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COAL RESOURCE OCCURRENCE MAPS AND COAL DEVELOPMENT POTENTIAL MAPS OF THE WATERFLOW QUADRANGLE, SAN JUAN COUNTY, NEW MEXICO

[Report includes 19 plates]

by

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WATERFLOW 7 1/2-MINUTE QUADRANGLE

INTRODUCTION

Purpose

This text is to be used in conjunction with the Coal Resource Occurrence (CRO) Maps and Coal Development Potential (CDP) Maps of the Waterflow quadrangle, San Juan County, New Mexico. These maps were compiled to provide a systematic coal resource inventory of Federal coal lands in Known Recoverable Coal Resource Areas (KRCRA's) in the western United States. The work has been performed under contract with the Conservation Division of the U.S. Geological Survey (Contract No. 14-08-001-17172).

The resource information gathered in this program is in response to the Federal Coal Leasing Amendments Act of 1976 and is a part of the U.S. Geological Survey's coal program. The information provides basic data on coal resources for land-use planning purposes by the Bureau of Land Management, state and local governments, and the public.

Location

The Waterflow 7 1/2-minute quadrangle is in northwestern San Juan County, New Mexico. The area is approximately 12 miles (19 km) northwest of Farmington, New Mexico. The Ute Mountain Indian Reservation encompasses the northern quarter of the quadrangle.

Accessibility

The Waterflow quadrangle is accessible from New Mexico State Route 550 which extends across the southern part of the area. Various light-duty roads extend from State Route 550 and provide access to other parts of the quadrangle. The Atchison, Topeka, and Santa Fe Railway operates a route approximately 93 miles (150 km) south of the area at Gallup, New Mexico.

Physiography

This quadrangle is in the northwestern portion of the Central Basin area and the Four-Corners platform area (Kelley, 1950) of the structural depression known as the San Juan Basin. Elevations range from 5,020 ft (1,530 m) in the Jewett Valley to 6,093 ft (1,857 m) in the Ute Mountain Indian Reservation. The San Juan River flows westward across the southwestern corner of the area. The floodplain is wide and bordered on the north by gravel terraces. Topographic relief varies from very low in The Meadows to more than 500 ft (152 m) in the north; most of the area is characterized by gentle slopes. The Hogback Monocline, a prominent structural feature, trends generally northeast-southwest across the northern and western parts of the area and is characterized by steeply dipping, deeply dissected beds.

Climate

The climate of the San Juan Basin is arid to semi-arid. Annual precipitation is usually less than 10 inches (25 cm) but varies across the basin due to elevational differences. Rainfall is rare in the early summer and winter; most precipitation is received in July and August as intense afternoon thundershowers. Annual temperatures in the basin range from below 0°F (-18°C) to above 100°F (38°C). Snowfall may occur from November to April.

Land Status

Approximately 42 percent of the quadrangle is in the northwestern portion of the San Juan Basin Known Recoverable Coal Resource Area. The Federal Government owns the coal rights for approximately 84 percent of the KRCRA land wihin the quadrangle as shown on Plate 2 of the Coal Resource Occurrence Maps. Coal leases (NM 045196, NM 045197, NM 045217, SF 071448), in the south, cover 41 percent of the quadrangle.

GENERAL GEOLOGY

Previous Work

Bauer and Reeside (1921) mapped the Fruitland Formation within the quadrangle with detailed emphasis on the outcrops of Fruitland coal. Reeside (1924) has mapped the Upper Cretaceous and Tertiary formations of the San Juan Basin at a scale of 1:250,000. Hayes and Zapp (1955) published a geologic map at a scale of 1:62,500 of the Barker Dome-Fruitland Area which includes this quadrangle. This map includes coal bed outcrops and measurements of various coal-bearing sections. Fassett and Hinds (1971) have made subsurface interpretations of the Fruitland Formation coal deposits throughout the San Juan Basin. The most recent publication in the area (Beach and Jentgen, 1978) is of shallow drill hole information used in the determination of coal-bearing zones. Western Coal Company is presently operating the San Juan Mine, a strip mine of the basal Fruitland coals exposed in the quadrangle; the extent of mining as of May 1978 is shown on CRO Plate 1.

Geologic History

The San Juan Basin, an area of classic transgressive and regressive sedimentation, provided the ideal environment for formation of coals during Late Cretaceous time. At that time a shallow epeiric sea, which trended northwest-southeast, was northeast of the basin. The sea transgressed southwesterly into the basin area and regressed northeasterly numerous times; consequently, sediments from varying environments were deposited across the basin. Noncarbonaceous terrestrial deposition predominated during Paleocene and Eocene time.

The first basin-wide retreat of the Late Cretaceous sea is indicated by the nearshore deposits of the Point Lookout Sandstone. These ancient barrier beaches formed a generally north-south-trending strandline in this part of the basin, behind which swamps developed. Organic material accumulated in the swamps and later became coal in the paludal deposits of the lower Menefee Formation. Deposition of materials which formed the coal beds was influenced by the strandline. This is shown by the more consistent thickness and greater lateral extent of the coals parallel to the strandline and also by the lack of continuity perpendicular to it, to the east, where the Menefee and underlying Point Lookout deposits interfinger. Streams which crossed the swamps also influenced deposition of organic matter; stream deposits may terminate even the most continuous coal beds.

During the continued retreat of the sea, the depositional environments in the quadrangle area became more terrestrial. This is evidenced by the transition within the lower Menefee from carbonaceous to noncoal-bearing deposits, in which there is an upward decrease in the occurrence and lateral continuity of the coals. As the sea retreated, the sediments of the Point Lookout Sandstone and overlying Menefee Formation were deposited in successively higher stratigraphic positions to the east.

The sea then reversed the direction of movement, and the transgressive sequence of nearshore Cliff House Sandstone and marine Lewis Shale was deposited in the quadrangle. A thin sand of the Cliff House Sandstone was deposited over the Menefee deposits. The marine facies which developed east and northeast of the strandline as it moved to the west and southwest is the Lewis Shale. This thick sequence, which thins to the southwest, overlies the Cliff House Sandstone and marks the last advance of the Late Cretaceous sea.

Evidence of the final retreat of the Late Cretaceous sea are the nearshore regressive Pictured Cliffs Sandstone and the overlying paludal Fruitland Formation which were deposited in successively higher stratigraphic positions to the northeast. Southwest (shoreward) of the beach deposits, swamps, which were dissected by streams, accumulated organic matter which later became coals of the Fruitland Formation. Again, deposition of organic material was influenced by the strandline as shown by both the continuity of the coal beds parallel to the north-south strandline and their discontinuity perpendicular to it to the east.

The brackish-water swamp environment of the Fruitland moved northeast of the area as the regression continued in that direction. Terrestrial freshwater sediments then covered the quadrangle as indicated by the lacustrine, channel, and floodplain deposits of the Kirtland Shale. This sequence of events is evidenced by both an upward decrease in occurrence and thickness of Fruitland coals and a gradational change to noncarbonaceous deposits of the Kirtland. Continuous deposition during Late Cretaceous time ended with the Kirtland. The sea then retreated beyond the limits of the quadrangle area, and modern basin structure began to develop. An erosional unconformity developed in a relatively short time as part of the Cretaceous Kirtland Shale was removed.

Terrestrial deposition resumed in the Paleocene as represented by the Ojo Alamo Sandstone and the overlying Nacimiento Formation. Alluvial plain and floodplain deposits of the Ojo Alamo were followed by the thick, lithologically varied deposits of the Nacimiento during continuous nonmarine deposition. The Nacimiento was later exposed to erosion.

The Eocene San Jose Formation was subsequently deposited over the Nacimiento erosional surface, reflecting various nonmarine environments which developed across the basin. Deposition and structural deformation of the basin then ceased, and the warped strata of the San Juan Basin have been exposed to erosional processes to the present time. A significant amount of erosion has occurred, as indicated by the removal of both the San Jose Formation and Nacimiento Formation from the area.

Stratigraphy

The formations studied in this quadrangle are Late Cretaceous in age. They are, in order from oldest to youngest: (the three formations of the Mesaverde Group) the Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone; Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, and the Kirtland Shale. A composite columnar section on CRO Plate 3 illustrates the stratigraphic relationships of these formations and is accompanied by lithologic descriptions of the individual formations.

The Point Lookout Sandstone, the basal formation of the Mesaverde Group, is composed of buff to gray, slightly dolomitic, micaceous sandstone and gray to brown siltstone and shale. It is fairly massive, averages about 330 ft (101 m) in thickness in this area, and displays a distinctive and consistent character on geophysical logs. This last characteristic was used by the authors to establish the top of the Point Lookout as a lithologic datum for correlation of overlying Menefee Formation coals.

The oldest coal-bearing formation in the quadrangle is the Menefee Formation of the Mesaverde Group. In previous studies the Menefee has been divided into the Cleary Coal Member, the barren Allison Member, and the upper coal-bearing member (Beaumont and others, 1956). These members are referred to as the undifferentiated Menefee Formation for the purposes of this report only. The formation consists primarily of gray-green to brown, carbonaceous to noncarbonaceous shale with plant fossils and a trace of pyrite, interbedded tan to light gray sandstone, interbedded gray-brown, micaceous siltstone, and lenticular coal beds. The formation has a total thickness of approximately 925 ft (282 m).

The Cliff House Sandstone in this area is a thin sand wedge which conformably overlies the Menefee Formation. This sand is about 60 ft (18 m) thick and consists of tan to light gray, micaceous sandstone.

The marine Lewis Shale conformably overlies the Mesaverde Group. In contrast to the underlying Cliff House Sandstone, it is comprised predominantly of gray, calcareous siltstone with plant fossils, interbedded gray to dark brown shale, and interbedded tan to light gray, micaceous sandstone. The thickness of the formation averages 1,390 ft (424 m) in this area. The upper contact is gradational with the overlying Pictured Cliffs Sandstone, and, therefore, a definite and consistent contact is difficult to establish.

The Pictured Cliffs Sandstone consists of about 150 ft (46 m) of tan to gray, micaceous, slightly calcareous sandstone commonly interbedded with gray to brown, micaceous siltstone near the base of the formation where it grades into the Lewis. The upper contact is more sharply defined than the basal contact, even though intertonguing with the overlying Fruitland Formation results in minor variations in the formational top and the occurrence of local Fruitland coal beds. Since the Pictured Cliffs Sandstone is present throughout most of the basin and displays a distinctive character on geophysical logs, the authors have used the top as a lithologic datum for correlation of Fruitland coals.

The Fruitland Formation is the major coal-bearing unit in the quadrangle. It averages 520 ft (158 m) of gray, carbonaceous shale with plant fossils, interbedded white to gray sandstone, interbedded gray to brown siltstone, and coal beds of varying thicknesses. The thickest and most continuous coal beds occur near the base of the formation, while discontinuous and lenticular coals are characteristic of the upper portion. The upper contact is gradational from nonmarine, lower coastal plain deposits of the Fruitland to upper coastal or alluvial plain deposits of the Kirtland Shale (Molenaar, 1977).

The freshwater deposits of the Kirtland Shale are composed of gray to brown shale with local plant fossils, interbedded white to gray sandstone, and interbedded gray to brown siltstone. The formation has previously been divided into several members by various authors; however, for the purpose of this report it was not necessary to distinguish between the individual members.

In this quadrangle the dip of the strata forming the structural feature, the Hogback Monocline, causes the exposure of great thicknesses of the Upper Cretaceous rocks. The Menefee Formation, the oldest formation exposed in the area, and the Cliff House Sandstone crop out in the northwestern corner of the quadrangle on the flank of the Hogback Monocline. The Lewis Shale, Pictured Cliffs Sandstone, and Fruitland Formation also are exposed along the monocline in the northern part of the area, but are not part of the monocline structure to the south. These outcrops trend generally east-west along the monocline and north-south to the south. The formations become younger to the southeast so that the Kirtland Shale, the youngest formation in the area, is exposed in the southeastern corner of the quadrangle.

Structure

The western end of the axis of the San Juan Basin is about 13 miles (21 km) northeast of the Waterflow quadrangle and trends easterly in an arcuate pattern across the northern portion of the Central Basin area (Baltz, 1967).

The Hogback Monocline extends across the western and northern parts of the area with the strata on its flank having a steep dip of between 15° to 25°. Southeastward of the Hogback Monocline the dip angle decreases rapidly to 1° (Reeside, 1924; Hayes and Zapp, 1955). The direction varies from east to southeast to south.

COAL GEOLOGY

Individual coal beds are not continuous across the San Juan Basin because the coal-related strata are progressively younger from southwest to northeast; the strata rise in steps due to minor transgressions which occurred during the overall retreat of the sea. However, for the exclusive purpose of reserve and reserve base calculations, the coals have been correlated and mapped as if each were a single bed, continuous throughout the basin.

A lithologic datum was used for correlation of the coals of the San Juan Basin. The primarily marine sandstone units (Point Lookout, Pictured Cliffs) which underlie the coal-bearing formations (Menefee, Fruitland) were used as datums since they represent a more laterally continuous boundary than any of the overlying paludal, fluvial, and lacustrine deposits of the coal-bearing formations. Also, the sandstone units are generally more easily recognized on geophysical logs.

In this quadrangle, Menefee coals in oil and gas test holes (El Paso Natural Gas Co., 1978, unpublished data in well log library, Farmington, New Mexico) were plotted in the columns (CRO Plate 3) using the Point Lookout Sandstone-Menefee Formation and the Menefee Formation-Cliff

House Sandstone contacts as datums which were used as the basis for correlations. Correlations of Menefee coals in measured sections were based upon geologic maps (Hayes and Zapp, 1955). Although the oil and gas test holes (El Paso Natural Gas Co., 1978, unpublished data in well log library, Farmington, New Mexico) and coal test holes (Beach and Jentgen, 1978; Beaumont, 1971) with Fruitland coal are plotted in columns (CRO Plate 3) with an elevational datum, correlations of these coals are based upon a lithologic datum (Pictured Cliffs Sandstone) from geologic maps (Beaumont, 1971) and lithologic and geophysical log interpretations (Beach and Jentgen, 1978). Correlations of Fruitland coals in measured sections are based upon geologic maps (Bauer and Reeside, 1921; Hayes and Zapp, 1955).

Nine coal beds (Menefee 1, Menefee 2, Menefee 3, Menefee 4, Menefee 5, Menefee 6, Fruitland 1, Fruitland 2, Fruitland 3) and a coal zone (Menefee) were identified in this quadrangle (CRO Plate 1). The Menefee 1 (Me 1) coal bed occurs near the base of the Menefee Formation. The coal bed crops out in the northwest part of the quadrangle. The Menefee 2 (Me 2) coal bed occurs stratigraphically above the Menefee 1 and also crops out in the northwest. The Menefee 3 (Me 3) coal bed is identified in the subsurface in the upper portion of the Menefee Formation. Above the Menefee 3 is the Menefee 4 (Me 4) coal bed, followed by the Menefee 5 (Me 5) and Menefee 6 (Me 6) coal beds, all of which crop out in the northwest part of the quadrangle. All of these coal beds have been informally named by the authors. In this quadrangle the Menefee 1, 2, 3, 4, and 5 coal beds are less than reserve base thickness (5 ft [1.5 m]) within the KRCRA. Therefore, derivative maps were not constructed.

The remaining coals of the Menefee Formation are designated as the Menefee coal zone (Me zone). Several of these coals crop out in the northwest. Since these coals are generally noncorrelative, discontinuous, and less than reserve base thickness (5 ft [1.5 m]), derivative maps were not constructed.

Menefee Formation coals in the northwestern part of the San Juan Basin are considered high volatile C bituminous in rank, although they vary from borderline subbituminous A--high volatile C bituminous to high volatile B bituminous. The rank has been determined on a moist, mineral-matter-free basis with calorific values averaging 12,563 Btu's per pound (29,222 kj/kg) (Amer. Soc. for Testing and Materials, 1977). The coal is hard, brittle, and black with a bright luster. The coal readily slakes with exposure to weather; however, it stocks fairly well when protected. The "as received" analyses indicate moisture content varying from 5.6 to 11.3 percent, ash content ranging from 3.1 to 6.3 percent, sulfur content less than 1 percent, and heating values on the order of 11,993 Btu's per pound (27,896 kj/kg). Analyses of several Menefee coals are given in Table 1 (Bauer and Reeside, 1921; Hayes and Zapp, 1955; Shomaker and Whyte, 1977).

The Fruitland 1 (Fr 1) coal bed is designated by the authors as the lowermost coal of the Fruitland Formation; it is generally directly above the Pictured Cliffs Sandstone. The Fruitland 1 in this study is referred to as the main bed by the Western Coal Company (1977), which operates the San Juan Mine. The coal bed crops out in the eastern part of the quadrangle. The Fruitland 2 (Fr 2) coal bed is above the Fruitland 1 and crops out in the northeast. The Fruitland 3 (Fr 3) coal bed is above the Fruitland 2 and

TABLE 1

Analyses of coal samples from the Menefee Formation

(Form of analysis: A, as received; B, moisture free; C, moisture and ash free)

U.S. Bureau Mines Lab No.	Well or Other Source	Location			Approx. Depth Interval of Sample (ft.)	Form of Analysis	Proximate, percent					Heating Value (Btu)	Remarks
		Section	T.N.	R.W.			Moisture	Volatile matter	Fixed Carbon	Ash	Sulfur		
J-58561	Merrion & Bayless #1, Union	9	29	15	2,494-2,500	A	5.6	40.4	47.7	6.3	0.8	12,740	
						B	——	42.7	50.7	6.6	0.9	13,490	
						C	——	45.8	54.2	——	1.0	14,450	
17750	Shiprock School Mine(?) (100 ft from entry) (Government Mine)	SW¼ 21	30	16	————	A	10.6	36.7	49.6	3.1	0.64	11,010	
						B	——	41.1	55.4	3.5	0.72	12,310	
						C	——	42.6	57.4	——	0.75	12,750	
A-46364	Shiprock School Mine (250 ft from entry)	21	30	16	————	A	9.8	38.7	46.5	5.0	——	11,870	
						B	——	42.9	51.5	5.6	——	13,170	
						C	——	45.4	54.6	——	1.5	13,940	
29006	Shiprock School Mine (350 ft from entry) (Government Mine)	SW¼ 21	30	16	————	A	10.1	39.9	45.8	4.2	0.85	12,010	
						B	——	44.4	50.9	4.7	0.95	13,370	
						C	——	46.6	53.4	——	1.00	14,020	
A-46365	Joe Duncan Mine (150 ft from entry)	21	30	16	————	A	10.5	39.1	47.2	3.2	——	12,240	
						B	——	43.7	52.7	3.6	——	13,670	
						C	——	45.3	54.7	——	1.0	14,180	
C-31312	Davidson Mine (tipple)	22	30	16	————	A	11.3	39.3	46.0	3.4	——	12,090	
						B	——	44.3	51.9	3.8	——	13,630	
						C	——	46.1	53.9	——	0.8	14,170	

To convert Btu's/lb to kj/kg, multiply Btu's/lb by 2.326.
To convert feet to meters, multiply feet by 0.3048.

crops out in the eastern part of the quadrangle (CRO Plate 1). There are several local (L) coals within the Fruitland Formation which are noncorrelative and less than reserve base thickness (5 ft [1.5 m]).

Fruitland Formation coals in the northwestern part of the San Juan Basin are considered high volatile C to high volatile B bituminous in rank. The rank has been determined on a moist, mineral-matter-free basis with calorific values averaging 12,900 Btu's per pound (30,005 kj/kg) (Amer. Soc. for Testing and Materials, 1977). The coal is hard, brittle, and black with a bright luster. The coal readily slakes with exposure to weather; however, it stocks fairly well when protected. The "as received" analyses indicate moisture content varying from 4.1 to 11.6 percent, ash content ranging from 8.3 to 15.3 percent, sulfur content varying from 0.60 to 2.36 percent, and heating values on the order of 10,530 to 12,056 Btu's per pound (24,493-28,042 kj/kg). Analyses of several Fruitland Formation coals are given in Table 2 (Bauer and Reeside, 1921; Beach and Jentgen, 1978; Fassett and Hinds, 1971; Hayes and Zapp, 1955).

Menefee 6 Coal Bed

The Menefee 6 coal bed has been mapped only in areas outside the Ute Mountain Indian Reservation. The coal bed dips generally to the east, as indicated by the structure contour map (CRO Plate 5). The angle of dip varies considerably, from nearly 35° along portions of The Hogback to less than 1° in the eastern part of the map. The overburden (CRO Plate 6) varies, as a result of topography and dip, from zero at the outcrop to more than

TABLE 2

Analyses of coal samples from the Fruitland Formation

(Form of analysis: A, as received; B, moisture free; C, moisture and ash free)

U.S. Bureau Mines Lab No.	Well or Other Source	Location			Approx. Depth Interval of Sample (ft.)	Form of Analysis	Proximate, percent					Heating Value (Btu)	Remarks
		Section	T.N.	R.W.			Moisture	Volatile matter	Fixed Carbon	Ash	Sulfur		
H-4051	Humble Oil & Gas Humble No. L-9	SE¼ 36	29	14	1,490-1,495	A	4.1	40.0	40.6	15.3	0.7	11,600	
						B	——	41.7	42.3	16.0	0.7	12,100	
						C	——	49.7	50.3	——	0.9	14,400	
22509	L.W. Hendsrickson (Smous) mine	SW¼ 3	29	15	————	A	10.5	38.6	41.7	9.2	0.60	11,210	
						B	——	43.1	46.6	10.3	0.67	12,530	
						C	——	48.0	52.0	——	0.75	13,970	
2464	Black Diamond Mine	SW¼ 4	29	15	————	A	9.9	38.4	41.5	10.2	0.64	11,300	
						B	——	42.7	46.0	11.3	0.71	12,540	
						C	——	48.1	51.9	——	0.80	14,140	
22508	Black Diamond Mine	SW¼ 4	29	15	————	A	11.6	38.6	39.9	9.9	0.60	10,990	
						B	——	43.6	45.2	11.2	0.68	12,430	
						C	——	49.2	50.8	——	0.77	14,000	
B-61218	Stalling mine (tipple)	4	29	15	————	A	10.1	39.1	41.7	9.1	——	11,460	
						B	——	43.5	46.3	10.2	——	12,750	
						C	——	48.4	51.6	——	——	14,200	
29026	Prospect Drift	NW¼ 16	30	15	————	A	9.6	37.2	40.5	12.7	2.36	10,530	
						B	——	41.2	44.8	14.0	2.61	11,660	
						C	——	47.9	52.1	——	3.04	13,560	
H-78945	N.M.P.S.C.C. Core Hole No. 7	21	30	15	69-70	A	5.6	39.7	43.3	11.4	0.7	11,850	Sample from core - not floated in CCl_4. A is air dried analysis
						B	——	42.0	46.0	12.0	0.7	12,540	
						C	——	47.8	52.2	——	0.8	14,260	
Number not available	Open File Report 78-960 drill hole SJ 23-4	23	30	15	589-590	A	4.6	42.6	41.1	11.7	0.6	12,056	
						B	——	44.7	43.1	12.2	0.6	12,639	
						C	——	50.9	49.1	——	0.7	14,402	
29025	Marcelius Mine	SW¼ 28	30	15	————	A	8.8	41.7	41.2	8.3	0.62	11,660	
						B	——	45.7	45.2	9.1	0.68	12,770	
						C	——	50.3	49.7	——	0.75	14,060	

To convert Btu's/lb to kj/kg, multiply Btu's/lb by 2.326.
To convert feet to meters, multiply feet by 0.3048.

2,400 ft (732 m) in the northeast. The isopach map (CRO Plate 4) shows that the coal bed is more than 10 ft (3.0 m) thick in the western and southern sections of the map, and thins in all directions away from these areas. There is no coal in the southwestern and southeastern corners, and in a small area in the central part of the map.

Chemical Analyses of the Menefee 6 Coal Bed - Analyses of several coals of the Menefee Formation from this quadrangle and the surrounding area are given in Table 1 (Bauer and Reeside, 1921; Hayes and Zapp, 1955; Shomaker and Whyte, 1977).

Fruitland 1 Coal Bed

The Fruitland 1 coal bed has been mapped only in areas outside the Ute Mountain Indian Reservation. The coal bed dips to the east as shown on the structure contour map (CRO Plate 9), varying from less than 1° in the south and east to a maximum of about 4° in the north. As a result of topography and dip, the overburden (CRO Plate 10) ranges from zero at the outcrop to more than 600 ft (183 m) at the eastern edge of the map. As illustrated by the isopach map (CRO Plate 8) the coal bed thickness is more than 20 ft (6.1 m) in part of the southeastern portion of the map, and, in general, thins in all directions from this area.

Chemical Analyses of the Fruitland 1 Coal Bed - Analyses of several coals of the Fruitland Formation from this quadrangle and the surrounding area are given in Table 2 (Bauer and Reeside, 1921; Beach and Jentgen, 1978; Fassett and Hinds, 1971; Hayes and Zapp, 1955).

Fruitland 2 Coal Bed

The Fruitland 2 coal bed has been mapped only in areas outside the Ute Mountain Indian Reservation. The coal bed dips to the east as indicated by the structure contour map (CRO Plate 13). The angle of dip varies from less than 1° in the south and east to about 4° in the north. As a result of topography and dip, the overburden (CRO Plate 14) varies in thickness from zero at the outcrop to more than 600 ft (183 m) at the eastern edge of the map. The isopach map (CRO Plate 12) shows that the coal bed is more than 10 ft (3.0 m) thick in the northwestern section of the coal-bearing area, and thins to the east and south. The coal bed is absent from the western half of the map and portions of the south.

Chemical Analyses of the Fruitland 2 Coal Bed - Analyses of several coals of the Fruitland Formation from this quadrangle and the surrounding area are given in Table 2 (Bauer and Reeside, 1921; Beach and Jentgen, 1978; Fassett and Hinds, 1971; Hayes and Zapp, 1955).

Fruitland 3 Coal Bed

The Fruitland 3 coal bed has been mapped only in areas outside the Ute Mountain Indian Reservation. The coal bed dips to the east as shown by the structure contour map (CRO Plate 16). The angle of dip ranges from less than 1° in the east to about 4° in the north. The overburden (CRO Plate 17) varies in thickness, as a result of topography and dip, from zero at the outcrop to more than 400 ft (122 m) in the eastern part of the mapped area.

As shown by the isopach map (CRO Plate 15) the coal bed has a thickness of more than 5 ft (1.5 m) in the east, which decreases to the north, west, and south.

Chemical Analyses of the Fruitland 3 Coal Bed - Analyses of several coals of the Fruitland Formation from this quadrangle and the surrounding area are given in Table 2 (Bauer and Reeside, 1921; Beach and Jentgen, 1978; Fassett and Hinds, 1971; Hayes and Zapp, 1955).

COAL RESOURCES

Coal resource data from oil and gas wells (El Paso Natural Gas Co., 1978, unpublished data in well log library, Farmington, New Mexico), coal test holes (Beach and Jentgen, 1978), geologic maps (Bauer and Reeside, 1921; Hayes and Zapp, 1955; Beaumont, 1971), and mining operations (Western Coal Company, 1977) were used in the construction of outcrop, isopach, and structure contour maps of coal beds in this quadrangle. The U.S. Geological Survey designated the Menefee 6, Fruitland 1, and Fruitland 3 coal beds for the determination of coal resources in this quadrangle. Coals of the Fruitland and Menefee zones were not evaluated because they are generally noncorrelative and less than the reserve base thickness of 5 ft (1.5 m).

For Reserve Base and Reserve calculations, each coal bed was areally divided into measured, indicated, and inferred resource categories (CRO Plates 7 and 11) according to criteria established in U.S. Geological Survey Bulletin 1450-B. Data for calculation of Reserve Base and Reserves for each category were obtained from the respective coal isopach (CRO Plates 4, 8, and 15) and areal distribution (CRO Plates 7 and 11) maps for each coal bed. The surface area of each isopached bed was measured by planimeter, in acres, for each category, then multiplied by both the average isopached thickness of the coal bed and 1,800 short tons of coal per acre-foot (13,239 tons/hectare-meter), the conversion factor for bituminous coal. This yields the Reserve Base coal, in short tons, for each coal bed.

In order to calculate Reserves, recovery factors of 85 percent and 50 percent were applied to the Reserve Base tonnages for strippable and underground coals, respectively. However, in areas of underground coal exceeding 12 ft (3.7 m) in thickness, the Reserves (mineable coal) were calculated on the basis of a maximum coal bed thickness of 12 ft (3.7 m) which represents the maximum economically mineable thickness for a single coal bed in this area by current underground mining technology.

Reserve Base and Reserve values for measured, indicated, and inferred categories of coal for the Menefee 6, Fruitland 1, and Fruitland 3 beds are shown on CRO Plates 7 and 11, respectively, and are rounded to the nearest hundredth of a million short tons. The total coal Reserve Base, by section, is shown on CRO Plate 2 and totals approximately 145 million short tons (132 million metric tons).

The coal development potential for each bed was calculated in a manner similar to the Reserve Base, from planimetered measurements, in acres, for areas of high, moderate, and low potential for surface and/or subsurface mining methods. The Waterflow quadrangle has development potential for both surface and subsurface mining methods (CDP Plates 18 and 19).

COAL DEVELOPMENT POTENTIAL

Coal beds of 5 ft (1.5 m) or more in thickness which are overlain by 200 ft (61 m) or less of overburden are considered to have potential for strip mining and are designated as having high, moderate, or low development potential according to the mining ratios (cubic yards of overburden per ton of recoverable coal). The formula utilized in the calculation of mining ratios for bituminous coal is:

$$MR = \frac{t_o \ (0.896)}{t_c \ (rf)}$$

where MR = mining ratio
t_o = thickness of overburden
t_c = thickness of coal
rf = recovery factor

Based on economic and technological criteria, the U.S. Geological Survey has established standards for the determination of high, moderate, and low coal development potentials for surface and subsurface coal beds of reserve base thickness (5 ft [1.5 m]) or greater. Mining ratio values for strippable coal (overburden less than 200 ft [61 m] thick) are 0 to 10, high; 10 to 15, moderate; and greater than 15, low. Underground coal beds (overburden 200 to 3,000 ft [61-914 m] thick) are assigned high, moderate, and low development potential according to the overburden thickness: 200 to 1,000 ft (61-305 m), high; 1,000 to 2,000 ft (305-610 m), moderate; and 2,000 to 3,000 ft (610-914 m), low. Tables 3 and 4 summarize the coal development potential, in short tons, for surface and underground coal, respectively, of the Menefee 6, Fruitland 1, and Fruitland 3 coal beds.

TABLE 3

STRIPPABLE COAL RESOURCES FOR FEDERAL COAL LANDS (IN SHORT TONS) IN THE WATERFLOW QUADRANGLE, SAN JUAN COUNTY, NEW MEXICO

[Development potentials are based on mining ratios (cubic yards of overburden/ton of underlying coal). To convert short tons to metric tons, multiply by 0.9072; to convert mining ratios in yd^3/ton coal to m^3/ton, multiply by 0.842]

Coal Bed	High Development Potential (0-10 mining ratio)	Moderate Development Potential (10-15 mining ratio)	Low Development Potential (15 mining ratio)	Total
Fruitland 3	--	--	20,000	20,000
Fruitland 1	1,680,000	--	--	1,680,000
TOTAL	1,680,000	--	20,000	1,700,000

TABLE 4

COAL RESOURCE DATA FOR UNDERGROUND MINING METHODS FOR FEDERAL COAL LANDS (in short tons) IN THE WATERFLOW QUADRANGLE, SAN JUAN COUNTY, NEW MEXICO

(To convert short tons to metric tons, multiply by 0.9072)

Coal Bed	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Fruitland 3	18,780,000	--	--	18,780,000
Fruitland 1	83,520,000	--	--	83,520,000
Menefee 6	--	40,820,000	350,000	41,170,000
TOTAL	102,300,000	40,820,000	350,000	143,470,000

Development Potential for Surface Mining Methods

Strippable coal of the Fruitland 1 bed has high development potential in a small area in the south-central part of the quadrangle (CDP Plate 18) where the coal crops out and is approximately 7 ft (2.1 m) thick (CRO Plate 8). The Fruitland 1 coal bed has low development potential in several small areas in the southeast corner of the quadrangle where the coal is 6 to 15 ft (1.8-4.6 m) thick, and overburden varies from zero to 200 ft (0-61 m) (CRO Plate 10). Several small areas of unknown development potential located in the southeast and northeast corners are the result of strippable coal of the Fruitland 1 and Fruitland 3 coal beds being less than the reserve base thickness of 5 ft (1.5 m). The majority of the area within the KRCRA study limit is beyond the outcrops of the Fruitland 1 and Fruitland 3 coal beds in the center of the quadrangle or beyond the 200-ft (61-m) stripping limit along the eastern border and, thus, have no development potential for surface mining methods. The Menefee 6 coal bed has no development potential for surface mining methods since the overburden thickness is greater than the 200-ft (61-m) stripping limit with the study boundary. Unpatterned areas in the quadrangle include several federal leases within the KRCRA boundary and the land outside the KRCRA study limit.

Development Potential for Subsurface Mining Methods

Underground coal of the Menefee 6 coal bed has moderate development potential in the central to south-central part of the quadrangle (CDP Plate 19) where the coal bed thickness varies from 5 to 13 ft (1.5-4.0 m) (CRO

Plate 4), and the overburden increases in thickness from 1,200 ft (366 m) in the south to 1,600 ft (488 m) in the center of the quadrangle. Underground coal of the Fruitland 1 and Fruitland 3 coal beds have high development potential along a large section of the east border of the quadrangle. Coal bed thickness ranges from 5 to 22 ft (1.5-6.7 m) for the Fruitland 1 (CRO Plate 8) and 5 to 7 ft (1.5-2.1 m) for the Fruitland 3 coal bed (CRO Plate 15). The overburden thickness ranges from 200 ft (61 m) in the south-central to 450 ft (137 m) in the east-central for the Fruitland 3 (CRO Plate 17), and 600 ft (183 m) in the east-central for the Fruitland 1 coal bed (CRO Plate 10).

Areas of unknown development potential found in the central, south-central, and southeast parts of the quadrangle are the result of the evaluated coal beds being less than the reserve base thickness of 5 ft (1.5 m). An area in the center of the quadrangle contains no Menefee 6, Fruitland 1, or Fruitland 3 and, thus, has no development potential. Unpatterned areas are either outside the KRCRA study limit along the west and north parts of the quadrangle or are within the KRCRA boundary but are Federal coal leases, as is a large part of the land in the eastern half of the Waterflow quadrangle.

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