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Geology and Coal Resources of the Hanging Woman Creek Study Area, Big Horn and Powder River Counties, Montana

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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ABSTRACT

In an area of 7,200 acres (29 sq km) in the Hanging Woman Creek study area, the Anderson coal bed contains potentially surface minable resources of 378 million short tons (343 million metric tons) of subbituminous C coal that ranges in thickness from 26 to 33 feet (7.9-10.1 m) at depths of less than 200 feet (60 m). Additional potentially surface minable resources of 55 million short tons (50 million metric tons) are contained in the 9-12 foot (2.7-3.7 m) thick Dietz coal bed which lies 50-100 feet (15-30 m) below the Anderson. Analyses of coal from 5 core holes indicates that the Anderson bed contains 0.4 percent sulfur, 5 percent ash, and has a heating value of 8,540 Btu/lb (4,750 Kcal/kg). The trace element content of the coal is generally similar to other coals in the Powder River Basin.

The two coal beds are in the Fort Union Formation of Paleocene age which consists of sandstone, siltstone, shale, coal beds, and locally impure limestone. A northeast-trending normal fault through the middle of the area, downthrown on the southeast side, has displaced the generally flat lying strata as much as 300 feet (91 m). Most of the minable coal lies northwest of this fault.

INTRODUCTION

This report was prepared as a contribution to the study of the reclamation potential of an area in southeast Montana in the northern part of the Powder River Basin, that has potential for surface mining of a thick coal bed. 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 Hanging Woman Creek study area is an area of 26.2 square miles (67.9 sq km) in the drainage basin of East Trail Creek, a tributary of Hanging Woman Creek. This area was mapped geologically in 1976 by W. C. Culbertson and M. C. Klett as part of their geologic investigation of the Forks Ranch and Quietus 7 1/2 minute topographic quadrangles (unpub. mapping). Five holes were cored in and near the study area by the Montana Bureau of Mines and Geology. J. R. Hatch sampled the coal beds from these cores and submitted them for analysis; the results of these analyses were statistically analyzed by J. R. Hatch and R. H. Affolter.

GEOLOGIC SETTING

The coal-bearing rocks underlying the Hanging Woman Creek study area comprise the Tongue River Member of the Fort Union Formation of Paleocene age, and the lower part of the overlying Wasatch Formation of Eocene age (pl. 1). The contact between the two formations is placed at the top of the Roland coal bed of Baker (1929). The stream bottoms of Trail Creek and East Trail Creek are underlain by alluvium that is comprised of sand, silt, clay, and some gravel.

The coal-bearing rocks are as much as 2,300 feet (700 m) thick and contain about 20 beds of coal, of which five are 10 or more feet (3 m) in thickness. The rocks between the coal beds consist of sandstone, siltstone, shale, and carbonaceous shale. The beds of sandstones and siltstones are generally poorly cemented, but locally some are well cemented or grade into limestones that form resistant ledges or benches. At the western end of the study area, the Anderson coal has burned back from the outcrop, and the resulting heat has baked and fused the overlying rocks. The baked rock, called clinker, is a brittle, resistant, reddish rock that is as much as 100 feet (30 m) thick along Hanging Woman Creek to the west.

The target coal bed for this investigation was the Anderson coal bed, which is 26-33 feet (7.9-10.1 m) thick in this area (pls. 2 and 4). In addition the Dietz coal bed, which is 9-12 feet (2.7-3.7 m) thick, may be recoverable because it is 50-100 feet (15-30 m) below the Anderson bed (pls. 3 and 4). Several drill holes in and near this area show that the Canyon coal bed is 15-21 feet (4.6-6.4 m) thick and is 180-250 feet (55-75 m) below the Anderson bed. Because it is considered to be too deep for surface mining, it was not investigated further. The coal beds above the Anderson coal bed (pls. 1 and 4) are generally thin, of poor quality, or of limited extent, so they are not considered to be of economic interest at present.

The coal-bearing strata are nearly flat lying except in the vicinity of the three northeast-trending normal faults. The largest fault, which trends through the middle of the mapped area, has displaced the rocks on the south side downward as much as 300 feet (91 m). As a result, the Anderson coal bed southeast of the fault is so deep that only a narrow strip adjacent to the creek bottom is under less than 200 feet (61 m) of overburden (pl. 2).

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 the kinds of plant materials (type), in degree of metamorphism (rank), and range of impurity (grade), are characteristics of the varieties of coal" (Schopf, 1956). Inherent in the definition is the specification that coal originated as a mixture of 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 the peat changed to coal, and the coal assumed the characteristics by which members of the series are differentiated 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 deposits.
2) The age of the deposits and their geographical distribution.
3) The structure of the coal-forming plant, 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 discussions 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 type 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 frequently used when utilization of the coal is being considered.

Rank of coal

The designation 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 coal is largely derived from plant material, it 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 major coal constituents: the higher rank coals have more carbon and less hydrogen and oxygen than the lower ranks.

Two standardized forms of coal analyses, the proximate analysis and the ultimate analysis, are generally made, though sometimes only the less complicated and less expensive proximate analysis is made. The analyses are described as follows (U.S. Bureau of 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 cakelike 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 materials 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: 1 Btu is the amount of heat required to raise the temperature of 1 pound of water 1°F (1 Btu equals 0.252 kilocalories). Additional tests are sometimes made, particularly to determine caking, coking, and other properties, such as tar yield, that affect classification or utilization.

Figure 1, compares in histogram form, the heating value, and the moisture, volatile matter, and fixed carbon contents of coals of different ranks.

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

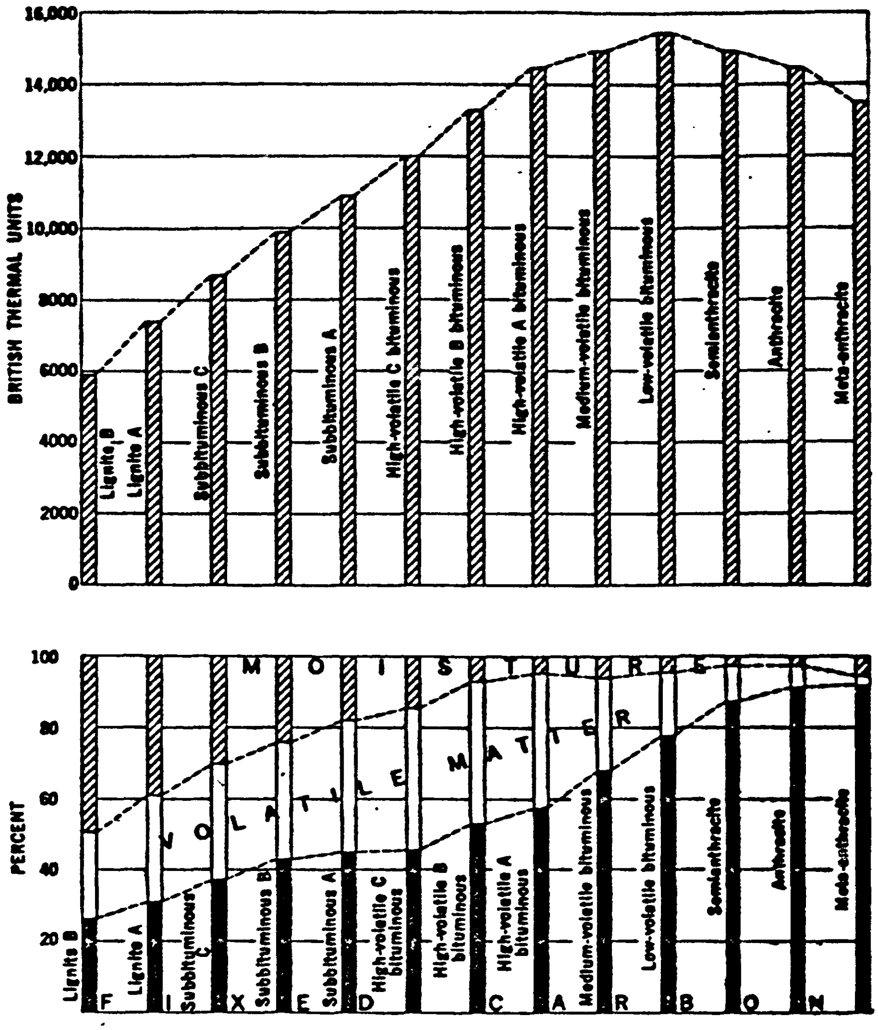

Figure 1.--Comparison on moist, mineral-matter-free basis of heat values; and proximate analyses of coal of different ranks.

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

[American Society for Testing and Materials Standard D388-66 (Reapproved 1972); 1 Btu equals 0.252 kilogram-calories]

Class	Group	Fixed Carbon Limits, percent (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, percent (Dry, Mineral Matter-Free Basis)		Calorific Value Limits, Btu per pound (Moist,[2] Mineral-Matter-Free Basis)		Agglomerating Character
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	
I. Anthracite	1. Meta-anthracite	98	---	---	2	---	---	nonagglomerating
	2. Anthracite	92	98	2	8	---	---	nonagglomerating
	3. Semianthracite[3]	86	92	8	14	---	---	nonagglomerating
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	---	---	commonly agglomerating[5]
	2. Medium volatile bituminous coal	69	78	22	31	---	---	commonly agglomerating[5]
	3. High volatile A bituminous coal	---	69	31	---	14 000[4]	---	commonly agglomerating[5]
	4. High volatile B bituminous coal	---	---	---	---	13 000[4]	14 000	commonly agglomerating[5]
	5. High volatile C bituminous coal	---	---	---	---	11 500	13 000	commonly agglomerating[5]
						10 500	11 500	agglomerating
III. Subbituminous	1. Subbituminous A coal	---	---	---	---	10 500	11 500	nonagglomerating
	2. Subbituminous B coal	---	---	---	---	9 500	10 500	nonagglomerating
	3. Subbituminous C coal	---	---	---	---	8 300	9 500	nonagglomerating
IV. Lignitic	1. Lignite A	---	---	---	---	6 300	8 300	nonagglomerating
	2. Lignite B					---	6 300	nonagglomerating

[1]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which 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 shall be 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 there are notable exceptions in high volatile C bituminous group.

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. "Coals which in the volatile matter determination produce either an agglomerate button that will support a 500-g weight without pulverizing, or a button showing swelling or cell structure, shall be considered agglomerating from the standpoint of classification" (ASTM, 1977, p. 216).

As pointed out by the ASTM (1977, p. 216), 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".

The apparent rank of the coals at the Hanging Woman Creek study area is subbituminous C.

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 used by Tomkeieff (1954, table II and p. 9), who divided the coals into three series; humic coals, humic-sapropelic coals, and sapropelic coals, based upon the nature of the original plant materials. The humic coals are largely composed of the remains of the woody parts of plants, and the sapropelic coals are largely composed of the more resistant waxy, fatty and resinous parts of plants, such as cell walls, spore-coatings, pollen, and resin particles, and coals composed mainly of algal material. Most coals fall into the humic series, with some coals being mixtures 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 coals of the United States, the Hanging Woman Creek coals fall largely in the humic series.

Grade of coal

Classification of coal by grade is based largely on the content of ash, sulfur, and other constituents that adversely affect utilization. Most detailed coal resource evaluations of the past did 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).

The range and average of the ash and sulfur contents of 642 coal samples from all parts of the United States were determined by Fieldner, Rice, and Moran (1942). Ash and sulfur contents of these U.S. coals as received were as follows:

Number of samples	Ash, percent		Sulfur, percent	
	Range	Average	Range	Average
642	2.5 - 32.6	8.9	0.2 - 7.7	1.9

The Anderson and Dietz coal beds in the Hanging Woman Creek study area are well below the national average in ash and sulfur content.

Chemical analyses of coal in the Hanging Woman Creek study area

Thirteen coal samples from five coal beds were collected by the U.S. Geological Survey from the five core holes in the Hanging Woman Creek study area. These samples are briefly described in table 2. Nine of the samples are from the Anderson bed (the principal coal bed of interest in this area), one from the Dietz coal bed 50-100 feet (15-30 m) below the Anderson bed, and one each from three thin coal beds 130-210 feet (40-64 m) above the Anderson bed (see pl. 4). Two samples were collected from the Anderson bed in each core hole, except in hole HWC-23 (locality H) where part of the core was lost. In hole HWC-20 (locality K, pl. 4), where the Anderson bed contains a shale parting near the base, one sample (D186445) was collected from the main bed above the parting; a second sample (D186446) represents the coal below the parting. In the other three holes, the topmost 2.4-2.6 feet (0.73-0.79 m) was sampled separately from the main bed.

Proximate and ultimate analysis, heat content, air-dried loss, forms-of-sulfur, and ash-fusion temperature determinations on these samples (table 3) were provided by chemists of the Coal Analysis Section, (Forrest W. Walker, Chemist-in-Charge) U.S. Bureau of Mines, Pittsburgh, PA., whose contribution is gratefully acknowledged. The analyses listed and summarized in this report were funded under USGS-ERDA Interagency Agreement No. E(49-18)-2005. Analyses for 33 major and minor oxides and trace elements in the laboratory ash (table 4) and analyses of nine trace elements in whole coal (table 5) were provided by the staff of chemical laboratory personnel in the U.S. Geological Survey, Denver, Colorado, under the direction of Claude Huffman, Jr.: James W. Baker, Ardith J. Bartel, Leon A. Bradley, Celeste M. Ellis, Patricia G. Guest, Raymond G. Havens, Roy J. Knight, Robert E. McGregor, Violet M. Merritt, Hugh T. Millard, Jr., Harriet G. Neiman, Charles A. Nelms, Charles A. Ramsey, Caryl L. Shields, Gaylord D. Shipley, James S. Wahlberg, and William J. Walz. Analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976). Table 6 contains data listed in table 4 converted to a whole-coal basis and the whole-coal analyses listed in table 5. Twenty-three additional elements were looked for but not found in amounts greater than their lower limits of detection (table 7). Unweighted statistical summaries of the analytical data in tables 3, 4, and 6 are listed in tables 8, 9, and 10, respectively. Data summaries for other Powder River region coal samples are listed for comparison.

Table 2.--USGS sample number, hole number, locality number, depth interval, and bed name for 13 coal samples from cores of drill holes in the Hanging Woman Creek study area, Big Horn County, Montana

[All samples are from the Fort Union Formation of Paleocene age. See plate 4 for locations and data on drill holes]

USGS sample number	Hole number	Map Locality symbol	Depth interval feet and (meters)	Coal Bed Name
D186451	HWC-27	C	23.0-27.2 (7.0-8.3)	Waddle
D186452	HWC-27	C	69.0-70.6 (21.0-21.5)	Unnamed
D186453	HWC-27	C	101.5-105.0 (30.9-32.0)	Smith
D186454	HWC-27	C	230.5-233.0 (70.2-71.0)	Anderson
D186455	HWC-27	C	233.0-259.2 (71.0-79.0)	Anderson
D186456	HWC-23	H	138.0-166.7 (42.1-50.8)	Anderson
D186443	HWC-21	A	114.0-116.5 (34.8-35.5)	Anderson
D186444	HWC-21	A	116.5-141.0 (35.5-43.0)	Anderson
D186445	HWC-20	K	93.4-119.5 (28.5-36.4)	Anderson
D186446	HWC-20	K	120.5-122.0 (36.7-37.2)	Anderson
D186448	HWC-25	L	73.0-75.5 (22.3-23.0)	Anderson
D186449	HWC-25	L	75.5-106.0 (23.0-32.3)	Anderson
D186450	HWC-25	L	165.5-176.6 (50.4-53.8)	Dietz

Table 3.--Proximate and ultimate analyses, heat content, forms-of-sulfur, free-swelling-index and ash fusio temperature determinations for 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montan

[All analyses except heat content, 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. Leaders (---) indicate no data. All samples are from the Fort Union Formation of Paleocene age. See plate 4 for locations and data on drill holes]

Sample number	Proximate Analysis				Ultimate Analysis					Heat Content	
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb.
D186451	27.7	30.9	34.2	7.2	6.5	47.9	1.1	35.6	1.7	4,650	8,370
	---	42.7	47.3	10.0	4.7	66.3	1.5	15.2	2.4	6,430	11,570
	---	47.5	52.5	---	5.3	73.6	1.7	16.9	2.6	7,140	12,860
D186452	29.5	29.3	34.8	6.4	6.4	47.4	1.2	38.0	.6	4,570	8,230
	---	41.6	49.4	9.1	4.4	67.2	1.7	16.7	.9	6,490	11,680
	---	45.7	54.3	---	4.9	73.9	1.9	18.4	.9	7,130	12,840
D186453	27.0	28.1	36.3	8.6	6.2	47.5	1.2	35.6	.9	4,560	8,210
	---	38.5	49.7	11.8	4.4	65.1	1.6	15.9	1.2	6,250	11,250
	---	43.6	56.4	---	5.0	73.8	1.9	18.0	1.4	7,090	12,750
D186454	27.9	27.6	40.5	4.0	6.4	50.9	1.0	37.5	.3	4,820	8,670
	---	38.3	56.2	5.5	4.6	70.6	1.4	17.6	.4	6,680	12,030
	---	40.5	59.5	---	4.8	74.7	1.5	18.6	.4	7,070	12,730
D186455	28.8	28.7	38.8	3.7	6.6	50.2	1.1	38.2	.2	4,810	8,660
	---	40.3	54.5	5.2	4.8	70.5	1.5	17.7	.3	6,760	12,170
	---	42.5	57.5	---	5.0	74.4	1.6	18.7	.3	7,130	12,840
D186456	27.4	29.8	37.3	5.5	6.4	49.8	1.0	36.6	.5	4,790	8,620
	---	41.0	51.4	7.6	4.6	68.6	1.4	16.9	.7	6,600	11,870
	---	44.4	55.6	---	5.0	74.2	1.5	18.2	.7	7,140	12,850
D186443	26.7	28.4	38.8	6.1	6.3	50.5	1.1	35.7	.3	4,780	8,610
	---	38.7	52.9	8.3	4.5	68.9	1.5	16.3	.4	6,530	11,740
	---	42.3	57.7	---	5.0	75.1	1.6	17.8	.4	7,120	12,810
D186444	27.9	28.6	38.2	5.3	6.3	50.0	1.0	36.9	.4	4,740	8,540
	---	39.7	53.0	7.4	4.4	69.3	1.4	16.8	.6	6,580	11,840
	---	42.8	57.2	---	4.8	74.9	1.5	18.1	.6	7,100	12,790
D186445	27.5	29.7	38.3	4.5	6.5	50.8	1.0	36.9	.3	4,840	8,720
	---	41.0	52.8	6.2	4.8	70.1	1.4	17.2	.4	6,680	12,040
	---	43.7	56.3	---	5.1	74.7	1.5	18.3	.4	7,120	12,820
D186446	23.3	26.9	26.3	23.5	5.5	36.3	.7	29.4	4.5	3,600	6,480
	---	35.1	34.3	30.6	3.8	47.3	.9	11.3	5.9	4,690	8,440
	---	50.6	49.4	---	5.5	68.2	1.3	16.3	8.5	6,760	12,160
D186448	29.8	28.0	37.0	5.2	6.4	48.8	.9	38.5	.3	4,600	8,290
	---	39.9	52.7	7.4	4.4	69.5	1.3	17.1	.4	6,560	11,810
	---	43.1	56.9	---	4.8	75.1	1.4	18.5	.5	7,080	12,750
D186449	29.9	29.3	35.7	5.1	6.7	48.3	1.0	38.3	.7	4,650	8,370
	---	41.8	50.9	7.3	4.8	68.9	1.4	16.7	1.0	6,630	11,940
	---	45.1	54.9	---	5.2	74.3	1.5	18.0	1.1	7,150	12,880
D186450	28.6	29.0	35.5	6.9	6.4	48.2	1.0	36.9	.6	4,610	8,300
	---	40.6	49.7	9.7	4.5	67.5	1.4	16.1	.8	6,460	11,620
	---	45.0	55.0	---	5.0	74.7	1.6	17.8	.9	7,150	12,870

Table 3.--Proximate and ultimate analyses, heat content, forms-of-sulfur, free-swelling-index and ash temperature determinations for 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.--Continued

		Forms of sulfur				Ash fusion temperature C°		
Sample number	Air-dried loss	Sulfate	Pyritic	Organic	Free swelling	Initial deform.	soften.	fluid
D186451	19.8	0.01	0.55	1.19	0.0	1,100	1,150	1,215
	---	.01	.76	1.65				
	---	.02	.84	1.83				
D186452	20.9	.01	.18	.44	.0	1,125	1,175	1,225
	---	.01	.26	.62				
	---	.02	.28	.69				
D186453	19.2	.02	.28	.59	.0	1,125	1,180	1,240
	---	.03	.38	.81				
	---	.03	.43	.92				
D186454	20.0	.01	.14	.13	.0	1,115	1,170	1,215
	---	.01	.19	.18				
	---	.01	.21	.19				
D186455	21.9	.01	.08	.13	.0	1,100	1,155	1,210
	---	.01	.11	.18				
	---	.01	.12	.19				
D186456	18.6	.01	.22	.28	.0	1,100	1,155	1,205
	---	.01	.30	.39				
	---	.01	.33	.42				
D186443	18.7	.01	.20	.07	.0	1,125	1,175	1,235
	---	.01	.27	.10				
	---	.01	.30	.10				
D186444	18.4	.02	.20	.19	.0	1,085	1,145	1,195
	---	.03	.28	.26				
	---	.03	.30	.28				
D186445	19.0	.01	.13	.20	.0	1,125	1,175	1,230
	---	.01	.18	.28				
	---	.01	.19	.29				
D186446	17.3	.02	3.12	1.40	.0	1,070	1,125	1,180
	---	.03	4.07	1.83				
	---	.04	5.86	2.63				
D186448	20.9	.01	.14	.12	.0	1,150	1,205	1,270
	---	.01	.20	.17				
	---	.02	.22	.18				
D186449	21.3	.01	.25	.44	.0	1,170	1,225	1,290
	---	.01	.36	.63				
	---	.02	.38	.68				
D186450	20.6	.01	.20	.37	.0	1,100	1,155	1,205
	---	.01	.28	.52				
	---	.02	.31	.57				

Table 4.--Major and minor oxide and trace element composition of the laboratory ash of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana

[Values in percent or parts per million. Coal ashed at 525°C. L means less than the value shown; N, not detected; B, not determined; S after element title indicates determinations by semiquantative emissionspectrography; to be identified with geometric brackets whose boundaries are part of the ascending series 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, 1.2, etc., but reported as mid-points of the 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. All samples are from the Fort Union Formation of Paleocene age. See plate 4 for locations and data on drill holes]

Sample number	Ash (percent)	SiO2 (percent)	Al2O3 (percent)	CaO (percent)	MgO (percent)	Na2O (percent)	K2O (percent)	Fe2O3 (percent)	TiO2 (percent)	P2O5 (percent)	Sample number
D186451	9.2	21	11	13	5.60	0.73	0.57	21	0.74	1.0L	D186451
D186452	7.7	31	13	18	4.10	5.38	.82	6.8	.89	1.0L	D186452
D186453	9.5	31	9.1	14	4.28	4.40	1.5	14	.60	1.0L	D186453
D186454	5.6	29	12	23	4.75	6.58	.44	4.7	1.3	2.8	D186454
D186455	4.5	27	12	23	4.93	7.50	.32	7.1	2.0	1.0L	D186455
D186456	6.2	24	15	21	4.18	6.33	.37	7.7	1.4	1.0L	D186456
D186443	6.7	39	9.2	19	3.83	6.18	.24	5.9	1.5	1.0L	D186443
D186444	6.3	27	13	18	3.80	6.80	.57	7.2	1.1	1.0L	D186444
D186445	5.2	22	11	26	5.25	7.25	.22	6.3	1.6	1.0L	D186445
D186446	25.1	37	14	5.0	1.68	1.83	1.6	27	.70	1.0L	D186446
D186448	6.2	35	8.3	23	7.60	2.85	.20	3.4	1.5	1.3	D186448
D186449	5.8	17	10	24	7.58	3.00	.25	11	1.1	1.0L	D186449
D186450	7.2	33	11	18	3.93	5.38	.50	6.8	1.3	1.0L	D186450

Sample number	SO3 (percent)	Ag-S (ppm)	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Cu (ppm)	Ga-S (ppm)	Ge-S (ppm)	Sample number
D186451	25	N	500	3,000	7	1.5	500L	145	20	N	D186451
D186452	20	N	700	1,500	15	1.0	500L	174	70	70	D186452
D186453	22	N	700	2,000	7	1.0L	N	99	30	30	D186453
D186454	13	N	700	10,000	7	1.0L	500L	89	20	N	D186454
D186455	11	N	700	10,000	3L	1.0L	N	191	15	N	D186455
D186456	20	N	500	7,000	3	2.0	N	227	20	N	D186456
D186443	15	N	700	7,000	3	1.5	N	181	15	N	D186443
D186444	21	N	700	5,000	N	1.0	N	201	20	N	D186444
D186445	16	N	700	7,000	3L	1.0	N	170	15	N	D186445
D186446	8.9	N	150	700	7	1.0	N	168	30	N	D186446
D186448	12	N	700	5,000	N	1.0L	N	109	15	N	D186448
D186449	24	N	700	3,000	3L	1.0	N	178	20	N	D186449
D186450	19	2	700	7,000	7	1.0L	N	125	30	N	D186450

Table 4.--Major and minor oxide and trace element composition of the laboratory ash of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana.--Continued

Sample number	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	Pb (ppm)	Sc-S (ppm)	Sr-S (ppm)	V-S (ppm)	Sample number
D186451	100L	28	124	15	20	70	35	20	2,000	300	D186451
D186452	N	28	154	15	30	150	75	30	2 000	300	D186452
D186453	N	22	466	20	30	70	30	30	1,500	200	D186453
D186454	100L	19	160	10	20	30	25L	20	7,000	100	D186454
D186455	N	28	290	7	20L	30	45	20	5 000	150	D186455
D186456	100L	58	150	15	20L	30	45	20	3,000	200	D186456
D186443	100L	36	158	7	30	20	80	20	3,000	100	D186443
D186444	100L	40	196	15	20L	30	80	15	3,000	150	D186444
D186445	100L	25	224	15	20	20	50	20	5.000	150	D186445
D186446	N	46	132	15	20L	70	25	30	500	150	D186446
D186448	N	15	230	7	20L	15	25	10	3,000	70	D186448
D186449	100L	34	212	10	20L	30	40	15	2,000	150	D186449
D186450	N	32	188	10	30	30	30	15	2,000	150	D186450

Sample number	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)
D186451	100	10	163	100
D186452	70	7	140	300
D186453	70	7	231	200
D186454	70	7	168	150
D186455	50	7	59	150
D186456	70	7	131	150
D186443	70	7	70	200
D186444	30	3	101	150
D186445	50	5	79	150
D186446	30	B	137	150
D186448	50	3	118	150
D186449	50	5	90	100
D186450	70	7	79	150

Table 5.--Content of nine trace elements in 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana

[Analyses on air-dried (32°C) coal. Values in parts per million (ppm). L, less than the value shown, B, not determined. All samples are from the Fort Union Formation of Paleocene age. See plate 4 for locations and data on drill holes]

Sample number	As (ppm)	Co (ppm)	Cr (ppm)	F (ppm)	Hg (ppm)	Sb (ppm)	Se (ppm)	Th (ppm)	U (ppm)	Sample number
D186451	16	B	5.6	65	0.12	0.3	0.1L	2.2	2.7	D186451
D186452	2.4	2.4	5.1	45	.03	.7	.5	1.0	.6	D186452
D186453	15	5.1	6.7	50	.07	3.1	.9	.8	1.5	D186453
D186454	.6	.8	2.5	35	.01	.2	.3	.7	.2L	D186454
D186455	.5	.9	2.4	30	.02	.1	.2	.6	.2L	D186455
D186456	1.1	1.1	3.2	40	.06	.2	.8	.9	.8	D186456
D186443	1.1	.5	2.5	30	.05	.1	.7	.6	.6	D186443
D186444	.8	1.1	3.2	40	.04	.1	.5	.9	.5	D186444
D186445	.8	.8	1.9	30	.03	.1	.6	.8	.6	D186445
D186446	39	5.2	27	115	.18	.8	.1L	3.3	4.6	D186446
D186448	.4	.5	2.3	35	.05	.1	.3	1.0	.5	D186448
D186449	2.5	1.5	2.6	40	.08	.1	.7	.7	.7	D186449
D186450	2.7	2.0	3.7	50	.07	.4	.7	1.0	.7	D186450

Table 6.--Major, minor, and trace element composition of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana

[Values in percent or parts per million. As, F, Hg, Sb, Se, Th, U, values are from direct determinations on air dried (32°C) coal; all ot values calculated from analyses of ash. S means analysis by emissionspectrography; L, less than the value shown; N, not detected; B, nc determined. All samples are from the Fort Union Formation of Paleocene age. See plate 4 for locations and data on drill holes]

Sample number	Si (percent)	Al (percent)	Ca (percent)	Mg (percent)	Na (percent)	K (percent)	Fe (percent)	Ti (percent)	Ag-S (ppm)	As (ppm)	Sampl numbe
D186451	0.90	0.54	0.85	0.31	0.050	0.044	1.4	0.041	N	16	D1864
D186452	1.1	.53	.99	.19	.31	.053	.37	.041	N	2.4	D1864
D186453	1.4	.46	.95	.24	.31	.12	.93	.034	N	15	D1864
D186454	.76	.36	.92	.16	.27	.021	.18	.044	N	.6	D1864
D186455	.57	.29	.74	.13	.25	.012	.22	.054	N	.5	D1864
D186456	.69	.49	.93	.16	.29	.019	.33	.052	N	1.1	D1864
D186443	1.2	.33	.91	.15	.31	.013	.28	.060	N	1.1	D1864
D186444	.79	.43	.81	.14	.32	.030	.32	.042	N	.8	D1864
D186445	.53	.30	.97	.16	.28	.010	.23	.050	N	.8	D1864
D186446	4.3	1.9	.90	.25	.34	.33	4.7	.11	N	39	D1864
D186448	1.0	.27	1.0	.28	.13	.010	.15	.056	N	.4	D18644
D186449	.46	.31	.99	.26	.13	.012	.45	.038	N	2.5	D18644
D186450	1.1	.42	.93	.17	.29	.030	.34	.056	.15	2.7	D18645

Sample number	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Sample number
D186451	50	300	0.7	0.14	50L	B	5.6	13	65	2	D18645
D186452	50	100	1	.08	50L	2.4	5.1	13	45	5	D18645
D186453	70	200	.7	.09L	N	5.1	6.7	9.4	50	3	D18645
D186454	50	500	.5	.06L	30L	.8	2.5	5.0	35	1	D18645
D186455	30	500	.15L	.04L	N	.9	2.4	8.6	30	.7	D18645
D186456	30	500	.2	.12	N	1.1	3.2	14	40	1.5	D18645
D186443	50	500	.2	.10	N	.5	2.5	12	30	1	D18644
D186444	50	300	N	.06	N	1.1	3.2	13	40	1.5	D18644
D186445	30	300	.15L	.05	N	.8	1.9	8.8	30	.7	D18644
D186446	30	150	1.5	.25	N	5.2	27	42	115	7	D18644
D186448	50	300	N	.06L	N	.5	2.3	6.8	35	1	D18644
D186449	50	150	.15L	.06	N	1.5	2.6	10	40	1	D18644
D186450	50	500	.5	.07L	N	2.0	3.7	9.0	50	2	D18645

Table 6.--Major, minor, and trace element composition of 13 coal samples from Hanging Woman Creek study area, Big Horn County, Montana
--Continued

Sample number	Ge-S (ppm)	Hg (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	P (ppm)	Pb (ppm)	Sampl numbe
D186451	N	0.12	10L	2.6	11	1.5	2	7	400L	3.2	D1864
D186452	5	.03	N	2.2	12	1	2	10	340L	5.8	D1864
D186453	3	.07	N	2.1	44	2	3	7	420L	2.8	D1864
D186454	N	.01	5L	1.1	9.0	.5	1	1.5	690	1.4L	D1864
D186455	N	.02	N	1.3	13	.3	1L	1.5	200L	2.0	D1864
D186456	N	.06	7L	3.6	9.3	1	1.5L	2	270L	2.8	D1864
D186443	N	.05	7L	2.4	11	.5	2	1.5	290L	5.4	D1864
D186444	N	.04	7L	2.5	12	1	1.5L	2	280L	5.0	D1864
D186445	N	.03	5L	1.3	12	.7	1	1	230L	2.6	D1864
D186446	N	.18	N	12	33	3	5L	15	1,100L	6.3	D1864
D186448	N	.05	N	.9	14	.5	1.5L	1	350	1.5	D1864
D186449	N	.08	7L	2.0	12	.7	1L	1.5	250L	2.3	D1864
D186450	N	.07	N	2.3	14	.7	2	2	310L	2.2	D1864

Sample number	Sb (ppm)	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)
D186451	0.3	2	0.1L	200	2.2	2.7	30	10	1	15	10
D186452	.7	2	.5	150	1.0	.6	20	5	.5	11	20
D186453	3.1	3	.9	150	.8	1.5	20	7	.7	22	20
D186454	.2	1	.3	500	.7	.2L	5	5	.5	9.4	10
D186455	.1	1	.2	200	.6	.2L	7	2	.3	2.7	7
D186456	.2	1.5	.8	200	.9	.8	15	5	.5	8.1	10
D186443	.1	1.5	.7	200	.6	.6	7	5	.5	4.7	15
D186444	.1	1	.5	200	.9	.5	10	2	.2	6.4	10
D186445	.1	1	.6	200	.8	.6	7	2	.2	4.1	7
D186446	.8	7	.1L	150	3.3	4.6	30	7	B	34	30
D186448	.1	.7	.3	200	1.0	.5	5	3	.2	7.3	10
D186449	.1	1	.7	100	.7	.7	10	3	.3	5.2	7
D186450	.4	1	.7	150	1.0	.7	10	5	.5	5.7	10

Table 7.--Elements looked for, but not detected in Hanging Woman Creek study area coal samples

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

Element	Lower limit of detection (ppm) in coal ash
Au	50
Bi	20
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
Tl	100
Tm	50
W	200

Table 8.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate and ultimate analyses, heat content, forms-of-sulfur and ash fusion temperatures for 13 coal samples from the Hanging Woman Creek study area, Big Horn County, Montana. For comparison, geometric means from 33 Powder River region, Wyoming coal samples (Swanson and others, 1976, Tables 31b and 32b) are included

[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. Leaders (---) indicate no data]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River Region, Wyo. geometric mean
		minumum	maximum			
Proximate and ultimate analyses						
Moisture	27.9	23.3	29.9	27.8	1.1	23.1
Volatile matter	28.8	26.9	30.9	28.8	1.0	32.0
Fixed carbon	36.3	26.3	40.5	36.1	1.1	36.0
Ash	6.9	3.7	23.5	6.2	1.6	7.5
Hydrogen	6.4	5.5	6.7	6.3	1.1	6.2
Carbon	48.2	36.3	50.9	48.0	1.1	50.3
Nitrogen	1.0	.7	1.2	1.0	1.2	.9
Oxygen	36.5	29.4	38.5	36.4	1.1	32.9
Sulfur	.8	.2	4.5	.6	2.3	.8
Heat content						
Kcal/kg	4,620	3,600	4,850	4,610	1.1	4,860
Btu/lb	8,310	6,480	8,720	8,290	---	8,7[illegible]0
Forms-of-sulfur						
Sulfate	0.01	0.01	0.02	0.01	1.4	0.02
Pyrite	.35	.08	3.1	.24	2.5	.29
Organic	.43	.07	1.4	.29	2.5	.31
Ash fusion temperature °C						
Initial deformation	1,114	1,068	1,168	1,114	1.0	----
Softening temperature	1,169	1,124	1,227	1,169	1.0	----
Fluid temperature	1,224	1,179	1,291	1,223	1.0	----

Table 9.--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 13 coal samples from the Hanging Woman Creek study area, Big Horn County, Montana. For comparison, geometric means for 410 Powder River region coal samples are listed (Hatch and Swanson, 1977, Table 6a)

[All samples were ashed at 525°C; all analyses are in percent]

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Powder River region geometric mean
		minimum	maximum			
(Ash)	7.9	4.5	25.1	7.2	1.5	9.0
SiO_2	29	17	39	28	1.3	28
Al_2O_3	11	8.3	15	11	1.2	14
CaO	19	5	26	18	1.5	15
MgO	4.8	1.7	7.6	4.4	1.5	3.6
Na_2O	5.3	.73	7.5	4.2	2.0	.93
K_2O	.58	.20	1.6	.46	2.0	.28
Fe_2O_3	9.9	3.4	27	8.3	1.8	5.8
TiO_2	1.2	.6	2.0	1.1	1.4	.61
SO_3	18	8.9	25	17	1.4	14

Table 10.--Arithmetic mean, observed range, geometric mean and geometric deviation of 28 elements in 13 coal samples from the Hanging Woman Creek study area, Big Horn County, Montana. For comparison, geometric means for 410 Powder River region coal samples are listed (Hatch and Swanson, 1977, Table 6b)

[All analyses are in parts per million and are reported on a whole-coal basis. As, Co, Cr, F, Hg, Sb, Se, Th and U values used to calculate the statistics were determined directly on whole coal. All other values used were calculated from determinations made on coal ash. L, less than the value shown]

Element	Arithmetic mean	Observed range minimum	Observed range maximum	Geometric mean	Geometric deviation	Powder River region geometric mean
As	5.6	0.4	39	2.1	4.3	2
B	50	30	70	50	1.3	50
Ba	300	100	500	300	1.7	300
Be	.7	.15L	1.5	.5	2.0	.5
Cd	.1	.04L	.25	.09	1.7	.04
Co	1.8	.5L	5.2	1.3	2.2	2
Cr	4.8	1.9	27	3.8	2.0	5
Cu	13	5.0	42	11	1.7	9.5
F	46	30	115	43	1.5	40
Ga	2	.7	7	1.5	2.1	2
Hg	.06	.01	.8	.05	2.1	.08
Li	2.6	1.1	12	2.2	1.9	3.9
Mn	16	9.0	44	14	1.6	34
Mo	1	.3	3	1	1.9	1.5
Nb	2	1L	3	1.5	1.5	1
Ni	5	1	15	3	2.5	3
Pb	3.5	1.4L	6.3	3.2	1.6	5.1
Sb	.4	.1	3.1	.2	3.0	.4
Sc	2	.7	7	1.5	1.9	1.5
Se	.6	.1L	.9	.5	1.6	.7
Sr	200	100	500	200	1.4	150
Th	1.1	.6	3.3	1.0	1.6	3.3
U	1.2	.2L	4.6	.9	2.1	.6
V	15	5	30	10	1.9	10
Y	5	2	10	5	1.7	3
Yb	.5	.2	1	.5	1.7	.3
Zn	10	2.7	34	8.1	2.0	13
Zr	15	7	30	10	1.6	15

Eight analyses (as received basis) of the Anderson coal (table 3), excluding the analysis of the coal below the parting in hole HWC-20 (D186446), show that its ash contents range from 3.7 to 6.1 percent, averaging 4.9 percent; its sulfur contents range from 0.2 to 0.7 percent, averaging 0.4 percent, and its heat content ranges from 8,290-8,720 Btu/lb (4,600-4,840 Kcal/kg) averaging 8,540 Btu/lb (4,750 Kcal/kg). The coal below the parting in HWC-20 (locality K) has a high ash and sulfur content (D186446), and presumably would not be mined with the coal above the parting. The one analysis of the Dietz bed (D186450) shows that its ash content is 6.4 percent, its sulfur content is 0.6 percent and its heating value is 8,300 Btu/lb (4,610 Kcal/kg).

Analyses of all 13 coal samples show an apparent rank of subbituminous C, as calculated according to ASTM designation D-388-77 (ASTM, 1977). In table 8, the geometric means of the proximate, ultimate, and forms-of-sulfur analyses 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). This comparison shows significant statistical differences (students' t test, 95 percent confidence level) only in the moisture and oxygen contents. Note that the unweighted arithmetic means can be misleading if analyses of thin beds with high ash and sulfur contents are averaged with thick beds with low ash and sulfur contents.

In table 9, the geometric means of the contents of nine major and minor oxides in the laboratory ash of 13 coal samples are compared with the geometric means of these oxides in 410 Powder River region samples. The values are similar (students' t test, 95 percent confidence level) except for the contents of Na_2O and TiO_2 which are significantly higher and Al_2O_3 which is significantly lower in the Hanging Woman Creek samples. At the 99 percent confidence level only Na_2O and TiO_2 contents are significantly different.

In table 10, the geometric means of the content of 28 elements in the 13 coal samples are compared with the geometric means of these elements in 410 Powder River basin samples. The contents for most elements are similar (student's _t_ test, 95 percent confidence level) except for the contents of Cd, Y, and Yb which are significantly higher and the contents of Co, Hg, Li, Mn, Pb, Th, and Zn which are significantly lower in the Hanging Woman Creek samples. At the 99 percent confidence level only Cd, Mn, Th, and Zn are significantly different.

As indicated by the statistics, coal from the Hanging Woman Creek study area is similar in chemical composition to other coals in the Powder River region. Coals of the Powder River region are characterized by low-ash, low-sulfur, relatively low heat and high-moisture contents. The contents of elements of environmental concern (As, Be, Cd, Hg, Mo, Sb, Se, and so forth) in these coals are generally low when compared to contents in Interior province coal (Hatch and Swanson, 1977). Coals of the Powder River region are or could be used in coal-fired power generating or coal gasification plants.

Explanation of 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 antilogarithms 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 of the common tendency for the amounts of trace elements in natural materials to exhibit positively skewed frequency distributions; these 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, neverthless, a biased estimate of the arithmetic mean. In the summary tables of data, 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 some of the data are censored.

ESTIMATION AND CLASSIFICATION OF COAL RESOURCES

In preparing the coal resource estimates for the Hanging Woman Creek study area, the procedures and definitions used are those of the Coal Resources Classification System of the U.S. Bureau of Mines and the U.S. Geological Survey (1976), which is published as U.S. Geological Survey Bulletin 1450-B. As used herein, the term "coal resources" designates the estimated quantity of coal in the ground in such form that economic extraction is currently or potentially feasible. Identified resources are specific bodies of coal whose location, rank, quality, and quantity are known from geologic evidence supported by engineering measurements.

Tabulation of coal resources

Table 11 summarizes that part of the identified coal resources in the site that have potential for recovery by surface mining methods, which in this area is assumed to be coal within 200 feet (60 m) of the surface. As such, these coal resources fall into a category called Reserve Base, which is defined as that part of identified coal resource from which reserves are calculated. Reserves are the actual amount of coal that can be economically recovered from this deposit at this time considering all legal, technological, and environmental restraints and are calculated by applying a percent recovery factor to reserve base. This recovery factor takes into account all coal remaining in the ground after mining is completed (considered to be "lost in mining") and includes all coal (1) left unmined beneath rivers, lakes, highways, and legal reservations, (2) left unmined adjacent to mine or property boundaries, or (3) left unmined because of environmental, quality, safety, hydrologic or legal restrictions. In the United States, the recovery factor for surface mining methods locally exceeds 90 percent. No recovery factor was applied to the reserve base coal in this area because of the many uncertainties about legal and other restrictions on surface mining.

Table 11.--Estimated resources of surface-minable coal in the Anderson and Dietz coal beds, Fort Union Formation, Hanging Woman Creek study area, Big Horn County, Montana

[In millions of short tons: 1 short ton = 0.907 metric tons. 1 foot = 0.305 m]

Overburden thickness (in feet)	Measured	Indicated	Inferred	Total
Anderson coal bed				
0-100	40.34	97.31	0.64	138.29
100-200	27.11	136.96	75.76	239.83
Total	67.45	234.27	76.40	378.12
Dietz coal bed				
0-200[1/]	10.56	37.04	7.75	55.35
Grand Total	78.0	271.31	84.15	433.47

[1/] Almost everywhere the overburden above the Dietz bed includes the Anderson coal bed, which is 50-100 feet above.

Characteristics used in resource evaluation

The characteristics used in evaluating resources can be divided into two main classes: (1) those that affect the economic feasibility of recovery and utilization of coal, and (2) those that characterize the coal resources according to the degree of geologic assurance that the coal resources exist in the amount stated. Characteristics affecting the economic feasibility of recovery and utilization of the coal include such factors as rank, grade, and density of the coal, and the depth and thickness of the bed. The rank and the grade of the coal in this area have been discussed previously.

Density

The density of the coal, or weight per unit volume, varies considerably with differences in rank and ash content. In areas such as the Hanging Woman Creek study area, where the density or specific gravity of the coals have not been determined, an average density or specific gravity based on determinations from other areas is used. For subbituminous coal the average density is taken as 1,770 short tons per acre-foot, and the average specific gravity is 1.30.

Thickness of coal beds

Because the thickness of coal beds is an important factor in determining the economic feasibility of recovery, most coal resource estimates prepared by the U.S. Geological Survey are tabulated according to three thickness categories. For subbituminous coal the categories are (1) thin, 2.5-5 feet (0.75-1.5 m), (2) intermediate, 5-10 feet (1.5-3 m), and (3) thick, more than 10 feet (3 m). In the study area, all of the resources tabulated in the Anderson coal bed are in the thick category, and the resources for the Dietz coal bed are both intermediate and thick (pl. 3).

The data on the thickness of the coal beds in the study area are from holes drilled by the Montana Bureau of Mines and Geology (see pl. 4), and from gamma ray logs of oil and gas test holes in and near the study area. The thicknesses of coal interpreted from these data are judged to be accurate within 1 foot (0.3 m).

Depth of coal bed

Coal resources are commonly divided into categories based on the depth of the coal bed, as follows: 0-1,000 feet (0-300 m), 1,000-2,000 feet (300-600 m), 2,000-3,000 feet (600-900 m) and 3,000-6,000 feet (900-1,800 m). Additional categories of depth for coal resources that can be recovered by surface mining methods are not standardized, because of the many factors that affect the amount of overburden that can be economically removed from a coal deposit. In this area it is assumed that coal beds to a depth of 200 feet (60 m) can be economically mined by surface-mining methods.

Resource categories according to degree of geologic assurance

The coal resources tabulated for the study area are all in the Identified category of geologic assurance, and are further subdivided into Measured, Indicated, and Inferred categories based on the nearness of the coal to a measurement of the coal bed, and on geologic evidence and projection.

Measured -- Coal for which estimates of the rank, quality, and quantity have been computed, within a margin of error of less than 20 percent, from sample analyses and measurements from closely spaced and geologically well known sample sites. In this area measured coal is within 1/4 mile (0.4 km) of a measurement in a drill hole.

Indicated -- Coal for which estimates of the rank, quality, and quantity have been computed partly from sample analyses and measurements and partly from reasonable geologic projections. In this area, indicated coal is the body of coal whose inner limit is 1/4 mile (0.4 km) from a measurement in a drill hole, and whose outer limit is 3/4 mile (1.2 km) from the measurement.

Inferred -- Coal in unexplored extensions of indicated resources for which estimates of the quality and size are based on geologic evidence and projection. In this area, inferred coal lies more than 3/4 miles (1.2 km) from a measurement in a drill hole, but not more than 3 miles (4.8 km).

Summary of coal resources

The Anderson coal bed contains estimated resources of 378 million short tons (343 million metric tons) of subbituminous C coal in an area of about 7200 acres (11.2 sq. miles or 29 sq. km), where the coal bed is at a depth of less than 200 feet (60 m), and is 26-33 feet (7.9-10.1 m) thick (table 11 and pl. 2. Of this amount 138 million tons (125 million metric tons) is at a depth of less than 100 feet (30 m). Most of these resources, 78 percent, are in the measured and indicated categories; the remainder is in the inferred. About 23 percent of the total resources lie southeast of the main fault where the coal is more than 100 feet (30 m) deep and therefore less favorable for economic recovery.

The Dietz coal bed contains estimated resources of 55 million short tons (50 million metric tons) of subbituminous C coal where it is less than 200 feet (60 m) deep (table 11 and pl. 3). Of this amount 86 percent is in the measured and indicated categories of resources. Because it is 50-100 feet (15-30 m) below the Anderson bed and is 9-12 feet (2.7-3.7 m) thick (pls. 3 and 4), it may be economically recoverable by surface-mining methods.

In addition to depth of the coal bed, another device that is used to evaluate a surface-minable deposit of coal is the stripping ratio, which is the ratio of the volume of overburden removed per unit weight of coal recovered, usually expressed as cubic yards of overburden per short ton of coal. In the study area the stripping ratio for coal in the Anderson bed at depths less than 100 feet (30 m) would be 2 or 2.5 to 1, depending on the recovery factor used; for Anderson coal at depths of 100-200 feet (30-60 m) it would be about 5 to 1. Inasmuch as the Dietz coal bed can not be surface mined without first mining the Anderson bed, no stripping ratio is calculated for the Dietz alone. In the area where both the Anderson and Dietz are less than 200 feet (60 m) deep the stripping ratio for the combined coal beds would be about 4 to 1.

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