HYDROGEOLOGY OF THE UPPER RIO PENASCO DRAINAGE BASIN BETWEEN JAMES AND COX CANYONS, OTERO COUNTY, NEW MEXICO (*)

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by

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Abstract

We report on the hydrogeologic characteristics of a 120 square mile area between James and Cox canyons, located on the mountainous western edge of the Roswell artesian basin in southeastern New Mexico. Water level measurements, driller's logs, chemical and tritium analyses of the water, and precipitation records, have been used to describe the groundwater system of the area. Three major ground water sources have been differentiated: the regional artesian system in the Yeso Formation, which is hydraulically connected with the Roswell Basin; a regional 'semi-perched' water body encircling the crest of the mountains and extending as far east as the R 12/ R 13 dividing line; and spring systems which occur under three conditions: numerous small springs issue near the San Andres/Yeso contact; other springs issue from a 100 feet thick zone of the 'semi-perched' aquifer system; larger but fewer springs issue where the piezometric surface intersects the stream channel in Cox Canyon.

The colder, wetter conditions at the crest of the mountains appear to be the major cause of the semi-perched water zone.

Well logs reveal that the most highly permeable zones in the area are underlain by a sand and gravel layer (presumably consolidated) in the Yeso. Permeability is smaller west of the line dividing townships 12 and 13, where water occurs in shales and noncavernous limestones. Transmissivity for the more western area averages about 3400 gpd/ft. Although underlying strata are variable vertically, they are quite continuous laterally. Underflow from the area was estimated at 3050 acre-feet per year as a minimum, which represents a recharge contribution to the Roswell Basin. Its diversion could have a negative effect on the Basin's water budget.

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ACKNOWLEDGMENT

The authors are deeply indebted to the New Mexico State Engineer Office in Roswell, most particularly to Mr. Sherman E. Galloway who suggested this study. The Office provided driller's logs and well schedules for the wells in the study area, as well as an irrigated acreage map. Invaluable assistance was provided by Lynn Brandvold (New Mexico Bureau of Mines and Mineral Resources) who performed chemical analyses on water samples of selected wells and springs. Tritium determinations were done by the tritium laboratory of New Mexico Institute of Mining and Technology. Additional thanks go to Dr. John Hawley of the New Mexico Bureau of Mines and Mineral Resources for his encouragement and practical insight into the hydrogeologic problems posed by the area, and to Mr. Kelly Summers (K. Summers and Associates) who graciously furnished raw pumping test data for a well in the study area. Prof. Bruce Buchanan (Department of Agronomy, New Mexico State University) provided data, based on his own research in a nearby area, on estimated evapotranspiration rates for the trees of the study area. Mr. Thomas L. Evans assisted with the drafting, reviewed the sections on geology, and offered greatly appreciated encouragement and advice. The final illustrations for this report were prepared by Messrs. Michael Wooldridge and Russell Wood, scientific illustrators for the New Mexico Bureau of Mines and Mineral Resources.

This work was performed under a grant from the New Mexico Interstate Streams Commission, and partial support from the New Mexico Water Resources Research Institute is gratefully acknowledged.

Last but far from least it should be noted that without the cooperation and interest of the farmers, ranchers, and other individuals living in the area, this project could not have been effectively completed.

INTRODUCTION

Area and Physiography

The area considered in this report encompasses the upper reaches of the Rio Peñasco between James and Cox canyons in Otero County of southeastern New Mexico (Fig. 1). From the crest of the Sacramento Mountains, Rio Peñasco flows down the Pecos slope (Kelley, 1971). After losing most of its discharge to the karstic San Andres Formation, it flows into the Pecos River about seven miles south of Artesia. The Peñasco's total length is about 115 miles (Renick, 1926). Streamflow is perennial above Elk and intermittent farther east. The study area extends from latitudes 33°N to 32°50' N, and longitudes 105°45' W to 105°22'30" W, a 120 square-mile region bounded physiographically by the crest of the Sacramento Mountains at the village of Cloudcroft to the west, James Canyon to the north, Cox Canyon to the south, and extending about two miles east of the confluence of the two canyons at the village of Mayhill.

Much of the area is mountainous, with peaks reaching over 9000 feet above sea level in elevation. Uplands consist of ridges capped by San Andres carbonate rocks, with relatively broad summits, conforming to the gentle eastward dip of the formation. The smaller valleys are V-shaped and deeply incised; the larger ones are steep-walled , but broader and flatter. Maximum local relief, between canyon floors and interfluve summits, is about 1300 feet. Cloudcroft, at the western edge of the area, lies at 8,575 feet above sea level, while Mayhill, 19 miles east, is at 6538 feet (Hood,1960). The mountains are densely covered with coniferous forests and are mainly uninhabited, although there is current activity aimed at putting housing developments on some of the lower slopes along James Canyon. By contrast, the broad, level main valleys, cut into the softer Yeso Formation, have long supported small-scale farming and ranching. James, Cox, Eightmile, and Hyatt canyons are the major valleys of this type. The other drainages of the area - Curtis, Dollins, Threemile and Pumphouse canyons - are too steep and too narrow for farming and are either unused or occupied by small housing developments. Curtis, Eightmile, and Hyatt canyons are the major internal drainages for the mountains between James and Cox canyons. Curtis Canyon and the northeast trending section of Cox Canyon near the eastern boundary of the study area are almost certainly fault valleys, for reasons discussed later.

All of the above-mentioned canyons, except lower Cox Canyon, contain intermittent streams which flow only after substantial rains or heavy snowmelt. Two-thirds of the way down the length of Cox Canyon, the upper Rio Peñasco flows into it from the southwest through Wills Canyon; Cox Canyon maintains a perennial flow from this confluence to several miles past Elk, a village ten miles east of Mayhill. The upper reaches of Cox Canyon, above Wills Canyon, have but intermittent flows. According to the 1952 USGS topographic map, a short stretch beginning at St. Joseph's Church and extending two or three miles downstream flowed perennially, but the flow has since ceased.

It should be noted that James and Cox canyons drain the heights of the Sacramento uplift at the far western boundary of the Roswell Basin recharge belt (Bean, 1949 and Fig. 1). The area studied is thus hydrologically linked with the Roswell artesian basin; surface water drains ultimately to the Pecos River at an elevation of about 3500 feet, at Artesia, 70 miles to the east (Fig. 1).

Climate

The climate of the upper Rio Peñasco drainage system reflects the high altitude of the Sacramento Mountains. Precipitation records for the area are shown in Tables I and II (taken from Climatological Records for New Mexico, compiled and published by the National Oceanic and Atmospheric Administration (NOAA)). Table III and Figures 2 to 4 present these data as (1) average yearly precipitation for the area, (2) as a histogram of seasonal distribution, and (3) as a histogram of a three-year running mean of precipitation, respectively. Using data from the Mayhill Ranger Station and Cloud Country Lodge, Mayhill received a yearly average of 18.44 in. and Cloudcroft 25.66 in. of precipitation over the period 1955-1975. Over 50% of the precipitation falls in July, August, and September, but the rest is fairly evenly distributed over the year (Fig. 3). The mean annual temperature at Mayhill is 52.2^{o}F, and at Cloudcroft, it is 46.2^{o}F. The coldest month at Mayhill averages a temperature above freezing, and no month has an average temperature of over 69^{o}F. At Cloud Country Lodge, slightly east of Cloudcroft, only during January does the temperature average below freezing, while the summertime temperature does not on the average exceed 61^{o}F. Cloudcroft may have a winter snowpack, whereas Mayhill rarely does.

By comparison, the city of Artesia, located 73 miles east of Mayhill on the west bank of the Pecos River, at an elevation of 3500 feet above sea level, receives an average annual precipitation of 11.2 inches, most of which falls in the summer as brief, violent thunderstorms. Artesia experiences large extremes in temperature, exceeding 90^{o}F on about 78 days in the summer, and dropping below freezing about 100 days in the winter (Hantush, 1957).

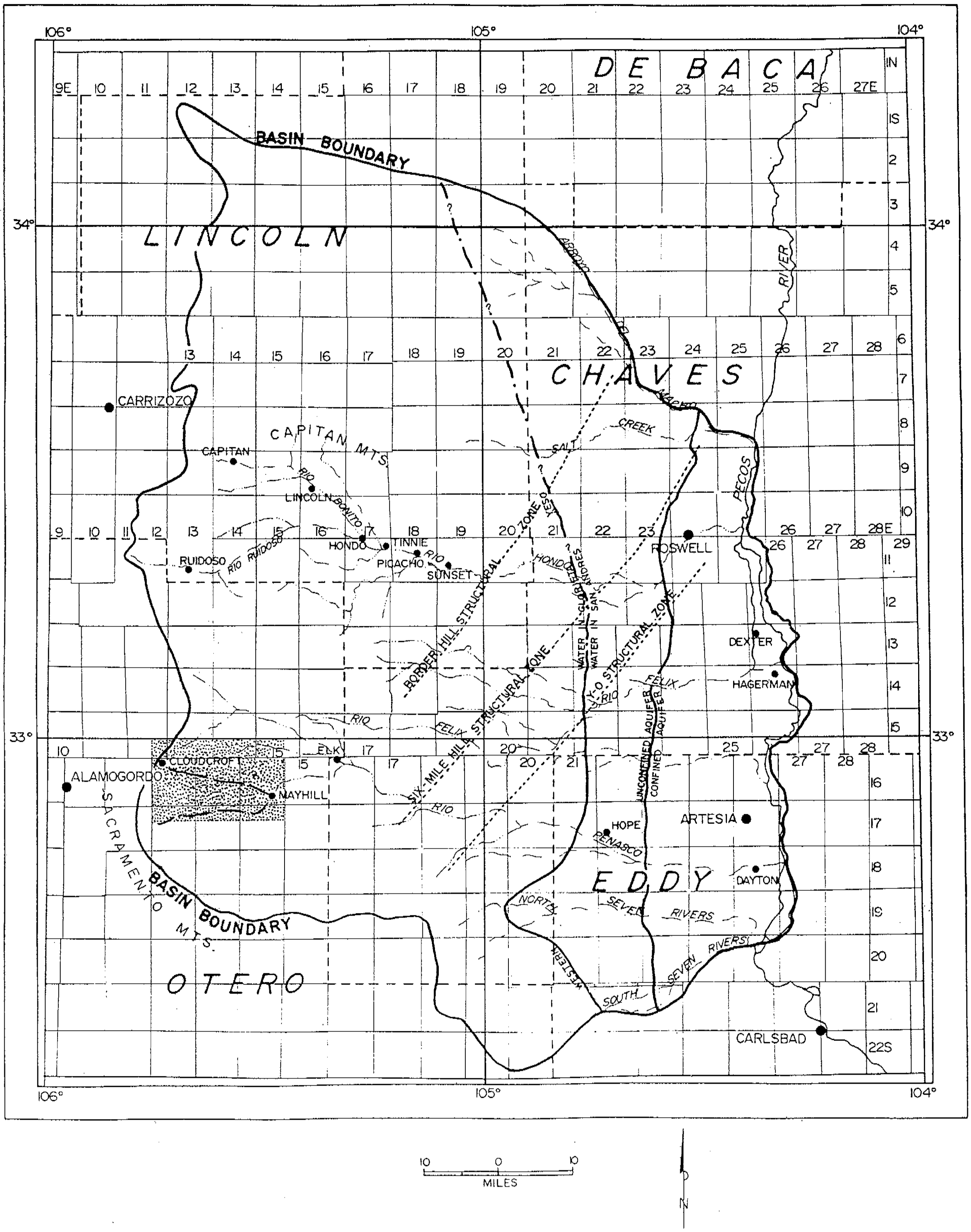


Figure 1. Location map. Stippled: approximate map area of Figs. 6, 8, 13, 18.

Table I. Precipitation for Cloud Country Lodge (inches)

Year	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1955	2.37	.55	3.82	0.00	0.81	0.44	10.48	5.37	0.55	2.06	0.16	0.22	26.82
1956	1.16	2.25	0.00	0.57	0.00	1.42	6.01	3.84	0.02	1.55	0.00	0.90	17.72
1957	1.50	2.74	3.51	1.01	0.56	0.40	3.02	7.02	0.41	4.72	2.40	0.34	27.63
1958	3.16	3.28	7.31	1.06	0.65	1.25	4.66	7.51	4.78	3.06	0.85	0.23	37.80
1959	0.04	1.31	0.10	0.05	0.32	1.53	8.84	6.90	0.05	0.64	0.06	1.22	21.06
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	23.05
1961	1.69	0.10	2.75	0.03	0.50	4.23	6.44	4.10	2.77	0.25	2.68	5.10	30.64
1962	3.13	0.91	1.36	0.05	0.22	1.72	9.61	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	24.43
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	21.31
1965	1.74	2.90	2.09	0.82	0.51	2.56	5.70	6.88	3.39	1.08	0.53	5.73	33.93
1966	1.59	1.64	1.22	0.96	0.00	3.15	3.81	6.27	3.15	0.00	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	0.00	1.54	0.27	0.27	2.94	4.23	3.21	2.26	4.44	0.74	23.90
1972	3.75	0.56	0.00	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	0.41	20.81
1974	3.01	0.99	0.80	0.07	0.07	1.21	5.86	5.03	4.70	5.22	0.83	1.77	29.55
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	3.70	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		1.96	station discontinued							
Averages:													
	1.81	1.49	1.78	0.41	0.65	1.53	5.53	5.03	2.91	1.68	1.20	1.64	25.66

Table II. Precipitation for Mayhill Ranger Station (inches)

Year	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1955	1.02	0.16	0.81	0.01	0.17	0.57	9.92	1.53	1.65	1.52	0.06	0.09	17.45
1956	0.13	1.56	0.06	0.30	0.66	1.48	2.65	3.17	0.15	1.08	0.00	3.40	11.64
1957	0.11	0.80	0.73	0.55	0.75	0.36	5.04	7.84	0.51	4.24	1.43	0.00	22.36
1958	1.29	2.14	3.15	0.56	0.95	1.47	2.68	0.91	2.86	2.35	0.14	0.15	18.65
1959	0.00	0.41	0.19	0.17	1.69	2.42	3.56	4.78	0.10	0.40	0.19	0.88	14.79
1960	1.00	0.49	0.33	0.11	0.49	3.08	5.21	2.64	0.56	2.42	0.06	2.27	18.66
1961	0.90	0.19	0.43	0.21	0.72	2.30	1.50	5.61	1.51	0.25	2.82	0.91	16.85
1962	1.21	0.57	0.90	0.78	0.00	1.30	5.64	1.67	5.27	2.13	0.77	1.10	21.34
1963	1.01	0.50	0.01	0.00	0.90	0.65	5.39	3.70	1.74	0.86	0.11	0.02	14.89
1964	0.27	0.95	0.78	0.15	1.23	0.17	2.19	1.42	3.02	0.00	0.16	0.70	11.04
1965	0.11	1.15	0.26	0.77	0.93	4.47	2.95	4.81	4.31	0.38	0.05	1.34	21.53
1966	0.93	0.46	0.74	2.43	0.40	3.50	3.18	5.56	1.63	0.11	0.36	0.04	19.34
1967	0.00	0.50	0.10	0.13	0.76	3.42	2.61	4.48	4.85	0.19	0.73	1.58	19.35
1968	0.83	1.04	1.38	0.22	0.58	1.12	9.58	3.77	0.04	0.97	1.24	0.63	21.40
1969	0.00	0.15	0.52	0.08	1.66	1.04	5.54	9.17	3.81	1.78	0.22	1.43	25.40
1970	0.00	0.33	0.35	0.02	0.71	2.55	2.31	6.31	1.87	0.83	0.00	0.55	15.63
1971	0.34	0.39	0.00	0.89	0.15	1.25	4.20	3.47	3.92	2.86	0.63	0.40	18.50
1972	0.74	0.00	0.00	0.00	0.39	2.91	2.14	6.81	6.42	3.44	0.75	0.90	24.50
1973	1.38	1.53	0.49	0.13	1.15	0.75	3.15	4.16	0.27	0.10	0.22	0.05	13.38
1974	0.50	0.15	0.06	0.23	0.20	0.49	5.06	3.39	9.21	6.40	0.11	2.23	28.03
1975	0.85	0.65	0.73	0.25	0.46	0.20	3.59	3.68	3.22	0.07	0.20	0.43	14.33
1976	0.45	0.43	0.42	1.20	1.75	1.33	5.04	2.65	station discontinued				
Averages:	0.59	0.66	0.57	0.42	0.74	1.67	4.23	4.16	2.59	1.47	0.47	0.87	18.44

Table III. Precipitation Averages for Cloudcroft/Mayhill Area (inches)

	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	3-Year Av.
1955	1.70	0.36	2.32	0.01	0.49	0.51	10.2	3.45	1.10	1.79	0.11	0.16	22.14	
1956	0.65	1.91	0.03	0.44	0.33	1.45	4.33	3.51	0.09	1.32	0.00	2.15	14.68	20.61
1957	0.81	1.77	2.12	0.78	0.66	0.38	4.03	7.43	0.46	4.48	1.92	0.17	25.00	22.64
1958	2.23	2.71	5.23	0.81	0.60	1.36	3.67	4.21	3.82	2.71	0.50	0.19	28.23	23.72
1959	0.02	0.86	0.15	0.11	1.01	1.98	6.20	5.84	0.08	0.52	0.13	1.05	17.93	22.34
1960	2.58	1.13	0.38	0.13	0.77	2.28	6.10	2.44	0.74	2.01	0.09	2.24	20.86	20.85
1961	1.30	0.15	1.59	0.12	0.36	3.27	3.97	4.86	2.14	0.25	2.75	3.01	23.75	23.17
1962	2.17	0.74	1.13	0.64	0.11	1.51	7.63	1.93	4.84	1.82	1.16	1.24	24.91	22.77
1963	1.54	0.94	0.03	0.30	0.57	0.72	5.44	6.47	1.85	1.23	0.40	0.21	19.66	20.25
1964	0.39	1.28	1.11	0.43	1.09	0.48	4.29	2.29	3.84	0.00	0.18	0.82	16.18	21.19
1965	0.93	2.03	1.18	0.80	0.72	3.52	4.33	5.85	3.85	0.73	0.29	3.54	27.73	21.95
1966	1.26	1.05	0.98	1.70	0.20	3.33	3.50	5.92	2.39	0.06	0.76	0.82	21.94	24.12
1967	0.00	0.98	0.19	0.11	0.39	3.04	2.63	6.22	4.76	0.11	0.87	3.42	22.69	22.96
1968	1.16	1.56	2.62	0.66	0.43	0.88	7.40	4.91	0.80	0.80	2.19	1.75	24.25	24.46
1969	0.72	0.91	1.04	0.06	2.11	0.67	4.88	8.15	4.52	1.59	0.21	1.61	26.44	22.06
1970	0.20	0.23	1.10	0.06	0.38	2.53	3.38	4.81	1.45	0.93	0.03	0.51	15.48	21.04
1971	0.50	1.20	0.00	1.22	0.21	0.76	3.57	3.85	4.08	2.56	2.54	0.57	21.20	21.75
1972	2.25	0.28	0.00	0.00	0.64	2.67	3.91	5.86	5.85	4.56	0.96	1.62	28.58	22.29
1973	1.84	1.30	2.78	0.25	1.17	1.56	4.08	3.28	0.31	0.12	0.60	0.23	17.10	24.82
1974	1.76	0.57	0.43	0.15	0.14	0.85	5.46	4.21	6.96	5.81	0.47	2.00	28.79	21.39
1975	1.91	2.40	1.47	0.32	0.48	0.60	4.08	2.95	4.00	0.18	0.53	0.38	18.27	
1976	0.49	1.18	0.39	0.66	1.14	0.67	5.97	3.43	station discontinued					
Averages:														
	1.20	1.16	1.19	0.44	0.65	1.59	4.96	4.63	2.76	1.60	0.79	1.32	22.29	

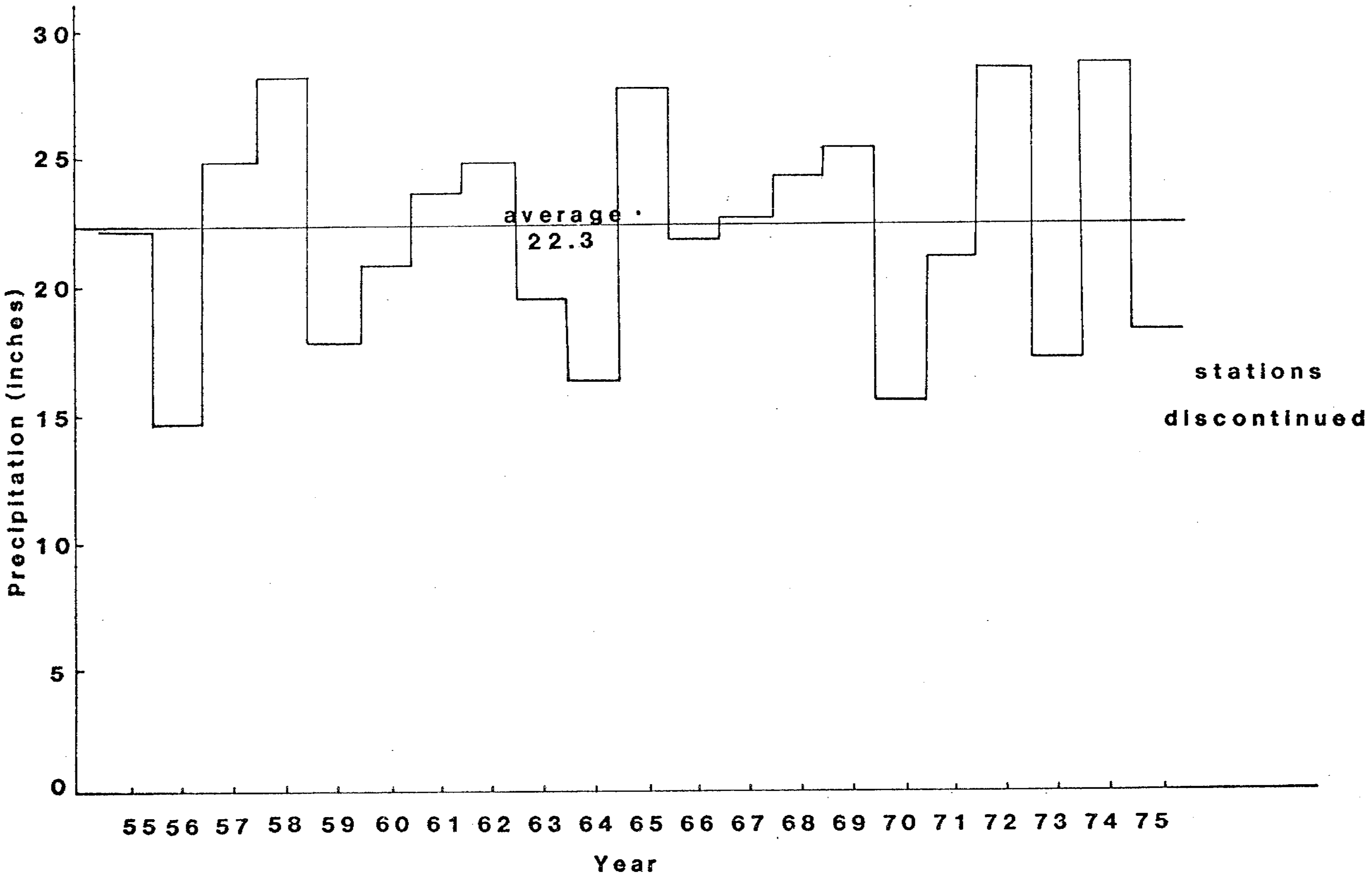


Figure 2. Histogram of yearly combined precipitation (1955 - 1975) at Cloudcroft and Mayhill.

No data are available on the relative humidities for Cloudcroft or Mayhill, or on average wind movement for the two villages. In general, it can be said that relative humidity is probably fairly low for this forested area, and wind movement is usually no more than a moderate breeze, except during the spring, when fairly strong winds blow, as in much of New Mexico.

Purpose and Scope

The lovely mountain valleys between the villages of Cloudcroft and Mayhill, traditionally areas of small farms, ranches, and orchards, are currently enjoying an influx of fairly well-to-do, retirement-minded people who are building homes and setting up recreational facilities such as golf courses. This is particularly true of James Canyon, through which Route 83 runs and along which most development is taking place. In the past, this area has had no problem in securing an adequate water supply, in both quantity and quality, for the people, cattle, and crops of the area. Water issues from springs, flows in the Rio Peñasco in Cox Canyon, and is available from wells of shallow to moderate depth. More water will be needed as development progresses. The study area is part of the Peñasco Declared Underground Water-Basin, established by the New Mexico State Engineer in 1974.

It seems therefore useful to study the hydrogeology of the area in order to make available to residents and developers alike the answers to such basic questions as: what kind of rocks underlie the area and in which formations is the water present; how much water is available in the formations of the area and under what conditions does it occur; what is its quality; and how do the local geologic and hydrologic conditions fit in with and affect the larger regional picture of the Roswell artesian basin, of which the study area is a part.

Although the first questions are of most immediate concern, the problem of regional coupling is, perhaps, underestimated. The Roswell artesian basin is one of the more productive agricultural areas in New Mexico. An undetermined amount of recharge to the principal regional aquifer of the Basin may be supplied by precipitation on the outcrops and canyons of mountains at its western boundary, such as the Cloudcroft-Mayhill area. The fact that surface water from the mountains is a component of recharge to the Basin is well documented (Bean, 1949; DeWilde, 1961; Hantush, 1957; Mourant, 1963; Duffy, 1978). The question of the connection between groundwater and surface water in the mountains, and the magnitude of the component of recharge to the Roswell Basin hydrologic system, contributed by underflow from the western mountain aquifers, is as yet undocumented, although researchers are beginning to deal

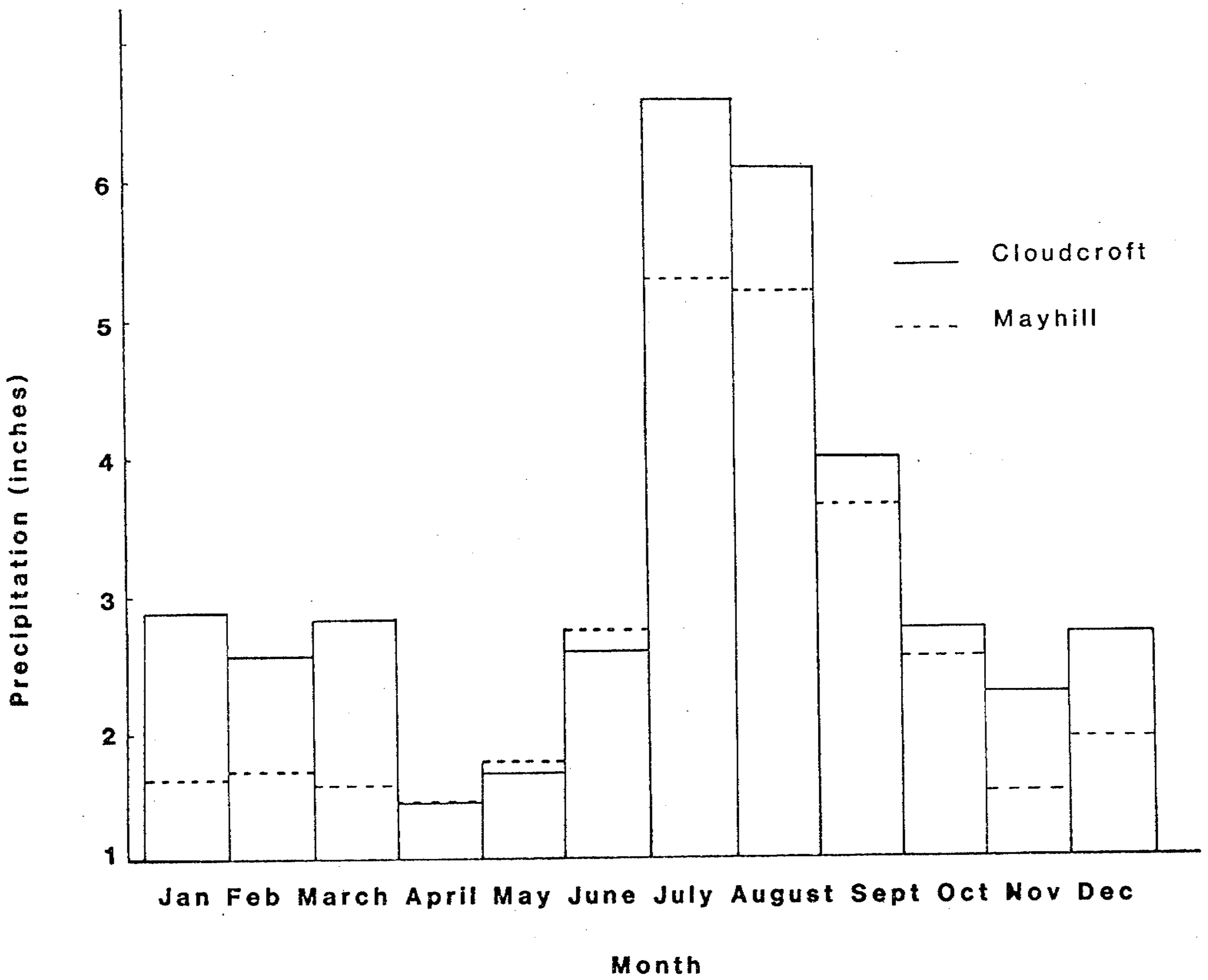


Figure 3. Seasonal distribution of precipitation at Cloudcroft and Mayhill (based on 1955 - 1975 records).

with this important problem (Bean, 1949; Duffy, et al., 1978; Rehfeldt and Gross, 1982). If there is a direct hydrologic connection between the mountains and the artesian basin, then large-scale groundwater withdrawals in the mountain region may have an adverse affect on the water availability in the Basin.

Previous Investigations

A large number of reports exist on the geology and hydrology of the Roswell Basin, of which the study area is a part; the emphasis is on the agricultural and oil-producing zone along the Pecos River. Little has been published on the western limits of the Basin, high in the Sacramento Mountains. Even less has been done on the specific area under study, making it necessary to piece together information from reports more general in nature.

The first hydrogeological report on the upper Rio Peñasco area seems to have been an investigation by C. Renick (1926). As a part of his report on the future of the village of Hope's water prospects, Renick briefly discussed the hydrologic and geologic characteristics of the upper Peñasco area. More recent research indicates that many of Renick's observations and much of his analysis of how the Upper Peñasco area operates hydrologically are incorrect. In a classical paper, Fiedler and Nye (1933) touched on the geology of the Sacramento Mountains and defined them as the western edge of the Roswell hydrologic basin. Among groundwater recharge mechanisms, they mention the possible importance of surface runoff from the western mountains. Bean (1949) estimated that about 8700 acre feet of water per year are lost from the Rio Peñasco to the artesian aquifer. He noted that this figure represented about 3.7% of the mean annual recharge to the artesian reservoir. Hantush (1957) prepared the first quantitative study of the Roswell groundwater basin. Taking into account the complex hydraulic relations he perceived in this system of several aquifers, he used his (then new) model of leaky aquifers to analyze pumping tests. He computed the coefficients of transmissivity and storage for the deep artesian and unconfined aquifers near Roswell, Dexter, Artesia, and Lakewood, towns in a north-south line about 70 miles east of the study area. These aquifers do not correspond to any present in the study area.

Hood (1960) discussed in general terms the geology and hydrology of the area. He documented springs and wells, and reported the first chemical analyses of the water from them. The only thorough hydrogeologic investigation of a stream draining west to east across the Basin was done by Mourant (1963) who studied the Rio Hondo drainage basin, north of the present study area.

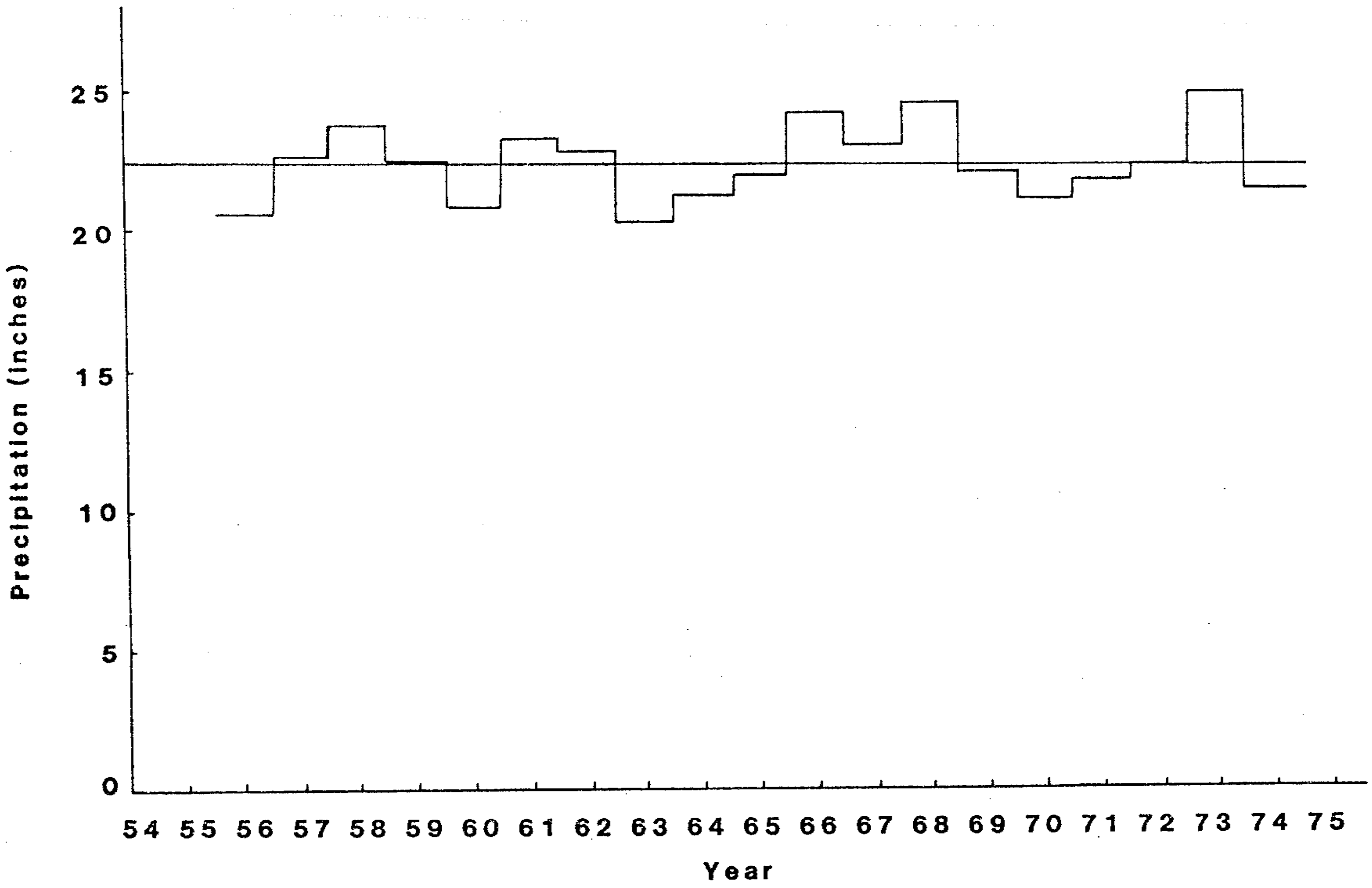


Figure 4. Histogram of three-year running mean combined precipitation at Cloudcroft and Mayhill.

Motts (1959) discussed the geomorphology of the eastern slope of the Sacramento Mountains, and in particular, the various erosional 'plains'. Their development may be related to profound changes in the drainage patterns of the Pecos basin. Present-day groundwater circulation could reflect the ancient stream patterns because subsurface erosion is related to surface drainage patterns and there is evidence, in this basin, of large-scale removal of evaporitic bedrock by groundwater (cf. Kelley, 1971, p. 9). This problem remains to be explored. Pray (1954; 1961) studied aspects of the geology of the Sacramento Mountains. Several of his detailed sections of the Yeso Formation along the Sacramento western escarpment, facing the Tularosa Basin, are adjacent to the study area. Kelley (1971) published a thorough investigation of the geology of the "Pecos Country", discussing in detail the tectonic structure of southeastern New Mexico and the geologic formations involved. The applicability of environmental tritium as an investigative tool in the area was examined by Rabinowitz and Gross (1972, cf. Rabinowitz et al., 1977), and in 1976 a follow-up study (with different conclusions) was published by Gross et al. These two studies dealt with the basin area as a whole, Duffy et al. (1978) came out with a stochastic stream-aquifer model of the western region of the Basin. This study pointed out that underflow from western aquifers into the groundwater system of the central basin could be a significant recharge component. Gross et al (1979) published a study of Paul Spring, a large spring on the western edge of the Basin and twenty miles east of Mayhill, which was considered to be typical of one recharge mechanism operative in the Basin. Davis et al. (1980) presented an overview of the chemistry and geologic characteristics of the larger springs of the western mountains. Gross et al. (1982) summarized isotope and modeling studies which point to the existence of an appreciable contribution of high-mountain recharge to the Roswell groundwater basin.

One of the studies most valuable to researchers interested in the western boundary of the Basin is the hydrologic map of the Mescalero Apache Indian Reservation due north of the study area (Sloan and Garber, 1971). As will be seen, the present study supports and further elucidates the hydrologic conditions presented in this map, although some of Sloan and Garber's interpretations of groundwater conditions are seen as oversimplifications of a more complex system.

Well Numbering System

To facilitate reference, the wells in the study area have been given number or letter designations. Numbered wells are wells for which there exist water-level data: they may or may not have driller's logs, while lettered wells indicate wells which have logs, but for which there are no water-level measurements. Springs are designated by an "S" followed by a dash and a number. Forty-seven wells and eleven springs were used in the study.

All the wells and springs of the area are precisely identified and located with the coordinate system used by the USGS and the New Mexico State Engineer (Fig. 5). The coordinates of a given well are given by township, range, section, and, if possible, ten-acre plot on the 640-acre section (Fig. 5). All the wells and springs are located in the southern townships and eastern ranges. Fig. 6 presents the locations of wells, springs and cross-sections referred to in this report.

GEOLOGY

Geologic History of the Area

The study area is located on the easterly dipslope of the Sacramento uplift, a tilted fault block in the Sacramento section of the Basin and Range Province. In a late Tertiary event, the mountains were faulted up along a huge normal or gravity fault-zone running along the western flank of the uplift (Kelley, 1971). The major streams of the mountains, the Rio Hondo, the Rio Peñasco, and the Rio Felix, drain and have dissected the east slope of the fault block (the Pecos slope of Kelley, 1971). Along the crest, the streams have removed most of the post-San Andres rocks and have developed an erosional surface on San Andres carbonates, the "Sacramento Plain" of Fiedler and Nye (1932) and of later workers. During this intense period of erosion, the Sacramento Mountains were uplifted again, as were the Guadalupe Mountains to the south (Pray, 1954). This new mountain crest was originally several miles farther west, but erosion has moved it east to its present location near Cloudcroft (Pray, 1954).

Prior to the initial uplift, the area had been located on the "west limb of a broad, comparatively shallow structural basin" (Fiedler and Nye, 1932, p. 76), the Permian Basin of southeastern New Mexico, western Texas, and parts of Oklahoma and Kansas. The area was subjected to alternating periods of sedimentation and erosion controlled to a large extent by the development of the Basin to the east and the rise of the Pedernal axis or landmass (Kelley, 1971, pp. 55-61) in late Pennsylvanian time. The Pedernal landmass continued to express itself through late Leonardian (early Permian) time, during which period the Yeso Formation was deposited either directly onto the Precambrian, or conformably onto the lower Permian Abo sandstone, as it was in other areas of the State. During even earlier Permian time, the Delaware Basin had begun to form in southeastern New Mexico as the Abo Reef developed to the east, creating backreef lagoons. In the eastern part of the Basin the Yeso was deposited as carbonates, muds, and great thicknesses of gypsum which precipitated out of the shallow sea waters. Along the crest of the Pedernal axis, however, the Yeso was far more continental in nature, consisting of yellow and red muds, minor sands, and gravels, with some limestone and dolomite towards the top of the section. Gypsum and anhydrite seem to be largely absent in the Yeso of the study area, to the extent that it is exposed or has been explored by drilling.

In early Guadalupian times, perhaps due to subsidence of the Delaware Basin or to a rise in sea level, great thicknesses of dense limestone, the San Andres Formation, were deposited throughout the area, including the Pedernal landmass. Only minor amounts of sand and shale are found in the San Andres Formation in the Cloudcroft-Mayhill area; the formation expresses itself almost exclusively as thick layers of limestone and dolomite. The deposition of the San Andres was followed by continuous accumulation of other sediments to late Tertiary time. Since none of those stratigraphic units remain in the study area, they will not be discussed here. The reader is referred to Kelley (1971) for further details. Erosion has left only the Yeso Formation in the valleys, and the lower San Andres limestone capping the mountains, with thick Quaternary gravel deposits filling some of the canyons. Following Cox and Curtis canyons, these limestone gravels are apparently of local origin, being composed almost exclusively of limestone and dolomite. Although some evidence of fluvial deposition is present, little rounding or other evidence of transport is indicated. Figure 7 presents a synopsis of the geologic formations exposed in the study area.

Geologic Structure

The San Andres and Yeso rocks dip gently east at 100 to 150 feet per mile along the almost north-south striking Sacramento uplift. The gentle dip is interrupted locally by small folds, an occasional large anticline like the one apparent in the hill south of Route 12 near the turnoff to Weed, a number of small local faults of indeterminate throw, and several large regional faults. Three of these are discussed in this report, apparently for the first time. Renick (1926, p. 124) makes reference to "unusual structural conditions...along the Mayhill-Cloudcroft road at least as far as the junction of this road with the Weed-Cloudcroft road", and notes that some of the beds are highly deformed and exhibit steep dips. More fieldwork is needed to ascertain the extent and throw of the projected faults, their inferred locations appear on Fig. 8. For the purpose of this discussion, the three will be called the 'Curtis Canyon fault', the 'McEwen Canyon fault', and the 'Mayhill fault', respectively, for the canyons and village

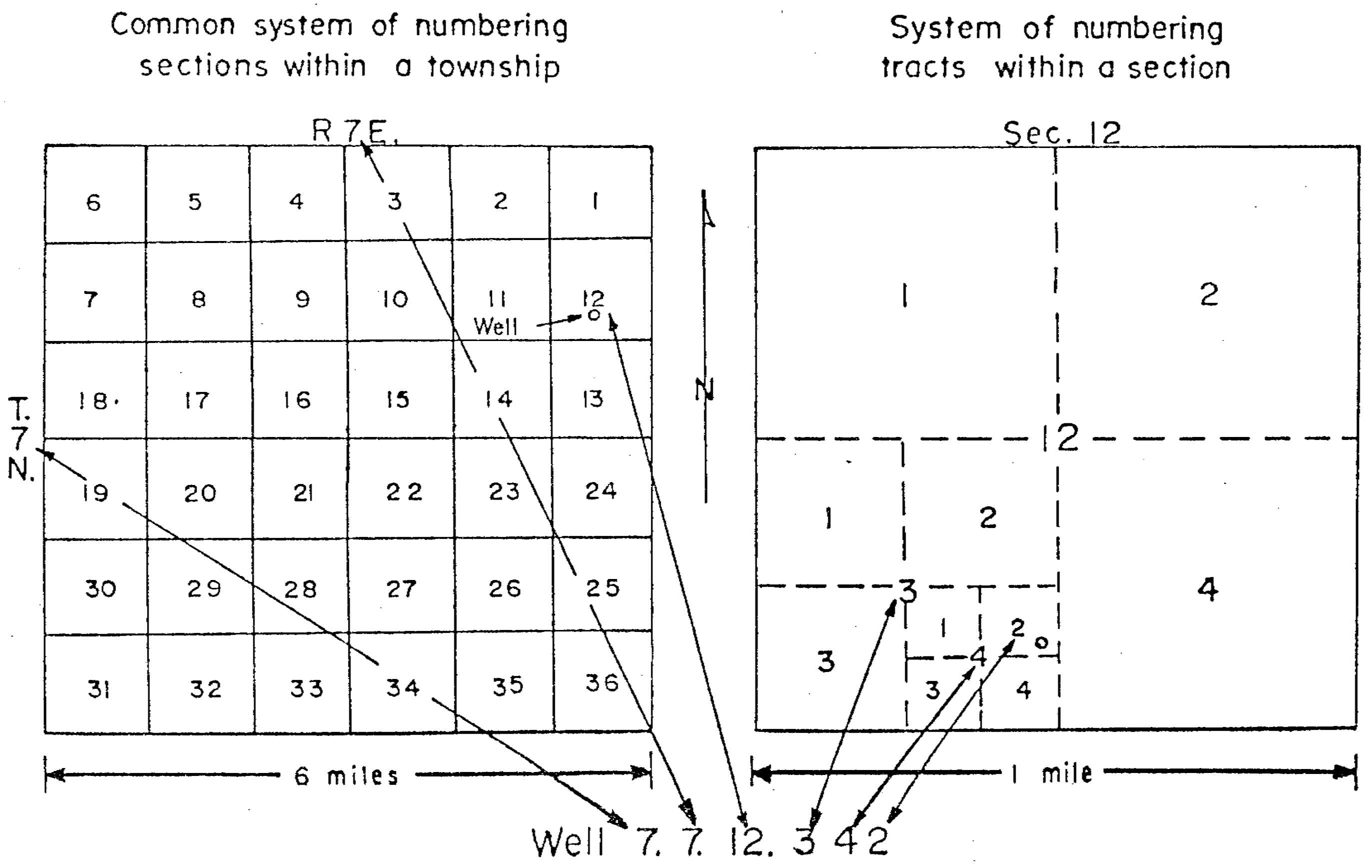


Figure 5. Well coordinate system.

with which they are associated.

Curtis Canyon fault

The existence of the Curtis Canyon fault was suspected even before fieldwork had commmenced. The canyon forms a lineament extending due east-west for three miles, and there is the curious absence of springs on the south side of the canyon. Most of the springs in the area occur at or near the contact between the San Andres and Yeso formations; therefore, any two springs at the same longitude should occur at similar elevations. On the north side of Curtis Canyon there are a number of springs at the elevation predicted for the San Andres/Yeso contact at that longitude. However, not one spring issues on the southern side of the Canyon. One possible explanation is that a fault runs along Curtis Canyon, downthrowing its southern side. This conclusion appears to be borne out by field observation, and though field time was not sufficient to permit an exact determination of the location of the fault, its trace probably coincides fairly closely with the inferred fault line. The western limit of the fault can be determined exactly, because the offset beds are easily seen from the road.

McEwen Canyon fault

The major piece of evidence for the presence of the McEwen Canyon fault is subsurface geology. Fig. 9 indicates the disparity between the strata in boreholes DD and CC, located a mile apart in longitude. If a fault is drawn as shown, passing near or through hole DD, with the north side downdropped, then both the broken nature of the DD rock and the apparently offset strata can be explained. The fault trace would express itself on the surface as a small east-west trending valley just north of hole DD.

Mayhill fault

The presence of the Mayhill fault is indicated by the physiography and can be appreciated on the topographic map. Twenty miles southeast of Cloudcroft, along Route 12, Cox Canyon makes an abrupt, 90 degree turn, and the Rio Peñasco flows north-northeast four miles to Mayhill. The eastern side of this northward trending canyon is a steep limestone escarpment; the western side a more gentle continuation of the Sacramento Mountain dip slope. There are perhaps several factors which could cause a stream to turn at right angles and produce an escarpment on one side, but the most obvious one is a fault. In addition, if the Border Hill structural zone (Kelley, 1971, p. 46) is projected southwest along its strike, it would coincide almost exactly with the proposed trace of the Mayhill fault. Evidence for some kind of major regional movement is to be found in the convoluted strata, noted by Renick (1926), which are visible in roadcuts near the proposed fault zone. In addition, analysis of groundwater conditions indicate that a large

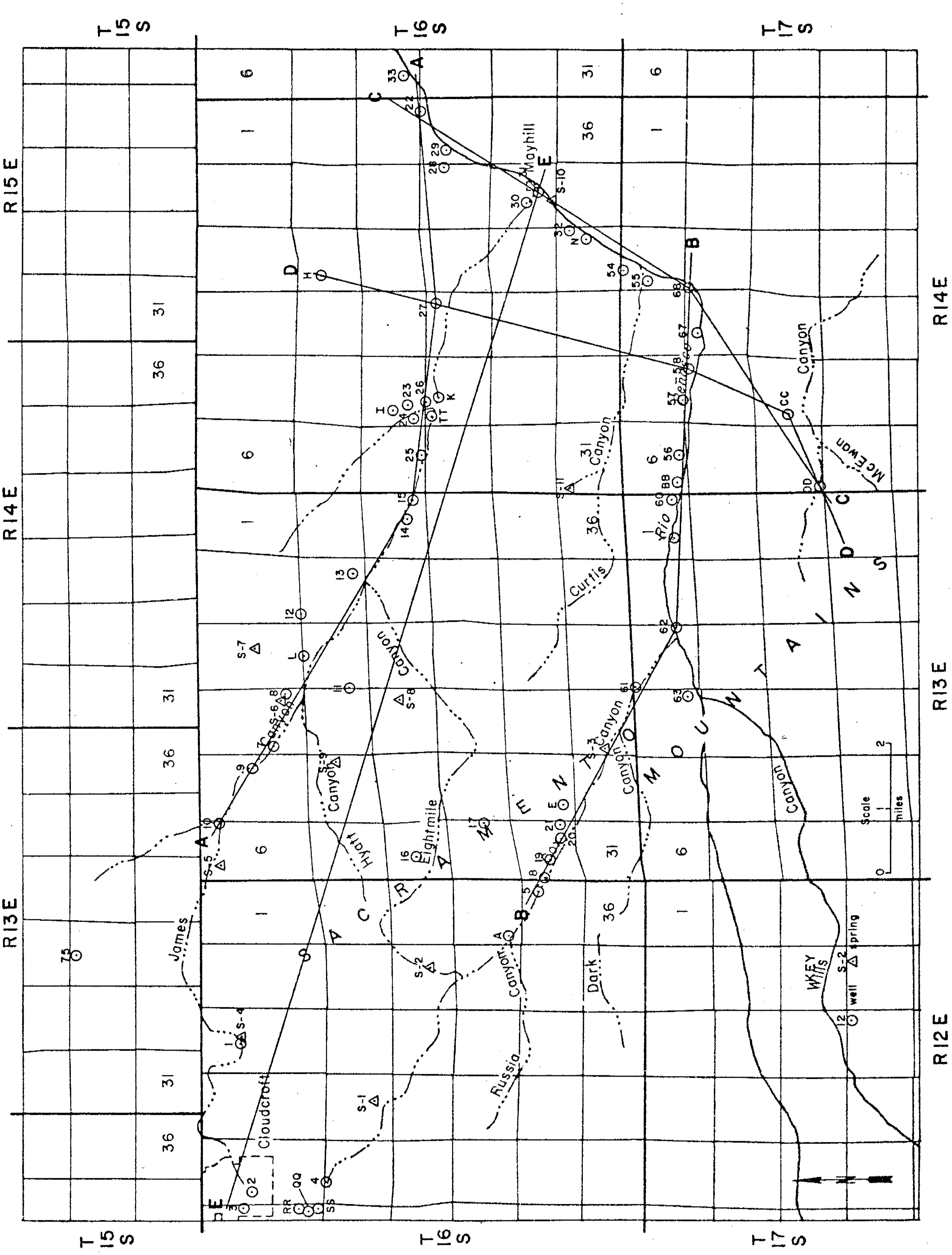


Figure 6. Map location of wells, springs, fence diagrams, and cross sections.

fault may be affecting the occurrence of springs in the Mayhill area. This evidence will be discussed in more detail later. Intensive geologic mapping of the area is needed to clarify and describe these structures in detail.

Geologic Formations and Their Water-Bearing Characteristics

Yeso Formation

The Yeso Formation (Nogal Formation of Fiedler and Nye, (1932)) is the oldest exposed Permian rock unit in the study area. It is assumed to rest either conformably on the Permian Abo sandstone or unconformably on the Precambrian. There are no drill holes deep enough in the study area to penetrate the lower Yeso beds, so whether or not the Abo was deposited on the ancient Pedernal high is a question yet unanswered. An oil test hole drilled in 1952 about two miles east of Elk (16.16.3.32) encountered Abo at a depth of 1650 feet and entered granite at 1770 feet (well log filed with the Oil Conservation Division, Santa Fe, N.M.). In this western area the Yeso is 1200 to 1800 feet thick (Pray, 1954), and composed mainly of interbedded red and yellow mudstone with subordinate shales, limestones and dolomites, with minor sandstones and gravels. Pray states that there is anhydrite in the Yeso of the Sacramento Mountains, but if present in this area, it either is deeper than any of the wells, or it has been removed by circulating groundwater. Although no mention of anhydrite is is made, driller's logs do occasionally note having drilled through cavities and crevices, which could have been caused by dissolution of gypsum.

There exists a thick, persistent limestone unit towards the top of the Yeso in this area (Fig. 10). It may be equivalent to Kelley's (1971, p. 7) medial dolomite member, observed elsewhere in the Sacramento Mountains. While grading southeastward into a high percentage of limestone near Artesia, the shalier Yeso of the study area is softer than the San Andres Formation and forms the broad valley bottoms. It has been commonly thought that these stream bottoms are the main areas of recharge to the Yeso in the western mountain region (Fiedler and Nye, 1932; Hantush, 1957).

Fence diagrams (Figs. 10-12) of the strata in this study region indicate that the Yeso is composed of varied lithologies that form laterally continuous layers. This lateral continuity implies that water may flow down the regional dipslope into the Roswell Basin. This conclusion is borne out by the few pumping tests available, all of which indicate a transmissivity averaging 3400 gallons per day per foot, a value near the low end of the range of T values for a fairly good aquifer. Water present in the Yeso is often under artesian pressure, even at high elevations near the extreme western edge of the basin, rising as much

	Groups, Formations, Members	Description
Holocene and Pleistocene	Alluvium	Present stream alluvium ≤100ft. Ponded sediments (charcoal, mollusks) 10-15 ft. Travertine terraces (charcoal, plant casts, mollusks). Older gravels, mainly composed of local limestones, >50ft above valley floors.
	San Andres Formation	
Permian Guadalupian to Leonardian	Undifferentiated	400-600 ft. Limited by the erosional land surface. Most of the San Andres in the study area probably corresponds to the lowest member, the Leonardian Rio Bonito Member, described as follows: predominantly dolomite and limestone; sandstone lenses (Glorieta) and a few shale lenses near base. Beds massive.
	Yeso Formation	
Leonardian		1200-1800(?) ft. Interbedded red, yellow, gray mudstone; some shale and fine-grained quartz sandstone. A persistent 'limestone' unit (50-400? ft. thick) near the top is possibly Kelley's (1971, p. 7) "prominent medial dolomite member".

Figure 7. Synopsis of geologic formations in the study area.

as 60 feet above the unit in which it was first encountered. The stratum which most often seems to bear water is a distinctive gravel-sand layer, although water is also present in limestones and shales. This is discussed in more detail below (see Well Logs). One of the 'old-time' water-well drillers of the area, Mr. Beatty, seems to have recognized the significance of the gravel layer for he stopped drilling as soon as he had passed through it (logs 14, 25, 27, 32, 33 in Appendix B). In some parts of the area, the water in the Yeso rose to a piezometric surface upon drilling, but in the western third of the study area, the water appears to be present under water-table conditions. Water lies between 0 and 500 feet below the canyon bottoms.

San Andres Formation

The lowest member of the San Andres Formation in the Roswell Basin is the Glorieta Sandstone, a fairly tight but clean quartz sand of Permian age. In the study area, the Glorieta seems to be mostly absent, appearing only as narrow sand lenses at the base of the massive limestone, and having minimal hydrologic significance. This is not true north of the study area. In the Hondo valley the Glorieta is the main aquifer and probably transmits significant amounts of water eastward into the overlying limestone (Rehfeldt and Gross, (1982).

In the study area, the Leonardian Rio Bonito member of the San Andres Formation (Kelly, 1971), conformably overlies the Yeso. It has much the same appearance in the western region as it does farther east in the basin area proper. It is a gray, massive limestone-dolomite complex that is sometimes fossiliferous, often cavernous, and interbedded with minor amounts of sandstone and shales. This limestone and overlying limestone units cap mountains and ridges to a maximum thickness of 500 feet, in contrast to the greater than 1000-foot thickness of limestone found in the eastern part of the State. These formations contain perched-water lenses that are tapped by a few wells.

Water enters the Yeso aquifer by direct seepage through valley alluvium and by downward percolation through the San Andres Formation. Hood (1960) states that the thick humus of the forest soils can absorb much water, which is then slowly transmitted down to the San Andres and the Yeso below it. He points out that the canyons and arroyos of the area flow only after very heavy rains.

San Andres/Yeso Contact Zone

The San Andres/Yeso contact zone and the strata 50 feet above and below deserve special mention because this is the zone from which many of the springs in the western region issue (Davis et al., 1980). Where this occurs, the San Andres is usually represented by a thick gray limestone,

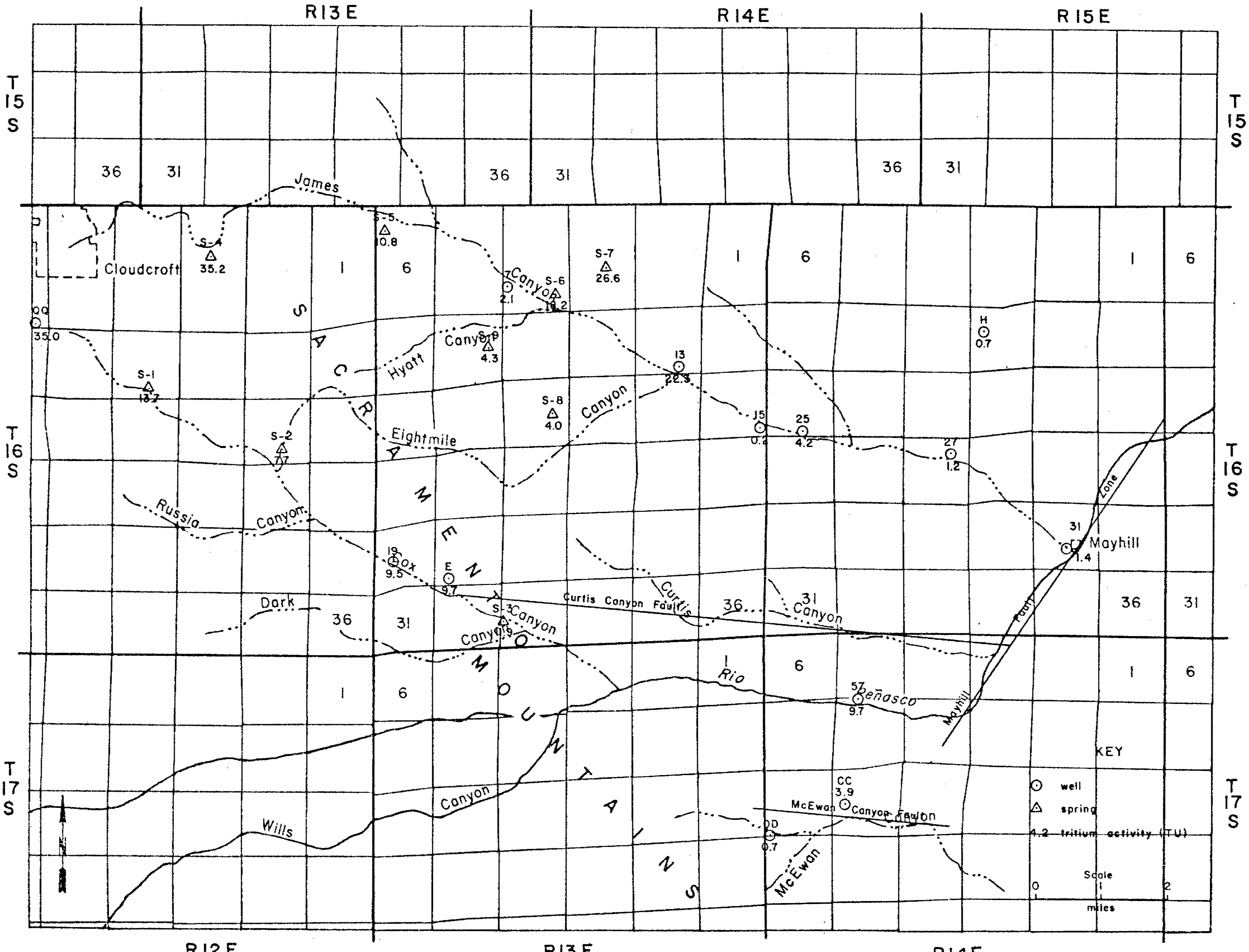
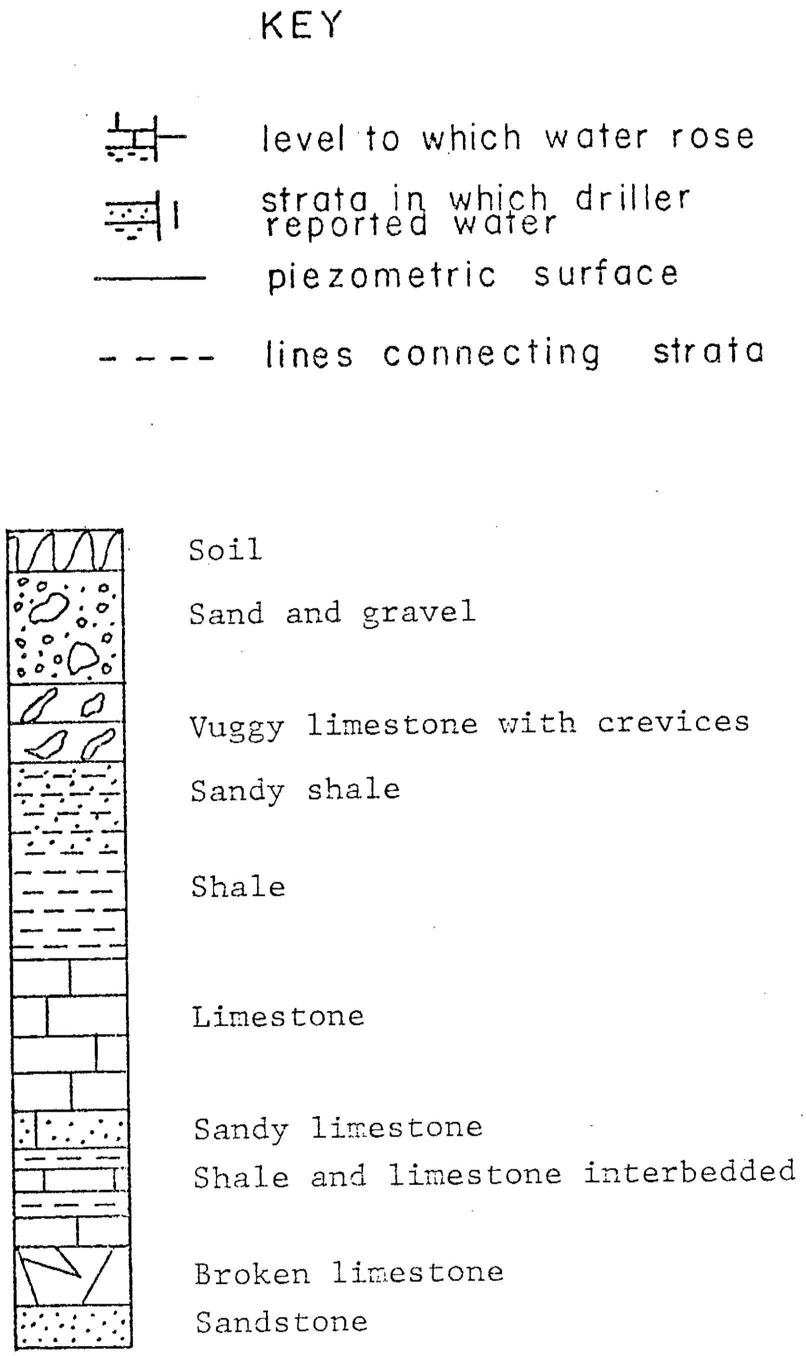
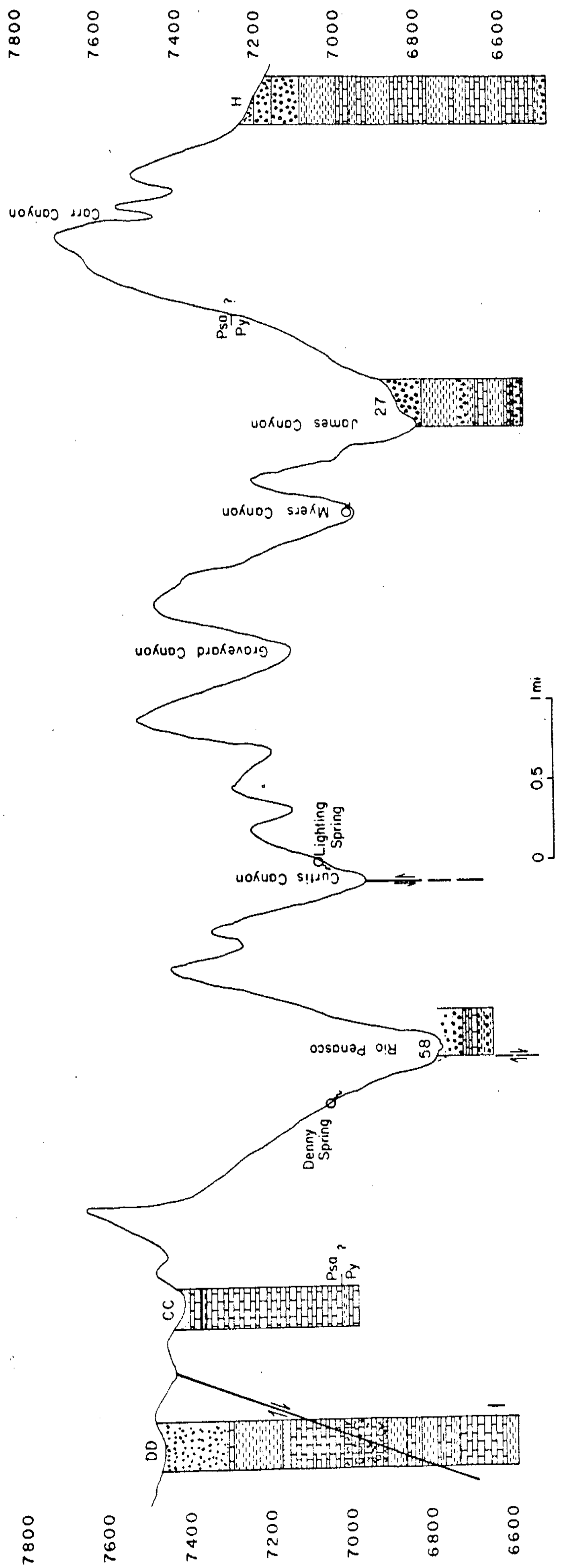


Figure 8. Map location of inferred faults and of tritium determinations.



Detailed logs in Appendix B

Figure 9. Fence diagram along line D-D' of Figure 6.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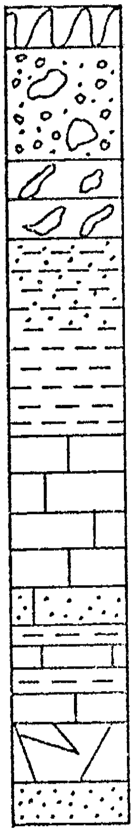
KEY

level to which water rose

strata in which driller reported water

piezometric surface

lines connecting strata



Soil

Sand and gravel

Vuggy limestone with crevices

Sandy shale

Shale

Limestone

Sandy limestone

Shale and limestone interbedded

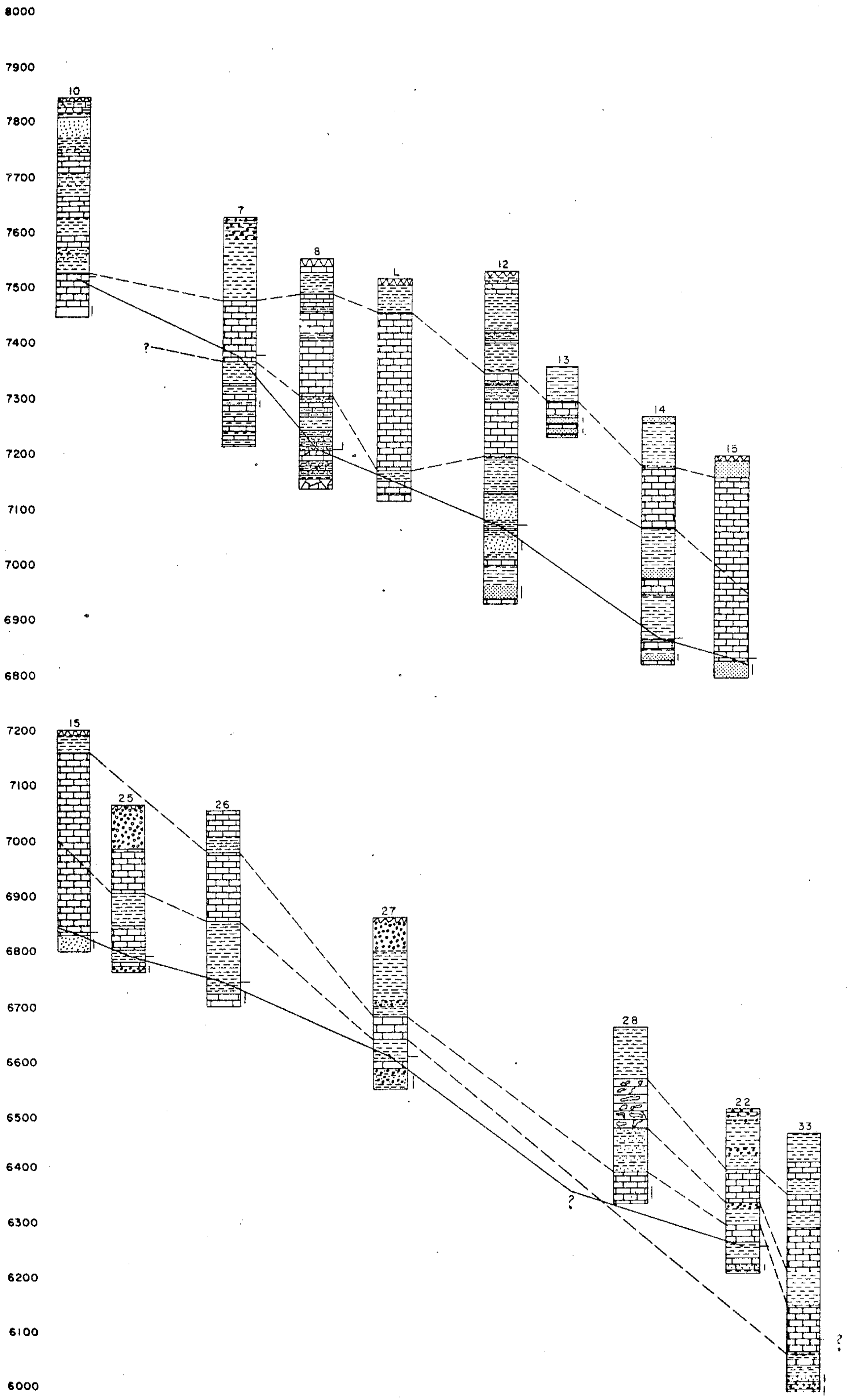
Broken limestone

Sandstone

Detailed logs in Appendix B

Figure 10. Fence diagram along line A-A' of Figure 6

NOTE: Line is broken at Well 15, and Well 15 is repeated for continuity.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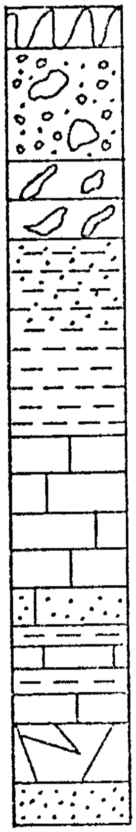
KEY

level to which water rose

strata in which driller reported water

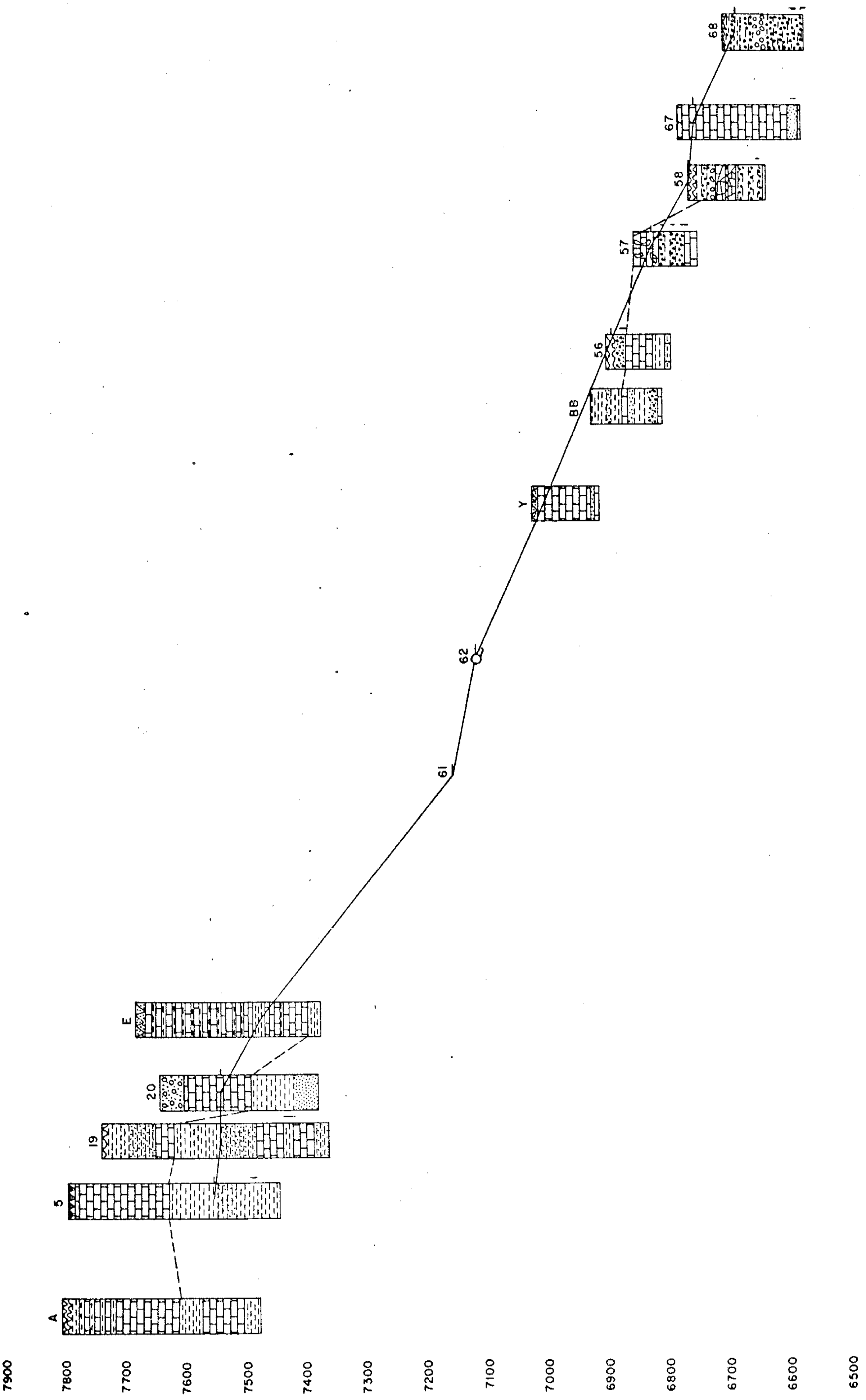
—— piezometric surface

- - - - lines connecting strata



Detailed logs in Appendix B

Figure 11. Fence diagram along line B-B' of Figure 6.



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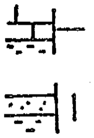
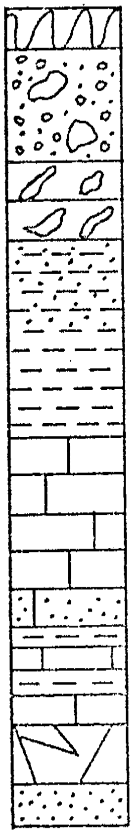


level to which water rose

strata in which driller reported water

——— piezometric surface

- - - - lines connecting strata



Soil

Sand and gravel

Vuggy limestone with crevices

Sandy shale

Shale

Limestone

Sandy limestone

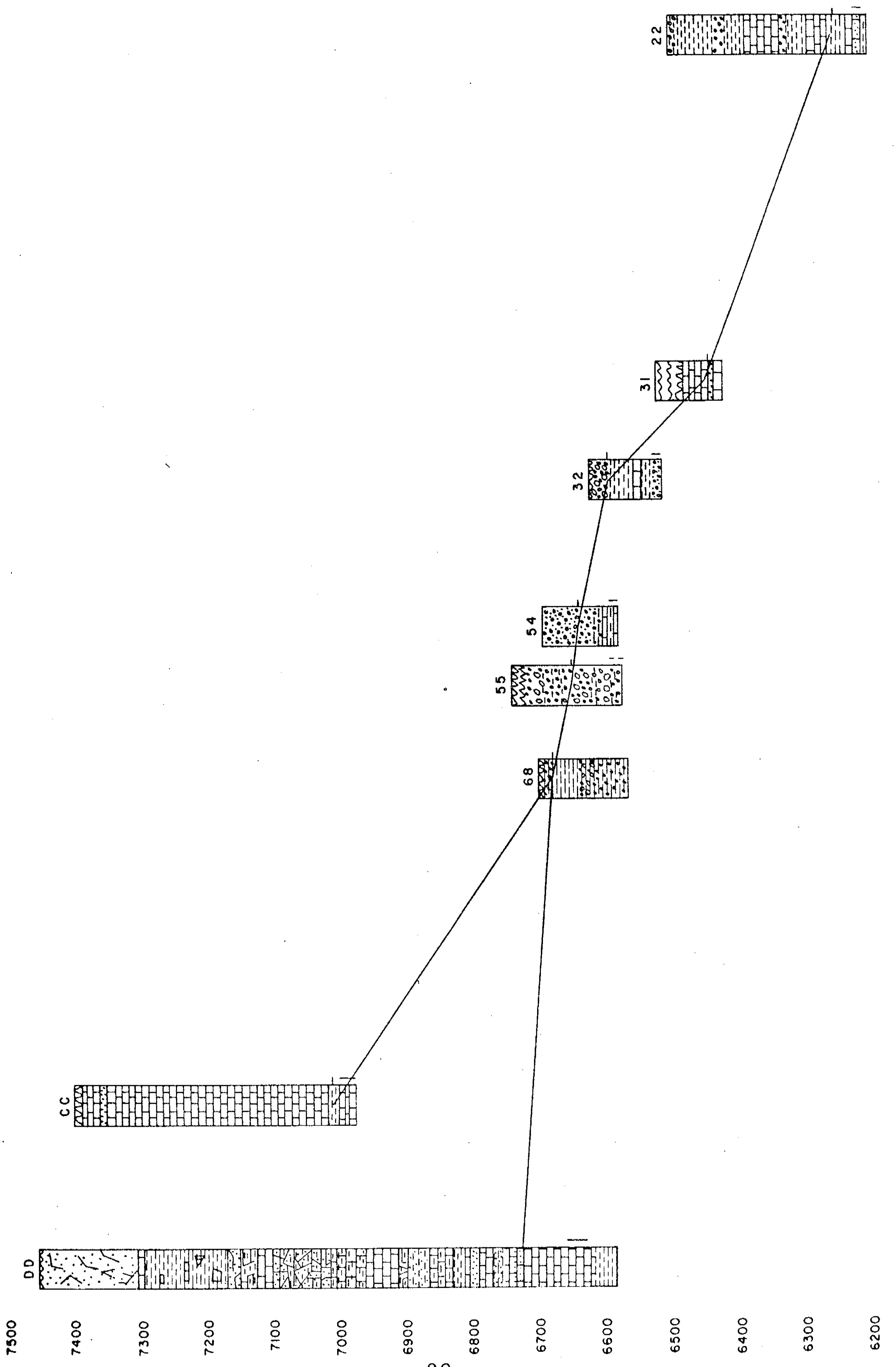
Shale and limestone interbedded

Broken limestone

Sandstone

Detailed logs in Appendix B

Figure 12. Cross section and fence diagram along line C-C' of Figure 6.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while the Yeso at the contact zone is often, but not always, a red mudstone or shale. Most probably the explanation for the issuance of springs from this zone is in part the commonly accepted one: precipitation falls on the limestone, infiltrates down through cracks, joints, and vugs until it hits the relatively impermeable Yeso mudstone, whereupon the water accumulates and flows laterally downdip to a point of emergence. However, tritium data indicate that the young meteoric water either mixes with much older water as it moves downdip, or it moves very slowly. The reader is referred to the section on Tritium for further details.

However, not all the springs of the area issue from the contact zone. The intersection of the regional Yeso piezometric surface with the land surface causes the issuance of large springs in Cox Canyon, and the existence of a considerable body of water present under water-table conditions in the western region of the study area causes springs to emerge in canyons which cut below its level.

Quaternary

Deposits of limestone gravel up to 100 feet thick are present in the study area, especially in the eastern half of Cox Canyon and along the Rio Peñasco past Mayhill. This gravel was clean and thick enough to be mined as road material from a pit located on a bench on the north side of Cox Canyon where the highway turns north to Mayhill. State Highway records rate the gravel as "excellent". In other areas the gravels are not always this thick and often contain more fines and a great deal of caliche. By its angularity and similarity to San Andres carbonates, the gravel appears to be locally derived. Remnants of what was undoubtedly an extensive deposit are exposed in roadcuts along incised drainages, such as Cox, Curtis, and the main Peñasco canyon in the vicinity of Mayhill. These are probably the remnants of Quaternary stream alluvium. Their presence implies alternating periods of canyon cutting and backfilling. There are no wells finished in these gravels because they lie above the regional water surface and contain only small amounts of perched water.

CHEMISTRY

Procedures

Chemical analyses of spring and well water samples were performed as soon as possible after return from the field. Conductivity measurements were taken in the field, but due to a malfunction of the pH meter, most of the pH readings were taken in the laboratory. The data (Tables IV and V) represent one analysis per well or spring, except in cases where that well or spring had been previously sampled by other investigators.

Table IV. Well Chemical Data

Well	Location	Sample	pH	Conduc-	TDS	HCO3		Cl		SO4		Na		K		Mg		Ca		Cat./An.
#		date		tivity		ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	% error
QQ	16.12.6.4344	9/30/80	7.9	615	386	378	6.2	9.8	.27	46	.96	6.3	.27	.48	.012	7.2	.59	127	6.34	2.95
7	16.13.4.3123	10/01/80	7.7	470	467	332	5.4	14	.39	130	2.71	16	.70	.83	.02	26.0	2.14	114	5.69	.01
13	16.13.11.4324	10/01/80	7.4	1150	764	395	6.48	81.0	2.29	233	4.85	57	2.48	.91	.02	55.0	4.52	140	7.0	2.9
15	16.13.13.4441	10/01/80	8.1	?	478	342	5.60	15.8	.45	133	2.77	12	.52	.70	.02	26.0	2.14	119	5.94	2.29
19	16.13.30.3211	9/30/80	7.3	645	451	276	4.52	9.8	.28	156	3.25	9	.39	.56	.014	22.0	1.81	116	5.79	.50
E	16.13.29.3342	9/30/80	7.8	700	454	322	5.28	11.8	.33	131	2.73	9.6	.42	.70	.02	22.0	1.81	118	5.89	2.43
H	16.14.3.1431	10/02/80	8.3	1000	873	298	4.88	25.6	.72	446	9.29	20.0	.87	1.10	.03	58.0	4.77	172	8.58	4.39
25	16.14.18.4333	10/01/80	8.0	650	520	317	5.20	16.0	.44	179	3.73	14.0	.61	.74	.02	29.0	2.39	123	6.14	1.14
27	16.14.21.2133	10/01/80	7.7	650	557	349	5.72	16.0	.45	186	3.87	14.0	.61	.83	.02	28.0	2.30	137	6.84	.30
31	16.14.26.4134	10/02/80	8.0	540	526	344	5.64	19.7	.56	160	3.33	16.0	.70	.79	.02	30.0	2.43	127	6.34	.42
63	17.13.4.4442	9/30/80	7.9	540	426	276	4.52	7.9	.22	143	2.98	7.3	.32	.83	.02	19.5	1.60	109	5.44	4.50
57	17.14.8.1211	9/30/80	7.5	900	726	354	5.80	35.5	1.00	268	5.58	23.0	1.00	1.10	.03	36.0	2.92	185	9.23	6.26
CC	17.14.17.3122	9/30/80	7.8	435	589	425	7.00	7.9	.22	15	.31	5.4	.24	.61	.02	12.0	.99	123	6.14	1.57
DD	17.14.18.3444	9/30/80	8.5	360	468	315	5.16	14.0	.39	125	2.60	11.0	.48	.91	.02	27.0	2.22	133	6.64	1.60
Deep Yeso Well Average : (omit H, QQ, CC)			7.9	569	483	338	5.23	13.9	.28	149	3.11	12.1	.53	.77	.02	25.5	2.10	122	6.10	1.47
Shallow Yeso Well Average: (13,15)			7.5	1025	745	374	6.13	24.8	1.65	199	5.22	19.5	1.74	1.00	.03	45.5	3.72	163	8.12	4.58

H is a deep Yeso well outside the study area

QQ is at the Psa/Py contact

CC probably taps San Andres

Table V. Spring Chemical Data

Spring	Location	Sample	pH	Conduc-	TDS	HCO3		Cl		SO4		Na		K		Mg		Ca		Cat./An.
#		date		tivity	ppm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	% error
S-5	16.12.1.242	10/01/80	7.8	410	399	307	5.04	14.0	.39	98	2.04	10.0	.44	.43	.01	15.0	1.23	108	5.39	5.50
S-4	16.12.3.144	/78	8.0	621	375	312	5.12	10.4	.29	63	1.32	10.0	.44	.48	.01	48.1	3.94	38	1.90	6.54
S-1	16.12.9.431	9/30/80	8.0	495	414	222	3.64	20.0	.56	150	3.12	20.0	.87	1.60	.04	16.5	1.36	95	4.74	4.30
S-7	16.13.3.411	10/01/80	7.3	610	431	349	5.72	15.8	.45	88	1.83	13.0	.57	.53	.01	16.0	1.32	123	6.14	.50
S-6	16.13.4.442	10/01/80	8.0	680	538	268	4.4	23.6	.67	210	4.34	25.0	1.09	.88	.02	27.5	2.26	117	5.84	2.47
S-9	16.13.8.421	10/02/80	8.0	415	391	230	3.76	7.9	.22	137	2.84	8.9	.39	.61	.02	14.0	1.20	108	5.39	2.47
S-8	16.13.16.243	10/01/80	7.9	415	511	329	5.40	7.9	.22	50	1.04	7.8	.34	.56	.01	17.0	1.40	99	4.94	.4
S-3	16.13.33.313	9/30/80	7.5	390	337	283	4.64	5.9	.17	74	1.54	9.0	.39	.65	.02	15.0	1.23	91	4.54	2.67
S-10	16.14.26.343	6/03/77	7.8	570	501	157	2.60	30.0	.85	242	5.03	27.0	1.17	3.50	.09	36.5	3.00	84	4.19	.3
S-11	16.14.31.113	6/03/77	7.7	420	285	190	3.12	13.0	.37	83	1.73	10.5	.46	.50	.01	14.3	1.18	69	3.42	2.90
Averages:			7.8	507	418	265	4.40	14.9	.46	120	2.53	14.1	.61	1.00	.02	22.0	1.53	93	5.25	2.80

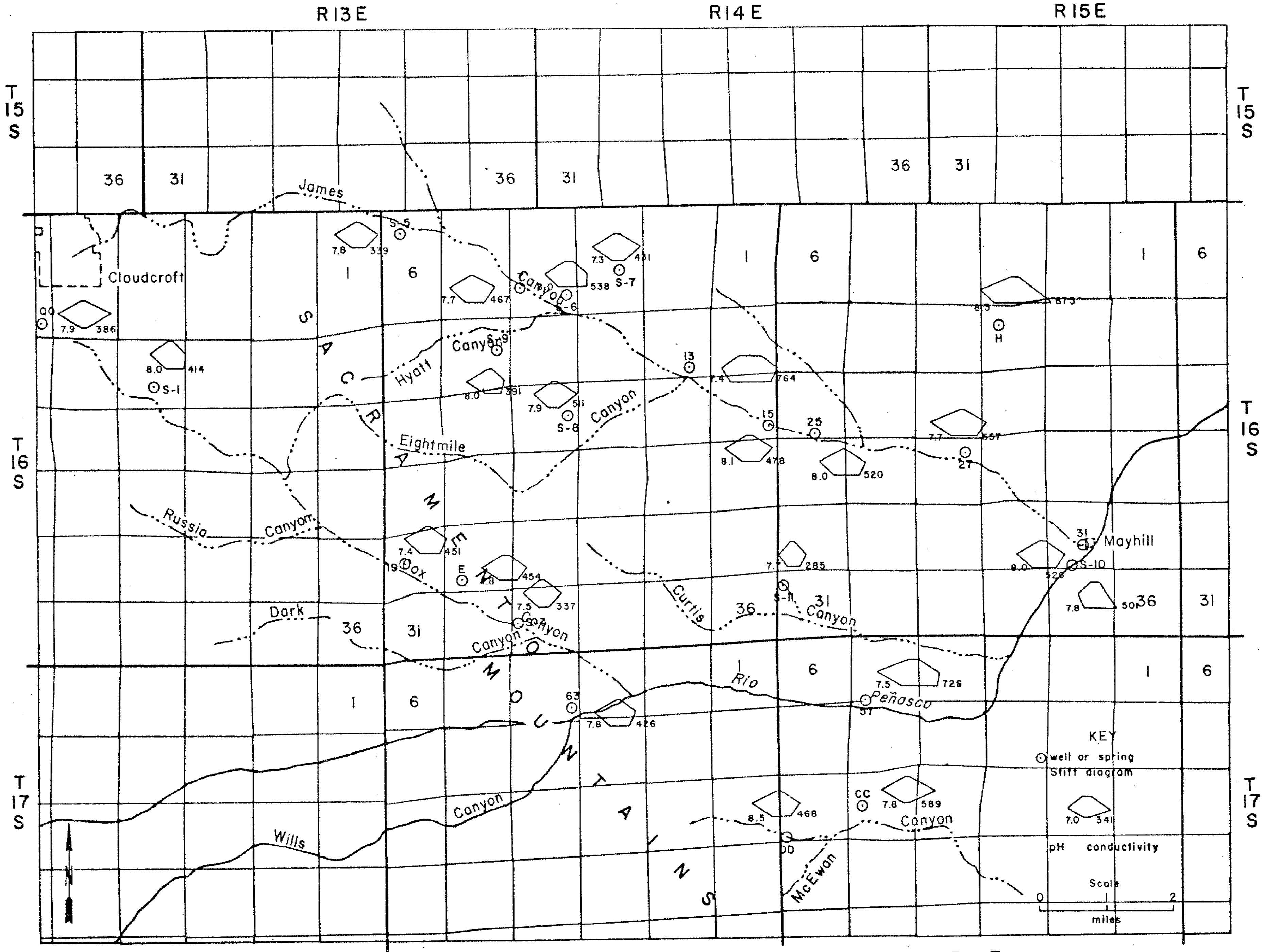

Figure 13. Water quality of wells and springs represented as Stiff diagrams. The numbers flanking each diagram are pH (left) and conductivity in micromhos/cm (right).

On Fig. 13 the chemical data have been plotted as Stiff diagrams (Stiff, 1951; Davis and DeWiest, 1966, p. 79, 82) at the location of each sample. Stiff diagrams provide a quick visual comparison between samples. Figure 14 shows a typical analysis presented by this method.

Figures 15, 16, and 17 are presentations of the data on Piper trilinear diagrams (Piper, 1944).

General Chemistry and Interpretation

Deep Wells in the Yeso Formation

As can be seen from Table IV and Figures 15 and 17, wells finished in the Yeso Formation yield a calcium-magnesium bicarbonate water of generally good quality, meeting all health standards. The chemical analyses of the various samples are quite similar. This is in contrast to the Yeso-finished wells near Artesia, 70 miles to the east, where the water often has very high TDS, especially sulfates, and the results from nearby wells can be quite variable (Hantush, 1957). In the Cloudcroft-Mayhill area, the water averages only 507 ppm dissolved solids; bicarbonate averages 338 ppm; chloride, 14 ppm; sulfates, 149 ppm; sodium, 12 ppm; potassium, 1 ppm; magnesium, 26 ppm; calcium, 122 ppm. The average pH is 7.9, and the average conductivity is 569 micromhos/cm.

The chemical characteristics of these samples appear to be similar to those discribed by Hall (1964) for the Hondo drainage basin adjacent to the north of the present study area. TDS, notably sulfate, seem to be lower in our samples; however, Hall's work extends to R18E, which is much farther downstream. This could easily account for an increase in average TDS values.

The relatively low sulfate content supports the contention, derived from examining the driller's logs of wells for the area, that there is far less gypsum present in the Yeso Formation of this area than anywhere else in the Roswell Basin. This may be attributed to the fact that at the time of Yeso deposition in this area, the Pedernal high still had expression, causing the Yeso to be laid down here predominantly as fluvial sands and gravels and deltaic muds, rather than as lagoonal sediments as was the case farther east.

The upper part of the Yeso in this area contains a persistent thickness of what the drillers term "limestone", "limerock", and "lime". It is likely that much of this limestone is actually dolomite, produced by chemical alteration from limestone (see section on Geologic Formations). The presence of dolomite would explain the relatively high magnesium content of the waters. The high calcium and bicarbonate contents are also explained by the

cations

Na + K = 0.5 epm
Ca = 1.0
Mg = 1.05
2.55

anions

Cl = 0.7 epm
HCO_3 = 1.4
SO_4 = 0.45
2.55

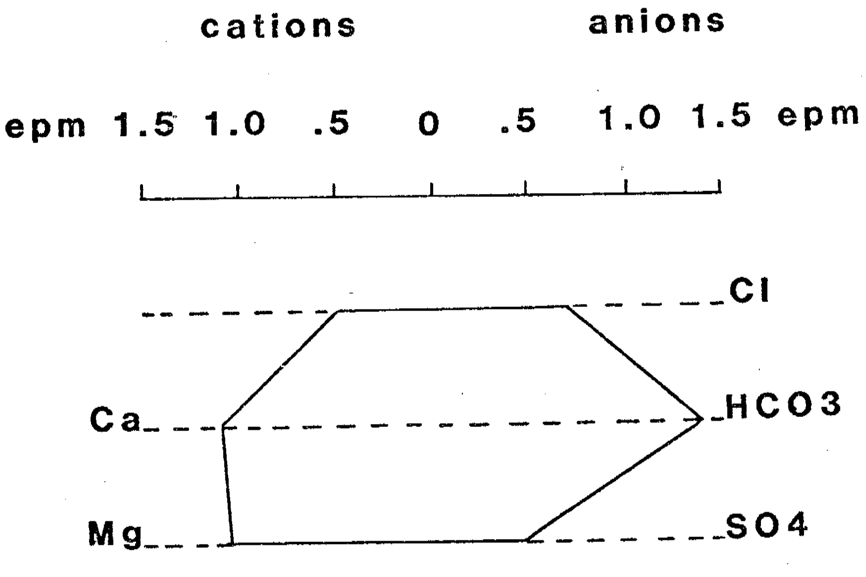

Figure 14. Typical Stiff diagram.

presence of limestone and/or dolomite in the strata, although part of the carbon dioxide probably comes from the soil root-zone. Cl, Na, and K are probably derived from minor amounts of evaporites present at depth and from the shales and muds themselves.

Shallow Yeso Wells

Wells 13 and 57 are shallow wells finished in Yeso. Well 57, located in Cox Canyon, taps the regional artesian water 30 feet below the land surface, while Well 13 (in James Canyon) is finished high above the regional system and presumably taps a body of unconfined perched water. Water taken from these wells exhibits slight but significant differences when compared to deeper Yeso wells. Interestingly, these differences are the opposite of what one might expect. First, the TDS content is much higher, reaching 764 ppm for well 13 and 726 ppm for Well 57. This is quite odd, since, in theory, the wells should contain at least some water from precipitation and hold it in storage a shorter time than the deep wells. Next, the bicarbonate and calcium contents are higher . This could be due to the infiltration of precipitation which has run over the prominent limestone outcrops of the area, dissolving the calcium carbonate, and picking up bicarbonate from the soil root-zone. However, the Cl, SO4, Na, and Mg contents all are also significantly higher. Of these, only magnesium can be derived from the limestone.

Springs

Chemical analyses of springs in the Cloudcroft-Mayhill area yielded the following average solute contents: bicarbonate, 265 ppm; chloride, 15 ppm; sulfate, 120 ppm; sodium, 14 ppm; potassium, 1 ppm; magnesium, 22 ppm; and calcium, 93 ppm. pH averaged 7.8 and conductivity averaged 507 micromhos/cm (Table V and Fig. 16). The variability in TDS is considerably greater than for the deep Yeso wells. The average TDS is 418 ppm, about 90 ppm lower than the deep well water. Much of this difference comes from lower bicarbonate, calcium, magnesium, and sulfate contents in the springs. Sodium and potassium remain much the same as for the well water, and chloride is just slightly less. The similarity between the two groups (springs and wells) is seen in Figure 17. The closeness of the plots is striking; it suggests a common source, with the spring water slightly diluted by precipitation. It is interesting to note that thick, but still actively depositing, tufa is present around many of the springs, indicating that the spring water is not only supersaturated with respect to $CaCO_3$ now, but has been for a long period of time.

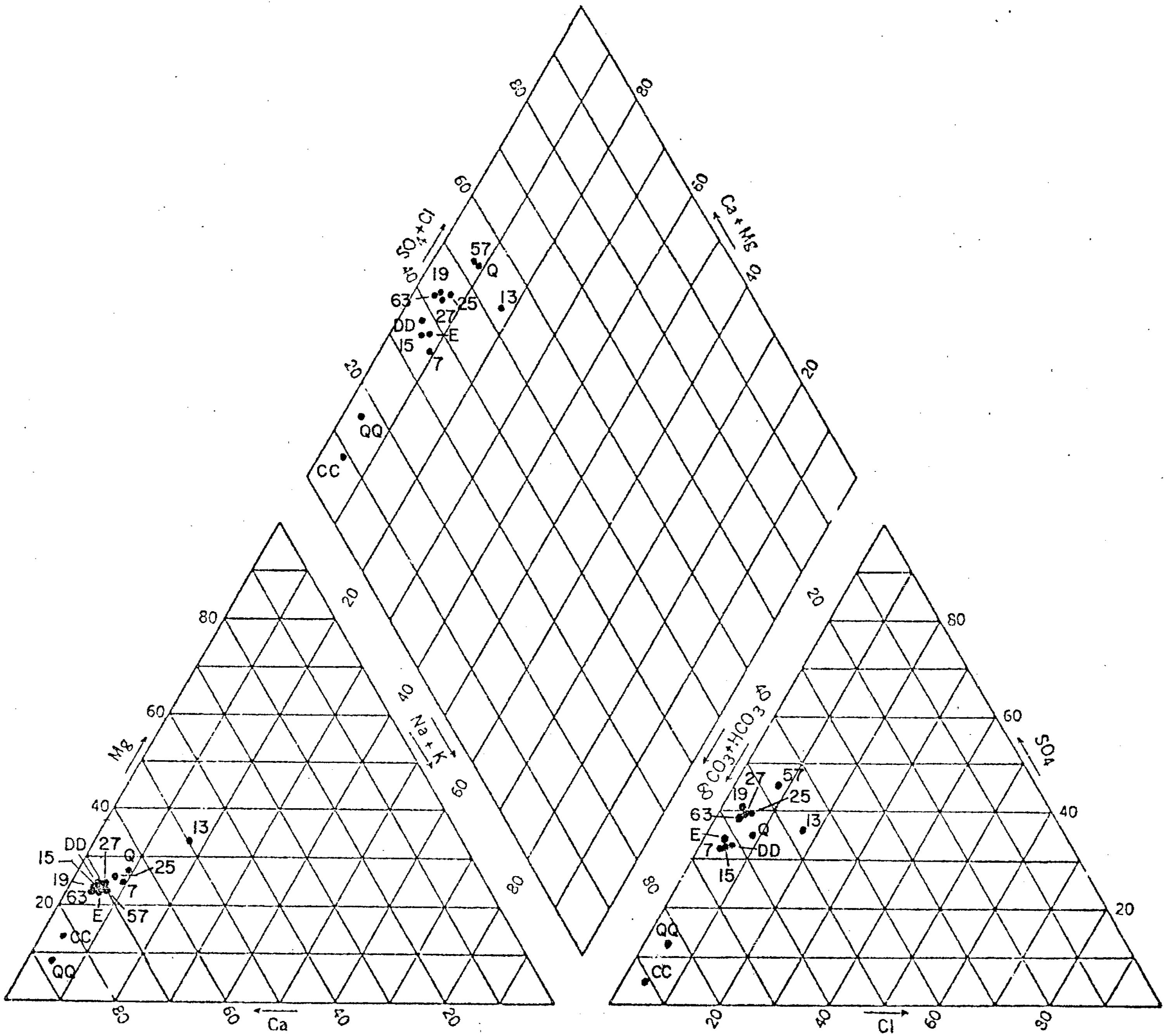

Figure 15. Piper diagram of well water chemistry in the study area.

TRITIUM

Procedures

Rabinowitz and Gross (1972) discuss the laboratory procedures followed in analyzing the tritium activity of a water sample. The same procedures were followed in analyzing the samples for this report. Application to the Roswell Basin is further discussed by Gross et al. (1976).

Theory

A detailed discussion of radioactive hydrogen production and its application as a groundwater tracer is presented in above reports. In brief, it should be emphasized that the tritium detected in these water samples was environmental tritium, and not a tracer deliberately injected into the streams or aquifers. Since 1953, atmospheric nuclear tests have introduced tritium into the atmosphere and thus into the precipitation. The tritium activity reached its maximum in 1963, peaking at about 10,000 TU (tritium units), and declining thereafter due to the Test Ban Treaty (Gross, et al., 1976).

The idea behind using environmental tritium as a tracer is based on the fact that tritium is radioactive and decays with a half-life of 12.4 years. If the tritium activity in the precipitation is known, then the 'age' of the water in a closed groundwater system can be calculated. Mixing of 'young' water, high in tritium, with 'old' water, low in tritium, will have the same effect as a long residence time for water without mixing. The two effects may occur together. When long-term records are available for both tritium activity in the precipitation of a given area, and for the groundwater occurring in specific wells and/or springs, it is possible to perform stochastic analysis on the data as did Gross et al (1979) for Paul Spring, which is located on the Rio Peñasco a few miles east of Elk (Fig. 1) 12-15 miles outside of the study area. This procedure may determine if there is a correlation between the ground water and precipitation, and may yield a time lag for recharge of the precipitation to the groundwater reservoir. It should be noted that Gross, et al. had difficulties with this analysis which could only be resolved by assuming mixing of new recharge with water in storage, rather than a single input (precipitation) system.

Results and Interpretation

As long-term records of tritium activity are not available for the wells and springs of the study area, average tritium activity in the precipitation of the area was obtained from records of the NMIMT Tritium Laboratory. This value was determined to be about 35 TU. Tritium

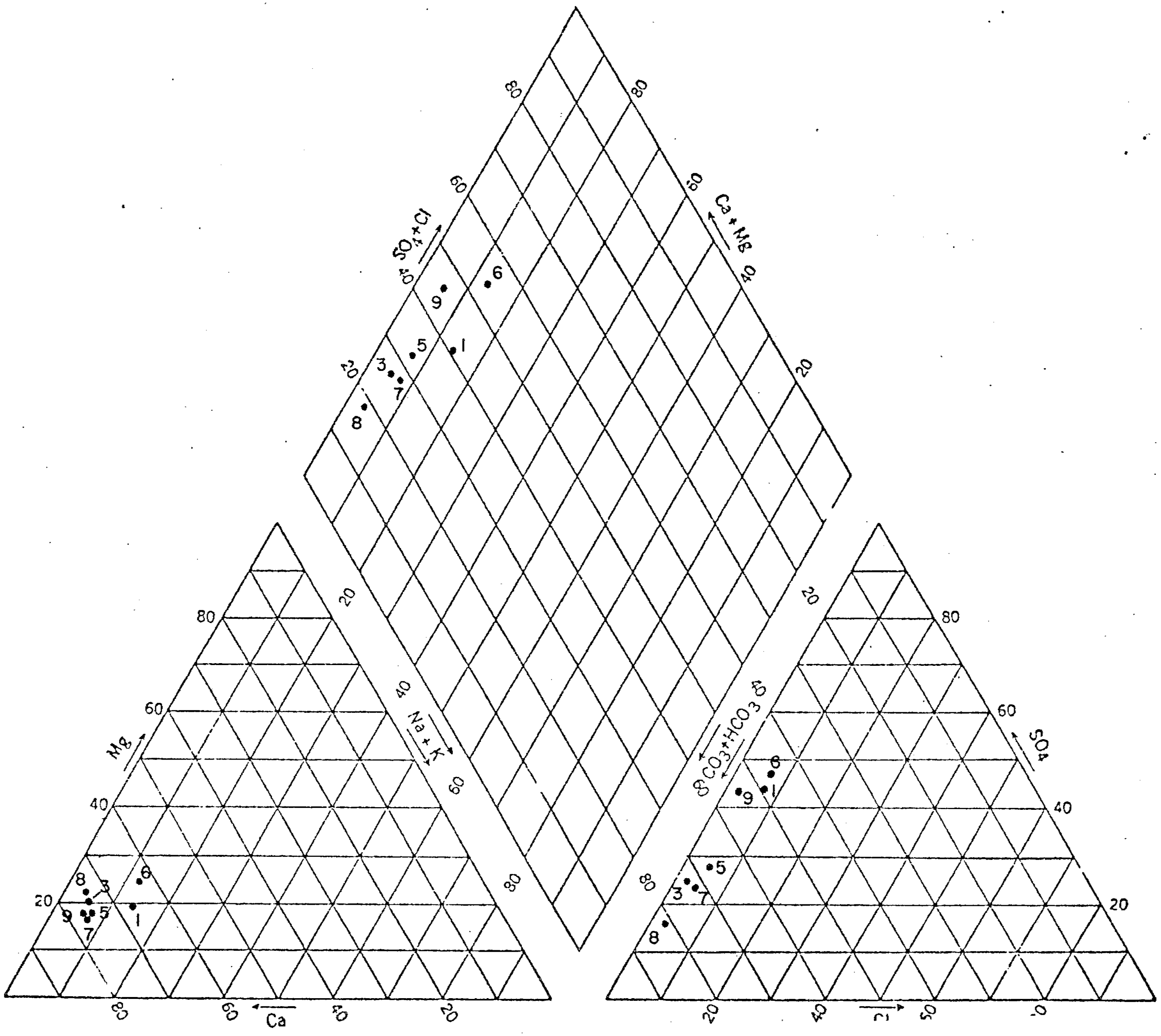

Figure 16. Piper diagram of spring water chemistry in the study area.

activity in water samples taken from wells and springs in the study area was measured. There are neither enough samples nor sufficient control depths to justify an attempt to devise a mathematical groundwater model that could account for variations in tritium activity with distance from the presumed source or due to dilution by mixing with older waters. Many more water samples taken from the same laterally continuous aquifer would be necessary to make such a model statistically significant. Vertical variations in tritium activity may be especially significant due to vertical mixing and vertical variations in hydraulic conductivity. Large vertical variations in hydraulic conductivity are strongly indicated by the well logs (Appendix B) and the fence diagrams (Figs. 9-12).

Still, significant information can be obtained from the tritium activity data. When values for tritium activity are plotted on a map at the location of the well or spring sampled (Fig. 8), an interesting pattern is evident. With few exceptions, very "young" water is only found at the highest elevations, west of the R12/R13 line. Water from Well QQ and Spring S-4 measured 35.0 and 35.2 TU respectively. These values are quite close to that for precipitation in the area. Three miles southeast of Pumphouse Canyon, along the southern side of the ridge dividing Cox and James Canyons, Well 19 exhibits a moderate tritium activity of 9.5 TU, and a mile farther east from 19, Well E has a similar tritium activity of 9.7 TU. A mile east of Well E, Spring S-3 also shows a moderate tritium activity, 11.9 TU. Interestingly, the wells and springs of James Cayon to the north, with the exception of Spring 6 and Well 13, all have low tritium activities, values ranging from .2 to 4.3 TU. There are not enough data available for the Cox Canyon wells to pinpoint where the tritium activity drops along that canyon.

The distribution of high-tritium water appears to coincide with the areas of 'semi-perched' water discussed in the section on 'Groundwater'. The indications are, therefore, that this accumulation of water is from precipitation and has a fairly rapid turnover. If this were not the case, the water would have much lower values of tritium activity. The tritium activity data indicate that little recharge to the regional groundwater system occurs east of the R12/R13 line in the northern part of the study area. In the southern part of the study area, regional groundwater recharge probably ceases by the R13/R14 line. Direct recharge to the groundwater system by percolation and seepage through the forest soils and fractured limestones thus seems to be limited to a band about six miles wide along the crest of the Sacramento Mountains, and to a narrow zone extending perhaps an additional six miles farther east along Cox Canyon. Note that due to topography the hydraulic head is more than 100 feet deeper beneath the floor of James

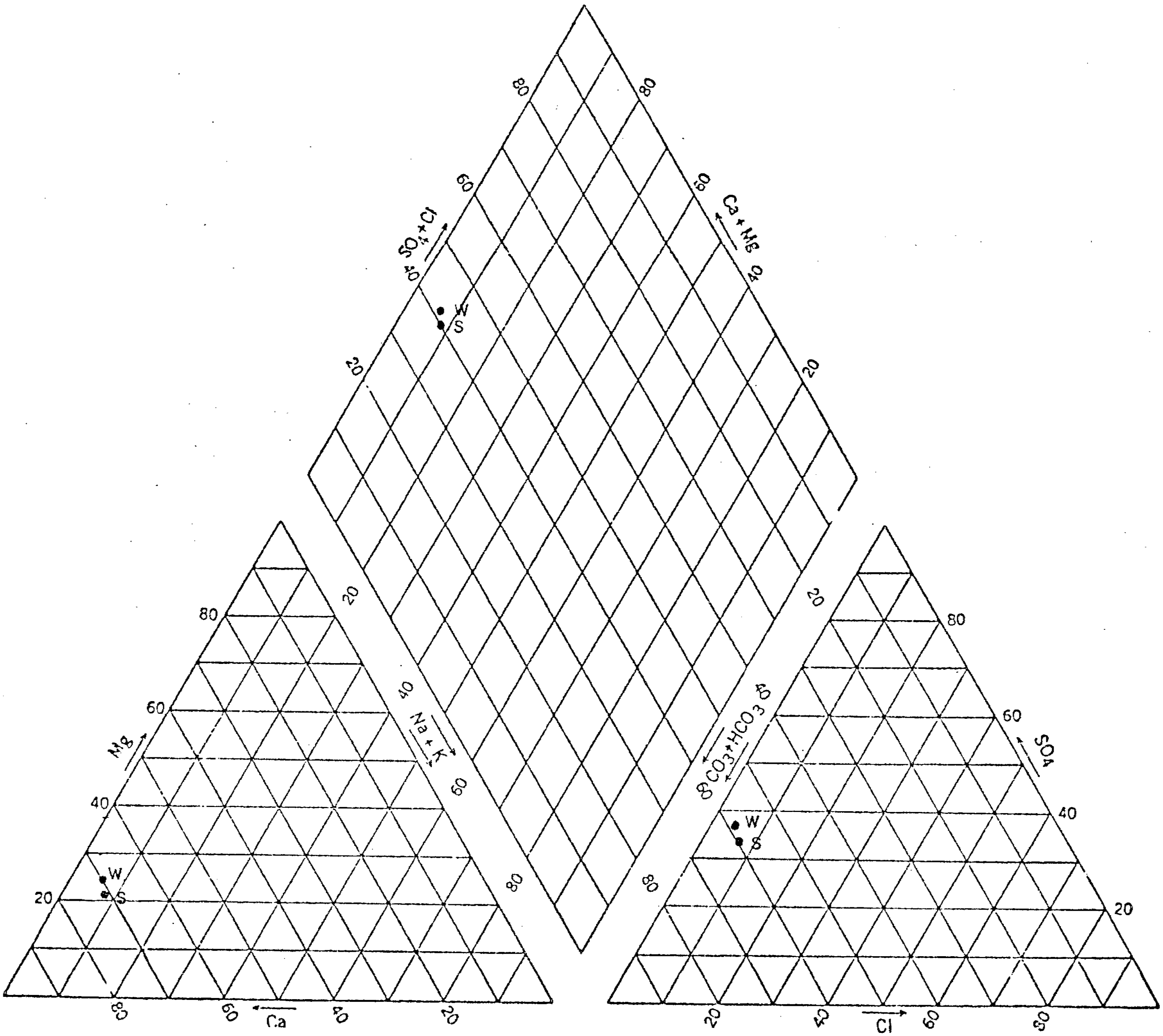

Figure 17. Piper diagram of average well and spring water chemistry.

Canyon than it is beneath Cox Canyon.

WELL LOGS

General

Well data are presented in Appendixes A (tabulation) and B (logs). They refer to wells that could be located in the field. Only 39 driller's logs were available for the study area. They were used to reconstruct the well logs shown in Appendix B.

Almost without exception, the driller's logs lack detail and proper geologic terminology. The drillers are familiar with (1) limestone, called lime, limerock, or limestone; (2) shale or mudstone, called clay or shale; and (3) sandstone, called sandstone or sand. Often these are described in the briefest possible language, for example, "gray lime", "red sand". With some exceptions, they tend to record lithologic changes at intervals that are multiples of 5 feet. In general, the logs give a rough outline of the underlying strata. They also reflect regional dip, show the presence of unusual and marker beds, indicate possible faulting, and enable a gross comparison between vertical and horizontal hydraulic conductivities to be made.

Discussion and Interpretation

When studied in conjunction with the water-level data, the well logs, reproduced in fence diagrams of Figs. 9-12, lead to the following conclusions:

(1) The Yeso Formation is the aquifer of the area. Even on the crest of the mountains near Cloudcroft, the San Andres Formation acts only as a localized perched aquifer. Well 4, the highest well in the area with both water-level data and a log, obtains its water just below the San Andres/Yeso contact zone. Water may occur in the San Andres limestone in Well CC, which was drilled in a down-dropped fault block. Well 7 may also be in San Andres limestone if the strata are down-faulted.

(2) The Yeso Formation is variable vertically but fairly continuous laterally. White, gray, brown, blue, and black limestones and/or dolomite, red, yellow, and blue shales, mudstones, and "clays", red and brown sands and gravels, are interbedded throughout the Yeso section, giving the formation a "layer cake" appearance. However, each layer appears to have been laid down continuously over a wide area. This lateral continuity implies that the hydraulic conductivity, or ability of the formation to transmit water, is probably much greater in a lateral direction than in a vertical one. In addition, the fact

that the beds are continuous laterally implies that if water is present and the permeability of the formation is adequate, water may be transmitted down- gradient to the east.

(3) There is a "marker" bed of thick limestone or dolomite towards the top of the Yeso formation. Kelley (1971, p. 7) mentions the presence of this unit (his "prominent medial dolomite member"), marked by dashed lines on Fig. 10. The bed thins to the east.

(4) There is a regional stratigraphic dip to the east of 130 to 150 feet per mile.

(5) Within the Yeso Formation, especially beneath the prominent carbonate bed, occur layers of gravel and sand, from 2 to 15 feet thick. They can be traced laterally and their occurrence can be predicted. They act as primary aquifer units in the area; water occurs in them in 50% of the wells. Water is present in limestone or dolomite in 25% of the wells, in shale in 12%, and in alluvium in 12%. The sand and gravel layers are not tongues of the Glorieta sandstone.

(6) Well logs DD and CC (Fig. 12) indicate that faulting may have occurred between the two wells (Fig. 9).

(7) Well DD indicates that there may be a deep water system 350 feet below the main piezometric surface. According to Fig. 18, at the location of DD, the water surface should be at about 7070 feet above sea level in elevation, rather than at 6657-6720 feet as deduced from the driller's log (Fig. 12). It is unknown whether or not the driller hit water at 7070 feet as well. If this deep system exists, the source of its recharge and the area of its discharge are important questions.

HYDROLOGY

Procedures

This investigation began with the collection of all available hydrologic and geologic records and reports for the Roswell Basin, especially for the upper Rio Peñasco drainage. These included all available driller's well logs and well schedules for the James and Cox Canyon area, and an irrigated-acreage map. Wells and springs were then selected for sampling. Wells were selected by the following criteria: (1) the existence of well logs, insuring that the water-bearing strata would be known; (2) an attempt was made to sample wells for which water levels had been taken by the State Engineer in 1974 and/or 1979; (3) wells currently in use were given priority; and (4) the area was sampled as thoroughly and evenly as possible. As expected, however, a number of the wells were no longer in use or had been shut down for the winter.

An attempt was made to select springs which either (1) issued at the San Andres/Yeso contact, or (2) had unusually large flow rates. Accessibility was also a consideration; there are at least 80-100 springs in the study area, and much rugged country.

A week was spent in the field in October of 1980 gathering water samples for chemical and tritium analyses, looking at the surface geology and geomorphology of the area, and talking with the local residents. Unpublished information was obtained from various consultants who had worked in the area. The result is a fairly extensive compilation of available hydrogeologic data and a first hydrogeologic evaluation of this complex area.

Surface Water

Although Cox and James canyons run in broad valleys and are capable of carrying large amounts of water, neither of them flows perennially in its upper reaches. The 1952 USGS Cloudcroft 15 minute quadrangle indicates that water did flow in Cox Canyon between miles 3.5 and 5.5 from Cloudcroft, but on the 7 1/2 minute sheets, printed in 1972 , that length of the stream is drawn as intermittent. The piezometric surface is probably not far below stream level , and sufficiently wet years could presumably recharge the alluvium enough to cause the stream to flow there again. Cox Canyon has perennial flow only below the point where the upper Rio Peñasco enters it from Wills Canyon. Also below this point in the canyon, the piezometric surface, which is in the Yeso Formation underlying the alluvium, intersects the land surface and causes the issuance of several large springs which contribute to stream flow. From that point to where it leaves the study area, the Rio Peñasco flows perennially in Cox Canyon as a gaining stream. It is interesting to note that Cox Canyon, west of where the piezometric surface intersects the stream bottom, is deeply incised, whereas the streambed east of that point is shallow. Farther east, outside of the study area, Rio Peñasco becomes intermittent again, and its water seeps into the karstic San Andres Formation.

When it rains heavily in the western mountains, James and Cox canyons and their tributary canyons carry off excess water that does not seep into the San Andres or through the alluvium of the canyon bottoms. The amount of water which flows out of the area can be substantial under severe storm conditions, but unfortunately there are no gauging stations in any of the canyons in the area, so the actual amount is unknown. Although there are no gauging stations in the upper reaches of the Rio Peñasco, baseflow of the Rio

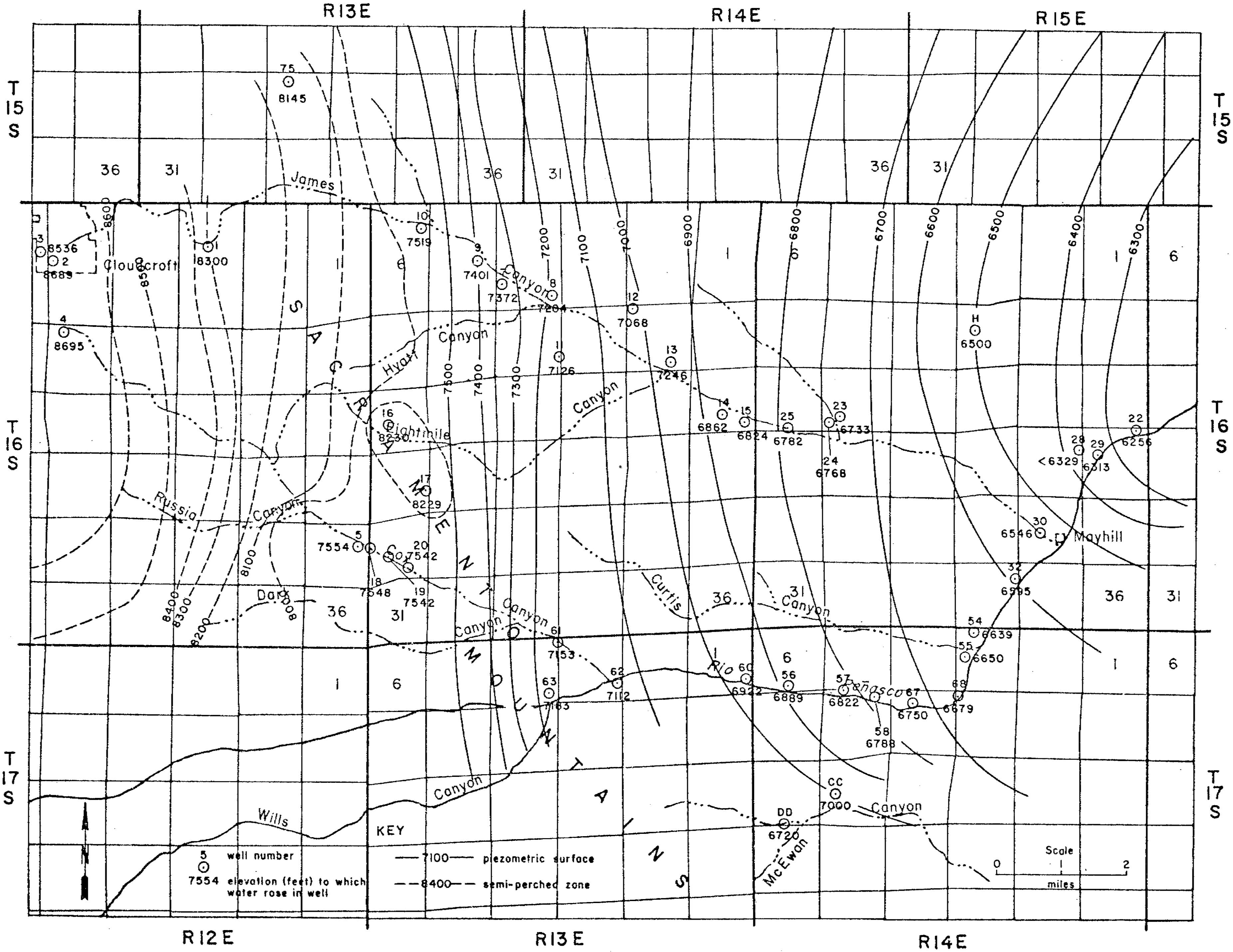

Figure 18. Groundwater contours in the study area.

Peñasco was estimated from spring flow in the section entitled "Water Budget". Except in very dry years, runoff through Cox Canyon occurs with sufficient regularity so that ranchers and farmers of the area use it to water stock and to irrigate.

Water from low and moderate precipitation events seeps into the forest soils or into the alluvium of the stream bottoms. Whatever is not consumed by vegetation contributes to underflow out of the area. The underflow component present beneath James Canyon must be fairly substantial, producing a zone of eastward-moving water several hundred feet higher than the potentiometric surface. Well 13 (Fig. 6) taps this zone at 127 feet. This overlying water table zone is not present in lower Cox Canyon since the piezometric surface is at the level of the channel (Fig. 18) and contributes water to the perennial Rio Peñasco. In lower Cox Canyon, therefore, surface runoff channeled into the canyon flows out of the area in the Rio Peñasco.

Groundwater

Within the study area, groundwater occurs under both confined and unconfined conditions. In general, the wells to the west of the dividing line between Ranges 12 and 13 East tap unconfined water, while those to the east of this line tap confined water. However, artesian conditions may exist locally west of the dividing line. For example, Hood (1960) states that water in Well 1, (Fig. 6) rose to within 60 feet of the surface when the well tapped a limestone aquifer at 145 feet.

Correlation of the driller's well log descriptions with their reports of water-bearing strata, and the State Engineer's measurements of water levels (Appendix A, B; Figs. 9-12) reveals that the Yeso Formation is the principal aquifer. Only in well CC is the overlying San Andres Formation productive; through most of the area the San Andres is high above both the water table and the artesian surface.

Water enters the Yeso groundwater system on the eastern slopes of the Sacramento Mountains, directly by seepage into the formation through high canyon floors throughout the study area, and indirectly by seepage through the overlying fractured and humus-covered San Andres carbonates, especially west of the R12/R13 line. Water may also enter the system as precipitation onto the western side of the crest. However, the amount of recharge which may occur in this fashion is probably limited by the steepness of the western face of the mountain block. Hood (1960) suggested that, after entering the system, the water probably flows eastward down the regional dip of the beds. He based his conclusion on the fact that few, if any, springs issue on the western face of the mountains near the top of the Yeso Formation, whereas on the eastern side there are numerous springs issuing from almost every canyon. He also notes that water in the San Andres Formation would be under water-table conditions, but that the Yeso water could occur locally under artesian conditions.

His interpretation is true in part, but the situation is more complex. Fig. 19 diagrams the probable configuration of the water table/piezometric surface and its relation to the San Andres/Yeso contact. Putting all the data together: well logs, water level data, tritium data, chemistry, and vegetation patterns, a number of conclusions can be drawn about the groundwater system of the area. Basically, it occurs in three forms: in an unconfined or water table zone, as spring flow, and under artesian pressure. Water under all conditions flows eastward towards the Pecos River and the Roswell Basin.

Water-Table Conditions

Water-table conditions are present at the crest of the Sacramento Mountains to the R12/R13 dividing line (Figs. 18, 19), at an altitude of about 8000 feet above sea level. Whether this unconfined zone is laterally connected to water under artesian conditions farther east, forming a continuous piezometric surface, or whether it is 'perched' above the artesian water is unknown. There are no wells in the area deep enough to pass through the water table zone and also to tap the artesian water zone which may be present several hundred feet below it (Fig. 19). It has been suggested (Summers, personal communication, 1981) that the water surface is continuous, with a steep hydraulic gradient between the water table and the artesian surface. It is more likely, however, that the artesian water surface actually continues west at its average slope of 134 feet/mile, and that the unconfined water zone collects several hundred feet above it in sands and limestones being held up by less permeable silts and shales. This water could conceivably be called 'perched', but most probably has a vertical hydraulic connection with the water present under artesian conditions. Therefore, the term 'perched', with its implications of permanent separation from the main groundwater system by impermeable strata or some other condition which prevents flow, is replaced by the term 'semi-perched'. The distribution of tritium data (discussed under Tritium) suggests the following inference: if there is a hydraulic connection between the semi-perched zone and the regional artesian groundwater system, either the 'semi-perched' water mixes with a very large volume of groundwater in the main water system, or the lag-time for that water to seep downward into the main water system is relatively long.

This water-table aquifer in the westernmost and highest part of the Sacramento Mountains is also noted on the potentiometric map for the Mescalero Apache Indian Reservation (Sloan and Garber, 1971) as an area of potential perched water.

The presence of this semi-perched zone in the west and its absence farther east may find an explanation in specific recharge conditions.

Recharge is produced by a complex interaction of numerous variables: geology, climate, topography, and vegetation. The effects of geology (including lithology and structure of bedrock and soil) have been alluded to previously. Soil is also a function of climate. Climate depends on geographical location, topography, and slope orientation ('aspect'). Vegetation depends on all of the previous variables as well as on ecological factors. Precipitation and vegetation may be controlling the distribution of the semi-perched zone.

In the western zone, at higher altitude, more precipitation falls in the course of a year and more remains on the ground as snow in winter. Keith (1980) discusses investigations of recharge in alluvial basins of the Southwest. He concludes that in many cases winter precipitation is more effective for recharge than is summer precipitation. This is due to the longer duration of winter storms, lower evapotranspiration rates in winter, and persistence of the snow cover for a longer period of time allowing greater depths of the soil to be saturated. These conditions could very well obtain in our study area.

Moreover, in the vicinity of Cloudcroft, from the crest to the village of Wimsatt (near the R12/R13 line and about 8000 feet above mean sea level) the predominant tree species is Douglas fir, mixed with white fir, Engelman spruce, and aspen, whereas the area between Wimsatt and Mayhill is forested predominantly by Ponderosa pine. Evapotranspiration rates and soil moisture in the study area have been investigated by Prof. B. Buchanan (Department of Agronomy, New Mexico State University, personal communication, 1981). The evapotranspiration rate for Ponderosa pine in the area is probably equal to precipitation, up to a maximum of about 30 inches per year. Douglas fir, on the other hand, show evapotranspiration rates of 20 inches per year. Water in excess of this amount is available for recharge. The quantitative implications of the varying ET rates on recharge in the Sacramento Mountains should be investigated further.

Occurrence of Springs

Many springs issue within plus or minus 50 feet of the San Andres/Yeso contact. Most of these are relatively

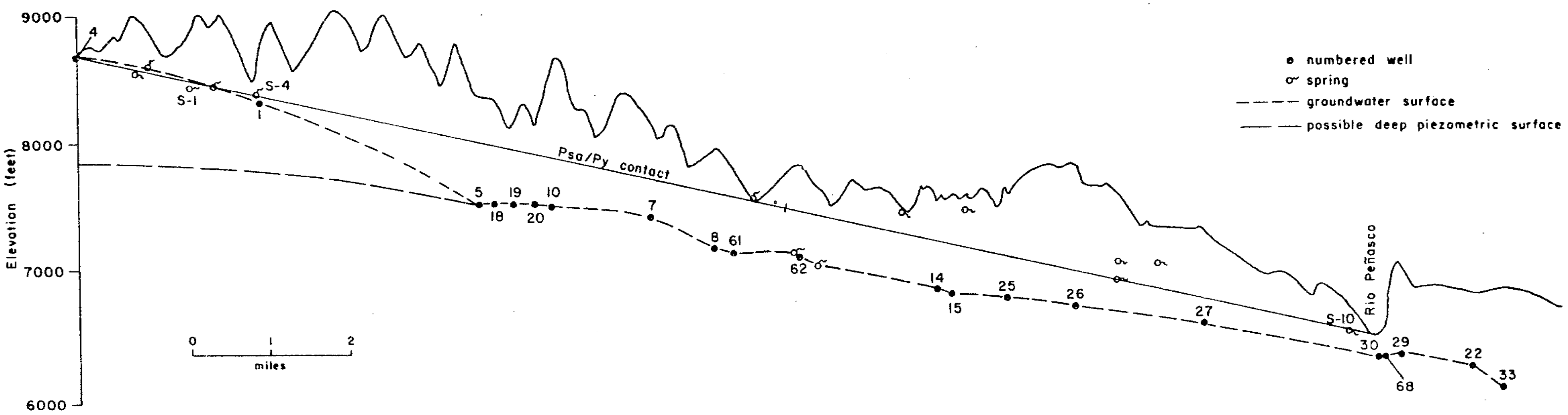

Figure 19. Schematic cross section along line E-E' of Figure 6.

small, averaging between three and five gpm. The city of Mayhill, however, is serviced by Well 31, a well of good yield dug at the issuing point of a spring (Fig. 6). From the description given by the owner and from the spring's stratigraphic position, this appears to be a contact zone spring issuing near the level of the regional piezometric surface. The owner of the well/spring stated that several years ago the well was pumped at 90 gpm for six days without lowering the water level in the well enough to reduce the discharge.

At the eastern edge of the study area, spring flow from the San Andres/Yeso contact zone may be controlled in part by a large fault trending north-norteast near Mayhill, (Fig. 8). As mentioned earlier (p. 16), this fault may be an extension of the Border buckle. The fault could act as a barrier to the flow of water in the San Andres/Yeso contact zone by cutting off the contact zone on the fault's downdropped eastern side. Springs would issue from the exposed contact zone on the fault's western side. These springs could be larger than springs issuing from the same zone farther west because the exposed contact zone provides an easy flow path and because a large volume of water could have accumulated in the zone. To support this fault theory further, it is noted that, east of the hypothetical fault zone, there appears a slight rise in the water table because the groundwater reservoir is recharged locally by the excess contact-zone water. Water from the contact zone also feeds the Rio Peñasco, because the contact zone is near the level of the stream bottom in the eastern part of the study region. Posey Spring may be an example of one of these feeder springs. It is located a half mile southwest of Mayhill. According to records of the State Engineer Office in Roswell, in 1961 and 1964, discharge of this spring into the Rio Peñasco was almost 2000 gpm. As can be seen in Figure 19, the spring (S-10) seems to be located at the projected San Andres/Yeso contact zone where the artesian surface intersects the stream bottom. The magnitude of the spring flow supports this idea.

Water probably enters the contact zone in two ways: (1) In the recharge belt near the crest of the mountains, water unused by vegetation seeps downward through the fractured San Andres limestone to the relatively impermeable shales of the underlying Yeso Formation, where it accumulates faster than it can seep downward. (2) Near the edge of the unconfined zone of water, the San Andres/Yeso contact zone crosses the water table at a steeper dip than that of the water surface. At this edge, water could pass from the unconfined semi-perched zone into the contact zone. The underlying shales would effectively trap the water and guide it downdip, that is, eastward.

As pointed out above (pp. 29 - 30), springs do not only issue from the contact zone, but also occur where the regional semi-perched aquifer intersects canyon sides or bottoms, and where the artesian surface is at or above the level of the stream channel bottoms, especially in areas where local faults and collapse features facilitate egress of the water. A plot of spring location versus elevation (Fig. 20), indicates that springs persistently occur over a 500-foot spread in elevation at any given location between Cloudcroft and Mayhill. The individually smallest springs are probably those fed by the semi-perched system. Contact springs and piezometric surface springs are of substantially greater magnitude than either of the other two spring types. As a group, springs issuing from the intersection of the piezometric surface with the land surface probably contribute the greatest volume of spring water to the area. It is possible that Posey Spring is of such magnitude because it is a piezometric surface spring that occurs at the San Andres/Yeso contact zone in the vicinity of the regional NE-trending fault.

Artesian System

In two-thirds of the study area, from about the dividing line between Ranges 12 and 13 eastward, wells tap an artesian system. The boundary is the approximate eastern edge of the semi-perched zone. The artesian system most probably extends westward beneath the semi-perched zone to an unknown distance, perhaps as far as the western escarpment of the mountains. Wells only tap the first water they encounter, which west of R12/R13 is the semi-perched zone and east of R12/R13 is the regional artesian system. Fig. 18 presents the artesian surface and the semi-perched water table. The heights to which water rose in each of the wells can be seen from the well logs (Appendix A) or Figures 10-12. This artesian surface, or surface of the heights to which water rose in the artesian wells, slopes to the east at 134 feet per mile from Well 10 to Well 8, and at 100 feet per mile from Well 8 to Well 30 at Mayhill (Fig. 6). The difference in the slopes is due to the difference in permeabilities of the strata in which the water occurs. Equipotential lines run nearly north-south, indicating an east-west direction of groundwater flow. The gaining Rio Peñasco has a predictable effect on the lines in the vicinity of Cox Canyon. The alluvium in the stream channel of Cox Canyon also has an effect: its higher permeability causes the lines to spread out. As can be seen by comparing the piezometric map of the area (Fig. 18) with a topographic map (USGS Cloudcroft 15 minute quadrangle), the artesian surface is just at or above the level of the stream channel bottom in lower Cox Canyon. Where the permeability of the stream alluvium permits, water from the regional piezometric surface flows into the Rio Peñasco, both as channel-bottom seepage and as springflow, maintaining its perennial discharge. This does not happen in James Canyon:

although the piezometric contours are essentially north-south, there is a greater formation thickness in James Canyon, causing the artesian surface to lie well below the bottom of the canyon floor, and preventing the James Canyon drainage from flowing.

This artesian water occurs regionally and constitutes the main Yeso groundwater system. The water in this system supplies the Rio Peñasco and most of the wells in the area; and it provides what is probably a substantial amount of underflow out of the area. The water which enters this groundwater system may eventually help recharge the Roswell Basin and even end up as discharge to the Pecos River, for the hydrologic system appears to be continuous from the mountains to the river (Fig. 21). The piezometric-surface map drawn for the Cloudcroft-Mayhill area agrees well with the maps derived by DeWilde (1961) for the Flying H ranch to the east, and by Sloan and Garber (1971) for the Mescalero Apache Indian Reservation to the north (Fig. 21).

Recharge and Discharge

Recharge to a groundwater system occurs when water, whether precipitation, underflow, streamflow, or irrigation runoff, enters the aquifers of a given area, becoming a part of the groundwater. Discharge occurs when water is removed from that system by pumping, streamflow, evapotranspiration, springflow, or underflow out of the area. Recharge in the study area occurs mainly by precipitation, with the possibility of an underflow component from the western side of the Sacramento Mountain escarpment. Most of the discharge from the area occurs via evapotranspiration by native forest vegetation. Outflow through the Yeso aquifer may also be important, as may be the contribution made to the gaining Rio Peñasco by springs and by inflow from the regional artesian groundwater system.

Tritium data and the position of the groundwater surface seem to indicate that the regional aquifer of the study area, the Yeso Formation, is recharged mainly by precipitation along a relatively narrow band from the crest of the Sacramento Mountains eastward to near the R12/R13 line. The water in the recharge zone occurs under water table conditions and it is apparently 'perched' at elevations higher than those predicted for the main artesian groundwater surface.

Both aquifer systems appear to be hydraulically connected. A probable explanation for the presence of water under unconfined conditions in the far western part of the study area and its absence farther east is offered in the section on Groundwater. There may exist additional recharge components to the Yeso aquifer: water in storage under artesian pressure may be forced up from deeper formations

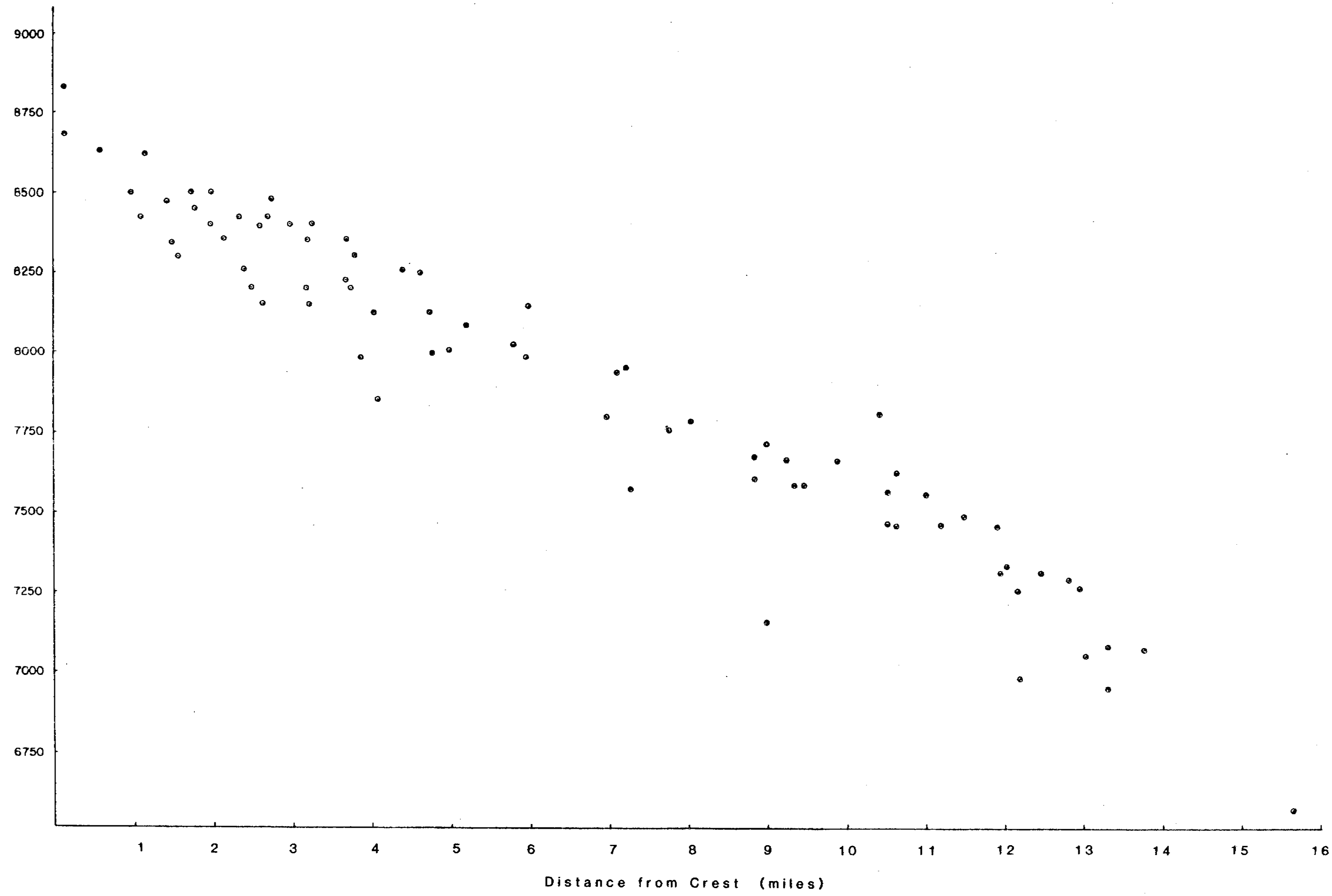

Figure 20. Elevation of springs vs. downdip (west-east) distance.

(Abo), or precipitation on the western side of the mountains may flow slowly eastward through the formation. Either of these ideas can be supported by the tritium data, but neither can be proven. Water flowing along the San Andres/Yeso contact is probably derived from precipitation over the eastern side of the mountains percolating down through the fractured limestones of the high mountains, or contributed by the semi-perched unconfined zone. After it has entered the groundwater system, water moves east down the San Andres/Yeso contact, issuing as numerous springs and seeps which increase in size to the east. It is emphasized that the spring system is a regional one, extending over a much larger region than the limits of this study area, and involves a substantial quantity of water. Davis et al (1980) suggested that, through the entire western flank of the Roswell Basin, springs often issue in the contact zone. Although many of these springs are used domestically, most of the spring water does not leave the area, but simply seeps into the alluvium of the canyon bottoms, either contributing to the shallow underflow out of the area, or recharging the deeper groundwater system. Water from the main artesian groundwater system in the Yeso does not discharge anywhere in James Canyon, because the piezometric surface is hundreds of feet below the canyon bottom. By contrast, a number of springs in lower Cox Canyon exist because the piezometric surface intersects the bottom of the canyon. This occurs not because the piezometric surface is higher in Cox Canyon than in James Canyon - the surface is continuous between the two canyons (Fig. 18) - but simply because a greater thickness of overlying strata has been stripped off in the area of the southern canyon. The water discharged into Cox Canyon leaves the area as streamflow in the Rio Peñasco.

The vegetation of the study area uses a substantial portion of the yearly precipitation, a conservative estimate for evapotranspiration being 50 percent of the precipitation. A more detailed and quantitative study of vegetation types and water use would greatly facilitate understanding of the plant-water relationships in this area.

Water also leaves the area through the Yeso Formation. The piezometric surface remains in this aquifer to beyond Elk, where it passes into the overlying San Andres Formation with a marked decrease in piezometric slope. The Yeso aquifer is therefore thought to be hydraulically continuous with the San Andres aquifer, a contention which is questioned by Maddox (1969) but supported by Mourant (1963) and Rehfeldt and Gross (1982). It is also supported by Fig. 21 of the present report. By this model, water which enters the Yeso at the western limit of the Roswell Basin near the crest of the Sacramento Mountains plays an important part in recharging the principal artesian aquifer of the Basin. It should be noted that this idea is supported by the low

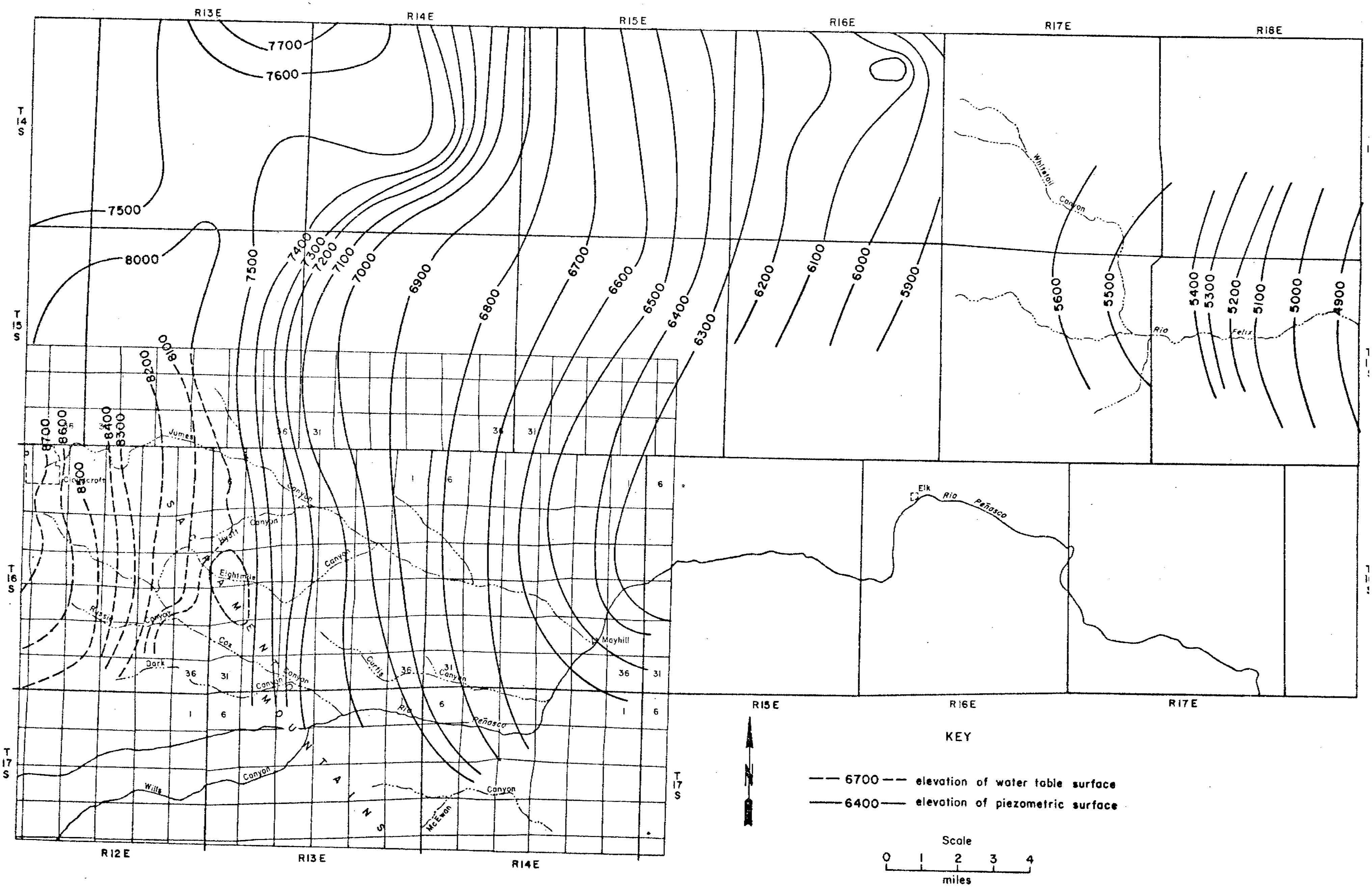

Figure 21. Regional groundwater contours. Those outside the study area were compiled from DeWilde (1961) and Sloan and Garber (1971).

tritium values, indicating old water, encountered in wells of the 'Principal Recharge Area' (Fiedler and Nye, 1932; Gross et al., 1976). These low values suggest that this area, formerly assumed to receive water mainly as precipitation, contains old water either leaking upward from lower formations where it is under pressure, or through lateral inflow from formations farther west.

It is interesting to note that the long-term monitored wells closest to the study area exhibit a pattern of water-level change similar to representative wells in the basin proper, only sooner (Figs. 22 and 23). Specifically, a marked rise in water levels which ended eight years of relatively stable water levels, occurred around 1968 in the western wells, whereas a steep rise began between 1971 and 1973 35 miles and farther east in the Basin. In the west, the rise in water levels seems to have been linked to three consecutive years of above average rainfall, 1966 to 1969 (Fig. 4). Since the rainfall for the rest of the Basin followed a similar pattern, the years of higher rainfall being previous to and not in the period during which the well levels to the east actually rose, it is suggested that a recharge component from the west actually caused the rise in water levels far east of the mountains.

Water Budget

A water budget is an inventory of all ground and surface water entering and leaving a given area. A balanced water budget must equate the amount of water which enters an area with the amount consumed in and discharged from it. Water may enter the system in the form of precipitation, streamflow, irrigation return flow, effluent from municipal or domestic waste systems, recharge to or inflow through one or more aquifers. Water may leave the system by evapotranspiration from native and planted vegetation, consumptive use by human and animal populations, stream discharge, underflow in alluviated channels, outflow through aquifers and springflow out of the area.

In the absence of accurate data, the magnitudes of almost all these components had to be estimated for the study area. This water budget, therefore, serves as a starting point for more quantitative studies in the future. One of the main purposes of deriving this water budget is to get a rough idea of the amount of water which may be involved and its recharge contribution to the Roswell artesian basin.

Recharge Components

The following recharge component symbols will be used in the discussion:

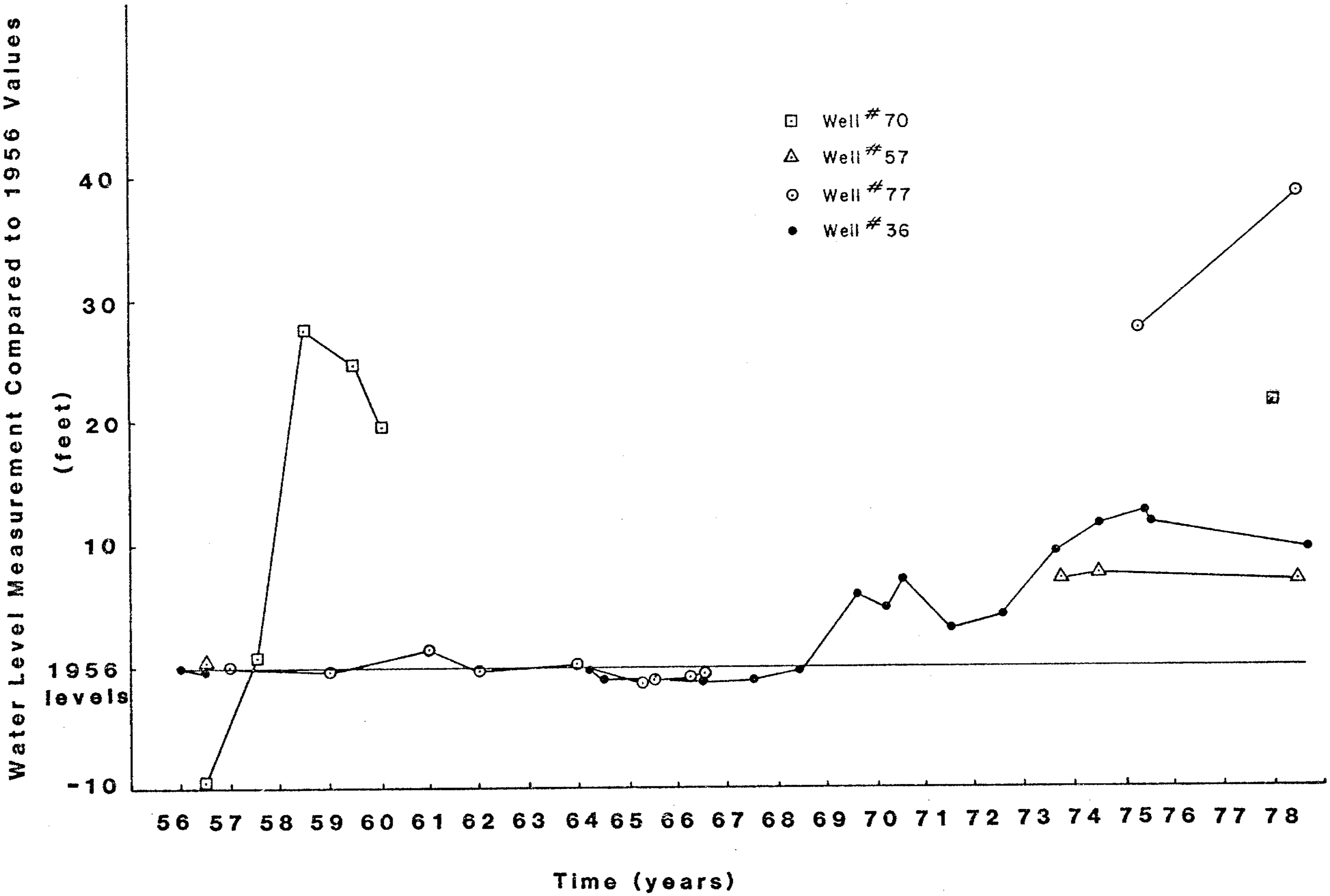

Figure 22. Hydrographs of selected wells in the upper Penasco drainage. All but Well 57 (Appendix A) are located outside of the study area shown in Figure 6. Well 36 (16.16.3.312132) is 163 ft. deep and entirely in alluvium. Well 57 (17.14.8.12111) is 105 ft. deep in alluvium. Well 70 (17.14.28.23311) is 215 ft. deep and entirely in Yeso; water is from a persistent sand-gravel bed below the medial limestone/dolomite. Well 77 (15.16.30.212233) is >261 ft. deep and in Yeso.

Rp	local precipitation
Rs	streamflow
Ry	underflow from the west or inflow from lower aquifer units
Rf	return flow from irrigation
Rm	treated waste effluent
Rl	leakage of precipitation through canyon bottoms
R	total recharge to the area

Recharge to the study area comes mainly from local precipitation, Rp. The Rio Peñasco flows into the southeastern edge of the area; it is a gaining, rather than a losing, stream within the area of study, and, as such, does not contribute to recharge of the groundwater reservoir. The total flow in the Rio Peñasco is augmented by the contribution from springs, an amount that can only be estimated, and by precipitation falling directly into the stream and draining into it from the adjacent land surface. No other streams flow into the study area, located as it is near the crest of the Sacramento Mountains. Rs is thus assumed to be zero.

Rm, the amount of treated municipal and domestic waste effluent returned to the groundwater system, is assumed by the N.M. State Engineer office to be about 50% of the water pumped or diverted for such use. This use amounts to about 115 acre-feet/year, as will be calculated in the next section, so Rm is about 58 acre-feet/year.

Inflow from a possible deep Yeso system, component Ry, may contribute to the regional artesian system, but the magnitude of this component is unknown. This water would come from either (1) precipitation on the western side of the mountains, which then moves eastward through the Yeso; (2) water which has been present in the Yeso at depth for a long time; or possibly (3) water from the Abo Formation under artesian pressure which is slowly leaking upward into the Yeso Formation. The Yeso is estimated to be about 1200 feet thick in the mountain area (Kelley, 1971), and may contain a great volume of water in storage. Under artesian pressure, this water may move upwards at a slow but steady rate, recharging the upper groundwater system of the area.

The magnitude of Rf, the return flow from irrigation, is assumed to be 50% of the amount of water applied to the fields. Whether this estimate is in error or not, it is insignificant, because the total composite acreage for the farms is low and the amount of water used for irrigation small when compared to the magnitude of the other input components. About 760 acres of land are irrigated in the study area (State Engineer Office in Roswell), mainly with surface water and springs. At this writing, the water rights for this area have not been adjudicated and, consequently, the duty of water has not been established.

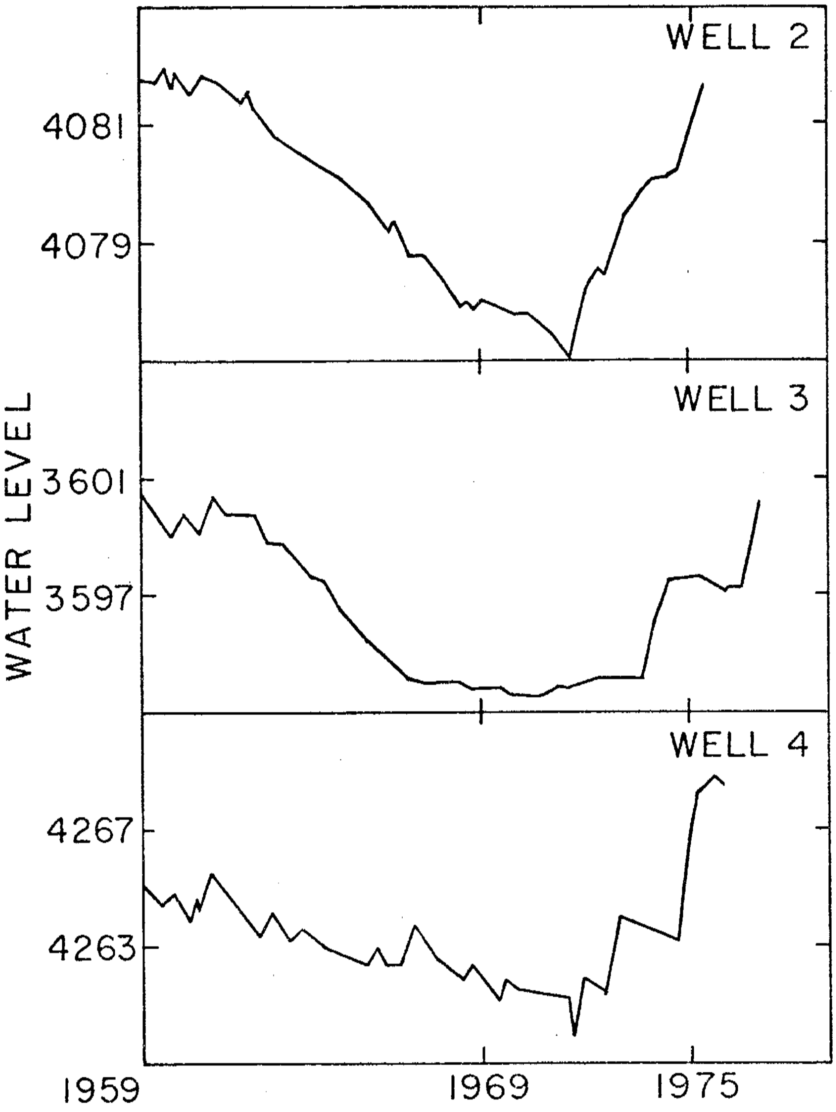

Figure 23. Hydrographs of three observation wells in the central Roswell Basin. Data courtesy of Pecos Valley Artesian Conservancy District. (From Duffy et al., 1978.)

For the purposes of this study, we assume a duty of 3 acre-feet per acre per annum. Under New Mexico law, this is the maximum amount allowable in unadjudicated areas. Rf would then be 1,140 acre-feet per year.

There are about 50 miles of dry open channels where the water table is below the surface of the stream bed. If these canyons average 10 feet in width, 60.6 acres of area is available for recharge. About 110 acre-feet per year of recharge, Rl, is possible. This figure accounts only for direct, maximum rainfall infiltration and assumes no significant additional infiltration during intermittent streamflow lasting beyond the duration of the rains. Since storms are usually brief and intense, and the ephemeral streams carry water only rarely in this area, the assumption is not unreasonable.

Precipitation over the area, Rp, is a substantial source of recharge. As shown in Table III, annual precipitation averages 22.3 inches yielding a value of 154,000 acre-feet over the 120 square-mile area. It is unequally distributed. Mean annual precipitation and the ratio of winter precipitation to annual precipitation both decline with the mean land surface elevation in an easterly direction. As pointed out earlier (p. 48), winter precipitation is more efficient for recharge than precipitation of other seasons. It was also noted that the disparity in the evapotranspiration rates of two dominant tree types could further alter the recharge distribution from west to east. Based on earlier discussion, the amount of precipitation between Mayhill and the R12/R13 line is assumed to be roughly equal to the evapotranspiration rate for the trees. The amount of recharge for this area, excluding stream canyon bottoms, is therefore negligible. The majority of recharge occurs from the R12/R13 line west to Cloudcroft, where altitudes are higher, winters are longer and wetter, and where Douglas fir and other conifers, excluding Ponderosa pine, dominate. Mean yearly precipitation over this 30,700 acre area is 24.5 inches, so Rp is 62,680 acre-feet per year.

The total amount of recharge for the area, R, is thus:

$$R = Rp + Rs + Ry + Rf + Rm + Rl$$

$$R = (62{,}680 + 0 + Ry + 1{,}140 + 58 + 110) \text{ acre-feet/year}$$

$$R \geq 64{,}000 \text{ acre-feet/year}$$

Discharge Components

These discharge component symbols will be used in the following discussion:

Det	evapotranspiration
Dc	change in groundwater storage
Df	base flow out of the area
Ds	spring flow out of the area
Dr	precipitation runoff which leaves the area
Dp	pumpage
Dq	groundwater outflow
D	total discharge from the study area

Removal of water from the groundwater system of the study area occurs mainly by evapotranspiration, or ET, from native and planted vegetation. Of the 120 square miles or 83,200 acres in the area, all but about 1280 acres are covered by native mixed conifers. The remaining 1280 acres are divided as follows: 760 acres planted (irrigated acreage map, New Mexico State Engineer Office in Roswell, 1978), about 210 acres in grass, and about 200 acres barren in roads and houses. Estimates on ET rates for mixed conifers and grass are as many as the authorities consulted, and seem to vary greatly from area to area. The average for an area with the climatological and topographic characteristics of the study area is probably between 15 and 22 inches per year. Recharge in the study region is believed to occur mainly west of R12/13 E, area of the semi-perched aquifer system, where forest vegetation is dominated by various species of fir. On the basis of soil moisture and evapotranspiration studies mentioned earlier, the evapotranspiration rate in this area is estimated at 20 inches per year. As discussed in the previous section, the study area west of R 12/13 encompasses about 48 square miles, or 30,700 acres. The evapotranspiration component of discharge, or Det, is thus about 51,170 acre feet per year.

There are two or three major sources of groundwater in this area: the shallow groundwater and spring system; the main groundwater reservoir in the Yeso; and underflow through the alluvium fill of the Peñasco valley. It is assumed that an insignificant change of storage has occurred in the Yeso aquifer over the 100 years or so during which this area has been inhabited, and that the rate of flow of the various springs will remain unchanged from year to year, so Dc, or change in storage, is 0, and Ds, or spring flow, is a constant. Thick and extensive travertine deposits around almost all the springs both in this area and throughout the Sacramento Mountains indicate that these springs have flowed for a long time and probably once at much higher volumes than they do today. No dates are available at this writing but the phenomenon was most likely linked to a colder, moister climate during the Holocene. Pumpage from the Yeso, P, can only be estimated, as no records have been kept. The main centers for pumping are the villages of Cloudcroft and Mayhill, several subdivisions near Cloudcroft which use the water for homes and golf courses; and in the summer, the Baptist Church camp in Pew

Canyon. Pumpage for the area is undoubtedly much less than would be the case in an area devoid of springs, for many of the local ranchers, farmers, and residents obtain a great part, if not all, of their water from springs, pumping their wells only occasionally at the peak of the summer. Robin Hood Estates, for example, a development of about a dozen houses, owns well 7, but obtains most of the water necessary from spring S-9 (Johnson Spring). The development complex of several dozen houses just west of Wimsatt is said to obtain all of its water from the small S-5 spring. Even the Burgett greenhouse complex, now closed, used wells only at the peak of the summer season, relying on a large spring issuing from the hill to the southwest of the complex. Many residents of the area obtain their water from springs which issue on forest service land. The U.S. Forest Service has been aware of this and is presently attempting to tabulate the hundreds of springs on its land in hopes of regulating their use (verbal communication from U.S. Forest Service Office, Alamagordo, N.M., 1980).

Pumpage at Cloudcroft is on the order of 82 acre feet per year. This number was derived by considering data from Dinwiddie (1960) on municipal water supplies in southeastern New Mexico. He states that in 1960 Cloudcroft had a permanent population of 467, and up to 1200 residents in the summer during the tourist season. The town has grown little since then; it is assumed to have 500 full-time residents and a three-month summer population of 1200. There being no reported figure for per capita consumption of water at Cloudcroft, a value of 110 gallons per day per person is assumed as consistent with the usage rates for other small towns in the mountains of southeastern New Mexico. About 10 acre feet of water is used by the Baptist Church camp, and 30 are claimed for Mayhill. Another 20 acre-feet is probably pumped for consumption by individuals who live scattered in the study area. The total amount of water pumped from the Yeso for municipal and domestic use is thus conservatively estimated at 142 acre-feet per year. As calculated in the previous section, the amount of water applied to the irrigated fields is about 2280 acre-feet per year. At least 75% of this amount is probably obtained from spring flow or diverted from the Rio Peñasco. Dp, or the total amount of water pumped from the groundwater system in the study area, is thus (142 + 570) acre-feet per year, or about 710 acre-feet per year.

There exists a component, Df, of total stream flow out of the area. The amount leaving the area as stream discharge is not equal to the amount entering in the Upper Rio Peñasco, but has been augmented by spring flow and runoff from precipitation. The contribution of Rio Peñasco to discharge through Cox Canyon has not been gauged and is consequently unknown. From scanty records (Cranston et al., 1981 and Table VI) it can be determined that prior to the

Table VI. Penasco Flow Records
(from Cranston et al., 1981).

Date	.25 mi above Posey Spring cfs	At Posey Spr. cfs	.25 mi below Posey Spring cfs	2 mi downstream from Mayhill cfs
2-17-60	0.49	5.6		5.1
11-10-60	0.65		6.3	5.2
3-21-61		4.0		
3-30-61	1.6			6.5
				Average: 5.6
3-31-61		3.9		
5-5-61		4.9		
3-30-62		4.6	6.2	
4-27-64	18.9	4.2		
10-7-75			26.4	26.4
		Average: 4.5		

start of irrigation season an average flow of 5.6 cfs (yearly rate of 4050 acre feet) leaves the area in the Rio Peñasco about 2 miles northeast of Mayhill. An average of 4.5 cfs of this is contributed by Posey Spring. Baseflow of the Rio Peñasco is therefore probably around 1.1 cfs. Some of this flow is diverted for irrigation in the spring and summer. According to local residents, the stream may occasionally dry up during the summer season, although shallow supplemental wells located along the stream never do. Since the amount of water entering Cox Canyon from the Rio Peñasco is unknown, it will be assumed to be equal to baseflow leaving the area. Therefore Df = 0. Values for spring augmentation of stream flow, Ds, and runoff from precipitation, Dr, are input into the discharge side of the water balance equation.

There are many springs in the area, most of which are not shown on maps. Some springflow measurements have been reported. They belong to springs for which water rights applications have been made to the New Mexico State Engineer. A list of springs in the study area, their locations, and some flow measurements have been assembled in Table VII. These are from records on file at the New Mexico State Engineer Office in Santa Fe. These records do not include all the springs of the area, or even the largest ones. A number of springs were visited and their flow rates estimated (Appendix A.) They include springs marked on the maps, as well as those mentioned in the literature as having unusually large flows. Conversations with local residents allowed the senior author to get a fairly realistic idea of the number of springs in the area, as well as their comparative sizes. From this information the following tentative conclusions have been drawn:

(1) There are between 80 and 100 springs in the area. Most of these are small; at least 7 springs have moderate discharge; and 11 are much larger (see flowrates below). Water rights applications have been filed for 60 springs.

(2) The small springs flow at rates between 1 and 5 gpm.

(3) Large springs at 16.13.10.4322; 16.13.10.3422; 16.13.36.32; 16.13.33.3111 (2 springs); and 17.13.3.4214 (2 springs) flow at least 50 gpm each. Johnson Spring (16.13.9.31) has a discharge of 30 gpm. The very large Posey Spring just south of Mayhill flows at an average of 2035 gpm; the spring up Eightmile Canyon at the old Harvey Ranch flows at about 20 gpm. Other discharges found in N.M. State Engineer records are: Lake Spring (16.14.33.4) 30 gpm, Mickison Spring (16.14.31.11) 35 gpm: Turkey Spring (17.13.14.22) 45 gpm; Culberson Spring (16.12.14.41) 200 gpm; unnamed spring at (17.11.11 & 2) 100 gpm. Four springs which discharge at an average of 15 gpm each are an

Table VII. PARTIAL LIST OF SPRINGS, THEIR LOCATIONS, AND SOME FLOWRATES, FROM N.M. STATE ENGINEER OFFICE FILES.

Name	Location	Flowrate	
		acre-feet/yr.	gpm
Mackison A & B	16.14.31.11		
Lightning 1 & 2	16.14.32.44		
Lower Lightning 1,2,3	17.14.5.22		
Experimental Forest 1,2,3,4,5	16.12.16.42 & .13		
Weems 1 & 2	17.14.7.249		
Mickison	16.14.31.11	56.5	35.1
Bird	16.12.36.11		
Young Canyon	16.12.2 Lot 11	3.2	2.0
Johnson	16.13.9.31	48	29.8
Pow	16.13.3.32		
Robertson	16.13.3.24	8.1	5.0
Forest Service	16.13.3.324	8.1	5.0
Brick Chimney	16.13.3.24	4.8	3.0
- - -	16.12.23.1		
Lower 3 L Canyon	16.13.22.22		
Upper 3 L Canyon Spr #1	16.13.22.24		
Upper 3 L Canyon	16.13.22.24		
Law Suit	16.13.10.432	8.1*	≥ 5.0*
Goldfish	16.13.10.413		
Headquarters	16.13.9.242		
Bear	16.13.9.24		
6 Springs	16.13.4.13		
16th Spring Canyon	?		
- - -	17.13.1.443	8 (24*)	5.0 (15*)
Goat	16.13.36.32	80.7	50.1
Lake	16.14.33.4	48.4	30.1
Lost	17.13.1.24	1.6	1.0
Dollins	16.14.30.4	24.2	15.0
Mars	16.14.21.4	1.6	1.0

Table VII (continued)

Big Hill	17.14.4.44	1.6	1.0
Lightning	17.14.4.11	4.8	3.0
Canyon	16.14.32.342	8.1	5.0
Deer	16.14.27.3	3.2	2.0
Robinson	16.14.31.34	5.6	3.5
Culberson	16.12.14.41	322.8	201
Fite	16.12.23.132	3.2	2.0
- - -	17.11.11 & 2	161.4	100
Bell	16.14.26.32		
Scott	17.14.8.441	4.6	2.9
Denny	17.14.8.414	0.8	0.5
Turkey	17.13.14.211	72.6	45.1
Little Hay	16.13.8.421	4.9	3.0
Cotton	16.13.16.2134	24.2	15.0
Iris	16.12.27.141	3.2	2.0
Split	16.12.26.121	24.2	15.0
Hog	16.13.3.112	0.2	0.1
Long	17.13.1.223		
Baird-Wimsatt	16.13.6 Lot 3	29	18
Bairds	16.13.5.32	72	44.7
Wimsatt Spring	16.13.6 Lot 3	65	40.4
Wimsatt Springs	16.13.6 Lot 9	130	81
Donaghe	16.13.6 Lot 12	58	36
Pumphouse Canyon	16.12.3.1	43	27
Posey	16.14.26.431	3276	2035
---	16.13.10.3422		≥50 *
---	16.13.33.3111 (2 springs)		≥50 *
---	17.13.3.4214 (2 springs)		≥50 *
Eightmile Canyon (old Harvey Ranch)	---		20 *

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* Estimated for this report

unnamed spring (17.13.1.443), Dollins Spring (16.14.30.4), Cotton Spring (16.13.16.2134), and Split Spring (16.12.26.121).

(4) The total spring discharge for the study area including small springs) is estimated to be of the order of 3000 gpm (4840 acre feet per year).

Most of the water from Posey spring leaves the area as flow in the Rio Peñasco. Some water from other large springs, conservatively estimated at 15% of springflow (based on water rights recorded) is used within the area or evaporates. Only an insignificant amount of water from smaller springs is assumed to leave the study area directly; small spring flows are either used within the area or re-enter the groundwater system by seeping into the alluvium or Yeso in the canyon bottoms. The real amount of spring discharge from the study area is therefore probably on the order of [2000 + 0.85 (830)] gpm, or 2705 gpm. Ds is thus about 4370 acre-feet/year.

The amount of surface runoff (due to snowmelt or precipitation) leaving the area, Dr, is not known, because none of the stream canyons are monitored with any type of gauge. Hood (1960) states that only after a very heavy storm do the canyons, including James Canyon, flow. In a short period of time, however, much water could flow out of the area. The Rio Peñasco will always, of course, transport out water which falls directly onto its flow. As the Rio Peñasco flows about 10 miles within the study area and has a flowing width of about 10 feet, a minimum of 23 acre-feet/year is contributed to outflow from this source.

According to records found in Cranston et al. (1981), the Peñasco flowed 18.9 cfs above Posey Spring on 10-07-75. (The normal flow, it will be remembered, is less than 6 cfs). It is probable that runoff events of this magnitude occur at least twice a year and last for at least 24 hours each time. Assuming this, then the Peñasco will carry out an additional 75 acre-feet per year. Ignoring the side canyons and James Canyon, Dr will then be of the order of 100 acre-feet per year, as a minimum.

Groundwater leaves the study area by several routes: through the deep Yeso aquifer; as underflow through the thick alluvial fill of the Peñasco valley; along the Yeso/San Andres boundary, and possibly through tongues of the semi-perched aquifer or other perched zones extending eastward from the crest of the Sacramento Mts. These contributions make up Dq. For only one of its components can a quantitative estimate be attempted. It is the deep Yeso aquifer. We make use of the piezometric map (Fig. 18), and one transmissivity determination (Appendix C). Darcy's equation $Q = BT\ dh/dr$, states that the amount of discharge from an area is equal to the width of the aquifer multiplied by the transmissivity of the aquifer, multiplied by the change in head or static level of the water surface per change in distance. With an hydraulic gradient of 100 feet per mile, and transmissivity of 3400 gpd/ft, and assuming an aquifer width of about 8 miles for the study area, the approximate discharge from the area is computed as:

$$Q = 8 \text{ mi} \times 3400 \text{ gpd/ft} \times 100 \text{ ft/mi} = 2.72 \times 10^{6} \text{ gpd.}$$

Converting to acre-feet per year,

$$\begin{aligned} Q &= 2.72 \times 10^{6} \text{ gpd} \times 1 \text{ ac-ft}/43{,}560 \text{ cu ft} \\ &\quad \times 365 \text{ day/yr} \times 1 \text{ cu ft}/7.48 \text{ gal} \\ &\cong 3050 \text{ acre feet per year.} \end{aligned}$$

The total amount of discharge from the study area is thus:

$$\begin{aligned} D &= Det + Ds + Dp + Dr + Dc + Dq + Df \text{ or} \\ D &= (51{,}170 + 4370 + 710 + 100 + 0 + 3050 + 0) \\ &\qquad \text{acre-feet/year} \\ D &= 59{,}400 \text{ acre-feet/year} \end{aligned}$$

As stated previously, for the water budget to balance, the total amount of recharge must be equal to the total amount of discharge from the area: R = D. In this case, R is about (64,000 + Ry) acre-feet/year and D is about 59,400 acre-feet/year. A discrepancy of about 8% exists.

It cannot be overemphasized that this balance is rough: several components may have been under or overestimated. The area which is forested by Ponderosa pine and a mixture of Ponderosa pine and Douglas fir may actually permit water to seep downward into the groundwater system at a slow but steady rate. The rate of movement would in fact have to be very slow, for tritium data indicate only relatively 'old' water in these types of areas. In addition, a recharge component Ry from the west or from deeper aquifers may exist and be contributing water to the groundwater system. Groundwater outflow is probably underestimated, for reasons discussed above and in Appendix C. Thus, the estimated value, 3050 acre-feet per year, should be considered a minimum. More pumping tests are required for an accurate determination.

SUMMARY OF CONCLUSIONS

(1) The Permian Yeso and San Andres Formations are the two major stratigraphic units of the area. The San Andres caps the crests of the mountains and ridges and lies for the most part high above the water table and above the piezometric surface within the study area. It is composed mainly of thick limestones interbedded with shales and some sand. The underlying Yeso Formation is exposed in stream canyons and valley bottoms, and comprises the major aquifer of the area. Thin limestones interbedded with much red and

yellow shale, sands and silts, and a persistent consolidated sand and gravel unit make up the Yeso. A persistent limestone unit is found near the top of the Yeso.

(2) The Yeso strata are very variable vertically, but are continuous laterally. Horizontal hydraulic conductivities are therefore probably much larger than vertical hydraulic conductivities. Recharging water will seep slowly down through the Yeso strata, but water within the groundwater system in the Yeso can move laterally with relative ease.

(3) Groundwater moves almost due east towards the Roswell Basin and the Pecos River.

(4) The transmissivity in the Yeso Formation is of the order of 3400 gpd/ft.

(5) The chemical quality of water in the Yeso is excellent, as is that of spring water.

(6) Water exists under unconfined, or water-table, conditions between the mountain crests in the west to the R12/R13 dividing line. This area is the major recharge belt for the area. The location and distribution of this regional semi-perched zone is controlled by a combination of factors, elevation (7000 ft), climate (predominant winter precipitation), and vegetation more restrained in water consumption.

(7) Most of the wells in the area tap a regional confined, or artesian, groundwater system in the Yeso Formation. This system extends eastward at least from the R12/R13 dividing line; it is hydrologically connected with the Roswell Basin. It may continue to the western side of the Sacramento Mountains where it is recharged by precipitation on the western side of the crest.

(8) The piezometric surface is above land surface in the middle and lower parts of Cox Canyon. The flow of the Rio Peñasco is augmented by this water as the river passes through Cox Canyon. The piezometric surface is several hundred feet below the channel bottom in James Canyon, which flows only after heavy storms.

(9) There are a large number of springs in the area. They are of three main types: those that issue at the San Andres/Yeso contact, those which issue where the unconfined water zone in the high mountains intersects the sides and bottoms of the canyons, and those that issue where the piezometric surface is above land surface. Areas of faulted and collapsed strata tend to be associated with springs. The largest of these springs, Posey Spring, is located at the San Andres/Yeso contact where the piezometric surface is

close to the stream bottom along a major fault.

(10) There are probably several major unrecognized faults in the area: one running east-west up Curtis Canyon, one running east-west up McEwan Canyon, and a very large one trending north-northeast along the lower part of Cox Canyon. This latter structure may be the southern extension of the Border Hills structural zone.

(11) An estimated 59,400 acre-feet of water per year are discharged from or used in the James/Cox Canyon area. Recharge is at least 64,000 acre-feet per year. Additional contributions may come from recharge to the western side of the mountain crest, implying a continous groundwater system through the mountains. Alternatively, it may come out of storage. It is emphasized that these figures are rough estimates.

(12) At least 3050 acre-feet of water per year are discharged from the area as underflow, and an undetermined amount leaves the area as flow in the Rio Peñasco. This is recharge to the Roswell Groundwater Basin.

RECOMMENDATIONS FOR FUTURE RESEARCH

The need for a correct understanding of the western flank of the Roswell Basin can only become more urgent with time. This is true not only because of the role the mountain region plays as a recharge zone for the Roswell Basin aquifers, but because the mountainous areas themselves are rapidly being developed. As more people move in, the water resources of the area will be more and more extensively tapped. This study of the area between James and Cox Canyons is but a small step towards such an understanding.

Additional research might include gauging of the drainages in order to (1) establish base flow in the Rio Peñasco, and (2) to correlate runoff in the tributary canyons with rainfall intensity and duration. With such information the amount of water discharged from the area as streamflow and channel losses could be calculated, and a more exact water budget could be developed. The Rio Peñasco should be gauged (1) where it enters the area at the mouth of Wills Canyon, (2) just before it begins to flow over the San Andres Formation near Elk, and (3) at several intermediate points along the stream's length. Spring flow into the Peñasco should be determined more exactly by direct measurement, and more rainfall gauges established in the area. In addition, water levels in wells in lower Cox Canyon and between Mayhill and Elk should be monitored at least bimonthly. If this information were gathered even for a year or two, a far better idea could be obtained of recharge, channel losses and rainfall/runoff relationships for the western part of the Roswell Basin in which the Yeso Formation acts as the aquifer. The evapotranspiration rate for the area should be determined by field monitoring. Hydrologic parameters, such as transmissivity and storativity, should be obtained by pumping tests. A pumping test done with an observation well would be particularly useful, as a storage coefficient could be obtained. This could most readily be done by using wells 7 and 8.

Projects similar to the one completed here should be done for other areas of the western region of the Roswell Basin, e.g., the upper Rio Felix drainage basin. Well inventories should be made and well logs and well schedules obtained. The information could then be treated much as has been done here. A far more accurate idea of the geology of the area would thus be obtained. In addition, tritium and chemical analyses should be performed regularly on selected wells and springs in the area, and at least once on all the wells and springs available. This, it should be noted, would be a monumental task.

The springs of the western region should be inventoried and studied more carefully and extensively than was done by Davis et al. (1980). More stream gauging stations throughout the area, especially on unmonitored drainages as the Rio Felix, Seven Rivers, and the Rio Peñasco, are certainly desirable, but in practice might be difficult to monitor.

In short, there is a wealth of possibilities for research which would contribute greatly both to an understanding of the role the western mountain zone plays in recharging the Roswell Basin, and to safe and sensible development of the areas involved.

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APPENDIX A: Tabulation of Well and Water Level Information

Symbols:

LSD	Land Surface Datum: elevation of land surface above sea level
N	No driller's log available for this well
Y	A driller's log is available for this well
R	Water level reported
M	Water level was measured

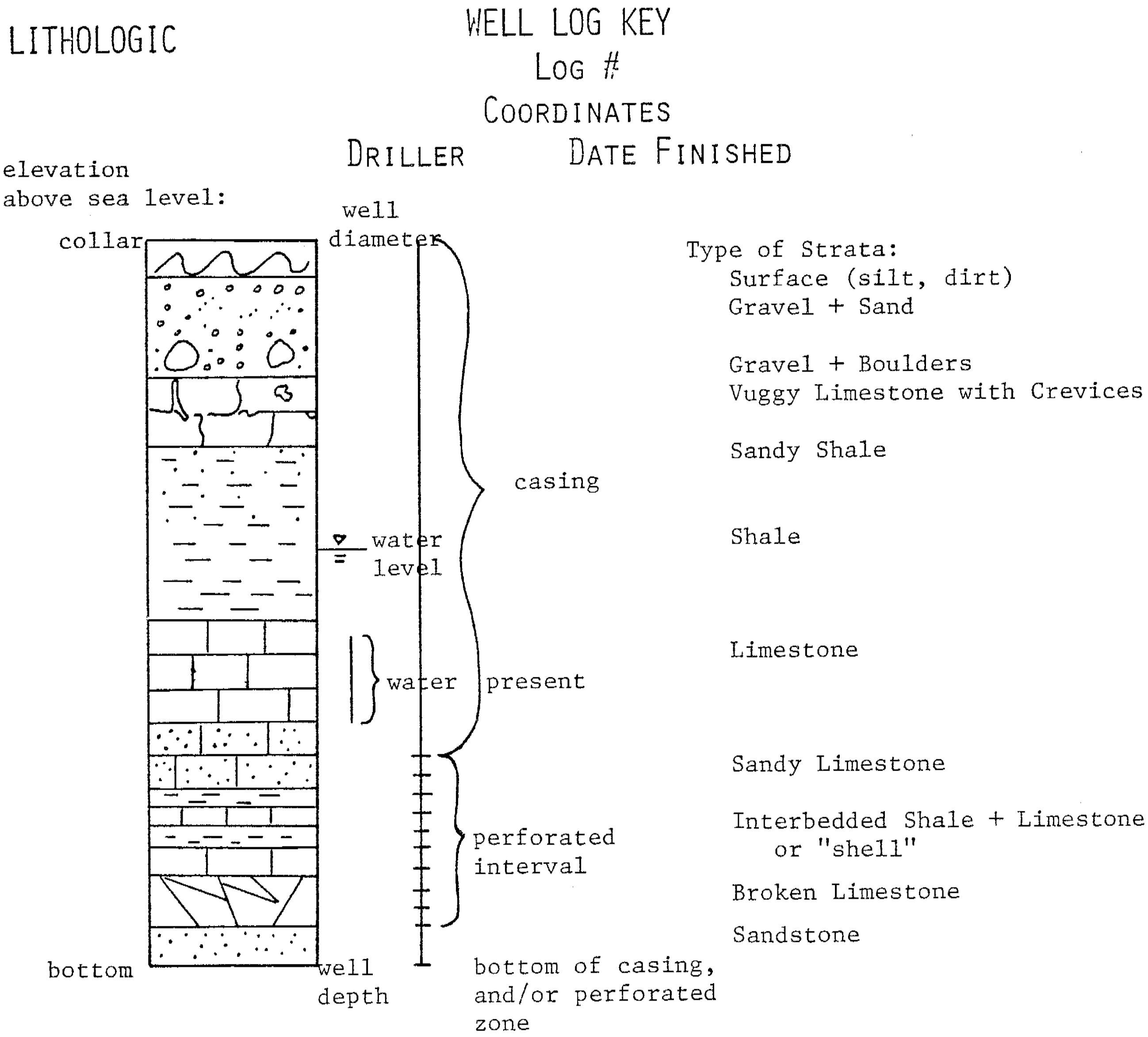
Tabulation of data

11 #	Coordinates	Depth of well (ft.)	Aquifer	Log?	L S D (ft.)	Water Level		
						Date	Depth to water from LSD (ft.)	R or M
75	15.13.28.12421		Py	N	8231.2	10/01/75	86.05	M
						1/24/79	56.12	M
1	16.12.3.142b	172	Py	Y	*8330			
2	16.12.5.333343		Py	N	8730.0	11/11/75	41.09	M
						1/23/79	17.26	M
PP	16.12.5.43131	840	Py	Y		1/04/74	460.0	R
QQ	16.12.6.434422	300	Py	Y	8796.1	i/07/74	255.0	R
						75	259	R
3	16.12.6.441313	336	Py	N	8765.1	11/11/75	229.38	M
4	16.12.8.114121a	226	Py	Y	8738.1	7/16/75	35.0	R
						11/11/75	43.07	M
A	16.12.24.33112	328	Py	Y	7805.6	3/20/62	295.0	R
						3/11/74	330.0	R
5	16.12.25.24142	348	Py	Y	7793.2	10/18/72	280	R
						3/12/74	238.60	M
7	16.13.31232	412	Py	Y	7622.6	5/18/64	300	R
							250.66	M
8	16.13.4.44141	415	Py	Y	7548.1	1/29/73	31	R
							343.70	M
10	16.13.6.24430	398	Py	Y	7841.5	3/15/74	322.35	M
						1/24/79	296.25	M
11	16.13.9.424434	652	Py	Y	7641.2	5/03/72	515	R
						3/20/74	514.94	M
L	16.13.10.12242	400	Py	Y		8/31/74	30	R
12	16.13.11.11122	596	Py	Y	7521.5	6/26/72	470	R
						3/15/74	454.21	M
						1/24/79	436.31	M
13	16.13.11.43244	127	Py	Y	7353.1	8/15/56	100	R
						3/12/74	106.90	M
						1/31/79	104.28	M
14	16.13.13.41343	445	Py	Y	7260.7	7/03/59	420	R
						3/15/74	398.95	M
15	16.13.13.44410	400	Py	Y	7190.2	/68	370	R
						1/24/79	366.57	M
16	16.13.18.32310	200	Py	N	*8230	3/16/74	133.40	M
17	16.13.19.42320		Py	N	*8220	3/16/74	126.84	M
D	16.13.23.44134	315	Psa	Y	*8235	2/25/78	Dry	R
E	16.13.29.3342	303	Py	Y	7625.5	8/03/62	245	R
18	16.13.30.13311	200	Py	Y	7741.7?	06/73	125	R
						3/12/74	193.43	M
19	16.13.30.32114	375	Py	Y	7737.5?	1/06/66	265	R
						3/12/74	194.79	M

						1/23/79	183.50	M
20	16.13.30.4320	260	Py	Y	7640.9	3/12/74	99.00	M
						1/23/79	86.81	M
21	16.13.30.44230	260	Py	Y	7646.6	2/01/60	176	R
						1/23/79	162.00	M
H	16.14.10.14311	740	Py	Y	*7210	11/03/60	716	R
22	16.14.13.4430	295	Py	Y	6501.9	7/17/58	255	R
						3/13/74	246.18	M
25	16.14.18.43331	305	Py	Y	*7057	9/6/75	277	R
						1/31/79	274.82	M
26	16.14.20.12122	354	Py	Y	7044.4	8/25/63	318	R
27	16.14.21.21333	315	Py	Y	6848.9	3/20/74	256.53	M
						1/31/79	253.32	M
28	16.14.23.24221	319	Py	Y	6648.4	10/05/55	280	R
						3/13/74	Dry > 319	M
						3/12/74	311.33	M
30	16.14.26.32121		Qal	N	6568.1	3/18/74	22.40	M
						1/31/79	18.96	M
31	16.14.26.41343	100	Qal?	Y	6523.4	1/22/74	25	R
						3/14/74	76.56	M
32	16.14.34.22440	110	Qal?	Y	6625.2	4/14/65	32	R
						3/14/74	29.93	M
						1/31/79	31.60	M
N	16.14.34.24333	110	Qal	Y	6642.7	6/01/56	52	R
33	16.15.18.32323	468	Py	Y	*6082	11/23/56	433	R
						2/01/79	374.91	M
34	16.16.3.133432	85	Qal	N	5754	8/03/54	47.18	M
						1/09/64	48.43	M
54	17.14.3.12144	114	Qal?	Y	6694.4	11/04/55	114	R
						3/14/7	54.90	M
						1/24/79	52.49	M
55	17.14.3.1341	165	Qal	Y	6740.4	10/30/55	122	R
						3/15/74	84.36	M
63	17.14.4.44421	250	Py	N	7250	3/13/74	89.6	M
						1/25/79	74.85	M
56	17.14.6.43331	105	Qal	Y	6895.8	7/02/55	20	R
						3/14/74	7.41	M
						1/23/79	10.71	M
57	17.14.8.12111	105	Qal	Y	6850.9	5/22/53	33	R
						3/14/56	36.87	M
						1/04/57	36.49	M
						3/15/74	29.78	M
						1/22/75	29.38	M
						1/23/79	29.81	M
58	17.14.8.22133	127	Qal	Y	*6760	6/01/61	5.5	R
						1/23/79	1.42	M
67	17.14.9.12333	202	Py	Y	6777.4	5/21/56	167	R
						1/23/79	27.80	M
68	17.14.10.11133	131	Qal	Y	6699.2	11/30/55	105	R
						3/15/74	19.73	M
						1/24/79	16.62	M
CC	17.14.17.31224	515	Py	Y	*7010	3/15/54	400	R
DD	17.14.18.34442	868	Py	Y	*7518	12/09/70	798	R

APPENDIX B

WELL LOGS



"water present" reported by driller

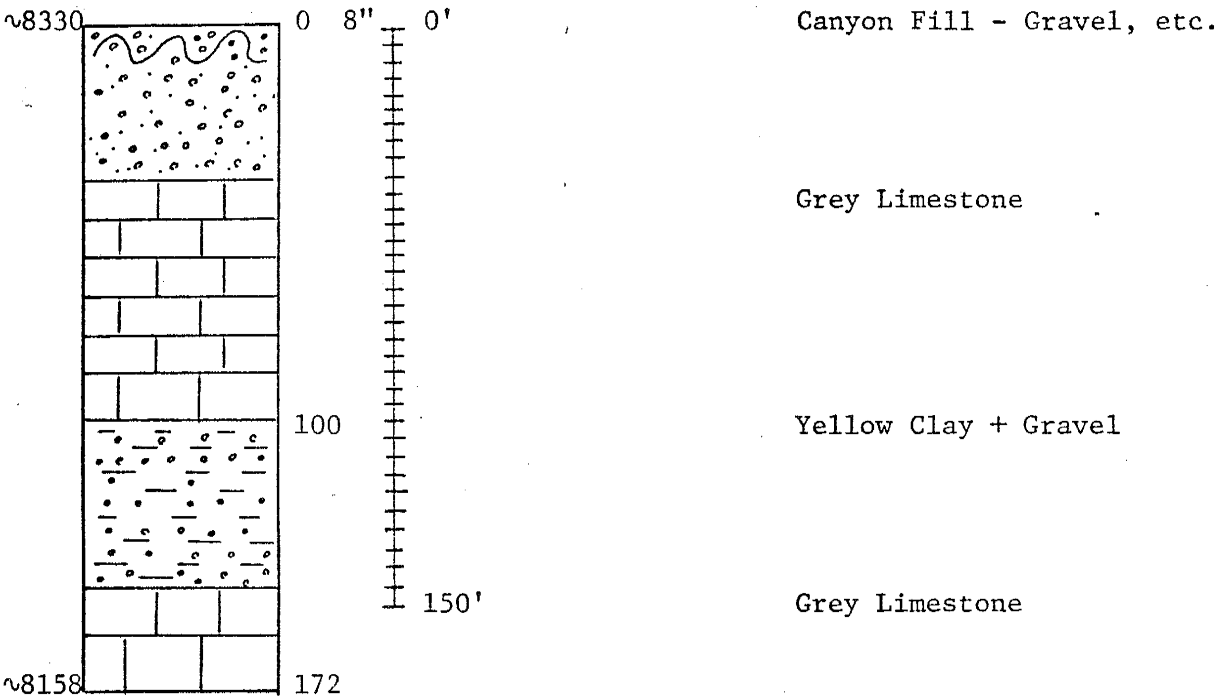
"water level" measured by Roswell State Engineer Office

Figure 24.

1

16.12.3.142b

Taylor 1956



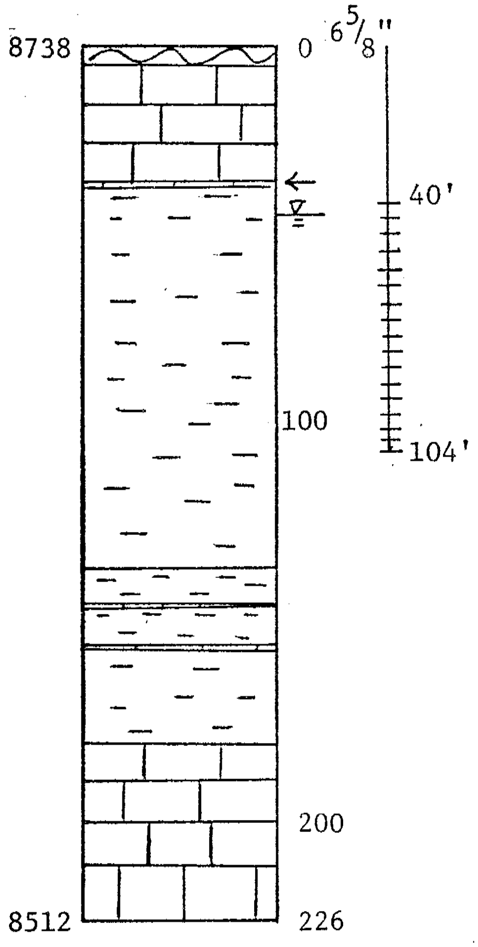
Water in canyon fill. Unknown where water 1st occurs if it is artesian. Probably is.

Figure 25

4

16.12.8.114121a

Weehunt 6/16/75



Top Soil
Brown Limestone
Grey Limestone
Brown Limestone + Water
Red Bed (clay + shale)

$\frac{\text{S.A.}}{\text{Yeso}}$

Brey Shale + Clay
Brown Limestone
Red Bed (clay + shale)
Grey Limestone
Red Bed (clay + shale)

Brown Limestone
Grey Limestone
Brown LImestone-sofe

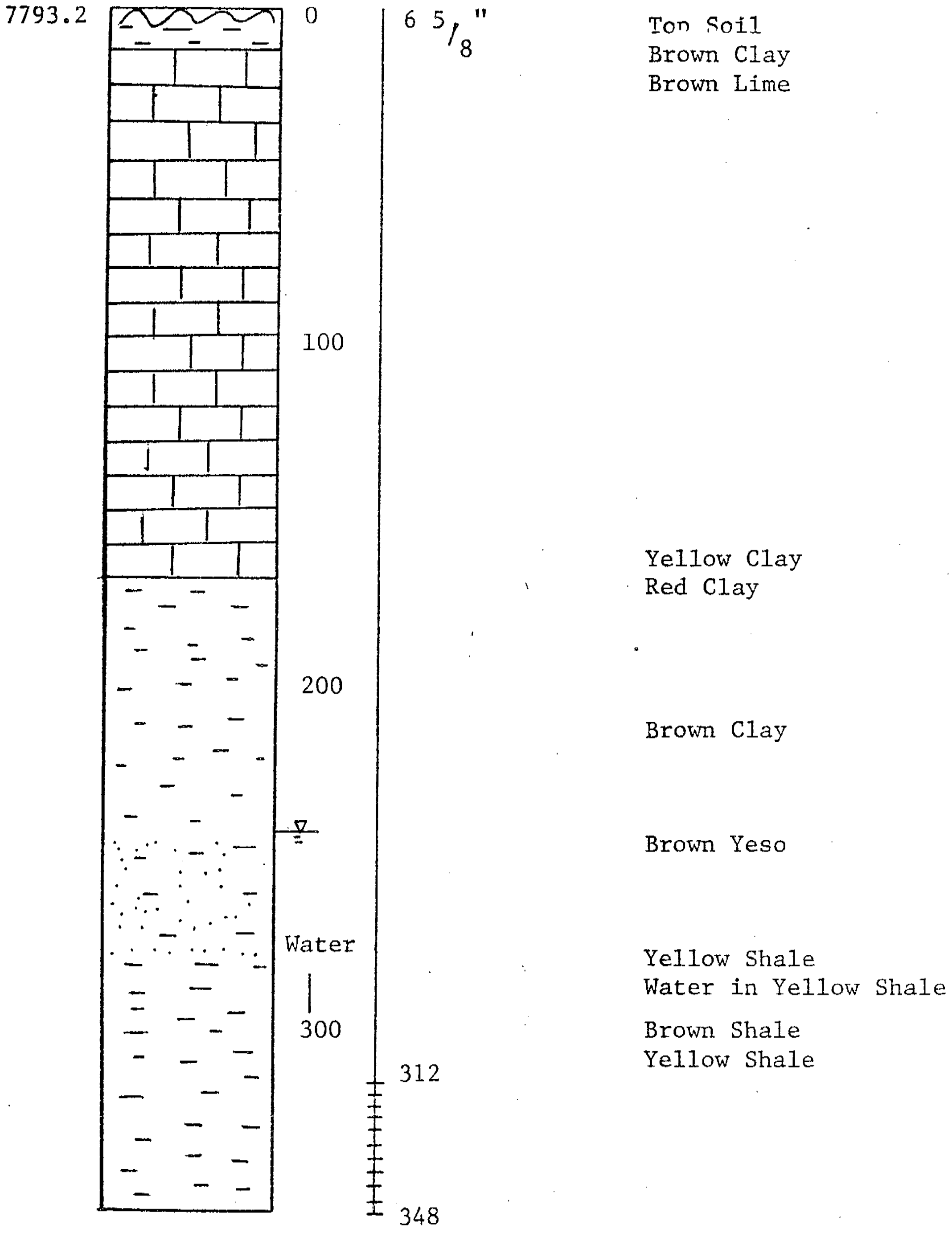
Water: 35' - 36' in Brown Limestone
1 gpm

Figure 26

5

16.12.25.24142

N.M. Drilling 10/18/72



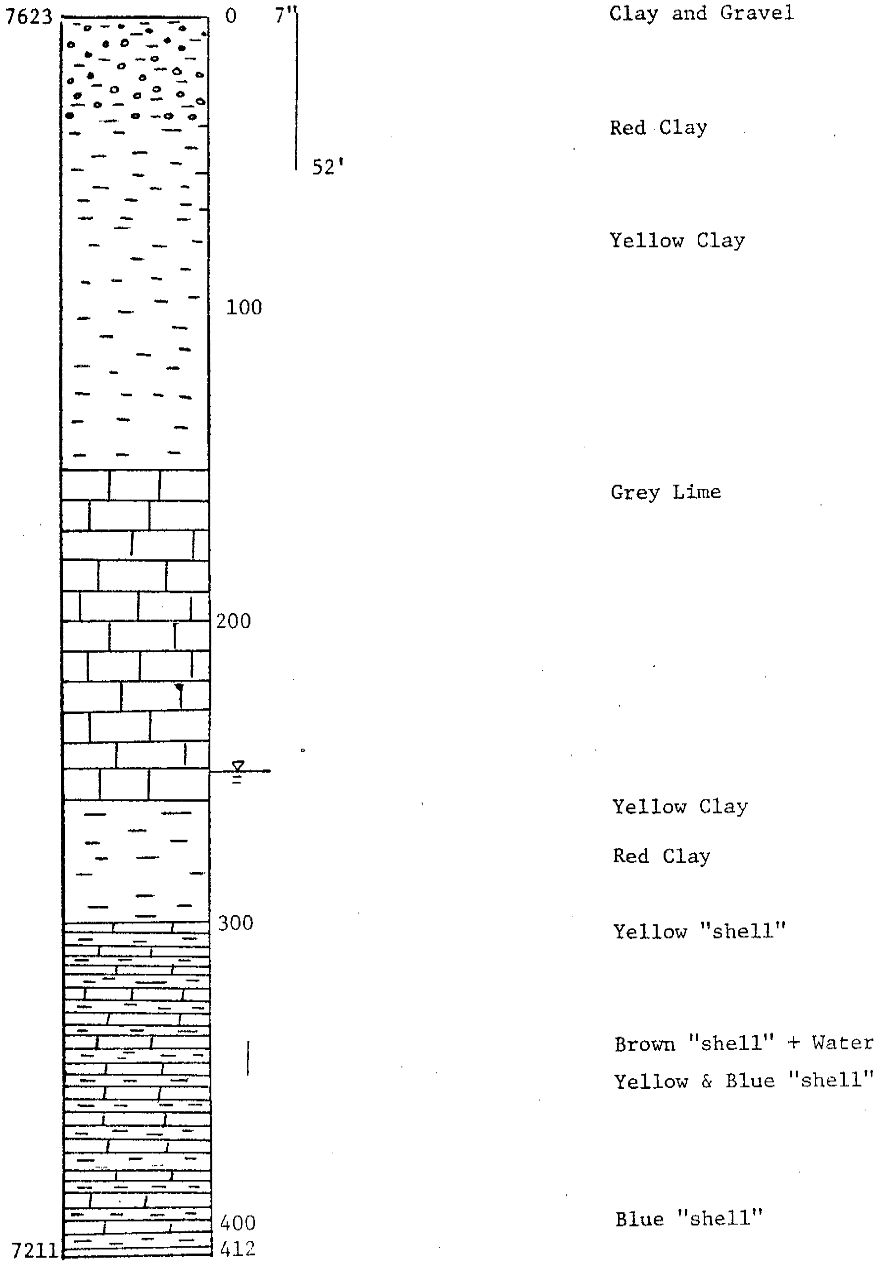
Water: 280 - 292' in Yellow Shale

Figure 27.

7

16.13.31232

5/18/64



went down
to 600'
summer '80
but no log
available

Water: 340-352' in brown shell with a little sand.

Figure 28

8

16.13.4.44141

N.M. Drilling 1/29/73

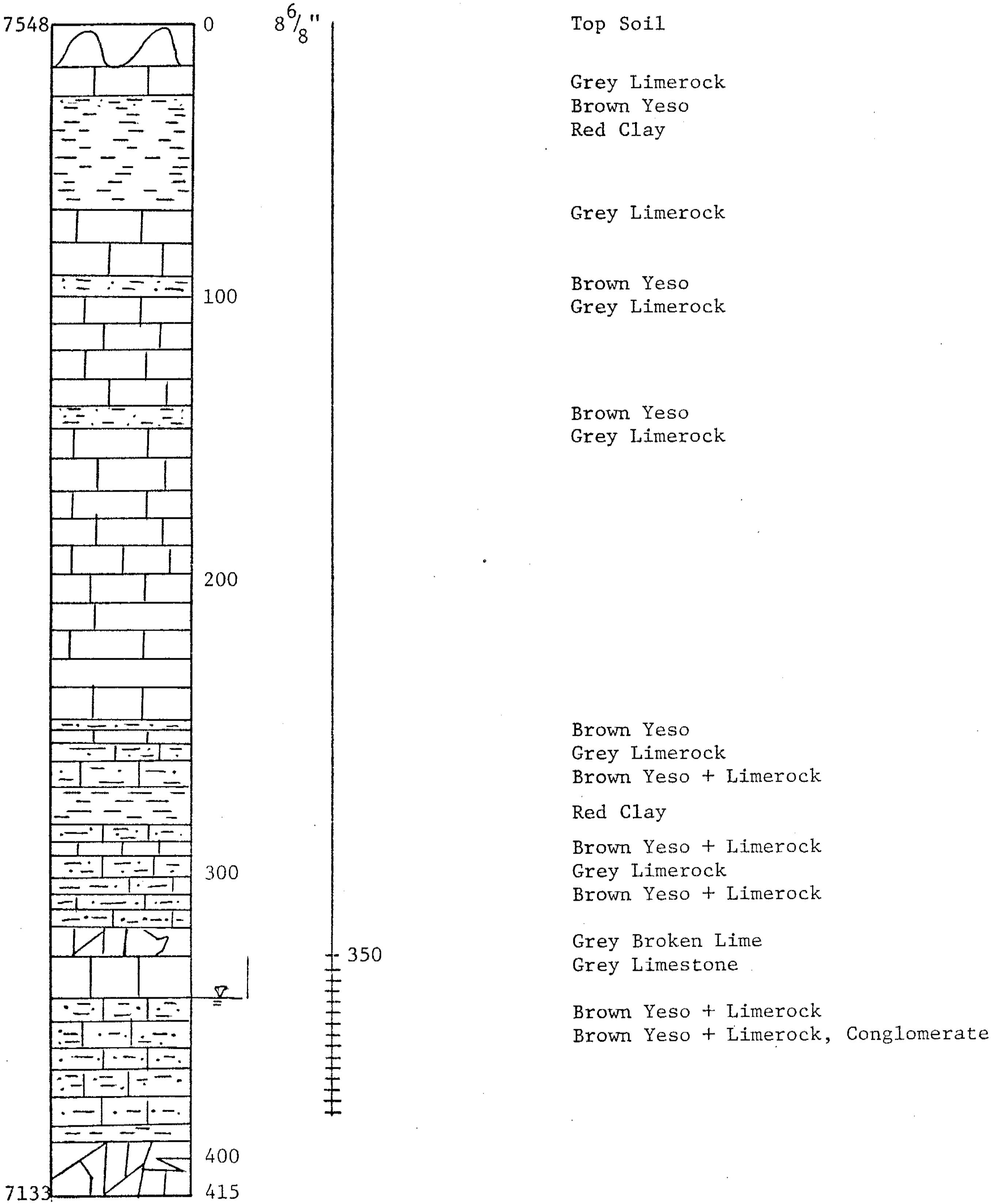


Figure 29

11

16.13.9.424434

N.M. Drilling 5/3/72

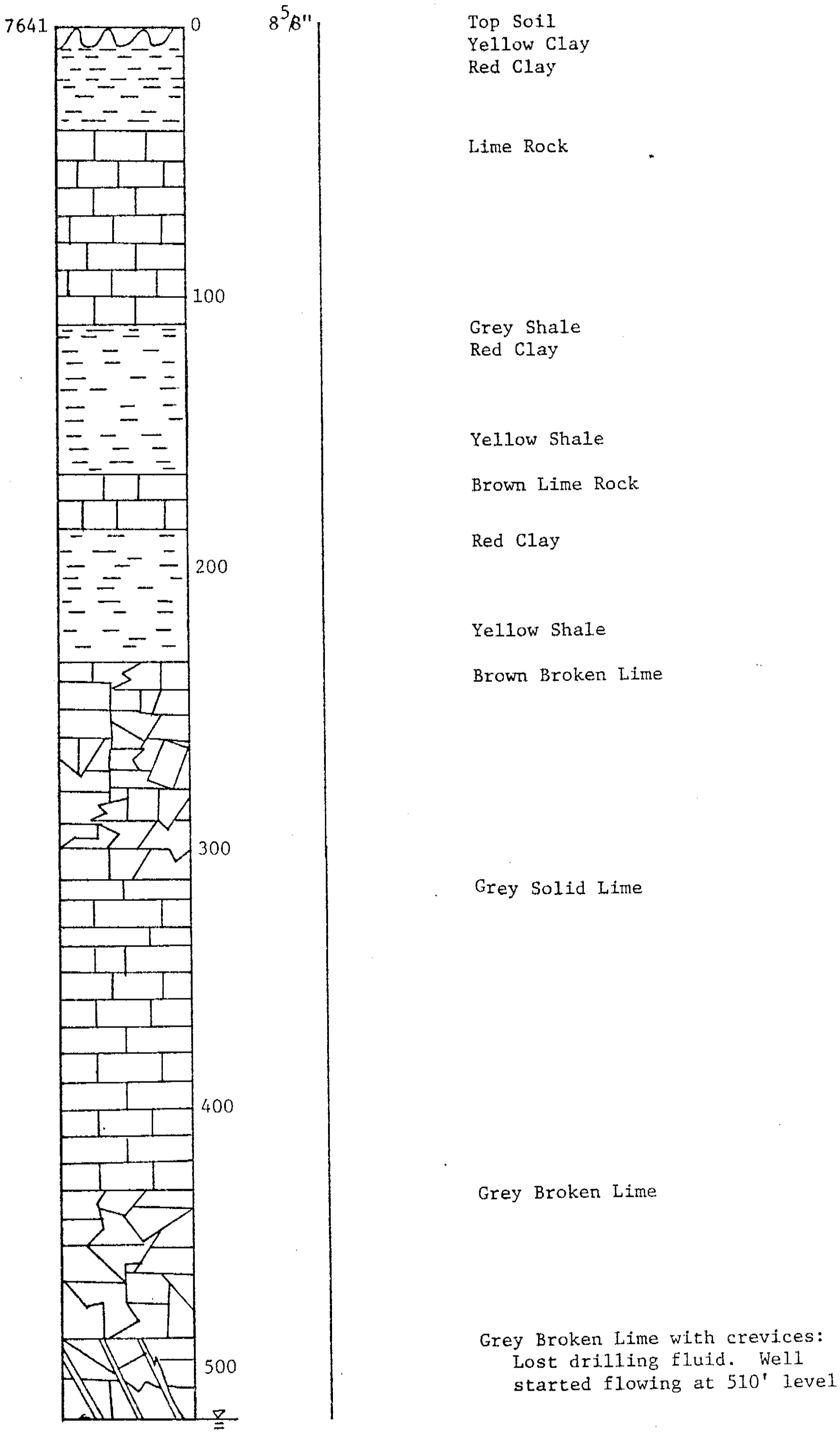


Figure 30

11 Cont.

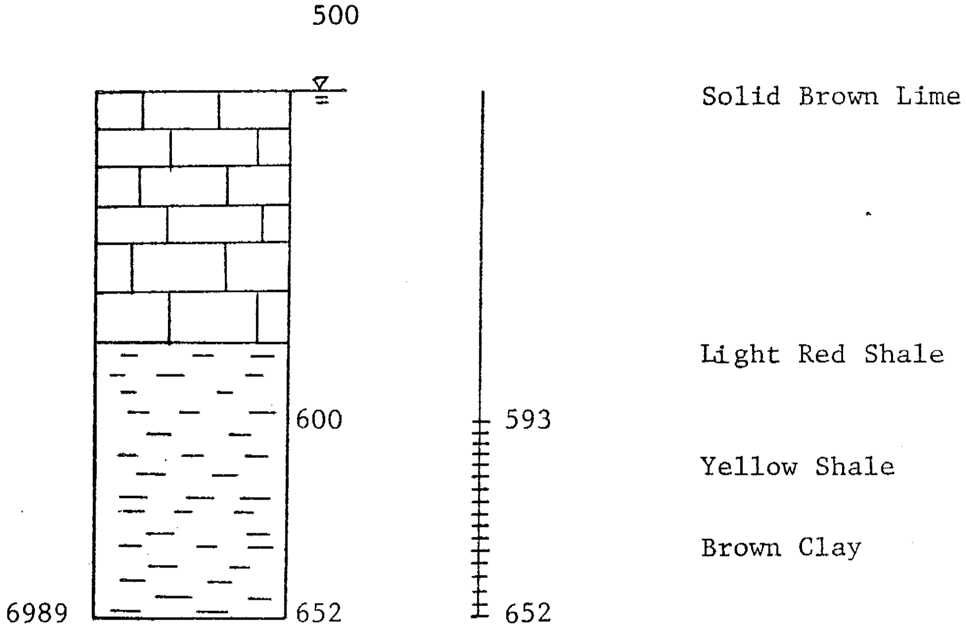


Figure 30 (con't)

10

16.13.6.24430

N.M. Drilling 8/10/72

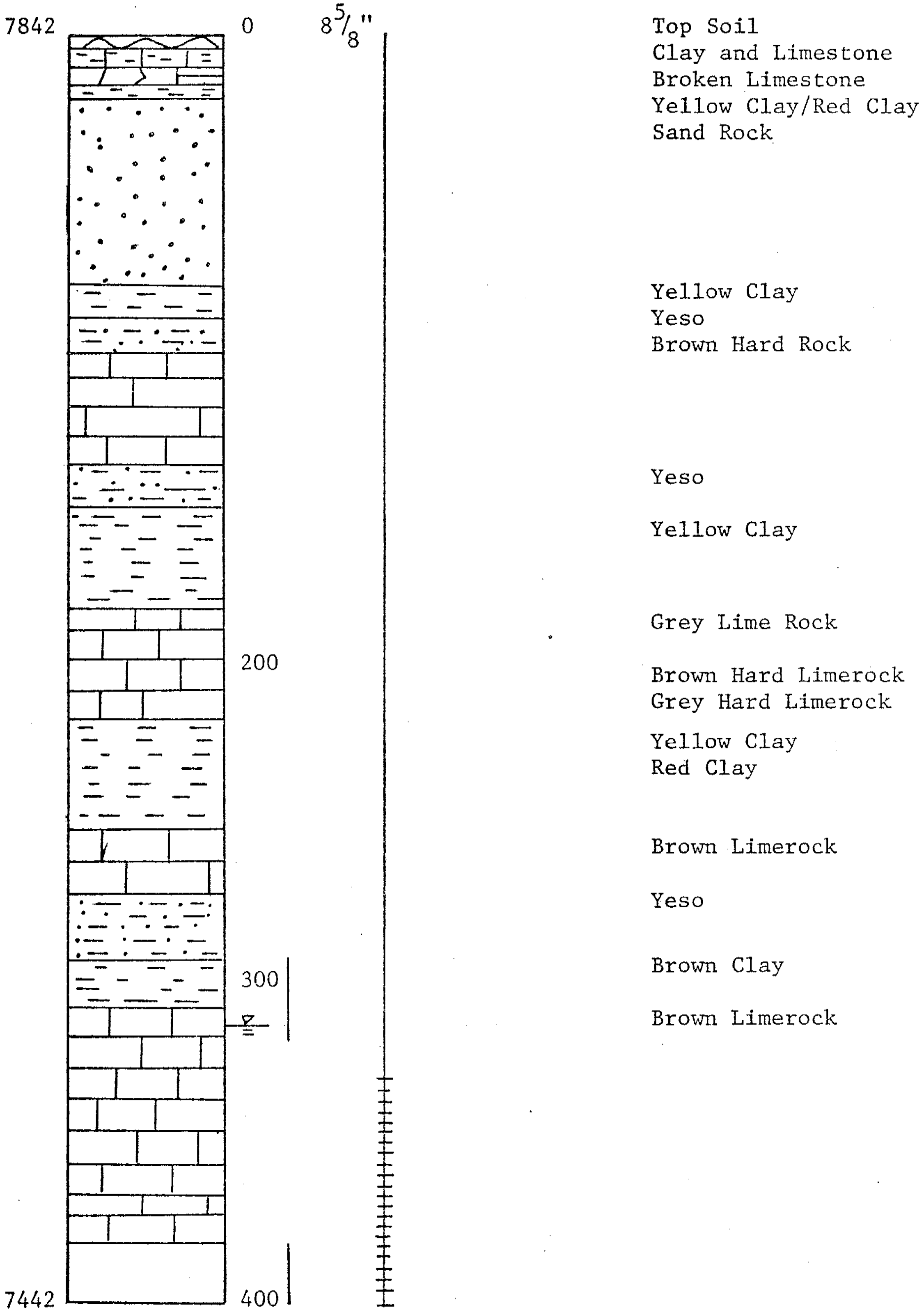


Figure 31

12

16.13.11.11122

N.M. Drilling

6/26/72

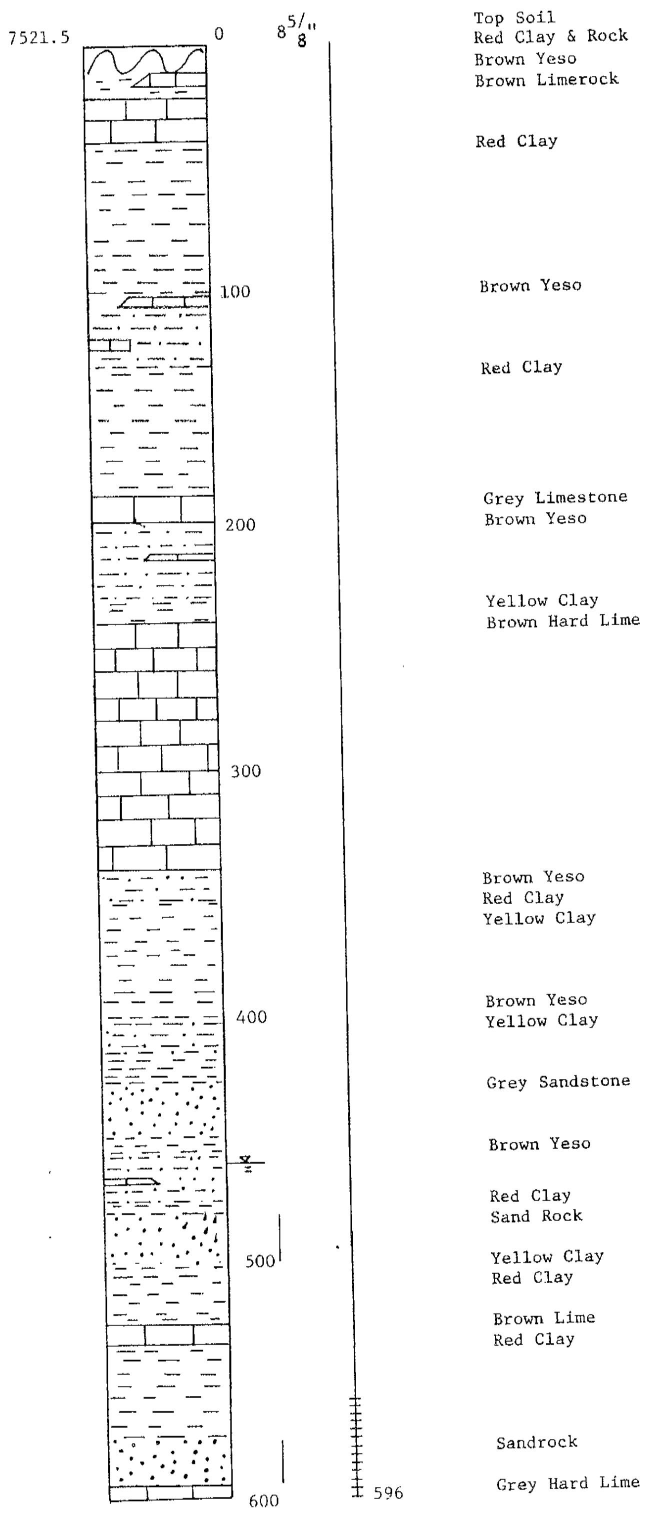
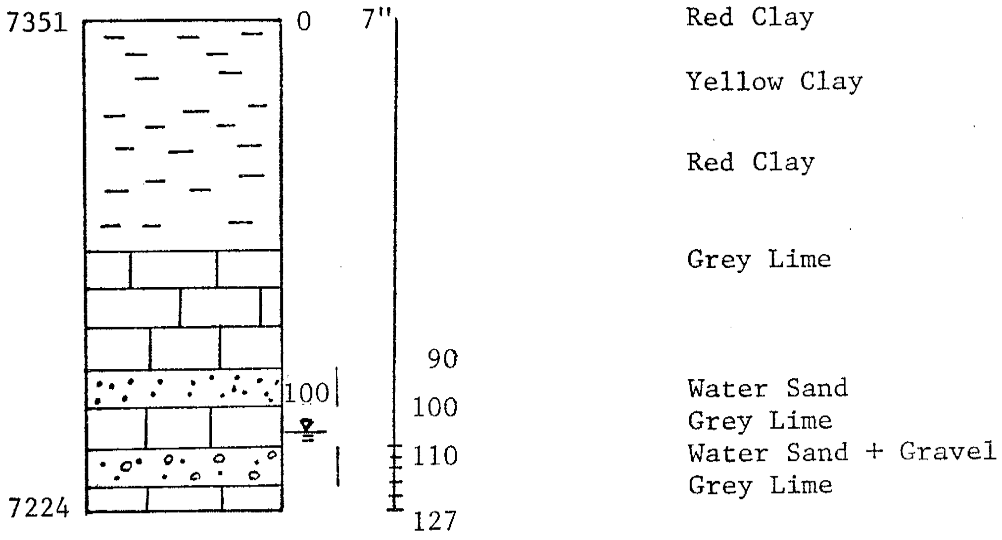


Figure 32

13

16.13.11.43244

Beaty 8/15/56



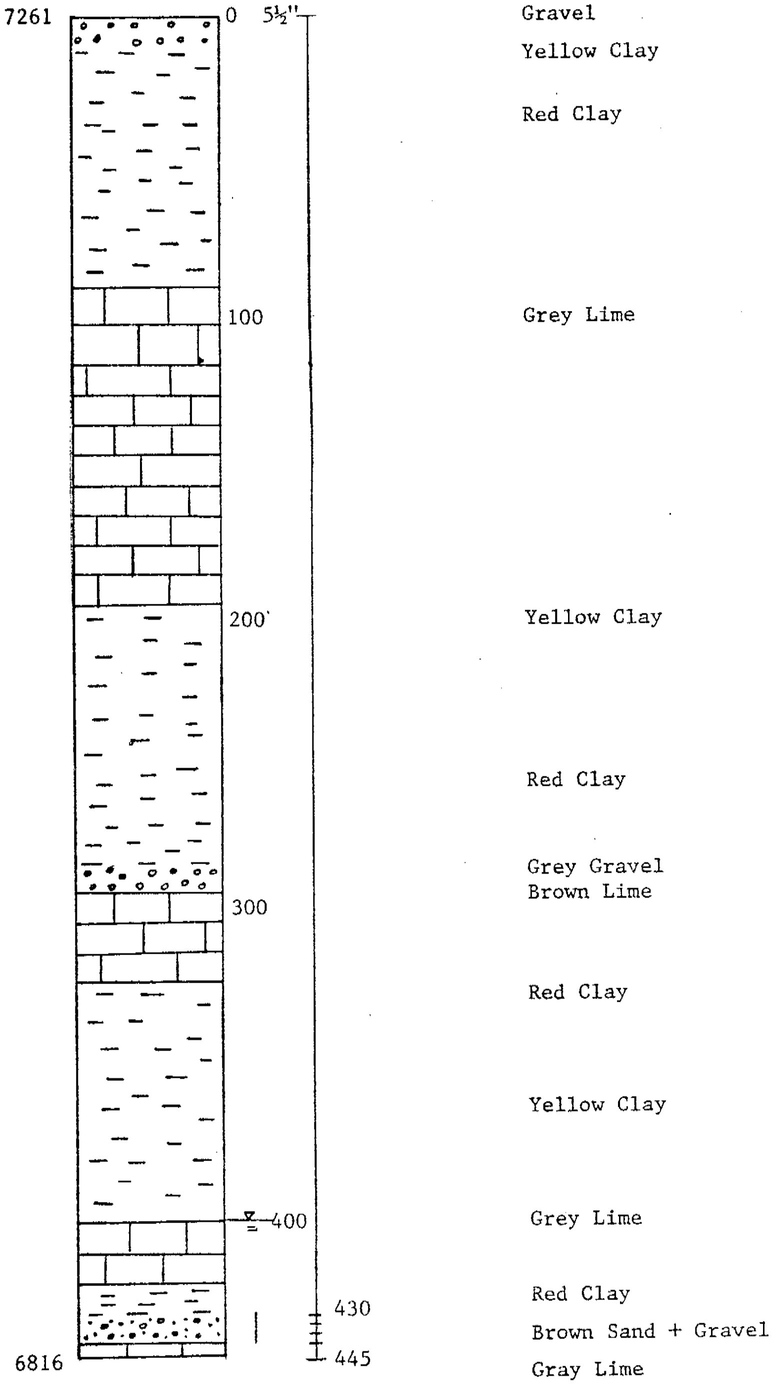
Water: 90 to 100' in sand; 110 to 120' in sand and gravel

Figure 33

14

16.13.13.41343

Beaty 7/3/59

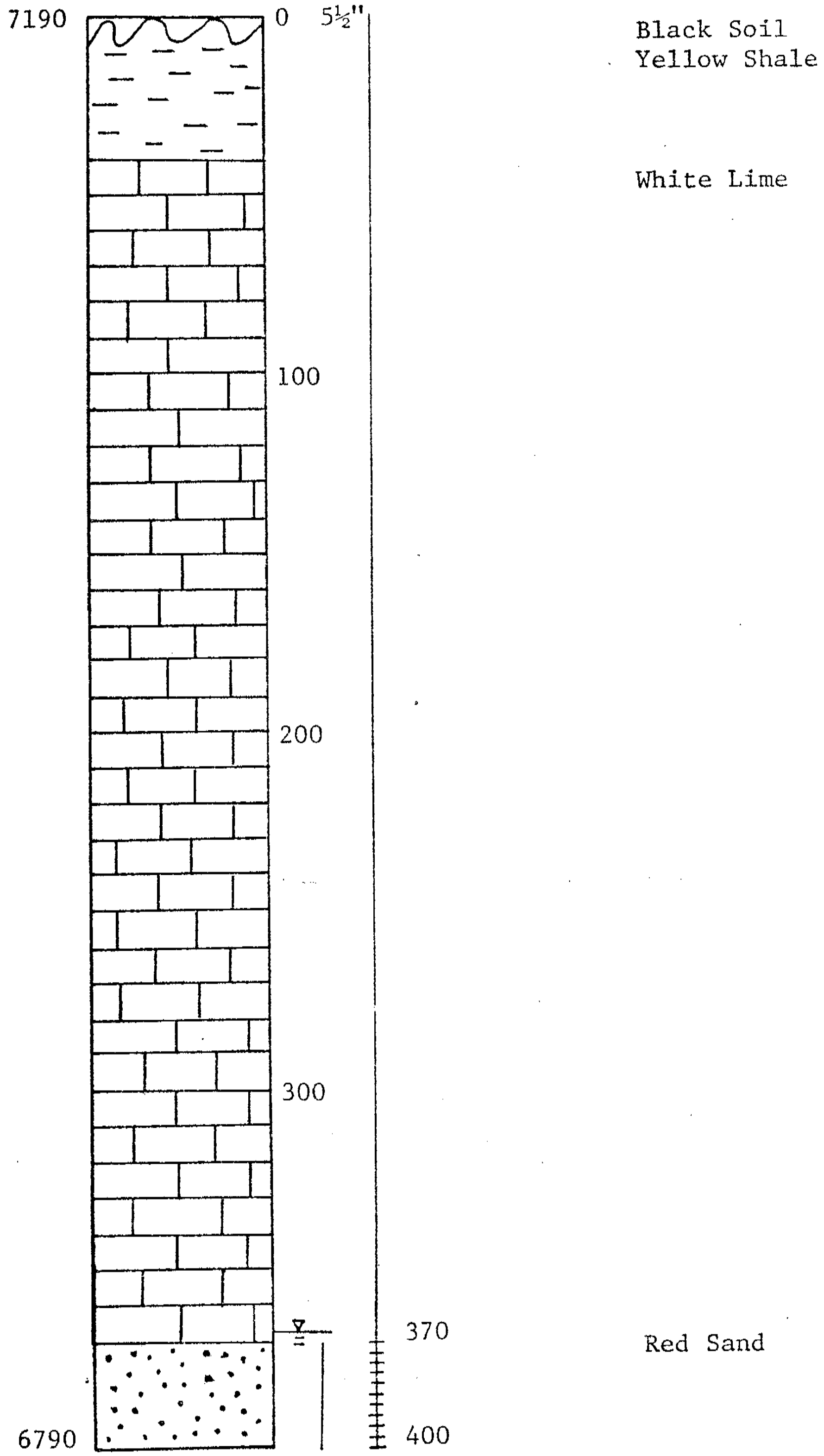


Water: 400 to 440' in sand + gravel

Figure 34

16.13.13.44410

Adkins



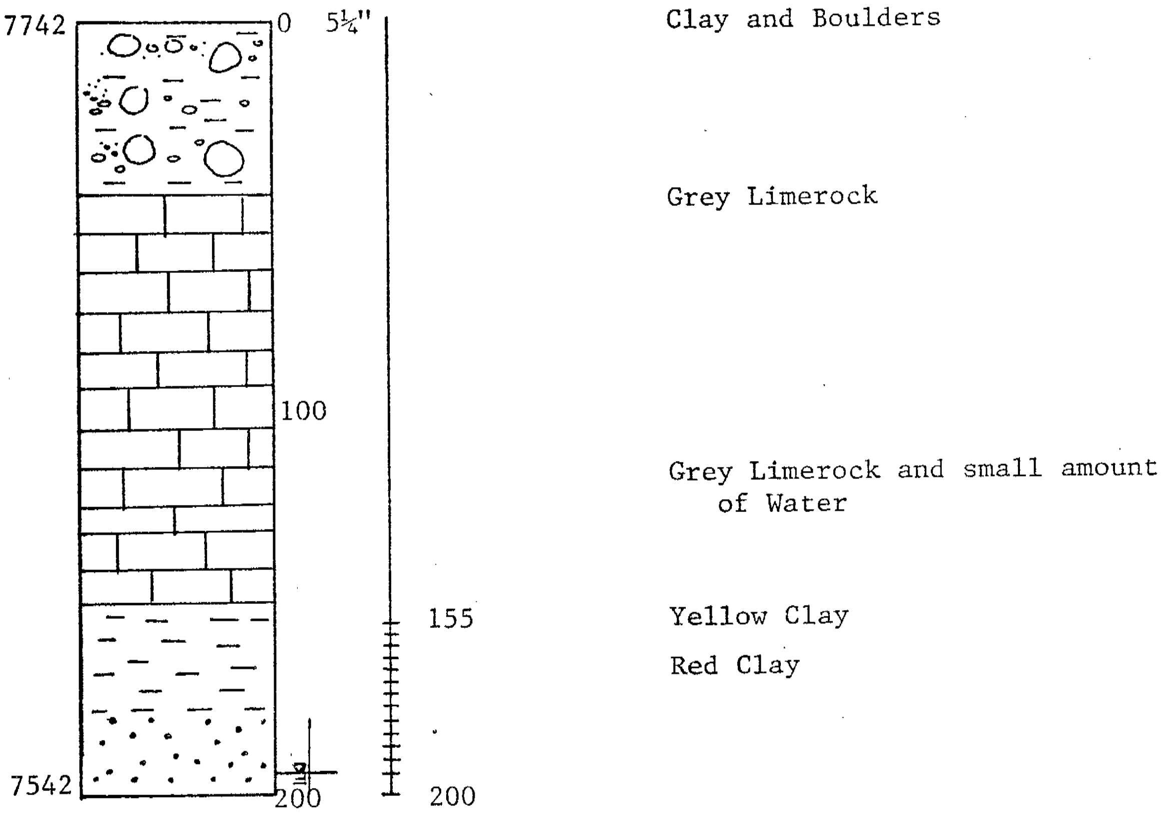
Water: 370 to 400' in Red Sand

Figure 35

18

16.13.30.13311

Quick 6/73



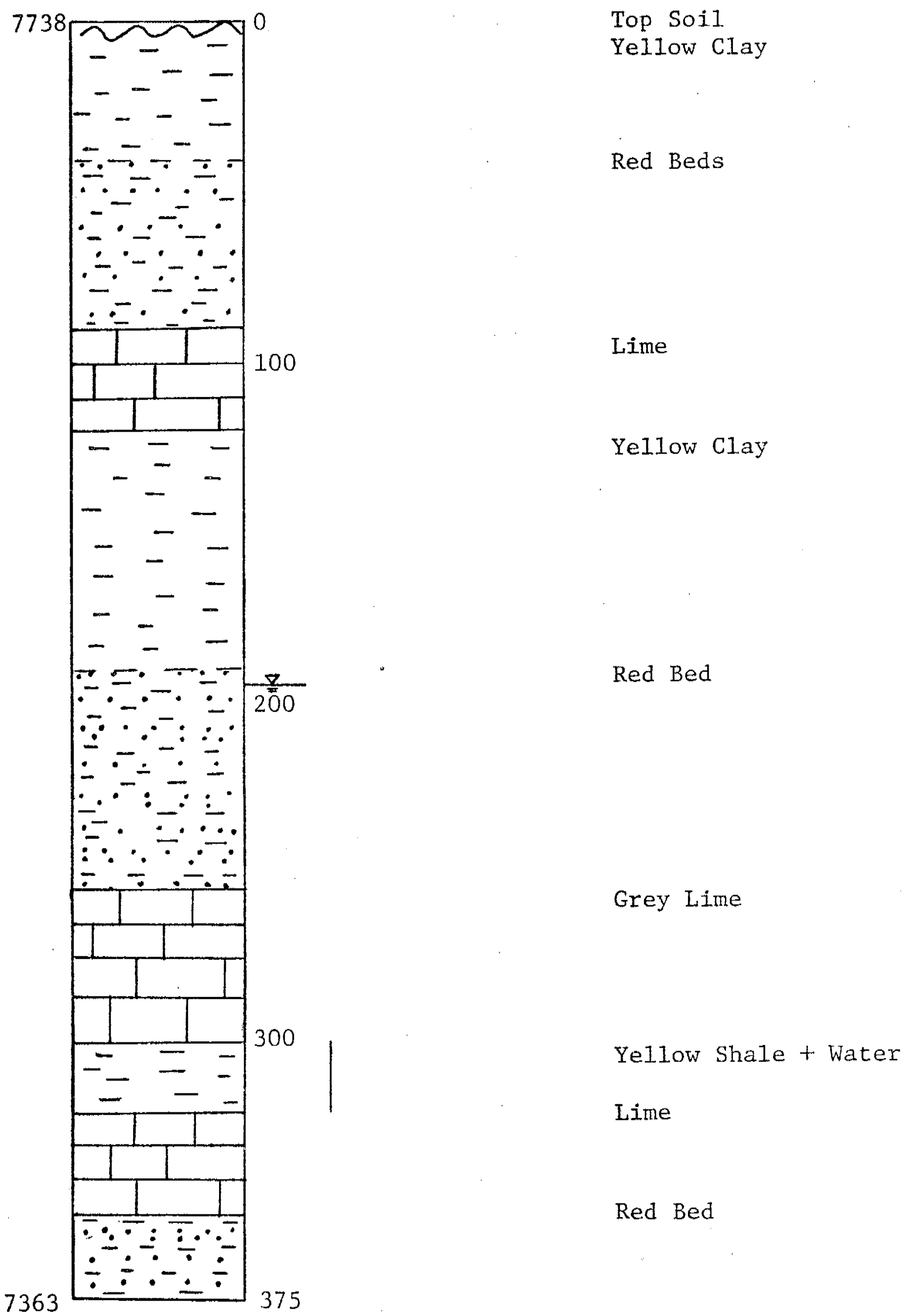
Water: 180 to 200' in Yellow Sand
Yields 30 gpm

Figure 36

19

16.13.30.32114

Beaty 6/66



Water: 300 to 320' in Yellow Shale

Figure 37

20

16.13.30.4320

Quick ~8/73

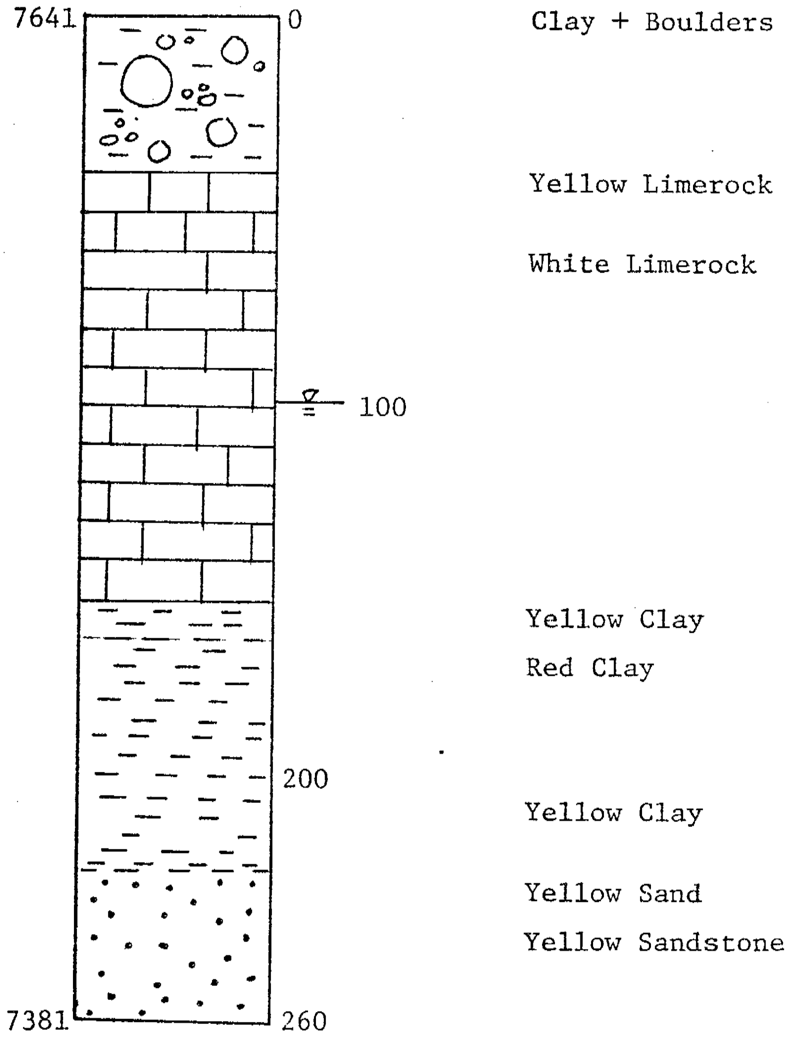


Figure 38

16.13.30.44230

Bonnell 2/1/60

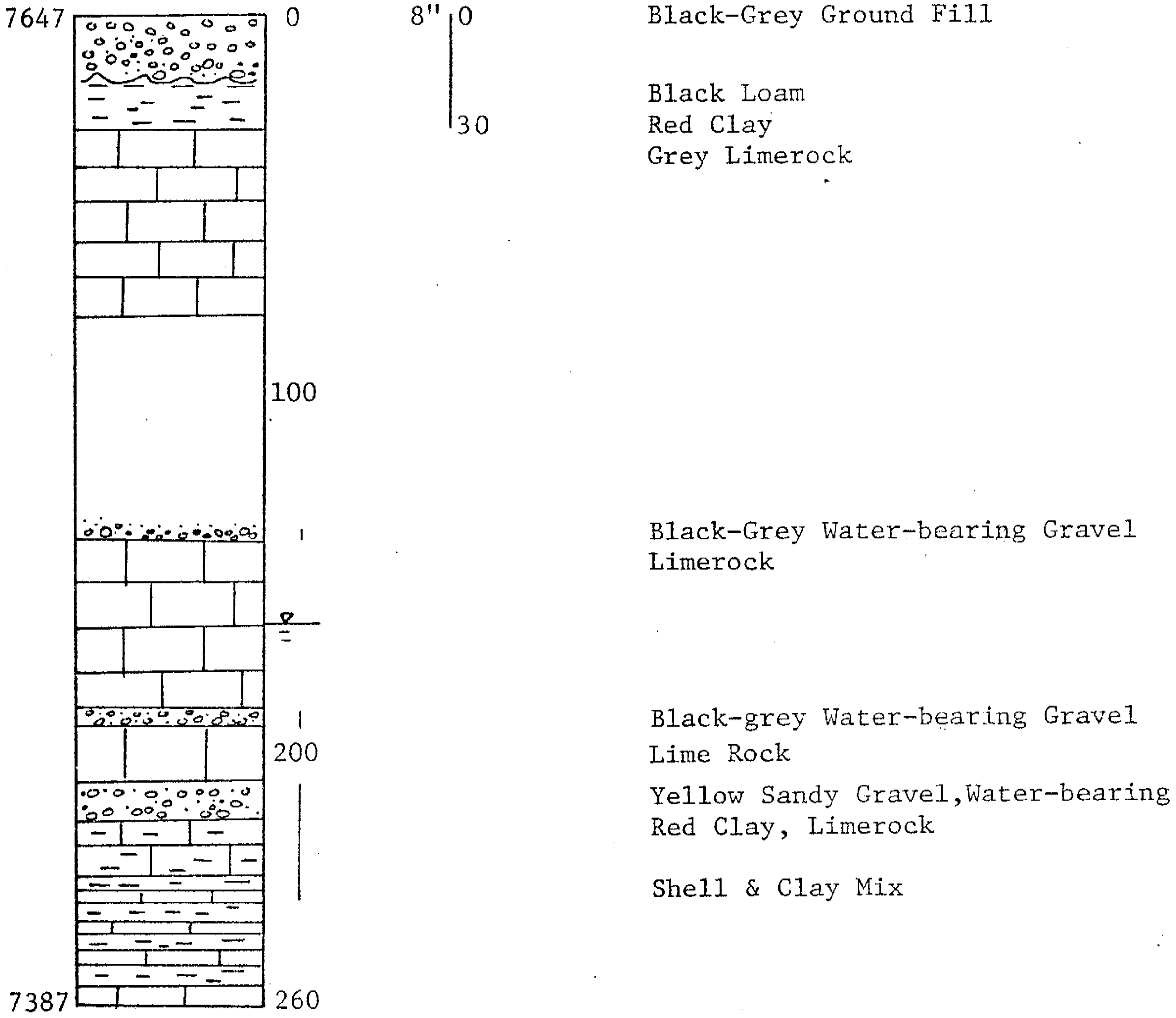


Figure 39

16.14.13.4430

Beaty 7/17/58

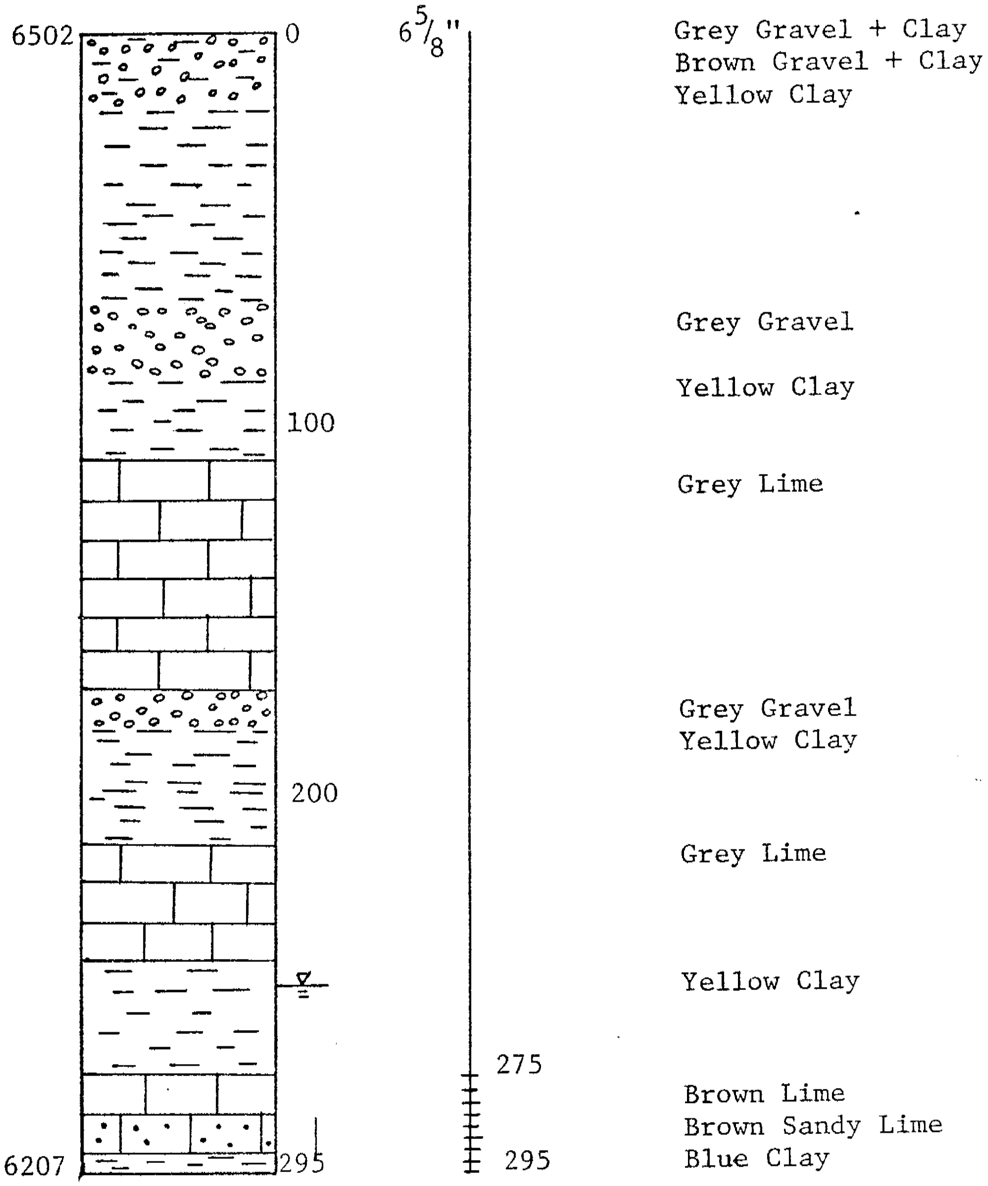


Figure 40

25

16.14.18.43331

Beaty 9/6/56

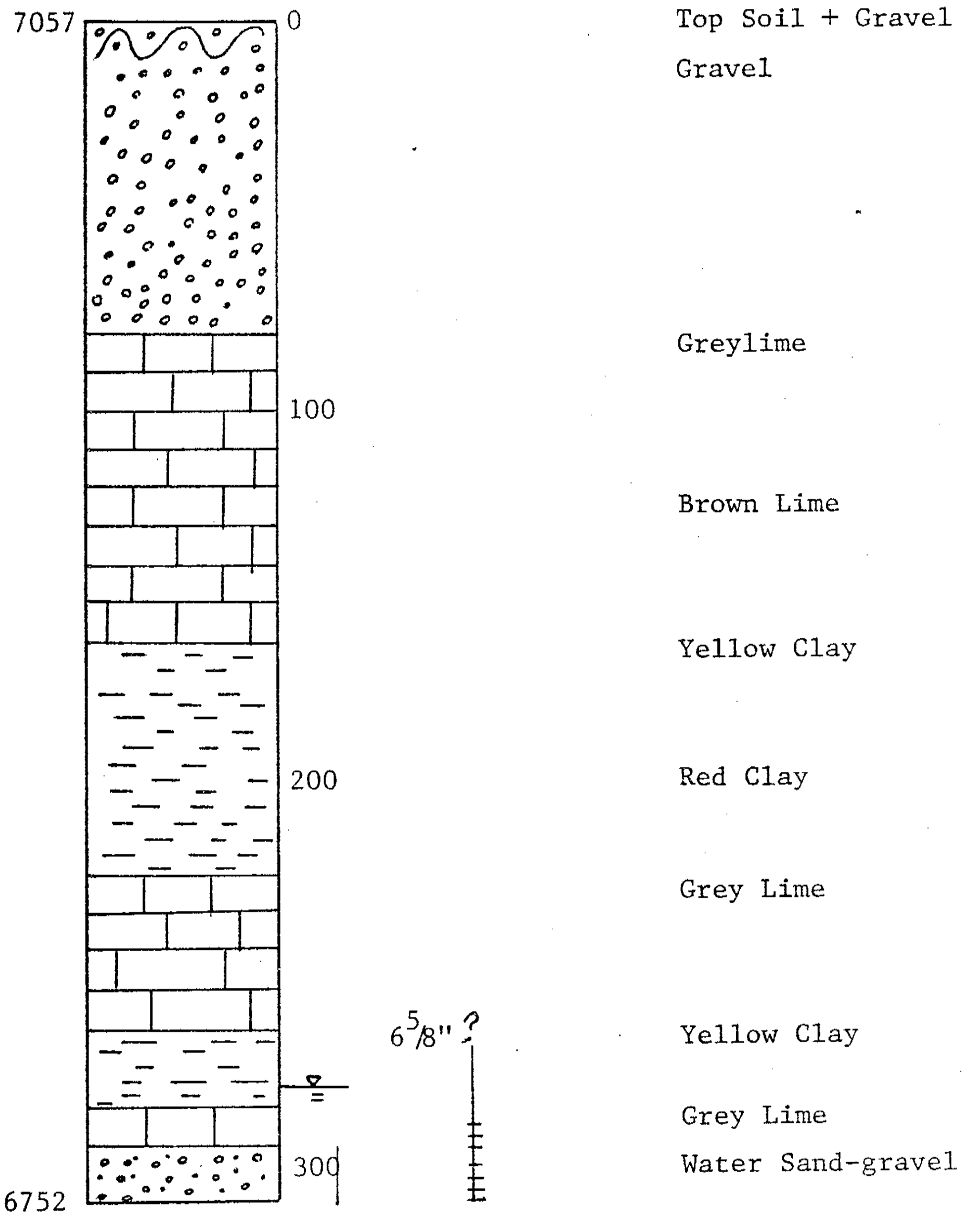


Figure 41

26

16.14.20.12122

Markes 8/25/63

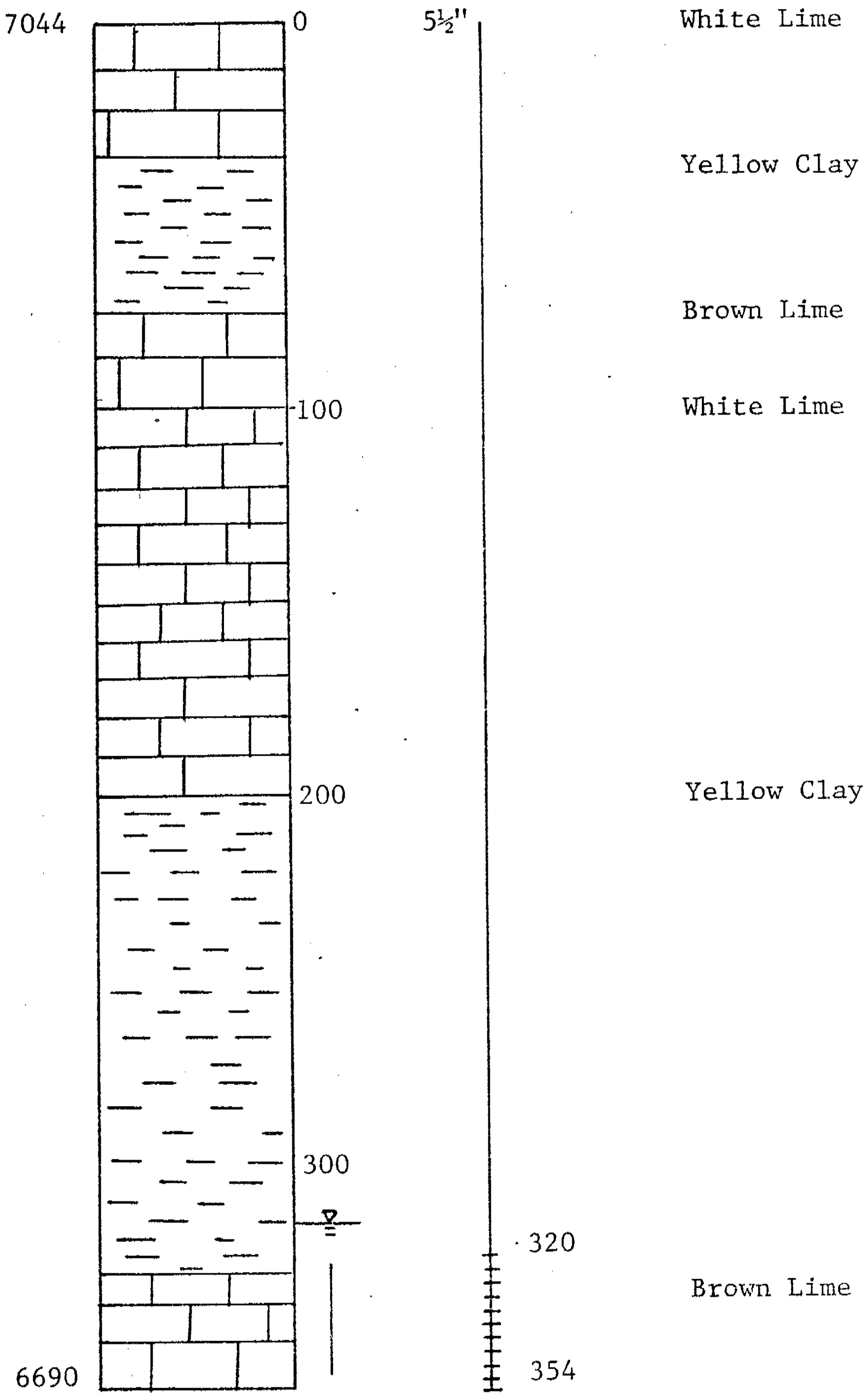


Figure 42

27

16.14.21.21333

Beaty 9/18/56

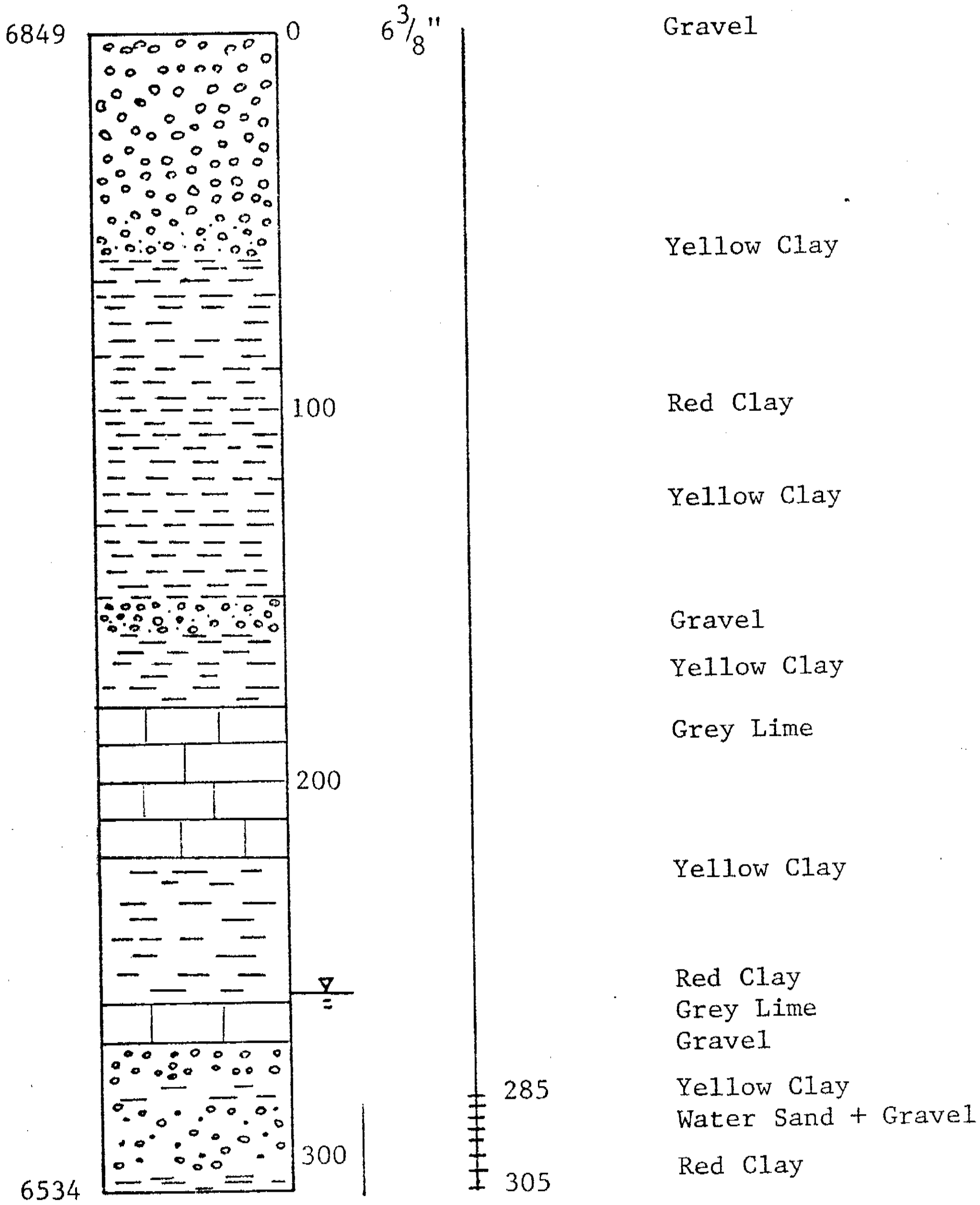
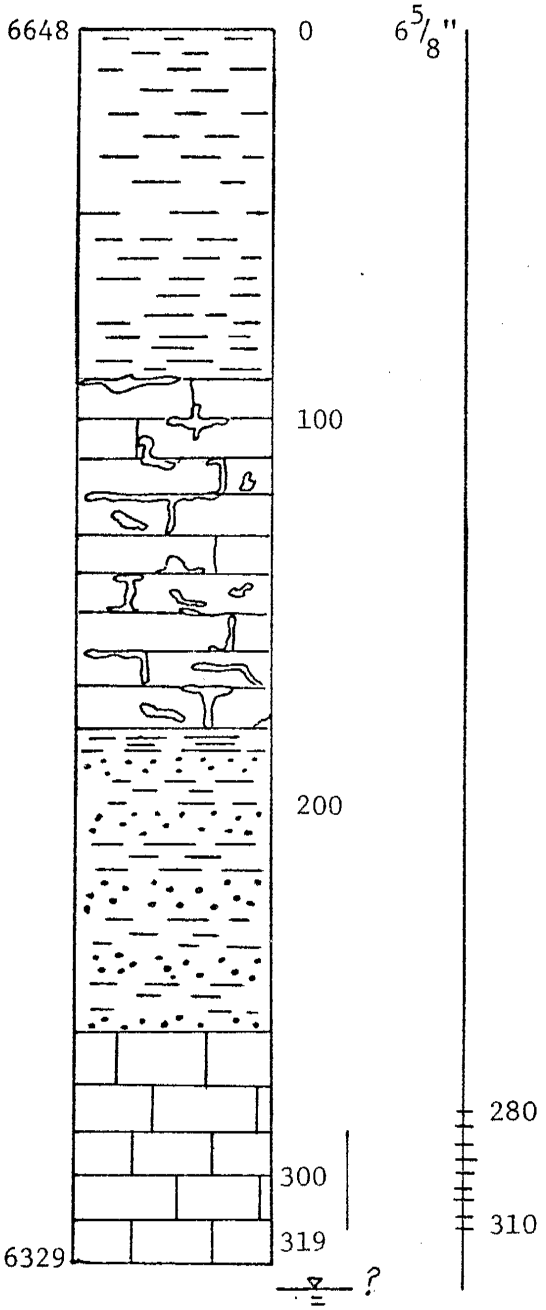


Figure 43

16.14.23.24221

Harris 10/5/55



Clay + Shale

Rotten Limestone

Clay, Shale + Sandstone

Blue Lime

Yellow Limestone, Water

Figure 44

31

16.14.26.41343

Bratiel 11/22/74

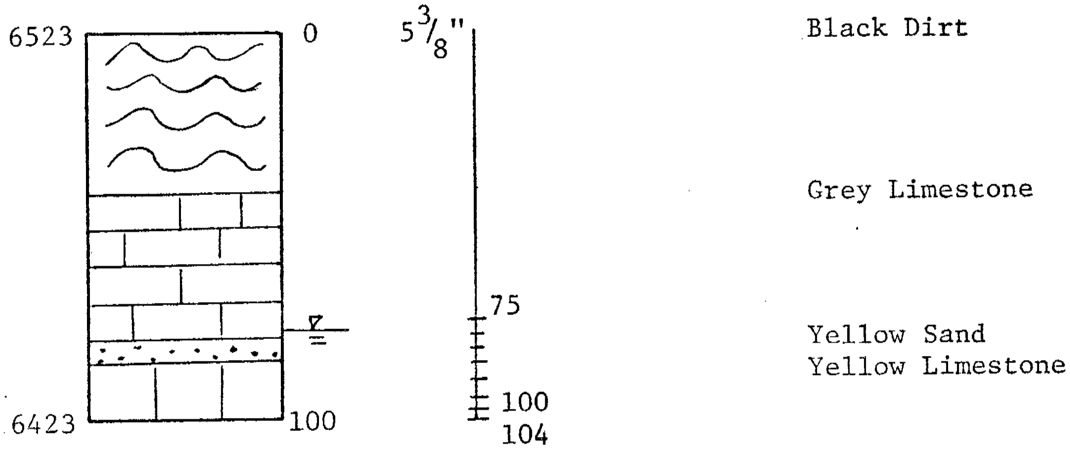
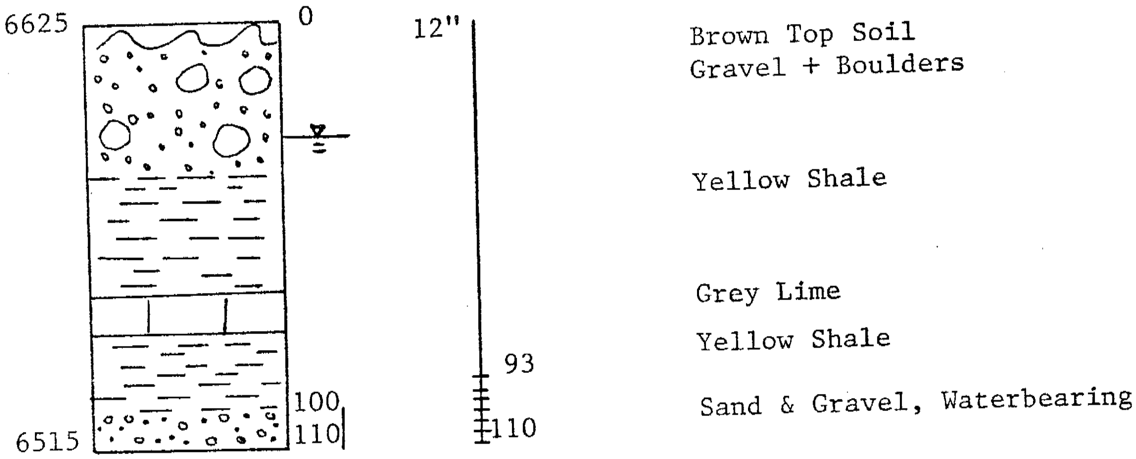


Figure 45

32

16.14.34.22440

Beaty 4/14/65



estm. 10 gpm water

Figure 46

33

16.16.3.133432

Beaty 12/23/56

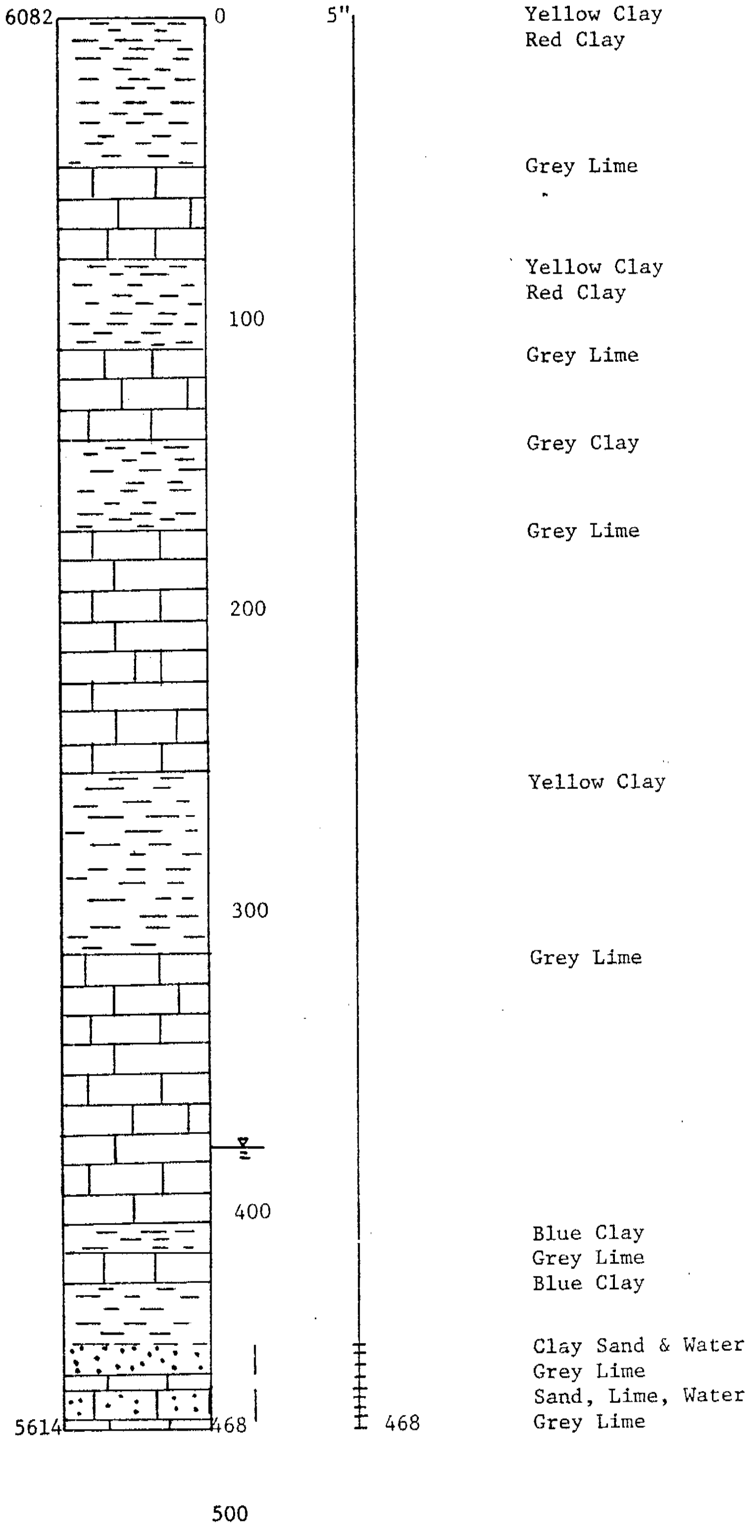


Figure 47

54

17.14.3.12144

Harris 11/4/55

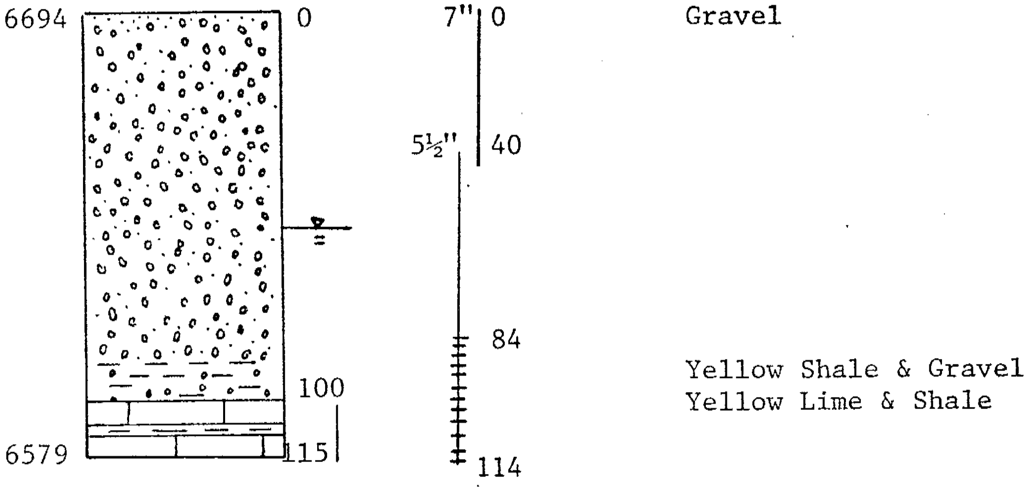


Figure 48

55

17.14.3.1341

Collins 10/30/55

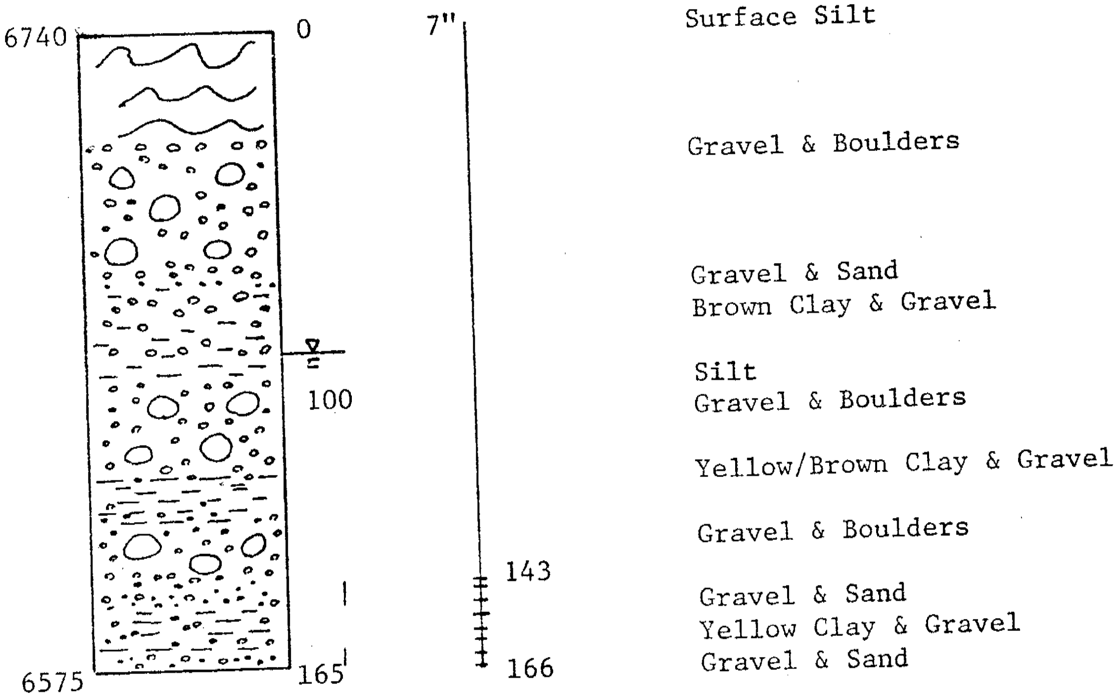
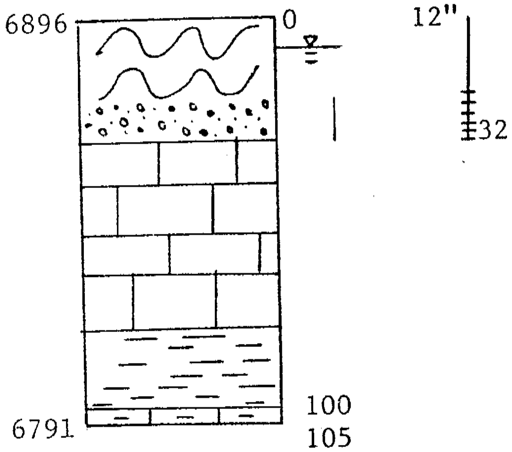


Figure 49

56

17.14.6.43331

Perry 7/2/55



Top Soil

Gravel Water Sand
Yellow Hard Limerock

Yellow Soft Lime
Red Soft Lime

Blue Shale

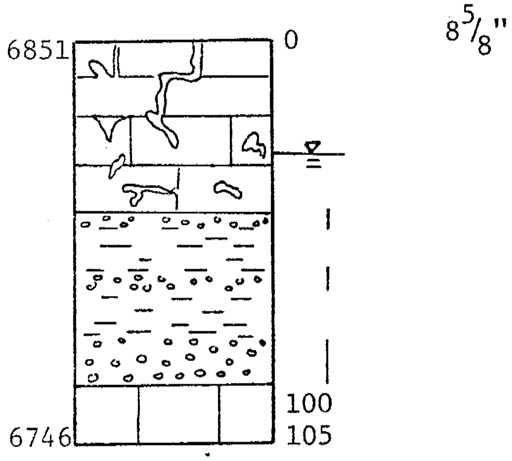
Shale or Brown Lime

Figure 50

57

17.14.8.12111

McClendon 5/22/53



Honeycomb Lime

Gravel
Clay
Gravel + Clay
Clay
Gravel

Brown Limerock

Figure 51

58

17.14.8.22133

Collins 6/1/61

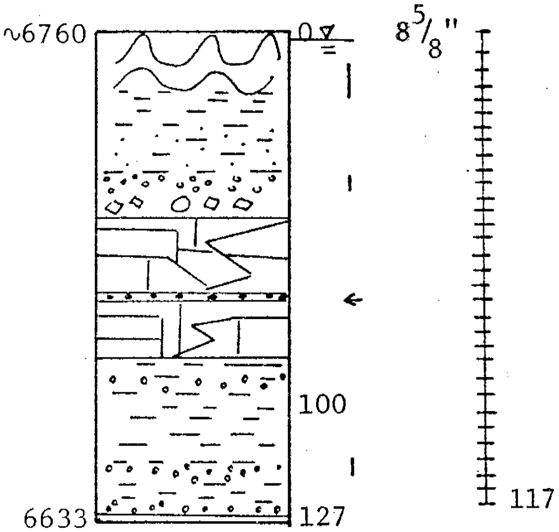


Figure 52

67

17.14.9.12333

Beaty 5/21/56

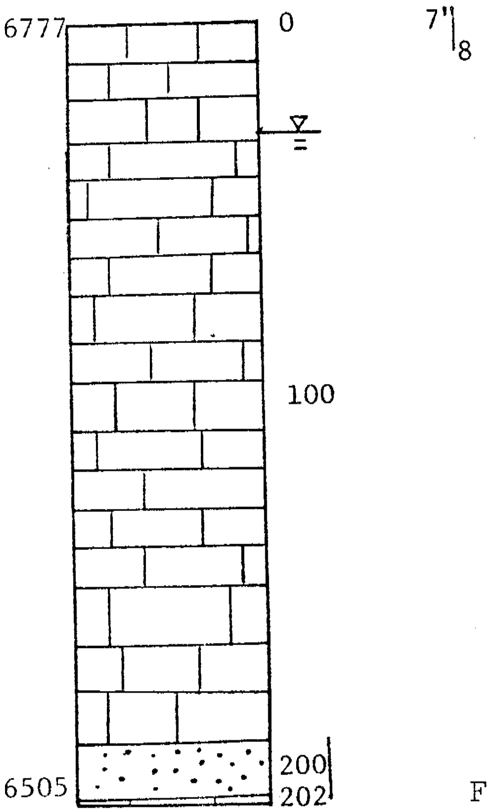
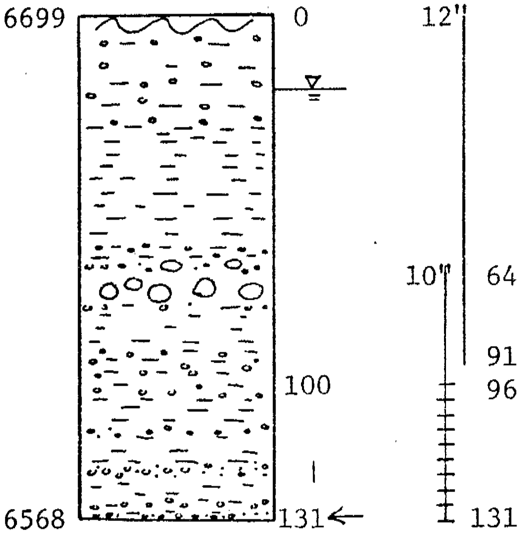


Figure 53

17.14.10.11133

Collins 11/30/55



Surface
Grey Clay + Gravel

Red Clay

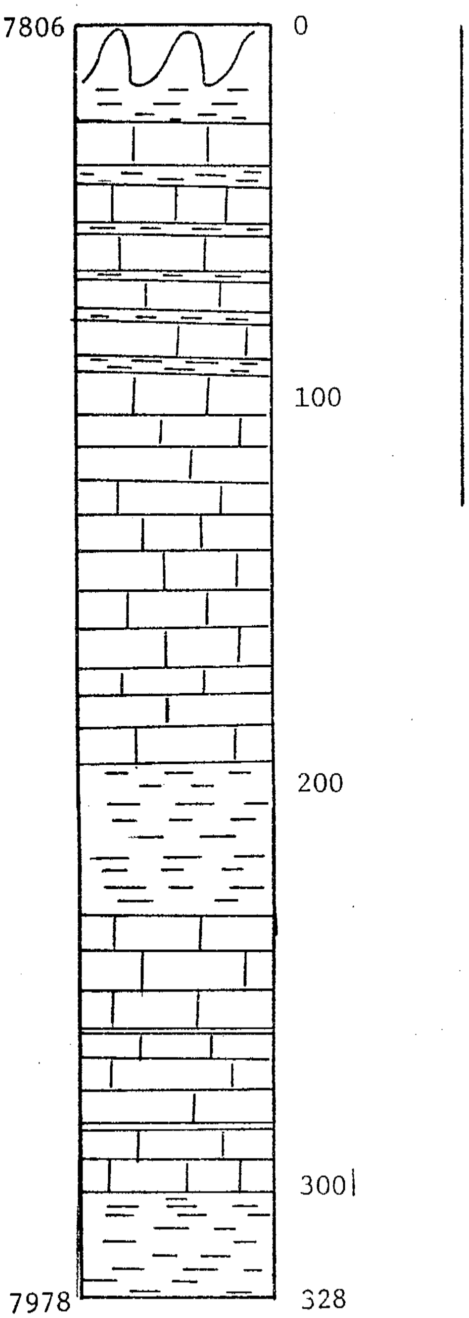
Grey Clay + Gravel
Gravel & Boulders
Boulders
Yellow Clay + Gravel
Brown Shale
Brown Clay, + Gravel
Brown/Red Clay
Brown Clay + Gravel
Sand + Gravel
Yellow Clay
Yellow Clay + Gravel
Fine Gravel + Sand

Figure 54

A

16.12.24.33112

Bonnell 2/20/62



Black Loam

Yellow Clay
Grey Limestone in layers of 1' to 6'
of Clay

Black Grey Solid Limestone

Yellow Clay
Red Clay

Grey Limestone with cracks at
258', 285'

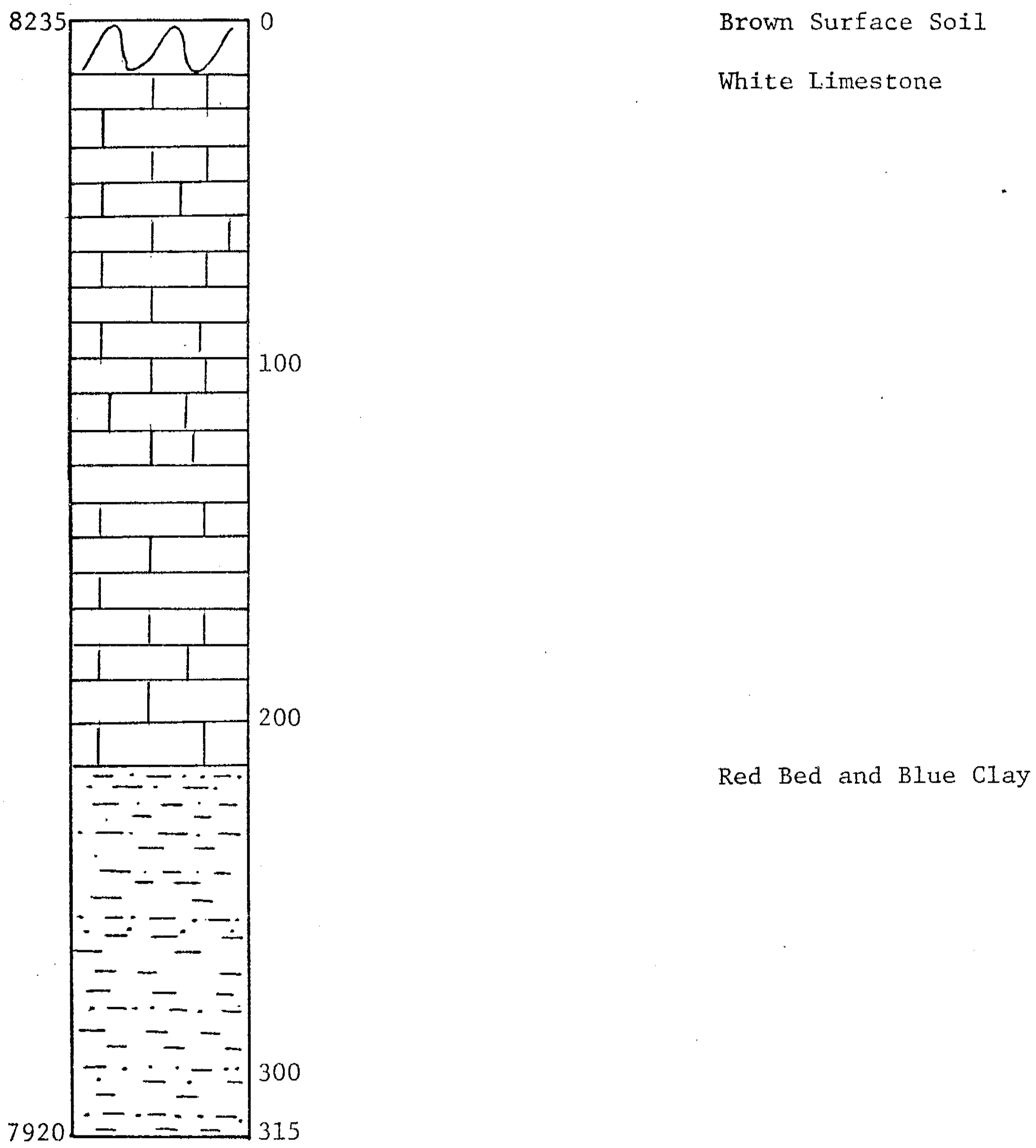
Waterbearing Gravel
Yellow Clay

Figure 55

D

16.13.23.44134

Stone 2/25/78



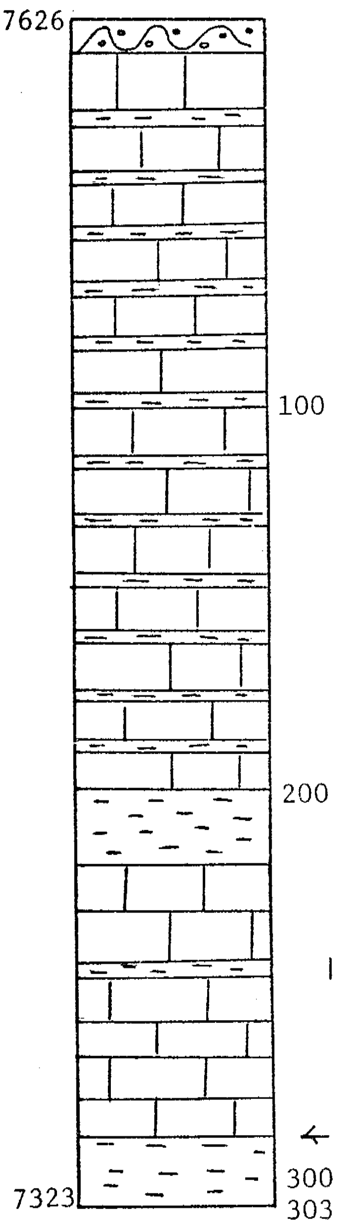
Drywell

Figure 56

E

16.13.29.3342

Bonnell 8/3/62



Black Loam Gravel
Grey Limestone Layers with
Grey Clay between layers

Red Clay

Black-grey Limestone Rock

Light Grey Clay carring water seam
Grey Limestone Rock

Red Clay

Figure 57

N

16.14.34.24333

Beaty 6/1/56

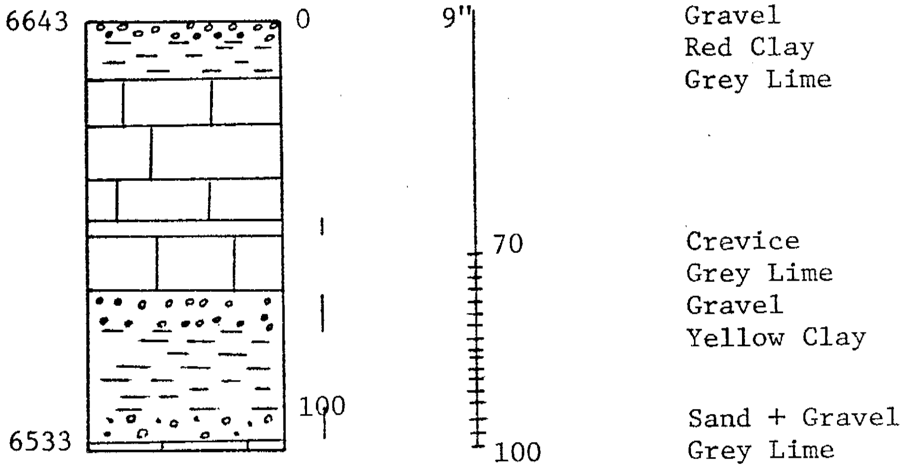


Figure 58

H

16.14.10.14311

Beaty 11/3/60

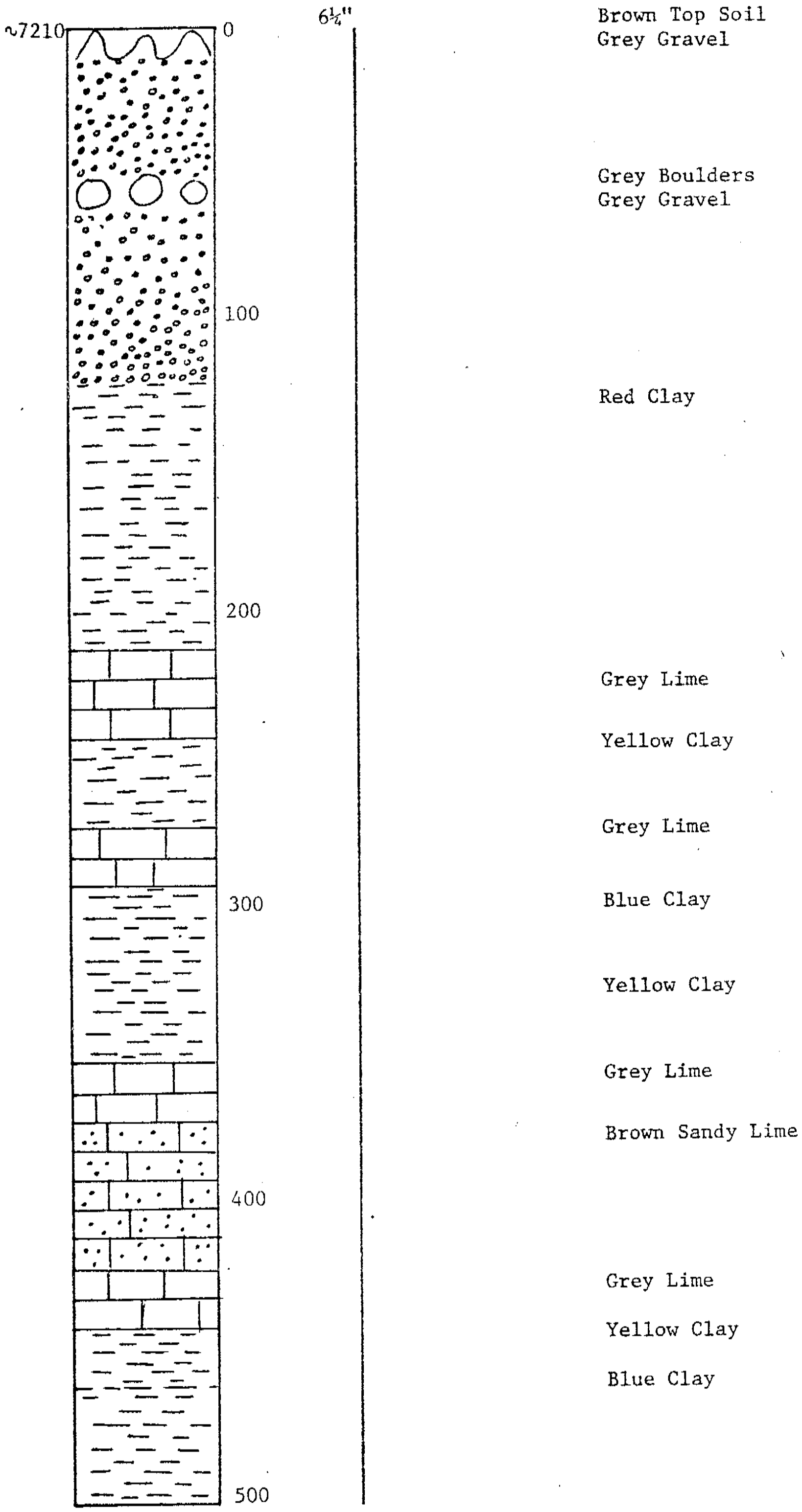


Figure 59

H Cont.

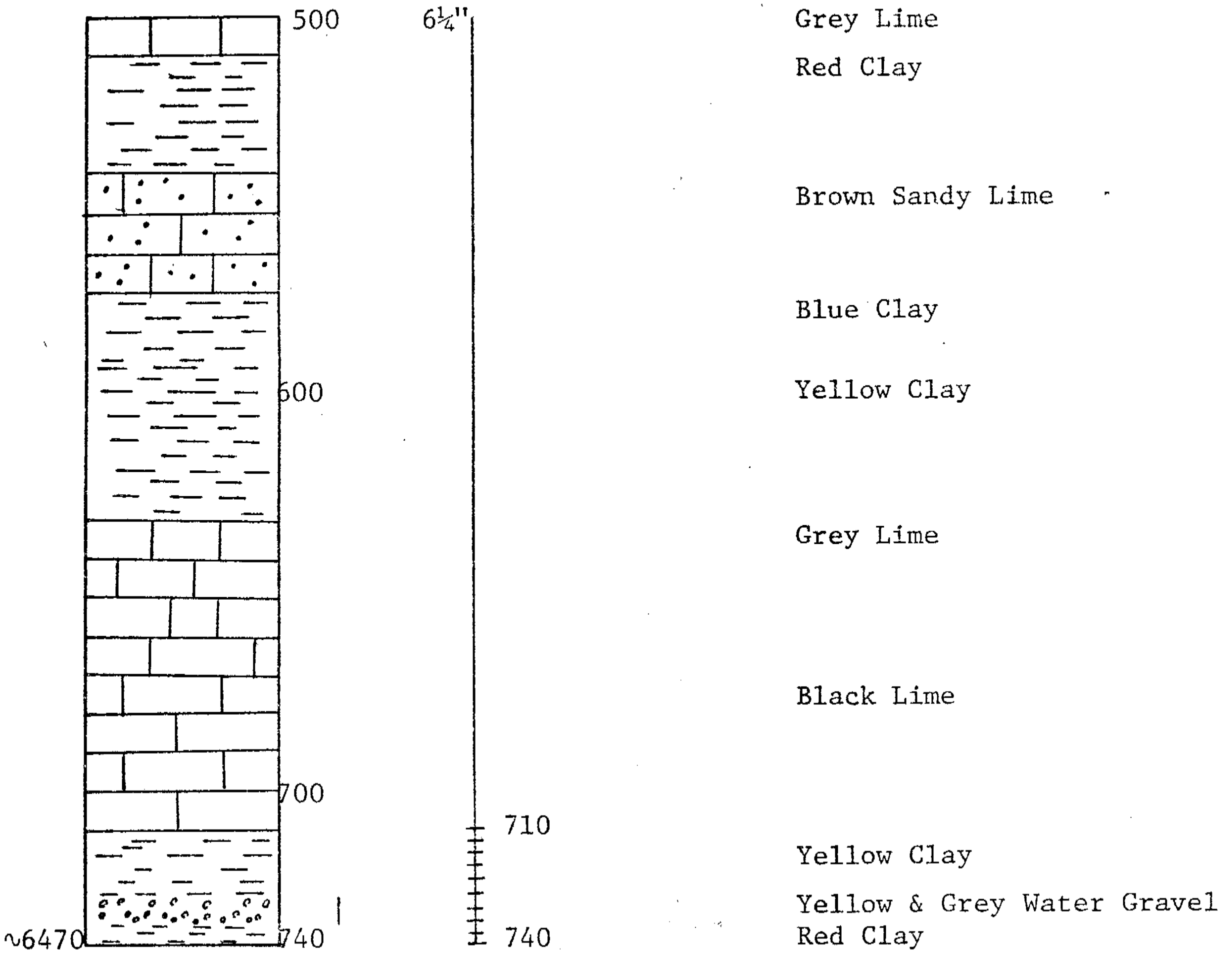
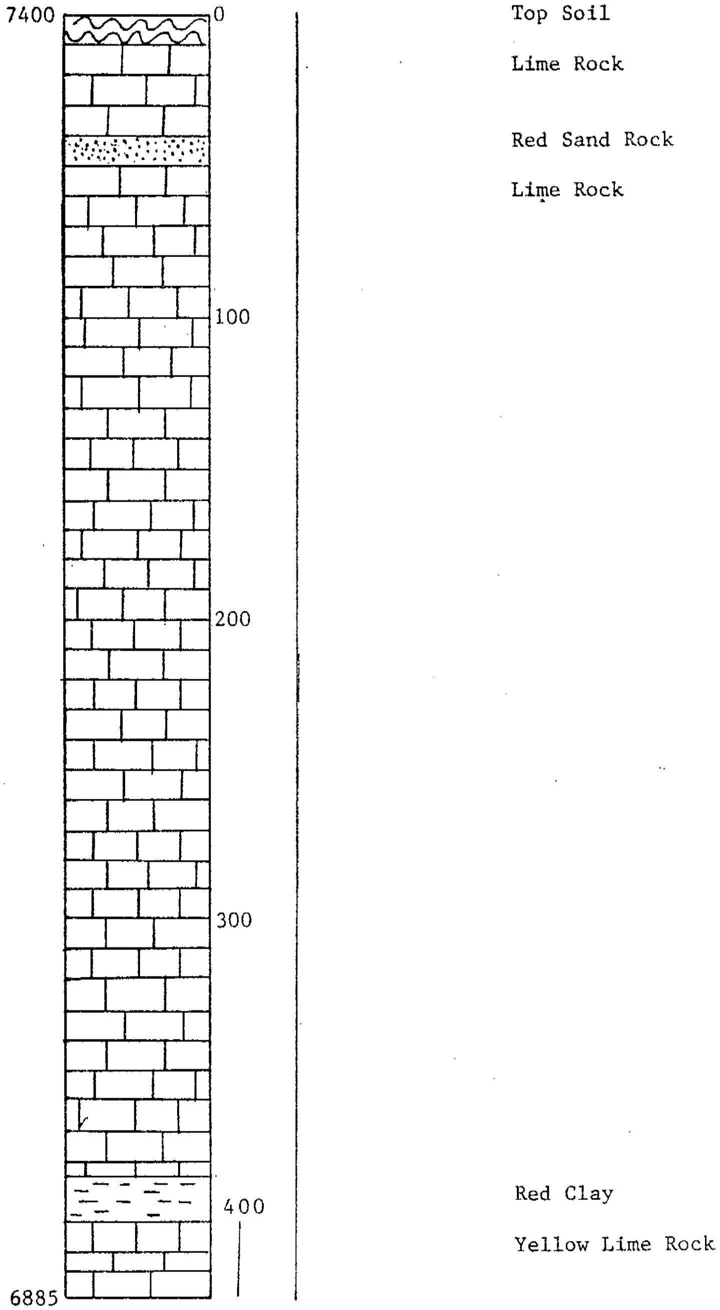


Figure 59 (Con't)

CC

17.14.17.31224

Perry 3/15/54



Water: 400-425' in yellow lime rock

Figure 60

QQ

16.12.6.43442

Braziel Water Well Drilling 1/7/74

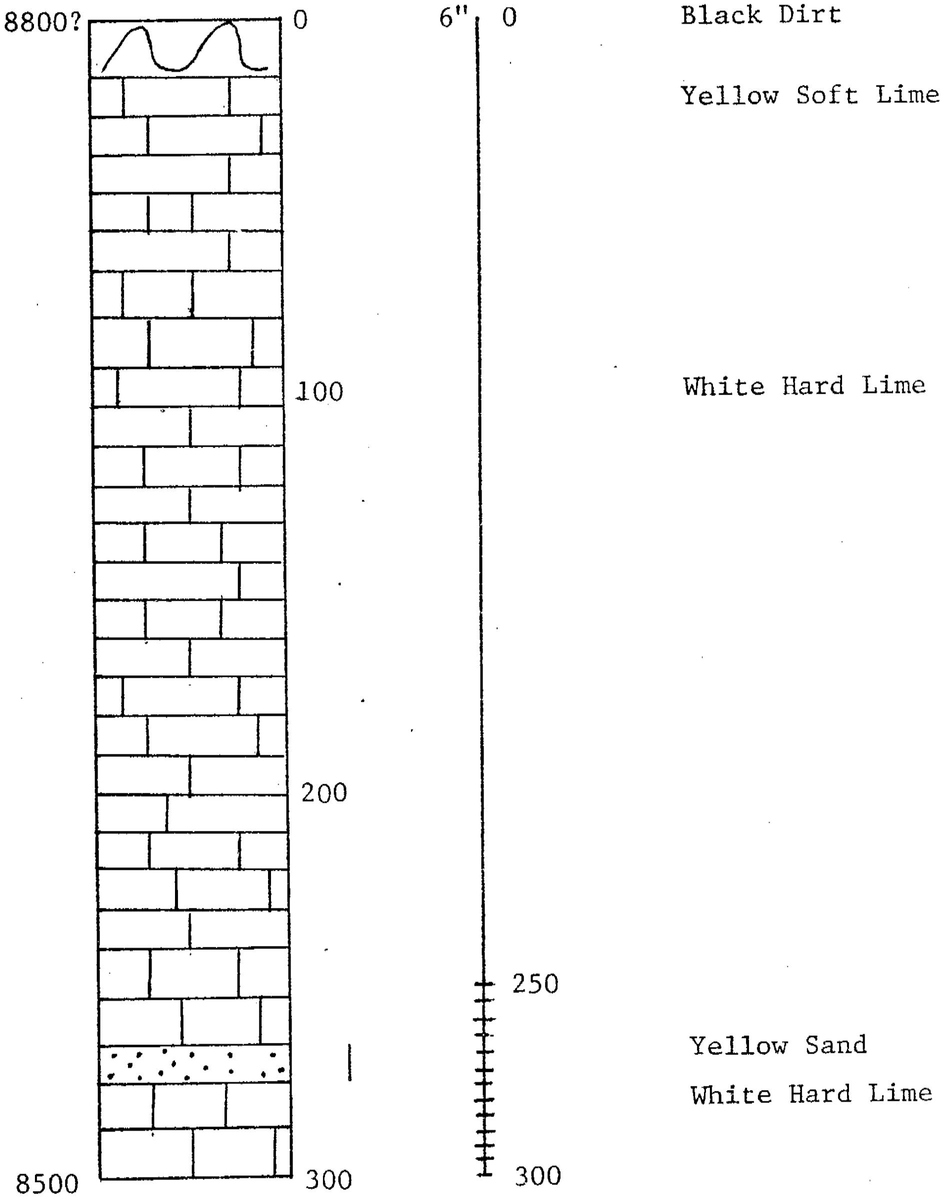


Figure 61

DD

17.14.18.34442

N.M. Drilling 12/9/70

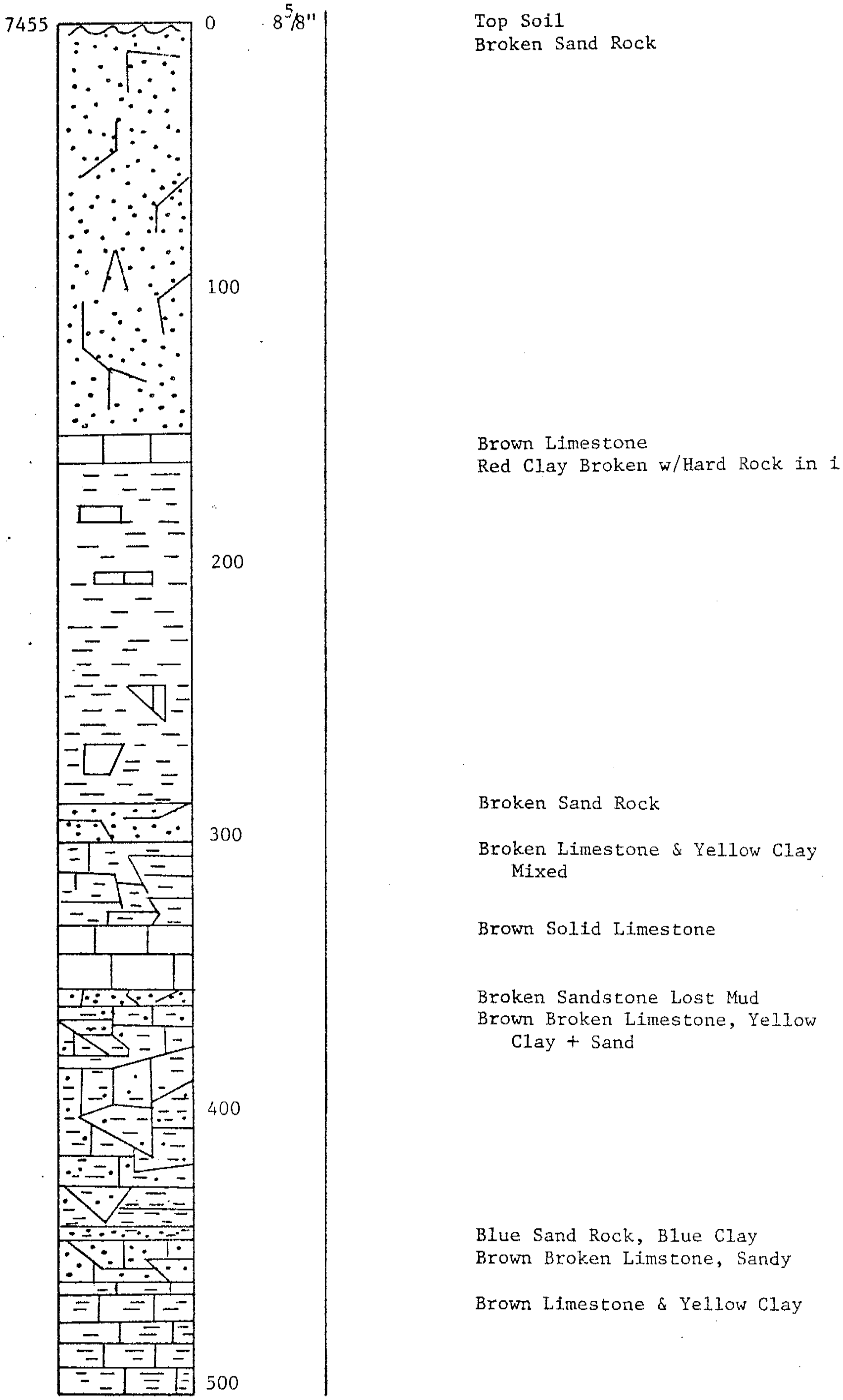
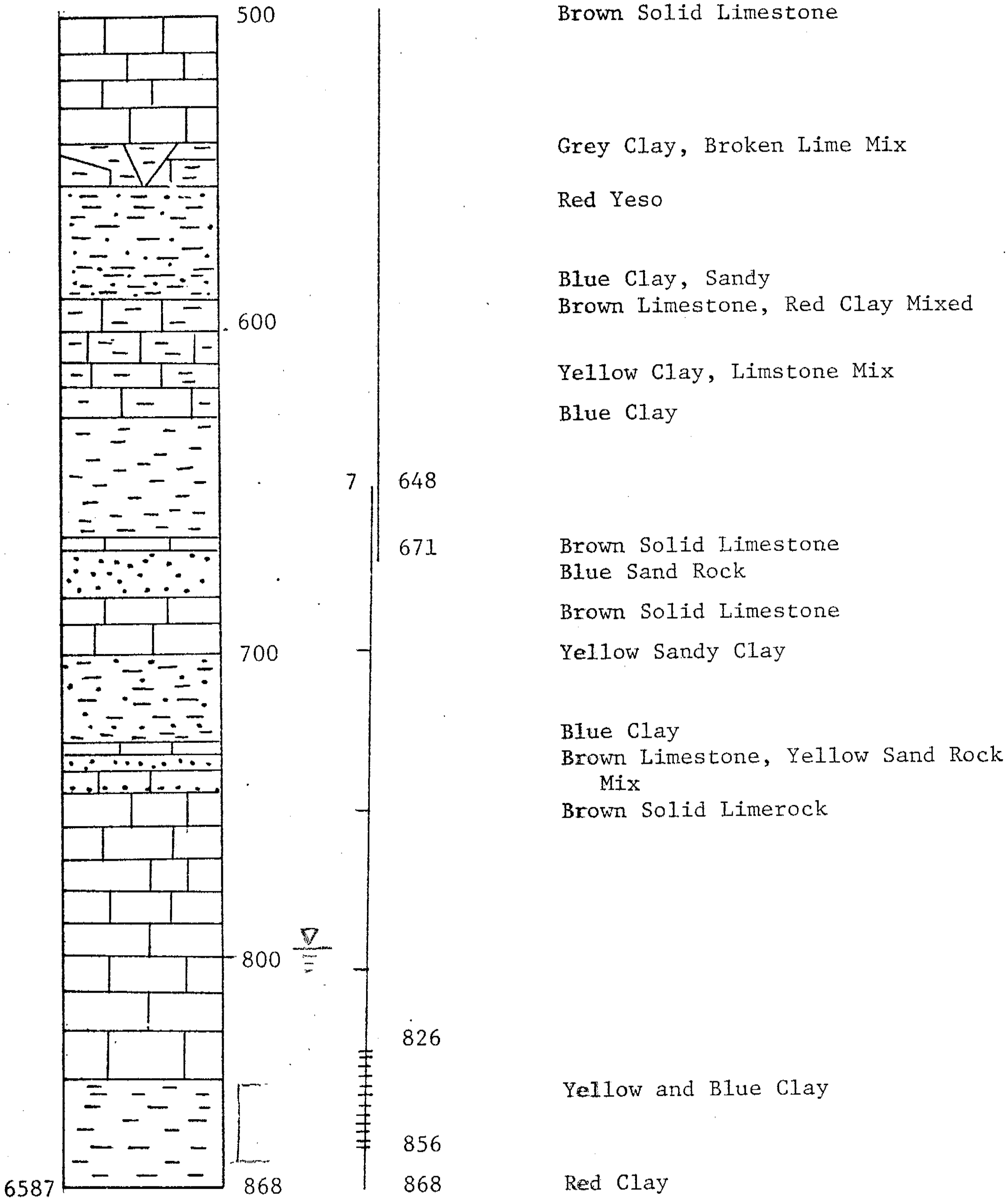


Figure 62

DD CONT.



NOTE: Estimates for the land surface datum of this well vary from 7518 ft (assumed in Fig. 12) to 7455 ft (this well log). This leads to an uncertainty of 63 ft in the piezometric surface intersected by this well.

Figure 62 (Con't)

PP

16.12.5.43131

McClendon 1/4/74

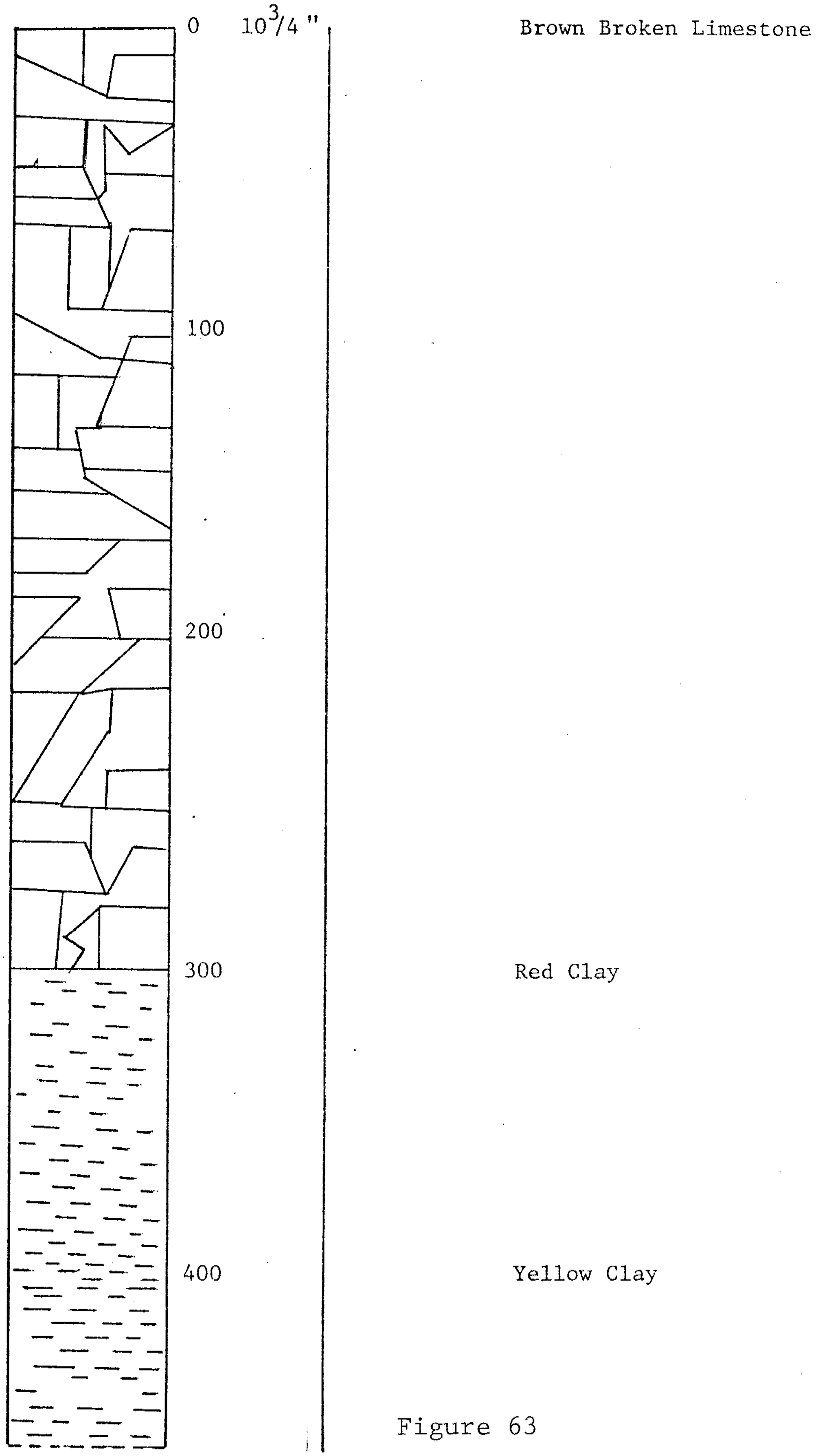


Figure 63

PP CONT.

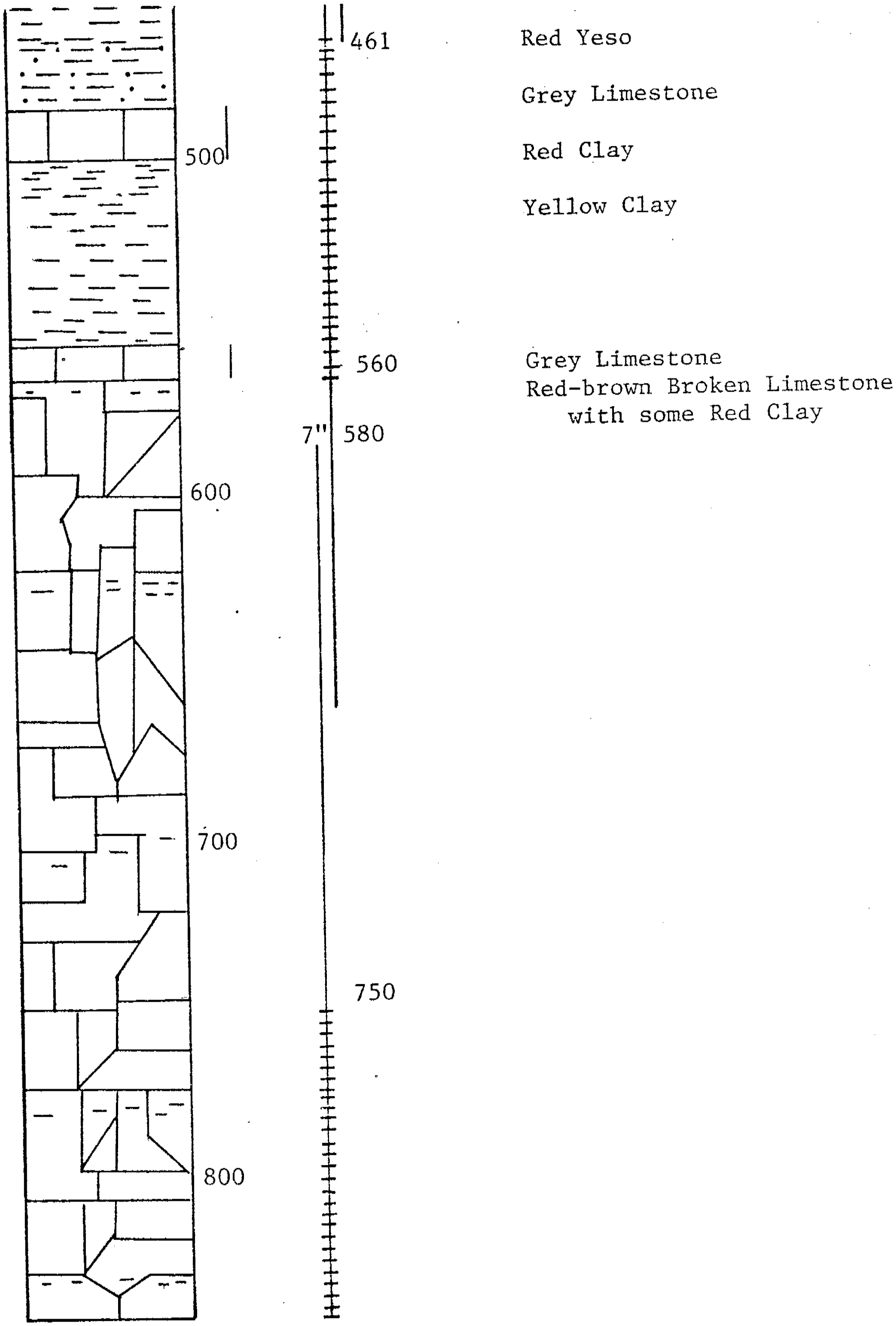


Figure 63 (Con't)

APPENDIX C

Transmissivity Estimates

Very few determinations of hydrologic parameters exist for the study area, or for the Yeso Formation in any area of the Roswell Basin. Hantush (1957) determined transmissivity values for the "artesian" aquifer and for the "shallow" aquifer in the vicinity of Artesia, Dexter, Roswell, and Lakewood, on the eastern edge of the Roswell Basin. However, as the depth to the top of the Yeso in that area lies several thousand feet below the land surface, and consequently has no water wells drilled into it, he could not determine the hydrologic parameters for this formation. The "artesian" and "shallow" aquifers were the upper San Andres and lower Artesia Formations, respectively.

In January, 1978, the consulting firm of K. Summers and Associates, of Socorro, N.M., ran step drawdown and constant drawdown tests on a well finished in the Yeso Formation. This well is located at coordinates 15.13.34.340 about 5 to 6 miles east of Cloudcroft. The firm obtained a transmissivity value of 25,000 gpd/ft and a storage coefficient of 0.2. Re-analysis of these data indicates that these values may be too high. Analyzing the step drawdown test data by the Brereton method (Brereton, 1979), a transmissivity value of about 3700 gallons per day per foot is obtained, (Figs. 64-65). Analyzing the constant discharge test by the Jacob straight-line method, a value of 1200 gallons per day per foot is arrived at (Fig. 66).

Not far from this well, at coordinates 16.12.3.142a and b, are two wells in Pumphouse Canyon which service the city of Cloudcroft. In 1960, Hood reported that the water level in Well A, finished in Yeso, dropped 56 feet when pumped at 170 gpm, and in Well B, also finished in the Yeso Formation, it dropped 115 feet when pumped at 160 gpm. Calculations yield specific capacities of 3.0 and 1.3 gpm/ft., or transmissivity value estimates of 6000 and 2760 gpd/ft., respectively, for these wells. Excluding the 6000 gpd/ft., the average value of transmissivity is 3400 gpd/ft. This is not a large transmissivity: 50 gpm is probably the maximum that wells in strata of this T value should pump for safe yield. However, it suggests that the Yeso Formation is able to transmit water and function as a viable aquifer.

The groundwater surface map (Fig. 18) indicates that transmissivity values of the area are highest to the east of the 6800 ft. equipotential line. West of that line, including the area for which T values were obtained, closely-spaced equipotential lines indicate that the value of transmissivity is lower. The explanation for this is easily seen from Figs. 10 and 11. In Well 12 and east along James Canyon (line AA of Fig. 6), and east along Cox

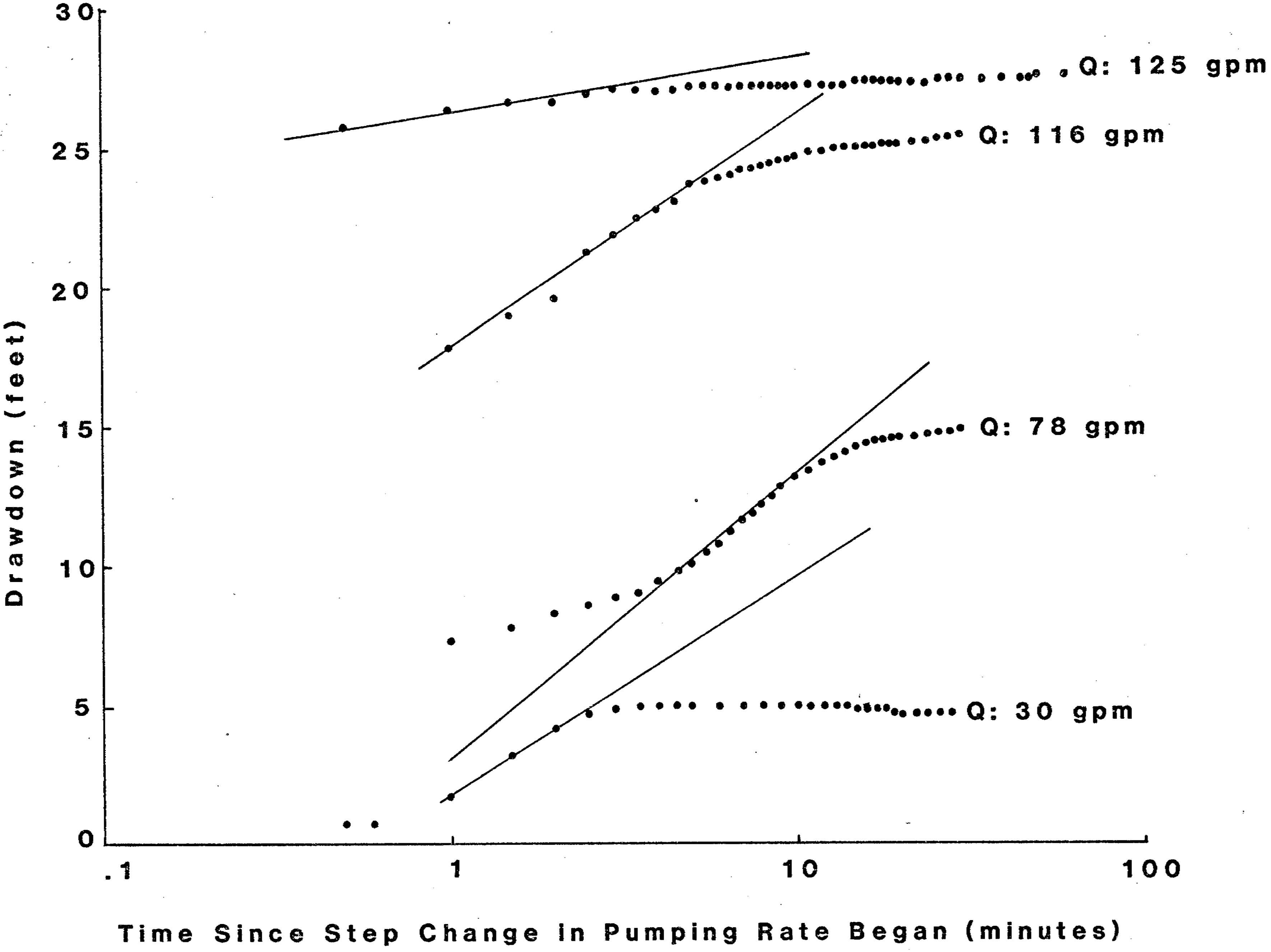


Fig. 64 Step Drawdown Pump

Canyon (line BB), water often occurs in a sand and gravel layer (presumably consolidated), a lithology type that should have a fair to good permeability. However, in Well L and west, water is found in shales and non-cavernous limestones; these strata are likely to have a lower permeability than the sands. It is unfortunate that there are no pumping test data for the more highly permeable zone. Quite conceivably a T value for this eastern zone may be much greater than that calculated for the less permeable zone west of the 6800 foot equipotential line.

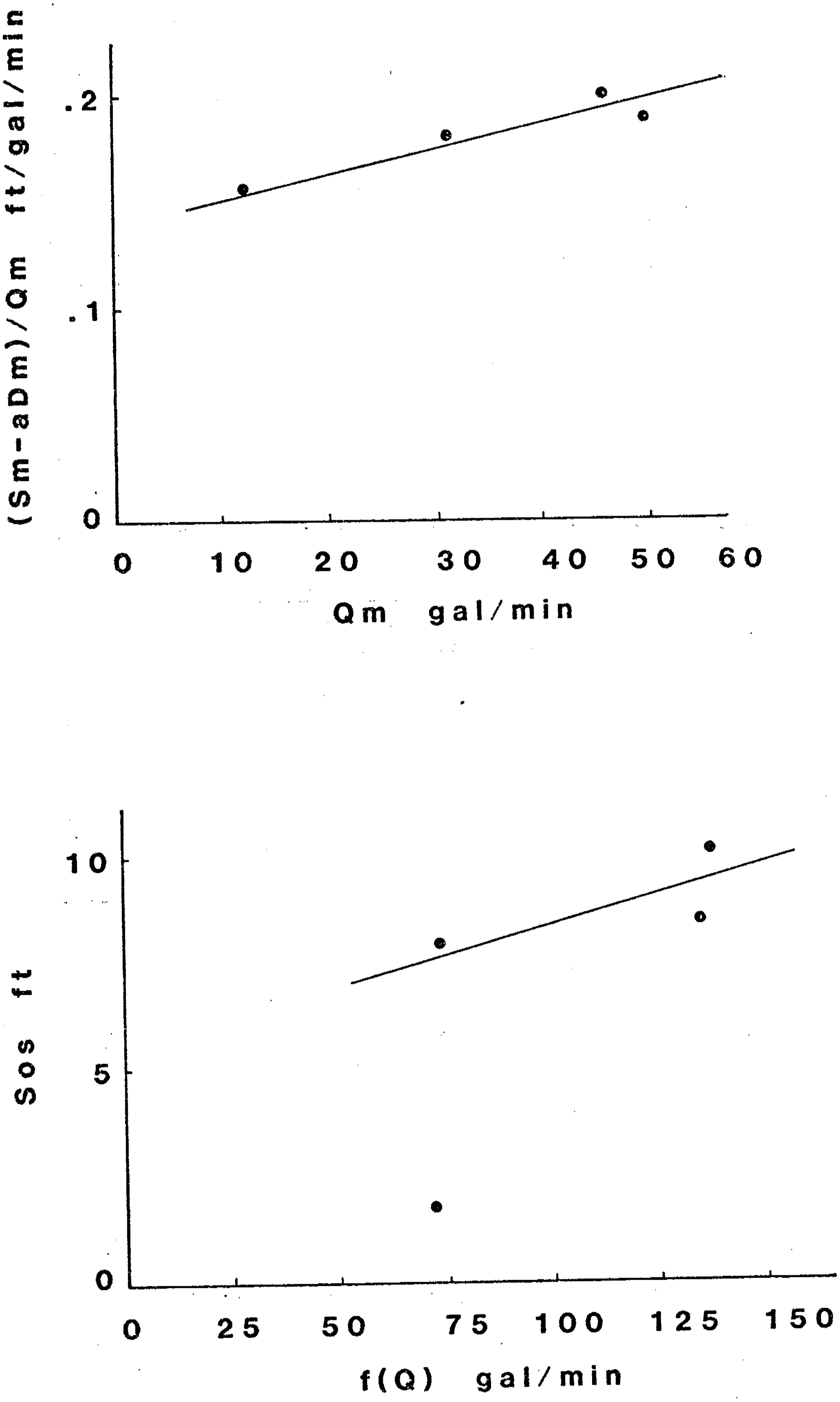


Fig. 65 Brereton Method Plots

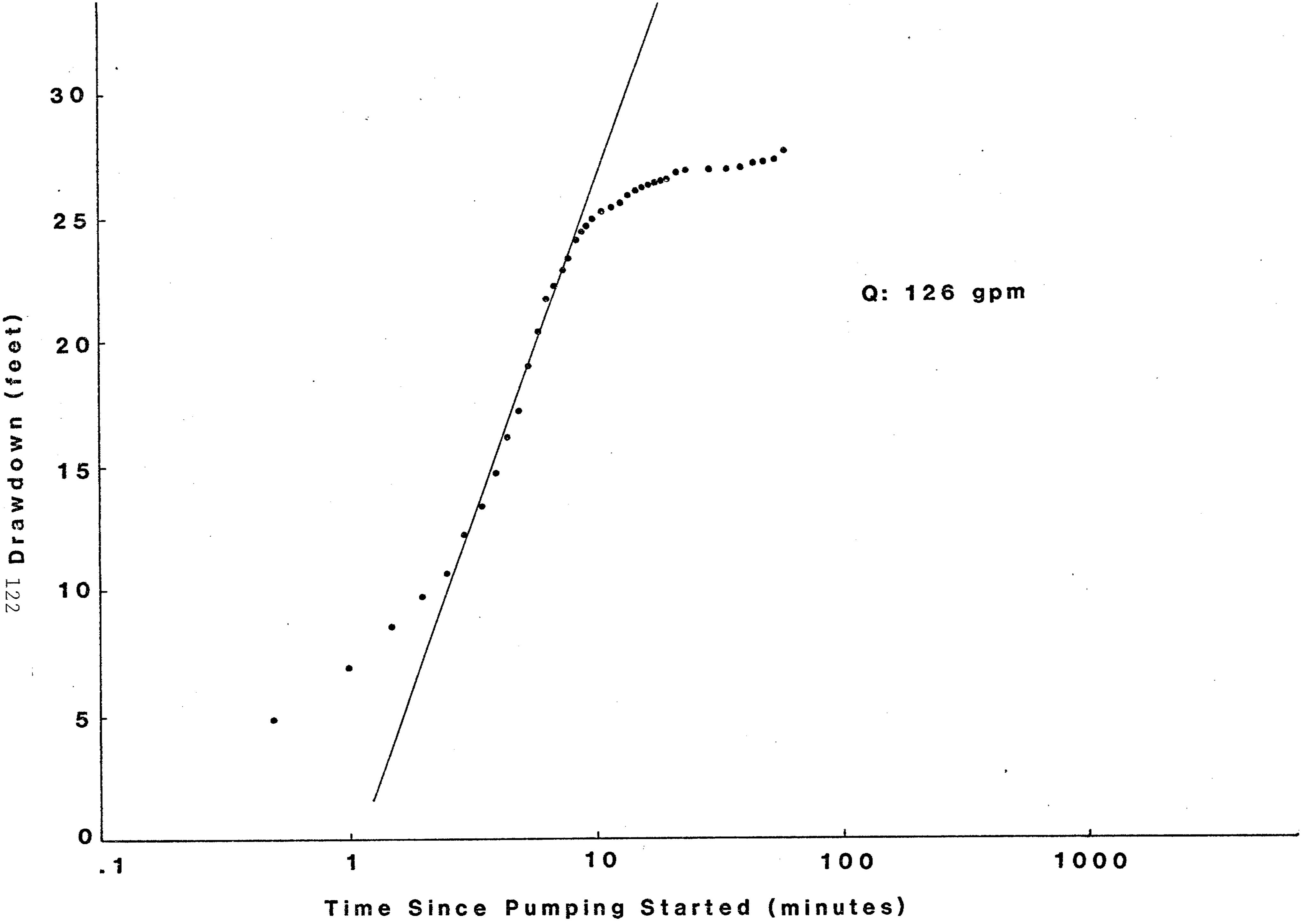


Fig. 66 Constant Discharge Pump Test