UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Chemical Analyses of Lignite from the Sentinel Butte Member of the Fort Union Formation, Dunn Center Field, Dunn County, North Dakota

By

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Introduction

As part of a continuing program by the U.S. Geological Survey to collect and chemically analyze representative samples of U.S. coals, 40 samples were collected from 16 core holes in the Sentinel Butte Member, Fort Union Formation of Paleocene age, in sections 3, 10, 11, 12, 14, and 15, T. 144 N., R. 94 W., Dunn County, North Dakota. This area is in the Dunn Center Field, which is part of the Fort Union lignite region (fig. 1). The distribution of the 16 holes, drilled in connection with the Horse Nose Butte EMRIA (Energy Mineral Rehabilitation Inventory and Analyses) study, is shown in figure 2. Detailed lithologic descriptions of the cores and a brief discussion of the geology of the study area are in U.S. Bureau of Land Management (1977). The 40 samples are briefly described in table 1. Using the bed designation listed in U.S. Bureau of Land Management (1977); 2 of the samples are from the A bed, 4 samples from B, 9 samples from E, 22 samples from F (the Dunn Center bed), 2 samples from G, and 1 sample from H. Figure 3 is generalized stratigraphic column showing the relative position and thickness of these beds.

Four of the sampled beds (A, B, E, and F) may be of economic significance. In the Horse Nose Butte study area, estimated demonstrated coal resources, between depths of 0 and 60 m (0-200 ft) for these four beds are as follows: for the A bed, 163,000 metric tons (180,000 short tons); B bed, 11,970,000 metric tons (13,200,000 short tons); E bed, 10,190,000 metric tons (11,240,000 short tons); F bed, 65,050,000 metric tons (71,720,000 short tons); and for all four beds combined, 87,380,000 metric tons (96,340,000 short tons) (U.S. Bureau of Land Management, 1977).

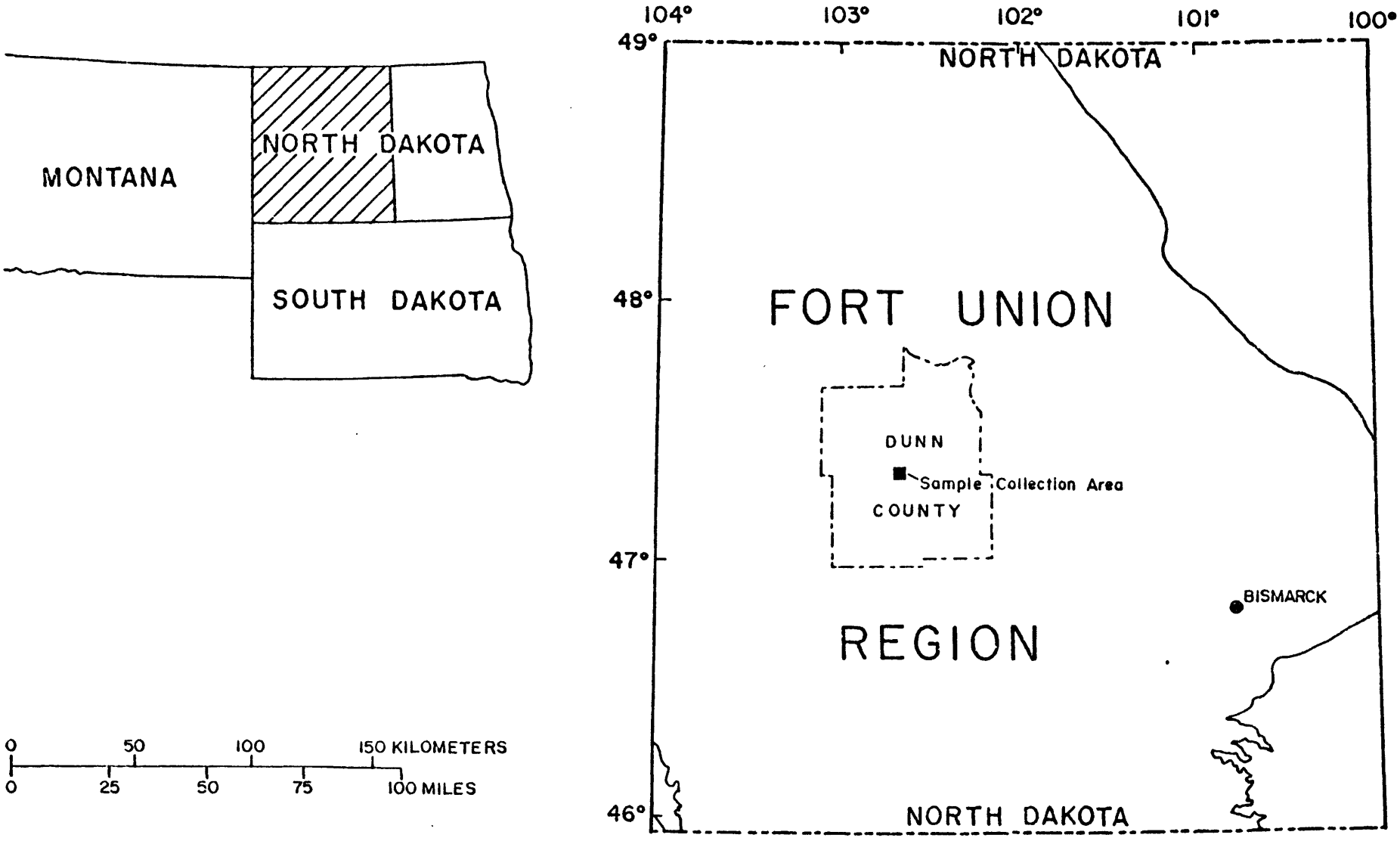


Figure 1.--Index map of western North Dakota showing the location of the sample collection area and an outline of the Fort Union lignite region. Map modified from Averitt (1942).

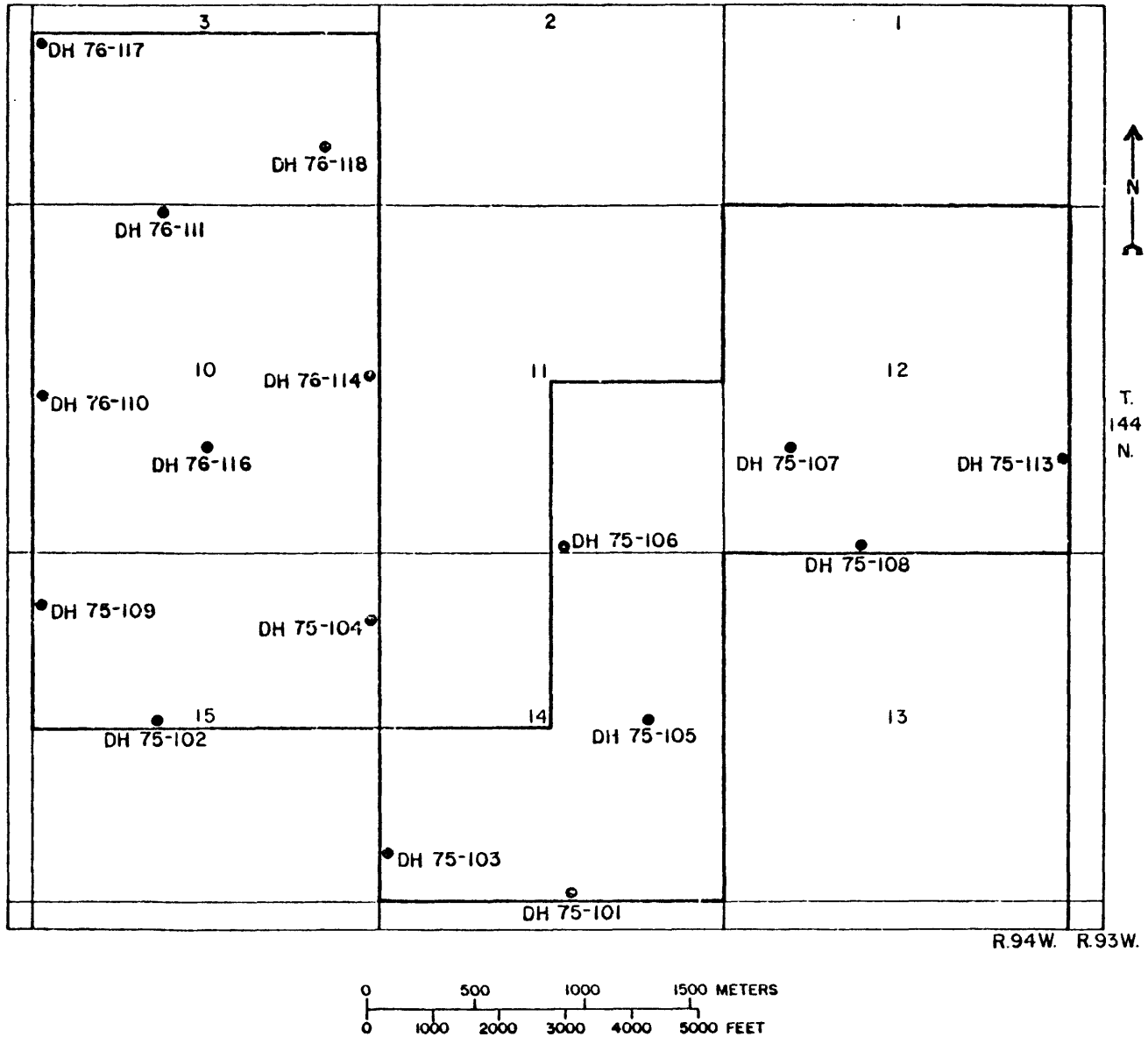


Figure 2.--Map of the sample collection area in Dunn County, N. Dak. showing the locations of drill holes and an outline of the Horse Nose Butte EMRIA study area. Map modified from U.S. Bur. Land Management (1977, plate 5).

Table 1.--USGS sample number, hole number, location, depth interval, and bed designation for 40 samples from the Dunn Center lignite field, Dunn County, N. Dak.

[All samples are from the Sentinel Butte member of the Fort Union Formation of Paleocene age. One foot = 0.3048 meters]

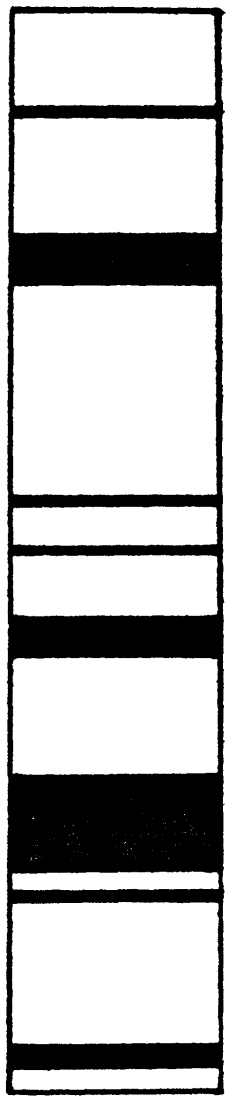
USGS sample number	Hole number	Location	Depth interval represented in meters and (feet)	Bed designation
D178498	DH 75-101	SW¼SE¼ sec. 14, T. 144 N., R. 94 W.	3.0- 4.1 (10.0- 13.4)	A
D178499	---do----	----------do----------	10.1- 12.5 (33.1- 41.1)	B
D178500	---do----	----------do----------	44.6- 46.4 (146.2-152.1)	E
D178501	---do----	----------do----------	48.1- 51.5 (157.9-169.0)	F
D178502	---do----	----------do----------	51.5- 53.9 (169.0-176.8)	Do.
D178503	---do----	----------do----------	64.6- 65.7 (212.1-215.5)	H
D178507	DH 75-102	SE¼NW¼ sec. 15, T. 144 N., R. 94 W.	7.6- 8.4 (25.0- 27.6)	A
D178508	---do----	----------do----------	13.7- 16.4 (44.8- 53.7)	B
D178509	---do----	----------do----------	30.9- 32.0 (101.1-104.9)	E
D178510	---do----	----------do----------	50.0- 51.4 (163.9-168.7)	F
D178511	---do----	----------do----------	51.4- 52.9 (168.7-173.5)	Do.
D178512	---do----	----------do----------	52.9- 54.3 (173.5-178.2)	Do.
D179369	DH 75-103	SW¼SW¼ sec. 15, T. 144 N., R. 94 W.	16.9- 19.9 (55.4- 65.2)	B
D179370	---do----	----------do----------	45.8- 47.2 (150.4-154.7)	E
D179371	---do----	----------do----------	51.7- 56.4 (169.6-185.1)	F

Table 1.--USGS sample number, hole number, location, depth interval, and bed designation for 40 samples from the Dunn Center lignite field, Dunn County, N. Dak.--Continued

USGS sample number	Hole number	Location	Depth interval represented in meters and (feet)	Bed designation
D178504	DH 75-104	NE¼NE¼ sec. 15, T. 144 N., R. 94 W.	14.2- 15.2 (46.5- 50.0)	E
D178505	---do----	----------do----------	24.6- 27.5 (80.8- 90.1)	F
D178506	---do----	----------do----------	27.5- 30.3 (90.1- 99.4)	Do.
D179372	DH 75-105	SE¼NE¼ sec. 14, T. 144 N., R. 94 W.	21.4- 23.3 (70.1- 76.5)	E
D179373	---do----	----------do----------	24.7- 31.2 (80.9-102.5)	F
D179374	DH 75-106	SW¼SE¼ sec. 11, T. 144 N., R. 94 W.	13.7- 16.9 (44.9- 55.3)	B
D179375	---do----	----------do----------	37.1- 38.1 (121.6-125.1)	E
D179376	---do----	----------do----------	39.2- 45.9 (128.6-150.7)	F
D179377	DH 75-107	NW¼SW¼ sec. 12, T. 144 N., R. 94 W.	11.5- 13.8 (37.6- 45.4)	E
D179378	---do---	----------do----------	17.1- 22.5 (56.0- 73.8)	F
D179379	DH 75-108	SE¼SW¼ sec. 12, T. 144 N., R. 94 W.	10.4- 13.2 (34.1- 43.3)	E
D179380	---do----	----------do----------	17.8- 19.6 (58.4- 64.3)	F
D179381	---do----	----------do----------	19.6- 21.4 (64.3- 70.3)	Do.
D179382	---do----	----------do----------	21.4- 23.2 (70.3- 76.2)	Do.
D179383	DH 75-109	NW¼NW¼ sec. 15, T. 144 N., R. 94 W.	34.0- 39.2 (111.7-128.5)	Do.

Table 1.--USGS sample number, hole number, location, depth interval, and bed designation for 40 samples from the Dunn Center lignite field, Dunn County, N. Dak.--Continued

USGS sample number	Hole number	Location	Depth interval represented in meters and (feet)	Bed designation
D180075	DH 75-110	NW¼SW¼ sec. 10, T. 144 N., R. 94 W.	14.6- 20.3 (47.8- 66.6)	F
D180076	DH 75-111	NE¼SW¼ sec. 10, T. 144 N., R. 94 W.	20.3- 25.5 (66.5- 83.6)	Do.
D180077	---do----	----------do----------	26.4- 27.1 (86.5- 88.8)	G
D179384	DH 75-113	NE¼SE¼ sec. 12, T. 144 N., R. 94 W.	8.8- 14.9 (29.0- 48.8)	F
D180078	DH 75-114	SW¼NW¼ sec. 11, T. 144 N., R. 94 W.	18.2- 24.3 (59.7- 79.8)	Do.
D180079	DH 75-116	NE¼SW¼ sec. 10, T. 144 N., R. 94 W.	8.2- 11.3 (27.0- 37.2)	Do.
D180080	DH 75-117	NW¼SW¼ sec. 3, T. 144 N., R. 94 W.	3.3- 8.3 (10.9- 27.3)	Do.
D180081	---do----	----------do----------	10.3- 10.9 (33.7- 35.7)	G
D180082	DH 75-118	SE¼SE¼ sec. 3, T. 144 N., R. 94 W.	6.9- 7.8 (22.2- 25.6)	E ?
D180083	---do----	----------do----------	9.0- 14.5 (29.5- 47.7)	F



A bed, average thickness 0.91 m (3 ft), range 0.8 to 1.1 m (2.6 to 3.6 ft) (two measured sections)

B bed, average thickness 2.83 m (9.3 ft), range 2.4 to 3.2 m (7.9 to 10.5 ft) (four measured sections)

C bed, no samples

D bed, no samples

E bed, average thickness 1.58 m (5.2 ft), range 0.9 to 2.8 m (3.0 to 9.2 ft) (nine measured sections)

F bed, average thickness 5.53 m (18.1 ft), range 1.7 to 10.9 m (5.6 to 35.8 ft) (fifteen measured sections)

G bed, average thickness 0.65 m (2.1 ft), range 0.6 to 0.7 m (2.0 to 2.3 ft) (two measured sections)

H bed, 1.1 m (3.6 ft) thick (one measured section)

Figure 3.--Generalized stratigraphic section showing the relative position of eight lignite beds encountered during coring in the Dunn Center lignite field, North Dakota. All beds are in the Sentinel Butte Member of the Fort Union Formation of Paleocene age. Figure is modified from U.S. Bureau of Land Management (1977, plate 6).

Proximate and ultimate analyses, heat-of-combustion, air-dried-loss, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations on 32 samples from the Dunn Center lignite field are listed in table 2. These analyses were provided by the U.S. Bureau of Mines, Pittsburgh, Pa. Analyses for ash content and 36 major and minor oxides and trace elements in the laboratory ash (table 3) and analyses of seven trace elements in whole coal (table 4) for all 40 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-coal basis plus the whole-coal 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 for the nine E bed samples in tables 2, 3, and 5 are listed in tables 7, 8, and 9 respectively; for the 22 F bed samples, tables 10, 11, and 12; and for all 40 samples from the Dunn Center field, tables 13, 14, and 15. For comparison, data summaries for other Fort Union region lignite samples are included in tables 13, 14, and 15. Data summaries for Ag, Cd, Ce, La, Nd, and Th contents in lignite were not included in tables 9, 12, and 15 because these elements were detected in an insufficient number of samples to calculate meaningful statistics. For the same reason, summaries of Nb content in the F bed (table 12) and P_2O_5 contents in lignite ash (tables 3, 8, and 11) are also not 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 subtitle 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 $\underline{t}$ 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" disribution. 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 samples from the Dunn Center field were calculated using the data in table 2 and the formulas in ASTM designation D-388-77 (American Society for Testing and Materials, 1977). The apparent rank ranges from lignite B (11 samples) to lignite A (21 samples).

When calculated to a moist-mineral-matter-free basis, the following heats of combustion were determined for each bed:

-A bed (2 samples)

range - 1,810-2,525 Kcal/kg (3,250-4,540 Btu/lb)

mean - 2,170 Kcal/kg (3,900 Btu/lb)

-B bed (4 samples)

range - 3,480-3,770 Kcal/kg (6,260-6,780 Btu/lb)

mean - 3,625 Kcal/kg (6,520 Btu/lb)

-E bed (7 samples)

range - 3,480-3,875 Kcal/kg (6,650 Btu/lb)

mean - 3,700 Kcal/kg (6,650 Btu/lb)

-F bed (18 samples)

range - 3,340-4,610 Kcal/kg (6,950 Btu/lb).

mean - 3,625 Kcal/kg (6,520 Btu/lb)

-H bed (1 sample) - 3,880 Kcal/kg (6,950 Btu/lb)

The heat of combustion for all 32 samples from the Dunn Center field ranges from 1,810 to 4,610 Kcal/kg (3,250-8,290 Btu/lb) with a mean of 3,560 Kcal/kg (5,400 Btu/lb).

The two samples from the A bed were collected from relatively shallow depths (3.0 to 4.1 m (10.0 to 13.4 ft) and 7.6 to 8.4 m (25.0 to 27.6 ft)) and, as indicated by their low heat of combustion, are partially weathered.

A statistical comparison (Student's t test, 95 percent confidence level) of the U.S. Bureau of Mines data for the Dunn Center samples with 32 other Fort Union region samples shows that the Dunn Center lignites have significantly higher contents of moisture, oxygen, and total sulfur, and significantly lower contents of volatile matter, fixed carbon, carbon, and nitrogen. The Dunn Center lignites also have a significantly lower heat of combustion. Contents of ash, hydrogen, and sulfate, pyritic, and organic sulfur are similar in both sets. When compared at the 99 percent confidence level, the total sulfur contents of both sets are similar.

A statistical comparison of the U.S. Bureau of Mines analyses for the E and F beds shows that the E bed has a significantly higher ash content and a lower initial ash-deformation temperature. All other parameters are similar. When compared at the 99 percent confidence level, both the ash content and initial ash-deformation temperatures are similar.

A statistical comparison of the mean contents of coal ash and nine major and minor oxides in ash from the 40 Dunn Center lignite samples with ash from 80 other lignite samples from the Fort Union region shows that the Dunn Center lignites have a significantly higher ash content, higher K_2O content in the ash and lower CaO content in the ash. Contents of SiO_2, Al_2O_3, MgO, Na_2O, Fe_2O_3, TiO_2, and SO_3 in the ash are similar for both sets.

A statistical comparison of the mean contents of coal ash and contents of nine major and minor oxides in ash for the E and F beds shows that the E-bed ash has a significantly higher K_2O content and significantly lower Al_2O_3 and CaO contents. Contents of ash and contents of SiO_2, MgO, Na_2O, Fe_2O_3, TiO_2, and SO_3 in ash are similar for both sets. When compared at the 99 percent confidence level, the Al_2O_3 and K_2O contents in ash from both sets are similar.

A statistical comparison of the mean contents of 34 elements in the 40 Dunn Center samples with 80 other Fort Union region samples shows that the Dunn Center samples have significantly higher contents of Si, Al, Mg, Na, K, Fe, Ti, Ba, Cr, Cu, Ga, Hg, Mn, Mo, Sb, U, V, Y, Yb, and Zn and significantly lower contents of Ca, B, Co, Pb, Sc, and Sr. The contents of As, Be, F, Li, Nb, Ni, Se, and Zr are similar for both sample sets. When compared at the 99 percent confidence level, Al, Fe, Pb, and U contents are similar in both sets.

A statistical comparison of the mean contents of 33 elements for the E and F beds shows that the E bed has significantly higher contents of K, Be, Cr, Cu, Sb, U, Y, Yb, and Zr. The contents of Si, Al, Ca, Mg, Na, Fe, Ti, As, B, Ba, Co, F, Ga, Hg, Li, Mn, Mo, Ni, Pb, Sc, Se, Sr, V, and Zn are similar for both beds. When compared at the 99 percent confidence level, contents of K, Cr, Sb, and Zr are similar for both beds.

Differences in the oxide composition of lignite ashes and the element contents of lignites 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 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 during burial; and extent of weathering. No evaluation of these factors has been made for any of the Dunn Center lignite beds.

Compared to other U.S. coals (Swanson and others, 1976; Hatch and Swanson, 1977), lignites of the Fort Union region are characterized by relatively low ash, low sulfur, low heat of combustion, and high moisture content. The contents of elements of environmental concern such as As, Be, Hg, Mo, Sb, and Se are low in Fort Union region lignite when compared to most other U.S. coals.

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U.S. Bureau of Land Management, 1977, Horse Nose Butte study area--Dunn Center lignite field, resource and potential reclamation evaluation: U.S. Bureau of Land Management EMRIA Report 9, 83 p. + Appendices A through F.

Table 2.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations for 32 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.

[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. Sample D178501* is a composite of D178501 and D178502; D178510* is a composite of D178510, D178511, and D178512; D178505* is a composite of D178505 and D178506. No Bureau of Mines analyses were run on samples D178504, D180077, D178001, and D1780082.

Sample number	Proximate Analysis				Ultimate Analysis					Heat of Combustion	
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
D178498	46.4	26.1	14.6	12.9	6.7	25.8	0.5	52.9	1.2	2,160	3,890
	---	48.7	27.2	24.1	2.9	48.1	.9	21.7	2.2	4,030	7,260
	---	64.1	35.9	---	3.8	63.4	1.2	28.6	2.9	5,310	9,560
D178499	40.5	25.6	24.3	9.6	6.8	33.6	.5	46.9	2.6	3,100	5,580
	---	43.0	40.8	16.1	3.9	56.5	.8	18.3	4.4	5,210	9,380
	---	51.3	48.7	---	4.6	67.3	1.0	21.8	5.2	6,210	11,180
D178500	35.3	24.0	21.8	18.9	6.3	32.3	.4	41.0	1.1	3,060	5,510
	---	37.1	33.7	29.2	3.7	49.9	.6	14.9	1.7	4,730	8,520
	---	52.4	47.6	---	5.2	70.5	.9	21.0	2.4	6,680	12,030
D178501	28.0	29.7	29.5	12.8	5.0	42.6	.4	38.4	.8	3,960	7,120
	---	41.2	41.0	17.8	2.6	59.2	.6	18.8	1.1	5,490	9,890
	---	50.2	49.8	---	3.2	72.0	.7	22.8	1.4	6,680	12,030
D178503	39.8	40.0	13.0	7.2	6.9	38.3	.5	46.3	.8	3,550	6,390
	---	66.4	21.6	12.0	4.1	63.6	.8	18.1	1.3	5,900	10,610
	---	75.5	24.5	---	4.7	72.3	.9	20.6	1.5	6,700	12,060
D178507	57.2	22.9	7.8	12.1	7.7	18.8	.3	59.8	1.3	1,560	2,810
	---	53.5	18.2	28.3	3.1	43.9	.7	20.9	3.0	3,650	6,570
	---	74.6	25.4	---	4.4	61.2	1.0	29.2	4.2	5,090	9,150
D178508	43.1	24.7	25.5	6.7	7.3	36.2	.4	48.4	1.0	3,370	6,060
	---	43.4	44.8	11.8	4.4	63.6	.7	17.7	1.8	5,920	10,650
	---	49.2	50.8	---	5.0	72.1	.8	20.1	2.0	6,710	12,070
D178509	36.1	21.8	22.3	19.8	6.2	30.5	.2	40.8	2.5	2,910	5,230
	---	34.1	34.9	31.0	3.4	47.7	.3	13.6	3.9	4,550	8,180
	---	49.4	50.6	---	5.0	69.2	.5	19.8	5.7	6,590	11,860
D178510	42.2	24.6	26.4	6.8	7.2	36.4	.4	48.5	.7	3,380	6,090
	---	42.6	45.7	11.8	4.3	63.0	.7	19.0	1.2	5,850	10,540
	---	48.2	51.8	---	4.9	71.4	.8	21.5	1.4	6,630	11,940
D179369	42.7	24.1	25.0	8.2	7.2	35.1	.4	47.7	1.4	3,280	5,910
	---	42.1	43.6	14.3	4.3	61.3	.7	17.0	2.4	5,730	10,310
	---	49.1	50.9	---	5.0	71.5	.8	19.8	2.9	6,690	12,040
D179370	40.5	24.1	26.9	8.5	7.0	36.1	.4	46.2	1.8	3,400	6,120
	---	40.5	45.2	14.3	4.2	60.7	.7	17.1	3.0	5,710	10,290
	---	47.3	52.7	---	4.9	70.8	.8	20.0	3.5	6,670	12,000
D179371	39.9	25.9	27.2	7.0	7.0	38.0	.5	46.3	1.2	3,540	6,380
	---	43.1	45.3	11.6	4.3	63.2	.8	18.0	2.0	5,900	10,620
	---	48.8	51.2	---	4.8	71.6	.9	20.4	2.3	6,680	12,020

Table 2.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations for 32 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Air-dried loss	Forms of sulfur			Free swelling	Ash fusion temperature, C°		
		Sulfate	Pyritic	Organic		Initial deformation	Softening	Fluid
D178498	22.3	0.57	0.04	0.60	0.0	1,075	1,115	1,130
	---	1.06	.07	1.12				
	---	1.40	.10	1.47				
D178499	23.1	.81	.39	1.44	.0	1,215	1,245	1,265
	---	1.36	.66	2.42				
	---	1.62	.78	2.89				
D178500	15.1	.04	.14	.91	.0	1,125	1,195	1,300
	---	.06	.22	1.41				
	---	.09	.31	1.99				
D178501	8.0	.05	.66	.14	.0	1,105	1,155	1,190
	---	.07	.92	.19				
	---	.08	1.11	.24				
D178503	18.4	.04	.09	.71	.0	1,125	1,180	1,215
	---	.07	.15	1.18				
	---	.08	.17	1.34				
D178507	19.0	.22	.14	.96	.0	1,145	1,180	1,215
	---	.51	.33	2.24				
	---	.72	.46	3.13				
D178508	23.4	.04	.11	.87	.0	1,285	1,335	1,350
	---	.07	.19	1.53				
	---	.08	.22	1.73				
D178509	20.3	.04	2.12	.34	.0	1,055	1,330	1,380
	---	.06	3.32	.53				
	---	.09	4.81	.77				
D178510	22.8	.04	.09	.58	.0	1,205	1,255	1,275
	---	.07	.16	1.00				
	---	.08	.18	1.14				
D179369	21.7	.01	.14	1.28	.0	1,200	1,230	1,250
	---	.02	.24	2.23				
	---	.02	.29	2.61				
D179370	23.6	.01	.10	1.68	.0	1,110	1,170	1,195
	---	.02	.17	2.82				
	---	.02	.20	3.29				
D179371	18.4	.02	.06	1.09	.0	1,215	1,260	1,315
	---	.03	.10	1.81				
	---	.04	.11	2.05				

Table 2.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion temperature determinations for 32 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Proximate Analysis				Ultimate Analysis					Heat of Combustion	
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
D178505	43.2	24.3	23.6	8.9	7.1	33.9	0.4	48.7	1.0	3,110	5,600
	---	42.8	41.5	15.7	4.0	59.7	.7	18.1	1.8	5,480	9,860
	---	50.7	49.3	---	4.8	70.8	.8	21.5	2.1	6,500	11,690
D179372	42.0	24.3	24.9	8.8	7.1	34.8	.5	48.1	.7	3,260	5,870
	---	41.9	42.9	15.2	4.2	60.0	.9	18.6	1.2	5,620	10,120
	---	49.4	50.6	---	4.9	70.7	1.0	21.9	1.4	6,630	11,930
D179373	43.3	23.1	23.4	10.2	7.0	33.2	.5	47.7	1.4	3,080	5,540
	---	40.7	41.3	18.0	3.9	58.6	.9	16.2	2.5	5,430	9,770
	---	49.7	50.3	---	4.7	71.4	1.1	19.8	3.0	6,620	11,910
D179374	40.1	25.9	26.1	7.9	7.0	36.5	.5	46.3	1.8	3,430	6,180
	---	43.2	43.6	13.2	4.2	60.9	.8	17.8	3.0	5,730	10,320
	---	49.8	50.2	---	4.9	70.2	1.0	20.5	3.5	6,600	11,880
D179375	37.9	25.0	24.0	13.1	6.6	34.2	.5	43.1	2.5	3,190	5,750
	---	40.3	38.6	21.1	3.8	55.1	.8	15.2	4.0	5,140	9,260
	---	51.0	49.0	---	4.9	69.8	1.0	19.2	5.1	6,520	11,730
D179376	39.1	26.4	27.1	7.4	6.9	38.0	.5	46.6	.6	3,530	6,360
	---	43.3	44.5	12.2	4.2	62.4	.8	19.4	1.0	5,800	10,440
	---	49.3	50.7	---	4.8	71.0	.9	22.1	1.1	6,600	11,890
D179377	45.4	23.6	25.8	5.2	7.3	35.4	.5	51.3	.3	3,280	5,900
	---	43.2	47.3	9.5	4.1	64.8	.9	20.0	.5	6,000	10,810
	---	47.8	52.2	---	4.6	71.7	1.0	22.2	.6	6,640	11,940
D179378	46.1	22.8	24.1	7.0	7.4	33.8	.5	50.3	1.0	3,140	5,650
	---	42.3	44.7	13.0	4.2	62.7	.9	17.3	1.9	5,820	10,480
	---	48.6	51.4	---	4.9	72.1	1.1	19.9	2.1	6,690	12,050
D179379	43.1	27.4	24.8	4.7	7.5	37.0	.4	49.7	.7	3,480	6,260
	---	48.2	43.6	8.3	4.8	65.0	.7	20.0	1.2	6,110	11,000
	---	52.5	47.5	---	5.2	70.9	.8	21.8	1.3	6,660	11,990
D179380	41.8	25.7	25.2	7.3	7.0	36.9	.6	47.9	.3	3,360	6,050
	---	44.2	43.3	12.5	4.0	63.4	1.0	18.5	.5	5,780	10,400
	---	50.5	49.5	---	4.6	72.5	1.2	21.1	.6	6,600	11,890
D179381	38.8	26.5	27.8	6.9	7.0	38.4	.6	46.9	.2	3,550	6,390
	---	43.3	45.4	11.3	4.4	62.7	1.0	20.3	.3	5,800	10,440
	---	48.8	51.2	---	5.0	70.7	1.1	22.9	.4	6,540	11,770
D179382	42.8	27.3	26.2	3.7	7.4	37.6	.5	50.5	.3	3,520	6,340
	---	47.7	45.8	6.5	4.6	65.7	.9	21.8	.5	6,160	11,080
	---	51.0	49.0	---	4.9	70.3	.9	23.3	.6	6,580	11,850

Table 2.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion temperature determinations for 32 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Air-dried loss	Forms of sulfur			Free swelling	Ash fusion temperature, C°		
		Sulfate	Pyritic	Organic		Initial deformation	Softening	Fluid
D178505	25.0	0.03	0.08	0.87	0.0	1,240	1,315	1,315
	---	.05	.14	1.53				
	---	.06	.17	1.82				
D179372	23.2	.01	.10	.54	.0	1,100	1,155	1,190
	---	.02	.17	.93				
	---	.02	.20	1.10				
D179373	22.1	.01	.21	1.12	.0	1,100	1,150	1,175
	---	.02	.37	1.98				
	---	.02	.45	2.41				
D179374	23.6	.01	.09	1.74	.0	1,195	1,240	1,255
	---	.02	.15	2.90				
	---	.02	.17	3.35				
D179375	20.4	.30	.41	1.79	.0	1,080	1,120	1,155
	---	.48	.66	2.88				
	---	.61	.84	3.65				
D179376	22.9	.01	.21	.34	.0	1,090	1,145	1,170
	---	.02	.34	.56				
	---	.02	.39	.64				
D179377	24.0	.01	.25	.04	.0	1,120	1,180	1,215
	---	.02	.46	.07				
	---	.02	.51	.08				
D179378	25.6	.01	.08	.89	.0	1,125	1,175	1,195
	---	.02	.15	1.65				
	---	.02	.17	1.90				
D179379	22.3	.01	.16	.50	.0	1,225	1,280	1,300
	---	.02	.28	.88				
	---	.02	.31	.96				
D179380	26.0	.01	.15	.13	.0	1,175	1,215	1,250
	---	.02	.26	.22				
	---	.02	.29	.26				
D179381	21.1	.01	.21	.02	.0	1,175	1,225	1,270
	---	.02	.34	.03				
	---	.02	.39	.04				
D179382	26.8	.01	.11	.15	.0	1,275	1,320	1,345
	---	.02	.19	.26				
	---	.02	.21	.28				

Table 2.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion temperature determinations for 32 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Proximate Analysis				Ultimate Analysis					Heat of Combustion	
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
D179383	47.0	24.0	23.7	5.3	7.6	34.0	0.4	51.9	0.8	3,170	5,710
	---	45.3	44.7	10.0	4.5	64.2	.8	19.1	1.5	5,990	10,770
	---	50.3	49.7	---	5.0	71.3	.8	21.2	1.7	6,650	11,970
D180075	43.8	26.9	24.7	4.6	7.4	37.1	.5	49.9	.5	3,460	6,230
	---	47.9	44.0	8.2	4.5	66.0	.9	19.5	.9	6,160	11,090
	---	52.1	47.9	---	4.9	71.9	1.0	21.3	1.0	6,710	12,070
D180076	44.0	26.2	21.6	8.2	7.3	34.4	.5	48.6	1.0	3,190	5,750
	---	46.8	38.6	14.6	4.3	61.4	.9	16.9	1.8	5,700	10,270
	---	54.8	45.2	---	5.0	72.0	1.0	19.9	2.1	6,680	12,030
D179384	47.4	22.3	24.1	6.2	7.5	33.3	.7	51.2	1.1	3,100	5,580
	---	42.4	45.8	11.8	4.2	63.3	1.3	17.2	2.1	5,890	10,610
	---	48.1	51.9	---	4.8	71.8	1.5	19.5	2.4	6,680	12,030
D180078	46.6	22.6	25.0	5.8	7.5	33.8	.5	51.7	.7	3,180	5,720
	---	42.3	46.8	10.9	4.3	63.3	.9	19.2	1.3	5,950	10,710
	---	47.5	52.5	---	4.9	71.0	1.1	21.6	1.5	6,680	12,020
D180079	44.4	24.5	25.7	5.4	7.3	35.4	.5	50.8	.6	3,310	5,950
	---	44.1	46.2	9.7	4.3	63.7	.9	20.4	1.1	5,950	10,700
	---	48.8	51.2	---	4.7	70.5	1.0	22.6	1.2	6,580	11,850
D180080	44.7	25.5	25.2	4.6	7.5	36.6	.5	50.4	.4	3,370	6,060
	---	46.1	45.6	8.3	4.6	66.2	.9	19.3	.7	6,090	10,960
	---	50.3	49.7	---	5.0	72.2	1.0	21.0	.8	6,640	11,950
D180083	44.3	26.2	22.6	6.9	7.2	34.7	.5	49.6	1.1	3,190	5,740
	---	47.0	40.6	12.4	4.1	62.3	.9	18.4	2.0	5,730	10,310
	---	53.7	46.3	---	4.7	71.1	1.0	20.9	2.3	6,530	11,760

Table 2.--Proximate and ultimate analyses, heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion temperature determinations for 32 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Air-dried loss	Forms of sulfur			Free swelling	Ash fusion temperature, C°		
		Sulfate	Pyritic	Organic		Initial deformation	Softening	Fluid
D179383	24.3	0.06	0.24	0.51	0.0	1,195	1,255	1,295
	---	.11	.45	.96				
	---	.13	.50	1.07				
D180075	27.2	.07	.41	.03	.0	1,320	1,370	1,400
	---	.12	.73	.05				
	---	.14	.79	.06				
D180076	28.9	.03	.18	.82	.0	1,265	1,305	1,330
	---	.05	.32	1.46				
	---	.06	.38	1.72				
D179384	25.5	.01	.10	.98	.0	1,440	1,505	1,540
	---	.02	.19	1.86				
	---	.02	.22	2.11				
D180078	27.3	.01	.53	.15	.0	1,100	1,175	1,205
	---	.02	.99	.28				
	---	.02	1.11	.32				
D180079	28.9	.01	.18	.36	.0	1,325	1,375	1,405
	---	.02	.32	.65				
	---	.02	.36	.72				
D180080	28.6	.01	.09	.30	.0	1,320	1,380	1,425
	---	.02	.16	.54				
	---	.02	.18	.59				
D180083	26.5	.09	.09	.89	.0	1,220	1,275	1,310
	---	.16	.16	1.60				
	---	.18	.18	1.82				

Table 3.--Major and minor oxide and trace element composition of the laboratory ash of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.

[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 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
D178498	22.8	28	8.3	10	2.90	1.07	0.21	13	0.83	1.0L	D178498
D178499	15.6	13	6.4	10	6.70	2.22	.14	17	.40	1.0L	D178499
D178500	23.2	53	8.5	5.0	2.50	2.84	1.3	7.6	.72	1.0L	D178500
D178501	9.5	15	10	19	8.47	4.65	.15	3.6	.67	1.1	D178501
D178502	14.0	45	7.6	10	5.01	3.24	.60	4.3	.88	1.0L	D178502
D178503	11.1	11	3.4	14	6.63	8.28	.31	13	.33	1.0L	D178503
D178507	27.9	23	16	12	2.34	.82	.64	7.3	1.5	1.0L	D178507
D178508	9.1	13	6.4	18	11.5	1.56	.22	5.9	.35	1.0L	D178508
D178509	18.1	51	4.8	6.2	2.64	2.68	.53	9.3	.72	1.0L	D178509
D178510	10.6	11	5.7	15	6.90	2.75	.14	15	.39	1.0L	D178510
D178511	12.0	23	14	17	7.89	1.54	.23	1.6	.58	1.0L	D178511
D178512	7.2	15	9.6	21	9.48	2.78	.30	7.0	.37	1.0L	D178512
D179369	10.8	19	9.7	16	6.78	1.85	.44	11	.70	1.0L	D179369
D179370	10.9	12	4.7	10	4.86	6.90	.36	21	.45	1.0L	D179370
D179371	9.4	9.5	8.2	20	8.84	1.69	.27	9.8	.61	1.0L	D179371
D178504	10.9	25	8.1	20	6.93	1.85	.49	5.4	.75	1.0L	D178504
D178505	19.8	8.1	5.4	31	3.93	1.40	.26	5.7	.31	1.0L	D178505
D178506	7.9	13	9.3	19	8.21	5.23	.40	6.0	.38	1.2	D178506
D179372	11.9	37	8.4	15	6.28	4.29	.70	4.5	.83	1.0L	D179372
D179373	14.2	23	9.1	12	5.16	3.33	.70	13	.68	1.0L	D179373
D179374	10.6	11	5.6	15	6.60	.92	.28	15	.62	1.0L	D179374
D179375	18.4	20	10	8.4	3.98	4.83	.71	17	.49	1.0L	D179375
D179376	10.7	26	9.7	15	6.58	8.43	.51	2.9	.73	1.0L	D179376
D179377	9.1	27	7.2	16	9.14	7.99	.50	2.1	.76	1.0L	D179377
D179378	11.9	8.9	7.2	14	5.65	6.34	.23	15	.38	1.0L	D179378
D179379	7.9	5.9	5.5	14	6.14	2.78	.27	20	.29	1.0L	D179379
D179380	10.6	26	8.9	16	6.63	.54	.38	4.4	1.2	1.0L	D179380
D179381	10.9	24	14	17	7.08	5.95	.37	1.7	.82	1.0L	D179381
D179382	6.8	10	9.4	21	8.31	.70	.39	2.7	.53	1.0L	D179382
D179383	9.6	9.5	9.1	18	7.93	.54	.34	3.1	.71	1.0L	D179383
D180075	9.6	20	11	23	6.45	.36	.21	1.1	.48	1.0L	D180075
D180076	10.6	20	11	19	6.73	.30	.34	3.6	.66	1.0L	D180076
D180077	21.7	39	14	7.1	3.20	1.24	1.7	7.1	.55	1.0L	D180077
D179384	11.6	12	7.4	13	5.41	3.88	.42	17	.45	1.0L	D179384
D180078	10.1	13	8.8	15	6.65	8.93	.29	7.9	.61	1.0L	D180078
D180079	9.3	13	9.9	23	5.93	1.55	.22	4.3	.33	1.6	D180079
D180080	9.2	11	8.6	19	7.90	.80	.10	4.4	.34	1.0L	D180080
D180081	15.5	37	12	8.5	4.63	3.28	1.4	6.0	.65	1.0L	D180081
D180082	7.8	10	9.8	24	11.4	2.09	.14	2.0	.49	1.6	D180082
D180083	8.9	16	11	20	8.33	1.95	.27	5.8	.59	1.2	D180083

Table 3.--Major and minor oxide and trace element composition of the laboratory ash of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	SO3 (percent)	Ag-S (ppm)	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Co-S (ppm)	Cr-S (ppm)	Cu (ppm)	Sample number
D178498	19	N	150	300	10	4.5	200	50	50	90	D178498
D178499	27	N	1,000	300	3	1.0L	N	10	20	42	D178499
D178500	11	N	300	1,500	5	1.0L	N	5	50	60	D178500
D178501	17	N	700	10,000	3	1.0L	N	N	20	42	D178501
D178502	18	N	500	2,000	N	1.0L	N	5	50	26	D178502
D178503	28	N	700	5,000	15	1.0L	N	20	20	56	D178503
D178507	25	N	70	20,000	15	9.5	300	70	150	278	D178507
D178508	21	N	1,500	1,000	10	1.0L	N	15	100	53	D178508
D178509	12	N	700	1,000	7	1.0L	N	7	30	62	D178509
D178510	31	N	700	1,500	5	1.0L	N	N	20	61	D178510
D178511	.94	N	700	2,000	N	1.0L	N	N	20	46	D178511
D178512	17	N	1,000	5,000	3	1.0L	N	15	50	34	D178512
D179369	28	N	1,000	1,000	N	1.0L	N	7	30	86	D179369
D179370	34	N	700	7,000	5	1.0L	N	10	15	32	D179370
D179371	28	N	700	7,000	N	1.0L	N	7	20	32	D179371
D178504	11	N	700	10,000	10	1.0L	N	10	30	116	D178504
D178505	15	N	300	3,000	N	1.0L	N	N	20	31	D178505
D178506	19	N	1,000	5,000	3	1.0L	N	15	20	37	D178506
D179372	19	N	500	7,000	N	1.0L	N	10	50	94	D179372
D179373	27	N	500	3,000	3	1.0L	N	10	30	55	D179373
D179374	34	N	1,000	1,500	N	1.0L	N	10	20	55	D179374
D179375	28	N	500	3,000	15	1.0L	N	15	50	105	D179375
D179376	22	N	1,000	7,000	N	1.0L	N	7	50	60	D179376
D179377	16	N	1,000	5,000	7	1.0L	N	7	50	63	D179377
D179378	27	N	700	5,000	N	1.0L	N	5	15	35	D179378
D179379	30	N	1,000	3,000	5	1.0L	N	10	15	40	D179379
D179380	21	N	700	15,000	7	1.0L	N	5	50	49	D179380
D179381	16	N	700	10,000	N	1.0L	N	N	20	75	D179381
D179382	27	N	700	10,000	N	1.0L	N	10	20	37	D179382
D179383	36	N	1,000	15,000	N	1.0L	N	10	20	40	D179383
D180075	20	N	700	5,000	N	1.0L	N	15	20	60	D180075
D180076	23	N	1,000	7,000	N	1.0L	N	5	50	49	D180076
D180077	13	N	500	1,000	20	1.0L	N	15	200	127	D180077
D179384	31	N	500	5,000	N	1.0L	N	7	20	35	D179384
D180078	28	N	700	10,000	N	1.0L	N	5	30	43	D180078
D180079	25	N	1,000	3,000	N	1.0L	N	10	20	36	D180079
D180080	31	7	1,000	5,000	N	1.0L	N	5	20	35	D180080
D180081	16	N	700	3,000	30	1.0L	N	15	150	111	D180081
D180082	16	N	1,000	7,000	3	1.0L	N	30	50	49	D180082
D180083	21	N	700	7,000	3	1.0L	N	5	30	46	D180083

Table 3.--Major and minor oxide and trace element composition of the laboratory ash of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Ga-S (ppm)	Ge-S (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Nd-S (ppm)	Ni-S (ppm)	Pb (ppm)	Sample number
D178498	15	N	100	15	950	20	N	200	150	25L	D178498
D178499	20	20	N	21	1,440	30	N	B	50	25L	D178499
D178500	20	N	N	30	160	20	20	B	7	25	D178500
D178501	20	N	N	46	410	10	N	B	7	30	D178501
D178502	20	N	N	21	190	20	20	B	15	25L	D178502
D178503	10	N	N	10L	265	30	N	B	30	25	D178503
D178507	30	N	150	19	590	1,000	N	300	300	25	D178507
D178508	20	30	N	35	2,360	50	N	B	20	25	D178508
D178509	20	N	N	19	530	30	20	B	10	25L	D178509
D178510	20	N	N	18	570	50	N	B	10	25L	D178510
D178511	20	N	N	64	575	10	N	B	15	25	D178511
D178512	20	N	N	19	580	30	N	B	30	35	D178512
D179369	20	N	N	25	1,460	15	20	B	15	120	D179369
D179370	15	N	N	13	390	30	N	B	20	25L	D179370
D179371	20	N	N	24	530	10	N	B	15	25	D179371
D178504	15	N	N	29	3,800	10	20	B	10	50	D178504
D178505	15	N	N	16	3,320	10	N	B	7	25	D178505
D178506	20	N	N	25	1,030	20	N	B	20	50	D178506
D179372	20	N	N	27	560	15	N	B	15	35	D179372
D179373	20	N	N	25	420	15	N	B	30	40	D179373
D179374	15	N	N	15	1,420	30	N	B	20	25L	D179374
D179375	20	N	N	34	485	20	N	B	50	25	D179375
D179376	20	N	N	37	705	20	N	B	20	25	D179376
D179377	10	N	N	24	960	10	N	B	10	25	D179377
D179378	15	N	N	33	705	20	N	B	20	35	D179378
D179379	20	N	N	11	605	30	20	B	7	25L	D179379
D179380	20	N	N	27	585	15	30	B	10	35	D179380
D179381	20	N	N	81	545	N	N	B	10	160	D179381
D179382	15	N	N	25	380	N	N	B	30	30	D179382
D179383	15	20L	N	32	1,550	20	N	B	20	35	D179383
D180075	15	N	N	39	635	20	N	B	20	70	D180075
D180076	20	N	N	33	1,720	10	20	B	7	30	D180076
D180077	30	30	70	37	415	50	20	N	50	30	D180077
D179384	20	N	N	23	295	10	20	B	10	30	D179384
D180078	15	N	N	32	705	10	N	B	15	25	D180078
D180079	20	N	N	33	2,140	10	N	B	20	25	D180079
D180080	15	N	N	20	970	10	N	B	7	25L	D180080
D180081	30	30	N	28	310	50	20	B	50	25	D180081
D180082	30	20L	70	23	830	10	20	N	10	25	D180082
D180083	15	N	N	33	650	15	N	B	15	25	D180083

Table 3.--Major and minor oxide and trace element composition of the laboratory ash of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Sc-S (ppm)	Sr-S (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)	Sample number
D178498	15	500	70	100	B	225	100	D178498
D178499	7	500	70	20	B	90	70	D178499
D178500	10	1,000	70	30	3	40	150	D178500
D178501	7	1,500	50	70	3	27	70	D178501
D178502	10	700	70	30	5	20L	150	D178502
D178503	10	1,000	30	70	B	71	20	D178503
D178507	50	150	300	300	30	314	150	D178507
D178508	20	1,000	150	70	7	41	100	D178508
D178509	7	1,000	70	70	7	30	200	D178509
D178510	7	1,000	50	70	B	23	70	D178510
D178511	5	1,000	70	N	N	40	100	D178511
D178512	5	2,000	50	50	3	87	70	D178512
D179369	10	2,000	100	30	B	73	100	D179369
D179370	7	2,000	30	30	B	38	70	D179370
D179371	5	3,000	30	20	B	46	70	D179371
D178504	15	700	70	70	7	91	100	D178504
D178505	N	1,000	50	20	2	25	50	D178505
D178506	7	1,500	50	70	7	73	70	D178506
D179372	7	2,000	70	50	3	52	150	D179372
D179373	7	2,000	70	50	B	67	70	D179373
D179374	N	1,500	70	20	B	18	70	D179374
D179375	20	1,500	150	70	B	101	100	D179375
D179376	10	3,000	70	50	5	27	150	D179376
D179377	10	3,000	70	70	5	38	150	D179377
D179378	5	2,000	50	20	B	55	70	D179378
D179379	7	2,000	50	50	B	22	70	D179379
D179380	15	3,000	70	70	7	30	150	D179380
D179381	7	3,000	50	20	2	93	100	D179381
D179382	5	5,000	30	20	2	29	70	D179382
D179383	5	3,000	50	20	2	35	70	D179383
D180075	5	500	50	20	2	76	100	D180075
D180076	5	1,500	70	20	2	36	100	D180076
D180077	30	1,500	500	100	15	344	200	D180077
D179384	7	2,000	50	30	B	84	70	D179384
D180078	7	3,000	70	20	2	27	100	D180078
D180079	5	2,000	30	30	2	29	100	D180079
D180080	N	2,000	50	N	2	38	70	D180080
D180081	50	1,000	300	150	15	88	150	D180081
D180082	10	5,000	70	70	5	43	100	D180082
D180083	5	3,000	70	20	2	39	100	D180083

Table 4.--Content of seven trace elements in 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.

[Analyses on air-dried (32°C) lignite. Values in parts per million (ppm). L, less than the value shown]

Sample number	As	F	Hg	Sb	Se	Th	U	Sample number
D178498	9.0	55	0.23	0.3	1.7	3.0L	1.2	D178498
D178499	5.0	20L	.12	.4	.9	3.0L	.7	D178499
D178500	13	70	.17	.8	.4	12	1.6	D178500
D178501	3.0	30	.10	.1	.2	4.7	.2L	D178501
D178502	2.0	35	.12	.2	.1L	3.0L	.2L	D178502
D178503	18	20L	.21	.1L	.1L	3.0L	.5	D178503
D178507	9.5	230	.40	.2	3.3	3.0L	11	D178507
D178508	3.0	30	.06	.3	.4	3.0L	2.9	D178508
D178509	5.5	40	.08	.4	.1L	3.0L	2.8	D178509
D178510	16	20L	.13	.4	.1L	3.0L	1.4	D178510
D178511	2.0	20L	.07	.1	.1L	3.0L	1.5	D178511
D178512	2.0	25	.12	.2	.2	3.0L	.6	D178512
D179369	5.0	20L	.18	.4	1.1	3.0L	.9	D179369
D179370	8.5	20L	.19	.1L	.2	3.0L	.4	D179370
D179371	4.0	20	.17	.1	.6	3.0L	.3	D179371
D178504	3.0	30	.10	.2	.1L	3.0L	1.5	D178504
D178505	5.0	20L	.11	.2	.4	3.0L	.9	D178505
D178506	1.5	35	.06	.1L	.1L	3.0L	.5	D178506
D179372	8.5	30	.12	.5	.4	3.0L	1.1	D179372
D179373	9.0	25	.22	.3	.6	3.0L	.8	D179373
D179374	3.0	20L	.15	.3	.7	3.0L	.8	D179374
D179375	39	25	.25	1.0	1.4	3.0L	2.4	D179375
D179376	2.5	25	.08	.4	.5	3.0L	1.1	D179376
D179377	1.5	20L	.06	.2	.5	3.0L	.8	D179377
D179378	5.0	20L	.24	.2	.8	3.0L	.7	D179378
D179379	13	20L	.26	.3	.4	3.0L	.4	D179379
D179380	4.5	20L	.07	.2	.5	3.0L	.6	D179380
D179381	1.5	20L	.05	.2	.6	3.0L	.8	D179381
D179382	1.5	20L	.05	.3	.2	3.0L	.2L	D179382
D179383	2.5	20L	.13	.3	.5	3.0L	.5	D179383
D180075	2.0	65	.07	.3	1.3	3.0L	.7	D180075
D180076	3.0	30	.11	.3	.5	3.0L	.8	D180076
D180077	24	120	.30	3.8	1.6	3.0L	6.2	D180077
D179384	14	20L	.20	.5	.6	3.0L	.6	D179384
D180078	7.5	20L	.19	.1	1.4	3.0L	.5	D180078
D180079	1.5	20L	.12	.2	.6	3.0L	.8	D180079
D180080	3.0	20L	.12	2.1	.7	3.0L	.3	D180080
D180081	17	70	.10	.3	1.0	3.0L	3.6	D180081
D180082	2.0	20L	.13	.4	.7	3.0L	.6	D180082
D180083	4.0	40	.15	.3	1.1	3.0L	1.0	D180083

Table 5.--Major, minor, and trace element composition of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.

[Values in percent or parts per million. As, F, Hg, Sb, Se, Th, and U values are from direct determinations on air-dried (32°C) lignite; 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]

Sample number	Si (percent)	Al (percent)	Ca (percent)	Mg (percent)	Na (percent)	K (percent)	Fe (percent)	Ti (percent)	Ag-S (ppm)	As (ppm)	Sample number
D178498	3.0	1.0	1.6	0.40	0.18	0.040	2.1	0.11	N	9.0	D178498
D178499	.93	.53	1.1	.63	.26	.018	1.9	.037	N	5.0	D178499
D178500	5.7	1.0	.83	.35	.49	.25	1.2	.10	N	13	D178500
D178501	.68	.52	1.3	.48	.33	.012	.24	.038	N	3.0	D178501
D178502	2.9	.56	1.0	.42	.34	.070	.42	.074	N	2.0	D178502
D178503	.54	.20	1.1	.44	.68	.029	1.0	.022	N	18	D178503
D178507	3.0	2.4	2.4	.39	.17	.15	1.4	.25	N	9.5	D178507
D178508	.54	.31	1.2	.63	.11	.017	.37	.019	N	3.0	D178508
D178509	4.3	.46	.80	.29	.36	.080	1.2	.078	N	5.5	D178509
D178510	.54	.32	1.1	.44	.22	.012	1.1	.025	N	16	D178510
D178511	1.3	.89	1.5	.57	.14	.023	.13	.042	N	2.0	D178511
D178512	.50	.36	1.1	.41	.15	.018	.35	.016	N	2.0	D178512
D179369	.96	.55	1.2	.44	.15	.040	.83	.045	N	5.0	D179369
D179370	.61	.27	.81	.32	.56	.033	1.6	.029	N	8.5	D179370
D179371	.42	.41	1.3	.50	.12	.021	.64	.034	N	4.0	D179371
D178504	1.3	.46	1.5	.45	.15	.044	.41	.049	N	3.0	D178504
D178505	.75	.57	4.4	.47	.21	.043	.79	.037	N	5.0	D178505
D178506	.48	.39	1.1	.39	.31	.026	.33	.018	N	1.5	D178506
D179372	2.0	.53	1.3	.45	.38	.069	.37	.059	N	8.5	D179372
D179373	1.5	.68	1.2	.44	.35	.083	1.3	.058	N	9.0	D179373
D179374	.54	.31	1.1	.42	.072	.025	1.1	.039	N	3.0	D179374
D179375	1.7	.97	1.1	.44	.66	.11	2.2	.054	N	39	D179375
D179376	1.3	.55	1.1	.42	.67	.045	.22	.047	N	2.5	D179376
D179377	1.2	.35	1.0	.50	.54	.038	.13	.041	N	1.5	D179377
D179378	.49	.45	1.2	.40	.56	.023	1.2	.027	N	5.0	D179378
D179379	.22	.23	.79	.29	.16	.018	1.1	.014	N	13	D179379
D179380	1.3	.50	1.2	.42	.042	.034	.33	.076	N	4.5	D179380
D179381	1.2	.82	1.3	.46	.48	.034	.13	.054	N	1.5	D179381
D179382	.32	.34	1.0	.34	.035	.022	.13	.022	N	1.5	D179382
D179383	.43	.46	1.2	.46	.038	.027	.21	.041	N	2.5	D179383
D180075	.91	.57	1.6	.37	.026	.017	.076	.028	N	2.0	D180075
D180076	.99	.62	1.4	.43	.024	.030	.26	.042	N	3.0	D180076
D180077	4.0	1.6	1.1	.42	.20	.30	1.1	.071	N	24	D180077
D179384	.66	.45	1.1	.38	.33	.041	1.4	.031	N	14	D179384
D180078	.63	.47	1.1	.40	.67	.024	.56	.037	N	7.5	D180078
D180079	.57	.49	1.5	.33	.11	.017	.28	.018	N	1.5	D180079
D180080	.47	.42	1.3	.44	.055	.008	.29	.019	.7	3.0	D180080
D180081	2.7	.98	.95	.43	.38	.19	.65	.060	N	17	D180081
D180082	.36	.40	1.3	.54	.12	.009	.11	.023	N	2.0	D180082
D180083	.65	.50	1.3	.45	.13	.020	.36	.031	N	4.0	D180083

Table 5.--Major, minor, and trace element composition of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cd (ppm)	Ce-S (ppm)	Co-S (ppm)	Cr-S (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Sample number
D178498	30	70	2	1.0	50	10	10	21	55	3	D178498
D178499	150	50	.5	.16L	N	1.5	3	6.6	20L	3	D178499
D178500	70	300	1	.23L	N	1	10	14	70	5	D178500
D178501	70	1,000	.3	.10L	N	N	2	4.0	30	2	D178501
D178502	70	300	N	.14L	N	.7	7	3.6	35	3	D178502
D178503	70	500	1.5	.11L	N	2	2	6.2	20L	1	D178503
D178507	20	5,000	5	2.7	100	20	50	78	230	10	D178507
D178508	150	100	1	.09L	N	1.5	10	4.8	30	2	D178508
D178509	150	200	1.5	.18L	N	1.5	5	11	40	3	D178509
D178510	70	150	.5	.11L	N	N	2	6.5	20L	2	D178510
D178511	100	200	N	.12L	N	N	2	5.5	20L	2	D178511
D178512	70	300	.2	.07L	N	1	3	2.4	25	1.5	D178512
D179369	100	100	N	.11L	N	.7	3	9.3	20L	2	D179369
D179370	70	700	.5	.11L	N	1	1.5	3.5	20L	1.5	D179370
D179371	70	700	N	.09L	N	.7	2	3.0	20	2	D179371
D178504	70	1,000	1	.11L	N	1	3	13	30	1.5	D178504
D178505	70	700	N	.20L	N	N	5	6.1	20L	3	D178505
D178506	70	500	.2	.08L	N	1	1.5	2.9	35	1.5	D178506
D179372	70	1,000	N	.12L	N	1	7	11	30	2	D179372
D179373	70	500	.5	.14L	N	1.5	5	7.8	25	3	D179373
D179374	100	150	N	.11L	N	1	2	5.8	20L	1.5	D179374
D179375	100	500	3	.18L	N	3	10	19	25	3	D179375
D179376	100	700	N	.11L	N	.7	5	6.4	25	2	D179376
D179377	100	500	.7	.09L	N	.7	5	5.7	20L	1	D179377
D179378	100	700	N	.12L	N	.7	2	4.2	20L	2	D179378
D179379	70	200	.5	.08L	N	.7	1	3.2	20L	1.5	D179379
D179380	70	1,500	.7	.11L	N	.5	5	5.2	20L	2	D179380
D179381	70	1,000	N	.11L	N	N	2	8.2	20L	2	D179381
D179382	50	700	N	.07L	N	.7	1.5	2.5	20L	1	D179382
D179383	100	1,500	N	.10L	N	1	2	3.8	20L	1.5	D179383
D180075	70	500	N	.10L	N	1.5	2	5.8	65	1.5	D180075
D180076	100	700	N	.11L	N	.5	5	5.2	30	2	D180076
D180077	100	200	5	.22L	N	3	50	28	120	7	D180077
D179384	70	700	N	.12L	N	.7	2	4.1	20L	2	D179384
D180078	70	1,000	N	.10L	N	.5	3	4.3	20L	1.5	D180078
D180079	100	300	N	.09L	N	1	2	3.3	20L	2	D180079
D180080	100	500	N	.09L	N	.5	2	3.2	20L	1.5	D180080
D180081	100	500	5	.16L	N	2	20	17	70	5	D180081
D180082	70	500	.2	.08L	N	2	5	3.8	20L	2	D180082
D180083	70	700	.3	.09L	N	.5	3	4.1	40	1.5	D180083

Table 5.--Major, minor, and trace element composition of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Ge-S (ppm)	Hg (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Nd-S (ppm)	Ni-S (ppm)	P (ppm)	Sample number
D178498	N	0.23	20	3.4	220	5	N	50	30	1,000L	D178498
D178499	3	.12	N	3.3	220	5	N	B	7	680L	D178499
D178500	N	.17	N	7.0	37	5	5	B	1.5	1,000L	D178500
D178501	N	.10	N	4.4	39	1	N	B	.7	460	D178501
D178502	N	.12	N	2.9	27	3	3	B	2	610L	D178502
D178503	N	.21	N	1.1L	29	3	N	B	3	490L	D178503
D178507	N	.40	50	5.3	160	300	N	100	100	1,200L	D178507
D178508	3	.06	N	3.2	210	5	N	B	2	400L	D178508
D178509	N	.08	N	3.4	96	5	3	B	2	790L	D178509
D178510	N	.13	N	1.9	60	5	N	B	1	460L	D178510
D178511	N	.07	N	7.7	69	1	N	B	2	520L	D178511
D178512	N	.12	N	1.4	42	2	N	B	2	310L	D178512
D179369	N	.18	N	2.7	160	1.5	2	B	1.5	470L	D179369
D179370	N	.19	N	1.4	43	3	N	B	2	480L	D179370
D179371	N	.17	N	2.3	50	1	N	B	1.5	410L	D179371
D178504	N	.10	N	3.2	410	1	2	B	1	480L	D178504
D178505	N	.11	N	3.2	660	2	N	B	1.5	870L	D178505
D178506	N	.06	N	2.0	81	1.5	N	B	1.5	400	D178506
D179372	N	.12	N	3.2	67	2	N	B	2	520L	D179372
D179373	N	.22	N	3.6	60	2	N	B	5	620L	D179373
D179374	N	.15	N	1.6	150	3	N	B	2	460L	D179374
D179375	N	.25	N	6.3	89	3	N	B	10	800L	D179375
D179376	N	.08	N	4.0	75	2	N	B	2	470L	D179376
D179377	N	.06	N	2.2	87	1	N	B	1	400L	D179377
D179378	N	.24	N	3.9	84	2	N	B	2	520L	D179378
D179379	N	.26	N	.9	48	2	1.5	B	.5	350L	D179379
D179380	N	.07	N	2.9	62	1.5	3	B	1	460L	D179380
D179381	N	.05	N	8.8	59	N	N	B	1	480L	D179381
D179382	N	.05	N	1.7	26	N	N	B	2	300L	D179382
D179383	2L	.13	N	3.1	150	2	N	B	2	420L	D179383
D180075	N	.07	N	3.7	61	2	N	B	2	420L	D180075
D180076	N	.11	N	3.5	180	1	2	B	.7	460L	D180076
D180077	7	.30	15	8.0	90	10	5	N	10	950L	D180077
D179384	N	.20	N	2.7	34	1	2	B	1	510L	D179384
D180078	N	.19	N	3.2	71	1	N	B	1.5	440L	D180078
D180079	N	.12	N	3.1	200	1	N	B	2	630	D180079
D180080	N	.12	N	1.8	89	1	N	B	.7	400L	D180080
D180081	5	.10	N	4.3	48	7	3	B	7	680L	D180081
D180082	1.5L	.13	5	1.8	65	.7	1.5	N	.7	540	D180082
D180083	N	.15	N	2.9	58	1.5	N	B	1.5	470	D180083

Table 5.--Major, minor, and trace element composition of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Pb (ppm)	Sb (ppm)	Sc-S (ppm)	Se (ppm)	Sr-S (ppm)	Th (ppm)	U (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Sample number
D178498	5.7L	0.3	3	1.7	100	3.0L	1.2	15	20	B	D178498
D178499	3.9L	.4	1	.9	70	3.0L	.7	10	3	B	D178499
D178500	5.8	.8	2	.4	200	12.2	1.6	15	7	.7	D178500
D178501	2.9	.1	.7	.2	150	4.7	.2L	5	7	.3	D178501
D178502	3.5L	.2	1.5	.1L	100	3.0L	.2L	10	5	.7	D178502
D178503	2.8	.1L	1	.1L	100	3.0L	.5	3	7	B	D178503
D178507	7.0	.2	15	3.3	50	3.0L	11	100	100	10	D178507
D178508	2.3	.3	2	.4	100	3.0L	2.9	15	7	.7	D178508
D178509	4.5L	.4	1.5	.1L	200	3.0L	2.8	15	15	1.5	D178509
D178510	2.7L	.4	.7	.1L	100	3.0L	1.4	5	7	B	D178510
D178511	3.0	.1	.7	.1L	100	3.0L	1.5	10	N	N	D178511
D178512	2.5	.2	.3	.2	150	3.0L	.6	3	3	.2	D178512
D179369	13	.4	1	1.1	200	3.0L	.9	10	3	B	D179369
D179370	2.7L	.1L	.7	.2	200	3.0L	.4	3	3	B	D179370
D179371	2.4	.1	.5	.6	300	3.0L	.3	3	2	B	D179371
D178504	5.5	.2	1.5	.1L	70	3.0L	1.5	7	7	.7	D178504
D178505	5.0	.2	N	.4	200	3.0L	.9	10	5	.5	D178505
D178506	4.0	.1L	.5	.1L	100	3.0L	.5	5	5	.5	D178506
D179372	4.2	.5	1	.4	200	3.0L	1.1	10	7	.3	D179372
D179373	5.7	.3	1	.6	300	3.0L	.8	10	7	B	D179373
D179374	2.7L	.3	N	.7	150	3.0L	.8	7	2	B	D179374
D179375	4.6	1.0	3	1.4	300	3.0L	2.4	30	15	B	D179375
D179376	2.7	.4	1	.5	300	3.0L	1.1	7	5	.5	D179376
D179377	2.3	.2	1	.5	300	3.0L	.8	7	7	.5	D179377
D179378	4.2	.2	.7	.8	200	3.0L	.7	7	2	B	D179378
D179379	2.0L	.3	.5	.4	150	3.0L	.4	5	5	B	D179379
D179380	3.7	.2	1.5	.5	300	3.0L	.6	7	7	.7	D179380
D179381	17	.2	.7	.6	300	3.0L	.8	5	2	.2	D179381
D179382	2.0	.3	.3	.2	300	3.0L	.2L	2	1.5	.15	D179382
D179383	3.4	.3	.5	.5	300	3.0L	.5	5	2	.2	D179383
D180075	6.7	.3	.5	1.3	50	3.0L	.7	5	2	.2	D180075
D180076	3.2	.3	.5	.5	150	3.0L	.8	7	2	.2	D180076
D180077	6.5	3.8	7	1.6	300	3.0L	6.2	100	20	3	D180077
D179384	3.5	.5	.7	.6	200	3.0L	.6	7	3	B	D179384
D180078	2.5	.1	.7	1.4	300	3.0L	.5	7	2	.2	D180078
D180079	2.3	.2	.5	.6	200	3.0L	.8	3	3	.2	D180079
D180080	2.3L	2.1	N	.7	200	3.0L	.3	5	N	.2	D180080
D180081	3.9	.3	7	1.0	150	3.0L	3.6	50	20	2	D180081
D180082	2.0	.4	.7	.7	500	3.0L	.6	5	5	.5	D180082
D180083	2.2	.3	.5	1.1	300	3.0L	1.0	7	2	.2	D180083

Table 5.--Major, minor, and trace element composition of 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center field, Dunn County, N. Dak.--continued

Sample number	Zn (ppm)	Zr-S (ppm)
D178498	51	20
D178499	14	10
D178500	9.3	30
D178501	2.6	7
D178502	2.8L	20
D178503	7.9	2
D178507	88	50
D178508	3.7	10
D178509	5.4	30
D178510	2.4	7
D178511	4.8	10
D178512	6.3	5
D179369	7.9	10
D179370	4.1	7
D179371	4.3	7
D178504	9.9	10
D178505	5.0	10
D178506	5.8	5
D179372	6.2	20
D179373	9.5	10
D179374	1.9	7
D179375	19	20
D179376	2.9	15
D179377	3.5	15
D179378	6.5	10
D179379	1.7	5
D179380	3.2	15
D179381	10	10
D179382	2.0	5
D179383	3.4	7
D180075	7.3	10
D180076	3.8	10
D180077	75	50
D179384	9.7	7
D180078	2.7	10
D180079	2.7	10
D180080	3.5	7
D180081	14	20
D180082	3.4	7
D180083	3.5	10

Table 6.--Elements looked for, but not detected, in lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center Field, Dunn County, N. Dak.

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

Element	Lower limit of detection in coal ash (ppm)
Au	50
Bi	20
Dy	100
Er	100
Eu	200
Gd	100
Hf	200
Ho	50
In	20
Lu	70
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 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 seven coal samples from the E bed (Sentinel Butte Member, Fort Union Formation) Dunn Center lignite field, Dunn County, N. Dak.

[All values are in percent except Kcal/kg, Btu/lb, ash-fusion temperatures, and free-swelling index and are reported on the as-received basis. °C = (°F-32)5/9; Kcal/kg = 0.556 (Btu/lb)]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation
		Minimum	Maximum		
Proximate and ultimate analyses					
Moisture	40.1	35.3	45.4	39.9	1.1
Volatile matter	24.3	21.8	27.4	24.3	1.1
Fixed carbon	24.4	21.8	26.9	24.3	1.1
Ash	11.6	4.7	19.8	9.8	1.8
Hydrogen	6.9	6.2	7.5	6.8	1.1
Carbon	34.3	30.5	37.0	34.3	1.1
Nitrogen	.4	.2	.5	.4	1.4
Oxygen	45.8	40.8	51.3	45.6	1.1
Sulfur	1.5	.3	2.5	1.1	2.2
Heat of combustion					
Kcal/kg	3,230	2,905	3,480	3,220	1.1
Btu/lb	5,810	5,230	6,260	5,800	1.1
Forms of sulfur					
Sulfate	0.05	0.01	0.30	0.02	3.6
Pyritic	.42	.10	2.12	.24	2.9
Organic	1.11	.04	1.79	.52	3.6
Ash-fusion temperatures, °C					
Initial deformation	1,120	1,055	1,225	1,115	1.0
Softening temperature	1,205	1,120	1,330	1,200	1.1
Fluid temperature	1,250	1,155	1,380	1,245	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 nine lignite samples from the E bed (Sentinel Butte Member, Fort Union Formation), Dunn Center lignite field, Dunn County, N. Dak.

[All samples were ashed at 525°C; all analyses except geometric deviation are in percent. L, less than the value shown]

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation
		Minimum	Maximum		
(Ash)	13.2	7.8	23.2	12.2	1.5
SiO_2	28	5.9	53	21	2.1
Al_2O_3	7.5	4.7	10	7.2	1.3
CaO	13	5.0	24	12	1.7
MgO	6.1	2.50	11.4	5.34	1.7
Na_2O	4.1	1.85	7.99	3.57	1.7
K_2O	.57	.14	1.3	.47	1.9
Fe_2O_3	11	2.0	21	7.2	2.5
TiO_2	.62	.29	.83	.58	1.4
SO_3	20	11	34	18	1.6

Table 9.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 34 elements in nine lignite samples from the E bed (Sentinel Butte Member, Fort Union Formation), Dunn Center lignite field, Dunn County, N. Dak.

[All analyses are in percent or parts per million and are reported on a whole-lignite basis. As, 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]

Element	Arithmetic mean	Observed range		Geometric mean	Geometric deviation
		Minimum	Maximum		
		Percent			
Si	2.1	0.22	5.7	1.2	2.9
Al	.53	.23	1.0	.46	1.7
Ca	1.1	.79	1.5	1.0	1.3
Mg	.40	.29	.54	.39	1.3
Na	.40	.12	.66	.32	1.9
K	.076	.009	.25	.048	2.7
Fe	1.1	.076	2.2	.61	3.0
Ti	.052	.014	.10	.043	1.9
		Parts per million			
As	11	1.5	39	6.6	2.8
B	100	70	150	70	1.3
Ba	500	200	1,000	500	1.8
Be	1	.2L	3	.7	2.6
Co	1.5	.7	3	1	1.6
Cr	7	1	10	5	2.2
Cu	9.8	3.2	19	7.8	2.0
F	29	20L	70	25	1.7
Ga	2	1	5	2	1.6
Hg	.15	.06	2.6	.14	1.7
Li	3.4	.87	7.0	2.7	2.0
Mn	99	37	410	77	2.0
Mo	3	.7	5	2	2.0
Nb	3	.15L	5	1.5	2.0
Ni	2	.5	10	1.5	2.4
Pb	3.2	2.0	5.8	2.6	2.0
Sb	.5	.1L	1.0	.4	1.9
Sc	1.5	.5	3	1	1.8
Se	.5	.1L	1.4	.4	2.2
Sr	200	70	500	200	1.7
U	1.3	.2L	10.9	1.1	2.0
V	10	3	30	10	2.0
Y	7	3	15	7	1.7
Yb	.7	.3L	1.5	.7	1.7
Zn	7.0	1.7	19	5.5	2.0
Zr	15	5	30	15	1.9

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 of 18 lignite samples from the F bed (Sentinel Butte Member, Fort Union Formation), Dunn Center lignite field, Dunn County, N. Dak.

[All values are in percent except Kcal/kg, Btu/lb, ash-fusion temperatures, and free-swelling index and are reported on the as-received basis. °C = (°F-32)5/9; Kcal/kg = 0.556 (Btu/lb)]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation
		Minimum	Maximum		
Proximate and ultimate analyses					
Moisture	42.7	28.0	47.4	42.4	1.1
Volatile matter	25.2	22.3	29.7	25.2	1.1
Fixed carbon	25.2	21.6	29.5	25.1	1.1
Ash	7.0	3.7	12.8	6.7	1.3
Hydrogen	7.1	5	7.6	7.1	1.1
Carbon	36.0	33.2	42.6	35.9	1.1
Nitrogen	.5	.4	.7	.5	1.2
Oxygen	48.7	38.4	51.9	48.6	1.1
Sulfur	.8	.2	1.4	.7	1.8
Heat of combustion					
Kcal/kg	3,340	3,080	3,975	3,335	1.1
Btu/lb	6,010	5,540	7,120	6,000	1.1
Forms of sulfur					
Sulfate	0.03	0.01	0.09	0.02	2.3
Pyritic	.20	.06	.66	.16	2.0
Organic	.66	.02	1.12	.33	3.3
Ash-fusion temperatures, °C					
Initial deformation	1,220	1,090	1,440	1,210	1.1
Softening temperature	1,270	1,150	1,510	1,270	1.1
Fluid temperature	1,300	1,170	1,540	1,300	1.1

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 22 lignite samples from the F bed (Sentinel Butte Member, Fort Union Formation) Dunn Center lignite field, Dunn County, N. Dak.

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

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation
		Minimum	Maximum		
(Ash)	10.7	6.8	19.8	10.4	1.3
SiO_2	17	8.1	45	15	1.6
Al_2O_3	9.3	5.4	14	9.1	1.3
CaO	18	10	31	18	1.3
MgO	7.00	3.93	9.48	6.83	1.2
Na_2O	3.33	.30	8.93	2.00	2.8
K_2O	.33	.10	.70	.29	1.6
Fe_2O_3	6.5	1.1	17	4.9	2.1
TiO_2	.58	.31	1.2	.54	1.4
SO_3	26	.94	36	20	2.1

Table 12.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 34 elements in 22 lignite samples from the F bed (Sentinel Butte Member, Fort Union Formation), Dunn Center lignite field, Dunn County, N. Dak.

[All analyses are in percent or parts per million and are reported on a whole-lignite basis. As, 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. Leaders (---) indicate means could not be calculated owing to an insufficient number of analyses above the lower detection limit]

Element	Arithmetic mean	Observed range		Geometric mean	Geometric deviation
		Minimum	Maximum		
		Percent			
Si	0.86	0.32	2.9	0.74	1.7
Al	.52	.32	.89	.50	1.3
Ca	1.4	1.0	4.4	1.3	1.4
Mg	.43	.33	.57	.43	1.1
Na	.27	.024	.67	.15	2.9
K	.030	.008	.083	.025	1.7
Fe	.50	.076	1.4	.36	2.3
Ti	.037	.016	.076	.034	1.6
		Parts per million			
As	4.3	1.5	16	3.4	2.0
B	70	50	100	70	1.2
Ba	700	150	1,500	700	1.8
Be	.2	.2L	.7	.2	2.4
Co	.7	.5L	1.5	.7	1.6
Cr	3	1.5	7	3	1.6
Cu	4.7	2.4	8.2	4.4	1.4
F	22	20L	65	19	1.8
Ga	2	1	3	2	1.3
Hg	.12	.05	.24	.11	1.6
Li	3.4	1.4	8.8	3.1	1.6
Mn	93	26	660	72	2.1
Mo	1.5	1L	5	1.5	1.6
Nb	-----	2L	3	-----	-----
Ni	1.5	.7	5	1.5	1.6
Pb	3.7	2.0L	17	3.2	1.8
Sb	.3	.1L	2.1	.2	2.1
Sc	.7	.3L	1.5	.7	1.7
Se	.6	.1L	1.4	.4	2.4
Sr	200	50	300	200	1.7
U	.7	.3L	1.5	.6	1.7
V	7	2	10	7	1.5
Y	3	1.5L	7	3	1.8
Yb	.3	.15	.7	.3	1.7
Zn	4.7	2.0L	10	4.1	1.7
Zr	10	5	20	10	1.4

Table 13.--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 32 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center lignite field, Dunn County, N. Dak. For comparison, geometric means for 32 Fort Union region, North Dakota and eastern Montana lignite samples are included (Swanson and others, 1974, table 8).

[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]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Fort Union region geometric mean
		Minimum	Maximum			
Proximate and ultimate analyses						
Moisture	42.4	28.0	57.2	42.1	1.1	34.9
Volatile matter	25.4	21.8	40.0	25.3	1.1	27.4
Fixed carbon	23.9	7.8	29.5	23.2	1.3	30.1
Ash	8.4	3.7	19.8	7.7	1.5	6.4
Hydrogen	7.1	5.0	7.7	7.0	1.1	6.7
Carbon	34.8	18.8	42.6	34.5	1.2	40.7
Nitrogen	.5	.2	.7	.5	1.2	.6
Oxygen	48.3	38.4	59.8	48.1	1.1	43.9
Sulfur	1.1	.2	2.6	.9	1.9	.6
Heat of combustion						
Kcal/kg	3,235	1,560	3,960	3,190	1.2	3,770
Btu/lb	5,820	2,810	7,120	5,740	1.2	6,780
Forms of sulfur						
Sulfate	0.06	0.01	0.81	0.03	3.6	0.02
Pyritic	.22	.04	2.12	.16	2.2	.13
Organic	.91	.02	1.79	.46	3.2	.36
Ash-fusion temperatures, °C						
Initial deformation	1,190	1,055	1,440	1,180	1.1	-----
Softening temperature	1,245	1,115	1,510	1,240	1.1	-----
Fluid temperature	1,275	1,130	1,540	1,270	1.1	-----

Table 14.--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 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center lignite field, Dunn County, N. Dak. For comparison geometric means of analyses of 80 Fort Union region, North Dakota, and Montana lignite samples (Hatch and Swanson, 1977, table 5a) are included.

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

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Fort Union region geometric mean
		Minimum	Maximum			
(Ash)	12.4	6.8	27.9	11.7	1.4	9.0
SiO_2	20	5.9	53	17	1.7	13
Al_2O_3	8.9	3.4	16	8.4	1.4	8.6
CaO	16	5.0	31	15	1.5	22
MgO	6.53	2.34	11.5	6.05	1.5	7.01
Na_2O	3.28	.30	8.93	2.22	2.4	1.43
K_2O	.43	.10	1.7	.35	1.9	.059
Fe_2O_3	8.4	1.1	21	6.3	2.1	5.0
TiO_2	.60	.29	1.5	.56	1.5	.49
SO_3	24	.94	36	20	1.8	19

Table 15.--Arithmetic mean, observed range, geometric mean, and geometric deviation of 34 elements in 40 lignite samples from the Sentinel Butte Member, Fort Union Formation, Dunn Center lignite field, Dunn County, N. Dak. For comparison, geometric means for 80 Fort Union region coal samples are included (Hatch and Swanson, 1977, table 5b).

[All analyses are in percent or parts per million and are reported on a whole-lignite basis. As, 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]

Element	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Fort Union region geometric mean
		Minimum	Maximum			
			Percent			
Si	1.3	0.22	5.7	0.95	2.2	.55
Al	.59	.2	2.4	.52	1.6	.41
Ca	1.3	.8	4.4	1.2	1.3	1.4
Mg	.43	.29	.63	.43	1.2	.38
Na	.3	.02	.68	.19	2.6	.095
K	.05	.008	.3	.03	2.3	.006
Fe	.78	.08	2.2	.51	2.5	.32
Ti	.05	.01	.25	.04	1.8	.028
			Parts per million			
As	6.9	1.5	39	4.8	2.4	4
B	100	20	150	70	1.4	100
Ba	700	50	5,000	500	2.5	300
Be	1	.2	5	.2	5.3	.2
Co	1.5	.5	20	1	2.4	1.5
Cr	7	1	50	5	2.4	1.5
Cu	8.2	2.4	78	6.3	2.1	3.8
F	30	20L	230	20	2.6	26
Ga	2	1	10	2	1.6	1.5
Hg	.21	.05	.40	.14	2.4	.09
Li	3.4	.9L	8.8	3	1.7	2.4
Mn	107	26	660	82	2.1	29
Mo	5	.7	300	2	3.0	1
Nb	1.5	1.5	5	1	2.3	1
Ni	3	.5	100	2	2.8	1.5
Pb	3.7	2.0L	17	3	1.9	3.8
Sb	.4	.1L	3.8	.3	2.3	.2
Sc	1.5	.3	15	1	2.6	1.5
Se	.7	.2L	3.3	.5	2.6	.6
Sr	200	50	500	150	1.7	500
U	1.3	.3L	10.9	.9	2.4	.6
V	10	2	100	7	2.4	3
Y	7	1.5	100	5	2.6	3
Yb	.7	.2	10	.5	2.8	.2
Zn	9.1	1.7L	88	5.8	2.6	2.3
Zr	15	2	50	10	1.9	10