Chemical analyses of lignite from the Sentinel Butte Member of the Paleocene Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

by

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INTRODUCTION

As part of a continuing program by the U.S. Geological Survey to collect and analyze representative samples of United States coals, 10 lignite samples were collected from three core holes in the Sentinel Butte Member of the Paleocene Fort Union Formation, Mercer County, North Dakota. These samples were provided by the Water and Power Resource Service who drilled holes during August of 1979 in connection with the U.S. Bureau of Land Management's North Beulah EMRIA (Energy Mineral Rehabilitation Inventory and Analyses) study. The North Beulah EMRIA study site is an area of approximately 1,120 acres of land underlain by Federally owned coal. The site is located approximately 1 mile (1.6 km) northwest of the town of Beulah, North Dakota within the Beulah 7 1/2 minute quadrangle (fig. 1).

In the study site the nonmarine Sentinel Butte Member consists of sandstone, sandy shale, and shale with several thin lenticular lignite beds and three thick continuous lignite beds; the Hazen bed, the Beulah-Zap bed and the Schoolhouse bed. The ten samples of lignite in this report are listed in table 1 and a generalized stratigraphic section is shown in figure 2. This report briefly summarizes the chemical data from these samples and statistically compares them with other samples of lignite of comparable age and rank.

EXPLANATION OF TABLES

Proximate and ultimate analyses, heat-of-combustion, air-dried-loss, forms-of-sulfur, and ash-fusion-temperature determinations on 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota, are listed in table 2. These analyses were provided by the U.S. Department of Energy, Pittsburgh, Pa. Analyses for ash content and 39 major and minor oxides and trace elements

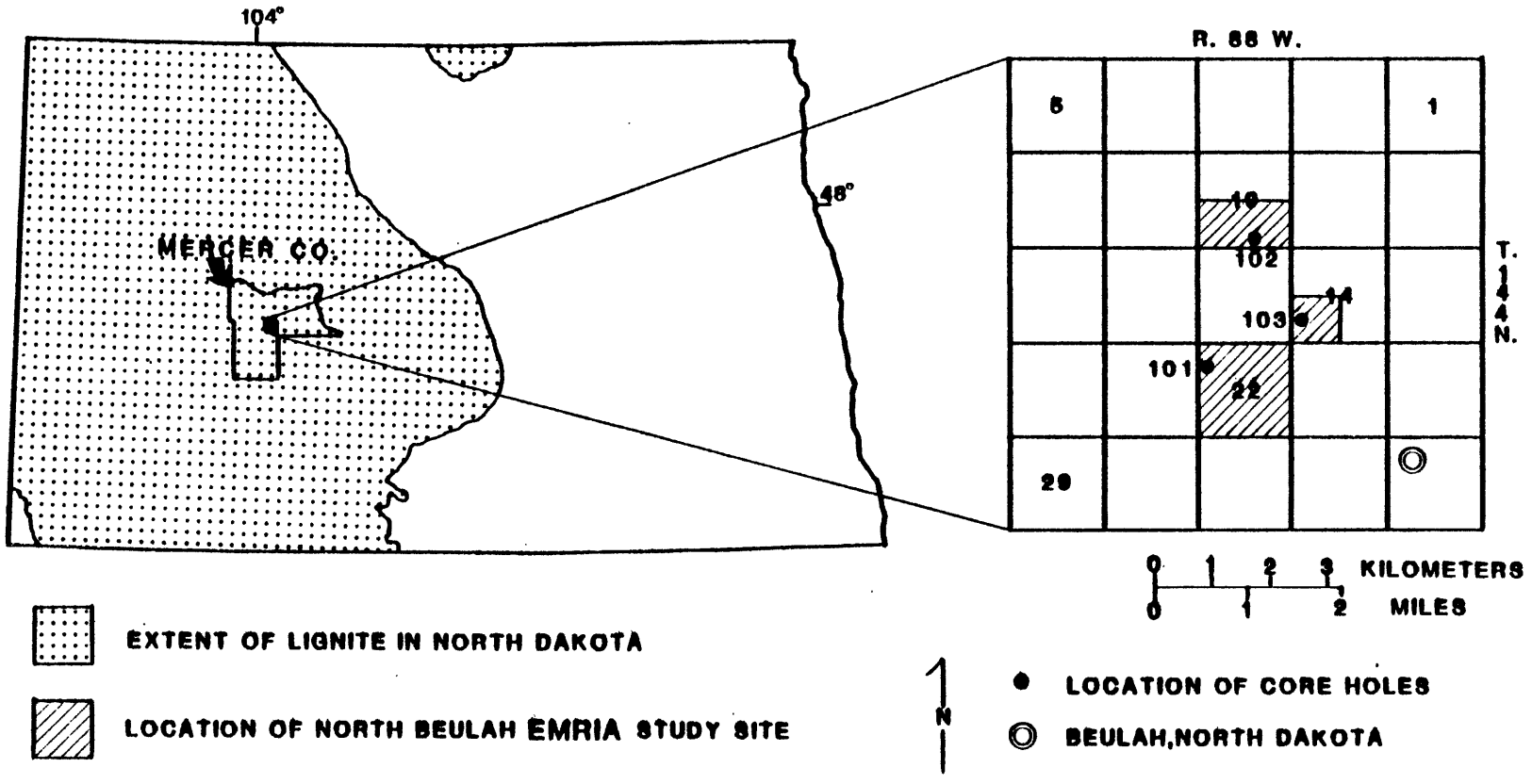

Figure 1.--Index map showing core hole locations in Mercer County, North Dakota, and location of North Beulah EMRIA study site

Table 1.--U.S. Geological Survey sample numbers, core-hole numbers, index map location, location, depth interval, and lignite bed name of 10 lignite samples from the North Beulah EMRIA study site, Mercer County, North Dakota

[All samples are from the Sentinel Butte Member of the Fort Union Formation of Paleocene age. One foot = 0.305 meters.]

USGS sample number	Index map location	Location	Depth interval in feet	lignite bed name
		Core-hole number 101		
D221097	101	775 fnl, 100 fwl, sec. 22, T. 144 N., R. 88 W.	127.8-131.0	Unnamed
D221098	-do-	----------do----------	241.1-246.6	Unnamed
D221099	-do-	----------do----------	257.6-260.5	Unnamed
D221100	-do-	----------do----------	272.6-284.7	Hazen
		Core-hole number 102		
D221101	102	2250 fel, 150 fsl, sec. 10, T. 144 N., R. 88 W.	48.4- 52.6	Schoolhouse
D221102	-do-	----------do----------	107.6-119.0	Beulah-Zap
D221103	-do-	----------do----------	121.6-126.5	Beulah-Zap Split
		Core-hole number 103		
D221104	103	1300 fsl, 30 fwl, sec. 14, T. 144 N., R. 88 W.	21.4- 26.5	Schoolhouse
D221105	-do-	----------do----------	71.7- 83.2	Beulah-Zap
D221106	-do-	----------do----------	85.1- 88.9	Beulah-Zap Split

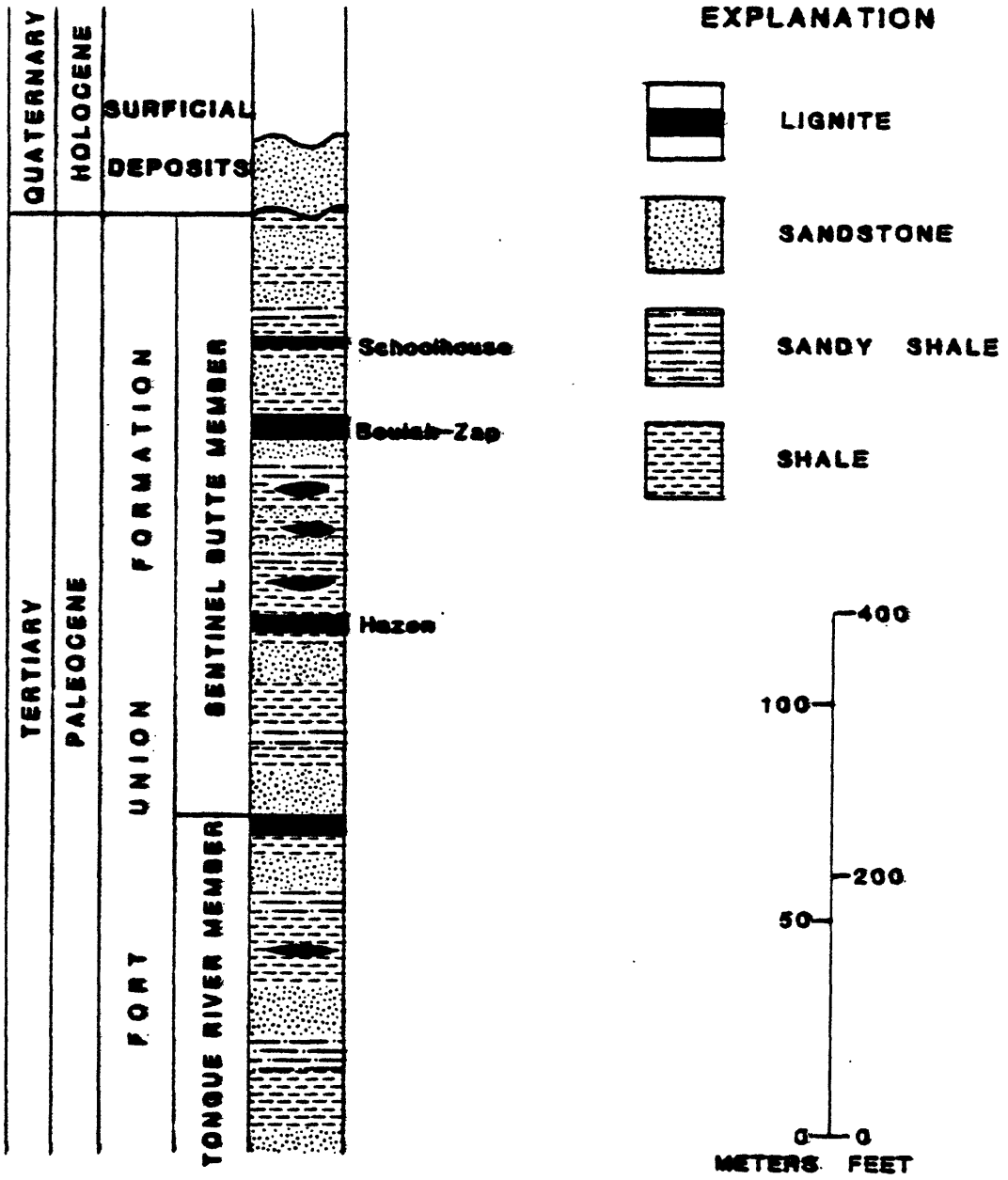

Figure 2.--Generalized stratigraphic section North Beulah EMRIA study site, Mercer County, North Dakota

in the laboratory ash (table 3) and analyses of nine trace elements in whole lignite (table 4) for all 10 samples 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 contains the data listed in table 3 converted to a whole-lignite basis plus, for completeness, the whole-lignite analyses listed in table 4. Twenty-two additional elements not listed in tables 3, 4, and 5 were looked for but not found in amounts greater than their lower limits of detection (table 6). Unweighted statistical summaries of analytical data in tables 2, 3, and 5 are listed in tables 7, 8, and 9. For comparison, data summaries for 32 other Fort Union region lignite samples (table 7) and 80 other Fort Union region lignite samples (tables 8 and 9) are included.

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 brackets (see headnote of table 3, or Swanson and Huffman, 1976, p. 6 for an explanation of six-step brackets.)

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 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. The estimates of the arithmetic means listed in the summary tables are Sichel's t statistic (Miesch, 1967).

A common problem in statistical summaries of trace-element data arises when the element content of 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 when the data are censored.

DISCUSSION

The apparent ranks of all 10 coal samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota, were calculated using the data in table 2 and the formulas in ASTM designation D-388-77 (American Society for Testing and Materials, 1978). The apparent ranks of these samples range from lignite B (one sample) to lignite A (three samples) to subbituminous C coal (six samples).

The subbituminous C coal samples (D221098, D221099, D221100, D221103, D221105, and D221106) have a lower moisture content than the other samples (28.7 percent vs an average of 32.8 percent for the other samples). This may

be due to drying of the samples because of incorrect storing procedures and would probably account for the relatively higher apparent rank.

A statistical comparison (student's t test, 95-percent confidence level) of the geometric mean contents of the U.S. Department of Energy data for 10 samples from the North Beulah EMRIA study site listed in this report with geometric means from 32 other Fort Union lignite samples shows that lignite from the North Beulah EMRIA study site has significantly higher contents of ash, nitrogen, total sulfur, and organic sulfur, and significantly lower contents of moisture, hydrogen, and oxygen. The heat of combustion and contents of volatile matter, fixed carbon, carbon, sulfate and pyritic sulfur are not significantly different. When compared at the 99-percent confidence level the contents of moisture, ash, and hydrogen are not significantly different.

A statistical comparison of the geometric mean contents of ash and contents of nine major and minor oxides in the ash for 10 samples from the North Beulah EMRIA study site with means for 80 Fort Union lignite samples shows that lignite from the North Beulah EMRIA study site has significantly higher contents of K_2O and significantly lower contents of CaO and MgO. The contents of ash, and SiO_2, Al_2O_3, Na_2O, Fe_2O_3 and TiO_2 content in the ash are not significantly different.

A statistical comparison of the geometric means of the contents of 35 elements in 10 lignite samples from the North Beulah EMRIA study site with 80 Fort Union region lignite samples shows that lignite from the North Beulah study site has significantly higher contents of Na, K, B, Be, Co, Cr, Mn, Nb, Ni, V, Y, Yb, Zn, and Zr and significantly lower contents of Ca, Sr, and Th. The contents of Si, Al, Mg, Fe, Ti, As, Ba, Cu, F, Ga, Hg, Li, Mo, Pb, Sb, Sc, Se, and U are not significantly different. When compared at the 99-percent

confidence level the contents of Na, B, Mn, and Nb are not significantly different.

Differences in the oxide composition of lignite ashes and the elemental contents of lignite 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 are dependent on the geologic history of the lignite bed. A partial listing of the 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 during burial; and extent of weathering. No evaluation of these factors has been made for any of the Fort Union Formation lignite samples listed in this report.

Compared to other United States coals (Swanson and others, 1976; Hatch and Swanson, 1977), lignite from the North Beulah EMRIA study site are characterized by relatively low ash, low sulfur, low heat of combustion, and a high moisture content. The contents of elements of environmental concern such as As, Be, Hg, Mo, Sb, and Se are low in Fort Union Formation lignites when compared to most other United States coals.

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Table 2.--Proximate and ultimate analyses, and heat-of-combustion, forms-of-sulfur, free-swelling-index and ash-fusion-determinations for 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

[All analyses except heat of combustion, 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 ssh free. All analyses by Coal Analysis Section, U.S. Department of Energy, Pittsburgh, Pa. Kcal/kg = 0.556 (Btu/lb); °F = (°C x 1.8) + 32; L, less than the value shown, B, not determined]

Sample number	Proximate Analysis				Ultimate Analysis					Heat of Combustion	
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
D221097	33.6	28.3	31.7	6.4	6.8	43.3	0.8	42.2	0.6	4,120	7,410
	---	42.6	47.7	9.6	4.6	65.2	1.2	18.6	.9	6,200	11,160
	---	47.2	52.8	---	5.1	72.2	1.3	20.6	1.0	6,860	12,350
D221098	28.6	27.9	33.4	10.1	6.2	44.1	.9	37.5	1.1	4,230	7,610
	---	39.1	46.8	14.1	4.2	61.8	1.3	16.9	1.5	5,920	10,650
	---	45.5	54.5	---	4.9	71.9	1.5	19.7	1.8	6,890	12,410
D221099	31.9	28.1	32.4	7.6	6.6	44.0	1.0	39.9	1.0	4,220	7,600
	---	41.3	47.6	11.2	4.5	64.6	1.5	17.0	1.5	6,200	11,160
	---	46.4	53.6	---	5.1	72.7	1.7	19.1	1.7	6,980	12,570
D221100	26.4	27.9	33.4	12.3	5.9	44.1	.9	35.5	1.2	4,190	7,550
	---	37.9	45.4	16.7	4.0	59.9	1.2	16.3	1.6	5,700	10,260
	---	45.5	54.5	---	4.8	71.9	1.5	19.6	2.0	6,840	12,310
D221101	28.7	25.1	29.2	17.0	5.8	39.0	.8	35.6	1.8	3,710	6,680
	---	35.2	41.0	23.8	3.7	54.7	1.1	14.1	2.5	5,200	9,360
	---	46.2	53.8	---	4.8	71.8	1.5	18.6	3.3	6,830	12,290
D221102	32.9	26.6	33.9	6.6	6.4	43.7	.9	41.7	.7	4,120	7,410
	---	39.6	50.5	9.8	4.1	65.1	1.3	18.6	1.0	6,140	11,050
	---	44.0	56.0	---	4.5	72.2	1.5	20.6	1.2	6,810	12,250
D221103	27.6	29.3	34.0	9.1	6.0	46.1	.9	35.7	2.1	4,390	7,900
	---	40.5	47.0	12.6	4.1	63.7	1.2	15.4	2.9	6,060	10,910
	---	46.3	53.7	---	4.6	72.8	1.4	17.6	3.3	6,930	12,480
D221104	36.0	28.3	17.9	17.8	5.7	28.0	.8	45.8	1.9	2,350	4,230
	---	44.2	28.0	27.8	2.7	43.8	1.2	21.6	3.0	3,680	6,620
	---	61.3	38.7	---	3.7	60.6	1.7	29.9	4.1	5,090	9,160
D221105	27.7	28.2	34.8	9.3	6.1	46.1	.9	36.4	1.3	4,330	7,790
	---	39.0	48.1	12.9	4.2	63.8	1.2	16.3	1.8	5,990	10,780
	---	44.8	55.2	---	4.8	73.2	1.4	18.7	2.1	6,870	12,370
D221106	30.0	28.3	35.7	6.0	6.4	46.6	.9	39.3	.8	4,400	7,920
	---	40.4	51.0	8.6	4.4	66.6	1.3	18.0	1.1	6,280	11,310
	---	44.2	55.8	---	4.8	72.8	1.4	19.7	1.2	6,870	12,370

Table 2.--Proximate and ultimate analyses, and heat-of-combustion, forms-of-sulfur, free-swelling-index and ash-fusion determinations for 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota--continued

Sample number	Air-dried loss	Forms of sulfur			Free swelling index	Ash fusion temperature, °C		
		Sulfate	Pyritic	Organic		Initial deformation	Softening	Fluid
D221097	27.3	0.01	0.18	0.39	0.0	1,195	1,240	1,300
	---	.02	.27	.59				
	---	.02	.30	.65				
D221098	21.9	.01	.56	.57	.0	1,020	1,065	1,125
	---	.01	.78	.80				
	---	.02	.91	.93				
D221099	26.2	.01	.38	.59	.0	1,015	1,060	1,110
	---	.01	.56	.87				
	---	.02	.63	.98				
D221100	19.4	.01	.40	.85	.0	1,050	1,115	1,155
	---	.01	.54	1.15				
	---	.02	.65	1.39				
D221101	23.3	.01	.45	1.30	.0	1,150	1,195	1,240
	---	.01	.63	1.82				
	---	.02	.83	2.39				
D221102	25.4	.01	.18	.54	.0	1,155	1,220	1,270
	---	.01	.27	.80				
	---	.02	.30	.89				
D221103	20.3	.01	.93	1.18	.0	1,190	1,240	1,280
	---	.01	1.28	1.63				
	---	.02	1.47	1.86				
D221104	28.7	1.34	.04	.47	.0	1,115	1,180	1,250
	---	2.09	.06	.73				
	---	2.90	.09	1.02				
D221105	20.9	.01	.42	.84	.0	1,120	1,170	1,220
	---	.01	.58	1.16				
	---	.02	.67	1.33				
D221106	23.4	.01	.19	.65	.0	1,245	1,275	1,315
	---	.01	.27	.93				
	---	.02	.30	1.02				

Table 3.--Major- and minor-oxide and trace element composition of the laboratory ash of 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

[Values in percent or parts per million. Coal ashed at 525°C. L, 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 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 midpoints 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]

Sample number	Ash (percent)	SiO2 (percent)	Al2O3 (percent)	CaO (percent)	MgO (percent)	Na2O (percent)	K2O (percent)	Fe2O3 (percent)	TiO2 (percent)	P2O5 (percent)	Sample number
D221097	8.0	16	9.3	22	5.97	1.11	0.23	12	0.38	0.50	D221097
D221098	9.6	26	12	12	4.81	8.49	.23	9.2	.42	.10	D221098
D221099	10.0	30	8.3	11	3.98	7.82	.64	10	.82	.10L	D221099
D221100	13.9	36	14	9.0	3.15	5.93	1.3	7.7	.50	.070	D221100
D221101	17.8	54	9.3	9.2	2.49	.20	.74	4.2	.68	.060	D221101
D221102	6.9	14	11	20	6.47	10.1	.24	4.9	.33	.14	D221102
D221103	10.1	4.5	2.5	15	6.96	6.61	.11	26	.17	.10L	D221103
D221104	19.9	39	9.5	12	5.31	.58	.62	8.3	.47	.10	D221104
D221105	10.3	21	8.3	17	8.95	5.80	.24	8.6	.47	.49	D221105
D221106	6.3	6.6	7.2	21	6.47	11.2	.24	6.2	.17	.16	D221106

Sample number	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Ce-S (ppm)	Cu (ppm)	Ga-S (ppm)	Ge-S (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Sample number
D221097	1,000	2,000	7	500L	69	10	3	50	31	527	D221097
D221098	1,000	3,000	10	500L	54	20	20L	50	32	523	D221098
D221099	1,000	7,000	7	150	70	20	15	30	23	332	D221099
D221100	1,000	7,000	7	150	82	20	5	50	38	149	D221100
D221101	1,000	1,000	5	100	50	15	10	30	29	1,080	D221101
D221102	2,000	3,000	3	100	39	20	5	50	41	547	D221102
D221103	1,500	2,000	5	500L	30	7	3	50	10L	495	D221103
D221104	500	7,000	3	150	53	10	5	50	24	530	D221104
D221105	1,500	3,000	3	100	45	10	5	50	28	849	D221105
D221106	2,000	2,000	7	100	38	7	20	50	15	572	D221106

Table 3.--Major- and minor-oxide and trace element composition of the laboratory ash of 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota--Continued

Sample number	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	Pb (ppm)	Sc-S (ppm)	Sr-S (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Sample number
D221097	30	20	15	54	10	3,000	20	70	5	27	D221097
D221098	30	50	50	33	15	3,000	150	70	5	71	D221098
D221099	20	30	20	38	20	3,000	100	70	5	40	D221099
D221100	20	30	50	43	20	3,000	150	50	5	52	D221100
D221101	10	50	30	26	20	1,500	100	70	5	20L	D221101
D221102	10	20	30	38	10	5,000	50	50	3	20L	D221102
D221103	20	20	50	30L	15	3,000	70	70	5	136	D221103
D221104	10	30	30	30L	15	2,000	100	70	5	44	D221104
D221105	7	20	30	30L	10	3,000	100	50	3	38	D221105
D221106	15	20	50	30L	20	10,000	50	100	7	332	D221106

Sample number	Zr-S (ppm)
D221097	200
D221098	300
D221099	300
D221100	300
D221101	300
D221102	200
D221103	100
D221104	200
D221105	200
D221106	100

Table 4.--Contents of nine trace elements in 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

[Analyses in air-dried (32°C) coal. L, less than the value shown]

Sample number	As (ppm)	Co (ppm)	Cr (ppm)	F (ppm)	Hg (ppm)	Sb (ppm)	Se (ppm)	Th (ppm)	U (ppm)	Sample number
D221097	9.6	10	18	25	0.15	0.2	0.6	1.0	1.7	D221097
D221098	4.3	16	19	25	.08	.5	.8	1.9	1.2	D221098
D221099	11	6.9	54	25	.14	1.3	1.1	1.1	1.1	D221099
D221100	14	10	54	55	.10	.9	1.6	1.8	2.0	D221100
D221101	3.9	12	64	50	.04	.3	.6	1.7	1.3	D221101
D221102	1.7	19	1.4L	20L	.03	.1	.4	.9	.3	D221102
D221103	7.8	48	52	20L	.26	.1	.5	.7	.2	D221103
D221104	7.1	13	50	65	.15	.3	.8	1.6	1.3	D221104
D221105	2.8	19	34	20L	.08	.2	.5	1.0	.6	D221105
D221106	2.6	68	30	20L	.08	.2	.4	.3	.2L	D221106

Table 5.--Major-, minor-, and trace-element composition of 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

[Values in percent of 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 lignite ash. S means analysis by emission spectrography; L, less than the value shown. N, not detected; B, not determined]

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
D221097	0.60	0.39	1.3	0.29	0.066	0.015	0.70	0.018	9.6	100	D221097
D221098	1.2	.62	.82	.28	.60	.018	.61	.024	4.3	100	D221098
D221099	1.4	.44	.80	.24	.58	.053	.70	.049	11	100	D221099
D221100	2.4	1.0	.89	.26	.61	.15	.75	.042	14	150	D221100
D221101	4.4	.87	1.2	.27	.026	.11	.52	.073	3.9	150	D221101
D221102	.46	.40	.97	.27	.52	.014	.23	.014	1.7	150	D221102
D221103	.21	.13	1.1	.42	.49	.009	1.8	.010	7.8	150	D221103
D221104	3.6	.99	1.7	.64	.086	.10	1.2	.056	7.1	100	D221104
D221105	1.0	.45	1.2	.55	.44	.021	.62	.029	2.8	150	D221105
D221106	.20	.24	.94	.25	.52	.013	.27	.006	2.6	150	D221106

Sample number	Ba-S (ppm)	Be-S (ppm)	Ce-S (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Ge-S (ppm)	Hg (ppm)	Sample number
D221097	150	0.7	50L	10	18	5.5	25	1	0.2	0.15	D221097
D221098	300	1	50L	16	19	5.2	25	2	2L	.08	D221098
D221099	700	.7	15	6.9	54	7.0	25	2	1.5	.14	D221099
D221100	700	1	20	10	54	11	55	3	.7	.10	D221100
D221101	200	.7	20	12	64	8.9	50	2	2	.04	D221101
D221102	200	.2	10	19	1.4L	2.7	20L	1.5	.3	.03	D221102
D221103	200	.5	50L	48	52	3.0	20L	.7	.3	.26	D221103
D221104	1,000	.7	20	13	50	11	65	2	1	.15	D221104
D221105	300	.3	10	19	34	4.6	20L	1	.5	.08	D221105
D221106	150	.5	7	68	30	2.4	20L	.5	1.5	.08	D221106

Table 5.--Major-, minor-, and trace-element composition of 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation North Beulah EMRIA study site, Mercer County, North Dakota--Continued

Sample number	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	P (ppm)	Pb (ppm)	Sb (ppm)	Sc-S (ppm)	Sample number
D221097	3	2.5	42	2	1.5	1.5	170	4.3	0.2	1	D221097
D221098	5	3.1	50	3	5	5	42	3.2	.5	1.5	D221098
D221099	3	2.3	33	2	3	2	44L	3.8	1.3	2	D221099
D221100	7	5.3	21	3	5	7	43	6.0	.9	3	D221100
D221101	7	5.2	190	2	7	5	47	4.6	.3	3	D221101
D221102	3	2.8	38	.7	2	2	42	2.6	.1	.7	D221102
D221103	5	1.0L	50	2	2	5	44L	3.0L	.1	1.5	D221103
D221104	10	4.8	110	2	7	7	87	6.0L	.3	3	D221104
D221105	5	2.9	87	.7	2	3	220	3.1L	.2	1	D221105
D221106	3	.9	36	1	1.5	3	44	1.9L	.2	1	D221106

Sample number	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
D221097	0.6	200	1.0	1.7	1.5	7	0.3	2.2	15	D221097
D221098	.8	300	1.9	1.2	15	7	.3	6.8	30	D221098
D221099	1.1	300	1.1	1.1	10	7	.5	4.0	30	D221099
D221100	1.6	500	1.8	2.0	20	7	.7	7.2	50	D221100
D221101	.6	200	1.7	1.3	20	10	1	3.6L	70	D221101
D221102	.4	300	.9	.3	3	3	.2	1.4L	15	D221102
D221103	.5	300	.7	.2	7	7	.5	14	15	D221103
D221104	.8	500	1.6	1.3	20	10	1	8.8	30	D221104
D221105	.5	300	1.0	.6	10	5	.3	3.9	20	D221105
D221106	.4	700	.3	.2L	3	7	.5	21	7	D221106

Table 6.--Elements looked for but not detected in lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

[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 Name	Symbol	Lower limit of detection (ppm) in lignite ash
Gold	Au	50
Bismuth	Bi	20
Dysprosium	Dy	100
Erbium	Er	100
Europium	Eu	200
Gadolinium	Gd	100
Hafnium	Hf	200
Holmium	Ho	50
Indium	In	20
Lutetium	Lu	70
Neodymium	Nd	150
Palladium	Pd	5
Praseodymium	Pr	200
Platinum	Pt	100
Rhenium	Re	100
Samarium	Sm	200
Tantalum	Ta	1,000
Terbium	Tb	700
Tellurium	Te	5,000
Thallium	Tl	100
Thulium	Tm	50
Tungsten	W	200

Table 7.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate and ultimate analyses, heat of combustion, forms of sulfur, and ash-fusion-temperatures of 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

[For comparison, geometric means for 32 other Fort Union region, North Dakota, and Montana lignite samples are included (Swanson and others, 1974, table 8). All values are in percent except Kcal/kg, Btu/lb, ash-fusion temperatures and geometric deviations and are reported on the as-received basis. L, less than the value shown. Leaders (---) indicate no data. Kcal/kg = 0.556(Btu/lb). $^{o}F = (^{o}C \times 1.8) + 32$]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Fort Union region geometric mean
		Minimum	Maximum			
Proximate and ultimate analyses						
Moisture	30.4	26.4	36.0	30.2	1.1	34.9
Volatile matter	27.8	25.1	29.3	27.8	1.0	27.4
Fixed carbon	31.8	17.9	35.7	31.1	1.2	30.1
Ash	10.3	6.0	17.8	9.5	1.5	6.4
Hydrogen	6.2	5.7	6.8	6.2	1.1	6.7
Carbon	42.6	28.0	46.6	42.1	1.2	40.7
Nitrogen	.9	.8	1.0	.9	1.1	.6
Oxygen	38.9	35.5	45.8	38.8	1.1	43.9
Sulfur	1.3	.6	2.1	1.2	1.5	.6
Heat of combustion						
Kcal/kg	4,025	2,350	4,400	3,955	1.2	3,770
Btu/lb	7,240	4,230	7,920	7,110	1.2	6,780
Forms of sulfur						
Sulfate	0.11	0.01L	1.34	0.02	7.4	0.02
Pyritic	.41	.04	.93	.29	2.4	.13
Organic	.74	.39	1.30	.69	1.5	.36
Ash-fusion temperatures, ^{o}C						
Initial deformation	1,125	1,015	1,240	1,120	1.1	---
Softening temperature	1,175	1,060	1,275	1,175	1.1	---
Fluid temperature	1,225	1,110	1,315	1,225	1.1	---

Table 8.--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 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer County, North Dakota

[For comparison, geometric means of analyses of 80 other Fort Union region, North Dakota and Montana lignite samples are included (Hatch and Swanson, 1977, table 5a). All samples were ashed at 525°C; all analyses except geometric deviation are in percent. Leaders (---) indicate no data]

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Fort Union region geometric mean
		Minimum	Maximum			
(Ash)	11.3	6.3	19.9	10.6	1.5	9.0
SiO_2	27	4.5	54	20	2.2	13
Al_2O_3	9.4	2.5	14	8.4	1.6	8.6
CaO	15	9.0	22	14	1.4	22
MgO	5.5	2.5	8.9	5.1	1.5	7.01
Na_2O	8.4	.20	11	3.4	4.0	1.43
K_2O	.47	.11	1.3	.35	2.1	.059
Fe_2O_3	9.7	4.1	26	8.5	1.7	5.0
TiO_2	.45	.17	.82	.40	1.7	.49
P_2O_5	.17	.06L	.50	.11	2.6	---

Table 9.--Arithmetic mean, observed range, gometric mean, and geometric deviation of 39 elements in 10 lignite samples from the Sentinel Butte Member of the Fort Union Formation, North Beulah EMRIA study site, Mercer Couunty, North Dakota

[For comparison, geometric means of analyses for 80 other Fort Union region North Dakota and Montana lignite samples are included (Hatch and Swanson, 1977, table 5b). All analyses except geometric deviation are in percent or 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 coal. All other values were calculated from determinations made on lignite ash. L, less than the values shown]

Element	Arithmetic mean	Observed range		Geometiric mean	Geometric deviation	Fort Union region geometric mean
		Minimum	Maximum			
			Percent			
Si	1.7	0.19	4.4	0.97	2.9	0.55
Al	.58	.13	1.0	.47	1.9	.41
Ca	1.1	.79	1.7	1.1	1.3	1.4
Mg	.35	.24	.64	.33	1.4	.38
Na	.51	.026	.61	.27	3.2	.095
K	.052	.009	.15	.031	2.8	.006
Fe	.75	.23	1.8	.63	1.8	.32
Ti	.033	.006	.072	.025	2.2	.028
P	.007	.004L	.022	.006	2.1	---
			Parts per million			
As	6.8	1.7	.14	5.3	2.0	4
B	150	100	150	150	1.2	100
Ba	500	150	1000	300	2.0	300
Be	.7	.2	1	.7	1.7	.2
Ce	10	7L	20	10	1.9	---
Co	21	6.9	68	16	2.0	1.5
Cr	40	18	64	34	1.8	1.5
Cu	6.2	2.4	11	5.4	1.8	3.8
F	31	25L	65	26	1.8	26
Ga	1.5	.5	3	1.5	1.8	1.5
Ge	1	.2L	2	.7	2.6	---
Hg	.11	.03	.26	.09	1.9	.09
La	5	3	10	5	1.5	---
Li	3.2	.9L	5.3	2.6	2.0	2.4
Mn	65	20	190	53	1.9	29
Mo	2	.7	3	1.5	1.7	1
Nb	3	1.5	7	3	1.9	1
Ni	5	1.5	7	3	1.7	1.5
Pb	3.2	2.6L	5.9	2.9	1.6	3.8
Sb	.4	.07	1.3	.3	2.5	.2
Sc	1.5	.7	3	1.5	1.7	1.5
Se	.7	.4	1.6	.7	1.6	.6
Sr	300	200	700	300	1.5	500
Th	1.2	.3	1.9	1.1	1.7	2.4
U	1.1	.2L	2	.7	2.6	.6
V	10	1.5	20	7	2.5	3
Y	7	3	10	7	1.4	3
Yb	.5	.2	1	.5	1.7	.2
Zn	7.4	2.1L	21	4.8	2.6	2.3
Zr	30	7	70	20	2.0	10