THE HYDROGEOLOGY OF THE SACRAMENTO MOUNTAINS BETWEEN CLOUDCROFT AND ALAMOGORDO, OTERO COUNTY, NEW MEXICO

Report H-17

by

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ABSTRACT

This report covers the hydrogeology of a 77 square mile area along the western flank of the Sacramento Mountains in southeastern New Mexico. The area lies between the city of Alamogordo and the village of Cloudcroft, New Mexico; the communities of High Rolls, Mountain Park, and La Luz lie within its boundaries. Water-level measurements, driller's logs, chemical analyses of water, and precipitation records have been used to describe the groundwater system of the area. Six water-bearing formations have been identified -- the Yeso, Abo, Bursum, Holder, Beeman, and Gobbler formations. Of these, the Yeso was shown to be the one with the highest yield while the Abo is the most frequently drilled due to its areal distribution. Springs are also abundant in the area, supplying a large amount of the domestic water supply. These are most often located near formation contacts, but a few are also found issuing from the Abo and Yeso formations. The quality of water which both the springs and wells produce is very poor. The flow direction has been shown to be predominantly towards the west, with the waters issuing from the formations as seeps or springs when they intercept the mountain's slope. It is possible, however, that some water along the eastern edge flows towards the east, recharging the Roswell Basin. The westward flowing waters recharge the Tularosa Basin.

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Special thanks goes to Amy Harrison for her encouragement and support throughout the project and to my parents, Jim and Anna Mae Jennings, for their support.

INTRODUCTION

AREA AND PHYSIOGRAPHY:

The study area encompasses approximately 77 square miles (11 miles east to west and 7 miles north to south) of the western escarpment of the Sacramento Mountains in Southeastern New Mexico (Figure 1). The area extends from latitude 32°55'N. to 33°00' N. and longitude 105°45'E. to 105°56' E., including portions of Townships 15 and 16 S., Ranges 10, 11, and 12 E.. The area is covered by the following U.S. Geological Survey topographic maps:

Alamogordo (1:100,000)
Alamogordo (1:62,500)
Alamogordo North (1:24,000)
High Rolls (1:24,000)

The area's eastern boundary is along the 105°45'E. longitude line, just west of the town of Cloudcroft and coinciding with both the crest of the mountain range and the western boundary of a similar study conducted by M. Wasiolek and G.W. Gross in 1983. The western boundary roughly parallels the edge of the large fault scarp which marks the geologic boundary between the Sacramento Mountains to the east and the Tularosa Basin to the west. This boundary lies just east of the city of Alamogordo and the village of La Luz, New Mexico. The northern boundary follows both the 33°00' N. parallel and the southern limit of the Mescalero Apache Indian Reservation. As access to the reservation is limited, this formed a somewhat natural boundary. The southern boundary was chosen more arbitrarily, but coincides with the periphery of the city of Alamogordo and with Marble Canyon. Development south of this area is very limited so that if the area had been extended, data would be very scarce. Hydrologically, the entire study area is situated between the Tularosa Groundwater Basin to the west and the Roswell Groundwater Basin to the east.

The Sacramento Mountains extend for about 30 miles along the east side of the Tularosa Basin, merging with Sierra Blanca to the north and declining towards the south into a low ridge which extends to the Hueco Mountains, located near the New Mexico - Texas border (Darton, 1928). They tend slightly west of north and rise abruptly 3000 to 5000 feet above the Tularosa Basin. The range averages 9000 feet above sea level for over 20 miles, rising to the height of 9700 feet at their highest point (Otte, 1959).

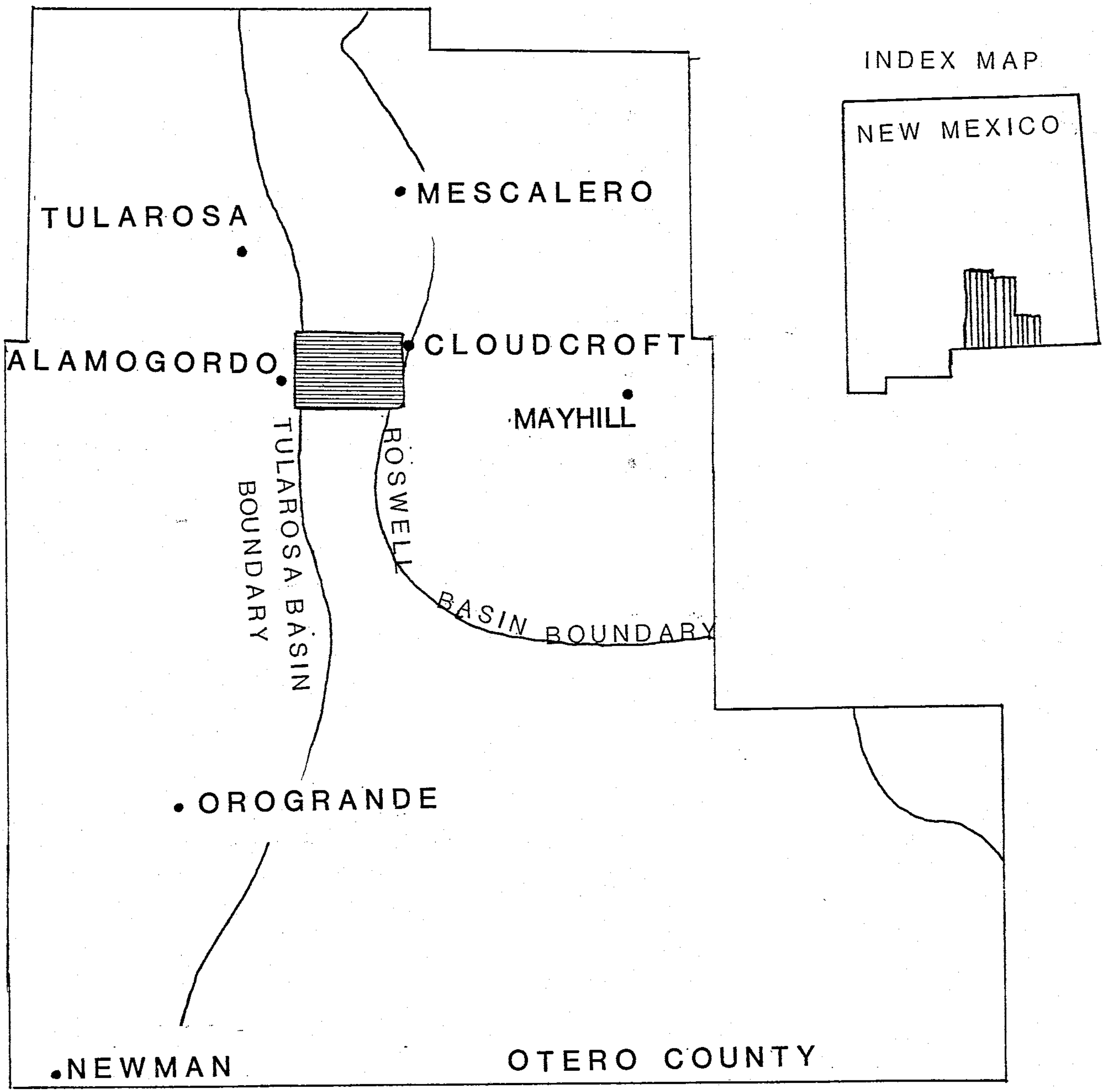


Figure 1. Location of the study area.

To the east of the crest, the mountains gently slope down to the Pecos River, some 80 miles away and 6000 feet lower in elevation, as shown in Figure 2 (Pray, 1954).

The Tularosa Basin is a long, narrow, intermontane basin, approximately 200 miles long and ranging between 24 and 60 miles wide (Canover et al, 1954). It is an interior plain of low relief (4000 to 4400 feet above sea level) which lies to the west of the steep fault zone marking the western edge of the study area. The basin has a hot desert climate, receiving 10 to 12 inches of rain annually, mostly during summer thunderstorms. The aquifer within the basin is a bolson fill of unconsolidated clays, sands, and gravel. The majority of the recharge comes from the flood waters of streams in the Sacramento Mountains and the Rio Tularosa (Busch, 1957).

The Roswell Basin bounds the study area to the east, encompassing an area from the crest of the Sacramento Mountains, east to the escarpment paralleling the east side of the Pecos River. The basin is marked by the broad, gently dipping slope of the east side of the Sacramento Mountains. Large quantities of water are withdrawn for agricultural and domestic purposes from the Yeso and San Andres Formations within this basin.

Three small communities lie within the boundaries of the study area. High Rolls and Mountain Park are both noted for their fruit, growing a supply of apples, as well as pears, peaches, and cherries. La Luz is the other community which extends into the study area. Even though the village proper is located on the alluvial plains of the Tularosa Basin, much of its population resides to the east in La Luz Canyon and on Burro Flats. The extended community stretches for over five miles to the east, acting mainly as a residential area, but also supporting a small number of limited orchards and small businesses.

A large portion of the study area is within the Lincoln National Forest (see Figure 3) and thus its water resources are relatively undeveloped. As a result, only a limited amount of data was available for these areas. Thus, the majority of the well data was gathered from the High Rolls and Mountain Park communities, along La Luz Canyon, and on Burro Flats. Springs, however, have been developed throughout the area and provide water to many of the more remote areas as well as piped water for several developed areas. Data from these springs is limited, but will be used where available.

The vegetation on the western flank of the Sacramento Mountains changes significantly between Alamogordo, at the base of the uplift, and Cloudcroft, near the crest. In this short span of only sixteen miles, there is approximately 4500 feet of elevation gain and three

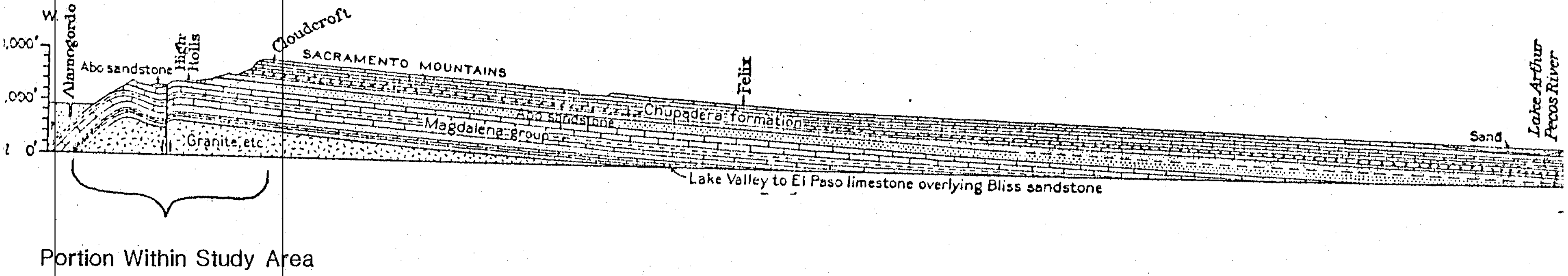


Figure 2. Geologic cross-section of the Sacramento Mountains between Alamogordo and the Pecos River (From Darton, 1922).

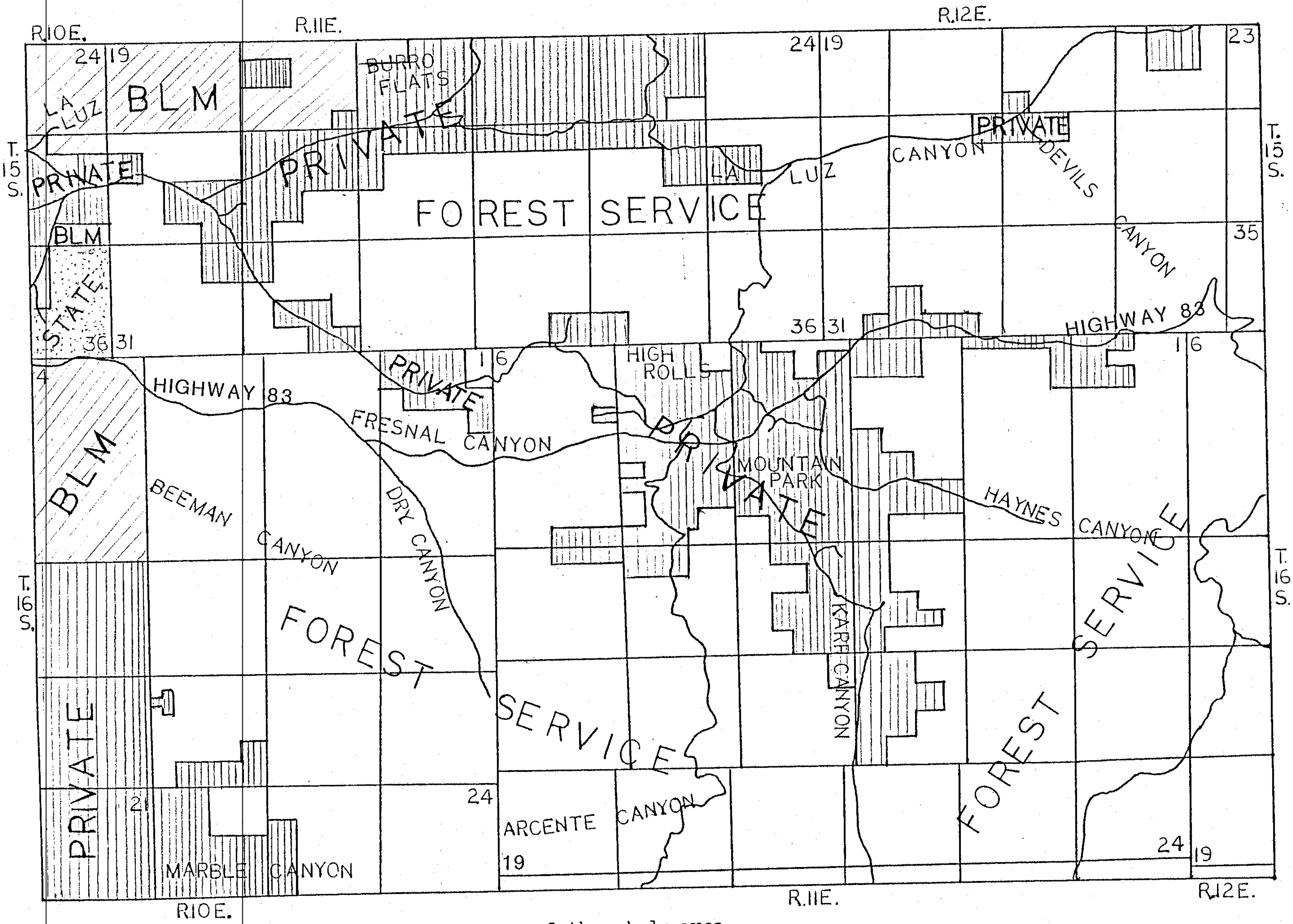


Figure 3. Land ownership map of the study area.

different life zones. At the lower altitudes, between 4000 and 6000 feet, lies the Upper Sonoran Zone, characterized chiefly by sagebrush, saltbush, scrub oaks, and scrub cedars, with a few pinon and juniper trees at the higher elevations. In this zone, rainfall is scarce during much of the year and evaporation rates are high. Except for small forested areas, shrubs usually stand only a few feet high and are thinly spaced. Near 6000 feet, the pinon and juniper forests thicken as the Transition Zone begins. Further up in this zone ponderosa pines are also present. The upper-most altitudes (above 7000 feet) are occupied by a third life zone, the Canadian Zone. These forests include ponderosa pine, Douglas and white fir, southwestern white pine, blue spruce, and aspen. It is the forests of these last two zones which compose much of the study area.

CLIMATE:

The area's climate reflects the large change in altitude across the area. Alamogordo, at the base of the Sacramento Mountains and along the western edge of the study area, has a climate that is varied from that of Cloudcroft, located near the crest of the range and approximately 4500 feet higher in elevation. Taking this into account, climatic data have been taken from the Climatological Records of New Mexico (compiled and published by the National Oceanic and Atmospheric Administration) for three locations of varying altitudes. Monthly precipitation data for 1960 to 1984 are given in Tables 1 , 2, and 3 as recorded at the Alamogordo, Mountain Park, and the Cloudcroft weather stations (locations listed in Table 4). Table 5 gives the total annual precipitation at each station while this data is shown graphically in Figure 4. Average annual precipitation ranges from 11.24 to 26.86 inches, over 50% of which falls during thunderstorms occurring in July, August, and September. The rest is fairly evenly distributed throughout the year as indicated in Table 6 and Figure 5. In the eastern portions of the area much of the winter precipitation comes in the form of snow.

Temperature variations also reflect the change in elevation across the area. The annual average temperature at Alamogordo is 61.7°F., at Mountain Park it is 52.9°F., while Cloudcroft's is 45.0°F.. During the winter months, Cloudcroft is usually about 10° colder than Alamogordo and 5° cooler than Mountain Park. During the summer months, Cloudcroft is 15 to 20° cooler than Alamagordo and 5 to 10° colder than Mountain Park. Average temperatures are

TABLE 1. TOTAL MONTHLY PRECIPITATION FOR THE ALAMOGORDO WEATHER STATION

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1960	1.41	0.30	0.14	T	0.66	0.98	2.27	0.55	0.74	0.79	0.09	1.54	9.47
1961	0.53	0.03	0.61	T	0.03	1.34	1.16	3.18	1.80	0.09	1.24	1.29	11.54
1962	1.29	0.49	0.19	0.21	T	0.29	4.53	0.79	2.85	1.04	0.44	0.84	3.16
1963	0.34	0.35	0.00	0.23	0.02	0.01	1.38	2.54	2.03	1.34	0.15	0.03	8.24
1964	0.15	0.43	0.42	0.17	0.11	T	0.99	1.32	2.85	0.02	T	0.28	6.74
1965	0.59	0.56	1.01	0.20	0.04	0.88	2.22	3.03	2.14	0.51	0.08	1.76	13.02
1966	0.96	0.48	0.02	0.33	0.28	2.19	2.55	1.51	1.18	0.01	0.15	0.10	9.76
1967	0.00	0.51	0.10	0.02	0.18	2.21	2.39	1.68	1.35	0.02	0.92	1.47	10.85
1968	0.89	0.99	1.73	0.04	0.22	0.09	3.26	2.90	0.01	0.19	1.20	0.43	11.95
1969	0.44	0.74	0.34	0.04	1.37	0.12	2.59	3.00	2.04	2.19	0.10	1.21	14.38
1970	0.09	0.40	0.74	0.03	0.56	0.53	1.09	1.00	0.23	0.87	T	0.34	5.88
1971	0.05	0.28	T	0.86	0.15	0.64	3.01	1.89	1.26	2.22	1.28	0.76	12.40
1972	0.80	0.07	T	0.00	T	1.32	1.69	5.73	2.50	4.45	0.64	0.83	18.03
1973	0.95	0.79	2.16	0.00	0.65	1.29	4.29	0.56	0.14	0.14	0.03	T	11.00
1974	0.94	0.14	0.22	0.05	0.00	0.85	4.22	1.22	2.39	5.66	0.28	0.76	16.73
1975	0.54	0.80	0.74	0.02	0.02	0.53	0.96	0.97	6.22	0.00	0.33	0.00	11.13
1976	0.12	0.16	0.04	0.55	2.36	0.47	6.36	0.52	3.64	1.25	0.81	0.00	16.28
1977	0.84	0.29	0.40	1.15	0.53	0.31	0.93	2.58	1.00	1.65	0.43	0.33	10.44
1978	1.30	1.15	0.33	0.07	1.19	1.38	1.07	2.63	1.80	2.19	2.91	1.48	17.50
1979	1.19	0.77	T	0.00	1.23	1.99	2.25	3.93	1.63	0.02	0.00	0.96	13.97
1980	0.88	0.79	0.15	0.07	0.56	0.15	0.29	3.74	3.29	0.14	0.10	0.09	10.25
1981	0.79	0.66	0.60	0.00	0.09	0.68	2.23	3.53	2.20	0.81	0.64	0.33	12.56
1982	1.20	0.29	0.00	0.00	0.66	0.41	1.25	2.26	4.01	0.00	0.33	2.36	12.77
1983	1.40	0.78	0.28	0.74	0.29	1.30	1.52	0.29	1.00	1.68	2.37	0.68	12.33
1984	0.15	0.00	0.05	0.18	0.73	1.87	1.62	4.13	0.22	3.27	2.12	3.01	17.35
AVE	0.65	0.50	0.44	0.14	0.48	0.90	2.38	2.29	1.67	1.24	0.61	0.80	11.24

TABLE 2. TOTAL MONTHLY PRECIPITATION FOR MOUNTAIN PARK WEATHER STATION

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1960	4.80	0.35	0.00	T	1.16	1.25	7.17	4.22	1.42	0.93	T	2.07	23.37
1961	1.70	0.20	2.40	0.00	0.00	3.30	5.46	2.88	3.90	T	1.71	4.50	26.05
1962	2.01	0.65	0.25	0.45	0.00	0.00	8.94	1.85	3.41	1.17	0.87	1.25	20.85
1963	1.52	1.27	0.00	0.68	0.57	0.64	2.38	5.97	2.07	1.30	0.63	0.25	17.28
1964	0.33	0.72	0.87	0.40	0.73	0.26	2.96	0.85	3.39	0.00	0.00	0.31	10.82
1965	2.60	2.02	1.10	0.52	0.27	3.10	2.90	4.39	3.64	1.17	0.31	4.26	26.28
1966	0.98	1.58	0.70	0.49	0.45	3.85	2.10	5.23	1.29	0.00	1.02	0.50	18.19
1967	0.00	0.86	0.18	0.00	0.00	1.54	3.73	5.07	2.51	0.00	0.97	2.30	17.16
1968	0.89	1.19	1.45	0.00	0.21	0.29	3.51	3.71	0.42	0.45	1.80	0.98	14.90
1969	1.68	1.47	0.79	0.00	1.43	0.00	1.76	6.17	6.43	1.25	0.24	1.68	22.90
1970	0.18	0.30	1.61	0.03	0.41	1.28	2.46	1.56	0.98	1.12	0.00	0.77	10.70
1971	0.06	0.61	0.00	1.23	0.11	0.74	3.81	5.59	1.00	4.18	2.20	1.11	20.64
1972	1.44	0.21	0.00	0.00	0.12	2.53	3.74	5.83	4.28	5.47	1.16	1.37	26.15
1973	1.83	0.56	2.51	0.03	0.74	1.91	4.42	1.69	0.41	0.08	0.34	0.04	14.56
1974	2.75	0.62	0.50	0.04	0.00	0.56	5.00	5.22	5.15	5.56	0.80	0.78	26.98
1975	1.08	1.12	0.99	0.08	0.41	0.56	4.52	2.44	6.99	0.04	1.09	0.54	16.86
1976	0.41	1.56	0.28	1.34	3.16	0.71	6.50	1.96	4.30	1.66	0.41	0.00	22.29
1977	1.10	0.97	0.15	2.11	0.55	0.63	4.23	2.63	1.62	1.72	0.80	0.64	17.15
1978	2.88	2.16	1.94	0.31	1.66	1.89	2.06	4.62	2.05	1.65	4.32	3.65	29.19
1979	1.74	2.31	0.57	0.02	1.80	1.61	2.39	5.81	1.78	0.36	0.16	1.44	19.99
1980	1.48	1.64	0.47	0.31	1.56	0.61	1.78	3.47	5.41	0.07	0.16	0.36	17.37
1981	0.79	1.54	1.64	0.36	0.30	2.11	2.19	5.30	1.93	1.49	1.66	0.57	19.88
1982	1.92	1.19	0.03	1.02	1.05	1.15	3.00	3.82	5.79	0.09	0.62	2.87	21.52
1983	1.21	1.79	1.40	1.07	0.55	0.70	2.38	2.71	4.26	2.68	3.47	1.62	23.84
1984	0.16	0.00	0.11	0.55	3.63	3.18	3.08	6.09	0.64	4.55	2.32	5.06	29.10
AVE	1.30	0.99	0.92	0.29	0.72	1.21	3.74	3.84	2.67	1.47	0.92	1.42	19.54

TABLE 3. TOTAL MONTHLY PRECIPITATION FOR CLOUDCROFT WEATHER STATION

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1960	4.16	1.77	0.43	0.14	1.04	1.47	6.98	2.23	0.92	1.59	0.11	2.21	23.09
1961	1.69	0.10	2.75	0.03	0.50	4.23	6.44	4.10	2.77	0.25	1.80	3.54	30.64
1962	3.13	0.91	1.36	0.50	0.22	1.72	9.63	2.19	4.41	1.50	1.54	1.38	28.47
1963	2.07	1.37	0.04	0.59	0.24	0.78	5.49	9.23	1.96	1.59	0.68	0.40	24.44
1964	0.51	1.60	1.44	0.71	0.95	0.78	6.39	3.16	4.65	0.00	0.19	0.93	21.33
1965	1.74	2.90	2.09	0.82	0.51	2.56	5.70	6.88	3.39	1.08	0.53	4.27	33.93
1966	1.59	1.64	1.22	0.96	T	3.15	3.81	6.27	3.15	T	1.15	1.59	24.53
1967	0.00	1.45	0.28	0.08	0.02	2.65	2.64	7.95	4.67	0.02	1.01	5.26	26.03
1968	1.49	2.07	3.85	0.11	0.28	0.64	5.21	6.05	0.76	0.62	3.14	2.87	27.09
1969	1.44	1.66	1.56	0.03	2.56	0.29	4.21	7.13	5.22	1.40	0.19	1.78	27.47
1970	0.40	0.13	1.84	0.10	0.04	2.51	4.44	3.31	1.02	1.03	0.05	0.46	15.33
1971	0.15	2.00	T	1.54	0.27	2.94	4.23	3.21	2.26	4.44	0.74	2.12	23.90
1972	3.75	0.56	T	0.00	0.89	2.42	5.68	4.91	5.27	5.68	1.16	2.33	32.65
1973	2.30	1.06	5.07	0.37	1.18	1.56	5.00	2.40	0.34	0.14	0.98	--	22.32*
1974	3.01	0.99	0.80	0.07	0.07	1.21	5.86	5.03	4.70	5.22	0.03	1.77	29.56
1975	2.97	2.15	2.21	0.38	0.49	1.00	4.57	2.21	4.78	0.28	0.85	0.32	22.21
1976	0.53	1.92	0.35	0.12	0.53	0.00	6.89	4.21	6.26	0.90	0.25	0.15	22.11
1977	0.59	0.25	0.06	0.32	0.21	1.72	5.79	2.95	2.17	2.32	0.62	0.81	17.81
1978	3.90	1.72	2.84	0.23	1.94	2.60	1.95	5.65	4.48	2.50	4.95	2.17	34.73
1979	1.69	0.75	1.53	T	1.96	--	--	--	--	--	0.33	1.49	25.00*
1980	2.45	1.73	0.86	0.82	1.61	0.62	4.20	3.88	7.00	0.57	0.49	0.26	24.49
1981	0.77	2.54	1.86	1.35	0.73	2.46	4.29	6.97	4.41	1.39	1.95	0.45	29.17
1982	3.84	1.54	0.11	0.19	1.72	1.50	5.11	4.02	5.15	0.40	1.15	4.13	28.86
1983	1.84	1.73	3.01	1.32	1.27	0.84	2.80	2.63	3.84	3.11	3.78	3.06	29.23
1984	0.25	0.24	0.47	0.59	2.26	3.73	2.78	10.94	0.49	5.35	2.22	6.50	35.82
AVE	1.82	1.42	1.49	0.43	0.83	1.88	5.07	5.14	3.47	1.69	1.14	1.92	26.85

* Average monthly precipitation values used where data is missing.

TABLE 4. WEATHER STATION LOCATIONS

NAME	YEARS USED	LATITUDE	LONGITUDE	ELEVATION	COMMENTS
ALAMOGORDO	1960 - 1984	32 53'	105 57'	4350	
MOUNTAIN PARK	1960 - 1984	32 57'	105 51'	6780	
CLOUDCROFT RANGER STATION	1960 - 1970	32 57'	105 44'	8695	
CLOUDCROFT LODGE	1970 - 1973	32 58'	105 45'	8827	CHANGED NAME FEB. 4, 1970 EQUIPMENT MOVED 0.5 MILES SW
CLOUD COUNTRY LODGE	1974 - 1978	32 58'	105 45'	8827	
CLOUDCROFT CABLE TV	1979 - 1985	32 58'	105 45'	8801	

TABLE 5. TOTAL ANNUAL PRECIPITATION

YEAR	ALAMOGORDO	MOUNTAIN PARK	CLOUDCROFT
1960	9.47	23.37	23.09
1961	11.54	26.05	30.64
1962	3.16	20.85	28.47
1963	8.24	17.28	24.44
1964	6.74	10.82	21.33
1965	13.02	26.28	33.93
1966	9.76	18.19	24.53
1967	10.85	17.16	26.03
1968	11.95	14.90	27.09
1969	14.38	22.90	27.47
1970	5.88	10.70	15.33
1971	12.40	20.64	23.90
1972	18.03	26.15	32.65
1973	11.00	14.56	22.32*
1974	16.73	26.98	29.56
1975	11.13	16.86	22.21
1976	16.28	22.29	22.11
1977	10.44	17.15	17.81
1978	17.50	29.19	34.73
1979	13.97	19.99	25.00*
1980	10.25	17.37	24.49
1981	12.56	19.88	29.17
1982	12.77	21.52	28.86
1983	12.33	23.84	29.23
1984	17.35	29.10	35.82
MEAN	11.24	19.54	26.85

* Average monthly precipitation values used where actual values were missing.

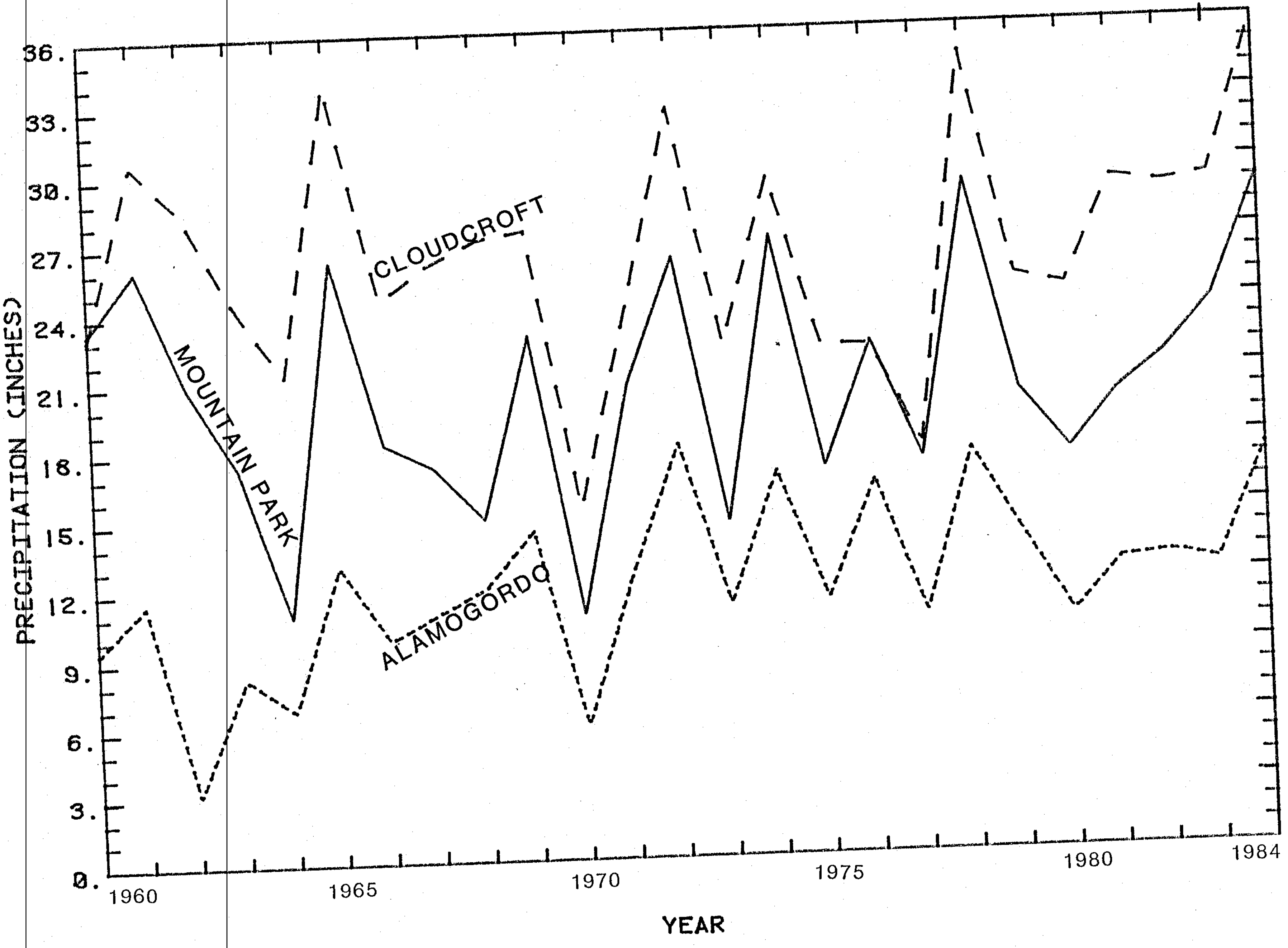
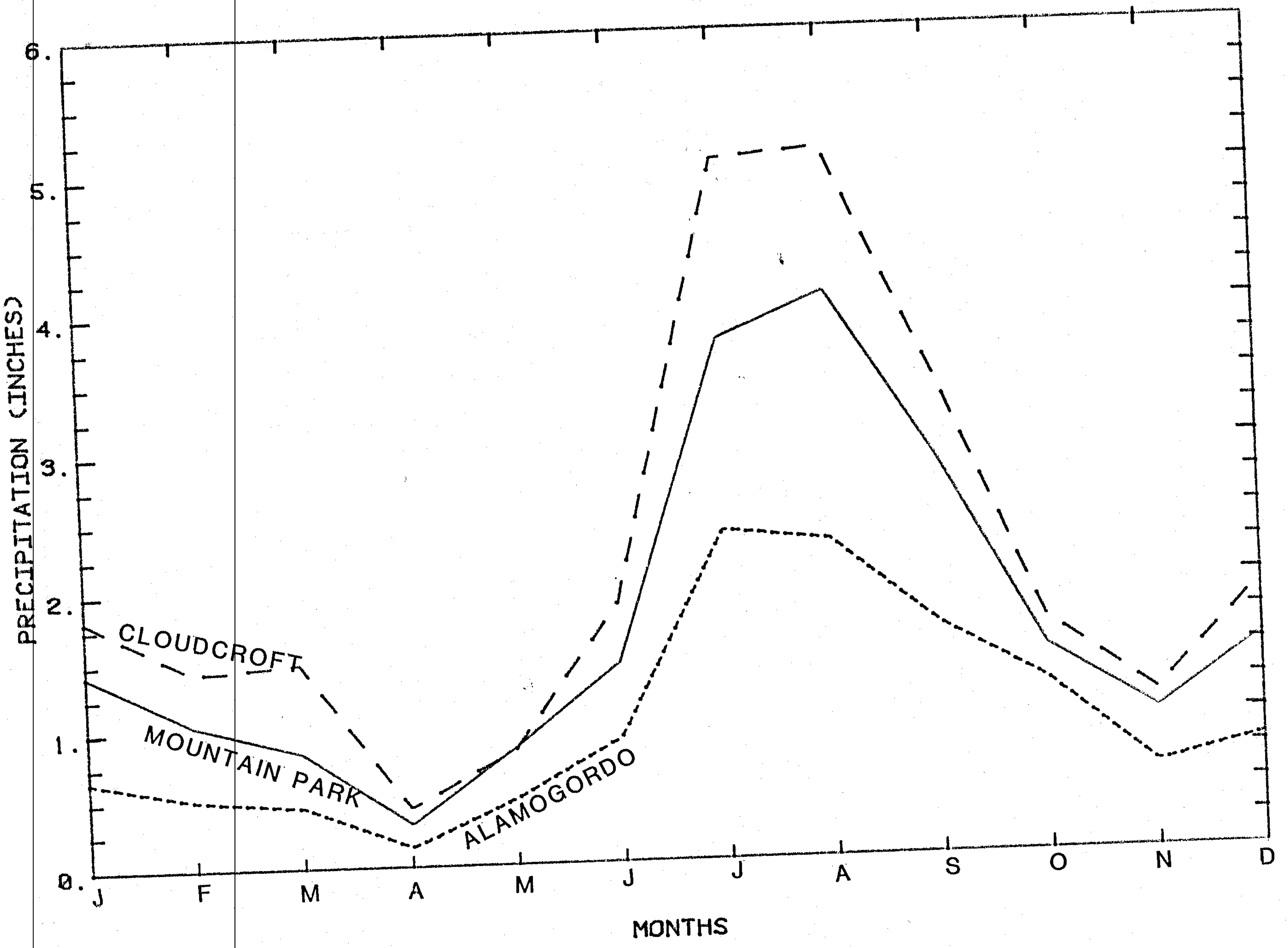

PRECIPITATION (INCHES)
36.
33.
30.
27.
24.
21.
18.
15.
12.
9.
6.
3.
0.
1960
1965
1970
1975
1980
1984
YEAR
CLOUDCROFT
MOUNTAIN PARK
ALAMOGORDO

TABLE 6. MEAN MONTHLY PRECIPITATION

MONTH	ALAMOGORDO	MOUNTAIN PARK	CLOUDCROFT
JANUARY	0.65	1.42	1.82
FEBUARY	0.50	1.04	1.42
MARCH	0.44	0.83	1.49
APRIL	0.14	0.31	0.43
MAY	0.48	0.85	0.83
JUNE	0.90	1.45	1.88
JULY	2.38	3.77	5.07
AUGUST	2.29	4.09	5.14
SEPTEMBER	1.67	2.88	3.47
OCTOBER	1.24	1.48	1.69
NOVEMBER	0.61	1.01	1.14
DECEMBER	0.81	1.54	1.92
ANNUAL	11.24	20.52	26.85


PRECIPITATION (INCHES)
6.
5.
4.
3.
2.
1.
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J
F
M
A
M
J
J
A
S
O
N
D
MONTHS
CLOUDCROFT
MOUNTAIN PARK
ALAMOGORDO

given in Table 7 and shown graphically in Figure 6.

PURPOSE AND SCOPE:

Although the study area lies between two groundwater basins which have been studied in some depth and in an area where the geology has been well studied, no work has yet been done on the area's hydrogeology. A number of springs near High Rolls and Mountain Park are currently supplying much of their water for domestic and irrigation purposes. These springs, however, can provide for only local needs and their flow is limited. Therefore, an increasing number of wells have been drilled as development of the area both increases and spreads. As a result, the quantity and quality of water from both these sources is becoming of increasing importance and will continue to do so as long as development continues. Therefore, it seems appropriate to study the various water sources and the area's hydrogeology now, so that as this information becomes important for planning, it will be available.

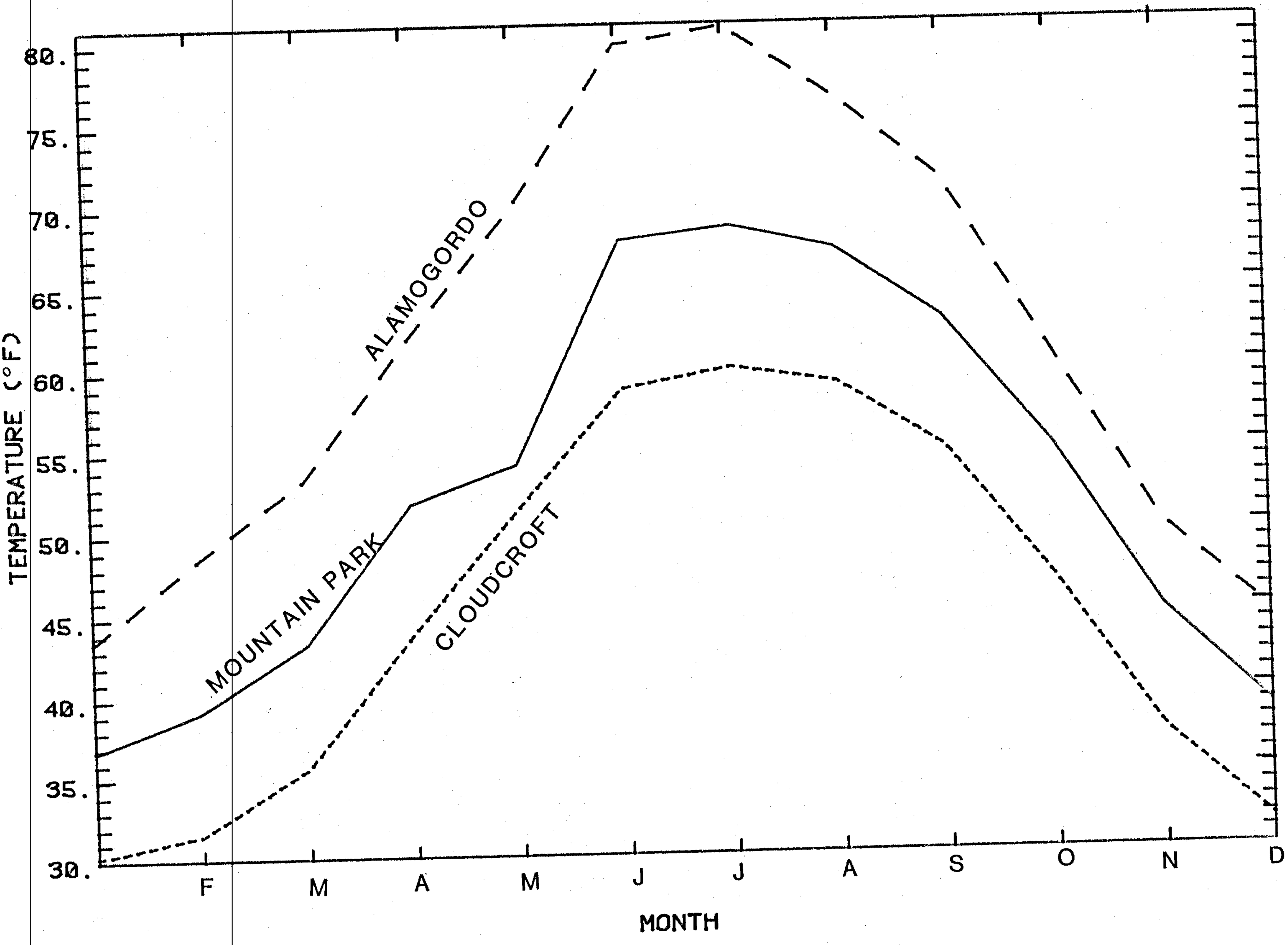
In addition to the interest of this area to those living within the area, the hydrogeology is also of interest to those studying the surrounding basins. The pattern of ground and surface water flow in this area could have a large affect on what is occurring in both the Tularosa and the Roswell basins. Hence, those studying both basins are interested in this area's hydrologic characteristics. Those researching the Roswell Basin would like to know if this area supplies any of recharge to that basin, while those studying the Tularosa Basin are interested not only in recharge but also in the water table elevations, or the piezometric surface, along this section of their basin's edge.

PREVIOUS INVESTIGATIONS:

The geology of this area was thoroughly studied by Carel Otte, Jr. (1959) and Lloyd Pray (1961) while each was with the New Mexico Bureau of Mines and Mineral Resources. Their maps and writings on the Pennsylvanian and Permian stratigraphy of the Northern Sacramento Mountains and the geology of the Sacramento Mountains, respectively, have been of great assistance in piecing

TABLE 7. MEAN MONTHLY TEMPERATURES

MONTH	ALAMOGORDO	MOUNTAIN PARK	CLOUDCROFT
JANUARY	43.5	36.8	30.0
FEBRUARY	48.6	39.2	31.6
MARCH	53.3	43.3	35.7
APRIL	61.9	51.8	43.8
MAY	69.9	54.1	51.3
JUNE	79.8	67.8	58.7
JULY	80.8	68.6	59.9
AUGUST	76.5	67.1	58.9
SEPTEMBER	71.4	62.7	54.8
OCTOBER	60.6	54.8	46.7
NOVEMBER	50.0	44.7	37.3
DECEMBER	44.4	38.6	31.6
ANNUAL	61.7	52.9	45.0



MONTHLY TEMPERATURES

together the complex geology of this area. Even though these two works cover the geology in much detail, neither deals with the hydrologic conditions within the study area. The only available reference which includes information on these conditions is a short insert in New Mexico Geological Society's fifth guidebook on Southeastern New Mexico (Pray, 1954).

A large amount of information does, however, exist on the two groundwater basins lying to the west and east of the study area. The hydrologic properties of the Tularosa Basin, to the west of the area, has been studied since the early 1900's. In 1915, O.E. Meinzer and R.F. Hare completed a very thorough study of the geology and water resources of the area. Since then, the New Mexico State Engineer Office has conducted two basic studies on the water supplies of the basin, one by W.C. Powell in 1928 and a second by S. Garza and J.S. McLean in 1977. In 1976 a number of investigators, including hydrologist Lynn Gelhar, compiled an economic feasibility study for an energy-water complex in the Tularosa Basin (Lansford et al., 1976). This report covered such topics as water supply, quality, availability, and use within the basin. The only other notable work is a distribution map of potable and inferior waters within the area by Herrick and Davis (1965).

The Roswell Basin, to the east, was first studied in 1926 when B.C. Renick wrote on the hydrologic conditions along the Rio Penasco Drainage Basin. Fiedler and Nye followed in 1933 with a study of the entire Roswell Basin, a work which still remains of great importance. Later, Kelley (1971) did an important study on the Pecos Valley while many others, including M.S. Hantush and G.W. Gross, have made numerous contributions. A study by M. Wasiolek and G.W. Gross (1983) on the area immediately east of the study area was particularly helpful.

Another study of some value was a study of the groundwater hydrology of the part of the Mescalero Apache Indian Reservation which lies due north of the eastern portion of the study area. In this report, Sloan and Garber (1971) estimate the altitude of the static water level throughout the reservation based on spring occurrences and well measurements. Thus, their interpretations were useful in determining what was occurring in the northeast corner of the study area.

WELL-NUMBERING SYSTEM:

In order to better reference the wells and springs within the area they have been numbered in accord with location, with the springs being distinguished from the wells by an "S" preceding the numbers. The locations of the 45 wells and 23 springs used in this study are given in Figure 7.

Both the wells and springs within the area have been identified with the coordinate system used by the U.S. Geological Survey and the New Mexico State Engineer Office. The coordinates of a well or spring are given by township, range, section, and, where possible, the ten-acre plot within the 640 acre section (Figure 8).

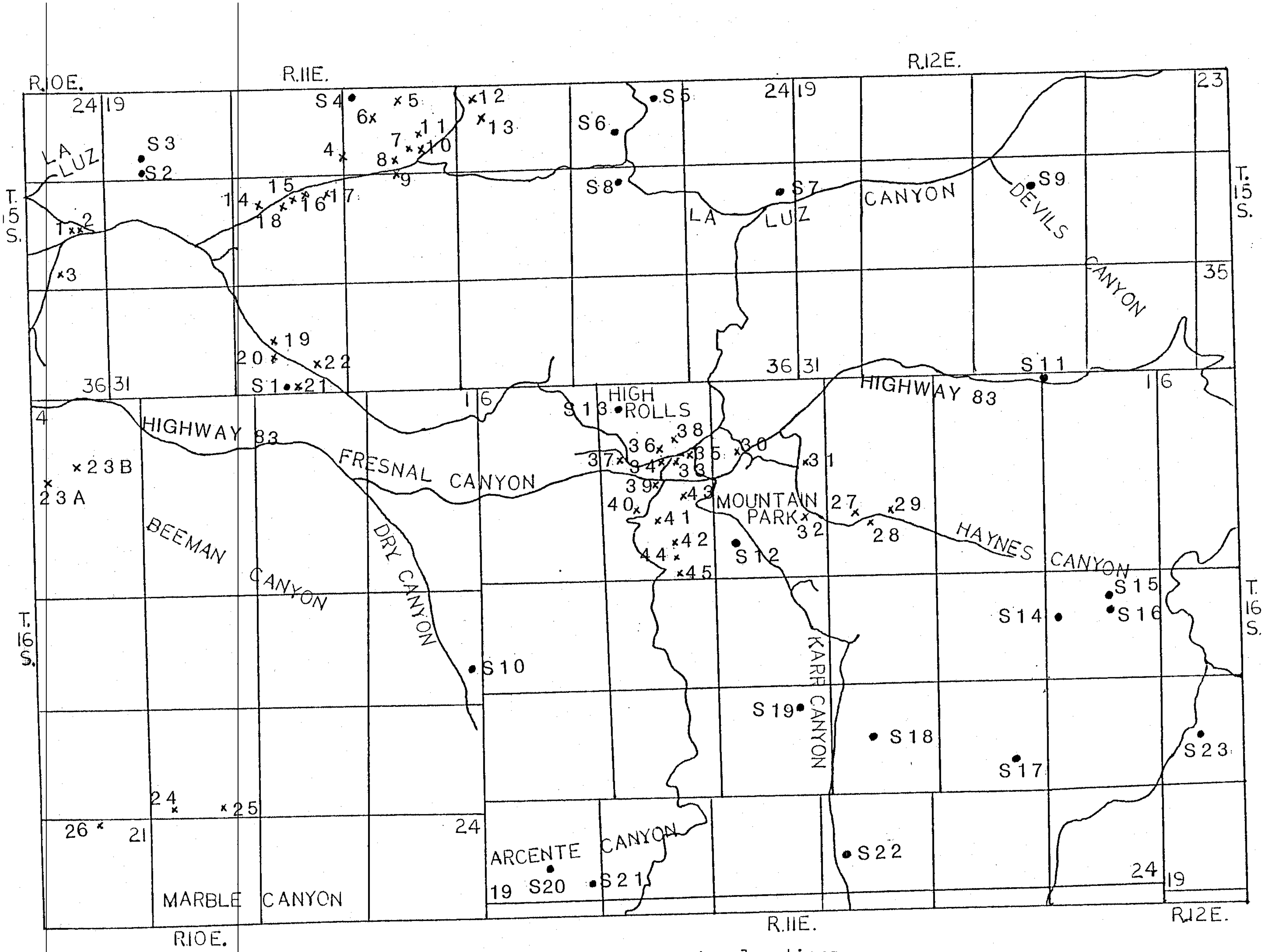


Figure 7. Well and spring locations.

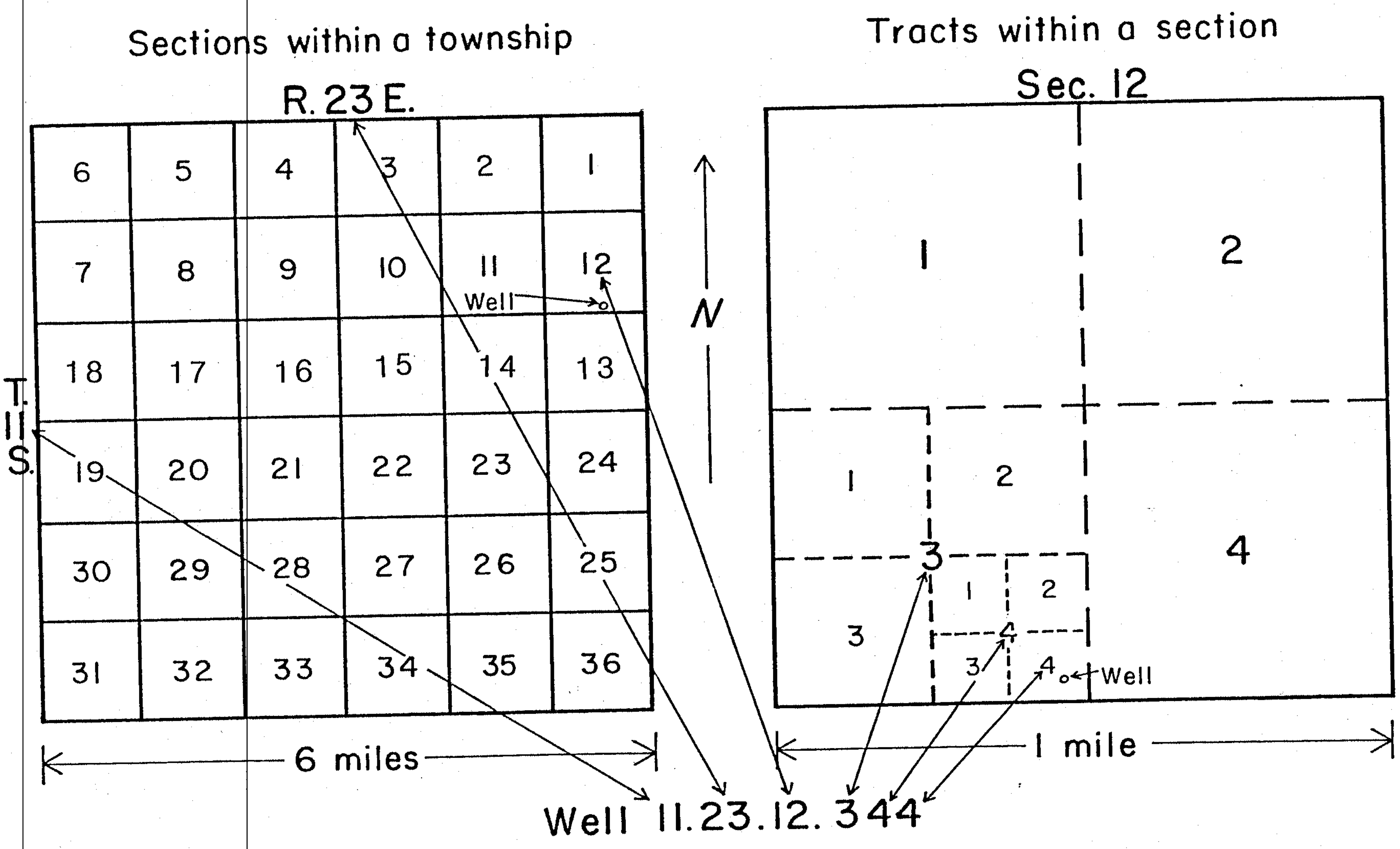


Figure 8. Well numbering coordinate system.

GEOLOGY

GEOLOGIC HISTORY:

The study area is located along the western fault scarp of the Sacramento Mountains, a tilted fault block along the eastern edge of the Basin and Range Province. This block is the result of a late Tertiary gravity fault zone lying on the western edge of the uplift and the eastern edge of the Tularosa Basin (Kelley, 1971). Intense erosion has removed much of the rock on the west side of the scarp, thus moving the mountain's crest several miles to the east and exposing a thick sequence of rocks representing Ordovician through Permian time.

The series of rocks along this western scarp reveals much about the geologic history of the entire area as Lloyd (1949) concisely discloses. From late Cambrian through Ordovician time, there was a nearly continuous period of sedimentation. Limestones and dolomites were deposited by epicontinental seas during the lower Ordovician while near-shore conditions dominated later on. During the lower Silurian, a long stage of sea withdrawal and erosion took place, followed by a carbonate-depositing sea which deposited the Fusselman Limestone in the Middle Silurian, and a withdrawal of the sea in the late Silurian. Once again, in the lower Devonian, a carbonate depositing sea invaded southeastern New Mexico, this time from the south and southeast. Darton (1917) proposed that this was followed by either a long emergence of the land or an extensive period of erosion which removed all signs of any Devonian deposits that may have been laid down prior to the Percha Shale. During a large portion of the Mississippian, most of southeastern New Mexico was above sea level and free of any type of deposition.

No evidence of mountain movement prior to the Pennsylvanian is present. The Pedernal Uplift, remnants of Precambrian mountains which were once a portion of the Ancestral Rocky Mountains, began to rise during the Pennsylvanian, creating coarse conglomerate deposits containing reworked quartzite and other metamorphic rocks (Thompson, 1942). Otte (1959) notes that deposits from this period show a cyclic repetition related to tectonic instability and episodic deformation coinciding with a gradual emergence of the area and a transition between marine and non-marine environments. The early Permian was again accompanied by mountain-building, as well as a large amount of faulting and local folding. Later, seas of Wolfcampian age deposited the thin beds of limestone interbedded with coarse conglomerates and sandstone that are now known as the Bursum Formation. As the sea again withdrew, the Abo Formation, composed of continental red beds and conglomerates, was deposited. During the upper Leonard seas covering most of southeastern New Mexico deposited the Yeso Formation. Shortly thereafter, a marine transgression, marked by the Glorieta Sandstone unit of the San Andres Limestone, was initiated. This later formation marks the Guadalupe epoch, a time where barrier reefs developed within the Permian seas and much deposition took place over the eastern slope of the Sacramento Mountains. The west face, however, has only a thin record of deposition from this time and no depositional record after that. It is at this point when deposition slowed and the geologic history becomes obscure. It is not until the early Tertiary that the record reappears with gentle folding and the intrusion of sills and dikes. This was followed, in the late Tertiary, by the large scale tectonic event which tilted the entire Sacramento Mountain landmass along the gravity fault mentioned earlier. Since this faulting event, the area has been quiet outside of some minor erosion, folding, and faulting.

STRATIGRAPHY:

Along the western escarpment of the Sacramento Mountains a large variety of geologic formations are present. The majority are Paleozoic in age and would make up nearly 8000 vertical feet of rock if a complete section were assembled. Pray (1954) has suggested that these strata fall into three groups of nearly equal thickness. The first group consists of rocks of Cambrian through Mississippian age. The youngest of these are mostly carbonate rocks of marine origin and deposited on relatively stable shelf areas while the older ones are mainly dolomites, with limestones occurring in the Upper Devonian and Mississippian strata. Terrigenous clastics are present only as minor components, with most of them occurring either just above formation contacts or within the thin Devonian layer. The middle third of the Paleozoic sequence is composed of rocks of Pennsylvanian age, largely, but not entirely, of marine origin. These form a complex interbedded sequence of limestones, sandstones, and shales. Permian rocks of both marine and non-marine origin form the final segment. Red beds are present in all but the top of this Permian sequence while evaporites are present within the middle section. The region's geology and stratigraphy are illustrated in a number of ways. Figure 9 is a stratigraphic column

FIGURE 9. STRATIGRAPHIC COLUMN

YSTEM	SERIES	ROCK UNIT		THICKNESS	DESCRIPTION
UATERNARY					ALLUVIUM, COLLUVIUM, ETC.
ERMIAN	GUADALUPIAN	SAN ANDRES LS.		700'+	
	LEONARDIAN	YESO FM.		1200-1800'	LIMESTONE, RED AND YELLOW MUDSTONE, GYPSUM, AND MINOR FINE QUARTZ SANDSTONE.
	WOLFCAMPIAN	ABO FM.		200-550'	ARKOSE AND RED MUDSTONE, THIN BEDDED LIMESTONE AND GRAY SHALE.
		MAGDALENA GROUP	BURSUM FM.	0-350'	SHALE, GRAY AND RED SANDSTONE; LIMESTONE AND LIMESTONE CONGLOMERATE.
ENNSYL- ANIAN	VIRGILIAN		HOLDER FM.	0-500'	LIMESTONE, GRAY AND RED CALCAREOUS SHALE, SANDSTONE, AND CONGLOMERATE. BIOHERMS AT BASE LOCALLY.
	MISSOURIAN		BEEMAN FM.	0-500'	SHALE, ARGILLACEOUS LIMESTONE AND FELDSPATHIC SANDSTONE.
	DES MOINESIAN ATOKAN MORROWAN		GOBBLER FM.	0-500'	LIMESTONE, SANDSTONE, AND SHALE, COARSE QUARTZ SANDSTONE IN LOWER PART. MASSIVE, GRAY, CHERTY LIMESTONE AT TOP GRADES LATERERALLY INTO SANDSTONE SHALE.
ISSIS- IPPIAN	OSAGAN	LAKE VALLEY FM.	DONA ANA MBR.	0-150'	LIMESTONE, GRAY, CHERTY, CRINOIDAL.
			ARCENTE MBR.	0-200'	LIMESTONE, DARK GRAY, ARGILLACEOUS, THIN BEDDED AND CALCAREOUS SHALE.
			TIERRA BLANCA MBR.	0-140'	LIMESTONE AND CRINOIDAL MARL.
			NUNN MBR.	0-120'	LIMESTONE AND CRINOIDAL MARL
			ALAMOGORDO MBR.	0-400'	LIMESTONE, CHERTY, LOCAL BIOHERM FACIES.
			ANDRECITO MBR.	0-23'	LIMESTONE, SILTY AND SHALE.
	KINDERHOOKIAN	CABALLERO FM.		15-60'	LIMESTONE, NODULAR AND CALCAREOUS SHALE.
EVONIAN	UPPER	SLY GAP		0-45'	SHALE AND LIMESTONE.
	LOWER	ONATE		0-60'	SILTSTONE, DOLOMITIC.
ILURIAN		FUSSELMAN FM.		0-100'	DOLOMITE, DARK, CHERTY, RESISTANT
RDOVICIAN	CINCINNATIAN	VALMONT DOL.		150-225'	DOLOMITE, LIGHT GRAY, SUBLITHOGRAPHIC THIN BEDDED.
		MONTOYA FM.		140-250'	DOLOMITE, UPPER MEMBER CHERTY, LOWER MEMBER MASSIVE; 0-12' QUARTZ SANDSTONE AT BASE.

illustrating this sequence of rock types, Figure 10 is a legend for the geologic map of the study area which is presented in Figure 11, the aerial photograph in Figure 12 shows the topography of the western half of the study area (the area to the west of High Rolls), and two geologic cross-sections are presented in Figure 13.

Not all of these formations are hydrologically important, but their presence along the western edge of the study area still warrants a brief discussion. The comments below are primarily a brief description of the physical attributes and general thicknesses of the units within the study area. For a more detailed physical description, or evidence concerning the specific age of the strata, one may consult Pray (1961), Otte (1959) or one of the other references cited below.

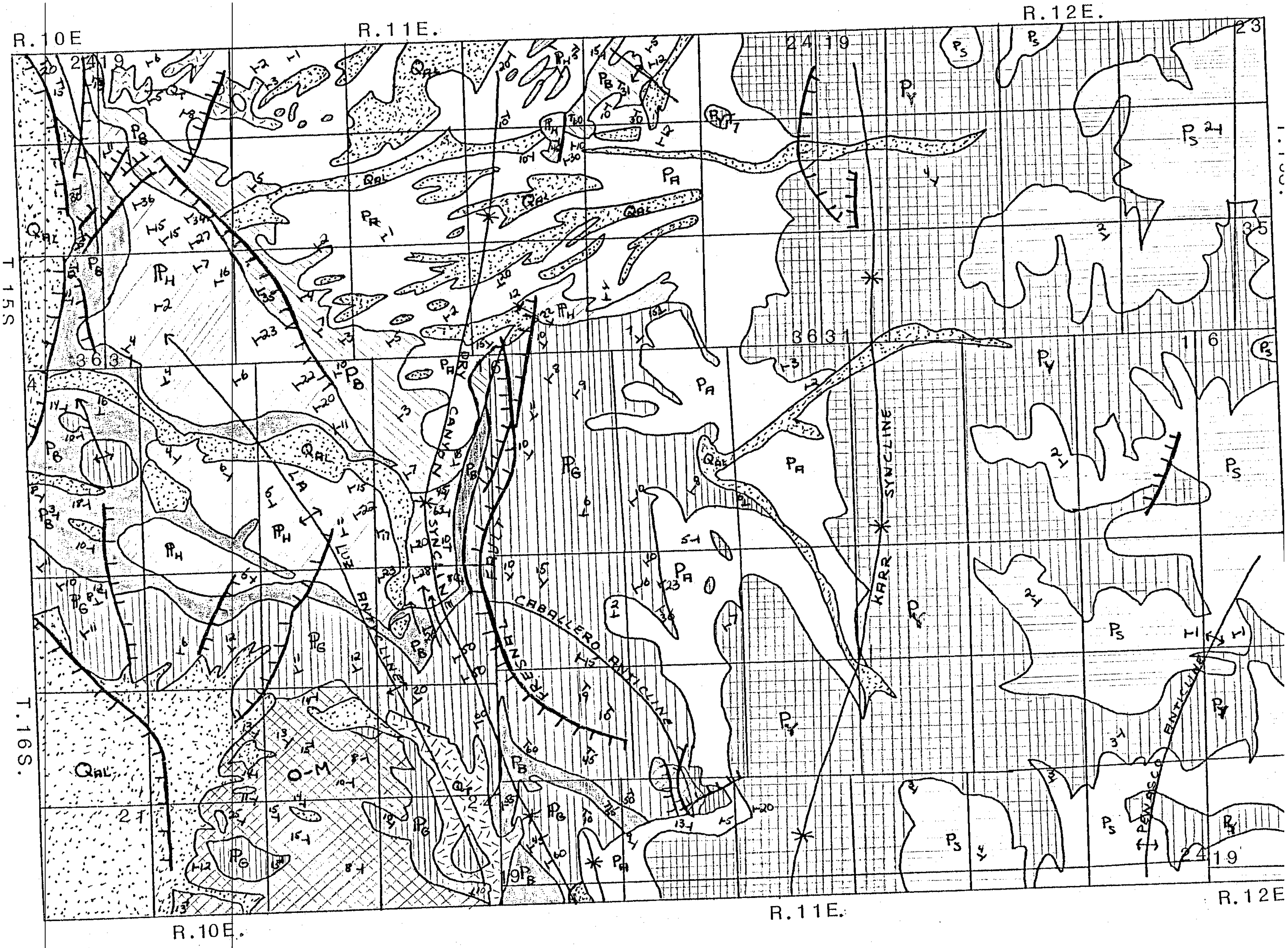
Montoya Formation: Although older formations occur in the Sacramento Mountains, the oldest one which outcrops within the study area is the Montoya Formation of upper Ordovician age. Appearing only on the southern edge of the area, the formation can vary from 140 to 250 feet thick in the Sacramento Mountains, but is between 200 and 225 feet thick in most areas (Pray, 1954). It consists of two distinct members, the lower one forming cliffs 75 to 120 feet high and the upper unit having an average thickness of 60 feet (Lloyd, 1949; Darton, 1928). Overlying the El Paso limestone and marked by a sharp contrast in character of material, the lower member consists of a 10 to 12 foot thick, coarse-grained, quartz sandstone topped by a dark, massive limestone. The upper unit consists of alternating thin beds of cherts and limestones. A one to three foot segment of very massive chert marks the upper contact.

Valmont Dolomite: The youngest Ordovician formation is the Valmont Dolomite, a formation sometimes classified as the lower member of the Fusselman Formation. This unit is commonly about 180 feet thick, but may range between 150 and 225 feet. It is approximately 175 feet thick in Alamo Canyon, just south of the study area (Pray, 1954). This unit is a medium to light gray, sublithographic to very fine-grained dolomite with very sharply defined and laterally persistent bedding planes, spaced a few inches to two feet apart. An argillaceous dolomite zone, some 50 to 70 feet from the base, forms a persistent niche and divides the unit into two zones, the bottom zone being slightly darker and more resistant, while the top has weathered to a white color.

Fusselman Formation: The Silurian is represented by 50 to 80 feet of a hard, dark, fine-grained limestone with abundant Niagaran fossils and areas of dark chert (Darton, 1928). This unit forms a prominent ledge south from the vicinity of Alamo Canyon, but rapidly disappears near the

FIGURE 10. LEGEND FOR GEOLOGIC MAP

Q_{AL}	Quaternary Alluvium Deposits
Q_{T}	Quaternary Intrusives
P_{S}	San Andres Limestone
P_{Y}	Yeso Formation
P_{A}	Abo Formation
P_{B}	Bursum Formation
P_{H}	Holder Formation
P_{B}	Beeman Formation
P_{G}	Gobbler Formation
O-M	Rocks of Ordovician to Mississippian Age
⊥⊥⊥	Fault
↕	Anticline
✳	Syncline
⊥10	Dip


R.10E
R.11E.
R.12E.
T.15S
T.16S.
R.10E.
R.11E.
R.12E
KARR SYNCLINE
DRY CANYON SYNCLINE
CABALLERO ANTICLINE
FRESNAL FAULT
LA LUZ ANTICLINE
PEÑASCO ANTICLINE
Qal
O-M
24 19
36 31
1 6
23
35
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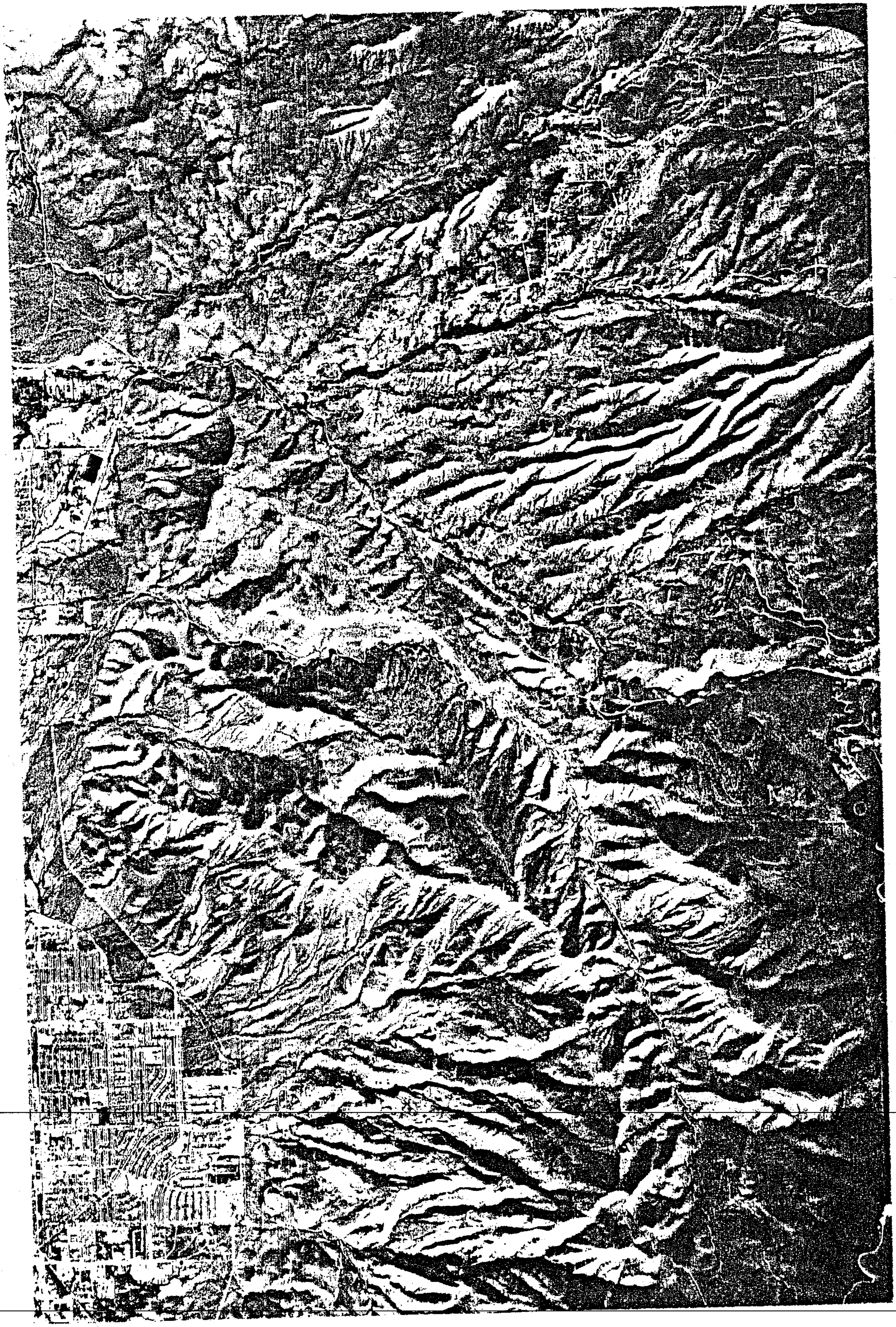
21

(After [illegible] 1961).



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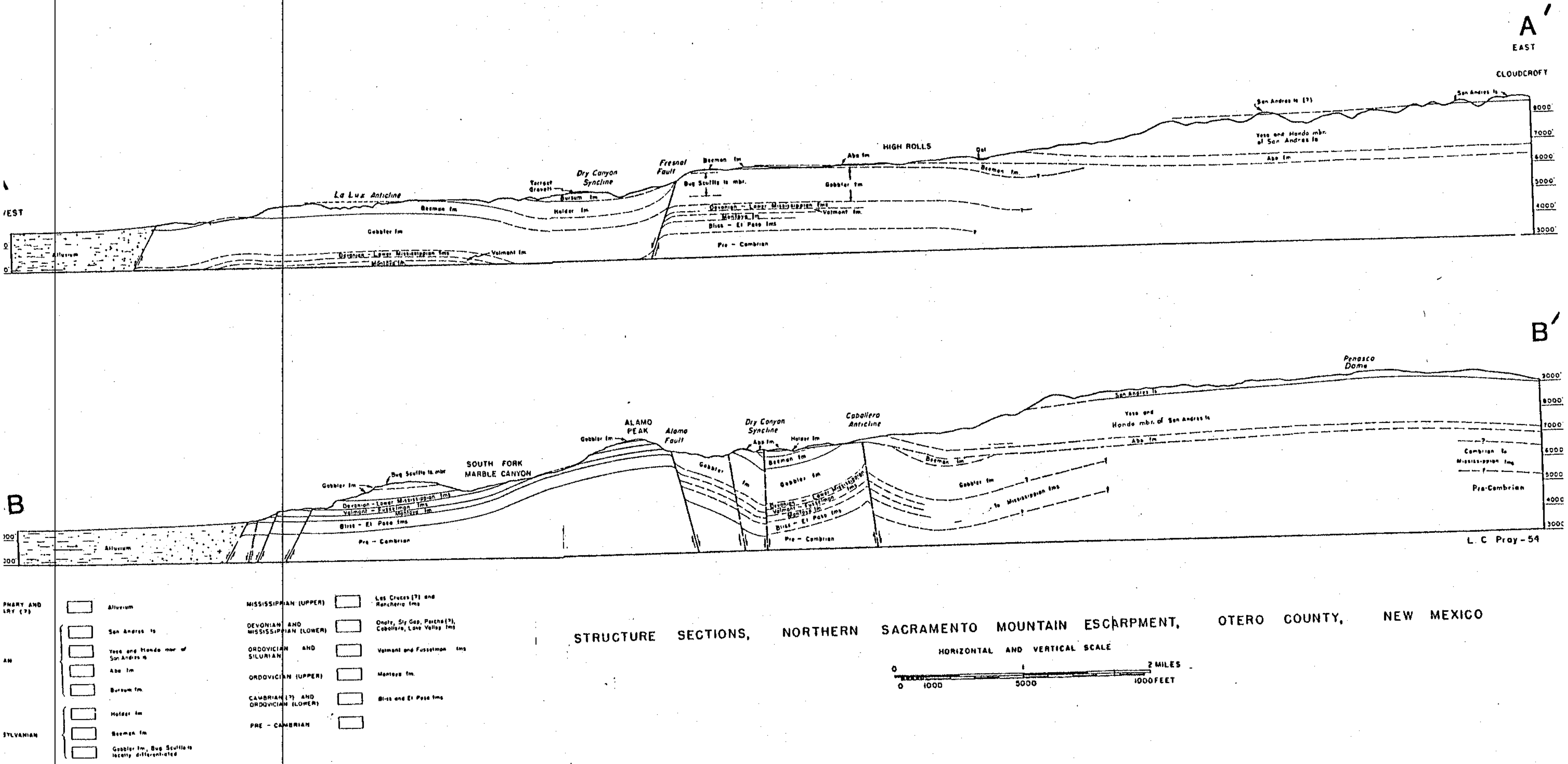


Figure 13. Two geologic cross-sections across the study area. A - A' is along State Highway 83 between Alamogordo and Cloudcroft while B - B' follows the study area's southern boundary. (From Pray, 1954).

southern edge of the study area.

<u>Onate Formation:</u> Averaging just 35 feet in the Sacramento Mountains, the Onate Formation, of late middle Devonian age, crops out from Marble Canyon, due east of Alamogordo, south to Agua Chiquita Canyon (Stevenson, 1945). In the Alamo Canyon area, this variable and intergradational series of shales, siltstones, fine sandstones, and dolomites with flagstone bedding averages 25 to 30 feet thick (Pray, 1954). In the section near Marble Canyon, a three-foot basal unit of thin-bedded calcareous sandstone is present.

<u>Sly Gap Formation:</u> The Sly Gap Formation of Devonian age also appears only in the southern portion of the study area. Its northernmost exposure is one canyon to the north of Marble Canyon where it plunges under the younger formations. Here the formation is 45 feet thick and thins gradually to the south and east so that it is about 35 feet thick at Alamo Canyon (Stevenson, 1945; Pray, 1954). The Sly Gap consists of dark gray, greenish gray, and yellowish calcareous shales with a somewhat nodular, argillaceous limestone in the upper portion.

<u>Percha Shale:</u> Overlying the Sly Gap Formation is the black Percha Shale, having an average thickness of 100 feet (Darton, 1928). This late Devonian unit is separated from both overlying and underlying formations by breaks in sedimentation. In addition, the unit is also separated from the younger Caballero Formation by an oxidized zone filled with phosphatic concretions. The formation itself is separated into three distinct units, the upper one being separated from the other two by an angular unconformity. The lower beds are composed of fissile shales while the upper ones are gray shales containing layers of slabby and nodular limestones.

<u>Caballero Formation:</u> The Caballero Formation of Kinderhookian age (lower Mississippian) is exposed from Indian Wells, three miles northeast of Alamogordo, to Grapevine Canyon (south of the study area). It reaches its maximum thickness of 60 feet in the Indian Wells area before plunging under the valley floor, and remains between 50 and 60 feet thick through the southern edge of the study area (Laudon and Bowsher, 1949; Pray, 1954). Due to pre- and post-Caballero erosion, however, its thickness varies greatly. The unit consists of gray, nodular, and in part mottled, shaley limestones with thin layers of gray calcareous shale curving between the nodular limestone beds. The basal layer often contains a thin layer of fissile black shale.

<u>Lake Valley Formation:</u> The Lake Valley Formation of Osagian age (middle Mississippian) has its maximum development in the northern part of the Sacramento

Mountains where it is up to 400 feet thick. The formation thins to the east and south along the escarpment due to non-deposition, tilting, and subsequent erosion (Pray, 1954). It is entirely absent in the southern and eastern parts of the escarpment. There are six distinct members in this formation, although within the northern Sacramento Mountains, three of these (the Alamogordo, Nunn and Tierra Blanca) are profoundly affected by large bioherm structures and will be treated as one unit. The basal member, the Andrecito, consists of 25 to 35 feet of thin-bedded gray, fossiliferous, silty limestone and calcareous shale (Pray, 1954, Laudon and Bowsher, 1949). Bioherms, which have their base in the Alamogordo member, affect the thickness and distribution of the upper five units. They are most abundant between Indian Wells and Alamo Canyon where the structures elongate into north-south trends. The cores of the bioherms, centered in the Alamogordo member, are masses of profuse crinoidal growth and form rocks of light gray, massive, very fine-grained limestone with abundant, partially recrystallized, crinoidal debris. The flanks of the bioherms are between 100 and 200 feet thick, and the total thickness can be twice that of the core. In areas unaffected by bioherms, the Alamogordo member is only 35 to 50 feet thick while the Nunn and Tierra Blanca members are only a few feet thick (Laudon and Bowsher, 1949). The Arcente and Dona Ana members, the two upper members, are only preserved on the flanks of major bioherms, as the formation in the core area was stripped off by erosion in the late Mississippian and early Pennsylvanian, if it was ever present. The upper Mississippian strata of the Rancheria and Helms formations are also absent within the study area.

Magdalena Group: The Magdalena group consists of four formations, the Gobbler, Beeman, and Holder formations of Pennsylvanian age and the Permian Bursum Formation. In the northern part of the Sacramento Mountains, the Pennsylvanian is at least 3000 feet thick, with the lower 2000 feet predominantly clastics of sandstones, fine conglomerates, siltstones, shales, and highly silty to argillaceous dark limestones. The upper 1000 feet consists of bluish-gray limestones with interbedded sandstones and conglomerates and a small amount of gray to red shale (Thompson, 1942). The basal Pennsylvanian was continuously deposited upon at least 100 feet of local relief from Morrowan to early Permian time (Pray, 1954). At Indian Wells and La Luz Canyon the section is 2980 feet thick, consisting of 1630 feet of the Gobbler Formation, 495 feet of the Beeman Formation, and 855 feet of the Holder Formation (Kottlowski, 1960).

The Gobbler Formation forms the lower 1200 to 1700 feet of the Pennsylvanian strata and consists of a large variety of lithologies (Pray, 1961). The basal Gobbler consists of up to 100 feet of either a coarse-grained quartz sandstone or a chert-cobble conglomerate with a sandy matrix. In the next 300 feet many rock types occur but the two most common are well-sorted quartz sandstones composed of angular, coarse-grained quartz grains, and dark limestones with conspicuous black chert masses. The top portion of the formation consists of two contemporaneous, interfingering facies which form about 1000 feet of strata. The first facies contains layers of calcium carbonate rocks and is commonly cherty while the second is composed almost entirely of shales and quartz sandstones, with only a minor amount of limestone.

The Beeman Formation consists largely of thin-bedded argillaceous limestone interbedded with calcareous shale. Green-gray feldspathic sandstones and a variety of light-colored, relatively pure limestones occur locally. The formation ranges between 350 and 500 feet thick (Pray, 1961).

The uppermost Pennsylvanian unit is the Holder Formation. It is up to 900 feet thick in the study area, thinning to the south and east. This formation consists of a large variety of sedimentary rocks including red shales, mudstones, marls of nodular limestone and limestone conglomerates, chert and quartzite pebble conglomerates, and a variety of sandstones. The basal portion of the sequence is believed to be almost entirely of marine origin while an increasing proportion of brackish to non-marine strata appear near the upper contact.

The Bursum Formation, composed of marine shales, sandstones, and limestones of lower Wolfcampian age (lower Permian), is found only locally within the study area. In Fresnal Canyon, it is 250 feet thick and thickens to 350 feet one mile to the north. To the south of this canyon, however, it thins rapidly and disappears within a few miles (Lloyd, 1949).

Abo Formation: It is the nonresistant shales alternating with the resistant sandstones of the Permian Abo formation which give rise to the cuestas forming the valley and ridge topography near the crest of the Sacramento Mountains. Ranging between 200 to 500 feet thick, this formation is generally composed of approximately 60% red shale and 40% sandstone, arkose and conglomerate (Pray, 1954; Needham and Bates, 1945). Within the study area three distinct members are present. The basal conglomerate member is locally distributed in basins and can range from a few feet to several hundred feet thick. It may appear as either a coarse limestone of 80% limestone and 20% quartzite and quartz or a quartzite conglomerate of 30% sandy matrix and 70% boulders and flat pebbles ranging between 1/4 and 4 inches, but averaging two inches, in diameter. The central Arkose member, 50 to 200 feet thick, consists of arkose beds, each a few feet thick, alternating with shale and siltstone beds. The youngest member is the Red Shale member, measuring between zero and several hundred feet thick. This member consists of brick red, thinly layered, shales and siltstones (Jerome et al., 1965).

Yeso Formation: The Yeso Formation of Leonardian age (middle Permian) is one of the thickest units in the area, ranging between 1200 and 1800 feet thick east of Mountain Park and averaging about 200 feet thick on the eastern slopes of the Sacramento Mountains (Pray 1954; Needham and Baker, 1943). These deposits of a saline, epicontinental sea are expressed as alternating beds of sandstone, shale, limestone, and gypsum which can be divided into four units. The basal unit is a zone of clastic material composed of pink and orange sandstone. The second unit is a thick succession of interbedded thin limestones, gypsum, siltstones, and sandy shales, sometimes known as the middle evaporites. Above this lies a 50 to 100 foot thick section of white gypsum. The youngest unit is a sandstone with a pink, orange and yellow color (Needham and Baker, 1943). The limestone units of this series form ledges and cap the cuestas while the sandstones form bare, rounded ledges.

The San Andres Limestone: The youngest unit in the study area is the upper Permian San Andres Limestone. It forms the resistant uppermost strata of the crest and most of the eastern slope of the Sacramento Mountains. This massive limestone is over 1000 feet thick to the east but is less than half of that at the crest. It progressively thins to the south (Pray, 1954). The unit is composed of biostromal beds composed of lightly cemented oolitic beds with oolitic to vuggy and cavernous porosity. The top is marked by thin beds of evaporites (mostly gypsum and anhydrite) and clastic rocks (usually sand) which are less than 25 feet thick (Maddox, 1969).

GEOLOGIC STRUCTURE:

The Sacramento Mountains represent a large cuesta, faulted and folded on the west edge and tilting at a one to two degree angle east of the crest. Gentle folding and faulting has affected most of the Permian strata while pre-Permian strata are more intensely deformed. Two major groups of deformation are present -- that related to the late Cenozoic deformation which resulted in the uplift of the range, and that which predates the uplift.

These mountains are the result of a Cenozoic faulting event which uplifted the mountains with respect to the Tularosa Basin, along a normal, or gravity, fault zone. The fault lies near the base of the escarpment in the area where alluvial and pediment scarplets are up to 80 feet deep. The base of the escarpment trends slightly west of north for most of its length but is slightly irregular in detail. Pray (1954) has estimated that the major fault has a minimum of 6500 feet of displacement, with over 2000 feet of alluvium west of the boundary structure. Close to the fault zone are several minor westerly-dipping gravity faults exhibiting dip-slip movement.

Prior to the uplift, most of the deformation occurred during Paleozoic time, with a small amount taking place during the Mesozoic and early Cenozoic. The area was tectonically stable from the Cambrian through the Devonian with only epeirogenic warping, intermediate marine inundations, and minor erosion. Increasing unrest followed, culminating in a major deformation during the late Pennsylvanian or early Permian. At this time, many structures were formed including the Caballero Anticline, Dry Canyon Syncline, Alamo Peak, Fresnal Fault, and Arcente Canyon Fault. Most of these trend roughly north to south with the folds open to moderately tight. Undulatory axial crests and troughs, as well as domes, appear along some of the anticlinal crests. Faults are mostly high angle and have a dip-slip displacement ranging up to one-third mile (Pray, 1954). Some deformation continued through the late Permian.

Faults: In addition to the boundary fault described above, two major faults are located within the area. These two parallel faults, the Fresnal and Salado faults, are mainly a result of pre-Abo, high-angle, normal faulting and may both be part of one major fault zone at depth. Movement along the various branches took place during late Pennsylvanian and early Permian time with parts reactivated in post-Abo time. The Salado Fault lies to the west and has been mapped by Otte (1959) for about a mile and a half between Salado Canyon and Fresnal Canyon but may extend further south. The easternmost fault is the Fresnal Fault. It is continuously exposed for about five miles between Salado and Arcente canyons. There is also evidence that both these faults occur as buried structural features at least as far north as La Luz Canyon.

Several periods of movement occurred along the Salado Fault in late Pennsulvanian and early Permian time while post-Holder, pre-Bursum displacements took place near the north end of Salado Canyon. The fault offsets strata of the Holder Formation about 200 feet in the north with displacements increasing to the south (Otte, 1959).

Paralleling the Salado Fault is the Fresnal Fault, a complex, west-dipping, high-angle fault. Movement of several hundreds of feet can be proved to have occurred during the late Pennsylvanian and pre-Bursum, post-Bursum and pre-Abo, and post-Abo time. Overall stratigraphic displacement near Fresnal Canyon has been estimated to be about 1600 feet with displacement increasing toward the south (Pray, 1961).

A north-trending high-angle fault in La Luz Canyon may be a northward extension of the Fresnal Fault. The strata east of this fault appear to be stratigraphically older than those to the west, thus indicating an upthrown eastern block. The strata east of the block resemble those of the Beeman Formation while those to the west belong to the Holder Formation. There is more recent displacement which offsets the basal strata of the Abo Formation and indicates a downward movement of this eastern block (Otte, 1959).

Also in the northwest corner of the study area are a number of step faults which can not be well defined as separate faults. These high-angle normal faults are nearly vertical with the displacements appearing to be largely dip-slip and averaging about 100 feet. Locally, displacements of up to 400 feet have been measured (Otte, 1959). These faults offset the folded strata of La Luz Anticline so are younger than the post-Abo deformation; a few also affect the tertiary intrusive rocks. Thus, Otte (1959) considers most of this small-scale faulting to be contemporaneous and related to the formation of the boundary fault zone of late Cenozoic time.

Folds: The folds from pre-Abo deformations are restricted to an area which extends for about three miles northward from Salado Canyon to about one mile north of La Luz Canyon. A number of small, asymmetric, plunging folds occur between the Salado and Fresnal faults near Salado Canyon. The folds are en echelon and have an average spacing of about 1000 feet. An overturned anticline whose axial plane dips about 45 degrees toward the east and plunges steeply toward the northwest is located on the north side of Salado Canyon (Otte, 1959). Toward the northeast, en echelon with this anticline, beds of the Bursum Formation are folded in a plunging syncline and unconformably overlie the Holder Formation. This folding appears to be contemporaneous with the movements along the Fresnal and Salado faults.

Near La Luz Canyon a number of northwest-trending, asymmetric, plunging folds are present. Within an area of about one and a half miles, Otte (1959) observed eight separate en echelon folds. The western limbs of most of these anticlines dip 30 to 50 degrees toward the southwest while the eastern flanks generally dip less than 10 degrees. The average plunge along the fold axis is five degrees. It appears these folds were formed during several periods of folding during late Virgilian and early Wolfcampian time in a manner similar to those in the Salado Canyon area. Otte (1959) feels that it is significant that all the folds occur en echelon and are restricted to this north-south belt of late Pennsylvanian - early Permian deformation.

There are several major post-Abo folds. Among them are the Caballero Anticline, the most tightly folded of the anticlines in the northern Sacramento Mountains, La Luz Anticline, Dry Canyon Syncline, and Maruchi Canyon Arch. La Luz Anticline is near the front of the escarpment and extends for about six miles from Marble Canyon to La Luz Canyon where it plunges northward at about ten degrees. The limbs of this symmetrical anticline have dips of about 30 degrees (Otte, 1959). Beds from at least the Abo and Bursum formations appear to be affected by the folds.

The most sharply defined syncline in the area is the Dry Canyon Syncline. It is a broad, open fold in the four miles between State Highway 83 (see Figure 7, p. 20, for location) and a point about a mile north of La Luz Canyon, where it gradually widens and dies out. In this section the fold is asymmetric, tends east of north, and has a steep eastern limb with a dip of about 30 degrees and a western limb which averages only about four degrees (Otte, 1959). Due to reversals of plunge along the axis, several structural basins occur along the syncline's length. Pray (1961) maps this syncline for an additional eight miles south of the highway. In this area the syncline is tightly folded, having dips of over 60 degrees on the flanks and several conspicuous zones of drag folding. Pray (1961) suggests that the main portion of this folding was pre-Abo although later minor folding occurred along the same line during and after the Abo Formation was deposited. The portion of the syncline north of the highway, however, was formed in post-Abo time.

The Maruche Canyon Arch, a gentle arch in the basal strata of the Abo Formation, is located about three miles east of the junction of La Luz and Fresnal canyons in Maruche Canyon. The arch is about a half mile wide and is part of the narrow deformed belt which extends for about four miles between Fresnal and La Luz Canyons and includes the Fresnal Fault zone (Otte, 1959). The arch plunges northward and dies out just north of the study area.

CHEMISTRY

PROCEDURES:

Water samples were collected from wells and springs throughout the study area between September 26 and September 29, 1985. Sampling locations are shown in Figure 14. At the time of collection, temperature readings were taken and alkalinity tests were performed. Conductivity and pH readings, however, were taken in the laboratory due to malfunctions in the field pH and conductivity meters. These, and the remainder of the chemical analyses, were performed in the chemistry laboratory of the New Mexico Bureau of Mines and Mineral Resources as soon as possible after collection. The data in Table 8 represent the results of the analysis for each sample. In addition, the results have been plotted as Stiff diagrams at the sampling locations in Figure 15, thus allowing a quick visual comparison between samples. Figure 16 is an example of a typical analysis using a Stiff Diagram. Figures 17 and 18 are presentations of the data on Piper trilinear diagrams, a method which categorizes water by the percentages of major ions present.

INTERPRETATION OF WELL SAMPLES:

Water samples were obtained from wells bottoming in the Yeso, Abo, Bursum, and Gobbler formations. Although the water of the Yeso Formation is of a strikingly better quality than that of other formations, the quality of all the area's well water is lower than the Environmental Protection Agency recommends for drinking water (see Table 9). The pH of each sample falls within the acceptable 6.5 to 8.5 range, but, this is almost the only standard measured in the analyses which is met. The one exception is the chloride content within the Yeso Formation which is much lower than standards. All the other water, however, exceeds the 250 ppm chloride limit by 15 to 200 ppm, while the same sulfate limit is exceeded by 50 ppm in the water from the Yeso Formation and by 150 to 1200 ppm in the other formations. All well water is classified as slightly brackish (over 1000 ppm TDS), although the Yeso water is fairly close to the fresh water limit (less than 1000 ppm TDS).

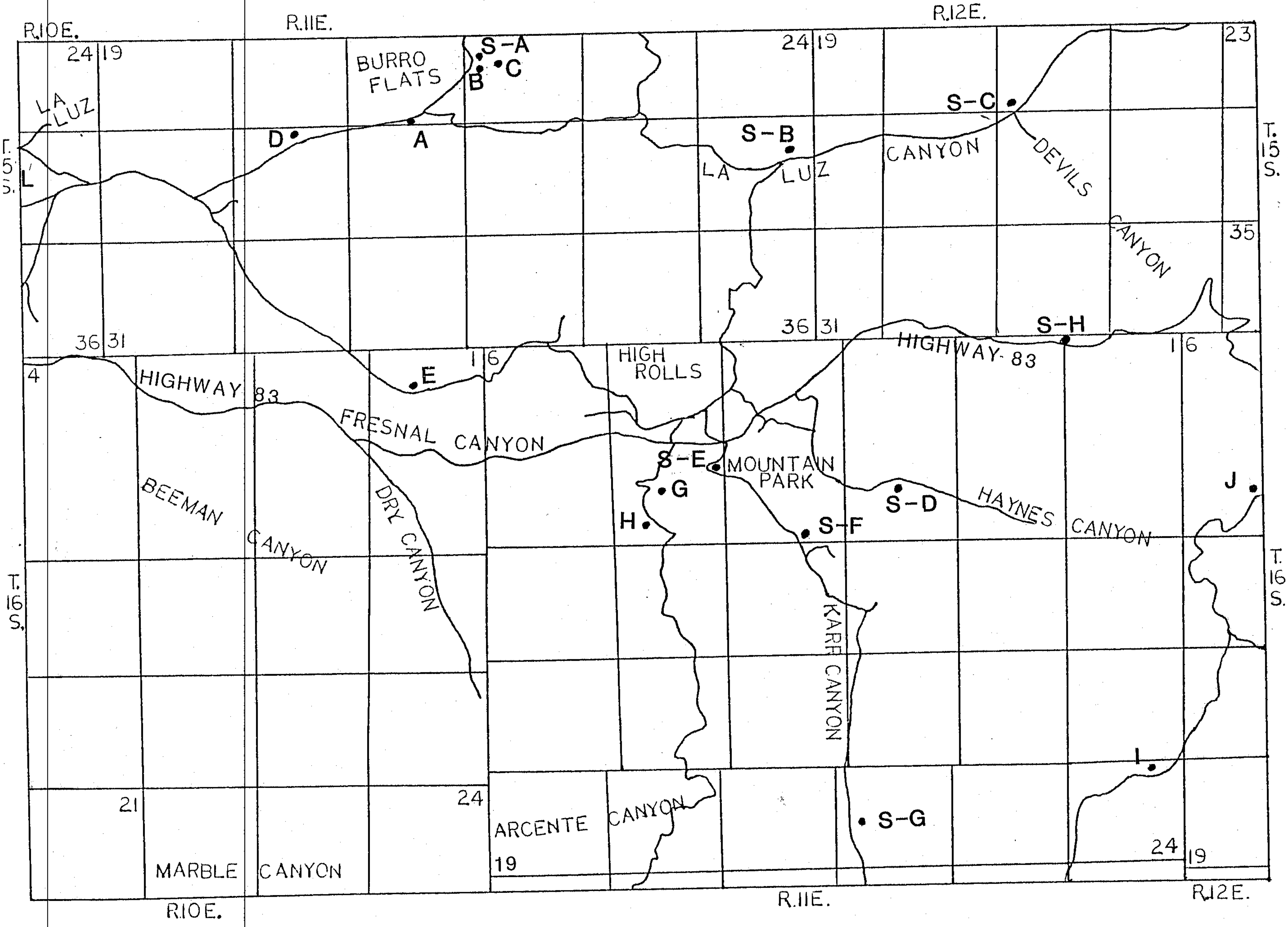


Figure 14. Location of water samples used in the chemical analysis.

TABLE 8. CHEMICAL ANALYSIS OF WELL AND SPRING SAMPLES

LOCATION	pH	TEMP	CONDUC-TIVITY	TDS	HCO3 ppm	HCO3 epm	Cl ppm	Cl epm	SO4 ppm	SO4 epm	Na ppm	Na epm	K ppm	K epm	Ca ppm	Ca epm	Mg ppm	Mg epm	cat/an % error	FORM-ATION
15S.11E.21.414	7.2	15	3100	1989	360	5.9	450.5	12.7	403	25.3	253.9	11.1	0.99	.03	376	18.7	144.2	11.8	2.8	ABO
15S.11E.22.124	7.3	17	2000	2172	400	6.5	246.1	6.9	870	18.1	135.2	5.9	1.22	.03	294	14.6	104.8	8.6	3.9	ABO
15S.11E.22.211	7.2	15	2790	2769	240	3.9	404.6	11.4	1374	28.6	191.1	8.3	1.40	.04	425	21.2	132.6	10.9	4.1	ABO
15S.11E.29.213	7.2	17	3300	3312	440	7.2	456.8	12.9	1445	30.1	278.3	12.1	1.78	.05	460	27.9	229.7	18.8	3.6	ABO
16S.10E.1.131	7.1	19	2290	1918	440	7.2	319.1	9.0	579	12.0	214.3	9.3	1.01	.03	262	13.1	102.5	8.4	4.4	BURSUM
16S.11E.5.324	7.2	24	3190	3319	560	9.2	427.6	12.1	1441	30.0	264.2	11.5	1.75	.05	410	20.4	214.8	17.8	1.5	GOBBLE
16S.11E.5.331	7.1	20	2320	2338	560	9.2	266.9	7.5	916	19.1	181.6	7.9	1.37	.04	301	15.0	111.6	9.1	5.3	GOBBLE
16S.11E.13.444	7.6	23	800	1058	440	7.2	43.8	1.2	312	6.5	8.9	0.4	0.51	.01	238	11.9	15.0	1.2	4.4	YESO
16S.12E.6.2	7.7	22	600	992	420	6.9	22.9	0.7	309	6.4	8.9	0.4	0.50	.01	217	10.8	13.3	1.1	6.2	YESO
15S.11E.22.112	7.3	18	2090	2022	360	5.9	241.9	6.8	885	18.4	148.9	6.5	0.96	.03	283	14.1	102.6	8.4	3.5	ABO
15S.11E.25.242	7.3	21	2100	1833	460	7.5	383.8	10.8	480	10.0	242.0	10.5	0.72	.02	223	11.1	43.9	3.6	4.7	YESO/A
15S.11E.30.244	7.7	20	1700	1637	480	7.9	296.1	8.4	406	8.5	205.4	8.9	0.82	.02	206	10.3	43.1	3.5	4.0	YESO
16S.11E.3.442	7.8	23	800	885	460	7.5	41.7	1.2	212	4.4	16.3	0.7	0.81	.02	125	8.7	29.3	2.4	5.0	YESO
16S.11E.5.422	7.9	24	890	971	420	6.9	60.4	1.7	261	5.4	25.1	1.1	0.80	.02	153	7.6	50.5	4.1	3.9	YESO
16S.11E.9.211	7.9	26	1950	2066	620	10.1	98.0	2.8	840	17.5	81.8	3.6	3.43	.09	261	13.0	162.5	13.3	0.5	ABO
16S.11E.22.414	7.6	28	600	1064	420	6.9	29.2	0.8	357	7.4	14.7	0.6	0.55	.01	219	10.9	24.3	2.0	5.3	YESO
16S.12E.2.222	7.6	22	690	955	480	7.9	21.6	0.9	224	4.7	21.6	0.9	0.69	.02	178	8.9	29.2	2.4	5.1	YESO

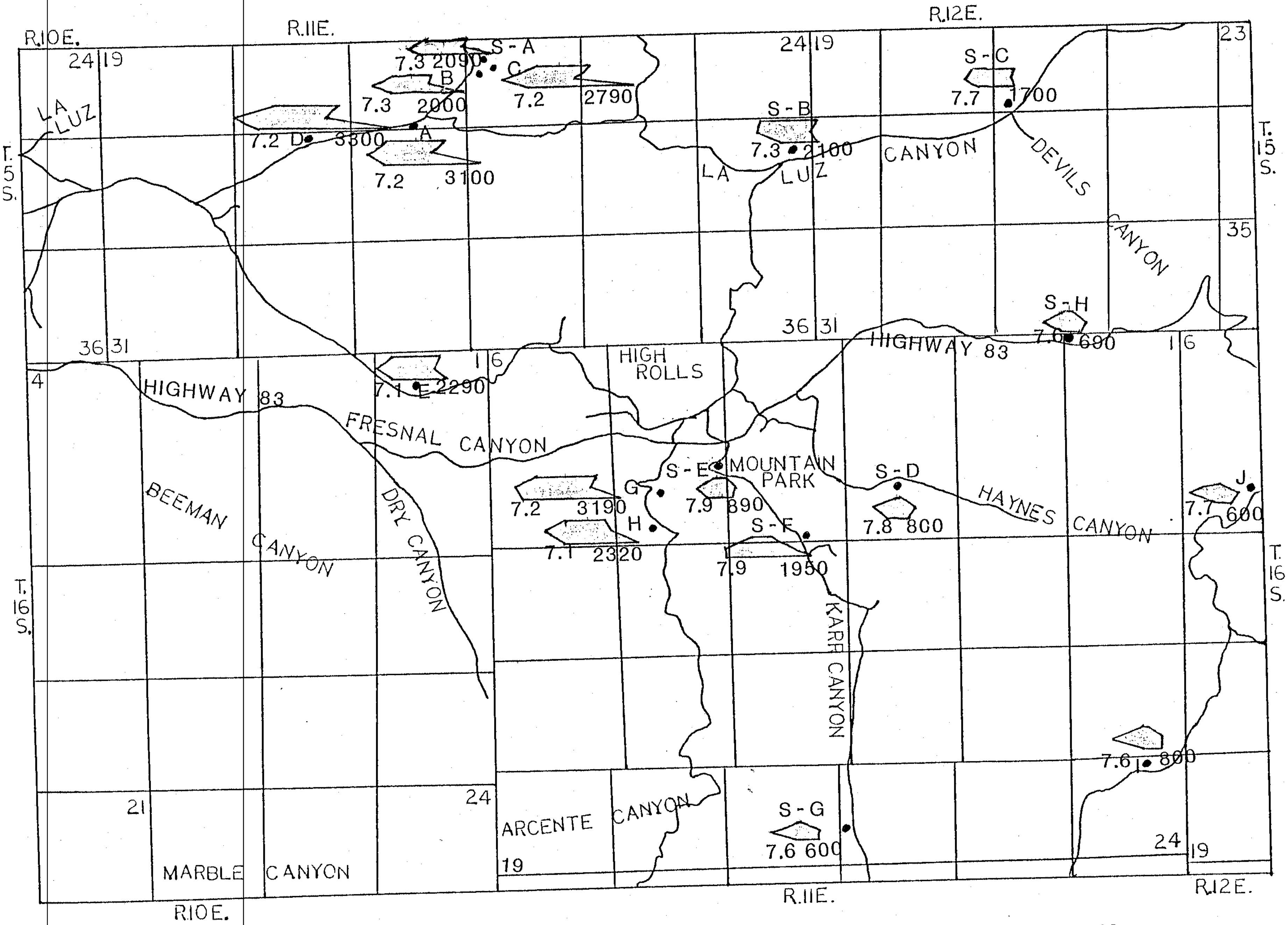


Figure 15. Water quality of the waters within the study area represented by Stiff

each diagram are pH (left) and

cations	anions
Na + K = 0.5 epm	Cl = 0.7 epm
Ca = 1.0	HCO_3 = 1.4
Mg = 1.05	SO_4 = 0.45
2.55	2.55

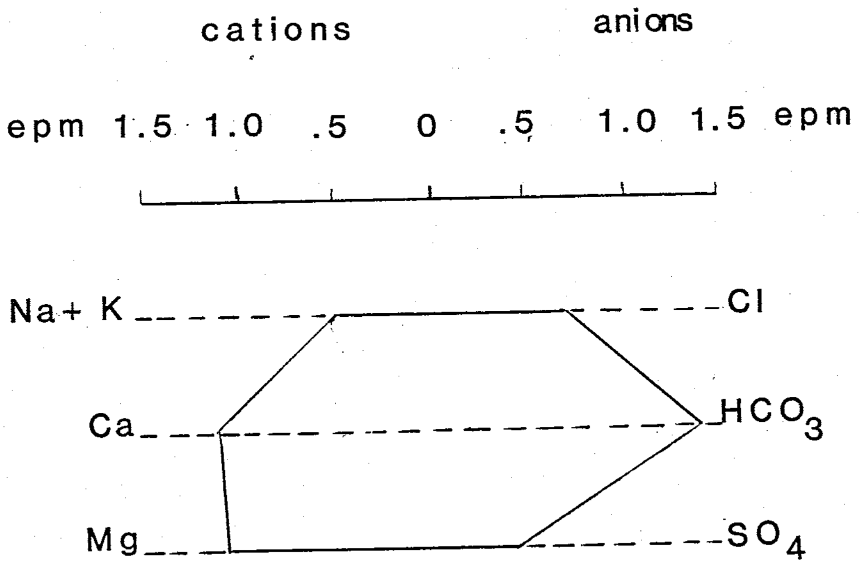


Figure 16. A typical Stiff diagram.

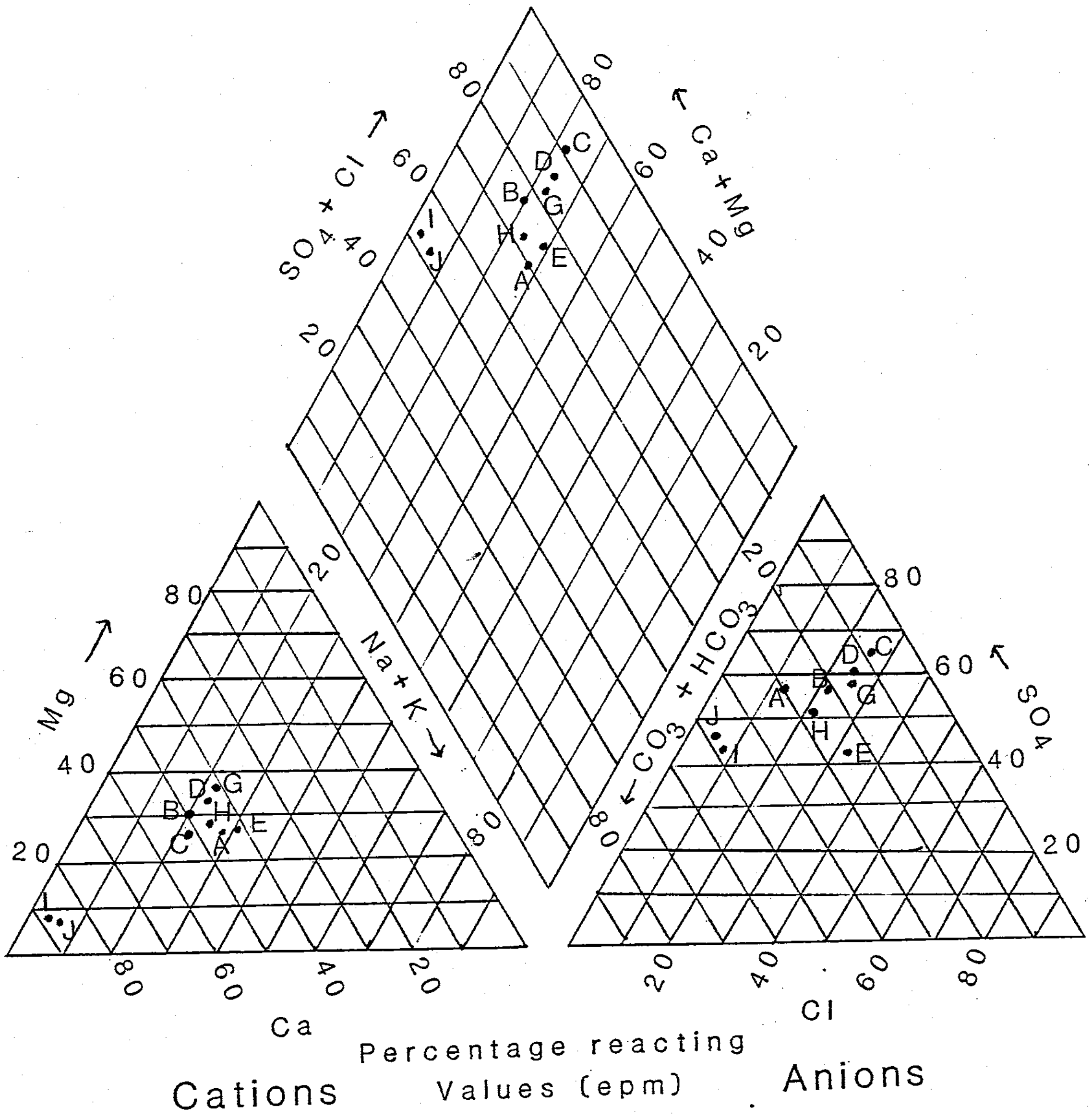


Figure 17. Piper trilinear diagram of the well water chemistry within the study area. For letter designations see Table 8.

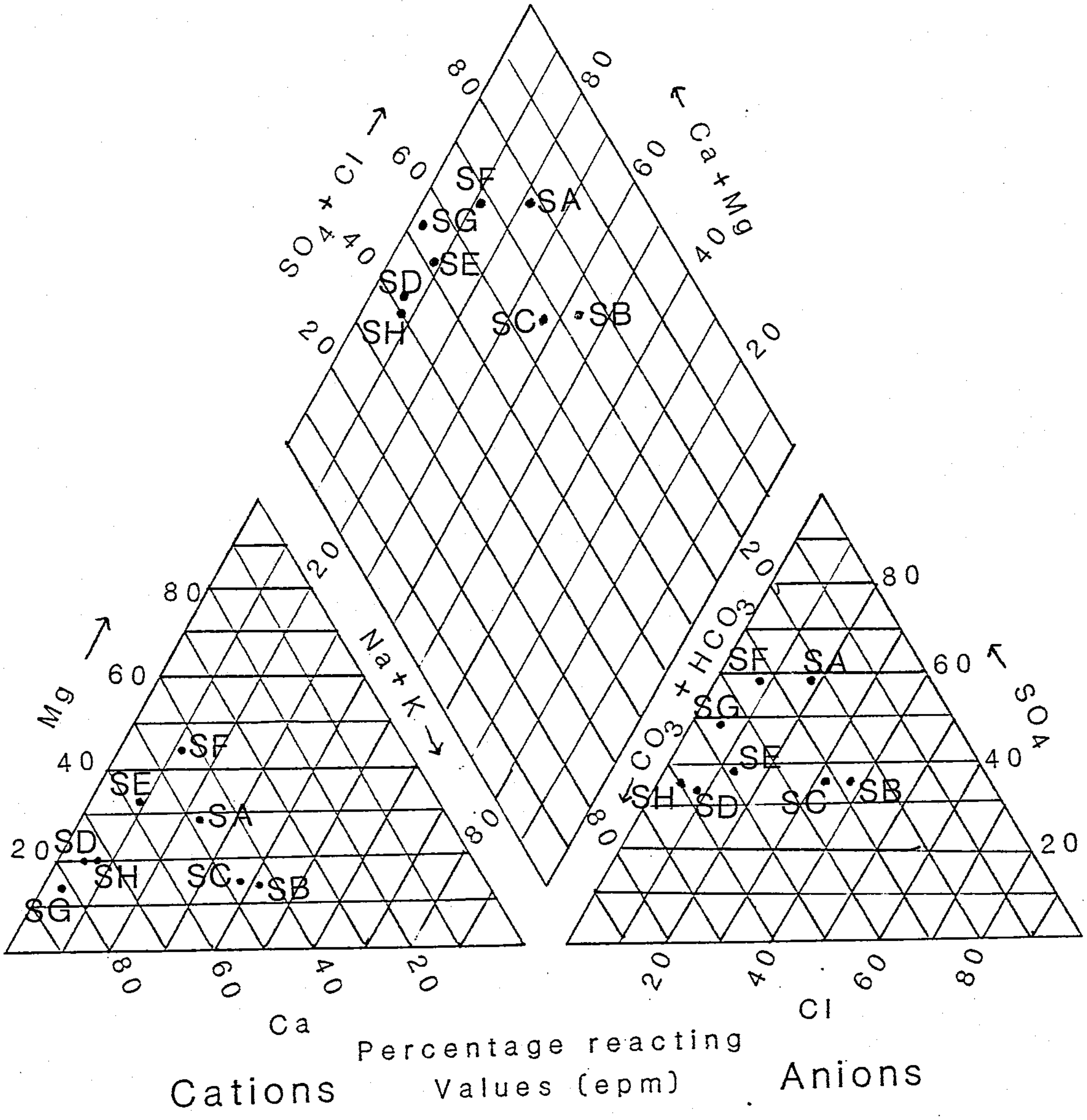


Figure 18. Piper trilinear diagram of the spring water chemistry within the study area. For letter designations see Table 8.

TABLE 9. DRINKING WATER STANDARDS FOR SOME INORGANICS

CONSTITUENT	RECOMMENDED LIMIT (ppm)
pH	6.5 to 8.5
TOTAL DISSOLVED SOLIDS	500
CHLORIDE (Cl)	250
SULFATE (SO4)	250
NITRATE (NO3)	45
IRON (Fe)	0.3
MANGANESE (Mn)	0.05
COPPER (Cu)	1.0
ZINC (Zn)	5.0
BORON (B)	1.0

When comparing the waters from the various formations note that the waters from the Abo, Gobbler, and Bursum formations have a very similar quality and major ions are present in approximately the same proportions. Each has a high sulfate and chloride content. This could possibly indicate a mixing of water between formations. The Yeso water, however, is of a different composition. Calcium is its major cation while bicarbonates and sulfates each represent about 50 percent of the anions.

The chemistry from wells A, B, C, and D in the La Luz Canyon area illustrate a phenomenon which often appears in the data. Here, there are samples from four wells located fairly close to each other yet the percentage concentration of the ions in each well differ. This varying chemistry seems to indicate that water is being withdrawn from different layers of strata, even though it appears the wells should be tapping similar strata.

INTERPRETATION OF SPRING DATA:

Water samples could only be taken from springs issuing from the Yeso and Abo formations. The spring water is of comparable quality to that withdrawn from wells bottoming in the same formation. Again, the Yeso water is slightly brackish while the Abo water is brackish. The chloride content is below recommended standards within the Yeso Formation but very close to, or slightly above, the limit in the Abo Formation. The sulfate content is above the recommended limit in all springs while all the pH values fall within the recommended range.

As Figure 18 illustrates, the sharp contrast in well water quality between the Yeso waters and that of other formations is not seen in the spring samples. Instead, the Yeso samples are distributed over a 30 to 50 percent range for each ion and tend to take on a chemical signature similar to that found in the Abo Formation. In most of the spring samples, calcium represents over 50 percent of the cations while between 30 and 60 percent of the anions are sulfates. This wider distribution is probably due to the springs being located near formation contacts, thus the water tends to take on the chemical signature of both formations it contacts. This seems to be especially true of springs SB and SC in the northwest corner of the study area and spring SG to the south. All three issue from the Yeso Formation but have a water quality which is intermediate between that which was found in wells bottoming in the Yeso and Abo formations.

Springs SB and SG are both contact springs so the water has been in contact with both the Yeso and Abo formations. Thus, it is reasonable for the water chemistry to show chemical signs of both formations. Spring SC, however, lies some distance from the contact. A mixing of water here would probably involve movement of water between the two formations either by leakage at the formation contact or through a crack of some form. From the available data, it is difficult to tell which of these is the source of this chemical mixing and whether it is a regional or local phenomenon. It would be useful to know, however, which mechanism is responsible, since, if it is a regional phenomenon, its effect on how the regional recharge and discharge systems are viewed could be important.

DRILLER'S WELL LOGS

GENERAL:

Data from driller's well records provided a great deal of information about the hydrologic conditions of the study area. Information derived from these records is given in Table 10 while the logs are presented in the Appendix. Forty-five well records from within the study area were available from the New Mexico State Engineer Office in Santa Fe, New Mexico. These were used to gather information on water levels, water-bearing formations, and well locations. As most of these wells have been drilled within the past few years, it has been assumed that the reported water levels are very similar to the current water levels.

Nearly all of the driller's logs lack detail and proper geologic terminology, identifying sandstone as sand and limestone as either lime or limerock. In other cases, the strata are identified only as rocks of a particular color, such as "red rock" or "gray rock". These brief descriptions have been interpreted as accurately as possible, using information from other logs in the same vicinity, and a general stratagraphic column. With this interpretation, the logs provided a general outline of the underlying strata and regional geologic patterns within the study area.

To aid in the evaluation process, four fence diagrams were drawn (see Figures 21 - 24; legend in Figure 20). Two of these trend north to south and two west to east. In choosing locations for these (Figure 19), it was attempted to use logs from all the various areas where records were present, thus covering the area as well as possible. The major areas void of well records, and therefore not covered, are the eastern and southern portions of the study area. As mentioned previously, these areas are basically undeveloped, therefore very few wells have been drilled. An exception to this is along the far eastern edge of the region where there are a few homes which have not filed any record of their water supply with the State Engineer Office.

TABLE 10. LEGEND FOR WELL RECORDS

LOG # -- Reference number as on file at the New Mexico State Engineer Office, Santa Fe, New Mexico.

DATE -- Drilling date (month - year).

ELEVATION -- Feet above mean sea level.

WELL DEPTH -- Feet.

WATER DEPTH -- Feet below ground depth.

WATER ELEVATION -- Feet above mean sea level.

USE -- D = Domestic
I = Irrigation
M = Municipal
N = Industrial
O = Observation
S = Stock
T = Test

YIELD -- Gallons per minute.

TABLE 10. WELL RECORDS

LOG #	LOCATION	DATE	ELEV-ATION	WELL DEPTH	WATER DEPTH	WATER ELEV-ATION	LITHOLOGIC DESCRIPTION	WATER BEARING FORMATION	USE	YIELD (GPM)
T-452	15S.10E.25.2433	2-68	4850	450	188	4652	----	---	I	-
T-542	15S.10E.25.2433	3-83	4850	100	39	4811	BLACK CARB. SHALE	BEEMAN	O	60
T-722	15S.10E.25.4	1-84	4850	206	119	4731	BLACK SHALE	BEEMAN	D	20
T-553	15S.11E.20.4	4-83	5400	90	20	5380	SAND & GRAVEL	ABO	D	-
	15S.11E.20.3									
T-1043	15S.11E.21.122	3-85	5600	120	DRY	----	----	---	O	SEEP
T-1119	15S.11E.21.144	7-85	5600	75	DRY	----	----	---	D	SEEP
T-883	15S.11E.21.324	5-84	5300	65	40	5260	RED GRAVEL	ABO	D	-
T-893	15S.11E.21.34	7-84	5450	60	25	5425	RED CLAY & ROCK	ABO	D	-
T-1112	15S.11E.21.344	5-85	5480	58	50	5430	SAND & GRAVEL	ABO	D	30
T-910	15S.11E.21.41	7-84	5550	60	10	5540	GRAVEL	ABO	D	-
T-965	15S.11E.21.411	9-84	5550	70	40	5510	GRAVEL	ABO	D	-
T-384	15S.11E.22.11	8-82	5750	95	25	5725	RED CLAY & GRAVEL	ABO	D	-
T-520	15S.11E.22.114	3-83	5800	87	29	5771	RED SAND & GRAVEL	ABO	D	-
T-890	15S.11E.29.1	7-84	5250	80	20	5230	SAND & GRAVEL	ABO	D	-
T-555	15S.11E.29.2	3-83	5400	110	20	5380	RED SAND & GRAVEL	ABO	D,S	-
T-556	15S.11E.29.2	3-83	5400	70	15	5385	RED SAND & GRAVEL	ABO	D	-
T-924	15S.11E.29.2	7-84	5450	260	30	5420	GRAVEL & SAND	ABO	D	0.5
T-1061	15S.11E.29.213	3-85	5280	150	12	5268	GRAVEL	ABO	D	SEEP
T-690	15S.11E.32.32	8-83	5150	102	27	5123	CLAY AND SANDSTONE BLUE LIMESTONE ORANGE CLAY & LIME	ABO HOLDER HOLDER	D	2 SEEP 3
T-1034	15S.11E.32.324	2-85	5200	130	20	5180	SAND & GRAVEL	BURSUM	T	15
T-1033	15S.11E.32.433	4-85	5240	100	20	5220	FRACTURE/SANDSTONE	BURSUM	T	20
T-683	15S.11E.32.44	9-83	5400	250	125	5275	CREVICE/BROWN STONE	BURSUM	D	5
T-388	16S.10E.4.13 (A) 16S.10E.4.14 (B)	7-82	4700	800	--	----	----	---	D,N,M	-
T-1070	16S.10E.15.343	3-85	4750	640	470	4280	LIME ROCK	YESI	D	60
T-1048	16S.10E.15.43	2-85	5000	690	475	4525	POROUS LIME ROCK	YESO	D	200
T-742	16S.10E.21.212	5-85	4900	326	295	4605	SAND & GRAVEL	ALLUVIUM	D	20
T-133	16S.11E.3.3	11-66	7230	247	227	7003	----		D	25
T-1014	16S.11E.3.32	2-85	7200	130	60	7140	BLACK SHALE	YESO	D	5
T-977	16S.11E.3.41	12-84	7350	90	60	7290	YELLOW ROCK	YESO	D	10
T-1066	16S.11E.4	3-85	6800	170	50	6750	SAND	ABO	D	2
T-1004	16S.11E.4.24	10-84	6600	300	--	----	----	---	D	-
T-1013	16S.11E.4.41	10-84	6600	400	--	----	----	---	D	-
	16S.11E.4.42									
T-53	16S.11E.5	8-55	6500	140	--	----	----	---	D	25
T-60	16S.11E.5	7-56	6500	101	--	----	----	---	D	6
T-342	16S.11E.5	9-82	6500	150-	--	----	----	---	D	-
T-616	16S.11E.5	6-83	6500	90	65	6435	YELLOW-GREEN GRAVEL	ABO	D,S	40
T-967	16S.11E.5.13	9-84	6500	281	118	6382	RED SANDSTONE	ABO	D	3
T-58	16S.11E.5.14	8-56	6500	135	63	6437	BLACK & BLUE SHALE	GOBBLER	D	15
T-12	16S.11E.5.144	8-49	6500	59	--	----	LIMESTONE BOULDERS	GOBBLER	-	-
T-138	16S.11E.5.3	11-82	6750	502	289	6461	BLUE LIMESTONE	GOBBLER	D	1
T-817	16S.11E.5.32	----	6550	500	---	----	---	---	-	-
T-849	16S.11E.5.4	3-84	6600	150	DRY	----	---	---	-	-
T-574	16S.11E.5.412	4-83	6550	149	50	6500	BROKEN LIME ROCK	GOBBLER	D	1
T-829	16S.11E.5.43	4-84	6720	623	480	6240	CREVICE	GOBBLER	T,D	5
[illegible]	[illegible]	2-84	6720	500	--	----	----	---	-	-

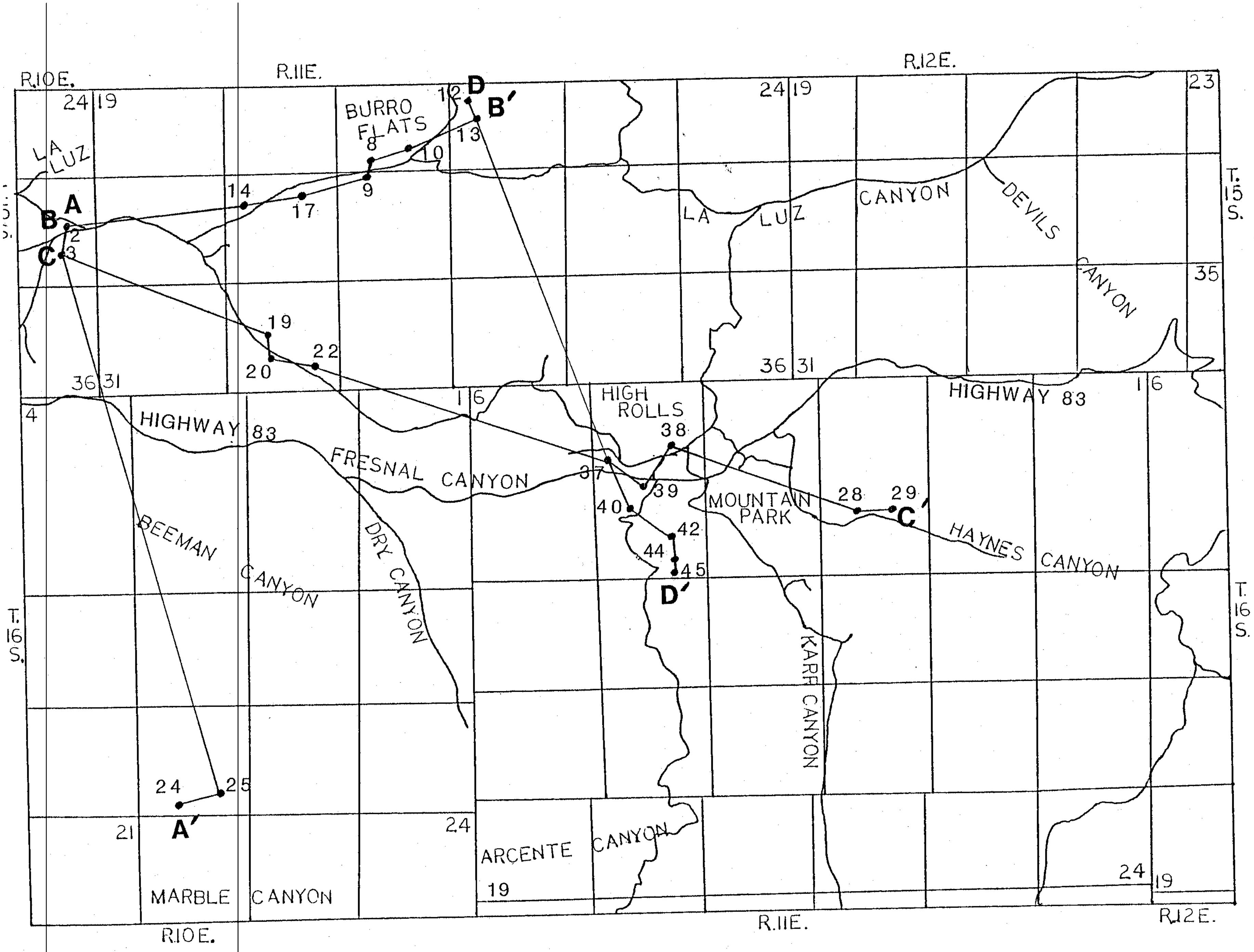


Figure 19 Location of the fence diagrams.

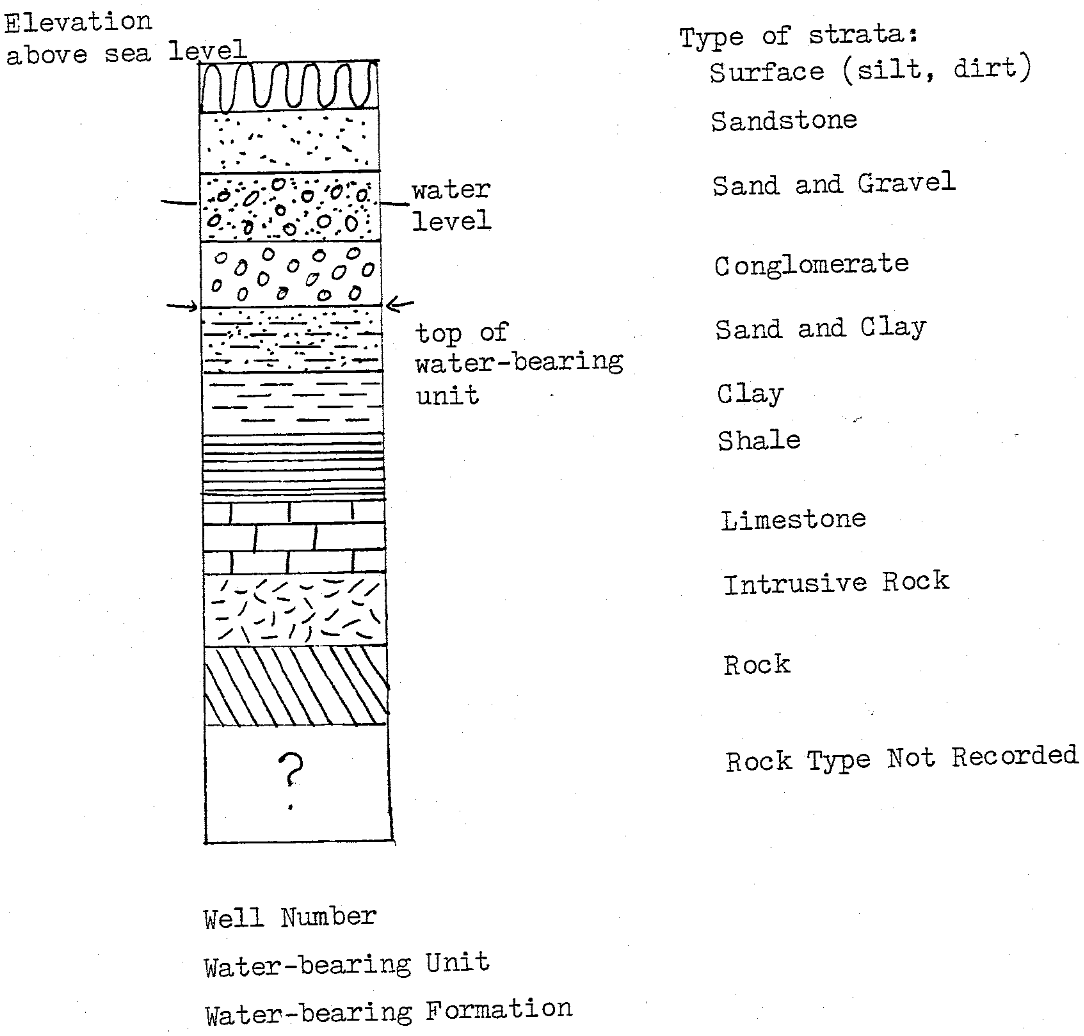


Figure 20. Legend for fence diagrams (Figures 22 to 25).

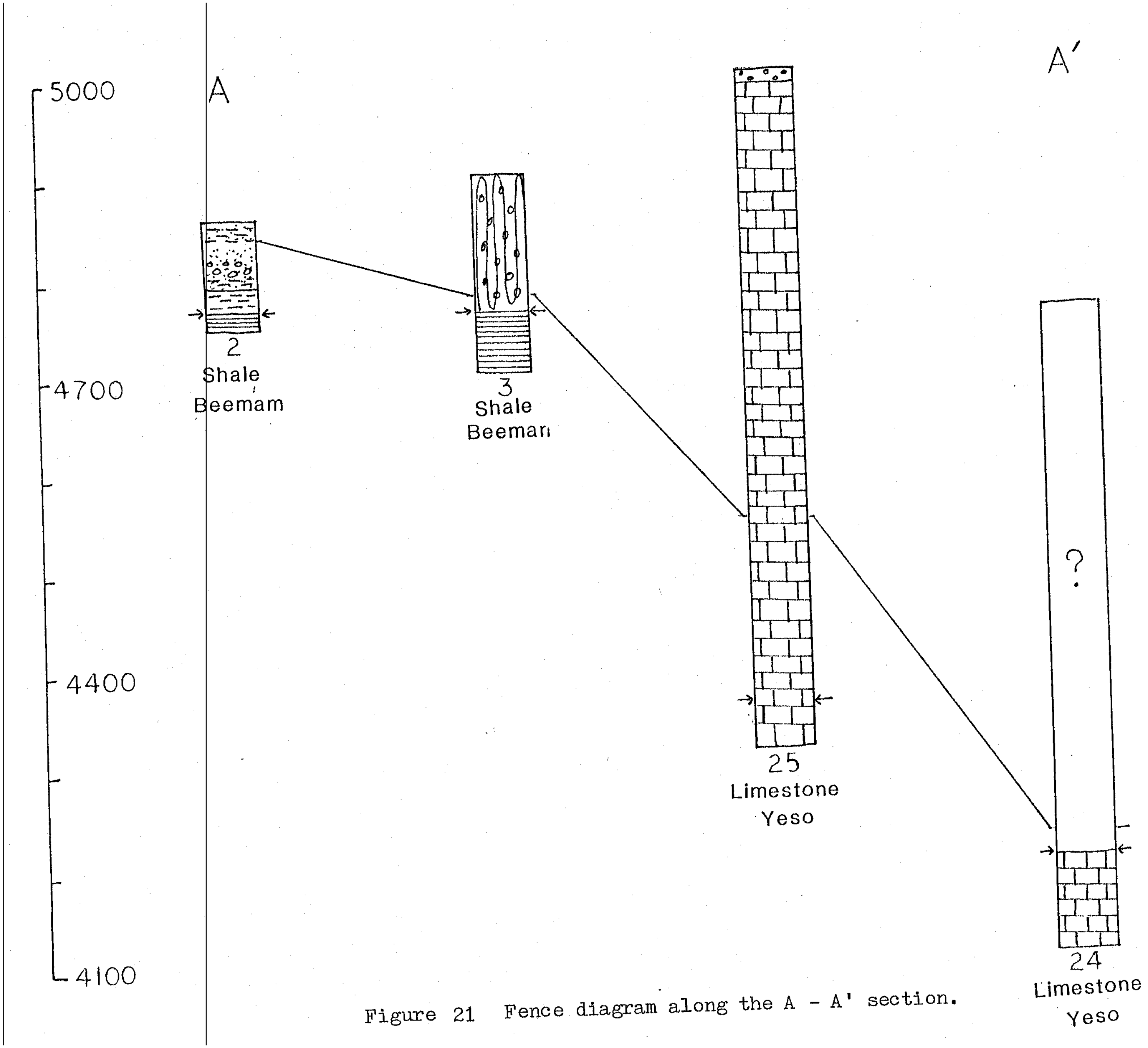


Figure 21 Fence diagram along the A - A' section.

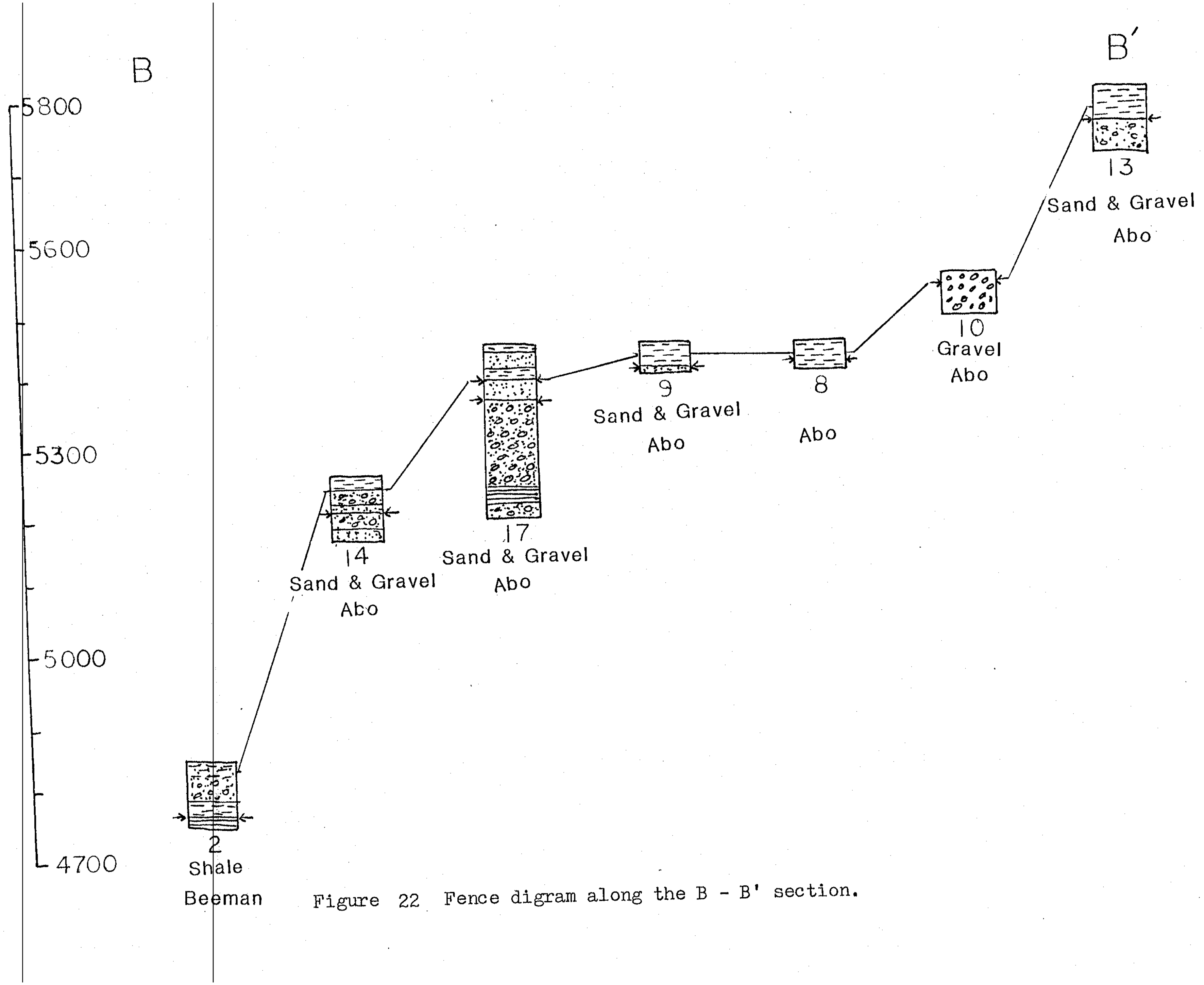


Figure 22 Fence digram along the B - B' section.

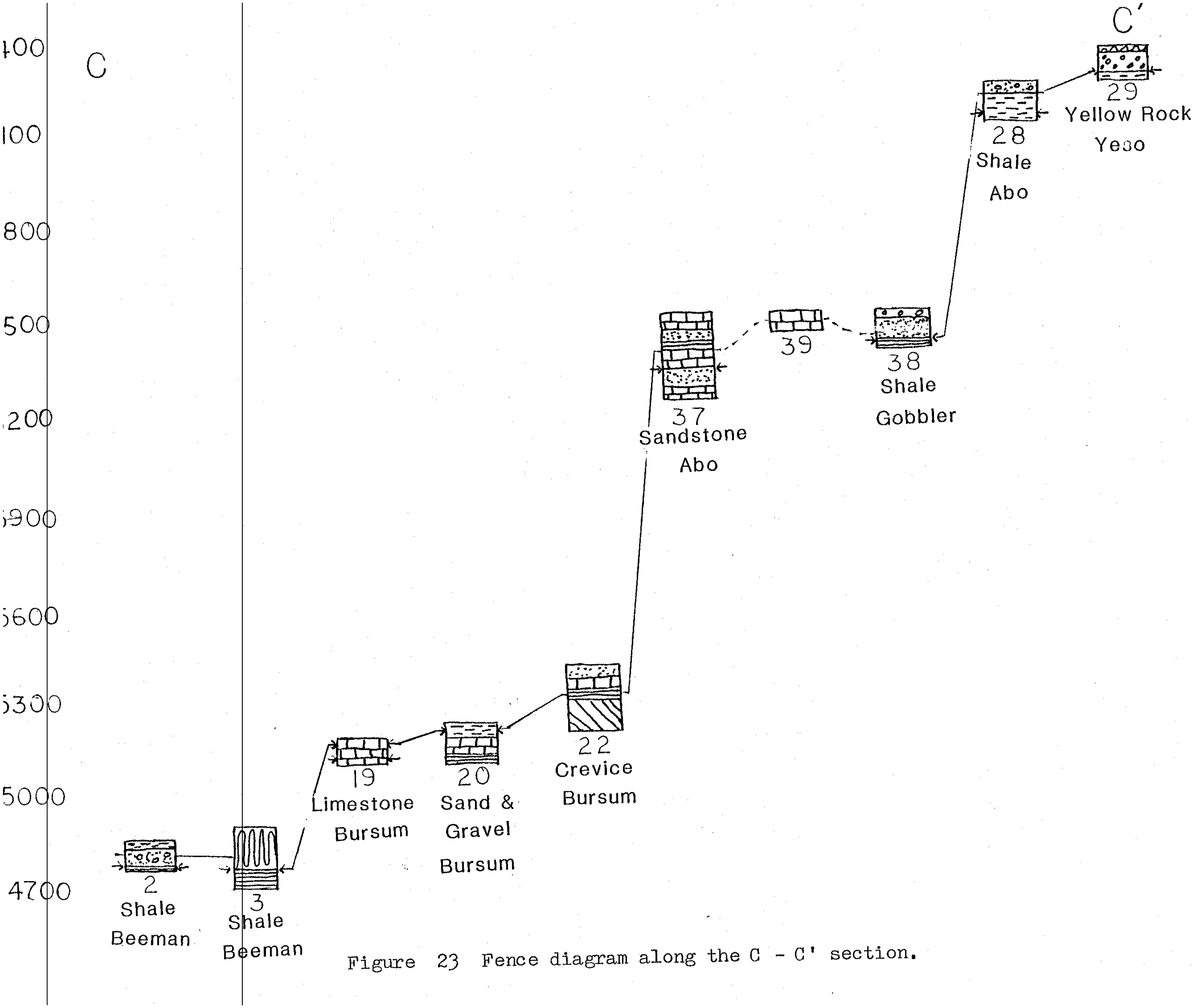


Figure 23 Fence diagram along the C - C' section.

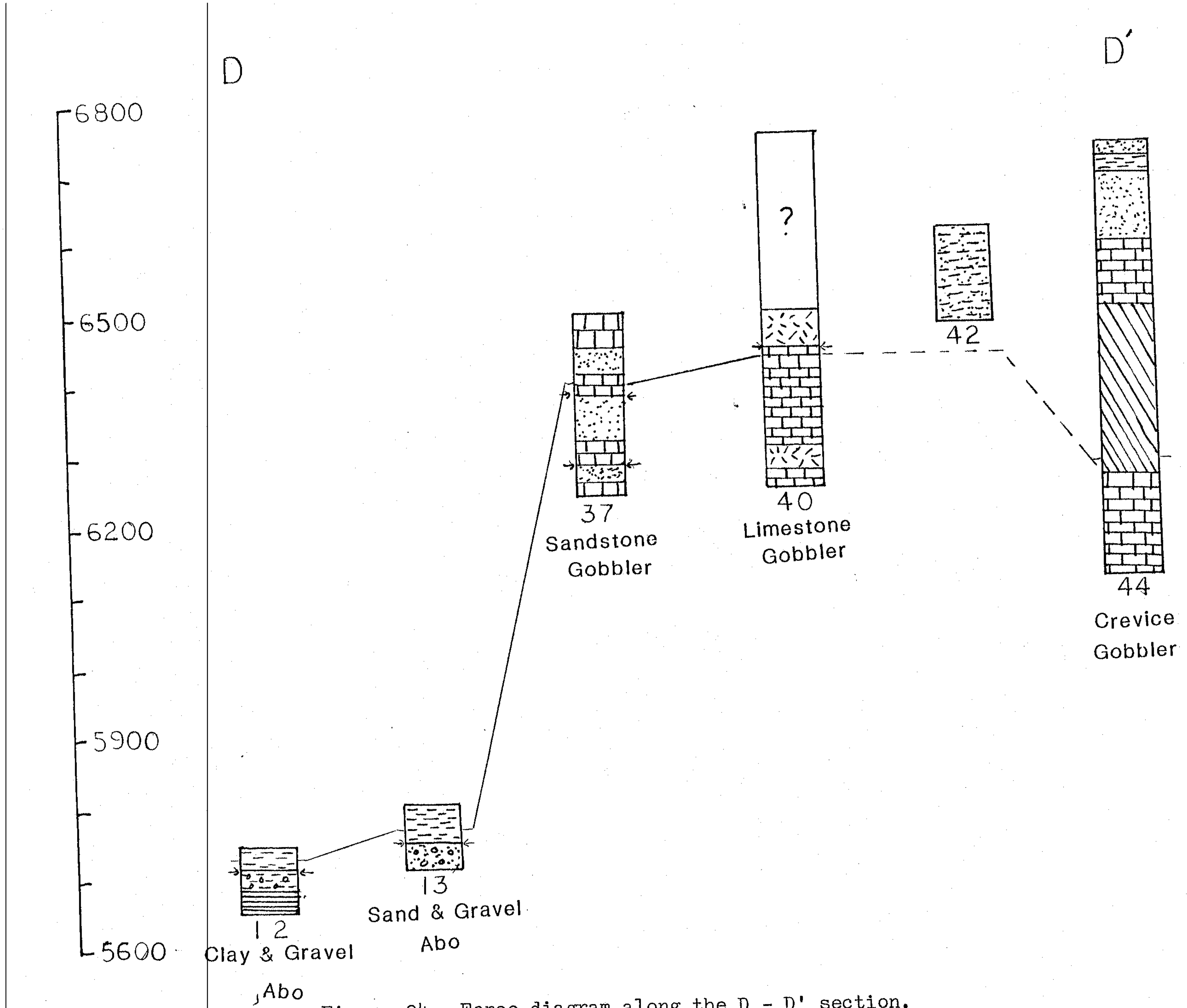


Figure 24 Fence diagram along the D - D' section.

DISCUSSION:

STRATIGRAPHY: The well logs report a record of the strata in accord with what one would expect to find after studying the area's geology and stratigraphy. The younger the unit, the further east and higher the elevation at which it is located. The steep topographic gradient in the east-west direction makes it difficult to draw any solid conclusions pertaining to the properties or continuity of a particular unit in this direction. Thus, for a larger lateral view of the formations and thus better results, the north-south cross sections need to be examined. From these, it appears that there is a lack of continuity within the layers of several formations. This is especially true for the multi-layered Abo Formation where rock types are found arranged in various sequences of varying thicknesses, even though the logs may be located fairly close to each other. Part of this variation is most likely due to the varying precision of recording by the drillers and some to the particular portions of the strata being observed, but part must also be contributed to the discontinuity of the formation.

WATER-BEARING UNITS: Despite the discontinuities and problems mentioned above, the well logs do provide a means of identifying the water-producing layers of a formation. On each cross-section the water-bearing units have been marked and a line connecting the various water levels drawn. Table 11 provides a summary of the water-bearing units and recorded yields.

The formation which has the highest yield is the Yeso Formation. Unfortunately, much of the area in which this formation is present is that area which is undeveloped. This aquifer is also tapped along the steep fault along the western edge of the study area.

In contrast to the Yeso Formation, the Abo Formation is the most frequently drilled, underlying the entire La Luz Canyon area and much of the High Rolls area. Wells in this formation appear to be tapping various layers and bottoming in several different rock types, suggesting a wide scatter in the water's location. The sand and gravel layers, or combinations of these and other rock types, seem to be the best producing layers, although some of the clays and shales provide smaller yields. The conglomerate and sandstone units, however, appear to be non-producing.

Of much less hydrologic importance are the Bursum, Holder, Beeman, and Gobbler Formations. Of these, the shales of the Beeman Formation are the best producers, but the formation's limited areal distribution restricts its importance as a water supply. The Gobbler also has a

TABLE 11. WATER BEARING UNITS

FORMATION	LAYER	YIELDS (GPM)
GOBBLER	SHALE	15
	SANDSTONE	SEEP - 3
	BLUE LIMESTONE	1
	BROKEN LIMESTONE	1
	CREVICE/BROWN STONE	5
BEEMAN	CARBONACEOUS SHALE	60
	SHALE	20
BURSUM	CLAY LIMESTONE	3
	BLUE LIMESTONE	SEEP
	FRACTURE/SANDSTONE	20
	CREVICE/BROWN STONE	5
ABO	SAND & GRAVEL	5 - 80
	GRAVEL	30 - 40
	CLAY AND ROCKS	40
	CLAY AND GRAVEL	10
	SHALE	5
	SAND	2
	CLAY	--
YESO	YELLOW ROCK	10
	LIMESTONE	60 - 200
ALLUVIUM	SAND AND GRAVEL	20

shale unit which has a fair yield, but a lateral trace of this unit is very difficult. The other units within the Gobbler and Bursum formations are also difficult to trace and have very low yields except where a well intercepts a crevice or fracture.

HYDROLOGY

PROCEDURES:

This investigation began with the collection of information on the geology and water resources within the study area. As there is not much written on the area's hydrology, reports on the water resources of the Roswell and Tularosa basins were consulted. Driller's well logs were then gathered from the New Mexico State Engineer Office. From September 26 to 29, 1985 a trip to the study area was made to study the area's water supply, collect water samples, and talk to the local residents about water supply and availability. It was found that many areas were inaccessible to the public so a sparser sample of wells was visited than originally hoped for. Also, a large number of the wells visited were covered and highly insulated, making an actual measurement of the water levels difficult. Thus, in compliance with the wishes of the owners, only a few water level measurements were taken. Therefore, the water levels used in this study are from the driller's logs instead of actual measurements. Even with fewer samples than would have been liked, the sampling was fairly evenly distributed throughout the region where wells have been drilled. Thus, a fairly extensive compilation of the available data has resulted, as has a hydrogeologic evaluation of this area.

SURFACE WATER:

EPHEMERAL STREAMS: A survey of the surface water patterns within the study area was conducted using the Alamogordo and High Rolls 1:24,000 topographic maps published by the U.S. Geological Survey in the early 1980's. These maps show ephemeral streams in nearly all the canyons, especially in the steeper western portion of the area as shown in Figure 25. Most of these begin near the top of the canyons, flowing downhill until they either reach a perennial stream or flow into the Tularosa Basin. Once in the basin they are either intercepted by an Alamogordo city aqueduct or disappear into the basin's bolson deposits.

There are, however, a few intermittent streams which flow eastward into Cox Canyon and the Rio Penasco. Thus, the water in Kerr, Russia, and Pierce Canyons, all located in the southeast corner of the study area, enter the Roswell Basin. Small ponds of water are located along the stream's pathway in both Pierce and Russia canyons. From Deerhead Canyon (located near the

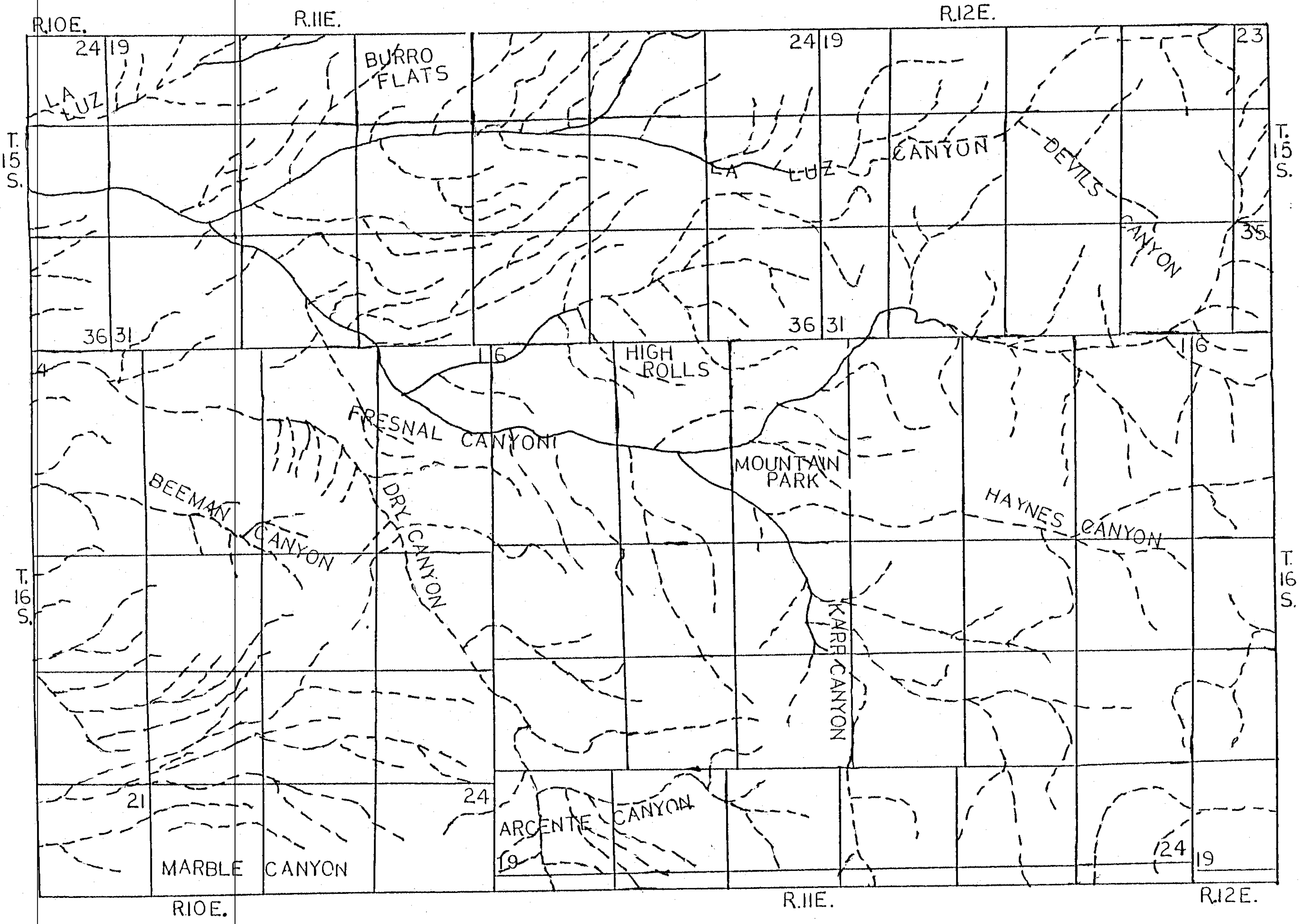


Figure 25. Perennial and ephemeral streams within the study area.

southern end of the village of Cloudcroft) north, the topography once again channels the water back towards the Tularosa Basin.

<u>PERENNIAL STREAMS:</u> Although there are many ephemeral streams within the area, there are very few perennial streams. La Luz Creek, flowing down La Luz Canyon, is the major stream of the area and has several other perennial streams feeding it. A stream in Fresnal Canyon flows into La Luz Creek approximately two miles east of La Luz. It, in turn, is fed by perennial streams in Salado Canyon and the lower part of Karr Canyon. A stream in Maruche Canyon also feeds into La Luz Creek east of Burro Flats. The only other perennial stream in the area is one which runs in portions of Cottonwood Wash. Both this stream and La Luz Creek disappear into the bolson deposits of the Tularosa Basin a short distance off the mountain's slope. The source of water for these streams are local springs and ephemeral streams.

In October, 1982, the U.S. Geological Survey began recording the discharge of La Luz Creek from a gaging station located approximately one mile east of La Luz. The creek was previously gaged from November, 1931 to September, 1932 (published in U.S. Geological Survey Water Supply Paper 733) but these records are noted as being unreliable and should not be used. Therefore, the discharge record from October, 1982 to May, 1985 (printed in the U.S. Geological Survey Water Resources Data for New Mexico) will be the only one examined. Monthly discharges are given in Table 12 and graphed in Figure 26 while mean monthly discharges for this period are presented in a similar form in Table 13 and Figure 27. It should be noted that the city of Alamogordo has the water rights to a portion of the flow in Fresnal Canyon which was not appropriated prior to their claim and that this water is diverted upstream from the gaging station. Also, there is one period, August 23 to 29, 1984, where the flood waters of La Luz Creek exceeded the gage capacity. In this case, discharge calculations were based on high water marks and slope-area measurements of peak flow. Thus, only an approximate discharge was obtained for that period.

From these data, several general trends in the discharge patterns can be identified, although the limited extent of the record must be kept in mind during the evaluation. It appears the stream's highest flow is between October and February while the lowest flow is during June and July with discharges appearing to increase after the late summer thunderstorms. This suggests that flow in ephemeral streams increases with both summer rains and, to a lesser extent, snow melt. Increased flow in these streams then leads to an increase in the perennial streams they feed. Comparing discharges with precipitation records, it appears that there may be a small delay between peak precipitation and maximum stream stage. The discharge record is too short, however, to draw any quantitative conclusions as to how long this delay might be, but, since precipitation highs occur from July through September and discharges do not peak until October, it is probable that such a lag does exist. The one apparent exception to this is in August, 1984, when not only

TABLE 12. MONTHLY DISCHARGES FOR LA LUZ CREEK (CUBIC FEET PER SECOND)

MONTH	TOTAL	MEAN	MAX	MIN	AC-FEET
10-82	151.52	4.89	10.00	0.92	301
11-82	84.15	2.81	5.30	0.95	167
12-82	164.60	5.31	9.00	2.60	326
01-83	95.60	3.08	7.70	1.60	190
02-83	113.30	4.05	7.10	1.60	225
03-83	136.10	4.39	7.10	2.70	270
04-83	79.39	2.65	6.60	0.89	157
05-83	31.15	1.00	2.90	0.35	62
06-83	9.19	0.31	0.59	0.00	18
07-83	3.13	0.10	0.62	0.00	6
08-83	35.16	1.13	3.40	0.04	70
09-83	90.17	3.01	23.00	0.13	179
10-83	170.55	5.50	68.00	0.06	338
11-83	173.82	5.79	22.00	0.36	345
12-83	190.24	6.14	15.00	0.50	377
01-84	183.20	5.91	7.90	4.30	363
02-84	99.58	3.43	6.20	0.03	198
03-84	32.94	1.06	5.50	0.12	65
04-84	43.03	1.43	4.20	0.15	85
05-84	44.10	1.42	27.00	0.05	87
06-84	58.29	1.94	13.00	0.01	116
07-84	127.05	4.10	46.00	0.00	252
08-84	759.60	24.50	423.00	0.50	1510
09-84	108.53	3.62	5.90	0.00	215
10-84	158.54	5.11	8.80	0.28	314
11-84	86.79	2.89	8.80	0.38	172
12-84	282.42	9.11	27.00	0.40	560
01-85	332.90	10.70	13.00	7.80	660
02-85	267.70	9.54	15.00	8.00	530
03-85	283.70	9.15	14.00	5.20	563
04-85	173.70	5.79	12.00	2.80	345
05-85	196.30	6.33	9.8	2.40	389

Location: 15S.11E.25.23
Latitude: 32 58' 56''
Longitude: 105 55' 30''
Altitude: 4870 feet above sea level
Drainage Area: 62.7 square miles
Water Stage Recorder

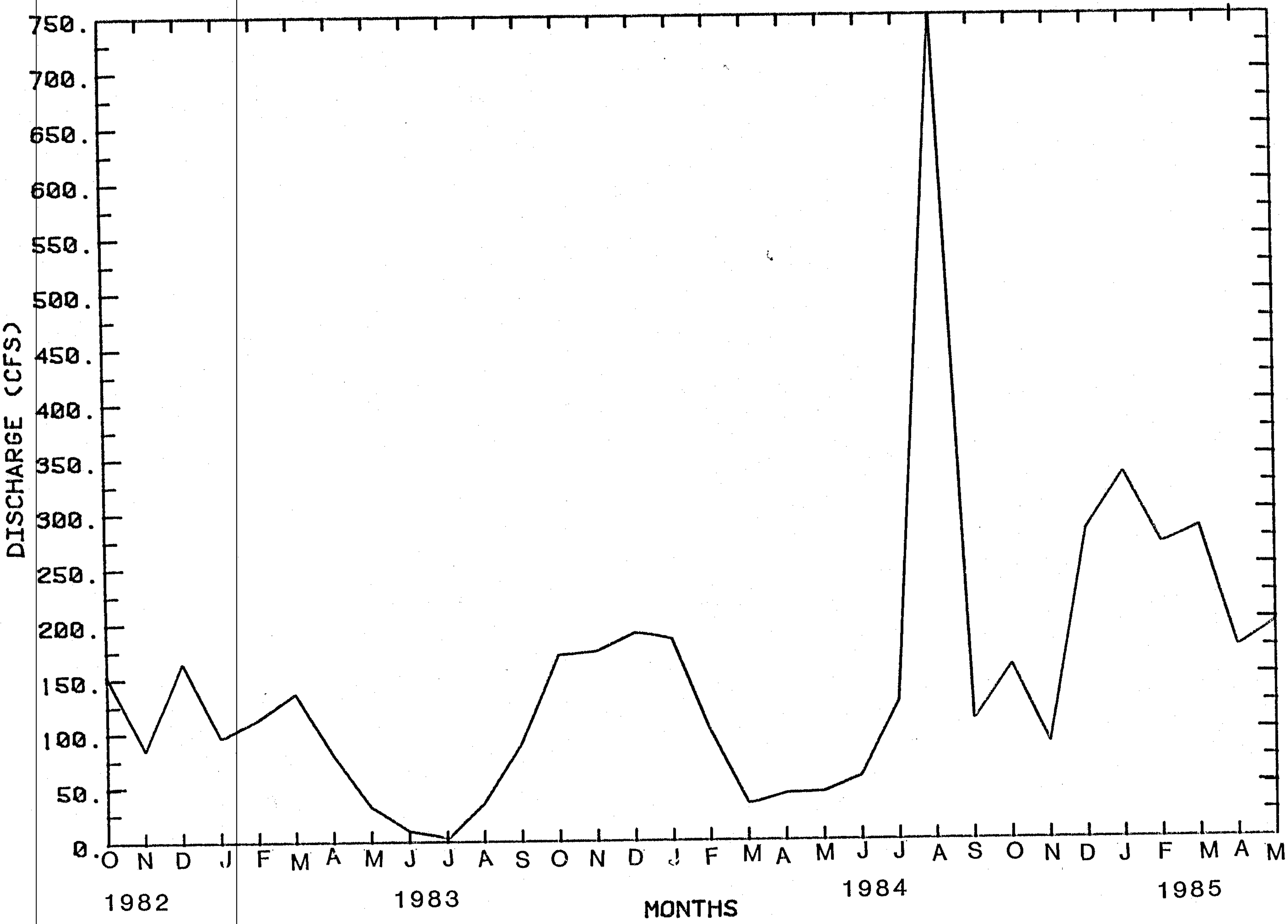


FIGURE 26. TOTAL MONTHLY DISCHARGE FOR LA LUZ CREEK.

TABLE 13. MEAN MONTHLY DISCHARGES FOR LA LUZ CREEK (CUBIC FEET PER SECOND)

MONTH	# OF YEARS OF DATA	MEAN
JANUARY	3	6.56
FEBUARY	3	5.67
MARCH	3	3.53
APRIL	3	3.29
MAY	3	2.91
JUNE	2	1.13
JULY	2	2.10
AUGUST	2	12.82*
SEPTEMBER	2	3.32
OCTOBER	3	5.12
NOVEMBER	3	3.83
DECEMBER	3	6.85

* Majority of flow is from flood waters of August 1984 which averaged 24.50 cfs vs. 1.13 cfs in August, 1983.

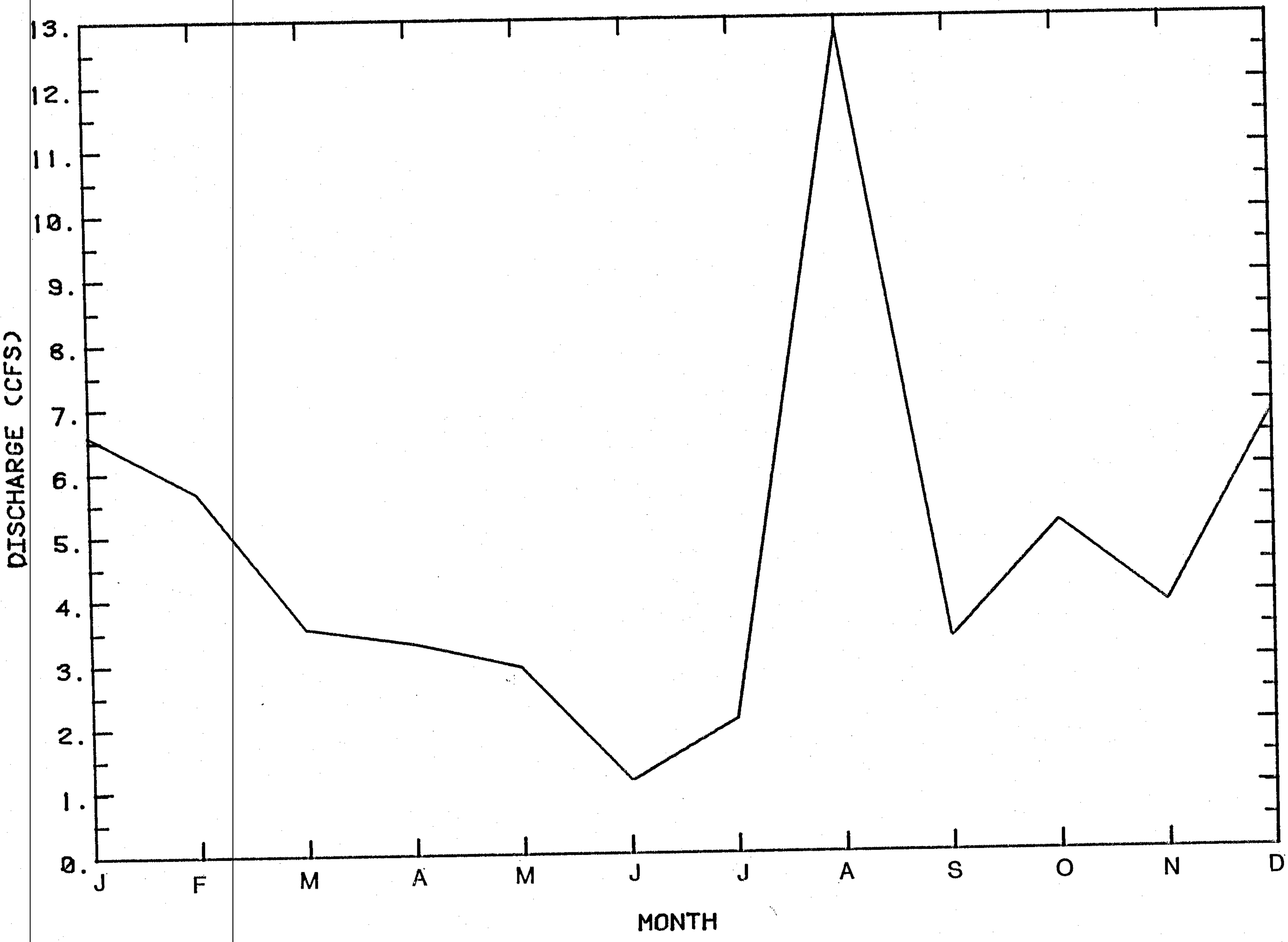


FIGURE [illegible] MEAN MONTHLY DISCHARGES FOR LA LUZ CREEK.

the river stage was high, but so was the month's precipitation. In order to examine this correlation, a closer examination of rain distribution during that month must be made. Table 14 and Figure 28 provides this daily analysis of precipitation and stream discharge for that August. Even here it is hard to make any definite correlations between these two factors since precipitation highs occur near the beginning of the month and the discharge values show two peaks, one near the first of the month and one near the month's end. A look at July's precipitation record does not provide any better explanation.

GROUNDWATER:

WELLS: Most of the wells within the study area seem to be flowing under unconfined conditions although the well logs suggest a few areas in which artesian conditions are present. Driller's logs for wells 2, 3, 9, 30, and 38 all record water levels 20 to 50 feet above the water-bearing strata. In addition, logs from wells 24, 25, and 28 have recorded levels 70, 185, and 106 feet above the water-bearing unit. In most cases clays act as the confining layer although limestones serve this role in wells 24 and 25. The formations in which these artesian conditions occur include the Gobbler, Beeman, Abo, and Yeso formations.

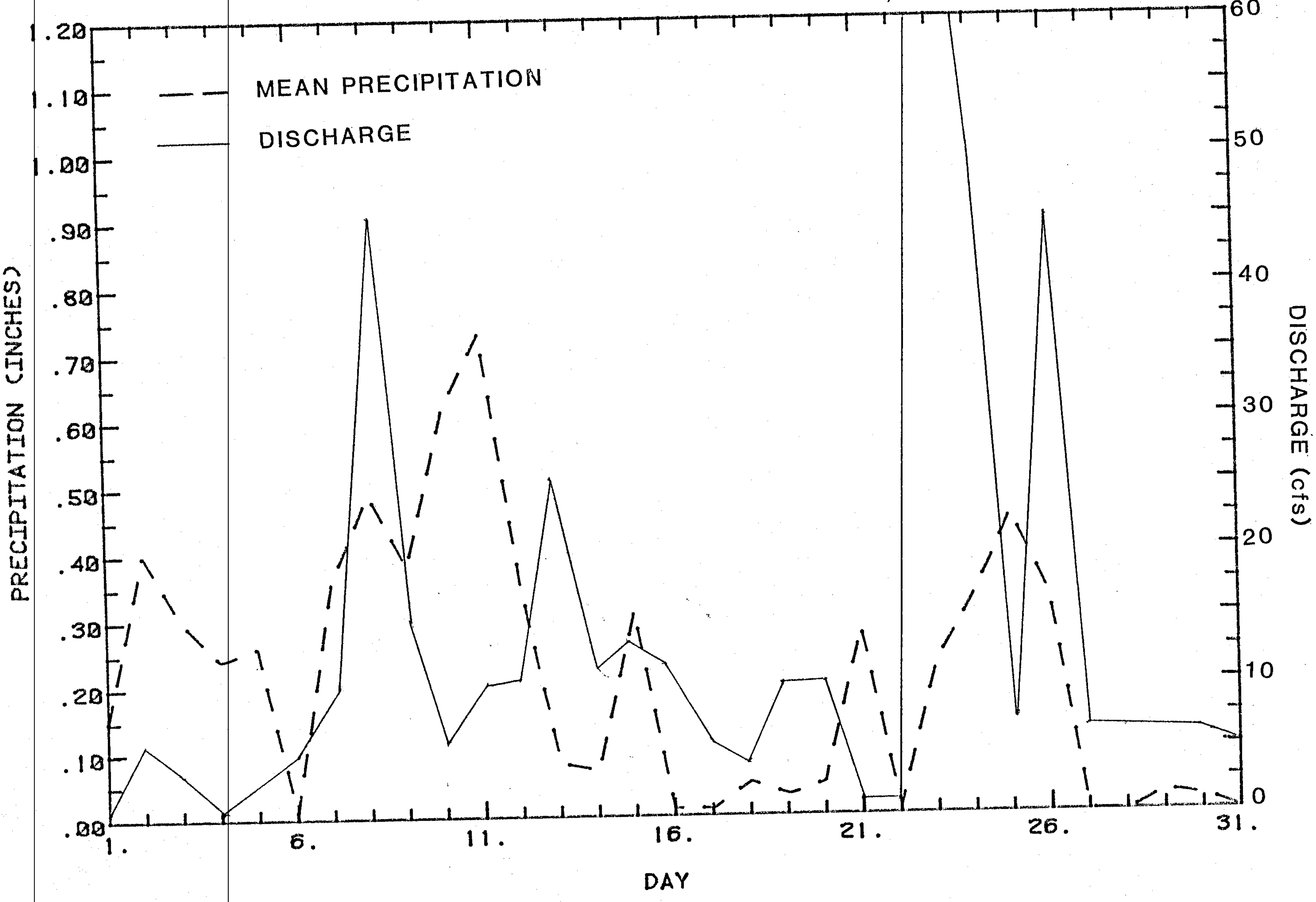
Some information on the aquifers within the study area has previously been given in the sections on drller's well logs and chemistry. These comments should be kept in mind during the following discussion on aquifer properties.

Yeso Formation: The limestones of the Yeso Formation are the highest producing unit within the study area. In addition, the water quality in the Yeso along the eastern side of the area is by far the best in the area. The Yeso Formation, however, is also present under the alluvial deposits along the study area's western edge, just west of the boundary fault. A few wells along this fault zone have been included in the study, even though they technically belong to the Tularosa Basin. A sharp contrast in water quality exists between these wells and those to the east. Dinwiddie (1963) reports the water quality for a La Luz city well located just west of the fault (location given by a "L" in Figure 14, data in Table 15), allowing us to compare it with the data previously reported for the Yeso Formation along the eastern edge (Table 8; wells I and J). It is quickly noticed that the water along the western edge is of much lower quality, having a conductivity of about three times that in the east and about twice the total dissolved solids. In addition, these wells are pumped from approximately 500 feet instead of the much shallower depths found in the east. But why is there such a difference in quality when the water is issuing from the same formation? The

TABLE 14. DAILY PRECIPITATION AND LA LUZ CREEK DISCHARGES AUGUST, 1984

DAY	ALAMOGORDO	MOUNTAIN PARK	CLOUDCROFT	DISCHARGE
1	0.33	T	0.13	0.5
2	T	0.57	0.65	6.4
3	--	0.15	1.00	3.6
4	--	0.34	0.35	0.8
5	0.08	0.25	0.45	3.0
6	--	--	0.04	4.2
7	0.20	0.81	0.08	10.0
8	0.15	0.90	0.41	44.0
9	0.81	0.54	0.09	15.0
10	0.21	0.50	1.15	5.0
11	1.02	0.41	0.76	9.6
12	--	0.05	1.00	10.0
13	--	0.15	0.11	25.0
14	--	0.17	0.04	11.0
15	--	0.25	0.68	13.0
16	--	T	0.04	11.0
17	--	0.02	--	5.5
18	--	0.16	--	4.0
19	--	0.13	0.20	9.9
20	--	0.04	0.12	9.9
21	--	T	0.85	1.3
22	0.02	T	--	1.1
23	0.28	0.19	0.28	423.0
24	0.49	0.22	0.29	50.0
25	0.54	0.14	0.67	7.0
26	--	0.10	0.90	45.0
27	--	--	--	6.5
28	--	--	--	6.5
29	--	T	0.10	6.5
30	--	--	0.05	6.2
31	--	--	--	5.1

Discharges in cubic feet per second
Precipitation in inches
T = trace



[illegible] within the study area and

TABLE 15. CHEMICAL ANALYSIS OF WATER FROM LA LUZ CITY WELL (WELL "L")

(FROM DINWIDDIE, 1963)

TEMPERATURE: 57 F.
MAGNESIUM: 73 ppm
SODIUM AND POTASSIUM: 164 ppm
BICARBONATE: 252 ppm
SULFATE: 723 ppm
CHLORIDE: 286 ppm
TOTAL DISSOLVED SOLIDS: 1670 ppm
SPECIFIC CONDUCTANCE: 2380 micromhos/cm
pH: 7.2

LOCATION: 15.10.25.320
OWNER: LA LUZ MUTUAL DOMESTIC WATER CONSUMERS ASSOCIATION
DEPTH: 512 FEET
ALTITUDE: 4800 FEET ABOVE SEA LEVEL
WATER LEVEL: APPROX. 500 FEET (1961)
STRATIGRAPHIC UNIT: YESO
MATERIAL: LIMESTONE
DATE COLLECTED: 10-11-61

answer lies in the evolution and pathway of each water source. Wasiolek and Gross (1983) have shown that the major component of recharge to the Yeso Formation in the east is precipitation, with the water entering a limestone terrane and remaining in a similar rock type until pumped. West of the fault zone, however, this is not the case as the limestones are overlain by thick alluvial deposits. Thus, if the major source of recharge was precipitation, the water would have to slowly migrate through the alluvial deposits before reaching the limestones, giving them the opportunity to chemically react with that environment, thus altering their chemical composition. Another source of recharge to this area is water flowing from the formations of the Sacramento Mountains. As will be discussed later, water from these units is flowing into the Tularosa Basin, thus recharging the alluvial deposits and the underlying formations. This conclusion is supported by the chemical similarities between the water from this section of the Yeso Formation and that along the slope. Therefore, the evidence indicates that water from the mountain slope recharges the Yeso Formation west of the fault zone and is then slightly altered by the carbonate environment of the Yeso Formation before being withdrawn.

Since water quality in this area is so different, it might be questioned whether this limestone really belongs to the Yeso Formation. In addressing this question, logs from well 24 and 25 (see Figures 53 and 54 in the appendix) were used as an indication of thicknesses of the limestone in the southwest corner. The geologic setting must first be taken into account. The mountain peaks in a thin layer of the San Andres Limestone which is underlain by the thick Yeso Formation. At the base of the fault then, the same type of strata should be present. Further evidence also leads to the same conclusion. Since all the well locations lie along the fault zone, it can be argued that the limestone units drilled could belong to either the Lake Valley Formation, the Yeso Formation or the San Andres Limestone. Since we find wells of similar depths, tapping similar limestone, to the north where the Lake Valley Formation is not present, the limestones can not be part of the Lake Valley Formation. Pray's (1954) estimates of the total thicknesses for these units is of great help. He lists the maximum thickness of the Lake Valley Formation at 400 feet, the San Andres Limestone as 500 feet, and the Yeso Formation ranging from 1200 to 1800 feet thick near the crest of the Sacramentos. Thus, the only formation thick enough to produce the 671 feet of limestone logged in well 25 is the Yeso Formation. It is possible that the San Andres Limestone does cap this part of the Yeso Formation, but the Yeso Formation produces the water.

<u>Abo Formation:</u> In comparison, the Abo Formation is a much lower yielding and less predictable aquifer. Its layered units frequently pinch out, starting again some distance away, making prediction of where water will be located quite difficult. Water is usually present within the sand and gravel units but absent within the conglomerates.

Other Units: The Gobbler, Holder, and Bursum formations have all had water-producing wells drilled into them. Productivity seems to be quite limited, however, and may be dependent upon hitting a fracture which will serve as a conduit for flow. The Beeman Formation is the only other formation in the area that has been drilled, although only to a limited extent due to its location. The formation does have a black shale unit that produces large quantities of water of a similar quality to that found in other formations along the slope.

SPRINGS: Twenty-three springs are present within the study area. Locations were given in Figure 7 while a list of their locations, elevations, formations from which they issue, and, in some cases, discharges are given in Table 16. The springs are distributed over most of the area, and usually issue along either formation or fault contacts. There are a few, however, which issue from both the Abo and Yeso formations in areas removed from formation contacts. The wide distribution of contact springs indicates limited flow from one formation into another, thus creating a channeling of water along the contact zones. The water is then released where the contact intercepts the mountain slope.

Most of the springs discharge only small quantities of water, less than 2 gpm in most cases. There are, however, four springs with higher yields -- Cottonwood, Elizer Johnson, Mud, and Hidden Springs. Each of these is tapped as a water supply for either La Luz, High Rolls, Mountain Park, or Alamogordo, as are many of the smaller streams. Thus, a large portion of the area's water supply comes from these springs.

FLOW DIRECTION: A piezometric or water table surface is hard to trace throughout the study area due to the uneven distribution of data points and the large topographic gradient across the region. These factors make it difficult to trace the flow of water not only within and between water-bearing units, but also between various wells bottoming in the same formation. In an attempt to gain a better understanding of what is happening at various locations, the depth to water and water level elevations have been considered.

The depth to water at various wells is given in Figure 29. In most places the water level is very shallow, less than 100 feet, with the exceptions noted below. In the area north of High Rolls the water level is between 50 and 100 feet deep. South of High Rolls, however, along the West Side Road, a much deeper water table is present. These wells must be drilled to over 300 feet before water can be withdrawn from the Gobbler Formation. The Mountain Park water supply is mostly spring water but a few wells have been drilled in Haynes Canyon. From the numbers in Figure 29 there appears to be some discrepancy as to the depth to water in this area as one well recorded water at 227 feet while the other two are around 60 feet. The deeper water level was reported in 1966 while the other two are from late 1985 and early 1986. This time difference, along with reports from local

TABLE 16. SPRINGS OF THE STUDY AREA

#	LOCATION	NAME	ELEV-ATION	SURFACE FORMATION	DISCHARGE	DATE MEASURED
1	15S.10E.32.4	LITTLE DRY CANYON SPRING	5220	HOLDER/BURSUM FAULT CONTACT	0.5 gpm	
2	15S.11E.19.341	----	5040	BURSUM/ABO		
3	15S.11E.19.342	----	5020	BURSUM/ABO		
4	15S.11E.22.111	----	5750	ABO		
5	15S.11E.23.24	----	6360	ABO		
6	15S.11E.23.32	COTTONWOOD SPRING	6220	BURSUM/ABO	22 to 32 gpm	1982 to 1984
7	15S.11E.25.224	----	6450	ABO/YESO		
8	15S.11E.26.211	----	6020	ABO		
9	15S.12E.28.124	5 SPRINGS	7300	YESO		
10	16S.10E.12.424	DRY SPRING SPRING #2	6150	GOBBLER FAULT CONTACT	0.5 gpm	
11	16S.11E.1.111 16S.11E.2.222	TWIN SPRINGS	7860	YESO		
12	16S.11E.4.31	ELIZER JOHNSON SPRING	6700	GOBBLER/ABO	17 gpm	
13	16S.11E.5.144	----	6320	GOBBLER/ABO		
14	16S.11E.12.1	SEEP SPRING #2	8000	YESO	1.5 gpm	
15	16S.11E.12.12	SEEP SPRING #1	8050	YESO/SAN ANDRES	1.5 gpm	
16	16S.11E.12.123	MUD SPRING	8050	YESO/SAN ANDRES	10 gpm	10-07-82
17	16S.11E.14.412	HIDDEN SPRING	8040	YESO	8 gpm	06-17-81
18	16S.11E.15.144	SEVEN SPRINGS	7420	YESO/ABO		
19	16S.11E.16.214	GOAT RANCH SPRINGS	6880	YESO/ABO		
20	16S.11E.19.341	DRY CANYON SPRING #1	7180	GOBBLER/ABO	1 gpm	
21	16S.11E.19.442	----	7180	ABO		
22	16S.11E.22.312	KARR CANYON SPRING	8000	YESO		
23	16S.12E.18.143	----	8800	YESO/SAN ANDRES		

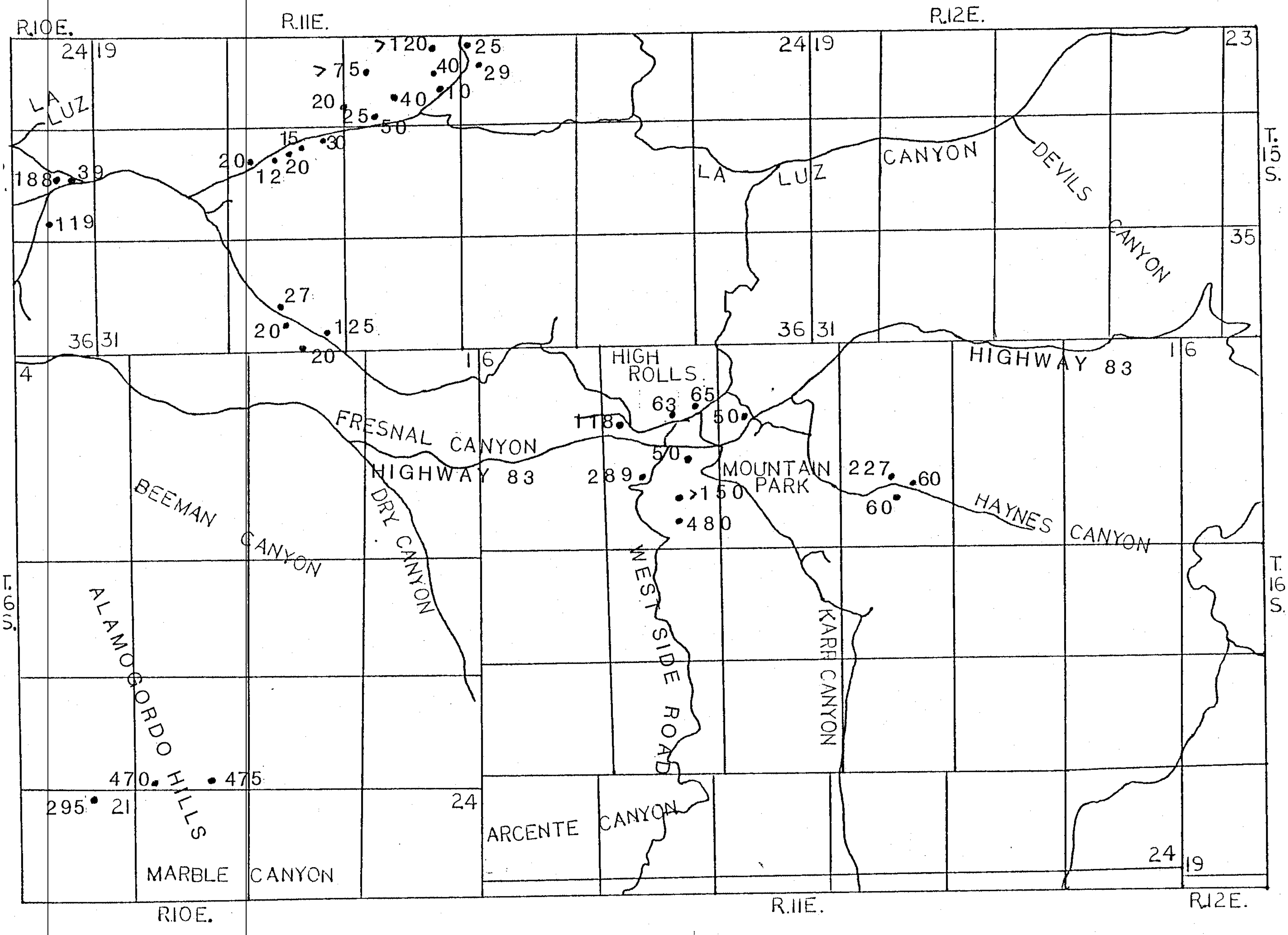


Figure 29 Depth to water (in feet) at wells within the study area.

residents of a very high water level throughout Haynes Canyon and lower Karr Canyon at the present time, indicates that the water level is currently at 60 feet and not the 227 feet reported earlier. Assuming that the difference is not the result of measurement error, these data suggest the types of changes which can occur with time and the effects that a change in recharge conditions, especially recharge by precipitation, can have on the water table. The water within La Luz Canyon is also very shallow, usually between 10 and 40 feet. These conditions hold in whichever formation is being tapped. Towards La Luz however, another set of seemingly contradictory figures occurs near the fault zone. Here, water levels in the Beeman Formation are reported at 39, 119, and 188 feet. This difference can be explained by the fault. Apparently, the fault line is somewhat shattered at this locality, with the down-thrust resulting in several blocks at differing depths, but limited widths. This would account for the increase in depth to water towards the west. The Alamagordo Hills area is also affected by this fault. Their water is between 300 and 500 feet deep and lies west of the fault line.

Figure 30 is a spatial plot of water level elevations. More than anything else, this map images the topography of the area. Water level changes within any one stratum are difficult to detect amidst the 4500 feet of elevation change. This figure shows the water level elevation decreasing towards the west but it must be realized that the water is usually not issuing from the same lithologic unit, even in adjacent wells. This fact makes the flow direction and hydraulic gradient for the area very difficult to evaluate. In the flatter section of the study area, east of La Luz, some continuity is maintained. Here, water-level elevations gradually decrease towards the west, thus indicating flow in that direction.

From this analysis, several possibilities exist as to the flow direction of the groundwater within the study area. The first is that the groundwater could be flowing downhill, traveling through the various formations as it descends. The general westward flow of water seems to be supported by water level elevations throughout the area. However, this may be reversed in areas where the strata dip towards the east, as along the eastern edge of the study area and in the vicinity of the folds. Unfortunately, we have very little information on how the area's structure affects the groundwater flow direction. In Darton's generalized cross-section (see Figure 2) the strata east of High Rolls are dipping significantly to the east. Pray's more detailed mapping, however, indicates subhorizontal bedding in this region (see Figures 11 and 13). Since no wells are located in this area and the topography tends to mask the area's structure on aerial photographs it is difficult to determine structural effects on the groundwater flow patterns. In the area near Dry Canyon Syncline, however, the stratigraphic dips are significant. In this locality the water probably flows down-dip towards the base of the syncline.

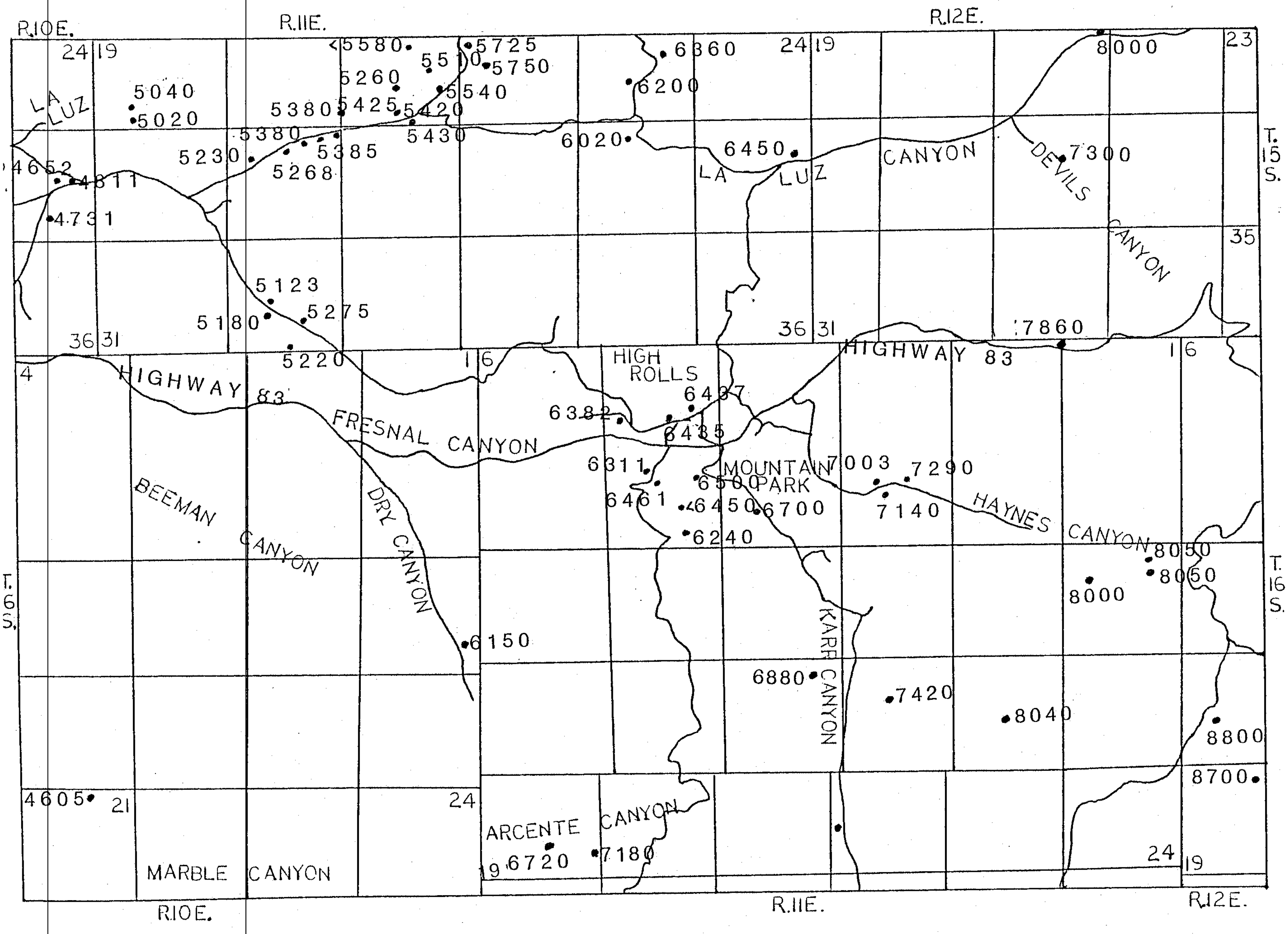


Figure 30 Elevation of the water levels within wells of the study area in feet above

There is also very little evidence to address the idea of leakage into underlying aquifers as the water moves west. We do know that water is not uniformly present throughout all portions of the Abo Formation, possibly indicating a lack of movement through certain layers, the basal conglomerate in particular. This then, suggests the possibility that instead of the water moving across formation boundaries it discharges in the form of springs or seeps as it intercepts the open slope. The large number of springs, especially contact springs, within the area supports this idea. Noticeable leakage near the tunnel west of High Rolls would also support the idea of discharge through seeps. These results, then, indicate that the water generally flows west, discharging onto the surface as either a seep or spring as it intercepts the slope's edge.

One other possibility is that a portion of the water flows east into the Roswell Basin. Unfortunately, the data for the eastern portion of the region are too sparse to identify a groundwater divide, thereby making an evaluation of water near the crest difficult. It has been shown by Wasiolek and Gross (1983) that the flow east of the region is towards the east, and the strata dip towards the east in several parts of the region, including the eastern edge of the study area, so it is probable that some water does flow in that direction. We need more data, however, to know how much water flows in each direction.

RECHARGE: The main source of recharge to the area's groundwater supply is local precipitation. There are several mechanisms, however, which limit the amount of precipitation which actually enters the groundwater system, the most significant being evapotranspiration. A portion of the precipitation is also contributed to the flow of both the ephemeral and perennial streams. This is especially true during the higher intensity rains which fall during summer thunderstorms.

A second source of aquifer recharge are the streams as water leaks through the stream beds and into the underlying materials. Leakage is especially common in the intermittent streams located within the area's canyons and valleys. Here, flow acts to wet the underlying materials and fill the empty pore spaces as it percolates through the beds. A good example of recharge by a stream is found in a section of Cottonwood Wash above La Luz Canyon (T.15S., R.11E., Section 25) where a perennial stream flowing from the north changes into an intermittent stream as it passes over the alluvium in the area, loosing waters to the aquifer below.

Other sources of recharge to a specific water-bearing unit are the flow of water between aquifers and flow into the region from outside of the study area. Both of these sources are very difficult to evaluate due to the scarcity of the data. As was noted previously, the groundwater flow paths through the area could not be accurately traced, although evidence suggests a flow of water towards the west. We do not know, however, if water from any of the formations enters the area from east of the study area. Potentiometric surface maps for the area immediately to the east of the study area suggest a flow of water in the Yeso Formation to the east (see Wasiolek and Gross, 1983) but we have no indication as to where this trend reverses, thus we can not identify a groundwater divide. If we assume that the groundwater divide approximately follows the topographic divide, we can conclude that there is no recharge entering from the east. Even less information is available on the north and south boundaries. Information on the interaction between the various water-bearing units in the area is also sketchy. With a westward flow of water, the water must either be discharged from the units at the slope's edge or move down into the underlying unit before reaching the slope. Evidence was previously given to support the first of these, thereby leading to an additional source of surface infiltration once the water leaves the aquifer.

Two other sources of potential recharge also exist. First, there is the return flow to the subsurface from irrigation. Often about half of the water applied to an irrigated surface returns to the groundwater system. There are approximately 5350 acres of irrigated land within the study area (estimated from the New Mexico State Engineer's Land Use Map (1968)). The usual quantity of water appropriated for small plots of irrigated land is three acre-feet per annum. This means that approximately 16,000 acre-feet of water is appropriated annually for irrigation of which 50%, or 8000 acre-feet per year, returns to the groundwater system, mostly in the area around the High Rolls, Mountain Park, and La Luz communities. Similarly, we have a component of recharge from the excess water appropriated for domestic use. Of the water pumped for these uses, up to half may be returned to the ground as waste water.

DISCHARGE: There are many mechanisms discharging the groundwater system of the area including evapotranspiration, spring discharge, pumpage, and flow into surrounding areas. The first of these, evapotranspiration, is one of the chief sources of discharge, especially in the more highly vegetated areas. As was seen earlier, springs are scattered throughout the area, discharging groundwaters at each locality. It appears they issue along formation contacts. Not only is water withdrawn from the aquifers through spring discharge, but water is currrently pumped from the Yeso, Abo, Holder, Bursum, Beeman, and Gobbler formations. Even though the amount of pumping has been limited by the tapping of local springs, pumpage rates are still the most significant in the High Rolls, Mountain Park and La Luz Canyon areas.

Again, as with recharge components, the quantity and sources of groundwater which moves out of the area is important, but difficult to evaluate. There should be a significant amount of discharge both to the Tularosa Basin along the western fault contact boundary and to the surface as the water intercepts the western slope. As was discussed in the recharge section, the water discharging along the slope may also recharge an adjoining formation, thus not resulting in any net discharge from the region.

It is also possible that there is a component of flow to the east and into the Roswell Basin. We have already seen the ambiguity in the data from this eastern portion of the study area, but assuming the flow pattern established by Wasiolek and Gross (1983) continues along the stratigraphic dip, some water is flowing into the Roswell Basin. It is impossible, however, to tell how many of the formations exhibit this behavior.

A final source which must be considered, if we look in terms of total water within the area and not just subsurface flow, is streamflow. Most of the area's streams have their headwaters within the region, being fed by springs and precipitation. Only in the north do we find a few streams entering the area. Thus, nearly all the surface water leaving the area must be considered a water loss to the area. Most of this recharges the Tularosa Basin, although a very small amount does flow east towards the Roswell Basin.

SUMMARY OF CONCLUSIONS

(1) The study area contains six formations from which water has been withdrawn -- the Yeso, Abo, Bursum, Holder, Beeman, and Gobbler formations. Of these, the Yeso is the formation of both highest yield and best quality while the Abo is the most frequently drilled. The other formations are of less hydrologic importance.

(2) Water quality within both the springs and wells of the area is very poor, exceeding the Environmental Protection Agency's recommended limits for drinking water for most items measured. The Yeso Formation yields the best quality water while the waters of the Abo, Bursum and Gobbler are all of a very similar quality, perhaps indicating some mixing between the water of the various formations.

(3) Within the area there are many small streams, all either recharging the bolson deposits of the Tularosa Basin directly or through La Luz Creek. These streams are fed by precipitation and spring waters.

(4) The Yeso Formation is present along both the study area's eastern edge and the western edge near the fault zone. The water from the Yeso Formation on the western edge, however, is of much lower quality since it is recharged from the waters off the mountain slope and not directly from precipitation, as is that in the east.

(5) Twenty-three springs are present throughout the area. A majority of these occur along either formation or fault contacts, but a few issue from the Yeso and Abo formations. The springs supply much of the domestic water for the area.

(6) The general direction of water flow is towards the west, although a small portion, along the eastern edge of the study area, is probably flowing east into the Roswell Basin. That which flows west appears to move along the layers of the various formations until they intercept the slope's edge. Here, they discharge as either seeps or springs and then either reenter the groundwater system, are tapped for domestic uses, or are lost in evapotranspiration processes. When the water reaches the fault zone along the area's western edge, it appears to move into the bolson deposits of the Tularosa

Basin.

(7) The main source of recharge to the study area is precipitation, with minor components coming from stream flow, flow between aquifers, flow from outside the study area, irrigation return, and unused domestic waters.

(8) Sources of discharge include evapotranspiration, spring flow, pumpage, and flow into surrounding areas. Of these, the two most important are probably evapotranspiration and discharge into the Tularosa Basin.

RECOMMENDATIONS FOR FUTURE RESEARCH

At the outset of this report it was stated that the information compiled was not only of interest to citizens relying upon the area's water supply for domestic purposes, but also for those researching both the Roswell and Tularosa basins. For each of these purposes, this report leaves certain questions unanswered, questions which can best be addressed by further research efforts.

For those interested in the area's water supply, we have defined the general water-bearing formations, but the scarcity of data necessitated the generalization of most conclusions. In order to better identify exactly which layers throughout a formation bear water, and in what quantity that water is present, a network of wells should be drilled, having a spacing such that continuous water-bearing layers can be identified. Not only would this help in identifying where the water was, but it would also help in calculating the quantity of water available for use, both of which are now very difficult to evaluate. This would also aid in the construction of an accurate potentiometric map of the area if the wells were located such that they covered a larger area than the present wells. It would also be beneficial if three deep wells were drilled in the eastern portion of the study area so that the regional structure could be studied in more detail. These wells should be drilled through the San Andres Limestone and the Yeso Formation, bottoming below the Yeso-Abo contact. If properly logged, these wells could provide some very useful information on this region's structural controls.

For research efforts there are several additional things which could be undertaken. First, in order to better quantify the amount of recharge entering the Roswell Basin from the west, the groundwater divide must be located, and permeabilities within the Yeso Formation must be determined. In order to establish the permeability of the materials within the Yeso Formation, pump tests should be conducted. It is possible these tests could be done using wells already drilled along the western edge of the basin. The establishment of the groundwater divide, however, would involve more work. A line of several wells should be placed along east-west transects at several locations along the crest. From water levels measured in these wells, flow directions and regional hydraulic gradients could be determined. For more accurate results, it would be useful to have a number of transects, each bottoming in a separate formation, thus allowing one to see if flow patterns are consistent would be very high. Lastly, it would be useful to gage the stream flow leaving the study area so that an accurate accounting of surface flow into the Roswell Basin could be obtained.

The efforts to quantify recharge to the Tularosa Basin should be very similar. The gaging of all streams flowing into the basin would give a good estimate of surface recharge to the basin. Efforts to monitor subsurface recharge, however, will be much more extensive of an effort. In order to do this, it would be necessary to monitor the amount of water flowing into the basin from each formation. This would involve running pump tests on all formations bordering the basin to determine their permeabilities. New wells would have to be drilled for each of these tests since there are very few wells in this area. Water levels would also have to be monitored throughout the boundary region so that a regional hydraulic gradient for each formation could be established. When the above well field is designed for the pump tests, the need to determine the regional gradient must also be kept in mind so that additional wells would not have to be drilled. This network of wells would also provide a more accurate record of the piezometric surface in the area. Although expensive, this may be the only way of determining how much recharge the slope supplies to the Tularosa Basin.

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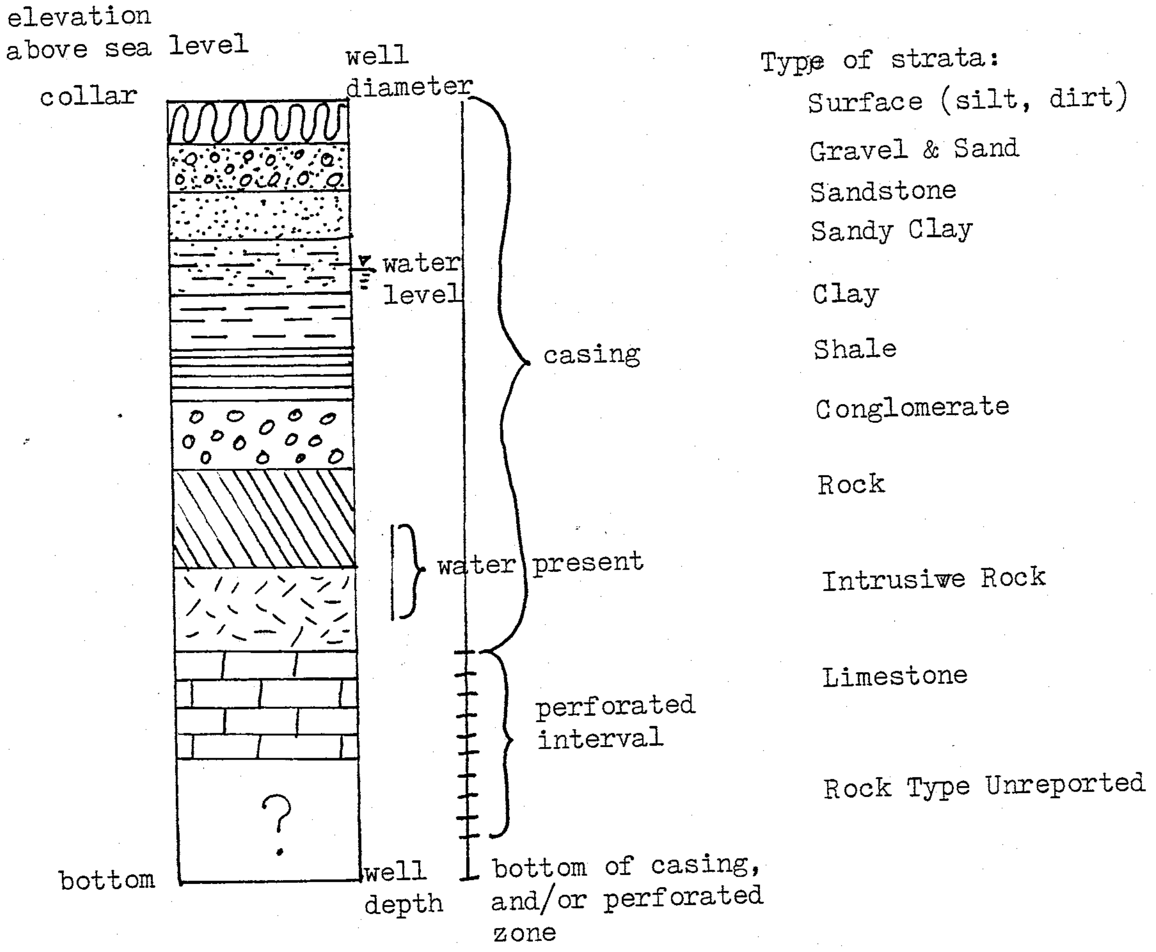
APPENDIX

DRILLER'S WELL LOGS

LOG #

LOCATION

DRILLER DATE FINISHED



Water-bearing Unit

Depth to Water

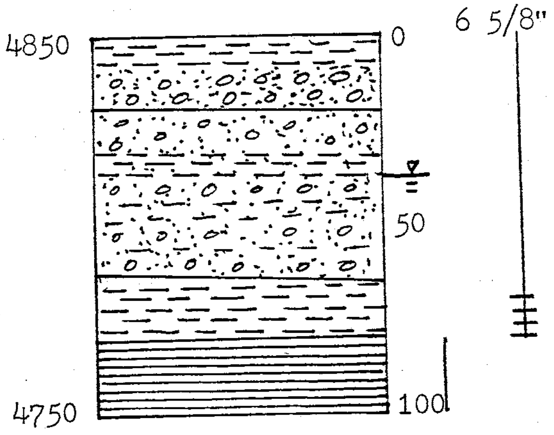
Water-bearing Formation

Figure 31. Legend for driller's well logs.

2

15S.10E.25.2433

Clements Pump Company 3/11/83



Brown Clay, Thin Gravel and Sand Lenses, Poorly sorted.

Brown Clay, Gravel, Sand, Cobbles and Boulders

Gray Clay

Gray-black Carbonaceous Shale, Fissile

Water: 80' - 100' Gray-black Carbonaceous Shale
60 gpm
specific conductance 2600 umhos at 18.5°C

Depth to Water: 38.6'

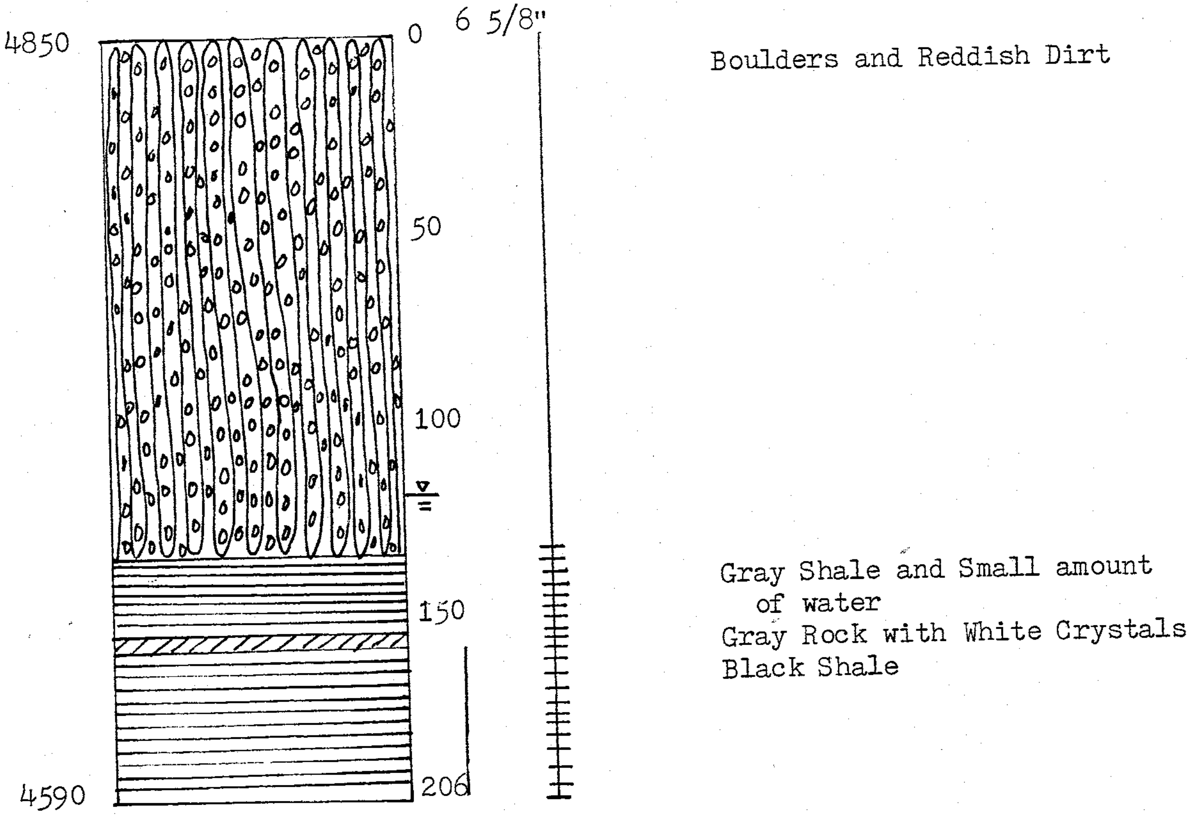
Water-bearing Formation: Beeman

Figure 32

3

15S.10E.25.4

Ray Quick 1/12/84



Water: 157 - 206' Black Shale
20 gpm

Depth to Water: 119'

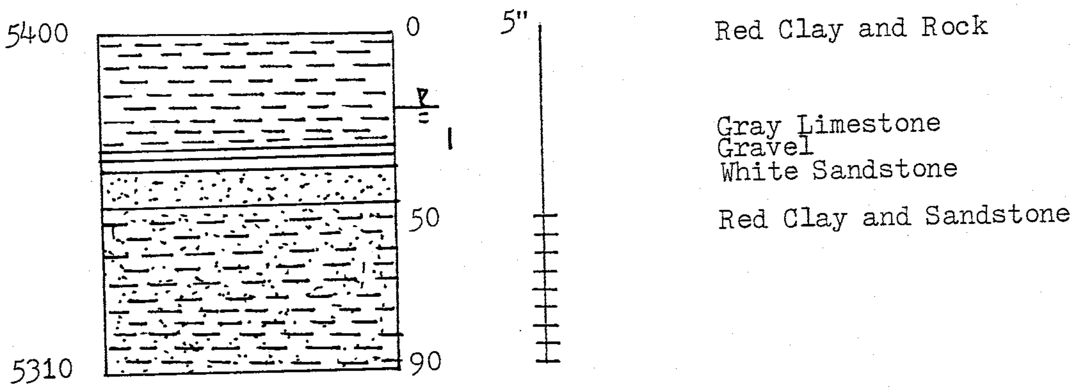
Water-bearing Formation: Beeman

Figure 33

4

15S.11E.20.4
15S.11E.21.3

Braziel Well Drilling, Inc. 4/1/83



Water: 27' - 30' Sand and Gravel
40 gpm

Depth to Water: 20'

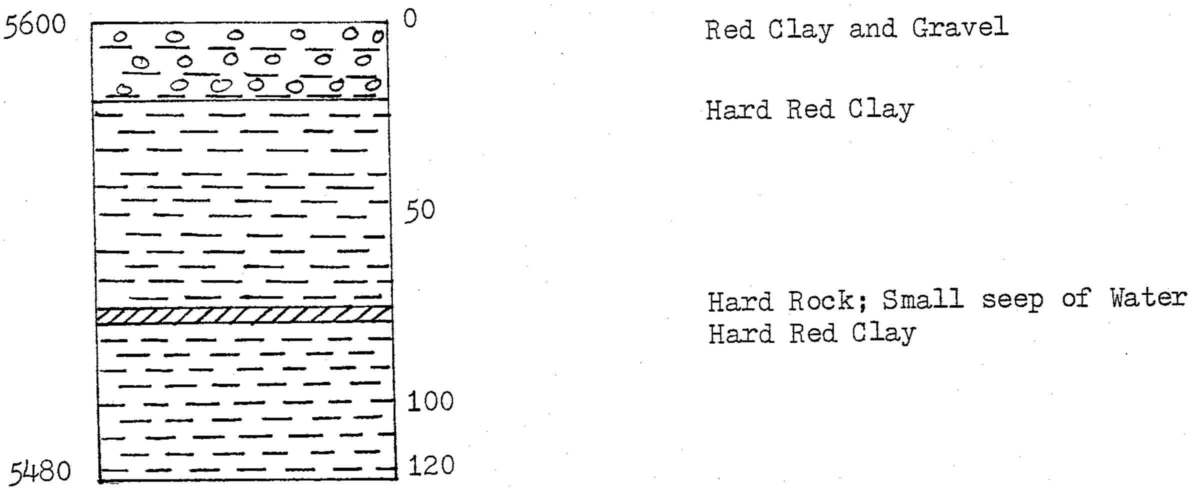
Water-bearing Formation: Abo

Figure 34

5

15S.11E.21.122

Ray Quick 3/1/85



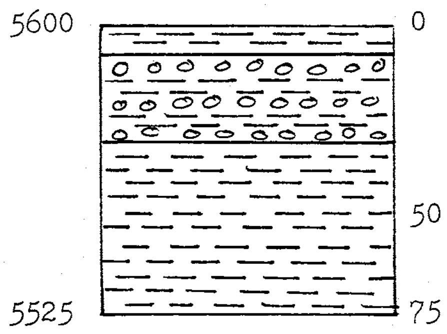
Dry Well: small unuseable seep at 75'

Figure 35

6

15S.11E.21.144

Ray Quick 7/22/85



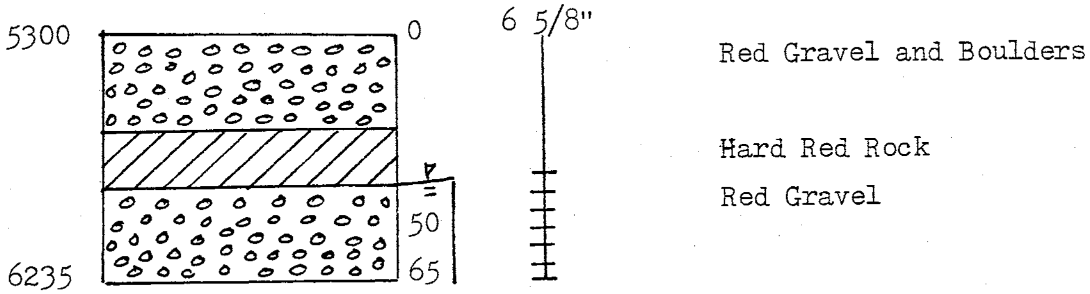
Dry Well: Very Small Seep at 65'
Unuseable

Figure 36

7

15S.11E.21.324

Ray Quick 5/4/84



Water: 40' - 65' Red Gravel
40 gpm

Depth to Water: 40'

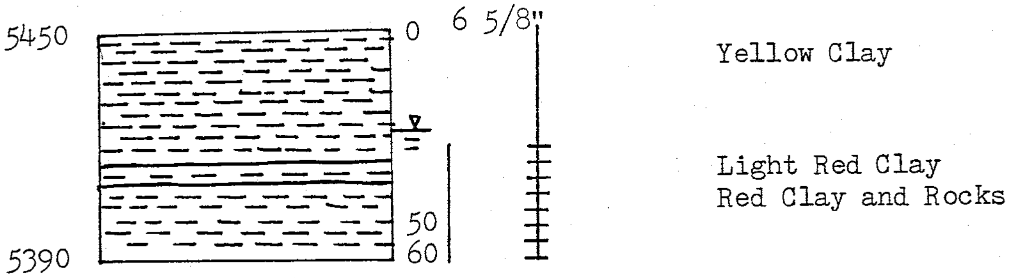
Water-bearing Formation: Abo

Figure 37

8

15S.11E.21.34

Ray Quick 6/27/84



Water: 30' - 60' Red Clay and Rock

Depth to Water: 25'

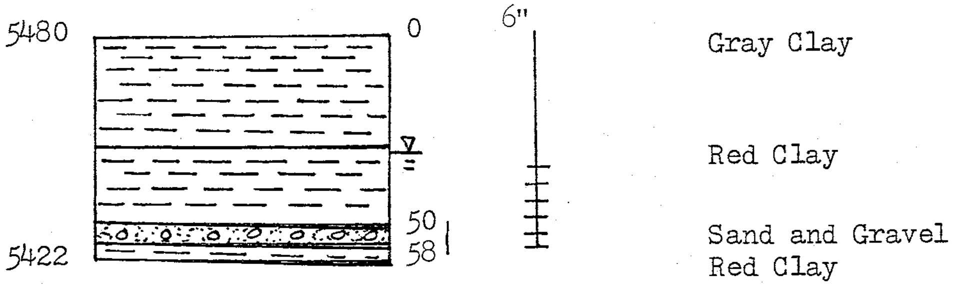
Water-bearing Formation: Abo

Figure 38.

9

15S.11E.21.344

Braziel Well Drilling Inc. 5/28/85



Water: 50 - 55' Sand and Gravel
30 gpm

Depth to Water: 30'

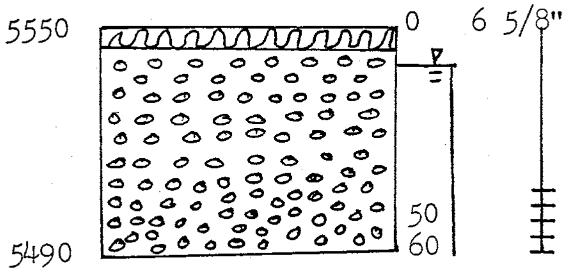
Water-bearing Formation: Abo

Figure 39

10

15S.11E.21.41

Ray Quick 7/6/84



Top Soil
Gravel and White Caliche

Water: 10' - 60' Gravel
30 gpm

Depth to Water: 10'

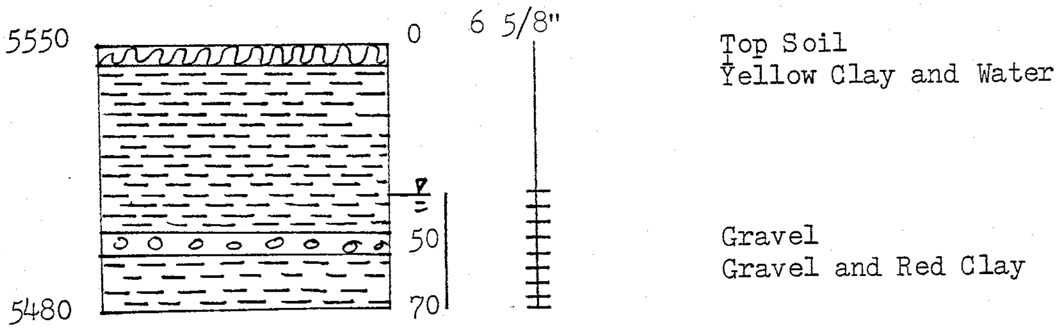
Water-bearing Formation: Abo

Figure 40

11

15S.11E.21.411

Ray Quick 9/27/84



Water: 40' - 70' Gravel
10 gpm

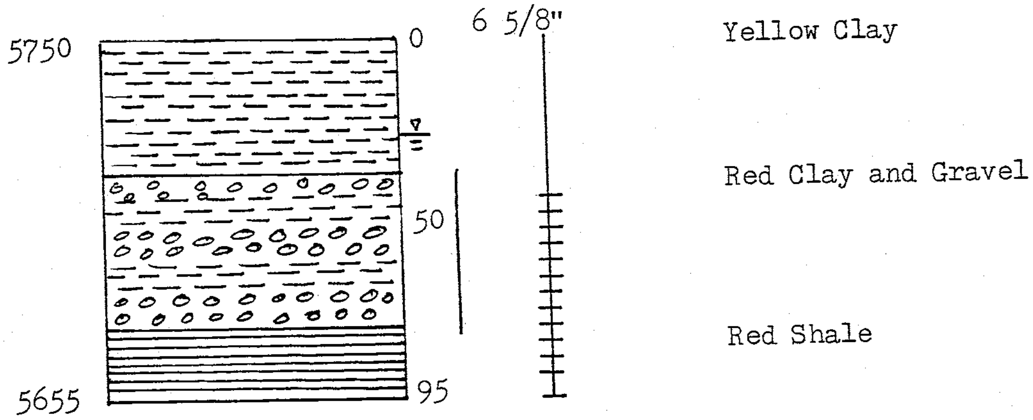
Depth to Water: 40'

Water-bearing Formations: Abo

Figure 41

15S.11E.22.11

Ray Quick 8/16/82



Water: 35' - 75' Red Clay and Gravel
10 gpm

Depth to Water: 25'

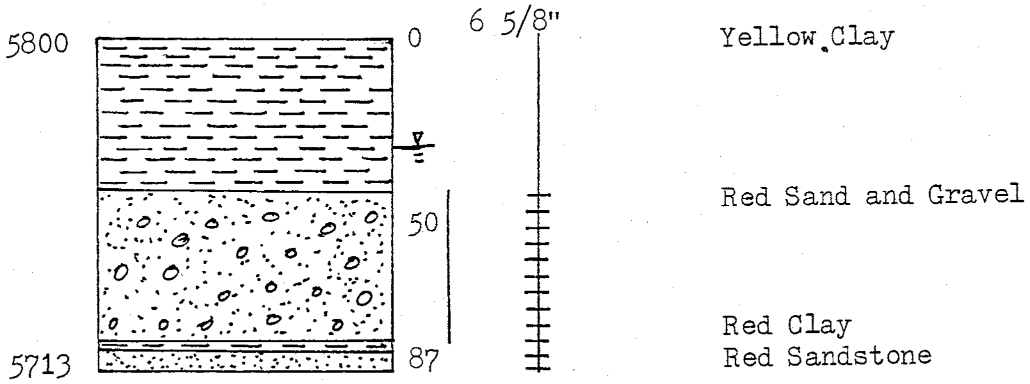
Water-bearing Formation: Abo

Figure 42

13

15S.11E.22.114

Ray Quick 3/18/83



Water: 40' - 80' Red Sand and Gravel
excellent yield

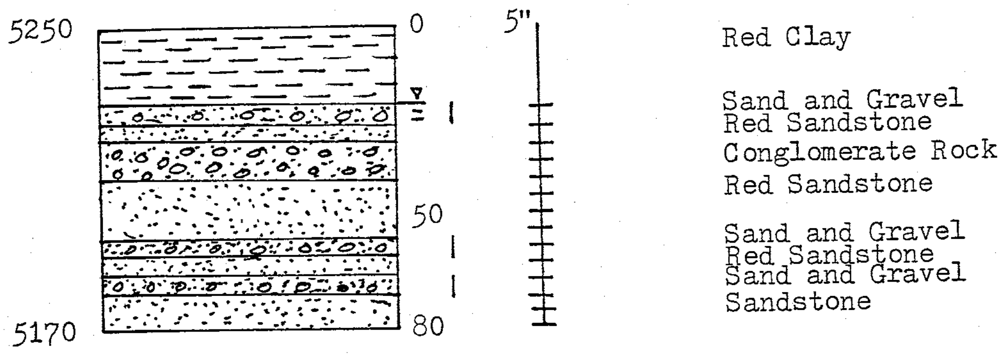
Depth to Water: 29'

Water-bearing Formation: Abo

Figure 43

15S.11E.29.1

Braziel Well Drilling, Inc. 7/14/84



Water: 20' - 25' Sand and Gravel
10 gpm
55' - 60' Sand and Gravel
10 gpm
65' - 70' Sand and Gravel
5 gpm

Depth to Water: 20'

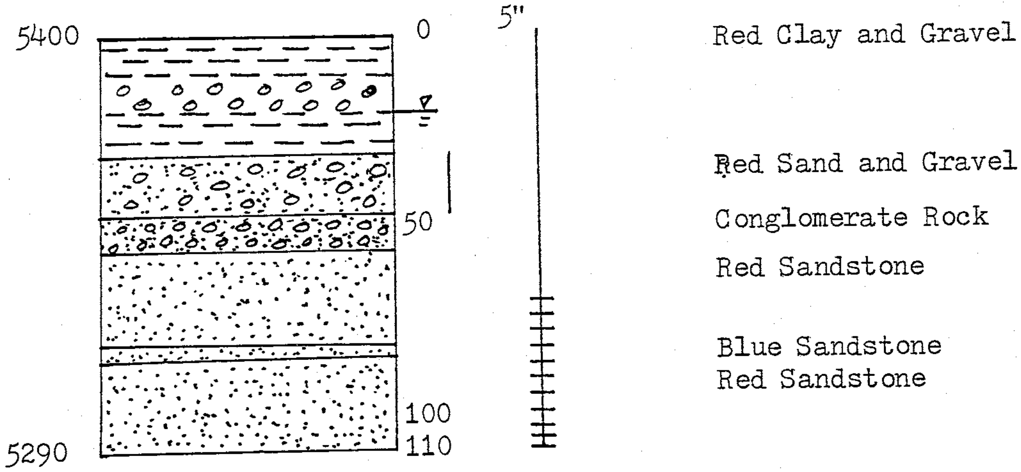
Water-bearing Formation: Abo

Figure 44

15

15S.11E.29.2

Braziel Well Drilling, Inc. 3/29/83



Water: 30' - 45' Red Sand and Gravel
80 gpm

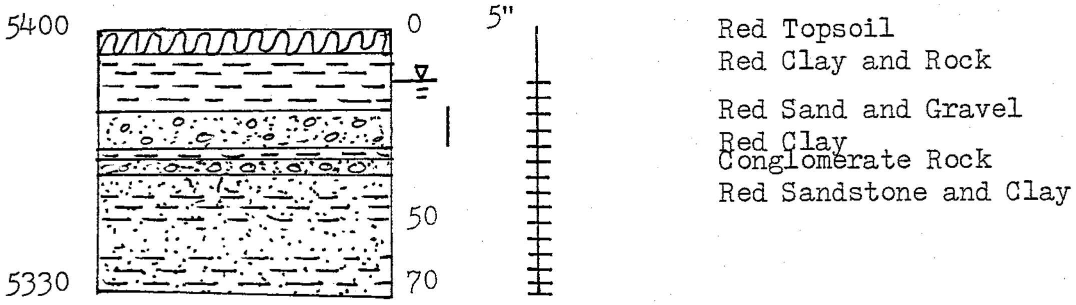
Depth to Water: 20'

Water-bearing Formation: Abo

Figure 45.

15S.11E.29.2

Braziel Well Drilling, Inc. 3/31/83



Water: 20' - 30' Red Sand and Gravel
60 gpm

Depth to Water: 15'

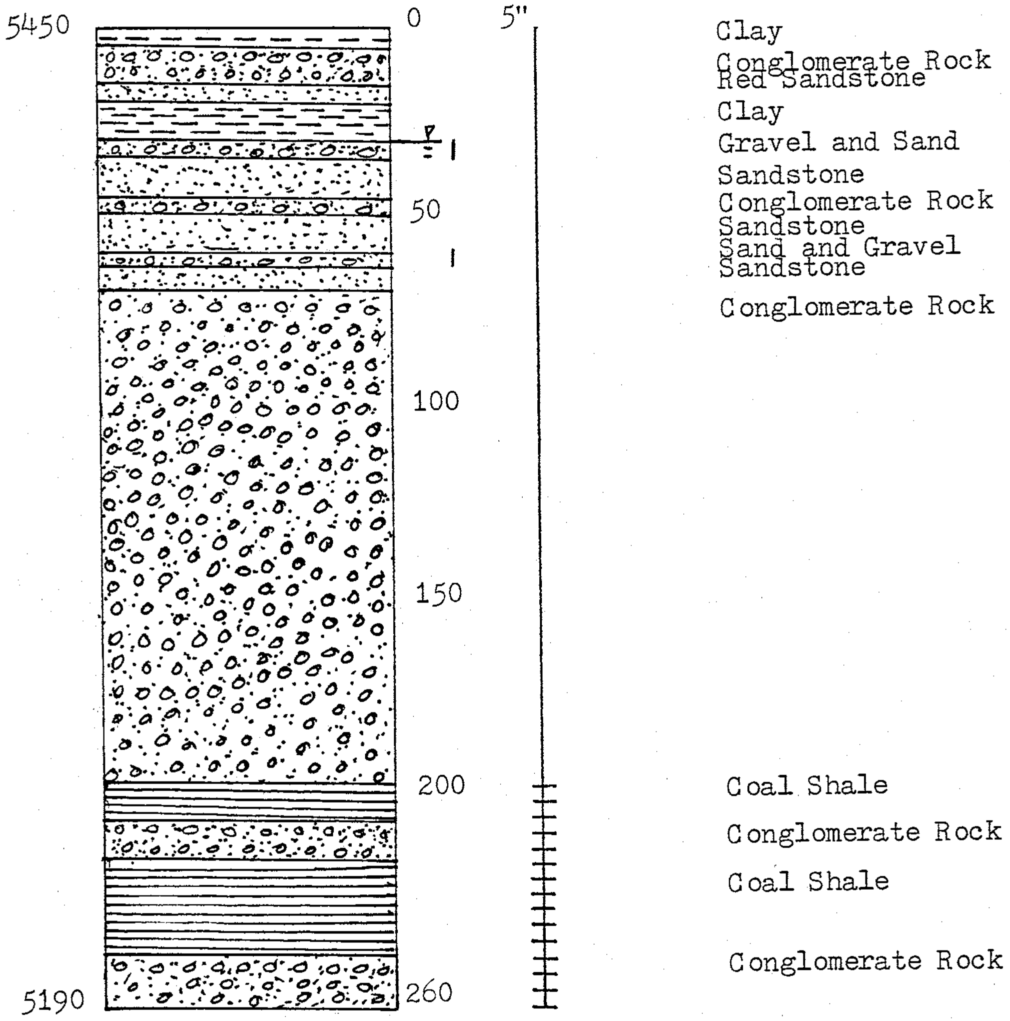
Water-bearing Formation: Abo

Figure 46

17

15S.11E.29.2

Braziel Well Drilling, Inc. 7/18/84



Water: 30' - 33' Sand and Gravel
0.5 gpm
60' - 62' Sand and Gravel
0.5 gpm

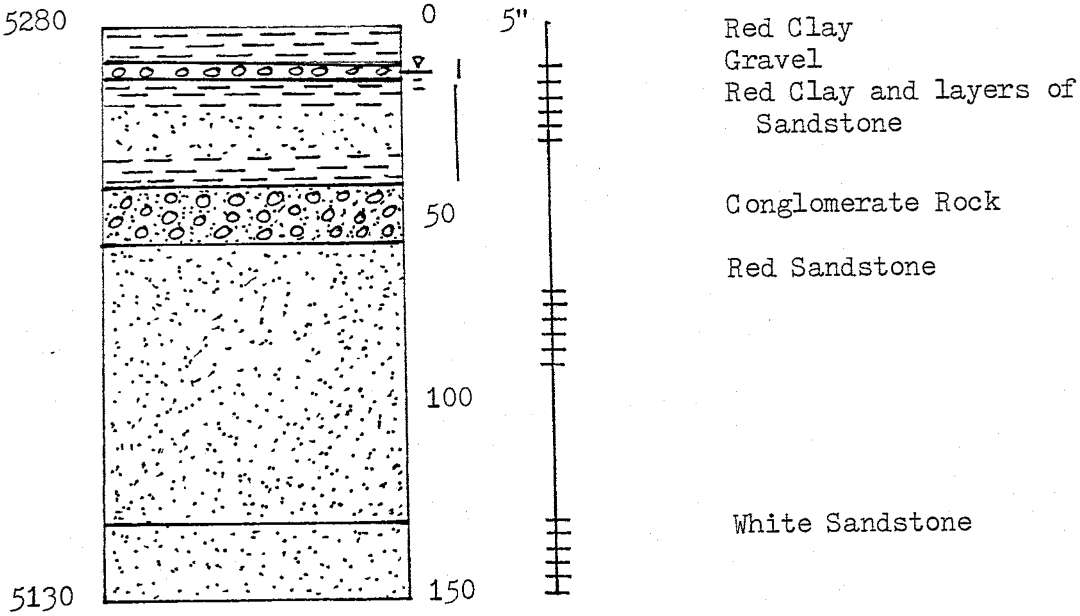
Depth to Water: 30'

Water-bearing Formation: Abo

Figure 47

15S.11E.29.213

Braziel Well Drilling Inc. 3/18/85



Water: 8 - 12' Gravel
Seep
15 - 40' Red Clay and layers of Sandstone
2 gpm

Depth to Water: 12'

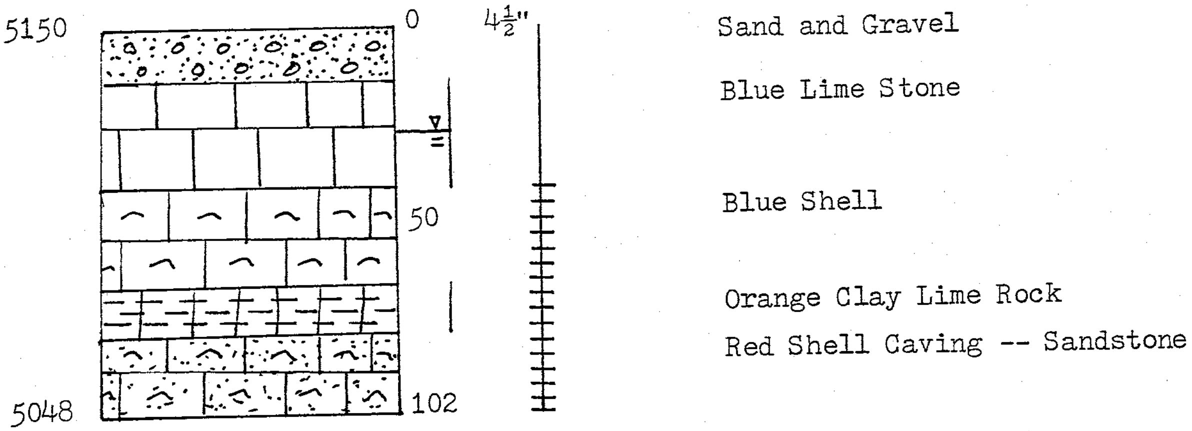
Water-bearing Formation: Abo

Figure 48

19

15S.11E.32.32

Wesley Weehunt 8/12/83



Water: 14' - 42' Blue Limestone
Seep
68' - 81' Orange Clay Lime Rock
3 gpm

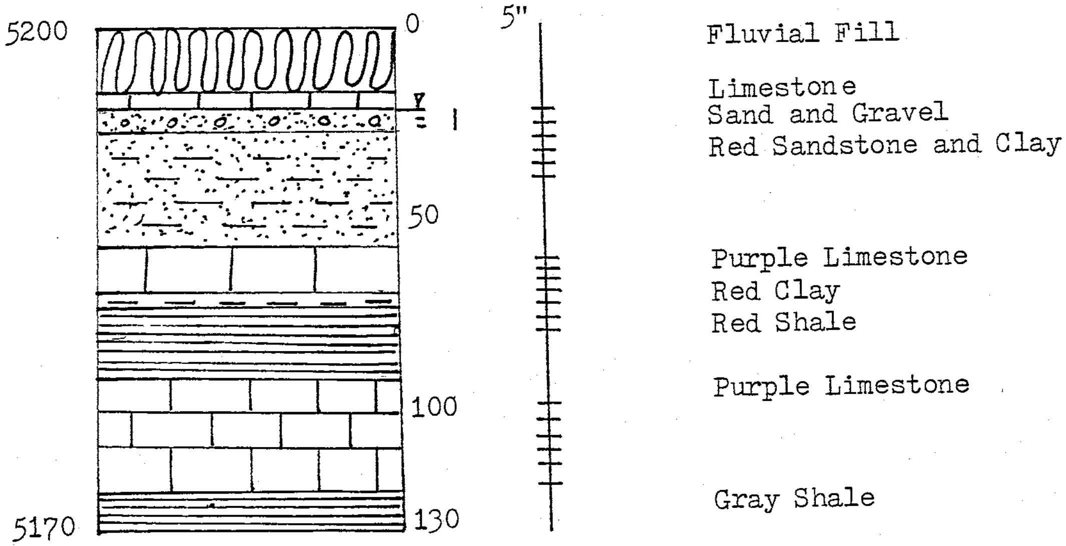
Depth to Water: 27'

Water-bearing Formation: Holder

Figure 49

15S.11E.32.433

Braziel Well Drilling Inc. 1/31/85



Water: 20 - 25' Sand and Gravel
15 gpm

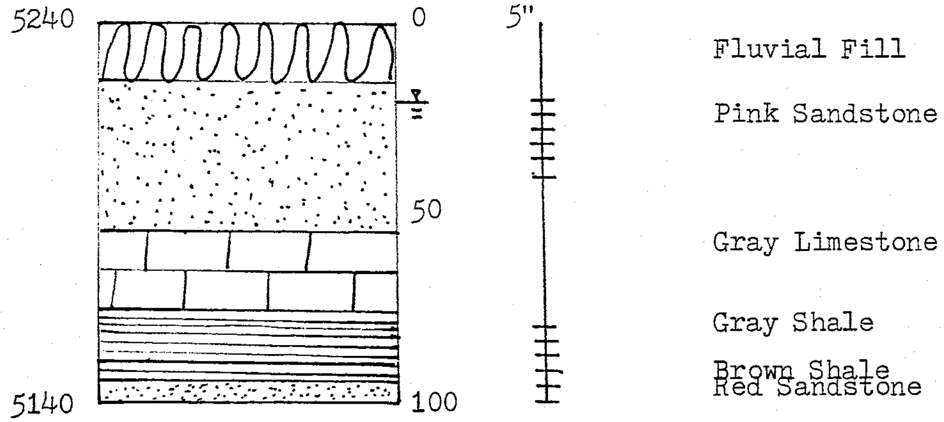
Depth to Water: 20'

Water-bearing Formation: Bursum

Figure 50

15S.11E.32.433

Braziel Well Drilling Inc. 3/27/85



Water: 20' Fracture
2 gpm

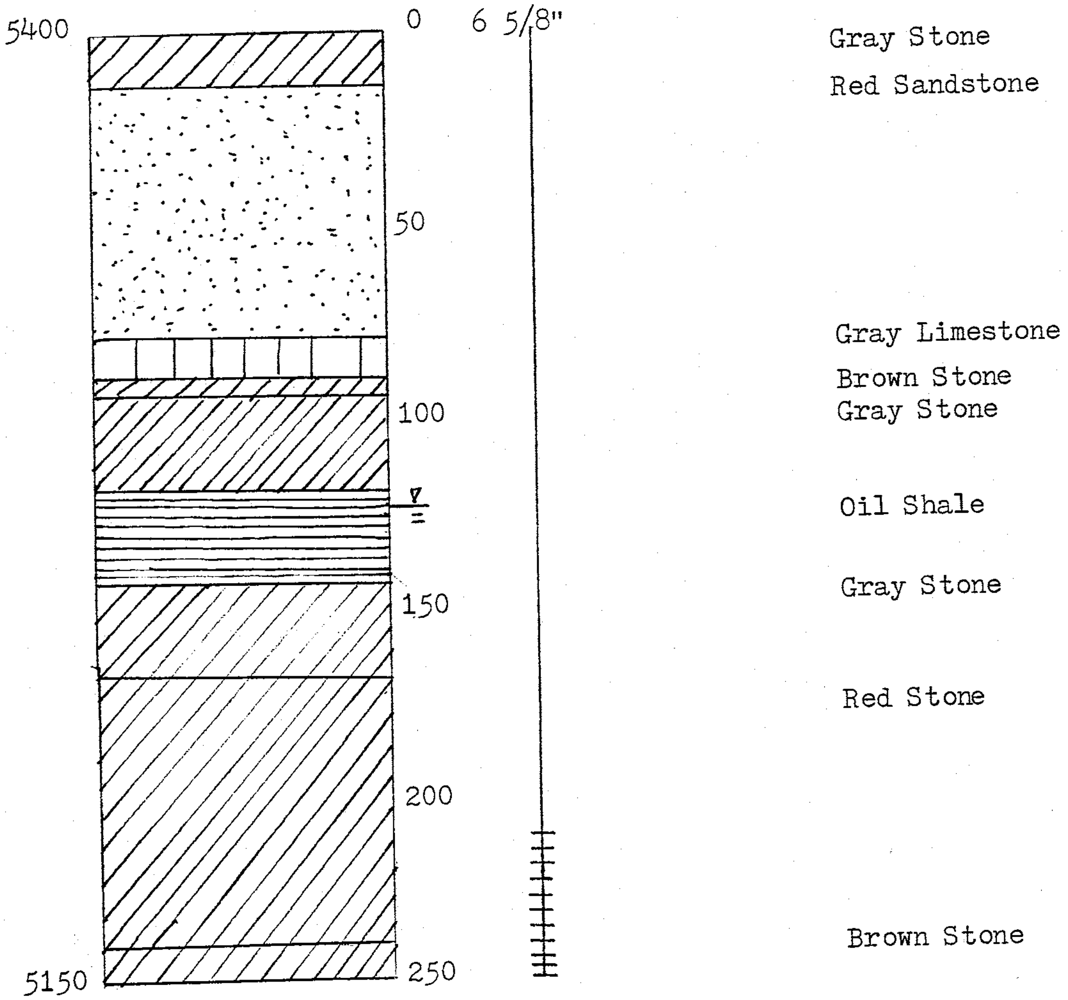
Depth to Water: 20'

Water-bearing Formation: Bursum

Figure 51

15S.11E.32.44

Clements Pump Co. 9/2/83



Water: in Crevice
5 gpm

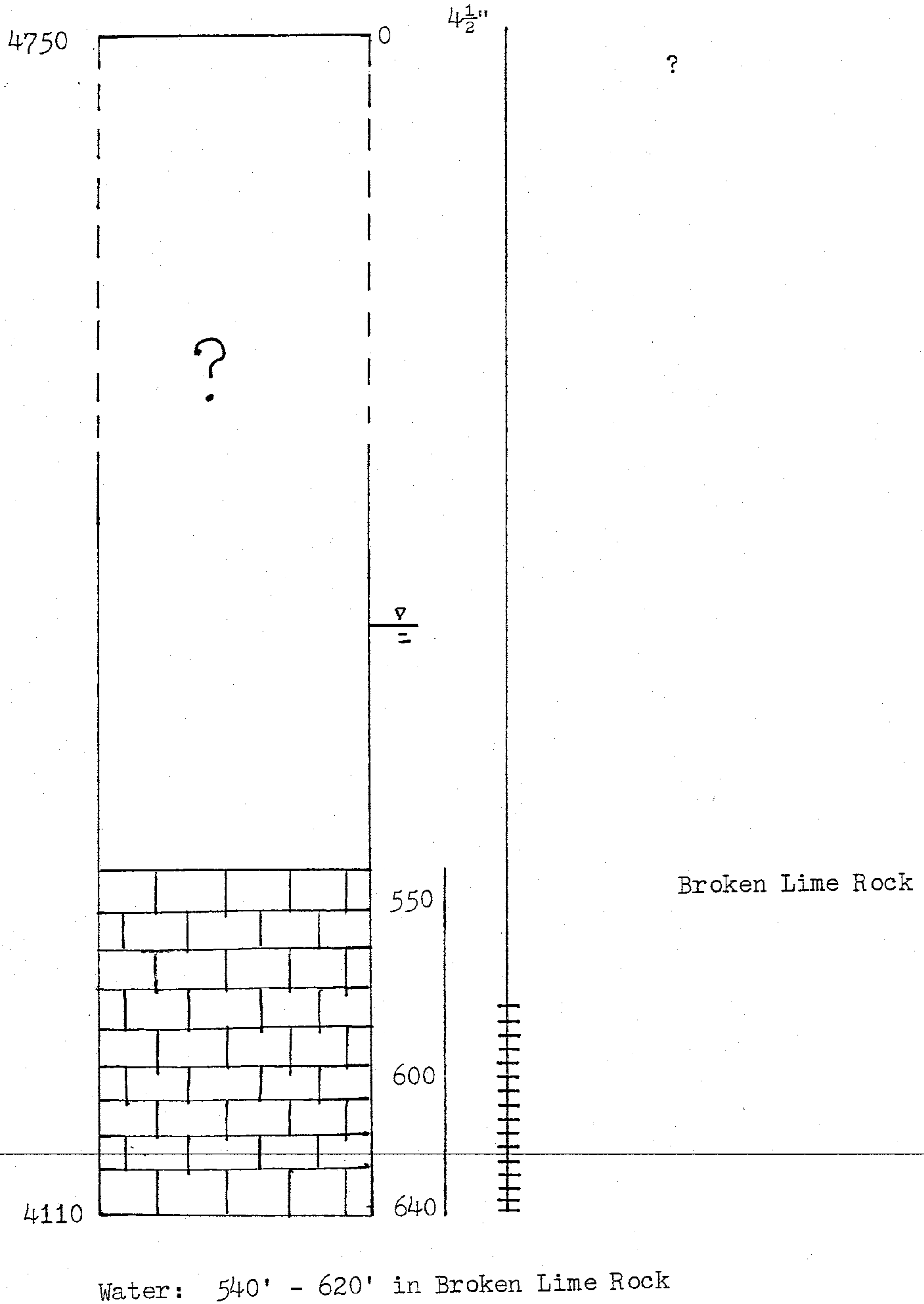
Depth to Water: 125'

Water-bearing Formation: Bursum

Figure 52

16S.10E.15.343

New Mexico Drilling, Inc. 3/28/85



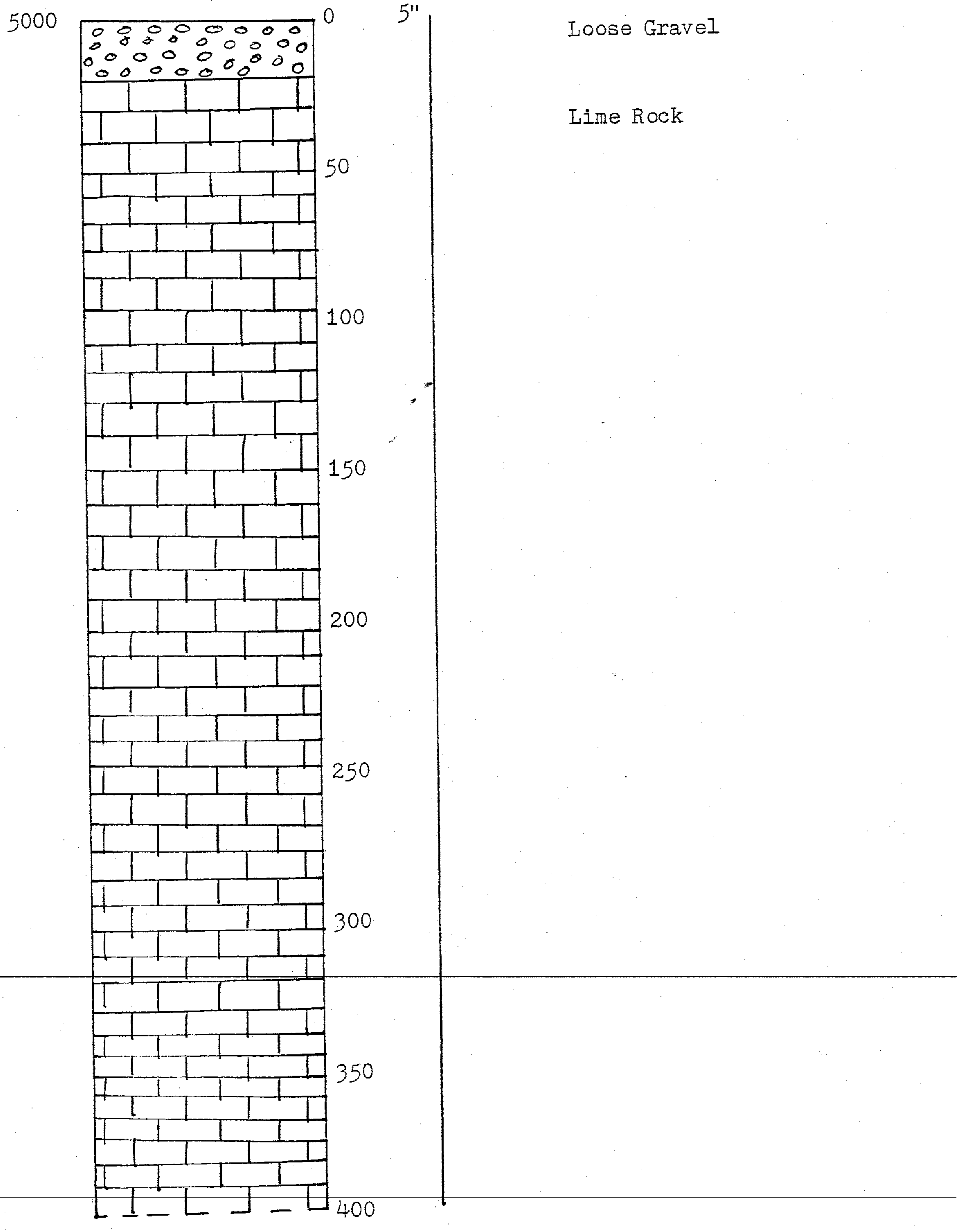
Water: 540' - 620' in Broken Lime Rock
60 gpm

Depth to Water: 470'

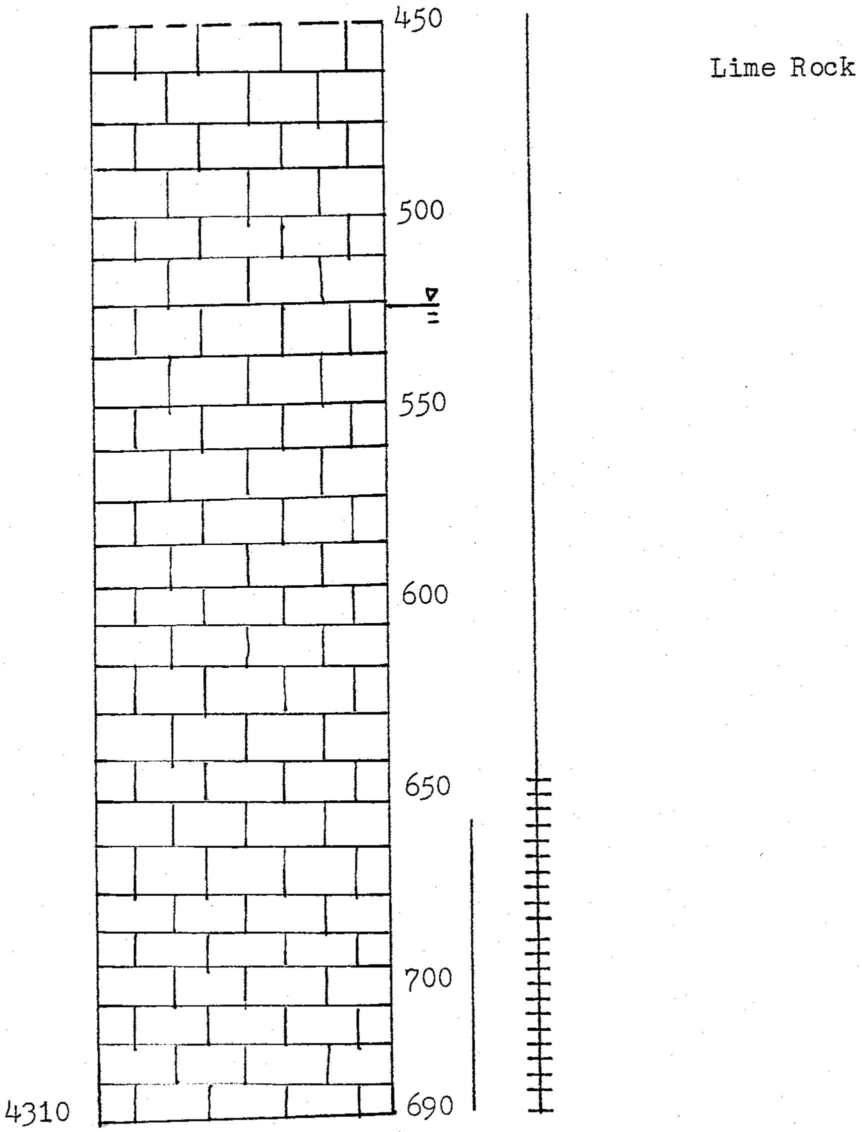
Water-bearing Formation: Yeso

16S.10E.15.43

New Mexico Drilling, Inc. 2/23/85



25 (Continued)



Water: 660' - 690' in Porous Lime Rock
200 gpm

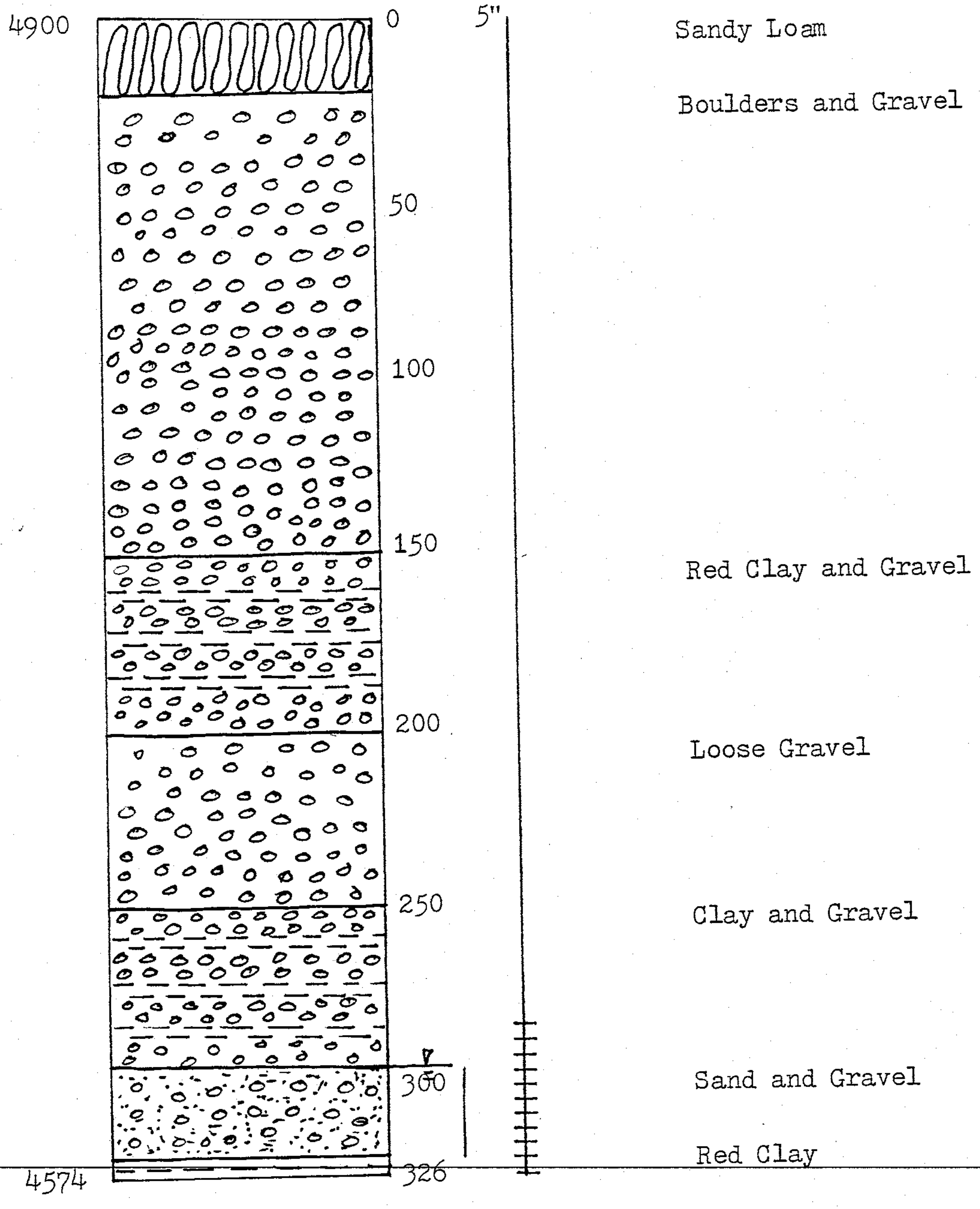
Depth to Water: 475'

Water-bearing Formation: Yeso

Figure 54

16S.10E.21.212

Everett A. Hadley 4/30/85



Water: 295' - 320' Sand and Gravel
20 gpm

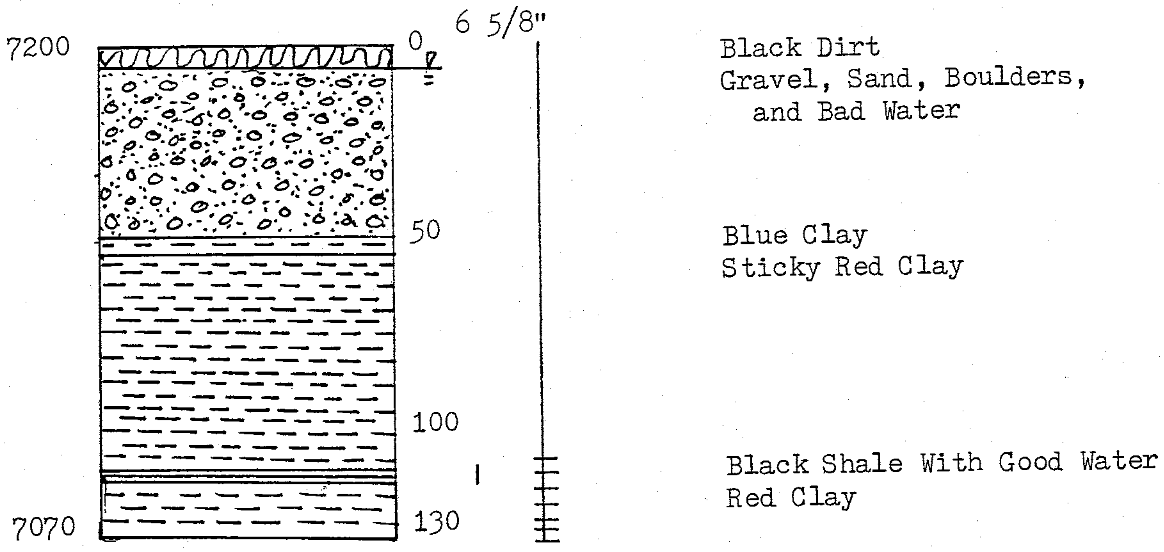
Depth to Water: 295'

Water-bearing Formation: Alluvium

Figure 55

16S.11E.3.32

Ray Quick 1/20/85



Water: 112' - 115' Black Shale
5 gpm

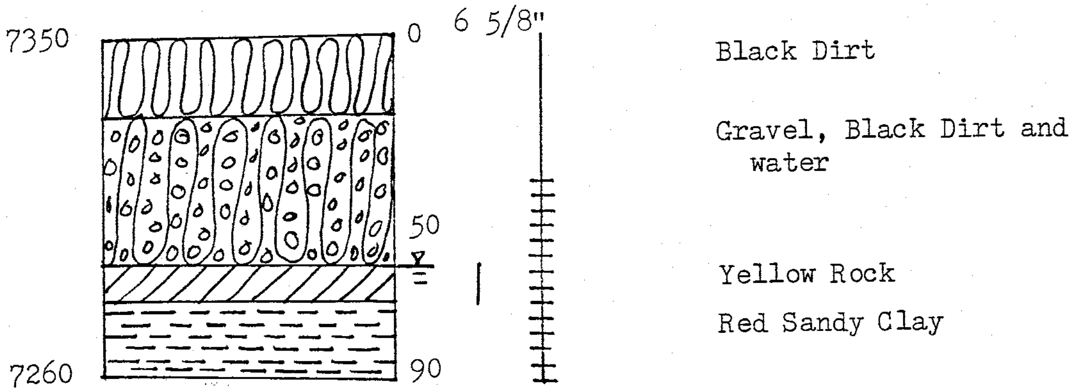
Depth to Water: 6'

Water-bearing Formation: Yeso

Figure 56

16S.11E.3.41

Ray Quick 11/15/84



Water: 60' - 70' Yellow Rock
10 gpm

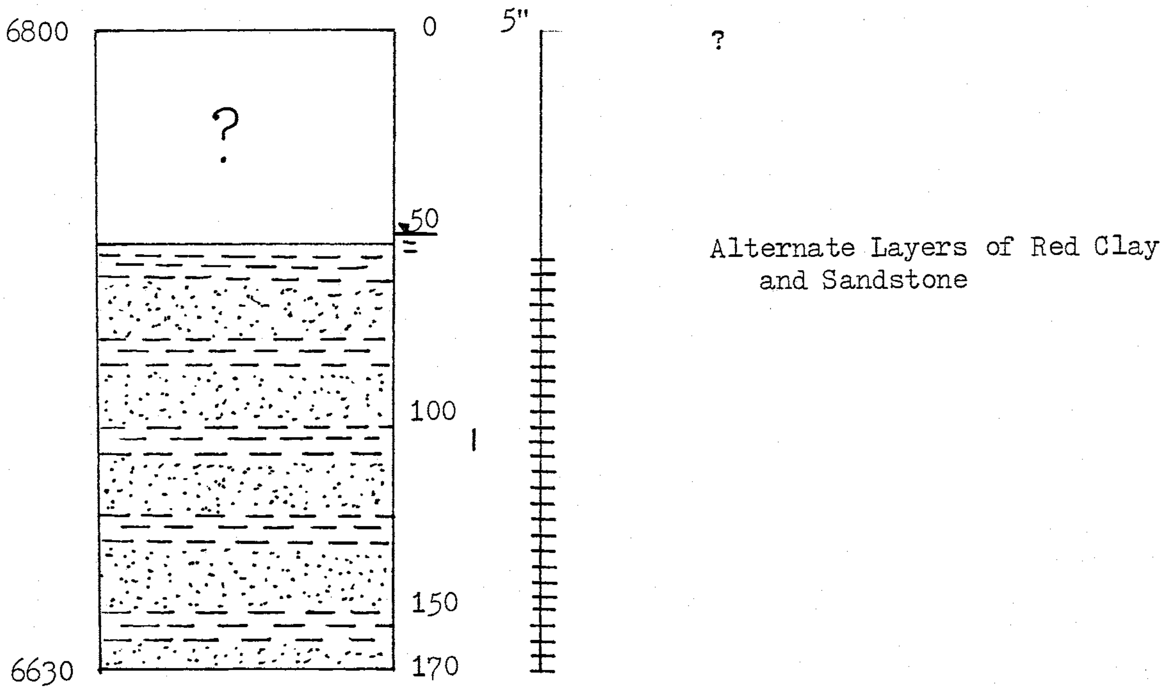
Depth to Water: 60'

Water-bearing Formation: Yeso

Figure 57

16S.11E.4

Braziel Well Drilling Inc. 3/13/85



Water: 105 - 106' Sand
2 gpm

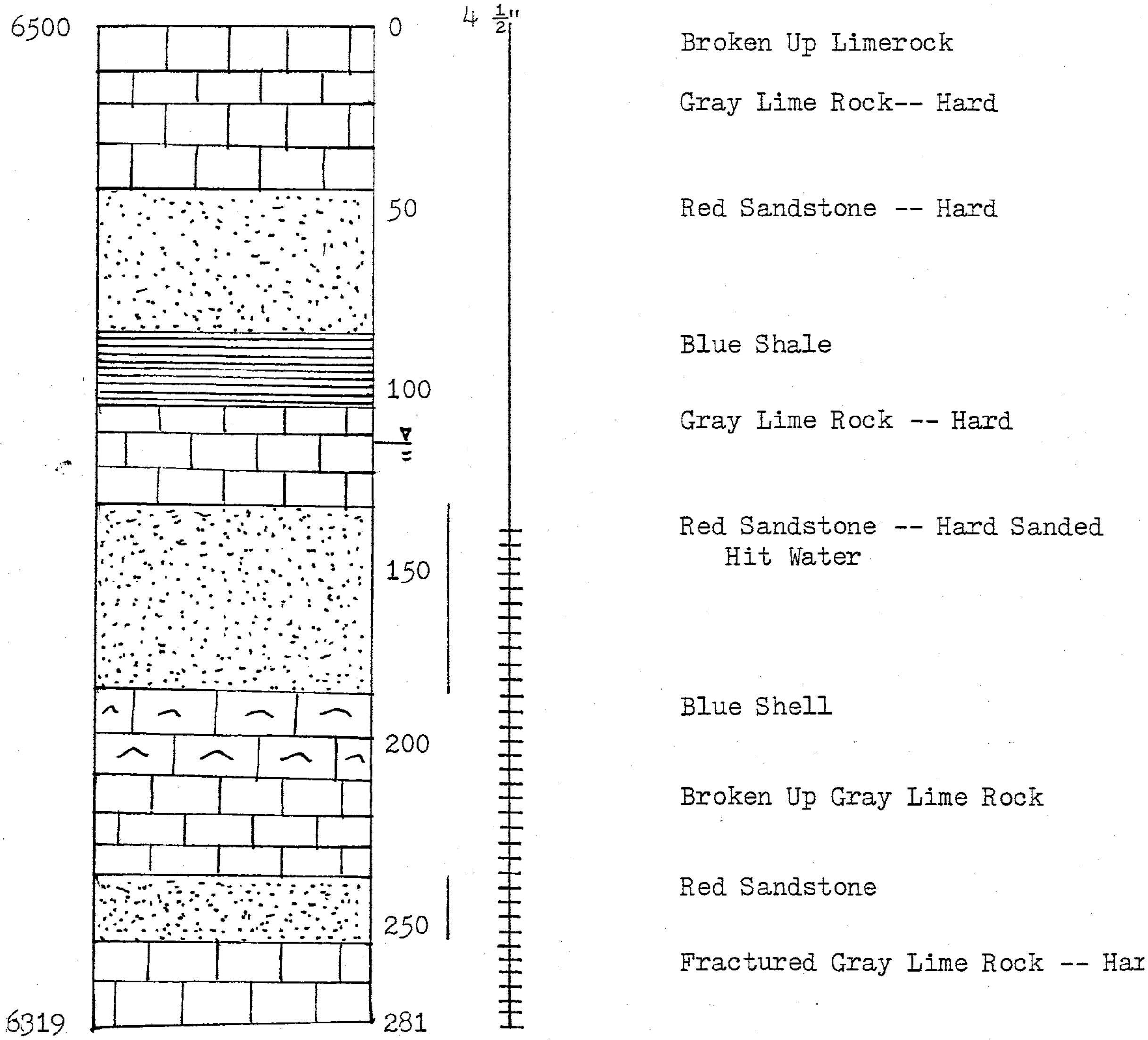
Depth to Water: 50'

Water-bearing Formation: Abo

Figure 58

16S.11E.5.13

Wesley Weehunt 9/8/84



Water: 134' - 186' Red Sandstone
Seep
238' - 256' Red Sandstone
3 gpm

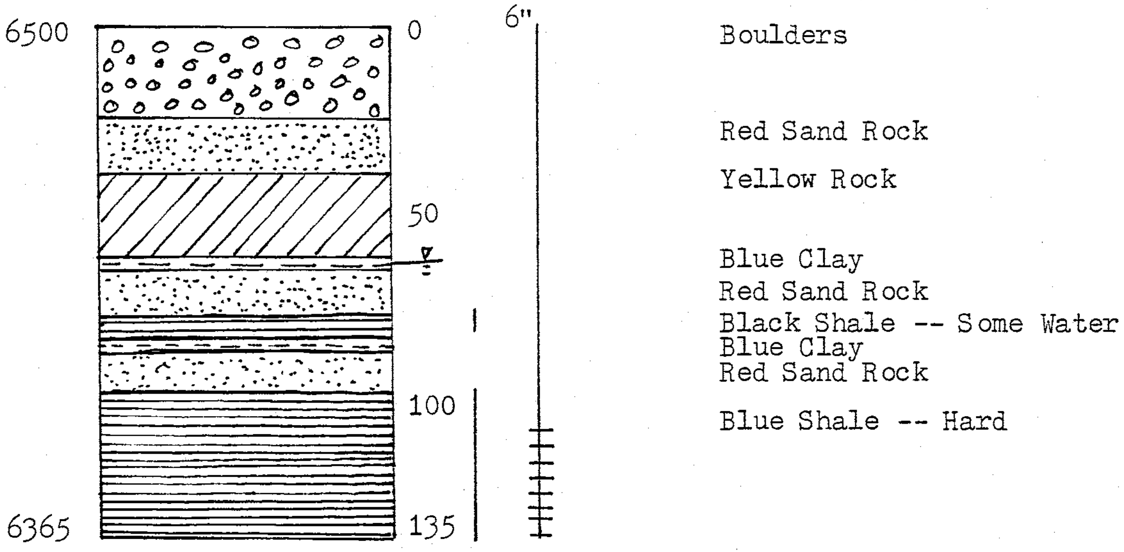
Depth to Water: 118'

Water-bearing Formation: Abo

Figure 59

16S.11E.5.14

Jim McBee 8/20/56



Water: 76' - 82' Black Shale -- Some Water
95' - 135' Blue Shale
Total yield: 15 gpm

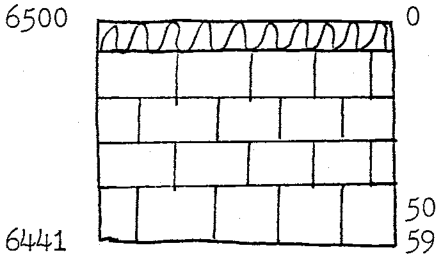
Depth to Water: 62.5'

Water-bearing Formation: Gobbler

Figure 60

16S.11E.5.144

Elzy Perry, Jr. 7/31/49

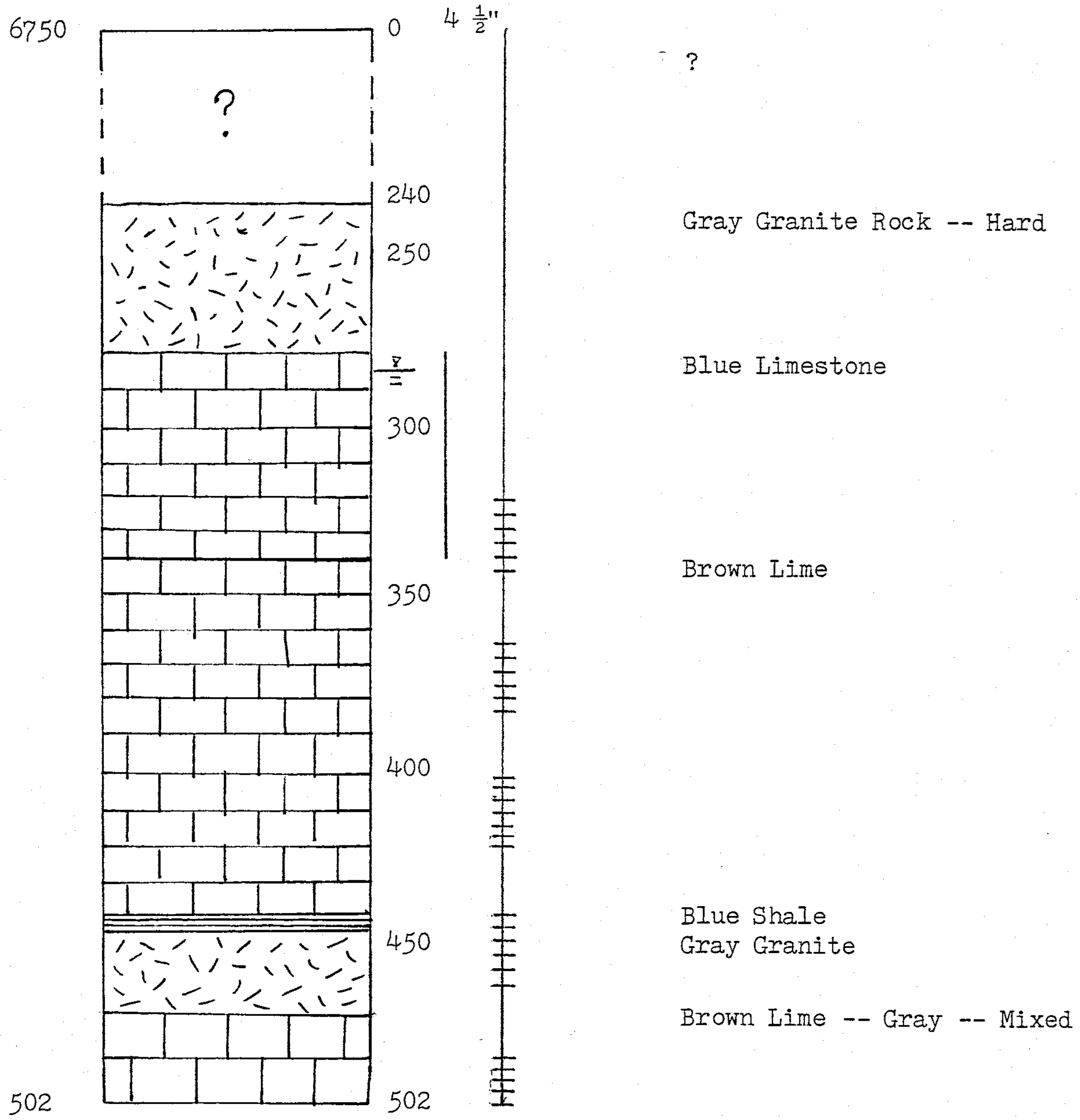


Top Soil
Limestone Boulders

Figure 61

16S.11E.5.3

Wesley Weehunt 10/16/82



Water: 284' - 343' Blue Limestone
1 gpm

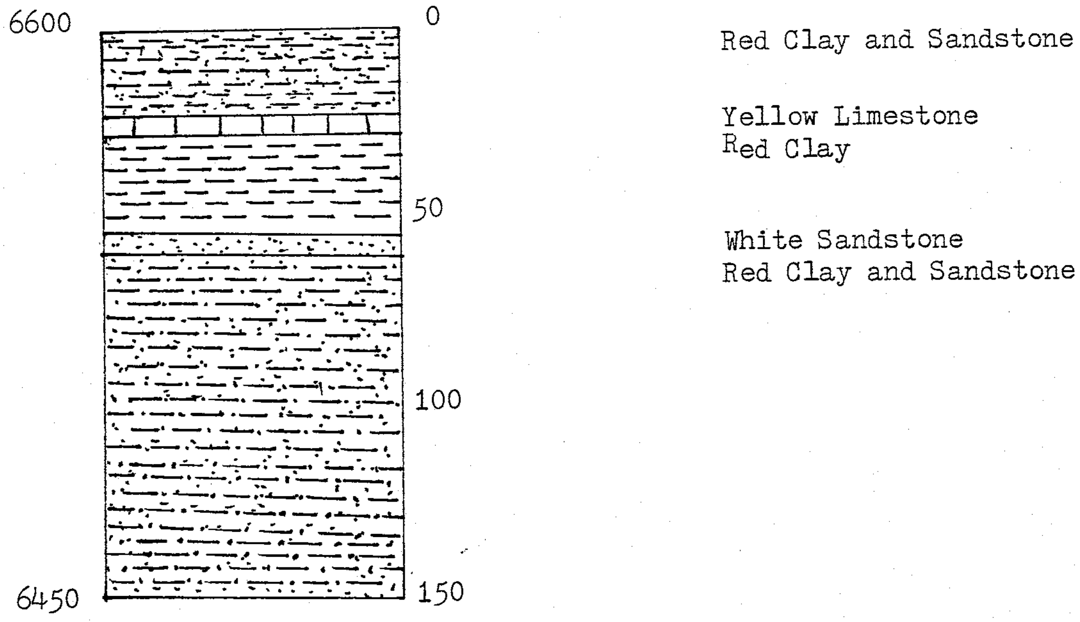
Depth to Water: 289'

Water-bearing Formation: Gobbler

Figure 62

16S.11E.5.4

Braziel Well Drilling, Inc. 3/30/84

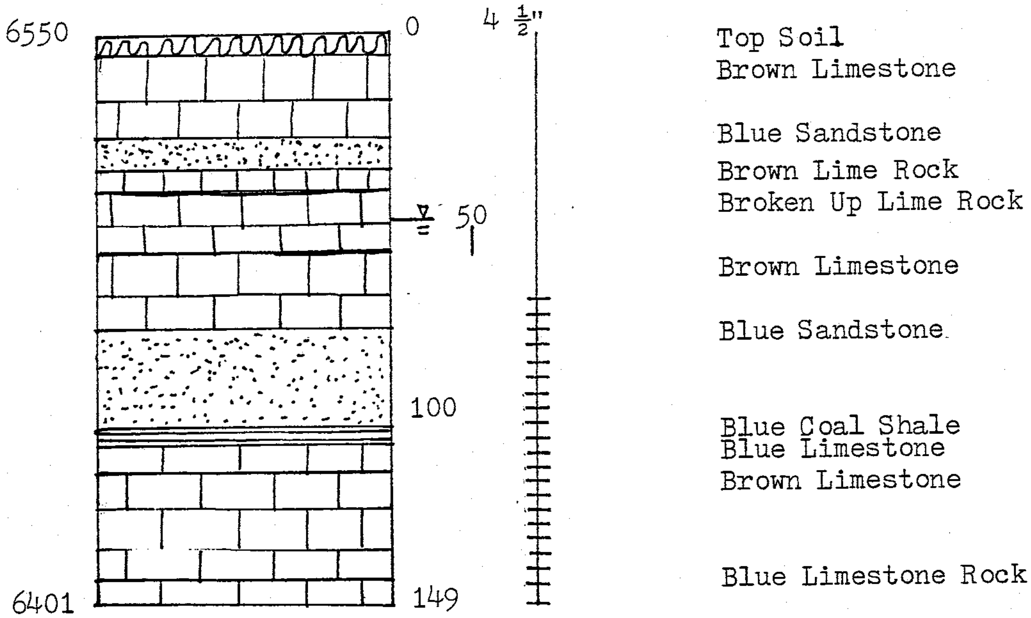


Dry Well

Figure 63

16S.11E.5.412

Wesley Weehunt 4/21/83



Water: 51' - 54' Broken Up Lime Rock
1 gpm

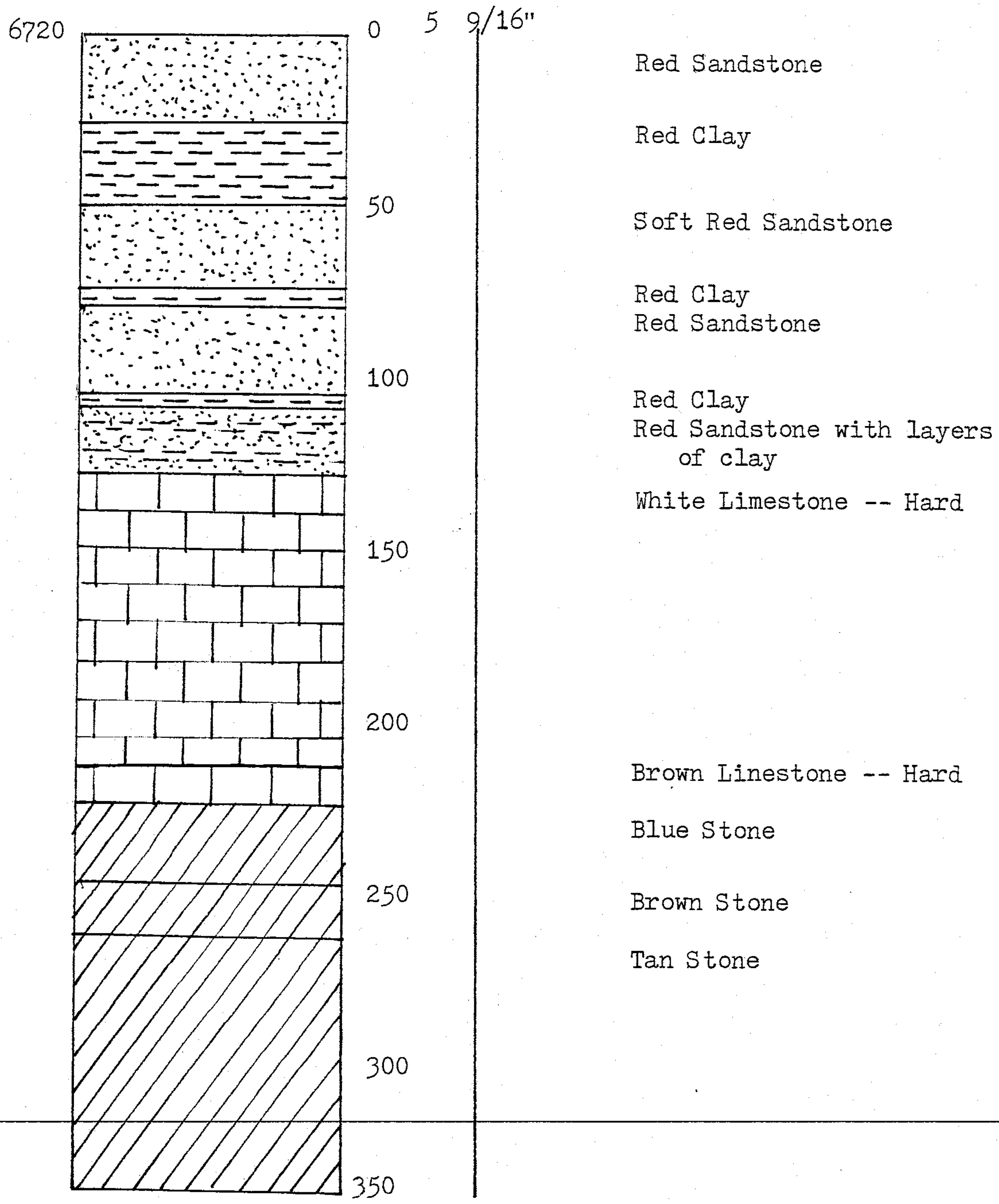
Depth to Water: 50'

Water-bearing Formation: Gobbler

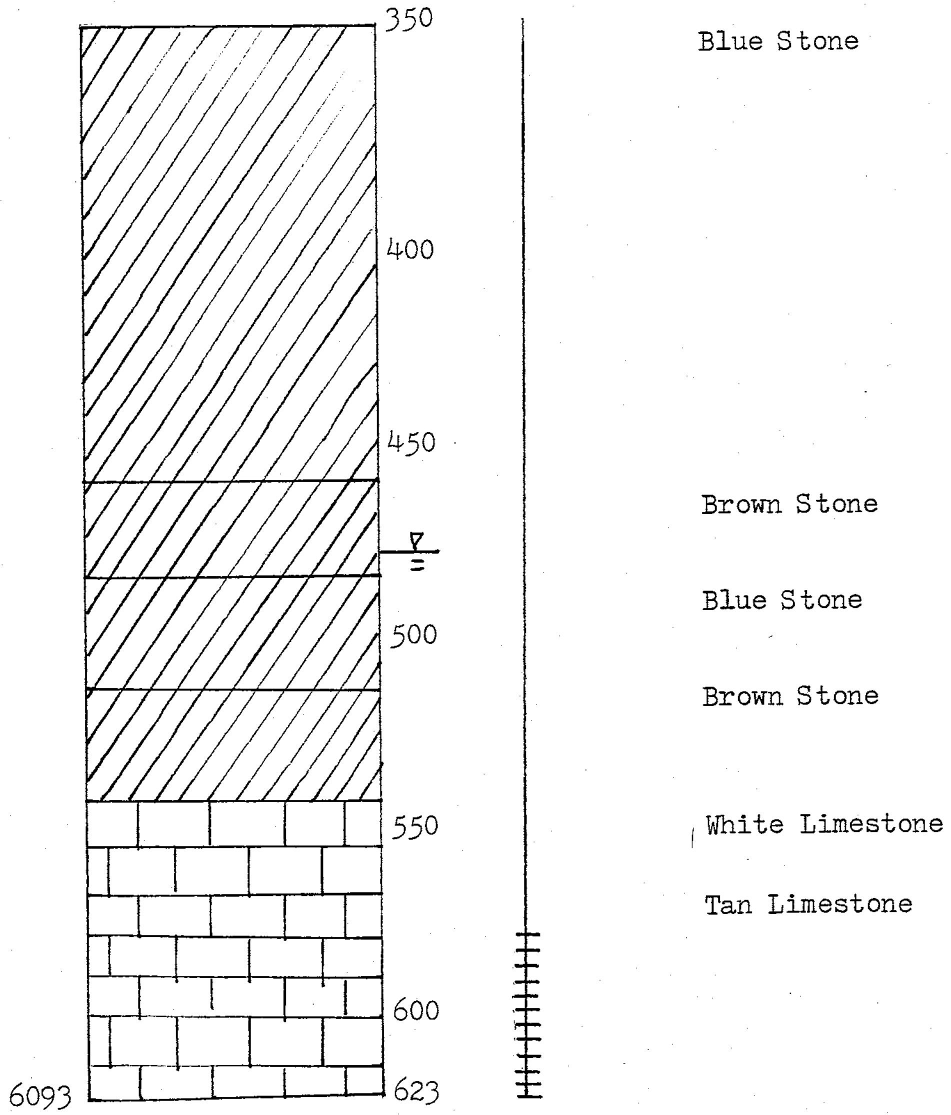
Figure 64

16S.11E.5.43

Clements Pump Co. 4/9/84



44 (Continued)



Water: 480' in Crevice
5 gpm

Depth to Water: 480'

Water-bearing Formation: Gobbler

Figure 65