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Coal resources of the Fish Creek EMRIA site, Routt County, Colorado

By

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

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Abstract

The Fish Creek EMRIA site, an area of about 3.7 square miles (9.6 km^2), is located in the southeastern part of the Yampa coal field on the steep to gently dipping beds of the Upper Cretaceous Williams Fork Formation.

The Fish Creek coal bed within 200 feet (60 m) of the surface was evaluated by five core holes. Coal resources--measured, indicated, and inferred--within the site are 2,512,000 short tons, 7,970,000 short tons, and 507,000 short tons respectively.

The coal has an apparent rank of bituminous C. The average Btu value of three core samples from the site on the as-received basis is 10,790, average ash content is 11.1 percent, and average sulfur content is 1.9 percent.

A comparison of the analyses of samples from the Fish Creek coal bed with other Rocky Mountain province coal sample analyses shows that nitrogen, total sulfur, and pyritic and organic sulfur contents are noticeably higher in the Fish Creek coal bed samples. A comparison of other element analyses shows that the Fish Creek coal bed is noticeably higher in As, Cr, F, Fe, Hg, and Sr, and noticeably lower in Th.

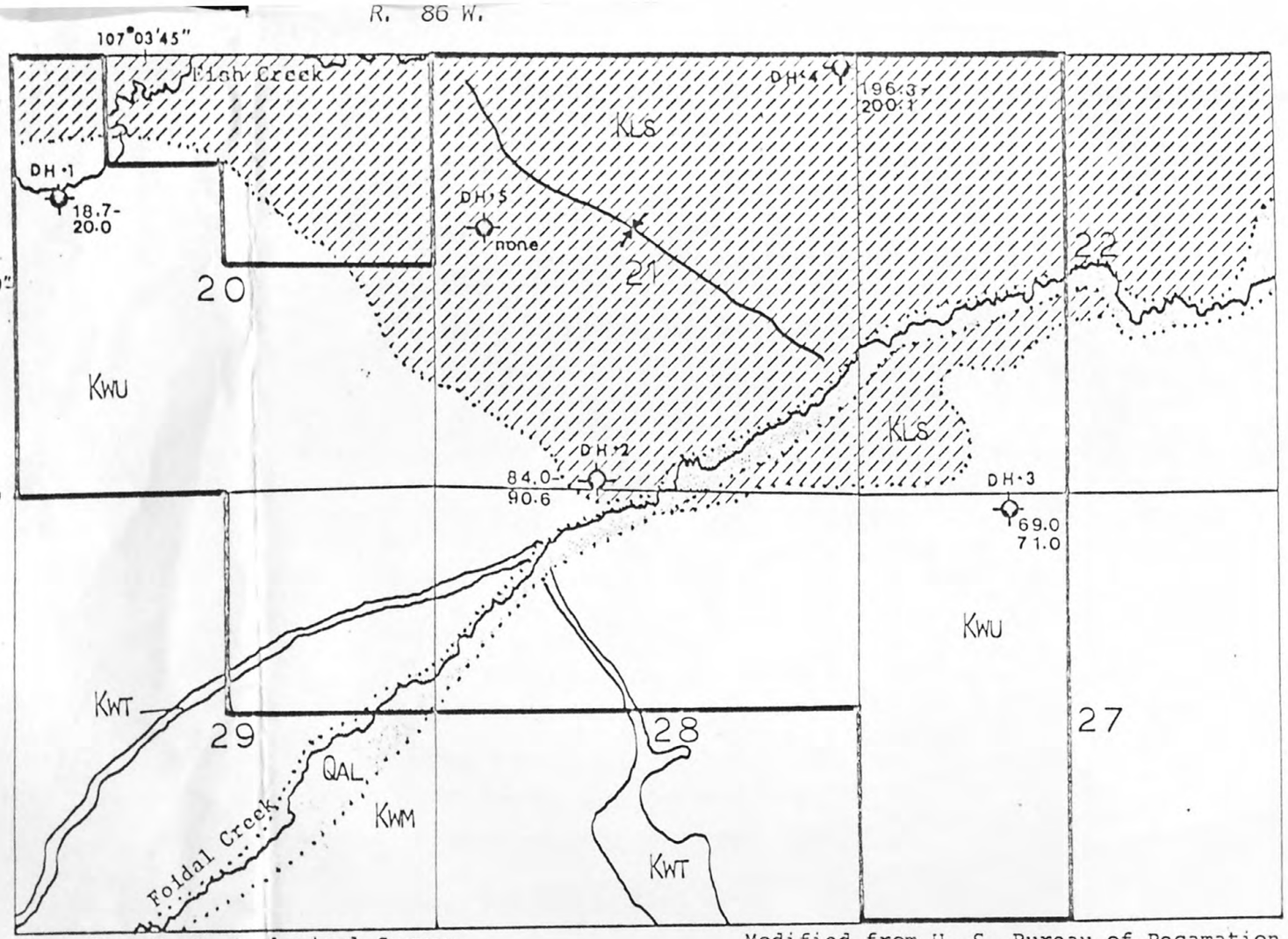
Introduction

This report was prepared as a contribution to the study of the reclamation potential of an area in the southeastern part of the Yampa coal field in northwest Colorado. The area was selected for investigation by the EMRIA (Energy Minerals Rehabilitation Inventory and Analysis) program of the U.S. Bureau of Land Management. This study is an adjunct to the Foidel Creek EMRIA, about 2 1/2 miles (4 km) to the southwest, for which a report is in preparation by the Bureau of Land Management (Ryer, 1977). The Fish Creek area was selected for evaluation of the shallower coal in this part of the field.

The Fish Creek site is an area of about 3.7 square miles (9.6 km^2) between Fish Creek and Foidel Creek, tributaries of the Yampa River. The site is within the Milner and Rattlesnake Butte 7 1/2-minute topographic quadrangles. Five holes were cored by the Bureau of Reclamation (fig. 1). J. R. Hatch sampled coal beds from these cores and submitted the samples for analysis. The results of the analyses are discussed by J. R. Hatch and R. H. Affolter in this report.

Geologic Setting

The coal evaluated for this study--the Fish Creek coal bed, as much as 5.4 feet thick (1.6 m)--is 2-20 feet (0.6-6 m) below the top of the Holderness Member Morris (1971) of the Upper Cretaceous Williams Fork Formation (fig. 2). The Holderness Member is a 200-foot (60-m) sequence of sandstone, siltstone, shale, and coal that overlies the massive, gray, ledge-forming Twentymile Sandstone Member of the Williams Fork Formation. The Holderness Member is overlain by dark-gray to black marine mudstone of the Lewis Shale of Late Cretaceous age. Deeper coal-bearing rocks of the Iles Formation, below the Williams Fork, were not evaluated in this study.



Base from U. S. Geological Survey, Rattlesnake Butte and Milner quadrangles, 1971

Modified from U. S. Bureau of Recamation by Gary B. Schneider

QAL — Alluvium (Quaternary)-- Clay, sand, gravel

KLS — Lewis Shale (Upper Cretaceous)-- Mudstone, dk. gray to black

Transitional contact

Kwu / Kwt / Kwm — Williams Fork Formation (Upper Cretaceous)--
Kwu, upper member (Holderness member of Morris, 1971) Sandstone; interbedded sandstone and mudstone limestone; silty shale; coal. Fish Creek bed, 1-5.4 ft thick, 2-20 feet from top
Kwt, Twentymile Sandstone Member Sandstone, gray, massive
Kwm, Marine shale member

Axis of Twentymile Park Syncline

Boundary of EMRIA study site

Contact - dotted where uncertain or transitional

DH-1 18.7-20.0 — Location of drill hole, coal interval in feet

Scale 1 .5 0 1 km; 0 1/2 1 mi

COLORADO

QUADRANGLE LOCATION

FIGURE 1.--PRELIMINARY GEOLOGIC MAP OF THE FISH CREEK EMRIA STUDY SITE, RATTLESNAKE BUTTE AND MILNER QUADRANGLES, ROUTT COUNTY, COLORADO.

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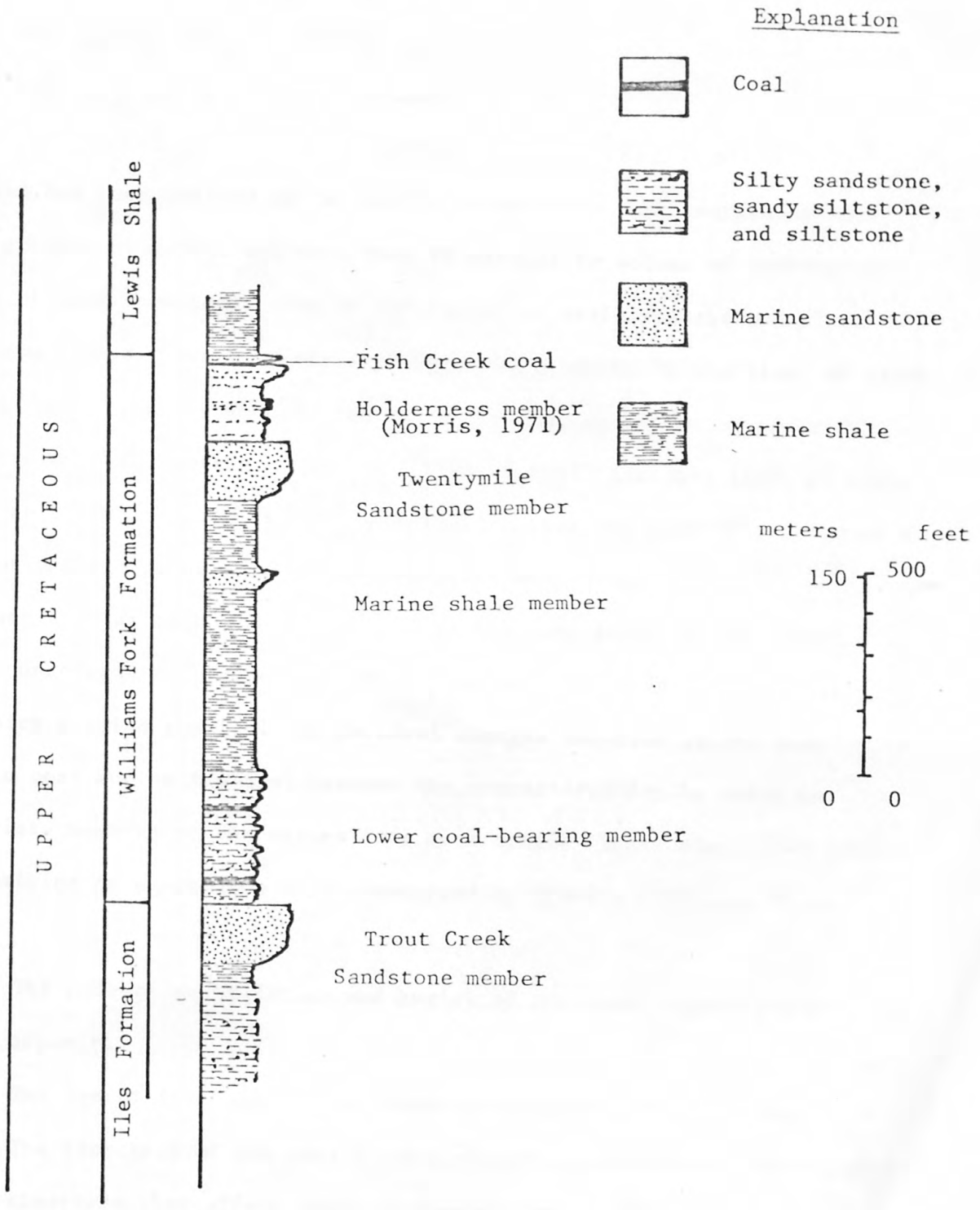

FIGURE 2.--GENERALIZED STRATIGRAPHIC SECTION FISH CREEK EMRIA STUDY SITE, NORTHWESTERN COLORADO (MODIFIED FROM RYER, 1977).

COAL

Origin

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

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

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

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

Classification

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

Rank of coal

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

of the coal constitutients--the higher rank coals have more carbon and less hydrogen than the lower ranks.

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

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

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

Figure 3 compares, in histogram form, the heating values and moisture, volatile matter, and fixed carbon contents of coals of different ranks.

Various schemes for classifying coals by rank have been proposed and

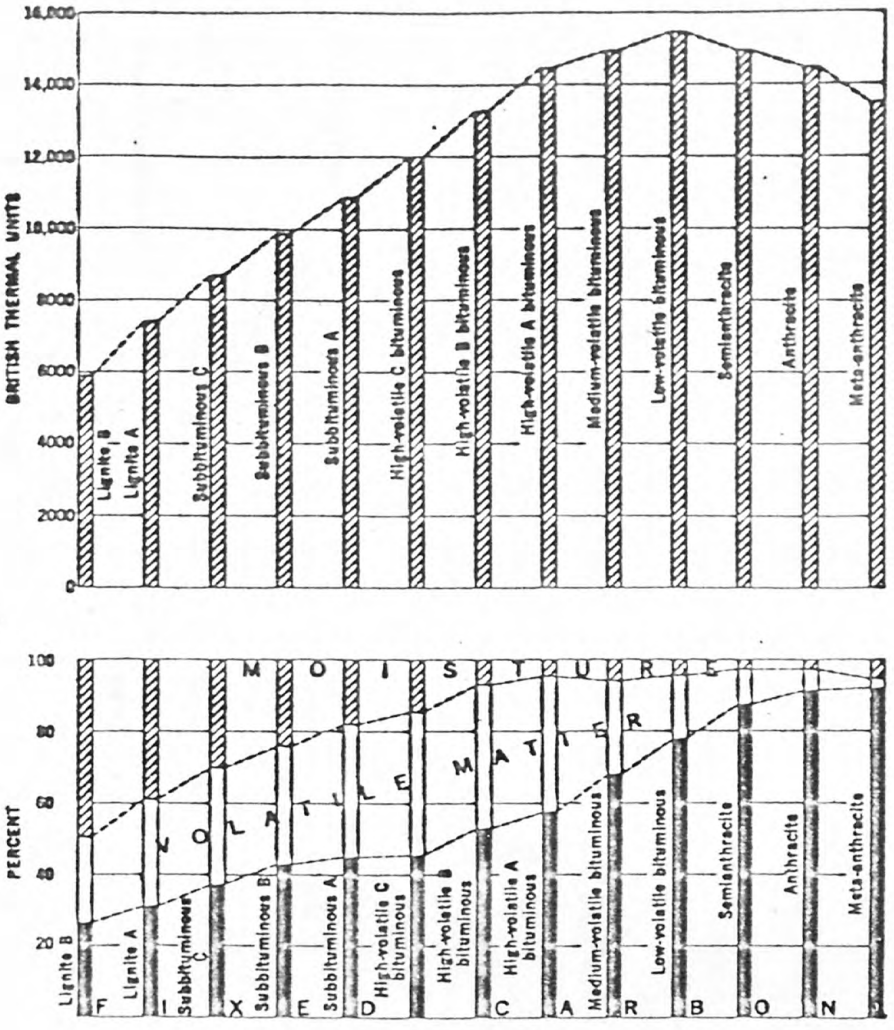

FIGURE 3.--COMPARISON ON MOIST, MINERAL-MATTER-FREE BASIS OF HEAT VALUES AND PROXIMATE ANALYSES OF COAL OF DIFFERENT RANKS

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

[American Society for Testing and Materials Standard D388-66 (Reapproved 1972); 1 Btu equals 0.252 kilogram-calories. Leaders (---) indicate category is not used in rank determination of group]

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

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

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

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

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

used, but the most commonly employed is that entitled "Standard specifications for classification of coals by rank," adopted by the American Society for Testing and Materials (1974, table 1).

The ASTM classification system differentiates coals into classes and groups on the basis of mineral-matter-free fixed carbon or volatile matter and the heating value, supplemented by determination of agglomerating (caking) characteristics. As pointed out by the ASTM (1974, p. 55), a standard rank determination cannot be made unless the samples were obtained in accordance with standardized sampling procedures (Snyder, 1950; Schopf, 1960). However, nonstandard samples may be used for comparative purposes through determinations designated as "apparent rank."

Three samples listed on tables 2 and 3 show an apparent rank of bituminous C. Because of the lack of definitive information about the distribution of coals of various groups in the Fish Creek coal, it is considered to be all bituminous C in rank in the area of the study.

Type of coal

Classification of coals by type--that is, according to the types of plant materials present--takes many forms, such as the "rational analysis" of Francis (1961) or the semicommercial "type" classification commonly used in the coal fields of the eastern United States (U.S. Bureau of Mines, 1965, p. 123). However, most of the type classifications are based on the same, or similar, gross distinctions in plant material as those used by Tomkeieff (1954, Table II and p. 9), who divided the coals into three series: humic coals, humic-sapropelic coals, and sapropelic coals, based upon the nature of the original plant materials. The humic coals are largely composed of the remains of the woody parts of plants; and the sapropelic coals are largely composed of the more resistant waxy, fatty, and resinous parts of plants, such

Table 2.--USGS sample number, hole number, and depth interval, for three core coal samples, Fish Creek EMRIA study site, Routt County, Colorado.

[All samples are from the Fish Creek coal bed, Williams Fork Formation of Late Cretaceous age]

USGS sample number	Hole number	Location	Depth interval, feet and (meters)
D186056	1	SW¼ NW¼ sec. 20, T. 5 N., R. 86 W.	18.7-20.0 (5.7-6.1)
D186057	2	SE¼ SW¼ sec. 21, T. 5 N., R. 86 W.	84.0-89.9 (25.6-27.4)
D186058	4	NE¼ NE¼ sec. 21, T. 5 N., R. 86 W.	196.7-200.1 (60.0-61.0)

Table 3.--Proximate and ultimate analyses, heat of combustion, forms-of-sulfur, free-swelling-index, and ash fusion temperature determinations for three coal samples from the Fish Creek EMRIA study site

[All analyses except Kcal/kg, 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 number	Proximate Analyses				Ultimate Analyses					Heat of combustion	
	Moisture	Volatile matter	Fixed Carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Kcal/kg	Btu/lb
D186056	10.3	36.0	43.9	9.8	5.3	61.3	2.0	19.9	1.7	6,050	10,880
	----	40.1	49.0	10.9	4.6	68.4	2.2	12.0	1.9	6,745	12,130
	----	45.0	55.0	----	5.2	76.8	2.5	13.5	2.1	7,565	13,610
D186057	10.8	34.9	37.1	17.2	4.9	55.3	1.7	18.7	2.2	5,450	9,800
	----	39.2	41.5	19.3	4.2	62.0	1.9	10.1	2.4	6,110	10,990
	----	48.5	51.5	----	5.2	76.8	2.4	12.6	3.0	7,570	13,620
D186058	9.8	35.9	47.8	6.5	5.6	65.6	1.9	18.6	1.8	6,495	11,680
	----	39.8	53.0	7.2	5.0	72.7	2.2	10.9	2.0	7,205	12,960
	----	42.9	57.1	----	5.3	78.4	2.3	11.8	2.2	7,760	13,960

Sample number	Air-dried loss	Forms of Sulfur			Free swelling index	Ash Fusion Temperature C°		
		Sulfate	Pyritic	Organic		Initial deform.	Soften.	Fluid
D186056	2.6	0.02	0.81	0.85	0.0	1,105	1,155	1,220
		.02	.90	.95				
		.02	1.01	1.06				
D186057	2.2	.03	1.43	.71	.0	1,125	1,175	1,240
		.03	1.60	.80				
		.04	1.98	.99				
D186058	2.1	.02	1.62	.17	.0	1,045	1,100	1,160
		.02	1.79	.18				
		.02	1.93	.20				

as cell walls, spore-coatings, pollen, resin particles, and coals composed mainly of algal material. Most coals fall into the humic series, with some coals being a mixture of humic and sapropelic elements and, therefore, falling into the humic-sapropelic series. The sapropelic series is quantitatively insignificant and, when found is commonly regarded as an organic curosity. In common with most of the U.S. coals, those from Fish Creek fall largely in the humic series.

Grade of coal

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

The range and average of the ash and sulfur content of 642 coals from all parts of the United States were determined by Fieldner, Rice, and Moran (1942).

Ash and sulfur contents of U.S. coals on an as-received basis

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

The ash and sulfur content of the three coal samples from the Fish Creek coal, as received, are ash range, 6.5 to 17.2 percent; average, 11.1 percent; sulfur-range, 1.7 to 2.2 percent; average, 1.9 percent.

Estimation and classification of coal resources

Coal resource estimates have been prepared for the Fish Creek coal within the Fish Creek EMRIA study site using standard procedures, definitions, and criteria established by the U.S. Geological Survey and U.S. Bureau of Mines for making coal resource appraisals in the United States. The term "coal resources" as used in this report means the estimated quantity of coal in the ground in such form that economic extraction is currently or potentially feasible.

Tabulation of estimated coal resources

Table 4 summarizes the estimated coal resources of the Fish Creek EMRIA study site. The resources in the study site are classed as measured, indicated, and inferred according to the degree of geologic assurance of the estimate:

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

Table 4.--Estimated identified coal resources of the Fish Creek coal bed, Fish Creek EMRIA site, Routt County, Colorado

[1 foot = 0.305 meters; 1 short ton = 0.907 metric tons]

Section	0-200 feet overburden								Section total
	2½-5 feet Coal				5-10 feet Coal				
	Measured	Indicated	Inferred	Total	Measured	Indicated	Inferred	Total	
20, NW¼NW¼, S½NW¼, S½	32	1,654	38	1,724	---	---	---	---	1,724
21, all	866	1,837	---	2,703	488	674	---	1,162	3,865
22, W½	387	1,521	---	1,908	147	206	---	353	2,261
27, W½	350	1,027	384	1,761	---	---	---	---	1,761
28, N½	229	919	---	1,148	13	---	---	13	1,161
29, NE¼	---	132	85	217	---	---	---	---	217
Grand totals	1,864	7,090	507	9,461	648	880	---	1,528	10,989

of observation or measurement.

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

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

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

Characteristics used in resource evaluation

The coal characteristics that are commonly used in classifying coal resources are the rank, grade, and weight of the coal; the thickness of the coal beds; and the thickness of the overburden. Rank and grade have been discussed previously.

Weight

The weight of the coal ranges considerably with differences in rank and ash content. In areas such as Fish Creek, where true specific gravities of the coal have not been determined, an average specific gravity value based on many determinations in other areas is used to express the weight of the coal for resource calculations. The average weight of bituminous coal is taken as 1,800 tons per acre-foot--a specific gravity of 1.32.

Thickness of beds

Because of the important relationship of coal-bed thickness to utilization potential, most coal resource estimates prepared by the U.S. Geological Survey are tabulated according to three thickness categories. Because the coal evaluated in this report is so close to the bituminous-subbituminous division of rank, the thickness categories used are thin--2.5 to 5 feet (0.75 to 1.5 m); intermediate--5 to 10 feet (1.5 to 3 m); and thick--more than 10 feet (3 m). About 86 percent of the estimated resources of the study area is in the thin category and about 14 percent is in the intermediate category. By way of comparison, Averitt (1975, Figure 5 and page 37) showed the distribution of the estimated resources of 21 states as 42 percent in the thin category, 25 percent in the intermediate category, and 33 percent in the thick category.

Thickness of overburden

All of the estimated coal resources in the Fish Creek EMRIA site are overlain by 200 feet (60 m) or less of overburden. No coal deeper than 200 feet (60 m) was evaluated.

Summary of resources

Total estimated identified original resources in the Fish Creek EMRIA site are 10,969,000 tons. The coal-bed thickness class of 2.5-5 feet contains 9,461,000 tons. The coal-bed thickness class of 5-10 feet contains 1,528,000 tons of the estimated resources. Maximum measured thickness of the coal bed is 5.4 feet.

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

Chemical analyses of coal from the Fish Creek EMRIA study site

Three coal samples of the Fish Creek coal bed were collected by the U.S. Geological Survey from three core holes in the Fish Creek EMRIA study site. These samples are briefly described in table 2. Although only three coal samples were available for analyses, they probably indicate the chemical composition of the Fish Creek coal bed in the study site.

Proximate and ultimate analysis, heat content, air-dried loss, forms-of-sulfur, and ash-fusion-temperature determinations on these samples (table 3) were provided by chemists of the Coal Analysis Section (Forrest E. Walker, Chemist-in-Charge), U.S. Bureau of Mines, Pittsburgh, Pa., whose contribution is gratefully acknowledged. Analyses for 33 major and minor oxides and trace elements in the laboratory ash (table 5) and analyses of nine trace elements in whole coal (table 6) were provided by chemical laboratory personnel in the U.S. Geological Survey, Denver, Colorado, under the direction of Claude

Table 5.--Major and minor oxide and trace element composition of the laboratory ash of three coal samples from the Fish Creek EMRIA study site.

[Values in percent or parts per million. Coal ashed at 525°C. L means less than the value shown; N, not detected; S after element indicates determinations by semiquantative emission spectrography: the spectrographic results are identified with geometric brackets whose boundaries are part of the ascending series 0.12, 0.18, 0.26, 0.38, 0.56, 0.83, 1.2, etc., but reported as mid-points of the brackets, 0.1, 0.15, 0.2, 0.3, 0.5, 0.7, 1.0, etc. Precision of the spectrographic data is plus or minus one bracket at 68-percent or plus or minus two brackets at 95-percent confidence level]

Oxide or element	Sample Number		
	D186056	D186057	D186058
	Percent		
Ash	10.0	14.5	6.3
SiO_2	29	53	27
Al_2O_3	16	13	12
CaO	16	3.0	9.9
MgO	1.16	1.47	1.15
Na_2O	.41	.63	2.68
K_2O	.90	1.7	.71
Fe_2O_3	20	18	27
TiO_2	.80	.76	.69
P_2O_5	8.5	1L	3.4
SO_3	7.0	3.8	12
	Parts per million		
B-S	700	700	2,000
Ba-S	5,000	700	2,000
Be-S	7	3	7
Cd	1L	3.5	1L
Cu	40	150	62
Ga-S	30	20	15
Ge-S	70	N	30
La-S	N	100L	100L
Li	68	56	64
Mn	425	570	770
Mo-S	15	N	15
Nb-S	30	20	30
Ni-S	20	30	20
Pb	25	70	25L
Sc-S	20	15	15
Sr-S	5,000	500	3,000
V-S	150	150	150
Y-S	70	70	70
Yb-S	7	7	7
Zn	71	132	62
Zr-S	200	150	200

Table 6.--Content of nine trace elements in three coal samples from the Fish Creek EMRIA study site

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

Element	Sample Number		
	D186056	D186057	D186058
As	12.5	7.1	15.4
Co	.9	5.1	.9
Cr	2.9	25.0	2.6
F	585	70	150
Hg	.42	.29	.32
Sb	.5	.1L	.3
Se	1.0	1.7	1.1
Th	1.9	2.5	.9
U	1.4	1.5	.4

Huffman, Jr.: James W. Baker, Ardith J. Bartel, Leon A. Bradley, Celeste M. Ellis, Raymond G. Havens, Roy J. Knight, Robert E. McGregor, Violet M. Merritt, Hugh T. Millard, Jr., Harriet G. Neiman, Ralph L. Nelms, Charles A. Ramsey, George O. Riddle, Caryl L. Shields, Gaylord D. Shipley, James A. Thomas, James S. Wahlberg, and William J. Walz. Analytical procedures used by the U.S. Geological Survey are described in Swanson and Huffman (1976). The analyses listed in this report were funded in part under USGS-ERDA Interagency Agreement No. E(49-18)-2005 and in part by the U.S. Bureau of Land Management. Table 7 contains the data listed in table 5 converted to a whole-coal basis, and the whole-coal analyses for nine trace elements are listed in table 6. Twenty-three additional elements were looked for but not found in amounts greater than their lower limits of detection (table 8). Arithmetic means of the data listed in tables 3 and 7 are listed in tables 9 and 10 respectively. Arithmetic means for other Rocky Mountain province coal samples are listed in tables 9 and 10 for comparison.

The analyses of the Fish Creek coal bed on an as-received basis, listed in table 3 show that ash content ranges from 6.5 to 17.2 percent, averaging 11.1 percent, sulfur content ranges from 1.7 to 2.2 percent, averaging 1.9 percent, and heat of combustion ranges from 5,450 to 6,495 Kcal/kg (9,800 to 11,680 Btu/lb), averaging 6,000 Kcal/kg (10,790 Btu/lb). All three samples show an apparent rank of bituminous coal, as calculated according to ASTM designation D-388-77 (ASTM, 1974).

A comparison of proximate, ultimate, heat-of-combustion, and forms-of-sulfur analyses of the samples from the Fish Creek coal bed with other Rocky Mountain province coal samples (table 9) shows that nitrogen, total sulfur, and pyritic and organic sulfur contents are noticeably higher in the Fish Creek coal bed samples. The contents of the other variables are similar in

Table 7.--Major, minor, and trace element composition of three coal samples from the Fish Creek EMRIA study site

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

Element	Sample Number D186056	D186057	D186058
	Percent		
Si	1.4	3.6	0.79
Al	.85	1.0	.40
Ca	1.1	.31	.45
Mg	.070	.13	.044
Na	.030	.068	.13
K	.075	.21	.037
Fe	1.4	1.8	1.2
Ti	.048	.066	.026
	Parts per million		
As	12.5	7.1	15.4
B-S	70	100	150
Ba-S	500	100	150
Be-S	.7	.5	.5
Cd	.10L	.50	.06L
Co	.9	5.1	.9
Cr	2.9	25.0	2.6
Cu	4.0	21.8	3.9
F	585	70	150
Ga-S	3	3	1
Ge-S	7	N	2
Hg	.42	.29	.32
La-S	N	15L	7L
Li	6.8	8.1	4.0
Mn	43	83	49
Mo-S	1.5	N	1
Nb-S	3	3	2
Ni-S	2	5	1.5
P	3,700	630L	940
Pb	2.5	10	1.5L
Sb	.5	.1L	.3
Sc-S	2	2	1
Se	1.0	1.7	1.1
Sr-S	500	70	200
Th	1.9	2.5	.9
U	1.4	1.5	.4
V-S	15	20	10
Y-S	7	10	5
Yb-S	.7	1	.5
Zn	7.1	19	3.9
Zr-S	20	20	15

Table 8.--Elements looked for but not detected in Fish Creek coal bed samples

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

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

Table 9.--Arithmetic means of proximate, ultimate, heat-of-combustion, and forms-of-sulfur analyses for three Fish Creek coal bed samples and for 86 other Rocky Mountain province coal samples (Swanson and others, 1976, Table 33A)

[All values are in percent, except heat of combustion, and are reported on the as-received basis]

	Fish Creek bed	Rocky Mountain province
Proximate and ultimate analyses		
Moisture	10.3	12.9
Volatile matter	35.6	36.0
Fixed carbon	42.9	42.0
Ash	11.2	9.1
Hydrogen	5.3	5.6
Carbon	60.7	59.7
Nitrogen	1.9	1.2
Oxygen	19.0	23.8
Sulfur	1.9	.6
Heat-of-combustion		
Kcal/kg	6,000	5,830
Btu/lb	10,790	10,480
Forms-of-sulfur		
Sulfate	0.02	0.05
Pyritic	1.3	.19
Organic	.58	.32

the two sets. A comparison of element analyses of samples from the Fish Creek coal bed with other Rocky Mountain province coal samples (table 10) shows that As, Cr, F, Fe, Hg, and Sr are noticeably higher and Th is noticeably lower in the Fish Creek bed samples.

Table 10.--Arithmetic means of 39 element contents in three Fish Creek coal bed samples and in 124 other Rocky Mountain province coal samples (Swanson and others, 1976, table 33C)

[All values are in percent or parts per million. Leaders (--) indicate arithmetic mean could not be calculated]

Element	Fish Creek bed	Rocky Mountain province
	Percent	
Si	1.9	2.5
Al	.75	1.2
Ca	.62	.59
Mg	.081	.10
Na	.076	.10
K	.11	.076
Fe	1.4	.45
Ti	.046	.061
	Parts per million	
As	12	2
B	100	70
Ba	200	200
Be	.7	.7
Co	2.3	2
Cr	10.2	5
Cu	9.9	9.1
F	268	70
Ga	2	3
Hg	.34	.06
Li	6.3	9.2
Mn	58	36
Mo	1.5	1.5
Nb	3	5
Ni	3	3
Pb	------	5.5
Sb	------	.4
Sc	1.5	2
Se	1.3	1.6
Sr	200	100
Th	1.8	3.6
U	1.1	1.6
V	15	15
Y	7	5
Yb	.7	.5
Zn	10	9.9
Zr	20	20

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