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Coal geology of the lower Moreno Hill Formation, Salt Lake Field, west-central New Mexico

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COAL GEOLOGY OF THE LOWER MORENO HILL FORMATION, SALT LAKE FIELD, WEST-CENTRAL, NEW MEXICO

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Abstract—The Salt Lake coal field in west–central New Mexico is defined by the arcuate outcrops of the Moreno Hill Formation of Late Cretaceous, Turonian age. This formation is divided into three informal units, the lower, middle and upper members. The lower member contains the Antelope, Cerro Prieto and Rabbit informal coal zones, in ascending order. The Antelope zone, just above the underlying marine Atarque Sandstone, has two relatively thin, high sulfur (1.2% avg.) coals in a fine-grained sequence deposited in a back–barrier swamp environment. As many as five coal beds are in the medial Cerro Prieto zone, although only two of these coastal–plain coals have lateral continuity. These coals range from 1 to 14 ft thick and often contain persistent claystone (tonstein) partings. The low sulfur (0.7%) coastal–plain Cerro Prieto coals developed landward of the marine Fite Ranch Member (Tres Hermanos Formation) pinchout and represent the majority of the economic coal resource in the Salt Lake field. The Rabbit zone contains up to four coal beds of fluvial swamp origin. The second bed above the base attains economic thickness (7.5 ft). All of the Moreno Hill lower member coals are relatively high in ash (18%) and combustion analyses indicate an average apparent rank of subbituminous C, although vitrinite reflectance data show a slightly higher rank, high volatile bituminous C. These coals tend to have a higher percentage of inertinite macerals than other coals from northwestern New Mexico, probably a result of greater oxidation or charring of the swamps before burial.

INTRODUCTION

The Salt Lake coal field covers 750 mi² in west–central New Mexico. It is separated from the Zuni coal field by the Atarque monocline, which trends southeast near Ojo Caliente, and by a tongue of the Bandera lava flows. Outcrops of the coal-bearing Moreno Hill Formation (McLellan et al., 1983) define the Salt Lake field, forming a west-facing arcuate belt centered around the Zuni Salt Lake and are traversed by NM-601 and NM-36 (Fig. 1). The field extends from the western border of New Mexico east to R15W and from T1N to T8N. The coal-bearing Moreno Hill strata are relatively flat lying, with dips of 3–5° to the southeast, have undergone minor displacement along faults, and show minor flexures in different parts of the field due to Tertiary volcanism (Campbell, 1989).

STRATIGRAPHY

General Features

The Moreno Hill Formation was named by McLellan et al. (1983) in the northwestern Salt Lake coal field. It consists of three informal members of continental origin, which overlie the marine Atarque Sandstone deposited during the first major retreat of the Late Cretaceous shoreline (R-1; Molenaar, 1983; Fig. 2) from the San Juan Basin, northwest New Mexico. Molenaar (1983) placed a pivot point near Gallup for this oldest, regressive Late Cretaceous shoreline (Fig. 2). The shoreline trend northwest of this point was N60°W and N30°W southeast. The pivot point appears to be a result of increased sediment supply to the southeast (Anderson, personal commun., 1993), resulting in braided stream deposits and short-lived flood-plain coal deposits. The Moreno Hill Formation at the type section (sec. 7 T4N R18W) is 520 ft thick and laterally equivalent to the Tres Hermanos, Gallup and Crevasse Canyon formations in the southwestern San Juan Basin (Fig. 3; Hook et al., 1983).

The lower member of the Moreno Hill consists of channel sandstones and crevasse splays that grade laterally into siltstone, mudstone and coal. Sandstone in this unit tends to be fine grained, well sorted, well rounded, predominantly quartzose, and is generally cemented by siliceous material. Carbonaceous mudstone containing coalified plant fragments is common. The lower member varies in thickness from 100 to 400 ft, thinning towards the west. Roybal (now Hoffman) and Campbell (1981) recognized the Antelope, Cerro Prieto, and Rabbit coal zones in the lower member of the Moreno Hill (Fig. 4). The lower member of the Moreno Hill is considered in part equivalent to the

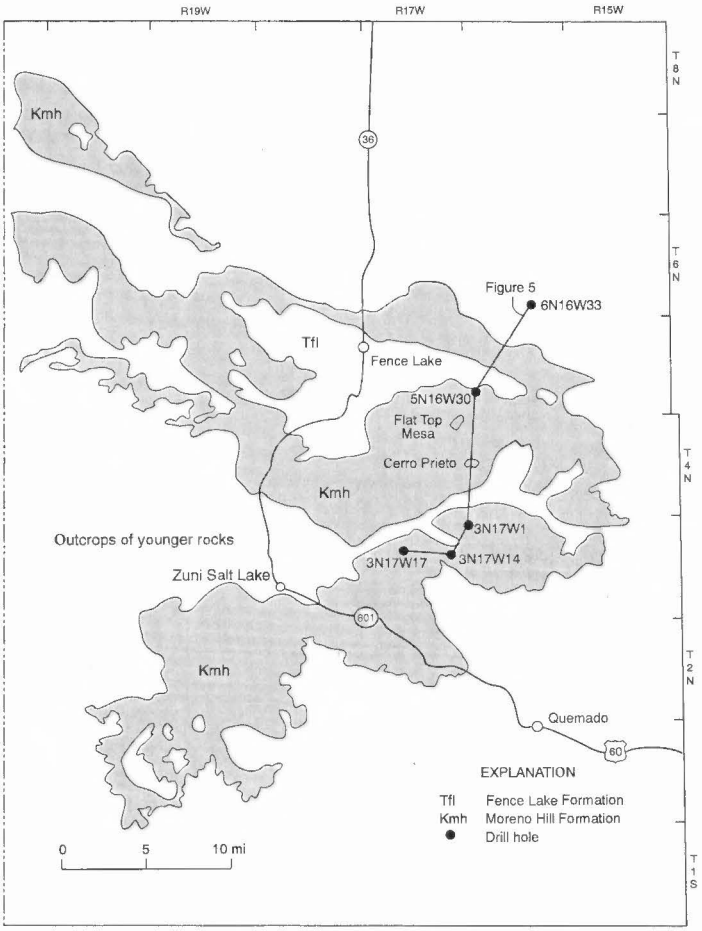


FIGURE 1. Salt Lake coal field, Moreno Hill Formation with drill site locations from NMRDI coal quality study. Kmh= Moreno Hill Formation, Tfl= Fence Lake Formation. Base map modified from Dane and Bachman, 1965.

Carthage and Fite Ranch Members of the Tres Hermanos Formation (Anderson and Stricker, 1987).

The middle member of the Moreno Hill is 60 ft of medium– to coarse-grained, poorly–sorted, subangular to subrounded, grain-

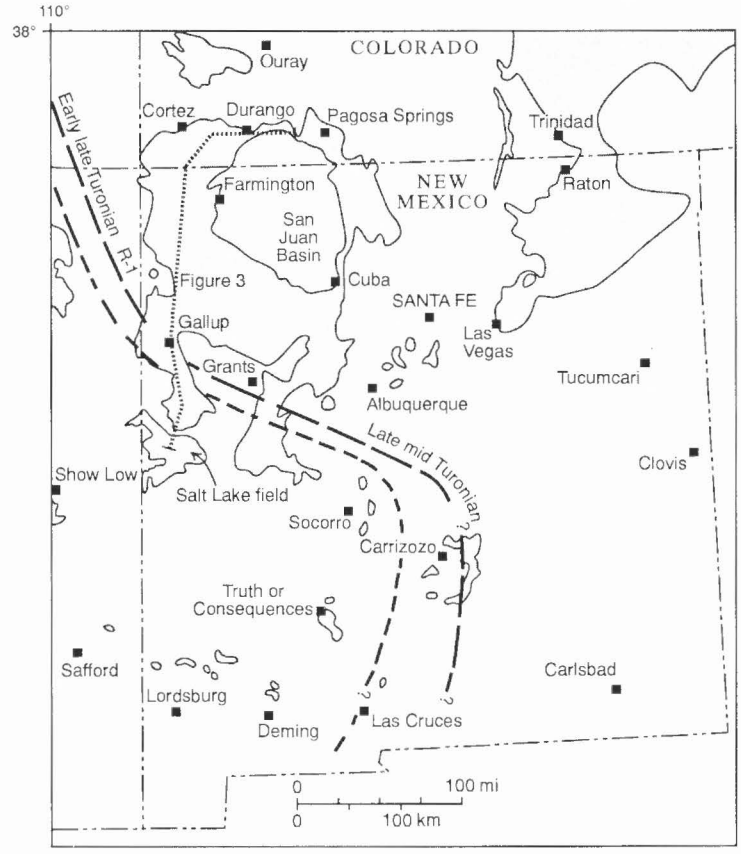


FIGURE 2. Restored position of the Turonian shoreline during maximum regression (R-1). Line of short dashes is seaward extent of subaerial–plain deposits of the regression (Moreno Hill and Tres Hermanos formations; see Fig. 3). Line of long dashes is seaward extent of shoreface sandstones of the regression (Atarque Sandstone). Modified from Molenaar (1983).

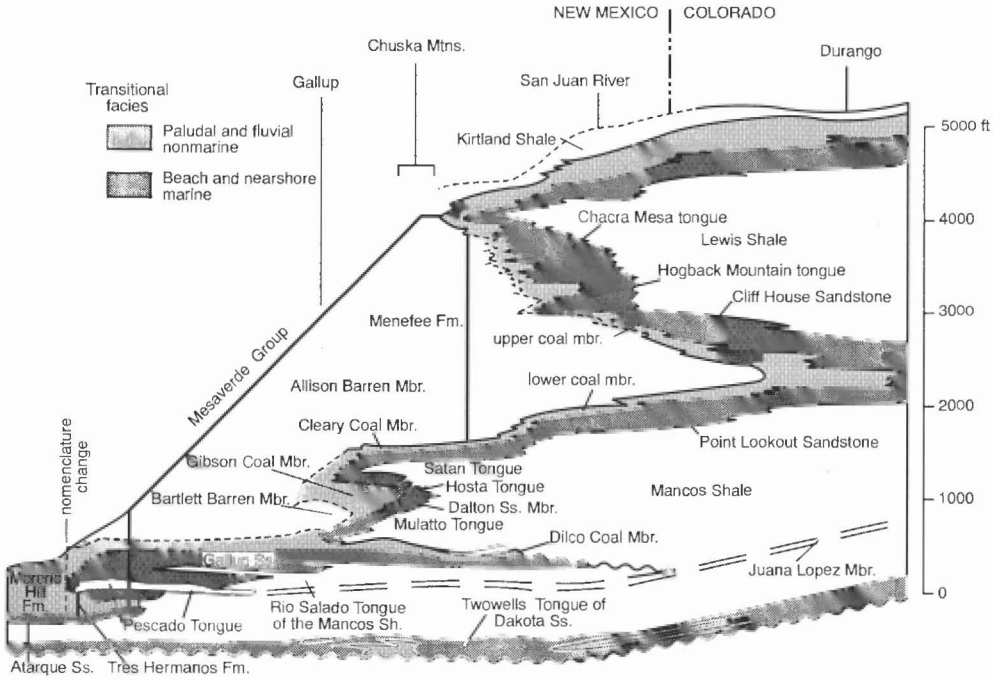


FIGURE 3. Stratigraphic diagram showing sequence, thickness and nomenclature of Cretaceous rocks in the San Juan Basin and Salt Lake coal field, New Mexico and Colorado. Modified from Beaumont (1982, fig. 2).

supported quartzose sandstone with a significant percentage of feldspars. Iron-stained concretions and a pinkish–orange color are common features of the cross-bedded middle member sandstone exposures. This unit represents a braided stream environment with coalescing channel sandstones that filled scours in the lower member. The middle member is equivalent to the Torrivo Member of Gallup Sandstone in the San Juan Basin (Campbell, 1981).

The upper member of the Moreno Hill has a similar lithologic sequence to the lower member, although this unit has a greater percentage of silty sandstone, siltstone and claystone. The total thickness of this unit varies from 30 to 250 ft. A few channel sandstones are within the first 100 ft and the Twilight coal zone (Fig. 4; Roybal and Campbell, 1981) is within this interval. The upper member was deposited in a low energy continental environment and is equivalent to the lower Crevasse Canyon Formation in the San Juan Basin.

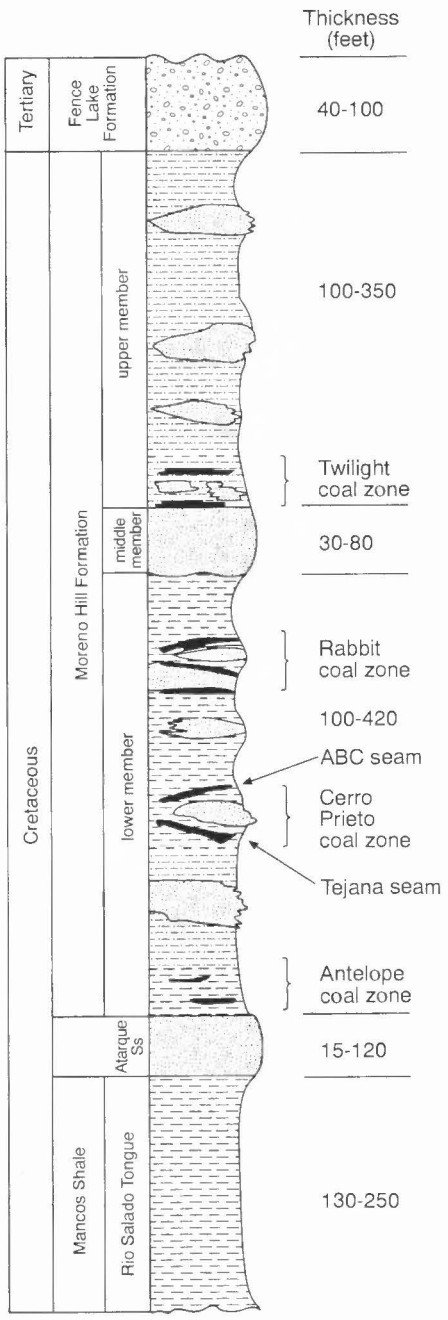


FIGURE 4. Generalized stratigraphic column of the Moreno Hill Formation, Salt Lake coal field with coal zones. Modified from Campbell (1989).

Coal zones of the lower member, Moreno Hill Formation

The Antelope zone described by Campbell (1987, 1989) is within the 50 ft interval above the Atarque Sandstone. A maximum of two relatively thin coals (1 to 3 ft) are in this zone in the southeastern part of the Salt Lake field.

Campbell (1989) characterized the Cerro Prieto zone as being approximately 150 ft below the middle member of the Moreno Hill Formation. In general, the Cerro Prieto zone contains some of the thickest coals in the Salt Lake field, ranging from 1 to 14 ft thick. A major coal bed, the Double T of Campbell (1987, 1989), in this zone is 6–14 ft thick in the vicinity of Cerro Prieto (Fig. 1), a Tertiary volcanic neck. The Double T has two laterally continuous kaolinitic partings, tonsteins, possibly of volcanic origin (0.5 and 0.25 in. thick, lower and upper, respectively). In some areas this bed splits into two coal beds with up to 20 ft of mudstone and sandstone between them. The upper split of the Double T is the A seam and the lower split is the BC seam (Fig. 4) of the Salt River Project (SRP; Ken Rodgers, personal commun., 1994). Three other thin coal beds are in the Cerro Prieto zone, although these tend to be discontinuous, including the Tejana seam named by the Salt River Project (SRP).

The uppermost coal zone of the lower member is the Rabbit zone, approximately 60 ft below the base of the middle member. A maximum of four beds are within this zone; the average total combined thickness is 4 ft and the average individual bed thickness is 3 ft. The second bed from the bottom of this zone has a kaolinitic parting and can be up to 7.5 ft thick (Campbell, 1989).

RECENT STUDIES

The New Mexico Bureau of Mines and Mineral Resources (NMBMMR) and the U.S. Geological Survey (USGS) mapped most of the Salt Lake coal field during the 1980s, studying the geology and coal resources of the area. Much of this work is summarized in a 1:100,000 geologic map (Anderson, 1986) and 1:50,000 geologic maps by Anderson (1987) and Campbell (1989). The coal geology of the Salt Lake and adjacent Zuni Basin were discussed in articles by Campbell (1987) and Anderson and Stricker (1987).

As part of a 1988 coal quality study at the NMBMMR, funded in part by the New Mexico Research and Development Institute (NMRDI), five drill sites were completed in the Salt Lake field along a southwest-northeast trend (Fig. 1, Fig. 5), perpendicular to the general shoreline trend during the Late Cretaceous. Drill sites were at the base or just above exposures of the middle member of the Moreno Hill Formation and most were completed in the Rio Salado Tongue of the Mancos Shale, below the marine Atarque Sandstone. A total of 220 to 300 ft of the lower member of the Moreno Hill was penetrated in these drill holes (Fig. 5).

All of the drill sites had coal beds greater than 1.5 ft thick in the lower member. Eleven coal core samples were taken from the five sites. At these locations, two to five lower member coal beds are within 260 ft of the surface. A majority of the coals in this sequence are thin, varying in thickness from 1.2 to 2.5 ft in the drilled sections. Due to the scale, these coals do not appear as individual beds on the cross section (Fig. 5). Lower member Moreno Hill coals have moderate banding and abundant vitrain, a lithotype in coal derived from woody tissue that is vitreous, and has high luster, some pyrite, and displays good cleat. The thicker coals (5.4 and 7.4 ft) often contain a thin kaolinitic parting or tonstein, characteristic of the Double T seam (Campbell, 1987, 1989).

The greatest frequency of coal in the drilled sections is 50 to 180 ft above the marine Atarque Sandstone. Thin coals just above the Atarque Sandstone are in the Antelope zone (Campbell, 1987, 1989). The thickest coals (5.4 and 7.4 ft) are 100 to 170 ft above the base of the lower member of the Moreno Hill Formation in the two holes near the geographic center of the field (3N17W1, 5N16W30). These thicker coal beds are assigned to the second coal zone above the Atarque Sandstone, the Cerro Prieto zone (3N17W14, 3N17W1, 5N16W30; Campbell, 1989). Some of the thicker coal beds are the lower split of the Double T seam. Cerro Prieto zone coals attain significant thickness (avg. 4.2 ft, max. 13.9 ft) and extent (12 to 15 mi) and have economic

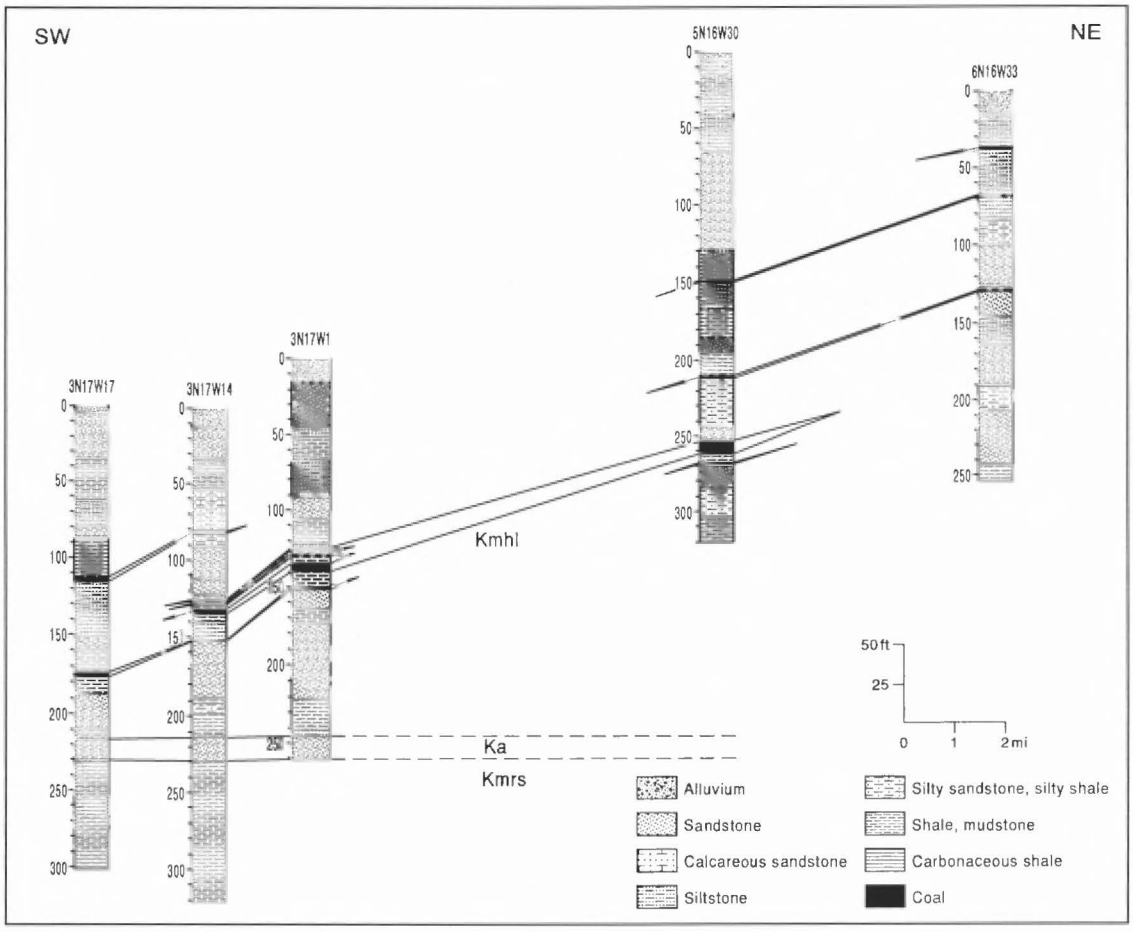


FIGURE 5. Correlation of drill holes in the Salt Lake field from NMRDI coal quality project. Kmrs=Rio Salado Tongue of the Mancos Shale; Ka=Atarque Sandstone; Kmhl=lower member of the Moreno Hill Formation. Modified from Hoffman, Campbell, and Beaumont (1993).

significance in this field. The Rabbit zone coals in the upper section of the lower Moreno Hill Formation are thinner (avg. 2.4 ft, max. 7.5 ft; Campbell, 1987).

Coal beds in the Antelope and Cerro Prieto zones are associated with shales. The Antelope zone coals, within close proximity of the marine Atarque Sandstone, are back barrier swamp deposits (Anderson and Stricker, 1987), and the coals in the Cerro Prieto zone are upper coastal plain deposits. However, the coals higher in the section (Rabbit zone) are commonly associated with siltstone, and the entire sequence becomes more siltstone- and sandstone-dominated upward, indicating greater influx of sediment. The Rabbit zone coals are fluvial in origin (Campbell, 1987). Comparison of the Cerro Prieto and Rabbit zone

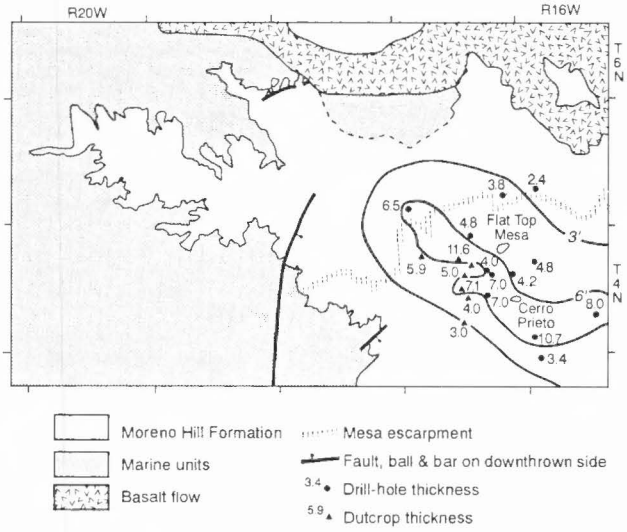


FIGURE 6. Isopach of total coal thickness, Cerro Prieto zone, eastern Salt Lake coal field (from Campbell, 1989).

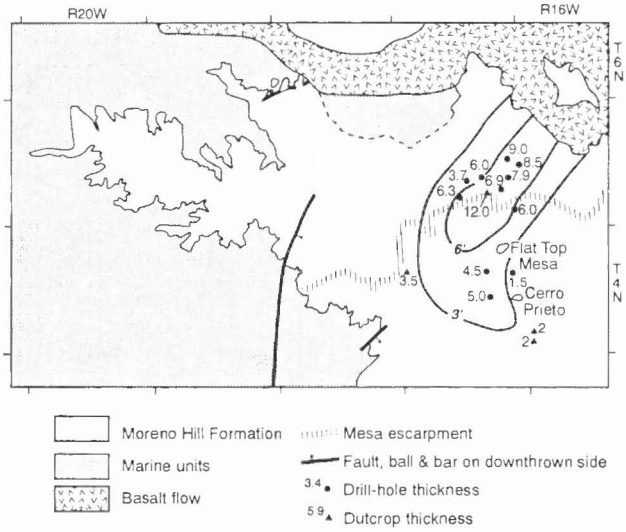


FIGURE 7. Isopach of total coal thickness, Rabbit zone, eastern Salt Lake coal field (from Campbell, 1989).

total coal isopachs (Figs. 6, 7) show a change from a northwest trend to a northeast trend, indicating a change from coastal plain swamps that tend to parallel the shoreline to fluvial–dominated swamps that parallel stream drainage patterns. Anderson and Stricker (1987) also noted the trend of the Cerro Prieto coal isopach and the relatively thick coals in this zone. They related these factors to the close proximity (6 to 8 mi) of the landward pinchout of the laterally equivalent Fite Ranch Member of the Tres Hermanos Formation to the northeast. It is common for thicker coals to have developed landward of marine sandstone pinchouts that represent reversals in the direction of shoreline migration; nearly stable conditions are created in coastal swamps during these periods of reversal. On a smaller scale, the Cerro Prieto coal zone is similar to the Gibson-Cleary coal members of the Menefee-Crevasse Canyon formations in the Gallup area (Fig. 3), southwest of the Point Lookout Sandstone pinchout.

COMPARISON OF ANALYTICAL DATA

The three major coal-bearing zones (Antelope, Cerro Prieto and Rabbit) were sampled during the NMRDI coal quality study. The population sizes were insufficient for comparison by coal zones. Table 1 is a statistical summary of the weighted average analyses (as–received basis) of the Salt Lake field coals, comparing the NMRDI coal quality study samples to previous studies samples (see footnote, Table 1). The sample analyses were weighted by the total individual bed thickness and all analyses in the comparison are from drill cores.

The weighted–average t-test comparison of these two data sets show statistical differences in the hydrogen and sulfur values, except for the sulfate, a consequence of oxidation. A progression from higher to lower sulfur with increased stratigraphic distance above the Atarque Sandstone is typical in both data sets, but a majority of the analyses (96%) in the data set from other studies are from the Cerro Prieto and Rabbit coal zones, resulting in a lower average sulfur value. Diversity in the sulfur values may result from 40% of the NMRDI study samples taken from the Antelope coals and lower seams in the Cerro Prieto zone. The Antelope coals of back barrier swamp origin were influenced by seawater invasion during shoreline oscillations or major storms and consequently tend to have greater percentage of total sulfur (avg. of all analyses 1.20%) than the Cerro Prieto and Rabbit zones coals (avg. of all analyses 0.85%), deposited in coastal–plain

TABLE 1. Weighted average analyses of the Salt Lake field, Moreno Hill Formation coals*.

	NMRDI data			Other studies[1]			t-test values	
	No. of samples	Mean	Std. dev.	No. of samples	Mean	Std. dev.	t-values	Degrees of freedom
Eq. moisture	5	14.72	6.64	0				
Moisture	5	14.56	0.36	53	14.73	3.34		
Ash	5	15.94	1.71	53	17.18	4.17		
Volatile matter	5	33.53	1.32	53	31.50	2.65		
Fixed carbon	5	35.96	1.19	53	36.21	3.88		
Calorific value	5	9070	252	51	9175	865		
Carbon	5	55.04	1.25	43	50.92	5.85		
Hydrogen	5	4.29	0.12	43	3.70	0.47		
Nitrogen	5	1.05	0.03	43	0.93	0.17		
Oxygen	5	7.95	0.16	43	9.73	1.98		
Total sulfur	5	1.17	0.25	22	0.68	0.13	6.39	25
Sulfide	5	0.51	0.28	22	0.15	0.13	4.47	25
Sulfate	5	0.01	0.01	22	0.06	0.06		
Organic sulfur	5	0.65	0.09	22	0.47	0.10	3.71	25
Ashed oxides								
SiO_2	4	56.83	4.59	29	56.84	2.79		
Al_2O_3	4	25.33	2.42	29	28.66	3.71		
TiO_2	4	1.62	0.20	29	1.44	0.26		
Fe_2O_3	4	7.43	3.73	29	3.66	0.90	4.89	31
MgO	4	1.09	0.31	29	0.58	0.19	4.48	31
CaO	4	4.41	0.86	29	4.08	1.24		
K_2O	4	0.43	0.05	29	0.19	0.18		
Na_2O	4	0.77	0.38	29	0.54	0.43		
Total oxides		97.91			95.99			

*Analyses on as-received basis. All values in percent except calorific value (Btu/lb).

[1]Sources of data from other studies: Campbell, 1981; Roybal and Campbell, 1981; and confidential data.

and alluvial–plain environments. Overall, the Moreno Hill lower member coals have a low total sulfur content (0.70%), predominantly organic sulfur. Average apparent rank is subbituminous A, although some individual coal beds have a high volatile bituminous C rank. These coals are moderately high ash (17%), similar to that of the Dilco Coal Member coals (Crevasse Canyon Formation) in the Gallup field (Fig. 3).

Ash in the lower coal member consists principally of silica and aluminum oxides (Table 1). Comparison of major oxide (weighted average) analyses of ash for the Salt Lake field between the NMRDI coal quality study and other studies indicate statistically significant differences between the iron and magnesium oxides; remaining major oxides are within the same population. The NMRDI samples are higher in Fe_2O_3, and MgO; the higher iron is a consequence of the higher percentage of sulfur in these samples, particularly in those analyses from the Antelope coal zone. Campbell (1989) also found the iron from whole coal oxide analyses to be greater in the Antelope coals compared to the Cerro Prieto or Rabbit zone coals. Iron oxides can influence the behavior of coal in boilers. Depending on the state of the iron, the ash fusion temperature may increase or decrease.

PETROGRAPHIC ANALYSES

During the NMRDI coal quality study petrographic analyses for vitrinite reflectance and maceral content were done on 11 coal samples from the Moreno Hill Formation. These analyses were compared to 64 Fruitland, 28 Menefee, and 20 Crevasse Canyon petrographic analyses from the same study.

Maceral content

Coal organic constituents are divided into three major maceral groups; vitrinite, liptinite and inertinite. Maceral analyses measure the proportion by volume of these organically derived components. Vitrinite, derived from wood, leaf or root tissue, is the dominant maceral (70–89%) in the Crevasse Canyon, Menefee and Fruitland coals in the San Juan Basin. The Moreno Hill Formation coals have a much lower and statistically different vitrinite percentage (avg. 63%) than the other coal–bearing formations (Fig. 8) within the San Juan Basin.

The source material of inertinite is cellulose and lignin from the cell walls of the plant, the same as that of vitrinite. This plant material has been oxidized either biochemically or by fire or desiccation early in the coalification process. The Moreno Hill Formation coals contain a significantly greater percentage of inertinite (27%) than the Crevasse Canyon, Menefee and Fruitland coals. Most of the inertinite maceral in the Moreno Hill coals is semifusinite resulting from charring.

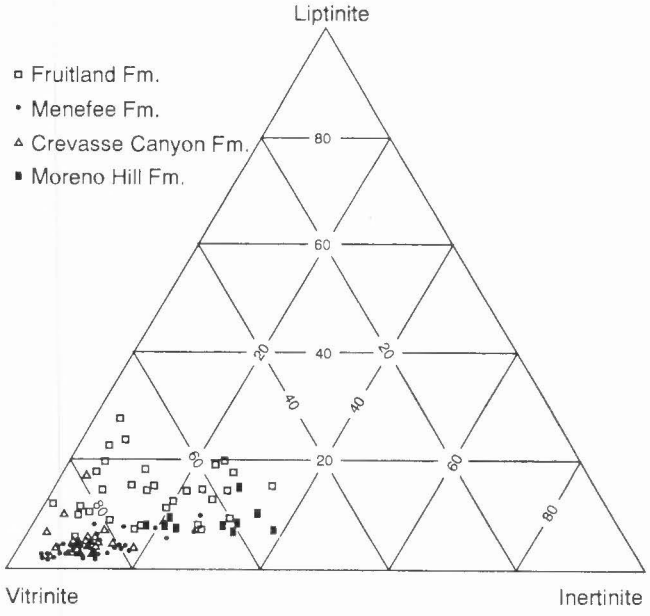


FIGURE 8. Maceral–group content (%) by formation of NMRDI coal quality samples (from Bellis, 1993.)

Liptinite is composed of spore and resin material. In the coal–bearing sequences analyzed during the NMRDI study, 2 to 27% of the total macerals were in this group. The Fruitland coals have the greatest percentage of liptinite, specifically resinite (13–17%; Hoffman, Campbell and Beaumont, 1993). The Moreno Hill Formation coals averaged 7% liptinitic material, a greater percentage than the Menefee and Crevasse Canyon coals but lower than the Fruitland Formation coals.

Maceral composition is affected by the nature of the plant material forming the peat, as well as by its oxidation. Statistical comparison of the coal–bearing formations in northwestern New Mexico indicates the Fruitland Formation and the Moreno Hill Formation are different from the other formations sampled for vitrinite, liptinite and inertinite content (Fig. 8). The Fruitland coals contain a greater percentage of liptinite macerals, in particular resinite, suggesting a swamp rich in trees rather than shrubs and grasses. The Moreno Hill has a higher percentage of inertinite, indicating that the swamps in which these coals formed were subjected to greater oxidation, perhaps the result of more numerous swamp fires before burial. The Menefee and Crevasse Canyon coals are statistically within the same population for all three major maceral groups and are vitrinite rich.

Vitrinite reflectance

Reflectance of the macerals increases with the degree of coalification. The petrographic properties of vitrinite change uniformly with increasing coalification, making it a good indicator of rank. The vitrinite reflectance methods used in the NMRDI study are described in Roybal et al. (1986, p.80). Vitrinite is used for reflectance studies because it is the most abundant maceral and is assumed to be representative of the reflectance of the coal. Moreno Hill coals have a slightly higher vitrinite reflectance (R_O= 0.49) than Crevasse Canyon coals (R_O= 0.47). The Moreno Hill coals are older than the Crevasse Canyon and Menefee coals (Turonian vs Conacian through Campanian) and may have experienced some thermal influence from Tertiary and Quaternary volcanics in the area. These factors lead to greater coalification and slightly higher vitrinite reflectance values for the Moreno Hill coals. The average vitrinite reflectance values of the Moreno Hill, Crevasse Canyon, and Menefee formations (0.49, 0.46, 0.50, respectively) indicate an apparent rank of high volatile bituminous C.

SUMMARY AND CONCLUSIONS

The lower member of the Moreno Hill Formation in west–central New Mexico contains moderately high–ash, low sulfur, subbituminous A to high–volatile C bituminous coals in three zones. The decreasing sulfur content and change in isopach trends of the coals in these zones demonstrate a progression from a back barrier environment (Antelope zone) to an alluvial plain environment (Rabbit zone). Maceral analyses indicates some oxidation or charring of the plant material in these swamps took place before burial. Tonsteins within several of the coal beds indicate swamp development was interrupted by deposition of fine-grained material, possibly volcanic ash. If these tonsteins are of volcanic origin, they could be the cause of charring or oxidation in the swamps, resulting in greater amounts of semifusinite in the Moreno Hill coals.

Economic coal beds in the lower Moreno Hill are in the medial Cerro Prieto zone. Coal in this zone averages 4.2 ft thick and beds show some lateral continuity (12 to 15 mi). Recent resource evaluations at the NMBMMR (Campbell, 1981, 1989; Roybal and Campbell, 1981; NMBMMR coal data base) indicate 341 million st of demonstrated coal resources (minimum 2.5 ft thick) with less than 250 ft of overburden in the Moreno Hill Formation, Salt Lake field. The majority of these resources are in the east–central part of the coal field (T17N to T15N, R3W to R4W).

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This article is dedicated to the memory of Frank Campbell (1947–1988) who spent several years doing geologic mapping, and coal quality and resource evaluations in the Salt Lake coal field. His initial mapping and that of others from the NMBMMR and USGS helped stimulate interest in the economic potential of coals in this field. Frank's open–file reports (1981) and final compilation of the coal geology in the southeast Salt Lake field (1989) are significant contributions to the geologic knowledge of this area. His work continues to be referenced by investigators in academia and industry.

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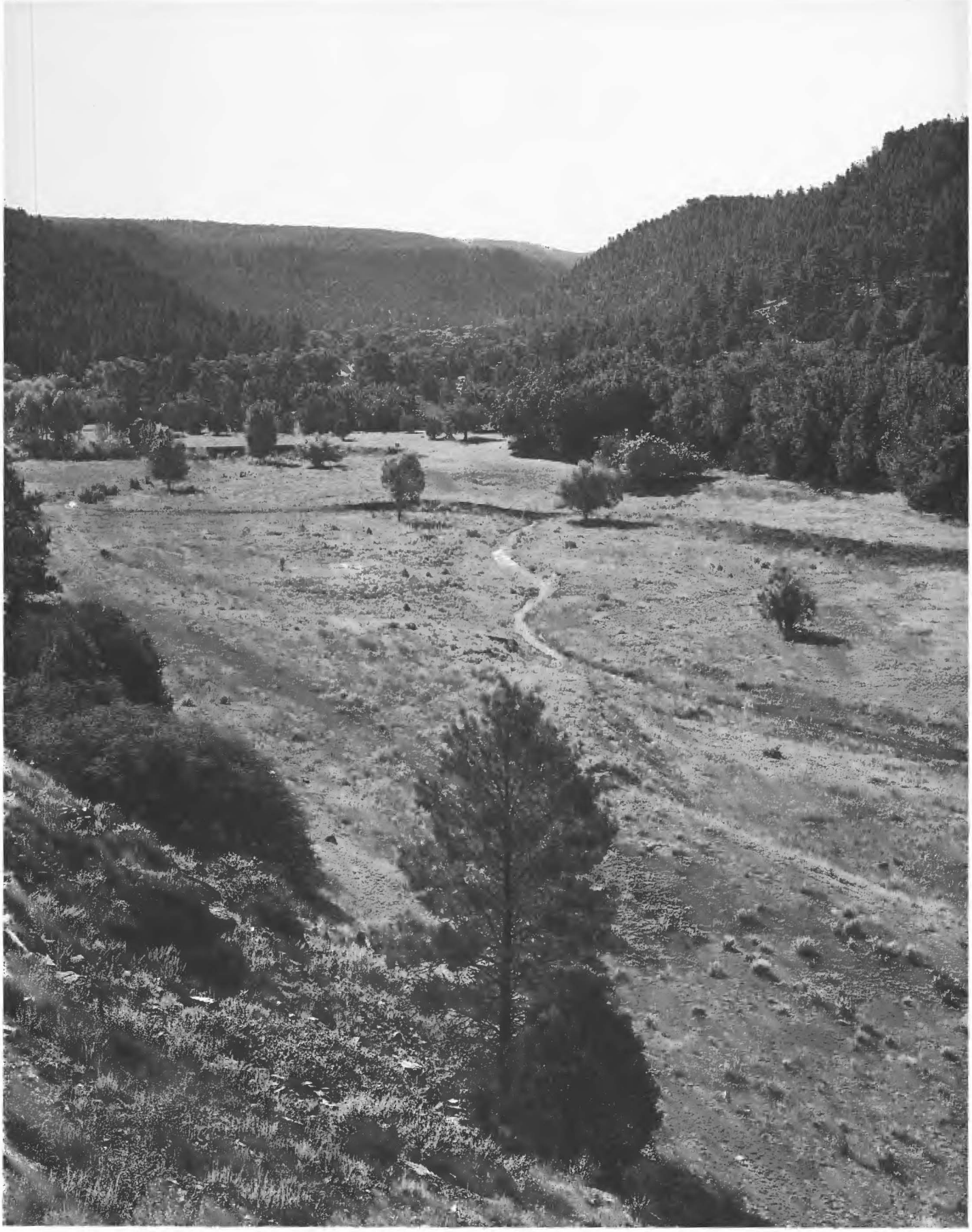
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Valley of Apache Creek about 12 km north of Apache Creek, New Mexico. View is S47°E, downstream. Looking down Hardcastle Canyon; rim rocks consist of cliff-forming andesite of Dry Leggett Canyon overlying volcaniclastic conglomerates and sandstones of the Pueblo Creek Formation. Several low terraces are present, but the grassy valley floor is largely undissected. Camera station is alongside Highway 32 in NW ¼ sec. 25, T4S, R18W. Altitude is about 2100 m. Wayne Lambert photograph 93L74. August 13, 1993, 9:53 a.m. MDT.