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COAL RESOURCE OCCURRENCE MAPS AND COAL DEVELOPMENT POTENTIAL MAPS OF THE FIRE ROCK WELL QUADRANGLE, SAN JUAN, MCKINLEY, AND SANDOVAL COUNTIES, NEW MEXICO

[Report includes 16 plates]

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FIRE ROCK WELL 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 Fire Rock Well quadrangle, San Juan, McKinley, and Sandoval Counties, 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) of the western United States. The work has been performed under contract with the Conservation Division of the U.S. Geological Survey (Contract No. 14-08-0001-17172).

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 Fire Rock Well 7 1/2-minute quadrangle is located in western Sandoval County, southeastern San Juan County, and northern McKinley County, New Mexico. The area is approximately 52 miles (84 km) southeast of Farmington and 66 miles (106 km) northeast of Gallup, New Mexico.

Accessibility

The Fire Rock Well quadrangle is less than 9 miles (14.5 km) from New Mexico State Route 44. A light-duty road originates from this route and extends southward to the northern boundary of this quadrangle. Numerous unimproved dirt roads provide access to the more remote areas. The Atchison, Topeka, and Santa Fe Railway operates a route which passes through Gallup approximately 66 (105 km) miles to the southwest.

Physiography

The quadrangle is in the southern portion of the Central Basin area (Kelley, 1950) of the larger structural depression known as the San Juan Basin. Elevations range from 6,400 ft (1,951 m) in Canada Alemita to 6,840 ft (2,085 m) in the north. The area is characterized by two major drainages: Canada Alemita, in the eastern and southern portion of the quadrangle, which drains to the south; and Escavada Wash, in the northwest, which drains to the west. Gallo Wash also drains to the west. These intermittent streams and their tributaries have dissected the plains forming broad, gently sloping mesas.

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, and most precipitation occurs in July and August as intense afternoon thundershowers. Annual temperatures range from below 0°F (-18°C) to over 100°F (38°C). Snowfall may occur from November to April with an average of 18 inches (45 cm) in the southern part of the basin.

Land Status

Approximately 96 percent of the quadrangle is in the southeastern part of the San Juan Basin Known Recoverable Coal Resource Area. The Federal Government owns the coal rights for approximately 70 percent of the KRCRA within the quadrangle as shown on Plate 2 of the Coal Resource Occurrence Maps. Preference Right Lease Applications (NM 8128, NM 8130, and NM 111670) in the south cover 16 percent of the KRCRA. There are no Federal coal leases in the area. The Federal Government owns the coal rights for less than 1 percent of the land outside the San Juan Basin Known Recoverable Coal Resource Area.

GENERAL GEOLOGY

Previous Work

Dane (1936) has mapped the Late Cretaceous and Tertiary strata in the area with detailed emphasis on the Fruitland coal field which is exposed across the southern portion of the quadrangle. A more recent publication by Fassett and Hinds (1971) includes subsurface interpretations of the Fruitland Formation coal deposits throughout the San Juan Basin.

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 northwest-southeast-trending strandline, 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 northeast, 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 northeast.

The sea then reversed the direction of movement, and the transgressive sequence of paludal upper Menefee Formation, nearshore Cliff House Sandstone, and marine Lewis Shale was deposited in the quadrangle. Swamps (Menefee) formed (in the southwest part of the quadrangle) shoreward of the transgressing beaches (Cliff House). Organic matter deposited in these swamps ultimately formed the coal beds of the Hogback Mountain Tongue (Beaumont, 1971) in the upper part of the Menefee Formation. At the same time in the northeast part of the quadrangle, thick beach sands of the La Ventana Tongue (Cliff House Sandstone) were being deposited. Minor fluctuations of the sea resulted in interfingering of the La Ventana (Cliff House) and Hogback Mountain (Menefee) Tongues.

Onlap continued as the sea moved southwestward across the basin area. The transgressing northwest-southeast-trending strandline is represented in the lithologic record by the Chacra Tongue (informal name of local usage) of the Cliff House Sandstone. The marine facies which developed northeast of the strandline as it moved to the 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 accumulated organic matter which became coals of the Fruitland Formation. Again, deposition of organic material was influenced by the strandline as shown by the continuity of the coal beds parallel to the northwest-southeast strandline and discontinuity perpendicular to it to the northeast.

The brackish-water swamp environment of the Fruitland moved northeast of the quadrangle as the regression continued in that direction. Terrestrial freshwater sediments covered the quadrangle area as evidenced 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 (Powell, 1973). 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 the present time. A significant amount of erosion has occurred, as indicated by the removal of the San Jose Formation and some of the Nacimiento Formation from the area.

Stratigraphy

The formations studied in this quadrangle are Late Cretaceous to Paleocene in age. They are, in order from oldest to youngest: the Point Lookout Sandstone, Menefee Formation, and Cliff House Sandstone, (the three formations of the Mesaverde Group); the Lewis Shale, Pictured Cliffs Sandstone, Fruitland Formation, Kirtland Shale, Ojo Alamo Sandstone, and Nacimiento Formation. 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, consists of gray, slightly calcareous sandstone, interbedded gray shale, and local coal beds. The thin, discontinuous coals occur in thin Menefee tongues. The Point Lookout Sandstone is fairly massive, has an average thickness of about 100 ft (30 m) in the area, and displays a distinctive character on geophysical logs. This last characteristic was used by the authors in establishing the top of the unit as a lithologic datum for correlation of overlying Menefee 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, the unnamed upper coal-bearing member (Beaumont and others, 1956), and the Hogback Mountain Tongue (Beaumont, 1971). The first three members are referred to as a single undifferentiated member for the purposes of this report only. This member is about 1,050 ft (320 m) thick in this area and is predominantly gray to gray-brown, carbonaceous shale with local siderite stringers, interbedded gray sandstone and siltstone, and random coal beds.

The informally named Hogback Mountain Tongue of the Menefee Formation (Beaumont, 1971) represents thick, paludal deposits shoreward (southwest) of the massive marine La Ventana Tongue (Cliff House Sandstone). This member is recognized as a major coal-bearing unit. The stratigraphic equivalence and complex interfingering of the Hogback Mountain Tongue with the La Ventana make it distinguishable in the area of interfingering. The thickness is approximately 530 ft (162 m) in the southwestern portion of the area; however, it thins in a northeasterly direction as the La Ventana tongues thicken. Similar in lithology to the underlying undifferentiated member, it is composed of gray to brown, slightly calcareous, carbonaceous shale, interbedded thin gray sandstone, and random coal beds.

Conformably overlying and intertonguing with the Menefee Formation is the basal member of the Cliff House Sandstone, the La Ventana Tongue, which is present in the northeast part of the quadrangle. The La Ventana overlies some of the basal deposits of the Hogback Mountain Tongue. Toward the southwest and higher in the section it interfingers, is contemporaneous with, and gradually wedges out into the Hogback Mountain Tongue. The massive tongues of the La Ventana are composed primarily of gray, argillaceous, calcareous sandstone.

The uppermost member of the Cliff House Sandstone is the Chacra Tongue (informal name of local usage), which overlies the Hogback Mountain Tongue of the Menefee in this quadrangle. The Chacra lithology in this area is transitional from a massive nearshore sandstone, typical of the type section at Chacra Mesa 5 miles (8 km) southwest of the quadrangle, to marine deposits of the Lewis Shale. These Chacra deposits are composed of gray, argillaceous, slightly calcareous sandstone with thinly interbedded shale, sandy shale, and siltstone.

The marine Lewis Shale conformably overlies the Mesaverde Group. In contrast to the underlying Cliff House Sandstone, it is predominantly a gray to gray-brown, slightly calcareous shale with local plant fossils and thin, gray sandstone beds. The Lewis ranges from 200 to 550 ft (61-168 m) thick in the quadrangle. The upper contact is gradational with the overlying Pictured Cliffs Sandstone and, therefore, it is difficult to determine.

The Pictured Cliffs Sandstone consists of cream to light gray, friable sandstone interbedded with thin, gray to brown shale 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. The indistinct nature of both contacts may account for the varying reported thickness values of the Pictured Cliffs in the quadrangle, from 50 to 150 ft (15-46 m). Since the Pictured Cliffs Sandstone is present throughout most of the basin and displays a distinctive character on geophysical logs, the authors have use the top of the unit as a lithologic datum for correlation of the overlying Fruitland coals.

The Fruitland Formation is the major coal-bearing unit in the quadrangle. It has an average thickness of 260 ft (79 m) and consists of green to gray carbonaceous shale, interbedded sandstone, and coal beds of varying thicknesses. The thickest and most continuous coal beds occur near the base of the formation, while discontinuous and lenticular coal beds 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). Authors have used various criteria in determining the upper contact but, in general, for the purposes of this report the uppermost coal was chosen (after Fassett and Hinds, 1971).

The freshwater deposits of the Kirtland Shale are the youngest Cretaceous strata in the area. The deposits average 190 ft (58 m) in thickness and are composed of brown to gray shale with local plant fossils, and interbedded sandstone and siltstone. The formation has previously been divided into several members by various authors; however, for the purposes of this report the individual members were not differentiated.

Unconformably overlying the Upper Cretaceous strata is the Paleocene Ojo Alamo Sandstone, which is 150 to 175 ft (46-53 m) of white to light gray, coarse-grained to conglomeratic sandstone containing quartz and feldspar grains, with interbedded thin, gray to brown shale in the lower portion of the formation.

The Nacimiento Formation grades into the underlying Ojo Alamo. Approximately 1,200 to 1,300 ft (366-396 m) of the Nacimiento are present, and consist of gray to brown sandy shale, thin conglomeratic lenses, and siltstone.

A total of six formations crop out within the quadrangle. The outcrop pattern trends in a general northwest-southeast direction, the formations becoming successively younger to the northeast. The oldest formation exposed is the upper portion of the Lewis Shale in the extreme southwestern corner of the quadrangle. The entire sections of the Pictured Cliffs Sandstone, Fruitland Formation, Kirtland Shale, and the Ojo Alamo Sandstone crop out consecutively across the quadrangle in a northeasterly direction. The lowermost beds of the Nacimiento Formation, the youngest formation in the area, crop out in the extreme northeastern corner of the quadrangle.

Structure

The axis of the San Juan Basin is about 37 miles (60 km) northeast of the Fire Rock Well quadrangle and trends in an arcuate pattern across the northern portion of the Central Basin area (Baltz, 1967). Regional dip within the quadrangle is approximately 1° to the northeast.

In the southern half of the quadrangle a large graben structure trends east-west across the area (CRO Plate 1), displacing the Fruitland Formation outcrop to the west within the central graben. There is a smaller graben structure on the north side of the larger one. In general, these graben-related faults are within the quadrangle limits; however, a portion of the southernmost fault extends westward into the Sargent Ranch 7 1/2-minute quadrangle.

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 Fruitland 1 and 2 coal beds 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 (CRO Plate 3). 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. As shown on CRO Pate 3, the tops of the sandstone units have been used as datums for each oil and gas test hole; the coals have been correlated based upon their position relative to the datum. Correlations of coals in coal test holes (Chaco Energy, unpublished data) are based upon previous correlations and geologic maps (Beaumont and Speer, 1976).

Two coal beds (Fruitland 1 and 2) were mapped on the surface and two coal zones (Menefee, Fruitland) were identified in the subsurface of this quadrangle. The Menefee Formation coals were designated and mapped as the Menefee coal zone (Me zone). Some of the coals in the Menefee zone are correlative over short distances, but most are less than the reserve base thickness of 5 ft (1.5 m) as set by the U.S. Geological Survey. Exceptions are two 5-ft (1.5-m) coal beds in drill holes 6, 20, and 22 (CRO Plate 1).

No published analyses of the quality of Menefee Formation coals are available for this quadrangle. However, information on the quality of coals from surrounding areas is assumed to be similar to that of the coals from this quadrangle. There is no apparent consistent difference between the various Menefee Formation coals. In the southern part of the San Juan Basin the coals vary from subbituminous B to high volatile C bituminous in rank. The rank is determined on a moist, mineral-matter-free basis with calorific values ranging from 9,983 to 11,966 Btu's per pound (23,220-27,833 kj/kg) (Amer. Soc. for Testing 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 12.1 to 20.0 percent, sulfur content from 0.6 to 2.8 percent, ash content ranging between 4.9 and 9.9 percent, and heating values on the order of 10,326 Btu's per pound (24,018 kj/kg). Analyses of several Menefee coals are given in Table 1 (Bauer and Reeside, 1921; Dane, 1936; Lease, 1971; Shomaker, 1971).

The Point Lookout Sandstone occasionally contains random Menefee coal beds in the upper portion where the units intertongue. They have been designated as local beds because they are random, discontinuous, and below the reserve base thickness of 5 ft (1.5 m).

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		
A47085	Mine Sample	SW¼ 31	19	1	----	A	15.8	34.5	43.8	5.9	0.6	10,900	Cleary Member
						B	----	41.0	52.0	7.0	0.7	12,950	
A46366	Mine Sample	SW¼ 31	19	1	----	A	15.7	32.0	45.1	7.2	0.6	10,790	Cleary Member
						B	----	38.0	53.5	8.5	0.7	12,800	
						C	----	41.5	58.5	----	0.8	13,990	
A47084	Prospect Pit	SW¼ 26	19	1	----	A	18.2	34.4	40.8	6.6	0.9	10,280	Cleary Member
						B	----	42.0	49.9	8.1	1.0	12,570	
A60026	Mine Sample	SE¼ 19	19	1	----	A	12.1	35.8	44.5	7.6	2.8	10,940	Allison Member
						B	----	40.7	50.6	8.7	3.2	12,460	
						C	----	44.6	55.4	----	3.5	13,640	
A64268	Mine Sample	SE¼ 35	19	2	----	A	20.0	32.5	42.6	4.9	0.7	10,240	Allison Member
						B	----	40.7	53.2	6.1	0.8	12,790	
						C	----	43.3	56.7	----	0.9	13,630	
A46367	Prospect Drift	35	19	2	----	A	14.8	33.9	41.4	9.9	1.2	8,910	Allison Member; sample may have been somewhat weathered
						B	----	39.8	48.6	11.6	1.4	10,460	
						C	----	45.1	54.9	----	1.6	11,840	
3823	Mine Sample	14	20	11	----	A	17.5	32.9	41.2	8.4	2.2	----	
23004	Outcrop Sample	14	20	11	----	A	14.4	34.8	42.3	7.5	1.5	10,220	
						B	----	40.7	50.5	8.8	1.8	11,940	

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

The Pictured Cliffs Sandstone which underlies the Fruitland Formation occasionally contains random Fruitland coal beds in the upper portion. Such coals have been designated as local beds because they are random, discontinuous, and below the reserve base thickness of 5 ft (1.5 m).

The Fruitland 1 (Fr 1) coal bed is defined by the authors as the lowermost coal of the Fruitland Formation; it is generally directly above the Pictured Cliffs Sandstone. The Fruitland 2 (Fr 2) coal bed overlies the Fruitland 1 coal bed. The remaining Fruitland coal beds were designated as the Fruitland coal zone (Fr zone). These coals are generally noncorrelative, discontinuous, and less than reserve base thickness of 5 ft (1.5 m); an exception is a 5-ft (1.5-m) coal in drill hole 5. Due to these characteristics, derivative maps were not constructed.

The Fruitland Formation coal beds in the southeastern part of the San Juan Basin are considered high volatile C bituminous in rank; however, they vary from subbituminous A to high volatile C bituminous. The rank of the coals has been determined on a moist, mineral-matter-free basis with calorific values ranging from 11,207 to 12,078 Btu's per pound (26,067-28,093 kj/kg) (Amer. Soc. for Testing Materials, 1977). The coal is hard, brittle, and black with a bright luster. It readily slakes with exposure to weather; however, it stocks fairly well when protected. The "as received" analyses indicate moisture content ranging from 10.7 to 13.6 percent, sulfur content generally less than one percent, ash content varying from 17.6 to 30.5 percent, and heating values on the average of 8,947 Btu's per pound (20,811 kj/kg). Analyses of several Fruitland coals are given in Table 2 (Dane, 1936; Shomaker and Lease, 1971).

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.			Mois-ture	Volatile matter	Fixed Carbon	Ash	Sulfur		
J-62557	Core Sample	SW¼ 26	21	8	----	A	13.6	33.4	35.4	17.6	0.53	9,110	
						B	----	38.6	41.0	20.4	0.62	10,540	
						C	----	48.5	51.5	----	0.77	13,240	
J-62604	Core Sample	SW¼ 26	21	8	----	A	12.6	28.7	28.2	30.5	0.49	7,510	
						B	----	32.8	32.4	34.8	0.56	8,590	
						C	----	50.3	49.7	----	0.86	13,180	
*TH-53400	Core Sample	-	20	6	----	A	12.44	34.95	34.05	18.56	0.56	9,499	
						B	-----	39.91	38.89	21.20	0.64	10,848	
+C-14108	Core Sample	-	20	6	----	A	10.7	33.4	37.5	18.4	0.65	9,667	
						B	----	37.4	42.0	20.6	0.72	10,826	
						C	----	47.1	52.9	----	0.91	13,637	

*analysis by Commercial Testing and Eng. Co.
+analysis by Illinois Geological Survey

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

Menefee Coal Zone

The Menefee coal zone extends from the top of the La Ventana Tongue (Cliff House) to the base of the Menefee Formation. Because of its contemporaneous relationship with the coal-bearing Hogback Mountain Tongue of the Menefee Formation, the top of the La Ventana was chosen to represent a mappable surface of the coal zone. It portrays the upper boundary of the coal-bearing zone more consistently than the randomly occurring uppermost Menefee coal.

The structure contour map of the Menefee coal zone (CRO Plate 5) was constructed using the top of the La Ventana Tongue. It shows that the coal zone dip varies from approximately 1° to 2° to the northeast. Due to topography and dip, overburden (CRO Plate 6) ranges from less than 400 ft (122 m) in the southwest to over 1,600 ft (488 m) in the northeast. The total amount of interburden, which is the noncoal portion of the zone, is also shown on CRO Plate 6. The interburden thickness ranges from less than 1,400 ft (427 m) to greater than 1,700 ft (518 m). The large values are the result of the stratigraphic spread of the coal beds and reflect the thickness of the Menefee Formation plus the intertonguing La Ventana. The isopach map (CRO Plate 4) illustrates the total combined thickness of the individual coal beds of the Menefee zone. The thickest accumulation of coal occurs in the center of the larger graben where there is more than 100 ft (30 m) of coal occurring as numerous coal beds, nearly all of which are less than reserve base thickness. From this area the thickness decreases.

Chemical Analyses of the Menefee Zone Coal Beds - No published analyses of the quality of Menefee Formation coals are available for this quadrangle. However, information from surrounding areas is assumed to be similar to that for the coals from this area. Analyses of several Menefee Formation coals are in reports by Lease (1971) and Shomaker (1971). The results of these analyses are given in Table 1.

Fruitland 1 Coal Bed

As illustrated by the structure contour map (CRO Plate 8), the coal bed dips approximately 1° to 2° to the northeast. Due to topography and dip, overburden (CRO Plate 9) ranges from zero at the outcrop in the southwest to over 800 ft (244 m) in the northeast. The isopach map of the coal bed (CRO Plate 7) shows that the coal bed is greater than 30 ft (9.1 m) thick in the central part of the quadrangle, to the north of the graben. From this region the coal thickness thins, and there is no coal in a small area to the west.

Chemical Analyses of the Fruitland 1 Coal Bed - Analyses of several Fruitland Formation coals in this quadrangle and the surrounding area were published by Shomaker and Lease (1971). The results of these analyses are given in Table 2.

Fruitland 2 Coal Bed

As illustrated by the structure contour map (CRO Plate 12), the coal bed dips approximately 1° to the northeast. Due to topography and dip, overburden (CRO Plate 13) ranges from zero at the outcrop to over 400 ft (122 m) at the eastern edge of the quadrangle. The isopach map (CRO Plate 11) shows that the coal bed is present only in the south. The coal bed is greater than 20 ft (6.1 m) thick in the central part of the graben and in an area to the south of the faulted area. From these areas, the coal thins.

Chemical Analyses of the Fruitland 2 Coal Bed - Analyses of several Fruitland Formation coals from this quadrangle and the surrounding area were published by Shomaker and Lease (1971). The results of these analyses are given in Table 2.

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 (Chaco Energy, unpublished data), and geologic maps (Beaumont and Speer, 1976) were utilized in the construction of outcrop, isopach, and structure contour maps of coals in this quadrangle. Outcrops of the Fruitland 1 and Fruitland 2 coal beds in the southern half of the quadrangle (CRO Plate 1) are modified from Beaumont and Speer (1976).

The U.S. Geological Survey designated the Fruitland 1 and Fruitland 2 coal beds for the determination of coal resources in this quadrangle. Coals of the Menefee Formation were not evaluated because the thickness of the coal beds is less than the reserve base thickness (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 10 and 14) 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 7 and 11) and areal distribution maps (CRO Plates 10 and 14) 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 Fruitland 1 and Fruitland 2 beds are shown on CRO Plates 10 and 14, 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 564 million short tons (512 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 Fire Rock Well quadrangle has development potential for both surface and subsurface mining methods (CDP Plates 15 and 16).

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 Fruitland 1 and Fruitland 2 coal beds.

TABLE 3

STRIPPABLE COAL RESOURCES FOR FEDERAL COAL LANDS (in short tons) IN THE FIRE ROCK WELL QUADRANGLE SAN JUAN AND SANDOVAL COUNTIES, 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 2	210,000	2,880,000	4,300,000	7,390,000
Fruitland 1	80,000	90,000	2,020,000	2,190,000
TOTAL	290,000	2,970,000	6,320,000	9,580,000

TABLE 4

COAL RESOURCE DATA FOR UNDERGROUND MINING METHODS FOR FEDERAL COAL LANDS (in short tons) IN THE FIRE ROCK WELL QUADRANGLE, SAN JUAN AND SANDOVAL COUNTIES, 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 2	27,160,000	--	--	27,160,000
Fruitland 1	527,710,000	--	--	527,710,000
TOTAL	554,870,000	--	--	554,870,000

Development Potential for Surface Mining Methods

Strippable coal of the Fruitland 2 coal bed has moderate development potential in three small areas in the southeastern part of the quadrangle (CDP Plate 15) where the coal thickness varies from 10 to 17 ft (3.0-5.2 m) (CRO Plate 11), and the overburden ranges from 100 to 200 ft (30.5-61.0 m) thick (CRO Plate 13). These represent the only areas with moderate development potential in the quadrangle. In the southeast corner of the area the Fruitland 1 and Fruitland 2 have low development potential in two small sections adjacent to the areas of moderate development potential for the Fruitland 2 coal bed. Thickness of the Fruitland 1 in this area ranges from 8 to 13 ft (2.4-4.0 m) (CRO Plate 7), whereas the Fruitland 2 varies from 5 to 15 ft (1.5-4.4 m) (CRO Plate 11) in the same area. The overburden thickness for the Fruitland 1 ranges from approximately 180 to 200 ft (55-61 m) (CRO Plate 9); the Fruitland 2 overburden in this area increases from 100 to 200 ft (30.5-61.0 m) (CRO Plate 13).

The remainder of the quadrangle has no development potential for surface mining methods and includes areas beyond the stripping limit and outside the outcrop.

Development Potential for Subsurface Mining Methods

Underground coal of the Fruitland 1 is responsible for the high development potential in most of the quadrangle (CDP Plate 16) where the thickness of the Fruitland 1 ranges from 5 to more than 25 ft (1.5-7.6 m)

(CRO Plate 7), and the overburden increases from 200 ft (61 m) thick in the southern part of the quadrangle to over 800 ft (244 m) in the northeast (CRO Plate 9).

The Fruitland 2 coal bed has high potential for subsurface development in the southeast corner of the high potential area only (CRO Plate 14) where it ranges from 5 to more than 15 ft (1.5-4.6 m) (CRO Plate 11) thick, and the overburden increases from 200 to more than 300 ft (61-91 m) thick (CRO Plate 13).

An area of unknown development potential occurs in the northwest corner (CDP Plate 16) where the Fruitland 1 coal bed is less than the reserve base thickness of 5 ft (1.5 m); the Fruitland 2 does not extend into this area (CRO Plate 13). Unknown potential areas in the southeastern corner of the quadrangle occur where the Fruitland 1 and/or Fruitland 2 coal beds are less than 5 ft (1.5 m) thick.

Areas with no coal development potential in the southwest corner (CDP Plate 16) are areas of strippable coal (inside the 200-ft [61-m] overburden stripping limit). The area at the central part of the southern quadrangle boundary is beyond the outcrops of the Fruitland 1 and Fruitland 2 coal beds and, thus, has no development potential.

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