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GEOLOGICAL SURVEY

Geology and chemical analyses of coal, Mesaverde Group (Cretaceous), Lower White River coal field, Moffat and Rio Blanco Counties, Colorado

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Introduction

The Lower White River coal field comprises an area of approximately 930 square miles underlain by coal-bearing strata in Moffat and Rio Blanco Counties, northwestern Colorado (Landis, 1959; Hornbaker and others, 1976). The field lies along the northwestern edge of the Piceance Creek basin near the Utah border (fig. 1).

Significant coal deposits in the Lower White River field occur in the Mesaverde Group of Late Cretaceous age; original resources are estimated to be as much as 11,763 million short tons to a depth of 6,000 feet (Hornbaker and others, 1976).

A total of 13 samples of coal (10 core samples and 3 samples of drill cuttings) were collected from five drill holes in the northwestern part of the Lower White River field during exploratory drilling conducted by the U.S. Geological Survey in 1976 (see Garrigues, 1976; Barnum and others, 1977). These samples represent several coal beds in the middle part of the Mesaverde Group. Table 1 gives brief descriptions of the samples; the general geology of the area and sample localities are shown in figure 2.

Geologic setting

Early investigations of the geology and coal resources of the Lower White River field were made by Gale (1909, 1910). More recent studies of the geology of the area include Gaskill and Horn (1961), Dyni (1968), Cullins (1968, 1969, 1971), Hail (1974, 1975), Barnum and others (1977), Barnum and Garrigues (1980), and Garrigues and Barnum (1980).

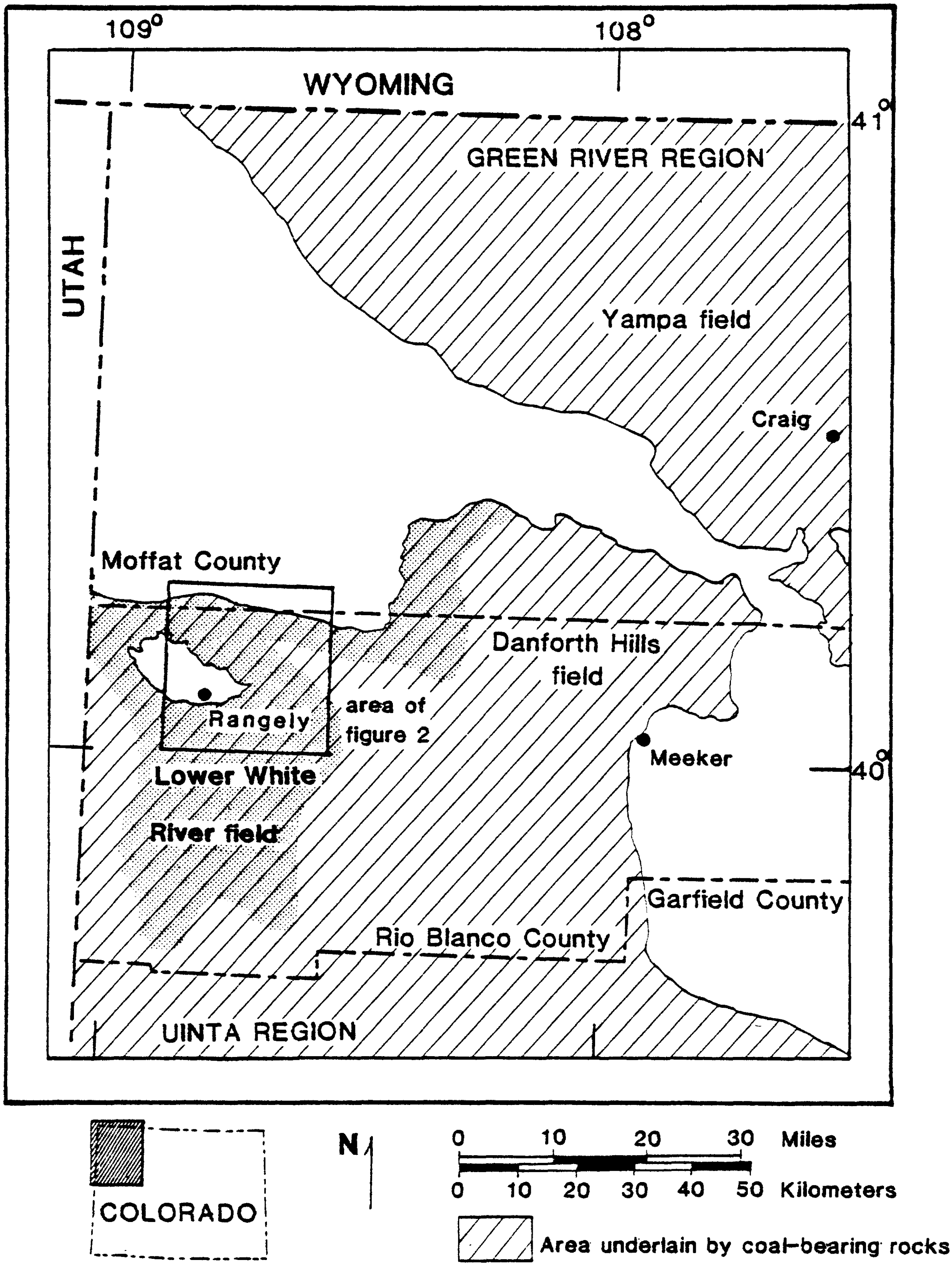

Figure 1.--Index map of the Lower White River coal field and vicinity (modified from Landis, 1959, and Jones, 1977).

Table 1.--U.S. Geological Survey Sample numbers, hole numbers, locations and depth intervals for 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[All samples collected by the U.S. Geological Survey]

USGS Sample number	Hole number	Location			Sample type	Depth interval (feet)
		Section	Township N.	Range W.		
			Moffat County			
D186083	LW-21-RN	15	3	102	Core	192.0-196.0
D186084	--do--	15	3	102	-do-	196.0-200.0
D186085	--do--	15	3	102	-do-	200.0-204.0
			Rio Blanco County			
D186086	LW-24-CR	11	2	101	Core	168.0-172.0
D186087	---do--	11	2	101	-do-	172.0-176.0
D186090	LW-12-GD	31	2	100	Cuttings	455.0-470.0
D186078	LW-16-GD	14	1	101	Core	193.2-197.2
D186079	---do--	14	1	101	-do-	276.0-281.0
D186080	---do--	14	1	101	-do-	282.0-285.5
D186081	---do--	14	1	101	-do-	290.0-294.0
D186082	---do--	14	1	101	-do-	294.0-300.0
D186088	LW-19-GD	32	1	101	Cuttings	220.0-235.0
D186089	---do--	32	1	101	-do-	380.0-390.0

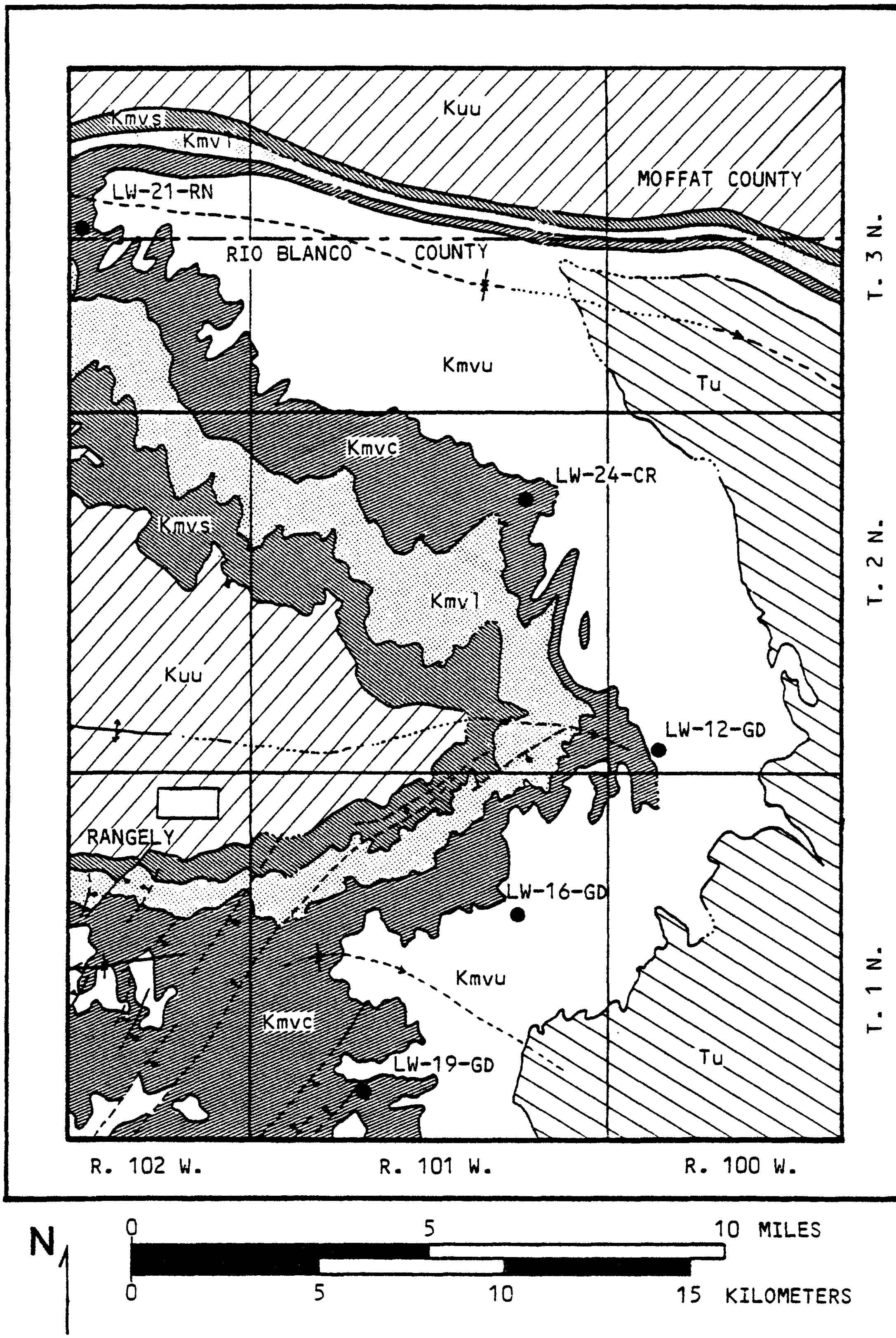

Figure 2.--Geologic map of part of the Lower White River coal field, showing locations of drill holes (modified from Garrigues, 1976, and Rowley and others, 1978).

EXPLANATION OF FIGURE 2

ROCK UNITS

TERTIARY

Tu	Tertiary rocks undivided

UPPER CRETACEOUS

MESAVERDE GROUP

Kmvu	Upper unit
Kmvc	Coal unit
Kmvl	Lower unit
Kmvs	Sego Sandstone
Kuu	Upper Cretaceous rocks undivided

CONTACT--dotted where concealed

FAULT--dashed where approximately located; dotted where concealed. Bar and ball on downthrown side

CREST OF ANTICLINE, SHOWING DIRECTION OF PLUNGE--Dashed where approximately located: dotted where concealed

TROUGH OF SYNCLINE, SHOWING DIRECTION OF PLUNGE--Dashed where approximately located; dotted where concealed

DRILL HOLE LOCALITY

The Mesaverde Group of Cretaceous age is the principal coal-bearing unit in the Lower White River field. Near Rangely, the Mesaverde Group is divided into the Sego Sandstone, lower unit, coal unit, and upper unit (Barnum and Garrigues, 1980). The main coal zone, ranging in thickness from 66 to 148 feet, is 164 to 295 feet above the base of the coal unit. Most of the coal in the Mesaverde Group is near the base of this zone in one to five beds which have thicknesses greater than three feet. The coal unit near Rangely is probably correlative to the lower part of the Williams Fork Formation in the Danforth Hills area (Barnum and Garrigues, 1980). The general stratigraphy of the various units present in the Lower White River field is shown in figure 3.

The sediments of the Mesaverde Group accumulated regionally in a series of marine, marginal marine, and nonmarine depositional environments along the western edge of the Interior Cretaceous Seaway (Masters, 1967; Berman and others, 1980). The coal beds in the middle member of the Mesaverde Group were probably deposited in brackish- and fresh-water swamps and marshes in interdelta and interdistributary regions along the shoreline of the regressing epeiric sea.

Chemical analyses of coal

Significant to any complete coal resource appraisal is an estimate of the chemical composition of the coal. Four somewhat overlapping reasons for obtaining comprehensive and precise chemical analyses of coal are as follows: (1) to help assess the environmental implications of coal mining and utilization, (2) to help determine the most suitable use of the coal, (3) to assess possible by-product recovery, and (4) to help interpret the geological and geochemical history of the coal-bearing rocks (Hatch and Swanson, 1977).

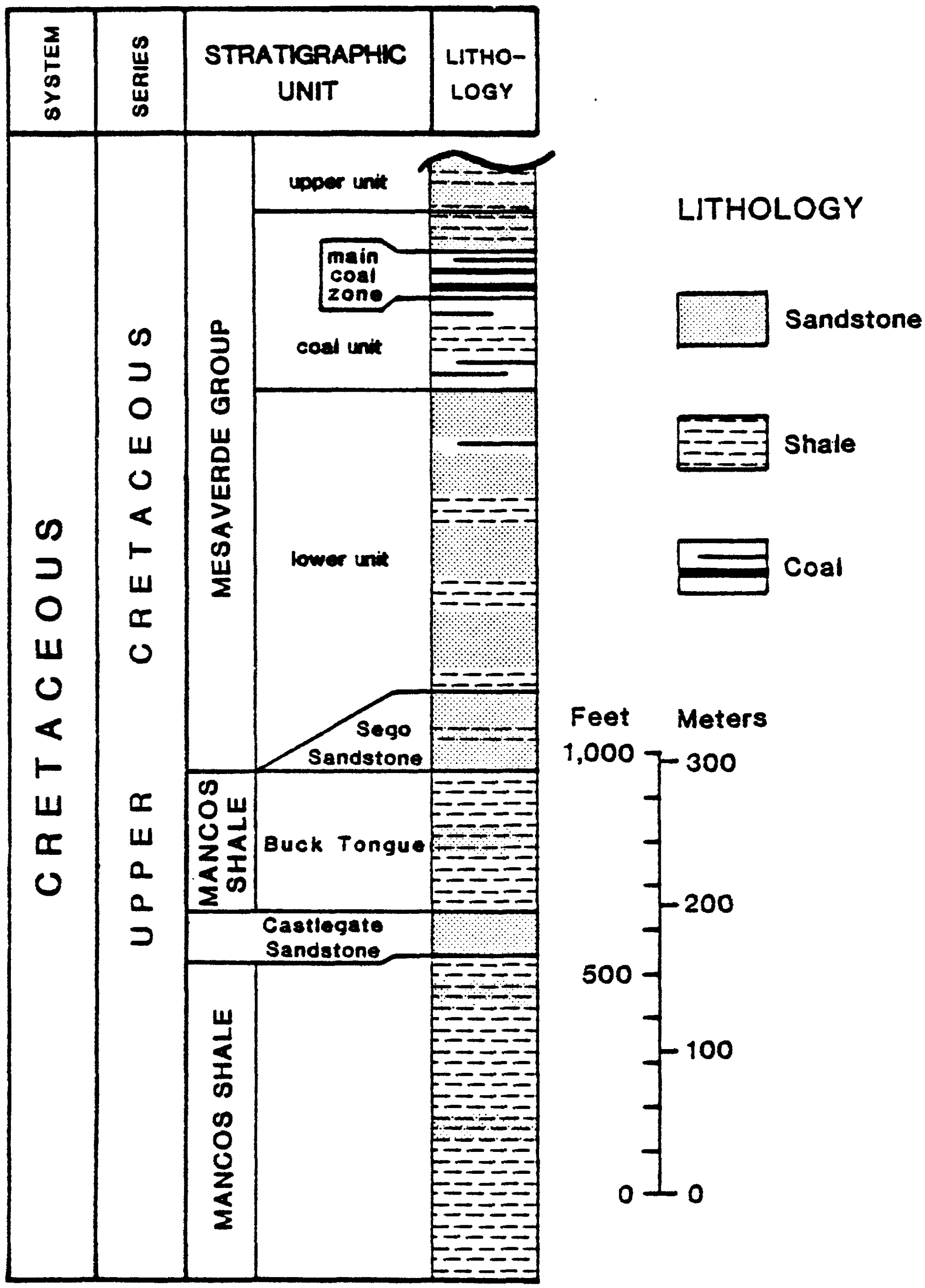

Figure 3.--Generalized stratigraphic column, western Lower White River coal field, Moffat and Rio Blanco Counties, Colorado (after Garrigues and Barnum, 1980).

Proximate and ultimate analyses, heat-of-combustion, air-dried-loss, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations for six single and three composite coal samples from the Lower White River field are given in table 2. These analyses were provided by the Coal Analysis Section, U.S. Bureau of Mines (now U.S. Department of Energy), Pittsburgh, Pa. Analyses for ash content, contents of 29 major and minor oxides and trace elements in the laboratory ash (table 3), and contents of nine trace elements in whole coal (table 4) for the 13 coal samples were provided by the U.S. Geological Survey in Denver, Colo. Table 5 contains the data listed in table 3 converted to a whole-coal basis and includes the whole-coal analyses listed in table 4. Twenty-seven additional elements not listed in tables 3, 4, and 5 were looked for but not found in amounts greater than their lower limit of detection (table 6).

Most of the analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976). Arsenic, antimony, selenium, and thorium contents for all samples were determined by instrumental neutron activation analysis (lower detection limit 0.1 ppm).

Unweighted statistical summaries of the analytical data in tables 2, 3, and 4 are given in tables 7, 8, and 9. Summary data for lanthanum content in whole coal is not included in table 9 because lanthanum was detected in an insufficient number of samples to calculate meaningful statistics.

Table 2.--Proximate and ultimate analyses, and heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations for nine coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[All analyses except kcal/kg, Btu/lb, free-swelling index (FSI), and ash-fusion temperatures in percent. For each sample number, the analyses are reported three ways: first, as received; second, moisture free; third, moisture and ash free. Kcal/kg = 0.556 x (Btu/lb); °F = (°C x 1.8) + 32. D186083* is a composite of samples D186083 and D186084; D186086* is a composite of D186086 and D186087; D186081* is a composite of D186081 and D186082]

Sample number	Proximate analysis				Ultimate analysis					Heat of combustion	
	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
D186083*	17.1	30.8	37.4	14.7	5.4	51.5	1.1	26.8	0.4	4,930	8,880
	---	37.2	45.1	17.7	4.2	62.1	1.3	14.0	.5	5,950	10,710
	---	45.2	54.8	---	5.1	75.5	1.6	17.0	.6	7,240	13,020
D186086*	12.1	33.6	45.6	8.7	5.5	62.0	1.3	21.9	.4	6,020	10,830
	---	38.2	51.9	9.9	4.7	70.5	1.5	12.7	.5	6,840	12,320
	---	42.4	57.6	---	5.2	78.3	1.6	14.1	.5	7,600	13,670
D186090	9.5	30.9	35.7	23.9	4.5	51.0	1.0	19.0	.5	4,940	8,900
	---	34.1	39.4	26.4	3.8	56.4	1.1	11.7	.6	5,460	9,830
	---	46.4	53.6	---	5.2	76.6	1.5	15.8	.8	7,420	13,360
D186078	10.2	34.5	39.7	15.6	5.1	57.8	1.3	19.6	.6	5,640	10,160
	---	38.4	44.2	17.4	4.4	64.4	1.4	11.7	.7	6,280	11,310
	---	46.5	53.5	---	5.3	77.9	1.8	14.2	.8	7,600	13,690
D186079	9.8	32.5	39.3	18.4	5.1	55.7	1.2	18.9	.7	5,450	9,810
	---	36.0	43.6	20.4	4.4	61.8	1.3	11.3	.8	6,040	10,880
	---	45.3	54.7	---	5.6	77.6	1.7	14.2	1.0	7,590	13,660
D186080	10.1	36.8	42.7	10.4	5.4	62.4	1.3	20.1	.5	6,080	10,950
	---	40.9	47.5	11.6	4.8	69.4	1.4	12.4	.6	6,760	12,180
	---	46.3	53.7	---	5.4	78.5	1.6	14.0	.6	7,650	13,770
D186081*	10.5	34.7	47.2	7.6	5.5	64.5	1.3	20.5	.5	6,320	11,380
	---	38.8	52.7	8.5	4.8	72.1	1.5	12.5	.6	7,060	12,710
	---	42.4	57.6	---	5.3	78.8	1.6	13.6	.6	7,720	13,890
D186088	6.9	35.5	49.6	8.0	5.3	66.9	1.4	17.9	.5	6,510	11,720
	---	38.1	53.3	8.6	4.9	71.9	1.5	12.6	.5	6,990	12,590
	---	41.7	58.3	---	5.3	78.6	1.6	13.8	.6	7,650	13,770
D186089	6.7	34.2	50.3	8.8	5.3	66.4	1.4	17.7	.5	6,500	11,710
	---	36.7	53.9	9.4	4.9	71.2	1.5	12.6	.5	6,970	12,550
	---	40.5	59.5	---	5.4	78.6	1.7	13.9	.6	7,700	13,860

Table 2.--Proximate and ultimate analyses, and heat-of-combustion, forms-of-sulfur, free-swelling-index, and ash-fusion-temperature determinations for nine coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado--continued

Sample number	Air-dried loss	Forms of sulfur: Sulfate	Forms of sulfur: Pyritic	Forms of sulfur: Organic	FSI	Ash fusion temperature, °C: Initial deformation	Ash fusion temperature, °C: Softening	Ash fusion temperature, °C: Fluid
D186083*	7.9	0.02	0.18	0.22	0.0	1,265	1,325	1,375
	---	.02	.22	.27				
	---	.03	.26	.32				
D186086*	4.1	.02	.26	.14	.0	1,420	1,480	1,535
	---	.02	.30	.16				
	---	.03	.33	.18				
D186090	4.0	.02	.13	.34	.0	1,215	1,265	1,325
	---	.02	.14	.38				
	---	.03	.20	.51				
D186078	2.9	.01	.32	.30	.0	1,540+	1,540+	1,540+
	---	.01	.36	.33				
	---	.01	.43	.40				
D186079	3.6	.04	.17	.45	.0	1,540+	1,540+	1,540+
	---	.04	.19	.50				
	---	.06	.24	.63				
D186080	3.1	.02	.21	.22	.0	1,540+	1,540+	1,540+
	---	.02	.23	.24				
	---	.03	.26	.28				
D186081*	3.6	.01	.13	.34	.0	1,260	1,315	1,380
	---	.01	.15	.38				
	---	.01	.16	.42				
D186088	2.1	.01	.14	.30	.0	1,430	1,485	1,540+
	---	.01	.15	.32				
	---	.01	.16	.35				
D186089	2.6	.01	.36	.11	.0	1,540+	1,540+	1,540+
	---	.01	.39	.12				
	---	.01	.43	.13				

Table 3.--Major- and minor-oxide and trace-element composition of the laboratory ash of 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[Coal ashed at 525°C. L means less than the value shown; N, not detected. 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 are 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
D186083	19.3	64	16	7.3	1.85	0.91	0.88	2.9	1.0	1.0L	D186083
D186084	8.6	36	20	21	3.73	2.11	.27	5.7	1.2	1.3	D186084
D186085	16.7	45	22	12	1.75	1.15	.29	3.7	1.1	1.0L	D186085
D186086	7.9	47	24	9.2	.97	1.73	.38	2.9	1.4	4.0	D186086
D186087	11.9	59	24	5.8	1.05	1.37	.65	3.3	1.3	1.1	D186087
D186090	25.1	55	18	4.4	1.50	.67	.99	11	.70	1.0L	D186090
D186078	16.6	71	16	1.7	.49	.92	1.2	1.6	1.0	1.4	D186078
D186079	22.7	67	22	1.4	.71	1.00	1.0	1.9	.92	1.0L	D186079
D186080	13.6	48	31	4.4	1.06	1.22	.37	4.2	1.0	1.5	D186080
D186081	6.8	43	19	11	2.45	2.26	.35	6.2	1.6	1.8	D186081
D186082	9.8	49	23	5.7	1.51	1.60	.28	6.2	1.3	1.4	D186082
D186088	8.6	56	20	5.6	1.38	1.31	.58	4.2	1.3	1.0L	D186088
D186089	10.0	58	23	6.0	.92	1.08	.57	2.6	.74	1.0L	D186089

Sample number	SO3 (percent)	B-S (ppm)	Ba-S (ppm)	Be-S (ppm)	Cu (ppm)	Ga-S (ppm)	La-S (ppm)	Li (ppm)	Mn (ppm)	Mo-S (ppm)	Sample number
D186083	3.6	300	2,000	3L	39	20	100L	56	40	N	D186083
D186084	7.8	700	7,000	3L	49	30	N	77	130	N	D186084
D186085	8.4	500	3,000	5	27	30	100	158	135	N	D186085
D186086	5.6	700	7,000	7	69	30	100	118	55	7	D186086
D186087	4.1	500	3,000	7	59	30	100	112	55	7	D186087
D186090	3.3	200	1,500	3	37	20	100L	57	2,140	7	D186090
D186078	1.6	200	3,000	7	67	20	100L	99	35	10	D186078
D186079	1.2	150	1,000	5	71	30	100L	63	45	10	D186079
D186080	3.6	300	5,000	7	45	30	100	75	60	10	D186080
D186081	8.0	700	7,000	5	83	30	100L	57	75	10	D186081
D186082	4.7	700	3,000	5	63	30	100L	80	65	7	D186082
D186088	4.0	700	1,500	5	73	30	150	86	115	10	D186088
D186089	2.6	700	1,500	7	43	20	100L	63	70	7	D186089

Table 3.--Major- and minor-oxide and trace-element composition of the laboratory ash of 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado--continued

Sample number	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)	Zr-S (ppm)	Sample number
D186083	30	15	40	15	700	100	30	3	64	150	D186083
D186084	30	15	50	15	3,000	70	50	5	97	200	D186084
D186085	50	15	35	15	1,000	70	70	7	82	300	D186085
D186086	50	20	55	20	3,000	150	70	7	48	200	D186086
D186087	50	30	45	15	1,000	150	70	7	46	300	D186087
D186090	50	30	165	15	700	70	70	7	75	150	D186090
D186078	30	50	25	15	1,500	150	70	7	101	150	D186078
D186079	30	30	45	15	500	150	70	7	123	150	D186079
D186080	30	30	75	10	2,000	70	70	7	88	200	D186080
D186081	30	30	25	15	3,000	150	70	7	95	200	D186081
D186082	50	20	40	15	1,500	70	70	7	53	300	D186082
D186088	50	30	85	15	1,500	150	70	5	287	300	D186088
D186089	50	20	55	15	300	70	70	7	79	150	D186089

Table 4.--Content of nine trace elements in 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[Analyses on 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
D186083	0.8	1.3	13	140	0.03	0.3	1.1	3.2	1.2	D186083
D186084	.6	.6	2.5	65	.03	.3	.1L	2.2	.9	D186084
D186085	.9	.9	5.8	50	.10	.6	1.4	6.7	3.0	D186085
D186086	.4	1.1	3.8	115	.03	.2	1.1	1.8	.2L	D186086
D186087	.4	1.2	.1L	115	.02	.2	1.2	2.9	1.3	D186087
D186090	.9	2.0	12	130	.04	.6	1.5	6.8	3.4	D186090
D186078	.1L	3.0	12	205	.06	.6	.8	3.0	2.2	D186078
D186079	.6	2.2	21	170	.06	.1L	1.4	6.4	3.4	D186079
D186080	.3	1.5	.1L	120	.03	.5	1.0	7.7	2.9	D186080
D186081	.3	1.1	3.8	105	.03	.1	.8	1.4	.8	D186081
D186082	.3	1.0	.1L	105	.03	.2	1.0	2.7	.9	D186082
D186088	.4	1.2	4.7	65	.02	.2	1.1	2.3	1.1	D186088
D186089	.4	1.3	4.1	60	.03	.2	.9	1.5	1.3	D186089

Table 5.--Major-, minor-, and trace-element composition of 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[As, Co, Cr, F, Hg, Sb, Se, Th, and U values are from direct determinations on air-dried (32°C) coal; all other values calculated from analyses of ash. S means analysis by semiquantitative emission spectroscopy. L, less than the value shown; N, not detected]

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
D186083	5.8	1.6	1.0	0.21	0.13	0.14	0.39	0.12	0.8	70	D186083
D186084	1.4	.91	1.3	.19	.13	.019	.34	.062	.6	70	D186084
D186085	3.5	1.9	1.4	.18	.14	.040	.43	.11	.9	100	D186085
D186086	1.7	1.0	.52	.046	.10	.025	.16	.066	.4	50	D186086
D186087	3.3	1.5	.49	.075	.12	.064	.27	.093	.4	70	D186087
D186090	6.4	2.4	.79	.23	.12	.21	1.9	.11	.9	50	D186090
D186078	5.5	1.4	.20	.049	.11	.17	.19	.099	.1L	30	D186078
D186079	7.1	2.6	.23	.097	.17	.19	.30	.13	.6	30	D186079
D186080	3.0	2.2	.43	.087	.12	.042	.40	.081	.3	50	D186080
D186081	1.4	.68	.53	.10	.11	.020	.29	.065	.3	50	D186081
D186082	2.2	1.2	.40	.089	.12	.023	.42	.076	.3	70	D186082
D186088	2.2	.91	.34	.071	.083	.042	.25	.067	.4	70	D186088
D186089	2.7	1.2	.43	.055	.080	.047	.18	.044	.4	70	D186089

Sample number	Ba-S (ppm)	Be-S (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	F (ppm)	Ga-S (ppm)	Hg (ppm)	La-S (ppm)	Li (ppm)	Sample number
D186083	500	0.7L	1.3	13	7.5	140	5	0.03	20L	11	D186083
D186084	700	.2L	.6	2.5	4.2	65	2	.03	N	6.6	D186084
D186085	500	1	.9	5.8	4.5	50	5	.10	15	26	D186085
D186086	500	.5	1.1	3.8	5.5	115	2	.03	7	9.3	D186086
D186087	300	1	1.2	.1L	7.0	115	3	.02	10	13	D186087
D186090	300	.7	2.0	12	9.3	130	5	.04	20L	14	D186090
D186078	500	1	3.0	12	11	205	3	.06	15L	16	D186078
D186079	200	1	2.2	21	16	170	7	.06	20L	14	D186079
D186080	700	1	1.5	.1L	6.1	120	5	.03	15	10	D186080
D186081	500	.3	1.1	3.8	5.6	105	2	.03	7L	3.9	D186081
D186082	300	.5	1.0	.1L	6.2	105	3	.03	10L	7.8	D186082
D186088	150	.5	1.2	4.7	6.3	65	2	.02	15	7.4	D186088
D186089	150	.7	1.3	4.1	4.3	60	2	.03	10L	6.3	D186089

Table 5.--Major-, minor-, and trace-element composition of 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado--continued

Sample number	Mn (ppm)	Mo-S (ppm)	Nb-S (ppm)	Ni-S (ppm)	P (ppm)	Pb (ppm)	Sb (ppm)	Sc-S (ppm)	Se (ppm)	Sr-S (ppm)	Sample number
D186083	7.7	N	7	3	840L	7.7	0.3	3	1.1	150	D186083
D186084	11	N	2	1.5	490	4.3	.3	1.5	.1L	200	D186084
D186085	23	N	10	2	730L	5.8	.6	2	1.4	150	D186085
D186086	4.3	.5	5	1.5	1,400	4.3	.2	1.5	1.1	200	D186086
D186087	6.5	1	7	3	570	5.4	.2	2	1.2	100	D186087
D186090	540	1.5	15	7	1,100L	41	.6	3	1.5	150	D186090
D186078	5.8	1.5	5	10	1,000	4.2	.6	2	.8	200	D186078
D186079	10	2	7	7	990L	10	.1L	3	1.4	100	D186079
D186080	8.2	1.5	5	5	890	10	.5	1.5	1.0	300	D186080
D186081	5.1	.7	2	2	530	1.7	.1	1	.8	200	D186081
D186082	6.4	.7	5	2	600	3.9	.2	1.5	1.0	150	D186082
D186088	9.9	1	5	2	380L	7.3	.2	1.5	1.1	150	D186088
D186089	7.0	.7	5	2	440L	5.5	.2	1.5	.9	30	D186089

Sample number	Th (ppm)	U (ppm)	V-S (ppm)	Y-S (ppm)	Yb-S (ppm)	Zn (ppm)	Zr-S (ppm)	Sample number
D186083	3.2	1.2	20	7	0.7	12	30	D186083
D186084	2.2	.9	7	5	.5	8.3	15	D186084
D186085	6.7	3.0	10	10	1	14	50	D186085
D186086	1.8	.2L	10	5	.5	3.8	15	D186086
D186087	2.9	1.3	20	10	1	5.5	30	D186087
D186090	6.8	3.4	15	15	1.5	19	30	D186090
D186078	3.0	2.2	20	10	1	17	20	D186078
D186079	6.4	3.4	30	15	1.5	28	30	D186079
D186080	7.7	2.9	10	10	1	12	30	D186080
D186081	1.4	.8	10	5	.5	6.5	15	D186081
D186082	2.7	.9	7	7	.7	5.2	30	D186082
D186088	2.3	1.1	15	7	.5	25	20	D186088
D186089	1.5	1.3	7	7	.7	7.9	15	D186089

Table 6.--Elements looked for but not detected in coal from the Mesaverde Group, Lower White River field, northwestern Colorado

[Approximate lower detection limits in ash, as determined by the atomic absorption (*) and spectrographic methods of the U.S. Geological Survey, are included for all elements]

Element name	Symbol	Lower limit of detection in ash (ppm)
Silver	Ag	1
Gold	Au	50
Bismuth	Bi	20
Cadmium*	Cd	1
Cerium	Ce	500
Dysprosium	Dy	100
Erbium	Er	100
Europium	Eu	200
Gadolinium	Gd	100
Germanium	Ge	20
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
Tin	Sn	20
Tantalum	Ta	1,000
Terbium	Tb	700
Tellerium	Te	5,000
Thallium	Tl	100
Thulium	Tm	50
Tungsten	W	200

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 GM 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 statistically analyzing and summarizing trace-element data on a logarithmic basis.

If the frequency distributions are lognormal, the GM 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 x 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 $GM \times (GD)^2$ (Connor and others, 1976).

Although the GM 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 samples is below the limit of analytical detection. This results in a "censored" distribution. Procedures developed by Cohen (1959) are used to compute biased estimates of the GM, GD, and arithmetic mean when the data are censored.

Discussion

The apparent ranks for nine samples from the Lower White River field were calculated using the data in table 2 and the formulae in ASTM designation D-388-77 (American Society for Testing and Materials, 1978). The heat of combustion (moist, mineral-matter free basis) for the samples ranges from 10,600 Btu/lb (5,890 kcal/kg) to 12,970 Btu/lb (7,210 kcal/kg). The apparent rank for the samples ranges from subbituminous B coal (one sample) to subbituminous A coal (eight samples).

Statistical comparisons, using the "t" and "f" tests (95-percent confidence) (Miller and Kahn, 1962), of the sample means and variances of the U.S. Bureau of Mines data for nine samples from the Lower White River coal field (table 7) with 76 coal samples from the Williams Fork Formation, northwestern Colorado (Hildebrand and others, 1981), show that the Lower White River field samples collectively have significantly higher sulfate and pyritic sulfur, and significantly lower organic sulfur. Contents of moisture, volatile matter, fixed carbon, ash, hydrogen, carbon, nitrogen, oxygen, and sulfur, and heat of combustion and ash-fusion temperatures are not significantly different.

Table 7.--Arithmetic mean, observed range, geometric mean, and geometric deviation of proximate and ultimate analyses, and heat of combustion, forms of sulfur, and ash-fusion temperatures of nine coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[All values are in percent except kcal/kg, Btu/lb, and ash-fusion temperatures, and are reported on the as-received basis. °F = (°C x 1.8) + 32; kcal/kg = 0.556 x (Btu/lb). For comparison, geometric means for 76 samples from the Williams Fork Formation, northwestern Colorado (Hildebrand and others, 1981, table 10,) are included]

	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Williams Fork Formation geometric mean
		Minimum	Maximum			
Proximate and ultimate analyses						
Moisture	10.4	6.7	17.1	10.0	1.3	8.3
Volatile matter	33.7	30.8	36.8	33.7	1.1	32.2
Fixed carbon	43.1	35.7	50.3	42.8	1.1	45.2
Ash	13.0	7.6	23.9	11.9	1.5	9.0
Hydrogen	5.2	4.5	5.5	5.2	1.1	5.4
Carbon	59.8	51.0	66.9	59.5	1.1	60.6
Nitrogen	1.3	1.0	1.4	1.2	1.1	1.3
Oxygen	20.3	17.7	26.8	20.1	1.1	18.0
Sulfur	.5	.4	.7	.5	1.2	.6
Heat of combustion						
Kcal/kg	5,830	4,930	6,510	5,800	1.1	5,890
Btu/lb	10,490	8,880	11,720	10,430	1.1	10,600
Forms of sulfur						
Sulfate	0.02	0.01	0.04	0.02	1.6	0.01
Pyritic	.21	.13	.36	.20	1.5	.10
Organic	.27	.11	.45	.25	1.6	.40
Ash-fusion temperatures, °C						
Initial deformation	1,320	1,215	1,540+	1,315	1.1	1,300
Softening temperature	1,375	1,265	1,540+	1,370	1.1	1,340
Fluid temperature	1,430	1,325	1,540+	1,425	1.1	1,370

Statistical comparisons of sample means and variances of coal ash and 10 major and minor oxides in the ash for 13 samples from the Lower White River coal field (table 8) with 100 coal samples from the Williams Fork Formation, northwestern Colorado (Hildebrand and others, 1981) show that the Lower White River field samples collectively have significantly higher contents of Na_2O, TiO_2, and P_2O_5 in ash. Contents of ash and SiO_2, Al_2O_3, CaO, MgO, K_2O, Fe_2O_3, and SO_3 in ash are not significantly different.

Statistical comparisons of sample means and variances of 36 elements (whole coal basis) for 13 samples from the Lower White River coal field (table 9) with 100 coal samples from the Williams Fork Formation, northwestern Colorado (Hildebrand and others, 1981), show that the Lower White River field samples collectively have significantly higher contents of Na, Ti, Ba, Nb, P, Sc, Th, U, Y, and Yb. The contents of Si, Al, Ca, Mg, K, Fe, As, B, Be, Co, Cr, Cu, F, Ga, Hg, Li, Mn, Mo, Ni, Pb, Sb, Se, Sr, V, Zn, and Zr are not significantly different.

Differences in the oxide composition of coal ash and the element contents of coal result from differences in the total and relative amounts of the various minerals in the coal, and the total and relative amounts of organically bound elements. The chemical form and distribution of a given element are dependent on the geologic history of the coal bed. A partial listing of the geologic factors that influence element distributions includes chemical composition of original plants; amounts and compositions of various detrital, diagenetic, and epigenetic minerals; temperatures and pressures during burial; and extent of weathering. No evaluation of these factors has been made for any of the coal beds in the Lower White River field.

Table 8.--Arithmetic mean, observed range, geometric mean, and geometric deviation of ash content and contents of ten major and minor oxides in the laboratory ash of 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[All samples were ashed at 525°C; all values except geometric deviation are in percent. L, less than the value shown. For comparison geometric means for 100 coal samples from the Williams Fork Formation, northwestern Colorado (Hildebrand and others, 1981, table 11) are included]

Oxide	Arithmetic mean	Observed range		Geometric mean	Geometric deviation	Williams Fork Formation geometric mean
		Minimum	Maximum			
(Ash)	13.7	6.8	25.1	12.6	1.5	10.1
SiO_2	54	36	71	53	1.2	47
Al_2O_3	21	16	31	21	1.2	21
CaO	7.6	1.4	21	5.9	2.1	5.4
MgO	1.50	.49	3.73	1.30	1.7	1.16
Na_2O	1.34	.67	2.26	1.26	1.4	.49
K_2O	.61	.27	1.2	.53	1.7	.69
Fe_2O_3	4.4	1.6	11	3.8	1.7	3.7
TiO_2	1.1	.70	1.6	1.1	1.3	.88
P_2O_5	1.3	1.0L	4.0	1.1	1.8	.24
SO_3	4.6	1.2	8.4	3.9	1.8	3.7

Table 9.—Arithmetic mean, observed range, geometric mean, and geometric deviation of 36 elements in 13 coal samples from the Mesaverde Group, Lower White River coal field, northwestern Colorado

[All analyses are in percent or parts per million and are reported on a whole-coal basis. L, less than the value shown. For comparison geometric means for 100 coal samples from the Williams Fork Formation, northwestern Colorado (Hildebrand and others, 1981, table 12) are included]

Element	Arithmetic mean	Observed range: Minimum	Observed range: Maximum	Geometric mean	Geometric deviation	Williams Fork Formation geometric mean
			Percent			
Si	3.6	1.4	7.1	3.1	1.8	2.3
Al	1.5	.68	2.6	1.4	1.5	1.1
Ca	.63	.20	1.4	.52	1.8	.40
Mg	.11	.046	.23	.099	1.7	.070
Na	.12	.080	.17	.12	1.2	.037
K	.080	.019	.21	.055	2.4	.059
Fe	.40	.16	1.9	.33	1.9	.26
Ti	.086	.044	.12	.082	1.4	.054
			Parts per million			
As	0.5	0.1L	0.9	0.5	1.6	0.6
B	70	30	100	70	1.4	70
Ba	500	150	700	500	1.7	200
Be	.7	.2L	1	.7	1.8	.5
Co	1.4	.6	3.0	1.3	1.5	1
Cr	7.0	.1L	21	4.7	2.5	3
Cu	7.2	4.2	16	6.7	1.5	6.0
F	110	50	205	105	1.5	87
Ga	3	2	7	3	1.6	3
Hg	.04	.02	.10	.04	1.6	.04
Li	11	3.9	26	10	1.6	7.9
Mn	23	4.3	540	11	3.5	15
Mo	1	.5	2	.7	1.8	.5
Nb	7	2	15	5	1.7	1.5
Ni	5	1.5	10	3	1.9	2
P	580	380L	1,400	500	1.7	120
Pb	8.1	1.7	41	6.2	2.1	4.1
Sb	.3	.1L	.6	.3	2.0	.3
Sc	2	1	3	2	1.4	1.5
Se	1.1	.1L	1.5	1.0	1.3	.9
Sr	150	30	300	150	1.7	100
Th	3.8	1.4	7.7	3.2	1.8	1.4
U	1.8	.2L	3.4	1.5	1.8	.9
V	15	7	30	15	1.6	10
Y	10	5	15	7	1.5	5
Yb	1	.5	1.5	.7	1.5	.5
Zn	13	3.8	28	11	1.9	8.0
Zr	20	15	50	20	1.5	20

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