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THE HYDROGEOLOGY OF THE PERMIAN YESO FORMATION WITHIN THE UPPER RIO HONDO BASIN AND THE EASTERN MESCALERO APACHE INDIAN RESERVATION, LINCOLN AND OTERO COUNTIES, NEW MEXICO

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Abstract—The Yeso Formation of late Early Permian (Leonardian) age is the principal aquifer of the western Pecos slope. Within the area of the upper Rio Hondo basin and the eastern part of the Mescalero Apache Indian Reservation the vertical thickness of the formation ranges from a few feet to nearly 1700 ft. Both the thickness and the nature of the formation were greatly affected by the continued expression of the ancient Pedernal high during the period of deposition. The upper two-thirds of the Yeso is composed mainly of interbedded limestone, dolomite, siltstone and silty sandstone, but it becomes less dominated by carbonates and more evaporitic with depth. The lower part of the formation is characterized by layers of gypsum and anhydrite interbedded with siltstone. Ground-water movement within the aquifer is eastward under water-table conditions. Flow is preferentially through fractured and dissolved limestone beds, although persistent thin beds of sandstone may also transmit ground water. In deep aquifer tests on the Mescalero Apache Indian Reservation, the hydraulic conductivity of the aquifer strata tests at 7.0 E-08 m/sec (0.02 ft/day) for unfractured siltstone and gypsum beds. The average hydraulic conductivity ranged from 2.1 E-06 to 5.3 E-06 m/sec (0.6 to 1.5 ft/day). These and other aquifer tests indicate that limestone beds with secondary permeability may be characterized by hydraulic conductivities which are several orders of magnitude higher than those of unfractured siltstone beds.

INTRODUCTION

From 1975 to 1982 a significant amount of hydrogeologic information was collected within the Mescalero Apache Indian Reservation by the Mescalero Apache Tribe and private consultants acting on the tribe's behalf. The investigations provided new information on the hydrogeologic characteristics of the Yeso Formation within the reservation, in preparation for the quantification of tribal water rights by the courts in the Mescalero section of the Lewis case (Reynolds v. Lewis). Much of the collected data are contained in two consultant reports. "Groundwater resource investigation, Mescalero Apache Indian Reservation" (Woodward-Clyde Consultants, unpubl., 1978) provides information on the geology of the entire reservation area and detailed descriptions of the installation and testing of four deep wells drilled in the Yeso Formation. "Numerical simulation of Pajarita well field, Mescalero Apache Indian Reservation" (Hydro-Geo-Chem, unpubl., 1982) tabulates numerous water-level measurements and chemical analyses of water from wells in and around the reservation and presents a finite-difference model of ground-water movement in the Yeso Formation. These reports, as well as miscellaneous water-level data and briefer documents (Welder, 1975; Ed L. Reed and Associates, unpubl., 1975), became available to the public as they were entered into the court record during the Mescalero Apache Indian water rights hearing held in State District Court in Roswell, New Mexico in spring 1987. However, the existence of much of this information still remains generally unknown and the documents are not readily available. Published geohydrologic information for the reservation area is limited to Sloan and Garber (1971), which provides a map of the water table within the Yeso Formation and valuable data on reservation wells and springs, but no estimates of hydraulic parameters.

The Rio Hondo drainage basin lies north and east of the Mescalero Apache Reservation. Mourant (1963) discussed the geology and hydrology of this area and tabulated water levels measured in numerous wells of the area between 1929 and 1957. Kelley (1971) encompasses both the Mescalero Reservation and the Rio Hondo Basin. In addition to a discussion of the major structural features of the area, this study includes estimates of the distribution and thickness of Permian formations between the Rio Ruidoso and Pajarito Mountain.

With the recent drilling of four deep oil tests (Table 1) in the upper Rio Hondo area, new information is available on the thickness of the Yeso Formation and its nature at depth. In addition, numerous water wells have been drilled in the area in the nearly 30 years since Mourant (1963) published his survey. The main purpose of this paper is to synthesize the recently available hydrologic data on the Yeso Formation within the eastern Mescalero Apache Indian Reservation and the upper Rio Hondo Basin (Fig. 1). This area covers only part of the area within which the Yeso Formation is a major aquifer; the water table within the aquifer is continuous at least as far as 10 mi south of the village of Mayhill (Wasiolek and Gross, 1983, fig. 3). The village of Ruidoso is located on the western ege of the study area, and the village of Riverside on the east. The Capitan Mountains define the northern boundary. The northern part of this area lies within the Rio Hondo drainage and ground water basin as declared (extended in 1985) by the New Mexico State Engineer Office. Water within that basin is administered

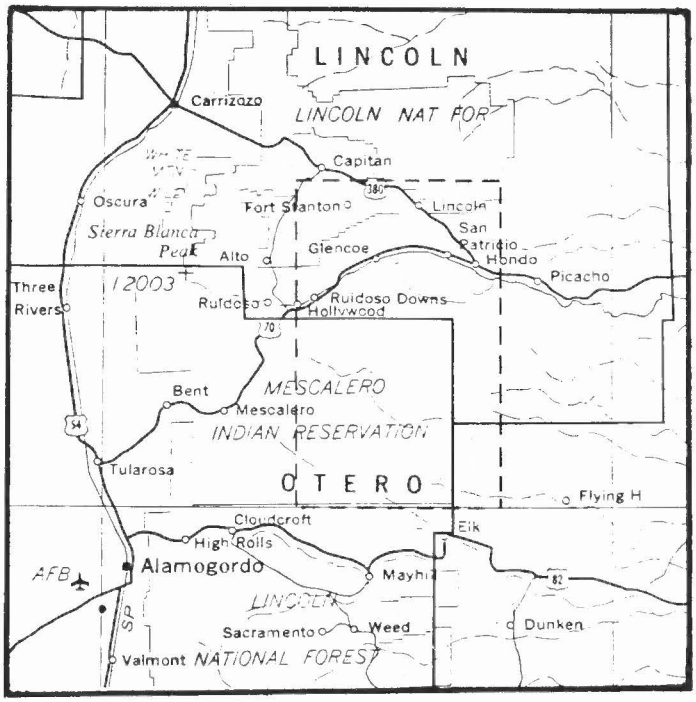


FIGURE 1. Location of study area.

TABLE 1. Data from selected oil test wells drilled in the upper Rio Hondo area. For location number see text for explanation. Depth of well is in feet below land surface; altitude is of land surface taken from drillers' logs; altitude of pC is altitude of the top of the Precambrian; formation thickness of Pa and Py is vertical thickness of Abo Formation and Yeso Formation in drill hole. All information was abstracted from records on file with the New Mexico Oil and Gas Commission.

Location number	Company name	Farm Name	Date well com-pleted	Total depth of well	Altitude above mean sea level (ft) well	pC	Formation thickness Py	Pa
10.15.10.224	Yates Pet.	Munoz Canyon	1985	2576	6991	4415	1685	466
10.15.16.433	Rio Petro	Nosker #1-Y	1984	1526	5889	4439	1383	0
11.18.21.212	Natl. Expl.	Picacho #1	1929	2191	5050	2859	1276	0
11.19. 4.310	Sanders Pet.	Tecolote #1-2	1982	2890	5288	2398	1407	643
11.19.10.441	Sanders Pet.	Koko #1	1982	3040	5072	2096	1523	746
12.18.10.121	Stanolind	Picacho #1	1945	2843	5903	3292	1622	0

by the State Engineer. Most of the reservation area does not lie within a declared basin, although it is hydrologically part of the Roswell Basin.

All interpretations of the data are the author's own, and are derived from work begun while she was a water-resource engineer with the New Mexico State Engineer Office.

THICKNESS AND EXTENT OF THE YESO FORMATION

The Precambrian core of the ancient Pedernal uplift underlies the Mescalero Reservation and much of the northern Sacramento Mountains (Foster, 1959; Kelley, 1971). Lithologic data collected during recent oil tests and deep water wells strongly suggest that sediments of the Yeso Formation were deposited directly on the Precambrian complex throughout the study area from west of the middle of R18E, and south of the middle of T10S. North and east of this area, oil test logs indicate the presence of the Permian Abo Formation between Yeso strata and the underlying Precambrian bedrock (Table 1). The presence of the Pedernal uplift probably influenced the spatial distribution of Yeso sediments, causing the formation to be thinly deposited over the axis of the uplift and to thicken along its flanks (Kelley, 1971). As a result, the thickness of the Yeso Formation is variable within the study area. It is a few feet thick over the crest of Pajarito Mountain, where the formation pinches out beneath the overlying San Andres Formation at an altitude of 7945 ft above sea level, but is nearly 1700 ft in the Munoz Canyon oil test (Fig. 2; Table 1) 15 mi to the northwest. East from Pajarito Mountain, the Yeso thickens rapidly. The Picacho #1 and Picacho #1 (Stanolind) oil tests, located 17 and 15 mi to the northeast, encountered 1276 and 1622 ft of Yeso strata at altitudes of 5403 and 4937 ft, respectively. The KoKo #1 and Tecolote #1–2 oil test, located 24 and 25 mi northeast of the mountain, encountered 1407 and 1523 ft of that formation at altitudes of 4548 and 4365 ft. West of Pajarito Mountain, over the central mass of the ancient upland, the formation was probably deposited more uniformly but to a lesser thickness. Lithologic logs seem to indicate that through the north-central part of the Mescalero Reservation, the Yeso Formation was deposited to a fairly uniform thickness of at least 1050 ft but no more than 1250 ft. A log for Pauls' well (Appendix 2; Welder, 1975, p. 12–15), located 12 mi southwest of Pajarito Mountain (Fig. 2), indicates that the top of the Yeso was encountered at an altitude of 8185 ft above sea level in this well, and at an altitude only 5 ft lower in a well 3 mi to the southwest. Paul's well penetrated 1051 ft of rocks belonging to the Yeso Formation. Because the bottom 300 ft of the strata comprise numerous anhydrite and gypsum beds typical of the lower part of the formation (Appendix 2), probably not more than an additional 200 ft of Yeso strata are present above the Precambrian bedrock.

The area north of the reservation and south of the Rio Ruidoso is complex. The presence of 1000 ft of exposed Yeso near the village of Ruidoso Downs (Greentree) (Kelley, 1971) indicates a minimum thickness of Yeso deposited in the area. However, due to later faulting and folding of the Yeso the thickness of the zone of saturation is reduced. The Yeso may be even thinner to the east; several water wells drilled within R15 and 16E reportedly encountered "granite" along the Rio Ruidoso and between that stream and the reservation boundary. These reports and the shape of the potentiometric surface in this area (Fig. 2) may indicate that the Pedernal axis here is at shallow depth.

North of the Rio Ruidoso, the Munoz Canyon and Nosker #1-Y oil tests (Table 1, Fig. 2) penetrated thicknesses of Yeso of 1685 and 1365 ft, respectively. The uniform hydraulic gradient in the area between the Rios Ruidoso and Bonito (Fig. 2) indicates that aquifer transmissivity, and therefore the saturated thickness of the aquifer, is also uniform. The thickness of the Yeso can therefore be expected to reach at least 1300 ft in this area.

ROCK CHARACTERISTICS

A complete section of Yeso is not exposed within the study area. Strata within the upper part of the formation crop out along Rio Bonito, and in the valleys of the Rios Ruidoso and Hondo from near Ruidoso Downs to below the village of Hondo. Drillers' logs for water wells drilled within the upper Rio Hondo valley describe strata mostly within the upper few hundred feet of the formation, although water wells on the Mescalero Apache Indian Reservation have been drilled deeper (Appendix 2). The nature of the bottom 500 ft or so of the complete section can be surmised from the 1200-ft-thick partial section of the formation measured along the western side of the Sacramento Mountains through T13S (Pray, 1961), and from deep oil tests penetrating the entire thickness of the formation. Mourant (1963, table 6) provided logs for complete sections of Yeso encountered in oil tests located at SW¼ SW¼ NE¼ sec. 11, T9S, R20E, and at NE¼ NW¼ NE¼ sec. 21, T11S, R18E. Brief logs of three additional oil tests drilled in the Yeso within the upper Rio Hondo area are presented in Appendix 3.

These records indicate that the Yeso Formation is a sequence of shallow marine and evaporite strata composed of thin-bedded limestone and dolomite, red and yellow siltstone and silty sandstone, shale, gypsum and anhydrite. The formation exhibits both horizontal and vertical spatial variability. The lower 500 ft of the formation are characterized by numerous evaporite beds, whereas the middle 500 ft or so are dominated by limestones and dolomites (Appendices 2, 3). Siltstones occur throughout the section, whereas sandstones are more often encountered in the upper part of the formation. The vertical variation in rock types was probably caused by a gradual change of depositional environment through Leonardian time, from shallow, closed seas to shallow open ocean. As the sea deepened, deposition of siltstone, gypsum and anhydrite beds was gradually replaced by precipitation of limestone and dolomite. When more information is available, the lateral variability of the Yeso Formation may eventually be found to be more evident on a local than on a regional scale. Lithologic logs from water



FIGURE 2. Potentiometric surface map of the ground water within the Yeso Formation. Numbers are altitudes of water level in feet above sea level; contours are equipotential lines on the water table in ft above sea level (contour interval 200 ft); four-pointed circle = oil test well. Designated wells and associated water levels are listed in Table 2 of this paper, in the table of wells of Sloan and Garber (1971), or in table 1 of Mourant (1963, p. 44–54).

wells and oil tests indicate that sandstone and carbonate beds and sequences of beds may persist over tens of miles within the study area. A 150-ft sequence of limestone and dolomite in the middle of the formation may correlate with the "medial limestone" of Kelley (1971) and extend through the southern Sacramento Mountains. South of the study area, Childers (1985) correlated porosity zones in the Yeso for more than 40 mi across the middle Roswell Basin using lithologic and geophysical logs of oil tests.

Sloan and Garber (1971) reported that solution openings enlarged along joints or other fractures in limestone or dolomite beds furnish most of the ground water in the Yeso Formation on the Mescalero Reservation. Numerous drillers' logs for wells drilled both on and off the reservation support this observation. Wells that encounter only siltstones and other fine-grained, unfractured rocks lacking secondary permeability, eventually fill with ground water to the level of the regional water table, but produce little water. Beds of sandstone may yield sufficient quantities of water for domestic use; south of the study area, in the upper Rio Peñasco area, a thin bed of sandstone is the main aquifer. Wells that penetrate beds of fractured limestone or are hydraulically connected with permeable geologic faults often produce significant quantities of water (several hundred gpm). The absence of significant thicknesses of limestone or dolomite strata at depth probably

precludes the presence of high-yielding aquifer strata within the Yeso Formation at depths greater than 800 or 1000 ft into the section.

AQUIFER TESTS

E-series tests

Four deep wells and four associated piezometers were installed in the Yeso Formation on the Mescalero Reservation between 1975 and 1977. Lithologic logs and details on well construction (Appendix 2) were collected, and aquifer tests averaging 48 hr in length (24 hr of pumping, 24 hr recovery) were run using the wells (Woodward-Clyde, unpubl., 1978). These tests were analyzed for the present report; the values reported here are significantly lower than those tabulated in the Woodward-Clyde report. The author believes that the values reported here are more representative of actual formation characteristics because delayed yield effects and the influence of hydrologic boundaries were considered. Since 24 hr of pumping may not be a sufficient test length for the determination of long-term hydraulic parameters of the unconfined aquifer, the reported results should be used with caution.

Well E-1, located at SE¼ SW¼ SW¼ sec. 35, T12S, R15E, was drilled to a depth of 1000 ft (Fig. 2). The drill hole encountered 475 ft of unsaturated San Andres strata before penetrating 525 ft of interbedded siltstone, limestone, dolomite, sandstone and anhydrite beds of the Yeso Formation (Appendix 2). Water was first encountered at 580 ft below land surface, although after well development the static water level stood at 555 ft below land surface. The well casing was perforated with triple mill slots (0.16 in. openings) from 580 to 1000 ft. Analysis of drawdown measurements collected at this well during a preliminary aquifer test indicated such low formation permeabilities and poor hydrologic connection between E-1 and a piezometer drilled to the same depth as the pumping well (only 125 ft distant), that it was concluded that the permeability of the aquifer was being artificially impaired by soft clays which had been disturbed by drilling. In an attempt to rehabilitate the well, the casing was pulled back to 650 ft and the borehole underreamed (Woodward-Clyde, unpubl., 1978). After rehabilitation, the well was pumped at a rate of 15 gpm for 1100 min and drawdowns at both the pumped well and the piezometer recorded. Recovery data was collected at the piezometer (Woodward-Clyde, unpubl., 1978). Transmissivities calculated from this test using the Theis non-steady radial flow curve ranged from 3.8 E-06 m^2/sec (3.5 ft^2/day) for the pumping well to 2.0 E-05 m^2/sec (19 ft^2/day) for the piezometer. Assuming that water was contributed by the entire screened interval, the hydraulic conductivity of that portion of the Yeso Formation ranges from 2.5 E-08 to 1.3 E-07 m/sec (0.007 to 0.036 ft/day). A storage coefficient of 0.00085 was calculated. These low permeabilities probably reflect actual conditions within the aquifer. They are related at least in part to the proximity of the Pedernal axis, which probably induced the local deposition of dominantly fine grained, non-carbonate sediments (Kelley, 1971). The proximity of the stable craton may have minimized subsequent faulting, which might have increased the permeability of the sediments.

Well E-6, located at SW¼ SW¼ SW¼ sec. 11, T14S, R15E (Fig. 2), was drilled to a depth of 1000 ft. A piezometer was drilled to the same depth 106 ft distant. All but the upper 50 ft of well E-6 is in the Yeso Formation. The driller's log for E-6 is incomplete, but that of the piezometer indicates that yellow claystone, siltstone and limestone were encountered in the upper part of the borehole, while in the bottom 200 ft of the hole, gypsum and siltstone dominate (Appendix 2). The well was cased with triple mill-slotted casing from a depth of 375 to 1000 ft below land surface. The depth to water upon completion of the well was 340 ft below land surface. Well E-6 was pumped at a rate of 300 gpm for 1460 min in July 1977. Drawdown and recovery water levels were measured at both the pumping well and the piezometer. An aquifer transmissivity of 1.0 E-03 m^2/sec (960 ft^2/day) was calculated from the pumping well recovery data, using a late time-delayed yield curve. If it is assumed that the entire screened interval is contributing water, the hydraulic conductivity of the tested thickness of Yeso Formation is about 5.3 E-06 m/sec (1.5 ft/day). Data collected at the piezometer exhibited evidence of hydrologic boundaries and were not usable.

Well E-3, located at NE¼ NW¼ SE¼ sec. 4, T15S, R14E (Fig. 2), was drilled to a depth of 1100 ft. The lithologic log (Appendix 2) records mostly limestone and silty claystone in the upper part of the borehole, whereas below about 680 ft below land surface, dolomite and siltstone interbedded with gypsum dominate. Only the Yeso Formation was penetrated. The well was cased with triple mill-slotted casing from 323 ft to the bottom of the hole. A piezometer was drilled 88 ft to the northwest to the same depth and its casing perforated over the same interval. The depth to water upon completion of the well was about 325 ft below land surface. Well E-3 was pumped at a rate of 326 gpm for 1580 min in May 1977 while water levels were measured at both the pumping well and the piezometer. Water levels in the piezometer responded immediately to pumping, and drawdowns measured in the piezometer were almost exactly those in the pumping well, indicating a direct connection, such as a fracture, between the two wells. A transmissivity value of 4.9 E-04 m^2/sec (454 ft^2/day) was obtained when recovery water level data were analyzed under the assumption of a recharging image well. If water is being contributed over the entire screened section below the water table, the hydraulic conductivity of this section of the Yeso Formation is about 2.1 E-06 m/sec (0.6 ft/day).

Well E-10, located at SE¼ NE¼ SW¼ sec. 10, T13S, R16E (Fig. 2) was drilled to a depth of 1118 ft. A lithologic log is not available for this well. The depth to water upon completion of the well was 401 ft below land surface within the Yeso Formation. The well was pumped at a rate of 500 gpm for 720 min. A transmissivity of 6.0 E-04 m^2/sec (560 ft^2/day) was calculated. If the entire interval below static water level is contributing water, the hydraulic conductivity in the tested thickness of Yeso Formation is about 2.8 E-06 m/sec (0.8 ft/day).

Other aquifer tests

A number of short-duration specific capacity tests were run, mostly by the U.S. Geological Survey in the late 1960s, using Mescalero Reservation wells. Although the value of these tests is limited, due to their brevity (usually a few hours), low pumping rate, and limited saturated thicknesses tested, rough estimates of transmissivity and hydraulic conductivity can be made from the data. Thirteen wells located throughout the eastern part of the reservation were used in the tests; the tested saturated thickness was less than 100 ft for 10 of the wells. The test rates for most wells were very low, between 4 and 12 gpm; three wells were pumped at more than 100 gpm. A few wells were pumped at both high and low rates in separate tests. Analysis of the data for these tests indicates that fracture-flow dominates ground-water movement to the wells. When more stress was applied to the aquifer, i.e., when the pumping rate was increased, the apparent transmissivity of the aquifer dropped, due to the rapid draining of fractures that do not act as a porous media, but as discrete conduits. Transmissivity values calculated from the specific capacity tests range from 1.9 E-05 to 6.3 E-08 m^2/sec (18 to 5900 ft^2/day) and average 1.5 E-03 m^2/sec (1350 ft^2/day). Hydraulic conductivity values range from 3.5 E-07 to 3.2 E-04 m/sec (0.1 to 92 ft/day) and average 9.0 E-05 m/sec (26 ft/day). The high hydraulic conductivities indicate fracture-flow near the well. If these wells had been pumped for a longer period of time or at higher rates, like the E-series wells, the calculated hydraulic conductivities would have dropped greatly as the fractures were drained and the pressure differential induced by the pumping well extended into the formation.

GROUND-WATER MOVEMENT

Water moves generally west to east through the Yeso Formation under water-table conditions, from the recharge area of the Sacramento Mountains eastward into the Roswell artesian basin (Fig. 2). Confined conditions may occur locally. According to Mourant (1963), the aquifer is recharged by (1) precipitation falling on upland outcrop areas of fractured and dissolved limestone of the San Andres Formation and moving downward; (2) streamflow infiltrating through alluvium-filled streambeds of the Rios Ruidoso, Bonito and Hondo into the underlying Yeso strata; and (3) precipitation falling directly on permeable outcrops of Yeso. Mourant (1963) maintained that ground water contributes water to the

Rio Ruidoso throughout its course, whereas Fiedler and Nye (1932) believed that the regional water table in the Yeso Formation lay hundreds of feet below the level of the mountain streams. The truth appears to lie somewhere between. A comparison of streambed elevation and water levels in wells finished in the Yeso Formation near the stream indicates that, from its headwaters to as far east as the village of Ruidoso, the Rio Ruidoso is almost certainly contributing water to the aquifer. From Ruidoso east to the stream's confluence with the Rio Bonito, water levels in wells that tap the Yeso Formation within the stream valley appear to be at or slightly below the level of the stream. Only from the village of Hondo to below Picacho have seepage runs established a measurable increase in stream flow due to ground-water inflow (USGS, 1950–1965; Bean, 1949). The Rio Bonito is almost always dry along its lower 10 mi, and evidence suggests that the stream never sustained a perennial flow even prior to the initiation of the yearly diversion from the early 1900s of over 3000 acre-ft of water from the Rio Bonito into the Tularosa Basin.

Rehfeldt (1982) and Childers and Gross (1985) concluded that east of R20E some of the ground water probably present in the Yeso moves laterally into the San Andres Formation and the Glorieta Sandstone. An unknown proportion of the water continues to move eastward and downward through the Yeso and into the underlying older sediments. Fig. 2 is a map of the water table in the Yeso Formation within the study area. Ground water flows perpendicular to the equipotential lines on the map, from areas of higher hydraulic head to areas of lower hydraulic head. Water-level measurements from Mourant (1963, table 1), Sloan and Garber (1971, table of wells) and Table 2 of this report were used in the construction of Fig. 2. Although these sources provide water-level measurements recorded over a period of more than 60 yr, systematic errors in Fig. 2 are unlikely because long-term records for a number of wells within the area indicate that the ground-water aquifer in the Yeso Formation is relatively undeveloped in this area. Water-level records for wells located at NW¼ SW¼ SE¼ sec. 15, T11S, R14E; at SE¼ SE¼ SE¼ sec. 16, T11S, R18E; at SE¼ SE¼ SE¼ sec. 16, T10S, R15E; at SE¼ SW¼ NE¼ sec. 29, T10S, R17E; at SW¼ SW¼ SW¼ sec. 15, T11S, R18E; and at SE¼ SE¼ SW¼ sec. 20, T11S, R19E indicate that from 1955 to 1979 water levels fluctuated but did not exhibit the steady decline shown at wells located farther to the east in the central and eastern part of the basin (data from USGS WATSTORE, collected in Hydro-Geo-Chem., unpubl., 1982).

Ground water appears to move continuously through the Yeso down a hydraulic gradient, which on a regional scale is fairly constant (Fig. 2). However, superimposed on the fairly regular water table surface are local aberrations in the hydraulic gradient caused by faults, localized thinning of the aquifer and the presence of the Precambrian core of the ancient Pedernal uplift. Pajarito Mountain, an outcrop of the Pedernal basement (Kelley, 1972), causes ground-water mounding on its up-gradient (western) side, and inhibits the eastward movement of ground water in its vicinity. As was discussed earlier, about 10 mi north of Pajarito Mountain the configuration of the water-table map in T11S, R15 E and 16E, coupled with reports of "granite" by well logs, indicates

TABLE 2. Water levels at selected wells finished in the Yeso Formation. Depths of well are in feet below land surface; altitude of land surface at well is interpolated from topographic maps, generally accurate to with ½ contour interval on same map; water-level depths are given to the nearest feet. With the exception of water levels taken from Hydro-Geo-Chem (wells marked with an * in the owner column) and wells on the Mescalero Apache Indian Reservation, all water levels were taken from well records on file with the New Mexico State Engineer Office, and therefore represent water-level measurements made by drillers after well completion. This table does not include water-level measurements available in Mourant (1963) or Sloan and Garber (1972).

Location number	Owner	Depth of well (ft)	Altitude above mean sea level (ft)	Water Level: Depth below land surface (ft)	Water Level: Altitude above mean sea level (ft)	Water Level: Date
9.15.13.341	Farnsworth	97	5860	54	5860	6-23-90
9.16.19.432	Gonzales	81	5820	57	5763	8- 7-88
.28.331	*	44	5711	36	5675	-55
.33.112	*	130	5703	31	5672	-72
9.18. 4.132	*	144	5493	92	5401	-79
.19.342	*	200	5536	202	5334	-79
.30.324	*	230	5514	210	5304	-79
10.14. 1.312	S.B.A.C	943	6740	722	6018	7-10-86
.22.310	Wilson	505	6680	468	6212	3-27-86
.31.121	Ensor	900	7240	dry	<6340	5-18-85
10.15.16.444	*	40	5891	26	5865	-79
.32.321	*	215	6062	160	5902	-79
10.16.11.442	*	85	5549	71	5478	-79
.19.143	Nosker	340	5800	197	5602	11-20-89
.20.342	Caperton	56	5570	9	5561	6-20-89
.26.443	Colvin	150	5440	87	5353	6-22-89
.26.411	Chaves	84	5400	57	5343	2-14-84
.27.231	Chavez	200	5480	150	5330	8-20-87
.28.142	Chavez	103	5590	53	5537	7-10-89
.35.142	Caraway	192	5510	147	5363	5- 2-90
.36.212	Torrez	60	5350	22	5328	5-13-85
10.17.25.223	*	600	5754	412	5342	-79
.29.234	*	288	5445	124	5321	-79
.31.322	Chavez	250	5300	230	5070	3-24-78
11.13. 3.114	Braswell	325	7400	25	7325	3-15-86
.11.214	Ruidoso	250	7070	75	6995	5-23-81
.12.111	Hawthorne	200	6960	46	6914	4-22-81
.14.222	Pearson	300	7020	230	6790	11-19-84
.14.423	Keefe	120	6760	71	6689	10-22-85
.15.344	Pearson	300	6860	74	6786	5- 1-87
.23.111	McCasland	205	6960	117	6743	9-19-88
.25.234	McCarty	254	6440	62	6378	4-10-87
.26.112	Morgan	220	6820	182	6638	12-22-89
.35.424	Jones	102	6680	64	6616	7-26-84
11.14. 6.114	Tisdale	150	6980	69	6911	1-15-87
.14.323	White	117	6240	87	6153	3-15-90
.14.342	Caswell	250	6320	128	6142	7-29-84
.21.313	Thompson	102	6300	41	6259	10-11-84
.21.314	Parker	203	6300	78	6222	3- 6-87
.22.123	Brown	151	6300	90	6210	6-30-90
.22.144	Herrera	318	6400	234	6166	5-21-85
.22.213	Hartley	255	6340	195	6145	11-14-88
.29.313	BWR Inc.	310	6540	260	6280	6-26-84
.30.343	Wells	200	6620	170	6450	7-20-84
.30.344	Brumlow	200	6600	180	6420	7- 5-84
11.15. 5.232	Chambers	33	5920	20	5900	7-25-84
. 5.233	Lore	150	5990	102	5888	4-29-85
.32.111	Abercrombie	825	7200	370	6830	8-16-83
11.16.19.132	Gipson	402	6320	342	5978	4-22-78
. 5.330	Hare	250	6500	192	6310	6-29-85
11.17. 3.342	Gonzales	158	5270	98	5172	6-29-83
. 4.311	Sanchez	52	5220?	19	5201	7-26-90
. 9.121	McTeigue	300	5360	230	5130	11-18-83
.10.212	Guiterrez	102	5195	47	5148	6- 2-90
.10.214	Talley?	140	5190	70	5120	7-15-81
.10.221	Guiterrez	120	5200	80	5120	1-28-89
.12.143	Savedra	130	5140	83	5057	5- 8-90
.15.234	*	190	5254	153	5101	-79
.16.342	Salcido	221	5370	161	5209	12- 5-79
.20.121	Salcido	72	5450	50	5400	4- 4-84
.27.134	*	800	5690	476	5214	-79
.30.212	Salcido	160	5542	126	5416	5- 8-84
.33.323	McTeigue	170	5800	142	5658	5-20-88
11.18.15.312	Fresques	115	4990	41	4949	6-21-80
.15.333	*	125	4972	50	4922	1- -80
.24.113	Fresquez	185	4980	156	4824	12-10-79
.35.134	Diamond A	310	5244	285	4959	11-17-77
11.19.20.344	*	160	4827	127	4700	6- -69
.26.311	*	158	4723	116	4607	-57
.31.123	*	273	4844	53	4791	-79
12.15.35.334	M.A.R.	1000	7090	555	6545	12- 3-76
12.16.20.43	M.A.R	450	6380	431	5949	-75
12.17. 1.121	Diamond A	665	5500	575	4925	2-21-84
.15.330	Peters	617	6100?	586	5514?	9- 2-66
.34.421	Joyce Bros.	660	6060	620	5440	7- 4-67
13.14.19.131	M.A.R.	1191	8325	197	8128	8- -74
13.15.22.210	M.A.R	454	6780	310	6470	-75
13.16.10.220	M.A.R	1118	6280	401	5879	8-26-78
13.17. 3.344	Cooper	800	6115	737	5380	10-19-79
13.18. 8.311	McKnight	600	5755	495	5260	5-27-86
.10.233	Skeen	625	5570	488	5082	11-24-80
.13.114	Block Dot	400	5410	352	5060	1-27-74
14.14. 5.124	M.A.R	790	8445	750	7695	summer-74
14.15.11.333	M.A.R.	1000	6820	340	6480	7-29-77
14.17.14.223	Davenport	600	5990	dry	<5390	2-27-82
.19.324	Vanderwart	300	6100	162	5938	3-12-70
15.14. 4.312	M.A.R	1100	7160	323	6837	5- 1-77
4.414	M.A.R.	440	7310	400	6910	?
15.17.10.414	Vanderwart	200	5700	130	5570	9-19-82

that the Pedernal uplift may be unusually high in that area. Its presence has an effect similar to that of Pajarito Mountain, mounding the water on its western side and blocking eastward movement through it. It is likely that this remnant of a Pedernal topographic high was once continuous with Pajarito Mountain to the south. However, a structural low has been created between the two high areas by the White Tail fault, a major regional structure that has faulted the Yeso down on its southern side. A ground-water trough has developed in the downthrown part of the formation.

An interesting characteristic of the area bounded by the middle Rio Bonito on the north and the middle Rio Ruidoso on the south is the low gradient of the water table. The equipotential lines are farther apart than they are in the rest of the mountain area. This probably occurs because the saturated thickness of the Yeso Formation is much greater in this area than it is to either the north, where the granitic mass of Capitan Mountain intrudes, or to the south, where the formation has been uplifted and folded and its saturated thickness greatly reduced.

Aquifer tests indicate that there are two major components of ground-water flow within the Yeso aquifer. Ground water moves relatively quickly through beds of limestone or dolomite, where permeability has been greatly increased by both the fracturing and subsequent dissolution of the rocks. It moves much more slowly through the unfractured siltstones and shales comprising the bulk of the formation. It is difficult to attach relative, let alone quantititative, values to these rates of movement. The available data suggest that the rate of ground-water movement through the unfractured siltstones is roughly 1.0 E-07 m/sec, through fractured limestones at 1.0 E-04 m/sec and at an average rate of about 5.0 E-06 m/sec.

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APPENDIX 1—WELL-NUMBERING SYSTEM

The system of numbering wells used in this paper is based on the Federal system of subdividing land into townships, ranges and sections (Fig. 3). The well number consists of four parts, separated by periods. The first part (from the left) represents the township, measured north or south of the New Mexico baseline; within the study area it is always south. The second part is the range, measured east or west of the New Mexico principal meridian; within the study area it is always east. The third part is the section number and the fourth part locates the well within the section. The section is divided into quarters, quarter-quarters, etc. which are numbered 1, 2, 3 and 4 as illustrated by Fig. 3. The first number in the fourth part of the well number therefore designates a 120-acre tract of land within which the well is located, the second number a 40-acre tract, and the third number a 10-acre tract. Thus, a well designated by location number 11.14.30.344 is located in the SE¼ of the SE¼ of the SW¼ of section 30, township 11 north, range 14 east. The well numbers in Table 2 are grouped by townships and ranges for easier reading, and the full well number is given only for the first well in each township and range.

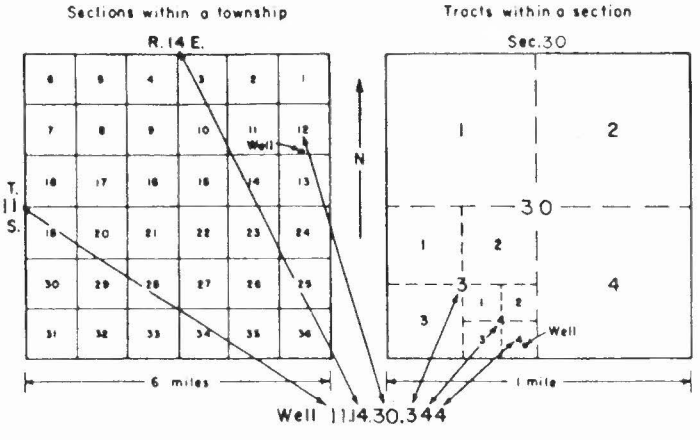


FIGURE 3. System of numbering wells in New Mexico.

APPENDIX 2—MESCALERO RESERVATION WELL LOGS

Lithologic logs of deep water wells located on the Mescalero Apache Reservation, Otero County, New Mexico are given below. Well location numbers are explained in Fig. 3; surface elevation is in feet above mean sea level. The E-series logs were prepared by Woodward-Clyde Consultants and are excerpted from that firm's consultant report on the geology and hydrology of the Mescalero Reservation. Paul's well was described by Welder (1975).

Unit	Lithology	Interval (ft)	Thickness (ft)
Well 12.15.35.334 E-1			
Surface elevation 7090 ft			
San Andres Fm. (Psa):			
	Limestone, slightly vuggy, arenaceous, iron-stained, light gray and tan	0- 50	50
	Siltstone, calcareous, tan	50- 60	10
	Limestone, slightly vuggy, arenaceous, iron-stained, gray and tan. Claystone interbeds 90-92 and 97-99 feet	60- 100	40
	Sandstone, medium-grained, calcareous, vuggy, tan	100- 120	20
	Limestone, argillaceous, arenaceous to lithographic, vuggy to slightly vuggy, tan to medium gray. Minor interbeds of sandstone, fine to medium-grained, calcareous, tan to reddish brown	120- 470	350

Unit	Lithology	Interval (ft)	Thickness (ft)
Yeso Fm. (Py):			
	Claystone, silty, arenaceous, calcareous, red. Minor interbeds of sandstone, argillaceous, calcareous, tan, and limestone, vuggy, arenaceous, gray	470- 580	110
	Limestone, argillaceous, arenaceous, vuggy to slightly vuggy, brown to medium gray. Numerous interbeds of sandstone, fine-grained, calcareous, tan, and siltstone, arenaceous, calcareous to non-calcaurous, gray	580- 720	140
	Siltstone, clayey, calcareous, tan to dark gray, minor interbeds of claystone, calcareous, red to gray, and limestone, argillaceous, brown to gray	720- 760	40
	Dolomite, vuggy, gray	760- 770	10
	Siltstone, calcareous, dark gray	770- 785	15
	Dolomite, dark gray	785- 790	15
	Claystone, calcareous, dark gray	790- 795	5
	Dolomite, arenaceous, dark gray	795- 800	5
	Limestone, argillaceous, arenaceous, medium to dark gray	800- 810	10
	Siltstone, calcareous, dark gray	810- 816	6
	Dolomite, dark gray	816- 823	7
	Claystone, non-calcareous, gray	823- 830	7
	Anhydrite, white	830- 836	6
	Siltstone, calcareous, gray	836- 843	7
	Anhydrite, white	843- 850	7
	Siltstone, calcareous, gray	850- 856	6
	Limestone, argillaceous, gray	856- 863	7
	Anhydrite, white	863- 870	7
	Siltstone, calcareous, gray	870- 880	10
	Dolomite, argillaceous, gray	880- 887	7
	Siltstone, calcareous, gray. Numerous thin interbeds of anhydrite, white; dolomite, gray; limestone, vuggy, gray; claystone, calcareous, red; and sandstone, fine to medium-grained, calcareous, tan to reddish-brown	887-1000	113

Well 15.14.4.312 E-3
Surface elevation 7160 ft

Yeso Fm. (Py):			
	Limestone, arenaceous, tan to medium gray, thin siltstone and claystone interbeds	0- 60	60
	Siltstone, calcareous, tan	60- 70	10
	Claystone, slilty, calcareous red and tan	70- 110	30
	Limestone, arenaceous, tan	110- 130	20
	Limestone, argillaceous, tan. Numerous soft red claystone interbeds	130- 170	40
	Claystone, silty, calcareous, red	170- 185	15
	Limestone, argillaceous, tan	185- 200	15
	Limestone, arenaceous and argillaceous, tan. Numerous red claystone interbeds	200- 240	40
	Limestone, arenaceous, tan to light gray	240- 290	50
	Claystone, silty, calcareous, tan	290- 296	6
	Limestone, arenaceous, tan	296- 304	8
	Claystone, silty, calcareous, tan	304- 315	11
	Limestone, lithographic to arenaceous, light gray	315- 380	65
	Claystone, silty, calcareous, red	380- 388	8
	Limestone, arenaceous, light gray	388- 396	8
	Claystone, calcareous, red and siltstone, calcareous, light gray	396- 406	10
	Limestone, arenaceous, light gray to tan. Numerous claystone and fine-grained sandstone interbeds	406- 475	69
	Limestone, lithographic, light gray	475- 520	45
	Limestone, argillaceous, light gray	520- 532	12
	Limestone, argillacrous, light to medium gray. Numerous gypsum and calcareous siltstone interbeds	532- 690	158
	Dolomite, dark gray. Numerous gypsum interbeds	690- 760	70
	Limestone, argillaceous, light gray Numerous thin gypsum and claystone interbeds	760- 785	25
	Dolomite, arenaceous, medium gray Numerous thin gypsum and sandstone interbeds	785- 865	80
	Siltstone, calcareous, medium gray. Numerous thin argillaceous dolomite interbeds	865- 945	80
	Dolomite, argillaceous, medium gray	945- 953	8
	Siltstone, calcareous, medium gray; Siltstone, non-calcareous, red-brown Minor thin argillaceous dolomite and limestone interbeds	953- 985	32
	Gypsum, white	985- 992	7
	Siltstone, calcareous, medium gray; Siltstone, non-calcareous, red-brown	992-1020	28
	Gypsum, white	1020-1027	7
	Siltstone, calcareous, medium gray; Siltstone, non-calcareous, red-brown	1027-1048	21
	Sandstone, fine-grained, red-brown	1048-1055	7
	Siltstone, calcareous, medium gray; Siltstone, non-calcareous, red-brown. Numerous gypsum interbeds	1055-1100	45

Well 14.15.11.333 E-6
Surface elevation 6820 ft

San Andres Fm. (Psa):			
	Limestone, arenaceous to lithographic, iron-stained, light gray	0- 55	55
Yeso Fm. (Py):			
	Claystone, soft, calcareous, red and yellow. Thin interbeds of limestone arenaceous, medium gray, and siltstone, calcareous, light gray to light green	55- 140	85
	Limestone, argillaceous, arenaceous vuggy, iron-stained, medium brown to light gray. Numerous interbeds of sandstone, argillaceous, fine-grained, calcareous, red-brown. Void 200-202	140- 230	90
	Sandstone, fine-grained, tan with siltstone, yellow and medium gray	230- 238	8
	Limestone, argillaceous, arenaceous, vuggy, light gray to tan with interbeds of siltstone, calcareous, yellow and medium gray, and sandstone, fine-grained, argillaceous, calcareous, tan to red	238- 403	165
	Claystone, calcareous, dark gray to red interbedded with limestone, argillaceous, brown	403- 410	7
	Siltstone, calcareous, dark gray to red, interbedded with limestone, argillaceous, brown	410- 445	35
	Limestone, lithographic, medium gray	445- 460	15
	Siltstone, calcareous, dark gray interbedded with limestone, argillaceous, brown	460- 500	40
	Limestone, argillaceous, tan and medium gray, interbedded with siltstone calcareous, dark gray	500- 545	45
	Claystone, calcareous, red	548- 555	7
	Limestone, argillaceous, arenaceous, tan to medium gray. Numerous thin interbeds of claystone, calcareous, red	555- 645	90
	Siltstone, calcareous, light gray	645- 652	7
	Limestone, argillaceous, medium gray	652- 665	13
	Siltstone, calcareous, medium gray Minor thin interbeds of limestone, argillaceous, medium gray, and claystone, calcareous, red	665- 780	115
	Siltstone, calcareous, medium gray interbedded with limestone, argillaceous, medium gray. Numerous thin interbeds of gypsum, white	780-1000	220

Well 13.14.19.131 Paul's well
Surface elevation 8325 feet

San Andres Fm. (Psa):			
	Limestone, brownish-gray, dolomitic clayey, some calcite	0- 80	80

Unit	Lithology	Interval (ft)	Thickness (ft)
	Limestone, grayish-yellow, clayey	80- 90	10
	Claystone, grayish-orange, calcareous, silty	90- 100	10
	Sandstone, reddish-brown to grayish-orange, very fine to fine quartz grains, hard, firmly cemented with clayey calcareous cement	100- 140	40
Yeso Fm. (Py):			
	Siltstone, reddish-brown, clayey, calcareous, with minor clay	140- 150	10
	As above, but with sand	150-160	10
	Sandstone, reddish-brown to light gray, very fine to fine quartz grains, hard, firmly cemented with clayey calcareous cement	160- 170	10
	No sample	170- 180	10
	Siltstone, reddish-brown, clayey, sandy, very calcareous	180- 210	30
	Clay, reddish-brown, silty, calcareous	210- 220	10
	Sandstone, reddish-brown, clayey, sandy, very calcareous	220- 230	10
	Siltstone, reddish-brown, clayey, sandy, very calcareous	230- 250	20
	No Sample	250- 260	10
	Siltstone, as above	260- 270	10
	Siltstone, grayish-orange, sandy, clayey and light-gray calcareous clay and dolomite	270- 300	30
	Sandstone, grayish-orange, very fine to fine grained quartz and carbonate grains, calcareous	300- 310	10
	Limestone, very light gray, crystalline, probably porous	310- 330	20
	Dolomite, light brownish-gray, very calcareous, noncrystalline, dense	330- 340	10
	Limestone, light-gray, dolomitic, crystalline	340- 350	10
	Sandstone, grayish-yellow, very fine quartz grains in calcareous clay matrix	350- 360	10
	Limestone, light-gray, dolomitic,	360- 380	20
	Claystone, light-gray, very fine quartz grains in very calcareous clay, silty	380- 400	20
	Limestone, light-gray, angular grains	400- 410	10
	Limestone, light-gray, dolomitic	410- 420	10
	No sample	420- 430	10
	Limestone, light-gray, dolomitic	430- 440	10
	Siltstone, light yellowish-orange, clayey, sandy, very calcareous	440- 450	10
	No sample	450- 460	10
	Siltstone, light-brown, clayey, sandy, clacareous	460- 470	10
	Sandstone, grayish-orange, very fine grains of quartz, calcareous cement, thin beds of light gray crystalline limestone	470- 480	10
	Sandstone, very light orange, very fine grained, clayey, calcareous cement	480- 490	10
	Limestone, light-gray, and sandstone, as above	490- 500	10
	Sandstone, as above	500- 510	10
	Limestone, light yellowish-brown to orange and gray, silty	510- 540	30
	No sample	540- 550	10
	Siltstone, light-brown, clayey, sandy, calcareous	550- 560	10
	Siltstone, as above with light-gray crystalline limestone	560- 570	10
	Limestone, light-gray, crystalline	570- 580	10
	Sandstone, pale yellowish orange to orange, very fine grained, clayey, calcareous cement	580- 600	20
	Siltstone, light-gray, very calcareous, and silty limestone	600- 610	10
	Limestone, brownish-gray, and siltstone, as above	610- 620	10
	Limestone, very light orange, silty	620- 630	10
	Sandstone, grayish-orange, very fine grained, white clayey calcareous cement	630- 640	10
	Siltstone, light reddusg-brown, clayey, calcareous	640- 650	10
	Limestone, light to yellowish gray, noncrystalline	650- 660	10
	Sandstone and siltstone, grayish-orange, clayey, calcareous, sandstone very fine grained	660- 690	30
	Limestone, light brownish-gray, dolomitic	690- 710	20
	No sample	710- 720	10
	Siltstone, grayish-orange, sandy, clayey, calcareous	720- 740	20
	Limestone, yellowish gray, and siltstone, as above	740- 750	10
	Siltstone, grayish-orange, sandy, clayey, calcareous	750- 760	10
	Siltstone, as above and light-gray sandy limestone	760- 770	10
	as above	770- 780	10
	Limestone, grownish-gray, crystalline	780- 790	10
	Siltstone, grayish-orange, clayey, calcareous	790- 810	20
	Claystone, medium light-gray, silty sandy, calcareous	810- 820	10
	Limestone, light brownish-gray, dolomitic, finely crystalline	820- 830	10
	Limestone, as above, and very fine sandstone	830- 840	10
	Siltstone, grayish-orange, sandy, clayey, calcareous	840- 850	10
	Dolomite, medium dark-gray, with very fine grained sandstone and dolomitic limestone	850- 880	30
	Limestone, light olive-gray, dolomitic and very fine sandstone, possibly arkosic	880- 890	10
	Anhydrite and gypsum, white	890- 910	20
	Siltstone, light brown, clayey, slightly calcareous	910- 920	10
	No sample	920- 930	10
	Sandstone, light-gray, very fine grained quartz, silty, slightly calcareous, muscovite mica	930- 970	40
	Siltstone, medium light gray, sandy, in calcareous muddy cement	970-1000	30
	Siltstone, as above, white gypsum	1000-1010	10
	Siltstone, light-brown, clayey, slightly calcareous	1010-1020	10
	Claystone, medium-brown, and light brown, silty, calcareous	1020-1030	10
	Siltstone, light olive-gray to light brown, silty, calcareous, very clayey	1030-1070	40
	Anhydrite, and gypsum (alabaster and selenite)	1070-1080	10
	Sandstone, light-gray and light brown, very fine grained, calcareous cement, and anhydrite and gypsum	1080-1090	10
	Siltstone, light olive-gray, calcareous, dolomitic (?)	1090-1100	10
	Dolomite, light olive-gray	1100-1120	20
	Sandstone, light-gray, very fine grained, silty, dolomite, anhydrite, and gypsum	1120-1140	20
	Siltstone, light yellow-brown, clayey, calcareous	1140-1160	20
	Anhydrite, light-gray, white non-crystalline gypsum, dolomite	1160-1170	10
	Anhydrite and gypsum as above	1170-1190	20

APPENDIX 3—UPPER RIO HONDO BASIN WELL LOGS

Lithologic logs for three oil tests drilled in the upper Rio Hondo Basin are given below. Terminology is taken from drillers' logs and may not correspond to common usage or be consistent between logs. Formation tops were designated by the drillers. Interval is measured in feet below land surface.

Unit	Lithology	Interval (ft)	Thickness (ft)
Well 11.19.10.441 KoKo #1			
San Andres Fm. (Psa):			
	Dolomite interbedded with shale	0- 535	535
Glorieta Ss. (Pg):			
	Sand and lime	535- 707	172

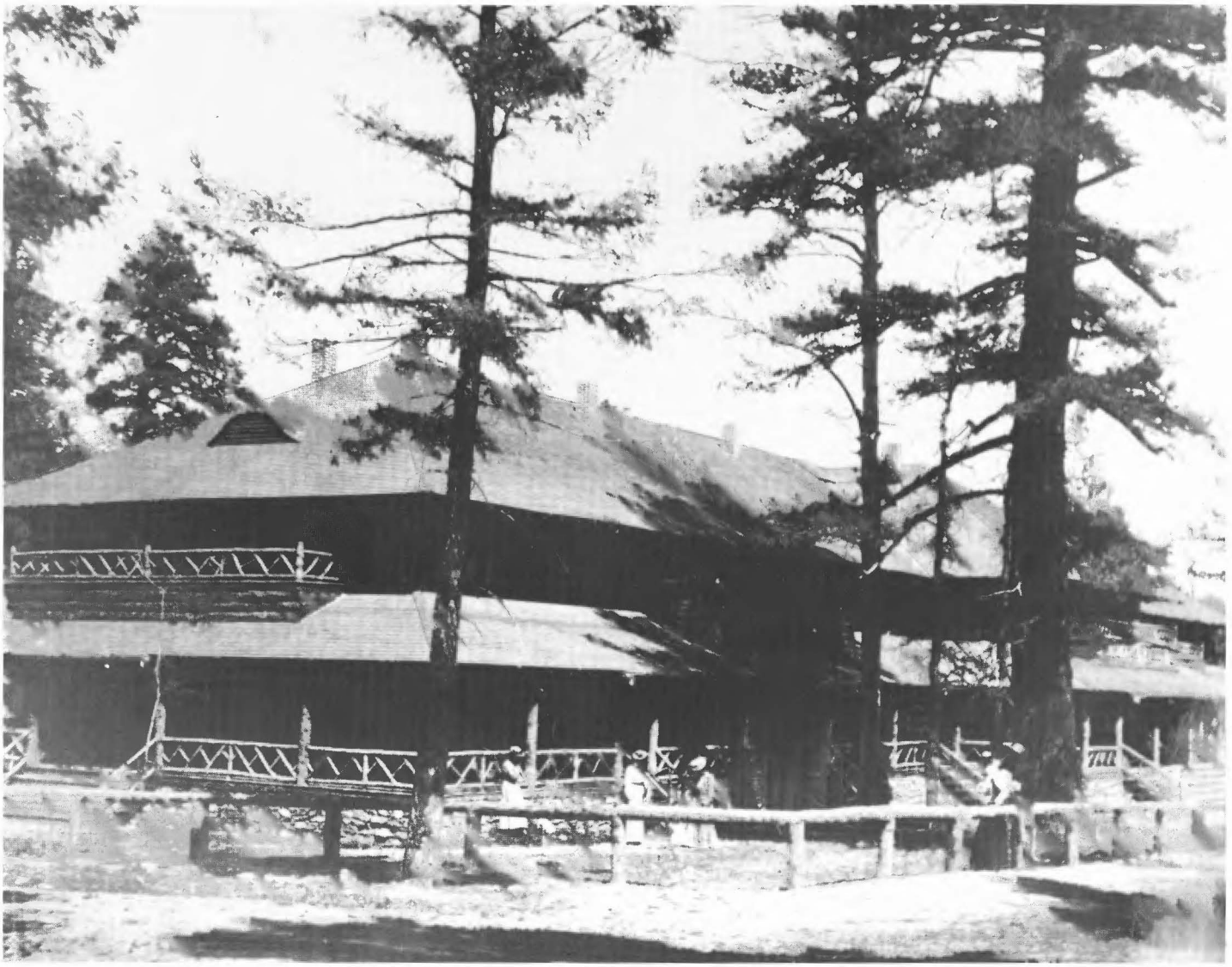
Unit	Lithology	Interval (ft)	Thickness (ft)
Yeso Fm. (Py):			
	Sand and limestone	707-1300	593
	Anhydrite with salt stringers	1300-1360	60
	Anhydrite, shale and sand	1360-1660	300
	Sand with lime stringers	1660-1900	240
	Anhydrite, lime, salt stringers	1900-2230	530
Abo Fm. (Pa):			
	Abo sand and shale	2230-2976	746
Precambrian			
	weathered granite and basement rocks	2976-3040	64

Well 11.19.4.314 Tecolote #1-2

San Andres Fm. (Psa):			
	Dolomite with streaks of redbeds	0- 547	547
Glorieta Ss. (Pg):			
	Sand	547- 680	133
	Anhydrite, lime, shale	680- 740	60
Yeso Fm. (Py):			
	Sand with lime streaks	740-1450	710
	Anhydrite with shale streaks	1450-1580	130
	Sand with anhydrite streaks	1580-1870	290
	Anhydrite and salt	1870-2020	150
	Anhydrite and shale	2020-2047	27
	Red shale	2047-2147	100
Abo Fm. (Pa):			
	Red shale	2147-2420	273
	Sand	2420-2890	470
Precambrian			
	Granite wash	2890	

Well 10.15.16.433 Nosker #1-Y

Quaternary (Qal)			
	Alluvium	0- 67	67
Yeso Fm. (Py):			
	Silty sand	67- 90	23
	Sand	90- 95	5
	Silty sand	95- 100	5
	Sand	100- 113	13
	Silty sand	113- 118	5
	Sand	118- 120	2
	Silty sand	120- 180	60
	Sand	180- 184	4
	Silty sand	184- 190	6
	Sand	190- 195	5
	Silty sand	195- 220	25
	Sand	220- 230	10
	Silty sand	230- 387	157
	Sand	387- 393	6
	Silty sand	393-1010	617
	Sand	1010-1020	10
	Silty sand	1020-1450	430
	Diorite	1450-1526	76



Large wooden pavilion at Cloudcroft. This was the main tourist facility until the larger lodge was opened in 1901. From the Alfred J. Black Collection; courtesy of Spencer Wilson.