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COAL RESOURCES OF THE SAN JUAN BASIN

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Abstract—The coal resources of the San Juan Basin are concentrated in Upper Cretaceous rocks and were, for the most part, deposited in back-shore swamp environments developed in association with regressions of the Western Interior seaway's western shoreline. All of the thicker coal deposits are located southwest of thick, vertical buildups of adjacent (northeast) shoreface sandstones. Coals are low sulfur, high-ash, have heating values averaging from 9000 to 10,000 Btu (2300 to 2500 kg calories), and range from subbituminous to medium- to low-volatile bituminous in rank. The Fruitland Formation contains more than 200 billion short tons of coal (93% of the basin total). Other important coal-bearing units are the Menefee Formation and the Gibson Coal Member and Dilco Coal Member (of the Crevasse Canyon Formation). These rocks may contain as much as 15 billion short tons of coal. San Juan Basin strip-coal mines produced 17.6 million tons of coal in 1987, down from a peak of 19.8 million tons in 1985. Nearly all of the basin's coal goes to feed electricity-generating power plants in New Mexico and Arizona. Over the past ten years Fruitland Formation coals have been found to contain large resources of coal-bed methane; recent studies estimate resources of 50 trillion cubic feet of gas. Commercial production of this gas is accelerating rapidly, mostly in the northern part of the basin.

COAL RESOURCES AND DISTRIBUTION

The coal resources of the San Juan Basin are in Upper Cretaceous rocks; the coal beds were deposited, for the most part, in association with shoreline regressions. Figure 1 shows the geometry of Upper Cretaceous rocks on a north-trending cross section. Commercial coal deposits are concentrated in the lower part of continental-rock units associated with each of the Upper Cretaceous regressive-shoreface sandstones shown on Figure 1. These units are: Dilco Coal Member of the Crevasse Canyon Formation on top of the regressive Gallup Sandstone; Gibson Coal Member of the Crevasse Canyon on the regressive Dalton Sandstone Member of the Crevasse Canyon; lower part of the Menefee Formation (Cleary Coal Member of the Menefee in the southwestern part of the basin) on the regressive Point Lookout Sandstone; and the lower part of the Fruitland Formation on the regressive Pictured Cliffs Sandstone. Some thin, discontinuous coal beds also are associated with the transgressive Dakota Sandstone and the Cliff House Sandstone. The Paleocene Nacimiento and Animas (upper part) formations contain rare, very thin, impure and discontinuous coal beds in some parts of the basin. An important coal-bearing unit is present in the upper part of the Menefee Formation ("Hogback Mountain Tongue" in some reports, for example, Whyte and Shomaker, 1977). This Menefee tongue is not named on Figure 1, but is between the words "La Ventana" and "Tongue." The coal beds in this unit were deposited in association with a regressive-marine sandstone near the base of the La Ventana (Fassett, 1977; Fig. 2).

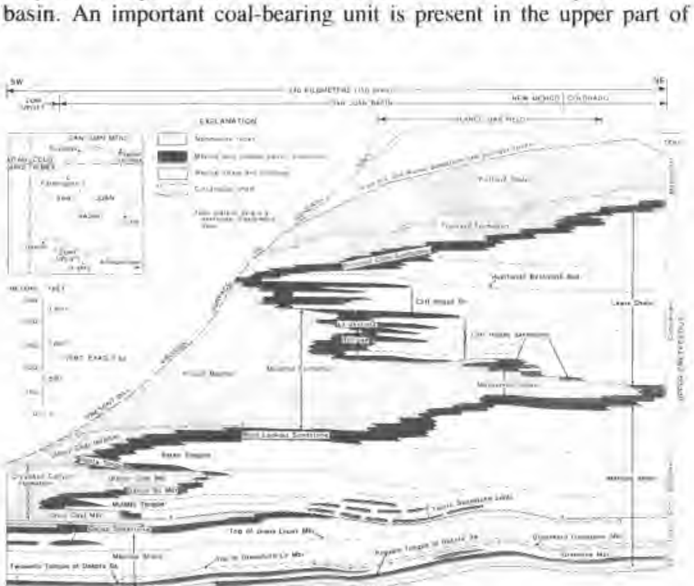

FIGURE 1. Stratigraphic cross section showing Upper Cretaceous rocks of the San Juan Basin of New Mexico and Colorado. Cen. = Cenomanian, Turon. = Turonian, Con. = Coniacian, Maestricht. = Maastrichtian; the Greenhorn Limestone Member of the Mancos Shale has been renamed the Bridge Creek Limestone Member of the Mancos. From Molenaar (1988).

The major coal-bearing unit in the San Juan Basin is the Fruitland Formation. The Fruitland contains over 200 billion short tons of coal. Fruitland coal crops out around the rim of the basin, except for the east-central part, and is at depths of slightly more than 4000 ft (1220 m) in a small area in the north-central part of the basin. The Fruitland is present over an area of about 7500 mi^2 (19,500 km^2) in the central San Juan Basin area. Table 1 shows Fruitland coal tonnages in various thicknesses of overburden ranges.

The Menefee Formation contains the next-largest total coal resource in the basin. No calculation of the total Menefee coal resources of the San Juan Basin has yet been published. The only published coal-tonnage estimate for Menefee coal is restricted to the southern part of the basin at depths of less than 4000 ft (1220 m); this estimate is 12 billion tons (Whyte and Shomaker, 1977). Over 11 billion tons of this total is in the "Hogback Mountain Tongue" of the Menefee Formation. If Menefee coals in the northern San Juan Basin at depths greater than 4000 ft (1220 m) were included, the total Menefee coal tonnage would be increased, but by how much is not known at this time. The Menefee is present over a much larger area than the Fruitland Formation; it is present throughout all of the central basin area and extends south over the Chaco slope and to the northern part of the Gallup sag.

The Gibson and Dilco members of the Crevasse Canyon Formation bring up the rear in the basin's total coal resources. Gibson coal is

TABLE 1. Coal resources of the Fruitland Formation in millions of short tons (from Fassett and Hinds, 1971).

Overburden (in feet)		Resource
0-500		14,638
500-1,000		13,868
1,000-2,000		27,937
2,000-3,000		58,808
3,000-4,000		82,824
>4,000		3,061
	TOTAL	201,136

present in a relatively small geographic area in the southwest part of the basin, and Dilco coal beds are relatively thin and discontinuous. Both of these units, however, provided coal for railroad steam locomotives during the period from the 1890's to 1940. Resource studies of the coals in these units have been reported on in Shomaker, Beaumont and Kottlowski (1971). Their totals represent less than one percent of the basin's total coal resources.

FRUITLAND FORMATION COAL

Physical characteristics and distribution

The Fruitland Formation has been the most intensively studied of the coal-bearing formations in the San Juan Basin. The following discussion of the Fruitland and its coal beds is from Fassett and Hinds (1971) and Fassett (1987, 1988a).

Fruitland Formation coal beds range from thin stringers to beds more than 40 ft (12.2 m) thick. Coal zones may contain several coal beds that total as much as 80 ft (24.4 m) of coal. Heating values of the coal generally range from about 9000 Btu (2300 kg calories) to more than 13,000 Btu (3300 kg calories), on an as-received basis. These values are for coal exclusive of non-coal partings. Channel samples or core samples through an entire coal bed generally yield lower values, between 9000 and 10,000 Btu (2300 to 2500 kg calories), because of the ash content contributed by non-coal partings in most coal beds. Vitrinite reflectance studies (Rice, 1983) and fixed-carbon-to-volatile-matter ratios (Fassett and Hinds, 1971) indicate that Fruitland coal rank ranges from subbituminous to medium- to low-volatile bituminous. Fruitland coal is non-coking except at the Chimney Rock mine area in the northeastern part of the basin.

The ash content of Fruitland coals is generally high, even in samples free of macroscopic non-coal partings. Ash content for such samples generally ranges from slightly less than 8% to as high as 30%. There seems to be a general increase in ash content eastward across the basin. Moisture content of the coal averages from 2 to 5%. Sulfur content is low, averaging 0.6 to 0.7%, with a range of 0.5 to 2.5%. Ratios of fixed carbon to volatile matter vary across the basin, with a general increase in fixed carbon from around 50% in the southwestern half to more than 70% in the area of the present structural axis of the basin. This trend indicates that fixed carbon in Fruitland coals is generally related to the present depth of burial of the coal beds, although Rice (1983) points out that coal with the highest known vitrinite reflectance in the basin (1.45%) comes from a point slightly north of the present structural axis of the basin.

The distribution of Fruitland coal throughout the San Juan Basin was determined to a large extent using geophysical logs from oil or gas drill holes. Figure 2 is an isopach map of Fruitland Formation total coal in beds more than 2 ft (0.6 m) thick throughout the San Juan Basin. A total of 324 control points (representing both subsurface and outcrop measurements) was used to construct the isopach map. The thickness at each control point represents from one to as many as a dozen or more coal beds.

The coal distribution shown on Figure 2 reveals an interesting pattern consisting of a thick pod of coal in the southwestern part of the basin; a swath of thin coal trending northwestward across the southwestern part of the basin; a band of thicker coal across the central basin area; and an area of thin coal in the northeasternmost part of the basin. These coal thickness patterns are related to environments of coal deposition during Fruitland time, which in turn are related to the mode of deposition of the underlying Pictured Cliffs Sandstone.

Pictured Cliffs Sandstone deposition

The Pictured Cliffs Sandstone underlies the Fruitland Formation throughout most of the San Juan Basin. The Pictured Cliffs is a very fine to fine-grained quartzose sandstone that, at most exposures, is made up of an upper part consisting of one or two beds of massive sandstone and a lower part consisting of interbedded sandstone and shale. Sandstone beds in the lower part become thinner and finer grained downward in the section. The Pictured Cliffs Sandstone was deposited during the final regression of the Late Cretaceous epeiric seaway from the San

FIGURE 2. Isopach map of total thickness of coal in the Fruitland Formation.

Juan Basin area in late Campanian time; it was deposited as a strandline-shoreface sandstone as the sea retreated northeastward out of the area (Fassett, 1988a; Fig. 2).

The model for deposition of the Upper Cretaceous rocks of the San Juan Basin associated with transgressing and regressing shorelines over a period of some 25 million years was first described by Sears and others in 1941 in their classic, landmark paper. Their model, simply put, supposed a continuously subsiding trough (the Upper Cretaceous Western Interior seaway) receiving sediment at a varying rate. A high rate of sediment influx resulted in outbuilding of the shoreline (regression), and a low rate of sediment influx resulted in landward advance of the shoreline (transgression). Thus, the Pictured Cliffs Sandstone strandline regressed from the southwestern part to the northeastern part of the San Juan Basin area in response to an increase in sediment being delivered to the shoreline by northeast-flowing streams. Figure 3 is an isopach map of the interval between the Huerfanito Bentonite Bed of the Lewis Shale and the top of the Pictured Cliffs Sandstone. The isopach lines are probably a fairly accurate portrayal of the positions of the Pictured Cliffs Sandstone shorelines throughout the time the sea was retreating across the basin area.

Figure 4 shows three stratigraphic cross sections oriented northeastward across the basin showing the relations of the Lewis Shale and its Huerfanito Bentonite Bed, Pictured Cliffs Sandstone, Fruitland Formation and overlying rocks. These sections show the time-transgressive nature of the Pictured Cliffs Sandstone, which becomes younger northeastward across the basin. These sections also show that the sea did not retreat steadily and evenly across the basin. For example, between wells 8 and 9 on cross section A–A' and 10 and 11 on B–B', there is a stratigraphic rise in the top of the Pictured Cliffs of about 200 ft (61 m). These rises indicate that, for a time, the shoreline in these areas ceased to regress northeastward and stayed in the same general geograhic area, building the strandline sands into a thick vertical stack. Figure 3 also shows this large stratigraphic rise of the top of the Pictured Cliffs Sandstone along a northwest trend across the north-central part of the basin.

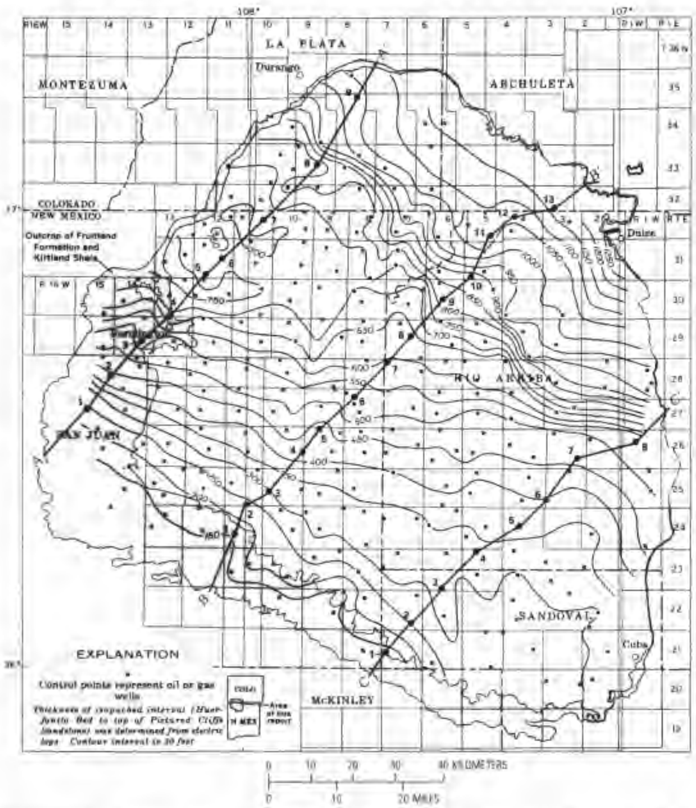

FIGURE 3. Isopach map of the interval between the Huerfanito Bentonite Bed of the Lewis Shale and the top of the Pictured Cliffs Sandstone. Lines of cross sections A–A′, B–B′ and C–C′ of Figure 4 are shown.

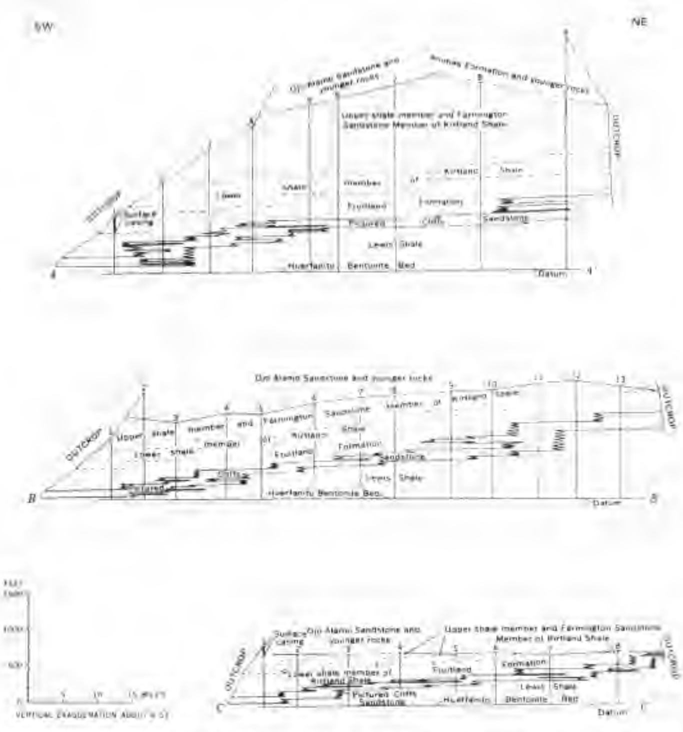

FIGURE 4. Northeast-trending stratigraphic cross sections showing the northeastward stratigraphic rise of the Pictured Cliffs Sandstone and associated rocks. Lines of cross sections are shown on Figure 3.

Fruitland coal deposition model

In 1941, Sears and others suggested that thick coal deposits should form landward of upbuilding beach-sand deposits. That suggestion was only theoretical at the time it was made because such an occurrence had not actually been documented. Later, however, with the availability of thousands of geophysical logs through the Fruitland Formation throughout the San Juan Basin, Fassett and Hinds (1971) were able to demonstrate that the theoretical prediction of Sears et al. (1941) is valid for the Pictured Cliffs–Fruitland rocks and that thick Fruitland coals did indeed develop shoreward of upbuilding, shoreface Pictured Cliffs sands. It is important to note, however, that this model is not universal, not even in the San Juan Basin, as demonstrated by Fassett (1987).

Figure 5 is a modified version of the Fruitland-coal isopach map (Fig. 2); it shows that the thickest zone of Fruitland coal is located southwest of the largest vertical buildup of the Pictured Cliffs Sandstone. The correspondence is not perfect, but considering the variability in natural systems, it is impressive. One of the problems with this depiction is that the total-coal isopach map represents several coal beds in the Fruitland that occur through a stratigraphic interval as much as 300 ft (91 m) thick. A series of isopach maps of individual coal beds in the Fruitland would probably demonstrate more clearly the relationship of thick Fruitland coal beds to this large stratigraphic rise in the Pictured Cliffs Sandstone.

Another way to portray the relations of thick Fruitland coal beds to stratigraphic rises in the Pictured Cliffs is in cross section. Figure 6 is a northeast-trending cross section (B–B′ of Fig. 3) showing Fruitland Formation coal beds and their relationship to the Pictured Cliffs Sandstone. The thickest Fruitland coals are clearly related to the largest stratigraphic rises of the Pictured Cliffs.

DEPOSITION OF OTHER COALS

It would be tempting to suggest that the Fruitland-coal-deposition model applies to the other coal-bearing rock units in the basin associated

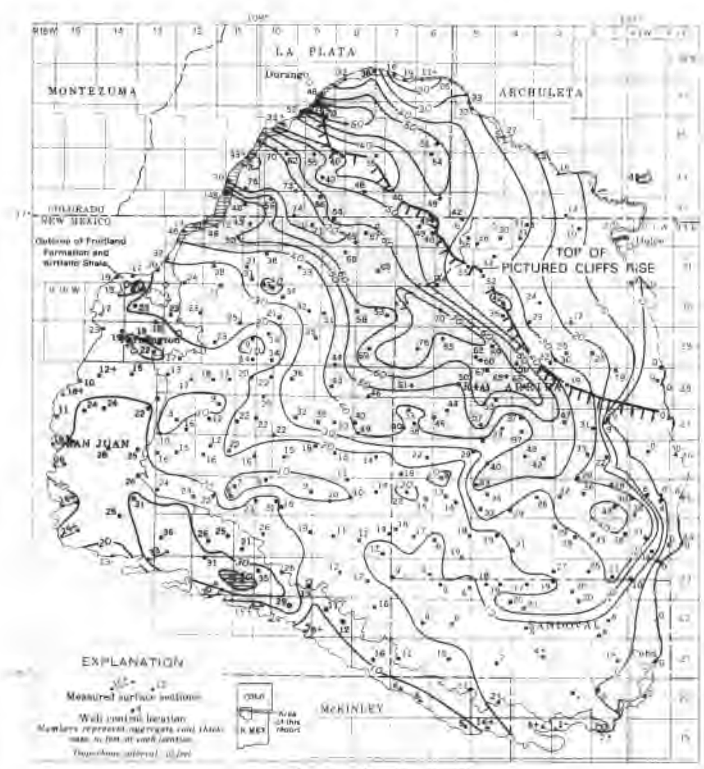

FIGURE 5. A modified version of the Fruitland-coal isopach map (Fig. 2) showing that the area of thickest Fruitland coal is located southwest of the greatest stratigraphic rise (Fig. 3) of the Pictured Cliffs Sandstone. Areas where total-coal thickness is greater than 40 ft (12 m) are patterned.

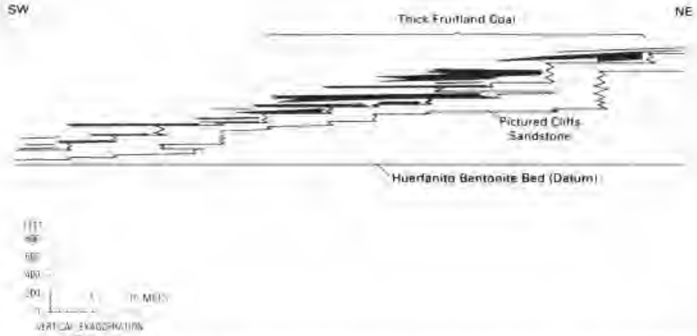

FIGURE 6. Northeast-trending stratigraphic cross section showing Fruitland Formation coal beds and underlying Pictured Cliffs Sandstone. This cross section is modified from section B–B′ of Figure 4; coal bed thicknesses are from plate 3 of Fassett and Hinds (1971).

with shoreline regressions. Fassett (1987), however, did a comparison of the coals of the Menefee Formation with Fruitland coals and concluded that even though there were apparent similarities in the mode of deposition of the Point Lookout Sandstone–Menefee Formation couplet and the Pictured Cliffs Sandstone–Fruitland Formation couplet, the Fruitland-coal-deposition model did not seem to work for the Menefee coals. Figure 7 portrays these formations in cross section. Coal deposition patterns for the coal-bearing Dilco and Gibson members and the "Hogback Mountain Tongue" have not yet been worked out in detail. However, Anderson and Reddy (1986) suggested that the thicker Dilco coal beds accumulated in a paralic setting just landward of the pinchout of the Dalton sandstone.

COAL PRODUCTION

Coal production data are from publications of the New Mexico Energy, Minerals, and Natural Resources Department. Coal reserves for operating coal mines were provided by the mining companies or from the literature.

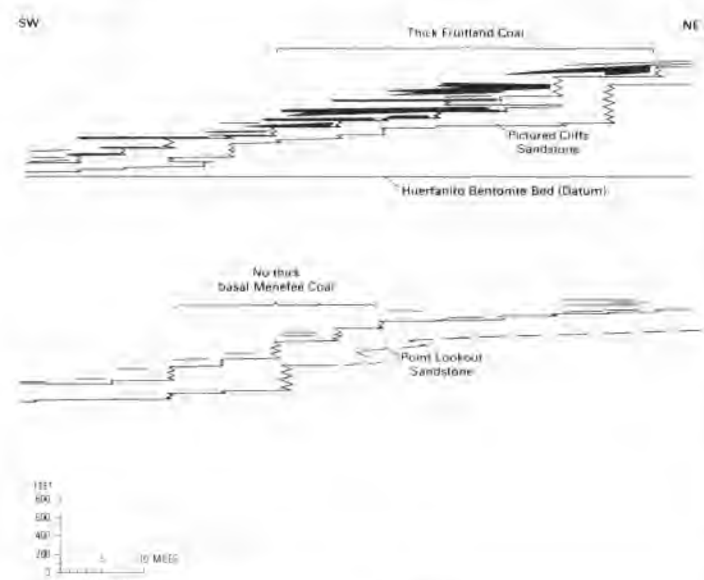

FIGURE 7. Northeast-trending stratigraphic cross section showing the presence of thick coal landward of a large stratigraphic rise of the Pictured Cliffs Sandstone and little or no coal landward of large stratigraphic rises of the Point Lookout Sandstone. This figure is a modification of an electric-log section from Fassett (1989). The extent and thickness of coal beds shown is based on electric log interpretation. The transgressive Cliff House Sandstone, located stratigraphically between the Point Lookout and the Pictured Cliffs, is not shown on this cross section in order to contrast more sharply the coal occurrence in the Menefee and Fruitland formations.

History

San Juan Basin coal has been utilized for hundreds of years; its first use was by the early Spanish explorers and later, coal use increased during the 1800's as growing numbers of settlers arrived from the east. (There is no indication that indigenous Native American Indians ever used coal for fuel in the San Juan Basin.) Toward the end of the 1800's, production increased as the railroads arrived. The big boom in coal production came with breakthroughs in long-distance power transmission capabilities which resulted in opening of the Navajo mine and adjacent Four Corners power plant in 1963 and the San Juan mine and adjacent San Juan Generating Station in 1972. The McKinley mine opened in 1962 and shipped coal by rail to a power plant in east-central Arizona. For a complete and detailed history of coal mining in the San Juan Basin during the last 100 yrs, see Nickelson (1988).

Peak annual coal production for New Mexico of 21.6 million tons came in 1985; 92% of this total, 19.8 million tons, came from the San Juan Basin. San Juan Basin coal mines produce most of their coal from the Fruitland Formation; the Menefee Formation and Gibson Member of the Crevasse Canyon Formation provide lesser amounts. The coal mines currently producing coal in the basin are discussed below by geologic formation.

Fruitland Formation

The rank of all Fruitland coals currently being mined in the basin, as determined from heating values and volatiles percentage, is high-volatile bituminous C. Classified based on weathering tendencies, Fruitland coals are subbituminous because of the slacking tendency of the coals. The rank of Fruitland Formation coals increases northeastward toward the basin's structural axis (Fassett and Hinds, 1971, figs. 25 and 26).

Several large strip mines are presently recovering Fruitland Formation coal in the New Mexico part of the San Juan Basin. The largest of these is the Navajo mine located west of Farmington and south of the San Juan River. This mine was opened in 1963 and provides coal to the Arizona Public Service Company Four Corners power plant located next to the mine. The heating value of the mined coal is variable, primarily because of differences in ash content within the mine, and the coal is blended to a power-plant feed of 9000 Btu (2300 kg calories). Coal production for 1987 was 7.3 million tons (6.6 million metric tons), down from its peak of nearly 9 million tons (8.2 million metric tons) in 1983. The coal lease is on the Navajo Indian Reservation. The lease is owned and operated by Utah International Inc., and has about 2 billion tons of coal in reserve, of which around 1 billion tons are minable between 30 and 250 ft (9 and 76 m) of overburden, and in beds more than 3 ft (0.9 m) thick. The plant can produce 2100 megawatts of electricity and is tied into a power grid including Los Angeles, Phoenix, Albuquerque and Tucson.

The San Juan coal mine, also west of Farmington, but north of the San Juan River, produced 3.2 million tons of coal in 1987, down from its peak of 5.2 million tons in 1986. The mine was opened in 1972. The coal is sold to the San Juan generating station located next to the mine. The generating station is owned by the New Mexico Public Service Company. Recoverable coal reserves on this Federal coal lease are around 83 million tons. Power from this plant goes to many different New Mexico cities and communities. The plant can produce 1700 megawatts of power.

The La Plata coal mine is located on a Federal coal lease about 17 mi (27 km) north of Farmington, just east of the La Plata River and just south of the New Mexico–Colorado state line. This mine produced 1.6 million tons of coal in 1987. All of this coal is trucked over the dedicated La Plata coal mine haulage road to the San Juan Generating Station, 22 mi (35 km) to the southwest. Recoverable coal reserves on this lease are 83 million tons.

Two small mines, the Gateway and the De-Na-Zin, are strip-mining Fruitland coal in an area about 30 mi (48 km) south of Farmington. They produced 172,000 and 51,000 tons of coal, respectively, in 1987. Most of the coal from these mines is trucked to the San Juan generation station. Both of these mines are on State of New Mexico coal leases.

The only coal strip mine to operate in the Colorado part of the San Juan Basin was the Chimney Rock mine. This mine is located in the northeast part of the San Juan Basin, about 25 mi (40 km) southwest of Pagosa Springs, Colorado, and about 24 mi (39 km) north of the New Mexico–Colorado state line. The mine was opened in 1976 and closed in 1987 because the lease was mined out. The mine was on a Federal coal lease, and total coal production was around 1.3 million tons. This mine produced the only known coking coal in the San Juan Basin. Coal from the Chimney Rock mine was the highest quality Fruitland coal ever produced in the San Juan Basin. The coal is high-volatile bituminous A in rank and has a heating value of from 11,600 to 13,200 Btu (2900 to 3300 kg calories) (Fassett, 1988b).

Menefee Formation and Gibson Coal Member

The McKinley mine, operated by Pittsburgh and Midway Coal Mining Co., is located about 20 mi (32 km) northwest of Gallup, New Mexico and about 3 mi (5 km) east of Window Rock, Arizona. It produced 3.6 million tons of coal in 1987, down from its peak of 5.3 million tons in 1982. Most of the coal is shipped by rail to the Salt River Project Coronado power plant and the Arizona Public Service Company Cholla generating station, both located in east-central Arizona. The coal-mine lease is on Federal, Navajo Indian and Santa Fe Pacific Railroad Company land. Coal reserves total 200 million tons. The coal mined from the McKinley mine is in both the Gibson Member of the Crevasse Canyon Formation and the Cleary Coal Member of the Menefee Formation. The mine is in an area west of the shoreline turn-around of the transgressive Hosta Tongue of the Point Lookout Sandstone and the regressive Point Lookout Sandstone, thus there is no lithologic boundary between the two coal-bearing rock units in the mine area. The coal is subbituminous, and the average heating value of mined coal ranges from 9500 to 10,500 Btu (2400 to 2600 kg calories).

The Lee Ranch coal mine is located about 12 mi (19 km) northeast of Grants, New Mexico and produces coal from the lower part of the Menefee Formation. The Lee Ranch mine is on Santa Fe Railroad land. Originally, the coal ownership in the present lease area was mixed Federal and Santa Fe Railroad. A recently completed land exchange allowed the Railroad to acquire title to the Federal coal land and thus form a solid block of Santa Fe–owned coal land in order to mine the coal as efficiently as possible and minimize the loss of coal resources. The Lee Ranch mine is operated by the Santa Fe Pacific Coal Corporation and produced around 2 million tons of coal in 1987, down from its peak production of 2.2 million tons in 1985. The mine opened in 1982, and minable reserves on the lease are 240 million tons of coal. The coal is subbituminous, and the average heating value of the mined coal is 9200 Btu (2318 kg calories). Coal from the Lee Ranch mine is shipped by rail to the Alamito Company power plant in Arizona and the Plains Escalante generating station near Prewitt, New Mexico.

CONCLUSION

The San Juan Basin is a vast storehouse of subbituminous to bituminous Upper Cretaceous coal resources. The Fruitland Formation contains over 200 billion tons of coal (about 93% of the basin total) in the central San Juan Basin area. The other coal-bearing rock units in the basin, the Menefee Formation, Gibson Coal Member and Dilco Coal Member (of the Crevasse Canyon Formation) may contain as much as 15 billion tons. Currently operating coal mines in the basin produced 12.1 million tons of coal from the Fruitland Formation and 5.5 million tons from the Menefee Formation and Gibson Member of the Crevasse Canyon Formation in 1987, for a total of 17.6 million tons, down from a peak of 19.8 million tons in 1985. Most of these mines are capable of greater production; however, because most San Juan Basin coal goes to feed electricity-generating power plants, current lower-than-potential production rates are largely the result of the current low demand for electricity. As oil and gas prices increase, making electricity (and coal) more competitive in the energy marketplace, there will be a concurrent increase in the amount of coal produced in the San Juan Basin from existing coal mines and from new coal mines.

The most exciting recent energy development in the San Juan Basin has been the realization that the basin's coal beds contain large resources of natural gas. Fruitland Formation coals have been estimated to contain more than 50 Tcf (trillion cubic feet) of gas, of which 25 Tcf or more is considered recoverable. The San Juan Basin has already produced 85 billion cubic feet of coal-bed gas, and the rate of coal-bed gas production has been accelerating rapidly. A detailed discussion of coal-bed methane in the San Juan Basin is beyond the scope of this report. The interested reader is referred to Fassett (1988c, 1989) for more information on this subject.

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Cow Springs Sandstone above Wanakah Formation looking N/NW near Church Rock. Photograph taken 29 December 1988 by Paul L. Sealey.