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Geology and coal resources of Cerro Prieto and The Dyke quadrangles, Cibola and Catron Counties, NM

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Cerro Prieto and The Dyke 7.5-min quadrangles are on the eastern edge of the Salt Lake coal field. The Dyke quadrangle is the northernmost of these adjacent quadrangles. The area covered includes portions of Ts. 3, 4, 5, and 6 N. and Rs. 16 and 17 W. (Fig. 1). Unpaved roads provide access to both quadrangles. The nearest large towns are: Gallup, 70 mi to the north; Quemado, 40 mi to the south; and St. Johns, 50 mi to the west. There are no railroads in the coal field; however, a railroad is being constructed in Arizona approximately 50 mi to the west.

Surface ownership

Surface ownership in the study area is divided among private (61.5%), state (33.1%), and federal (5.4%) lands. In Cerro Prieto quadrangle, the state owns 38.8% of the surface land, and the federal government owns 7.1%; the remaining land (54.1%) is owned privately. In The Dyke quadrangle, private ownership totals 83.6%, the state owns 16.0%, and the federal government owns 0.4%. All state and federal surface-land holdings are leased for grazing.

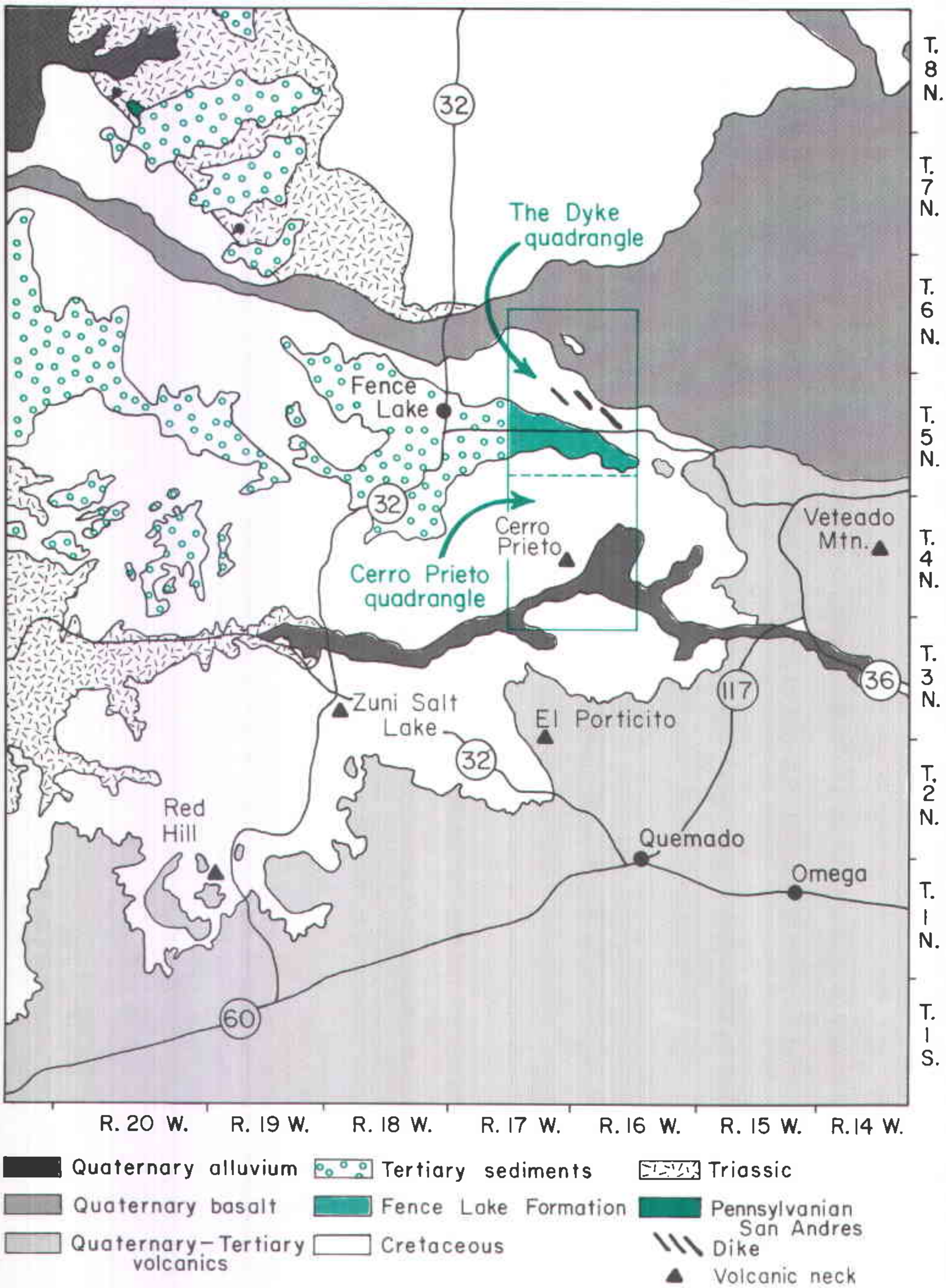

FIGURE 1—Generalized geologic map of Salt Lake coal field. The study area is outlined in blue.

Previous work

Shaler (1907) first designated the Salt Lake coal field in a reconnaissance study of the Durango–Gallup coal field. He measured thin coal-bearing sections, several of which were in the Cerro Prieto quadrangle, and he assigned an early Mesaverde age to them. Herrick (1900) traversed the area in order to make a reconnaissance study of Socorro and Cibola (then Valencia) Counties. Pike (1947) discussed the major transgressions and regressions of the Cretaceous seas in New Mexico. He recognized the Atarque Sandstone as a member of the Mesaverde Formation. Molenaar (1973) revised some of the stratigraphic nomenclature of Pike by dropping Horsehead Tongue of the Mesaverde Formation and designating the Atarque Member as the basal member of the Gallup Sandstone. He also tentatively extended the Torrivio Member of the Gallup Sandstone into the Fence Lake area.

This study is part of a cooperative project with the U.S. Geological Survey to map the coal-bearing Cretaceous rocks in the Salt Lake coal field and to evaluate the coal resources of that area. One of the more comprehensive reports from this project gives drilling and stratigraphic data (Roybal and Campbell, 1981). In addition, many of the individual 7.5-min quadrangle reports are available.

Geologic structure

No major faults cross either of the quadrangles; however, some minor faulting is present. Dips in the study area are generally less than 5 degrees; in Cerro Prieto quadrangle, dips are mostly to the southeast. Numerous minor flexures are present, especially near Cerro Prieto volcanic neck. A prominent anticline, with a north-south axis and flanks dipping east-west at 5 degrees, occurs in the north-central part of Cerro Prieto quadrangle. An east-west syncline occurs in the central portion of this quadrangle. In the northern portion of The Dyke quadrangle, dips tend to flatten out to 1–2 degrees, generally in a northeast direction.

Igneous rocks

The northeast half of The Dyke quadrangle is covered by a 60–70-ft-thick andesine basalt flow (Fig. 1). This flow, in T. 6 N., R. 17 W., was dated by Laughlin and others (1979), using K–Ar methods, at 1.41 ± 0.29 m.y. The flow unconformably overlies the Moreno Hill Formation. A "window" in the flow exposes upper Moreno Hill strata in secs. 28, 29, 33, and 34, T. 6 N., R. 16 W., marking the position of a high knoll formed by the Moreno Hill Formation, around which the basalt flowed. No outcropping coal was observed in these exposures. However, drilling penetrated several coal beds relatively near the surface in this area.

Cerro Prieto is a volcanic neck in the center of Cerro Prieto quadrangle (Fig. 1), composed of olivine basalt. It was intruded through the Cretaceous sediments and probably was the cause of the folding, flexuring, and jointing found in these Cretaceous units.

In the northeast corner of the Cerro Prieto quadrangle and the southeast quarter of The Dyke quadrangle is an en echelon Oligocene-age dike composed of olivine basalt (Fig. 1). Each segment is approximately 1 mi in length and approximately 15 ft thick, with left lateral offset. This dike cuts the Cretaceous units in the area, but is overlain by the Fence Lake Formation. Laughlin and others (1979) dated the dike near Pie Town at 27.67 ± 0.59 m.y., using K–Ar methods.

Stratigraphy

Two major sedimentary stratigraphic units crop out in the study area: the Fence Lake Formation (Tertiary) and the Moreno Hill Formation (Cretaceous) (Fig. 2).

Fence Lake Formation—"Fence Lake gravel" was a term informally applied by Marr (1956) to the coarse boulder-conglomerate rocks capping the mesa tops in the Salt Lake field. It was named formally by McLellan and others (1982). The Fence Lake Formation unconformably overlies the Moreno Hill Formation and occurs in the southeast quarter of The Dyke quadrangle, the northeast quarter of Cerro Prieto quadrangle, and on top of Flattop Mesa and Hawkins Peak. Rubble surfaces, composed of the Fence Lake Formation, are present in sec. 21, T. 4 N., R. 17 W. and sec. 1, T. 3 N., R. 16 W., and they form distinctive, northwest-trending lineations.

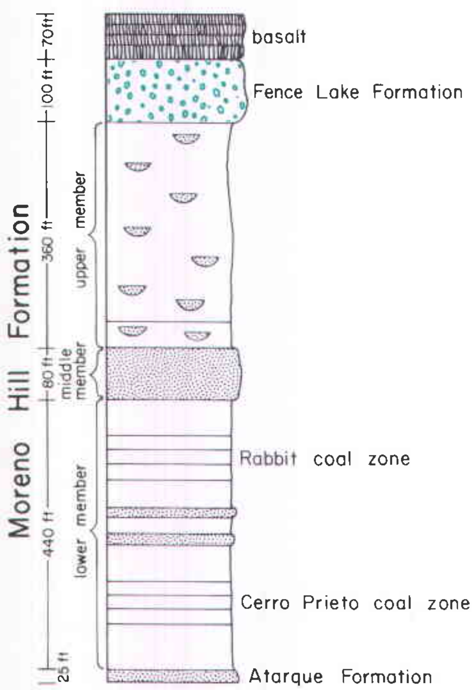

FIGURE 2—Generalized geologic column for Cerro Prieto and The Dyke quadrangles, scale: 1 inch = 200 ft.

The formation locally attains a thickness of 100 ft, but is commonly approximately 60 ft thick. Well-rounded, vesicular-basalt boulders, up to 3 ft in diameter, are a dominant characteristic. Also present, but smaller in size (less than 1 ft), are well-rounded clasts of rhyolite, chert, petrified wood, calcite, and some sandstones. These large clasts are in a matrix of fine-grained calcareous sand.

The clasts in the Fence Lake Formation appear to have been derived from three sources: the petrified wood and sandstone resulted from channeling into the underlying Moreno Hill Formation; the most likely source for the basaltic boulders is a nearby basalt flow; and the remaining clasts are probably from the Datil volcanic units. Clasts in the Fence Lake Formation also occur in the Datil Group. The Fence Lake Formation forms a west-trending apron at the base of sediments from a prominent outcrop of Datil Group volcaniclastic rocks east of the study area. Based on clast orientation, the direction of flow is apparently to the west. No thinning of the total thickness of the gravels or reduction in grain size was observed in the study area. A similar gravel also is found in the Datil Mountains coal field, along with outcrops of the Datil Group.

Moreno Hill Formation—The only outcropping Cretaceous unit in the study area is the Moreno Hill Formation (McLellan and others, 1983), which is divided readily into three members: a lower sandstone/mudstone sequence, a middle sandstone, and an upper mudstone/claystone unit. The formation is 858 ft thick in the study area.

The lower member is 440 ft thick and principally consists of fluvial-channel sandstones with crevasse splay, floodplain deposits, and coals. It overlies the Atarque Sandstone, a marine beach sand that does not crop out on either The Dyke or Cerro Prieto quadrangle, but it can be recognized in geophysical logs.

Channel deposits in this lower unit are 10–20 ft thick, trough crossbedded, with the scale of crossbedding decreasing upward. Asymmetrical ripples with linguoid and lunate ripple marks are often present on the tops of these fluvial sandstones. Lithologically, they consist of 95% quartz grains (2.0–4.0 phi) that are well-sorted and rounded. Feldspars, mostly altered to kaolinite, are the second most abundant grains. Mica is a common trace constituent and can make up as much as 1% of the total composition. Mafic minerals and rock fragments are rare (less than 1%). Petrified wood does occur within the body of the channels, but it is mostly found at the upper and lower contacts. The uniform grain size, roundness, and predominance of quartz indicate that the streams were mature and part of a low-energy, meandering stream system.

Gray to black mudstones, rich in plant fragments and finely disseminated organic material, are prevalent within the lower Moreno Hill Formation. Most of the coal in the study area is in this lower member. Two coal zones are present: one in the top 70 ft of the unit and the second approximately 150 ft below the middle sandstone member. The upper coal zone is characterized by a bed that has a single kaolinite-rich parting (possibly tonsteins), 0.25-inch thick (Williamson, 1961), approximately 23 inches from the top of the coal. The lower coal zone contains a coal bed with two kaolinite-rich partings that are separated by a constant 15 inches of coal. The upper parting is 0.25-inch thick; the lower parting is one inch thick.

The upper coal zone is exposed only in the southwest portion of The Dyke quadrangle and the northwest portion of Cerro Prieto quadrangle. The lower coal zone is much more extensive, reaching in subsurface from the northern portion of Cerro Prieto quadrangle southward to the northern edge of Tejana Mesa 7.5-min quadrangle.

The lower and upper units of the Moreno Hill Formation are separated by a thick fluvial sandstone sequence. This sandstone ranges in thickness from 40 to 80 ft, averaging 60 ft. The sandstones are light tan on fresh surfaces, but weather to a pinkish-orange color. The sand grains are coarse grained, subangular to subrounded, and commonly composed of 85% quartz and 15% plagioclase feldspar. The grains are fabric supported and lack a matrix. The unit consits of both trough and planar crossbeds that decrease upward in set size. The contact with the lower Moreno Hill is erosional. Channels are abundant, offset laterally, and cut into each other. Measurements of current direction on the crossbeds indicate a stream flow to the northwest. Iron concretions are present throughout the unit; they increase in size (0.25–1.0 inch) and frequency upward. The larger concretions are nearly perfect spheres, whereas the smaller ones are irregular. This sandstone sequence is distinguished readily from other sandstones in the area by grain size, pinkish-orange coloration, grain-supported fabric, no clay or silt fraction, and large feldspar grains; it was deposited in a braided-stream environment.

The upper unit of the Moreno Hill Formation is 358 ft thick and is composed primarily of claystones and mudstones. Very few channel and crevasse-splay deposits are present. The channel deposits are thin, rarely exceeding 4 ft in thickness. They differ from the lower Moreno Hill channel sandstones in that they are much more silty, do not form ledges, and do not extend laterally for more than 50–60 yards. The claystones and mudstones are mostly yellow and green; only a few are organic and black. Scattered carbonaceous shales are present, as well as a few thin coals. Coalified logs were found in several locations, usually associated with organic mudstones. An erosional surface with mudstone in contact with mudstone is near the top of this unit. Large fragments (1–2 inches) of fusain mark this surface and they appear to be the remnants of an ancient forest fire that was followed by flooding and transportation of the burned plant material. No charred logs or stumps were found. ☞

The upper unit of the Moreno Hill Formation appears to have been deposited during a drier period than the lower unit of the Moreno Hill Formation. The fewer channels, with a greater silt fraction, as well as the green and yellow mudstones, indicate a drier climate in the upper unit. Only a few swamps were present, as indicated by a paucity of organic-rich, black mudstones and carbonaceous shales.

Coal geology

The major area of outcropping coal is in the northwest corner of Cerro Prieto quadrangle and in the southwest portion of The Dyke quadrangle, mainly along the escarpment. Outcropping coals are thin and sparsely present throughout the remaining area of the two quadrangles.

There are two coal horizons present in the outcrops. The upper horizon is exposed mainly along the face of the mesa escarpment. This zone consists of one major coal that has an outcrop thickness of up to 12 ft; it contains a single kaolinite tonstein, with several minor, thinner coals above and below. This zone, called the Rabbit zone, is in a 70-ft interval below the middle sandstone.

The lower horizon, termed the Cerro Prieto zone, is approximately 150 ft below the middle sandstone. This zone is exposed only in the northwest quarter of Cerro Prieto quadrangle. The thickest coal in this zone is 7.5 ft in outcrop and 9.5 ft in subsurface. This zone, like the upper zone, has thinner coals both above and below the main bed. The total thickness of this zone is approximately 25 ft. This zone is distinguished from the upper zone by the presence of two kaolinite tonsteins in the main coal.

Along the boundary of the two quadrangles are extensive outcrops of clinker, or burned coal. At several locations, the ash from the burned coal can be seen; the maximum thickness of ash observed was 13 inches. Most of the clinker is due to burning of the main seam in the upper zone. A second clinker layer occurs in a 3-ft-thick coal seam above this main bed. A clinker was observed in the lower coal zone, just west of Cerro Prieto quadrangle, on Fence Lake SW quadrangle. Ranchers report that in sec. 31, T. 4 N., R. 16 W., a coal associated with an abandoned mine is still burning.

Coal characterization

Forty-five coal samples were analyzed for quality parameters. These analyses were done on both cores and cuttings. The average proximate, ultimate, and BTU values for the Salt Lake coals are compared to the values of the coals of the nearby Datil Mountains and Gallup coal fields in Table 1. Due to differential moisture loss between core and cuttings, these comparisons were made on a dry, rather than on an as-received, basis. The coals from the study area have a much higher ash content than those from either the Gallup or Datil Mountains fields.

Because of analytical bias resulting from variable moisture loss, an equilibrium moisture analysis was run on these coals. The average equilibrium moisture for these coals is 13.95 ± 0.73%; further discussion of the quality of the coals in the study area is based on a moisture content of 13.95% rather than on an as-received basis. The average heating value for these coals is 9,381 BTU/lb, which results in a moist, mineral-matter-free BTU of 11,229 BTU/lb. These coals show some agglomerating properties; therefore, they are assigned a rank of high-volatile C bituminous. Table 2 shows the averages of the various quality analyses that were run for the two zones present in the study area.

Fifteen coal cores were analyzed for major oxides. Table 3 shows the averages of these major-oxide analyses on a whole-coal basis. X–RD analyses indicate the dominant mineralogy of these coals to be kaolinite and quartz, with minor amounts of pyrite, illite, rutile, gypsum, and calcite. Base-to-acid ratio, as calculated from the XRF-analyses values, is 0.11, indicating that a temperature greater than 2,900°F is needed to reach an ash fluidity of 250 poises. No difference in ash fluidity was noted between the two zones. This high fluidity temperature results from the ash's high kaolinite content. Except for those coals with tonsteins, very few beds contained partings. SEM analyses indicate that most of the mineral matter is finely disseminated throughout the organic fabric; this reduces the possibility of washing the coals to reduce the mineral-matter content. This would increase the shipping weight, as well as the amount of ash that would enter possible boilers.

Three cores were analyzed for selected trace elements; the results are presented in Table 4. Analyses from the nearby Datil Mountains and Gallup coal fields are shown for comparison. The elements selected are generally the more important ones environmentally. From this table, it can be seen that the Salt Lake coals appear to be enriched in Cu, F, Sb, Th, U, and Zn and depleted in As, Li,

TABLE 1—Average dry-basis quality values for the Salt Lake, Datil Mountains, and Gallup coal fields; s.d. = standard deviation.

	Salt Lake coal field			Datil Mountains coal field			Gallup coal field		
	Number of samples	Mean value	s.d.	Number of samples	Mean value	s.d.	Number of samples	Mean value	s.d.
Moisture	45	—	—	25	—	—	131	—	—
Ash	45	17.1%	±7.9	25	13.5%	±5.6	131	9.9%	±5.4
Volatile matter	45	38.1%	±3.4	25	39.3%	±4.0	131	43.3%	±4.0
Fixed carbon	45	45.2%	±6.1	25	47.4%	±4.6	131	49.1%	±4.3
Carbon	9	62.8%	±7.8	25	67.5%	±6.8	50	69.7%	±5.3
Hydrogen	9	4.9%	±0.4	25	5.4%	±4.1	50	6.2%	±0.81
Nitrogen	9	1.2%	±0.2	25	1.2%	±0.21	50	1.2%	±0.1
Sulfur	45	0.9%	±0.3	25	0.6%	±0.1	131	0.7%	±0.2
Oxygen	9	12.3%	±1.5	25	17.1%	±8.4	50	20.9%	±5.6
BTU	45	10,901	±1,217	25	11,639	±1,597	131	12,578	±869

TABLE 2—Average quality values for lower and upper zones in the study area; s.d. = standard deviation.

	Lower zone			Upper zone		
	Number of samples	Mean value	s.d.	Number of samples	Mean value	s.d.
Moisture	26	13.95%	±0.7	19	13.95%	±0.7
Ash	26	14.22%	±5.7	19	15.21%	±5.2
Volatile matter	26	32.79%	±3.2	19	32.74%	±3.8
Fixed carbon	26	39.28%	±3.7	19	38.55%	±6.0
Carbon	4	53.66%	±7.8	5	54.37%	±3.2
Hydrogen	4	4.23%	±0.2	5	4.12%	±0.24
Nitrogen	4	1.05%	±0.2	5	1.08%	±0.10
Oxygen	4	9.70%	±1.4	5	11.48%	±0.61
Sulfur	26	0.77%	±0.2	19	0.82%	±0.3
BTU	26	9,234	±1,131	19	9,527	±791

TABLE 3—COMPARISON OF MAJOR OXIDES AND TRACE ELEMENTS IN SALT LAKE COAL FIELD WITH COALS IN THE DATIL MOUNTAINS AND GALLUP COAL FIELDS ON A WHOLE-COAL BASIS; s.d. = standard deviation.

	Salt Lake coal field		Datil Mountains coal field		Gallup coal field	
Number of Samples	15		7		8	
Oxide	Mean value percent	s.d.	Mean value percent	s.d.	Mean value percent	s.d.
Ash	17.0	—	22.2	—	9.2	—
SiO_2	9.8	3.8	13.0	8.2	4.5	2.9
Al_2O_3	4.7	2.1	3.7	1.9	2.0	1.4
CaO	0.6	0.2	1.0	0.9	0.4	0.1
MgO	0.1	0.1	0.3	0.4	0.1	0.1
Na_2O	0.04	0.03	0.1	0.2	0.10	0.1
K_2	0.05	0.06	0.2	0.2	0.04	0.1
Fe_2O_3	0.8	0.8	1.0	0.7	0.5	0.2
TiO_2	0.3	0.1	0.3	0.2	0.1	0.1
SO_3	0.5	0.2	0.5	0.2	0.6	0.1

TABLE 4—TRACE-ELEMENT CONCENTRATIONS OF SALT LAKE COALS COMPARED WITH COALS FROM THE DATIL MOUNTAINS AND GALLUP COAL FIELDS; s.d. = standard deviation; ppm = parts per million.

	Salt Lake coal field		Datil Mountains coal field		Gallup coal field	
Number of Samples	3		7		8	
	ppm	s.d.	ppm	s.d.	ppm	s.d.
As	1.2	0.8	4.9	10.9	1.9	2.2
Be	0.5	0.5	2.0	1.6	0.5	0.4
Cu	18.0	13.1	11.9	7.0	5.4	1.8
F	73.3	59.7	21.3	41.5	35.0	14.9
Hg	0.08	0.09	0.2	0.3	0.03	0.01
Li	4.3	2.3	10.5	5.8	3.4	1.9
Mn	210	87	57	176	10	4
Pb	6.3	0.6	7.9	4.9	2.4	1.1
Sb	15.3	11.2	2.9	3.8	0.3	0.2
Se	1.1	0.9	2.8	1.3	1.6	0.3
Th	9.7	8.3	5.6	3.8	3.0	0.2
U	5.0	1.7	2.2	8.1	0.5	0.4
Zn	70	44	12	10	16	8

and Sr. More work in the elemental composition of these coals is needed to increase the sample sizes in order to establish trends.

Coal resources

For this study, a total of 24 holes were drilled and geophysically logged; also, cuttings were collected at 5-ft intervals, and nine water wells were logged.

The coals in the Salt Lake field are high-volatile C bituminous in rank; therefore, the resource figures for this report are based on coals of 1.2 ft or greater thickness. Resource calculations were done according to Wood and others (1983) for measured and indicated categories. The weight of bituminous coal is estimated to be 1,800 tons/acre-ft.

Mineral ownership of the coal in the study area is split into federal, state, and private categories. The largest owner of mineral rights in the study area is the federal government with 40.5%, followed by the state government with 38.4%; only 21.1% of the mineral rights are privately owned. These percentages are not equally distributed over the two quadrangles. In The Dyke quadrangle, 38.4% of the mineral rights are owned by the federal government, 8.6% by the state government, and 53.0% are privately owned. In Cerro Prieto quadrangle, 43.3% of the mineral rights are owned by the federal government, 35.2% by the state government, and 22.1% are privately owned.

Measured coal resources in the two quadrangles are estimated at 53.6 million tons based on outcrop and drill data. Indicated coal resources of 202.9 million tons are based on drill data only. The demonstrated coal resources for the study area are 256.4 million tons. The average depth of this coal is 116 ft, ranging from surface outcrop to 252 ft in depth. Separating the coals into depth categories shows that 176.9 million tons of demonstrated coal are within 150 ft of the surface, and 51.9 million tons have overburden of between 150 and 250 ft. Only 6.1 million tons of coal are greater than 250 ft in depth. The average bed thickness for these resources is 3.1 ft, ranging from 1.2 ft to 12 ft. Table 5 shows the demonstrated tonnages in the three depth categories. When demonstrated resources were separated based on stripping ratios, 82.5 million tons were less than 10:1, 27.7 million tons were between 10 and 20:1, and 43.1 million tons were between 20–30:1. The remaining 102.6 million tons have a stripping ratio of greater than 30:1.

TABLE 5—DEMONSTRATED COAL RESOURCES OF CERRO PRIETO AND THE DYKE QUADRANGLES.

	0–150 ft (tons)	150–250 ft (tons)	>250 ft (tons)
T. 6 N. R. 17 W.	5.4	0.0	0.0
T. 6 N. R. 16 W.	0.6	0.8	0.0
T. 5 N. R. 17 W.	46.8	15.0	0.0
T. 5 N. R. 16 W.	10.9	13.4	3.4
T. 4 N. R. 17 W.	66.5	14.9	0.0
T. 4 N. R. 16 W.	39.1	7.8	2.8
T. 3 N. R. 17 W.	3.4	0.0	0.0
T. 3 N. R. 16 W.	3.6	0.0	0.0

No coal resources are currently calculated in Ts. 3 and 6 N., R. 17 W. as a result of lack of drill data. Based on projections from holes drilled to the south and east, T. 6 N., R. 17 W. probably has no coal present; however, the few geophysical logs available indicate that T. 3 N., R. 17 W. probably contains extensive coal resources.

Based on the information gathered from the drilling and geologic mapping, further drilling is needed in Tejana Mesa quadrangle to the south of Cerro Prieto quadrangle and Chimney Hill quadrangle to the east of The Dyke quadrangle. Logs from the southern part of Cerro Prieto quadrangle show a 9-ft-thick bed that apparently extends south into Tejana Mesa quadrangle. The Cerro Prieto coal zone, present on Cerro Prieto quadrangle, dips about five degrees to the east. This coal, if present as projected, would be deeper than 250 ft, the limit for strip mining under present economic conditions.

Conclusions

The coals present in the study area are high-volatile C bituminous in rank. The high ash and volatile-matter content, as well as low fixed-carbon content, indicate that they are used best for steam coal. Mining of these coals is feasible due to their shallow depth; however, transportation is a problem because of the remoteness of the area. Possible destinations for this coal would be the generating plants presently under construction at Showlow and St. Johns, Arizona.

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Geographic names

U.S. Board on Geographic Names

Barela Mesa—mesa, 8 km (5 mi) long, highest elevation 2,658 m (8,720 ft.); bound by Burro Mesa to the north, Horseshoe Mesa and Little Mesa to the east, and Horse Mesa and Little Fishers Peak Mesa to the west; 16.9 km (10.5 mi) northeast of Raton, New Mexico; named for Senator Casimiro Barela, a prominent Spanish-American resident of Trinidad, Colorado, in the 1890's; Colfax County, New Mexico and Las Animas County, Colorado; T. 35 S., R. 62 W., Sixth Principal Meridian and T. 32 N., R. 61 W., NMPM; 36°59'59" N., 104°18'48" W.; *not:* Barilla Mesa, Raton Mesa.

Bear Wallow Ridge—ridge, 4.8 km (3 mi) long, in Sangre de Cristo Mountains, highest elevation 2,965 m (9,727 ft), 7.2 km (4.5 mi) southeast of Ranchos de Taos; Taos County, New Mexico; 36°19'15" N., 105°32'40" W. (northwest end), 36°17'05" N., 105°30'35" W. (southeast end).

Beclabito—populated place, on the north side of Beclabito Wash 31 km (19 mi) northwest of Shiprock; a Navajo Indian name reportedly meaning "water underneath"; San Juan County, New Mexico; T. 30 N., R. 21 W., NMPM; 36°50'30" N., 109°01'10" W.; 1937 decision revised; *not:* Beclabato, Beklabito, Biclabito, Biltabito (BGN 1915), Bitlabito (BGN 1937).

Beclabito Spring—spring, in Beclabito 31 km (19 mi) northwest of Shiprock; a Navajo Indian name reportedly meaning "water underneath"; San Juan County, New Mexico; T. 30 N., R. 21 W., NMPM; 36°50'28" N., 109°01'05" W.; 1937 deci-

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Ash-flow tuffs of northeast Mogollon–Datil volcanic field

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Volcanoes and lava flows are a common sight throughout New Mexico. Most of the youngest rock types are basaltic lava flows and associated cinder cones, volcanic rocks that are relatively poor in SiO_2 (45–55%). Young, high-silica rocks (rhyolites) are scarce in New Mexico except in the Jemez Mountains, northwest of Santa Fe. However, within the older Mogollon–Datil volcanic field (Oligocene and early Miocene) that covers most of southwest New Mexico, rhyolitic rocks make up an appreciable percentage of volcanic materials. These rhyolites occur both as lava flows and domes and as pyroclastic deposits. Pyroclastic rocks dominate volumetrically and are also the most important for stratigraphic purposes. Ash-flow tuffs or ignimbrites (a New Zealand term for ash-flow tuffs) are by far the most voluminous and important pyroclastic rocks. Ignimbrites are the clastic deposits left behind by hot gas-and-particle slurries of volcanic origin. These move as ground-hugging, gravity-controlled pyroclastic flows (nuées ardentes) that are often very fluidal and travel long distances (many tens of km) from their source. Pyroclastic flows conserve heat very well, and their deposits are commonly so hot (>500–600°C) that the soft glassy particles weld together to form dense, solid rocks. These rock units are usually recognizable even after structural disruption and provide superb marker horizons (time lines) for reconstructing events within volcanic fields.

If ignimbrites are to be used as marker horizons, it is imperative that individual genetic units are separated and that ignimbrites are distinguished from rhyolite lavas with similar characteristics. Textural and mineralogical characteristics that are useful in distinguishing one ignimbrite from another are: color; proportions of ash, pumice, rock fragments, and phenocrysts; and the degree of welding and induration of the unit. Many of these textural characteristics vary laterally and vertically within the same unit and must be applied with caution. In the Socorro–Magdalena area, the amount and relative percentages of the various phenocrysts have proven to be the single most important correlation tool. Ignimbrites are often petrographically and chemically zoned in vertical sections; however, at least in this area, lateral zonation has not been observed in the many tens of kilometers of exposure. The same general sequence of units and zoning within units is observed from the Joyita Hills to Datil, a distance of approximately 100 km. For detailed descriptions of these units, the reader is referred to New Mexico Bureau of Mines and Mineral Resources Stratigraphic Chart 1 (Osburn and Chapin, 1983a) and to a summary article by the same authors (Osburn and Chapin, 1983b).

Because ignimbrites were originally fragmental, they usually can be distinguished from similar lava flows by the presence of pumice, lithic fragments, and broken crystal fragments in hand samples, and by the presence of glass shards (if preserved) in thin sections. Many papers in the geologic literature have treated these features in more detail; two of the best, *Ash-flow tuffs—their origin, geologic relations, and identifications* (Ross and Smith, 1961) and *Zones and zonal variations in welded ash-flow tuffs* (Smith, 1960) have been recently reprinted as New Mexico Geological Society Special Publication 9.

Figures 1–8 below are representative photomicrographs of each of the eight major regional ignimbrites found in the Socorro–Magdalena area. These photomicrographs are presented in ascending stratigraphic order (oldest to youngest). They were photographed at the same scale (for ease in comparing textures and phenocryst percentages) and with crossed polarizers rotated a few degrees from orthogonal to reduce contrast for photography. These side-by-side comparisons illustrate that, although many of these units are grossly similar and can be confused on cursory examination, differences do exist. All of these units have been defined in areas where thick sequences expose several units in unambiguous stratigraphic successions. The best areas for the units below Hells Mesa Tuff are in the western Gallinas Mountains and Datil Mountains (Harrison, 1980; Coffin, 1981; and Lopez and Bornhorst, 1979). Excellent exposures of the younger units are found in the Joyita Hills (Spradlin, 1976).

A variety of petrographic, vitroclastic, devitrification, and vapor-phase alteration textures are visible in these photomicrographs; these textures are discussed where pertinent. Obviously, many of the units can be easily distinguished from each other; however, some units are very similar and great care must be taken in identification. Rock House Canyon Tuff, La Jencia Tuff, and Vicks Peak Tuff (phenocryst-poor units) have mineralogies similar enough to be confusing; upper Lemitar Tuff and Hells Mesa Tuff (phenocryst-rich units) are nearly indistinguishable. Identification is especially difficult when dealing with isolated outcrops or less welded, distal deposits. A sequence containing several units is the best tool where identification is uncertain.