Geology and Coal Resources of the Fence Lake 1:50,000 Quandrangle Catron and Cibola Counties, New Mexico

by

Frank W. Campbell and Gretchen H. Roybal

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INTRODUCTION

The area of study is the northern part of the Salt Lake coal field and covers part of Townships 3, 4, 5, 6 North and Ranges 16, 17, 18, 19, 2Ø, 21 West. This 1:5Ø,ØØØ-scale map (Plate 1) is the southwest quarter of the Fence Lake 1:1ØØ,ØØØ-scale quadrangle map. The purpose of this report is to evaluate the geology, structure, and the quality and quantity of coal beds in this part of the Salt Lake coal field. Cretaceous rocks extend over an area of about 4ØØ sq miles (643 sq km) in the mapped area, with coal-bearing strata present over an area of approximately 22Ø sq miles (4ØØ sq km). The oldest exposed unit mapped is the Triassic Chinle Formation, while the youngest consolidated unit is the Bandera basalt flow dated at 1.3+/-.23 my (Laughlin and others, 1979).

The central portion of the Salt Lake coal field, an area comprising eight quadrangles (Fig. 1), has been mapped jointly by the U.S. Geological Survey Coal Resources Branch and the New Mexico Bureau of Mines and Mineral Resources. Figure 1 shows the general location of the Salt Lake coal field, the area of study, the authorship of the eight quadrangles used in this compilation, and their relationship to the areal extent of the coal-bearing Moreno Hill Formation. In addition to this surface geologic data, geophysical logs from 32 drill holes were obtained (Fig. 2). Drilling penetrated both Tertiary and Cretaceous strata. These units have characteristic and readily recognized geophysical log signatures.

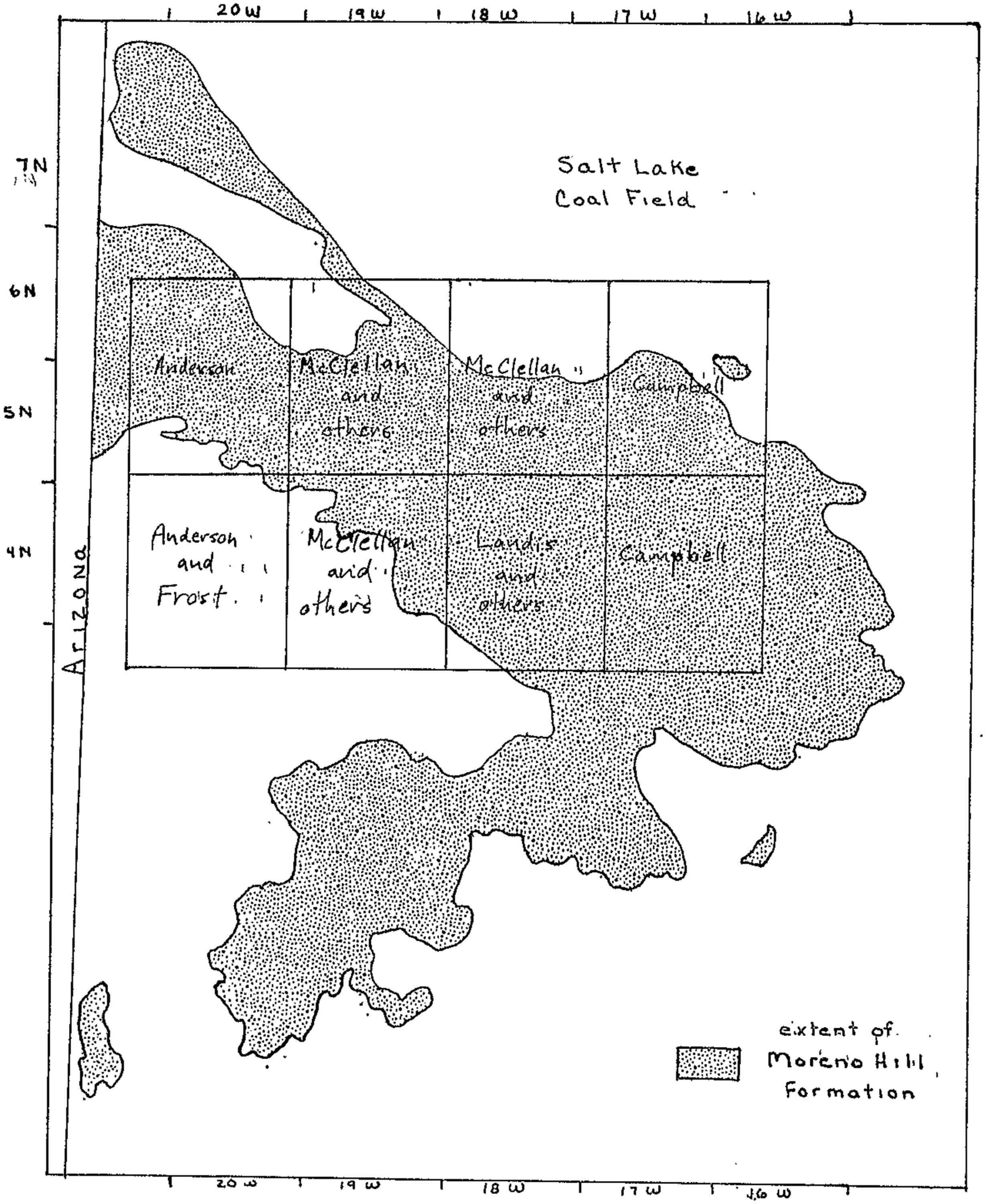
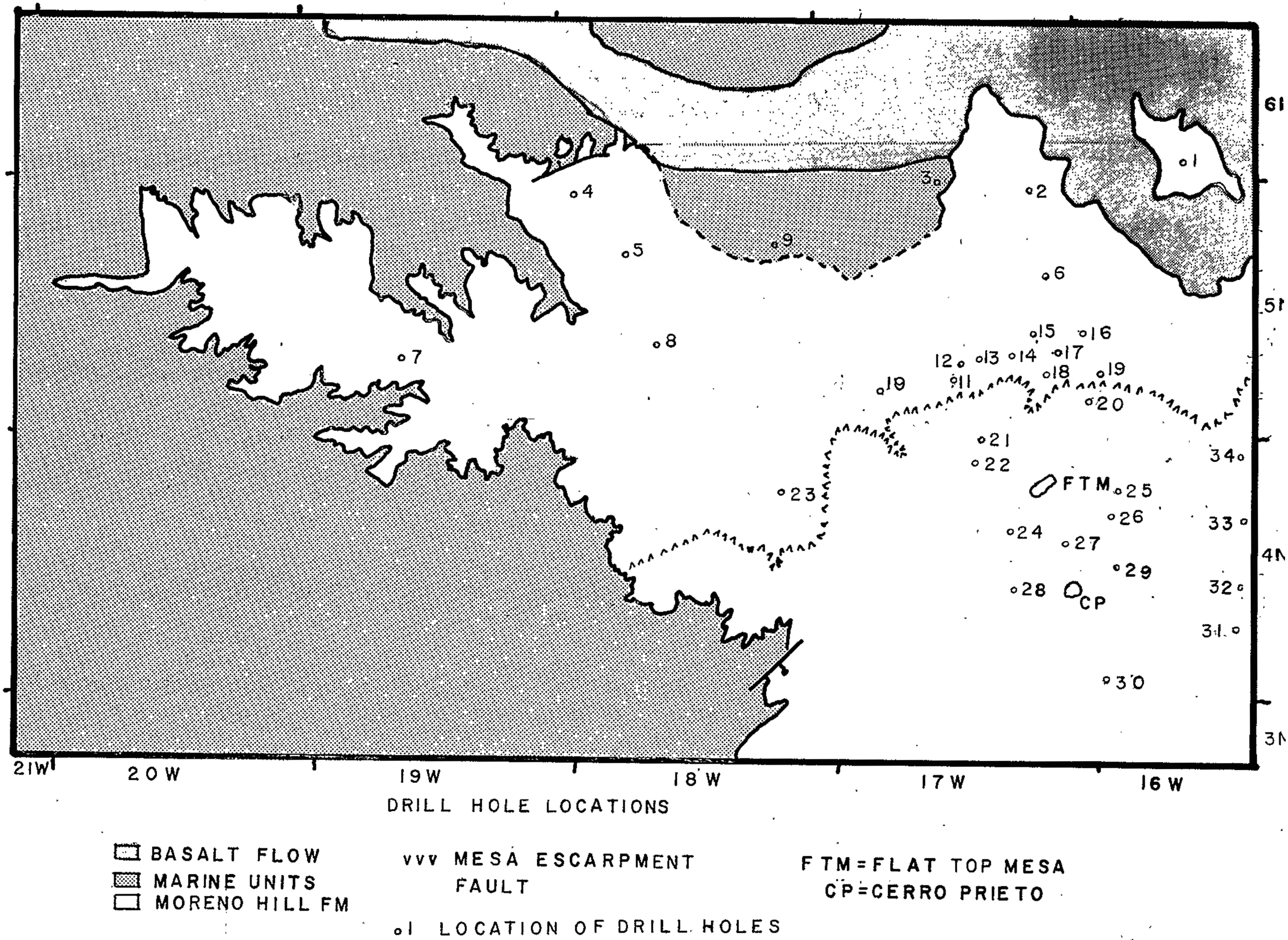


Fig. 1 Authorship Map of Fence Lake 1:50000 Geologic Map



21W
20 W
19 W
18 W
17 W
16 W
DRILL HOLE LOCATIONS
FTM
CP
1
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BASALT FLOW
MARINE UNITS
MORENO HILL FM
vvv MESA ESCARPMENT
FAULT
FTM=FLAT TOP MESA
CP=CERRO PRIETO
o1 LOCATION OF DRILL HOLES

FIG. 2

DRILL HOLE IDENTIFICATION

1)	616-33-1	18)	517-25-1
2)	517-2-1	19)	516-30-1
3)	517-4-1	20)	516-31-1
4)	518-6-1	21)	517-34-1
5)	518-17-1	22)	427-3-1
6)	517-13-1	23)	418-11-1
7)	519-20-1	24)	417-14-1
8)	518-28-1	25)	416-7-1
9)	518-13-1	26)	416-7-2
10)	517-31-1	27)	417-13-1
11)	517-27-1	28)	417-23-1
12)	517-27-3	29)	416-18-1
13)	517-27-2	30)	416-31-1
14)	517-26-1	31)	416-27-1
15)	517-24-1	32)	416-22-1
16)	516-19-1	33)	416-10-1
17)	517-25-3	34)	416-3-1

STRATIGRAPHY

The rocks in the Fence Lake 1:50,000 quadrangle map range from Triassic to Quaternary in age. The outcropping units are predominantly Cretaceous in age, consisting of marine and non-marine sediments, overlain by Tertiary and Quaternary units. The descriptions that follow of these units are based on outcrop data and on geophysical logs. Plate 2 is a generalized composite geologic column for the Salt Lake coal field, compiled from both outcrop and subsurface data.

The Chinle Formation unconformably underlies the Dakota Sandstone in the southwestern part of the study area and the Zuni Sandstone in the northcentral part. The unit is as much as 240 ft (72.3 m) thick and consists of grayish red to reddish brown and purple mudstones, siltstones and claystones, with scattered lenses of sandstones and conglomerates. The Chinle Formation outcrops in the study area are correlated with the Petrified Forest Member of the Chinle Formation.

Descriptions of the sequence ranging from the Zuni Sandstone to the Twowells Tongue of the Dakota Sandstone in the study area are from Anderson (1982), McLellan and others (1983), and Hook, Molenaar, and Cobban (1983). Geophysical data for these units is sparse. Geophysical data from the Tejana Mesa quadrangle (Roybal, 1982), and other nearby drill holes, has been inferred for the lower marine units of the Cretaceous strata.

The Zuni Sandstone is present only in the north-central part of the study area (McLellan and others, 1983), overlying the Chinle Formation, but has been mapped in detail to the north in the Mesita de Yeso quadrangle (Anderson, 1982). The Zuni

Sandstone is an eolian, white to pink, fine to medium-grained sandstone. Within the sandstone are high-angle cross beds and a few pebble conglomerates concentrated along bedding planes. It is a maximum of 90 ft (27.1 m) thick and unconformably overlies the Chinle Formation.

Above the Zuni Sandstone is the "main body" of the Dakota Sandstone (Plate 2) which consists of both marine and non-marine sediments in a 65 to 85 ft (19.6-25.6 m) sequence. The upper 50 to 60 ft (15.1-18.1 m) consists of gray to yellow-gray claystones and siltstones with a few persistent very fine to fine-grained calcareous sandstones 1 to 5 ft (0.3-1.5 m) thick. The sandstones and siltstones are commonly bioturbated and in places fossiliferous. The claystones contain fossiliferous limestone concretions. The lower 15 to 25 ft (4.5-7.5 m) of the Dakota 55 is predominantly cross-bedded fine- to coarse-grained, resistant sandstone with beds up to 5 ft (1.5 m) thick. In places, in both the lower and upper part, the "main body" is partially to completely composed of carbonaceous siltstones, shales and coals. The coals are thin (2 to 3 ft [0.6-0.9 m]) and confined to the lower part of the main body Dakota Sandstone.

The main body Dakota Sandstone is marked by the geophysical log signatures of silty sandstones with thin calcareous sandstones, with a low sp reading, varying from 5 to 15 mv. The resistivity of the siltstone/sandstone sequence is variable owing to beds of cleaner sandstones (90 ohm) interbedded with silty sandstones (30 ohm). The gamma log is only 10 cps lower than the gamma of the overlying shales, indicating the higher overall clay content in this unit than in a clean sandstone.

The lower Mancos Shale is a dark-gray or dusky yellow marine shale with interbedded claystones and siltstones ranging in thickness from 55 to 75 ft (16.6-22.6 m) overlying the main body Dakota Sandstone. There are moderate amounts of limestone concretions in this unit; no fossils were found associated with these concretions or in the rest of the lower Mancos shale (McLellan and others, 1983).

The lower Mancos Shale shows a gradual change from the silty sands of the main body Dakota to silty claystones and shales on the geophysical log. The resistivity varies from 20 ohms to 5 ohms from the top of the unit to the bottom. The sp log of the lower Mancos Shale varies from the shale line only at the top of the unit, showing higher silt content than the lower portion. A few thin, high density, high gamma kicks with very low resistivity readings within this unit may indicate bentonite beds.

The contact between the Lower Mancos and the overlying Paguate Tongue of the Dakota Sandstone is reflected by a gradual change from shales to sandstone. The Paguate Tongue of the Dakota Sandstone is a massive to irregularly bedded marine sandstone 20 to 55 ft (6.1-16.6 m) thick. The yellow to grayish-yellow sandstone is a poorly cemented, poorly sorted, fossiliferous (*Pycnodonte* cf. *P. kellumi*), fine-grained sandstone. The Paguate Tongue weathers to pebble size angular fragments forming sandy slopes above the lower Mancos Shale.

The sharp upper contact of the Paguate Tongue is shown in geophysical logs. The sandstone unit shows a coarsening upward sequence with several interbedded siltstones on both the resistivity and sp logs. The resistivity ranges from 100 to 20 ohms and the sp readings go from 70 to 10 mv within this unit. The gamma reading is high at the bottom of the unit, indicating a higher clay content in the basal Paguate Tongue sandstone, and progressively gets lower towards the top of the unit, indicative of a cleaner sand.

Above the Paguate Tongue of the Dakota Sandstone is the Whitewater Arroyo Tongue of the Mancos Shale. This unit consists largely of medium-dark gray shales with a few siltstones containing the large oyster Exogyra trigeri. Thin bentonite layers and cone-in-cone limestone concretions occur within this 55 ft (16.6 m) tongue of the Mancos Shale.

The Whitewater Arroyo Tongue on a geophysical log appears siltier than the younger Rio Salado Tongue of the Mancos. The resistivity averages 8 ohms from the shale line, and the gamma-gamma density is lower than that of the shale units above the Whitewater Arroyo Tongue. The upper part is about 40 ft (12.1 m) thick (Roybal, 1981) and is predominantly siltstones. Several bentonite beds 1 to 2 ft (0.1-0.6 m) thick occur in this unit and characteristically have high gamma readings of 25 cps and low resistivity readings, registering below the shale line (-15 ohm). A few thin limestone beds are recognizable on the geophysical logs that penetrate the Whitewater Arroyo, indicated by high resistivity and low gamma readings.

Above the marine shales of the Whitewater Arroyo Tongue of the Mancos Shale is a sandstone sequence named the Twowells Tongue belonging to the Dakota Sandstone. The Twowells Tongue is an offshore shallow marine sandstone. This thin unit, which is about 3Ø ft (9.Ø m) thick, consists of a very fine-grained to medium-grained yellow-brown to dark-gray sandstone, and coarsening upwards sequence. Using outcrop and geophysical log data, the Whitewater Arroyo Tongue can be divided into three units. In outcrop the lower unit is a flat bedded very fine to fine-grained sandstone with a few burrows, the middle unit is an intensely burrowed and bioturbated very fine to fine-grained sandstone, and the upper unit is a fine to medium-grained planar crossbedded unit, approximately 6 to 8 ft (1.8-2.4 m) thick. On geophysical logs the resistivity of the Twowells Tongue ranges from 1ØØ-16Ø ohm. Two breaks occur in the overall sp log reading of 45 mv. The lower portion of the unit shows a coarsening upward on the resistivity log. The middle unit has a blocky signature and the upper unit has an abrupt contact with the overlying Rio Salado Tongue of the Mancos Shale, showing no gradation between the shale and sandstone units. The gamma log throughout the Twowells Tongue interval is low, indicative of a fairly clean sand.

Above the Twowells Sandstone is the Rio Salado Tongue of the Mancos Shale. The Rio Salado Tongue varies in thickness from 13Ø ft (99.2 m) to 24Ø ft (72.9 m) thickening to the north. This unit is composed predominantly of olive gray to yellow brown interbedded shales, with thin beds of fossiliferous limestone concretions and glauconitic calcarenite. The shales have a consistent geophysical log signature throughout the Rio Salado Tongue interval. The shales have a low resistivity averaging 14 ohms/m, and a higher gamma of 1ØØ api, than the overlying Atarque

Sandstone. Density of the shales averages 2.25 g/cc matrix density, indicative of high clay (illite or kaolinite) content. Limestones indicated from the logs in the Rio Salado Tongue are either limestone concretions or calcarenites. The concretions stand out on the geophysical logs because of their low gamma, 60 api and high density (2.55 g/cc). The resistivity readings appear low for limestones, 40 to 28 ohm, owing to the thinness of the beds. The limestone density is slightly higher than the surrounding shales, 2.55 g/cc. The thin calcarenite beds often contain fossils in outcrop; these are ammonites in the upper part of the unit and Pycnodonte newberri, (Anderson, 1981) in the lower part of the Rio Salado Tongue.

Three bentonite beds occur in the Rio Salado Tongue ranging from 0.5 ft (15.2 cm) to 1 ft (30.1 cm) thick. These beds have high gamma readings of 200 api and low resistivity averaging 15 ohm, and a density of 2.1 to 2.2 g/cc. Beds with a very high gamma, 150 cps, and no noticeable change in the resistivity or spontaneous potential logs (sp) indicates the presence of glauconite in the Rio Salado Tongue; these glauconitic beds are approximately 1 ft (30.1 cm) thick. The glauconite is indicative of a marine environment with slow sedimentation and reducing conditions.

The Atarque Sandstone is the youngest marine unit in the area. This formation is a regressive marine beach deposit. The thickest section of the Atarque Sandstone is 98 ft (25.5 m) and the thinnest is 15 ft (4.5 m). The Atarque Sandstone is not always a single sandstone unit, in places consisting of as many as three sandstones over a 25 ft (7.5 m) vertical interval. The Atarque Sandstone is characterized by a sharp upper contact and a gradational lower contact. The lower contact shows a high density reading owing to carbonate present in the fossiliferous lower beds. This sandstone has a high resistivity reading, averaging 350 to 345 ohms/m in the upper part and 118 to 23 ohms/m in the lower section. This variation in resistivity indicates a coarsening upward of the grain size. The gamma readings are low, 40 to 60 api, for the upper part of the Atarque Sandstone and indicate a clean sand. The lower portion of the Atarque Sandstone has a higher silt and clay content, recognized by an increased gamma reading, 80 api.

Overlying the Atarque Sandstone is the Cretaceous Moreno Hill Formation, a name proposed for the coal-bearing continental sediments in the Salt Lake coal field by McLellan and others (1983b). The type section for this formation is located in T 4 N., R. 18 W. sec 7, where 519 ft (156.5 m) of Moreno Hill Formation is present. This formation thins to the west to 100 ft (30.1 m) on the Cantaralo Spring Quadrangle (Anderson, 1981). In the eastern portion of the field, in the Cerro Prieto Quadrangle, Campbell (1981), reported a thickness of 750 ft (226.1 m) for the Moreno Hill Formation.

This unit is a series of fluvial channel-fills, crevasse splays, and floodplain deposits. The Moreno Hill Formation can be divided into three members, based on both outcrop and subsurface data. The lower member of the Moreno Hill Formation is dominated by fluvial sandstones, with crevasse splays, dark-gray mudstones/claystones, and coals. The middle member is a sandstone sequence, consisting of coarse-grained sand, with no matrix. The upper member consists of mudstones and claystones, with a few channel sandstones.

The lower member of the Moreno Hill Formation sequence is characterized by fluvial sandstones with siltstones, mudstones, claystones, and coals. The thickest section for this member is in the eastern portion of the field and it thins to the west, where Anderson (1981) has mapped only 100 ft (30.1 m) of total Moreno Hill sediments. In the Cerro Prieto quadrangle, using both geophysical and outcrop data, 440 ft (132.6 m) of the lower member of the Moreno Hill Formation are indicated. The sandstones present in this lower member have a clay and silt matrix, that can amount to as much as 15% of the total rock, with the grains being matrix supported. Some of these sands have a sharp basal contact indicated by a sudden increase in the resistivity on a geophysical log. The decreasing resistivity from the base up is indicative of a channel sandstone. The gamma indicates a greater silt content at the top of the channel with 60 api at the base, increasing to 80 api gamma reading at the top, as would be expected in a channel deposit. Individual channels are not correlatable from hole to hole, but are present in nearly all holes that penetrate the lower member of the Moreno Hill Formation, indicating a discontinuous lateral distribution. This type of sandstone body geometry is suggestive of a meandering stream deposit. Crevasse splays are also recognizable in this sequence. The resistivity patterns of these crevasse splays have sharp contacts at both the upper and lower boundaries, indicating an abrupt change in grain size. The gamma logs show a slightly higher value, 120 api, than the upper member mudstones/claystones, due to the lower member mudstones having a greater organic fraction, which tends to concentrate uranium and thorium. The resistivity is generally less than 9 ohm/m for these mudstones/claystones. There are no limestones or dolomites in the lower member, indicating an absence of lacustrine deposits. These mudstones and claystones probably represent floodplain deposits with swamps represented by those intervals with carbonaceous shales and coals.

The middle member of the Moreno Hill Formation has not been mapped throughout western part of the Salt Lake coal field. To the south, in T. 1 and 2 N. R. 18-20 W., the middle member is a dominant feature. This member is dominantly a medium- to coarse-grained sandstone. No silt or clay matrix is present and the fabric is grain supported. The sand grains are predominantly coarse grained, angular quartz with up to 15% feldspar clasts (some clasts are up to 1/2" in diameter), and some iron concretions. Coloration of this member is generally pinkish-yellow, probably due to the feldspar and concretions. Both trough and planar cross-beds are present. The resistant nature of this unit makes it one of the most dominant ledge formers in the area. Thickness of this member ranges from 28 ft (8.4 m) in the type section to a maximum of 80 ft (24.1 m) on the Cerro Prieto quadrangle.

The geophysical log signatures for the middle member of the Moreno Hill Formation are distinctive and readily identifiable. The resistivity pattern for the middle member is pronounced, ranging from 530 to 250 ohm/m, being higher than other sandstones in either the upper or lower members of the Moreno Hill Formation. This reflects the coarser grained nature of this sandstone. The density log averages 2.1 g/cc, which is indicative of a clean sand having a porosity of approximately 20%. Gamma logs show low values in the 60 api range, due to a lack of potassium-bearing minerals, specifically clays, in the matrix. There is no general fining upward of grain size for the entire member, as would be expected from a single channel fill deposit. The upper and lower contacts show sharp changes, which are reflected in both the resistivity and gamma readings. The overall resistivity pattern is blocky, with small members showing a fining upward of individual channels. There are no systematic changes in the gamma value within this member. Although individual channels cannot be correlated from hole to hole, the entire sequence can be correlated, indicating a sheet-like structure, that represents a braided stream deposit.

The upper member of the Moreno Hill Formation contains very few channel sandstones, and is dominated by mudstones and claystones, with some carbonaceous shales and a few thin coals. The coloration of this unit is generally greenish yellow to light gray. The few sandstones in the upper member have a high silt and clay content and are poorly cemented, resulting in a non-resistant sandstone. The upper member of the Moreno Hill Formation is poorly exposed, except where overlain by the Fence Lake Formation. The upper Moreno Hill Formation varies in thickness from 250 ft (75.4 m) on the Cerro Prieto quadrangle to less than 30 ft (9.0 m) on the Rincon Hondo quadrangle. In the

Tejana Mesa quadrangle Roybal (1982), reported thicknesses of 761 ft (225.4 m) for the upper member. The log signature for the upper member shows an interbedded sequence of siltstones and mudstones, with a few sandstones. The resistivity generally indicates a dominance of fine-grained materials (mudstones, claystones, and siltstones), with a few sandstones. The resistivity of these sands is low, due to their fine-grained, silty nature. Gamma log readings for these sands are high due to the abundance of clays in the matrix.

Overlying the Moreno Hill Formation is the Fence Lake Formation, a Tertiary unit consisting of basaltic boulders. This Formation was first informally described by Marr (1956), as the "Fence Lake Gravel". McLellan and others (1982b) renamed this unit as the Fence Lake Formation. The following descriptions are from their paper. The type section for this formation is located in T. 4N., R. 18W. sec 1, where 221 ft (66.6 m) of Fence Lake Formation is present. This formation occurs as two units, a lower conglomeratic unit and an upper sandstone unit. The lower unit consists of large basaltic boulders (up to 2 ft [0.6 m] in diameter), smaller clasts of rhyolite, chert, petrified wood, and Cretaceous sandstone fragments, in a calcareous sandstone matrix. In the type section the lower unit is 41 ft (12.4 m) thick, however, in other areas, this unit may be as much as 100 ft (30.1 m) thick (Campbell, 1981). The upper unit consists of calcareous, gray-pink sandstone and a 15-ft (4.5 m) thick cap of volcanic boulder conglomerate, giving a combined upper unit thickness of 180 ft (54.3 m). Picking the base of this formation using geophysical logs is relatively simple. Calcareous cement and the conglomeratic layers result in a high resistance reading, generally higher than that of the sandstones in the underlying Moreno Hill Formation. The absence of clays and other sources of hydrogen result in a high neutron reading. The density log shows higher than normal densities, in the 2.4+ g/cc range, due to the calcite and basalt.

The youngest Tertiary sedimentary unit is the Bidahochi Formation, as recognized by Anderson (1981) and Anderson and Frost (1982) on the Cantaralo Spring and Twenty-two Springs quadrangles, respectively. These westernmost quadrangles are the only place the Bidahochi crops out in the Fence Lake 1:50,000 map study area; maximum thickness here is 300 ft (90.4 m). Anderson (1981) described the Bidahochi Formation as "highly variable light-brown sands, light-gray sandstones, and pebbly conglomerates, generally poor to fair cementation..." with lenses of calcareous cement and volcanic clasts. The pebble conglomerates within the Bidahochi are matrix supported, consisting of basalt and rhyolite pebbles with minor amounts of quartzite pebbles.

STRUCTURE OF THE SALT LAKE COAL FIELD

The structure of this field is relatively simple. A few major faults are present, the most prominent of which is located in the western portion of the field, along State Highway 32. Extensive faulting is indicated on the Fence Lake and Rincon Hondo quadrangles, in the central portion of the field. Displacement on these faults is difficult to determine, as there are no dips recorded for this area and outcrops are sparse.

Based on the dips derived from three point problems the displacements on these faults is only a few feet at maximum. The regional dip is 3 to 5 degrees to the southeast although Tertiary volcanism has resulted in many small flexures due to local deformation throughout the field.

COAL GEOLOGY

Work by Campbell (1981), Roybal and Campbell (1981) and Roybal (1982) has shown that the coals in the eastern portion of the Salt Lake coal field are bituminous B and C in rank. Coal resources were calculated by projecting this rank for coals to the western portion of the field and using the minimum thickness for resource calculations of 1.2 ft (96 cm) for bituminous coals according to U.S. Geol. Surv. Circ. 891 (Wood and others, 1983). Based on the data from this study, the coal resources for the Salt Lake coal field amount to 390 million tons, of which 142 million tons has a stripping ratio of 20:1 or less. These resources are distributed between four coal-bearing zones in the Salt Lake area. Table 1A shows the measured and indicated tonnages for three depth categories and a stripping ratio of 20:1, for the four coal zones in the Moreno Hill Formation.

TABLE 1A

COAL RESOURCES

(1.2 FT [0.4 M] MINIMUM THICKNESS)

COAL ZONE	20:1		0-150 FT (0-45.2 m)		151-250 FT (45.5-75.4 m)		250+ FT (75.4 + m)	
	MEAS.	IND.	MEAS.	IND.	MEAS.	IND.	MEAS.	IND.
ANTELOPE	4.1	30.2	5.5	39.4	4.7	33.5	1.7	13.6
CERRO PRIETO	11.7	64.7	20.3	80.3	8.0	26.0	2.8	9.6
RABBIT	6.6	24.9	18.5	82.7	3.5	10.0	1.7	13.6
TWILIGHT	0.0	0.0	1.8	10.7	2.3			

TABLE 1B

Analyses of Coal Zones in the Fence Lake 1:50,000 Map
(As determined)

	no.	Avg.	S.D.		no.	Avg.	S.D.
Antelope Zone							
Moist	4	7.32	3.57	Carbon	3	48.78	9.14
Ash	4	22.09	3.57	Hydrogen	3	3.91	0.50
V.M.	4	32.83	2.42	Nitrogen	3	0.96	0.20
F.C.	4	38.02	4.90	Oxygen	3	11.41	1.24
Btu	5	9454.	846.	Sulfur	3	0.69	0.08
Cerro Prieto Zone							
Moist	20	8.02	4.91	Carbon	5	55.12	8.46
Ash	20	16.85	5.65	Hydrogen	5	5.33	0.41
V.M.	19	34.08	3.58	Nitrogen	5	1.09	0.16
F.C.	19	40.89	4.97	Oxygen	5	10.34	1.23
Btu	15	10069.	1240.	Sulfur	10	.79	.33

	no	Avg.	S.D.		no.	Avg.	S.D.
Rabbit Zone							
Moist	15	8.48	5.80	Carbon	5	60.91	3.20
Ash	15	15.50	5.09	Hydrogen	5	4.62	0.19
V.M.	14	34.86	3.92	Nitrogen	5	1.09	0.16
F.C.	14	42.05	6.56	Oxygen	5	10.34	1.23
Btu	17	10083	899	Sulfur	10	0.77	0.27
Twilight Zone (outcrop)							
Moist	4	3.07	0.39				
Ash	4	24.94	3.85				
V.M.	4	34.12	0.88				
F.C.	4	37.87	2.71				
BTU	4	8926	1136				
Sulfur	4	0.79	0.38				

Most of the coal resources are in the eastern portion, in The Dyke and Cerro Prieto quadrangles, where the thickest beds (in excess of 9 ft [2.7 m]) in the field occur. Roybal (1982) indicated a southward continuation of the coals, in the southern portion of the Cerro Prieto quadrangle, into the Tejana Mesa quadrangle. The Moreno Hill Formation thins to the west, thus reducing the thickness of the potential coal-bearing strata.

The oldest coal zone is in the Dakota Formation, present in T.3 N., R. 19 W. sec 1 & 2 and in T. 6 N., R. 18 W. sec 18. These coals are poorly exposed, but appear to be thin, 2-3 ft (Ø.6-.9 m) maximum thickness and generally discontinuous. No analyses are available from these coals and no resources were calculated for them.

Four coal zones present in the Moreno Hill Formation, Antelope, Cerro Prieto, Rabbit, and Twilight, are identifiable from outcrop and geophysical log data. The lowest zone is the Antelope coal zone in the 5Ø ft (15.1 m) interval above the top of the Atarque Sandstone. The coals of this zone do not crop out in the eastern portion of the field, but are found in some drill holes. In the western portion of the field only the Antelope zone is present in the Moreno Hill Formation. Based on available data, there is no trend in thickness for these coals, other than that the thickest coals are in the western portion of the field. Fig. 3 shows the areal distribution of Antelope Zone coals, with the thicknesses indicated. Both drill and outcrop data indicate that these areas are separated by non-coal bearing intervals. This zone consists of at most two beds, with their average aggregate thickness being 2.8 +/- 1.3 ft (.84+/-.39 m). They

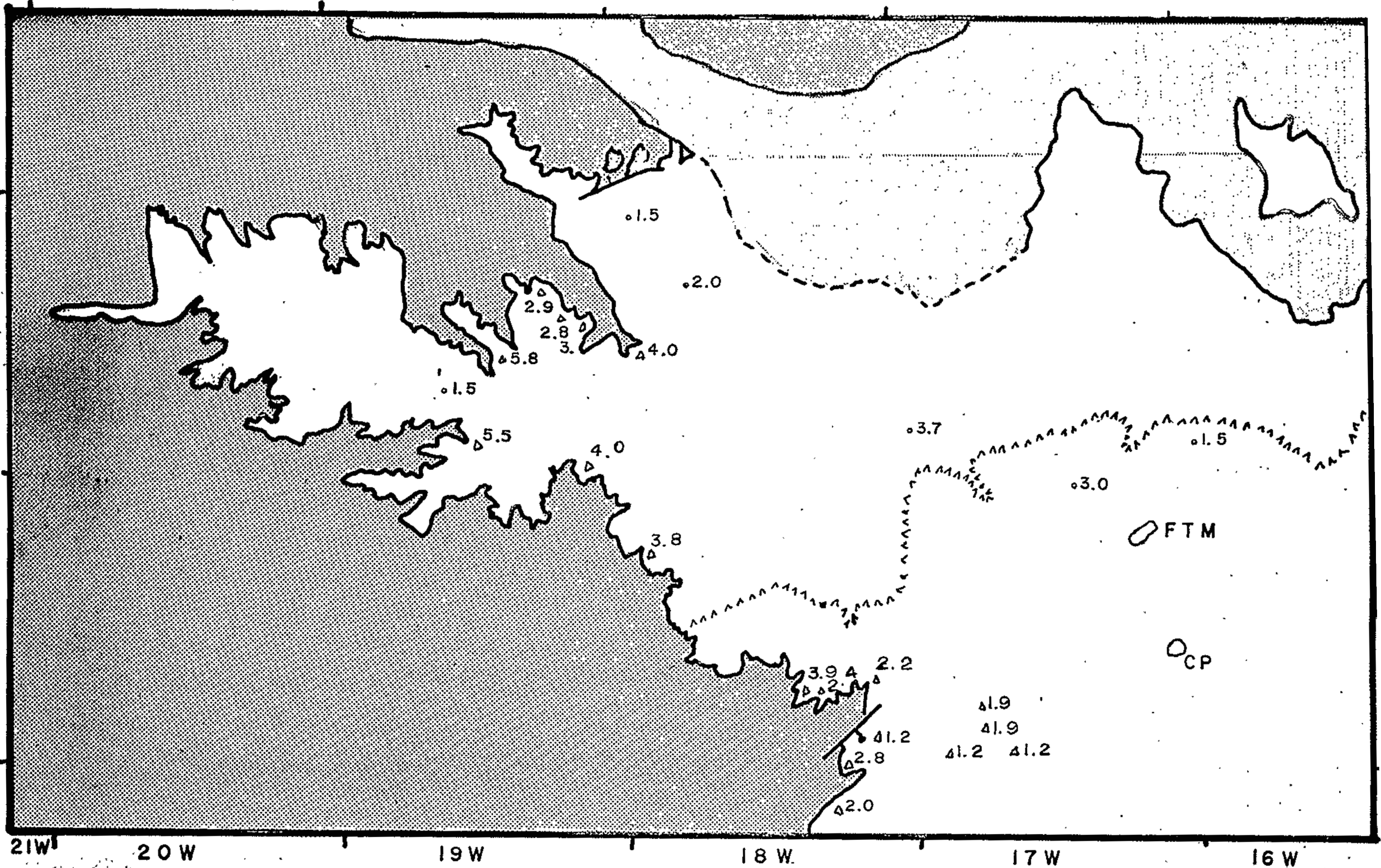


FIG. 3

OCCURRENCE OF ANTELOPE ZONE COALS

BASALTS

MARINE UNITS

MORENO HILL

vvv MESA ESCARPMENT

FAULT

∘ 1.5 DRILL HOLE THICKNESS

Δ 1.5 OUTCROP THICKNESS

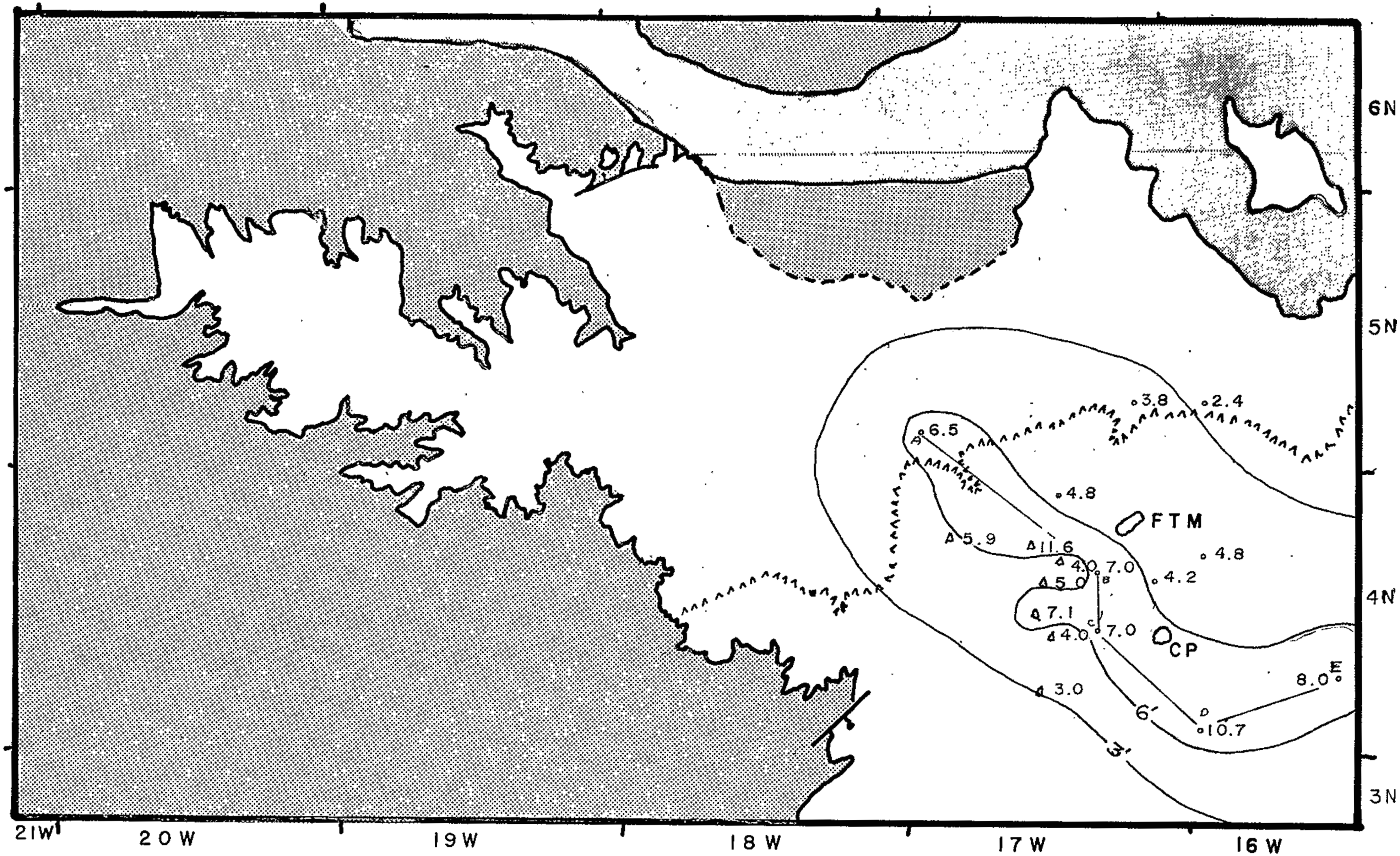
FTM FLAT TOP MESA

CP CERRO PRIETO

FIG 3

appear to be thin beds, averaging 1.9 +/- .9 ft (.6 +/-.3 m), that rapidly grade into carbonaceous shales. Locally the Antelope Zone coals are thick, up to 5.8 ft (1.8 m) in an outcrop in T. 5 N., R. 18 W. sec. 31, but these thicknesses do not continue for any distance laterally. In some outcrops these beds have thin kaolinitic layers, which often cover the entire thickness of the beds. The demonstrated reserves in the Antelope zone amount to 47 million tons, with 26 million tons having a stripping ratio of less than 20:1. The few analyses available for these coals, show a high ash content (22.1%), and a low as received Btu content of 9454 Btu/lb. The moist mineral-matter free Btu value is 11,194, indicating a rank for this zone of high volatile C Bituminous. Sulfur content for these coals is only .7 +/-.1%. Table 1B gives a complete breakdown of the average analyses available for the Antelope Zone.

The next zone above the Antelope Zone is the Cerro Prieto zone. In the eastern portion of the field this is approximately 150 ft above the Atarque Sandstone. This zone is not present in the western portion of the field, but attains a thickness of 76 ft (22.9 m) in the eastern portion of the field. A maximum of four beds comprise the Cerro Prieto zone, with coal beds ranging in thickness from 1 to 9.5 ft (.3 to 2.9 m). Fig. 4 is an isopach map of the total coal thickness of the Cerro Prieto zone. This map shows the thickest coal to have a northwest-southeast trend. There is one major bed in the Cerro Prieto zone that varies from 6 to 10 ft (1.8 to 3.0 m) in thickness and is readily recognizable, having two thin kaolinitic partings. These partings are uniformly 22 in (55 cm) apart, with the upper parting being .25



DISTRIBUTION OF CERRO PRIETO ZONE COALS

BASALT FLOW
MARINE UNITS
MORENO HILL FM

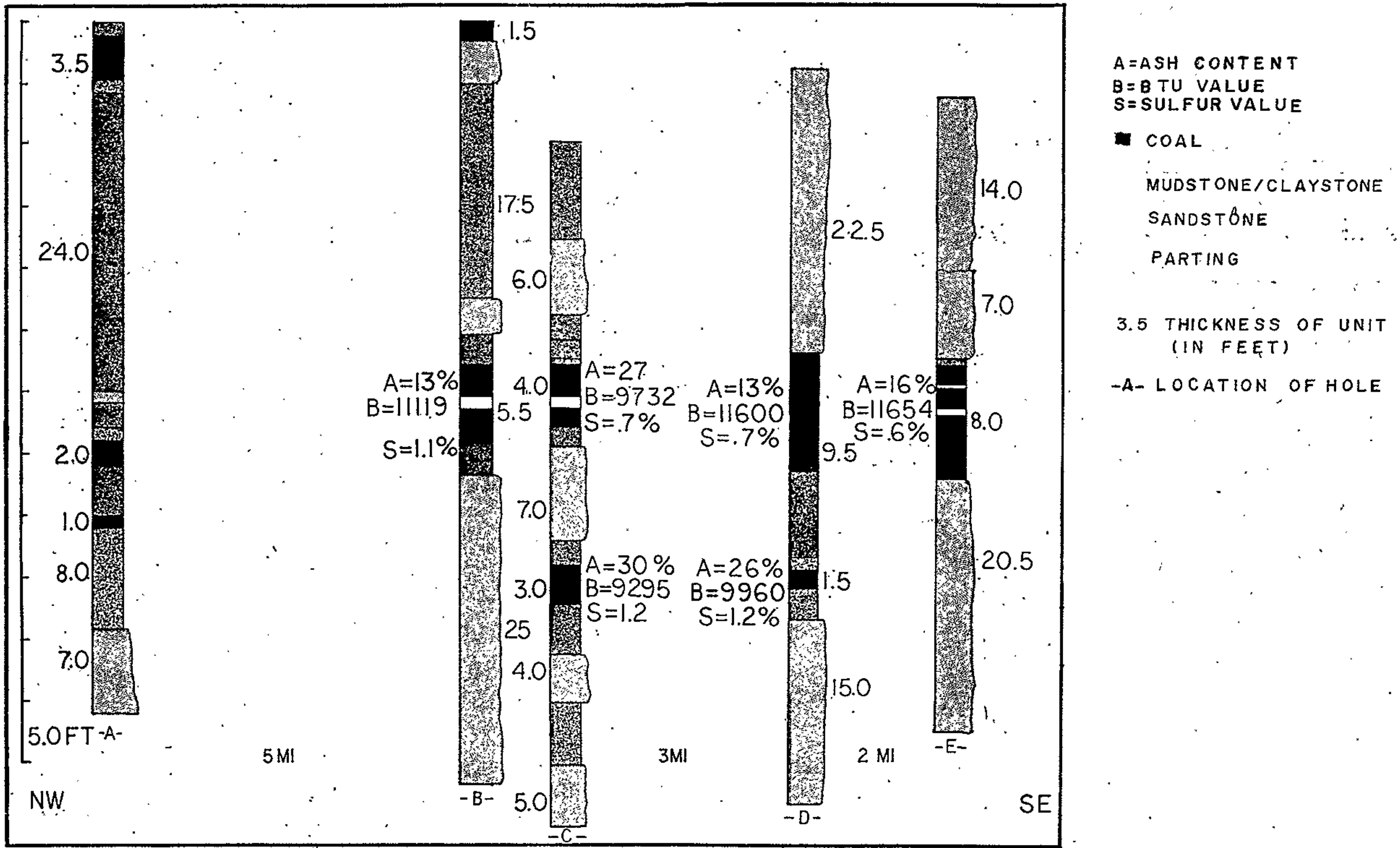
vvv MESA ESCARPMENT
FAULT
∘1.5 DRILL HOLE THICKNESS
Δ1.5 OUTCROP THICKNESS

FTM=FLAT TOP MESA
CP=CERRO PRIETO
A–B–C LINE OF COLUMNAR SECTION

FIG 4

in (.6 cm) thick and the lower parting being .5 in (1.2 cm) thick. This bed is referred to as the Double T bed. This coal bed with partings is best exposed in a 7.5-ft (2.3 m) bed in a bulldozer cut in sec. 9, T. 4 N., R. 17 W. and in a 9.5 ft (2.9 m) coal cored in T. 4 W., R. 16 W., sec 31. The three remaining coal beds present in the Cerro Prieto zone are discontinuous and grade laterally into carbonaceous shales. Fig. 5 is a series of columnar sections through the Cerro Prieto Zone, showing the distribution of these thicknesses.

The northwest portion of the Cerro Prieto quadrangle contains numerous thin beds of coal. These coals, although laterally continuous, rarely exceed 3 ft (.9 m) in thickness. Coals in this area are interbedded with channel sandstones which in many cases cut into the coals. The vertical interval between sandstone bodies is generally less than 15 ft (4.5 m). This high frequency of thinner coals with numerous channels indicates a higher intensity of channeling, restricting coal swamp development. In the area south of Flat Top Mesa, the frequency of channel sandstones is much less, with the vertical interval being 30+ ft (9.0 m). The Cerro Prieto zone coals in the area south of Flat Top Mesa are generally 5 to 6 ft (1.5 to 1.8 m) thick. Where the thickest coals occur, in T. 4 N., R. 16 W., sec 31, there are only three sandstones within a 260 ft (78.4 m) vertical interval. These thicker coals associating with thicker sands is due to a more stable area that allowed for thicker coal development. This sequence is graphically represented in Fig. 5. A drill hole located in T. 5 N., R. 17 W., sec 31 penetrates the entire lower Moreno Hill Formation the Cerro Prieto zone is present as three



COLUMNAR SECTION SECTION CERRO PRIETO ZONE

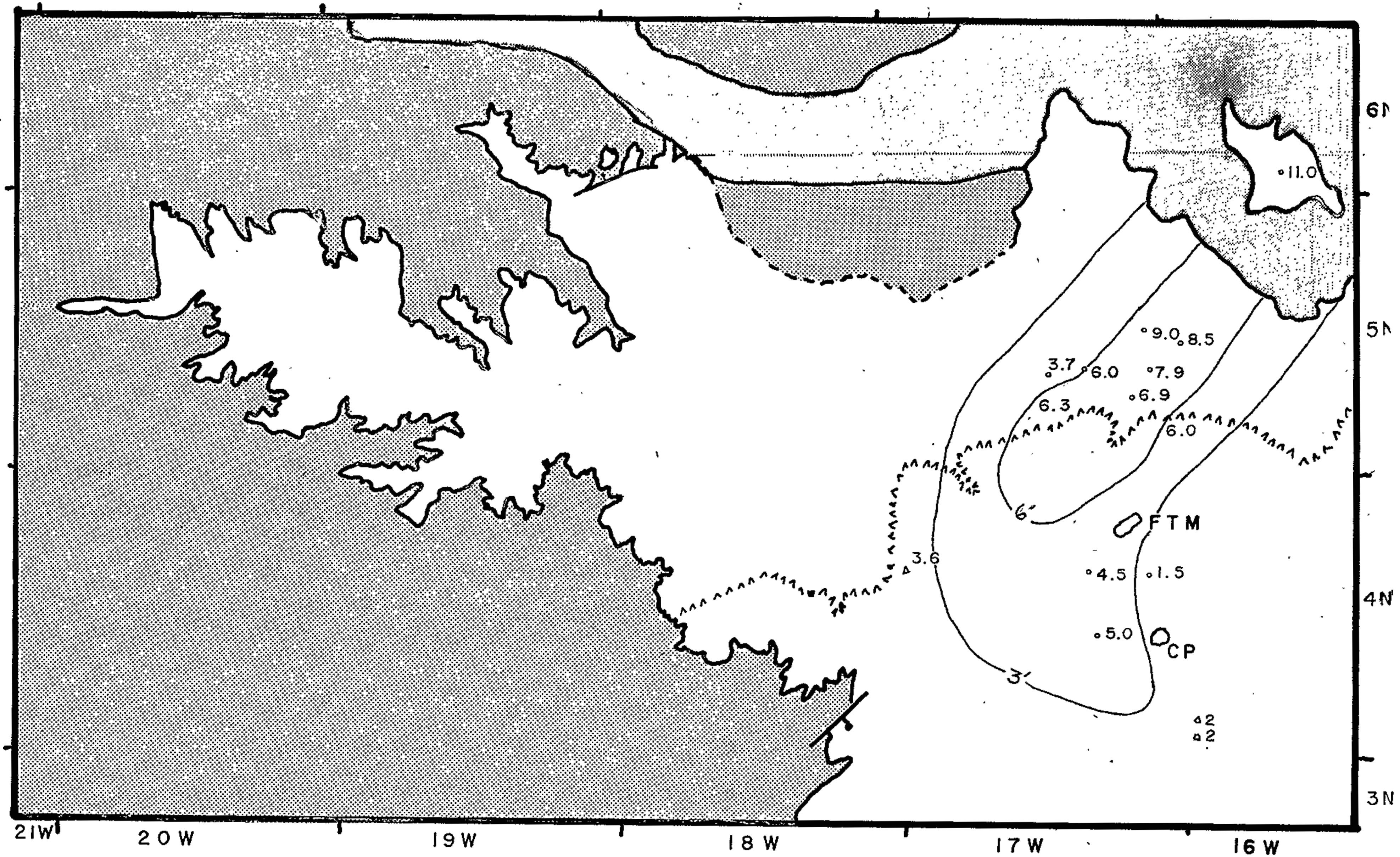
FIG 5

thin beds over a 40 ft interval. This indicates a western boundary for this zone. There are only two 1 ft thick sands present in this interval.

The average total coal thickness for the Cerro Prieto zone in the study area is 5.2 +/-3.2 ft (1.8+/1.0 m), and the average individual bed thickness is 3.6 +/-1.9 ft (1.1 +/-.6 m). The known demonstrated reserve base for the Cerro Prieto zone is 114 million tons, of which 76 million tons has a stripping ratio of less than 20:1. Ash content of coals from this zone is 16.9 +/-6.7%, an average moisture content of 8.0 +/-4.9% and an average sulfur content of .8 +/-.3%. The Double T bed does not vary significantly from the other Cerro Prieto coals, except in ash content. This bed has an average ash content of 13.9 +/-6.7%. Coals from this zone have an average as received heating value of 10,069 BTU/lb, and an average moist mineral matter-free Btu of 11,496 Btu/lb, indicating a rank of high volatile C Bituminous. Table 1b gives analyses of these coals.

The next highest coal zone in the Moreno Hill Formation is the Rabbit zone, located approximately 290 ft (87.4 m) above the top of the Atarque Sandstone, and approximately 60 ft (18.1 m) below the base of the middle member of the Moreno Hill Formation in the eastern part of the Salt Lake field. The thickness of this zone varies from west to east, as does the Cerro Prieto zone, being 3.0 ft (.9 m) thick in the westernmost extent and 70 ft (21.1 m) thick in the east. The Rabbit zone has up to four beds; generally the second coal from the bottom is the thickest. One bed has a single kaolinitic parting, which distinguishes this zone from the lower Cerro Prieto zone; this bed is referred to as the Lagus bed. The kaolinitic parting has a uniform thickness of .5 inch (1.2 cm), and is found near the top of the Lagus bed. This bed has a maximum thickness of 12.0 ft (3.6 m), in an outcrop in T. 5N. R. 17 W. sec 27. In a drill hole in T. 5N. R. 16 W. sec 30, this bed is 7.5 ft (2.3 m) thick; the bed is not present in T. 5N. R. 16 W. sec 23, indicating a rapid thinning to the east. Coal in T. 6N. R. 16 W. sec 28, also contains a single tonstein indicating northeast trend for the Rabbit zone. In this drill hole, 11 ft (3.3 m) of coal was present over a 60 ft (18.1 m) vertical interval as three beds. Coal present in this hole does not continue to the north, as shown from drilling.

Fig. 6 is an isopach map of total coal thickness in the Rabbit zone, shows the trend of greatest coal thickness to be northeast-southwest. In contrast to Cerro Prieto Zone coals, the thickest coals are located north of Flat Top Mesa. The Rabbit zone does not extend north of T. 5 N., R. 17 W. sec 12, where it is present as a 2.0 ft (.6 m) bed. To the south Rabbit zone coals are found as a 2.0 ft (.6 m) outcrop in T. 4N. R. 16 W. sec 31. Roybal (1982) noted the presence of Rabbit coals on the Tejana Mesa quadrangle. The average total bed thickness in the Rabbit zone is 4.4+/-3.1 ft (1.3+/-1.0 m), while the average single bed thickness is 3.2+/-1.9 ft (1.0+/-.6m). The known demonstrated reserve base for the Rabbit zone is approximately 70 million tons of coal, with 25 million tons having a stripping ratio of less than 20:1. The average as-received Btu value for this zone is 10,083 Btu/lb, with the average moist, mineral matter free value being 11,282 Btu/lb, indicating a rank of High Volatile C Bituminous. The average as-received ash is 15.5+/-



DISTRIBUTION OF RABBIT ZONE COALS

BASALT FLOW
MARINE UNITS
MORENO HILL FM

vvv MESA ESCARPMENT
FAULT
1.5 DRILL HOLE THICKNESS
1.5 OUTCROP THICKNESS

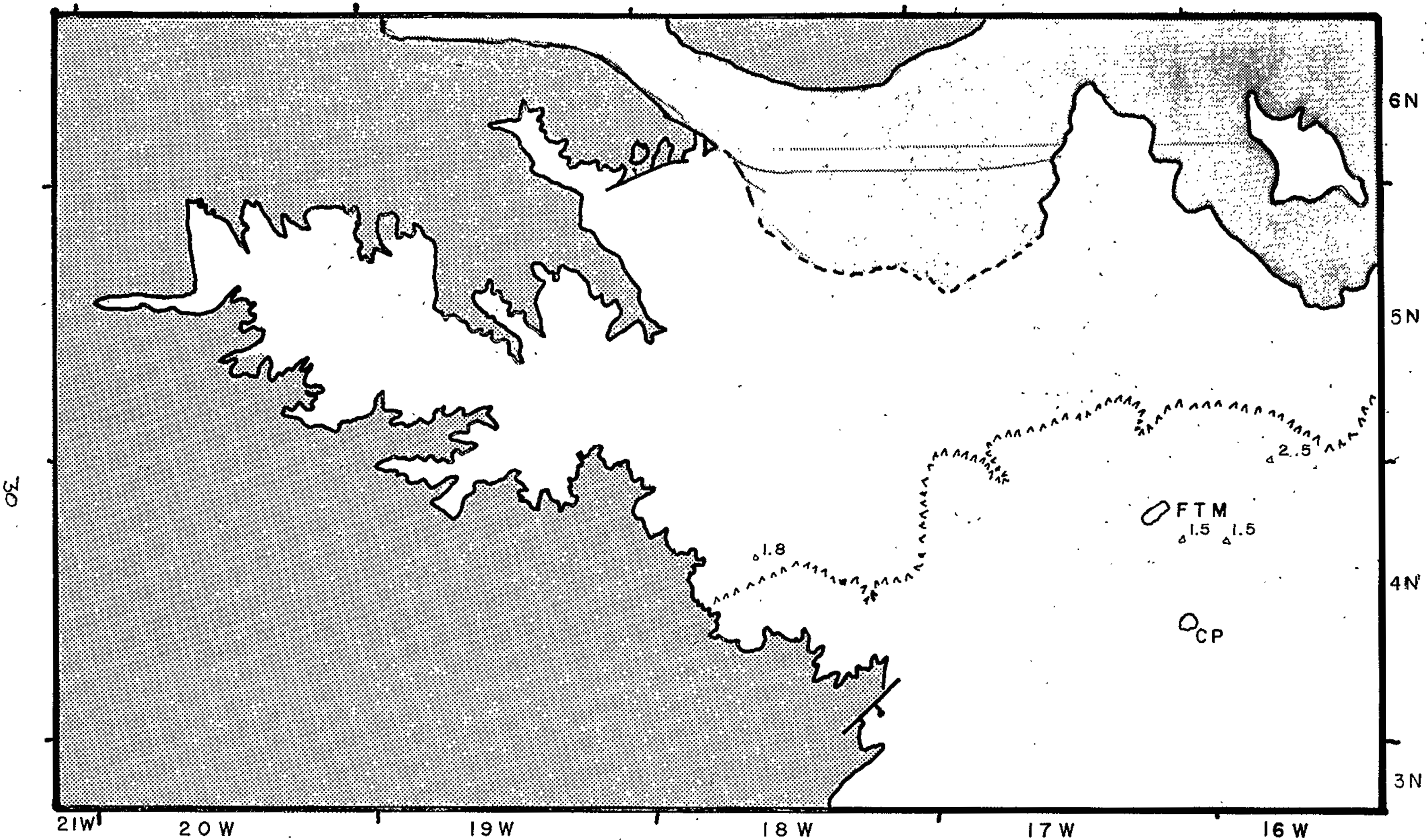
FTM=FLAT TOP MESA
CP=CERRO PRIETO

FIG. 6

5.1% with a moisture content of 8.5+/-5.8%. Average analyses are given in Table 1b. No ultimate analyses are available for this zone, however these averages are given in Table 1b for comparison with other zones.

The highest coal zone in the Moreno Hill Formation is the Twilight zone, found in the 50 ft (15.1 m) interval above the middle member of the Moreno Hill Formation, the upper member of the Moreno Hill Formation. This zone consists of from 1 to 3 beds, which are up to 2.5 ft (.9 m) in thickness in the study area. From the data available, no beds in the Twilight zone are traceable for any extent. Fig. 7 shows that this zone is restricted to the eastern portion of the field. Contouring was not attempted due to their isolated nature. The average bed thickness is 1.8+/-.5 ft (.7+/-.2 m). The known demonstrated reserve base for the Twilight zone was not calculated due to a lack of data. Coals from this zone have an average as-received ash content from outcrop of 24.9+/-3.9%, moisture of 3.1+/-.4%, and a Btu value of 8926+/-1136. This coal has a moist mineral matter free Btu of 12,229, indicating a rank of high volatile Bituminous B.

The mineral content of the Moreno Hill Formation coals, as determined by x-ray diffraction data, consists of calcite, ilmenite, kaolinite, quartz, gypsum, rutile, and pyrite. The kaolinite and quartz occur as finely disseminated grains within the coals. Pyrite, calcite, and gypsum are found largely as sheet-like growths along cleat surfaces. Present on outcropping coals and in shallow cores is gypsum, probably the result of weathering. At present, none of the zones can be characterized



DISTRIBUTION OF TWILIGHT ZONE COALS

BASALT FLOW
MARINE UNITS
MORENO HILL FM

vvv MESA ESCARPMENT
FAULT
o 1.5 DRILL HOLE THICKNESS
Δ 1.5 OUTCROP THICKNESS

FTM=FLAT TOP MESA
CP=CERRO PRIETO

FIG. 7

based on mineral content of the coal. Some macroscopic difference is noted. The amount of kaolinitic partings in the Antelope zone outcrops indicate a high percentage of kaolinite in the mineral content.

Samples from cuttings and core were taken from the four coal zones found in the Moreno Hill Formation. These samples were analyzed for proximate, ultimate, and Btu values according to ASTM procedures. Table 1b shows the results of these analyses for each of the coal zones on an as-received basis. Coals found in the Rabbit and Cerro Prieto zones are the best quality. These two zones are very similar in quality, showing very little difference in proximate or ultimate values. The ash content of both the Antelope and Twilight zones are considerably higher than that of the Rabbit or Cerro Prieto zones while the Btu values are lower.

CONCLUSIONS

The major coal-bearing formation in the Salt Lake Coal Field is the Moreno Hill Formation. This and the other Cretaceous units show a regional dip of approximately 5 degrees to the southeast. The major area of faulting is in the Santa Rita Mesa area. Faulting has little influence in the eastern part of the field where the coals of the lower Moreno Hill have the greatest stripping potential.

The northern half Salt Lake coal field contains an estimated 390 million tons of coal. This resource occurs in four coal zones in the Moreno Hill Formation. These zones are, from bottom to top: Antelope, Cerro Prieto, Rabbit, and Twilight. The

Antelope and Twilight zones have small resources (78 and 30 million tons respectively), and high stripping ratios, with the Antelope zone averaging 66:1 and the Twilight zone averaging 48:1. The Cerro Prieto and Rabbit zones have the greatest mining potential. The Cerro Prieto zone has a demonstrated resource of 133 million tons with an average stripping ratio of 23:1. The Rabbit zone has a demonstrated resource of 130 million tons with an average stripping ratio of 21:1.

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S.W. 1/4 FENCE LAKE 1:100,000 SHEET

SCALE 1:50,000

CONTOUR INTERVAL = 20 METERS

NMBMMR: OPEN FILE 207

PLATE I

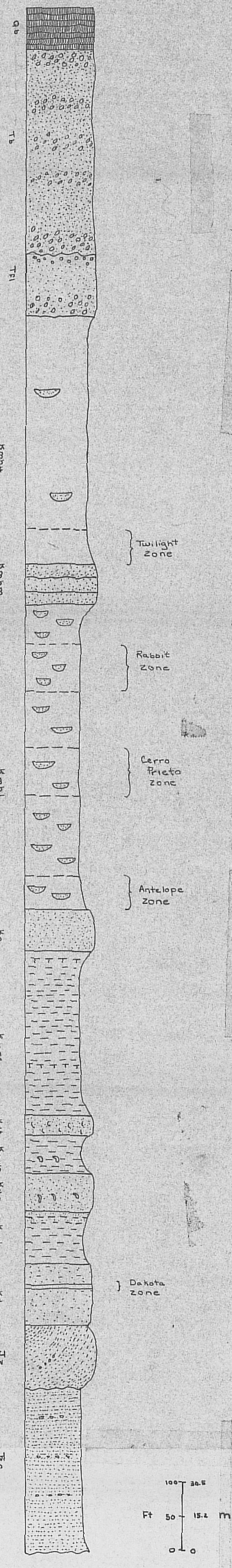
LEGEND

Qal - QUATERNARY ALLUVIUM
Qb - QUATERNARY BASALT
Tb - BIDAHOCHI
Tfl - FENCE LAKE
Ti - TERTIARY INTRUSIVE
KMhu - MORENO HILL upper member
Kmhm - MORENO HILL middle member
Kmhl - MORENO HILL lower member
Ka - ATARQUE SANDSTONE
Kmrs - MANCOS SHALE rio salado tongue
Kdt - DAKOTA SANDSTONE twowells tongue
Kmwa MANCOS SHALE whitewater arroyo tongue
Kdp - DAKOTA SANDSTONE paguate tongue
Kml - MANCOS SHALE lower part
Kdm - DAKOTA SANDSTONE main body
Jz - ZUNI SANDSTONE
Trc CHINLE
Trcp CHINLE petrified forest member

SYMBOLS

DIP & STRIKE | FAULT | INFERRED FAULT

Generalized Geologic Column - Fence Lake 1:50,000 Geologic Map



Quaternary basalt

Bidahochi Formation - Light gray, coarse to fine-grained sandstones, highly variable light brown sands, and pebbly conglomerates. Fair to poor cementation with calcareous cemented lenses and volcanic clasts. Conglomerates consist of basaltic and rhyolitic pebbles and minor amounts of quartzite pebbles.

Fence Lake Formation -
- Upper unit - Poorly-sorted, very fine to coarse-grained, grayish-pink, calcareous sandstones containing quartz, feldspar and mafic mineral fragments.
- Lower unit - Coarse conglomerate in a calcareous sandstone matrix. Pebbles, cobbles, and boulders are subrounded to subangular basalts, rhyolites, cherts, quartzites and petrified wood fragments.

Moreno Hill Formation -
- Upper Member - Green to yellow-gray to light-gray fluvial mudstones, claystones and siltstones, with a few thin silty, fine-grained sandstones, and a single zone of thin coals.
- Middle Member - Laterally continuous, pinkish-yellow, subangular, medium- to coarse-grained fluvial quartz sandstones, with subangular feldspar fragments. Sandstones are planar to trough crossbedded.
- Lower Member - Non-marine series of yellow-gray, medium to fine-grained sandstones, interbedded dark-gray to black mudstones and claystones, carbonaceous mudstones and three predominant coal zones.

Atarque Formation -
- Upper unit - Marine, yellow fine-grained, intensely burrowed sandstones.
- Middle unit - Highly crossbedded sandstones.
- Lower unit - yellow, flat-bedded, burrowed sandstone, coarsening upward to fine to very fine-grained fossiliferous sandstones.

Mancos Shale -
- Rio Salado Tongue - Offshore marine, olive-gray to yellow-brown shales with thin fossiliferous limestone concretions, calcarenites, and glauconite beds.

Dakota Sandstone -
- Twowells Tongue - yellow-brown to dark-gray, fine to medium-grained sandstone, planar crossbedded at top. Middle: very fine to fine-grained, massive, burrowed sandstone. Bottom: fine-grained, poorly bedded, sandstones.

Mancos Shale
- White Water Arroyo Tongue - Medium dark gray fossiliferous shales and siltstones, thin bentonite beds and cone-in-cone limestone concretions.

Dakota Sandstone -
- Paguate Tongue - Yellow to grayish-yellow, fine-grained sandstone. Sandstone is poorly-sorted, poorly cemented, with massive to irregular bedding. Fossiliferous.

Lower Mancos

Mancos Shale -
- Lower Part - Marine dark gray to dusky yellow shales with interbedded siltstones, and limestone concretions.

Dakota Sandstone -
- Main body - Marine to non-marine. Upper 2/3 yellow-gray to gray claystones and siltstones with a few resistant very fine to fine-grained calcareous sandstones. Claystones are fossiliferous. Lower 1/3: fine to coarse-grained sandstones. In both upper and lower portions, carbonaceous siltstones, claystones, and coals occur locally.

Zuni Sandstone - Eolian, white to pink, fine to medium-grained sandstone. High angle crossbedding and a few pebble conglomerates concentrated along bedding planes within the unit.

Chinle Formation - Non-marine grayish-red to reddish-brown, light green to grayish green and purple mudstones, siltstones and claystones. Scattered lenses of sandstones and conglomerates.