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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GROUND-WATER INVESTIGATIONS OF THE PROJECT GNOME AREA, EDDY AND LEA COUNTIES, NEW MEXICO*

By

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This report is preliminary
and has not been edited for
conformity with Geological
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U. S. Atomic Energy Commission.

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ABSTRACT

The U.S. Atomic Energy Commission, through the Office of Test Operations, Albuquerque Operations Office, plans to detonate a nuclear device in a massive salt bed 1,200 feet beneath the land surface. The project, known as Project Gnome, is an element of the Plowshare program--a study of peacetime applications of nuclear fission. The location of the proposed underground shot is in a sparsely-populated area in southeastern Eddy County, N. Mex., east of the Pecos River and about 25 miles southeast of the city of Carlsbad. The area is arid to semiarid and ground water is a vital factor in the economic utilization of the land, which is primarily used for stock raising. An investigation of the Project Gnome site and surrounding area for the purposes of evaluating the ground-water resources and the possible effect upon them from the detonation of the nuclear shot was desired by the Commission. This report describes work done by the U.S. Geological Survey on behalf of the Commission and presents results of the investigation of the ground-water resources and geology of the area.

The most intensive investigations were made within a 15-mile radius of the site of Project Gnome and mainly on the east side of the Pecos River. The total area of study of over 1,200 square miles includes parts of Eddy and Lea Counties, N. Mex.

The Project Gnome site is in the sedimentary Delaware Basin. It is underlain by about 18,000 feet of sedimentary rocks ranging in age from Ordovician to Recent. Upper Permian evaporitic rocks, which contain the principal source of potash available in the United States, are worked in nearby mines. The potash minerals are found in a massive salt bed about 1,400 feet thick in the Salado Formation of Permian age. The land surface of the area is covered mostly by wind-blown sand and caliche; however, rocks of the Rustler Formation of Permian age and younger rocks of Permian, Triassic, Pleistocene(?) and Recent age crop out at several localities. Solution by ground water of salt at the top of the Salado Formation and of anhydrite within the Rustler Formation has removed thick sections of these rocks. A subsequent lowering of the land surface and differential collapse of the Rustler has formed many sinkholes and has created a karst topography over much of the western part of the area.

Ground water is obtained from rocks of Permian, Triassic, Tertiary, and Quaternary age in the general region. However, the only aquifer at the Gnome site is the Culebra Dolomite Member of the Rustler Formation of Permian age. The aquifer is about 500 feet beneath the surface at the site and is about

30 feet thick. An aquifer, immediately above the top of the salt, contains a brine solution in Nash Draw, a few miles west of the Gnome site. This aquifer discharges into the Pecos River and is a major source of contamination of the river water. No potable water is known to be present in the area below the top of the salt of the Salado Formation.

The ground water in the area is generally under artesian pressure. The general direction of ground-water movement is toward the Pecos River both east and west of the river. At the Gnome site the artesian head of the water in the Culebra Dolomite Member is about 75 feet. The water moves westward through the aquifer at a rate of about ½ foot per day. The most widespread utilization of ground water east of the river is for stock use. Irrigation usage west of the Pecos River accounts for the largest withdrawal of water. Wells range in depth from a few tens of feet to nearly 800 feet. Water levels range from a few feet to about 500 feet below the surface. A test well at the Gnome site drawing water from the Culebra Dolomite Member was pumped at a rate of 100 gpm (gallons per minute); however, most wells east of the river yield only a few gpm. Irrigation wells west of the river yield as much as 3,500 gpm.

Most of the water in the area is highly mineralized and is suitable only for use by livestock. Water of better quality is present in formations of Pleistocene(?), Tertiary, and Quaternary age in parts of the area.

No adverse affects upon the ground-water resources of the area are anticipated if the shot effects are contained, as planned, within the massive salt of the Salado Formation. If forces of the explosion are not contained within the massive salt and fissuring extends upward into the Culebra Dolomite Member the water contained in the dolomite will be contaminated by fission products. This contamination probably could be controlled or eliminated through the use of deep disposal wells. More serious would be the possibility of creating paths for water movement downward from the Culebra Dolomite Member to the rocks immediately above the top of the salt, and thence, into the existing brine aquifer system which discharges into the Pecos River.

Four monitoring wells will be in operation near the Gnome site at the time of the nuclear shot. The pressure head of the water in the aquifer in the Culebra Dolomite Member will be recorded, and, in one well, any changes in hydrologic conditions in the rocks immediately above the salt will be observed. These data will be interpreted to assess the immediate effect of the shot upon the ground-water regime. Observations will continue in these monitoring wells for some time following the shot.

Records of 70 wells, radiochemical analyses of 24 samples of waterrfrom wells, geologic cross sections, subsurface formation maps, and a contour map showing the altitude and configuration of the water level in the area are included in the report.

Introduction

Project Gnome is an element of the Plowshare program of the U.S. Atomic Energy Commission. Operation Plowshare is the Commission's program of experiments to determine peaceful applications of nuclear explosions. The plans for Project Gnome call for a 5-kiloton shot to be exploded at a depth of 1,200 feet beneath the land surface and about 500 feet below the top of a thick massive salt formation. The objective of the project is to study the feasibility, for industrial applications of the generation of useful power, utilizing the heat released from such an explosion, and the production and recovery of valuable radioisotopes, by means of a contained nuclear detonation.

The water supply for livestock and for domestic use by the ranchers of the Project Gnome area is obtained from drilled wells. The possibility that a nuclear detonation might result in physical damage to these wells or that radioactive matter might be introduced into the formations supplying water to the wells was considered by the Atomic Energy Commission. In order to safeguard the public and access the hazard to existing and future water supplies a study of the ground-water resources of the area was desired by the Commission.

The U.S. Geological Survey was asked by the Office of Test Operations, Albuquerque Operations Office of the Commission, to make an investigation of the geology and hydrology of the Gnome site and surrounding areas to determine the possible effect of a nuclear detonation upon the underground water.

The area of investigation is in southeastern Eddy County and southwestern Lea County and includes Tps. 21-26 S., Rs. 28-33 E., a total area of over 1,200 square miles. The site of Project Gnome is in the approximate center of this area in sec. 34, T. 23 S., R. 30 E. (See fig. 1.) It is east of the Pocos River, about 25 miles

Figure 1.--Map showing the location of the Project Gnome site and the area of investigation. (shaded), Eddy and Lea Counties, N. Mex.

southeast of Carlsbad, 13 miles southeast of Loving, and 12 miles northeast of Malaga, N. Mex.

The Project Gnome area is sparsely populated and is utilized for cattle ranching, farming, potash mining, and petroleum production. The site is 10 miles southeast of the U.S. Borax and Chemical Co. refinery and 11 miles southeast of the refinery and main shaft of the International Mineral and Chemical Corp.- underground workings of this mine extend to within 8½ miles of the site. The nearest petroleum production to the site is the Texaco Inc. No. 1 Remuda Basin unit, about 4½ miles northwest of the site. The Shell Oil Co. No. 1 James Ranch gas well is about 6 miles northeast, and the Richardson and Bass No. 1 Federal-Legg oil well, about 7½ miles north. Several oil and gas wells are located about 9 miles south of the site, and, near Malage, about 10 miles southwest of the site a small oil and gas field has been developed.

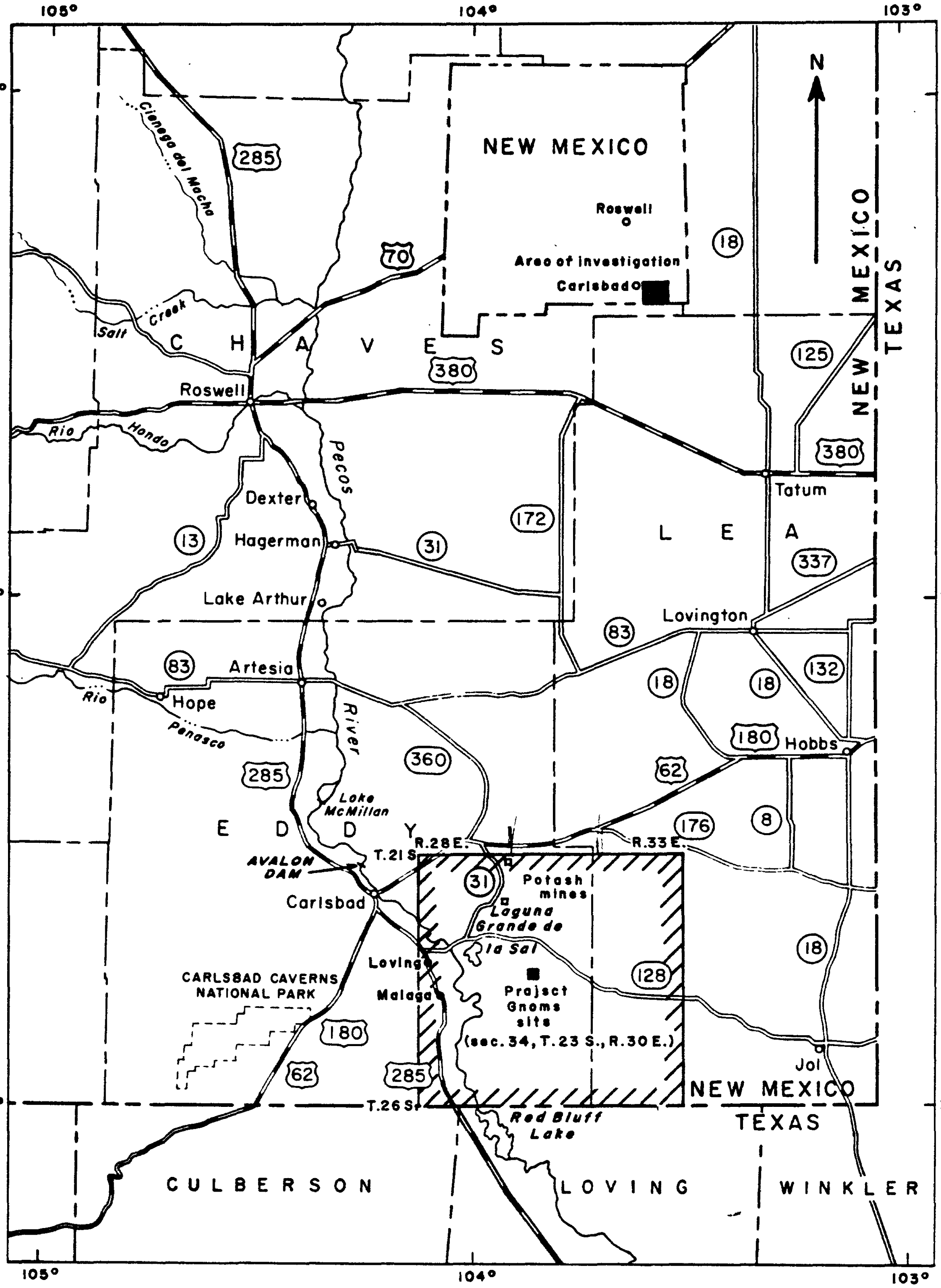

Figure I.--Map showing the location of the Project Gnome site and the area of investigation (shaded), Eddy and Lea Counties, N. Mex.

The purpose of this investigation is to provide basic information on the underground water in the vicinity of the Project Gnome site. The study included an investigation of the surface and subsurface geologic formations and in particular those which yield water to wells. All water wells which could be located, within an approximate 15-mile radius of the Gnome site, were visited and water-level measurements made where possible. Well owners and well drillers were contracted for information about most of the wells investigated. Water samples were collected from wells and analyzed for radiochemical quality.

Reconnaissance fieldwork for this investigation was done in October 1958. The well inventory, water-level measurements, collection of water samples, and the collection of well logs and subsurface data was done from February through May 1959. Additional data were collected from July 1960 to June 1961. During this period test holes were drilled at and near the proposed shot site and observations were made in the shaft and tunnel being constructed for access to the shot point.

To determine accurately the water level, depth, capacity, casing size, and other characteristics of some wells in the proximity of the Gnome site it was necessary to remove the pumping equipment from the wells for entry of measuring devices. This phase of the well inventory was done in March and April, 1959. Fifteen wells were investigated by this method. Nine wells were within a 5-mile radius of the Gnome site. The 6 other wells investigated were either just outside a 5-mile radius from the Gnome site or measurements in them were considered important to an understanding of the areal ground-water conditions.

The following data were obtained for the 15 wells: 1) depth to well; 2) depth to water; 3) casing diameter; 4) amount of casing in well (when measurement could be obtained); 5) bailing test and measurement of drawdown of water level (when measurement could be obtained); 6) electrical resistivity and self-potential logs; 7) gamma-ray log; 8) temperature measurement of water and sample for radio-chemical analysis; and 9) photograph of each well.

The wells in which pumping equipment was removed and detailed measurements were made ranged in depth from 85 feet to 700 feet. Well diameters ranged from 5 inches to 8 inches. Some of the wells were cased from top to bottom, others were uncased or partly cased. Steel or wood windmill towers were over all except one of the wells investigated.

Bailing measurements and caliper measurements of casing and hole diameters could not be made in some of the wells due to the small diameter of the casing or, in two instances, crookedness of the hole. The electrical logs obtained were in most cases unsatisfactory due to the thinness of saturated section in the well or because the hole was cased.

A record of the pertinent details of the well and construction data on the size and amount of pump pipe and rods in the well was furnished to the owner for his information.

Two test holes were drilled near the site in August and September 1960. These test holes are known as USGS test holes 1 and 2 and are located 1,000 feet south of the Gnome shaft and about 2 miles southwest of the shaft, respectively.

They were drilled for the purpose of expanding the knowledge of the water-bearing formations in the immediate vicinity of the Gnome site and for use as water-level observation wells during the Gnome experiment. Well cuttings were collected after each drilling cycle (5 feet or less) and were processed immediately and examined microscopically. A current log of the hole was maintained at all times and stratigraphic horizons were identified as drilling progressed. Tests to determine the presence or absence of water were made at major changes of formations and whenever the presence of water was suspected.

A preliminary appraisal of the ground-water conditions of this area was prepared by W. E. Hale and Alfred Clebsch, Jr. in 1958. J. D. Vine mapped the surface geology of a part of the area in 1958 and 1959. In 1959, E. H. Baltz prepared a diagram showing relations of Permian rocks in a part of the area and C. L. Jones prepared a paper which discussed the evaporites of the Upper Permian of the area. The writer in 1960 prepared a cross section of the rocks between the Gnome site and Carlsbad Caverns. In 1961 the writer compiled a report which presented the basic geologic and hydrologic data obtained during the drilling of two test holes for ground-water exploration near the Gnome site.1/ A number of other published reports discuss the geology and ground-water resources of parts of Eddy County and the surrounding areas. Titles of these reports appear in the list of references accompanying this report. Information from these reports has been used in the preparation of the present report.

The subsurface formations beneath the Project Gnome site, in the approximate center of sec. 34, T. 23 S., R. 30 E., are known accurately to a depth of 1,500 feet. In 1958 a rotary hole was drilled to this depth at this location and a full section of rock core was obtained. This hole is designated AEC drill hole 1. The core was examined by George W. Moore and a full description of it is contained in a Trace Elements Memorandum Report (Moore, 1958). In 1959, AEC hole 2 was drilled by cable-tool and rotary methods to a depth of 1,200 feet about 500 feet northeast of the center of sec. 34. The hole was drilled for use in an underground high explosive experiment. Also in 1959, a rotary hole 800 feet deep was drilled about 3,700 feet north-northeast from the center of sec. 34. This hole is known as the Sandia Instrument Hole and was used for observation purposes during underground high explosives experiments.

The cooperation of the well owners of the area in contributing information regarding their wells and in allowing the removal of pumping equipment and the temporary loss of use of the well is gratefully acknowledged. Logs of test holes used in the preparation of maps and cross sections in this report were furnished by the offices of T. F. Stipp, Regional Geologist, Roswell, and R. S. Fulton, Regional Mining Supervisor, Carlsbad, both of the Conservation Division, U.S. Geological Survey.

The project area lies in the Pecos Valley section of the Great Plains physiographic province (Fenneman, 1931, fig. 1). The Pecos River flows through the southwestern part of the area and divides it physiographically into the Mescalero pediment east of the river (the primary area of interest in this report),

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1/ Test holes drilled in support of ground-water investigations, Project Gnome, Eddy County, New Mexico - basic data report, 1961: U.S. Geol. Survey TEI 786.

and the alluvial plain north of Malaga and the Gypsum Hills south of Malaga, both west of the river. West of the river the land surface of the alluvial plain slopes gently eastward towards the river and that of the conical hills and rolling uplands of the Gypsum Hills area slopes generally northeast and east to the Pecos River. The general slope of the land surface east of the river is about 30 feet per mile westward.

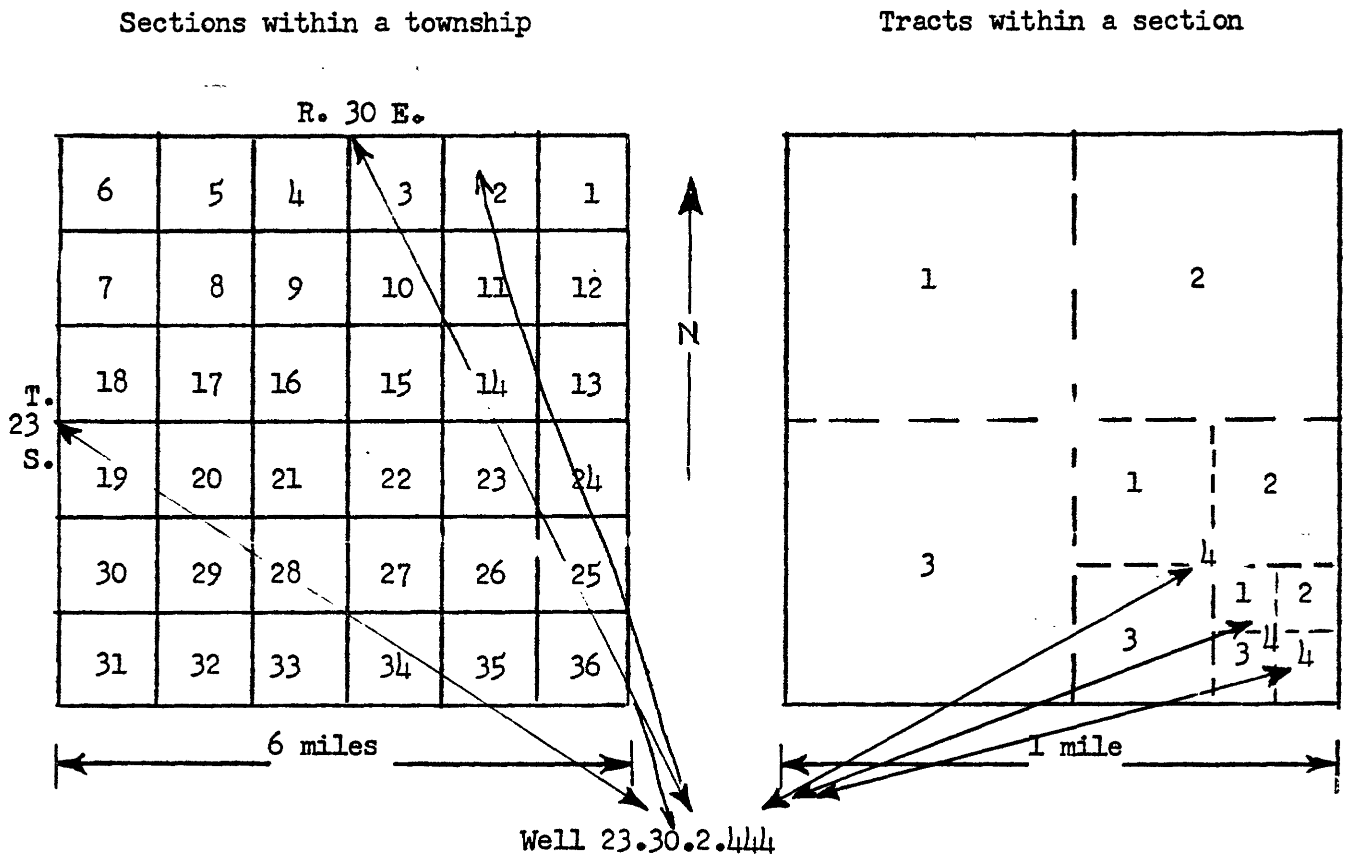
This surface is chiefly a karst topography and contains numerous depres, sions ranging in width from a few tens of feet to about 5 miles. Nash Draw is the largest depression in the area. This depression extends southward through the west-central part terminating in the vicinity of Loving and Malaga. Within it are several smaller depressions, the largest of which is Laguna Grande de la Sal (Salt Lake). Much of the pediment is mantled by dune sands although in places on the upland surface caliche is exposed and elsewhere older formations crop out. The land surface east of the river is poorly drained by short drainage courses that terminate in depressions except near the river where a narrow belt of land is dissected by short arroyos draining to the Pecos River.

The climate of the area is semiarid. Records of the U.S. Weather Bureau indicate that the average annual precipitation is about 12 inches. More than two-thirds of the precipitation is from June to October, generally in the form of thundershowers. Snowfall contributes only very minor amounts of moisture to the area. The winters are generally mild and the average annual temperature in January is above 40°F. Summers are quite warm. The average July temperature is slightly higher than 80°F.

This investigation was made under the general supervision of P. E. LaMoreaux, Chief of the Ground Water Branch, U.S. Geological Survey, and under the direct supervision of W. E. Hale, District Engineer, in charge of ground-water investigations in New Mexico.

All wells referred to in this report are identified by a location number used by the Geological Survey and the State Engineer for numbering water wells in New Mexico. The location number is a description of the geographic location of the well, based on the system of public land surveys. It indicates the location of the well to the nearest 10-acre tract, when the well can be located that accurately. The location number consists of a series of numbers corresponding to the township, range, section, and tract within a section, in that order, as illustrated below. If a well has not been located closely enough to be placed within a particular section or tract, a zero is used for that part of the number.

System of numbering wells in New Mexico



General Geology

Sedimentary rocks of Permian to Quaternary age crop out in the Project Gnome area. The strata dip gently east and southeast and older rocks are progressively mantled to the east by younger formations. (See fig. 2.) The oldest rocks exposed crop out at the western side of the area and belong to the Castile Formation of Permian age. Rocks of the Rustler Formation of Permian age crop out in numerous exposures in the west-central part of the area and in the Gypsum Hills south of Malaga. The Pierce Canyon Redbeds (Dewey Lake Redbeds of West Texas) of Permian age are exposed at several localities and crop out in a narrow and discontinuous north-south belt a few miles east of the river in the north-central part of the area. Rocks of Triassic age are represented by the Santa Rosa Sandstone in the north-central and southeast parts of the area. Unconsolidated rocks of

Figure 2.--Map showing areal geology of the Project Gnome area, Eddy and Lea Counties, N. Mex.

Tertiary age crop out near the eastern edge of the area.

Rocks of Quaternary age include the Gatuna Formation of Pleistocene(?) age and alluvium, windblown sand, caliche, and playa lake deposits of Recent age. Alluvium occurs chiefly near the Pecos River north of Malaga. Much of the land surface of the area is covered by windblown sand that obscures the underlying caliche and older formations. A generalized section of the rocks exposed in the Gnome area is given in table 1.

The Project Gnome area is in the northwest part of the Delaware Basin. The Delaware Basin is a deep, oval, sedimentary basin, about 135 miles long and 75 miles wide in southeastern New Mexico and western Texas (Newell and others, 1953, p. 8). It is generally considered to be the area surrounded by the reef of Capitan Limestone of Late Permian age; however, in its broader sense it includes also the area back of the reef into which the older and deeper lying basin sediments, sands of Delaware Mountain Group of the Guadalupe Series and the dark carbonates and shales of the Bone Spring Limestone of the Leonard Series, extend.

The reef of Capitan limestone, with notable exceptions, is buried beneath the present land surface. The longest section of reef now exposed is "La Barrera del Guadalupe" about 40 miles long southwest of Carlsbad. The reef crops out for a few miles also at two localities farther south in Texas. At the southern end of the Guadalupe Mountains, in Texas, the exposed reef forms the distinctive peak known as El Capitan. This impressive landmark is in view for 50 miles or more when approached from its eastern side. The world-famous Carlsbad Caverns are located near the northern end of the exposed section of the reef in New Mexico. In Eddy County the reef of Capitan extends northeastward from near the southwest corner of the county through the vicinity of Carlsbad and thence eastward through the county line at about T. 20 S. into Lea County. The reef then swings southeastward and intersects the south line of Lea County at about R. 36 E. and extends into Texas. (See fig. 2A.)

Figure 2A.--Map showing extent of the Delaware Basin in New Mexico and adjacent structural and geographic features.

The Delaware Basin first formed as a structural feature in Late Pennsylvanian time (New Mexico Geological Society, 1954, p. 132). Downwarping and minor movements of the basin continued in conjunction with the deposition of sediments of the Wolfcamp, Leonard, and lower and middle Guadalupe Series of Early and Late Permian age. Limestone reef building began in middle Guadalupe time and culminated in late Guadalupe time in the elongate mass of the Capitan Limestone which formed around almost the entire circumference of the basin. By the end of Guadalupe time and during the early part of Ochoa time the shelves around the basement were emergent and the deposition of the Castile Formation of the Ochoa Series of Permian age was confined to the basin itself. The basin was nearly filled by sedimentary rocks of the Castile so that the area of deposition of the succeeding Salado and younger formations of Permian age spread over the reef and shelf zones into surrounding areas.

Table 1.--Generalized section of the rocks exposed in the Project Gnome area, Eddy and Lea Counties, N. Mex.

System	Series	Group	Formation	Member	Thickness (feet)	Physical Character	Water Supply
Quaternary	Recent		Windblown sand		0-100±	Very fine to coarse reddish-brown sand	Yields no water to wells in Project Gnome area.
			Playa lake deposits		?	Silt, quartz and gypsum sand	May yield small quantities of water in large playa lakes.
			Alluvium		0-200±	Silt, sand, gravel, and conglomerate	Yields large quantities of water to wells near Pecos River.
			Caliche		0-30±	Limestone with included sand grains and rock fragments	Yields no water to wells in Project Gnome area.
	Pleistocene(?)		Gatuna		0-200±	Clay, silt, sand, gravel, and conglomerate. Reddish-orange to gray	Yields small quantities of water to wells in parts of area.
Tertiary	Pliocene		Ogallala		0-300±	Silt, sand, and gravel	Yields fairly large quantities of water to wells north and east of project area.
Triassic	Upper	Dockum	Upper red beds		0-1,000±	Shale, siltstone,and sandstone. Red to brown	Yields small quantities of water to wells in some localities.
			Santa Rosa Sandstone		0-300±	Sandstone, conglomeratic, interbedded with claystone. Red to gray	Yields small quantities of water to wells in places in eastern part of area.
Permian	Ochoa		Pierce Canyon Redbeds (Dewey Lake Redbeds of West Texas)		0-350±	Siltstone, sandy shale, shale, and sandstone. Red to reddish-orange with greenish-gray reduction spots	Not known to yield water to wells in Project Gnome area.
			Rustler	Forty-niner	0-80±	Gypsum, gray to white. Siltstone, claystone, and sandstone, reddish-brown with greenish-gray reduction spots	May yield water to wells in parts of the area.
				Magenta	0-30±	Dolomite, gray to magenta. Anhydrite and selenite	Yields small quantities of water to wells in Nash Draw.
				Tamarisk	0-120±	Gypsum, gray to red. Siltstone and claystone, reddish-brown	May yield water to wells in parts of the area.
				Culebra Dolomite	10-40±	Dolomite, grayish-white	Principal aquifer at site of Project Gnome.
				Lower	90-180±	Sandstone, claystone, and gypsum. Reddish-brown to light-gray	May yield water to wells in parts of the area.
			Castile		0-1,600±	Gypsum and siltstone. Gray to red	Not known to yield water to wells in area.

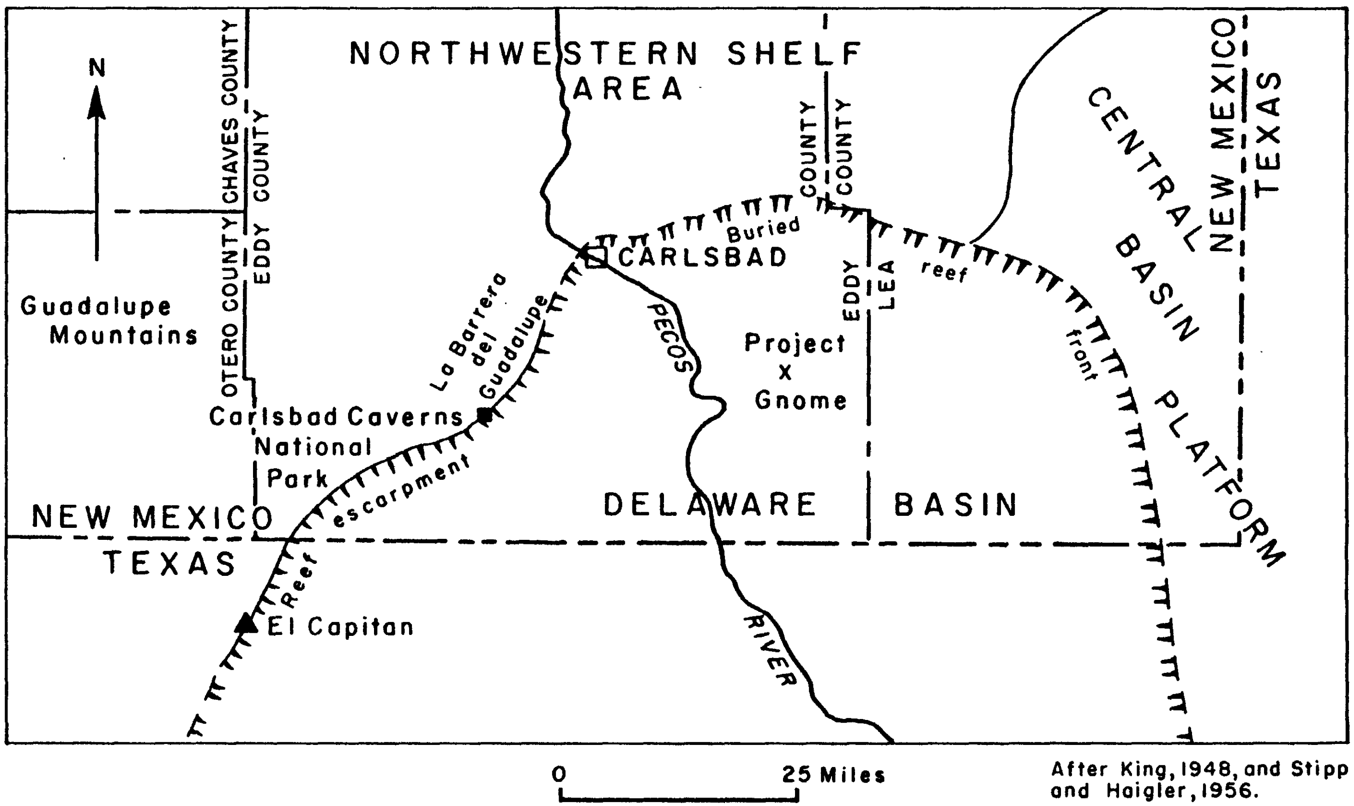


Figure 2a.--Map showing extent of the Delaware Basin in New Mexico and adjacent structural and geographic features

The Delaware Basin has been subjected to progressive tilting to the east and southeast through its history. Minor amounts of tilt occurred during late Permian time; however, the present structure of the deeper parts of the basin probably formed in Cenozoic time (New Mexico Geological Society, 1954, p. 132). In the Gnome area the eastward and southeastward dip of the Guadalupe and lower Ochoa sedimentary rocks is about 75 feet per mile. In places local flattening of the dip occurs or the sediments are warped into small folds.

The sequence of sedimentary rocks in the Delaware Basin in New Mexico is more than 18,500 feet thick. The sediments rest upon a basement which is a complex of metasedimentary, metavolcanic, volcanic, and plutonic rocks. These basement rocks are a part of the great granitic stable crustal block which is called the Texas Craton (Flawn, 1954, p. 901).

The subsurface sedimentary rocks are approximately 18,000 feet thick at the Project Gnome site. No igneous rocks are known to occur beneath the site above the basement rocks; however, Jones (1959, p. 15) reports that the evaporites of the Upper Permian rocks are cut by a northeastwardly trending system of narrow, steeply dipping dikes of alkalic rock in the underground workings of the International Minerals and Chemical Corp. mine north of the Gnome site and were penetrated at about a depth of 2,200 feet in an oil test in the SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 9, T. 22 S., R. 29 E., about 12 miles northwest of the site. The sedimentary rocks range in age from Ordovician to Quaternary. The Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian rocks consist mainly of cherty limestone interbedded with gray and black shales. The lower rocks of Permian age consist chiefly of sandstone and thin-bedded limestone, which interfinger north, west, and east with the limestone of the reef zone. The upper rocks of Permian age are mainly evaporites except for the uppermost unit which consists of red beds.

A generalized columnar section of rocks beneath the surface at the Project Gnome sits is given in figure 3.

Figure 3.--Generalized section of rocks at the Project Gnome site, Eddy County, N. Mex.

The area has been subjected to little faulting. No deeply buried faults are known and Jones (1959, p. 16) reports that in the evaporites of the area no faults with vertical displacements of more than 20 feet are known. Vine (1959) records but one fault visible at the surface within the Nash Draw quadrangle. This fault is in sec. 18, T. 23 S., R. 30 E., about 3 miles northwest of the Gnome site. Structural features of the rocks are due to the regional dip of the beds in the subsurface and to solution of the evaporite sections of the Permian rocks. Locally, there are structural features that are related to the hydration and chemical change of anhydrite to gypsum. This hydration results in a considerable increase in volume of the affected rocks and causes them to assume deformed and often domed appearances where they are exposed.

Solution of the Permian evaporitic rocks by ground water has removed considerable thicknesses of the geologic section in parts of the area, particularly on the west side. Maley and Huffington (1953, p. 543) state that tilting of the Delaware Basin to the east, mostly in late Tertiary time, caused the western part of the evaporite section to be elevated and to some extent exposed, with the consequent removal of salt and much of the anhydrite by solution. Nash Draw, in the western part of the Gnome area, is a noticeable surface expression of evaporite solution, as are numerous sinkholes scattered throughout the area. In the southern part of the area solution of evaporites has caused the formation of a deep trough which has been subsequently filled with sediments of Tertiary and Quaternary age to a maximum thickness of approximately 1,900 feet (Maley and Huffington, 1953, p. 539).

Rocks of pre-Permian age

Deep-lying sedimentary rocks older than Permian in age have been penetrated in several oil tests in and near the Project Gnome area and basement rocks of Precambrian age have been reached in one oil test about 20 miles northeast of the Gnome site. Generally, the age of the deep sediments has been satisfactorily determined; however, rocks of Ordovician, Silurian, and Devonian ages are not well understood, and separation of the basal part of the Permian and Upper Pennsylvanian units is difficult.

A graphic description of well cuttings from one of the deepest oil tests in New Mexico is given by Hughes (1954, p. 125). This test is the Richardson and Bass, No. 1, Federal-Harrison, about 8 miles south of the Gnome site in sec. 12, T. 25 S., R. 30 E. The hole did not reach Precambrian rocks but was abandoned in rocks assigned to a Silurian and Devonian age at a depth of 16,705 feet, or 13,327 feet below sea level. The Shell Oil Co., No. 1, James Ranch well, a gas well about 6 miles northeast of Gnome site in sec. 36, T. 22 S., R. 30 E., was drilled to a depth of 17,555 feet, or 14,229 feet below sea level, without reaching Precambrian rocks. Precambrian basement rocks were reached at a depth of 16,396 feet, or 12,881 feet below sea level, in the Richardson and Bass, No. 1, Federal-Cobb well located in sec. 23, T. 20 S., R. 31 E.

Data from these wells indicate that at the Gnome site the Precambrian basement rocks are at a depth of about 18,000 feet beneath the surface, or about 14,600 feet below sea level. The sedimentary rocks of pre-Permian age are probably about 5,500 feet thick at the Gnome site. The character and structure of the rocks are shown on figure 4, which is a cross section from north to south through

Figure 4.--Generalized geologic cross section from north to south through a part of the Delaware Basin near the site of Project Gnome, Eddy County, N. Mex.

a part of the Delaware Basin near the Gnome site.

The rocks of pre-Permian age in this area are not described fully in this report because they are not known to contain usable ground water. Scant information is available on the water-bearing characteristics of these rocks; however, there is little doubt that water is present in some of the sandstone, limestone, and dolomite beds within the section. The water can be expected to be highly mineralized and of no known economic value.

Rocks of Permian age

Rocks of Permian age in the Project Gnome area are approximately 12,000 feet thick. The rocks are assigned to the Wolfcamp, Leonard, Guadalupe, and Ochoa Series, in ascending order. Only the uppermost formations of the Ochoa Series are exposed in the Gnome area. This system of rocks contains extensive evaporite deposits in which are found economically important potassium minerals, Commercial quantities of oil and gas are produced from sandstone and limestone beds and important water-bearing formations are in the upper part of the unit.

The Wolfcamp Series is about 1,750 feet thick and overlies unconformably rocks of the Pennsylvanian System. Individual formations have not been identified in this area and the series remains undivided. The series consists of brown and gray limestone interbedded with brown and gray shales. A sandstone bed several hundred feet thick is reported at the top. No information is available regarding water that may be present in these rocks. As in the case of older formations water in these rocks probably is highly mineralized.

The Leonard Series is about 3,000 feet thick and consists of the Bone Spring Limestone which overlies conformably the rocks of the Wolfcamp Series. The limestone is principally brown to gray and in parts of the section is interbedded with gray sandstone and brown and gray shale. No information is available on the water-bearing characteristics of this limestone.

The Guadalupe Series lie conformably upon the Bone Spring Limestone. It is about 3,800 feet thick in the Project Gnome area and consists of sandstone and thin-bedded limestone which interfinger to the northwest with the limestone of the buried Capitan reef. In the Gnome area the Guadalupe Series consists of the Delaware Mountain Group which includes, from oldest to youngest, the Brushy Canyon Formation, the Cherry Canyon Formation, and the Bell Canyon Formation. In the subsurface the contacts of the middle formation, the Cherry Canyon, are difficult to distinguish from the overlying and underlying formations.

The Brushy Canyon Formation is about 1,600 feet thick beneath the Gnome site. It consists chiefly of gray sandstone and minor amounts of brown and black shale and brown limestone. Oil is produced from the lower part of this formation at several wells in Eddy County and from one well within the project area in sec. 27, T. 22 S., R. 30 E. Water in the Brushy Canyon Formation in the Gnome area is highly mineralized.

The Cherry Canyon Formation is about 1,050 feet thick and consists of thin-bedded, fine-grained sandstone and tan to gray limestone beds with minor amounts of gray and brown shale. In the project area no wells obtain water from this formation. The water is reported to be highly mineralized. Hendrickson and Jones (1952, p. 18) report that a sandstone tongue of the lower quarter of the formation crops out locally in canyons in the west-central part of Eddy County outside the project area where it may yield water to wells and springs.

The Bell Canyon Formation is about 1,150 feet thick and consists of brown and gray sandstone and some thin limestone beds. The Lamar Limestone Member, black to brown in color, lies near the top of the formation. This limestone member is persistent throughout the area and is reported in numerous logs of oil tests. Saline water is reported to be present in the Lamar Limestone Member and the underlying sandstone of the Bell Canyon. No fresh water has been reported and no wells are known to produce water from this horizon within the Gnome area. Wells near Malaga, and elsewhere in the area produce oil from the Lamar Limestone Member.

The Ochoa Series in the Gnome area is about 3,800 feet thick and consists of four formations, the Castile, Salado, Rustler, and Pierce Canyon Redbeds (Dewey Lake Redbeds of West Texas), from oldest to youngest. These formations are chiefly evaporites and consist principally of anhydrite, gypsum, salt, and red siltstone. The Ochoa formations overlie conformably the Guadalupe sedimentary rocks in the Delaware Basin. They butt against the buried reef front composed of Capitan and the three youngest formations extend over the reef where they rest unconformably upon older rocks. The lowermost rocks of the Ochoa Series are easily distinguishable in the subsurface from the underlying older rocks due to the marked lithologic change from light-colored evaporites to the dark sands, shales, and limestones of the Guadalupe Series.

Castile Formation

The Castile Formation is composed principally of anhydrite and calcite-banded anhydrite. Other constituents are salt, and minor amounts of limestone, clastics, and other evaporites. At the Gnome site the top of the Castile is about 2,250 feet beneath the surface and the formation is about 1,600 feet thick. This formation is confined to the Delaware Basin where it thins to the northwest and pinches out against the reef of Capitan Limestone. It thickens to the southeast toward the lower part of the basin where it is reported to be more than 2,500 feet thick.

The approximate average composition of the Castile Formation in the northwest part of the Delaware Basin (Project Gnome area) in New Mexico is one-half anhydrite, one-third salt, and one-sixth calcite (Hayes, 1958, p. 9). Thinly laminated brownish limestone commonly is present at the base of the formation and grades upward into calcite-banded anhydrite and brown limestone. Salt beds, in places more than 350 feet thick, are interbedded with the calcite-banded anhydrite. These beds are composed of practically pure sodium chloride--no potash salts have been reported. The salt beds are extensive and are the principal stratigraphic markers in the Castile. The calcite-banded anhydrite is composed of alternating layers of white or gray anhydrite and brown bituminous-stained calcite. The anhydrite in the lower part of the Castile does not mark a time-stratigraphic horizon, but the difference in lithology has been used to divide the Castile Formation into a lower banded unit and an upper massive unit. The calcite-banded anhydrite and limestone generally grade upward into a pure white anhydrite.

The bands extend several hundred feet up into the basal part of the Salado in the south-central part of the Delaware Basin and are approximately 800 feet below the top of the Castile near the northeast rim (Adams, 1944, p. 1605). Near the margins of the basin the upper part of the calcite-banded grades laterally into white anhydrite. A decrease in thickness of the anhydrite accompanies this gradation. The decrease is in part due to lateral transition to salt of the

Salado Formation accomplished by depositional pinchouts of anhydrite tongues extending reefward from the basin and the thinning and pinchout of intercalated salt tongues toward the basin. These tongues thicken and coalesce in a northeasterly direction and form the basal salt strata in the Salado Formation over the reef zone (Jones, 1954, p. 109).

The boundary between the Castile and Salado Formation was placed by Lang (1939, p. 1572) at the base of the Fletcher Anhydrite Member of the Salado. This anhydrite member is the lowest unit overlying the reef and thus restricts the Castile to the Delaware Basin. This boundary has been accepted by most geologists who have worked in the area.

Extensive outcrops of the Castile Formation are present on the western side of the Delaware Basin just southwest of the Project Gnome area and two small patches of the formation crop out along the west side of the area. The formation, where exposed, contains no salt and the anhydrite has been hydrated to gypsum, probably to depths of several hundreds of feet, by ground water.

Hendrickson and Jones (1952, p. 21) report that in the outcrop of the Castile the formation yields water to many stock and domestic wells. The water from these wells is high in sulfate and undesirable for human consumption. No wells obtain water from the Castile within the Project Gnome area and it is not known if the formation beneath the Gnome site contains water. An oil well in sec. 23, T. 24 S., R. 29 E., about 6½ miles west-southwest of the Gnome site reported a slight show of gas and a hole full of salt water at depths of 1,835 to 1,840 feet in the Castile Formation. Robinson and Lang (1938, p. 87) report that an oil test in sec. 3, T. 24 S., R. 29 E., about 6½ miles southwest of the Gnome site encountered an exceptionally large yield of water at a depth of 1,725 feet. The water-bearing bed in this well was between 60 and 90 feet thick and yielded a sodium chloride brine.

Salado Formation

The Salado Formation is mostly salt. Salt comprises over 75 percent of the formation except where the section has been thinned by removal of part of the salt by solution by ground water. The remainder of the formation consists of potassium minerals and minor amounts of sandstone, siltstone, shale, anhydrite, and dolomite. At the Gnome site the top of the salt in the Salado Formation is about 710 feet below the surface and the formation is about 1,550 feet thick. Here, as elsewhere in the Delaware Basin, the Salado overlies the Castile. Lower salt beds of the formation tongue southward into anhydrite beds of the Castile Formation (Jones, 1959, p. 14).

The upper part of the Salado Formation in this area contains extensive deposits of Potassium minerals. The potassium minerals occur in the evaporite deposits as accessory minerals, stratified deposits in the sulfate strata, bedded deposits in the mixed salt-clastic strata, and vein or lens deposits that have replaced or displaced the strata (Jones, 1954, p. 111). These deposits are presently being mined in Eddy and Lea Counties, N. Mex. The nearest mine to the Gnome site is that of the International Minerals and Chemical Corp. whose underground workings extend to within about 8½ miles of the Gnome site. At the

Gnome site itself potassium minerals in commercial quantities have not been found.

Several units within the Salado are persistent through the area and can be recognized in the subsurface. The most important of these stratigraphic markers are the Vaca Triste Sandstone Member of Adams (1944), a sandstone member in the upper part of the Salado; the Union Anhydrite bed of local usage near the middle of the formation; the Cowden Anhydrite Member in the lower part of the formation; and the Fletcher Anhydrite Member which forms the basal bed of the Salado Formation on the Capitan Limestone to the north and east of the area. Polyhalite rock marker beds in the formation are identified by number. Stratigraphic markers in the Salado Formation beneath the Gnome site, recognized and described by Moore (1958) are the Vaca Triste Sandstone Member of Adams (1,026.5 to 1,030.4 feet); marker bed 120 (1,178.6 to 1,179.7); and the Union anhydrite bed of local usage (1,242.5 to 1,261.3 feet).

Generally the salt of the Salado Formation is somewhat less pure than that in the Castile Formation. Where potassium minerals are present the salt has a pinkish or blue color. A grayish color is also common, probably due to the presence of mud and clay. Thin beds of anhydrite within the salt are also a common impurity. Polyhalite is widely distributed and relatively abundant in the Salado Formation above the Cowden Anhydrite Member. Dolomite occurs as impurities in some of the anhydrite beds.

West of the Pecos River in the Project Gnome area most of the salt in the Salado Formation has been removed by solution. In the northwestern part of the area, over the buried reef of Capitan Limestone, the salt is absent. In the south-central part of the area subsurface data indicate that the salt of the Salado is thin or absent over an extent of nearly one hundred square miles. Within Nash Draw solution has removed, and is presently removing, salt of the uppermost Salado.

Figure 5 is a map showing, by means of contour lines, the configuration

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Figure 5.--Map showing altitude and configuration of the top of the salt of the Salado Formation in the Project Gnome area, Eddy and Lea Counties, N. Mex.

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and altitude of the top of the salt in the Salado Formation in the Project Gnome area. The contours in the area of the Nash Draw quadrangle (103°45' to 104°00' W. longitude; 32°30' to 32°15' N. latitude) are modifications of the contour lines, by Bruno A. Alto, on the geologic map of the Nash Draw quadrangle (Vine, 1959). Contours in the remainder of the area covered by figure 5 were prepared from subsurface data obtained from logs of potash and oil tests and from an unpublished map prepared by Mr. Alto and made available to the writer by Mr. Alto and T. F. Stipp, Conservation Division, U.S. Geological Survey.

Figure 6 is a cross section showing the structure of the rocks between the

Figure 6.--Diagram showing structure of Upper Permian rocks in the south-central part of the Project Gnome area, Eddy and Lea Counties, N. Mex.

surface and the top of the Delaware Mountain Group in the south-central part of the area. This cross section illustrates the thinning, by solution, that has taken place in the Salado Formation and to some extent in the Rustler Formation. No evidence of solution thinning is apparent in the underlying Castile Formation. Maley and Huffington (1953, p. 543) include this area in their description of localities of evaporite solution within the Delaware Basin and attribute the solution to the action of downward percolating waters in late Tertiary time during an eastward tilting of the basin.

The contact between the Salado and the overlying Rustler Formation is usually gradational; however, in the Nash Draw area a layer of solution breccia or residuum immediately above the salt makes the determination of the contact indefinite. This solution breccia consists of brecciated and collapsed layers of gypsum separated by irregular seams and masses of reddish-brown and gray clay and silt. The breccia shows evidence of salt solution. The layer of solution breccia ranges in thickness from a few feet to as much as 150 feet (Jones, 1959, p. 13). This breccia is derived partly from rocks of the overlying Rustler Formation and partly from rocks of the Salado Formation.

Geologists are not in total agreement as to the position in the geologic section of this layer of breccia. Some geologists place the top of the Salado Formation at the base of the Culebra Dolomite Member of the Rustler Formation, thus including the breccia and a few tens of feet of predominantly anhydrite and clastic beds in the Salado. Others place the contact at the top of the highest thick salt bed in the Salado Formation (this bed has an irregular surface that generally marks the change from weathered to unweathered rocks) and consider the breccia to be a part of the Rustler Formation. Moore (1958, p. 3) considers the breccia layer as part of the Salado and identifies it as the upper leached member of the Salado Formation. At the Gnome Site about 60 feet of this material is present. In this report the top of the Salado Formation is considered to be the top of the highest thick salt bed and the solution breccia to be a part of the Rustler Formation.

The salt of the Salado does not crop out in the project area and it is not known to contain ground water. No water has been reported to occur in the formation in the potash mines nor in any of the numerous drill holes scattered throughout the area. The salt is virtually impermeable because the weight of the overlying formations causes plastic flow in the salt and prevents the development of open spaces which might contain water.

Rustler Formation

The upper surface of the Salado Formation according to Jones (1954, p. 110) is conformably overlain by the Rustler Formation. King (1942, p. 762) and Adams (1944, p. 1608) state; however, that the Salado in the Delaware Basin was truncated and completely overlapped by beds of the succeeding Rustler Formation.

The Rustler Formation is composed chiefly of anhydrite (commonly altered to gypsum) and fine quartz grains in the form of gray, carbonaceous sandstone and red siltstone. Dolomitic limestone and some red and gray shale is also present in the formation. In the east part of the Project Gnome area, thin beds of salt are present in the lower part of the formation. The thickness of the Rustler ranges from about 90 feet to more than 500 feet within the area. At the Gnome site the top of the Rustler is about 290 feet below the surface and the formation is about 420 feet thick.

A stratigraphic section of the Rustler Formation in this area was described by W. B. Lang (in Robinson and Lang, 1938, p. 84). This section is 500 feet thick and consists of the following, from top to bottom:

Type	Thickness (feet)
Gypsum	30
Dolomitic gypsum	30
Gypsum	100
Red beds	30
Gypsum	20
Dolomitic limestone	35
Red beds	30
Gray sand	70
Red beds	20
Gypsum	130
Red beds	5

Lang divided the formation into two parts; an upper part consisting of five beds and a lower part consisting of six beds.

Since Lang's work on the Rustler Formation, geologists have further divided the formation into five members. These are, from oldest to youngest: lower member; Culebra Dolomite Member; Tamarisk Member; Magenta Member; and the Forty-niner Member. The layer of residuum, previously described, which lies immediately above the top of the salt of the Salado Formation, in this report, also is considered to be a part of the Rustler.

All members of the Rustler Formation, with the exception of the lower member and layer of residuum, crop out in the Project Gnome area. The exposures are limited to the western part where they are found in the vicinity of Nash Draw and southward along both sides of the Pecos River. Most of the Rustler Formation, particularly in the outcrop, has been weathered. The anhydrite has been altered to gypsum or selenite and partial or total solution of the gypsum layers has caused the collapse of the harder and less soluble beds. Where the carbonate members are present they are commonly warped and broken into discontinuous tilted blocks. Some outcrops, particularly in the Nash Draw area, where solution has been severe, have a slumped and draped appearance and are tilted downward at high angles toward the center of the collapse area.

In the subsurface the structure of the Rustler Formation is mildly undulating where these beds are 200 to 300 feet below the surface. However, locally, solution and collapse have affected the formation at considerable depth (Robinson and Lang, 1938, p. 84). Logs of potash test holes drilled in and near Nash Draw indicate that in many places within Nash Draw the Rustler has been so altered that individual members are unrecognizable. The formation, in many instances, has been reduced in thickness to 100 feet or less.

Generally the carbonate members are the least affected by solution and are present throughout most of the area. The two carbonate members of the formation, the Magenta Member and the Culebra Dolomite Member, are separated by 150 feet of gypsum and red beds in the section of Lang (1938, p. 84). In the Nash Draw area solution and collapse has, in some localities, removed all the rock section between the two members and the Magenta Member rests directly upon the Culebra Dolomite Member. Most of the gypsum section in the formation in Nash Draw has been removed or severely altered and only a residuum of red, brown, or gray silt remains in many places. Farther east in the area where the Rustler Formation is overlain by rocks of Permian age or by rocks of Triassic age less alteration of the members of the Rustler has occurred. At the Gnome site, even though the thickness is less than in Lang's section, all members of the formation are present. Here the two carbonate members are separated by about 117 feet of anhydrite, gypsum, and siltstone.

The Culebra Dolomite Member of the Rustler Formation is an excellent subsurface marker because its lithology is unlike that of any other rock in the area. It is widespread over the Delaware Basin and has been identified in many hundreds of drill holes. It is the principal aquifer at the Gnome site and yields water to wells in the western half of the project area. The depth to the top of the Culebra ranges from zero in the Nash Draw-Pecos River area to more than 1,200 feet in the east part of the area in Lea County. (See fig. 7.) To a large degree the configuration of the top of the Culebra is similar to that of the top

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Figure 7.--Map showing altitude and configuration of the top of the Culebra Dolomite Member of the Rustler Formation in the Project Gnome area, Eddy and Lea Counties, N. Mex.

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of the salt in the Salado Formation (fig. 5). Apparently as salt in the Salado was removed by solution the overlying beds settled downward and their upper surfaces assumed, in general, the shape of the surface of the salt.

With the exception of the Culebra Dolomite Member rocks of the Rustler Formation do not generally yield water to wells in the Gnome area. The Tamarisk Member, which overlies the Culebra, is reported (Theis and Sayre, 1942, p. 32) to contain scattered bodies of perched water in some localities. In Nash Draw where solution has lowered the Magenta Member below the saturated zone this member yields water to a few wells. It is not known to yield water in other parts of the area. The lower member contains water in Nash Draw and east of Nash Draw southwest of Gnome site. In most places the permeability of the member is quite low and it yields only small quantities of water to wells.

In Nash Draw the brecciated or residuum layer at the base of the Rustler Formation contains a brine solution. The water cannot be used for domestic or stock use and no wells tap this aquifer. The brine solution discharges into the Pecos River in sufficient quantities to create a salinity problem in the river below the town of Malaga.

Pierce Canyon Redbeds

(Dewey Lake Redbeds of West Texas)

The Pierce Canyon Redbeds are composed of a series of fine sandy to earthy red beds and thin beds of sandstone, polka-dotted with green reduction spots and generally irregularly veined with thin secondary selenite fillings. The color and texture of the beds are nearly uniform (Lang, 1935, p. 264). The green reduction spots are a most distinguishing feature of the red beds and are generally noted in logs of drill holes. The reduction spots, however, are not diagnostic of this particular formation. Most red beds of this type contain similar spots. The spots are caused by reduction of iron around an enclosed fragment of organic material or some similar reducing agent.

The Pierce Canyon Redbeds in the SW$\frac{1}{4}$SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 4, T. 24 S., R. 30 E. directly overlying the gypsum of the Middle members are of the Rustler. At the base of the red beds, here, USGS test hole 2 penetrated a 5-foot layer of unconsolidated rubble and gravel. This layer is composed mainly of rocks of the Rustler Formation and consists of angular to sub-angular pieces of dolomite similar to the Magenta Member, and slightly rounded pieces of gypsum. Individual pieces of the rubble range in size from fine gravel to cobbles 4 inches or more in diameter.

The Pierce Canyon Redbeds crops out at a number of localities within the project area. Particularly good exposures are present in the north part about 15 or 16 miles north of the Gnome site. At the Gnome site the Pierce Canyon Redbeds were encountered at a depth of about 80 feet and were about 210 feet thick.

The Pierce Canyon Redbeds are not known to yield water to wells. A possibility exists that small bodies of perched water could be present where sandstone beds occur within the formation.

Triassic Formations

Overlying the Pierce Canyon Redbeds, unconformably, in the eastern half of the project area are sandstones and red beds of the Dockum Group of Late Triassic age. The oldest formation is the Santa Rosa Sandstone which is a pink to gray, conglomeratic, very poorly sorted, cross-stratified sandstone locally interbedded with dark reddish-brown claystone and red siltstone. The sandstone crops out in the north part of the area in the steep cliffs east of the U.S. Borax and Chemical Co. mine. It has been penetrated in drill holes east of its outcrop, where it is nearly 300 feet thick. It is not present at the Gnome site.

A thick series of red shale, siltstone, and sandstone is present in the eastern third of the project area overlying the Santa Rosa Sandstone. These red beds are probably the Chinle Formation of the Dockum Group. They are not known to crop out in the project area. In the subsurface they are more than 1,000 feet thick in places in the extreme eastern part of the area.

Figure 8 is a diagram showing the structure of Upper Permian

Figure 8.--Diagram showing structure of Upper Permian and younger rocks at the Project Gnome site, Eddy County, N. Mex.

and younger rocks at the Gnome site and the relationship of these rocks of Triassic age.

Wells obtain potable water from rocks of Triassic age in the eastern part of the area. Generally the yield of the wells is small from the upper red beds where permeable beds may be thin and discontinuous. Larger yields of water are obtained from the Santa Rosa Sandstone where the formation is saturated. The quality of the water in the rocks of Triassic age is generally better than water in the Rustler Formation although locally highly mineralized water may occur.

Tertiary Formations

The Ogallala Formation of late Tertiary (Pliocene) age covers relatively small areas in the northeastern and southeastern parts of the project area, in Lea County. The outcrops are westward extensions or remnants of the southern High Plains. The formation lies on an erosional surface of the underlying red beds of the Triassic. The Ogallala is composed of clay, silt, sand, and gravel and in places it is partially cemented. The beds are not continuous within the formation and often change composition in a short lateral distance. Generally a layer of sand and gravel is present at the base of the formation where it may occupy channels in the red beds of the Triassic. In its outcrop area the Ogallala reaches a maximum thickness of 300 feet.

The formation yields water of good quality to wells in its outcrop area. Large quantities of water are obtained from the Ogallala north of the project area.

Quaternary Formations

Rocks of Quaternary age unconformably overlie older rocks. The Gatuna Formation of Pleistocene(?) age is the oldest known Quaternary formation in the area. The Gatuna crops out at several localities in the area and is present at the Gnome site from about 40 to 80 feet below the land surface. In other parts of the area drill holes have penetrated as much as 200 feet of this formation. Outcrops are discontinuous in the area. The extent of the formation in the subsurface has not been determined. The Gatuna is composed of poorly consolidated sand, silt, and clay. Locally beds of medium- to coarse-grained sandstone and pebble conglomerate are present. The dominant color is reddish-orange, grading to pink, gray, or yellow.

Locally the Gatuna formation yields water to wells. The water apparently is perched in permeable sand lenses of limited occurrence. Where water is found it is of excellent mineral quality. Yields of the wells are small but are usually sufficient for stock and domestic uses.

Sediments believed to be Tertiary or Quaternary in age are present also in the south-central part of the area where they have been deposited in a deep trough that was created by solution of the underlying evaporites (Maley and Huffington, 1953, p. 541). Sparse information is available on the age and character of these sediments. Drillers' logs record a sequence of sand, sandy shale, and blue shale commonly overlain by a section of red shale. The total thickness of the sediments deposited in this trough is about 1,900 feet.

Several wells obtain water from these sediments of Tertiary or Quaternary age. Water is reported to occur in sand beds. The water is of fair quality and yields of several hundred gallons per minute are reported from some wells.

Other formations of the Quaternary System present in the area are of Recent age and consist of caliche, alluvium, playa lake deposits, and windblown sand.

Caliche forms calcareous zones in soil and near-surface deposits. It ranges in composition from dense to thinly-banded and contains sand grains and rock fragments. Where it has long been exposed at the surface it is commonly very hard and resistant; however, where it has remained covered it may be soft and friable. The color is primarily white to gray but may be stained brown or red.

In much of the Gnome area caliche forms a cap over older formations of several ages in the topographically high and less eroded parts of the land surface. It is mostly covered with a layer of windblown sand; however, in many places where the sand and soil cover has been removed caliche crops out. Caliche is present also within the windblown sand deposits of the area. USGS test hole 1 penetrated a thin zone of caliche at 8 feet and a 3-foot bed between 11 and 14 feet. Caliche zones 1 foot or less in thickness were penetrated at depths of about 4 feet and about 12 feet in USGS test hole 2. The beds of caliche are generally less than 10 feet in thickness and the maximum thickness probably does not exceed a few tens of feet. At the Gnome site a layer of friable caliche is present from about 7 to 10 feet beneath the land surface.

Alluvium in the form of sand and silt, locally conglomeratic, is present on some gentle slopes and in valley bottoms of the area. The most extensive deposits are on the west side of the Pecos River north of Malaga. Scattered small patches occur along both sides of the river throughout its course in the area. The thickness is generally not great except in the vicinity of the river where the alluvium is as much as 300 feet thick.

The alluvium near the river, and west of the river north of Malaga, yields fairly large quantities of water to wells in most places. The quality is not good but the water is used for irrigation and other purposes.

Relatively small playa lakes occur mainly in the Nash Draw vicinity. The playas consist of silt, sand, and gypsum sand deposited in shallow and intermittent lakes. Laguna Grande de la Sal is a shallow lake that occupies a part of a large playa formed in a depression in the southern end of Nash Draw. The lake has no surface outlet and contains a brine solution that has been concentrated by evaporation. It is reported that salt was harvested from the lake as early as 1875. On the lowest swales of this playa there is a thin black mud layer which is mantled by a heavy crust of salt which is in some places as much as 2 feet thick (Robinson and Lang, 1938, p. 85). Since 1932 Laguna Grande de la Sal has been used as a disposal area for the waste brine, and impure salts and clays, which result from refining operations of potash at the refinery, now operated by the U.S. Borax and Chemical Co., near the west edge of the lake.

The gypsum and other materials deposited in the playas in Nash Draw often contain water. Wells finished in these sediments generally yield highly mineralized water that usually can be tolerated by stock but is not suitable for domestic purposes.

Windblown sand deposits are common in the area east of the Pecos River. They overlie nearly all the land surface except where they have been removed by the wind. Generally the sands are but a few feet thick but where they have been concentrated by the wind conspicuous dunes have been formed. In the vicinity of the Gnome site numerous large dunes are present. The greatest concentration of conspicuous dunes in the area is about 5 miles northeast of the Gnome site where several square miles of the surface is covered by them. At the Gnome site about 40 feet of sand, with some caliche, overlies rocks assigned to the Gatuna Formation. The windblown sands in this area are continuous with those that cover most of the land surface between the Pecos River and the High Plains and which extend many tens of miles northward from the State line. These sands were called Mescalero sands by Darton (1928, p. 59).

No wells in the area are known to obtain water from these windblown sands. The sands readily take up water and probably are a source of recharge to underlying formations. It is possible that beneath large dunes which overlie impermeable rocks some perched water may be present.

Ground Water

All the potable water yielded to wells in the Gnome area is obtained from rocks above the top of the salt of the Salado Formation. The water-bearing rocks range widely in age, composition, and depth. No individual unit is persistent throughout the area from which potable water can be obtained. The Culebra Dolomite Member of the Rustler Formation underlies the entire area; but in places it contains highly mineralized water and in other localities its depth and the presence of overlying water-bearing rocks preclude its use as an aquifer. Generally wells in the eastern part of the area obtain water from sandstone beds in rocks of Triassic age; in the south-central portion from sand beds in rocks of Tertiary or Quaternary age; west of the river from sand and gravel of Quaternary age; and from the Culebra in the remainder of the area. (See fig. 9.)

Figure 9.--Map showing general distribution of water-bearing rocks in the Project Gnome area, Eddy and Lea Counties, N. Mex.

The occurrence and movement of ground water in the area is controlled largely by geologic factors. Wells obtain water from the various formations at depths ranging from 30 feet to about 800 feet. The depth to water below the land surface ranges from a few feet to about 500 feet. The water is under water-table conditions in the Rustler outcrop area in Nash Draw and in the alluvium west of and along the Pecos River. Confined water with varying degrees of artesian pressure head, never sufficient to cause water to rise above the land surface (an exception to this is in Laguna Grande de la Sal where occasional surface flows have been noted), is present in the remainder of the area. Bodies of water perched upon impermeable beds, above the piezometric surface of the water in the deeper aquifers, are known to exist at several localities.

Figure 10 shows the movement of ground water in the geologic formations of

Figure 10.--Map showing location of wells and the general direction of ground-water movement in geologic formations in the Project Gnome area, Eddy and Lea Counties, N. Mex.

the Project Gnome area by means of contour lines. The contours reflect the direction of movement of the ground water, which is generally right angles to the contours in the direction of slope.

Three sets of contours are shown, contours on the piezometric surface of the confined water, or on the water table, in rocks of Quaternary or Tertiary age and in rocks of Permian age, and contours on the piezometric surface of the confined water in rocks of Triassic age.

Water in the deep Tertiary and Quaternary basin deposits in the south-central part of the area moves southwestward. The alluvium and the underlying Rustler Formation west of the Pecos River are hydrologically interconnected and water movement is eastward toward the river. Water in the Rustler Formation moves southward in Nash Draw and to the west and southwest east of Nash Draw. Several ground-water divides in the rocks of Triassic age are indicated by the contour lines. The general direction of ground-water movement is southwestward west of R. 33 E., except for a north and west component of movement in Tps. 21-22 S., Rs. 31-32 E. In R. 33 E. water moves east and southeastward.

The point at which rocks of Triassic age overlap the Pierce Canyon Redbeds, generally along a northwest-southeast line a few miles east of the Gnome site, constitutes a boundary between water in the Triassic and water in the Rustler Formation. Water levels in wells just east of the boundary are as much as 200 feet higher than in wells to the west of the boundary.

Two wells, 24.31.4.430 and 24.31.33.124, east of the boundary penetrate the entire section of Triassic rocks and apparently yield water from the underlying Rustler Formation. The altitude of the water surface in these two wells is much too low to conform with that of the water in nearby wells known to be finished in rocks of Triassic age. On the basis of the altitude of the water level in these two wells the 3,000-foot contour line, on the piezometric surface of water in the Rustler, which passes Gnome site, was extended across the boundary to encompass these wells and to further define the direction of movement of water in the Rustler Formation. This results in a convergence of contour lines indicating that in sec. 21, T. 24 S., R. 30 E. the piezometric surface of the water in rocks of Triassic age is the same as that in the Rustler Formation. In sec. 26, T. 24 S., R. 30 E. the piezometric surface of the water is the same in rocks of Triassic age, Permian age, and Tertiary or Quaternary age.

A hydrologic connection between the water in the Tertiary and Quaternary basin deposits, in the south-central part of the area, and water in rocks of Triassic and Permian age appears to exist. No disconformity of water levels or contour lines is apparent between water in this basin and water in the adjacent formations.

In August and September 1960 USGS test hole 1 (about 1,000 feet south of the shaft) and USGS test hole 2 (about 2 miles southwest of the shaft) were drilled for the purpose of testing the occurrence of water in every formation and every possible water-bearing zone in the rocks above the top of the massive Salado Formation. The holes were drilled with cable-tool equipment and upper segments of the hole were cased as the holes were deepened so that no mingling of water in the various formations was possible and so that testing operations could be carried out with no danger of caving in the upper part of the hole.

A tabulation of the basic geologic and hydrologic data obtained from these two test holes is contained in a report prepared by the writer in 1961 (Cooper, 1961).

At the site of USGS test hole 1 water was found only in the Culebra Dolomite Member of the Rustler Formation. In USGS test hole 2 the Culebra was dry and water was found only in the section of rocks between the Culebra and the top of the massive Salado Formation.

As it is not known what effect, if any, the detonation of a nuclear device will have upon the water levels in the aquifer at and near the Gnome site USGS test holes 1 and 2 were completed as permanent observation wells. They are equipped with continuous water-stage recorders for the purpose of monitoring the level of the water in the aquifers prior to, during, and after the planned nuclear experiment.

The Atomic Energy Commission has authorized the drilling of two additional monitoring holes, designated USGS test holes 4 and 5, which are scheduled for completion in late November of 1961. These holes will be located in the $SE\frac{1}{4}SE\frac{1}{4}NE\frac{1}{4}$ sec. 33, T. 23 S., R. 30 E., about three-quarters to one mile directly west of the Gnome shot point.

One of these holes will be completed in the Culebra Dolomite Member of the Rustler Formation at a depth of about 500 feet. The second hole will be completed in the residuum layer of the Rustler and Salado Formations, directly above the top of the massive salt, at a depth of about 700 feet. Both holes will be completed as permanent observation wells and equipped with continuous water-stage recorders.

The distance from the shot point to these monitor wells is such that no structural damage to them is anticipated. They are, however, located directly down gradient in the direction of movement of the water in the aquifer in the Culebra Dolomite Member which has passed the shot point and it is anticipated that post-shot monitoring of these wells will quickly detect any physical or chemical change which may take place in the aquifer in the Culebra Dolomite Member or in the rocks directly above the top of the salt.

An unusual opportunity for inspection and study of the rocks beneath the surface at Gnome site was presented when excavation work started July 1, 1960 on the vertical access shaft. The shaft, 1,200 feet deep, is circular in design, has an inside diameter of 10 feet, and is lined with concrete from the surface to a depth of 745 feet, about 35 feet into the salt of the Salado Formation. In the rocks above the top of the salt an approximate 12-foot diameter hole was excavated. Personnel of the USGS were present at the site during the construction of the shaft and examined each segment of rocks penetrated. Samples of all rock types were obtained and notes made on the structure, bedding, configuration, and type of rocks present. Special efforts were made to examine the rocks for the presence of ground water. No water could be detected in the rocks above or below the Culebra Dolomite Member of the Rustler Formation.

The layer of residuum above the top of the salt in the shaft was about 60 feet thick and consisted of red silty clay and claystone with randomly oriented blocks of gypsum, siltstone, and polyhalite. Because this residuum layer contains a brine aquifer west of the shaft site it was very carfully examined in the shaft for the presence of water. No water was present at this horizon.

Samples of the rock formations underlying the Culebra Dolomite Member were obtained for laboratory analysis of moisture content, porosity, permeability, and other factors. It is anticipated that the results of these analyses and a detailed description of the rocks penetrated by the shaft and tunnel will be contained in a separate report to be issued at a later date.

In accordance with plans based on prior data of the water-bearing rocks at the site excavation work was stopped in the shaft at a depth of 461 feet, about 35 feet above the top of the Culebra Dolomite Member, and the water-sealing program to shut off water in the aquifer was begun. Holes were drilled into the dolomite and cement and chemical grout mix was injected, under pressure, into the formation.

The release of water and pressure from the Culebra Dolomite Member of the Rustler Formation during the water-sealing program in the shaft and during excavation of the dolomite section was recorded graphisally on the recording gage installed in USGS test hole 1. The water level in the test hole stood at about 442 feet below land surface before drill holes for grout injection were drilled into the aquifer on December 9, 1960. Between this date and February 10, 1961 the water level in the test hole declined to about 444 feet. The total amount of water discharged from drill holes in the aquifer and from the aquifer itself during shafting operations and pumped up the shaft during this period is not known accurately; however, the discharge of water into the shaft at any one time generally did not exceed 15 gpm and varied from less than 1 gpm to about 30 gpm.

Figure 10A is a reproduction of the trace of the fluctuation of water

Figure 10A.--Hydrograph showing fluctuation of water level in USGS test hole 1 during final phase of the water-sealing program in the Project Gnome shaft.

level in the aquifer as recorded by the gage in USGS test hole 1 during the final phase of the water-sealing program in the shaft. On February 10 injection of grout behind the concrete liner, against the Culebra Dolomite Member, in the interval from 515 to 525 feet, reduced water leakage into the shaft from about 13 gpm to about 5 gpm. In response to this partial sealing of the aquifer the water level in the observation well rose about 1 foot. An additional water level rise of about half a foot was noted in the observation well on February 14 when the interval from 490 to 515 feet was grouted and the leakage of water into the shaft was reduced to minor seepage only. After February 14 the water level in the aquifer gradually rose and returned to normal level.

Fluctuations of water level in the aquifer due to diurnal changes in barometric pressure are evident on the graph after February 10. The release of water and pressure from the aquifer in the shaft cancelled out this effect and it is not recognizable on the graph immediately prior to February 10.

At the Gnome site data obtained from observations in the shaft and from test holes show that water is present only in the Culebra Dolomite Member of the Rustler Formation. The water is contained in fractures and openings in the rock and is confined by gypsum and anhydrite beds above and below the dolomite member. The approximate upper half of the dolomite apparently is more severely fractured and contains more open voids than does the lower half. The aquifer is generally about 30 feet thick and its top at the Gnome site is at a depth of about 500 feet below the land surface. The artesian head of the water in the aquifer is sufficient to cause it to rise about 75 feet above the point at which it is found. The direction of movement of water at the Gnome site is westward although both southwestward and northwestward components of movement occur within short distances of the site.

Rustler Formation

The Culebra Dolomite Member and the brine aquifer, immediately above the top of the salt in the Salado Formation in Nash Draw, are the principal aquifers in the Rustler Formation.

In most of Nash Draw and southwest to Malaga the basal beds of the Rustler Formation contain a concentrated sodium chloride brine. The presence of this brine was investigated by Robinson and Lang (1938). Their studies showed that this brine aquifer covered a narrow strip 2 to 8 miles in width and about 20 miles in length. Its position as defined by them is shown on figure 9. Data from test holes drilled during their investigation indicated that the brine horizon ranged in thickness from about 10 feet to 60 feet, and that its average thickness was about 24 feet. The eastern limit of this brine aquifer, as presently defined in the Nash Draw vicinity, is about 4 miles west of the Gnome site. The aquifer was not present in the holes drilled at the Gnome site; however, it may approach the site closer than presently known.

The concentration of the brine increases from north to south in the aquifer. Lang (in Robinson and Lang, 1938, p. 86) believes that water may enter the formation northwest of Nash Draw and may migrate south and east to Nash Draw. The migrating water would first dissolve calcium carbonate and calcium sulphate from gypsum beds in the Rustler Formation and then could penetrate the lower member through fractures and come in contact with the salt of the underlying Salado Formation. The investigation of Robinson and Lang (1938) confirmed Lang's previous assumption that the structural conditions that caused the development of Nash Draw also controlled the position of the brine aquifer body.

The brine is under artesian pressure and moves from north to south down Nash Draw. Hale (in Hale and others, 1954, p. 22) estimated that the average gradient of the piezometric surface of the brine along the aquifer in Nash Draw between the Malage Bend of the Pecos River and Laguna Grande de la Sal is about 1.4 feet per mile and that the aquifer has a coefficient of transmissibility of about 60,000 gpd per foot in the Malaga Bend area. (The coefficient of transmissibility (T) was introduced by Theis (1935) and is expressed as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent, or it may be expressed as the flow in gallons per day through a section of the aquifer 1 mile wide under a hydraulic gradient of 1 foot per mile.) Assuming these figures for the gradient of the piezometric surface and for the transmissibility and further assuming that the average width of the brine aquifer is about 5 miles, the rate of brine moving southward in Nash Draw past a given cross section is about 420,000 gpd.

Hale (in Hale and Clebsch, 1958, p. 11) calculated the rate of movement of the brine at about 0.2 foot per day. His calculation was based upon an assumed effective porosity of the aquifer of 20 percent and an aquifer thickness of 50 feet. If the average thickness of the brine aquifer is only 24 feet as reported by Robinson and Lang (1938, p. 88) and the effective porosity figure remains constant the rate of movement would be in the order of 0.4 foot per day.

The major discharge point of the brine aquifer is in the Malaga Bend area. This area is underlain by alluvium, which is in places over 150 feet thick. The beds of clay, gypsum, and sandstone which overlie the brine aquifer in most of Nash Draw have largely been removed in the Malaga Bend area by erosion and solution and no longer act as a confining bed restricting upward movement of the water. The artesian pressure in the brine aquifer at the Malaga Bend is greater than that in the alluvium and is several feet higher than the normal river level. The brine percolates upward through the fill, mingles with water in the alluvium and discharges into the river. Theis (in Theis and others, 1942, p. 69) estimated that between the head and the lower end of the Malaga Bend, the increase, to the river, of sodium chloride, presumably all coming from the brine aquifer at the base of the Rustler Formation, amounts to 342 tons per day and that the brine is emerging at a rate of about 200 gpm.

Robinson and Lang (1938) made a careful study of Laguna Grande de la Sal and the area between it and the Malage Bend to determine if brine in the lake moved toward the river. The source of the water in the lake is precipitation and surface drainage, spring discharge and ground-water inflow, and effluent from the refinery of the U.S. Borax and Chemical Co. Test wells drilled in the vicinity of the lake found water of a different type and much lower chloride content in permeable formations below the bottom of the lake. These data indicated that the lake brine was not leaking downward into the brine aquifer. In addition, water levels in the fill have a gradient towards the lake indicating ground-water movement into the lake, rather than away from it. Also, occasionally, artesian conditions are present which cause the water to flow above the top of the salt crust. Robinson and Lang (Robinson and Lang (1938, p. 100) believed that these artesian conditions indicated that there is little or no percolation of the lake brine downward to the underlying Rustler Formation, as otherwise the artesian head would not exist.

Theis (1942, p. 71) found that generally water levels in the lake is high in winter and low in summer, whereas the head of the water in the brine aquifer is high in the irrigation season and low between irrigation seasons. He supports the conclusion of Robinson and Lang that there is no connection between the lake and the brine aquifer.

Water of the Pecos River that flows southward from the Malaga Bend is stored in the Red Bluff reservoir just south of the State line in Texas. The water is used in several irrigation districts in Texas where several tens of thousands of acres of land are irrigated in normal years. The chemical deterioration of the water in the river below Malaga Bend, caused by the discharge of the brine aquifer, has been for many years a source of much concern to downstream irrigators and to those in charge of the irrigation districts. In some years the high mineralization of the river water has forced serious decreases in crop irrigation.

Beginning in 1951 the Pecos River Commission, the agency responsible for administering the terms of the Pecos River Compact, entered into a cooperative agreement with the Geological Survey to investigate means of improving the quality of water in the river, particularly in the Malaga Bend. A number of possibilities for effecting an improvement in the quality of the river water have been investigated; however, at this time no satisfactory solution has been found and the investigation is continuing. Because of the Pecos River Compact and the economic and agricultural factors involved in the usage of river water for irrigation in Texas any event that possibly could involve the brine aquifer in Nash Draw is of major interest to a number of groups and individuals.

It is not inconceivable that a severe earth shock in the Nash Draw area could disturb the present equilibrium of the brine aquifer and cause changes in the aquifer system. What these changes would be or what effect they would have on the problem of contamination of Pecos River water is mostly a matter of conjecture at the present time. Possibly the discharge of the aquifer might be permanently increased. This would be a serious matter to the Pecos River Commission. On the other hand compressive forces, if present, might cause a decrease in transmissibility of the aquifer which would in turn decrease the discharge and be of benefit to users of river water.

It is not considered likely that the proposed nuclear shot will affect the brine aquifer if the explosive forces from the blast are contained, as planned, within the massive salt. However, it is more than likely that any change in the discharge of the brine aquifer into the Malaga Bend and any effect upon the river water being used for downstream irrigation will be evaluated by the irrigators and the Pecos River Commission.

The yield of water from the Culebra Dolomite Member depends upon the number of openings and fractures which in turn apparently is related to the thickness of the overlying formations. In the upper part of Nash Draw the dolomite is near the surface and has been subjected to extensive solution weathering. It contains large fractures and openings through which water can move freely. Large yields have been obtained from wells in this vicinity. Formerly, wells were used to supply water for the operations of the potash mine of the International Minerals and Chemical Corp. Several of their wells, in secs. 5 and 6, T. 22 S., R. 30 E., yielded as much as 700 gpm. East of Nash Draw where the Culebra Dolomite Member is covered by several hundreds of younger rocks yields of wells finished in the formation are generally not great.

Yields of wells finished in the Culebra Dolomite Member at and near the Gnome vary considerably. This is in part due to the methods used to test for yield. However, because of the fracture-type permeability of the aquifer and the possibility of localized solution channels variance in yields of wells only short distances apart is to be expected.

About 140 gpm reportedly were bailed from AEC hole 2 near the shaft site. The well was tested for a $\frac{1}{2}$-hour period and no lowering of water level was noticed. USGS test hole 1, which is 1,000 feet south of the shaft, was test pumped for a period of 24 hours at a rate of 100 gpm and a downdown of about 41 feet. At the end of the test the pumping water level was about 484 feet below land surface.

Well 23.30.2.444a, about $4\frac{1}{2}$ miles northeast of the Gnome site, reached the top of the Culebra Dolomite Member at a depth of 315 feet. Water was found in the top of the dolomite and the well was finished at a depth of 318 feet. The water rose to a static level of 260 feet or about 55 feet above the aquifer. A bailing test of about 40 minutes, at a rate of 12 gpm, caused the water level to lower to within a few feet of the bottom of the well. Within 1 hour after bailing stopped the water level had recovered to about its original level. Well 24.30.18.231, about 4 miles southwest of the Gnome site apparently obtains water from the Culebra at a depth of about 400 feet. The static level of the water in this well is 228 feet or about 170 feet higher than the aquifer. This well was bailed for 1 hour at a rate slightly over 10 gpm. The water level lowered about 85 feet during the test.

The water in the Rustler Formation at the site of USGS test hole 2, about 2 miles southwest of the shaft site, is not contained in the Culebra Dolomite Member as is the case at the Gnome site. The piezometric surface of the water at USGS test hole 2 is at or slightly above the altitude of the base of the dolomite member; however, its source is in the rocks of the lower member and probably in the residuum layer immediately above the top of the salt. As the elevation of the Culebra Dolomite Member rises to the southwest from the Gnome site the water in it apparently leaks through the gypsum of the lower confining bed and enters permeable zones in the underlying rocks. This probably is a relatively local feature related to the high elevation of the Culebra in this locality. Further west and southwest where the Culebra dips towards Nash Draw it again carries the majority of the water found in the Rustler Formation.

The water in the Culebra Dolomite Member is under artesian pressure except west of the Pecos River, beneath the alluvium, in the vicinity of Laguna Grande de la Sal, and in its outcrop where the water in the formation occurs under water-table conditions.

The coefficient of transmissibility of the aquifer in the Culebra Dolomite Member at USGS test hole 1 has been calculated, from data obtained from a 24-hour pumping period and a 24-hour water-level recovery period, to be about 4,000 gpd per foot. (See figs. 11 and 12.)

Figure 11.--Water-level drawdown plot, USGS test hole 1, Project Gnome.

Figure 12.--Water level recovery plot, USGS test hole 1, Project Gnome.

The coefficient of transmissibility of the aquifer at the site of USGS test hole 2 is extremely small. Using data obtained from an 18-hour period of water-level recovery measurements a value of only 17.2 gpd per foot was obtained (fig. 13).

Figure 13.--Water level recovery plot, USGS test hole 2, Project Gnome.

The slope of the surface of the water is generally southwestward toward the Pecos River on the east side of the river (fig. 10). Theis (1942, p. 68) states that the surface of the water slopes at a rate of 10 to 13 feet per mile down the axis of the draw toward Laguna Grande de la Sal. A depression in the piezometric surface in the vicinity of the lake indicates that much of the water is discharged at this point. South of the lake there is a general southward slope of the water table. In the vicinity of the Gnome site data indicate

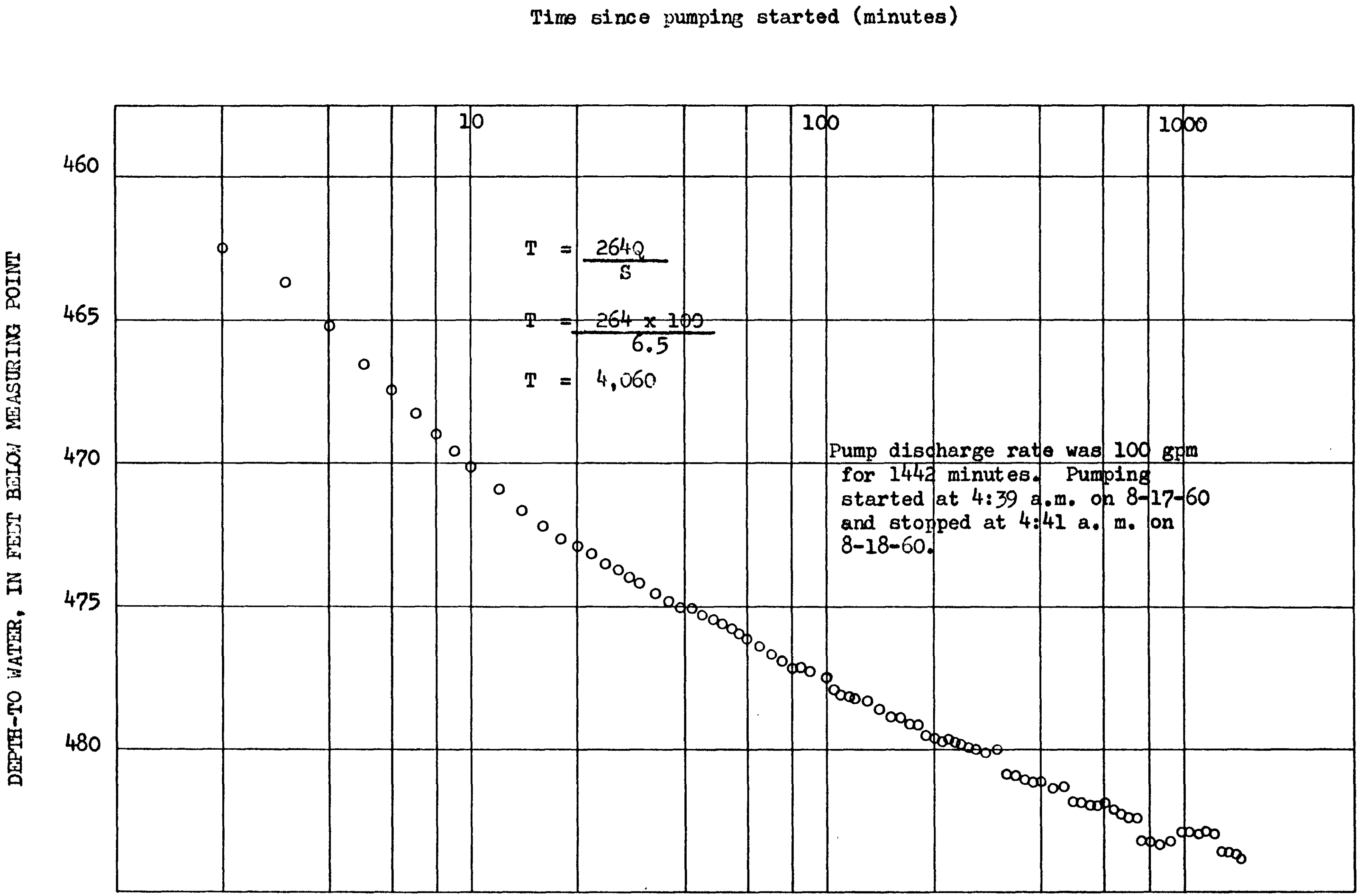

Figure 11.--Water-level drawdown plot, USGS, test hole 1, Project Gnome

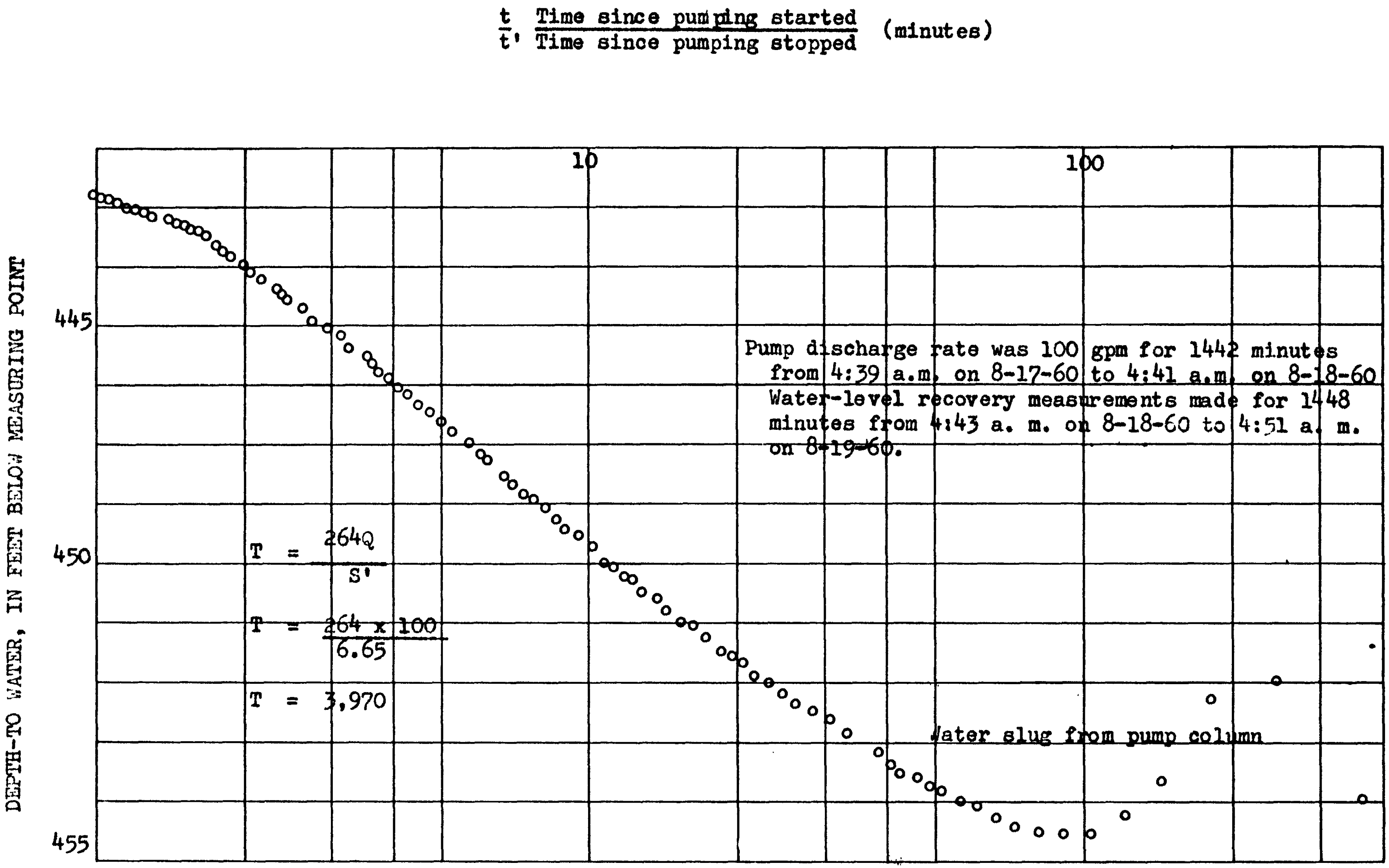

Figure 12.--Water level recovery plot, USGS test hole 1, Project Gnome

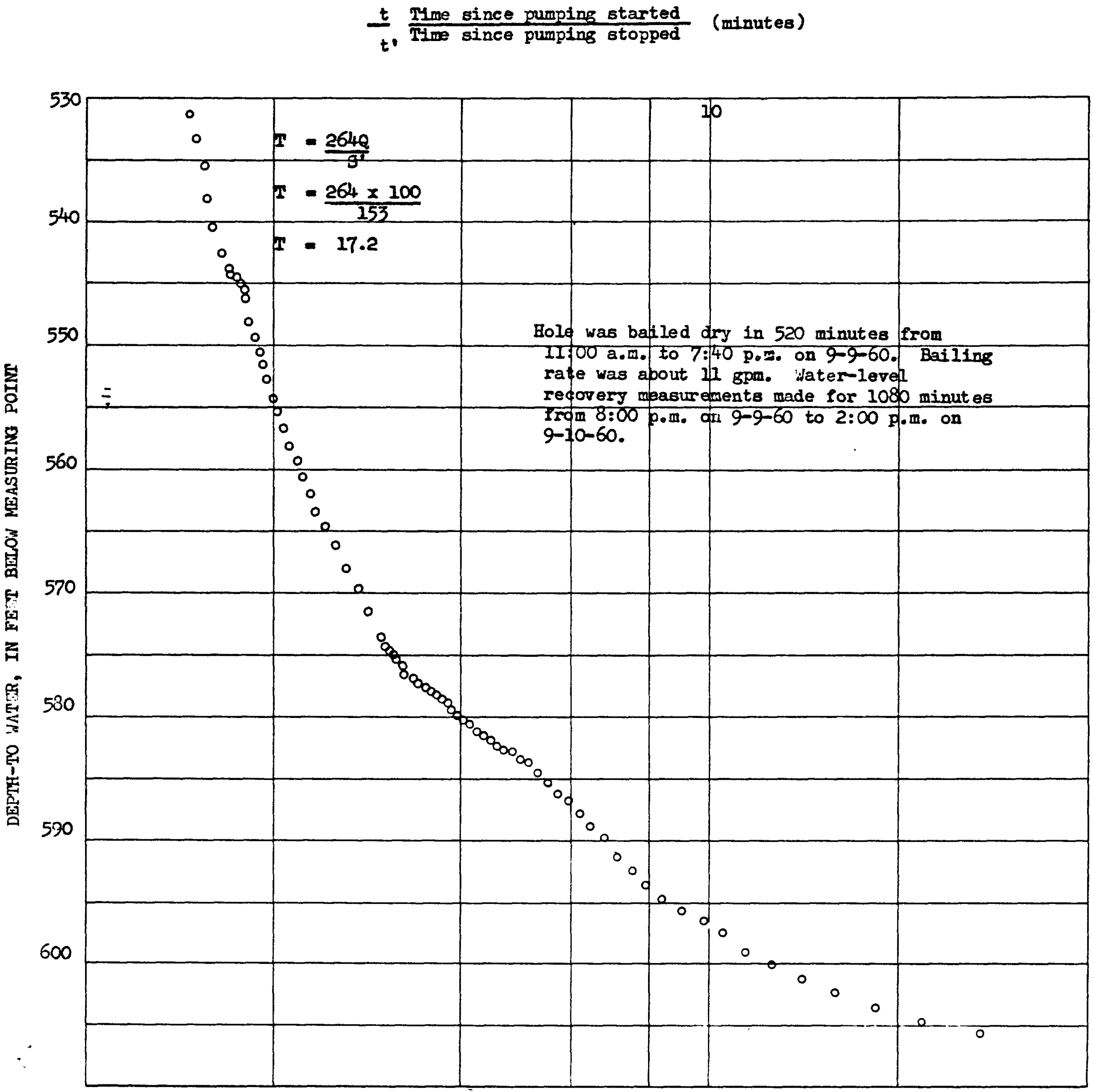

Figure 13.--Water-level recovery plot, USGS test hole 2, Project Gnome

that the slope of the piezometric surface is somewhat greater than in Nash Draw, probably about 12 to 15 feet to the mile.

West of the river where the water in the Culebra Dolomite Member and the water in the alluvium are connected hydraulically, probably because the primary source of the water in the two aquifers is from surface irrigation, the water surface slopes eastward and southward toward the river. Robinson and Lang (1938, p. 93) found that the slope of the water in this area ranged from 20 to 30 feet per mile and that locally for about 4 miles above the mouth of Black River the slope appeared to be towards the stream from both the north and south.

The rate of movement, or the velocity (V), of water in an aquifer is directly proportional to the slope of the piezometric surface (I) and to the permeability of the materials (P). It is inversely proportional to the porosity (p) of the materials. It is expressed by the formula $V = \frac{PI}{p}$.

The apparent coefficient of permeability of the aquifer in the Culebra Dolomite Member near the Gnome site can be computed from the coefficient of transmissibility which was obtained for the aquifer and from the average thickness of the aquifer. The coefficient of transmissibility as calculated from the pumping test at USGS test hole 1 was about 4,000 gpd per foot. The average thickness of the dolomite aquifer in the Gnome vicinity is about 30 feet. These values result in an apparent coefficient of permeability of 133 gpd (17.8 cubic feet) per square foot for the aquifer.

The slope of the piezometric surface in the vicinity of Gnome site is about 12 to 15 feet to the mile.

Samples of dolomite of the Culebra Dolomite Member, obtained during the excavation of the Gnome shaft, were analyzed for porosity by the Hydrologic Laboratory of the U.S. Geological Survey. A sample taken from a depth of 505 feet had total porosity of 14.4 percent and effective porosity of 7.8 percent. A sample from 515 feet had total porosity of 13.7 percent and effective porosity of 11.1 percent. These porosity determinations were made from blocks of dolomite taken from the aquifer and probably are not wholly representative of the porosity of the entire rock unit.

A reasonable average value for porosity of the Culebra Dolomite Member near the Gnome site appears to be about 10 percent. A somewhat higher value would be obtained in zones of interconnected joints and openings and lower values can be expected if more consolidated portions of the rock unit exist.

A calculation of the average rate of movement of water through the Culebra Dolomite Member in the vicinity of the proposed shot, using the values quoted above, result in a figure of about one-half foot per day.

The source of the recharge to the Culebra Dolomite Member has not been defined clearly. In its outcrop the dolomite receives water directly from precipitation and in Nash Draw surface water drains directly into it through sinks. The direction of movement of water in the aquifer as shown on figure 10 indicates a source of recharge to the north and east of the Gnome site.

Triassic Formations

Rocks of Triassic age yield water to wells in the eastern part of the Gnome area. The Santa Rosa Sandstone is the principal aquifer in the Triassic. A number of wells in the Eddy County part of the area, east of the outcrops of the Triassic and Permian, are believed to obtain water from it. Farther east in Rs. 32 and 33 E. the sandstone is overlain by several hundreds of feet of younger Triassic rocks and wells usually are completed in sandstone beds of the younger rocks. No quantitative tests have been made of the yields of wells finished in these rocks. Observations of several wells just east of the outcrop area indicate that yields in excess of 10 gpm are obtained. Farther east wells were observed to be yielding much smaller quantities of water; probably not over 2 gpm each. It seems probable that the outcrop area of the Santa Rosa Sandstone is a point of recharge for this formation. Water in the Santa Rosa Sandstone is under artesian pressure where it is covered by younger formations. Water in the upper part of the Triassic section is probably under water table or, in places, perched-water conditions.

The rate of movement of water in the rocks of Triassic age is not well known. The water may move through joints and along bedding planes, as well as through the sandstone and conglomerate beds. Hale and Clebsch (1958, p. 14) estimate that average velocities of water movement may be on the order of 0.3 foot per day through these rocks.

Tertiary and Quaternary Formations

A number of wells obtain water from sand beds in rocks of probable Tertiary (Ogallala(?)) and Quaternary age that fill the deep basin in the south-central part of the area, a few miles south of the Gnome site. The yield of some wells finished in these rocks is reported to be large.

Two wells owned by the El Paso Natural Gas Co. are located in sec. 5, T. 26 S., R. 30 E. Well 1 is 770 feet deep and was pump tested for 20 hours at a rate of 150 gpm with a drawdown of water level of 14 feet. The static water level was 173 feet below land surface. The drilling log records that 20 to 30 gpm were present at a depth of 210 feet and that additional water-bearing beds were at 580 feet, 665 feet, and 725 to 770 feet. Well 2 was finished at a depth of 775 feet. It was not pump tested following completion; however, it was tested when at a depth of 570 feet. The static water level was 175 feet, and the pumping level was 295 feet at a discharge rate of 105 gpm. Water-bearing beds were reported to occur in this well at depths of 195 to 230 feet, 255 to 295 feet, 535 to 570 feet, 695 to 735 feet, and 740 to 750 feet.

Other wells finished in rocks of Tertiary and Quaternary age in this area are used primarily for stock water. They are not as deep as the wells owned by the El Paso Natural Gas Co., because they apparently found a sufficient supply of water in the upper sand beds.

The sand beds of the Tertiary and Quaternary deposits probably receive recharge locally. Much of the area underlain by these rocks is mantled with sand and conspicuous sand dunes that provide a catchment area for rainfall which could then percolate downward into the underlying rocks. In addition, several fairly large depressions form catchment basins for surface runoff from precipitation.

The water-level contour map (fig. 10) shows that the slope of the water in the sediments averages about 10 feet per mile and that the water moves to the west and southwest through the basin.

Gatuna Formation

Sand and conglomerate beds in the Gatuna Formation of Pleistocene(?) age yield water to wells at two locations within the area. Well 24.30.8.113, about three miles southwest of the Gnome Site, and well 24.31.17.111, about 4½ miles southeast of the site, obtain water from this formation.

The water in the Gatuna Formation probably is perched over relatively impermeable beds of the Pierce Canyon Redbeds. The water level in the wells finished in the Gatuna is at a considerably higher altitude than that of nearby wells that are finished in either rocks of Triassic or Permian age. The altitude of the water surface in well 24.31.17.111 is over 400 feet above the piezometric surface of water in the Culebra Dolomite Member at the same location.

The Gatuna Formation occurs erratically in the area and no continuous zone of saturation exists in it. Less than 20 feet of saturated thickness of the formation is present at the two wells in the area and continuous yields of but only a few gallons per minute could be expected from either well. The extent and size of the bodies of perched water is not known. It is possible that they could extend over an area of a few square miles and in places could have a greater saturated thickness which would yield larger amounts of water to a well.

The source of the water in the Gatuna Formation is local precipitation. Both of the wells previously mentioned are located near surface sand dunes of large extent which probably serve as recharge areas to the formation. The chemical quality of the water indicates that it has not been long in storage nor has traveled long distances through various rock types. The water is exceptionally low in sulfate and dissolved solids and is the softest water known to exist in the Gnome area.

Alluvium

West of the Pecos River and north of Malaga many wells obtain water from alluvium. Most of the wells have large yields and are used for irrigation. Several wells have reported yields in excess of 2,000 gpm and one well is reported to yield 3,750 gpm. Some of the most productive wells are reported to obtain water from crevices and solution cavities in conglomerate (Hendrickson and Jones, 1952, p. 45). The average depth of wells in this section is about 200 feet and the depth to water in most of the irrigated area ranges from about 10 feet near the river to about 100 feet west of Loving.

The water in the alluvium is under water-table conditions and is continuous with water im the underlying Rustler Formation. Occasionally small bodies of perched water are found in the alluvium as much as 50 feet above the main water table. Water in the alluvium moves east and southeast towards the Pecos River and moves towards Black River, just north of Malaga, from both the north and south. The slope of the water table between Loving and Malaga is about 20 feet per mile. The rate of movement of the water has not been determined. Hale and Clevsch (1958, p. 15) estimate that the rate of movement expected would be less than one foot per day except where the water moves through solution channels in the conglomerate. In solution channels the rate of movement might be more than 100 times that through the unconsolidated part of the alluvium.

Recharge to the alluvium, west of the river, is from surface runoff from precipitation and from Pecos River water that enters the alluvium through leaking canals and water applied to the irrigated lands during the growing season.

East of the Pecos River in the Malaga Bend area and north to Laguna Grande de la Sal an area of several square miles of alluvium is present. A well in this vicinity was test pumped at a rate of about 800 gpm. Hendrickson and Jones (1954, p. 76) believe that other wells of similar capacity could be developed here; however, their pumping would reduce the flow of the river and new development is not permitted by the State Engineer of New Mexico. Wells 23.28.14.241, 23.28.14.241a, and 23.28.14.243, located just south of State Highway 31 and on the east side of the river, are among the few wells which obtain water from the alluvium east of the river. These wells are 100 to 150 feet deep and are reported to yield between 1,500 to 3,000 gpm each. The wells are pumped for irrigation water during periods of low river stage in the irrigation season.

The source of the water in the alluvium adjacent to the east side of the river is precipitation, inflow of ground water from the east, in the irrigated areas penetration of irrigation water, and from the river itself.

Away from the river, on the east side, only a few wells are believed to be finished in alluvium. In sec. 15, T. 22 S., R. 28 E., several wells of low capacities are reported to obtain water from alluvium. Well 24.32.10.344 in the eastern part of the area is probably obtaining water from a perched-water body in Quaternary alluvium.

Utilization of water

Ground water in the Project Gnome area is used for domestic and stock purposes, industrial supplies, irrigation, and for construction use. A part of the area, near the Pecos River, consisting of T.'s 22-24 S., R. 28 E. and the west four tiers of sections in T.'s 23-24 S., R. 29 E. is included in the Carlsbad Underground-Water Basin. This basin was declared by the New Mexico State Engineer in 1947. The declaration placed control of well construction within the basin under the administration of the State Engineer. The construction of new irrigation wells, since that time, in the area, has been permitted only to supplement surface-water rights or to replace damaged wells.

A surface-water diversion dam, known as Harroun dam, is located on the Pecos River just north of the river bridge on State Highway 31. Water from the river is diverted into a canal, on the east side of the river, that carries water downstream to irrigate about 3,000 acres of land owned by D. S. Harroun. Most of the irrigated land is located between the diversion dam and the lower part of the Malaga Bend. An additional small acreage, east of the river on the Livingston Farms, is irrigated by water pumped from the river at the Malaga Bend.

West of the river surface water is diverted from the Pecos River and from Black River, a tributary of the Pecos, by the Carlsbad Irrigation District. The water is used for crop irrigation in the vicinity of Loving and Malaga. The water from Black River is shared between the Carlsbad Irrigation District and Mr. Guy Reed who irrigates land near Malaga. A part of the water is stored by Mr. Reed in Willow Lake, 2 miles south of Malaga, and is used on land east of the lake.

During this investigation all known wells, used or unused, located on the east side of the Pecos River within a radius of 15 miles of the Gnome site, were visited. In addition, data were obtained on several wells at a greater distance from the site. Most of the wells are used for stock watering; however, the largest withdrawal of water is for irrigation use west of the river and for irrigation and industrial use east of the river. The two potash refineries within the area are the largest single users of water. The source of their water, however, is not from wells located within the area. The International Mineral and Chemical Corp. obtains water by pipeline from wells located about 18 miles west of their refinery. The U.S. Borax and Chemical Co. uses water from the Pecos River, which is diverted at Harroun dam. Records of the 70 wells visited are given in table 2. Their location is shown on figure 10.

Wells east of the Pecos River were supplying water for domestic use to 12 installations at the time of this investigation. These installations include several ranch headquarters, single domiciles, and a group of houses at the Pecos turbine station of the El Paso Natural Gas Co. Several habitations which are equipped with domestic supply wells are not permanently occupied but are used intermittently during the year as temporary living quarters for the ranchers of the area.

Most of the wells used for domestic supplies also furnish water for stock. In addition, most ranches have several separate well installations distributed over the land used for grazing. All of the domestic and stock wells, except those of the turbine station, are equipped with cylinder pumps and windmills and usually with auxiliary gasoline engines. Vertical turbine pumps driven by internal combustion engines are used in the wells of the El Paso Natural Gas Co.

The only wells, presently in operation, supplying water for industrial usage are the two wells owned by the El Paso Natural Gas Co. located on the "pipeline" private road in the southwestern part of the area. Water is pumped from the wells and carried by pipeline a distance of about 7 miles westward to the turbine station where it is utilized for steam boilers and other purposes in the operation of the station which distributes natural gas into cross-country pipelines.

A small irrigation development, consisting of three wells, is located adjacent to the east side of the river just south of the river bridge on State Highway 31. During times of low streamflow these wells pump water into a nearby canal to supplement the river water normally used for downstream irrigation of crops. These wells are equipped with vertical turbine pumps driven by gasoline engines.

A water supply needed for the drilling and construction of a deep oil or gas test well is often obtained by the drilling contractor from a water well drilled near the location chosen for the deep test. A number of wells have been drilled in the Gnome area for this purpose. Upon completion of the deep drilling the water well is no longer needed for construction purposes by the drilling contractor and it is often converted to a stock well by the land owner or the rancher holding the grazing rights on the land.

Many domestic, stock, and irrigation wells are in use on the west side of the Pecos River. The irrigation wells are mostly located north of Malaga and the water is used primarily to supplement the river water normally used for irrigation. Large-yield wells are uncommon south of Malaga; however, a number of stock and domestic wells exist.

Quality of water

The chemical and radiochemical character of ground water in the Gnome area is indicated by the analyses of water from 22 wells given in table 3. The analyses do not indicate the sanitary condition of the water but show only the dissolved mineral content and measures of radioactivity. The location of the wells from which the samples were obtained and their relation to the Gnome site is shown on figure 14. Analyses are given for water from 10 wells

Figure 14.--Map showing location of radiochemical analyses and principal constituents in water from wells near the Project Gnome site, Eddy County, N. Mex.

completed in the aquifer in the Culebra Dolomite member, from 1 well finished in rocks of the lower member of the Rustler Formation, from 4 wells completed in rocks of Triassic age, and from 2 wells completed in the Gatuna Formation.

Dissolved mineral constituents

The following discussion of the chemical constituents of ground water has been adapted in part from publications of the U.S. Geological Survey.

The dissolved constituents are reported in parts per million by weight (ppm). One ppm represents one unit weight of a constituent in a million unit weights of solution. It is equivalent to 8.34 pounds per million gallons of solution. For some purposes, such as the graphic comparison of the composition of water (fig. 15), analyses are converted to equivalents per million (epm). An epm is a unit chemical combining weight of a constituent in a

Figure 15.--Analyses of ground water from the Project Gnome area, Eddy County, N. Mex.

million unit weights of solution. Ppm values may be converted to epm by multiplying ppm by the reciprocals of combining weights of the appropriate ions.

The reciprocals of chemical combining weights of the most commonly reported constituents are given in the following list:

Constituent	Factor	Constituent	Factor
Iron (Fe++)	0.358	Chloride (Cl-)	0.0282
Iron (FE+++)	.0537	Fluoride (F-)	.0526
Sodium (Na+)	.0435	Nitrate (NO_3-)	.0161
Potassium (K+)	.0256	Sulfate (SO_4--)	.0208
Magnesium (Mg++)	.0822	Carbonate (CO_3--)	.0333
Calcium (Ca++)	.0499	Bicarbonate (HCO_3-)	.0164

Safe limits for any of the mineral components usually found in water are very difficult to establish. The limits usually quoted in the United States for drinking water are based on the U.S. Public Health Service drinking-water standards (1946). These standards were established to regulate the drinking and culinary water provided by common carriers for the use of passengers carried in interstate traffic.

In sections of the United States, and particularly in many parts of New Mexico, the quality of water available does not meet the standards in one or more respects. However, residents of such areas have used these waters, often for many years, without visible adverse effect.

Most of the more common constituents in drinking water appear to be objectionable only when they are present in such high concentrations as to be noticeable to the taste. Exceptions to this are the constituents fluoride and nitrate. Fluoride in water in excess of 1.5 ppm may cause mottled enamel on the teeth of children who drink this water during the period of formation of the permanent teeth. Smaller amounts of fluoride may lessen the incidence of tooth decay. Studies of the effect of fluoride in drinking water upon childrens teeth indicate that in New Mexico 0.7 ppm of fluoride may be considered the optimum level (New Mexico Department of Public Health, 1957, p. 5). Climate, which affects the amount of water required and hence the intake of fluoride, is a controlling factor upon the optimum amount of fluoride content. Nitrate (reported in ppm of NO_3) in excess of 44 ppm is a possible source of the so-called "blue baby" disease or cyanosis in infants whose feeding formulas are

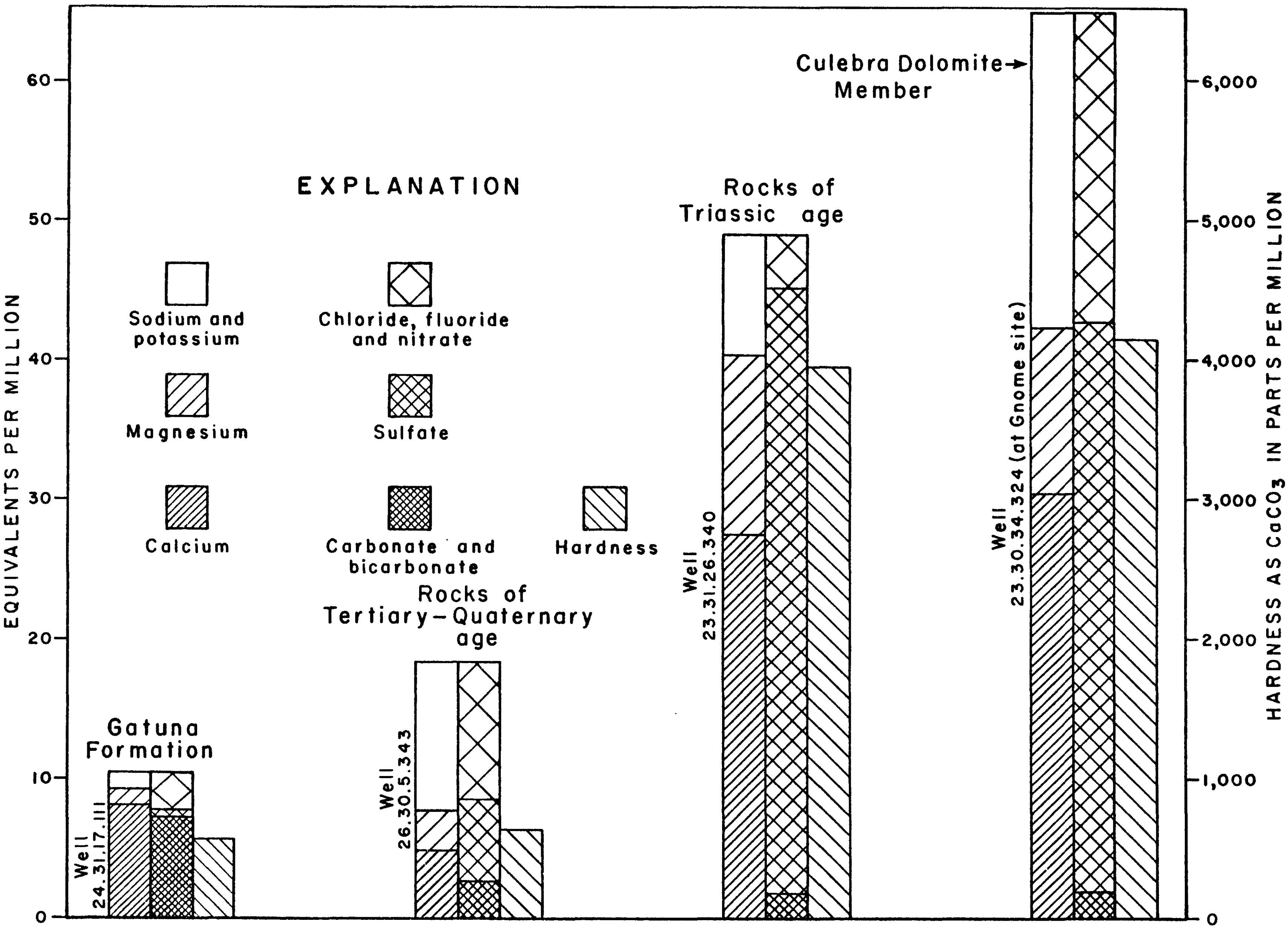

Figure 15.-- Analyses of ground water from the Project Gnome area, Eddy County, N. Mex.

mixed with these waters (Hem, 1959, p. 229).

The amount of fluoride in the samples collected in the Gnome area ranged from 0.3 to 1.8 ppm. Twelve of the 22 samples contained 1.5 ppm or higher. Only two of the samples contained less than 0.7 ppm. Thus in the Gnome area the concentration of fluoride in the ground water is somewhat above the suggested optimum level.

Nitrate in water does not appear to be a serious problem in the area. Several samples contained no nitrate and only two contained slightly more than 44 ppm.

The upper limits for some of the other constituents, normally reported in water analyses, according to the Public Health Standards are: dissolved solids, 500 to 1,000 ppm; chloride, 250 ppm; sulfate, 250 ppm; magnesium, 125 ppm; iron and manganese (together), 0.3 ppm. These components, separately, or in combination with each other or with other constituents, are ones which primarily affect the taste and suitability of most water for drinking purposes.

Most of the water samples collected in the Gnome area contained dissolved solids far in excess of the established limits. Concentrations ranged from 268 to 21,900 ppm. Only four samples contained less than 1,000 ppm. Samples collected from wells yielding water from the Gatuna Formation and from rocks of Tertiary and Quaternary age contained the lesser amounts of dissolved solids. All samples collected from Permian and Triassic rocks contained excessively high concentrations.

Chloride concentrations in the samples ranged from 18 to 10,600 ppm. Amounts varied greatly, even in water from the same formation, although generally water from Permian and Triassic rocks contained the largest concentration of chloride.

The concentration of sulfate in the samples ranged from 23 to 3,047 ppm. Only four samples contained less than 250 ppm, the suggested upper limit. Water from the Gatuna Formation was exceptionally low in sulfate. Water from rocks of Permian age generally contained the largest concentrations.

Magnesium concentrations reported in the samples ranged from 13 to 492 ppm. Twelve of the samples contained more than 125 ppm. The largest amounts are in water from rocks of Permian age.

All but two of the samples collected contained excessive amounts of iron and manganese. Concentrations of iron and manganese together, in the 20 samples where they were present, ranged from 0.37 to 9.5 ppm. The manganese concentration in most samples was minor; iron being the dominant constituent. The concentration in samples collected from the same formation varied widely. Some of the higher concentrations may be due to physical conditions of the sampling point, such as rust flakes from casing and pump equipment and may not represent natural-occurring iron in the ground water.

Water containing excessive concentrations of certain of the above constituents can be tolerated by many individuals; however, high concentrations of sulfate will have a laxative effect on some people and a salty taste to the water will result when a chloride content of 200 to 300 ppm is present in combination with an equivalent amount of sodium.

The hardness of the water is a property that usually receives considerable attention, particularly in water used for domestic purposes. The meaning of the term "hard" is different in different areas, dependent upon the hardness to which the user is accustomed. Calcium and magnesium cause virtually all the hardness of ordinary water. Also they are the cause of the scale formed in cooking vessels and in the piping of heating units and steam boilers. The table of analyses shows total hardness and noncarbonate "permanent" hardness. Carbonate hardness, the difference between total and noncarbonate hardness, can be removed by boiling. No difference exists between these two types of hardness with reference to the use of soap. Generally water having a hardness of 60 ppm or less is regarded as soft; of 60 to 120 ppm, moderately hard; 120 to 200 ppm, hard; and more than 200 ppm, very hard.

Water samples collected in the Gnome area ranged in total hardness from 176 to 4,720 ppm. All of the water is classed as very hard and some is so excessively hard that it is unsuitable for most purposes. Water with the least amount of hardness occurs in the Gatuna Formation and in rocks of Tertiary or Quaternary age. Generally, the Permian rocks contain the hardest water.

The upper limits of mineral constituents in water used for livestock is many times greater than in water used for human consumption and ordinary domestic use. It is reported (Hem, 1959, p. 241) that range cattle in the western United States use water containing from 5,000 to 10,000 ppm of dissolved solids, although a high proportion of sodium or magnesium and sulfate in such water would make it undesirable for stock use.

Radioactivity measurements

Most natural waters are radioactive to some extent due to the presence of radioactive isotopes which exist in nature. Most of the natural radioactivity in water is produced by disintegrations of certain atoms of the U-238 (uranium series) and Th-232 (thorium series). A few other naturally occurring isotopes are radioactive but they are not very important as a source of radioactivity in water. The radiant energy given off by these series of disintegrations is emitted primarily in the form of alpha radiation. Beta and gamma radiation is given off by some of the members of these series but it is usually insignificant in nature and is emitted mainly from products of atomic fission.

The naturally occurring radioactive substance in water which are now being determined by the Quality of Water Branch, U.S. Geological Survey, are the long-lived alpha emitters of the uranium series, beta and gamma emitters, and natural radium and uranium. The analyses include also measurements of Strontium-90. Strontium-90 is absent in natural waters. It is a fission product that is especially dangerous biologically. The determinations of these factors is considered useful largely as a screening test for contamination.

The values given for radiochemical data in the table of analyses are the "background count", or measure, of the naturally occurring and artifically induced (if any) radioactivity of the ground water in the Gnome area.

The radioactivity of water is reported by the Geological Survey in picocuries per liter (pc/l) (a picocurie is the equivalent of a micromicrocurie) of alpha and beta-gamma activity and of radium. Uranium is reported in micrograms per liter (ug/l). These terms are expressions of an equivalent quantity of radium or of the rate of radioactive disintegration (curies). One curie is defined as 3.7×10^{10} disintegrations per second, which is the approximate specific activity of a gram of radium in equilibrium with its disintegration products.

The radioactivity of water samples collected from wells in the Gnome area is given in table 3. None of the samples analyzed contained concentrations of radioactive elements large enough to cause harmful effects to animals or humans.

For a complete discussion of maximum permissible concentrations of radioactive elements in water the reader is referred to National Bureau of Standards Handbook 69, which may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, D. C.

Possibilities for water-supply development

At the time of this report no supply well, at or near the Project Gnome site, was available for the use of construction contractors or others working at the site. Potable water for drinking and other uses was transported by individuals to the site from Carlsbad, Loving, or other distant sources. Water used for construction purposes was hauled to the site by tank trucks from nearby salt lakes, or if water of better quality was needed, from sources at Loving or Carlsbad.

Water suitable for drinking by humans is not available from wells drilled at the Gnome site. The water in the Culebra Dolomite Member contains excessive amounts of sulfate and chloride and is quite objectionable to the taste. It could be tolerated, perhaps occasionally, in small amounts but drinking of large quantities or continued intake of the water would certainly cause laxative effects in most persons. The water is suitable for sanitary purposes and construction use.

If it should become necessary, or desirable, in the future to equip the Gnome site with a water supply, or water-distribution system, three possible sources of ground water should be considered:

1) Water from rocks of Tertiary or Quaternary age. Wells directly south of the Gnome site, and within a 15-mile radius, yield water of acceptable mineral quality for human consumption. Existing wells in this locality range in depth from about 300 to about 800 feet. Yields of 100 to 150 gpm were obtained from the deeper wells. The water is present in relatively thin beds of sand which are interbedded with thicker layers of silt and shale. This

sequence of rocks is present in the area only in the south-central portion where it fills a deep solution basin developed in the underlying evaporite-type rocks. The approximate area underlain by these rocks is shown on figure 9. These rocks are known to extend to within about 6 miles of the Gnome site and they may approach more closely. A suitable supply well probably could be developed in this area.

Test wells would be needed to determine the presence and adequacy of water-bearing formations and to locate a site for a permanent well that would be within a reasonable distance of the Gnome site. The most favorable physical conditions for a well site is a few miles south and southeast of the Gnome site. Moreover, if water contamination problems do arise from experiments at the Gnome site, the water at this locality should not be affected. Water that passes the Gnome site moves west and southwest from the site and probably does not pass through rocks of Tertiary or Quaternary age which are deposited in this deep basin.

2) Water from the Gatuna Formation. Water of less than 700 ppm total dissolved solids is present in this formation about 3 miles southwest of the site and about 4½ miles southeast of the site. Wells at these locations yield only a few gpm from the aquifer. Greater thicknesses of the aquifer, however, may be present in the general area from which larger yields could be obtained. The formation underlies most of the surface south of the Gnome site. In most places it does not contain water. It is probable, however, that at certain localities, particularly in topographically low areas, water is present in the formation, possibly at depths no greater than about 200 feet. Again, test holes would be needed to locate a suitable water supply from this formation. The most promising area to explore is 2 or 3 miles south of Gnome site and between the two wells known to be obtaining water from the formation. Water in this aquifer is not connected with water present at the Gnome site, thus, possible contamination problems from Gnome experiments are minimized.

3) Water from the Culebra Dolomite Member. If it is not necessary to supply potable water to the Gnome site, a sufficient supply for construction and sanitary needs could be obtained from this aquifer. Yields of 50 gpm or more could be expected from a well drilled to a depth of 550 to 600 feet near the site of Project Gnome. A well located north or northeast of the site would be least subject to possible contamination from Gnome experiments.

Consideration of effects of proposed shot on ground water

Inasmuch as the water-bearing formations of the area are several hundred feet above the planned detonation point of the proposed shot it is unlikely that structural damage to the aquifers or the introduction of radioactive contaminants into them will occur, if the forces released by the shot are contained, as planned, within the massive salt.

Consideration must be given to possible effects upon the rocks, the aquifer systems of the area, and the quality of water in the aquifers if the forces released by the explosion are of such magnitude as to create fissures in the salt and overlying rocks and cause rupture of the aquifer in the Culebra Dolomite Member.

The rocks between the Culebra and the top of the salt are composed primarily of fine-grained silty sandstone, siltstone, and claystone with thin layers of gypsum and anhydrite. Near the base of the dolomite and near the top of the salt layers of gypsum and anhydrite, rock several feet thick is present. Much of the siltstone and claystone is semi-plastic to plastic. These rocks are nearly impermeable as shown by the absence of water in them at the shaft site and the extremely low transmissibility determined in them in USGS test hole 2. if small fractures did develop in these rocks they probably would seal themselves, particularly if wet from leakage from the aquifer in the Culebra. If large fractures occurred they would seal more slowly, if at all. Fractures in the salt would seal due to the plastic flow of the salt.

Water in the aquifer in the Culebra would drain into fractures below the dolomite, and, if fractures extended above the aquifer, would rise in them about 75 feet. As no other aquifer now exists at the site, and the rocks both above and below the dolomite are nearly impermeable, little or no movement of water would occur in the fractures. Some salt would be dissolved away until the water became a saturated brine in the zone of salt. The fractures would fill with water which, in the absence of permeable rocks, would remain static with but minor seepage through the walls of the fractures into the rocks. The head of water in the aquifer in the Culebra would return to normal or nearly so. Water in the aquifer would be subject to contamination by fission products.

If fracturing is severe and extensive at the top of the salt and in the anhydrite and gypsum rock layer directly overlying the salt, particularly in a southwestward direction from the site, connection may be made with the brine aquifer. Water in the Culebra Dolomite Member would drain down fractures to the top of the salt and then move through interconnected fractures towards the brine aquifer. With circulation of water thus established the fractures in the rocks above the salt would tend to be kept open by flushing action and movement of fresh water along the salt would continue to dissolve more and more salt thus creating a larger area of the brine aquifer system. Probably the drainage through fractures and into the brine aquifer, at least at the beginning, would represent only a part of the water moving into the fractured zone of the Culebra, thus some water will continue to move in the dolomite past the fracture zone. Probably the head of the water in the aquifer in the Culebra will be lowered and remain so. Both the aquifer in the Culebra and the brine aquifer would be subject to contamination by fission products.

If either of these situations occur, or are suspected, following the shot, determination of fracture extent would be necessary before corrective measures could be undertaken. Many core holes to obtain rock samples, and test holes to obtain water samples, would be needed.

Possibilities for controlling spread of contamination and loss of water from the aquifer in the Culebra would include: 1) Discharge wells to remove contaminated water and to create a cone of depression in the piezometric surface of water in the aquifer. The number of discharge wells needed and determination of pumping rates would be dependent upon the extent of the fracture zone. The pumped water would be monitored and uncontaminated water could be discharged on the surface. Contaminated water would need to be disposed of in such a manner that it could never reach potable water supplies. Possibly a feasible method of disposal of contaminated water would be through a deep disposal well. Sandstones of the Delaware Group, which underlie the Gnome site at depths of from about 3,900 to 7,500 feet and contain highly saline water, offer possibilities for disposal of contaminated water. 2) Grouting with cement or other material in the fracture zone.

The recorder-equipped monitoring wells near the site will provide records of water-level changes that may occur in the aquifer in the Culebra Dolomite Member. No provision has been made to monitor changes that may occur in the brine aquifer system. An observation well finished in the brine aquifer similar to the existing wells, near the edge of the brine aquifer west of the test site would provide information on changes in the brine aquifer system.

Summary of conclusions

Within a 15-mile radius of the site of the proposed nuclear shot ground water is obtained from wells finished in rocks of several different ages. In addition, an aquifer is present in Nash Draw from which no water is utilized for beneficial purposes but which has an economic importance to users of Pecos River water, for irrigation, downstream from the Gnome site. All of these aquifers lie above the top of the massive salt of the Salado Formation, the formation in which it is planned to detonate the shot. No water is known to exist within the salt and no fresh water is known in the underlying rocks.

Ground water that reaches the Gnome site from recharge areas to the northeast moves generally southwestward and ultimately discharges into the river.

It has been established that the only aquifer at the Gnome site is the Culebra Dolomite Member of the Rustler Formation. This aquifer lies nearly 200 feet above the top of the massive salt and above 500 feet beneath the land surface.

Most of the ground water in the area is highly mineralized and unsuitable for human consumption; however, because it is widely utilized for stock water it is a valuable resource. Radiochemical analyses of water samples from all used wells within a 5-mile radius of the site have been obtained. A physical examination of all wells within a 15-mile radius of the site, on the east side of the Pecos River, has been made. Observations of the water level in the Culebra Dolomite Member at, and in, the vicinity of the Gnome site are being made and will continue to be made following the proposed shot.

The depth of burial of the proposed shot, the rock type enclosing it, and the vertical distance from the shot point to the overlying water-bearing formation all tend to minimize effects upon the aquifer from the atomic explosion. However, it is beyond the scope of this report to state definitely that the aquifer will remain undisturbed or that physical or chemical deterioration will not take place in it because of the shot.

If changes of any kind are observed in the aquifer system from observations in the monitoring wells or from other evidence the kind and extent of the changed conditions must be determined as soon and as accurately as possible.

Dependent upon determination of changed conditions in the aquifer system, and considerations of the effects of these changes upon the ground-water regime of the area and its relation to the public welfare, plans could be formulated for any corrective measures deemed necessary.

If desired to dispose of water in the aquifer which passes the shot point, deep disposal wells seem feasible. Structural damage to the aquifer possibly could be corrective or minimized by grouting open fractures with cement or other suitable materials.

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Table 2.--Records of wells in the Project Gnome area, Eddy and Lea Counties, N. Mex.

Location number: See text for explanation of well-numbering system.
Owner or name: The owner of, or name used for, well at time of visit.
Altitude: Altitudes of land surface at the wells have been extrapolated from topographic maps except for wells 23.30.34.324 and 24.30.4.333 which were obtained by spirit level.
Depth of wells and water levels: Reported depths are given to the nearest foot; measured depths are given to the nearest 0.1 foot. P, pumping level.
Diameter: The diameter of the casing, if cased, or the mean diameter of the hole, if uncased.
Measuring point: Epb, edge of pump base; Ls, land surface; Tal, top of air-line flange; Tap, top of access pipe; Tc, top of casing; Tcb, top of concrete block; Tcm, top of metal cover; Tpc, top of pipe clamp; Tpp, top of pump pipe; Twc, top of wood cover.
Geologic source: Prl, lower member of the Rustler; Prc, Culebra Dolomite Member of the Rustler; Prm, Magenta Member of the Rustler; Tr, rocks of Triassic Age; QTu, undifferentiated rocks of probable Quaternary and Tertiary Age; Qg, Gatuna Formation; Qal, Quaternary alluvium.
Type of pump, power, and use: Pump designations: T, turbine; L, cylinder; N, none. Power designations: W, windmills; Ic, internal combustion; N, none. Use designations: S, stock; D, domestic; I, irrigation; In, industrial; O, observation; N, none.
Remarks: Name enclosed in quotation marks is local name of well. CA, chemical analysis available; L, electric logs available; R, reported.

Location No.	Owner or name	Altitude above sea level (feet)	Depth (feet)	Diameter (inches)	Water level: Depth below land-surface datum (feet)	Water level: Date of measurement	Measuring point: Description	Measuring point: Distance above land surface datum (feet)	Geologic source	Type of pump, power, and use	Remarks
21.29.25.441	A. V. Pugh	3,320	210	10	180	4-15-59	-	-	Prc or Prm	L,W,D,S	Two wells at this location. Surface casing only, R.
25.441a	do.	3,320	210	10	175	do.	-	-	Prc or Prm	L,Ic,D,S	Well cased to total depth, R.
21.30.18.333	Wayne Cowden	3,220	175.3	6	124.3	do.	Tc	0.5	Prc or Prm	L,W,S	Well not used recently.
22.423	do.	3,180	219.4	6	104.6	do.	Tc	.6	Prc	L,W,S	Well not used recently. Water salty, R.
21.31.18.322	Cowden and Smith	3,310	-	6	P158.8	do.	Tc	1.0	Tr	L,W,S	-
22.28.15.334a	L. J. Culley	3,095	85.6	6	75.4	4-17-59	Tc	.9	Qal	L,W,D,S	Five wells at this location, 2 dry, 3 used. Water gypy, R.
15.334b	do.	3,095	86.2	6	76.0	do.	Tc	1.0	Qal	L,Ic,D,S	Surface casing only, R. Water gypy, R.
15.334c	do.	3,095	88.1	6	86.5	do.	Tc	.6	Qal	L,W,S	Well not in use.
22.29.11.144	Mark Smith and Sons	3,091	170.9	10	149.2	4-14-59	Tc	.1	Prc	L,W,S	Do.
33.241	Mrs. Dublin	3,020	69.9	6	55.0	do.	Tpc	.6	Prm(?)	L,W,S	Two wells at this location

Table 2.--Records of wells in the Project Gnome area, Eddy and Lea Counties, N. Mex. - Continued

Location No.	Owner or name	Altitude above sea level (feet)	Depth (feet)	Diameter (inches)	Water level: Depth below land-surface datum (feet)	Water level: Date of measurement	Measuring point: Description	Measuring point: Distance above land surface datum (feet)	Geologic source	Type of pump, power, and use	Remarks
22.29.33.241a	Mrs. Dublin	3,020	56.5	6	53.0	4-14-59	Tc	0.1	Prm(?)	L,W,S	Well not in use.
22.30. 5.431	International Minerals and Chemical Corp.	3,120	-	14	66.4	do.	Tc	2.3	Prc	N,N,N	Unused supply well for potash refinery.
5.443	do.	3,100	-	14	57.1	do.	Tc	1.0	Prc	N,N,N	Do.
8.241	do.	3,155	180.3	24	104.8	do.	Twc	.2	Prc	N,N,N	Do.
10.311	Mark Smith and Sons	3,135	66.7	6	60.7	2-19-59	Tc	1.3	Qg(?)	L,W,D,S	"Ranch Headquarters well."
20.120	do.	3,070	128.7	5	73.0	do.	Tc	3.3	Prc	N,N,N	Salty water, R.
32.111	do.	3,010	107.0	6	45.2	do.	Tc	1.0	Prc	L,W,S	CA.
22.31.15.130	do.	3,460	-	6	P158.2	do.	Tpc	2.8	Tr	L,W,S	Two wells at this location.
15,130a	do.	3,460	167.3	12	150.9	do.	Tc	2.7	Tr	N,N,N	-
23.28.14.241	D. C. Harroun	2,980	124.3	16	16.2	2- 6-59	Tc	.2	Qal	T,Ic,I	Well cased to total depth, R.
14.241a	do.	2,980	114.4	16	14.8	do.	Tal	1.1	Qal	T,Ic,I	Do.
14.243	do.	2,980	145.7	16	14.7	do.	Epb	1.8	Qal	T,Ic,I	Do.
23.30. 2.444	C. H. and W. O. James	3,250	317.6	6	260.8	4- 3-59	Tc	1.0	Prc	N,N,N	Well filled. Replaced by well 444a at same location. L. CA.
2.444a	do.	3,250	318.4	7	260.5	4-20-59	Tc	1.0	Prc	L,W,S	"Little Windmill well." Well cased to 314 feet. Drilled in 1959.
6.424	James and Briones	2,980	30.0	6	6.5	8-19-58	Tc	.0	Qal	L,W,S	"Nash Well."
19.123	do.	3,045	89.0	7	70.4	4- 7-59	Tc	1.3	Prc	L,W,S	"South Well." Surface casing only. L. CA.
21.122	C. H. and W. O. James	3,165	203.6	5	179.2	4- 6-59	Tc	1.3	Prc	L,W,S	"Indian Well." Cased to 160 feet. L. CA.
34.324	Atomic Energy Commission	3,426	567.0	20 to 12	442.3	9-22-60	Tc	2.8	Prc	N,N,O	USGS test hole 1. Drilled to 723 feet. L. CA.
23.31. 6.320	C. H. and W. O. James	3,300	212.9	12	144.7	2- 4-59	Tc	1.0	Tr	L,W,S,D	Surface casing only, R. Poor quality water, R.

Table 2.--Records of wells in the Project Gnome area, Eddy and Lea Counties, N. Mex. - Continued

Location No.	Owner or name	Altitude above sea level (feet)	Depth (feet)	Diameter (inches)	Water level: Depth below land-surface datum (feet)	Water level: Date of measurement	Measuring point: Description	Measuring point: Distance above land surface datum (feet)	Geologic source	Type of pump, power, and use	Remarks
23.31. 6.444	C. H. and W. O. James	3,310	166.4	6	105.6	2- 4-59	Tc	1.8	Tr	L,W,S,D	"Ranch Headquarters well." Poor quality water, R.
7.222	do.	3,300	122.4	10	94.4	do.	Tc	1.1	Tr	L,Ic,S	Well not used recently.
7.222a	do.	3,300	94.5	5	-	do.	Tc	.2	Tr	N,N,N	Well dry.
7.240	do.	3,315	138.2	4	94.7	4- 2-59	Tpp	2.8	Tr	L,W,S	"Conoco well." L. CA.
17.310	do.	3,305	354.0	10	109.4	3-27-59	Tcb	.9	Tr	L,W,S	"Unger well." Well uncased. L. CA.
26.340	C. H., W. O., and F. James	3,480	361.3	6	P256.9	2- 4-59	Tpc	1.2	Tr	L,W,S	"Fairview well." Well uncased, R. CA.
29.113	C. H. and W. O. James	3,335	223.9	4	138.4	3-26-59	Tc	.7	Tr	L,W,S	"Walker well." Surface casing only. L. CA.
23.32. 4.222	do.	3,630	550	8	-	-	-	-	Tr	L,W,S	"Clifton well." Surface casing only, R.
21.222	C. H., W. O., and F. James	3,700	550	8	500	-	-	-	Tr	L,Ic,S	"Swag well." Two wells at this location. Surface casing only, R.
21.222a	do.	3,700	550	6	510	-	-	-	Tr	L,W,S	Well cased to total depth, R.
24.30. 4.333	Atomic Energy Commission	3,403	608.0	20 to 8	397.1	9-22-60	Tc	2.5	Prl	N,N,O	USGS test hole 2. L. CA.
8.113	Bill Eaton	3,280	191.9	6	176.0	3-23-59	Tc	.0	Qg	L,W,S,D	"Ranch Headquarters well." Well cased to 190 feet. L. CA.
12.430	W. M. Snyder	3,510	500	6	367.1	6-14-61	Tc	.6	Tr	L,Ic,S	"Poker well."
18.231	Bill Eaton	3,200	451.6	6	227.8	3-19-59	Tc	.4	Prc or Prl	L,W,S	"Two mile mill." Well cased to 229 feet. L. CA.
23.312	W. M. Snyder	3,425	428.1	6	423.1	3-26-59	Tc	.7	Tr	L,W,S	"New well." Well cased to total depth, R. Well reported to be 474 feet deep. L.
36.333	do.	3,450	476.8	6	445.3	3-19-59	Tc	1.2	QTu	L,W,S	"Windy well." Well cased to 412 feet. L. CA.
24.31. 4.430	do.	3,420	626.5	5	423.6	3-13-59	Tcb	.9	Prc	L,W,S	"Ingle well." Well not cased. L. CA.
17.111	do.	3,510	85.0	7	68.4	3-25-59	Tc	1.2	Qg	L,W,S,D	"Ranch Headquarters well." Well cased to total depth, R. L. CA.

Table 2.--Records of wells in the Project Gnome area, Eddy and Lea Counties, N. Mex.,- Continued

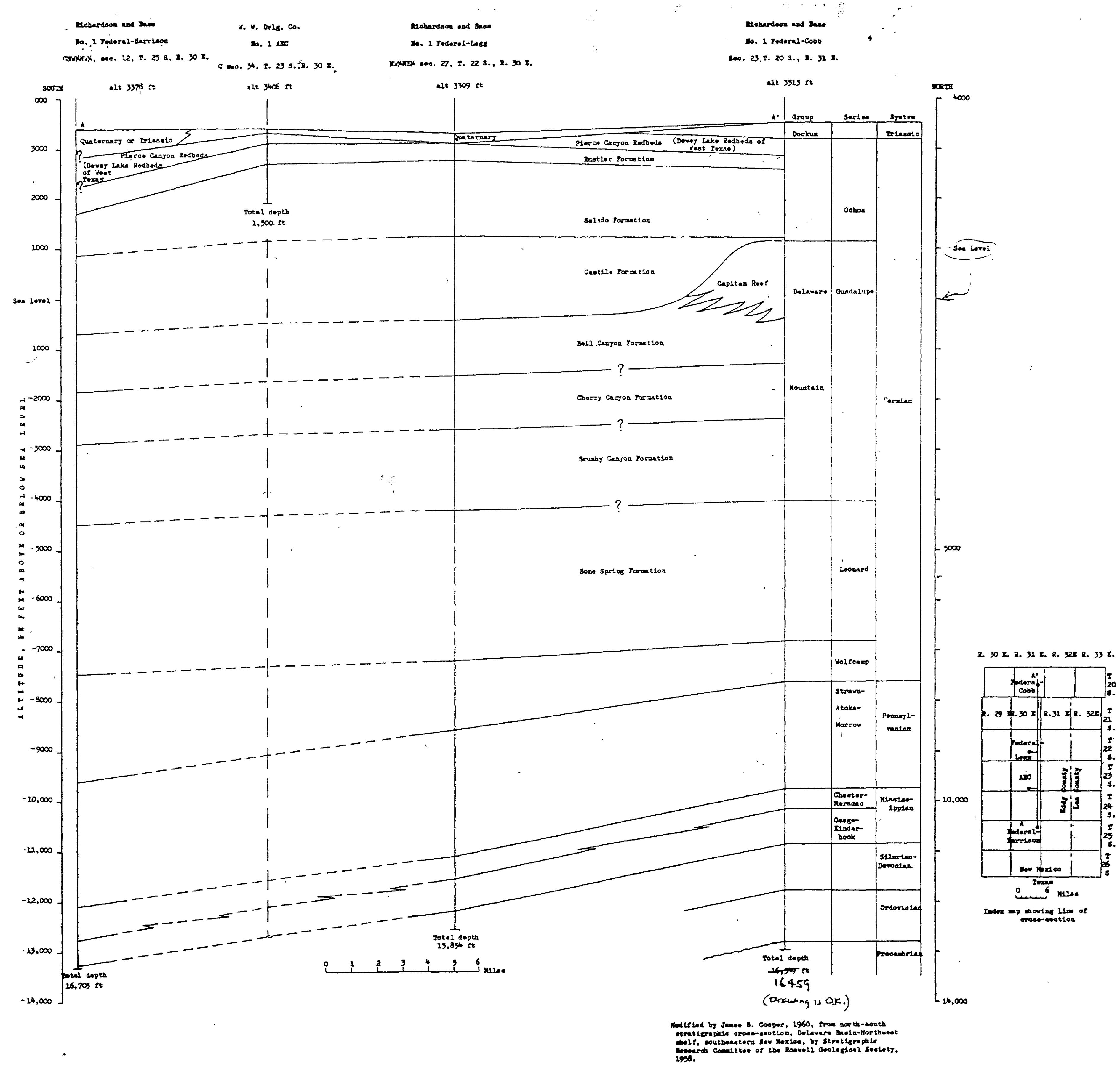
Location No.	Owner or name	Altitude above sea level (feet)	Depth (feet)	Diameter (inches)	Water level: Depth below land-surface datum (feet)	Water level: Date of measurement	Measuring point: Description	Measuring point: Distance above land surface datum (feet)	Geologic source	Type of pump, power, and use	Remarks
24.31.33.124	W. M. Snyder	3,460	698.0	5	474.2	3-12-59	Tc	1.0	Prc	L,W,S	"Keyhole well." Well cased to total depth, R. L. CA.
24.32. 3.322	Frank James	3,650	550	10	-	-	-	-	Tr	L,W,S	"New well." Two wells at this location. Surface casing only, R.
3.322a	do.	3,650	500	8	-	4-13-59	-	-	Tr	N,N,N	Well dry and caved in. Surface casing only, R.
10.344	do.	3,588	60	6	33.6	do.	Tc	1.0	Qal	L,W,S,D	"Ranch Headquarters well." Surface casing only, R.
33.422	Richard Ritz	3,510	366.4	12	313.4	2-18-59	Tc	.6	Tr	L,W,S	"Burro well."
25.29. 2.111	-	3,000	140.0	8	100.6	10-23-58	Ls	.0	Prc(?)	N,N,N	Potash test hole. Drilled to 857 feet.
16.444	J. G. Ross	3,025	200(?)	6	170.1	8-19-58	Tc	1.2	Prc	L,W,S	"Pickett well." Well cased to total depth, R. CA.
32.211	do.	2,985	110.6	8	98.7	3-24-59	Tc	.9	Prc	N,N,N	Surface casing only. Potash test hole. L. CA.
25.30. 7.111	W. M. Snyder	3,170	385.6	7	263.3	3- 7-59	Tc	.0	QTu	L,W,S	"Carper well." Well cased to 250 feet. Oil test hole converted to water well. L. CA.
7.330	Ralph Lowe	3,180	295.0	7	-	6-14-51	-	-	QTu	N,N,N	Drilled to supply water for oil tests.
8.224	W. M. Snyder	3,220	343.5	7	309.7	8-19-58	Tc	.0	QTu	N,N,N	Three wells at this location.
8.224a	do.	3,220	-	-	-	-	-	-	QTu	N,N,N	Hole crooked, R.
8.224b	do.	3,220		7	P332.55	6-14-61	Tc	1.0	QTu	L,W,S	"Tomcat well."
12.113	-	3,375	460.3	5	391.3	3-25-59	Tc	.7	QTu	N,N,N	Drilled to supply water for oil test. L.
21.333	J. G. Ross	3,200	298.1	6	P266.1	2- 5-59	Tc	1.0	QTu	L,W,S,D	Well cased to total depth, R. CA.
25.31.21.400	Mrs. E. R. Johnson and others	3,340	400	7	P318.0	2-17-59	Tc	.4	QTu	L,W,S,D	Do.
25.33.20.443	-	3,395	200-250	6	-	-	-	-	Tr	L,W,S	-
26.29.22.340	J. G. Ross	2,875	200.0(?)	6	68.7	8-19-58	Tc	2.0	Prc	L,W,S	Well not used recently.
26.30. 5.334	El Paso Natural Gas Co.	3,090	770	11	169.9	2-18-59	Epb	1.9	QTu	T,Ic,In, D	Water well No. 1 Pecos Turbine station. Cased to total depth.

Table 2.--Records of wells in the Project Gnome area, Eddy and Lea Counties, N. Mex. - Continued

Location No.	Owner or name	Altitude above sea level (feet)	Depth (feet)	Diameter (inches)	Water level: Depth below land-surface datum (feet)	Water level: Date of measurement	Measuring point: Description	Measuring point: Distance above land surface datum (feet)	Geologic source	Type of pump, power, and use	Remarks
26.30. 5.343	El Paso Natural Gas Co.	3,100	775	11 to 9	182.6	8-18-58	Tap	3.3	QTu	T,Ic,In, D	Water well No. 2, Pecos Turbine station. Cased to total depth. CA.
8.111	Mrs. E. R. Johnson and others	3,085	400	7	163.8	2-18-59	Tcm	.3	QTu	L,W,S	"West well."
26.31. 8.310	Ross Estate	3,230	309.6	6	P287.1	do.	Tc	1.4	QTu	L,W,S,D	"Ranch Headquarters well." Two wells at this location.
8.310a	do.	3,230	324.5	6	275.8	8-18-58	Tc	1.5	QTu	N,N,N	Well has never been placed in service.

Table 3.--Radiochemical analyses of well water in the Project Gnome area - Continued

Location No.	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved solids	Total	Noncarbonate	Specific conductance (μ mhos at 25°C)	pH	Alpha activity (pc/ℓ) as of:	Beta activity (pc/ℓ) as of:	Uranium (U) (ug/ℓ)	Radium (Ra) (pc/ℓ)	Extractable alpha (net) (pc/ℓ)	Strontium 90 (pc/ℓ)
22.30.32.111	2,080	152	1.6	12	0	3,260	2,280	2,160	3,570	7.6	21 ± 18 6-8-59	72 ± 13 7-7-59	18±1.8	0.3±0.1	< 4	< 5
23.30.2.444	2,110	550	1.5	0	0	4,000	2,000	1,900	4,980	7.5	71 ± 44 6-8-59	200 ± 30 7-6-59	38 ± 4	13 ± 3	17 ± 6	< 5
19.123	1,690	22	1	12	0	2,590	1,900	1,740	2,760	7.5	< 21 6-5-59	72 ± 11	9.5 ± .9	6 ± .1	< 2	< 5
21.122	2,070	580	1.5	12	.1	4,030	2,240	2,090	4,930	7.4	< 35 6-9-59	120 ± 1.6	16 ±1.6	.5 ± .1	10 ± 4	< 5
34.324	1,960	770	.3	7.8	0	4,110	2,120	2,020	5,200	7.6	68 ± 41 12-2-60	54 ± 8 11-15-60	7.1 ± .7	8.9±1.8	9.5±4.6	< .6
23.31.7.240	539	89	1.7	49	0	1,220	619	412	1,740	7.5	11 ± 8 6-9-59	12 ± 7 6-23-59	6.3 ± .6	.2±.1	4.3±1.8	-
17.310	1,720	270	1.6	12	0	2,980	2,100	1,980	3,490	7.4	62 ± 57 6-8-59	100 ± 15 7-7-59	8.6 ± .9	.1±.1	3 ± 2	< 4
26.340	2,080	128	1.6	1.5	0	3,200	2,020	1,920	3,540	7.4	100 ± 56 5-26-59	210 ± 32 7-7-59	16 ±1.6	.8±.2	< 3	< 5
29.113	-	-	-	-	-	-	-	-	-	-	23 ± 19 3-10-59	25 ± 4 4-22-59	9 ± .9	< .1	2.5±1.5	< 5
29.113	1,750	330	1.5	4.1	0	3,080	2,160	2,050	3,670	7.4	< 25 6-9-59	27 ± 13 6-23-59	9.9 ± 1	.4±.1	< 2	< 5
24.30.4.333	3,050	10,600	1.0	0	0	21,900	4,720	4,510	34,800	7.3	350 ± 110 12-2-60	620 ± 90 11-15-60	3.8 ± .4	20 ± 4	6 ± 2.5	< 6
8.113	-	-	-	-	-	-	-	-	-	-	3.0 ± 2.0 3-9-59	3.1 ± 1.7 4-22-59	2.8 ± .3	.1 ± .1	< .8	< 5
8.113	23	18	.8	3.5	.14	268	193	39	422	7.6	6.0 ± 3.4 6-8-59	18 ± 3 7-6-59	1.7 ± .2	.2 ± .1	.5 ± .6	< 5
18.231	2,270	2,230	1.4	0	0	6,960	2,380	2,330	10,100	7.4	< 36 5-26-59	320 ± 60 7-6-59	2.8 ± .3	.9 ± .2	4.2 ± 1.6	< 5
36.333	167	74	1.2	4.1	0	501	324	198	847	7.3	3.9 ± 3.4 6-9-59	30 ± 4 7-6-59	5.2 ± .5	.2 ± .1	3.8 ± 1.4	< 5
24.31.4.430	2,030	375	1.5	5.0	0	3,540	2,140	2,060	4,240	7.5	67 ± 61 6-8-59	250 ± 40 7-6-59	9.2 ± .9	4.7±.1	< 2	< 5
17.111	32	59	.3	55	0	625	466	105	1,080	7.0	< 7.4 6-9-59	36 ± 5 7-16-59	4.1 ± .4	1.8±.4	1.2 ± .8	< 5
33.124	2,130	850	1.5	0	0	4,400	2,580	2,520	5,610	7.3	110 ± 63 6-9-59	81 ± 26 6-16-59	32 ± 3	9.8 ± 1	57 ± 15	< 5
25.29.16.444	546	440	1.1	0	0	1,580	1,050	936	2,390	7.5	16 ± 12 6-5-59	98 ± 15 7-7-59	6.6 ± .7	.1 ± .1	< 2	< 4
32.211	1,210	5,510	1.6	0	0	11,000	2,920	2,740	17,600	6.8	< 52 5-26-59	670 ± 100 7-6-59	3.1 ± .3	.7 ± .2	2 ± 1.3	< 5
25.30.7.111	188	72	1.8	0	0	491	176	76	843	8.0	4.5 ± 2.5 8-4-59	10 ± 2 6-23-59	1 ± .1	2.8±.6	8.4 ± 1.4	< 5
21.333	347	370	1.1	5	0	1,230	492	370	2,020	7.6	43 ± 37 6-5-59	74 ± 11 7-7-59	6.2 ± .6	.2 ± .1	1.9 ± 1.5	< 4
25.31.21.400	794	92	1.4	5.1	0	1,400	761	654	1,900	7.5	< 12 6-8-59	48 ± 7.2 7-6-59	9.6 ± .9	.2 ± .1	4 ± 3	< 6
26.30.5.343	285	340	1.6	0	0	1,100	391	254	1,900	7.8	28 ± 15 6-8-59	68 ± 10 7-7-59	1.1 ± .1	.4 ± .1	< .2	< 4



Modified by James B. Cooper, 1960, from north-south stratigraphic cross-section, Delaware Basin-Northwest shelf, southeastern New Mexico, by Stratigraphic Research Committee of the Roswell Geological Society, 1958.

Figure 4.—Generalized geologic cross-section from north to south through a part of the Delaware Basin near the site of Project Gnome, Eddy County, N. Mex.

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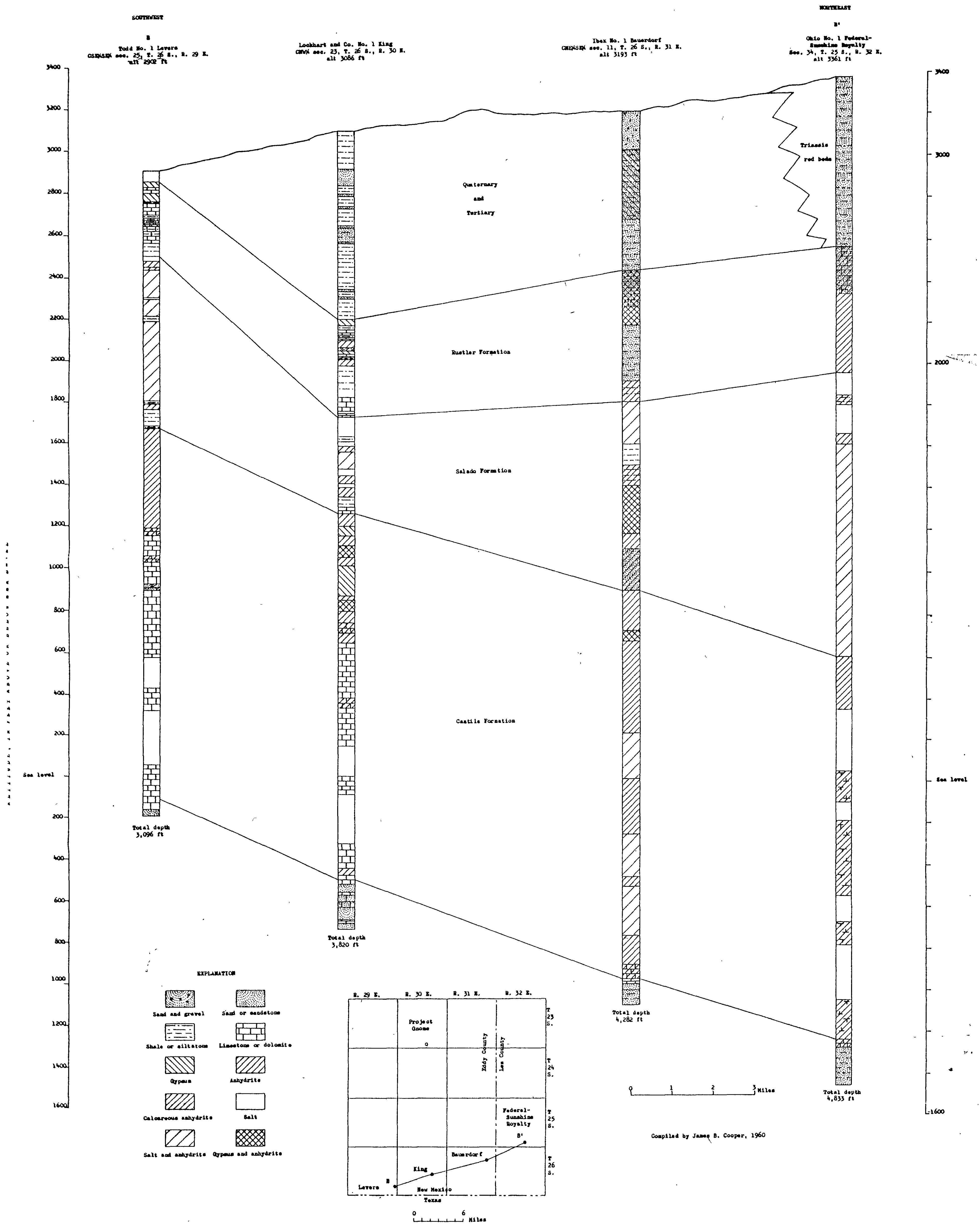


Figure 6.--Diagram showing structure of upper Permian rocks in the south-central part of the Project Gnome area, Eddy and Lea Counties, N. Mex.

62-29

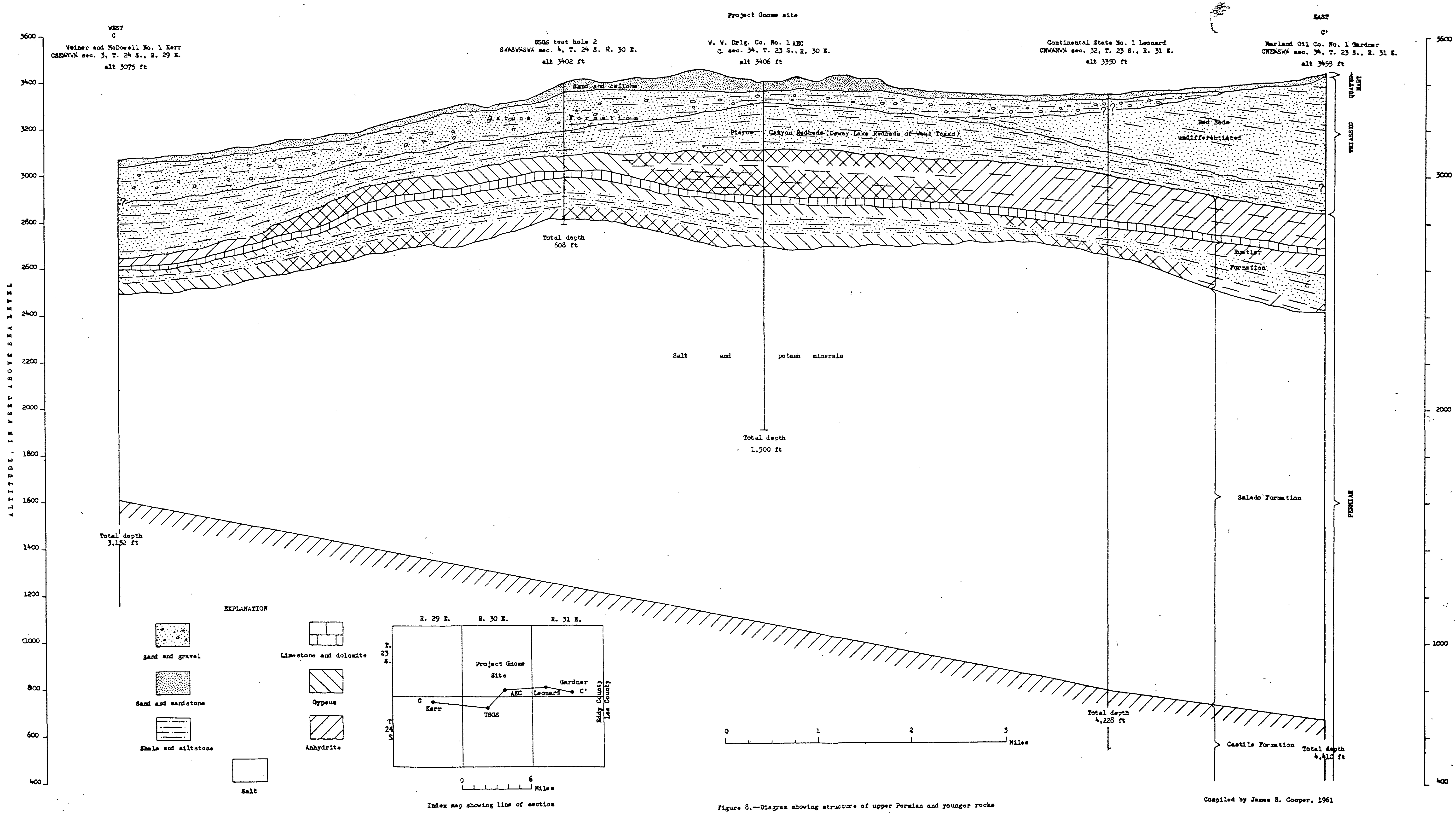


Figure 8.--Diagram showing structure of upper Permian and younger rocks at the Project Gnome site, Eddy County, N.Mex.

Compiled by James B. Cooper, 1961

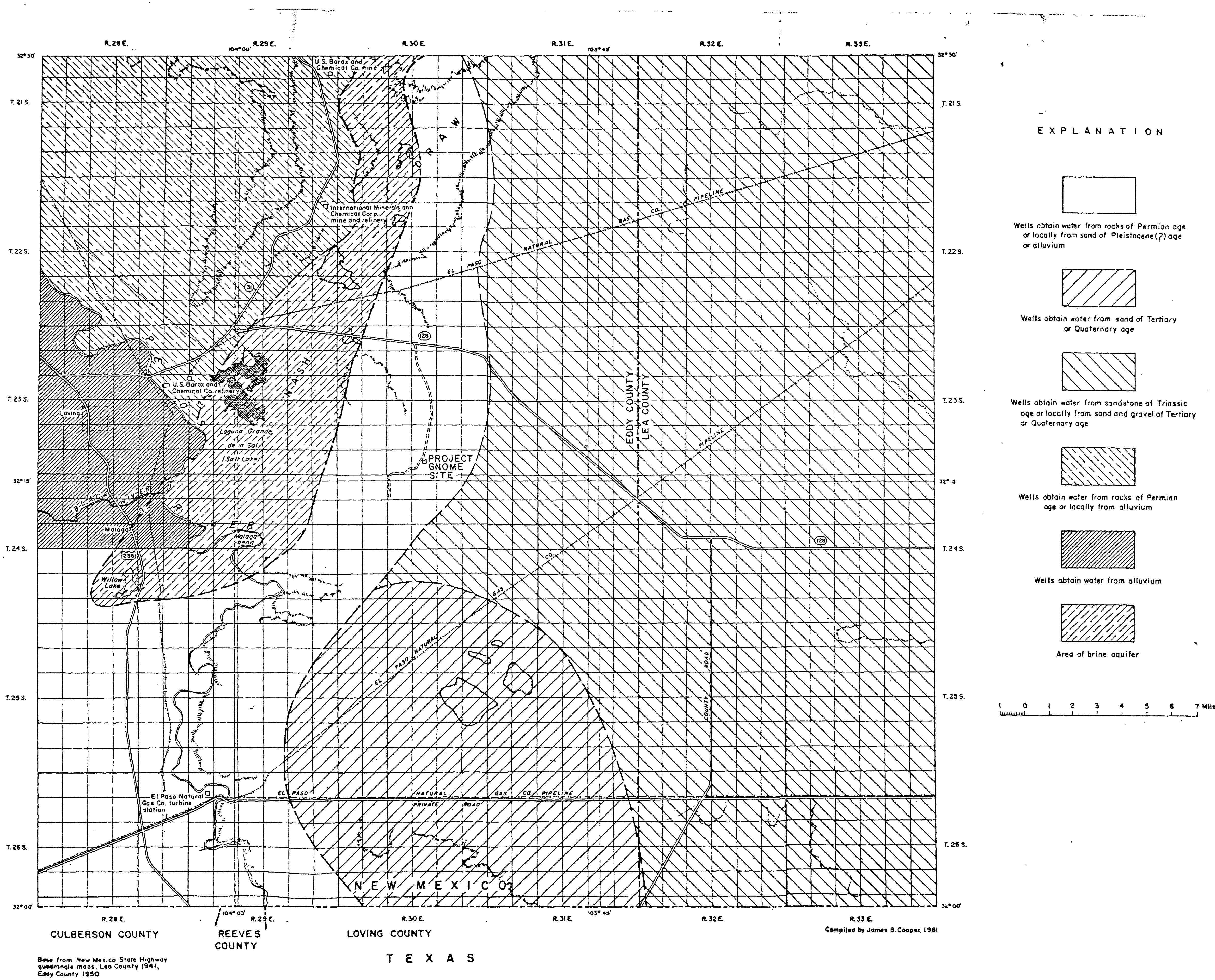
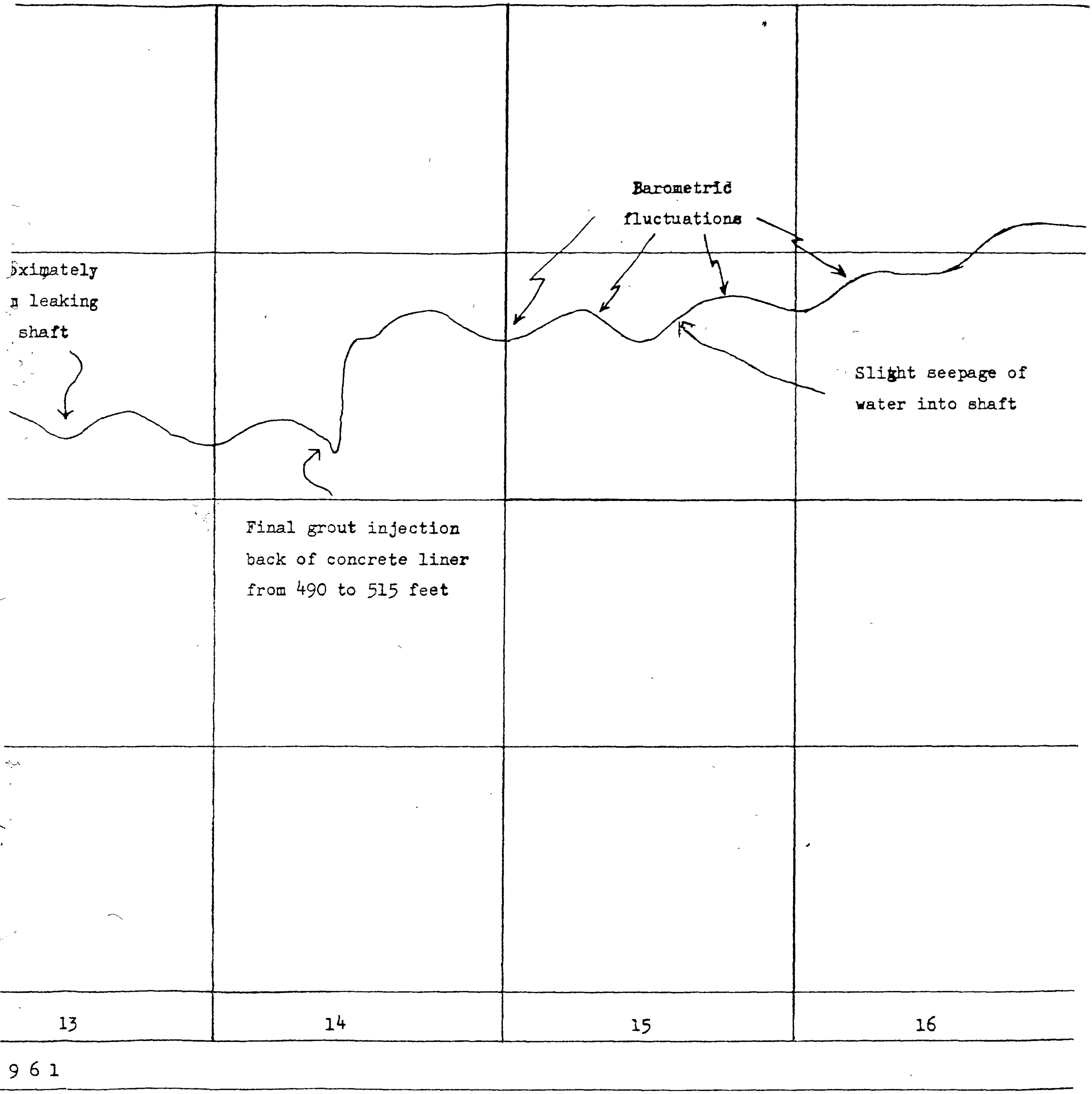


Figure 9.-- Map showing general distribution of water-bearing rocks in the Project Gnome area, Eddy and Lea Counties, N. Mex.

62-29


ximately
leaking
shaft
Barometric
fluctuations
Slight seepage of
water into shaft
Final grout injection
back of concrete liner
from 490 to 515 feet
13
14
15
16
9 6 1

aft.

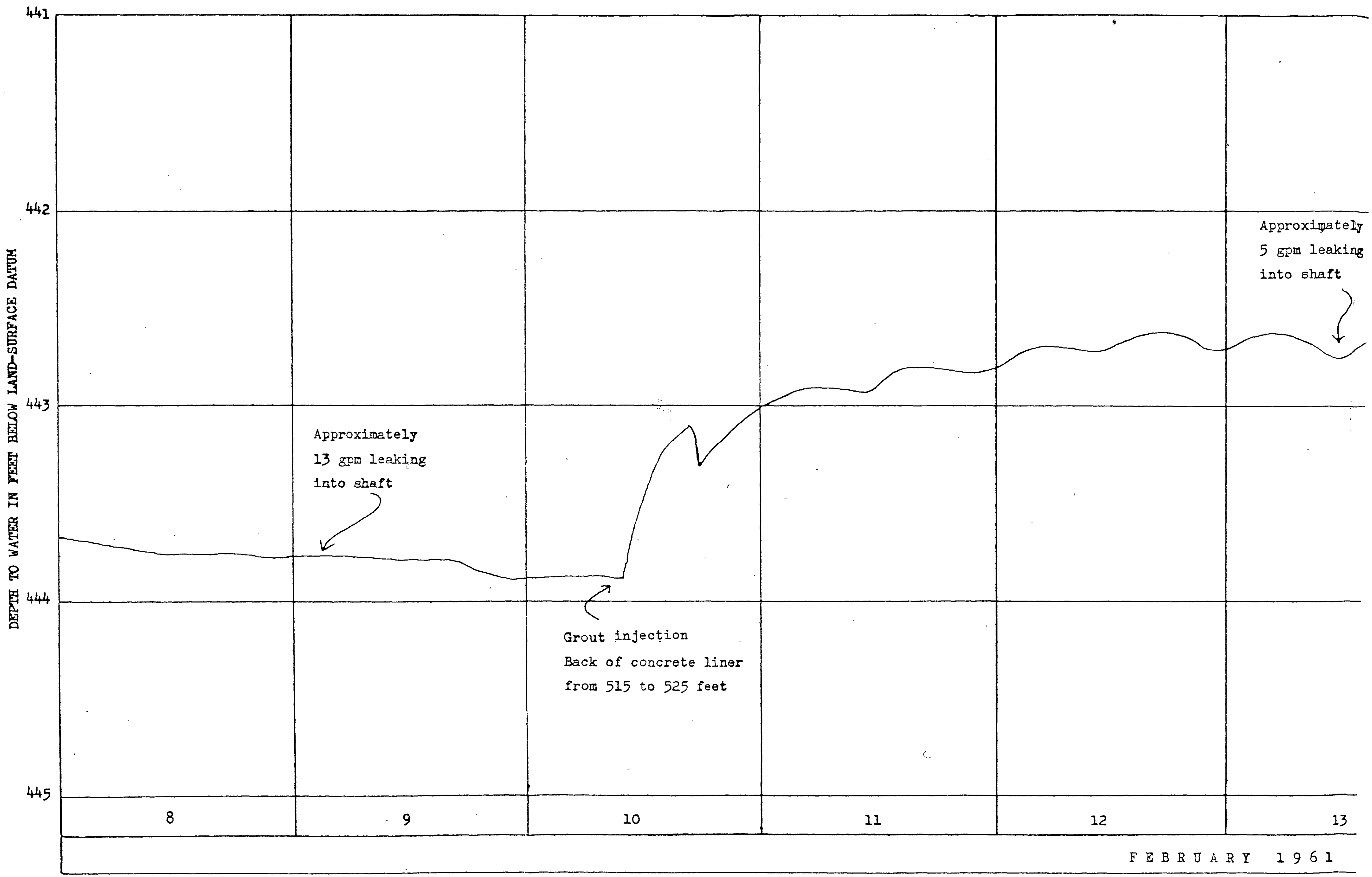


Figure 10A.--Hydrograph showing fluctuation of water level in USGS test hole 1 during final phase of the water-sealing program in the Project Gnome shaft.

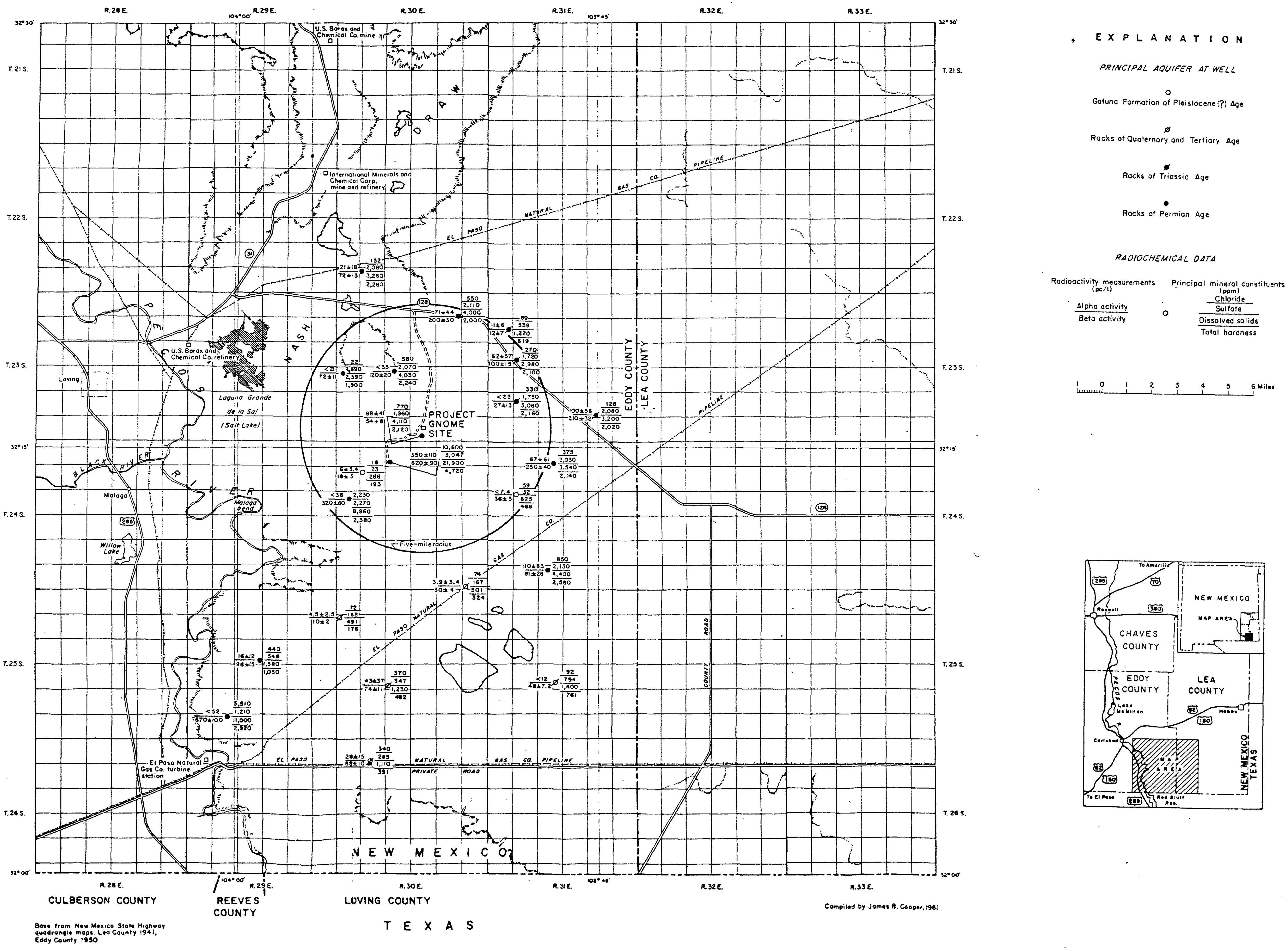


Figure 14.--Map showing location of radiochemical analyses and principal constituents in water from wells near the Project Gnome site, Eddy County, N. Mex.

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