Coal Availability Study—Fruitland Formation in the Fruitland and Navajo fields, Northwest New Mexico

Final Report for the US Geological Survey Contract No. 00HQAG0200– Availability of Coal Resources in the Fruitland Formation, Fruitland field, San Juan Basin, northwest New Mexico September 15,2000-December 15 2001

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Introduction

New Mexico ranks 12th in the nation in coal production (2000) and the state's coal industry contributes significantly New Mexico's educational funds through royalties and taxes. Production in the state comes primarily from the San Juan Basin with three mines producing from the Fruitland Formation and two mines producing coal from the Cleary Coal Member of the Menefee Formation

Coal from the Fruitland Formation is mined at the San Juan, Navajo, and La Plata mines, all near Farmington, New Mexico. The four 7.5 minute quadrangles chosen for this study are Waterflow, Youngs Lake, Fruitland, and Kirtland east of the San Juan and Navajo mine areas (Fig. 1). The cropline of the Fruitland Formation defines the western edge of the 238-sq mi study area. East of the study area is Farmington, New Mexico on State Highway 64. This highway is the main east-west highway across the northern part of the state; it intersects with State Highway 550 at Bloomfield that goes south to Bernalillo, just north of Albuquerque. Farmington is the largest urban area in northwest New Mexico. There are no rail lines into the area, therefore all coal mined here is sent to either the San Juan (Public Service of New Mexico) or Four Corners (Arizona Public Service) generating station and electricity is transmitted to other parts of New Mexico, Arizona and California.

Mining History

Small coal mines in the Fruitland field were opened in the 1890s and early 1900s to supply fuel for domestic use (Nickelson, 1988, p. 126). The documented mines in this area are located on the Fruitland and Waterflow quadrangles in T29N and T30N, R15W, along the Fruitland outcrop. Production was limited; the total from the State and Territorial Mine Inspector reports is 43,049 tons. This total may be low because of the variability in reporting production and 75,000 tons may be a better estimate. Many of these small mines are within the present-day surface mine areas.

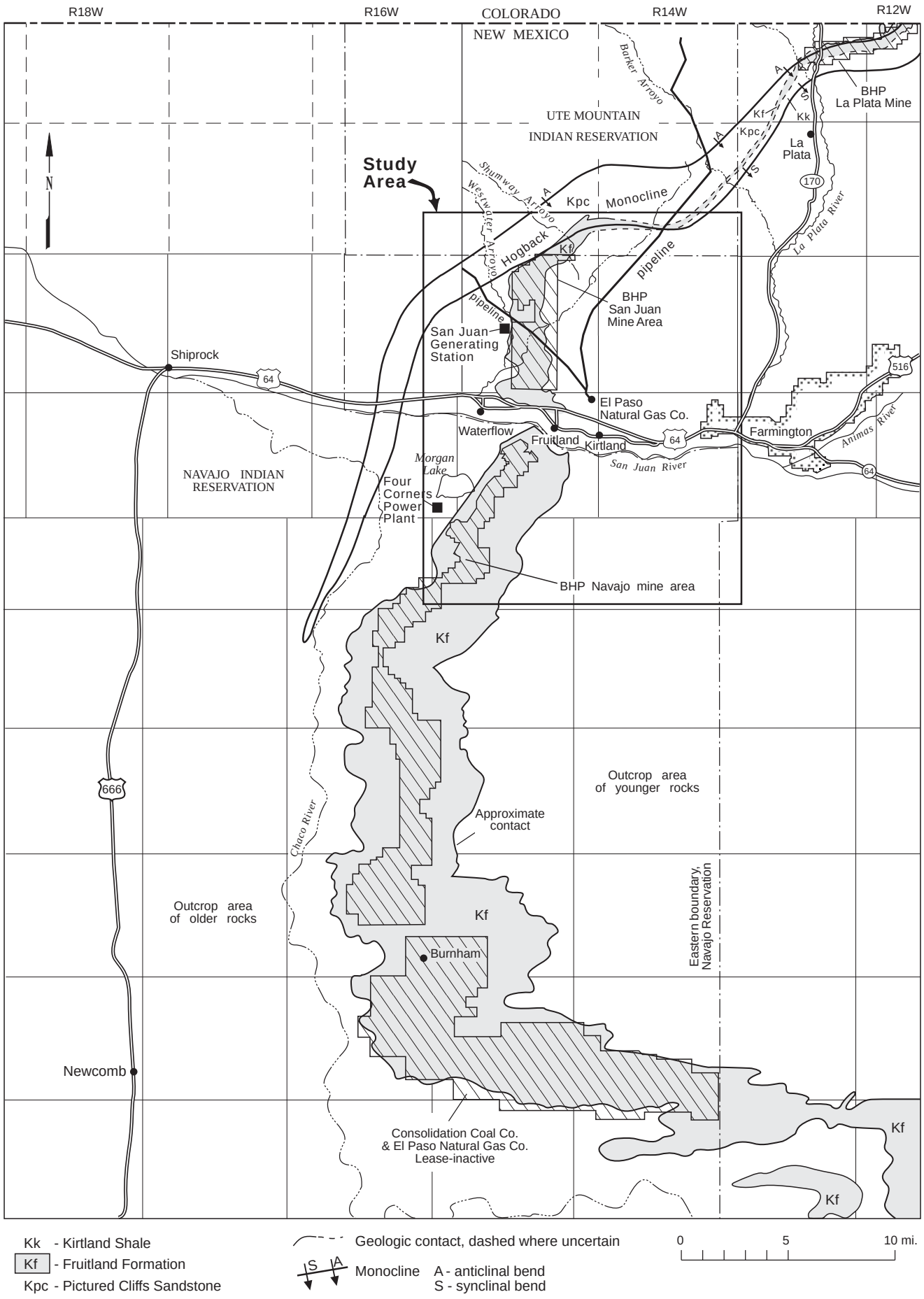


Figure 1. Map of the Fruitland and Navajo coal field. Modified from Shomaker, Beaumont, and Kottlowski, 1971.

Very little large-scale mining took place in the Fruitland field before 1958. At that time, exploration projects were started that resulted in some of the present-day large surface mining operations. Most of the surface–minable resources of the Fruitland field are within the lease areas of the San Juan and La Plata mines operated by San Juan Coal Co., a subsidiary of BHP Minerals (Fig.1). The Fruitland coal area between these two mines is on the Ute Mountain Indian Reservation. Public Service Company of New Mexico delineated 10–14 million st of surface–minable coal through drilling on the Ute Mountain property. The coal beds in this area have steep dips owing to their proximity to the Hogback monocline (Shomaker and Holt, 1973). At the northern end of the Fruitland field, the La Plata mine produces coal from three coal zones of thick coal. The San Juan Mine is in transition from a surface to underground operation. San Juan Coal Co. has acquired leases to the east, adjacent to south end of the present mine, for their longwall operation. They are also using continuous mining methods along the highwall of the existing surface pits before reclamation. All the coal from the San Juan and La Plata mines is consumed at the San Juan Generating station adjacent to the San Juan mine (Fig. 1).

Very little mining, except for small, temporary pits opened by the local Navajos for home heating fuel, was done before 1953 in the Navajo field (Fig. 1). Utah Construction and Mining became interested in the Navajo field in the early 1950s and obtained a permit to mine from the Navajo Nation in 1957. In 1958, the company obtained a permit for water use. Arizona Public Service Co. became interested and negotiated with the Navajo Tribe for a power plant site. The Four Corners power plant was constructed and became operational with three units in 1963. By 1970 two additional units had been built and Utah Construction reached full production at the Navajo mine (Nickelson, 1988). In 1986 BHP Minerals, Inc. acquired Utah International and is the present operator of the Navajo mine, which hold the leases for the northern two thirds of the Navajo field (Fig. 1). A 35-year contract between the Navajo mine to supply the Four Corners generating station expires in 2004, but there is a 15-year extension option (Beaumont, 1998). The contract is with a consortium of utilities including Arizona Public Service, Public Service Company of New Mexico, Salt River Project, Tucson Electric Power, and El Paso Electric. Navajo mine is the largest surface mine in

New Mexico mining up to nine seams in the Fruitland Formation. The mining sequence is progressing south from the power plant, just south of the San Juan River (Fig. 1), and an 18-mile rail line is used to transport coal from the newest pits.

Geologic Setting

The Fruitland field includes the Late Cretaceous Fruitland Formation exposures from the San Juan River north to the New Mexico-Colorado state line, trending N–NE for about 25 mi. The overlying Kirtland Formation is similar in lithology but lacks significant coal beds, therefore the contact between the Fruitland and Kirtland Formations is chosen arbitrarily at the uppermost significant coal bed. The Fruitland Formation is relatively flat lying (3-5°E) in the southern part of this field. The angle of dip increases from 18 to 30°SE at the Hogback monocline on the western edge of the northern Fruitland field.

The Navajo field, south of the Fruitland field, is within the Navajo Indian Reservation, and extends a distance of approximately 35 mi from the San Juan River south to Hunters Wash and Coal Creek (T23N) and east to the boundary of the reservation. The predominant dip of the Fruitland beds is less than 5°E–NE. Little or no significant faulting is evident in the Navajo field. The Chaco River dissects this area. North of the river, badlands are the dominant topography and to the south are rolling hills.

Coal Geology

The Fruitland Formation represents the last development of coals in the San Juan Basin during the Late Cretaceous (Late Campanian-Maaststrichtian). Outcrops of this formation extend from the Colorado border on the western edge of the basin, south-southeast to south of Cuba, New Mexico. The east side of the basin has a thin outcrop of Fruitland, but this area has an abbreviated section with little coal. In the Monero area there is some Fruitland coal, but it is not extensive. The rank of the Fruitland coal decreases from north to south and has been influenced by the San Juan Volcanic complex. This formation has some of the highest ash coals in the entire Late Cretaceous sequence deposited in the San Juan Basin, indicative of large amounts of sediment being brought into the mires by flooding.

Several economical coal seams occur in the Fruitland Formation within the Fruitland field, averaging about 16 ft thick. Near the Colorado border, one seam is nearly 30 ft thick. In the Navajo field, numerous coal beds in the Fruitland Formation occur near the base of the formation with the number of minable beds increasing to eight in the southern part of the field (Shomaker, Beaumont, and Kottlowski, 1971). Oscillations of the Late Cretaceous shoreline with minor stillstands, helped to create the relatively thick coal beds en echelon to the north, with increasingly older beds southward (Shomaker, Beaumont, and Kottlowski, 1971, p. 108).

Within the study area four zones were recognized in ascending order: the 7, 8, 9 and 10 zones (Fig. 2). The designations for these zones come from the San Juan and Navajo Mine nomenclature. The coal bed designation used by Roberts (1991) for the Ute Mountain Ute Indian Reservation of Main and Upper Main correlate to zone 8 and Ute Canyon and Lower Ute Canyon correlate to zone 9. The local beds 1 and 2 of Roberts (1991) probably correlate to zone 10 in this study. The oscillations in the shoreline and the stepping of the Pictured Cliffs Sandstone to the northeast dictate the upward progression of the coal zones in this direction. Zone 7 is recognized south of the San Juan River and zone 8 is the predominant coal zone in the San Juan mine area. Zone 9 is mainly in the northeast part of the study area. Although zone 10 is recognized in the surrounding quadrangles north and east of the study area, there are not enough data points within the study area to warrant resource evaluations for this zone. Figure 2 illustrates the coal zones and there relation to the base of the Fruitland Formation.

The seam average for the three zones (7,8,9) varies from 4.95 ft to 7.47 ft with zone 8 having the thickest seams (Fig. 3). Zones 7 and 9 have a very similar maximum seam thickness of 22 ft and 23 ft, respectively. Zone 8 differs greatly from these two zones with a maximum seam thickness of 43.95 ft. Both zones 7 and 8 average two coals per zone and zone 9 averages one seam. The parting thickness within a coal seam is consistent throughout all three zones (0.7-0.78 ft). Parting is used here as defined by Wood et. al. (1983). Interburden between coals within a zone is similar for zone 7 and 8, but is much greater for zone 9. The average zone thickness, including coal, interburden and partings, is about twice

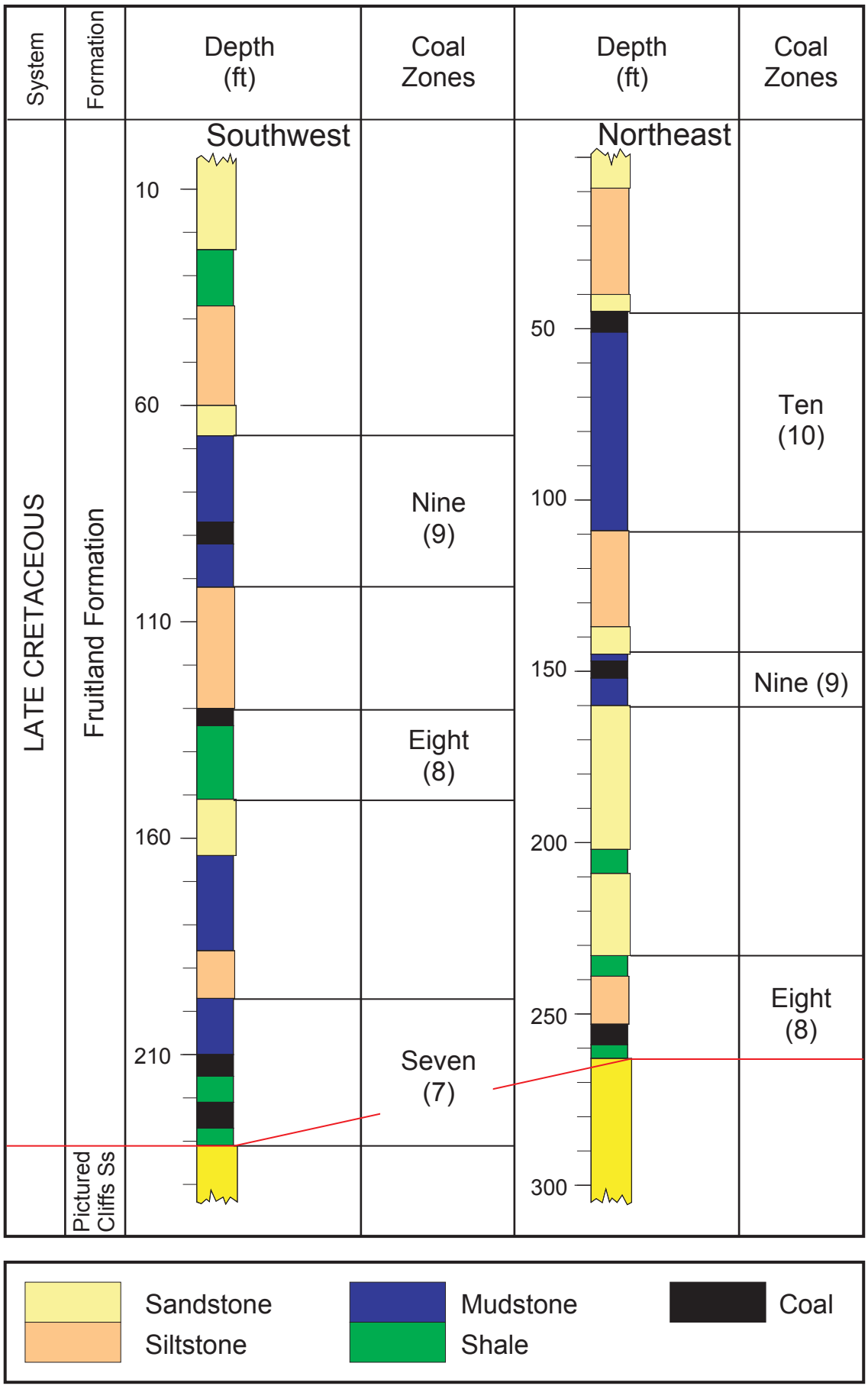
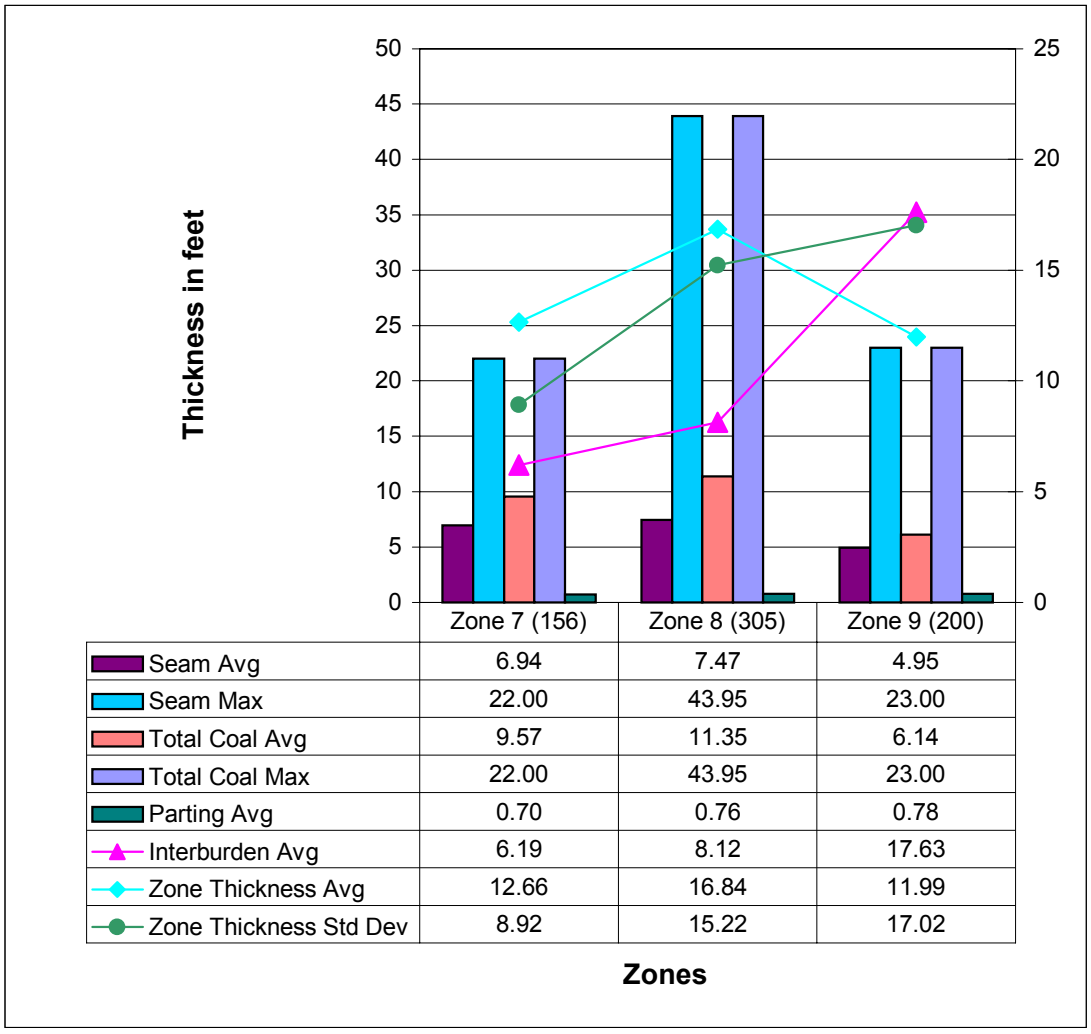


Figure 2. Generalized stratigraphic column of Fruitland Formation, southwest and northeast section of Fruitland-Navajo Study area.

the coal seam average thickness for each of the three zones. Generally, the average zone thickness is relatively thin, but the standard deviation indicates a significant variability, particularly in zone 9.



	Zone 7 (156)	Zone 8 (305)	Zone 9 (200)
Seam Avg	6.94	7.47	4.95
Seam Max	22.00	43.95	23.00
Total Coal Avg	9.57	11.35	6.14
Total Coal Max	22.00	43.95	23.00
Parting Avg	0.70	0.76	0.78
Interburden Avg	6.19	8.12	17.63
Zone Thickness Avg	12.66	16.84	11.99
Zone Thickness Std Dev	8.92	15.22	17.02

Figure 3. Coal thickness and interburden characteristics by zone. Seam refers to individual coal beds; total coal is total coal thickness within a zone. Numbers in parenthesis are number of data points for each zone. Interburden Avg., Zone Thickness Avg., and Zone Thickness Std. Dev. are plotted on secondary y-axis.

The locations of the two cross sections (Figs. 5-6) are on the general geologic map of the area (Fig. 4). Figure 5 is perpendicular to the general NW-SE trend of the Late Cretaceous shoreline and Figure 6 is parallel to that trend. Correlation of the seams on these cross sections and for resource

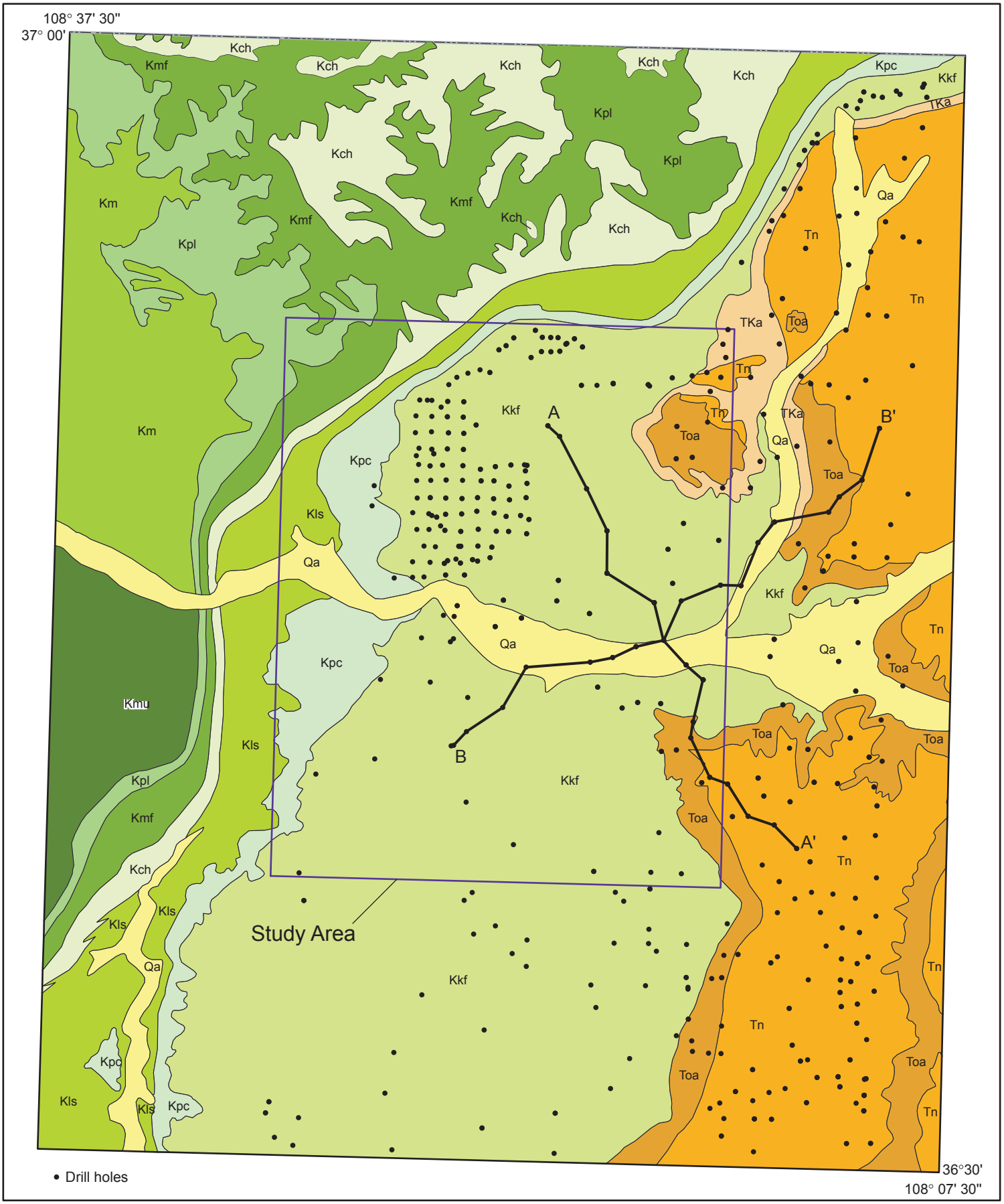


Figure 4. Geologic map of Fruitland-Navajo Study area with cross section locations. Geology is from Anderson, Jones and Green, 1997. Note Fruitland Formation cropline used in study for Arc Info files is not on this map. Toa-Ojo Alamo Sandstone, Kkf-Fruitland Formation, Kpc-Pictured Cliffs Sandstone, Kls- Lewis Shale, Kch- Cliff House Sandstone, Kmf- Menefee Formation

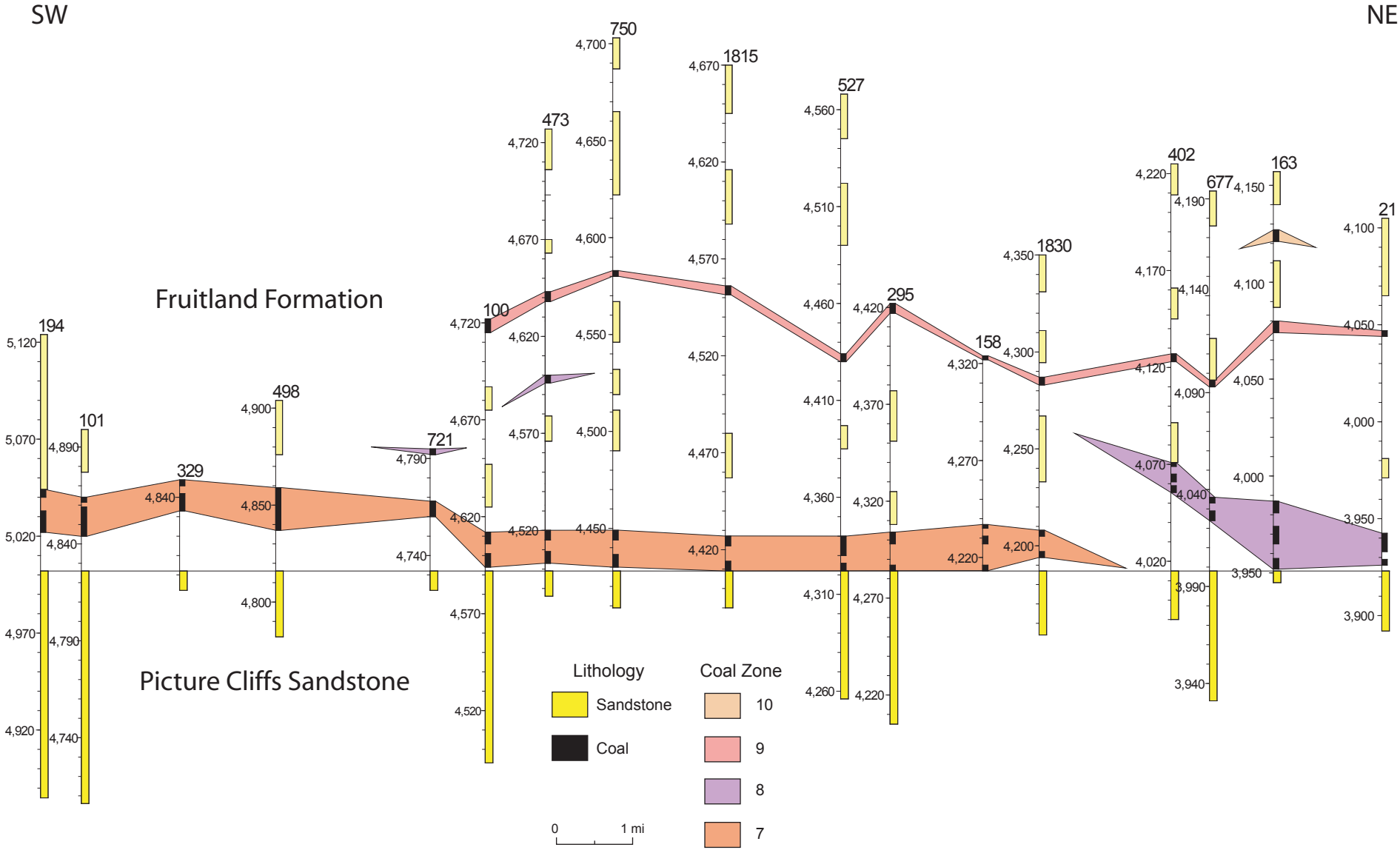


Figure 5. Cross section in Fruitland-Navajo Study area. See Figure 4 for locations. Datum is top of Picture Cliffs Sandstone.

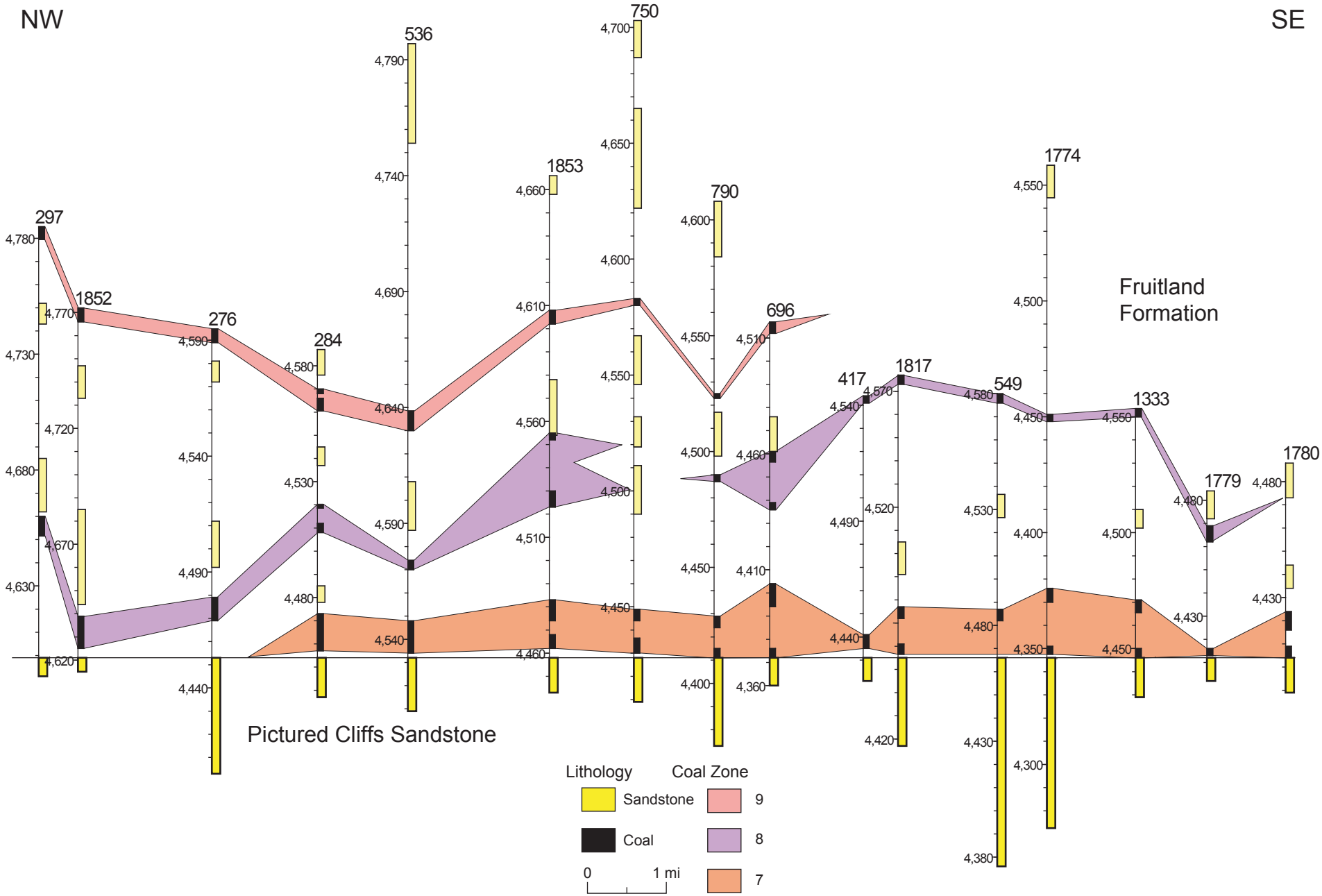


Figure 6. Cross section in Fruitland-Navajo Study area. See Figure 4 for locations. Datum is top of Pictured Cliffs Sandstone.

calculations is by zone rather than by individual coal bed. Any coal in one section does not necessarily represent the same bed on an adjacent section; rather the coals are correlated as being within the same zone. Both of the cross sections illustrate the lateral lenticularity of these coals, although the Fruitland Formation coals show greater continuity than the other coal-bearing sequences within the San Juan Basin. The coals near the base of the formation tend to show the greatest continuity. The numbers identifying each section refer to the ID number used in the Microsoft Access® database constructed for this study (See Appendix).

The total coal isopachs for zones 7,8,9 (Figs. 7-9) illustrate the variability of thickness between zones and within the zones. Zone 7 coals are concentrated below the San Juan River (Fig. 7) and the thicker coals are near the river in a northeast-southwest trend. Zone 8 coals (Fig. 8) have the widest distribution in the study area in the 5-15 ft thickness range. Zone 9 (Fig. 9) coals are concentrated in the 5-10 ft range.

Coal Quality

The coal beds in the Fruitland field, Fruitland Formation are high in ash content (17.95% weighted average, 105 samples) and have low sulfur values (0.8% weighted average, 103 samples). The apparent rank of the Fruitland field coal is high–volatile C and B bituminous (American Society for Testing and Materials, 1981). Weighted–average analyses on an as–received basis are in Table 1 for the Fruitland and Navajo fields (Hoffman, 1996a) and the zones in this study area. Coal in the Navajo field has an apparent rank of subbituminous A to high-volatile C bituminous, with a slight decrease in quality southward owing to an increase in ash yield, lower calorific values, and greater moisture content. The lower calorific values and greater moisture content are indicative of a lower degree of coalification. Average ash for the Navajo field coals is 19.29% (weighted average, 39 samples) and 0.79% sulfur (37 samples). Figure 10 illustrates weighted averages for the zones recognized in the study area and for the Fruitland and Navajo fields.

High ash content is notable in the analyses for the zones and for the fields. The Fruitland field and zone 8 have the lowest ash content (17.95%, 17.51%). Zone 10, which is not being considered for resource

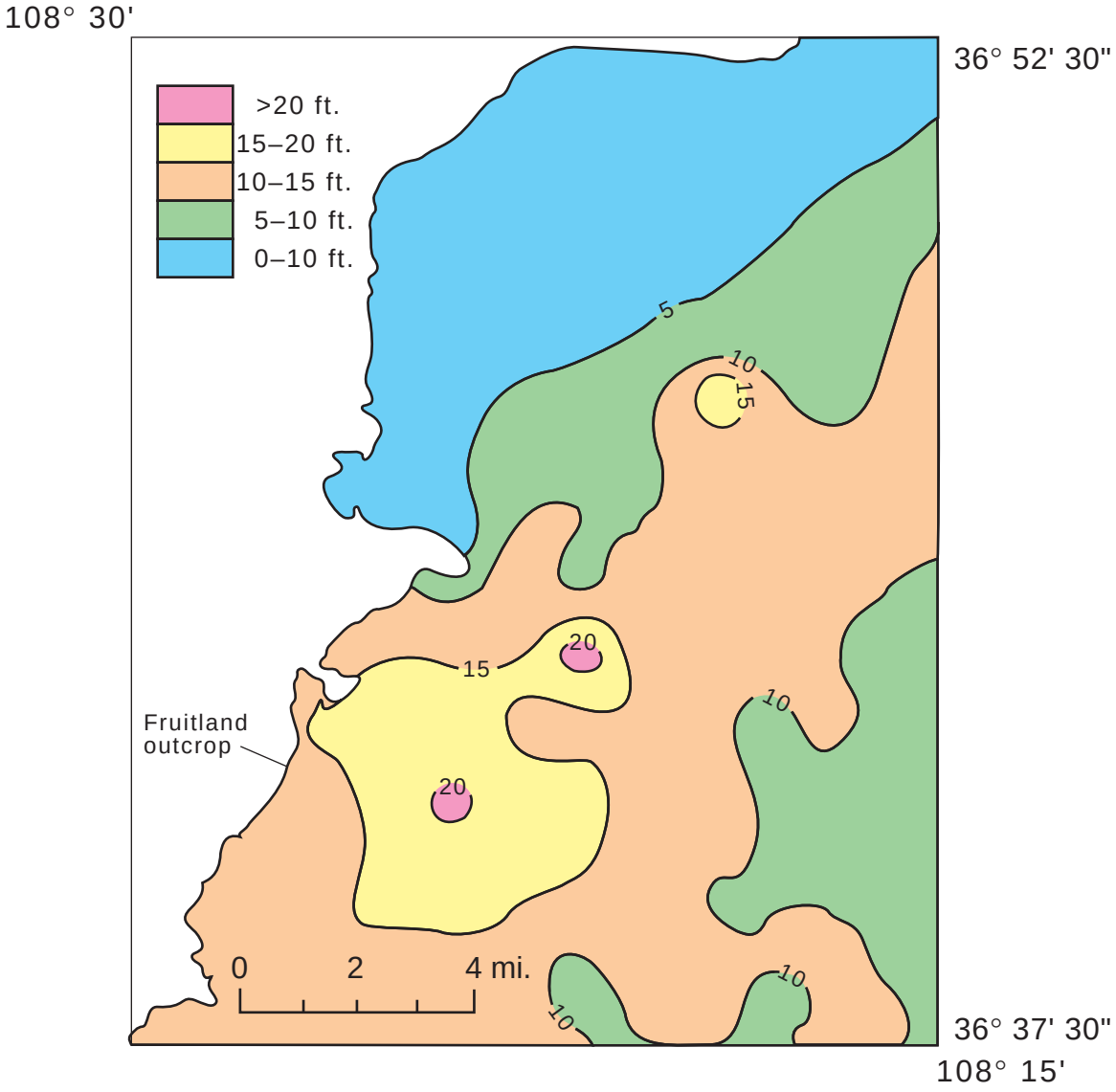


Figure 7. Zone 7 isopach of total coal in Fruitland-Navajo Study area, Northwest New Mexico. Scale = 1:200,000. Fruitland outcrop from Beaumont, 1998.

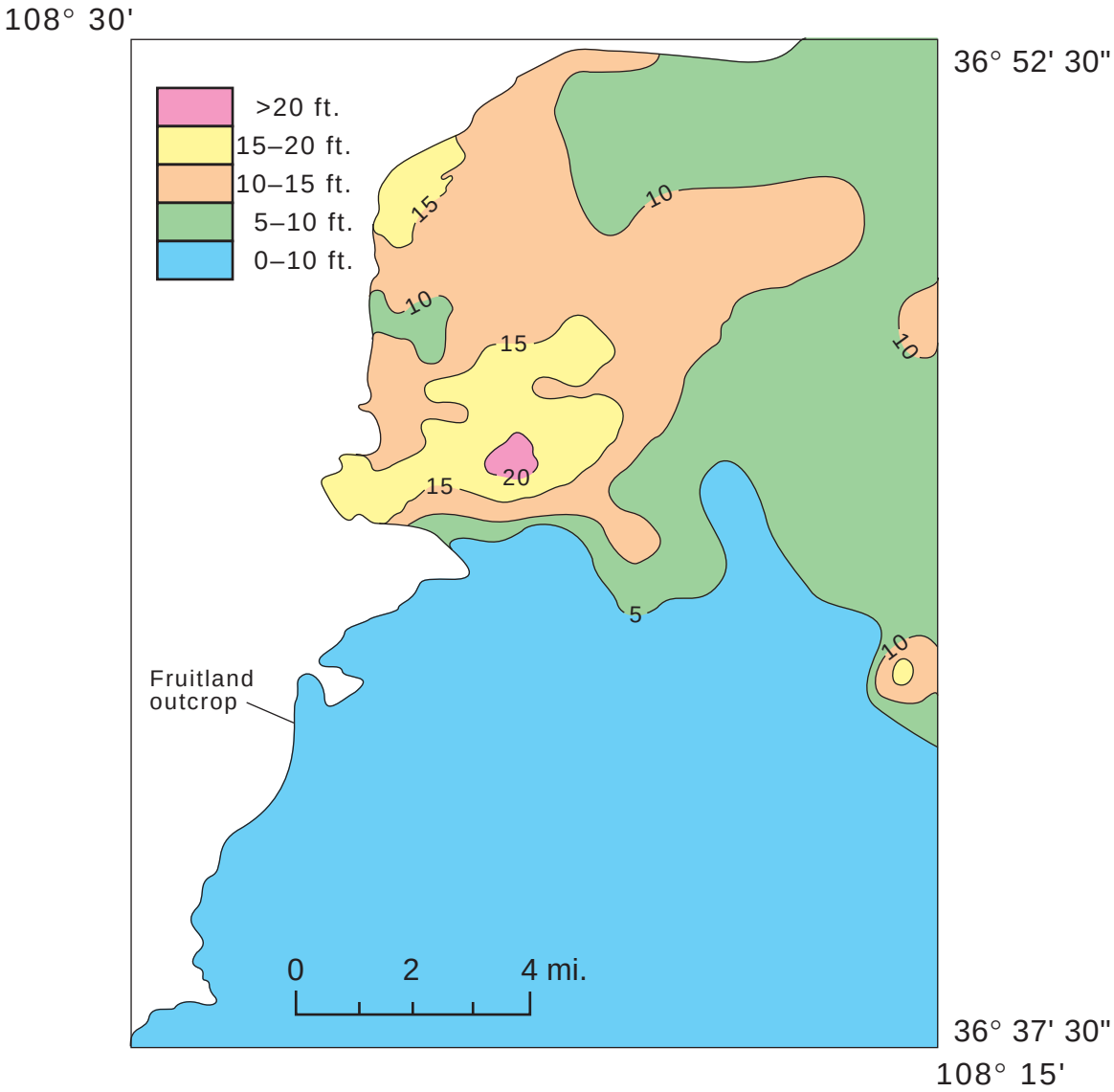


Figure 8. Zone 8 isopach of total coal in Fruitland-Navajo Study area, Northwest New Mexico. Scale = 1:200,000. Fruitland outcrop from Beaumont, 1998.

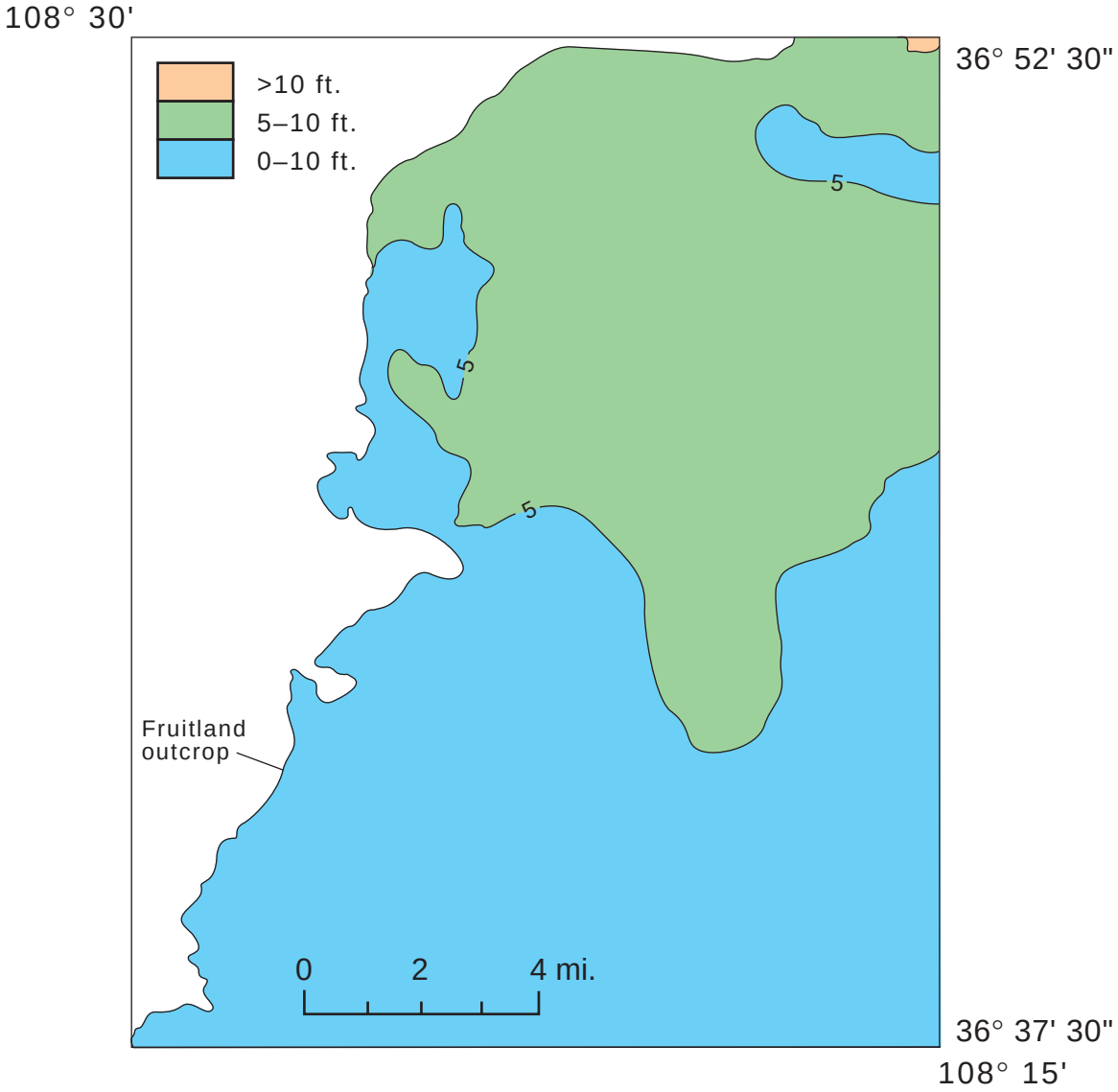


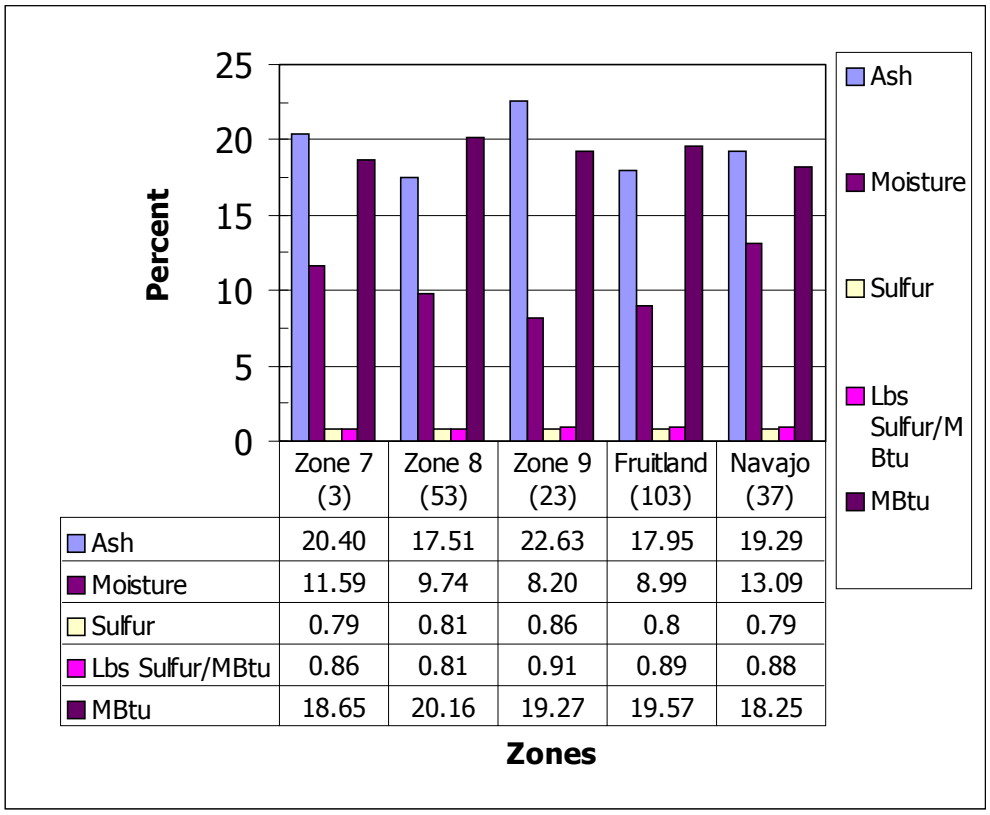
Figure 9. Zone 9 isopach of total coal in Fruitland-Navajo Study area, Northwest New Mexico. Scale = 1:200,000. Fruitland outcrop from Beaumont, 1998.

Table 1 . Weighted averages for the Fruitland Formation coals in the Fruitland and Navajo and the individual zones within the Fruitland study area. Number in parentheses is the number of weighted averages for each zone.

	Fruitland Field (Hoffman, 1996a)			Navajo Field (Hoffman, 1996a)			Average for Zones this study		
	Average	Std Dev.	No. of Samples	Average	Std Dev.	No. of Samples	7 (3)	8 (53)	9 (23)
Moisture(%)	8.99	4.67	105	13.09	1.89	39	11.59	9.74	8.20
Ash(%)	17.95	5.69	105	19.29	3.23	39	20.40	17.51	22.63
Volatile matter(%)	31.76	7.25	85	31.36	2.61	39	33.63	33.72	31.98
Fixed carbon(%)	37.08	8.26	86	35.90	3.78	39	34.33	37.82	37.39
Sulfur(%)	0.80	0.30	103	0.79	0.27	37	0.79	0.81	0.86
Calorific value (Btu/lb)	9,786	1,954	105	9,124	647	39	9,323	10,080	9,636
Lbs of Sulfur/MBtu	0.89	0.3	108	0.88	0.36	40	0.86	0.81	0.91

calculations, has an average ash content of 26.6% (9 samples). The moisture content progressively increases from zone 9 to zone 7. Zone 8 has the highest calorific value of all the zones, but on a moist, mineral-matter free basis; the Btu value is slightly higher for zone 9. There is an increased coalification the closer the Fruitland coal-bearing sequence is to the San Juan Volcanic complex in southern Colorado. Zone 7 has very few analyses, and this figure could be misleading, although zone 7 is the predominant coal in the Navajo field and the values are similar to the weighted average analyses for the entire field.

The sulfur values of all the zones fall within the range of typical sulfur contents for the Fruitland Formation. These coals do not meet New Source Performance Standards of the Clean Air Act of 1.2 lbs of SO_2 per million Btu (Energy Information Administration, 1993). Only zone 8 and 9 have forms of sulfur analyses available to determine what form of sulfur is predominant. The pyritic sulfur values average 30% of



	Zone 7 (3)	Zone 8 (53)	Zone 9 (23)	Fruitland (103)	Navajo (37)
Ash	20.40	17.51	22.63	17.95	19.29
Moisture	11.59	9.74	8.20	8.99	13.09
Sulfur	0.79	0.81	0.86	0.8	0.79
Lbs Sulfur/MBtu	0.86	0.81	0.91	0.89	0.88
MBtu	18.65	20.16	19.27	19.57	18.25

Figure 10. Weighted averages of quality analyses by zone in the Fruitland-Navajo study area. Numbers in parenthesis are number of weighted averages for each zone.

the total sulfur content for zone 8 and over 40% of the total sulfur for zone 9 suggesting that washing might be beneficial in lowering the sulfur content as well as lowering ash content of these coals.

The coals in the study area are high-ash, low-sulfur High volatile C bituminous coals. The rank of these coals is higher than most of the coal elsewhere in the San Juan basin within New Mexico. Oxide analyses are available for zone 8 and 9, from the New Mexico Bureau of Mines (now New Mexico Bureau of Geology) coal quality project (Hoffman, Campbell, and Beaumont, 1993). Zone 8 (23 analyses) and 9 (6 analyses) are predominantly SiO_2 (54.52%, 60.45%), Al_2O_3 (26.48%, 25.64%), CaO (6.23%, 3.79%), and Fe_2O_3 (3.93%, 3.93%). Zone 8 has greater percentages of MgO and Na_2O (1.28%, 1.55%) than zone 9 (0.69%, 0.97%). K_2O and TiO_2 are individually less than 1% for both zones. Both of these zones are mined at either the San Juan or La Plata mines and burned at the San Juan Generating station and produce a Class F fly ash that is marketed as a pozzolanic admixture in concrete (American Society for Testing and Materials, 1995). Most of the ash is returned to the San Juan mine and put into the pits, but about 15% is marketed by Phoenix Cement for concrete products.

Available Data

The database for the Fruitland study area is a subset of the data collected and entered by the New Mexico Bureau of Geology, NMBG&MR into the National Coal Resource Data System (NCRDS). The NMBG&MR has had cooperative grants with the U. S. Geological Survey (USGS) to enter data into the NCRDS for the past 22 years. One source of drill hole data was the NMBG&MR Coal Quality Drilling Project as well as mine plan data from the San Juan, La Plata, and Navajo mines. Many of the data points are oil and gas logs from the NMBG&MR subsurface library. Other sources of data include the USGS Coal Resource Occurrence and Coal Development maps (Dames and Moore, 1978a-d), USGS Bulletin 1938 (Roberts, 1991), and NMBG&MR Circular 134 (Shomaker and Holt, 1973). After the project began additional drill holes were entered into the database, particularly oil and gas logs from the subsurface library.

A total of 186 data points were evaluated for the four-quadrangle study area (Waterflow, Fruitland, Kirtland, Youngs Lake). Additionally, 215 data points from the quadrangles surrounding this area were evaluated and used in the resource calculations. The number of drill holes used in this study is greater than

previous evaluations because of the greater drilling activity in this area by oil and gas companies and the proximity of three operating mines. The data is clustered because of the kind of data sources; much of the mine plan data is near the crop line and the oil and gas logs are in the deeper coal areas. The western third of the Waterflow and Fruitland quadrangles are outside of the Fruitland Formation cropline and therefore have no data for this resource evaluation.

Coal availability studies in New Mexico

Detailed methodology

Coals in the Fruitland Formation are typically subbituminous in rank, however, coals in the Fruitland field are high volatile C bituminous because of the thermal influence of the San Juan volcanic complex. Bituminous coal resource calculations are based on a minimum thickness of 14 inches and an average weight per unit volume of 1800 tons/acre ft (Wood, et al, 1983). In past studies (Hoffman, 1996b) this average weight per unit volume has been discussed as being too low because of the high ash content of these coals. Using a 1.23 g/cm^3 for pure coal (Levine, 1993) and a density of 2.5 g/cm^3 as an average for ash, Figure 11 illustrates the ash percent and weight per unit volume with varying ash content. With ash contents from 18% to 23%, the weight per unit volume of these coals would be 170-270 tons/acre ft greater than the standard 1800tons/acre ft. For consistency the 1800 tons/acre ft value was used in these resource calculations to comply with standards set in Wood, et al (1983). The high ash content of these coals would be a consideration in determining reserves for mine development. The following are the resource criteria used in this study:

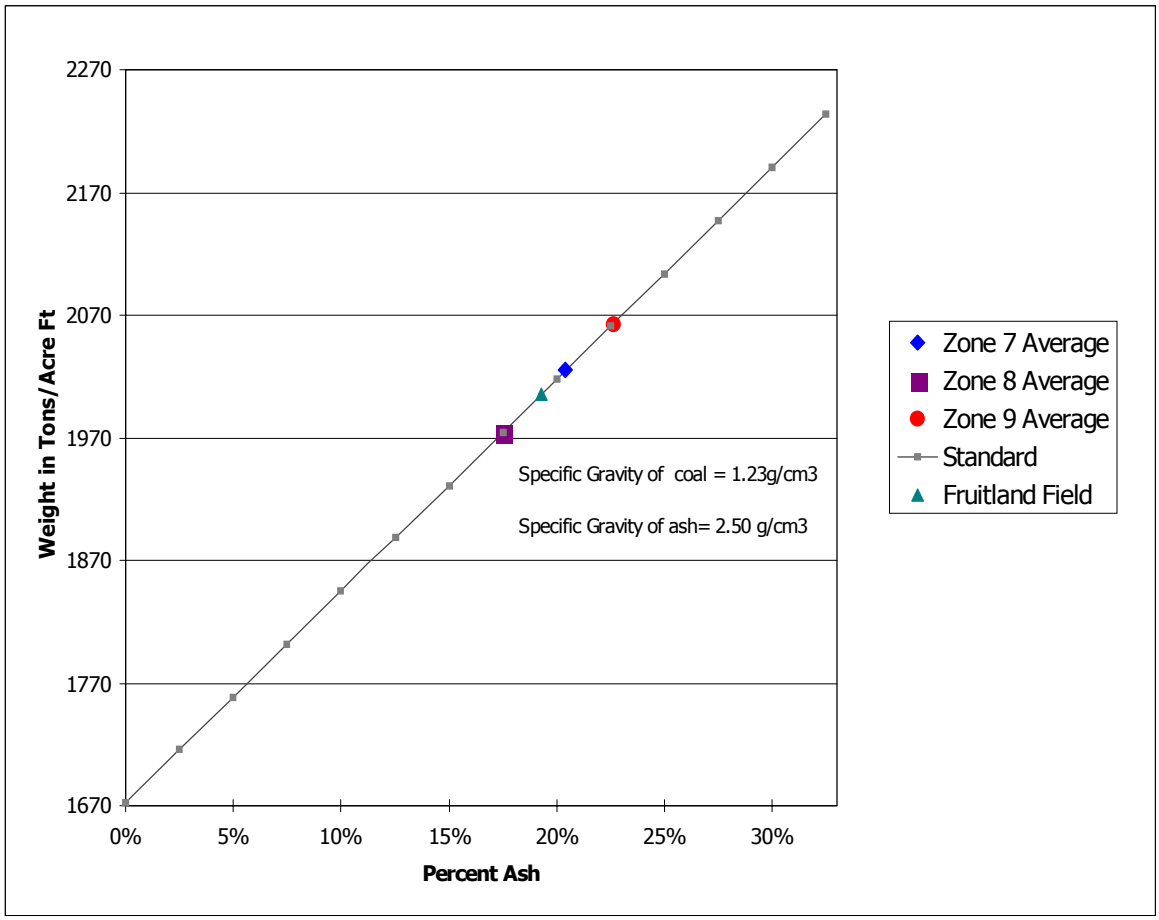


Figure 11. Percentage of ash vs tons per acre-feet.

Thickness (ft)	Depth (ft)	Reliability
1.2–3.5	10: 1 Stripping ratio	Measured (1/4 mi)
3.5–7	0–250	Indicated (1/4–3/4 mi)
7–14	250–500	Inferred (3/4–3 mi)
>14	500–1000	
	>1000	

Reliability categories are limited to measured, indicated and inferred. No hypothetical reliability category was used in this study because of the lenticular nature of these coals.

Line data for the Fruitland Formation contact was digitized from Beaumont (1998). These line data form a boundary mask between the Fruitland Formation and the Pictured Cliffs at the base of the Fruitland. Data files with elevations for tops of coal zones were used to generate grid files in Arc Info® and overlain with a digital elevation model (DEM) grid from the National Elevation Data set. From this combined layer, the overburden maps for each zone were generated. This overburden layer supplied the

zero depth line, or crop line for each zone. The resulting overburden maps for zones 7,8, and 9 are illustrated in Figures 12-14. The upper depth limits for the categories are highlighted on these maps.

From the original database created for this study, subset files were created for each zone with latitude, longitude, total thickness, and point identification. These files included data from the four-quadrangle study area as well as the surrounding quadrangles. By using data from the surrounding quadrangles, reliability categories that overlap into the study area are included in the resource calculations. From these data files coal thickness grid and polygon files for the reliability categories were produced. The reliability polygons were gridded and each cell (28.213 m^2) assigned a thickness by applying the thickness grid. By overlaying the overburden layer on the reliability and thickness layers (calculated in m^2 and converted to acres) volumes for each thickness, depth, and reliability category were determined in the four-quadrangle area. Volumes (acre-ft) were multiplied by 1800 tons/acre ft to result in the original resource tonnage for each zone.

Land-use restrictions were digitized from the 7.5-minute quadrangles (Waterflow, Fruitland, Kirtland, and Youngs Lake). The latest photo revision on these quadrangles was 1979 so high-resolution and low-resolution (orthophoto quads) TIFF images were used to enhance the quadrangle data, particularly for the buildings and roads. A few abandoned mines are in the study area, but most are within the present surface mines. The mined out areas from the present surface mines were digitized from high-resolution and low-resolution TIFF images as well as from a portable document file (PDF) from the San Juan mine. Technical restriction filters were applied to the remaining resource layers for each zone. Appropriate buffers, as discussed in the following section, were assigned to the digitized land-use restrictions. These restriction layers were consecutively overlain on the combined overburden, reliability, and thickness layers after the mined-out areas and technical restrictions had been applied to calculate the resource tonnage removed by each restriction.

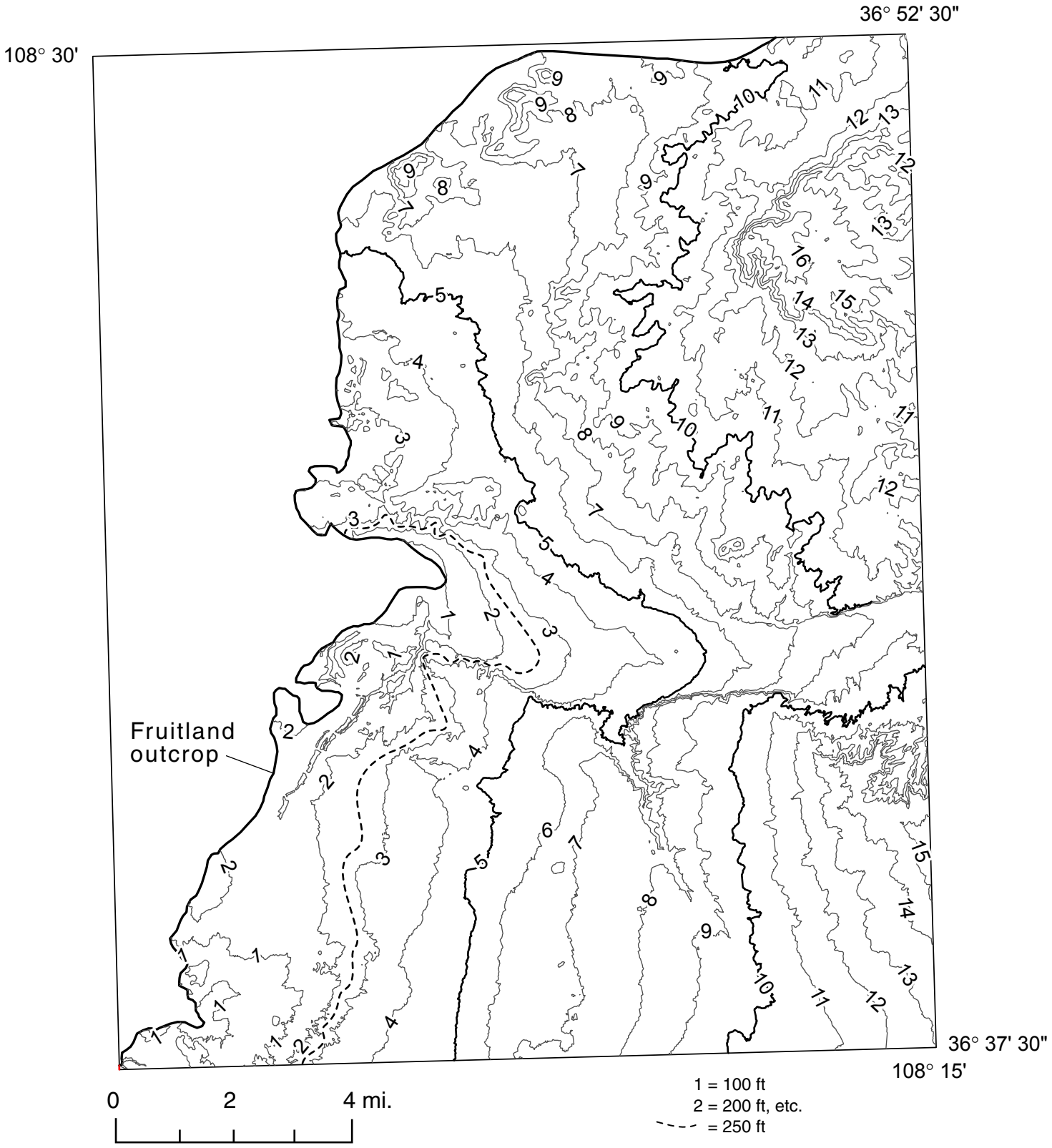


Figure 12. Overburden on top of coal zone 7. Fruitland-Navajo Study area, Northwest New Mexico. Fruitland outcrop from Beaumont, 1998. Contour interval 100 ft.

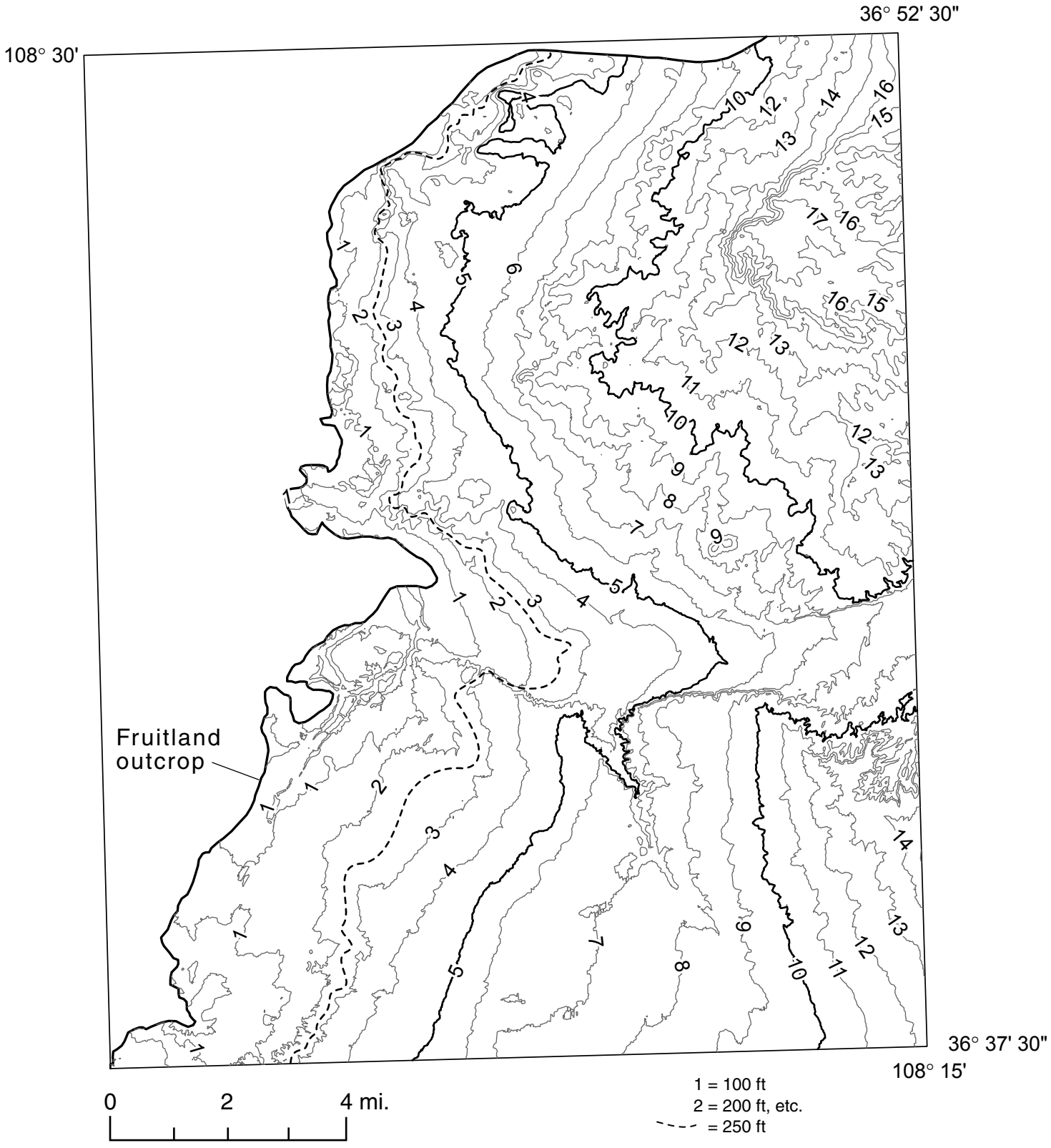


Figure 13. Overburden on top of coal zone 8. Fruitland-Navajo Study area, Northwest New Mexico. Fruitland outcrop from Beaumont, 1998. Contour interval 100 ft.

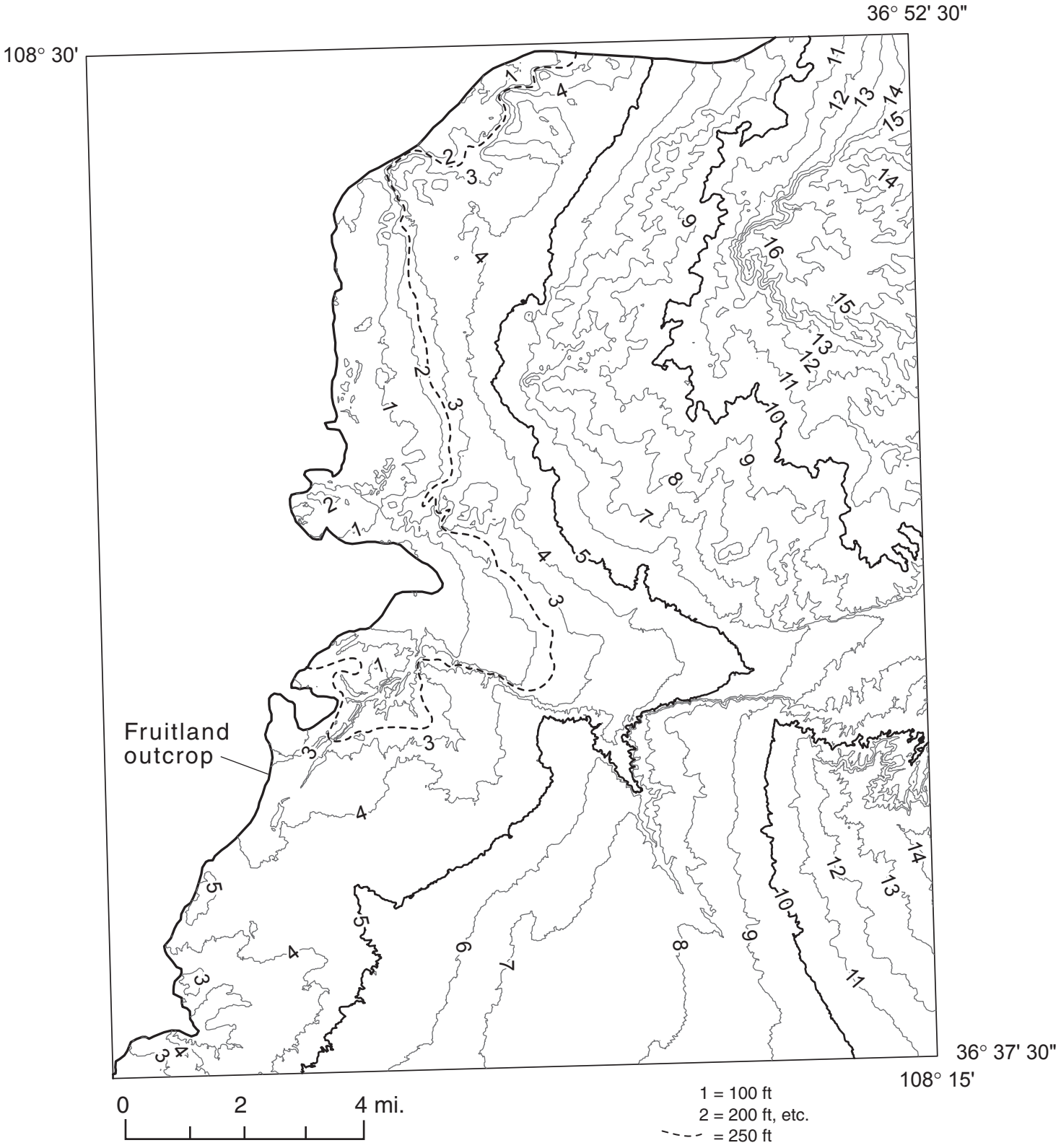


Figure 14. Overburden on top of coal zone 9. Fruitland-Navajo Study area, Northwest New Mexico. Fruitland outcrop from Beaumont, 1998. Contour interval 100 ft.

Overview of restrictions

The following are the restrictions considered for this area. The buffers applied to these restrictions adhere to the New Mexico Coal Surface Mining Regulations 19 NMAC 8.2 subpart 2, (Energy, Minerals, and Natural Resources Department, Mining and Minerals Division, 1997) which follow the Federal regulations. There is no specified buffer for oil and gas wells so a minimum 100-ft buffer was applied.

Restrictions	**Buffer**
Highways, major roads, runways	100 ft on either side
Pipelines, powerlines	50 ft on either side
Buildings, public or private	300 ft
Cemeteries	100 ft
Ponds, lakes, San Juan River	100 ft
Oil and Gas Wells	100 ft

Figure 15 illustrates these restrictions along with the Fruitland out crop for the study area.

Technological restrictions

Technical parameters that influence the resource of this study are:

Coal too close to the surface. Coal with less than 20 ft of overburden is subtracted from the remaining resource estimate. Coal with less than 20 ft of overburden is removed because San Juan Basin coal within this interval is generally weathered or sometimes burned and can not be used for energy production. Most operating mines in the San Juan Basin use the greater-than-20-ft depth guideline for calculating mine reserves

Coal too thin at depth. Coal beds from 1.2 ft to 3.5 ft thick are not considered minable at depths greater than 250 ft. The original resources are calculated for this depth category but these results are removed under the technical restrictions.

Land-use restrictions

Restrictions to mining in the project area are greater than in past availability studies in the San Juan Basin. This study area is just west of Farmington, a center of commerce for the Four Corners area.

NM State Highway 64, pipelines, and powerlines transect the study area (Fig. 15) and there are numerous small communities within the area. The San Juan River is an important source of water for the region and supports agriculture so it is considered an Alluvial Valley Floor and is buffered accordingly. Large-scale surface mining at the San Juan and Navajo mines has removed significant amounts of coal from the original Fruitland Formation resource. Several oil and gas wells exist in the study area and have some impact on the original resources.

Fruitland -Navajo Study Area Resources

Total original resources in the Fruitland-Navajo study area are 4.3 billion short tons (st). Mining removes 220 million st from the original value. The technological restrictions remove 23 million st from the surface minable coal, within 20 ft of the surface and 143 million st of thin coal (1.2-3.5 ft) at depths greater than 250 ft removed. This restriction represents about 21% of the total restrictions to mining that would not be mitigated. Technological restrictions are greatest for Zone 8, closely followed by Zone 9 (Tables 2,3).

The San Juan River valley grouped with some major reservoirs removes 283 million st from the resource, particularly impacting Zone 7 at all depths and for Zone 9 coals at depths greater than 250 ft. Although this layer contains a few other water bodies in the study area, the main area removed is from the San Juan River valley. This represents about 35% of the total restrictions that as a whole are unlikely to be mitigated. Although it is possible to mine in an alluvial valley floor, there are restrictions. Mining can not interrupt, discontinue or preclude farming unless the land before mining was used as undeveloped rangeland or the area affected would be small and would provide negligible support for farming activity (New Mexico Surface Coal Mine Regulations, 1997, subpart 23). The San Juan River valley is the largest restriction to this study areas coal resource. Pipeline and powerlines remove 32 million st and roads remove 29 million st. Oil and gas wells and cemeteries represent have minor impact on the resource. Figure 16a-c illustrates the proportion of coal removed by these restrictions for each of the zones. Figure 17, Tables 2 and 3 show the original resource, restrictions, available resource and percent available for

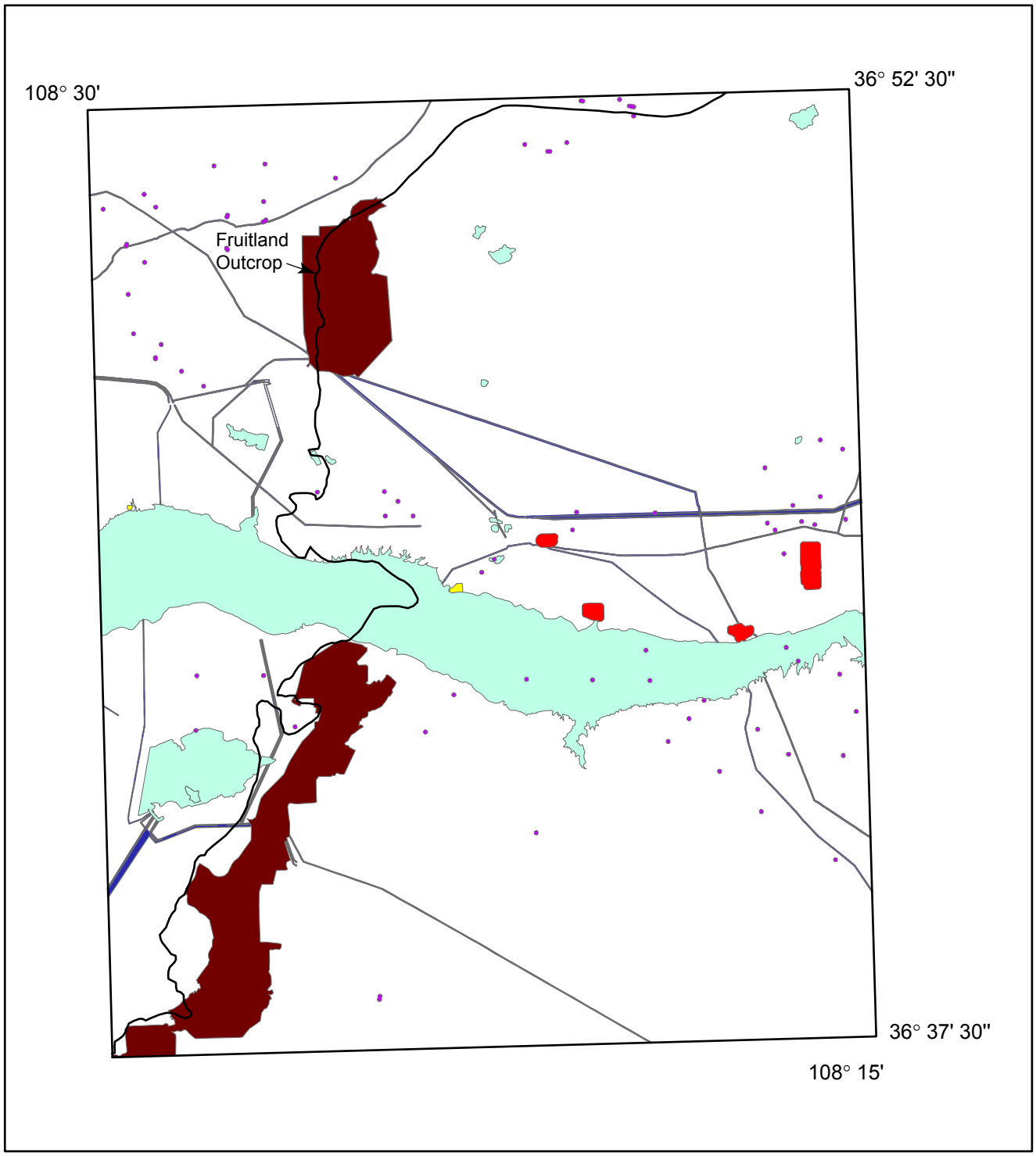


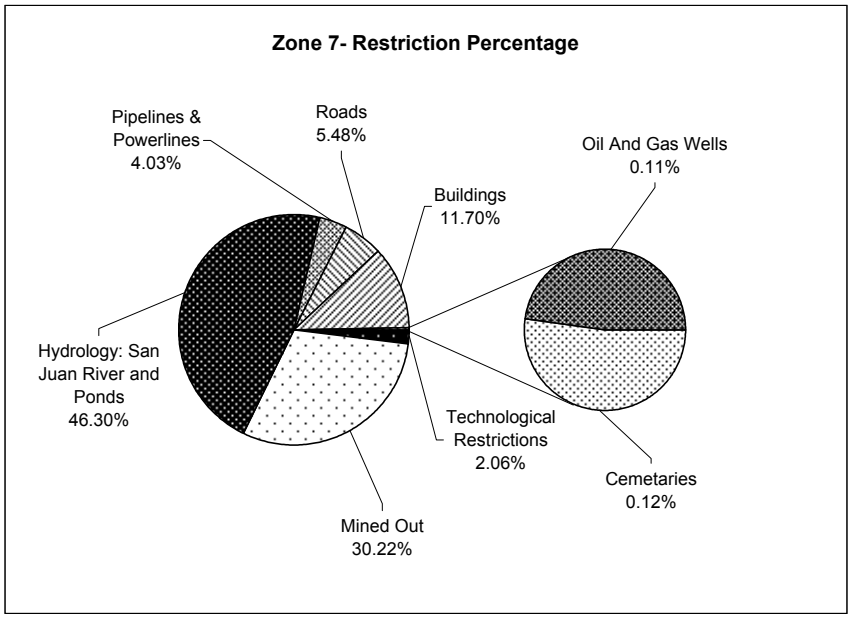
Figure 15. Land-use restrictions in Fruitland-Navajo Study area, Cropline from Beaumont, 1998.

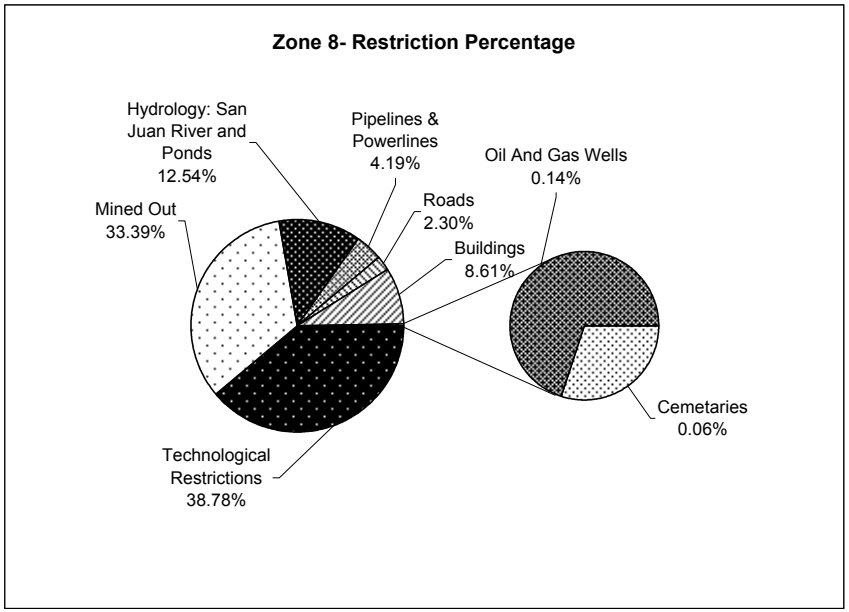
Table 2. Summary of surface and underground coal resources and available coal by zone for the upper Fruitland-Navajo area, reported in millions of st.

Depth Categories	Coal Zone	Original Resources	Likely Restrictions to mining								Restrictions that might be mitigated			
			Technological Restrictions	Mined Out	Hydrology: San Juan River and Ponds	Cemetaries	Oil And Gas Wells	Pipelines & Powerlines	Roads	Total Restrictions	Available	%Available	Buildings	Total Land use restrictions
10:1 Stripping ratio	Zone 7	61	0	41	1	0	0	0	1	45	16	27%	1	45
	Zone 8	81	0	33	2	0	0	0	0	38	43	53%	2	38
	Zone 9	4	0	2	1	0	0	0	0	3	1	22%	1	3
	Overall	*146*	*0*	*76*	*4*	*0*	*0*	*0*	*1*	*86*	*60*	*41%*	*4*	*86*
Surface (0-250 ft)	Zone 7	311	8	118	40	0	0	2	4	176	135	43%	3	167
	Zone 8	233	13	70	16	0	0	1	1	103	130	56%	2	90
	Zone 9	94	2	21	12	0	0	1	0	37	57	61%	0	35
	Overall	*637*	*23*	*209*	*68*	*0*	*0*	*4*	*5*	*315*	*322*	*50%*	*5*	*292*
Underground (>250 ft->1000	Zone 7	1,672	0	0	142	0	0	14	17	216	1,455	87%	43	216
	Zone 8	1,156	79	9	14	0	0	9	5	134	1,022	88%	19	56
	Zone 9	830	64	1	60	0	0	6	2	143	687	83%	10	79
	Overall	*3,657*	*143*	*10*	*215*	*0*	*1*	*28*	*24*	*494*	*3,164*	*87%*	*72*	*351*

Table 3. Summary of coal resources and available coal by zone for the upper Fruitland-Navajo area, reported in millions of st.

Coal Zone	Original Resources	Likely Restrictions to mining								Restrictions that might be mitigated			
		Technological Restrictions	Mined Out	Hydrology: San Juan River and Ponds	Cemetaries	Oil And Gas Wells	Pipelines & Powerlines	Roads	Total Restrictions	Available	%Available	Buildings	Total Land use restrictions
Zone 7	1,982	8	118	181	0	0	16	21	392	1,590	80%	46	384
Zone 8	1,389	92	79	30	0	0	10	5	237	1,151	83%	20	145
Zone 9	924	66	22	72	0	0	6	2	180	744	81%	11	114
Overall	*4,294*	*166*	*220*	*283*	*1*	*1*	*32*	*29*	*809*	*3,485*	*81%*	*77*	*643*





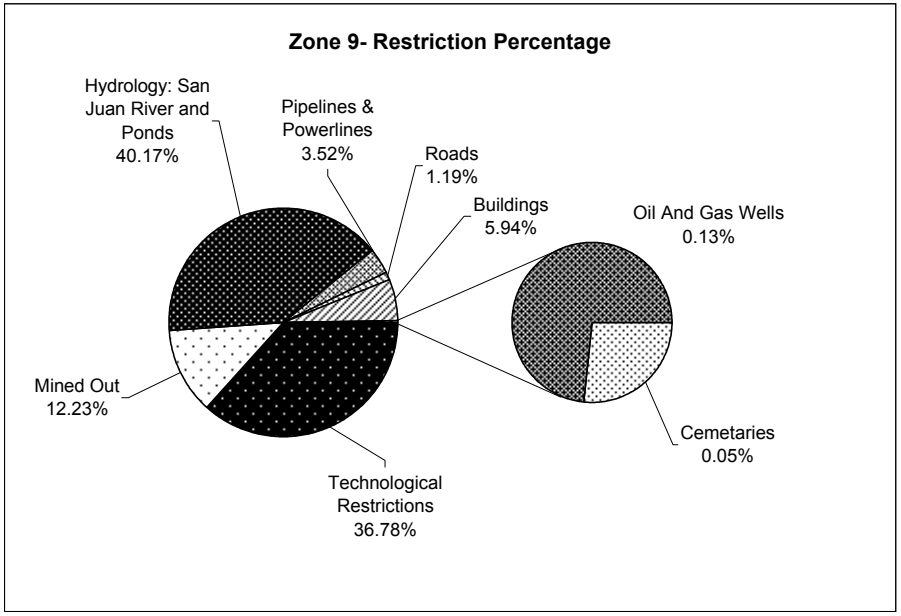


Figure 16a-c. Percentages of resources removed by technological and land-use restrictions by zone.

each zone. The available resource is calculated removing all land-use restrictions except for the buildings, which have the potential for mitigation.

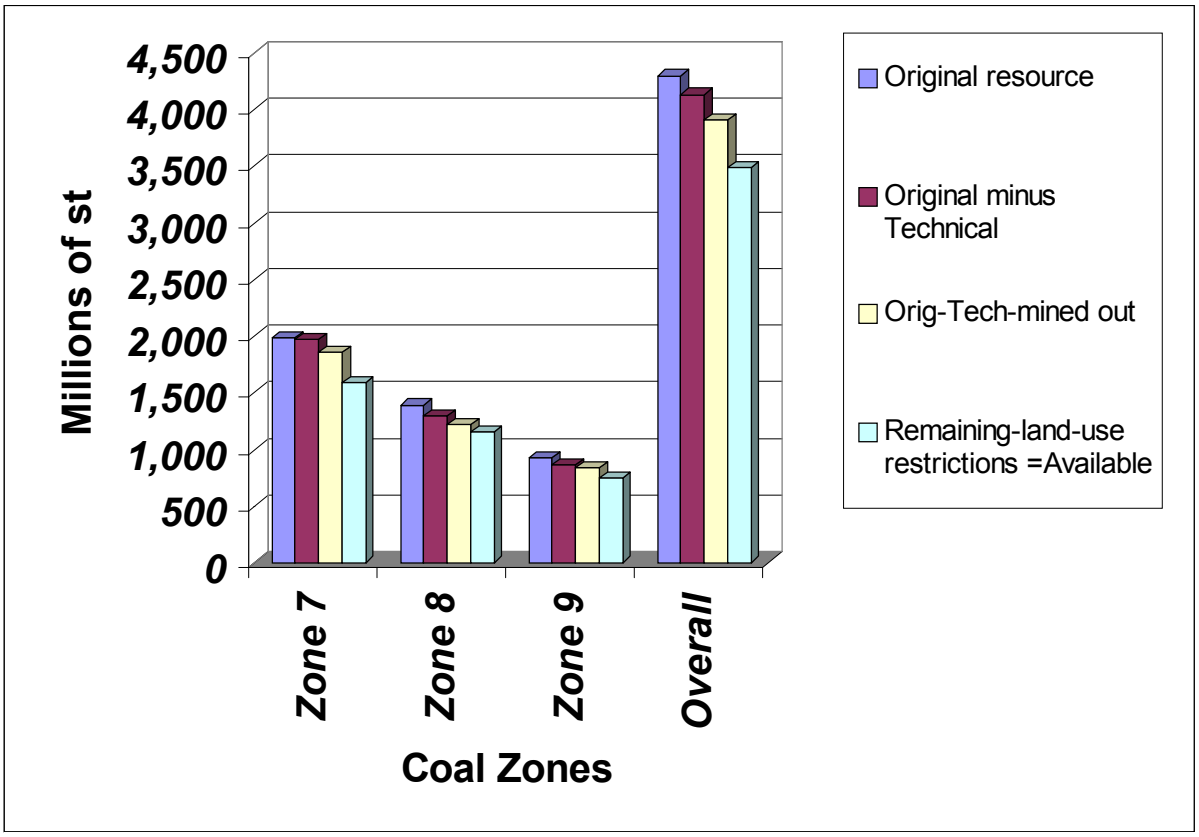


Figure 17. Fruitland-Navajo study area resources by zone.

Restrictions with potential for mitigation

Buildings remove 77 million st from the total available resource, but in many cases buildings have the potential for mitigation. If mining were to take place, some of these buildings, many of which are homes or mobile homes, would be moved and the owners compensated. There are several businesses along the main highway that might not be considered for mitigation so the entire buildings layer may not be available for mitigation.

Comparison with other resource studies

Shomaker, Beaumont, and Kottlowski (1971) estimated surface coal reserves for T29-31N, R15W to be 140 million st for depth 0-250 ft for the main bed, which is equivalent to zone 8 in this report. This figure is about 80% of the total for zone 8 from this study in the 0-250 ft depth category. Estimates for T28-29N, R15-16W from Shomaker, Beaumont, and Kottlowski (1971) are 114.4 million st for depth 10-250 ft with a stripping ratio of 10:1. In the 10:1 stripping ratio category of this investigation, the original resources are 146 million st. Again the estimate by Shomaker, Beaumont, and Kottlowski (1971) is about 80% of the total from this study. The area investigated by Roberts (1991) includes sections in T30N, R14W and T31N, R14-15W at the northern edge of this study area, but it represents a small portion of the total area covered by this report. The estimated total coal resources from Roberts's study (1991) are 252 million st, about 10% of the estimated total for zones 8 and 9 in this study.

The DOE demonstrated reserve base study (Hoffman, 1996) estimate for the Fruitland field for near surface reserves (<200 ft) was 536 million short tons and for deep coal, (>200 ft) 863 million st. The entire Fruitland field extends northeast of the present study area and includes zone 10 coals that were not part of the zone calculations for this investigation. The demonstrated reserve base estimate does not include the inferred category of reliability that was used in the estimates for this report. The present study area also includes areas within the Navajo field, south of the San Juan River that would have been included in the Navajo field demonstrated reserve estimate. These factors make it difficult to compare the two studies results. Subtracting the inferred data from this study's available resource would leave 1.78 million st. and the total demonstrated reserve base for the Fruitland field is 1.39 million st. New point source data was added in this study, particularly for the deeper coal areas and has increased the estimate for deep coals.

Summary

The Fruitland coals in the Fruitland-Navajo study area are high-ash, low-sulfur, high volatile C bituminous coals. Although the coals are low in sulfur (0.8%) they do not meet compliance coal standards of less than 0.6 lbs sulfur/MBtu. Four zones are recognized in the Fruitland Formation within in the study

area, but only three were evaluated because the fourth and highest zone in the section was primarily identified in the drill holes outside the study area. Zones 7, 8, and 9 have coal seams averaging 5 to 7.5 ft thick. Zones 7 and 8 averaging two seams within the zone, but zone 9 generally has only one seam. Zone 8 has the greatest seam average and the greatest total coal average.

Original resources for this study area are 4.3 billion short tons. Mining has removed 219 million st from this resource. Technical restrictions remove 166 million st from the area's resource. Land-use restrictions total 643 million st with hydrology and buildings being the greatest restrictions to mining. The available resource is calculated without the restriction for buildings. Zone 7 has 80% of the total original resource available, zone 8, has 83%, and zone 9 has 81% of the total original resource available after removing restrictions. Only half of the surface minable original resource is available for all three zones. The majority of the resource available in the study area is at depths greater than 250 ft. It is not surprising in light of this information the San Juan Mine has decided to discontinue surface mining at their operations and go underground.

Acknowledgements

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Appendix-Cross Section Drill Holes for Navajo-Fruitland Availability Study

ID	WellNumber	Source	Quadrangle	NMBG Pet Record ID	Twnshp	Range	Section	Latitude	Longitude	Elevation
21	#1 BELL FED. GAS "B"	PAN AM PETRO CORP -CROCDP	FARMINGTON NORTH	13726	30N	13W	11	364956	1081004	5872
100	#1 FOUTZ-STATE	SOUTHWEST PRODUCTION -CROCDP	KIRTLAND	13393	29N	14W	16	364336	1081847	5181
101	#1 FRUITLAND AMARILLO	JAMES R. PICKETT -CROCDP	FRUITLAND	13424	29N	15W	26	364131	1082336	5228
158	#1 LAPLATA	EL PASO NATURAL GAS -CROCDP	FARMINGTON NORTH		30N	13W	29	364647	1081402	5480
163	#1 MADDOX-C	SINCLAIR OIL & GAS -CROCDP	FARMINGTON NORTH	20529	30N	13W	14	364832	1081037	5719
194	#1 NAVAJO TRIBE	TEXACO INC -CROCDP	FRUITLAND	17168	29N	15W	34	364108	1082401	5407
276	#1-20 SAN JUAN 30-14	STONE DRILLING -CROCDP	YOUNGS LAKE	13758	30N	14W	20	364807	1081948	5532
284	#1-28 STRAT TEST	MALCO REFINERY -CROCDP	YOUNGS LAKE	34101	30N	14W	28	364700	1081905	5492
295	#1-6 SOUTHWEST MOUNDS	COMPASS EXPLORATION -CROCDP	FARMINGTON NORTH	13329	29N	13W	6	364537	1081434	5388
297	#1-7 STRAT TEST	MALCO REFINERY -CROCDP	YOUNGS LAKE	34085	30N	14W	7	364947	1082109	5375
329	#1-NAVAJO D	BRITISH AMERICAN -CROCDP	KIRTLAND		29N	14W	30	364211	1082225	5446
402	#13 MCCORD	SOUTHERN UNION GAS CO -CROCDP	FARMINGTON NORTH	34077	30N	13W	22	364739	1081142	5739
417	#14 L NAVAJO	HUMBLE OIL & REFINING -CROCDP	KIRTLAND		29N	14W	25	364156	1081603	5613
473	#1DUNCAN	CANDADO PRODUCTION -CROCDP	KIRTLAND	13390	29N	14W	15	364355	1081801	5287

ID	WellNumber	Source	Quadrangle	NMBG Pet Record ID	Twnshp	Range	Section	Latitude	Longitude	Elevation
498	#2 FRUITLAND NAVAJO	CONTINENTAL OIL -CROCDP	KIRTLAND	17195	29N	15W	13	364317	1082140	5157
527	#2 NM FEDERAL "I"	T.A DUGAN -CROCDP	YOUNGS LAKE	43109	29N	14W	1	364537	1081515	5550
536	#2 RUSSEL	PUBCO DEVELOPMENT-CROCDP	YOUNGS LAKE	21232	30N	14W	33	364552	1081903	5443
549	#2-7 FEDERAL	ASPEN CRUDE PURCHASE CO. -CROCDP	KIRTLAND	33469	28N	13W	7	364027	1081527	5928
677	#4 MCCORD	SOUTHERN UNION GAS CO -CROCDP	FARMINGTON NORTH	13738	30N	13W	22	364804	1081122	5707
696	#4H NAVAJO	PAN AM PETRO CORP -CROCDP	KIRTLAND	13405	29N	14W	24	364304	1081545	5347
721	#5G NAVAJO	PAN AM PETRO CORP -CROCDP	KIRTLAND	13396	29N	14W	17	364328	1081932	5172
750	#7 NM FED. "I"	SUNRAY MIDCONTINENT -CROCDP	KIRTLAND	17925	29N	14W	11	364406	1081706	5450
790	#8H	PAN AM PETRO CORP -CROCDP	KIRTLAND	13387	29N	14W	14	364327	1081620	5235
1333	JONES #1	BENSON-MONTIN-GREER	FARMINGTON SOUTH	8708	28N	13W	17	363926	1081408	6012
1774	C. J. HOLDER 2	PAN AMERICAN PET. CORP	FARMINGTON SOUTH	14010	28N	13W	8	364017	1081451	5975
1779	C. J. HOLDER # 15	PAN AM PETRO CORP -CROCDP	FARMINGTON SOUTH	12970	28N	13W	21	363913	1081316	6044
1780	ROBINSON #12	AZTEC OIL & GAS -CROCDP	FARMINGTON SOUTH	33479	28N	13W	22	363836	1081230	6063
1815	SOUTHWEST MOUNDS 1-2	COMPASS EXPLORATION -CROCDP	YOUNGS LAKE	13381	29N	14W	2	364538	1081651	5455
1817	NAVAJO #6-L	HUMBLE OIL & REFINING -CROCDP	KIRTLAND	45311	29N	14W	25	364130	1081607	5896

ID	WellNumber	Source	Quadrangle	NMBG Pet Record ID	Twnshp	Range	Section	Latitude	Longitude	Elevation
1830	KING GAS UNIT #1	PAN AM PETRO CORP -CROCDP	FARMINGTON NORTH	13745	30N	13W	29	364721	1081330	5467
1852	MONTE CARLO #1	DUGAN PRODUCTION - CROCDP	YOUNGS LAKE	32219	30N	14W	7	364930	1082045	5377
1853	LOCKE # 1	SOUTHLAND ROYALTY COMPANY	YOUNGS LAKE	32392	29N	14W	3	364506	1081727	5476