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CONCENTRATION OF GERMANIUM IN THE ASH OF AMERICAN COALS A PROGRESS REPORT

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ABSTRACT

The rapidly expanding use of germanium by the electronic industry has stimulated search for new sources of the element. Previous investigators in various parts of the world have found as much as 0. 1 to 1. 0 percent germanium in the ash of certain coals. The ash of most coals, however, contains less than 0. 01 percent of the element. As a special part of a general geochemical study of minor elements in American coals, a systematic search is being made for beds rich in germanium. This paper reports analyses made for germanium in the ashes of over 700 samples of American coals. Methods of collecting columnar samples of coals, of ashing the coals, and of analyzing the resultant ash spectrographically are described.

The highest concentrations of germanium have been found in coalified logs and pieces of woody coal occurring isolated in sediments. Lignitic logs of Cretaceous age distributed sporadically in the Atlantic Coastal Plain contain very high amounts of the element, as much as 7. 5 percent Ge in the ash. The richest commercial coal that has been found is the bottom horizon of the Lower Kittanning bed of Pennsylvanian age in Ohio, whose ash contains 0. 2 percent germanium.

Usually the top and bottom layers of a coal bed show the highest concentrations of germanium. Laterally, over a distance of many miles, beds in Ohio have about a fifteenfold range of variation. Among the components of coal, germanium is most highly concentrated in bright woody coal (vitrain) with much less concentration in fusain (mineral charcoal), and no detectable concentration in pyrite or sphalerite. Simple gravity separation of crushed germaniferous coal produces fractions high in woody coal, whose ash is richer in germanium than the original coal by a factor of 2 to 2. 5.

Coal beds of certain fields in the Western States contain very little germanium in spite of being rich in woody coal. This suggests the possibility of a regional variation in the abundance of germanium.

INTRODUCTION

This report on the concentration of germanium in the ashes of American coals deals with one part of a broader study on the occurrence of fifteen minor elements in these coals. Although the study is not complete, the preliminary data for germanium are being published at this time because of the current interest in new sources for this element.

Increasing amounts of germanium are needed in the electronic industry for the manufacture of such devices as crystal diodes and transistors, which are replacing certain types of vacuum tubes. At the present time, practically all the germanium produced in this country comes as a byproduct of zinc smelting (Clark, 1951).[1] As future demands may far exceed what can be supplied from this source, active research is being carried on in both industry and government to find new domestic sources of the element.

Only three minerals containing more than 1 percent of germanium are known—germanite [(Cu, Ge) (S, As)], argyrodite [Ag_8GeS_6], and the recently discovered renierite $(Cu, Fe)_3 (Fe, Ge, Zn, Sn) (S, As)_4$ [2] (Vaes, 1948), and none of them has been found in the United States. Deposits of the first two are either exhausted or extremely rare, and the amount of renierite that will become available is at present unknown. Sphalerite, containing a few hundredths of a percent of germanium, is the present major source of the element, which is recovered as a byproduct of zinc smelters. The current production of germanium, according to Clark (1950), is entirely dependent on zinc production—

"Concern was expressed by consumers (in 1948) as to the adequacy of future supplies in view of probable expanding requirements, combined with the possibility that Tri-State district zinc output, from which most germanium comes as a by-product, seemed certain to continue to decline."

Coals in several countries have been found to contain appreciable concentrations of germanium in their ash. They represent a potentially important source that merits thorough investigation.

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The cooperation of Dr. A. P. Thompson and his staff and of Mr. R. L. Hallows, all of the Eagle-Picher Co., throughout this study is deeply appreciated. Several hundred of the analyses reported in this paper were made in their Laboratory.

The senior author wished to express her hearty thanks to the coal miners, superintendents, and coal operators for help and permission to work in the mines; to Dr. A. C. Fieldner, of the U. S. Bureau of Mines, for permission to use the laboratory facilities of the Pittsburgh Experimental Station; to Mr. H. P. Greenwald, superintendent of the station, and all the members of the coal analyses section; to

[1] See page 11 for references.
[2] The possibility that renierite is a ferroan variety of germanite has been discussed by Fleischer (1950).

Charles McConnell, Donald M. Brown, B. W. Dyer, Arne A. Mattila, George Bywater, H. B. Lindeman, Percy Pierce, and other members of the Geological Survey who helped her in the field. Mr. H. I. Smith of the Mining Branch of the Conservation Division, Geological Survey, made many arrangements with various field offices of the Division that greatly facilitated the field work.

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PREVIOUS WORK

The literature on the occurrence of germanium in coals has been summarized by Gibson and Selvig (1944) and by Fleischer and Harder (1946); the reader is referred to these sources for a more complete review. We shall briefly recall the salient features of historical developments and point out the worldwide interest and research in the field.

During the early 1930's, Goldschmidt (1930) and Goldschmidt and Peters (1933) first called attention to the unusual concentration of germanium and other rare elements in certain European coals. A sample of ash from the Hartley coal of Newcastle, England, was shown by them to contain the high concentration of 1.1 percent Ge. The average content of the richer samples studied by them was 0.05 percent Ge in the ash.

Morgan and Davies (1937) in England found that a significant loss of germanium occurs when coals are burned under conditions of industrial practice and ascribed the loss to the volatility of the oxide and sulfide of divalent (reduced) germanium. They also demonstrated that a certain part of the volatilized germanium is concentrated in flue dusts, many samples of which were found to contain 0.1 to 1.0 percent Ge. A method of recovery of the element from flue dusts of gas works by distillation of the tetrachloride was studied by them. Our analyses to date of flue dusts from power plants in this country do not show such concentrations of germanium.

Since the pioneering work of Goldschmidt, investigators have studied the germanium content of coal and coal products in the following countries:

England: Horton and Aubrey, 1950; Jones and Miller, 1939; Morgan and Davies, 1937; Powell, Lever, and Walpole, 1951; Aubrey, 1952.

Russia: Egorov and Kalinin, 1940; Katchenkov, 1948; Kostrikin, 1939; Ratynskii, 1943, 1945, and 1946; Vakhrushev, 1940; Zilbermintz, 1936; Zilbermintz, Rusanov, and Kostrikin, 1936.

Australia: Cooke, 1938.

Czechoslovakia: Simek, 1940; Simek, Coufalik, and Stadler, 1948.

India: Mukherjee and Dutta, 1949 and 1950.

Argentina: Lexow and Maneschi, 1950.

New Zealand: Wilson and Rothbaum, 1950.

Spain: Lopez de Azcona and Puig, 1948.

United States of America: Headlee and Hunter, 1951; Stadnichenko, Murato, and Axelrod, 1950.

Germanium content of coals of this country has been but little studied; however active research is now under way in several laboratories.

Headlee and Hunter (1951) have recently reported on germanium in coals of West Virginia. The Eagle-Picher Co., the major producer of germanium in this country, has been carrying on extensive research both on the germanium tenor of various coals and on commercial extraction of the element from coal ash.

In 1935, the senior author of this report submitted 19 samples of coal from the Lower Kittanning bed of western Pennsylvania (Stadnichenko, 1934) to George Steiger, former chief chemist of the Geological Survey, who spectrographically detected germanium in one sample derived from woody plants collected at the Victor No. 29 mine in Indiana County. In 1942, Steiger spectrographed 28 ash samples prepared by the senior author from American coals of various types and rank. He detected germanium in 5 samples, all of which were derived from coals rich in woody plant remains.

The present project on the geochemistry of minor elements in American coals was initiated by the senior author in 1948, and two brief reports of the findings have been made (Stadnichenko, Murata, and Axelrod, 1950; Stadnichenko and Murata, 1951).

In this report 588 analyses from ash of the 95 columnar samples, 29 channel, and 15 grab samples are given. In addition, 63 samples of Cretaceous lignite logs from the Atlantic Coastal Plain have been analyzed in order to determine the areal extent of this material, which in the original discovery site in Maryland, contains as much as 7.5 percent Ge in the ash. The main body of the results is presented in tables 6 to 16, and the localities at which the samples were collected are indicated on small-scale maps (figs. 1 to 11).

We are collecting coal samples in the different coalfields of the Western and Eastern States, and plan to publish the results of analyses in subsequent reports on germanium, as well as on Ga, Be, Ti, V, Cr, Cu, Sn, Zn, Ni, Co, Mo, Y, La, and B, in all of the important deposits of the Nation. Full discussion of the geologic and geochemical relationships bearing on the concentration of germanium and the other elements in coal will be reserved for these later reports. This study outlines the methods used for sampling and ashing of coal and for spectrographically analyzing the ash, and presents the analytical results obtained to date on germanium.

METHODS

Sampling of coal

To obtain representative mine samples, columnar samples are cut from the fresh face of the coal. This method of sampling in some mines requires much less time than does channel sampling. By selecting a protruding ledge on the working face, only two sides need to be cut to obtain a columnar sample.

The size of the column that is collected varies, depending on whether the particular coal had been previously studied for other work. The larger columns collected from mines not previously studied may have a cross section of 6 by 8 inches or even 10 by 12 inches. No attempt is made to collect the columns intact, but it is necessary to preserve the main benches of the bed. The natural parting into benches usually results in conveniently sized blocks, and the parting surface may show the nature of the change in the character of deposition that ultimately produced a plane of weakness in the coal bed.

The individual blocks, cut from the face of the coal bed, are laid out in consecutive order and a label with a code number for the mine and block is attached at the top of each block with friction tape. The thickness of each block is then measured, though if time does not permit in the field, this may be done when the blocks are unwrapped in the laboratory. Samples of lignites and subbituminous coal are wrapped at first in several thicknesses of newspaper, and then with aluminum foil to keep them from slacking, whereas bituminous coals are wrapped with aluminum directly. The key label, indicating the total thickness of the column, number of blocks, and other pertinent data, is put in the bag or the box in which the samples are taken out of the mine.

A columnar sample, in contrast to a channel sample, makes possible the detailed study of the germanium content of a bed, block by block. It also makes possible the preparation of thin sections and other special samples for petrographical and chemical study of those portions of a bed that are found to be enriched in germanium or other minor elements.

Ashing of coal

In the laboratory, the blocks of coal are divided into two parts, either manually with chisel and hammer or by means of a motor-driven circular saw. One part is reserved for possible detailed petrographic and chemical studies as mentioned above. The other half is ground to pass a 60 mesh sieve.

Five-gram samples of the ground material are weighed in shallow aluminum trays, 8 cm x 10 cm x 1. 8 cm, which serve both as weighing pans and sample holders. The samples are then weighed and placed in a cold muffle furnace. The door of the furnace is lowered to within an inch of complete closure and the temperature is raised rather rapidly to 125° C and held there for 20 to 30 minutes. Then the temperature is raised to and held at 180° to 225° C in order to destroy the coking property of the coal. This expedites the oxidation of the coal, which takes place at 400° C. Periodic gentle shaking of the trays speeds the oxidation. Low-rank coals may be ashed within 3 hours; higher rank coals require almost 8 hours. At the end, the temperature may be raised to 430° to 450° C in order to burn the last particles of unoxidized carbon.

Recently, Wendell P. Tucker and Claude L. Waring (1952) studied the effect of ashing temperatures on the volatility of germanium in three lignite samples. They found that neither temperature, which varied from 200° to 1000° C, nor time of ashing (1 to 4 hours) affected the germanium content in the ash. These findings contrast sharply with the results reported in the literature cited of substantial losses of germanium during the ashing process. Morgan and Davies (1937), for example, noted that 30 to 50 percent of the germanium originally present in coal is lost during ashing. Some unpublished results of tests made by Eagle-Picher Co. show losses as much as 50 percent, depending on ashing conditions. It is evident that more work needs to be done to find the reasons for the apparently contradictory results obtained by different investigators.

Analysis of coal ash

Spectrographic methods have been used in the laboratories of both the Geological Survey and the Eagle-Picher Co. to analyze the coal ashes, and the techniques used in both places will be outlined. In the future, we shall also use the newly developed phenylfluorine colormetric method for germanium (Hoste and Clayes, 1947; Cluley, 1951). We have found this method very satisfactory for determining germanium in coal ash, and its use will check and augment the spectrographic determinations.

The general spectrographic method used in the Geochemistry and Petrology Branch of the Geological Survey for simultaneously determining a large number of minor elements in silicate rocks has already been described (Gordon and Murata, 1952); so only the steps required to adapt it for the analysis of coal ashes need be mentioned here. The method involves d. c. arc excitation and the use of pegmatite-base comparison standards. The matrix of the pegmatite standards consists of 60 parts of quartz, 40 parts of microcline, and 1 part of specially purified ferric oxide. This mixture burns very smoothly in the carbon arc at around 16 amperes. Germanium and other elements are incorporated into the pegmatite base as oxides, and standards containing the elements in steps of 1. 00, 0. 464, 0. 215, 0. 100, 0. 0464. . . . . . 0. 001 percent are prepared by successive dilution with the base.

Coal ashes vary greatly in their chemical composition (Gibson and Selvig, 1944, p. 2). To overcome the effect of this variable composition on the accuracy of the analysis, all ashes, after a preliminary grinding in an agate mortar, are mixed with one-half of their weight of germanium-free pegmatite base. This proportion of ash to pegmatite base represents a compromise between the desire to make the samples more uniform in composition and the desire to avoid excessive dilution of the ash, which would result in loss of sensitivity. Twenty-five milligram duplicates of the prepared samples are arced to completion in the carbon arc, and the percentages of the various elements determined densitometrically through the use of previously established analytical curves based on pegmatite standards. No internal standard element is used.

Samples showing 0. 05 percent or more of germanium are diluted further with sufficient pegmatite base so that their reanalysis would be done at a germanium-concentration level of about 0. 01 percent. The final values for the other elements, whenever possible, are also obtained during the reanalysis. This practice results in greater accuracy for samples high in germanium because they (in the diluted state) closely approach the comparison standards in composition. All determination of germanium were made with the line at 2651. 18A.

The analytical work by the Geochemistry and Petrology Branch of the Geological Survey was done partly in Washington, D. C., and partly in Denver, Colo., and these two laboratories will herein be designated as G-1 and G-2, respectively. The limit of detection attained in G-1 was 0. 002 percent Ge, and in G-2, 0. 001 percent Ge on account of the superior quality of the grating in the Denver spectrograph. The early qualitative analyses by Steiger, in Washington, with the medium quartz spectrograph are coded as G-3 in the tables, and the limit of the detection of this instrument is about 0. 01 percent Ge.

The Eagle-Picher Co. has kindly furnished us with a concise description of the method used in its research laboratory, and this description is quoted below. The method differs from ours principally in that a semiquantitative analysis involving visual estimation of line densities on the spectrographic plate is first made on all samples. In this step a heavier exposure may be used than in quantitative analysis, and this heavier exposure leads to a higher sensitivity of detection (0.0004 percent). The results of this initial analysis are coded as E in the tables. Samples found to be rich in germanium are reanalyzed according to a quantitative procedure, the values from which are labelled as EQ in the tables. The details of the two techniques used by Eagle-Picher laboratory are as follows:

A. Semiquantitative analysis.

"Preparation of sample: The entire ash was ground and mixed in a mullite mortar. A 20-mg portion of the mixed ash was weighed on an analytical balance and packed in a conventional center-post type graphite anode. The counter electrode was of 1/8 inch rod sharpened in a pencil sharpener.

Excitation: The entire sample was vaporized in a 10 ampere DC arc maintaining a 3 mm arc gap throughout the arc period.

Photography: Spectra were recorded on SA"1 film with radial sector opening of 15 percent and a 20 micron slit. The films were developed in D-19 at 73° F.

Calculations: The lines Ge 3039.1A, Ge 2651.3A, and Ge 2691.3A were appraised visually and assigned density values from 1 to 10 by comparison with a prepared chart. Prepared standards, having a similar base, have been arced under the same conditions and the line density numbers plotted vs log percent concentration. Concentration values were then read from this curve for unknowns. If indium is present in the sample, the line In3039.4A interferes with Ge 3039.1A which necessitates the use of the other Ge lines only."

B. Quantitative analysis

"Buffer: The buffer used was 2 parts Ge-free Li_2CO_3 to which was added 1 part graphite powder.

Sample preparation: The ash was ground and mixed as for semi-quantitative analysis. To 10 mg of ground ash was added 30 mg of buffer. After thoroughly mixing in an agate mortar two 15-mg portions were packed in thin-walled graphite anodes whose cup diameter is 2.5 mm and cup depth is 4 mm. The counter electrode was 1/8 inch graphite rod not sharpened.

Excitation: The entire sample was vaporized in a 10 ampere DC arc with 3 mm arc gap throughout the arc period.

Photography: Same as for semi-quantitative except a 50 micron slit and a 10 percent filter were used. The filter was placed in front of the camera at 3230A so that the line Li3232.6A could be used as reference line.

Calculations: The calculations were made according to standard relative intensity procedures using the line pairs Li3232.6A/Ge 3039.1A (net) and Li3232.6A/Ge 2651.3A (net). Background correction was necessary on both Ge lines. The method used was I (net) = I (line / bkg.) - 1 in terms of the emulsion calibration curve."

ANALYTICAL RESULTS

General remarks

Altogether, 989 analyses were made and germanium was detected in 539, which is 55 percent of the samples. The percentage of samples in which germanium was detected varies greatly from locality to locality—from 22 percent in coals of Pennsylvania to 95 percent in the eastern Coastal Plain lignites. These percentages do not have any precise meaning, but give a crude idea of our experience. It must be remembered that the three laboratories making the analyses have different limits of sensitivity (0.0004 to 0.002 percent Ge). Presumably, if all laboratories had worked at the detection limit of 0.0004 percent, the percentage of detection would have been higher. On the other hand, most of our work so far has been of the reconnaissance type, and we have tended to select the top and bottom block and those richest in woody material (vitrain) from any given bed for initial analyses. As such blocks are most likely to show concentration of germanium, the practice would improve our chances of detecting the element and keep us from making large numbers of analyses of unpromising beds.

The analytical data are given in tables 6 to 16 at the end of this report. The results are grouped by localities within a state or a group of states. Modern estimates of the average content of germanium in the sedimentary rocks have ranged between 1×10^{-4} percent (Fersman, 1933) to 7×10^{-4} percent (Rankama and Sahama, 1950). An average value of 4×10^{-4} percent germanium in sedimentary rocks may be assumed in order to judge the degree of enrichment represented by the various percentages for the ashes in our tables.

Special attention is called to table 11 where the germanium content of samples from the Lower Kittanning bed of Ohio are given. The discovery of tenths of percent germanium in the ash of this industrially important coal was one of the most gratifying developments in our work. Some general features of the distribution of germanium, noted during the study, will be described in the following four sections. We shall reserve discussing the geochemical significance of these features for a later report because it is necessary to consider the data on many other elements to get as comprehensive a view as possible.

Concentration of germanium in isolated pieces of woody coal

We (Stadnichenko, Murata, and Axelrod, 1950) have previously reported on the high concentration of germanium, as much as 6 percent of the ash, in logs of Cupressinoxylon occurring sporadically in the Cretaceous clays and sands of the District of Columbia and vicinity. Later analyses have raised the maximum concentration found to 7.5 percent Ge in the ash of a specimen from the original discovery site on the campus of the University of Maryland. None of the other localities of the region has produced samples with such high percentages, although many of them have yielded samples that contain 1 to 2 percent Ge in the ash (see table 5).

The occurrence and nature of these logs have been described by Knowlton (1889). In May 1951, we were fortunate in discovering a locality in Prince Georges County, Md. (table 7) where a score of coalified stumps of Cupressinoxylon complete with roots were found in an upright position in clay, apparently remains of trees that were buried at sites where they grew during the Cretaceous period. This find suggests that the widely scattered logs of this region had a local origin and were not transported long distances before burial. The logs represent a possible commercial source of germanium, but their sporadic distribution over an area generally densely populated makes their recovery difficult. However, the clays that contain the logs are mined in several places for manufacturing bricks; so there is a possibility that the logs could be gathered as a byproduct from such clay pits.

Another example of isolated coalified wood containing a very high concentration of germanium was found in coal adhering to the so-called "kettle bottoms" (tree stumps) collected from the shale overlying the Roundup coal bed in Klein No. 2 mine at Klein, Mont. (table 16). The ash of this coal contained 3 to 5 percent Ge, whereas that of the richest block of the main bed contained only 0.02 percent Similar, unusually high concentrations of a number of minor elements have been reported by Jones and Miller (1939) for kettle bottom coal found in shales overlying certain British coals.

In their report on the germanium content of coals of Kazakhstan, Egorov and Kalinin (1940) note that "Thin coal beds and lenses, as well as separate pieces of coal occurring among sandy and clayey rocks, show a higher germanium content. Headlee and Hunter (1951) have found a similar enrichment in isolated thin lenses of coal in sandstone and shale overlying certain West Virginia coals. Reynolds (1948) has reported unusual concentrations of other minor elements, such as V, Cr, and Ni, likewise in bands and fragments of vitrainlike coals in rocks immediately above or below certain coal beds in England.

Distribution of germanium within coal beds

In common with a number of other investigators, we have noticed that germanium is not distributed uniformly throughout the thickness of a bed but tends to be concentrated at the top or bottom or both. This relationship does not hold invariably, but it has been observed by us and others frequently enough so that the trend is clear and should be looked for in every new bed studied. Some examples of variations in the vertical distribution of germanium within coal beds studied by us are presented in table 1.

Table 1.--Vertical variation of germanium content in the ash of various coals

Mine and bed	Block	Ash (percent)	Ge in ash (percent)
Sunlight mine, D bed, Cattle Creek, Colo. Analyzed by Lab. G-2.	1 (top)	8.72	0.02
	2	8.06	([1])
	6	2.84	([1])
	10	2.28	([1])
	11 (bottom)	2.14	([1])
Tuss mine, east of Lewistown, Mont. Morrison formation. Columnar sample 5.8 ft thick. Analyzed by Lab. E.	1(v) (woody coal from top block).	3.71	.21
	2	23.39	.0042
	3	10.75	.0052
	4	8.68	.0045
	5	5.70	.042
	6	6.38	.038
	7	30.21	([1])
	9	9.68	.0060
	10	6.62	.0060
	11	5.90	.0021
	12	10.56	.0042
	13	11.77	.0048
	14 (bottom)	9.48	.0049
Sunnyhill Coal Co., New Lexington, Ohio. Lower Kittanning bed. Analyzed by Lab. G-1.	1 (top)	16.24	.006
	2	17.56	([1])
	3	10.68	([1])
	4	7.08	([1])
	5	6.54	([1])
	6 (bottom)	12.30	.02
Stark Ceramics Co., Cameron property, Carroll County, Ohio. Lower Kittanning bed. Analyzed by Lab. G-1.	1 (top)	27.88	.003
	2	26.14	.004
	3	3.56	([1])
	4	3.00	.003
	5	3.34	.002
	6	4.50	.01
	7 (bottom)	3.54	.20

[1]Germanium not detected. For limits of detection of the different laboratories, see page 3.

The results in table 1 indicate the reason for first analyzing the top and bottom blocks when searching for germaniferous coal beds. Negative results on these blocks would justify regarding the beds concerned as unpromising with only a small risk of overlooking a rich deposit. In this manner, a large number of beds could be examined for the element with a minimum of effort. The bed at the Tuss mine in Montana is one of the few we have found to show a marked enrichment toward the middle. Through an oversight only a selected sample of woody coal from the uppermost block of this bed was analyzed; so the germanium content of the whole block is not known. However, this does not in any way obscure the fact of enrichment in the middle blocks. Although examples of such a distribution are rare, they must be kept in mind when formulating any general theory to account for the distribution of germanium in coal beds.

Headlee and Hunter (1951) state that there is an enrichment of germanium in coal that is adjacent to a parting. Our samples from the Ramsey mine in Colorado (table 13) seem to offer an example of such enrichment. In the middle of the bed at the Tuss mine mentioned above, there is a layer of bony coal containing 30 percent ash. If this layer is considered as a sort of parting, the germanium-rich layer immediately above it would constitute another example of this relationship.

The enrichment at the top and bottom of beds is also of interest in connection with the problem of commercial extraction of germanium. We are of the same opinion as Headlee and Hunter (1951) in believing that such enriched layers constitute the most valuable ore and should be selectively mined. Such a practice would correspond to what is done in mining ores of more common elements, such as copper.

Evidence is given below to show that germanium is combined with certain organic matter of coal so that a high percentage of ash, arising from an abundance of inorganic impurities, such as clay or calcite, lowers its concentration in the ash. This general inverse relationship between percentage of ash and percentage of germanium in the ash has been noted by a number of investigators. However, the enrichment at the top or bottom of a bed occurs regardless of whether the coal at these horizons is high or low in ash. This may upset the general inverse relationship; therefore it is necessary to take into account the position within the bed when comparing one coal sample with another.

We have obtained some data on the variation of germanium laterally in Middle Kittanning and Lower Kittanning beds over a distance of more than 100 miles in Ohio. To overcome the difficulty posed by the nonuniform, vertical distribution of germanium within these beds, the germanium content (calculated as grams per ton of coal) of the bottom block at each locality is used for comparison. The results are presented in table 2 and figure 1.

The germanium content of the Lower Kittanning bed varies from 10 to 127 grams Ge per ton of coal; that of the Middle Kittanning varies from 2 to 32 grams per ton; a thirteenfold to sixteenfold range of variation. There does not seem to be any consistent trend going from northeast to southwest across the State, so that this appears to be the magnitude of random variation to be expected laterally. More detailed work is needed. To establish the average content of any bed or portion of a bed even at a single locality, a number of samples should be analyzed because there may be large fluctuations in the germanium content between points only a few feet apart along the bed.

The data for the Cretaceous logs of the Atlantic Coastal Plain (table 1) give an idea of the range of variation found among samples of this type of material from many widely separated localities and also from single localities.

Distribution of germanium among components of coal

Even a casual glance at a coal bed reveals the sedimentary origin of this rock, which may be regarded as a lithified and metamorphosed peat deposit. Just as it is possible to identify fragments of many different plants in a present-day peat deposit, so it is possible by means of microscopic examination of thin sections and polished surfaces to recognize remains of ancient plants in coals. The nature and terminology of different types of plant material found microscopically and the correlation of these materials with megascopic features of coal are discussed in the following references: Raistrick and Marshall, 1939; Stadnichenko, 1934; Thiessen and Francis, 1929; Stopes, 1919.

A number of investigators including Ratynskii (1946) and Horton and Aubrey (1950) have demonstrated that germanium is most highly concentrated in vitrain, that component of coal which has a characteristic pitchy luster and conchoidal fracture and which was derived from woody tissues. We shall use the more general term woody coal to cover not only the typical vitrain, as seen in bituminous coal, but also the duller less coalified wood that is found in subbituminous and lignitic coals. Another component of coal studied by us is the friable, charcoallike material called fusian. We have selected and analyzed woody coal and fusian mostly from the Cupressinoxylon deposits of the Atlantic Coastal Plain because of their richness in germanium; the results are given in table 3.

Table 2.--Germanium content of the bottom blocks of the Lower and Middle Kittanning coals of Ohio

[Analyses by Lab. G-1]

Bed	Letter on fig. 1	Locality	Ge (g/ton)
Lower Kittanning.	a	Stark Ceramics Co., pit 13, Stark County	52
	b	Stark Ceramics Co., pit 14, Stark County	46
	c	Stark Ceramics Co., pit 20, Stark County	39
	d	Magnolia Coal Co., Stark County	63
	e	Metropolitan Clay Products, Stark County	27
	f	Billman Coal Co., Stark County	10
	g	Stark Ceramics Co., Cameron pit, Carroll County	107
	h	Copperhead Coal Co., Tuscarawas County	24
	i	Sunnyhill Coal Co., Perry County	34
	j	Junction City, Perry County	127
Middle Kittanning.	a	J & R Coal Co., Columbiana County	16
	b	Stark Ceramics Co., pit 14, Stark County	32
	c	Stark Ceramics Co., Cameron pit, Carroll County	31
	d	Sunnyhill Coal Co., Perry County	20
	e	Metropolitan Clay Products, Stark County	2

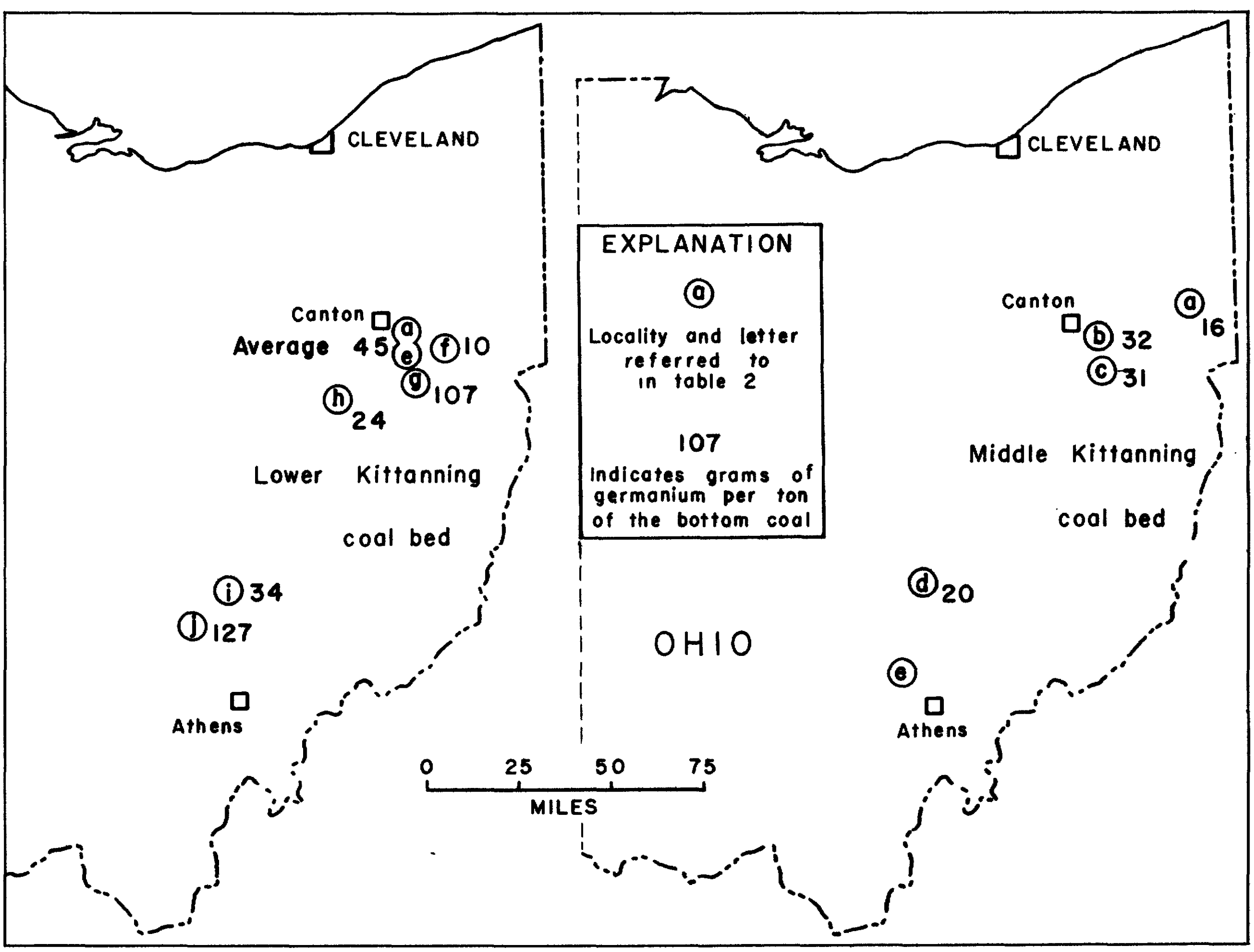

Figure 1.--Lateral variation in germanium content of the Lower Kittanning coal bed and the Middle Kittanning coal bed in eastern Ohio.

Table 3.--Germanium content in the ash of woody coals and fusains

[Analysis by Lab. G-1]

Locality	Woody coal		Fusain	
	Ash (percent)	Ge in ash (percent)	Ash (percent)	Ge in ash (percent)
Cupressinoxylon wardi, Edgewood, Md.--------------------	2.62	0.90	7.10	([1])
C. wardi, Muirkirk, Md.--------------------------------	3.2	1.3	19.6	0.005
C. wardi, University of Maryland, site 2---------------	2.40	3.0	12.20	.07
C. wardi, 18th and Montana Ave. NE, Washington, D.C.---	3.82	1.5	20.43	.02
Sewell bed, Pottsville group, Thurmond, W. Va.---------	1.4	.03	5.0	.005

[1] Germanium not detected; less than 0.002 percent.

Most Cupressinoxylon logs are preserved solely as woody coal, but a few of them have fusain in the interior. Also fragments of logs showing both types of preservation are found occasionally. The data in table 3 clearly show the greater enrichment of germanium in woody coal compared to fusain. The ash content of fusain is higher than that of woody coal, but the disparity in the concentration of germanium is far greater than can be explained by a simple diluting effect of the higher amount of ash. These results confirm the findings of previous workers in other parts of the world. The state of chemical combination of germanium in woody coal in unknown. The woody coal of Cupressinoxylon, which contains the highest concentration of germanium among coaly materials, seems to be a favorable study material for an inquiry into this fundamental question.

Although the concentration of germanium in woody coals is well established, very little is known about the genera and species of plants represented in germanium-rich woody coals. Among coals studied by us, the Cupressinoxylon logs and the kettle bottoms of Klein mine in Montana are known to be remains of conifers. If germanium and other elements that are found concentrated in woody coals were accumulated by plants while they were living, a marked variation in the degree of concentration might be expected from genus to genus and possibly from species to species. Horton and Aubrey (1950) have argued that the large variation found by them in the minor-element content of woody coal (vitrain), isolated from a single coal bed at several localities, constitutes evidence unfavorable for biological accumulation. This argument is weakened, however, by the lack of assurance that the same species of plant is represented in the woody coal from the several localities.

It is common practice today in many mines to beneficiate high-ash coals by removing inorganic impurities, such as shale and ankerite, by methods that take advantage of differences in specific gravity. For commercial recovery of germanium from coal ash, such an elimination of mineral impurities is highly desirable because it minimizes the dilution of the element in the ash. It is possible through carefully controlled gravity separations to obtain fractions low in extraneous mineral matter and fusain and very high in woody coal (vitrain). Such fractions would constitute the most favorable raw material for commercial recovery of germanium.

With this commercial aspect of gravity separation in mind, we have subjected 4 samples of Ohio coals, 2 with low and 2 with high ash, to gravity separation to see what degree of practical enrichment could be obtained in this way. Carbon tetrachloride and ethanol mixtures of different specific gravities were used. The coals were crushed to pass an 8 mesh sieve and the separations made on material retained by a 100-mesh sieve. To determine the amount of germanium that would be lost in the fines, the part that passed through the 100-mesh sieve was analyzed as a single fraction. The results of these experiments are given in table 4.

With the low-ash samples 1 and 2 of table 4, it is evident that a separate with specific gravity of 1.30 would represent about 75 percent of the original bulk of the coal, and its ash would contain germanium at concentrations higher by a factor of 2 to 2.5 over that of the original. Such an enriched product would require physical handling and chemical treatment of less weight of material per pound of recoverable germanium. In the preceding section, we advocated selective mining of the part of a coal bed that is richest in germanium. Such selectively mined material could be subjected to a gravity separation to yield the most favorable ore.

Samples 3 and 4 are bony coals high in ash, but they contain sufficient germanium to rank among germanium-rich coals in terms of grams of the element per ton of coal. As may be seen from table 4, however, gravity separation made on these coals result in a low yield of the enriched product with consequent loss of much germanium in the heavier fractions. Some improvement might be obtained by finer grinding or by changing other variables in the process, but it is already clear that bony coals are less amenable to beneficiation through gravity separations. Compared to the original samples, the -100-mesh fractions of all 4 coals show a higher percentage of ash and a

Table 4.--Germanium content in the ash of different gravity fractions of Lower Kittanning coals of Ohio

Fraction	1			2			3			4		
	Coal (percent)	Ash (percent)	Ge in ash (percent)	Coal (percent)	Ash (percent)	Ge in ash (percent)	Coal (percent)	Ash (percent)	Ge in ash (percent)	Coal (percent)	Ash (percent)	Ge in ash (percent)
Original------	100	3.54	0.20	100	6.86	0.20	100	20.48	0.03	100	18.30	0.01
-100 mesh-----	13.0	4.6	.064	5.7	11.26	.12	6.3	31.52	.01	7.0	21.20	.006
Float 1.26----	47.5	1.56	.46	---	---	---	---	---	---	---	---	---
1.28----	---	---	---	68.3	3.0	.55	---	---	---	25.9	3.74	.02
1.30----	27.7	2.28	.52	7.7	6.76	.25	10.2	5.68	.11	17.4	7.02	.02
1.32----	4.6	4.70	.14	---	---	---	10.3	10.16	.02	---	---	---
Sink 1.30----	---	---	---	18.8	23.96	.022	---	---	---	49.5	27.40	.004
1.32----	6.3	40.02	.015	---	---	---	73.3	25.06	.01	---	---	---

[1] Stark Ceramics Co., Malvern pit, block 7, Carroll County.
[2] Stark Ceramics Co., Cameron property, block 7, Stark County.
[3] Magnolia Mining Co., block 1, Stark County.
[4] Magnolia Mining Co., block 2, Stark County.

lower percentage of germanium. This is to be explained by the fact that fusain and some extraneous minerals tend to be easily broken into fine particles during the grinding process.

Pyrite is commonly found in coal, in some localities in great abundance. Other sulfides, such as sphalerite, chalcopyrite, and millerite, are less commonly found. Because germanium occurs in high percentages in a number of sulfide minerals, the question naturally arises whether the germanium that is found in coal might not be mostly concentrated in the pyrite of the coal.

The distribution of germanium among the different gravity separates, previously described, gives a strong indication that the element is not in pyrite or other sulfide minerals. The element is seen to concentrate in the lighter fractions whereas sulfide minerals are known to go into the heavier fractions.

We have separated pyrite from 12 coals and a mixture of pyrite and sphalerite from two others. In table 5, the germanium content of these sulfides is contrasted with that of the ash of the host coal. All the pyrite samples gave negative tests (less than 0.002 percent). Samples 13 and 14 of table 5, showing 0.01 percent germanium, were crude separates containing both pyrite and sphalerite. Sample 13A was prepared from the same Cupressinoxylon log as sample 13, and it was carefully freed of adhering coaly material. It contained 0.002 percent germanium whereas the coal ash contained 0.8 percent. Thus, our results, like the results of Ratynskii's (1946) study of sulfides from the germaniumrich Kumarinskii coal deposit of Caucasus, showed no appreciable concentration of germanium. The lack of concentration in secondary sulfide minerals in germanium-rich coals contrasts sharply with the existence of germanium-rich sphalerites, tennantites, and particularly argyrodite, renierite, and germanite and poses a very interesting geochemical question of the origin of germanium-rich sulfides, in general.

Possible regional variation in the abundance of germanium

From the results discussed above, it is evident that the greatest enrichment of germanium in coaly materials is most likely to be found (1) in woody coal occurring isolated in sediments (logs, kettle bottoms, etc.) and (2) in woody coals in the top and bottom of coal beds. However, the bed of Eocene age at pit 1 of Nugget Coal Co. in the Hanna field of Wyoming (table 14) consists largely of clean woody coal, and one would expect it to contain a higher concentration of germanium than the 0.001 percent found only in the ash of the top block. Likewise, the germanium content of Finch beds 1 to 4 at the Gary mine, also in the Hanna field, is very low in spite of much woody coal in these beds. Only a well-preserved coalified coniferous log found in clay overlying Finch No. 4 bed at Gary mine showed 0.01 percent Ge in the ash. The question comes to mind whether these low values might not be an expression of an abnormally low percentage of germanium in the rocks of the region. We do not, as yet, have sufficient analyses of rocks from here and other regions to answer this question.

Table 5.--Germanium content of sulfide minerals from coals

[Asterisk (*) indicates germanium in concentrates less than 0.002 percent]

Sample no.	Mine and bed	Block	Ge in sulfide (percent)	Ge in ash (percent)
1	Upperman mine, Deer Park, Md.----------------------------	4	*	*
2	Junction City, Ohio. Lower Kittanning--------------------	4	*	0.002
3	Billman Coal Co., Stark County, Ohio. Lower Kittanning---	6	*	.002
4	Billman Coal Co., Stark County, Ohio. Lower Kittanning. Bottom of bed.	6	*	.002
5	Tuscarawas County, Ohio. Lower Kittanning----------------	6	*	.002
6	Columbianna County, Ohio. Middle Kittanning--------------	3	*	*
7	Magnolia Mining Co., Stark County, Ohio. Lower Kittanning.	2	*	.01
8	Stark Ceramics Co., Cameron property, Stark County, Ohio. Lower Kittanning.	7	*	.20
9	Sunnyhill Coal Co., New Lexington, Ohio. Lower Kittanning.	6	*	.02
10	Sunnyhill Coal Co., New Lexington, Ohio. Middle Kittanning.	10	*	*
11	Stark Ceramics Co., pit 14, Stark County, Ohio. Lower Kittanning.	3	*	.005
12	Stark Ceramics Co., pit 13, Stark County, Ohio. Middle Kittanning.	9	*	.02
13	Cupressinoxylon, Good Luck Road, East Riverdale, Md. Lignified tree trunk 1.		0.01	.80
13A	Cupressinoxylon, Good Luck Road, East Riverdale, Md. Second sample from same lignified tree trunk.		.002	.80
14	Cupressinoxylon, Good Luck Road, East Riverdale, Md. Lignified tree trunk 9.		.01	[1]

[1]Looked for, but not found.

Farther west in Wyoming, the coals of the Rock Springs field of late Cretaceous age show appreciable concentrations of germanium. In Montana (table 16) the coals of the Red Lodge field and of Rosebud County of Eocene age are very low in germanium whereas the coals of the Great Falls and Lewiston fields of late Jurassic age are notably richer.

Although the number of samples analyzed by us from Wyoming and Montana is still too small to provide the basis for any generalizations, we are, nevertheless impressed by these differences among coals from various basins.

A factor that may prove to be of great significance in explaining these variations is the presence or absence of mineralization adjacent to or within coalfields. There are zinc deposits near the germaniferous coal beds of Stark and Athens County, Ohio, and the coal beds of the Great Falls field in Montana. Conceivably, germanium could be introduced into the rocks of an area during the formation of a zinc deposit or during its subsequent weathering. Mueller (1924) has reported 0.3 ppm of germanium in the mine water of a zinc mine in Kentucky. If a correlation could be established between regional mineralization and germanium content of coals, it would be a very valuable guide in searching for germaniferous coals.

We are also studying the effect of metamorphism, both igneous and regional, on the germanium content of coal and plan to present the data in a future report.

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Table 6.--List of American coals showing high concentrations of germanium

State and county	Bed and formation	Location	Thickness of block (feet)	Ash (percent)	Ge in ash (percent)	GeO_2 (lbs per ton of coal)	Remarks
Ohio, Carroll--------	Lower Kittanning, Allegheny, Pennsylvanian.	Cameron pit, Stark Ceramics Co., East Canton.	0.3	3.54	0.20	0.20	Bottom block of the bed. Taken at two locations.
			.3	10.88	.18	.56	
			.3	6.86	.20	.40	
Do--------------	Middle Kittanning, Allegheny.	-----do----------	.37	8.27	.05	.12	Bottom block of the bed.
Ohio, Columbianna----	Middle Kittanning---	J & R Coal Co. Near Guilford Lake, Bisbon.	.55	20.3	.03	.18	Do.
Ohio, Coshocton------	Lower Kittanning----	Harris farm, near Sunnybrook.	.4	7.90	.06	.14	Block 2.
Ohio, Perry----------	-----do------------	Strip mine, near Junction City	.3	19.98	.072	.41	Bottom block of the bed.
Ohio, Stark----------	-----do------------	Pit 13, Stark Ceramics Co., East Canton.	.95	3.4	.2	.29	Bottom block of the seam collected May 1950.
			.55	7.85	.11	.25	Bottom block of the seam collected September 1951.
		Pit 14, Stark Ceramics Co., East Canton.	.45	5.55	.14	.21	Bottom block of the bed.
Do--------------	Middle Kittanning, Allegheny.	-----do----------	.12	18.56	.022	.12	Do.
Do--------------	Lower Kittanning, Allegheny.	Pit 20, Stark Ceramics Co., East Canton.	.65	10.72	.05	.15	Do.
	-----do------------	Metropolitan Clay Co., southwest of East Canton.	.60	8.63	.055	.13	Do.
Do--------------	Lower Kittanning, Allegheny.	Magnolia Mining Co., near Waynesburg.	.35	7.23	.13	.27	Bottom block of the bed.
		Billman Coal Co., Millers farm near Waynesburg	.05	10.40	.09	.27	Bony coal in the top part of the bed.
Ohio, Tuscarawas-----	-----do------------	Copperhead Coal Co., Millers farm near Waynesburg.	.55	11.39	.03	.10	Bottom block of the bed.
North Dakota, Mclean.	Garrison Creek bed--	Custer mine, Garrison.	.25	16.50	.043	.21	Do.
Montana, Fergus------	Unnamed bed, Morrison, Jurassic.	C. M. Tuss mine, east of Lewistown.	.5	3.71	.21	.23	Jetty coal at the top of the bed.
Montana, Casdade-----	-----do------------	East Belt mine, Belt.	3.0	21.56	.037	.23	Composite sample of the bottom 3 feet thick seam.
Ohio, Perry----------	Lower Kittanning----	Sunnyhill mine, Sunnyhill Coal Co., New Lexington.	---	7.55	.057	.12	Lowest block of the columnar sample.
Do--------------	Middle Kittanning---	-----do----------	---	11.50	.03	.1	Do.
Ohio, Stark----------	Lower Kittanning----	Metropolitan Clay Co., pit, southeast of East Canton.	.60	8.63	.054	.15	Do.

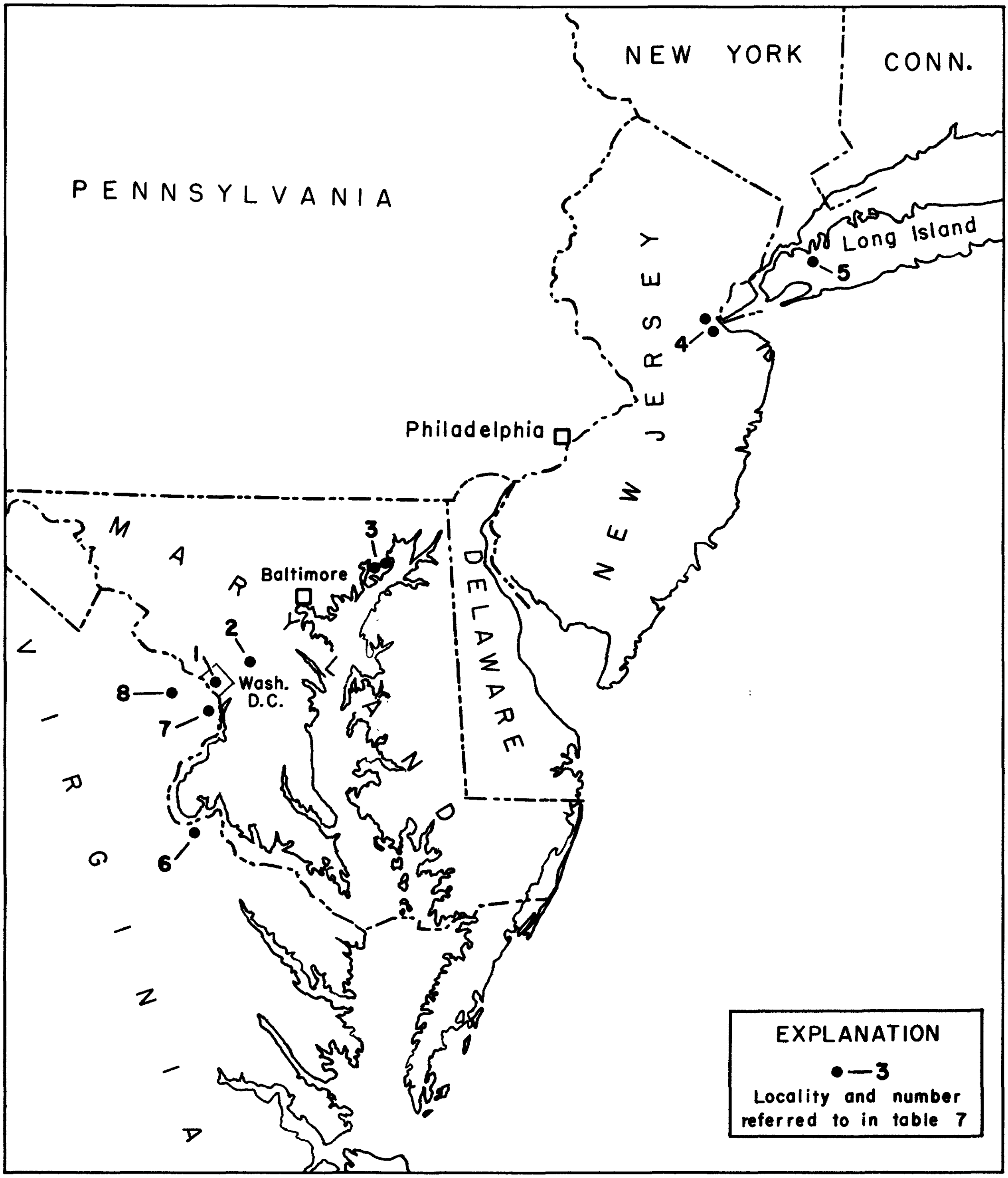

Figure 2.--Map showing localities of lignites from the Atlantic Coastal Plain.

Table 7.--Germanium content in the ash of the lignites of Cretaceous age from the Atlantic Coastal Plain

Laboratory: G-1, U. S. Geol. Survey Washington laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; G-3, U. S. Geol. Survey Washington laboratory (G. W. Steiger), sensitivity 0.01 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.0004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis]

No. on fig. 2	County	Bed and formation	Location	Sample no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	District of Columbia.	Potomac group (Cretaceous).	Banneker play-ground, 9th and Euclid Sts., NW.	1	3.38	0.2	G-1	Lignitic remains of *Cupressinoxylon* log.
1	-----do-----	-----do-----	Branch Ave. near Pennsylvania Ave., SE.	1	2.03	.2	G-1	Samples: 1, lignitic remains in clay. Road excavation; 2, Comminuted pieces of lignite same locality.
				2	51.4	.003	G-1	
1	-----do-----	Magothy (Upper Cretaceous).	Nichols Ave., near Fort Grebble, SE.	1	3.30	2.3	G-1	Pieces of lignite.
1	-----do-----	-----do-----	Alsoph Quarry, Nichols Ave., SE.	1	47.7	.01	G-3	Mineralized block of *Cupressinoxylon* log.
1	-----do-----	Potomac Group (Cretaceous).	Clay pits, Bladensburg Rd., near Pennsylvania RR.	1	6.40	.03	G-1	Samples: 1, part of a log; 2 and 3, composite of many logs and pieces of logs; 4, part of a log about 20 ft long.
				2	13.00	.5	G-1	
				3	31.30	*	G-1	
				4	3.36	2.0	G-1	
1	-----do-----	-----do-----	Rhode Island Ave., and 13th St., NE.	1	3.64	2.80	G-1	Lignite, found in excavation for an apartment building.
1	-----do-----	-----do-----	Montana Ave. and 18th St., NE.	1	3.82	1.5	G-1	Samples: 1, road excavation, jetlike lignite (*Cupressinoxylon*), woody; 2, soft lignite part of the above sample: 3, Same locality, different, samples of lignite; 4, Same as 3; 5, Fusain, same locality.
				2	3.26	2.2	G-1	
				3	8.33	2.4	EQ	
				4	4.40	3.4	EQ	
				5	7.10	.02	G-1	
2	Prince Georges County, Md.	----do----	Northwest Branch Anacostia River, near gas tanks.	1	4.40	.03	G-1	Various parts of a large trunk of *Cupressinoxylon* taken from the stream.
				2	3.30	.01	G-1	
				3	10.00	.01	G-1	
2	-----do-----	-----do-----	Public school grounds, Sunnybrook.	1	6.54	1.06	EQ	Composite of several samples of *Cupressinoxylon* logs and broken pieces.
2	-----do-----	-----do-----	Good Luck Rd. and Washington-Baltimore Parkway, near East Riverdale.	1	9.9	.8	G-1	Trunks of *Cuppressinoxylon* found in place, collected, May 1951. Samples: 1 to 6 tree trunks in upright position; 7 and 8, lignified roots of trunks 3 and 4; 9 to 11, lignite remains scattered in the locality. The latter were collected March 1950.
				2	7.1	.6	G-1	
				3	8.7	.4	G-1	
				4	3.7	1.9	G-1	
				5	4.1	.7	G-1	
				6	7.54	.8	G-1	
				7	4.6	1.11	G-1	
				8	3.7	2.0	G-1	
				9	4.6	1.1	G-1	
				10	7.74	2.3	G-1	
				11	4.04	4.9	G-1	
2	-----do-----	Patuxent (Lower Cretaceous).	Byrd Stadium, University of Maryland, College Park, Md.	1	2.85	7.5	G-1	*Cupressinoxylon* lignite remains. Collected at different sites, January-August 1950. Samples: 1 to 4, collected at the highest bed; 5 to 10, various samples taken from lower bed; 11, fusain from sample 7.
				2	3.4	2.3	G-1	
				3	2.8	5.0	G-1	
				4	2.85	6.7	G-1	
				5	2.04	2.4	G-1	
				6	4.12	.8	G-1	
				7	2.40	3.0	G-1	
				8	3.00	3.3	G-1	
				9	4.18	2.8	G-1	
				10	3.2	4.87	G-1	
				11	12.2	.07	G-1	
2	-----do-----	-----do-----	-----do-----	1	4.0	3.0	G-1	Site 4, a trench in which copper mineralization was evident. Most of the samples are rich in copper.
				2	4.2	3.9	G-1	
				3	8.0	.5	G-1	
				4	10.7	1.5	G-1	
				5	6.9	1.0	G-1	
				6	39.6	2.7	G-1	
2	-----do-----	Arundel (Upper Cretaceous).	Clay pit, Washington Brick Co., Muirkirk, Md.	1	3.2	1.3	G-1	Samples of *Cupressinoxylon* in clay. Samples: f, fusain taken from logs; j, jetty log.
				2	3.6	1.3	G-1	
				f	19.6	.005	G-1	
				j	8.07	.6	G-1	
3	Harford, Md.-----	-----do-----	Clay pit, near Edgewood, Md.	1	2.6	.9	G-1	Samples: 1 and 2, small pieces of lignite; f, fusain.
				2	2.02	.9	G-1	
				f	7.1	*	G-1	
3	-----do-----	-----do-----	Aberdeen, Md.-----	1	2.22	.29	G-1	Sewer excavation sample, presented by O. M. Bishop, U. S. Bur. Mines.
4	Monmouth, N. J.---	Magothy (Upper Cretaceous).	Oschwalt Brick Co., Cliffwood, N. J.	1	4.14	.01	G-1	Samples: 1, broken pieces of lignite in clay; 2, fusain in clay.
				2	2.27	.007	G-1	
5	Nassau, Long Island, N. Y.	---do-----	O'Bryan Pits, Port Washington.	1	4.48	.34	G-1	Samples collected by Wallace Laguna, U. S. Geol. Survey.
				2	3.08	.16	G-1	
6	King George, Va.	Potomac Group (Cretaceous).	Van Valsah farm, near Osso.	1	7.28	2.0	G-1	Lignite in marly micaceous clay. Presented by John J. Bernard.
7	Arlington, Va.---	-----do-----	Seminary Rd., 1 mile southeast of Bailey's Cross Roads.	1	1.8	1.4	G-1	Sample taken from a well diggings. Presented by George Schoechle, U. S. Geol. Survey.
8	Fairfax, Va.-----	Triassic-----	Chantilly, Va., 8 miles east.	1	3.5	*	G-1	Log, collected by R. S. Cannon, U. S. Geol. Survey.

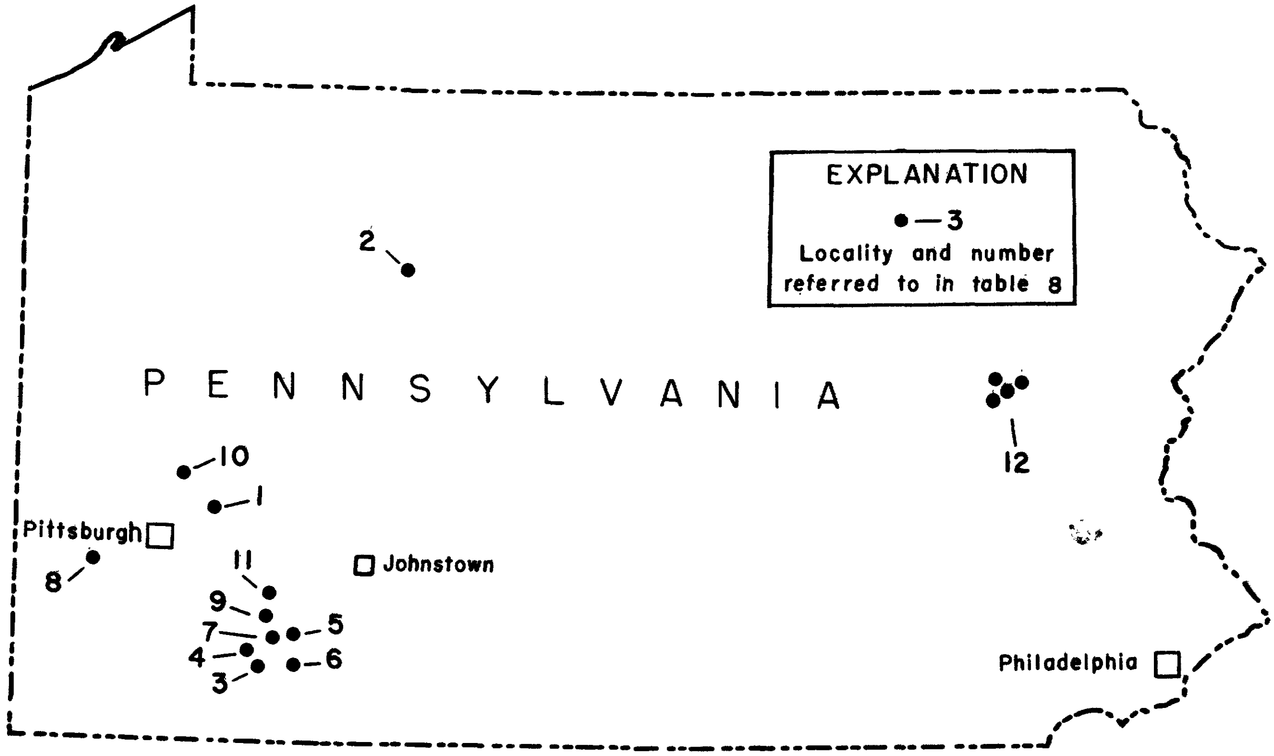

Figure 3.--Map showing localities of coals from Pennsylvania.

Table 8.--Germanium content in the ash of coals from Pennsylvania

Laboratory: G-1, U. S. Geol. Survey Washington laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; G-3, U. S. Geol. Survey Washington laboratory (G. W. Steiger), sensitivity 0.01 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis]

No. on fig. 3	County	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	Armstrong----------	Lower Kittanning, Allegheny (Pennsylvanian).	Cadogan No. 1 mine, Cadogan.	1 2		* *	G-3 G-3	Blocks: 1, woody coal; 2, fusain. Selected from the columnar sample.
2	Elk----------------	--do--------	Proctor No. 9 mine, near St. Mary's	1 2 3		* * *	G-3 G-3 G-3	Blocks: 1, woody coal; 2, durain; 3, fusain.
3	Indiana------------	--do--------	Victor No. 29 mine, Clymer.	1 2 3		0.01 * *	G-3 G-3 G-3	Blocks: 1, woody coal; 2, durain; 3, fusain.
4	-----do------------	--do--------	Cresson No. 9 mine, Cresson.	1 2 3		* * *	G-3 G-3 G-3	Blocks: 1, woody coal; 2, durain; 3, fusain.
5	Cambrian-----------	--do--------	Ehrenfeld, Ehrenfeld-----	1 2		* *	G-3 G-3	Blocks: 1, woody coal; 2, durain.
6	-----do------------	--do--------	Franklin, Johnson--------	1 2 3		* * *	G-3 G-3 G-3	Blocks: 1, woody coal; 2, durain microdebris; 3, fusain.
7	Cambria------------	Lower Kittanning, Allegheny (Pennsylvanian).	Maryland, No. 1 mine, St. Michael.	1 2 3		* * *	G-3 G-3 G-3	Blocks: 1, woody coal; 2, durain; 3, fusain.
8	Allegheny----------	Pittsburgh Monangahela (Pennsylvanian).	Bur. Mines, Experimental mine, Bruceton.	1 2	12.6 12.4	* *	G-1 G-1	Channel sample, sent by T. Fraser, U. S. Bur. Mines.
9	Indiana------------	Lower Kittanning.	Waterman No. 2 mine, Rochester and Pittsburgh Coal. Co., Homer City.	1 2d 2f 2w 4 4w	1.8 14.2 12.3 3.97 3.7 3.1	.012 * * * * *	E G-1 G-1 G-1 G-1 G-1	Columnar sample, 3.7 ft thick. Blocks: 1, woody coal, 0.4 ft thick; 2d, selected coal rich in plant microdebris (durain); 2f, fusain; 2w, woody coal, same block; (block 2, thickness 0.9 ft); 4, thickness 1.2 ft; 4w, woody coal selected from block 4.

Table 8.--Germanium content in the ash of coals from Pennsylvania--Continued

No. on fig. 3	County	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
10	Armstrong---------	Lower Kittanning.	Pittshaw No. 15. Strip mine, Freebrook Corp., Kittanning.	1 2 3 4	11.10 6.62 10.2 37.48	0.01 .0017 .0017 .0012	G-1 E E E	Columnar sample, 2.8 ft thick, taken in 4 blocks. Block 1, thickness 1.2 ft.
11	Indiana------------	Upper Freeport Allegheny (Pennsylvanian).	Drill Core no. 836, Rochester & Pittsburgh Coal Corp., Indiana.	1	2.2	*	G-1	Selected sample of woody coal. The core was sent by Dr. C. J. Porter, Indiana.
12	Luzerne-----------	Anthracite, location and bed unknown.	Middle Western Region. Jeddo Highland. Loree Spiral plant silt. Susquehanna, Flotation Plant.	1 1 1 1		* * * *	G-1 G-1 G-1 G-1	Samples of anthracite ash sent by Pennsylvania State College.

Table 11.--Germanium content in the ash of Ohio coals

Laboratory: G-1, U. S. Geol. Survey Washington laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.0004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis]

No. on fig. 6	County	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	Athens------------	Lower Kittanning, Allegheny (Pennsylvanian).	Exposure at the Nelsonville Hospital.	4	12.1	0.004	G-1	Columnar sample, 2.1 ft thick. Analyzed selected blocks only. 6f, fusain in block 6.
				6f	4.9	.007	G-1	
1	-----do------------	Middle Kittanning, Allegheny.	Strip mine, near Nelsonville Hospital.	6	5.6	.003	G-1	Columnar sample, 6 ft thick. Selected block rich in woody matter.
2	Belmont-----------	Pittsburgh, Monongahela (Pennsylvanian).	Georgetown, No. 10 mine, near Neff.	4	7.4	*	G-1	Columnar sample. Selected block of woody coal.
3	Columbiana--------	Middle Kittanning.	Guilford Lake, J. & R. Coal Co., near Lisbon.	1	12.24	.01	G-1	Columnar sample, 4.5 ft thick, taken in 8 blocks.
				2	8.55	.0026	E	
				3	12.62	.0013	E	
				4	13.00	*	G-1	
				5	13.00	.0029	G-1	
				6	9.50	.003	G-1	
				7	8.38	.029	EQ	
				8	20.3	.03	G-1	
4	Carroll-----------	Lower Kittanning.	Cameron pit, Stark Ceramics Co., near Malvern.	1	27.88	.003	G-1	Columnar sample, 1.9 ft thick, taken in 7 blocks. Block 7a taken at the bottom of the bed 6.6 ft from the columnar sample.
				2	26.14	.004	G-1	
				3	3.71	.0014	E	
				4	3.00	.003	G-1	
				5	3.34	.002	G-1	
				6	4.50	.01	G-1	
				7	3.54	.20	G-1	
				7a	10.88	.18	EQ	
4	-----do------------	Middle Kittanning.	-----do------------------	1	6.34	.03	G-1	Columnar samples, taken in 6 blocks. Block 4: 4f, fusain; 4w, woody coal.
				2	11.64	.008	G-1	
				3	17.90	*	E	
				4	8.85	.0012	E	
				4f	13.04	*	G-1	
				4w	3.50	.002	G-1	
				5	5.56	.002	G-1	
				6	8.27	.048		
5	Coshocton----------	---do-------	Stewart Coal Co. strip mine, 14 miles southwest of Coshocton.	1	6.5	.034	G-1	Columnar sample, 6 ft thick. Block 1, thickness 0.9 ft.
6	-----do------------	Lower Kittanning.	Abandoned strip mine, Harris Farm, near Sunnybrook.	1	11.87	.0029	E	Selected samples of the columnar sample 5.2 ft thick. Block 2, thickness 0.4 ft.
				2	7.9	.061	EQ	
				3	10.24	.0005	E	
				4	4.48	.0005	E	
				5	4.76	.0008	E	
6	-----do------------	Middle Kittanning.	-----do------------------	1	1.50	.002	G-1	Columnar sample. Selected blocks. Block 5, woody coal below parting.
				2	2.80	.004	G-1	
				3	2.10	.003	G-1	
				4	2.70	.004	G-1	
				5	6.00	.02	G-1	
7	Jackson-----------	Sharon 1, Pottsville (Pennsylvanian).	McKittrick mine, Jackson.	1	10.8	.008	G-1	Drill sample of the entire bed, 5.5 ft thick.
				5f	26.5	*	G-1	Blocks: 5f, coal rich in fusain; 8f, fusain; 8, dull (durain) coal.
				8f	19.6	*	G-1	
				8	21.9	*	G-1	
8	Perry-------------	Lower Kittanning.	Sunnyhill mine, New Lexington.	1	15.21	.014	EQ	Columnar sample, taken in 6 blocks.
				2	14.88	.0018	E	
				3	10.09	.0016	E	
				4	7.19	.002	E	
				5	2.77	.0027	E	
				6	7.55	.057	EQ	
8	----do------------	Middle Kittanning.	-----do------------------	1	38.75	.0018	E	Columnar sample, taken in 17 blocks. Most of the blocks are either bony or form bone partings in the bed.
				2	43.76	.004	G-1	
				3	28.68	.003	G-1	
				4	19.53	.0023	G-1	
				5	28.84	*	E	
				6	25.70	*	E	
				7	32.40	*	G-1	
				8	24.8	*	G-1	
				9	6.13	.0012	E	
				10	6.72	.0034	E	
				11	6.02	.0014	E	
				12	79.97	*	E	
				13	7.14	.003	E	
				14	6.24	.0014	E	
				15	4.81	.0018	E	
				16	7.78	.0016	E	
				17	11.50	.03	G-1	
9	----do------------	Lower Kittanning.	Strip mine, near Junction City.	1	24.42	.010	E	Columnar sample, taken in 8 blocks.
				2	22.96	.012	E	
				3	18.81	.0022	E	
				4	20.34	.0020	E	
				5	13.51	.0016	E	
				6	5.78	.0025	E	
				7	7.20	.016	E	
				8	19.98	.072	G-1	

Table 11.--Germanium content in the ash of Ohio coals--Continued

No. on fig. 6	County	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
10	Stark------------	Lower Kittanning.	Pit 13, Stark Ceramics Co., East Canton.	1	---	0.033	G-1	Blocks 1 and 3 of columnar sample, collected December 1948. Bp, bottom part of the bed.
				3	---	.10	G-1	
				Bp	3.85	.26	EQ	
10	-----do-----------	---do-------	-----do------------------	Bp	3.7	.2	G-1	Bottom part of the columnar sample, 0.95 ft thick.
10	-----do-----------	---do-------	-----do------------------	1	9.21	.013	EQ	Columnar sample, 2.1 ft thick. Collected in 5 blocks, September 26, 1951. Blocks: 3f, fusian from top of block; 5, thickness 0.5 ft.
				2	9.38	*	G-1	
				3f	7.54	*	G-1	
				3	3.00	.004	G-1	
				4	5.67	.03	G-1	
				5	7.85	.11	EQ	
11	-----do-----------	---do-------	Pit 14, Stark Ceramics Co., East Canton.	1	7.20	.004	G-1	Columnar sample, 3.1 ft thick, taken in 4 blocks, lowest block 0.45 ft thick.
				2	3.51	.0023	E	
				3	3.74	.005	G-1	
				4	5.55	.13	EQ	
11	-----do-----------	Middle Kittanning.	-----do------------------	1	13.21	.03	G-1	Columnar sample, 3.1 ft thick, taken in 9 blocks. Block 1, thickness 0.25 ft. Middle Kittanning coal lies 30 ft above the lower Kittanning. The sample was taken 30 ft below the samples of the Lower Kittanning bed. (See columnar sample for pit 14, above.)
				2	8.73	.013	EQ	
				3	6.14	.0019	E	
				3f	18.10	*	G-1	
				4	17.5	*	G-1	
				4f	13.6	*	G-1	
				5	4.68	*	G-1	
				6	8.96	.0014	E	
				7	8.72	.004	G-1	
				8	23.52	.0013	E	
				9	18.57	.022	EQ	
12	-----do-----------	Lower Kittanning.	Pit 20, Stark Ceramics Co., East Canton.	1	12.04	.02	G-1	Columnar sample, 2.15 ft thick, taken in 6 blocks. Block 6, thickness 0.65 ft.
				2	15.14	.02	G-1	
				3	13.35	.0059	EQ	
				4	31.31	*	E	
				5	17.78	.002	G-1	
				6	10.72	.05	EQ	
13	-----do-----------	---do-------	Metropolitan Clay Co., pit, southeast of East Canton.	1	24.73	.0082	EQ	Columnar sample, 1.95 ft thick, taken in 7 blocks. Block 7, thickness 0.6 ft.
				2	29.66	.004	G-1	
				3	32.60	.002	G-1	
				4	27.84	.0016	E	
				5	8.03	.005	G-1	
				6	9.08	.0019	E	
				7	8.63	.054	EQ	
14	-----do-----------	---do-------	Magnolia Mining Co., McCall's Farm near Waynesburg.	1	21.03	.06	EQ	Columnar sample, 1.8 ft thick, taken in 7 blocks. Block 7, thickness 0.35 ft.
				2	14.93	.019	EQ	
				3	6.16	.003	G-1	
				4	26.54	.0022	E	
				5	4.38	.003	G-1	
				6	3.84	.004	G-1	
				7	7.23	.13	EQ	
15	-----do-----------	---do-------	Billman Coal Co., Miller's Farm, Waynesburg.	1	10.40	.091	EQ	Columnar sample, 4.25 ft thick, taken in 11 blocks. Block 1, thickness 0.05 ft.
				2	7.05	.025	EQ	
				3	26.62	.004	G-1	
				4	13.20	.001	G-2	
				5	15.65	.0019	E	
				6	7.24	.002	E	
				7	21.9	.003	G-2	
				8	5.48	.004	G-2	
				9	10.36	.006	G-1	
				10	7.02	.005	G-1	
				11	9.78	.014	EQ	
16	Tuscarawas---------	---do-------	Copperhead mine, Sugar Creek.	1	99.88	.03	G-2	Columnar sample, 3 ft thick, taken in 7 blocks. Block 7, thickness 0.55 ft.
				2	9.54	.0022	E	
				3	7.08	.0016	E	
				4	5.61	.0015	E	
				5	14.56	.0021	E	
				6	25.20	.0022	E	
				7	8.40	.03	G-2	

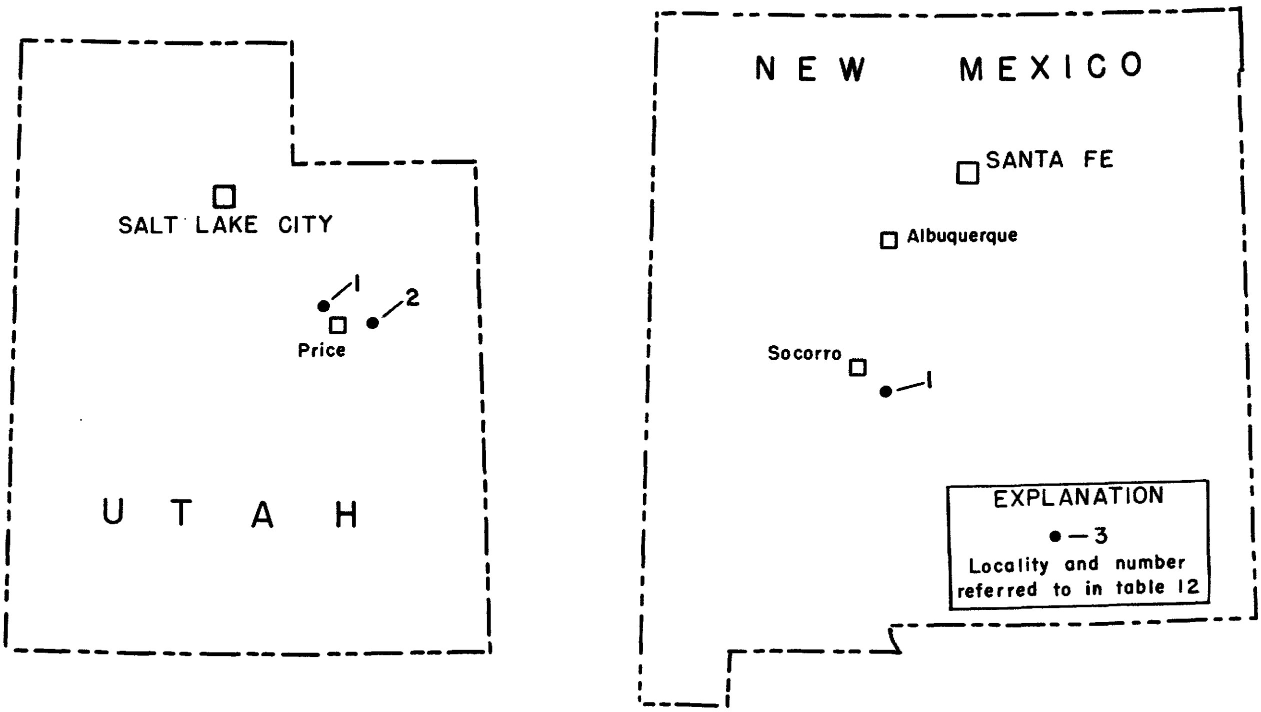

Figure 7.--Map showing localities of coals from New Mexico and Utah.

Table 12.--Germanium content in the ash of the Upper Cretaceous coals from New Mexico and Utah

Laboratory: G-1, U. S. Geol. Survey Washington laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.0004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis]

No. on fig. 7	County, field, and state	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	Socorro, Carthage, N. Mex.	Carthage, Mesaverde.	Boca mine, New Carthage.	1	12.56	0.001	G-2	Columnar sample. Selected blocks analyzed.
				3	9.65	.0012		
1	Carbon, Castlegate, Utah.	Kenilworth, Mesaverde.	Kenilworth mine, Independent Coal & Coke Co.	1	7.64	*	G-1	Columnar sample, 12 ft thick. Selected blocks analyzed.
				5	5.50	.001	E	
				8	4.02	.0063	E	
				10	5.84	*	E	
2	-----do------------	Sunnyside, Mesaverde.	Sunnyside No. 2 mine, Kaiser Steel Corp., Sunnyside.	1	3.74	.001	E	Columnar sample, 10 ft thick. Selected blocks analyzed.
				2	13.96	.001	E	
				5	5.82	*	G-1	
				6a	2.42	.0022	E	Last block in the column, 28a. Upper part, block 1, rich in woody coal.
				6b	1.55	*	E	
				6c	4.86	*	E	
				10	2.20	.0018	E	
				28a	3.58	*	G-1	

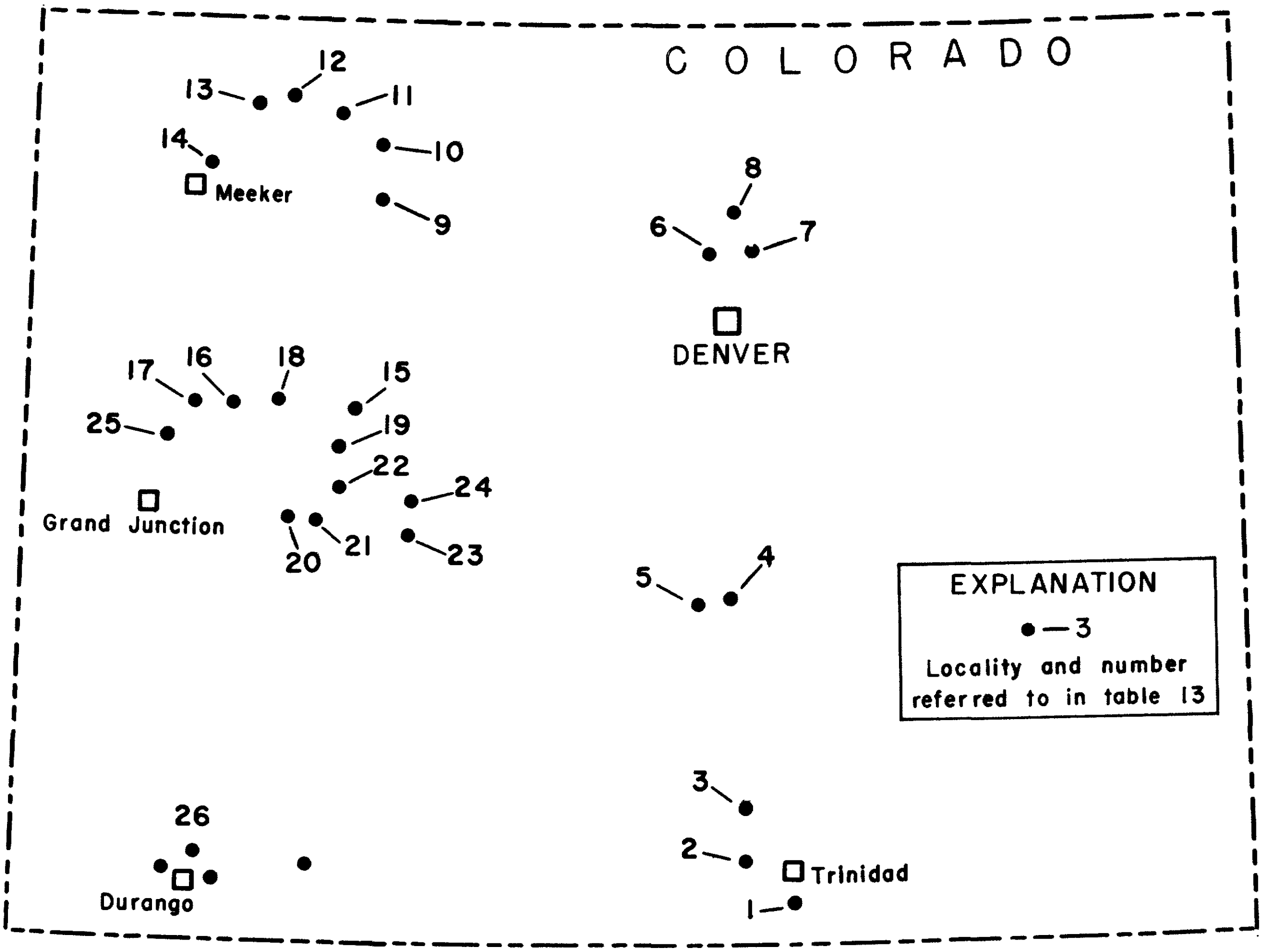

Figure 8.--Map showing localities of coals from Colorado.

Table 13.--Germanium content in the ash of coals from Colorado

Laboratory: G-1, U. S. Geol. Survey Washington laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.0004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis]

No. on fig. 8	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	Los Animas, Trinidad.	Frederick, Raton (Eocene).	Frederick mine, Colorado Fuel & Iron Corp., Valdez.	1	9.12	0.004	G-2	Columnar sample. Selected blocks.
				2	17.56	.003	G-1	
				3	8.70	*	G-1	
				4	16.04	*	G-2	
2	Huerfano, Trinidad.	Walsen, Vermejo (Upper Cretaceous).	Kebler No. 2 mine, Tioga---	1	0.72	.005	G-1	Do.
				20	9.60	*	G-2	
3	-----do------------	Unnamed, Vermejo	Five miles west of La Veta on Route 160.	1	21.20	*	G-1	Grab sample, collected by Larry Warner, U. S. Geol. Survey.
4	Fremont-------------	---do--------	Double Dick mine, southeast of Canon City.	1	13.60	*	G-1	Do.
5	-----do------------	Brookside, Vermejo	Between Canon City and Florence, Route 50.	1	8.20	*	G-1	Do.
6	Boulder, Denver region.	Unnamed, Laramie (Upper Cretaceous).	Black Diamond, Lafayette.	1	6.30	*	G-1	Do.
7	Weld, Denver region.	---do--------	Washington mine, Erie-----	1	7.80	*	G-1	Do.
8	-----do------------	---do--------	Lincoln mine, Erie--------	1	7.28	.002	G-1	Columnar sample. Selected blocks. Rich in woody coal. 1w, part of block 1, woody.
				1w	6.05	.002	G-1	
				3	4.30	*	G-1	
9	Routt, Green River region.	Lennox, Mesaverde (Upper Cretaceous).	Edna mine, Oak Creek------	5	4.85	.0005	E	Columnar sample. Selected blocks.
				7	4.41	.0005	E	
				9	5.20	*	G-1	

Table 13.--Germanium content in the ash of coals from Colorado--Continued

No. on fig. 8	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
10	Routt, Green River region.	Pinnacle, Mesaverde.	Keystone mine, Routt-----	1	7.74	0.0087	G-1	Columnar sample, 8.65 ft thick. Selected blocks.
				7	3.28	*	G-1	
				11	10.64	*	G-1	
				12	2.50	*	G-1	
11	-----do-----------	Wadge, Mesaverde.	Harris mine, Mt. Harris.	15	6.80	*	G-1	Columnar sample, 9.6 ft thick. Selected block rich in woody coal.
12	-----do-----------	Pinnacle, Mesaverde.	Ramsey mine, Hayden------	1	2.64	.01	EQ	Columnar sample. Selected blocks of the upper part of the bed, 1.8 ft thick.
				5	3.79	.0023	E	
12	-----do-----------	---do-------	-----do------------------	1	3.00	.01	G-1	Lower part of the bed, 7.4 ft thick. 1w, woody coal from block 1.
				1w	2.60	.04	G-1	
				3	7.03	.0015	E	
				4	3.69	.0005	E	
				5	3.76	.001	E	
				6	3.29	.0005	E	
				8	2.67	.0044	E	
				11	18.34	.0014	E	
				12	22.83	.0005	E	
13	Moffat, Green River region.	Wise Hill, Mesaverde.	Wise Hill mine, near Craig.	1	5.42	*	G-1	Columnar sample, 9.95 ft thick, taken in 12 blocks. Selected blocks.
				2	13.56	*	G-1	
				5	7.96	*	G-1	
				7	3.72	*	G-1	
				9	4.58	*	G-2	
				12	2.34	*	G-2	
14	Moffat, Uintah----	Collum, Mesaverde.	Red Wing mine, Axial-----	1	4.14	*	G-1	Columnar sample, 23 ft thick. Selected samples rich in woody coal (upper part of the sample).
				17	4.96	*	G-2	
				19	3.82	*	G-2	
14	-----do-----------	---do-------	-----do------------------	3	2.08	*	G-1	Lower part of the columnar sample. Composed largely of woody coal.
				4	1.74	*	G-2	
15	Garfield, Uintah region.	"A," Mesaverde.	Sunlight mine, Cattle Creek.	1	3.56	*	G-1	Columnar sample, 5.6 ft thick, taken in 23 blocks. Selected samples, representing different coal ingredients. Three additional beds of different thicknesses were sampled in the mine.
				3	10.76	*	G-1	
				6	7.06	*	G-1	
				7	8.12	*	G-1	
				8	4.38	*	G-1	
				10	7.82	*	G-1	
				13	8.90	*	G-1	
				15	15.34	*	G-1	
				18	8.84	*	G-1	
				20	8.96	*	G-1	
				22	6.18	*	G-1	
				23	5.04	*	G-1	
15	-----do-----------	"B," Mesaverde.	-----do------------------	1	3.76	.01	G-1	Columnar sample, 2.75 ft thick, taken in 5 blocks.
				2	5.60	*	G-1	
				3	7.78	*	G-1	
				4	3.96	*	G-1	
15	-----do-----------	"C," Mesaverde.	-----do------------------	1	5.26	.001	G-2	Columnar sample, 4.3 ft thick, taken in 7 blocks. Selected blocks of different coal types.
				5	2.06	*	G-2	
				6	3.10	*	G-2	
				7	6.08	*	G-2	
15	-----do-----------	"D," Mesaverde.	-----do------------------	1	6.72	.02	G-2	Columnar sample, 5.8 ft thick, taken in 13 blocks. Selected blocks, most of which are rich in woody coal.
				2	8.06	*	G-2	
				5	1.52	*	G-1	
				6	2.84	*	G-2	
				8	2.14	*	G-1	
				10	2.28	*	G-2	
				11	2.14	*	G-2	
				13	2.36	*	G-1	
16	-----do-----------	Unnamed, Mesaverde.	Ten miles north of Riffle.	1	12.9	*	G-1	Grab samples, collected by Larry Warner, U. S. Geol. Survey.
17	-----do-----------	---do-------	Seven miles north to northeast of Riffle.	1	8.60	*	G-1	Do.
18	-----do-----------	---do-------	Near Reservoir 8 miles north of Silt.	1	9.80	*	G-1	Do.
19	Pitkin, Uintah----	---do-------	Four miles south of Redstone. State Route 327.	1	11.70	*	G-1	Do.
20	Gunnison, Uintah region.	Somerset "B," Mesaverde.	Somerset mine, Somerset---	1	11.70	*	G-1	Lower part of the bed. Columnar sample, 7.55 ft thick, taken in 7 blocks.
				2	4.50	*	G-1	
				3	4.21	.0015	E	
				4	7.30	.0005	E	
				5	10.18	.0005	E	
				6	3.34	.0005	E	
				7	6.17	.0015	E	
20	-----do-----------	Somerset "C," Mesaverde.	-----do------------------	2	3.17	.0014	E	Upper part of bed, 3 ft thick, taken in 5 blocks.
				3	16.65	*	E	
				4	6.19	.0014	E	
				5	3.83	.0012	E	
21	-----do-----------	Hawk's Nest, Mesaverde.	Hawk's Nest mine, Somerset.	1	7.19	.0011	E	Columnar sample. Selected blocks.
				2	5.95	.0012	E	
				3	6.23	.0017	E	
22	-----do-----------	Redglow, Mesaverde.	Oliver No. 2 mine, Oliver.	1	5.45	.0078	E	Do.
				3	1.69	.0017	E	
				4	1.68	.0059	E	
				7	3.20	.0005	E	
				8	5.68	.0005	E	

Table 13.--Germanium content in the ash of coals from Colorado--Continued

No. on fig. 8	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
23	Gunnison, Crested Butte.	Upper Mesaverde, Mesaverde.	Crested Butte, Crested Butte.	1 7 10 12	6.80 2.20 2.62 2.40	0.0026 .0015 .0012 .0014	G-1 E E E	Columnar sample. Selected blocks.
24	-----do------------	Unnamed, Mesaverde.	Mine on east side of Slate Creek. Four miles north of Crested Butte.	1 2	16.80	*	G-1	Grab sample, collected by Larry Warner, U. S. Geol. Survey.
25	Mesa, Uintah------	Cameo, Mesaverde.	Cameo mine---------------	1 3 5 6 7w 8	8.88 5.26 12.44 8.88 1.30 12.74	.0018 .0005 .0005 .0005 .02 .0005	E E E E G-1 E	Columnar sample, 5 ft thick, taken in 8 blocks. 7w, woody coal, selected from block 7.
26	La Plata, San Juan River region.	Unnamed, Fruitland?	Castle mine, 5 miles northwest of Durango.	1	3.90	.002	G-1	Grab sample, collected by Larry Warner, U. S. Geol. Survey.
26	-----do--------------	---do--------	O. K. mine, 4 miles northwest of Durango.	1	4.50	.002	G-1	Do.
26	-----do------------	Unnamed, Fruitland (Upper Cretaceous).	Exposure 2 miles south of Durango on Route 160.	1	36.80	*	G-1	Channel sample, 22 ft bed. Collected by Larry Warner, U. S. Geol. Survey.
26	-----do--------------	---do--------	Yellow Jacket, near Bayfield.	1	16.60	*	G-1	Grab sample, collected by Larry Warner, U. S. Geol. Survey.

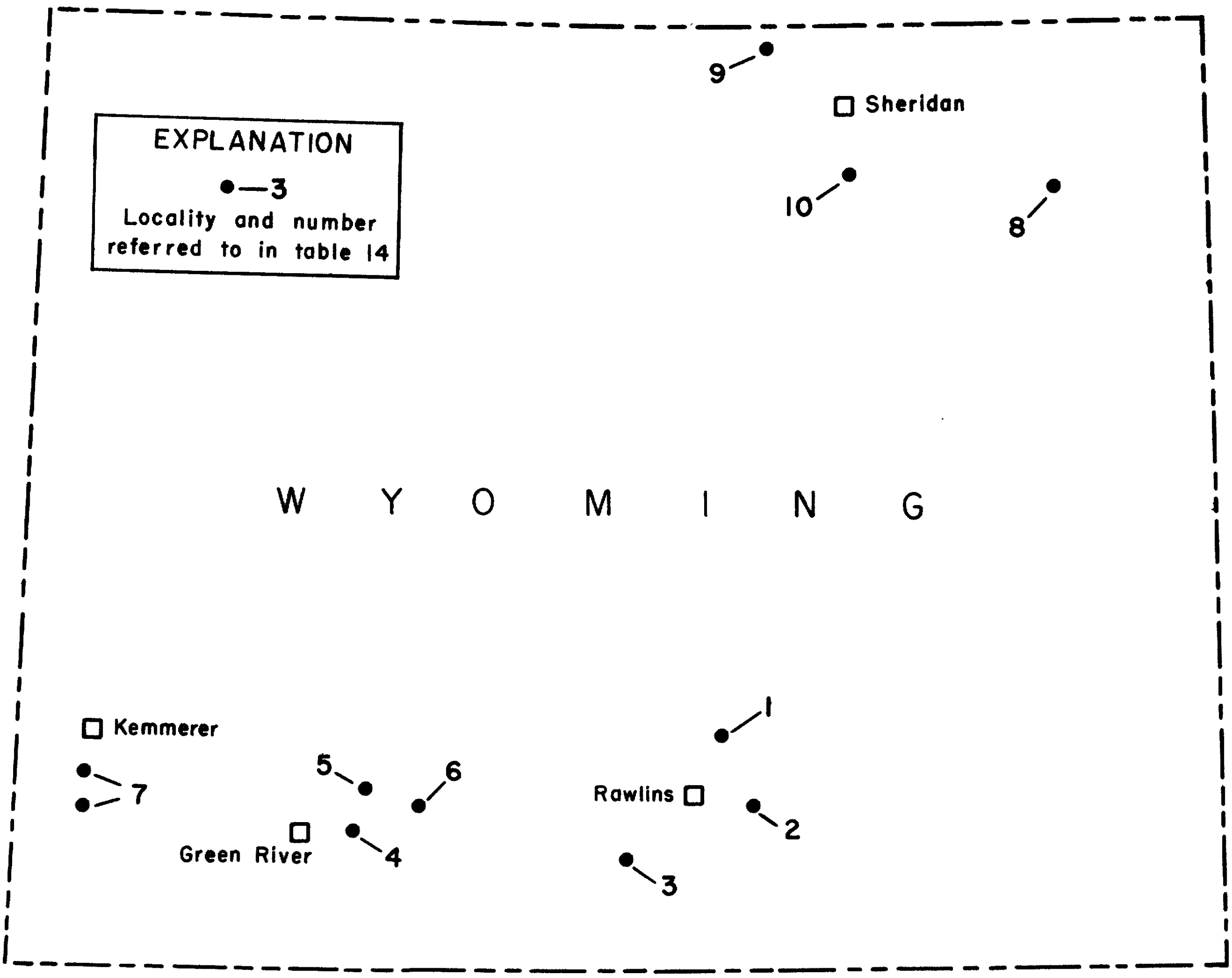

Figure 9.--Map showing localities of coals from Wyoming.

Table 14.--Germanium content in the ash of coals from Wyoming

Laboratory: G-1, U. S. Geol. Survey Washington laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.0004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis]

No. on fig. 9	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	Carbon, Hanna------	Hanna No. 1, Hanna formation (Eocene).	Pit 1, Nugget Coal Co., Hanna.	1 1w 7 9	1.9 2.7 2.2 2.3	0.001 * * *	G-2 G-1 G-1 G-1	Columnar sample, 9.9 ft thick. Selected blocks of woody coal. Block 1, thickness 0.9 ft; 1w, bright glossy coal (vitrain).
1	-----do------------	Hanna No. 2, Hanna.	Pit 2, Nugget Coal Co., Hanna.	1 2	1.0 1.7	* *	G-1	Columnar sample, 10.1 ft thick. Selected samples of glossy coal (vitrain) from the top part of the bed.
1	-----do------------	---do--------	Monolith Portland Midwest Coal Co., Hanna.	1	1.0	*	G-1	Selected sample of woody coal 0.8 ft thick from the top of the bed, 18 ft thick.
1	-----do------------	---do--------	Union Pacific Coal Co. mine, Hanna.	1 2 3	1.7 10.5 3.5	* * *	G-1 G-1 G-1	Type samples, selected at the tipple. Samples: 1, woody coal; 2 microdebris with fusain; 3, durain.
2	-----do------------	Finch No. 1, Hanna.	Gary mine, Elk Mt. Coal Co., 12 miles south to southeast of Hanna.	3 4 5 6	6.0 4.2 3.6 6.6	* * * *	G-1 G-1 G-1 G-1	Columnar sample, 2.1 ft thick. Selected blocks analyzed.
2	-----do------------	Finch No. 2, Hanna.	-----do-------------------	1 2 7	4.4 5.1 5.6	* * *	G-1 G-1 G-1	Columnar sample, 1.3 ft thick. Selected blocks analyzed.

Table 14.--Germanium content in the ash of coals from Wyoming--Continued

No. on fig. 9	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
2	Carbon, Hanna-----	Finch No. 3, Hanna.	Gary mine, Elk Mt. Coal Co., 12 miles south to southeast of Hanna.	2	6.7	*	G-1	Columnar sample, 3.1 ft thick. Selected blocks analyzed.
				3	4.9	*	G-1	
				4	2.8	*	G-1	
				5	5.4	*	G-1	
2	-----do-----------	Finch No. 4, Hanna.	-----do------------------	1	1.2	.01	G-1	Columnar samples, 1.6 ft thick. Blocks: 1, coalified log about 1 ft long found in clay roof above the top of the bed; 2, topmost block of the bed.
				2	1.5	*	G-1	
2	-----do-----------	Finch No. 5, Hanna.	-----do------------------	1	12.04	.001	G-2	Columnar sample, 7.5 ft thick, taken in 33 blocks. Block 1, thickness 0.75 ft.
				3	12.92	*	G-2	
				5	9.98	*	G-2	
				7	4.02	*	G-2	
				10	7.82	*	G-2	
				12	5.80	*	G-2	
				15	6.14	*	G-2	
				22	5.06	*	G-2	
				26	5.96	*	G-2	
				31	5.50	*	G-2	
				33	4.48	*	G-1	
3	Carbon, Green River region.	Unnamed, Mesaverde (Late Cretaceous).	18 miles south of Wamsetter.	1	6.26	*	E	Grab sample, collected by H. B. Lindeman, U. S. Geol. Survey.
4	Sweetwater, Rock Springs.	Rock Springs No. 3, Mesaverde.	Stansbury mine, Union Pacific Coal Co., Stansbury.	1	2.74	.0017	E	Columnar sample, 6.5 ft thick. Selected blocks of woody coal.
				5	2.57	.0012	E	
				7	2.61	.0015	E	
				11	2.47	.0015	E	
4	-----do-----------	Rock Springs No. 7½, Mesaverde.	-----do------------------	1	2.66	.062	EQ	Columnar sample, 7.1 ft thick taken in 17 blocks. Blocks: 1, thickness 0.9 ft; 2, thickness 0.4 ft.
				2	.06	.048	EQ	
				4	2.90	.0011	E	
				6	2.36	.0012	E	
				7	3.44	.0014	E	
				8	3.42	*	E	
				9	2.54	*	E	
				10	3.45	.0010	E	
				12	9.37	.0017	E	
				14	2.51	.0009	E	
				17	2.30	.0012	E	
5	-----do-----------	Rock Springs No. 7, Mesaverde.	Reliance mine, Union Pacific Coal Co., Reliance.	1	4.51	.0016	E	Columnar sample, 5.2 ft thick, taken in 11 blocks. Selected blocks.
				3	3.13	.0011	E	
				5	3.43	.001	E	
				8	1.85	.0031	E	
				11	8.02	.0022	E	
5	-----do-----------	Rock Springs No. 11, Mesaverde.	-----do------------------	1	2.90	.0017	E	Columnar sample, 8 ft thick, taken in 14 blocks. Block 6, thickness 2.3 ft, was divided in the laboratory into 6 and 6a.
				2	2.15	.0013	E	
				6	2.05	.0013	E	
				6a	5.43	.0020	E	
				7	1.97	.0016	E	
				8	2.33	.0012	E	
				14	4.09	.0033	E	
5	-----do-----------	Rock Springs No. 9, Mesaverde.	-----do------------------	1	2.55	.052	EQ	Columnar sample, 6.8 ft thick. Only two blocks (1 and 3) of bright woody coal were analyzed.
				3	2.60	.043	EQ	
6	-----do-----------	-----do-------	Superior D. O. Clarke mine, Superior.	1	2.55	.052	EQ	Columnar sample, 7.5 ft thick. Maximum Ge concentration in block 1, thickness 1.2 ft.
				2	1.77	.065	EQ	
				3	2.60	.043	EQ	
				5a	2.55	.0018	E	
				6	1.53	.0052	E	
6	-----do-----------	Rock Springs No. 15, Mesaverde.						
6	-----do-----------	Unnamed, Mesaverde.	Copenhagen mine, Superior.	1	10.2	*	G-1	Grab sample, collected by Larry Warner, U. S. Geol. Survey
7	Lincoln, Ham's Fork region.	Elkol, Adaville (Upper Cretaceous).	Elkol mine, Kammerer Coal Co., Kammerer.	1	3.08	.0014	E	Channel sample. Total thickness of the bed, 85 ft.
				2	2.30	*	G-1	
8	Campbell, Powder River region.	Smith bed, Fort Union (Paleocene).	Wiodak east of Gillette---	1	6.7	*	G-1	Block samples selected at the different levels of the bed 55 ft thick.
				2	7.2	*	G-1	
				3	6.9	*	G-1	
9	Sheridan, Powder River region.	Monarch, Fort Union (Paleocene).	Monarch Coal Co., Monarch.	1	7.32	.0007	E	Columnar sample, 10.2 ft thick, taken in 13 blocks, selected blocks analyzed.
				2	9.34	.0005	E	
				5	4.30	*	G-1	
				5w	4.70	*	G-1	
				6	4.80	*	G-1	
				9	4.6	*	G-1	
				10	5.79	.0005	E	
				13	3.6	*	G-1	

Table 14.--Germanium content in the ash of coals from Wyoming--Continued

No. on fig. 9	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
10	Johnson, Powder River region.	Healy, Fort Union formation.	Lake de Smet area--------					Channel samples, collected by W. J. Mapel, Jr., U. S. Geol. Survey.
				1	23.4	*	G-1	15.67 ft thick.
		Unnamed at Dry Creek level.	-----do-------------------	2	22.9	*	G-1	11.58 ft thick.
		Unnamed, 24 ft below Healy.	-----do-------------------	3	17.4	*	G-1	2.25 ft thick.
		Unnamed, 160 ft below Healy.	-----do-------------------	4	14.4	*	G-1	7.1 ft thick.
		Unnamed, 335 ft below Healy.	-----do-------------------	5	9.5	*	G-1	13.0 ft thick.
		Unnamed, 110 ft below Healy.	-----do-------------------	6	25.7	*	G-1	8.0 ft thick.

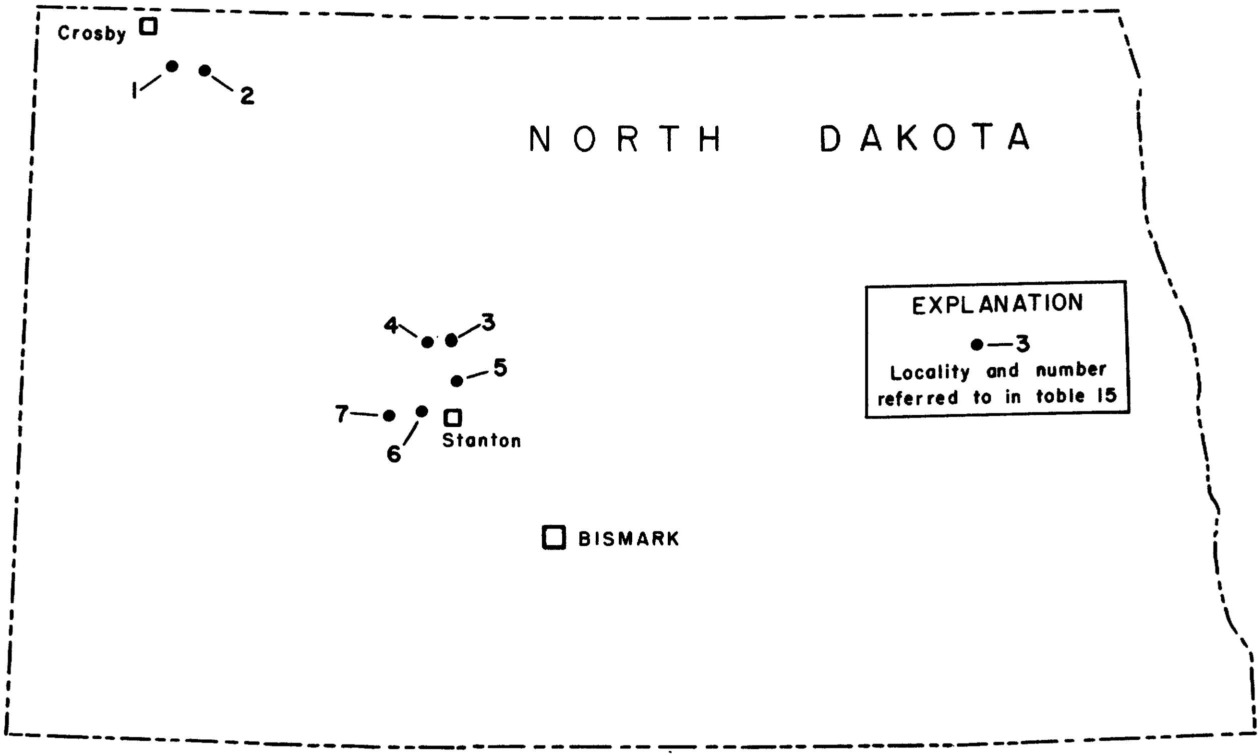

Figure 10.--Map showing localities of coals from North Dakota.

Table 15.--Germanium content in the ash of coals from North Dakota

Laboratory: G-1, U. S. Geol. Survey Washington laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.0004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis]

No. on fig.10	County and field	Bed and formation	Locality	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	Divide, Fort Union region.	Noonan, Fort Union (Paleocene)	Baukol-Noonan mine, Noonan.	1	7.26	0.02	G-2	Columnar sample, 7 ft thick, taken in 17 blocks. Block 1, thickness 0.35 ft.
				2	6.86	*	G-1	
				3	6.96	*	G-1	
				4	6.48	*	G-1	
				5	9.68	*	G-1	
				6	5.82	*	G-1	
				7	5.58	*	G-1	
				8	4.92	*	G-1	
				9	4.92	*	G-1	
				10	6.50	*	G-1	
				11	8.74	*	G-1	
				12	7.88	*	G-1	
				13	10.14	*	G-1	
				14	8.88	*	G-1	
				15	7.30	*	G-1	
				16	6.88	*	G-1	
				17	15.68	*	G-1	
1	-----do-----	-----do-----	-----do-----	1	11.30	*	G-1	Blocks: 1 and 2, glossy jetlike lignite; 3f, semifusain from same column.
				2	22.04	*	G-1	
				3f	14.22	*	G-1	
1	-----do-----	Unnamed, local bed, 30 ft above Noonan.	-----do-----	1	23.4	*	G-2	Brown coal in shale above the bed. Topmost block of the bed.
				2	6.46	*	G-2	
1	-----do-----	Unnamed, 50 ft above Noonan bed, Fort Union.	-----do-----	1	12.24	*	G-1	Columnar sample including shale at bottom part of block 22. Block 18 includes block 19, and 20 includes block 21; 22b, bony coal.
				2	6.88	*	G-1	
				3	6.02	.01	G-1	
				4	5.02	*	G-1	
				6	8.46	*	G-1	
				8	7.28	*	G-1	
				12	7.56	*	G-1	
				14	9.74	*	G-1	
				16	9.84	*	G-1	
				17	20.78	*	G-1	
				18	13.86	*	G-1	
				20	6.54	.006	G-1	
				22	7.28	.03	G-1	
				22b	28.24	.004	G-1	

Table 15.--Germanium content in the ash of coals from North Dakota--Continued

No. on fig.10	County and field	Bed and formation	Locality	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
2	Burke, Fort Union region.	Unnamed, 30 ft above Garrison Creek, Fort Union.	Cateau mine, near Cateau.	1	9.17	0.0013	E	Columnar sample. Selected blocks analyzed.
				4	7.86	*	E	
				9	7.81	*	E	
				19	5.68	*	E	
				20	5.26	*	G-1	
				23	6.41	*	E	
				28	7.93	.002	E	
				31	7.04	.0013	E	
				36	6.86	.0013	E	
				40	7.84	.0012	E	
				42	8.16	.0012	E	
				49	14.17	*	E	
				52	19.63	*	E	
				55	12.90	*	E	
				63	9.88	.0012	E	
3	Mclean, Fort Union region.	Garrison Creek, Fort Union.	Custer mine, near Garrison.	1	10.9	.0011	E	Columnar sample, 6 ft thick. Selected block analyzed.
				2- 4	6.75	.001	E	
				6	7.05	.001	E	
				7	4.6	.001	E	
				8- 9	11.76	.001	E	Lowermost block (30), 0.25 ft thick.
				13-14	6.47	.0012	E	
				17	6.56	.001	E	
				18-19	6.52	.001	E	
				20	7.05	.001	E	
				21-22	9.40	.001	E	
				25	7.74	.0046	E	
				27	6.11	.0013	E	
				28	9.05	.0012	E	
				30	16.64	.043	EQ	
4	----do------------	Unnamed, 30 ft above Garrison Creek.	----do-------------------	1	2.5	.005	G-1	Lignite of the outer part of mineralized upright tree trunk.
4	----do-------------	----do----------	----do-------------------	1	9.0	.001	G-1	Selected samples from same bed: 1, woody lignite; 2, fusain.
				2	33.0	*	G-1	
5	Mercer------------	Unnamed, Fort Union.	Dakota Star mine, Truax-Traer Coal Co., Hazen.	1	2.7	*	G-1	Columnar sample. Selected blocks.
				2	4.2	*	G-1	
6	----do-------------	---do---------	Beulah mine, Knife River Coal Co., Beulah.	1	14.61	.0005	E	Columnar sample, 10 ft thick. Selected blocks.
				2	10.6	*	G-1	
				5	12.35	.0005	E	
				6	7.78	.0005	E	
				9	9.49	.0005	E	
				10	14.59	.0008	E	
				15	22.4	.0008	E	
7	Oliver------------	Fort Union---	Western part of the county.	1	7.6	*	G-1	Seven samples, collected by Wm. Johnson, U. S. Geol. Survey.
				2	9.7	*	G-1	
				3	14.7	*	G-1	
				4	10.5	*	G-1	
				5	20.0	*	G-1	
				6	9.0	.002	G-1	
				7	21.1	*	G-1	

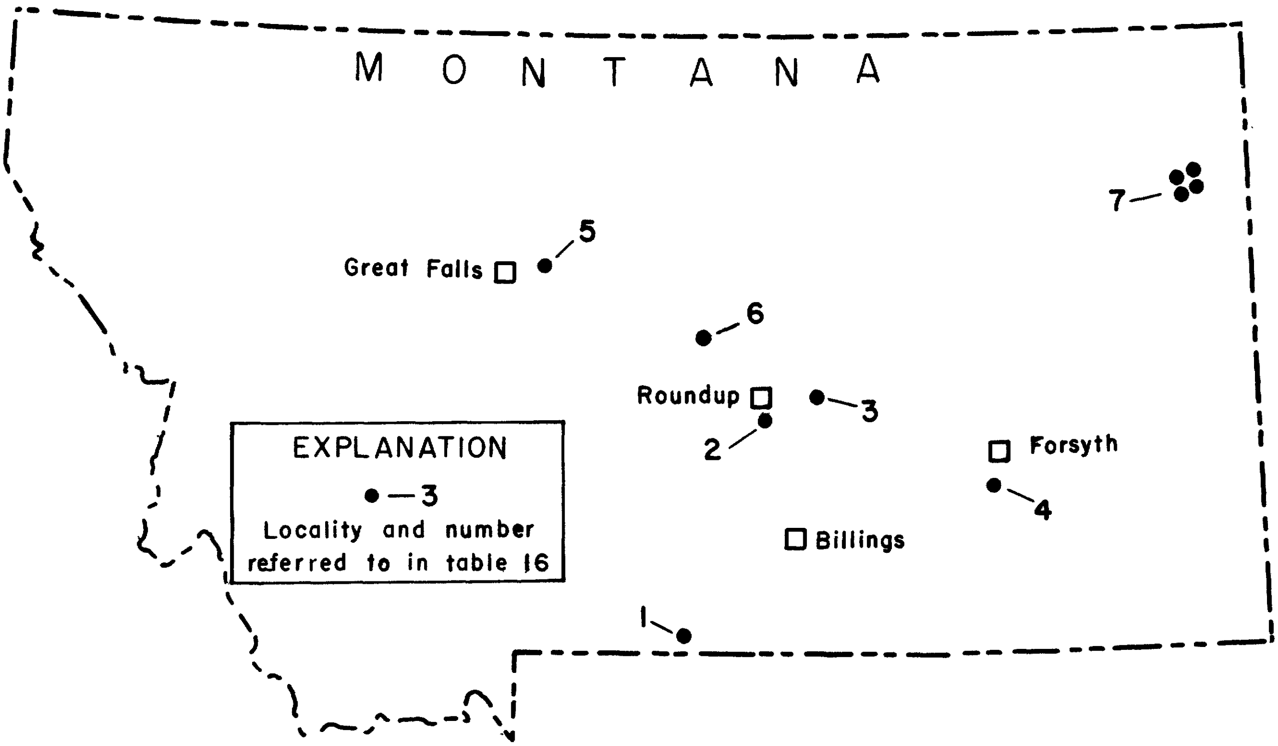

Figure 11.--Map showing localities of coals from Montana.

Table 16.--Germanium content in the ash of coals from Montana

Laboratory: G-1, U. S. Geol. Survey Washington Laboratory, sensitivity 0.002 percent; G-2, U. S. Geol. Survey Denver laboratory, sensitivity 0.001 percent; E, Eagle-Picher Co. Research Laboratory, sensitivity 0.0004 percent (semiquantitative method); EQ, Eagle-Picher Co. Research Laboratory, quantitative method.

[*Asterisk (*) signifies that germanium content is below sensitivity limit of method used in analysis*]

No. on fig. 11	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
1	Carbon, Red Lodge--	No. 3, Fort Union (Paleocene).	Foster Creek mine, Montana Coal Iron Co., Washoe.	1	5.86	*	E	Columnar sample, 6.5 ft thick. All blocks analyzed, except bony coal, block 2.
				3	15.23	*	E	
				3a	12.32	*	E	
				4	5.74	*	E	
				5	14.33	*	E	
				6	9.78	*	E	
2	Musselshell, Bull Mountain.	Roundup, Tongue River member, Fort Union.	Klein No. 2 mine, Republic Coal Co., Klein.	1	10.30	0.01	G-1	Columnar sample, 5.3 ft thick. Selected blocks were analyzed. Sample 6w, woody coal; 6f, sample rich in fusain.
				2	12.90	*	E	
				4	5.22	.0012	E	
				5	11.00	*	E	
				6f	7.08	*	G-2	
				6w	3.98	.02	G-2	
2	----do------------	---do--------	----do--------------------	1	2.4	2.8	G-1	"Kettle bottoms" found in shaly roof of the coal bed.
				2	3.0	3.4	G-1	
				3	2.7	4.7	G-1	
3	----do------------	Carpenter Creek, 50 ft below Roundup bed; Fort Union.	Keene No. 2 mine, Bair-Collins Coal Co., Keene.	3	3.50	.01	G-1	Columnar sample, 6.8 ft thick. Selected blocks analyzed: 3, the entire block; 3a, central part of the coalified log in block 3; 3b, outer part of the log; 3c, bark of the log.
				3a	2.60	*	G-1	
				3b	3.50	*	G-1	
				3c	3.90	*	G-1	
				7	5.10	*	G-1	
				8	3.00	*	G-1	
				12	10.60	.0005	E	
4	Rosebud, Forsyth--	Rosebud, Fort Union.	Rosebud mine, Colstrip Bench 1.	2	7.62	.0017	E	Columnar sample, 26.5 ft thick. Selected blocks from 5 benches analyzed.
			Bench 2-----------------	4	6.91	*	E	
				8	8.38	*	E	
				9	9.69	*	E	
				14	8.59	*	E	
			Bench 3-----------------	1	11.15	*	E	
				3	7.03	*	E	
				4	8.01	*	E	
				5	8.84	.0011	E	
				8	8.11	*	E	
			Bench 4-----------------	1	9.48	*	E	Bench 4, block 7f is largely fusain.
				3	10.54	.0013	E	
				6	7.32	.0017	E	
				7f	20.68	*	E	
				9	5.77	.0011	E	
				12	6.02	*	E	
			Bench 5-----------------	1	9.13	.0013	E	
				2	7.77	*	E	
				3	8.75	*	E	
				4	7.96	*	E	

Table 16.--Germanium content in the ash of coals from Montana--Continued

No. on fig.11	County and field	Bed and formation	Location	Block no.	Ash (percent)	Ge in ash (percent)	Laboratory	Remarks
5	Cascade, Great Falls.	Unnamed, Morrison (Upper Jurassic).	East Belt mine, Belt-----	1	3.88	0.03	G-1	Woody coal, selected from upper part of the bed; 5.2 ft thick.
	-----do-------------	---do---------	-----do-------------------	1	21.78	.037	EQ	Composite sample of the lower part of the bed, 3 ft thick.
6	Fergus, Lewistown.	---do---------	C. M. Tuss, sec. 34, T. 15 N., R. 20 E.	1w	3.71	.21	EQ	Columnar sample, 5.8 ft thick. Maximum concentration in block 5; 1w, selected woody coal.
				2	23.39	.0042	E	
				3	10.75	.0052	E	
				4	8.68	.0045	E	
				5	5.70	.042	EQ	
				6	6.38	.038	EQ	
				7	30.21	*	E	
				9	9.98	.0060	E	
				10	6.62	.0060	E	
				11	5.90	.0021	E	
				12	1056	.0042	E	
				13	11.77	.0048	E	
				14	9.48	.0049	E	
				15	19.68	*	G-1	Blocks 7 and 15, bony coal.
7	Richland, Girard.	Different beds in Tongue River member, Fort Union.	Sections from T. 27 N., R 55 E. to T. 25 N., R. 57 E.	1	59.16	*	G-1	Channel and auger samples, collected by George S. Prichard, U. S. Geol. Survey.
				2	15.92	*	G-1	
				3	25.32	*	G-1	
				4	7.80	*	G-1	
				5	16.10	*	G-1	
				6	10.02	*	G-1	
				7	9.80	*	G-1	
				8	14.14	*	G-1	
				9	14.10	*	G-1	
				10	24.20	*	G-1	
				11	9.80	*	G-1	
				12	24.20	*	G-1	

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