weathering at higher pH values. As the pH values drop in stream water, some $Be(OH)_2$ may be formed, but because of the initial low content of this element little accretion could take place. The particles would be of colloidal or subcolloidal size and would be transported into the swamp. Because of the lower pH of the swamp water, the particles would redissolve and the beryllium would be available to plants and for the formation of organic complexes.

In general, beryllium forms very stable inert metallo-organic complexes with hydroxylated organic compounds. Whether such complexes would form and be retained in the coal depends upon the solubility of the complexes and the concentration of beryllium. Because most coals have some beryllium in their organic part, and some have quite large amounts, it is possible that plant adsorption and formation of complexes are responsible for the beryllium in coal.

This is a simplified picture of a complex process. It is certain that vegetation was growing in the areas of weathering and it is known that plants growing where there are beryllium-rich rocks can accumulate the element. Upon death and decomposition of this vegetation, beryllium could be transported to the coal swamp in fragments of the decomposing material or as dispersed metallo-organic complexes formed in the decomposing media. Either way, the beryllium would be incorporated into the growing peat moss.

An interesting corollary to the explanation just given is observed in the Arkansas lignite beds (sample Ark–M–UE and –LE, table 2) which contain above-average quantities of beryllium. Gordon and Murata (1952, p. 178) observed that beryllium found in parent nepheline syenite rocks did not follow aluminum into bauxite according to ionic-potential principles; rather beryllium was found to be less concentrated in most of the bauxite in the Wilcox group of Eocene age. The lignite samples given in table 2 of this report are also from the Wilcox group, but farther south. These Arkansas lignite beds are presumed to have an allochthonous origin. It is possible that they are remnants of the vegetation growing in the nepheline syenite weathering zone and that the beryllium now found in the lignite beds is a result of plant or plant humus accumulation of beryllium as it weathered out of the parent rock. The explanation could account for the small accumulation of beryllium in bauxite, but its validity cannot be proven until more data are accumulated.

ECONOMICS OF BERYLLIUM IN COAL

The physical and chemical properties of beryllium are such that an increasingly important part is being played by this element in our complex technology. Its lightness and strength and that of its alloys promise an ever-increasing role in industry. At present the only source of the element is the mineral, beryl; other minerals contain the element in varying amounts but not enough of these are available to ensure a continuous source. A large part of the beryllium used in this country is imported.

Although by present standards none of the concentration now found in coal can be considered to be a source of beryllium, it is important that such data be made available as a guide for some future needs. A short list of the higher concentrations of beryllium in ash is given in table 8. These data are also recalculated to show the beryllium in coal. The maximum values .or beryllium in ash and in coal are found in samples Ky–IH and Ky–SX eastern Kentucky. Several coal samples from beds in Indiana have beryllium contents in ash which are above average; other high values are found in samples from localities scattered throughout the provinces. Except for the two samples from eastern Kentucky, the averages for beryllium for the majority of the coal samples fall within a narrow range of 1 to 6 ppm. It is doubtful that such a low beryllium content could ever be profitably extracted unless done as a byproduct of the extraction of other minor elements.

TABLE 8.—*Maximum beryllium concentration in the columnar coal samples*

Sample	Ash in coal (percent)	Beryllium in ash (percent)	BeO in ash (ppm)	Beryllium in coal (ppm)
Ky–IH	2.85	0.11	3,000	31
Ky–SX	6.46	.081	2,200	19
Ind–H–III	4.71	.018	500	6.8
Ill–S–Da	4.35	.017	470	5.7
Ala–De–BC	1.71	.015	420	2.6
O–SB–MK	3.02	.014	400	4.2
Ind–L–VII	8.12	.013	360	5.1
K–Col$_2$	1.91	.013	360	2.4
Ala–TH–M	3.64	.012	330	4.4
Ind–M–M	7.15	.012	330	3.7
Ind–S–VI	7.40	.012	330	4
Ok–RC–BA	2.72	.011	300	3
Ky–Hop	4.84	.01	280	2.3
Mont–Su	5.95	.0094	260	5.6
Ill–B–2	5.57	.0086	240	4.3

The authors believe that a more detailed study should be made of the beds that show the highest amount of beryllium. Detailed study is desirable not only from an economic standpoint, but also for the evaluation of the possibility that beryllium compounds can pollute the air in areas where large quantities of coal are used.

SUMMARY AND CONCLUSIONS

The study of 1385 samples of coal from most of the coal-producing regions of the United States shows a wide variation in beryllium content. The areal distribution of the sample localities shows beryllium-rich and beryllium-poor regions. The rich and the poor distribution of beryllium in coal beds depends upon the availability of beryllium to the swamps at the time of deposition of the coal. This availability was dependent upon the type of rock being eroded in the surrounding borderlands.

There is also a pattern in the distribution of beryllium in coal in a basin. Coal sampled near the edge of a basin has a higher beryllium content than that sampled in the center. Coal that was deposited near eroding rocks rich in beryllium, or that had access to water from such areas is also high in beryllium.

In sink-float experiments, beryllium is consistently associated with the lighter organic-rich fractions. The beryllium content of the sink fractions, particularly those with a high percentage of ash, consistently is below the average for that of the earth's crust. The analysis of petrographic constituents of coal shows that beryllium is most often associated with vitrain and least with fusain.

The accumulation of beryllium in coal is concluded to be a syngenetic process. The beryllium now present in the coal probably is a result of accumulation by plants and (or) by the adsorption from solution by the organic matter in the coal-forming swamps to form metallo-organic complexes. Although some of the original beryllium may have been lost, there is no possible way to ascertaln this. Further studies should be made of coal beds which contain large amounts of beryllium. The economic aspects of the beryllium in coal are not predictable.

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CONTENTS

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