UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

COAL RESOURCES AND COAL QUALITY OF PUMPKIN CREEK EMRIA SITE,

Powder River County, Montana

By

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with a section on chemical analyses of lignite and lignitic shale by

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This report is preliminary and has not been

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Geological Survey Standards.

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Abstract

The Pumpkin Creek EMRIA site, an area of about 94 square miles, is located mainly in the southwestern part of the Coalwood coal field on the slightly westward dipping beds of the Tongue River Member of the Paleocene Fort Union Formation in Powder River County, Montana.

Three coal beds, A, Sawyer, and Mackin-Walker, were evaluated by 32 drill holes. Coal resources--measured, indicated, and inferred--within the site and in beds more than 5 feet thick are 191,660,000 short tons, 1,356,950,000 short tons, and 34,400,000 short tons, respectively.

The coal has an apparent rank of lignite A as shown by the analyses of 17 core samples. The average Btu value of 15 core samples of the Sawyer from the site on the as-received basis is 6,970, average ash content is 6.8 percent, and average sulfur content is 0.4 percent.

A comparison of the analyses of samples from the Sawyer coal bed with other analyses of Powder River region coal samples shows that moisture, hydrogen, and oxygen contents are significantly higher, and volatile matter, fixed carbon, carbon, nitrogen, and total sulfur contents and heat of combustion are significantly lower in the Sawyer bed samples. A statistical comparison of the elemental compositions of the two sample groups shows that the Sawyer bed has significantly higher contents of B, Ba, Mn, Nb, U, Y, and Yb and significantly lower contents of Be, Co, Cr, Cu, Ni, Pb, Sc, Se, and Th.

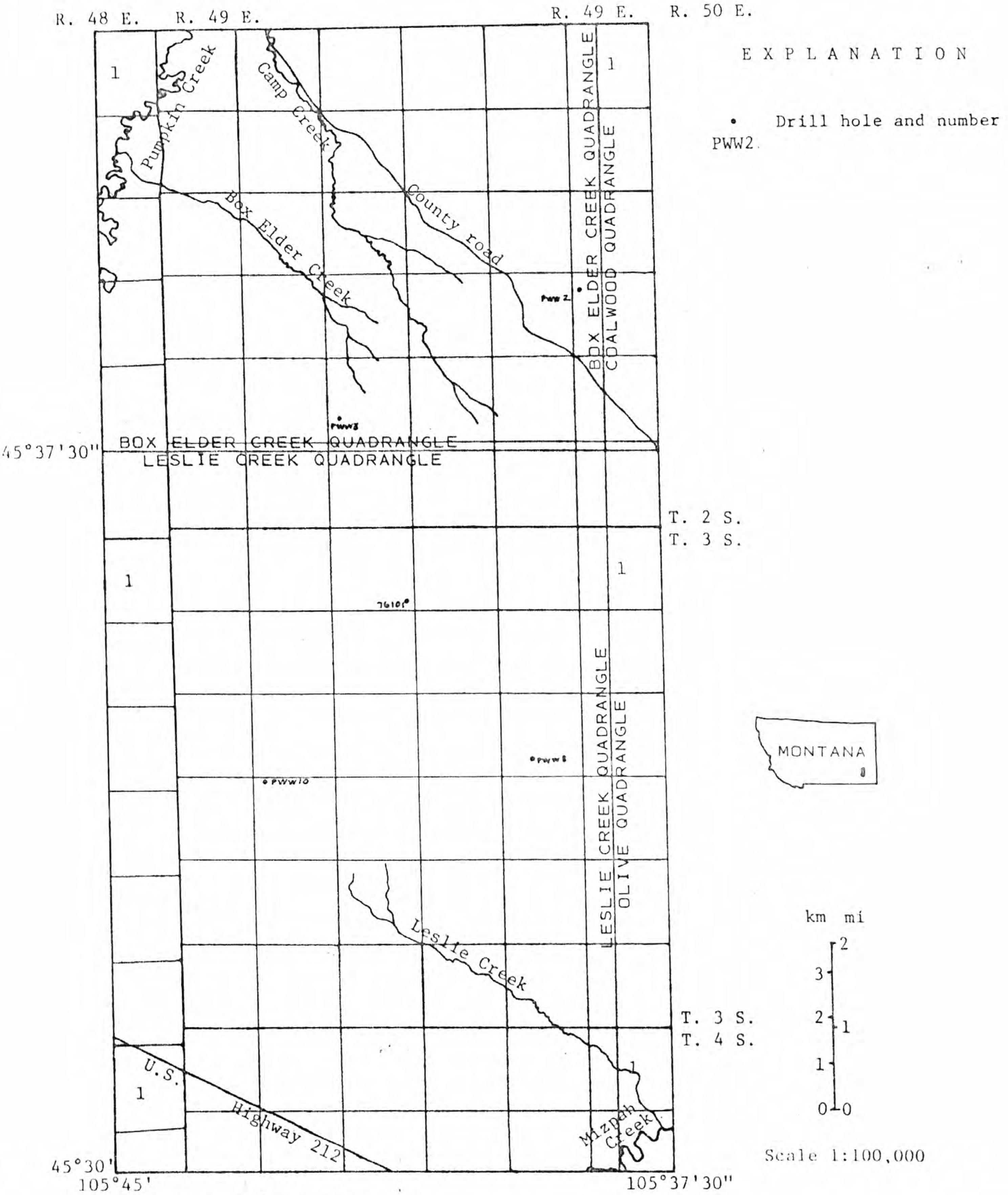
The sample of the lower split of the Sawyer bed (bed A) in drill hole PWW8 has a relatively high sulfur content of 1.7 percent, and presumably would not be mined with the rest of the Sawyer.

The Mackin-Walker has a Btu value of 7,220, an ash content of 6.9 percent, and a sulfur content of 1.0 percent.

Introduction

This report was prepared as a contribution to the study of the coal mining potential of an area in the southwest part of the Coalwood coal field, the southeast part of the Ashland coal field, and the north part of the Birney-Broadus coal field in southeast Montana. The area was selected for investigation by the EMRIA (Energy Minerals Rehabilitation Inventory and Analysis) program of the U.S. Bureau of Land Management. The Pumpkin Creek area was selected for evaluation of the coal beds A, Sawyer, and Mackin-Walker. This report summarizes information on resources and coal quality gained during the study, and is based on maps and drill logs already released as Open-File Reports 78-614 (geologic map) (Glenn, 1978a) and 78-897 (locality map, structure and resource maps, drill hole sections, and tables) (Glenn, 1978b).

The Pumpkin Creek site is an area of about 94 square miles (241 km^2) between Pumpkin Creek, a tributary of the Tongue River, and Mizpah Creek, a tributary of the Powder River (fig. 1). The site includes the Leslie Creek 7 1/2 minute topographic quadrangle and parts of Box Elder Creek, Coalwood, and Olive 7 1/2 minute topographic quadrangles. The geology of the coal beds was mapped with the assistance of Jeanette Hartman during the summers of 1976 and 1977. Aerial photographs were used to locate outcrops and outline areas of burned beds as a supplement to field observations. Fresh coal samples, coal quality information, and coal thicknesses used in resource calculations were obtained from 12 holes drilled and cored by the Geological Survey, 10 holes cored by the Bureau of Reclamation, and 10 holes drilled by the Montana Bureau of Mines and Geology and the U.S. Geological Survey during 1976 and 1977, and from about 3 dozen previously drilled holes. J. R. Hatch sampled the coal cores for analysis. The results of the analyses are discussed by J. R. Hatch and R. H. Affolter in the concluding section of this report.



Base reduced from U.S. Geological Survey Leslie Creek, Box Elder Creek, Coalwood, and Olive 7 1/2' quadrangle maps

Figure 1.--Index map of the Pumpkin Creek EMRIA study site, Powder River County, Montana, showing drill holes from which coal samples were taken, 1978.

The area included in the Pumpkin Creek EMRIA site and the holes from which coal samples were analyzed are shown in figure 1. A geologic map, structure contour maps, localities where coal was measured or observed on surface, locations of abandoned mines, holes drilled for the EMRIA study, previously drilled holes from which thickness data were used, and lines of drill hole sections are shown in earlier reports (Glenn, 1978a and 1978b).

Coal

Origin

Coal has been defined as "a readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, formed from compaction or induration of variously altered plant remains similar to those of peaty deposits. Differences in kinds of plant materials (type), in degree of metamorphism (rank), and range of impurity (grade) are characteristics of the varieties of coal" (Schopf, 1966, p. 588). Inherent in the definition is the specification that the coal originated as a mixture of organic plant remains and inorganic mineral matter that accumulated in a manner similar to that in which modern-day peat deposits are formed. The peat then underwent a long, extremely complex process called "coalification", during which diverse physical and chemical changes occurred as peat changed to coal and as the coal assumed the characteristics by which we differentiate members of the series from each other. The factors that affect the composition of coals have been summarized by Francis (1961, p. 2) as follows:

1) The mode of accumulation and burial of the plant debris forming the deposit.
2) The age of the deposits and their geographical distribution.
3) The structure of the coal-forming plants, particularly details of structure that affect chemical composition or resistance to decay.

4) The chemical composition of the coal-forming debris and its resistance to decay.

5) The nature and intensity of the plant-decaying agencies.

6) The subsequent geological history of the residual products of decay of the plant debris forming the deposits.

For extended discussion of these factors, the reader is referred to such standard works as Moore (1940), Lowry (1945, 1963), Tomkeieff (1954), and Francis (1961).

Classification

Coals can be classified in many ways (Tomkeieff, 1954, p. 9; Moore, 1940, p. 113; Francis, 1961, p. 361), but the classification by rank--that is, by degree of metamorphism in the progressive series that begins with peat and ends with graphocite (Schopf, 1966)--is the most commonly used system. Classification by types of plant materials is commonly used as a descriptive adjunct to rank classification when sufficient megascopic and microscopic information is available, and classification by type and quantity of impurities (grade) is also frequently used when utilization of the coal is being considered. Other categorizations are possible and are commonly used in discussion of coal resources--such factors as the weight of the coal, the thickness and areal extent of the individual coal beds, and the thickness of overburden are generally considered.

Rank of coal

The position of a coal within the metamorphic series, which begins with peat and ends with graphocite, is dependent upon the temperature and pressure to which the coal has been subjected and the duration of time of subjection. Because it is, by definition, largely derived from plant material, coal is mostly composed of carbon, hydrogen, and oxygen, along with smaller quantities of nitrogen, sulfur, and other elements. The increase in rank of coal as it undergoes progressive metamorphism is indicated by changes in the proportions of the coal constituents--the higher rank coals have more carbon and less hydrogen than the lower ranks.

Two standardized forms of coal analyses--the proximate analysis and the ultimate analysis--are generally used in the world today, though sometimes only the less complicated and less expensive proximate analysis is made. The analyses are described as follows (U.S. Bur. Mines, 1965, p. 121-122):

> "The proximate analysis of coal involves the determination of four constituents: (1) water, called moisture; (2) mineral impurity, called ash, left when the coal is completely burned; (3) volatile matter, consisting of gases or vapors driven out when coal is heated to certain temperatures; and (4) fixed carbon, the solid or cokelike residue that burns at higher temperatures after volatile matter has been driven off. Ultimate analysis involves the determination of carbon and hydrogen as found in the gaseous products of combustion, the determination of sulfur, nitrogen, and ash in the material as a whole, and the estimation of oxygen by difference."

Most coals are burned to produce heat energy so the heating value of the coal is an important property. The heating value (calorific value) is commonly expressed in British thermal units (Btu) per pound: one Btu is the amount of heat required to raise the temperature of 1 pound of water 1 degree fahrenheit (in the metric system, heating is expressed in kilogram-calories per kilogram). Additional tests are sometimes made, particularly to determine the caking, coking, and other properties, such as tar yield, which affect classification or utilization.

Figure 2 compares, in histogram form, the heating values and moisture, volatile matter, and fixed carbon contents of coals of different ranks.

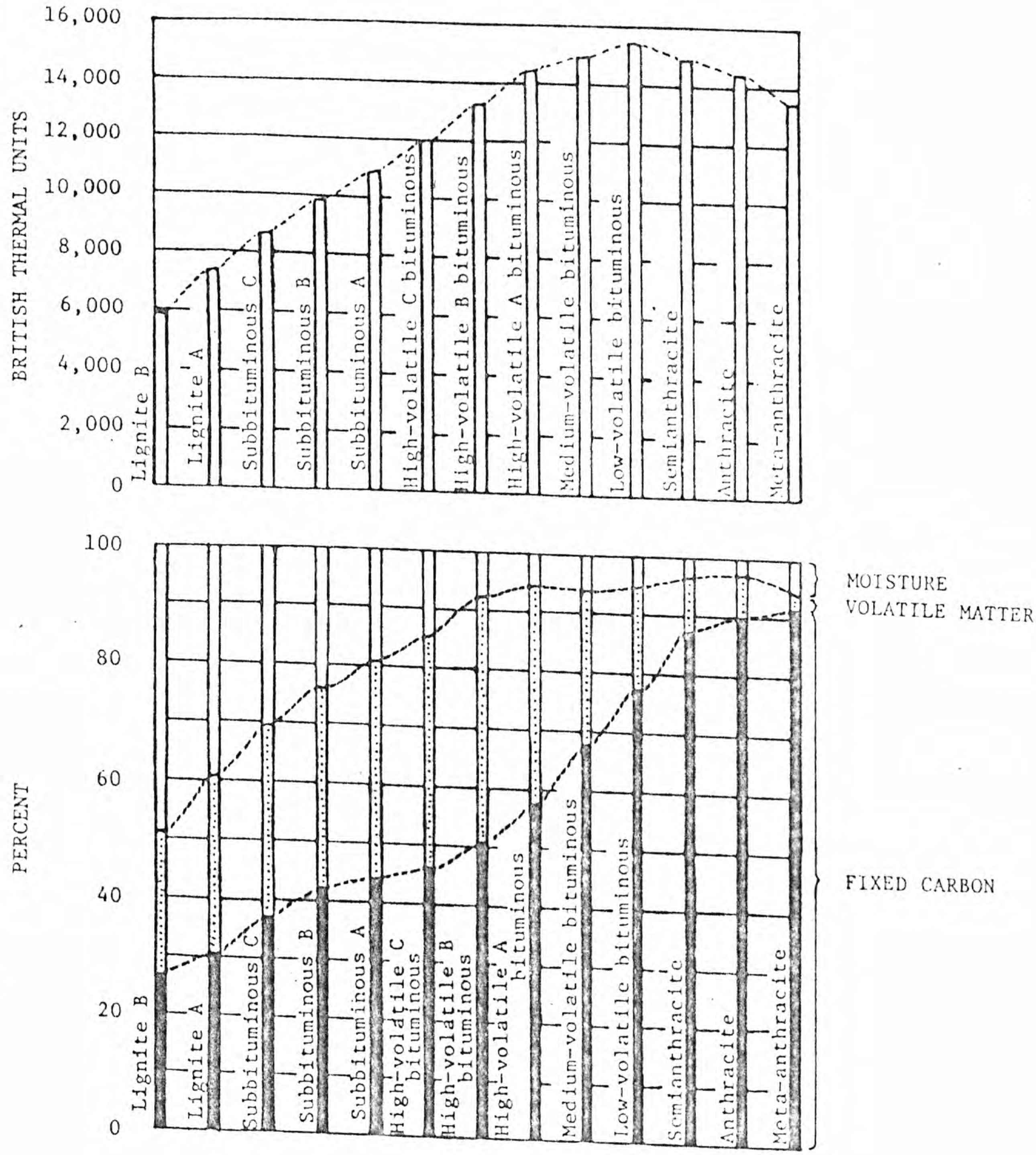


Figure 2.--Comparison on moist, mineral-matter-free basis of heat values and proximate analyses of coal of different ranks (modified from Trumbull, 1960).

Various schemes for classifying coals by rank have been proposed and used, but the most commonly used is that entitled "Standard specifications for classification of coals by rank," adopted by the American Society for Testing and Materials (1977). It is reproduced here as table 1.

The ASTM classification system differentiates coals into classes and groups on the basis of mineral-matter-free fixed carbon or volatile matter and the heating value, supplemented by determination of agglomerating (caking) characteristics. As pointed out by the ASTM (1977), a standard rank determination cannot be made unless the samples were obtained in accordance with standardized sampling procedures (Snyder, 1950; Schopf, 1960). However, nonstandard samples may be used for comparative purposes through determinations designated as "apparent rank."

Table 1.--Classification of coals by rank[1]

[American Society for Testing and Materials Standard D388-77; 1 Btu equals 0.252 kilogram-calories. Leaders (---) indicate category is not used in rank determination of group]

Class	Group	Fixed carbon limits, percent (dry, mineral-matter-free basis): Equal or greater than	Fixed carbon: Less than	Volatile matter limits, percent (dry, mineral matter-free basis): Greater than	Volatile matter: Equal or less than	Calorific value limits, Btu per pound (moist[2]) mineral-matter-free basis): Equal or greater than	Calorific value: Less than	Agglomerating character
I. Anthracitic	1. Meta-anthracite	98	---	---	2	---	---	Nonagglomerating
	2. Anthracite	92	98	2	8	---	---	
	3. Semianthracite[3]	86	92	8	14	---	---	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	---	---	Commonly agglomerating[5]
	2. Medium volatile bituminous coal	69	78	22	31	---	---	
	3. High volatile A bituminous coal	---	69	31	---	14 000[4]	---	
	4. High volatile B bituminous coal	---	---	---	---	13 000[4]	14 000	
	5. High volatile C bituminous coal	---	---	---	---	11 500	13 000	
						10 500	11 500	Agglomerating
III. Subbituminous	1. Subbituminous A coal	---	---	---	---	10 500	11 500	Nonagglomerating
	2. Subbituminous B coal	---	---	---	---	9 500	10 500	
	3. Subbituminous C coal	---	---	---	---	8 300	9 500	
IV. Lignitic	1. Lignite A	---	---	---	---	6 300	8 300	
	2. Lignite B					---	6 300	

[1]This classification does not include a few coals, principally nonbanded varieties, that have unusual physical and chemical properties and that come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[2]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[3]If agglomerating, classify in low-volatile group of the bituminous class.

[4]Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis are classified according to fixed carbon, regardless of calorific value.

[5]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class and that there are notable exceptions in the high-volatile C bituminous group.

Pumpkin Creek EMRIA site

Geologic setting

The coal beds in the Pumpkin Creek area are in the lower part of the Tongue River Member of the Fort Union Formation of Paleocene Age. Approximately 800 feet of mudstone, siltstone, sandstone, silty limestone, and coal comprise the Tongue River Member in the study site. The top of the member is eroded and the base is not exposed. The coal and enclosing strata generally dip less than 1 degree to the west. The regional westward dip is interrupted locally by very low amplitude undulations, probably related to differential compaction of the rocks of the Tongue River Member.

Mollusks were collected in the NW 1/4 NW 1/4 sec. 20, T. 3 S., R. 49 E. (USGS Cenozoic Loc. D 1287 NM.). They were identified by John H. Hanley as bivalves *Plesielliptio priscus* (Meek and Hayden) and *Pisidium spp. indet.*, gastropods *Campeloma nebrascensis nebrascensis* (Meek and Hayden), *Lioplacodes limnaeformis* (Meek and Hayden), and *Lioplacodes nebrascensis* (Meek and Hayden), and the ostrocode *Ostracoda*: *indeterminate*. These species inhabited a permanent fresh-water environment.

Description of the coal beds

The names and relative positions of the coal (lignite) beds in the study site are shown in figure 3. The names are those used previously by other geologists mapping in the area. The Allen, Broadus, Flowers-Goodale, Knobloch, A, Sawyer, Mackin-Walker, Stump, and X beds as used in Tps. 2 and 3 S., R. 49 E., are taken from Bryson (1951) who mapped these beds in the Coalwood coal field. Along the west edge of the area in Tps. 2 and 3 S., R. 48 E., the names Knobloch, A, and Sawyer had been used previously by Bass (1932) in the Ashland coal field. The name Sawyer was first used by Dobbin (1929, p. 28, 49-50) in the Forsyth field. The name Pawnee is from a report by Warren (1959) who mapped the bed

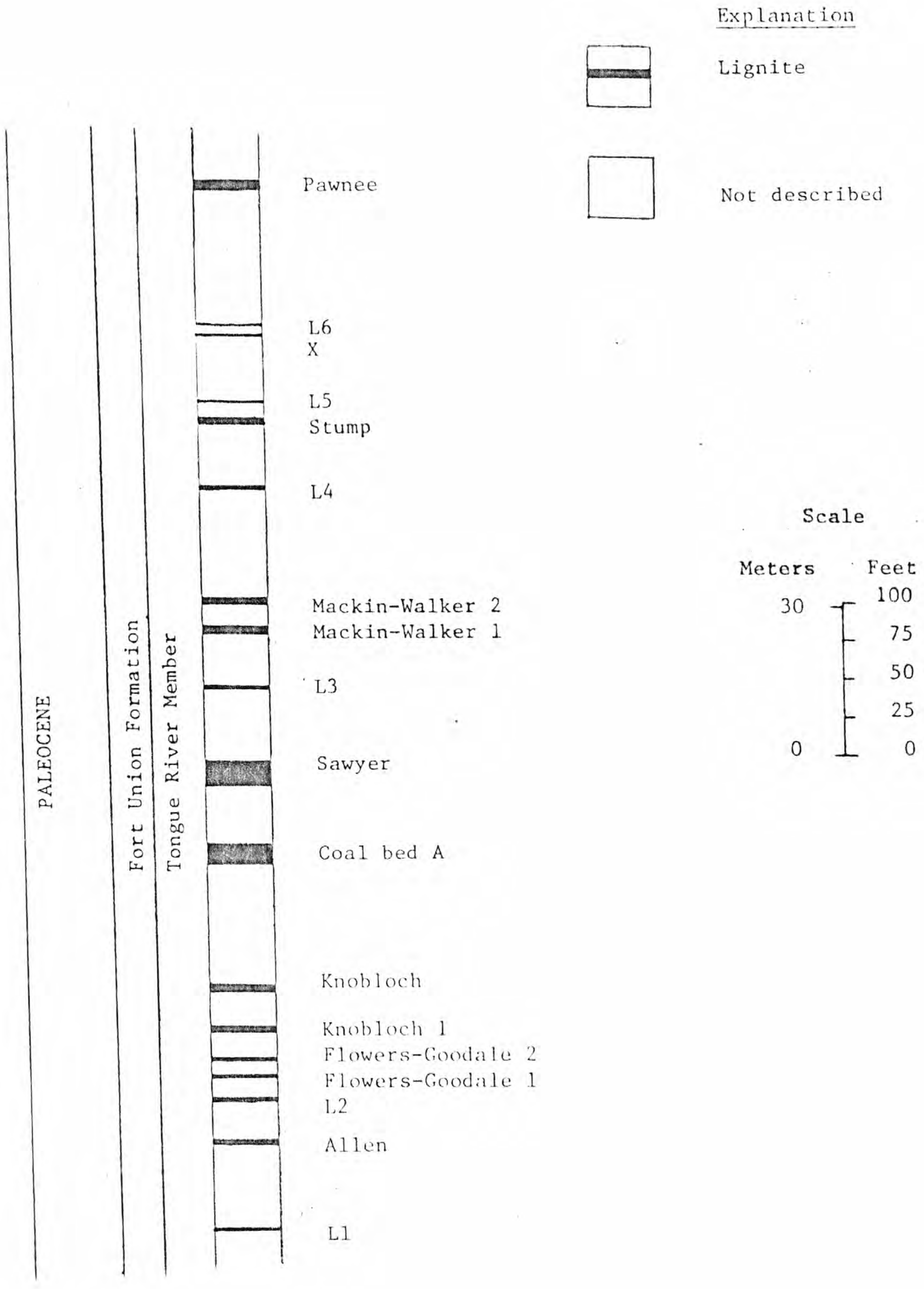


Figure 3.--Generalized section showing relative stratigraphic positions of lignite beds in Pumpkin Creek EMRIA study site, southeastern Montana.

in T. 4 S., R. 49 E., of the Birney-Broadus coal field. Brown and others (1954, p. 186-190) and Matson and others (1973) also have discussed the coal beds in this area.

Local bed L1 below the Allen bed

A local (L1) coal bed outcrops in sec. 31, T. 1 S., R. 49 E., where it is 2.7 ft (0.8 m) thick. It extends also into sec. 6, T. 2 S., R. 49 E. It is about 100 ft (30.5 m) below the Flowers-Goodale coal bed.

Allen bed

The Allen coal bed outcrops in T. 1 S., R. 49 E., and extends into the north part of T. 2 S., R. 49 E. It is 1.2--2.9 ft (0.7--0.9 m) thick and is about 40 ft (12.2 m) below the Flowers-Goodale coal bed.

Local bed L2 below the Flowers-Goodale bed

A local coal bed (L2) outcrops about 15 ft (4.6 m) below the Flowers-Goodale, locally, in the northwest part of T. 2 S., R. 49 E. It is 1.7--3.7 ft (0.5--1.1 m) thick.

Flowers-Goodale beds

The Flowers-Goodale coal bed outcrops in the south part of T. 1 S., R. 49 E., the north part of T. 2 S., R. 49 E., and in T. 2 S., R. 48 E. It ranges in thickness from less than 2 ft (0.6 m) to about 4 ft (1.2 m) and locally in sec. 5, T. 2 S., R. 49 E., it splits into 2 beds of similar thickness. The Flowers-Goodale was considered by Bryson (1951, p. 75) to be the equivalent of the Broadus coal bed, which is about 135 ft (41 m) above the base of the Tongue River Member of the Fort Union Formation. The name Broadus is used in this study to refer to a thicker coal bed reported in drill holes in the south and east parts of the area, and the name Flowers-Goodale is used for the thinner coal bed exposed on the surface in the north.

Knobloch bed

The Knobloch coal bed is about 60 ft (18 m) above the Flowers-Goodale and about 120--140 ft (38--43 m) below the Sawyer in the north part of the area. It ranges from 2 to 12 ft (0.6--3.6 m) in thickness, and locally occurs as two beds of similar thickness about 30--40 ft (9--12 m) apart. It outcrops in the north part of the study site and is reported in drill holes throughout the study site.

Sawyer and A beds

The main coal bed of the study site is the generally 30-foot-thick Sawyer. Although the Sawyer has burned extensively along the outcrop edges, large unburned resources of it underlie the south half of T. 2 S., R. 49 E., most of T. 3 S., R. 49 E., and most of Tps. 3 and 4 S., R. 48 E., and T. 4 S., R. 49 E.

In the middle of the Sawyer coal bed is a persistent shale parting, 0.5--2 ft (0.15--0.6 m) thick, that thickens abruptly in the southern third of T. 3 S. and continues southward into T. 4 S. where it becomes as much as 50 ft (15 m) thick.

The name A is used for the lower split of the Sawyer where the parting between the two coals is more than 2 ft (0.6 m) thick. In T. 4 S., R. 49 E., coal bed A is split into as many as 3 coal beds. Just north of the study site in sec. 33, T. 1 S., R. 49 E., coal bed A is 3.3--4.5 ft (1--1.4 m) thick and lies about 40 feet (12 m) below the Sawyer. In the north part of T. 2 S., R. 49 E., however, coal bed A and the Sawyer coal bed both are burned and so difficult to distinguish that, in most places, they are mapped together. In the southern part of the study site coal bed A ranges from 9 to 16 ft (2.7--4.9 m) in thickness and the Sawyer from 12 to 20 ft (3.7--6.1 m).

Local bed L3 above the Sawyer bed

In the south part of T. 3 S., R. 49 E., and the north part of T. 4 S., R. 49 E., a local coal (L 3) is 50--75 ft (15--23 m) above the Sawyer. The thickness of the coal is 1--3 ft.

Mackin-Walker beds

The next higher coal bed is the Mackin-Walker, which lies 80--120 ft (24--38 m) above the base of the Sawyer and extends over the north half of T. 3 S., R. 49 E., and the south half of T. 2 S., R. 49 E. It is 9.7 ft (3 m) thick at an abandoned mine in sec. 35, T. 2 S., R. 49 E., but thins in all directions from this point. In the southwest part of T. 2 S., R. 49 E., it occurs as 2 beds 30--40 ft apart. It was named for a mine once worked in sec. 28, T. 2 S., R. 49 E., where it was 6.2 ft (1.9 m) thick (Bryson, 1951, p. 76, 84).

Local bed L4 above the Sawyer bed

A local coal bed (L4) is 185-200 ft (56--61 m) above the Sawyer in the southwest part of T. 3 S., R. 49 E. It is 1--2.5 ft (0.3--0.8 m) thick.

Stump bed

The Stump coal bed is 250--300 ft (73--92 m) above the Sawyer. It is usually 2--3 ft (0.6--0.9 m) thick and somewhat shaly, but it is distinctive because nearly everywhere it contains silicified, partly carbonized tree stumps in growing position. It was correlated tentatively with the C bed in the Ashland field (Bryson, 1951, p. 76).

Local bed L5 below the Pawnee

In the southwest corner of the study site, a local coal bed (L5) occurs about 250 ft (76 m) above the Sawyer and 120--130 ft (38--40 m) below the Pawnee. It is 2--3 ft (0.6--0.9 m) thick and may equal the Stump coal bed.

X bed

The X bed is about 55--80 ft (17--24 m) above the Stump coal and about 300 ft (91 m) above the Sawyer. Bed X has burned to form a 20-foot-thick (6.1-meter-thick) clinker. The clinker remains only in sec. 34, T. 2 S., R. 49 E., the highest part of the divide between Pumpkin Creek and Mizpah Creek. Bryson tentatively correlated it with the X bed in the Ashland field (1951, p. 77).

Local bed L6 below the Pawnee bed

Another local coal bed, L6, 2--3 ft (0.6--0.9 m) thick, occurs locally in the southwest corner of the study area. It is about 300 ft (91 m) above the Sawyer and 70--90 ft (21--27 m) below the Pawnee on Two Tree Butte.

Pawnee bed

The highest coal bed in the study site is the Pawnee. It is represented by the clinker on Two Tree Butte. No unburned sections could be measured.

Coal resources

Estimation and classification of coal resources

Coal resource estimates have been prepared for the coal beds A, Sawyer, and Mackin-Walker within the Pumpkin Creek EMRIA study site as summarized on tables 2 and 3 using standard procedures, definitions, and criteria established by the U.S. Geological Survey and U.S. Bureau of Mines for making coal resource appraisals in the United States. The term "coal resources" as used in this report means the estimated quantity of coal in the ground in such form that economic extraction is currently or potentially feasible. The resources in the study site are classed as measured, indicated, and inferred according to the degree of geologic assurance of the estimate.

Measured resources

Resources are computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced and the thickness and extent of coals are so well defined that the tonnage is judged to be accurate within 20 percent of true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of the coal differs from region to region according to the character of the coal beds, the points of observation are no greater than 1/2 mile (0.8 km) apart. Measured coal is projected to extend as a 1/4 mile (0.4 km) wide belt from the outcrop or points of observation or measurement.

Indicated Resources

Resources are computed partly from specific measurements and partly from projections of visible data for a reasonable distance on the basis of geologic evidence. The points of observation are 1/2 (0.8 km) to 1 1/2 miles (2.4 km) apart. Indicated coal is projected to extend as a 1/2-mile (0.8-km) wide belt that lies more than 1/4 mile (0.4 km) from the outcrop or points of observation or measurement.

Inferred resources

Quantitative estimates are based largely on broad knowledge of the geologic character of the bed or region, because few measurements of bed thickness are available. The estimates are based primarily on an assumed continuation from measured and indicated coal for which geologic evidence exists. The points of observation are 1 1/2 (2.4 km) to 6 miles (9.6 km) apart. Inferred coal is projected to extend as a 2 1/4-mile (3.6-km) wide belt that lies more than 3/4 mile (1.2 km) from the outcrop or points of observation or measurement.

All of the estimated resources in beds thicker than 5 feet (1.5 m) and at depths of 1000 feet (305 m) or less fall into a category called reserve base, which is defined as that portion of the identified coal resource from which reserves are calculated. Reserves are that portion of the identified coal resource that can be economically mined at the time of determination. The reserve is derived by applying a recovery factor to that component of the identified coal resource designated as the reserve base. On a national basis the estimated recovery factor for the total reserve base is 50 percent. More precise recovery factors can be computed by determining the total coal in place and the total coal recoverable in any specific locale.

Characteristics used in resource evaluation

The coal characteristics that are commonly used in classifying coal resources are the rank, grade, and weight of the coal; the thickness of the coal beds; and the thickness of the overburden. Rank and grade are discussed in a later section of this report.

Weight

The weight of the coal ranges considerably with differences in rank and ash content. In areas such as Pumpkin Creek, where true specific gravities of the coal have not been determined, an average specific gravity value based on many determinations in other areas is used to express the weight of the coal for resource calculations. The average weight of lignite is taken as 1750 tons per acre-foot--a specific gravity of 1.29.

Thickness of beds

Because of the important relationship of coal-bed thickness to utilization potential, most coal resource estimates prepared by the U.S. Geological Survey are tabulated according to three thickness categories. Because the coal evaluated in this report is so close to the subbituminous-lignite division of rank, the thickness categories used are intermediate--5 to 10 feet (115 to 3 m) thick and more than 10 feet (3 m). Resources in beds thinner than 5 feet were not estimated. About 2.5 percent of the estimated resources of the study site is in the intermediate category and about 97.5 percent is in the thick category. By way of comparison, Averitt (1975, fig. 5 and p. 37) showed the distribution of the estimated resources of 21 states as 25 percent in the intermediate category, and 33 percent in the thick category.

Thickness of overburden

All of the estimated lignite resources in the Pumpkin Creek EMRIA site are overlain by 1,000 feet (305 m) or less of overburden (table 2). Resources with less than 200 feet of overburden are shown on table 3. No resources were calculated for coal beds below coal bed A.

Summary of resources

Total estimated identified original resources in the Pumpkin Creek EMRIA site are 1,583,010,000 short tons (1,437,056,478 metric tons). The coal-bed thickness class of 5-10 feet (1.5-3 m) contains 39,270,000 short tons (35,642,306 metric tons) of the estimated resources. The coal-bed thickness class of more than 10 feet (3 m) contains 1,543,740,000 short tons (1,402,950,172 metric tons) of estimated resources. Maximum measured thickness of the Sawyer coal bed is 34 feet (10.4 m) split by a 0.9 foot (0.3 m) parting near the middle (Glenn, 1978b, sheet 5, hole 77107).

The estimated resources presented in this report are original resources: that is, resources in the ground before the beginning of mining operations.

Table 2.--Measured, indicated, and inferred resources of lignite in the Tongue River Member of the Paleocene Fort Union Formation in beds more than 5 feet (1.5 m) thick, under less than 1,000 feet (305 m) of overburden, as of January 1, 1978, based on measurements at the outcrop and subsurface data.

[In thousands of short tons (1 short ton = 0.9078 metric tons); totals are rounded. The coal is assumed to weigh 1,750 short tons per acre foot (1.3 metric tons/m^3). One foot = 0.3 meter. Leaders (----) indicate no data]

Location		Measured		Indicated		Inferred		
Township South	Range East	Thickness of coal in feet 5-10	>10	Thickness of coal in feet 5-10	>10	Thickness of coal in feet 5-10	>10	Totals
				Mackin-Walker bed				
2	49	20,220	-----	6,380	-----	-----	-----	26,600
3	49	4,400	-----	3,400	-----	-----	-----	7,800
Totals		24,620	-----	9,780	-----	-----	-----	34,400
				Sawyer bed				
2	48	-----	10,320	-----	-----	-----	-----	10,320
2	49	-----	274,950	-----	143,500	-----	4,510	422,960
3	48	-----	34,920	-----	63,100	-----	730	98,750
3	49	580	297,600	-----	373,880	-----	760	672,820
4	48	-----	620	-----	88,200	-----	6,100	94,920
4	49	-----	22,050	-----	35,050	-----	80	57,180
Totals		580	640,460	-----	703,730	-----	12,180	1,356,950
				Coal bed A				
3	48	-----	1,570	-----	18,790	-----	750	21,110
3	49	-----	40,780	-----	54,970	-----	-----	95,750
4	48	-----	430	-----	9,910	-----	6,500	16,840
4	49	2,210	19,120	1,960	31,330	120	3,220	57,960
Totals		2,210	61,900	1,960	115,000	120	10,470	191,660
Grand totals		27,410	702,360	11,740	818,730	120	22,650	1,583,010

Table 3.--Measured, indicated, and inferred resources of lignite in the Tongue River Member of Paleocene Fort Union Formation, possibly recoverable by surface mining methods, in beds more than 5 feet (1.5 m) thick, under less than 200 feet (61 m) of overburden, as of January 1, 1978.

[In thousands of short tons (1 short ton = 0.9078 metric tons); totals are rounded. The coal is assumed to weigh 1,750 short tons per acre foot (1.3 metric tons/m^3); these resources are included in table 1. Leaders (----) indicate no data]

Location		Measured		Indicated		Inferred		
Township South	Range East	Thickness of coal in feet 5-10	>10	Thickness of coal in feet 5-10	>10	Thickness of coal in feet 5-10	>10	Totals
Mackin-Walker bed								
2	49	20,220	-----	6,310	-----	-----	-----	26,530
3	49	4,400	-----	3,400	-----	-----	-----	7,800
Totals		24,620	-----	9,710	-----	-----	-----	34,330
Sawyer bed								
2	48	-----	10,320	-----	-----	-----	-----	10,320
2	49	-----	273,900	-----	127,800	-----	4,510	406,210
3	48	-----	34,920	-----	63,100	-----	730	98,750
3	49	580	286,110	-----	339,780	-----	760	627,230
4	48	-----	-----	-----	7,700	-----	470	8,170
4	49	-----	18,080	-----	24,900	-----	80	43,060
Totals		580	623,330	-----	563,280	-----	6,550	1,193,740
Coal bed A								
3	48	-----	1,570	-----	17,900	-----	680	20,150
3	49	-----	39,740	-----	45,110	-----	-----	84,850
4	48	-----	-----	-----	290	-----	-----	290
4	49	2,150	16,580	1,650	15,800	120	240	36,540
Totals		2,150	57,890	1,650	79,100	120	920	141,830
Grand totals		27,350	681,220	11,360	642,380	120	7,470	1,369,900

References

American Society for Testing and Materials, 1977, Standard specifications for classification of coals by rank (ASTM designation D-388-77): 1977 Annual book of ASTM standards, pt. 26, p. 214-218

Averitt, Paul, 1975, Coal resources of the United States, January 1, 1974: U.S. Geol. Survey Bull. 1412, 131 p.

Bass, N. W., 1932, The Ashland coal field, Rosebud, Powder River, and Custer Counties, Montana: U.S. Geol. Survey Bull. 831-B, p. 19-105.

Brown, Andrew, Culbertson, W. C., Dunham, R. J., Kepferle, R. C., and May, P. R., 1954, Strippable coal in Custer and Powder River Counties, Montana: U.S. Geol. Survey Bull. 995-E, p. 1-199.

Bryson, R. P., 1951, The Coalwood coal field, Powder River County, Montana: U.S. Geol. Survey Bull. 973-B, p. 23-106.

Dobbin, C. E., 1929, The Forsyth coal field, Rosebud, Treasure, and Bighorn Counties, Montana: U.S. Geol. Survey Bull. 812-A.

Francis, Wilfried, 1961, Coal, its formation and composition: London, Edward Arnold (Publishers) Ltd., 806 p.

Glenn, Marguerite, 1978a, Preliminary geologic map of the Pumpkin Creek EMRIA study site, Box Elder Creek, Leslie Creek, Coalwood, and Olive quadrangles, Powder River County, Montana: U.S. Geol. Survey Open-File Rept. 78-614.

______1978b, Locality and structure contour maps of the Pumpkin Creek EMRIA study site, Powder River County, Montana: U.S. Geol. Survey Open-File Rept. 78-897, 4 maps, 3 section sheets, and tables.

Lowry, H. H., ed., 1945, Chemistry of coal utilization, Volumes I and II: New York, John Wiley and Sons, Inc., 1968 p.

______1963, Chemistry of coal utilization, supplementary volume: New York, John Wiley and Sons, Inc., 1142 p.

Matson, R. E., Blumer, J. W., and Wegelin, L. A., 1973, Quality and reserves of strippable coal, selected deposits, southeastern Montana: Montana Bur. Mines and Geology Bull. 91, 135 p.

Moore, E. S., 1940, Coal, its properties, analysis, classification, geology, extraction, uses, and distribution: New York, John Wiley and Sons, Inc., 473 p.

Schopf, J. M., 1960, Field description and sampling of coal beds: U.S. Geol. Survey Bull. 1111-B, 70 p.

_____ 1966, Definitions of peat and coal and of graphite that terminates the coal series (Graphocite): Jour. Geology, v. 74, no. 5, pt. 1, p. 584-592.

Snyder, N. H., 1950, Handbook of coal sampling: U.S. Bur. Mines Tech. Paper 133 (revised), 10 p.

Tomkeieff, S. I., 1954, Coals and bitumens and related fossil carbonaceous substances: London, Pergamon Press, Ltd., 122 p.

Trumbull, J. V. A., 1960, Coal fields of the United States, Sheet 1: U.S. Geol. Survey.

U.S. Bureau of Mines, 1965, Bituminous coal, in Mineral facts and problems 1965; p. 119-147.

Warren, W. C., 1959, Reconnaissance geology of the Birney-Broadus coal field, Rosebud and Powder River Counties, Montana: U.S. Geol. Survey Bull. 1072-J, p. 561-585 (1960).

Chemical analyses of lignite and lignitic shale

By

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Introduction

Seventeen lignite and one lignitic shale sample were collected from cores from five holes in the Tongue River Member of the Fort Union Formation in the Pumpkin Creek EMRIA study site by the U.S. Geological Survey (fig. 1). Four of the holes, PWW2, PWW3, PWW8, and PWW10, were drilled by the U.S. Geological Survey; hole 76101 was cored by the U.S. Bureau of Reclamation. The samples are briefly described in table 4. Fifteen of the samples are from the Sawyer bed (the principal bed of interest in this area), one (D189026) is from the Mackin-Walker bed, 87 feet (26.5 m) above the Sawyer bed, and one (D187015) is from an unnamed bed 15 feet (4.5 m) above the Sawyer bed. Two samples were collected from the Sawyer bed in holes PWW2 and PWW10; four samples of the Sawyer bed were collected in holes PWW3 and 76101. In hole PWW8 the Sawyer bed contains two partings, one at a depth between 94.7 and 97.9 feet (28.9 to 29.8 m), the second at a depth between 111.9 and 112.2 feet (34.1 to 34.2 m). One sample was collected from the interval above the upper parting (D187023), one between the two partings (D187025), and one below the lower parting (D187026). The upper parting was sampled separately (D187024); the lower parting was not.

Table 4.--Hole number, USGS sample number, location, depth interval, and description of 18 lignite and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana

Hole number	USGS sample number	Location	Depth interval feet and (meters)	Description
PWW2	D187017	SW¼NW¼NW¼ sec. 24, T. 2 S., R. 49 E.	82.8- 98.0 (25.2- 29.9)	Lignite, Sawyer bed.
PWW2	D187018	------do------	98.0-112.2 (29.9- 34.2)	Lignite with minor pyrite, Sawyer bed.
PWW3	D187019	S½NW¼SW¼ sec. 28, T. 2 S., R. 49 E.	125.9-130.0 (38.4- 39.6)	Lignite, Sawyer bed.
PWW3	D187020	------do------	130.0-139.6 (39.6- 42.6)	Do.
PWW3	D187021	------do------	139.6-149.7 (42.6- 45.6)	Do.
PWW3	D187022	------do------	149.7-159.5 (45.6- 48.6)	Do.
PWW8	D187023	NE¼NW¼SE¼SW¼ sec. 14, T. 3 S., R. 49 E.	80.2- 94.7 (24.4- 28.9)	Do.
PWW8	D187024	------do------	94.7- 97.9 (28.9- 29.8)	Shale, with shaly lignite.
PWW8	D187025	------do------	97.9-111.9 (29.8- 34.1)	Lignite with minor pyrite, Sawyer bed.
PWW8	D187026	------do------	112.2-113.7 (34.2- 34.7)	Lignite, Sawyer bed.
PWW10	D187014	N½N½NW¼NW¼ sec. 20, T. 3 S., R. 49 E.	54.9- 55.6 (16.7- 16.9)	Lignite, unnamed bed.
PWW10	D187015	------do------	70.4- 84.8 (21.5- 25.8)	Lignite, Sawyer bed.
PWW10	D187016	N½N½NW¼NW¼ sec. 20, T. 3 S., R. 49 E.	85.3-100.6 (26.0- 30.7)	Do.
76101	D189026	NW¼SE¼SE¼SE¼ sec. 4, T. 3 S., R. 49 E.	173.9-179.1 (53.0- 54.6)	Lignite, Mackin-Walker bed.
76101	D189027	------do------	266.0-271.0 (81.1- 82.6)	Lignite, Sawyer bed.
76101	D189028	------do------	271.0-281.1 (82.6- 85.7)	Do.
76101	D189029	------do------	281.1-291.0 (85.7- 88.7)	Do.
76101	D189030	------do------	291.0-299.0 (88.7- 91.1)	Do.

Grade of coal

Classification of coal by grade, or quality, is based largely on the content of ash, sulfur, and other constituents that adversely affect utilization. Most detailed coal resource evaluations of the past do not categorize known coal resources by grade, but coals of the United States have been classified by sulfur content in a gross way (DeCarlo and others, 1966).

According to Fieldner and others (1942), ash content of 642 U.S. coal samples ranges from 2.5 to 32.6 percent, averaging 8.9 percent, and sulfur contents range from 0.2 to 7.7 percent, averaging 1.9 percent.

The ash content of the 17 samples from the Sawyer coal, on an as-received basis, ranges from 4.4 to 14.2 percent, averaging 6.8 percent; sulfur content of those samples ranges from 0.2 to 1.7 percent, averaging 0.4 percent.

Seventeen samples listed on tables 4 and 5 show an apparent rank of lignite A. Because of the lack of definitive information about the distribution of coals of various groups in the Pumpkin Creek coal, it is considered to be all lignite A in rank in the area of the study.

Type of coal

Classification of coals by type--that is, according to the types of plant materials present--takes many forms, such as the "rational analysis" of Francis (1961) or the semicommercial "type" classification commonly used in the coal fields of the eastern United States (U.S. Bureau of Mines, 1965, p. 123). However, most of the type classifications are based on the same, or similar, gross distinctions in plant material as those used in Tomkeieff (1954, Table II and p. 9), who divided the coal into three series: humic coals, humic-sapropelic coals, and sapropelic coals, based upon the nature of the original plant materials. The humic coals are composed largely of the remains of the woody parts of plants; and the sapropelic coals are composed largely of the more resistant waxy, fatty, and resinous parts of plants, such as cell walls, spore coatings, pollen, resin particles, and coals composed mainly of algal material. Most coals fall into the humic series, with some coals being a mixture of humic and sapropelic elements and, therefore, falling into the humic-sapropelic series. The sapropelic series is quantitatively insignificant and, when found, is commonly regarded as an organic curiosity. In common with most of the U.S. coals, those from Pumpkin Creek fall largely in the humic series.

Analytical results

Acknowledgments and summary of analytical tables

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Proximate and ultimate analyses, heat of combustion, air-dried-loss, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations on these samples (table 5) were provided by the U.S. Bureau of Mines, Pittsburgh, Pa. Analyses for 32 major and minor oxides and trace elements in the laboratory ash (table 6) and analyses of nine trace elements in whole coal and shale (table 7) were provided by the U.S. Geological Survey, Denver, Colo. Analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976).

Table 5.--Proximate and ultimate analyses, heat of combustion, forms of sulfur, free-swelling index, and ash-fusion temperature determinations for 17 lignite and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana

[All analyses except Kcal/kg, Btu/lb, free swelling index, and ash-fusion temperatures in percent. For each sample number, the analyses are reported three ways; first, as received, second, moisture free, and third, moisture and ash free. All analyses by Coal Analysis Section, U.S. Bureau of Mines, Pittsburgh, Pa. °C = (°F-32) 5/9; Kcal/kg = 0.556 (Btu/lb)]

		Proximate analysis				Ultimate analysis					Heat of combustion	
Hole number	Sample number	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
PWW2	D187017	36.4	26.6	30.1	6.9	6.9	41.0	0.6	44.3	0.4	3,840	6,910
		---	41.8	47.3	10.8	4.5	64.5	.9	18.8	.6	6,040	10,860
		---	46.9	53.1	---	5.0	72.3	1.1	21.1	.7	6,770	12,180
	D187018	37.7	26.1	30.1	6.1	7.0	40.8	.7	45.0	.5	3,850	6,930
		---	41.9	48.3	9.8	4.5	65.5	1.1	18.4	.8	6,180	11,140
		---	46.4	53.6	---	5.0	72.6	1.2	20.4	.9	6,850	12,350
PWW3	D187019	36.2	26.7	31.8	5.3	6.8	42.1	.7	44.7	.3	3,950	7,100
		---	41.8	49.8	8.3	4.4	66.0	1.1	19.6	.5	6,180	11,130
		---	45.6	54.4	---	4.7	72.0	1.2	21.4	.5	6,740	12,150
	D187020	37.3	25.9	32.2	4.6	6.9	41.6	.6	46.2	.2	3,910	7,030
		---	41.3	51.4	7.3	4.4	66.3	1.0	20.8	.3	6,230	11,220
		---	44.6	55.4	---	4.7	71.6	1.0	22.5	.3	6,720	12,110
	D187021	34.9	27.5	31.2	6.4	6.8	42.2	.6	43.8	.2	3,970	7,150
		---	42.2	47.9	9.8	4.5	64.8	.9	19.6	.3	6,100	10,980
		---	46.8	53.2	---	5.0	71.9	1.0	21.8	.3	6,770	12,180
	D187022	35.3	27.4	29.4	7.9	6.8	41.2	.7	42.8	.6	3,900	7,010
		---	42.3	45.4	12.2	4.4	63.7	1.1	17.7	.9	6,020	10,840
		---	48.2	51.8	---	5.1	72.5	1.2	20.1	1.1	6,860	12,350
PWW8	D187023	38.4	26.4	30.1	5.1	7.0	40.6	.6	46.4	.2	3,810	6,850
		---	42.9	48.9	8.3	4.4	65.9	1.0	19.9	.3	6,180	11,120
		---	46.7	53.3	---	4.8	71.9	1.1	21.7	.4	6,740	12,120
	D187024	20.8	13.6	9.3	56.3	3.8	14.9	.3	24.1	.6	1,290	2,310
		---	17.2	11.7	71.1	1.9	18.8	.4	7.1	.8	1,620	2,920
		---	59.4	40.6	---	6.5	65.1	1.3	24.5	2.6	5,610	10,100
	D187025	37.5	26.0	30.3	6.2	7.0	40.5	.7	45.4	.4	3,820	6,880
		---	41.6	48.5	9.9	4.5	64.8	1.1	19.3	.6	6,120	11,000
		---	46.2	53.8	---	5.0	71.9	1.2	21.4	.7	6,790	12,200
	D187026	36.2	25.3	27.9	10.6	6.8	37.9	.6	42.4	1.7	3,660	6,600
		---	39.7	43.7	16.6	4.4	59.4	.9	16.0	2.7	5,740	10,340
		---	47.6	52.4	---	5.2	71.2	1.1	19.2	3.2	6,890	12,400
PWW10	D187015	35.8	26.7	31.9	5.6	6.8	42.0	.7	44.6	.3	3,930	7,070
		---	41.6	49.7	8.7	4.4	65.4	1.1	19.9	.5	6,120	11,010
		---	45.6	54.4	---	4.8	71.7	1.2	21.8	.5	6,700	12,050
	D187016	34.8	27.5	30.8	6.9	6.7	42.0	.7	43.2	.4	3,950	7,110
		---	42.2	47.2	10.6	4.3	64.4	1.1	18.8	.6	6,060	10,920
		---	47.2	52.8	---	4.9	72.0	1.2	21.0	.7	6,780	12,210
76101	D189026	35.2	29.3	28.6	6.9	6.9	42.2	.7	42.4	1.0	4,010	7,220
		---	45.2	44.1	10.6	4.6	65.1	1.1	17.1	1.5	6,190	11,150
		---	50.6	49.4	---	5.2	72.9	1.2	19.2	1.7	6,930	12,480
	D189027	34.8	27.4	31.0	6.8	6.7	42.9	.7	42.4	.3	4,030	7,260
		---	42.0	47.5	10.4	4.3	65.8	1.1	17.6	.5	6,190	11,140
		---	46.9	53.1	---	4.9	73.5	1.2	19.6	.5	6,910	12,440
	D189028	35.4	26.9	33.3	4.4	6.7	43.4	.7	44.6	.2	4,030	7,250
		---	41.6	51.5	6.8	4.3	67.2	1.1	20.3	.3	6,230	11,220
		---	44.7	55.3	---	4.6	72.1	1.2	21.8	.3	6,690	12,040
	D189029	30.3	32.3	31.6	5.8	6.8	42.4	.7	44.1	.2	3,990	7,180
		---	46.3	45.3	8.3	4.9	60.8	1.0	24.6	.3	5,720	10,290
		---	50.5	49.5	---	5.4	66.4	1.1	26.9	.3	6,240	11,230
	D189030	34.4	23.9	27.5	14.2	6.4	36.9	.6	41.4	.5	3,480	6,260
		---	36.4	41.9	21.6	3.9	56.3	.9	16.5	.8	5,300	9,540
		---	46.5	53.5	---	5.0	71.8	1.2	21.1	1.0	6,770	12,180

Table 5.--Proximate and ultimate analyses, heat of combustion, forms of sulfur, free-swelling index, and ash-fusion temperature determinations for 17 lignite and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana--Continued

Hole number	Sample number	Air-dried loss	Forms of sulfur: Sulfate	Forms of sulfur: Pyritic	Forms of sulfur: Organic	Free swelling	Ash-fusion temperature, C°: Initial deformation	Ash-fusion temperature, C°: Softening	Ash-fusion temperature, C°: Fluid
PWW2	D187017	28.0	0.01	0.06	0.32	0.0	1,175	1,230	1,285
		---	.02	.09	.50				
		---	.02	.11	.56				
	D187018	28.7	.01	.07	.40	.0	1,155	1,215	1 265
		---	.02	.11	.64				
		---	.02	.12	.71				
PWW3	D187019	27.4	.01	.08	.22	.0	1,165	1,230	1,290
		---	.02	.13	.34				
		---	.02	.14	.38				
	D187020	28.3	.01	.06	.10	.0	1,215	1,270	1,325
		---	.02	.10	.16				
		---	.02	.10	.17				
	D187021	27.0	.01	.07	.10	.0	1,205	1,265	1 320
		---	.02	.11	.15				
		---	.02	.12	.17				
	D187022	26.3	.01	.39	.24	.0	1,120	1,180	1,235
		---	.02	.60	.37				
		---	.02	.69	.42				
PWW8	D187023	29.7	.01	.13	.05	.0	1,125	1,180	1,235
		---	.02	.21	.08				
		---	.02	.23	.09				
	D187024	17.7	.01	.33	.26	.0	1,435	1,485	1,540
		---	.01	.42	.33				
		---	.04	1.44	1.14				
	D187025	28.5	.01	.14	.21	.0	1,155	1,215	1,275
		---	.02	.22	.34				
		---	.02	.25	.37				
	D187026	29.6	.01	.53	1.16	.0	1,075	1,130	1,180
		---	.02	.83	1.82				
		---	.02	1.00	2.18				
PWW10	D187015	27.6	.01	.15	.17	.0	1,150	1,215	1,265
		---	.02	.23	.26				
		---	.02	.26	.29				
	D187016	26.4	.01	.18	.26	.0	1,180	1,230	1,295
		---	.02	.28	.40				
		---	.02	.31	.45				
76101	D189026	16.3	.01	.25	.74	.0	1,125	1 180	1,235
		---	.02	.39	1.14				
		---	.02	.43	1.28				
	D189027	16.9	.00	.17	.17	.0	1,150	1,205	1 265
		---	.00	.26	.26				
		---	.00	.29	.29				
	D189028	14.9	.01	.13	.05	.0	1,205	1,265	1,320
		---	.02	.20	.08				
		---	.02	.22	.08				
	D189029	19.8	.01	.10	.09	.0	1,180	1,240	1,290
		---	.01	.14	.13				
		---	.02	.16	.14				
	D189030	20.1	.01	.14	.38	.0	1,205	1 265	1,315
		---	.02	.21	.58				
		---	.02	.27	.74				

Table 6.--Major and minor oxide and trace element composition of the laboratory ash of 18 lignite and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana

[Values in percent or parts per million. Lignite ashed at 525°C. L means less than the value shown; N, not detected; B, not determined; S after element title indicates determinations by semiquantitative emission spectrography. The spectrographic results are to be identified with geometric brackets, 0.1, 0.15, 0.2, 0.3, 0.5, 0.7, 1.0, etc. Precision of the spectrographic data is plus-or-minus one bracket at 68 percent or plus-or-minus two brackets at 95 percent confidence level]

Hole number	Sample number	Ash (percent)	SiO_2 (percent)	Al_2O_3 (percent)	CaO (percent)	MgO (percent)	Na_2O (percent)	K_2O (percent)	Fe_2O_3 (percent)	TiO_2 (percent)	P_2O_5 (percent)	Sample number
PWW2	D187017	10.5	29	11	26	4.35	4.63	0.78	5.5	1.2	1.0L	D187017
	D187018	9.1	27	13	25	5.08	5.20	.30	6.5	.72	1.0L	D187018
PWW3	D187019	8.4	20	10	33	5.15	6.55	.34	5.9	.86	1.0L	D187019
	D187020	7.5	19	12	35	5.43	7.00	.36	5.8	.86	1.0L	D187020
	D187021	8.7	30	13	31	4.65	5.88	.41	5.0	1.1	1.0L	D187021
	D187022	9.4	27	11	24	4.08	5.83	.93	9.1	.63	1.0L	D187022
PWW3	D187023	7.5	18	11	33	4.93	7.05	.40	7.3	.78	1.0L	D187023
	D187024	68.0	64	17	2.1	1.21	.47	3.5	2.9	.69	1.0	D187024
	D187025	8.9	26	12	30	4.73	5.83	.48	6.4	.81	1.0L	D187025
	D187026	15.8	33	13	14	2.70	3.18	1.5	13	.51	1.0L	D187026
PWW10	D187014	31.5	31	8.0	6.1	1.98	1.09	1.7	34	.86	1.0L	D187014
	D187015	8.7	18	10	33	4.20	5.88	.41	6.7	.73	1.0L	D187015
	D187016	9.5	30	14	26	3.75	3.50	.57	6.1	.77	1.0L	D187016
76101	D189026	8.7	16	7.8	25	4.95	6.38	.42	11	.58	1.0L	D189026
	D189027	8.1	21	14	31	5.10	6.50	.30	7.0	.60	1.0L	D189027
	D189028	6.5	17	11	35	5.75	7.58	.32	6.2	.87	1.0L	D189028
	D189029	8.3	22	11	28	4.50	5.55	.23	4.7	1.0	1.0L	D189029
	D189030	13.7	42	15	15	3.08	3.30	1.9	6.8	.64	1.0L	D189030

Hole number	Sample number	SO_3 (percent)	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Cu (ppm)	Ga-S (ppm)	Ge-S (ppm)	La-S (ppm)	Sample number
PWW2	D187017	14	700	15.000	2	1.0L	N	53	15	N	N	D187017
	D187018	17	1,000	3,000	3	1.0	N	72	20	N	N	D187018
PWW3	D187019	13	1,500	15,000	7	1.0L	N	46	N	30	100	D187019
	D187020	5.6	1,500	15.000	2	1.0L	N	46	N	N	70	D187020
	D187021	7.1	1,000	7,000	2	1.0L	N	67	15	N	N	D187021
	D187022	18	1,500	3,000	7	1.0L	N	84	15	N	N	D187022
PWW8	D187023	11	1,500	7,000	3	18.0	N	46	20	N	N	D187023
	D187024	2.0	150	1,500	3	1.0L	N	58	30	N	70	D187024
	D187025	15	1,500	3,000	2	1.0L	N	67	30	N	N	D187025
	D187026	21	700	700	15	1.0	N	138	30	N	N	D187026
PWW10	D187014	16	200	7,000	7	1.0L	N	68	100	700	100	D187014
	D187015	18	700	7,000	3	1.0L	N	50	15	N	N	D187015
	D187016	14	700	3,000	3	1.0L	N	74	30	N	N	D187016
76101	D189026	27	700	1,500	10	1.0L	B	53	15	50	N	D189026
	D189027	14	700	3,000	10	1.0L	B	37	15	20	N	D189027
	D189028	7.1	1,000	7,000	N	1.0L	B	42	15	N	N	D189028
	D189029	17	700	7,000	N	1.0L	B	40	15	N	N	D189029
	D189030	11	700	2,000	5	1.0L	N	58	15	N	N	D189030

Table 6.--Major and minor oxide and trace element composition of the laboratory ash of 18 lignite and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana--Continued

Hole number	Sample number	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	Pb (ppm)	Sc-S (ppm)	Sr-S (ppm)	V-S (ppm)	Y-S (ppm)	Sample number
PWW2	D187017	63	1,000	7	20	10	40	10	3,000	70	30	D187017
	D187018	80	480	5	20	15	35	N	3,000	70	50	D187018
	D187019	53	805	N	30	10	30	20	7,000	70	70	D187019
PWW3	D187020	90	835	5	20	15	35	10	7,000	30	70	D187020
	D187021	116	830	5	20	15	30	10	3,000	70	50	D187021
	D187022	63	765	15	20	30	40	15	2,000	70	70	D187022
	D187023	55	795	30	20	15	60	15	7,000	70	70	D187023
PWW8	D187024	45	80	10	20	70	45	15	200	70	70	D187024
	D187025	71	500	15	20	15	35	10	3.000	70	50	D187025
	D187026	53	460	30	20	100	50	15	1,500	150	70	D187026
	D187014	20	2,060	N	100	70	25L	30	700	300	150	D187014
PWW10	D187015	45	905	15	20	20	25	15	7,000	70	70	D187015
	D187016	55	720	10	20	30	45	15	3 000	70	50	D187016
	D189026	14	550	10	N	20	25L	20	5,000	150	100	D189026
	D189027	67	825	7	N	10	50	15	3,000	50	50	D189027
76101	D189028	55	1,010	7	N	10	55	7	3,000	30	20	D189028
	D189029	94	940	7	N	7	30	7	3,000	50	20	D189029
	D189030	56	535	10	N	15	45	10	150	70	20	D189030

Hole number	Sample number	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)
PWW2	D187017	7	98	150
	D187018	5	69	150
	D187019	7	120	300
	D187020	7	102	150
PWW3	D187021	3	112	150
	D187022	7	122	150
	D187023	7	2,100	150
PWW8	D187024	7	221	150
	D187025	5	66	150
	D187026	7	200	70
	D187014	15	193	1,500
PWW10	D187015	5	105	150
	D187016	7	186	150
	D189026	7	83	150
	D189027	5	94	150
76101	D189028	2	103	70
	D189029	2	128	100
	D189030	5	144	70

Table 7.--Content of nine trace elements in 18 lignite and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana

[Analyses on air-dried (32°C) lignite. L, Less than the value shown]

Hole number	Sample number	As (ppm)	Co (ppm)	Cr (ppm)	F (ppm)	Hg (ppm)	Sb (ppm)	Se (ppm)	Th (ppm)	U (ppm)	Sample number
PWW2	D187017	1.4	0.8	3.3	45	0.09	0.3	0.5	1.7	1.1	D187017
	D187018	1.5	.9	2.7	20	.11	.3	.7	1.4	.5	D187018
PWW3	D187019	1.0	.5	2.0	40	.05	.3	.1L	1.3	.5	D187019
	D187020	.6	.5	1.6	35	.05	.1	.2	1.3	.9	D187020
	D187021	1.0	.7	2.2	35	.09	.3	.4	1.3	.9	D187021
	D187022	2.5	1.0	4.0	45	.12	.7	.4	1.3	1.2	D187022
PWW8	D187023	.9	.7	2.9	35	.05	.4	.3	1.4	.6	D187023
	D187024	13	23	48	585	.37	2.2	1.7	9.8	6.0	D187024
	D187025	1.3	.7	1.0L	35	.06	.3	.5	1.5	.7	D187025
	D187026	18	7.6	10	80	.46	2.1	1.0	2.8	4.7	D187026
PWW10	D187014	420	8.1	50	155	1.40	6.2	1.1	2.4	5.6	D187014
	D187015	1.4	.7	2.1	55	.09	.3	.4	1.4	1.0	D187015
	D187016	2.6	1.9	3.3	40	.15	.6	.1L	1.3	1.1	D187016
76101	D189026	7.1	1.1	5.3	50	.08	.5	.4	.9	1.2	D189026
	D189027	1.6	.5	1.7	35	.07	.3	.3	1.7	1.4	D189027
	D189028	1.0	.6	1.4	45	.04	.2	.1L	.8	.7	D189028
	D189029	1.3	.7	2.0	40	.08	.2	.4	1.1	1.1	D189029
	D189030	7.3	1.3	8.3	95	.24	1.1	.5	1.9	2.0	D189030

Table 8 contains the data listed in table 6 converted to a whole-coal basis and the whole-coal analyses listed in table 7. Twenty-four additional elements were looked for but not found in amounts greater than their lower limits of detection (table 9). Unweighted statistical summaries of the analytical data on the Sawyer beds in tables 5, 6, and 8 are listed in tables 10, 11, and 12, respectively. Data summaries for other Powder River region coal samples are listed for comparison.

To be consistent with the precision of the semiquantitative emission spectrographic technique, arithmetic and geometric means of elements determined by this method are reported as the midpoint of the enclosing six-step bracket. (See headnote of table 6, or Swanson and Huffman, 1976, p. 67, for an explanation of six-step brackets.)

Table 8.--Major, minor, and trace element composition of 18 coal and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana

[Values in percent or parts per million. As, Co, Cr, F, Hg, Sb, Se, Th, and U values are from direct determinations on air dried (32°C) coal; all other values calculated from analyses of ash. S means analysis by emission spectrography; L, less than the value shown; N, not detected; B, not determined]

Hole number	Sample number	Si (percent)	Al (percent)	Ca (percent)	Mg (percent)	Na (percent)	K (percent)	Fe (percent)	Ti (percent)	As (ppm)	B-S (ppm)	Sample number
PWW2	D187017	1.4	0.61	1.9	0.27	0.36	0.068	0.40	0.075	1.4	70	D187017
	D187018	1.1	.63	1.6	.28	.35	.023	.41	.039	1.5	100	D187018
PWW3	D187019	.78	.44	2.0	.26	.41	.024	.35	.043	1.0	150	D187019
	D187020	.67	.48	1.9	.25	.39	.022	.30	.039	.6	100	D187020
	D187021	1.2	.60	1.9	.24	.38	.030	.30	.057	1.0	100	D187021
	D187022	1.2	.55	1.6	.23	.41	.073	.60	.035	2.5	150	D187022
PWW8	D187023	.63	.44	1.8	.22	.39	.025	.38	.035	.9	100	D187023
	D187024	20	6.1	1.0	.50	.24	2.0	1.4	.28	13	100	D187024
	D187025	1.1	.56	1.9	.25	.38	.036	.40	.043	1.3	150	D187025
	D187026	2.4	1.1	1.6	.26	.37	.20	1.4	.048	18	100	D187026
PWW10	D187014	4.6	1.3	1.4	.38	.25	.45	7.5	.16	420	70	D187014
	D187015	.73	.46	2.0	.22	.38	.030	.41	.038	1.4	70	D187015
	D187016	1.3	.70	1.8	.21	.25	.045	.41	.044	2.6	70	D187016
76101	D189026	.65	.36	1.6	.26	.41	.030	.67	.030	7.1	70	D189026
	D189027	.79	.60	1.8	.25	.39	.020	.40	.029	1.6	70	D189027
	D189028	.52	.38	1.6	.22	.37	.017	.28	.034	1.0	70	D189028
	D189029	.85	.48	1.7	.22	.34	.016	.27	.050	1.3	70	D189029
	D189030	2.7	1.1	1.5	.25	.34	.22	.65	.053	7.3	100	D189030

Hole number	Sample number	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Ge-S (ppm)	Sample number
PWW2	D187017	1,500	0.2	0.11L	N	0.8	3.3	5.6	45	1.5	N	D187017
	D187018	300	.3	.09	N	.9	2.7	6.6	20	2	N	D187018
PWW3	D187019	1 500	.7	.08L	N	.5	2.0	3.9	40	N	2	D187019
	D187020	1,000	.15	.07L	N	.5	1.6	3.5	35	N	N	D187020
	D187021	700	.15	.09L	N	.7	2.2	5.8	35	1.5	N	D187021
	D187022	300	.7	.09L	N	1.0	4.0	7.9	45	1.5	N	D187022
PWW8	D187023	500	.2	1.4	N	.7	2.9	3.5	35	1.5	N	D187023
	D187024	1,000	2	.68L	N	23	48	39	585	20	N	D187024
	D187025	300	.2	.09L	N	.7	1.0L	6.0	35	3	N	D187025
	D187026	100	2	.16	N	7.6	10	22	80	5	N	D187026
PWW10	D187014	2,000	2	.31L	N	8.1	50	21	155	30	200	D187014
	D187015	700	.2	.09L	N	.7	2.1	4.4	55	1.5	N	D187015
	D187016	300	.3	.09L	N	1.9	3.3	7.0	40	3	N	D187016
76101	D189026	150	1	.09L	B	1.1	5.3	4.6	50	1.5	5	D189026
	D189027	200	.7	.08L	B	.5	1.7	3.0	35	1.5	1.5	D189027
	D189028	500	N	.07L	B	.6	1.4	2.7	45	1	N	D189028
	D189029	700	N	.08L	B	.7	2.0	3.3	40	1.5	N	D189029
	D189030	300	.7	.14L	N	1.3	8.3	7.9	95	2	N	D189030

Table 8.--Major, minor, and trace element composition of 18 coal and shale samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana--Continued

Hole number	Sample number	Hg (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	P (ppm)	Pb (ppm)	Sb (ppm)	Sample number
PWW2	D187017	0.09	N	6.6	110	0.7	2	1	460L	4.2	0.3	D187017
	D187018	.11	N	7.3	44	.5	2	1.5	400L	3.2	.3	D187018
PWW3	D187019	.05	10	4.5	68	N	2	1	370L	2.5	.3	D187019
	D187020	.05	5	6.8	63	.3	1.5	1	330L	2.6	.1	D187020
	D187021	.09	N	10	72	.5	1.5	1.5	380L	2.6	.3	D187021
	D187022	.12	N	5.9	72	1.5	2	3	410L	3.8	.7	D187022
PWW8	D187023	.05	N	4.1	60	2	1.5	1	330L	4.5	.4	D187023
	D187024	.37	50	31	54	7	15	50	3,000	31	2.2	D187024
	D187025	.06	N	6.3	45	1.5	2	1.5	390L	3.1	.3	D187025
	D187026	.46	N	8.4	73	5	3	15	690L	7.9	2.1	D187026
PWW10	D187014	1.4	30	6.3	650	N	30	20	1,400L	7.9L	6.2	D187014
	D187015	.09	N	3.9	79	1.5	1.5	1.5	380L	2.2	.3	D187015
	D187016	.15	N	5.2	68	1	2	3	420L	4.3	.6	D187016
76101	D189026	.08	N	1.2	48	1	N	1.5	380L	2.2L	.5	D189026
	D189027	.07	N	5.4	67	.7	N	.7	350L	4.1	.3	D189027
	D189028	.04	N	3.6	66	.5	N	.7	280L	3.6	.2	D189028
	D189029	.08	N	7.8	78	.7	N	.7	360L	2.5	.2	D189029
	D189030	.24	N	7.7	73	1.5	N	2	600L	6.2	1.1	D189030

Hole number	Sample number	Sc-S (ppm)	Se (ppm)	Sr-S (ppm)	Th (ppm)	U (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)	Sample number
PWW2	D187017	1	0.5	300	1.7	1.1	7	3	0.7	10	15	D187017
	D187018	N	.7	300	1.4	.5	7	5	.5	6.3	15	D187018
PWW3	D187019	1.5	.1L	700	1.3	.5	7	7	.7	10	20	D187019
	D187020	.7	.2	500	1.3	.9	2	5	.5	7.7	10	D187020
	D187021	1	.4	200	1.3	.9	7	5	.2	9.7	15	D187021
	D187022	1.5	.4	200	1.3	1.2	7	7	.7	11	15	D187022
PWW8	D187023	1	.3	500	1.4	.6	5	5	.5	160	10	D187023
	D187024	10	1.7	150	9.8	6.0	50	50	5	150	100	D187024
	D187025	1	.5	300	1.5	.7	7	5	.5	5.9	15	D187025
	D187026	2	1.0	200	2.8	4.7	20	10	1	32	10	D187026
PWW10	D187014	10	1.1	200	2.4	5.6	100	50	5	61	500	D187014
	D187015	1.5	.4	700	1.4	1.0	7	7	.5	9.1	15	D187015
	D187016	1.5	.1L	300	1.3	1.1	7	5	.7	18	15	D187016
76101	D189026	1.5	.4	500	.9	1.2	15	10	.7	7.2	15	D189026
	D189027	1.5	.3	200	1.7	1.4	5	5	.5	7.6	15	D189027
	D189028	.5	.1L	200	.8	.7	2	1.5	.15	6.7	5	D189028
	D189029	.7	.4	200	1.1	1.1	5	1.5	.15	11	10	D189029
	D189030	1.5	.5	20	1.9	2.0	10	3	.7	20	10	D189030

Table 9.--Elements looked for, but not detected, in lignite samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana

[Approximate lower detection limits for these elements in lignite ash by the six-step spectrographic method of the U.S. Geological Survey are included]

Element	Lower limit of detection (ppm) in lignite ash
Ag	1
Au	50
Bi	20
Ce	500
Dy	100
Er	100
Eu	200
Gd	100
Hf	200
Ho	50
In	20
Lu	70
Nd	150
Pd	5
Pr	200
Pt	100
Re	100
Sm	200
Sn	20
Ta	1,000
Tb	700
Te	5,000
Tm	50
W	200

Table 10.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate and ultimate analyses, heat of combustion, forms of sulfur, and ash-fusion temperatures for 15 Sawyer bed lignite samples from the Fort Union Formation in the Pumpkin Creek EMRIA study site, Powder River County, Montana

[All values are in percent except Kcal/kg, Btu/lb, and ash-fusion temperatures and are reported on the as-received basis. °C = (°F-32) 5/9; Kcal/kg = 0.556 (Btu/lb). Leaders (--) indicate no data. For comparison, arithmetic means from 33 Powder River region coal samples (Swanson and others, 1976, tables 31B and 32B) are included]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		Minimum	Maximum			
Proximate and ultimate analyses						
Moisture	35.7	30.3	38.4	35.6	1.1	23.1
Volatile matter	26.8	23.9	32.3	26.8	1.1	32.6
Fixed carbon	30.6	27.5	33.3	30.6	1.1	36.0
Ash	6.8	4.4	14.2	6.5	1.4	7.5
Hydrogen	6.8	6.4	7.0	6.8	1.0	6.2
Carbon	41.2	36.9	43.4	41.1	1.1	50.3
Nitrogen	.7	.6	.7	.7	1.1	.9
Oxygen	44.1	41.4	46.4	44.1	1.0	32.9
Sulfur	.4	.2	1.7	.4	1.8	.8
Heat of combustion						
Kcal/kg	3,880	3,480	4,040	3,880	1.0	4,860
Btu/lb	6,970	6,260	7,260	6,970	1.0	8,740
Forms of sulfur						
Sulfate	0.01	0.01	0.01	0.01	1.0	0.02
Pyritic	.16	.06	.53	.13	1.9	.29
Organic	.26	.05	1.16	.19	2.3	.31
Ash-fusion temperature °C						
Initial deformation	1,164	1,074	1,213	1,163	1.0	--------
Softening temperature	1,222	1,132	1,271	1,221	1.0	--------
Fluid temperature	1,276	1,179	1,324	1,276	1.0	--------

Table 11.--Arithmetic mean, observed range, geometric mean, and geometric deviation of ash content and contents of nine major and minor oxides in the laboratory ash of 15 Sawyer bed lignite samples from the Tongue River Member of the Fort Union Formation in the Pumpkin Creek EMRIA study site, Powder River County, Montana

[All samples were ashed at 525°C; all analyses are in percent. For comparison, geometric means for 410 Powder River region coal samples are listed (Hatch and Swanson, 1977, table 6a)

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		Minimum	Maximum			
(Ash)	9.4	6.5	15.8	9.1	1.3	9.0
SiO_2	25	17	42	24	1.3	28
Al_2O_3	12	10	15	12	1.1	14
CaO	28	14	35	27	1.3	15
MgO	4.5	2.7	5.8	4.4	1.2	3.6
Na_2O	5.6	3.2	7.6	5.4	1.3	.93
K_2O	.6	.23	1.9	.5	1.9	.28
Fe_2O_3	6.8	4.7	13	6.6	1.3	5.8
TiO_2	.81	.51	1.2	.79	1.3	.61
SO_3	14	5.6	21	13	1.5	14

Table 12.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 27 elements in 15 Sawyer bed lignite samples from the Tongue River Member of the Fort Union Formation, Pumpkin Creek EMRIA study site, Powder River County, Montana

[All analyses are in parts per million and are reported on a whole-lignite basis. As, Co, Cr, F, Hg, Sb, Se, Th, and U values used to calculate the statistics were determined directly on whole lignite. All other values used were calculated from determinations made on lignite ash. L, less than the value shown. For comparison, geometric means for 410 Powder River region coal samples are listed (Hatch and Swanson, 1977, table 6b]

Element	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		Minimum	Maximum			
As	2.5	0.6	17.5	1.7	2.4	2
B	100	70	150	100	1.3	50
Ba	700	100	1500	500	2.1	300
Be	.5	.15	2	.3	2.2	.5
Co	1.1	.5	7.6	.9	2.0	2
Cr	3.4	1.0L	10	2.8	1.8	5
Cu	6.1	2.7	22	5.3	1.7	9.5
F	45	20	95	42	1.4	40
Ga	2	1L	5	2	1.5	2
Hg	.1	.04	.46	.09	1.9	.08
Li	6.3	3.6	10	6.0	1.4	3.9
Mn	69	44	105	67	1.2	34
Mo	1.5	.3L	5	1	2.1	1.5
Nb	2	1.5L	3	2	1.2	1
Ni	2	.7	15	1.5	2.2	3
Pb	3.8	2.2	7.9	3.6	1.4	5.1
Sb	.5	.1	2.1	.4	2.1	.4
Sc	1.5	.5L	2	1.1	1.5	1.5
Se	.5	.2	1.0	.4	1.5	.7
Sr	300	20	700	200	2.3	150
Th	1.5	.8	2.8	1.4	1.3	3.3
U	1.2	.5	4.7	1.0	1.8	.6
V	7	2	20	7	1.8	10
Y	5	1.5	10	5	1.7	3
Yb	.5	.15	1	.5	1.8	.3
Zn	18	5.9	160	12	2.3	13
Zr	15	5	20	15	1.4	15

Statistical terms used in summary tables

In this report the geometric mean (GM) is used as the estimate of the most probable concentration (mode); the geometric mean is calculated by taking the logarithm of each analytical value, summing the logarithms, dividing the sum by the total number of values, and obtaining the antilogarithm of the result. The measure of scatter about the mode used here is the geometric deviation (GD), which is the antilog of the standard deviation of the logarithms of the analytical values. These statistics are used because the quantities of trace elements in natural materials commonly exhibit positively skewed frequency distributions; such distributions are normalized by analyzing and summarizing trace-element data on a logarithmic basis.

If the frequency distributions are lognormal, the geometric mean is the best estimate of the mode, and the estimated range of the central two-thirds of the observed distribution has a lower limit equal to GM/GD and an upper limit equal to GM·GD. The estimated range of the central 95 percent of the observed distribution has a lower limit equal to $GM/(GD)^2$ and an upper limit equal to $GM \cdot (GD)^2$ (Connor and others, 1976).

Although the geometric mean is, in general, an adequate estimate of the most common analytical value, it is, nevertheless, a biased estimate of the arithmetic mean. In the summary tables, the estimates of the arithmetic means are Sichel's *t* statistic (Miesch, 1967).

A common problem in statistical summaries of trace-element data arises when the element content in one or more of the samples is below the limit of analytical detection. This results in a censored distribution. Procedures developed by Cohen (1959) were used to compute unbiased estimates of the geometric mean, geometric deviation, and arithmetic mean where the data are censored.

Discussion of the analyses

The analyses of the Sawyer bed on an as-received basis (table 5) show that ash content ranges from 4.6 to 14.2 percent, averaging 6.8 percent, sulfur content ranges from 0.2 to 1.7 percent, averaging 0.4 percent, and heat of combustion ranges from 3,480 to 4,030 Kcal/kg (6,260 to 7,260 Btu/lb), averaging 3,880 Kcal/kg (6,970 Btu/lb). The lignite below the lower parting in PWW8 has a relatively high sulfur content (1.7 percent), and presumably would not be mined with the lignite above the parting. The analysis of the Mackin-Walker bed shows that its ash content is 6.9 percent, its sulfur content is 1.0 percent, and its heat of combustion is 4,010 Kcal/kg (7,220 Btu/lb). The apparent ranks of the samples were calculated using the data in table 5 and the formulas in ASTM designation D-388-77 (American Society for Testing and Materials, 1977). The apparent rank of all 17 samples is lignite A.

In table 10, the geometric means of the proximate and ultimate analyses for the Sawyer bed samples are compared with the geometric means of analyses of 33 coal samples from other areas in the Powder River region, as listed in Swanson and others (1976). The apparent rank of these 33 samples ranges from subbituminous C to subbituminous B coal. Because the Sawyer bed in the Pumpkin Creek area is of lower rank than the average of the 33 samples, its moisture, hydrogen, and oxygen contents are significantly higher (Student's t test, 95 percent confidence level) and volatile matter, fixed carbon, carbon contents, and heat of combustion are significantly lower than in the 33 other Powder River region samples. Contents of nitrogen and total sulfur are also significantly lower in the Sawyer bed samples.

In table 11, the geometric means of the contents of nine major and minor oxides in the laboratory ash of 15 Sawyer bed samples are compared with the geometric means of these oxides in 410 Powder River region samples. The contents are similar (Student's test, 95 percent confidence level), except for those of

CaO, Na_2O, K_2O, and TiO_2, which are significantly higher in the Sawyer bed. At the 99 percent confidence level only the CaO and Na_2O contents are significantly higher.

In table 12, the geometric means of the contents of 27 elements in the Sawyer bed samples are compared with the geometric means of these elements in 410 Powder River region samples. In the Sawyer bed the contents of B, Ba, Mn, Nb, U, Y, and Yb are significantly higher, and contents of Be, Co, Cr, Cu, Ni, Pb, Sc, Se, and Th are significantly lower. Contents of As, F, Ga, Hg, Li, Mo, Sb, Sr, V, Zn, and Zr are similar for both sets. At the 99 percent confidence level, B, Mn, Y, Yb, Co, Cr, Cu, Ni, and Th contents are significantly different.

When compared to other U.S. coals (Swanson and others, 1976), Powder River region coals are characterized by relatively low ash, low sulfur, and high moisture contents, and a low heat of combustion. The contents of elements of environmental concern (such as As, Be, Cd, Hg, Mo, Sb, and Se) in Powder River region coals are low when compared to other U.S. coals. Powder River region coals are, or will be, used in coal-fired power-generating plants or in coal-gasification plants.

Differences in the oxide compositions of coal ashes and the element contents of coals result from differences in the total and relative amounts of the various inorganic minerals, the elemental composition of these minerals, and the total and relative amounts of any organically bound elements. The chemical form and distribution of a given element is dependent on the geologic history of the coal bed. A partial listing of the geologic factors that influence element distributions would include chemical composition of original plants; amounts and compositions of the various detrital, diagenetic, and epigenetic minerals; chemical characteristics of the ground waters that come in contact with the bed; temperatures and pressures reached during burial; and extent of weathering.

References

American Society for Testing and Materials, 1977, Standard specifications for classification of coals by rank (ASTM designation D-388-77): 1977 Annual book of ASTM standards, pt. 26, p. 214-218.

Cohen, A.C., 1959, Simplified estimators for the normal distribution when samples are singly censored or truncated: Technometrics, v. 1, no. 3, p. 217-237.

Connor, J. J., Keith, J. R., and Anderson, B. M., 1976, Trace-metal variation in soils and sagebrush in the Powder River basin, Wyoming and Montana: U.S. Geol. Survey Jour. Research, v. 4, no. 1, p. 49-59.

DeCarlo, J. A., Sheridan, E. T., and Murphy, Z. E., 1966, Sulfur content of United States coals: U.S. Bur. Mines Inf. Circ. 8312, 44 p.

Fieldner, A. C., Rice, W. E., and Moran, H. E., 1942, Typical analyses of coals of the United States: U.S. Bur. Mines Bull. 446, 45 p.

Francis, Wilfried, 1961, Coal, its formation and composition: London, Edward Arnold (Publishers) Ltd., 806 p.

Hatch, J. R., and Swanson, V. E., 1977, Trace elements in Rocky Mountain coals: Geology of Rocky Mountain Coal--a symposium (D. K. Murray, editor), Colorado Geol. Survey Resource ser. no. 1, p. 143-165.

Meisch, A. T., 1967, Methods of computation for estimating geochemical abundances: U.S. Geol. Survey Prof. Paper 574-B, 15 p.

Swanson, V. E., and Huffman, Claude, Jr., 1976, Guidelines for sample collecting and analytical methods used in the U.S. Geological Survey for determining chemical composition of coal: U.S. Geol. Survey Circ. 735, 11 p.

Swanson, V. E., Medlin, J. H., Hatch, J. R., Coleman, S. L., Wood, G. H., Jr., Woodruff, S. D., and Hildebrand, R. T., 1976, Collection, chemical analysis, and evaluations of coal samples in 1975: U.S. Geol. Survey Open-File Rept. 76-468, 503 p.

Tomkeieff, S. I., 1954, Coals and bitumens and related fossil carbonaceous substances: London, Pergamon Press, Lt., 122 p.

U.S. Bureau of Mines, 1965, Bituminous coal, <u>in</u> Mineral facts and problems 1965; p. 119-147.