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GEOLOGICAL SURVEY

Coal resources of the Fruitland Formation, Ojo Encino EMRIA study site, McKinley County, New Mexico

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ABSTRACT

The Ojo Encino EMRIA study site, an area of about 6.5 square miles ($17\ km^2$), is located on the south margin of the San Juan Basin where the Upper Cretaceous Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale dip gently northward. The coal evaluated in this study comes from the Fruitland Formation. The coal beds are lenticular in nature, have a maximum total thickness of 22 feet (6.7 m), as measured in a drill hole, and are treated as zones of coal intervals as much as 68 feet (20.7 m) thick. Overburden ranges from 16 feet (4.9 m) to 160 feet (49 m) thick in five drill holes. The coal has potential for mining by surface methods because it occurs at shallow depth and is of economic thickness.

Coal resources--measured, indicated, and inferred--in the study site are 19,700,000 short tons (17,880,000 metric tons), 88,130,000 short tons (79,930,000 metric tons), and 25,020,000 short tons (22,690,000 metric tons), respectively. Total identified resources for the study site are 132,850,000 short tons (120,490,000 metric tons), and 79 percent of this amount is in beds more than 10 feet (3.1 m) thick.

The apparent rank of the coal ranges from subbituminous A to high-volatile C bituminous. The average heat-of-combustion value of eight core samples from the site, on the as-received basis, is 8,953 Btu/lb (4978 kcal/kg); average ash content is 21.0 percent and average sulfur content is 0.55 percent.

INTRODUCTION

This report was prepared as a contribution to the study of the reclamation potential of the Ojo Encino EMRIA study site in the south part of the San Juan Basin in northwest New Mexico. The area was selected by the U.S. Bureau of Land Management to be included in the EMRIA (Energy Minerals Rehabilitation Inventory and Analysis) program in order to evaluate the reclamation potential of sediments from the Upper Cretaceous Fruitland Formation in this part of the basin.

The Ojo Encino EMRIA study site is an area of about 6.5 square miles (17 km^2) located 2 miles (3.2 km) east of the Star Lake Trading Post within the Star Lake and Ojo Encino Mesa 7 1/2-minute quadrangles. Coals of the study site were evaluated on the basis of drill-hole data. Five holes were cored by the U.S. Bureau of Reclamation between August and November of 1978 (fig. 1). The geology of the area was mapped on a scale of 1:24,000 in two reports by Scott and others, 1980.

GEOLOGIC SETTING

The San Juan Basin is a large structural basin in northwest New Mexico and southwest Colorado. The Ojo Encino EMRIA study site is on the south margin of the basin where the Upper Cretaceous Pictured Cliffs Sandstone, Fruitland Formation, and Kirtland Shale dip gently northward.

The marine Pictured Cliffs Sandstone is composed of mostly thick-bedded and crossbedded sandstone and some thinly bedded sandstone and silty shale. Overlying and intertonguing with the Pictured Cliffs is the nonmarine Fruitland Formation, which consists of a highly varied sequence of interbedded lenticular claystone, silty and sandy shale, crossbedded sandstone, and coal. The Fruitland Formation was fully penetrated in five drill holes in the study site, and thickness ranges from 87 feet (27 m) to 164 feet (50 m). The overlying nonmarine Kirtland Shale has a lithology similar to that of the Fruitland Formation but lacks coal of commercial thickness (fig. 2).

The coal evaluated in the study is in the Upper Cretaceous Fruitland Formation, which includes one to three major lenticular coal beds that achieve a maximum total thickness measured in a drill hole of 22 feet (6.7 m) (fig. 3). Due to the uncertainties of correlation, these beds were assumed to constitute coal zones that include coal beds greater than 2.5 feet (0.8 m) in thickness in intervals as much as 68 feet (21 m) thick.

Overburden on coal beds greater than 2.5 feet (0.8 m) thick ranges from 16 feet (4.9 m) to 160 feet (49 m) in thickness in the five drill holes.

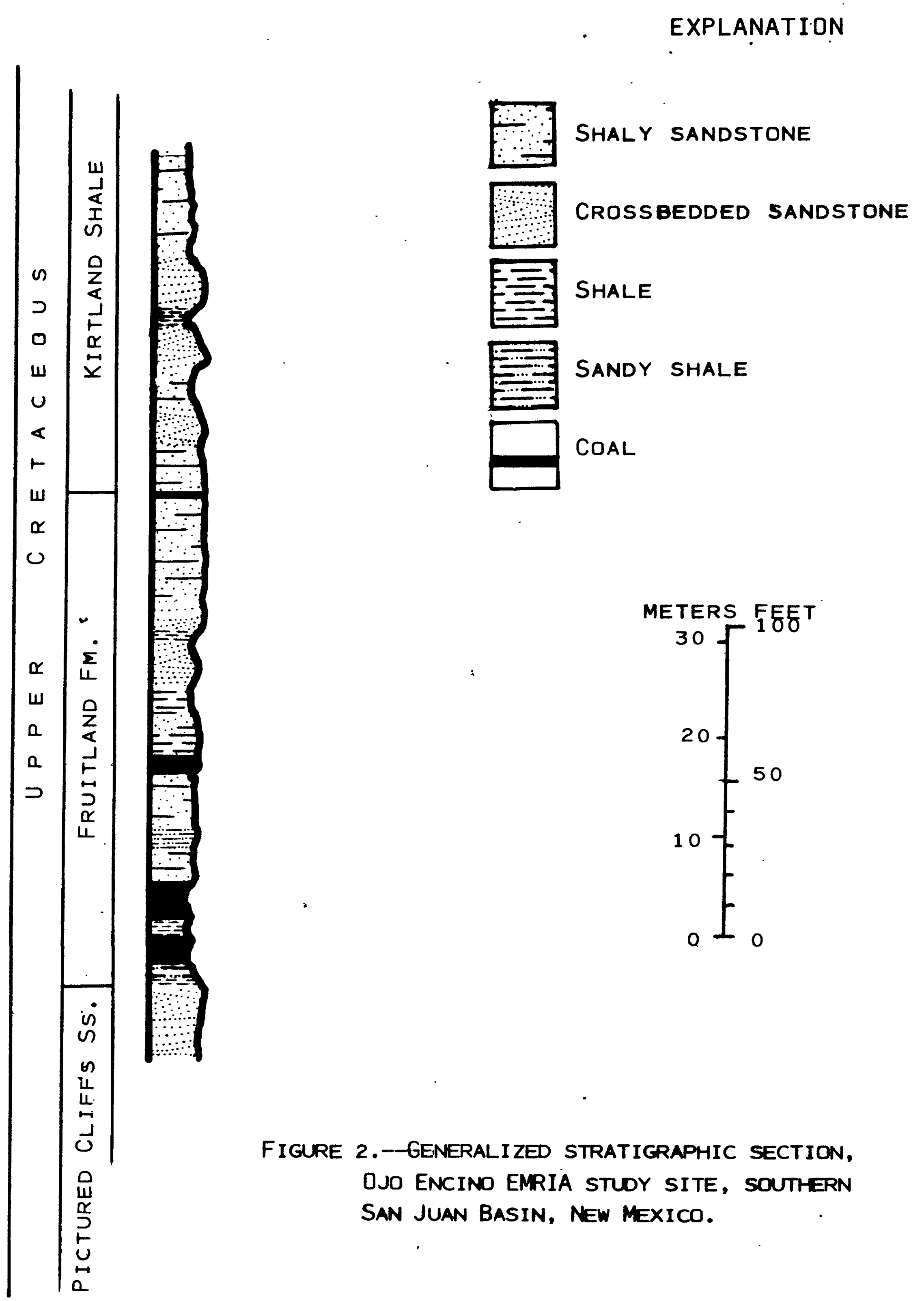

FIGURE 2.--GENERALIZED STRATIGRAPHIC SECTION, OJO ENCINO EMRIA STUDY SITE, SOUTHERN SAN JUAN BASIN, NEW MEXICO.

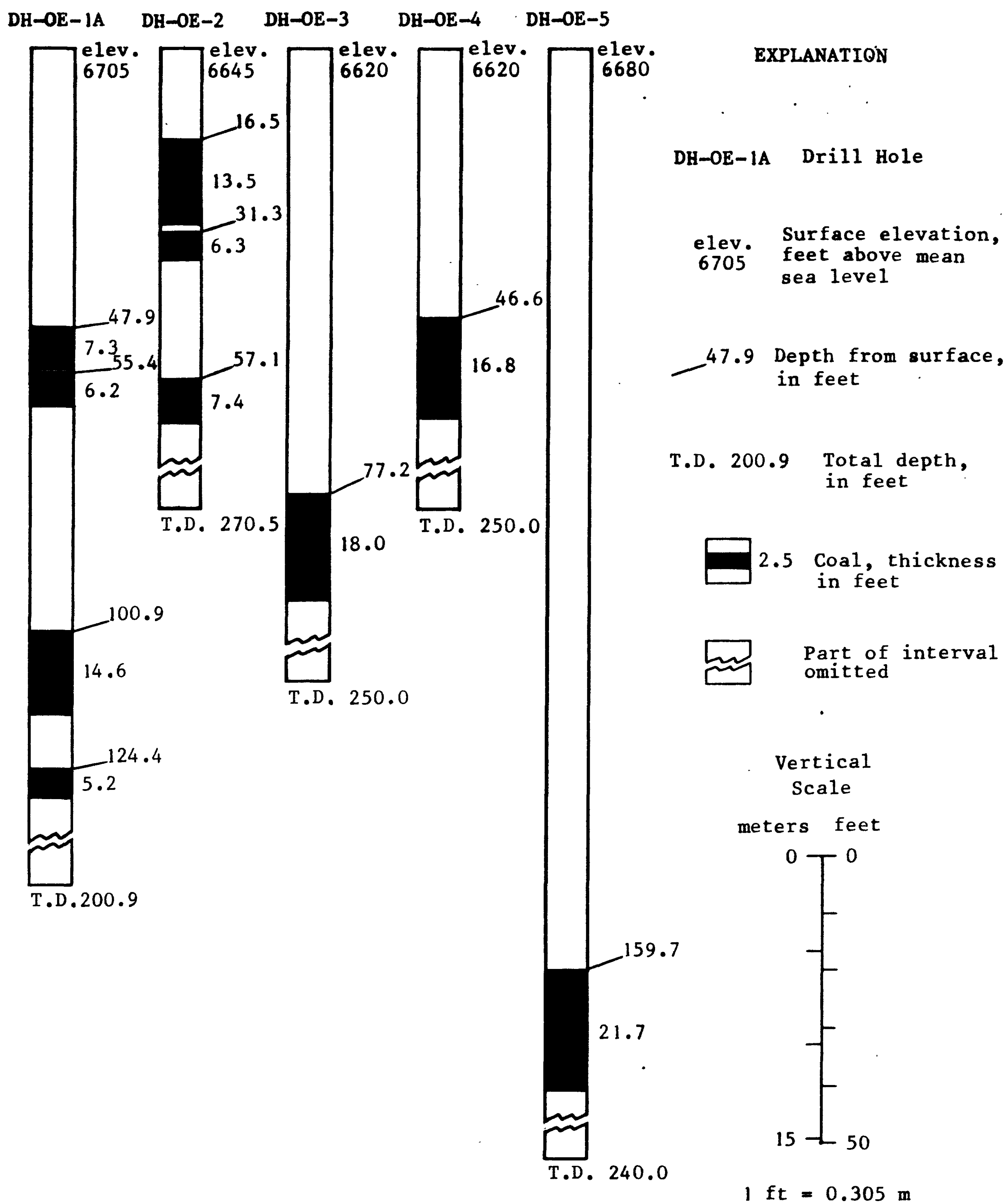

Figure 3.--Generalized drill holes showing coal greater than 2.5 feet (0.8 m) in thickness from the Ojo Encino EMRIA study site.

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 underwent a long, 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 members of the series are differentiated from each other. The factors that affect the composition of coals have been summarized by Francis (1961, p. 2) as follows:

1) The mode of accumulation and burial of the plant debris forming the 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.

These factors are discussed in greater detail by Moore (1940), Lowry (1945, 1963), Tomkeieff (1954), and Francis (1961).

Classification

Coals are 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. Factors such as weight of the coal, thickness and areal extent of individual coal beds, and 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 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 constituents; that is, the higher rank coals have more carbon and less hydrogen than the lower rank coals.

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

> The proximate analysis of coal involves the determination of four constituents: (1) water, called moisture; (2) mineral impurity, called ash, left when the coal is completely burned; (3) volatile matter, consisting of gases or vapors driven out when coal is heated to certain temperatures; and (4) fixed carbon, the solid or 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 heat of combustion (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, heat of combustion 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 4 compares, in histogram form, the heat of combustion and moisture, volatile matter, and fixed-carbon contents of coals of different ranks.

Various schemes for classifying coals by rank have been proposed and used, but the most commonly employed is that entitled "Standard specifications for classification of coals by rank," adopted by the ASTM (American Society for Testing and Materials, 1977, 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 heat of combustion, supplemented by determination of agglomerating (caking) characteristics. As pointed out by the ASTM (1977, p. 216), a standard rank determination cannot be made unless the samples were obtained in

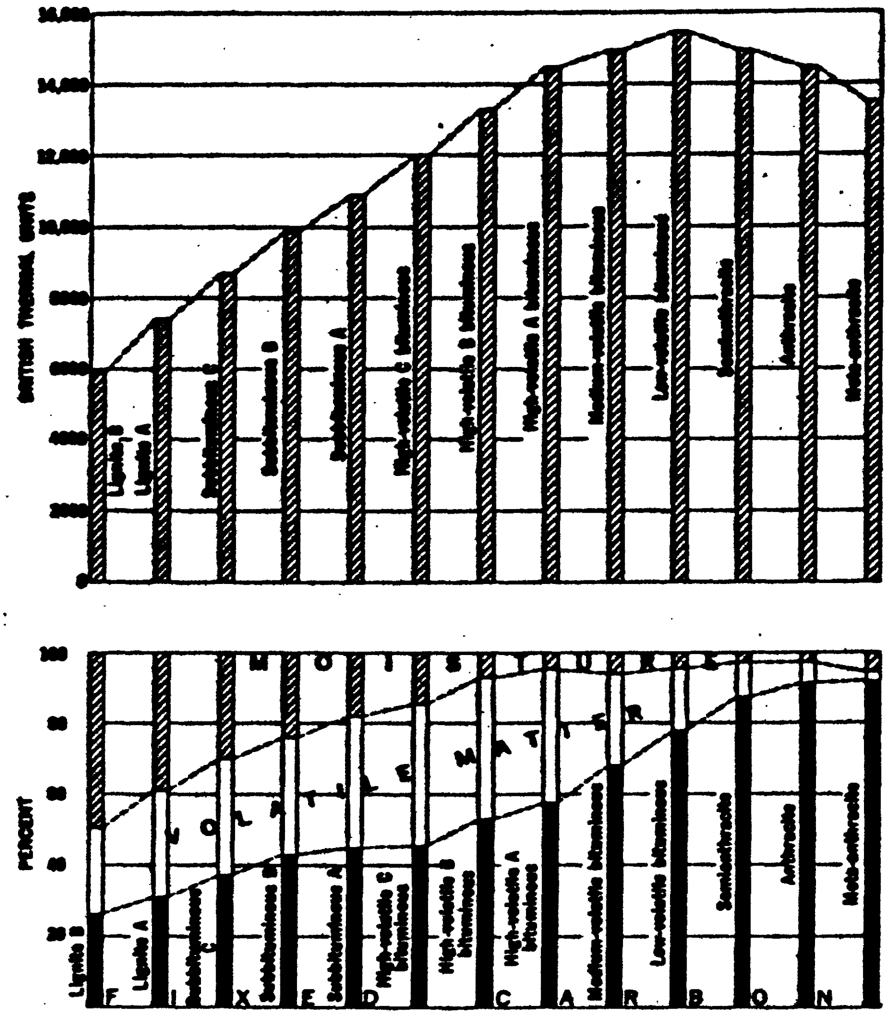

Fig. 4.--Comparison (on moist, mineral-matter-free basis) of heat of combustion and proximate analyses of coal of different ranks (from Averitt, 1975, p. 17)

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): Equal or greater than	Fixed carbon limits, percent (dry, mineral-matter-free basis): Less than	Volatile matter limits, percent (dry, mineral-matter-free basis): Greater than	Volatile matter limits, percent (dry, mineral-matter-free basis): Equal or less than	Calorific value limits, Btu per pound (moist[2], mineral-matter-free basis): Equal or greater than	Calorific value limits, Btu per pound (moist[2], mineral-matter-free basis): Less than	Agglomerating character
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.

[5] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class and that there are notable exceptions in the high-volatile C bituminous group.

accordance with standardized sampling procedures (Snyder, 1950; Schopf, 1960). However, nonstandard samples may be used for comparative purposes through determinations designated as "apparent rank." For this study area, eight samples analyzed by the Department of Energy show heat-of-combustion values that range from 7888 to 9990 Btu/lb on the as-received basis (table 2).

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 as cell walls, spore-coatings, pollen, resin particles, and coals composed mainly of algal material. Most coals fall into the humic series, but some coals are a mixture of humic and sapropelic elements and, therefore, fall into the humic-sapropelic series. The sapropelic series is quantitatively insignificant and, when found, is commonly regarded as an organic curiosity. In common with most of the U.S. coals, those from the Ojo Encino EMRIA study site fall largely in the humic series.

Table 2.--Chemical analyses of eight coal samples of the Fruitland Formation from the Ojo Encino EMRIA study site

[All analyses are in percent except Btu/lb; to convert feet to meters multiply by 0.305; to convert Btu/lb to Kcal/kg multiply by 0.556]

			Proximate				Ultimate	
Laboratory number	Drill hole number	Depth interval in feet	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Btu/lb (as received)
K96421	DH-OE-1A	47.9- 61.6	12.6	31.6	33.9	21.9	0.6	8835
K96422	DH-OE-1A	101.0-115.6	12.8	28.2	30.7	28.3	.5	7888
K96423	DH-OE-1A	124.4-129.6	13.1	32.1	36.0	18.8	.5	9343
K96424	DH-OE-5	159.7-180.0	13.1	32.2	31.8	22.9	.6	8670
K96425	DH-OE-2	16.0- 37.6	12.3	33.0	34.0	20.7	.5	9012
K96426	DH-OE-2	56.2- 64.2	15.8	32.4	40.2	11.6	.5	9990
K96430	DH-OE-3	77.2- 95.2	12.5	31.0	34.8	21.7	.6	8943
K96433	DH-OE-4	46.6- 63.4	12.2	31.1	34.7	22.0	.6	8943
Range			12.2-15.8	28.2-33.0	30.7-40.2	11.6-28.3	0.5-0.6	7888-9990
Average			13.1	31.4	34.5	21.0	.55	8953

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; however coals of the United States have been classified by sulfur content in a gross way (DeCarlo and others, 1966).

The ash content of eight coal samples from the Fruitland Formation of the Ojo Encino study site, on the as-received basis, ranges from 11.6 to 28.3 percent, averaging 21.0 percent; the sulfur content ranges from 0.5 to 0.6 percent, averaging 0.55 percent. For comparison, the ash content of 67 coal samples taken from the Fruitland coal in the San Juan Basin, on the as-received basis, ranges from 9.8 percent to 35.7 percent, averaging 18.9 percent; and the sulfur content ranges from 0.5 percent to 2.2 percent, averaging 0.75 percent (Fassett and Hinds, 1971). When these samples are compared to 488 samples of other U.S. coal (Swanson and others, 1976, p. 17), coal of the Ojo Encino study site has a relatively high ash content and low sulfur content.

Chemical analyses of coal in the Ojo Encino study site

Proximate analysis, sulfur content, and heat content of eight coal samples from the Fruitland Formation were provided by chemists from the Coal Analysis Section (John Puskas, Acting Chief), Department of Energy, Pittsburgh, PA, whose contribution is gratefully acknowledged (table 2).

Eight samples of Fruitland coal show heat-of-combustion values that average 8953 Btu/lb (4978 Kcal/kg) on the as-received basis. When the heat of combustion values are calculated on a moist-mineral-matter-free basis, the apparent rank of the coal ranges from subbituminous A to high volatile C bituminous. For the purposes of this report, resource calculations were made on the basis of weight per ton of subbituminous coal.

ESTIMATION AND CLASSIFICATION OF COAL RESOURCES

Coal resource estimates have been prepared for the Fruitland coal within the Ojo Encino EMRIA study site using standard procedures, definitions, and criteria established by the U.S. Bureau of Mines and U.S. Geological Survey (1976) 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

Tables 3 and 4 summarize the estimated subbituminous coal resources of the Ojo Encino EMRIA study site. Coal resources were calculated on the thickness of coal beds greater than 2.5 feet (0.8 m) in thickness. Due to the uncertainties of correlation, coal beds were treated as zones of coal and were divided into two categories: coal beds from 5 to 10 feet (1.5 to 3.1 m) in thickness were treated as one zone, and coal beds greater than 10 feet (3.1 m) in thickness were treated as another zone. The resources in the study site are classified as measured, indicated, and inferred according to the degree of geologic assurance of the estimate.

Table 3.--Estimated identified subbituminous coal resources of the Fruitland Formation, Ojo Encino EMRIA study site, McKinley County, New Mexico, as of July 1, 1980

[Leaders (---) indicate not present. In millions of short tons.
1 foot = 0.305 meters; 1 short ton = 0.907 metric ton]

Location	Thickness of coal in zone								Section Total
	5-10 feet				10 ft or more				
	Measured*	Indicated*	Inferred*	Total	Measured*	Indicated*	Inferred*	Total	
T. 19 N., R. 5 W.									
sec. 2	---	2.35	5.75	8.10	0.26	2.52	0.09	2.87	10.97
sec. 3	---	1.33	1.39	2.72	3.06	1.24	.63	4.93	7.65
sec. 4	0.67	1.83	---	2.50	2.05	15.84	1.27	19.16	21.66
sec. 5	1.44	5.76	.86	8.06	4.98	21.36	3.99	30.33	38.39
N 1/2 sec. 7	.28	.74	.54	1.56	2.31	6.66	3.24	12.21	13.77
N 1/2 sec. 9	.22	1.11	.36	1.69	.87	6.98	1.15	9.00	10.69
Township Total	2.61	13.12	8.90	24.63	13.53	54.60	10.37	78.50	103.13
T. 20 N., R. 5 W.									
SE 1/4 sec. 33	---	---	---	---	---	5.37	2.40	7.77	7.77
S 1/2 sec. 34	---	---	---	---	3.43	11.12	---	14.55	14.55
S 1/2 sec. 35	---	0.42	1.88	2.30	.13	3.50	.31	3.94	6.24
SW 1/4 sec. 36	---	---	1.16	1.16	---	---	---	---	1.16
Township Total	---	.42	3.04	3.46	3.56	19.99	2.71	26.26	29.72
Total for Site	2.61	13.54	11.94	28.09	17.09	74.59	13.08	104.76	132.85

*Defined on p. 18.

Table 4.—Summary of estimated identified subbituminous coal resources of the Fruitland Formation, Ojo Encino EMRIA study site, as of July 1, 1980

[Leaders (---) indicate not present. In millions of short tons. 1 foot = 0.305 meters]

	T. 19 N., R. 5 W.	T. 20 N., R. 5 W.	Total
Coal beds 5 to 10 feet thick			
Measured resources	2.61	---	2.61
Indicated resources	13.12	0.42	13.54
Inferred resources	8.90	3.04	11.94
Total	24.63	3.46	28.09
Coal beds more than 10 feet thick			
Measured resources	13.53	3.56	17.09
Indicated resources	54.60	19.99	74.59
Inferred resources	10.37	2.71	13.08
Total	78.50	26.26	104.76
Total identified resources	103.13	29.72	132.85

Measured - Resources are computed from thicknesses 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 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 1,000 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 rank, grade, and density of the coal; thickness of the coal beds; and thickness of the overburden. Rank and grade have been discussed previously.

Density

The density of the coal varies considerably with differences in rank and ash content. In areas such as the Ojo Encino EMRIA study site, where true densities of the coal have not been determined, an average density based on many determinations in other areas is used to express the density of the coal for resource calculations. The average density of this subbituminous coal is assumed to be 1770 tons per acre-foot, and the specific gravity is 1.30.

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. The thickness categories used for subbituminous coal 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 79 percent of the estimated resources of the study area is in the thick category, about 21 percent is in the intermediate category, and none is in the thin category. By way of comparison, Averitt (1975, fig. 5 and p. 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

Coal resources are usually divided into categories based on the thickness of overburden, as follows: 0-1,000 feet (0-305 m), 1,000-2,000 feet (305-610 m), and 2,000-3,000 feet (610-915 m). No standardized thickness categories exist for overburden removal during surface mining because of the many economic factors. At the Ojo Encino study site, overburden on the uppermost coal bed in the five drill holes ranges from 16 feet (4.9 m) to 160 feet (49 m) thick. The coal has potential for mining by surface methods because it occurs at shallow depth and is of economic thickness.

SUMMARY OF RESOURCES

Total estimated identified original resources in the Ojo Encino EMRIA site are 132,850,000 tons (120,490,000 metric tons). The coal bed thickness class of 2.5-5 feet contains no significant measurable resources. The coal-bed thickness class of 5-10 feet contains 28,090,000 tons (25,480,000 metric tons) of the estimated resources. The coal bed thickness class of greater than 10 feet contains 104,760,000 tons (95,020,000 metric tons) of the estimated resources.

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

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