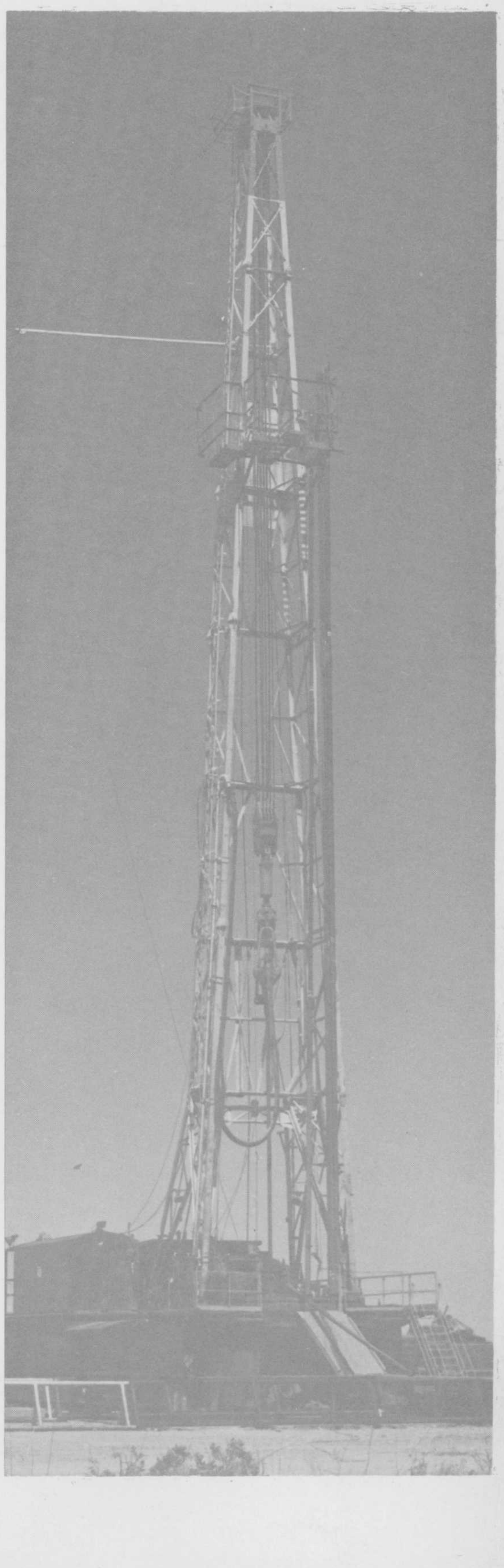
INTERIM DATA REPORT ON THE GEOHYDROLOGY OF THE PROPOSED WASTE ISOLATION PILOT PLANT SITE SOUTHEAST NEW MEXICO



PREPARED IN COOPERATION WITH THE DEPARTMENT OF ENERGY

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS 79-98

BIBLIOGRAPHIC DATA SHEET

1. Report No.

2.

3. Recipient's Accession No.

4. Title and Subtitle

INTERIM DATA REPORT ON THE GEOHYDROLOGY OF THE PROPOSED WASTE ISOLATION PILOT PLANT SITE, SOUTHEAST NEW MEXICO

5. Report Date

July 1979

6.

7. Author(s)

J. W. Mercer and B. R. Orr

8. Performing Organization Rept. No. USGS/WRI-79-98

9. Performing Organization Name and Address

U.S. Geological Survey
Water Resources Division
P.O. Box 26659
Albuquerque, New Mexico 37125

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. Sponsoring Organization Name and Address

U.S. Geological Survey
Water Resources Division
P.O. Box 26659
Albuquerque, New Mexico 87125

13. Type of Report & Period Covered

Final

14.

15. Supplementary Notes

Prepared in cooperation with the Department of Energy

16. Abstracts Data collected at the proposed Waste Isolation Pilot Plant site in southeast New Mexico through September 1977 help define hydrologic conditions at the contact between the Salado and Permian-Rustler Formations, and Culebra and Magenta Dolomite Members of the Rustler Formation. Preliminary calculations of transmissivity along the Rustler-Salado contact range from 10^{-1} feet squared per day to 10^{-4} feet squared per day. Rustler-Salado fluids contain from 311,000 to 325,800 milligrams per liter total dissolved solids.

Fluids in the Culebra Dolomite move to the southeast at gradients ranging from 7 to 120 feet per mile. Preliminary transmissivity calculations range from 140 feet squared per day to 10^{-4} feet squared per day. Total dissolved solids range from 23,721 milligrams per liter to 29,683 milligrams per liter.

The extremely low vertical hydraulic conductivity within the Rustler Formation prevents fluid from communicating between the Magenta and Culebra Dolomites, and between the Culebra and the Rustler-Salado contact. Heads are highest in the Magenta and lowest at the Rustler-Salado contact.

17. Key Words and Document Analysis. 17a. Descriptors

Nuclear wastes, Disposal, Radioactive waste disposal, Radioactive wastes, Water pollution, Groundwater movement, Aquifers, Permeability, Transmissivity, Deep wells, Test wells, Subsurface investigations

17b. Identifiers/Open-Ended Terms

Waste Isolation Pilot Plant, New Mexico, Eddy County, southeastern New Mexico, Salado Formation, Rustler Formation, Magenta Dolomite Member, Culebra Dolomite Member

17c. COSATI Field/Group

18. Availability Statement

No restriction on distribution

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)
UNCLASSIFIED

21. No. of Pages
178

22. Price

INTERIM DATA REPORT ON THE GEOHYDROLOGY OF THE PROPOSED WASTE ISOLATION PILOT PLANT SITE SOUTHEAST NEW MEXICO

BY J.W. MERCER & B.R. ORR

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS 79-98

PREPARED IN COOPERATION WITH THE DEPARTMENT OF ENERGY

JULY 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

Cecil D. Andrus, Secretary

GEOLOGICAL SURVEY

H. William Menard, Director

For additional information write to:

U.S. Geological Survey
P.O. Box 26659
Albuquerque, New Mexico 87125

Contents

Contents - Concluded

Illustrations

Tables

Tables - Concluded

Inch-pound unit to metric unit conversion factors

In this report figures for measurements are given in inch-pound units only. The following table contains factors for converting to metric units.

Multiply inch-pound units	By	To obtain metric units
foot (ft)	.3048	meter (m)
foot per mile (ft/mi)	.1894	meter per kilometer (m/km)
foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
foot cubed per day (ft^3/d)	.0283	meter cubed per day (m^3/d)
mile (mi)	1.609	kilometer (km)
gallon per minute (gal/min)	.06309	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	.2070	liter per second per meter [(L/s)/m]
pound per square inch (lb/in^2)	.07031	kilogram per square centimeter (kg/cm^2)

Chemical concentrations are given only in metric units--milligrams per liter (mg/L), micrograms per liter (μg/L), or picocuries per liter (pCi/L).

Liquid densities are given only in metric units--grams per cubic centimeter (g/cm^3).

INTERIM DATA REPORT ON THE GEOHYDROLOGY OF THE

PROPOSED WASTE ISOLATION PILOT PLANT SITE,

SOUTHEAST NEW MEXICO

By J. W. Mercer and B. R. Orr

Abstract

Data were collected during hydrologic investigations at the Waste Isolation Pilot Plant site in southeast New Mexico through September 1977. These data will be considered as part of a site characterization study evaluating the feasibility of nuclear-waste storage within bedded salt of the Salado Formation of Permian age.

Liquids in the rocks overlying the Salado Formation are found at the contact between the Permian-Rustler and Salado Formations, and in the Culebra and Magenta Dolomite Members of the Rustler Formation.

Calculations of hydraulic gradient and direction of flow of water moving along the Rustler-Salado contact have been hindered because heads are stabilizing very slowly. Preliminary calculations of transmissivity range from 10^{-1} feet squared per day on the western margin of the site to 10^{-4} feet squared per day on the eastern margin. Liquids from the Rustler-Salado contact contain from 311,000 to 325,800 milligrams per liter total dissolved solids. Liquid chemistry suggests long residence times and extensive liquid-rock interaction, increasing with decreasing permeability.

Liquids in the Culebra Dolomite Member move southeast at gradients ranging from 7 to 120 feet per mile. Preliminary transmissivity calculations range from 140 feet squared per day on the western margin to 10^{-4} feet squared per day to the east. Total dissolved solids range from 23,721 milligrams per liter along the western margin of the site to 118,292 milligrams per liter to the east. Liquid chemistry within the Culebra varies from well to well probably as a function of fracture distribution.

Liquids in the Magenta Dolomite Member move southwest at a gradient of about 50 feet per mile. Preliminary transmissivity estimates range from less than 1 foot squared per day to 40 feet squared per day. Total dissolved solids range from 10,347 milligrams per liter to 29,683 milligrams per liter.

The extremely low vertical hydraulic conductivity within the Rustler Formation restricts liquid migration between the Magenta and Culebra Dolomite Members, and between the Culebra and the Rustler-Salado contact. Heads are highest in the Magenta and lowest at the Rustler-Salado contact.

Liquid levels in wells tapping the Permian Bell Canyon Formation near the site are lower than levels in wells tapping the Rustler Formation. Liquids from the Bell Canyon Formation contain 189,000 milligrams per liter total dissolved solids. Liquid density and chemistry indicate long residence times and extensive liquid-rock interaction.

Introduction

A proposed site for a nuclear waste isolation pilot plant is in eastern Eddy County, 30 miles east of Carlsbad, N. Mex., in an area known as Los Medanos (fig. 1). The geohydrology of this area is being studied by the U.S. Geological Survey at the request of the Waste Isolation Pilot Plant (WIPP) Project Office of the U.S. Department of Energy. The study was designed to supplement the technical program of Sandia Laboratories, which is responsible for technical development of the WIPP facility. The proposed WIPP facility would be constructed in the bedded salts of the Permian-Salado Formation for the disposal of defense-associated nuclear wastes.

The site covers about 54 square miles and encompasses all of T.22 S., R.31 E., the eastern part of T.22 S., R.30 E., and the northern part of T.23 S., R.31 E.

Los Medanos is part of the gently sloping terrain which rises eastward from the Pecos River Valley. Topographic relief is less than 50 feet and the surface is comprised of desolate sand dunes. The area straddles a low divide between Nash Draw to the west and San Simon Swale to the east.

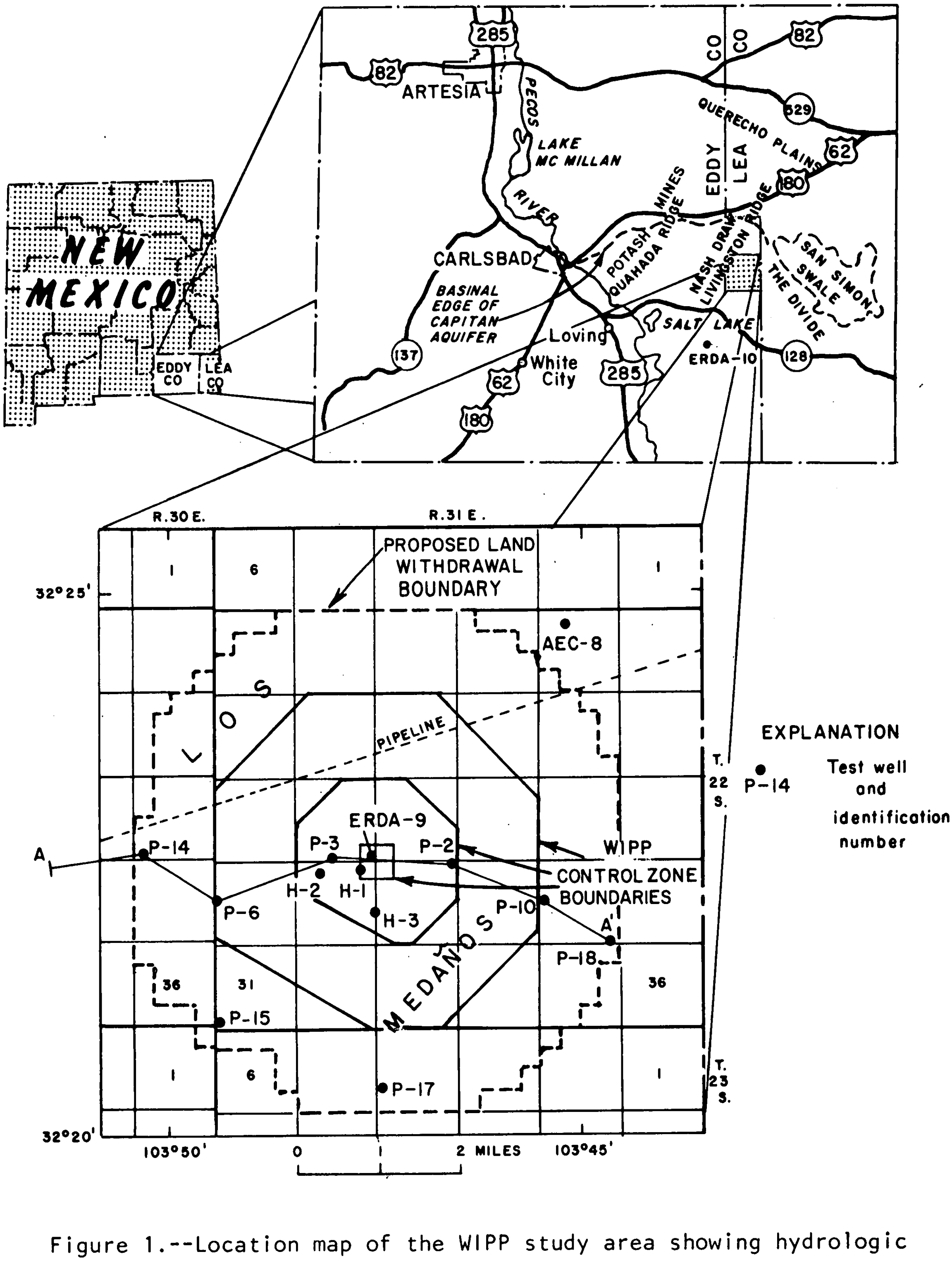


Figure 1.--Location map of the WIPP study area showing hydrologic and selected geologic test holes at Los Medanos.

This report contains geohydrologic and water-quality data, hydrologic testing methods, and preliminary interpretations related to the site area and it supplements a report in which the regional hydrogeologic regime was described (Mercer and Orr, 1977).

The feasibility of confining wastes within geologic formations for a specified time period is an important technical consideration when siting a radioactive waste isolation facility. Two factors are directly related to the confining property of the aquifer: (1) the geologic stability of the formation or formations in which the wastes are to be isolated, and (2) the occurrence of liquid that could transport radionuclides away from the site. Because the formation proposed for waste isolation is easily dissolved halite, the waste confining property is dependent upon the hydrologic regime within and around the isolation horizon.

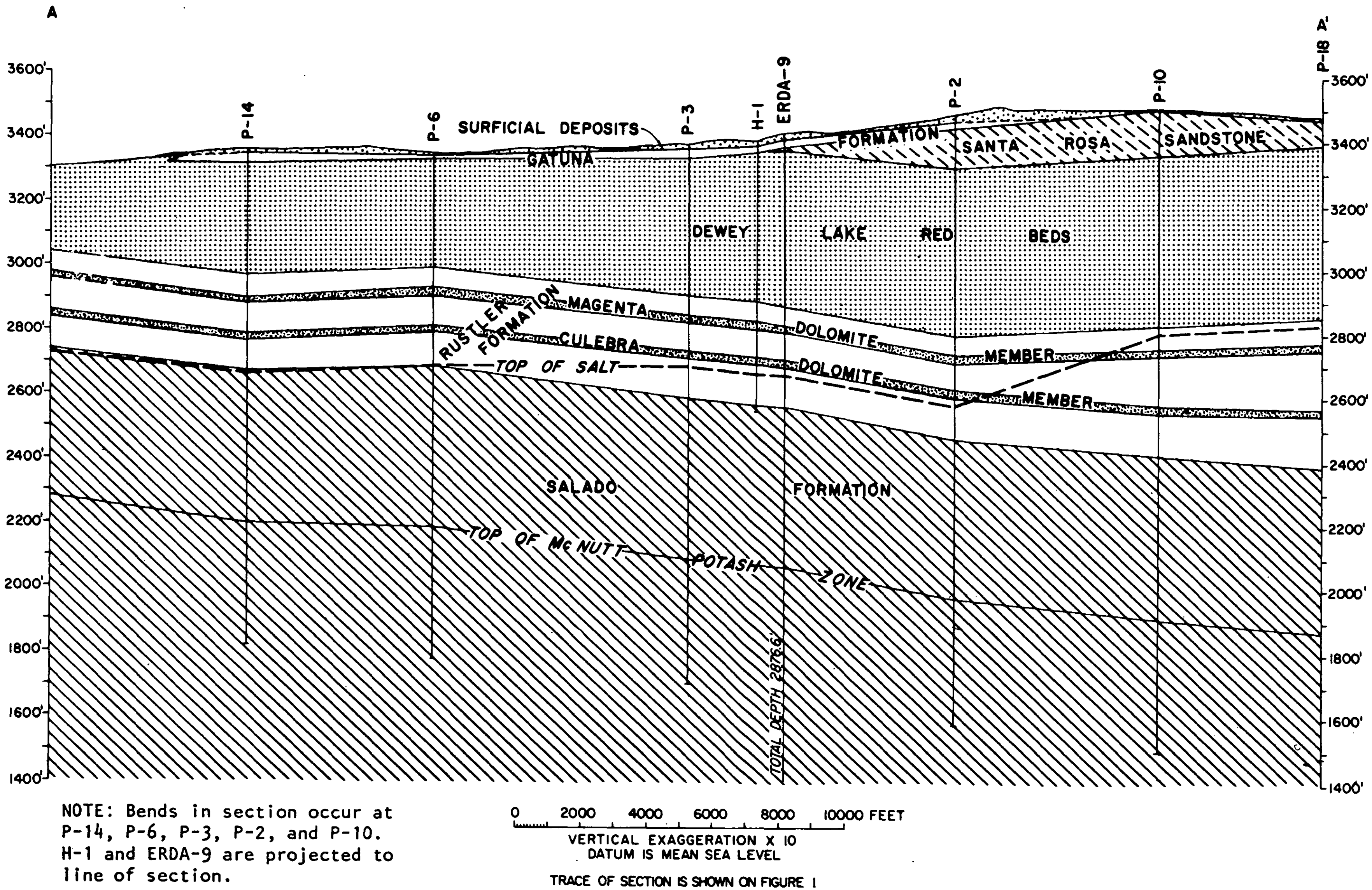
Pressure heads, magnitude and direction of flow, and liquid chemistry in the formations from the top of the salt up to the ground surface (shallow hydrology) need to be evaluated. Unsaturated waters migrating along the upper surface of the salt beds will affect the stability of the storage formations. The pressure heads, directions and rates of flow, and liquid chemistry below (deep hydrology) the storage horizon also need to be evaluated to predict transport of radionuclides should they be accidentally discharged into the liquid-bearing zones.

General site geohydrology

General setting

Sedimentary rocks exposed at the WIPP site range in age from Early Permian to Quaternary. The oldest rocks lie to the west and progressively younger rocks lie to the east. A detailed knowledge of the stratigraphy must be obtained from drill holes because the rocks generally are covered by Quaternary caliche and semistabilized and active dune sands.

A total of 31 test holes have been drilled for geologic and hydrologic investigations. Test holes (P-18, P-10, P-2, ERDA-9, P-3, P-6, P-14) were used to construct an east-west geologic section (fig. 2). The rocks penetrated by drilling (table 1) consist mainly of Permian sandstone, evaporites, and red beds, but include some Triassic sandstone and Pleistocene bolson-type deposits.



NOTE: Bends in section occur at P-14, P-6, P-3, P-2, and P-10. H-1 and ERDA-9 are projected to line of section.

Figure 2.--Geologic section across WIPP site.

Table 1.--Summary of rock units of Permian (Ochoan and Guadalupian) and younger age, WIPP site area, Eddy and Lea Counties, New Mexico

Age		Rock Unit	Thickness (feet)	Description
Quaternary	Holocene	Sand of Mescalero surface	0-19	Dune sand, uniformly fine-grained, light-brown to reddish-brown
				UNCONFORMITY
Quaternary	Holocene	Caliche	0-5	Limestone, chalky, includes fragments of underlying rock
				UNCONFORMITY
Quaternary	Pleis-to-cene(?)	Gatuna Formation	0-32	Sandstone and siltstone, poorly indurated, dominantly reddish-orange
				UNCONFORMITY
Triassic	Late Triassic	Santa Rosa Sandstone	0-255	Sandstone, medium- to coarse-grained, commonly cross-stratified, gray and yellowish-brown, contains conglomerate and reddish-brown mudstone
				UNCONFORMITY
Permian	Ochoan	Dewey Lake Red Beds	250-535	Siltstone and sandstone, very fine to fine-grained, reddish-orange to reddish-brown, contains interbedded reddish-brown claystone, small-scale lamination and cross-stratification common
				UNCONFORMITY
Permian	Ochoan	Rustler Formation	298-462	Anhydrite and rock salt with subordinate dolomite, sandstone, claystone, and polyhalite; includes Magenta Dolomite and Culebra Dolomite Members
Permian	Ochoan	Salado Formation	1,976-2,000±	Rock salt with subordinate anhydrite, polyhalite, potassium ores, sandstone, and magnesite
Permian	Ochoan	Castile Formation	1,300±	Anhydrite and rock salt with subordinate limestone
Permian	Guadalupian	Delaware Mountain Group: Bell Canyon Formation	1,000±	Sandstone, brown and gray, with minor limestone and shale
Permian	Guadalupian	Delaware Mountain Group: Cherry Canyon Formation	1,000±	Sandstone, gray and brown, with limestone and minor shale
Permian	Guadalupian	Delaware Mountain Group: Brushy Canyon Formation	1,000±	Sandstone, gray, with brown and black shale and brown limestone

Permian rocks

Guadalupian Series.--The Delaware Mountain Group consists, in ascending order, of the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations, and is composed predominantly of sandstone containing interbedded limestone. The Delaware Mountain Group is of hydrologic importance in WIPP investigations because it is the first liquid-bearing zone below the potential waste-repository horizons. The Bell Canyon Formation, the uppermost rock unit in the Delaware Mountain Group, is the oldest rock penetrated by WIPP boreholes and forms the basin floor for the overlying Ochoan evaporites.

The Bell Canyon Formation was penetrated in the AEC-8 borehole (fig. 1) at a depth of 4,315 feet, or at an elevation of 783 feet below mean sea level. The top of the Bell Canyon in the ERDA-10 borehole, 8.5 miles southwest of the site center (fig. 1), lies at a depth of 3,829 feet, or at an elevation of 458 feet below mean sea level.

Ochoan Series.--The Ochoan rocks penetrated at the WIPP site are predominantly rock salt and anhydrite, but include potash as well as some limestone, dolomite, and fine-grained clastics. The Ochoan Series in ascending order consists of the Castile, Salado, and Rustler Formations and the Dewey Lake Red Beds.

The Castile Formation, (Richardson, 1904) was penetrated at the WIPP site at a depth of 2,824 feet in ERDA-9 and 2,982 feet in AEC-8 (fig. 1). The Castile lies conformably over the Bell Canyon Formation and consists of a massive to banded anhydrite interbedded with halite seams. The predominance of anhydrite in the Castile differentiates it from the predominantly halitic Salado Formation. The upper contact of the Castile is conformable, with lateral and vertical gradation from anhydrite to rock salt.

The Salado Formation, differentiated from the Castile by Lang (1935), is one of the most extensively evaluated formations at the WIPP site. It is in selected salt horizons of this formation that the wastes would be placed. The Salado Formation was found at varying depths across the site. From west to east the Salado was penetrated in P-14 at a depth of 687 feet or an elevation of 2,671 feet, in H-1 at a depth of 808 feet or an elevation of 2,595 feet, and in P-18 at a depth of 1,088 feet or an elevation of 2,391 feet (fig. 2).

The Salado Formation consists of a heterogeneous sequence of thick layers of salt interbedded with anhydrite and polyhalite. It also contains potassium-bearing evaporites. The regional dip of the formation is to the east under the site. Drilling has confirmed that there is minor salt dissolution at the top of the Salado west of the site area.

The Rustler Formation (Richardson, 1904) is the uppermost evaporite unit penetrated by boreholes at the WIPP site. The Rustler conformably overlies the Salado Formation, and consists of interbedded anhydrite, siltstone, and mudstone, thin continuous dolomite beds, and halite.

The eastward dipping Rustler Formation was penetrated in P-14 at a depth of 387 feet, or an elevation of 2,969 feet, in H-1 at a depth of 507 feet, or an elevation of 2,896 feet, and in P-18 at a depth of 628 feet, or an elevation of 2,851 feet above mean sea level (fig. 2). The overall thickness decreases to the west, ranging from 460 feet in P-18 to 300 feet in P-14, and corresponds to a westward removal of Rustler salt (fig. 2). The upper contact of the Rustler is sharp and is marked by a distinct change from reddish-brown mudstone to gray anhydrite.

The Magenta and Culebra Dolomite Members, two regionally persistent, thin carbonate marker beds within the Rustler, are found in all WIPP test holes, and act as the principal hydrologic units in rocks overlying the repository horizons. The Magenta ranges in thickness from 23 to 27 feet and the Culebra ranges in thickness from 18 to 28 feet (fig. 2).

The Dewey Lake Red Beds (Page and Adams, 1940) comprise the youngest rocks in the Ochoan sequence at the WIPP site and mark an abrupt change in the depositional environment. The evaporitic anhydrite of the Rustler Formation changes sharply to the clastic sediments of the Dewey Lake Red Beds in which no evaporite deposition is observed. The Dewey Lake Red Beds were deposited fluvially on broad mud flats after the final regression of Permian seas and consist of a heterogenous sequence of interbedded siltstones, mudstones, and sandstones (Brokaw, 1972, p. 26). Silt-filled mud cracks occur at the top of many mudstone layers, and sections of the unit are intruded by horizontal and crisscrossing veins of selenite.

The Dewey Lake Red Beds were intercepted by P-14 at a depth of 42 feet, or at an elevation of 3,316 feet; by H-1 at a depth of 35 feet, or at an elevation of 3,368 feet; and by P-18 at a depth of 87 feet, or at an elevation of 3,392 feet (fig. 2). In the western half of the site, the Dewey Lake is covered only by thin surficial deposits or by the bolson-like fill of the Gatuna Formation. To the east, the Dewey Lake is overlain by the Santa Rosa Sandstone (fig. 2), which thickens eastward. The Dewey Lake increases in thickness from 350 feet in P-14 to 541 feet in P-18 (fig. 2). The varying thickness is probably a result of post-Permian erosion, primarily west of ERDA-9.

Triassic rocks

Dockum Group.--The Santa Rosa Sandstone, named by Darton (1922) in the area, covers the eastern one-half of the WIPP site, thinning to a featheredge along a north-south line through the site center near ERDA-9 (fig. 2). The basal contact is marked by an erosional unconformity on the underlying Dewey Lake Red Beds. The Santa Rosa Sandstone consists predominantly of crossbedded sandstone, siltstone, and conglomerate. The Santa Rosa Sandstone was penetrated in P-18, where it is 78 feet thick, and in AEC-8, where it is 127 feet thick. The sandstone is truncated by a nodular to laminar limestone of middle Pleistocene age, informally named the Mescalero caliche by Bachman (1974, p. 31).

Jurassic, Cretaceous, and Tertiary rocks

No rocks of Jurassic, Cretaceous, or Tertiary age occur within the site area.

Quaternary rocks

The Quaternary Gatuna Formation, named by Lang (1938), occurs as discontinous bolson-type deposits in channels and depressions possibly related to solution within the Salado and Rustler Formations. It is found sporadically in the drill holes. A thin caliche caprock of Holocene age extends across the site and is overlain by a shifting mantle of semistabilized dune sands.

Important deep geohydrologic units

The occurrence of liquids within rock units lying beneath the Salado Formation is important because of the potential for liquids to transport radionuclides away from the burial site. Brines occur in the sandstone of the Delaware Mountain Group. Previous investigations (Hiss, 1976) indicate that these brines move northeast across the Delaware Basin and discharge into the Guadalupian Capitan Limestone and associated back-reef rocks. The uppermost rock unit of the Delaware Mountain Group, the Bell Canyon Formation, directly underlies the evaporite rocks of the Castile Formation. It is the liquid-bearing zone most likely to affect proposed storage horizons from below the Salado Formation. Testing of these deep hydrologic environments for the WIPP studies has primarily taken place in AEC-8.

Important shallow geohydrologic units

The liquid-bearing rocks of the Rustler Formation have been the primary study zones in WIPP hydrologic investigations because they directly overlie the Salado Formation and furnish a potential avenue for salt dissolution and radionuclide transport. Work prior to WIPP investigations (Mercer and Orr, 1977) had indicated several zones of hydrologic interest within the Rustler Formation. The Magenta and Culebra Dolomite Members are productive aquifers in other areas within the Delaware Basin. Water in the Rustler dolomites appears to move slowly southward across the western half of the Delaware Basin along fractures (Cooper, 1971, p. 8) eventually discharging near Malaga Bend. Recharge probably occurs by infiltration through fractures and exposed contacts in upper Nash Draw and Clayton Basin to the north. The contact between the Rustler and Salado Formations transmits liquid near Nash Draw ("brine aquifer" horizon) (Mercer and Orr, 1977, p. 20). The Magenta and Culebra Dolomite Members, and Rustler-Salado contact are considered to be the most probable liquid-producing zones within the Rustler in the study area. Otherwise, the predominant lithology, anhydrite with siltstone, has not been known to produce appreciable amounts of liquid. Rocks within the Rustler in which previous halite leaching had occurred (salt residue zones) were proposed as additional hydrologic testing horizons (C. L. Jones, 1976, oral commun.).

The siltstones and mudstones of the Dewey Lake Red Beds limit liquid transmission capability. However, zones of permeability, as indicated by loss of circulation of drilling fluid, have previously been encountered within the Dewey Lake Red Beds in the vicinity of the WIPP site by well drillers. Permeability is a measure of the rock's ability to transmit fluid under hydropotential gradient. These zones have been tested briefly during the test-well drilling program of the Rustler as potential avenues of liquid transmission, but no appreciable liquid flows were found.

Data collection

The objectives of the hydrologic testing program at the WIPP site are to determine the static head or reservoir pressure, the magnitude and direction of flow, and the chemistry of formation waters. Commonly, these hydrologic tests are made in exploratory test holes either during drilling or after the hole has been drilled to total depth. Hydrologic tests were made in 11 exploratory test holes at the WIPP site--H-1; H-2 a, b, and c; H-3; P-14; P-15; P-17; P-18; AEC-8; and ERDA-10 (fig. 1). Of these 11 holes, 5 were specifically designed for hydrologic testing (H-1; H-2 a, b, and c; and H-3).

The hydrologic test holes (H-1; H-2 a, b, and c; and H-3) were placed in a triangular array measuring approximately one-half mile long on each side. This array was selected to determine hydraulic gradients in the liquid-bearing zones above the salt section.

The H-2 complex (H-2a, H-2b, and H-2c) was designed in a closely spaced triangular array (fig. 1) to provide long term open-hole testing and pump testing for vertical and (or) horizontal communications between liquid-bearing zones.

The potash-hydrologic test holes (P-14, P-15, P-17, and P-18) were not drilled specifically for hydrologic testing but were designed for potash mineral evaluation. These particular holes were selected for hydrologic testing in the liquid-bearing zones above the salt because of their location near the outer boundary of the WIPP site.

The two remaining holes (AEC-8 and ERDA-10) were deep test holes used to test liquid-bearing zones below the salt section. AEC-8, drilled prior to the WIPP project, was deepened for testing of liquid-bearing zones below the salt. Hydrologic testing of this interval is now (October, 1977) being conducted in ERDA-10, a test hole drilled for offsite geologic evaluation.

Methods of drilling and testing

The air-rotary drilling method was used to drill the holes designed specifically for hydrologic testing at the WIPP site (H-1, H-2a, H-2b, H-2c, and H-3). This method differs from standard rotary drilling in that the drilling fluid or mud gel used to cool the bit and remove cuttings is replaced by compressed air which is pumped down the drill pipe and moves back up the annular space between the drill pipe and the borehole wall. Dry compressed air is used unless moist zones or liquid are encountered, at which time soap and water are added to assist in removal of the cuttings. This procedure is referred to as mist drilling. The air method was used to make it easier to identify zones that might contain liquid and to decrease aquifer-test-zone plugging which may occur using bentonitic-based drilling fluids.

Open-hole testing procedures are preferred as they allow exposure of the maximum surface area of the test interval. If, however, the zones are of very low permeability requiring long periods of recovery time, this type of testing may be too expensive and the hole must be cased.

Cased holes were prepared for hydrologic testing by perforating the casing with jet shots (shaped explosive charges) 0.5 inch in diameter and 3 holes per foot of casing. Because of difficulties that occur due to perforating in dry holes, the perforating tool was generally cushioned by water which was bailed or swabbed after the tool was fired.

General methods of investigation for hydrologic testing usually began with geophysical logging of the open borehole. These logs provided detailed information on lithologic changes, formational characteristics, potential zones of water yield, and borehole diameter changes. These parameters were initially needed for selection of intervals to be tested, as well as to provide information on hole conditions in the selection of packer seats. For a detailed discussion of logging and log interpretation see Keys and MacCary (1971).

Hydrologic testing at the WIPP site frequently utilized hydraulically inflatable packers. These packers enabled selected intervals in either open holes or cased holes to be effectively isolated and tested. The advantages of using inflatable packers over other mechanical devices are found in the greater running clearance and in the more positive seal of an inflatable element. For a detailed discussion of the inflatable packer and its uses, refer to Blankennagel (1967, p. 41-45).

Following logging, a proposed test zone was isolated by an inflatable packer or packers, and a preliminary drill-stem test was conducted. The drill-stem test is designed to provide representative samples of water from the formation, undisturbed pressures in the formation, and indications of the permeability of the formation. Standard oil-field drill-stem tests were run on AEC-8 and ERDA-10, but in most cases the procedures were modified. The modification most commonly made was in the method of recording formation pressures. In standard oil-field drill-stem tests, pressures are recorded throughout the test by a bourdon-tube pressure-recording gage (pressure bomb) located near the bottom of the drill string. Data from this pressure bomb cannot be retrieved until after completion of the test. In the modified drill-stem tests used in WIPP hydrologic investigations, the tubing was opened to the test zone, liquid was removed from the tubing, and the rising formational liquid level was measured in the drill string. This modification allowed continuous monitoring during the test. Additionally, pressure-monitoring devices were placed above and below packers to determine whether the zone was effectively isolated from the rest of the borehole.

Hydrologic test procedures at the WIPP site, whether performed as drill-stem tests, open-hole tests, or cased-hole tests, generally consisted of bailing or swabbing a known volume of liquid at a known rate and observing the rate of recovery following liquid withdrawal. Yields from test zones could then be calculated from the rate of change in water levels with time.

The bailing tests are conducted using a bailer, which is a hollow steel cylinder usually 20 feet long and slightly smaller than the borehole. The bailer is equipped with a dart-door valve (check valve) at the bottom. When the bailer is surged up and down in the borehole, the dart allows water to enter the bailer where it is entrapped. The bailer is then removed from the hole and the liquid is dumped into a calibrated tank.

Swabbing tests are similar to bailing tests in that their purpose is to extract a known volume of liquid from the hole or are used to remove mud and other liquid from the hole prior to testing. General procedures are as follows:

After the drill pipe or tubing is lowered into the hole, the swab is attached to a wire line and lowered into the tubing. The swab consists of a hollow supporting mandrel with an upward opening valve (check valve), sinker bar, and rubber cups (Uren, 1946). As the swab is lowered into the hole and into the liquid, the liquid in the hole passes up through the check valve and enters the space above. At some depth below the liquid level, the swab is pulled up and out of the hole. The check valve keeps the liquid from again passing through the swab. The weight of the liquid flattens the rubber cups and expands their diameter until they press firmly against the pipe. This prevents leakage of the liquid around the swab and the pipe, and the liquid is lifted to the surface and into a calibrated tank (Blankennagel, 1967, p. 27-29).

Radioactive-tracer tests were conducted in some of the WIPP hydrologic test holes after they had been cased and perforated at selected intervals. These tests were employed primarily to check for cement bond between the casing and the borehole wall. These tests also yielded information on vertical distribution of permeability across the test interval. The tracer consisted of an aqueous solution of radioactive iodine, 131 (^{131}I).

Several methods of running tracer tests are available; however, because of the low permeabilities involved, the depth-drive technique was used at the WIPP site (Blankennagel, 1967 p. 16). In this technique, water is pumped at a nearly constant rate into the borehole and a slug of ^{131}I is injected above the perforations. The slug is then followed downhole with a scintillation gamma detector. As the detector makes passes at timed intervals through the slug, a surface recorder picks up the increase in gamma activity. The depth, direction, and rate of movement of the slug can be calculated by comparison of successive gamma traces.

With regard to collection of water samples the test zones were bailed or swabbed until liquid temperature, conductivity, and density stabilized. This resulting condition was the guide used to determine that representative formational liquid had been drawn into the hole. Samples were then collected and treated according to standard USGS techniques as outlined by Brown and others (1970). These samples were analyzed for the major and trace elements and for radiochemistry (table 2). This information will be used to provide background level chemistry and to determine if water chemistry can provide information on liquid histories.

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico

	Rustler-Salado contact				Culebra Dolomite Member of Rustler Formation		
	Well H-1	Well H-2C	Well H-3	Well P-14	Well H-1	Well H-2B	Well H-2C
Date of sample (year,month,day)	77- 2-23	77- 2-23	77- 2-23	77- 2-24	77- 3-17	77- 2-22	77- 3-16
Elevation of land surface datum (ft above mean sea level)	3,403	3,377	3,389	3,358	3,403	3,377	3,377
Total depth of well (ft below land surface datum)	856	795	894	1,545	856	661	795
Depth to bottom of sample interval (ft below land surface datum)	827	795	837	700	703	661	652
Depth to top of sample interval (ft below land surface datum)	803	743	813	676	675	611	624
pH (unitless)	7.9	5.9	7.6	7.2	7.3	8.4	8.2
Temperature (in degrees Celcius)	21.0	20.5	21.5	24.5	22.5	21.5	20.5
Dissolved Chloride (Cl) (mg/L)	210,000	200,000	210,000	180,000	49,000	2,800	4,700
Dissolved Fluoride (F) (mg/L)	-	-	-	-	.8	2.0	1.6
Dissolved Silica (SiO_2) (mg/L)	.0	2.0	1.0	2.0	.6	1.7	3.5
Dissolved solids (sum of constituents) (mg/L)	325,000	311,000	326,000	313,000	97,300	8,890	12,500
Dissolved Nitrite plus Nitrate (N) (mg/L)	.29	1.1	.77	.34	.03	.01	.16
Dissolved Orthophosphorus (P) (mg/L)	.00	.00	.00	.08	.00	.03	.00
Dissolved Boron (B) (µg/L)	110,000	150,000	1,900	1,700	18,000	9,500	10,000

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico - Continued

Culebra Dolomite Member of Rustler Formation					Magenta Dolomite Member of Rustler Formation			Bell Canyon Formation
Well H-3	Well P-14	Well P-15	Well P-17	Well P-18	Well H-1	Well H-2A	Well H-3	Well AEC-8
77- 3-17	77- 3-14	77- 5-10	77- 5-10	77- 5-10	77- 5-10	77- 2-22	77- 5-10	77- 9-22
3,389	3,358	3,310	3,340	3,479	3,403	3,377	3,389	3,532
894	1,545	1,465	1,660	1,988	856	563	894	4,910
703	601	437	585	937	588	563	592	4,827
675	573	409	557	911	560	511	564	4,821
7.4	6.0	10.2	7.4	7.2	7.2	8.6	8.0	6.0
21.5	21.5	21.5	22.5	24.5	22.0	22.0	22.5	30.0
24,000	20,000	11,000	54,000	80,000	10,000	4,100	15,000	120,000
.5	.9	1.2	1.5	1.2	2.0	-	1.8	1.2
1.2	33	1.6	1.0	1.0	1.7	6.0	6.4	3.6
51,600	33,700	23,700	92,500	118,000	22,200	10,300	29,700	189,000
.07	.01	.04	.06	.81	.04	.04	.08	.11
.00	.02	.03	.11	.40	.03	.01	.04	.05
20,000	700	4,700	1,700	100,000	3,300	220	13,000	53,000

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico - Continued

	Rustler-Salado contact				Culebra Dolomite Member of Rustler Formation		
	Well H-1	Well H-2C	Well H-3	Well P-14	Well H-1	Well H-2B	Well H-2C
Date of sample (year,month,day)	77- 2-23	77- 2-23	77- 2-23	77- 2-24	77- 3-17	77- 2-22	77- 3-16
Dissolved Manganese (Mg) (μg/L)	52,000	78,000	3,800	3,400	2,800	200	140
Total Organic Carbon (C) (mg/L)	-	-	-	-	-	-	-
Hardness (Ca, Mg) (mg/L)	160,000	130,000	150,000	6,400	9,500	2,400	2,200
Noncarbonate hardness (mg/L)	160,000	130,000	150,000	6,200	9,400	2,300	2,100
Dissolved Calcium (Ca) (mg/L)	13,000	9,200	18,000	570	820	690	680
Dissolved Magnesium (Mg) (mg/L)	30,000	25,000	25,000	1,200	1,800	160	120
Dissolved Sodium (Na) (mg/L)	56,000	66,000	59,000	120,000	29,000	2,100	3,600
Sodium absorption ratio (unitless)	62	81	67	655	130	19	33
Dissolved Potassium (K) (mg/L)	17,000	9,100	14,000	1,300	5,600	91	120
Bicarbonate (HCO_3) (mg/L)	675	199	467	222	100	59	62
Carbonate (CO_3) (mg/L)	0	0	0	0	0	5	0
Total Sulfide (S) (mg/L)	-	-	-	-	-	-	-
Dissolved Sulfate (SO_4) (mg/L)	520	1,300	370	10,000	11,000	3,000	3,200
Total Arsenic (As) (μg/L)	7	1	8	1	0	1	2
Dissolved Arsenic (As) (μg/L)	0	0	0	1	0	0	0
Total Cadmium (Cd) (μg/L)	-	1	-	5	90	20	40

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico - Continued

Culebra Dolomite Member of Rustler Formation					Magenta Dolomite Member of Rustler Formation			Bell Canyon Formation
Well H-3	Well P-14	Well P-15	Well P-17	Well P-18	Well H-1	Well H-2A	Well H-3	Well AEC-8
77- 3-17	77- 3-14	77- 5-10	77- 5-10	77- 5-10	77- 5-10	77- 2-22	77- 5-10	77- 9-22
120	500	20	3,000	4,500	950	<5	220	14,000
-	-	-	-	-	-	-	-	-
6,500	11,000	2,200	11,000	80,000	4,400	2,700	5,000	35,000
6,400	11,000	2,100	11,000	80,000	4,300	2,700	4,900	35,000
1,500	3,100	770	1,700	5,600	1,000	820	1,200	10,000
670	760	63	1,600	16,000	460	170	480	2,500
19,000	7,600	6,900	30,000	9,200	6,200	2,700	9,300	55,000
103	32	64	125	14	41	22	57	127
630	600	1,700	120	6,200	840	81	250	860
115	357	63	77	310	93	74	51	420
0	0	24	0	0	0	0	0	0
-	-	-	-	-	-	-	-	0
5,700	1,400	3,200	5,000	980	3,600	2,400	3,400	240
14	4	5	2	0	21	2	7	2
0	2	0	0	0	0	2	1	1
60	40	30	90	160	50	2	40	210

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico - Continued

	Rustler-Salado contact				Culebra Dolomite Member of Rustler Formation		
	Well H-1	Well H-2C	Well H-3	Well P-14	Well H-1	Well H-2B	Well H-2C
Date of sample (year,month,day)	77- 2-23	77- 2-23	77- 2-23	77- 2-23	77- 3-17	77- 2-22	77- 3-16
Dissolved Cadmium (Cd) (μg/L)	1	1	12	5	2	0	14
Total Chromium (Cr) (μg/L)	<50	<50	<50	<50	0	130	0
Dissolved Chromium (Cr) (μg/L)	<50	<50	<50	<50	0	10	0
Total Cobalt (Co) (μg/L)	5	15	20	5	500	150	100
Dissolved Cobalt (Co) (μg/L)	2	4	4	2	0	1	0
Total Copper (Cu) (μg/L)	190,000	2,400	190,000	6,000	8,400	220	32,000
Dissolved Copper (Cu) (μg/L)	500	1,600	16,000	5,000	1,500	1	420
Total Iron (Fe) (μg/L)	130,000	75,000	140,000	30,000	71,000	110,000	180,000
Dissolved Iron (Fe) (μg/L)	1,500	2,500	1,500	2,100	790	20	110
Total Lead (Pb) (μg/L)	320,000	2,800	340,000	14,000	13,000	800	40,000
Dissolved Lead (Pb) (μg/L)	15,000	2,800	29,000	14,000	150	1	38
Total Manganese (Mn) (μg/L)	52,000	110,000	30,000	3,400	4,000	1,700	2,900
Dissolved Manganese (Mn) (μg/L)	52,000	78,000	3,800	3,400	2,800	200	140
Total Mercury (Hg) (μg/L)	.0	.0	.0	.0	.0	.5	.1
Dissolved Mercury (Hg) (μg/L)	.0	.0	.0	.0	.0	.0	.0
Total Selenium (Se) (μg/L)	0	0	1	1	1	2	2
Dissolved Selenium (Se) (μg/L)	0	0	1	0	1	0	1

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico - Continued

Culebra Dolomite Member of Rustler Formation					Magenta Dolomite Member of Rustler Formation			Bell Canyon Formation
Well H-3	Well P-14	Well P-15	Well P-17	Well P-18	Well H-1	Well H-2A	Well H-3	Well AEC-8
77- 3-17	77- 3-14	77- 5-10	77- 5-10	77- 5-10	77- 5-10	77- 2-22	77- 5-10	77- 9-22
2	1	0	1	2	1	0	1	3
0	0	80	100	180	600	<50	100	80
0	0	80	100	130	100	<50	100	90
<50	200	100	400	850	350	10	150	1,500
0	3	0	0	0	0	2	0	0
12,000	100	1,400	660	1,100	27,000	25	2,200	480
1,200	4	190	250	330	3	0	150	19
84,000	19,000	16,000	67,000	48,000	660,000	6,800	43,000	73,000
50	17,000	100	1,200	540	220	60	40	23,000
17,000	200	1,100	1,100	2,100	27,000	200	2,200	2,000
12	8	10	6	2,100	0	2	6	40
1,000	560	190	4,000	44,000	9,600	110	600	15,000
120	500	20	3,000	4,500	950	<5	220	14,000
.0	.1	.0	.1	.0	.1	.0	.0	.0
.0	.0	.0	.0	.0	.0	.0	.0	.0
2	1	0	1	0	1	1	7	0
1	1	0	1	0	0	1	6	0

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico - Continued

	Rustler-Salado contact				Culebra Dolomite Member of Rustler Formation		
	Well H-1	Well H-2C	Well H-3	Well P-14	Well H-1	Well H-2B	Well H-2C
Date of sample (year,month,day)	77- 2-23	77- 2-23	77- 2-23	77- 2-24	77- 3-17	77- 2-22	77- 3-16
Total Zinc (Zn) (μg/L)	22,000	30,000	22,000	4,100	900	1,700	3,100
Dissolved Zinc (Zn) (μg/L)	190	29,000	210	3,000	140	20	30
Total nonfilterable residue (mg/L)	10,000	1,000	1,200	62	9	3,200	2
Dissolved Gross Alpha as natural Uranium (U) (μg/L)	<6,300	<5,000	<6,000	<3,700	2,100	330	360
Suspended Gross Alpha as natural Uranium (U) (μg/L)	290	190	68	6.3	<.4	380	<.4
Dissolved Gross Beta as Cesium-137 (CS-137) (pCi/L)	16,000	8,400	12,000	<2,000	6,000	120	230
Suspended Gross Beta as Cesium-137 (CS-137) (pCi/L)	160	91	26	2.3	1.0	110	<.4
Dissolved Gross Beta as Strontium 90/ Yttrium 90 (SR90/Y90) (pCi/L)	12,000	6,700	9,600	<1,600	4,900	97	180
Suspended Gross Beta as Strontium 90/ Yttrium 90 (SR90/Y90) (pCi/L)	120	76	21	1.9	.1	88	<.4
Dissolved Radium 226 (RA-226) (Radon method) (pCi/L)	64	4.8	51	15	78	4.6	19
Dissolved natural Uranium (U) (μg/L)	-	-	-	-	-	4.2	3.8
Dissolved Uranium (U) (μg/L)	.02	2.4	.06	1.3	.10	-	-

Table 2.--Chemical and radiochemical analyses of water from wells in the WIPP site area, New Mexico - Concluded

Culebra Dolomite Member of Rustler Formation					Magenta Dolomite Member of Rustler Formation			Bell Canyon Formation
Well H-3	Well P-14	Well P-15	Well P-17	Well P-18	Well H-1	Well H-2A	Well H-3	Well AEC-8
77- 3-17	77- 3-14	77- 5-10	77- 5-10	77- 5-10	77- 5-10	77- 2-22	77- 5-10	77- 9-22
1,000	120	400	1,700	6,300	3,800	1,600	400	10,000
90	120	400	400	6,200	400	60	400	12,000
9	9	<1	<1	<1	<1	120	<1	13
<880	<390	2,000	2,900	<4,800	<400	<160	550	<3,200
<.4	<.4	<.4	<.4	<.4	<.4	12	<.4	10
850	790	1,900	1,300	7,700	940	69	330	1,600
<.4	<.4	<.4	<.4	.5	<.4	2.6	<.4	4.2
710	620	1,600	1,000	6,100	790	55	260	1,300
<.4	<.4	<.4	<.4	.5	<.4	2.0	<.4	3.7
57	68	23	84	190	170	6.1	44	280
-	-	2.3	-	-	-	-	4.1	-
.09	<.01	-	.10	.33	.60	.80	-	<.01

Well H-1

Drilling History.--ERDA Hydro No. 1 (H-1) is located 1,084 feet from the east line (FEL) and 620 feet from the north line (FNL) of sec. 29, T.22 S., R.31 E., in Eddy County, New Mexico. The ground level at the test hole is 3,403.2 feet above mean sea level. An abbreviated well chronology is included in table 3.

The test hole was spudded (drilling started) on May 20, 1976, and was rotary drilled using air as the circulatory medium until moist cuttings were encountered at a depth of 180 feet. The open hole was then monitored for liquid entry for nine hours, but it was dry. Air-drilling was resumed and a partial loss of drill cuttings and circulation was observed at about 580 feet. At a depth of 592 feet, liquid entered the hole from the Magenta Dolomite Member. Liquid levels were monitored for 23 hours in which time the liquid level rose from 592 feet to 406 feet below ground level. Then a short bailing test was run. However, up-hole caving and water-thieving zones resulted in poor hole conditions, suggesting that the zone could better be tested with packers at a later time. After bailing, the liquid level had risen to 364 feet in 21 hours and was still rising after 24 hours.

Drilling continued from 592 feet to 731 feet using air mist (one gallon of soap per barrel of water). At 731 feet, an interval was cored through the Rustler-Salado formational contact. The core was cut in three runs from 731 to 842 feet with a recovery of 92 feet of core (83 percent core recovery). The hole was then conditioned with drilling fluid and geophysically logged by the USGS prior to hydrologic testing. Following open-hole testing from May 31 to June 5, it was decided that, because of the low yield of the zones, the hole should be reamed and cased for long-term testing and monitoring. On June 6 the hole was reamed to a 9 7/8-inch diameter to 848 feet. The fluid was displaced with mud and Dresser Atlas[1] borehole geophysical logs were run (fig. 3).

Casing was set and cemented on June 8 to a depth of 848 feet. The hole was then temporarily abandoned pending later hydrologic testing. The final hole configuration and well construction specifications are included in figure 4.

1/The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Table 3.--Chronology of well H-1

[All depth measurements adjusted to ground level, 3,403.2 ft above mean sea level]

Date	
1976	
May 15	Surface pipe set.
May 20	Hole spudded.
May 24	Open-hole test (0-546 ft); dry.
May 25-27	Rotary drilled to 592 ft; first water (Magenta). 23-hour recovery test bail 21-hour recovery test
May 27-29	Rotary drilled, 592-731 ft.
May 29	Cored Rustler-Salado contact, 731-842 ft.
May 30	Monitored liquid levels.
May 31- June 1	Set single-inflatable packer at 699 ft; Rustler-Salado contact drill-stem test.
June 1-2	Set inflatable-straddle packer, 667-699 ft; drill-stem test (modified) in the Culebra.
June 2	Set inflatable-straddle packer, 626-667 ft; salt residue drill-stem test (modified).
June 3-4	Set inflatable-straddle packer, 562-592 ft; drill-stem test (modified) in the Magenta.
June 5-7	Reamed hole to 848 ft for casing.
June 8	Dresser Atlas geophysical logs, casing landed at 848 ft.
June 9	Cemented casing, hole temporarily abandoned.

Table 3.--Chronology of well H-1 - Concluded

Date	
1977	
Jan. 21-22	Drilled cement plug, 797-831 ft.
Jan. 22	Bailed hole dry; perforated casing at Rustler-Salado contact, 803-827 ft.
Jan. 22-Feb. 23	Monitored liquid levels.
Mar. 4	Set inflatable packer at 790 ft.
March 7	Perforated casing at Culebra, 675-703 ft.
March 8	Bailed hole (432 gallons).
March 8-17	Monitored liquid levels.
March 17	Bailed hole for samples (180 gallons).
March 21	Ran radioactive tracer log (^{131}I) on Culebra zone.
Mar. 22-23	Bailed hole.
Mar. 24	Latched on to packer; reopened to Rustler-Salado contact.
Mar. 24-30	Dual monitoring of liquid levels (Rustler-Salado, Culebra).
Mar. 30	Shut in Rustler-Salado contact; pulled tubing.
Apr. 1	Set inflatable packer at 651.3 ft; pulled tubing.
Apr. 5	Perforated casing at Magenta (562-590 ft).
Apr. 6	Bailed hole.
Apr. 6-May 10	Monitored liquid levels.
May 10	Bailed and sampled for liquid in the Magenta.
May 13-Oct. 1	Reran tubing and reopened to Culebra; hole was left in a dual-completion configuration for monthly measurements.

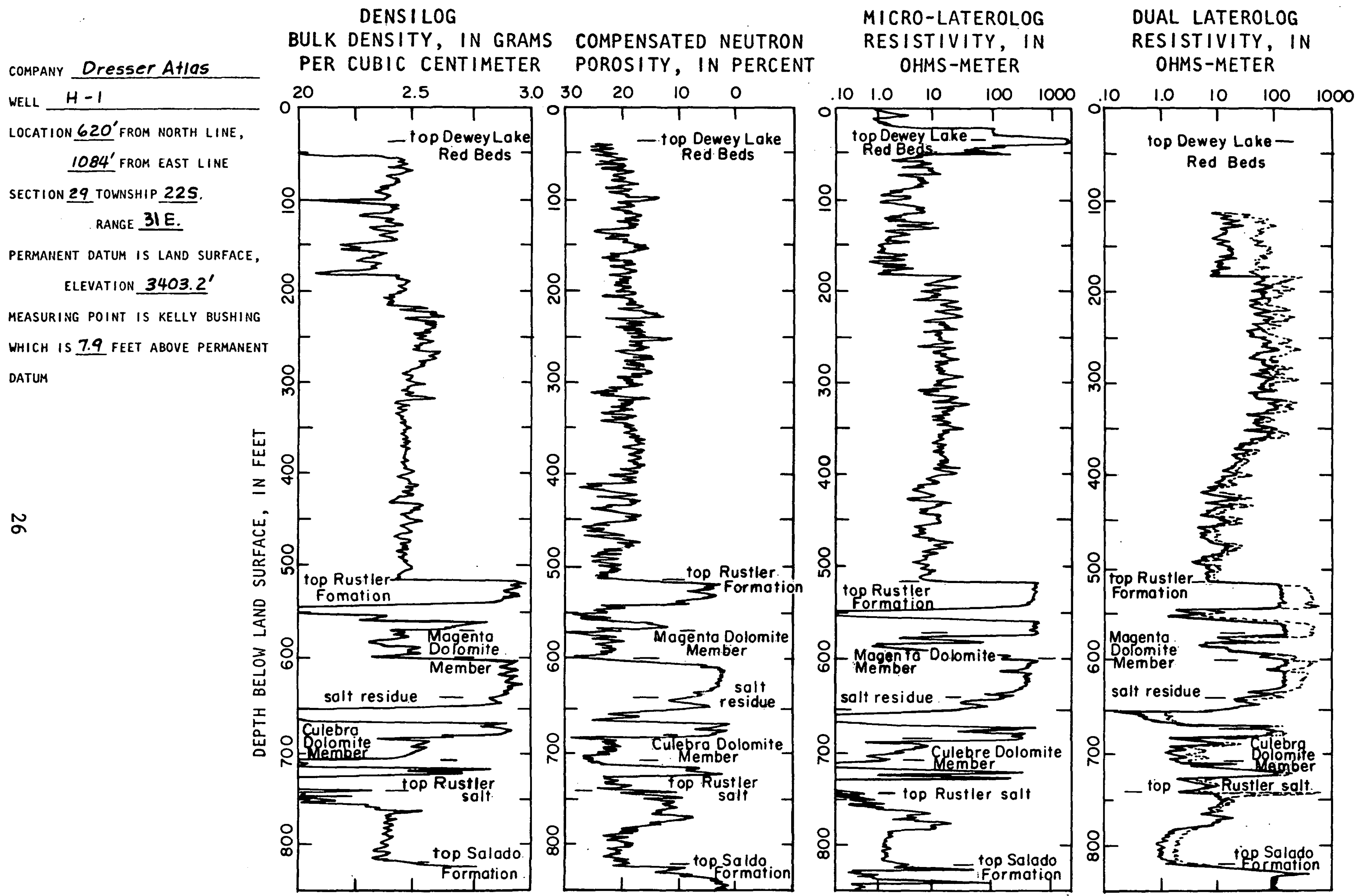
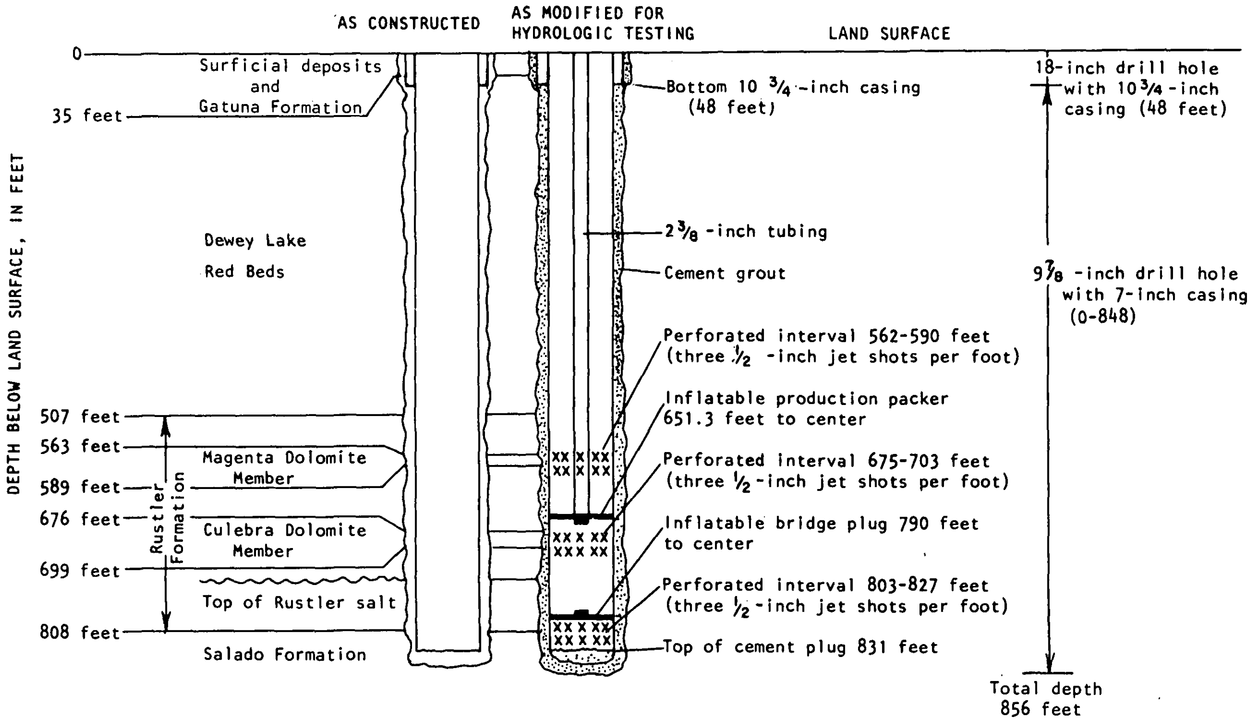


Figure 3.--Selected geophysical logs for well H-1.



LOCATION: 620 feet from north line, 1,084 feet from east line, section 29, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,403.2 feet (ground level)

DEPTH DRILLED: 842 feet, reamed after open-hole testing to 856 feet, cement plug drilled back to 831 feet

DATE COMPLETED: June 9, 1976

DRILLING CONTRACTOR: Sonora Drilling Company, Carlsbad, New Mexico.

DRILLING METHOD: Auger 18-inch hole (0-48 feet); Rotary 7 7/8-inch hole with air and air mist (48-731 feet); Core 4 3/4-inch hole with air mist (731-842 feet); Ream 9 7/8-inch hole (48-856 feet) Rotary cement plug (797-831 feet)

WELL CASING RECORD: 10 3/4-inch outside diameter steel surface pipe (0-48 feet) cemented to surface 7-inch outside diameter steel casing, 26 pounds, 1.61 gallons per foot (0-848 feet), centralizers at 525 and 835 feet, cemented to surface (cement plug to 797 feet, drilled to 831 feet)

GEOPHYSICAL LOGS:

Shown in figure 3: Compensated Densilog, Dual Laterolog, Microlaterolog, Compensated Neutron

Not shown in figure 3: Differential Temperature, BHC Acoustic, Sperry-Sun Magnetic Survey, Gamma

Figure 4.--Well H-1 construction, completion, and specifications.

Hydrologic Testing.--In open-hole hydrologic tests of H-1, the modified drill-stem method was used (see methods of testing). The main purpose of these drill-stem tests was to gain preliminary hydrologic information upon which decisions for subsequent hydraulic testing could be based.

The modified drill-stem tests in H-1 were made at the contact between the Rustler Formation and the Salado Formation (zone of Nash Draw dissolution), the liquid-bearing Culebra Dolomite Member of the Rustler, a possible salt-residue zone in the Rustler (determined from geophysical logs), and the Magenta Dolomite Member of the Rustler (fig. 5).

The drill-stem test of the contact between the Rustler and Salado Formations was made in an open-hole interval from 699 to 848 feet (fig. 5). A single-inflatable packer was set at 699 feet, sealing the test interval from the rest of the hole. The zone was opened to the tubing and the tubing was swabbed dry. After 20 hours the zone produced only 9.1 gallons of liquid. The slow rate at which liquid entered the hole precluded continued open-hole testing.

The modified drill-stem test of the Culebra Dolomite Member was made in an open-hole interval from 667 to 699 feet. After 11.5 hours the test interval produced 10.6 gallons of liquid. As with the Rustler-Salado test, low yields precluded continued testing.

The modified drill-stem test of the suspected salt-residue zone was made in an interval of open hole from 626 to 667 feet below land surface. After 12 hours of liquid-level monitoring, the test interval yielded 11.2 gallons of liquid. The well was swabbed in an attempt to stimulate water flow from the zone, but it could not be further developed.

The modified drill-stem test of the Magenta Dolomite Member was made in an open-hole interval from 562 to 592 feet isolated with straddle packers, and the zone was developed by swabbing. After 13.5 hours of monitoring, the liquid level had risen only 83 feet, which is equivalent to 13 gallons of produced liquid.

Continued open-hole drill-stem tests of the low-yielding zones in H-1 were not feasible. In H-1, long-term testing of the zones in cased holes appeared to be the best way to obtain the needed information.

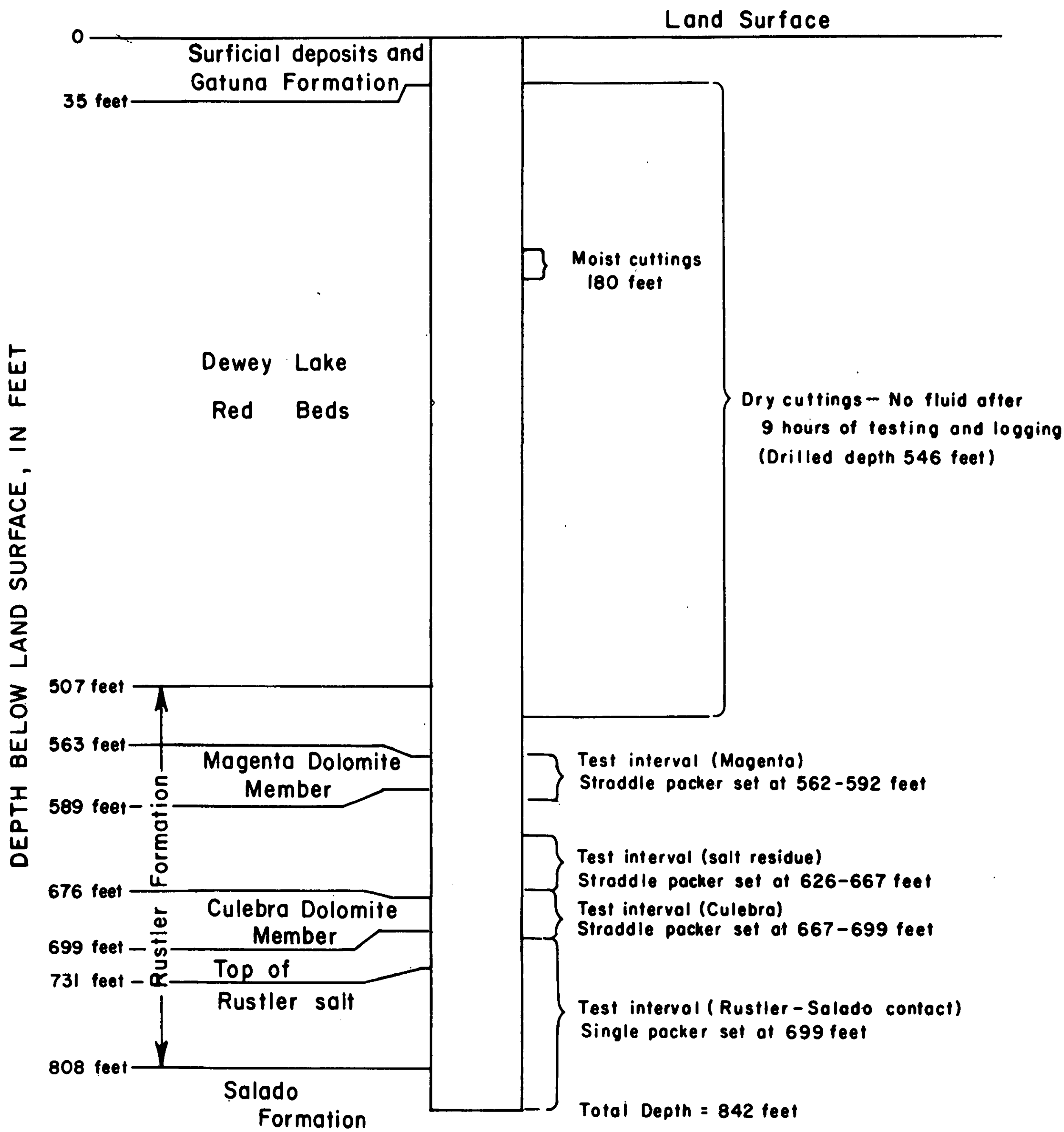


Figure 5.--Open-hole intervals tested in well H-1.

Casing was set and cemented on June 9, 1976, and H-1 then was temporarily abandoned until January 22, 1977, when testing was again initiated. The hole was bailed dry and the casing adjacent to the Rustler-Salado contact was perforated from 803 to 827 feet (fig. 4). After perforating, the liquid level in the hole was monitored for 33 days (table 4) during which time the water slowly continued to enter the casing, raising the water level from 826.5 to 811.1 feet, still 8 feet below the top perforations. Twenty-five gallons of liquid were produced from the test interval. The hole was bailed on February 23, 1977, and a liquid sample was collected and analyzed (table 2).

On March 4 an inflatable packer was set at 790 feet, sealing off the Rustler-Salado perforations from the rest of the hole. The tubing was pulled and the casing opposite the Culebra Dolomite Member was perforated on March 7, 1977, from 675 to 703 feet (fig. 4). After nine days, the liquid level had risen from 665 to 406 feet (table 5), producing a total of 416 gallons of liquid from the zone. Liquid levels were still rising at the end of the test. On March 17 the hole was bailed (180 gallons), and a liquid sample was collected and analyzed (table 2).

A tracer (^{131}I) and temperature survey was conducted in the perforated interval of the Culebra on March 21, 1977 to determine the interval of liquid loss and to detect possible communication or channeling within the cemented annulus. Liquid was pumped down the hole at rates of approximately 8 gal/min. A total of 1,634 gallons was injected into the formation. The results of the radioactive tracer and temperature profiles (fig. 6) indicated that no liquid was moving within the cemented annulus. Both the radioactive tracer and injection temperature gradients indicated that the major liquid loss to the formation was from 675 to 694 feet. There was no flow in the interval 694 to 703 feet. After the injection test, the hole was bailed dry.

On March 24 tubing was reopened to the Rustler-Salado zone and liquid levels were monitored for six days (table 4). Little change of water level was noted during the test. The test interval was then shut in, sealing the zone from the rest of the hole.

An inflatable packer was set at 651.3 feet, sealing the Culebra from the rest of the hole in preparation for perforating the Magenta. The casing adjacent to the Magenta was perforated on April 6, 1977, from 562 to 590 feet (fig. 4). After the hole was perforated, 804 gallons of liquid used to cushion the perforating gun were bailed from the hole. The zone appeared to be fairly productive as the liquid level could not be bailed much below 424 feet. Liquid levels were monitored for 33 days at which time the liquid level was at 340.7 feet and still rising (table 6). On May 10, 1977, 612 gallons were bailed from the hole and a liquid sample was collected and analyzed (table 2).

Table 4.--Liquid-level recovery data, well H-1 (Rustler-Salado contact)

[Perforated interval 803-827 ft below land surface]

Method of testing: The casing was perforated and the liquid level was monitored in the open casing.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
1-22-77	1250	0	-	Zone perforated, no liquid at time of perforation
	1400	89	826.5	-
	1413	102	826.5	-
	1427	116	826.5	-
	1448	137	826.6	-
	1500	149	826.6	-
	1525	174	826.6	-
1-23-77	1120	1,369	826.2	-
1-24-77	1100	2,789	824.7	-
1-27-77	1145	7,154	824.2	-
2- 2-77	1305	15,874	822.8	-
2-6-77	1037	21,486	818.4	-
2-12-77	1341	30,126	813.4	-
2-15-77	1515	34,724	811.5	-
2-17-77	1225	37,434	811.1	-
2-23-77	1019	-	-	Bailed hole dry; end test

Table 4.--Liquid-level recovery data, well H-1 (Rustler-Salado contact) - Concluded

Method of testing: A modified drill-stem test was conducted in the cased hole.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
3-24-77	1705	0	-	Sheared packer plug to open tubing to zone
	1712	7	806.1	-
3-26-77	1222	2,597	805.5	-
3-27-77	1024	3,919	806.0	-
3-28-77	1301	5,516	804.6	-
3-29-77	1057	6,832	802.2	-
3-30-77	1019	8,234	798.2	Shut in, temporarily abandoned.

Table 5.--Liquid-level recovery data, well H-1 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 675-703 ft below land surface]

Method of testing: The casing was perforated, the hole was bailed, and the liquid level was monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3- 8-77	1130	0	-	-	36 bailers = 432 gallons
	1355	144	0	-	-
	1402	151	7	665.2	-
	1408	157	13	661.7	-
	1415	164	20	658.2	-
	1425	174	30	654.7	-
	1430	179	35	652.0	-
	1440	189	45	645.7	-
	1450	199	55	641.4	-
	1500	209	65	636.6	-
	1515	224	80	630.0	-
	1530	239	95	621.8	-
	1545	254	110	615.2	-
	1600	269	125	609.6	-
	1615	284	140	604.2	-
	1630	299	155	598.6	-
	1640	309	165	595.2	-
	1730	359	215	587.5	-
	1835	424	280	559.3	-
	1945	494	350	542.3	-
3- 9-77	0735	1,204	1,060	454.4	-
	1310	1,539	1,395	434.6	-
3-10-77	0930	2,759	2,615	416.4	-
3-11-77	1244	4,393	4,249	410.2	-
3-12-77	1037	5,706	5,562	408.8	-
3-13-77	1233	7,262	7,118	408.5	-
3-14-77	1653	8,962	8,818	408.3	-
3-15-77	1644	10,393	10,249	406.8	-
3-17-77	1041	12,910	12,766	406.0	-

Bailed for sample - end of test

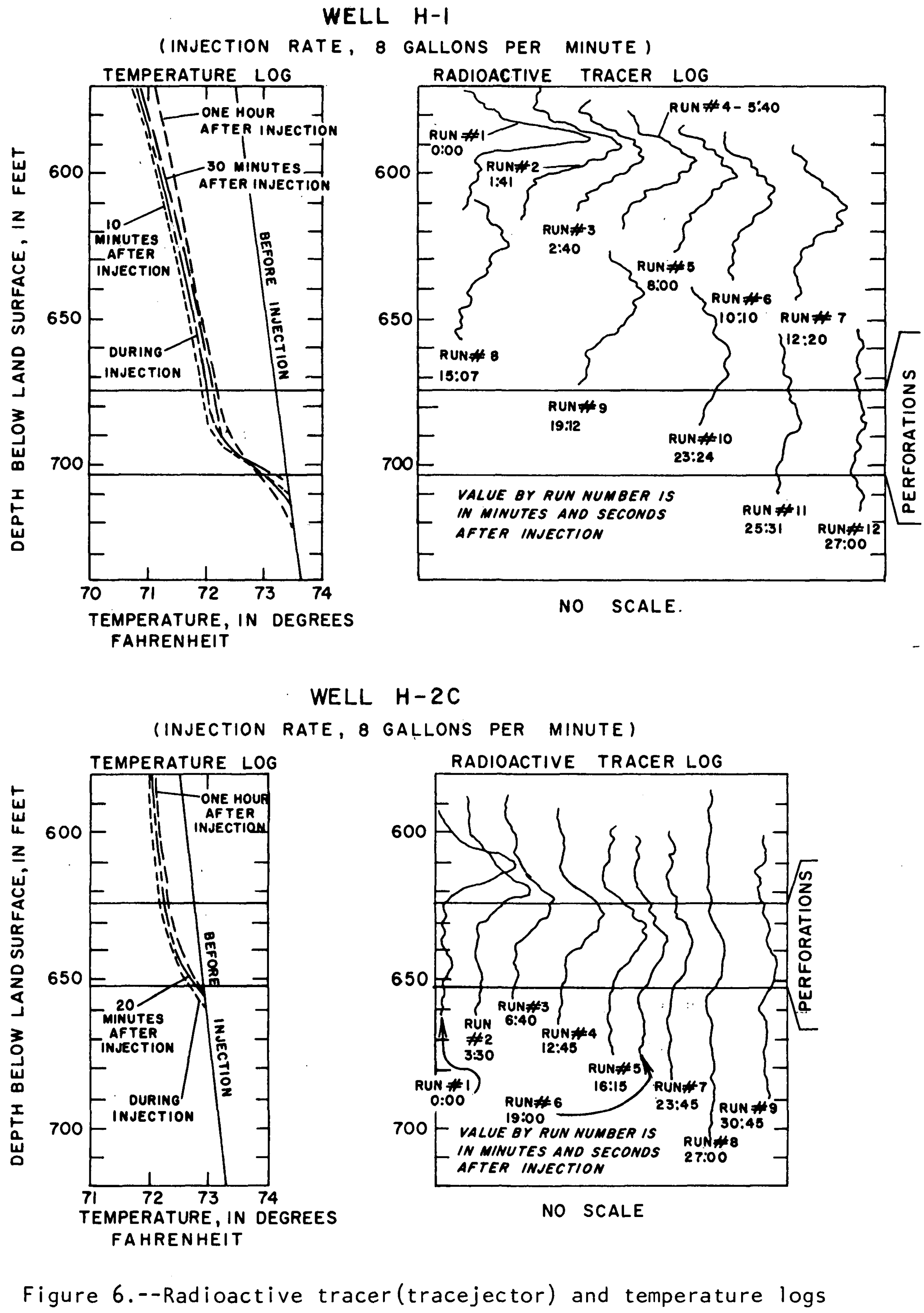


Figure 6.--Radioactive tracer(tracejector) and temperature logs in the Culebra Dolomite Member of Rustler Formation for wells H-1 and H-2c.

Table 6.--Liquid-level recovery data, well H-1 (Magenta Dolomite Member of Rustler Formation)

[Perforated interval 562-590 ft below land surface]

Method of testing: The casing was perforated, the well was bailed, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
4- 6-77	1430	0	-	-	Bailed 67 runs
	2020	350	0	-	-
	2200	450	100	424.5	-
	2240	490	140	421.4	-
	2255	505	155	420.5	-
4- 7-77	1002	1,172	822	391.2	-
	1745	1,635	1,285	383.2	-
4- 8-77	1120	2,690	2,340	363.7	-
4-11-77	1828	7,438	7,088	344.6	-
4-12-77	1142	8,472	8,122	344.6	-
4-13-77	1330	10,020	9,670	344.2	-
4-14-77	1137	11,347	10,997	344.2	-
4-15-77	1212	12,822	12,472	343.4	-
4-22-77	1000	21,330	20,980	343.0	-
5- 6-77	1029	41,519	41,169	341.5	-
5-10-77	0830	47,160	46,810	340.7	-

Bailed for samples - end test

Tubing with a latch-on tool was run on May 13, 1977 to the packer set at 651.3 feet and the tubing was opened to the Culebra zone allowing long-term monitoring of liquid levels in the Culebra through the tubing and of the Magenta in the annulus. The test hole configuration is shown in figure 4. Measurements through October 1977 suggest that the liquid levels in the Culebra were approaching prepumping levels at about 390 feet (table 7) and those in the Magenta at about 249 feet (table 8).

Well H-3

Drilling history.--ERDA Hydro No. 3 (H-3) is located 3,200 feet FNL and 140 feet FEL of sec. 29, T.22 S., R.31 E., in Eddy County, New Mexico. The elevation of the land surface at the drill site is 3,388.7 feet above mean sea level. An abbreviated well chronology is included in table 9.

Surface casing was set on July 15, 1976, to a depth of 38 feet. The test hole was spudded on July 27, 1976. A moist zone was detected in drill cuttings at 175 feet and drilling continued to a depth of 553 feet where geophysical logs were run and hydrologic tests were conducted. After eight hours, no liquid was detected in the open hole. Drilling with air continued until water was encountered at 570 feet where mist drilling was started.

The drill pipe and bit were removed from the hole at 600 feet and a single packer was set at 530 feet to isolate the liquid zone from the rest of the hole. The zone appeared productive and after 30 hours of monitoring the liquid level had risen to 301 feet. After the packer was released and pulled from the hole, drilling of the hole continued from 600 to 894 feet using air mist (1 gallon soap per barrel of water). Geophysical logs were run by the U.S. Geological Survey after drilling was completed. The hole was then cleaned prior to hydrologic testing. After testing (August 2-10, 1976) the hole was reamed in preparation for running casing. The liquid was displaced with brine mud and borehole geophysical logs were run by Dresser Atlas (fig. 7).

Drill-stem tests in the open hole indicated the necessity for further hydraulic testing and the hole was cased on August 12 to a depth of 891 feet. The final hole configuration and well construction specifications are included in figure 8.

Table 7.--Long-term liquid-level recovery data, well H-1 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 675-703 ft below land surface]

Method of testing: A modified drill-stem test was conducted. The packer was opened after being shut in for 1.5 months.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-13-77	1200 (est.)	0	-	Sheared packer plug to open tubing to zone
	1523	203	373.6	-
5-25-77	1120	17,240	388.1	-
6-16-77	1726	49,286	385.65	-
6-23-77	1340	59,140	389.32	-
8- 4-77	1255	119,575	392	-
9- 4-77	1241	164,201	389	-
10- 2-77	0955	204,355	390	-

Table 8.--Long-term liquid-level recovery data, well H-1 (Magenta Dolomite Member of Rustler Formation)

[Perforated interval 562-590 ft below land surface]

Method of testing: Long-term monitoring in annulus was conducted.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-10-77	0930	1,105 hrs.	-	Bailed for sample (51 bailers) 612 gallons
5-12-77	-	-	-	Ran tubing to packer
5-13-77	-	-	-	Ran tubing to packer
5-25-77	1130	-	268.05	-
6-16-77	1720	-	260.2	-
6-23-77	1350	-	258	-
8- 4-77	1250	-	254	-
9- 3-77	1214	-	252	-
10- 3-77	1340	-	249	-

Table 9.--Chronology of well H-3

[All depth measurements adjusted to ground level 3,388.7 ft above mean sea level]

Date 1976	
July 15	Surface pipe set.
July 27	Hole spudded; moisture detected at 175 ft.
July 28	USGS geophysical logs at 384 ft total depth.
July 29	USGS geophysical logs at 524 ft total depth.
July 30	Rotary drilled to 600 ft; liquid encountered at 570 ft; single-inflatable packer set at 530 ft.
July 30-Aug. 1	Liquid levels monitored; released and pulled packer.
Aug. 2	Rotary drilled to 894 ft total depth; USGS ran geophysical logs.
Aug. 3	Set inflatable-straddle packer 800-868 ft; Rustler-Salado contact drill-stem test.
Aug. 3-4	Set inflatable-straddle packer 703-780 ft; salt-residue drill-stem test.
Aug. 6-8	Set inflatable-straddle packer 672-703 ft; drill-stem test in the Culebra.
Aug. 9-10	Set inflatable-straddle packer 558-605 ft; drill-stem test in the Magenta.
Aug. 10-11	Reamed hole for casing.
Aug. 11	Dresser Atlas geophysical logs.
Aug. 12	Casing landed 891 ft; cemented; hole temporarily abandoned.

Table 9.--Chronology of well H-3 - Continued

Date 1977	
Jan. 17-18	Bailed hole dry.
Jan. 20	Drilled cement plug (804-864 ft).
Jan. 21	Bailed hole dry.
Jan. 22	Perforated casing (Rustler-Salado contact, 813-837 ft).
Jan. 22-Feb. 23	Liquid levels monitored.
Feb. 23	Bailed hole dry and sampled (Rustler-Salado).
Feb. 23-Mar. 4	Liquid levels monitored.
Mar. 4	Set inflatable packer (793.5); tubing pulled; hole bailed dry.
Mar. 7	Perforated casing (Culebra, 675-703 ft).
Mar. 9	Bailed hole.
Mar. 9-17	Liquid levels monitored.
Mar. 17	Bailed hole and sampled (Culebra).
Mar. 21	McCullough radioactive tracer survey (^{131}I).
Mar. 23	Bailed hole dry.
Mar. 24	Reran tubing to packer; reopened Rustler-Salado zone.
Mar. 24-30	Liquid levels monitored.
Mar. 30	Closed packer to pull tubing; dropped packer; fishing; pulled packer.
Mar. 31	Set inflatable packer (793.5 ft); pulled tubing.
Apr. 1	Set inflatable packer (652.6 ft).
Apr. 6	Perforated casing (Magenta, 562-590 ft).

Table 9.--Chronology of well H-3 - Concluded

Date	
1977	
Apr. 6-7	Bailed hole.
Apr. 7	Liquid levels monitored.
May 10	Bailed hole and sampled (Magenta).
May 13	Ran tubing with airline; latched on to packer; reopened to Culebra.
May 13-Oct. 1	Monthly measurements.

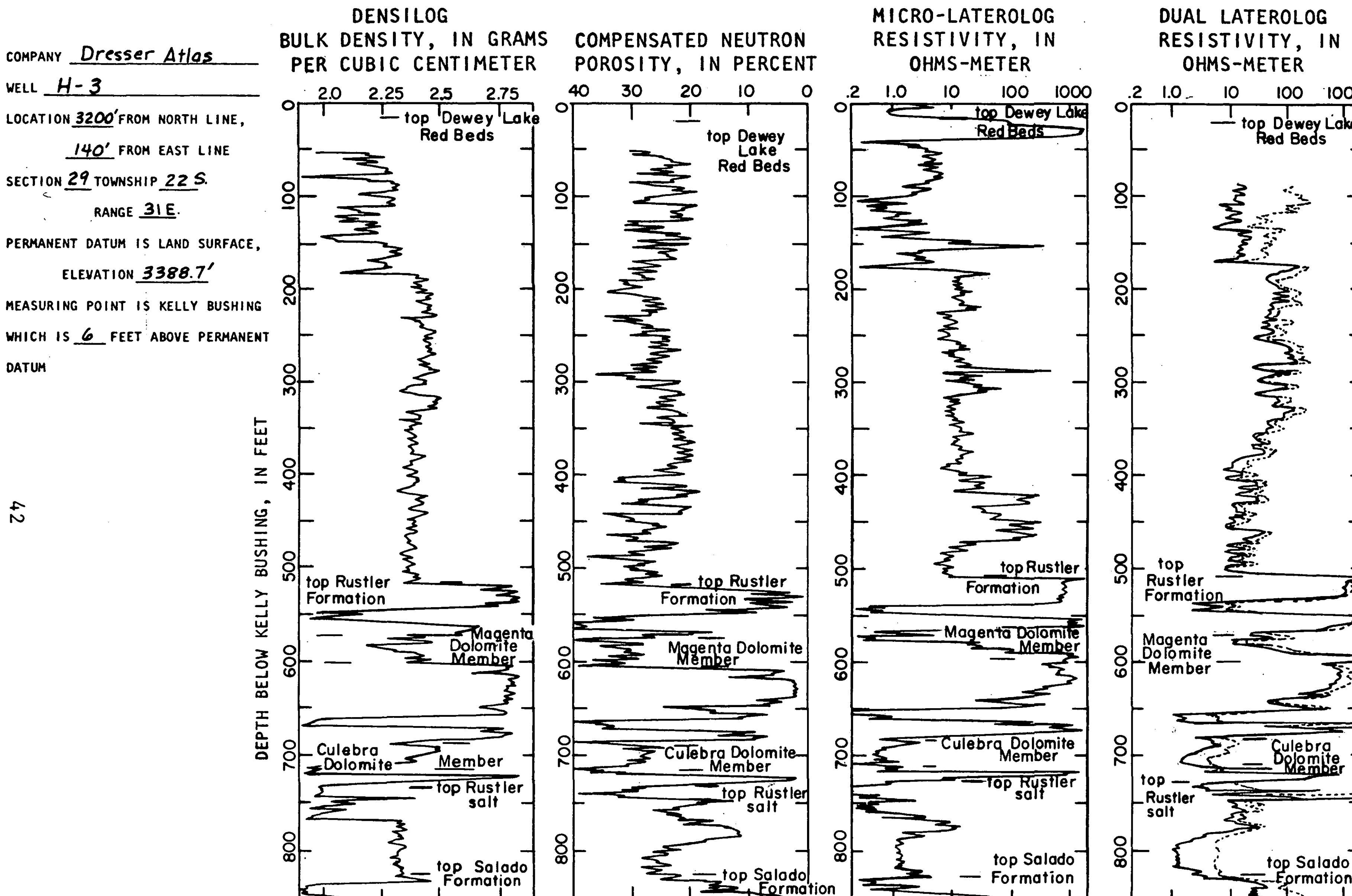
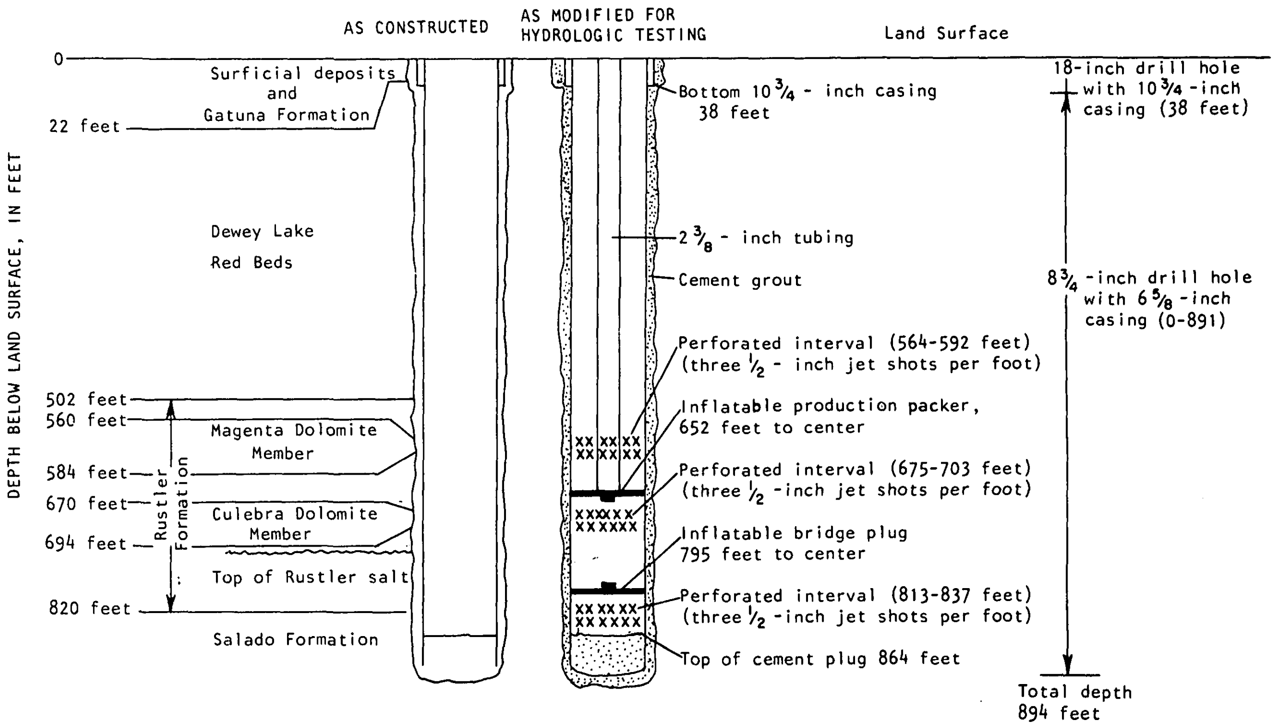


Figure 7.--Selected geophysical logs for well H-3.



LOCATION: 3,200 feet from north line, 140 feet from east line, section 29, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,388.7 feet (ground level)

DEPTH DRILLED: 894 feet (864 feet to top cement plug)

DATE COMPLETED: August 12, 1976

DRILLING CONTRACTOR: Pennsylvania Drilling Company, Carlsbad, New Mexico

DRILLING METHOD: Auger 18-inch hole (0-38 feet)
Rotary 7 7/8-inch hole with air and air mist (38-894 feet)
Ream 8 3/4-inch hole (38-894 feet)
Rotary cement plug (804-864 feet)

WELL CASING RECORD: 10 3/4-inch outside diameter steel surface pipe (0-38 feet) cemented to surface, 6 5/8-inch outside diameter steel casing, 24 pounds, 1.43 gallons per foot (0-891 feet), cemented to surface (cement plug to 804 feet, drilled to 864 feet)

GEOPHYSICAL LOGS:

Shown in figure 7: Compensated Densilog, Microlaterolog, Dual Laterolog, Compensated Neutron

Not shown in figure 7: BHC Acoustilog, Differential Temperature, Gamma

Figure 8.--Well H-3 construction, completion, and specifications.

Hydrologic testing.--As in H-1, modified drill-stem tests of ERDA H-3 were conducted at the contact between the Rustler and Salado Formations, the Culebra Dolomite Member of the Rustler, a possible salt-residue zone in the Rustler, and the Magenta Dolomite Member of the Rustler (fig. 9).

The drill-stem test of the contact between the Rustler and Salado Formations (potential "brine aquifer" horizon) was made in an interval of open hole from 800 to 868 feet using an inflatable straddle packer to isolate the interval from the rest of the hole (fig. 9). After the tubing was swabbed, the packer was opened and after 16.5 hours of monitoring, the test zone had produced only 1.8 gallons of liquid. Low permeability resulting in long intervals of recovery time thus precluded continued testing. An attempt was made to swab and develop the zone but the formation would not yield liquid.

The drill-stem test of the Culebra was made using an inflatable straddle packer to isolate an interval of open hole from 672 to 703 feet (fig. 9). The tubing was opened to the test zone and after 21.5 hours the liquid level had risen in the tubing only 13.5 feet, representing 2.1 gallons of produced liquid. Low formation yields resulting in long recovery periods were again characteristic of this interval. The test zone was swabbed with a recovery of only 10 gallons of liquid.

The drill-stem test of the suspected salt-residue zone (picked from geophysical logs) was made in an interval of open hole from 703 to 780 feet which had been isolated from the rest of the hole by inflatable straddle packers (fig. 9). The tubing was opened to the test zone and after 26 hours of monitoring the formation had produced only 2 gallons of liquid.

Two drill-stem tests were made on the Magenta Dolomite Member. Data from the first drill-stem test on the Magenta, with a single packer at 530 feet, was suspect because liquid monitoring in the annulus indicated possible communication around the packer, therefore, a second drill-stem test of the Magenta was made in an isolated interval of open hole from 558 to 608 feet (fig. 9). The zone was developed by swabbing and after 37.5 hours of monitoring, the zone produced 23 gallons of liquid. Swabbing of the zone after the drill-stem test produced 442 gallons of liquid.

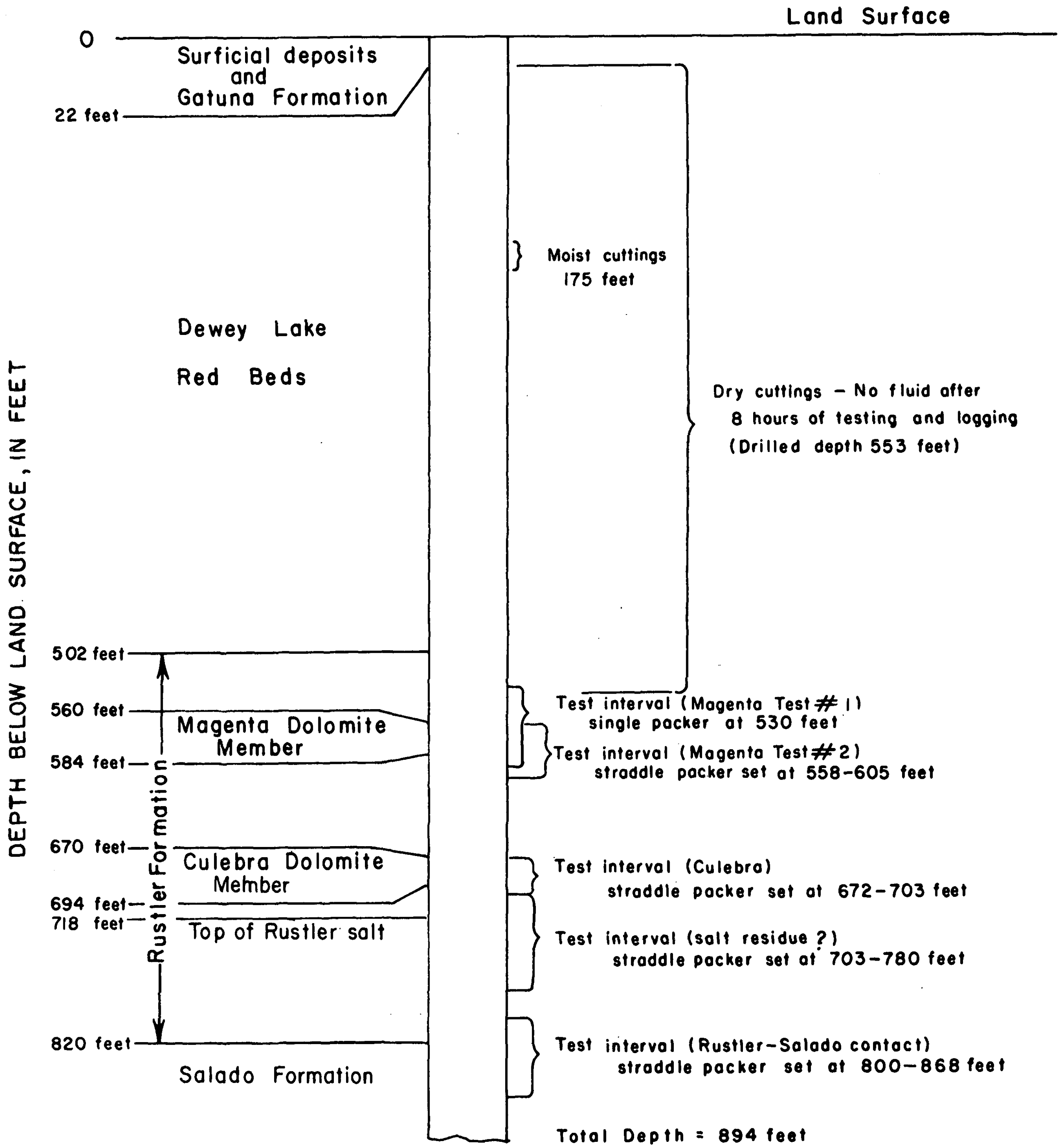


Figure 9.--Open-hole intervals tested in well H-3.

After casing was set and cemented on August 12, 1976, H-3 was temporarily abandoned until January 20, 1977. At that time the cement at the bottom of the hole was drilled out and the hole was bailed dry. On January 22, the casing opposite the Rustler-Salado contact was perforated from 813 to 837 feet (fig. 8). Liquid levels were monitored in the hole and after 32 days the liquid level had risen from 850 to 824 feet, about 12 feet below the top perforations (table 10) and was still rising. Thirty-seven gallons of liquid were produced from the test interval. The hole was bailed and a liquid sample was collected for chemical analyses on February 23, 1977 (table 2). An inflatable packer was run on tubing and set at 793.5 feet on March 4, sealing off the Rustler-Salado perforations from the rest of the hole. Casing adjacent to the Culebra was perforated in a dry hole from 675 to 703 feet on March 7 (fig. 8). A total of 480 gallons of liquid was bailed from the hole after perforating. After 8 days, the liquid level had risen from 550 to 410 feet (table 11) and 200 gallons of liquid had been produced from the formation. On March 17 the hole was bailed (168 gallons) and a liquid sample was collected for chemical analyses (table 2).

A tracer (^{131}I) and temperature survey was run on the perforated interval of the Culebra on March 21, 1977, to determine the interval of liquid loss and to detect possible communication or channeling within the cemented annulus. The survey was run with liquid injection rates of approximately 8 gal/min with a total of 450 gallons of liquid injected into the formation. The radioactive tracer (fig. 10) indicated major liquid losses of 36 percent in the interval from 684 to 692 feet and of 64 percent in the interval from 692 to 695 feet. There was no indicated flow below 696 feet. The tracer survey also gave no indication of communication or channeling within the cemented annulus above or below the perforated interval. After the injection test, the hole was bailed dry.

On March 24 a latch-on tool on tubing was run and latched onto the bridge packer that had been set at 793.5 feet. The tubing was then opened to the Rustler-Salado contact and liquid levels were monitored for six days (table 10). There was very little change in water levels from those of the test made on February 23. The zone was shut in and tubing was removed from the hole.

Table 10.--Liquid-level recovery data, well H-3 (Rustler-Salado contact)

[Perforated interval 812-837 ft below land surface]

Method of testing: The casing was perforated and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
1-22-77	0836	0	-	Perforated zone 813-837 ft
	0945	69	850	-
	1000	84	850	-
	1015	99	850	-
1-23-77	1042	1,566	851.0	-
1-24-77	1130	3,054	850.6	-
1-27-77	1100	7,344	848.0	-
2- 2-77	1220	16,064	842.2	-
2- 6-77	1100	21,744	837.6	-
2-12-77	1400	30,564	832.3	-
2-15-77	1532	34,976	831.1	-
2-17-77	1540	37,864	829.3	-
2-23-77	1051	46,215	823.6	-

End test - bailed, shut in

Table 10.--Liquid-level recovery data, well H-3 (Rustler-Salado contact) - Concluded

Method of testing: The shear plug was knocked out, opening the zone to the tubing for monitoring.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
3-24-77	1429	0	-	Packer opened
	1448	19	820.4	-
3-25-77	1324	1,335	825.3	-
3-26-77	1240	2,691	821.7	-
3-27-77	1048	3,939	819.7	-
3-28-77	1150	5,481	822.0	-
3-29-77	1149	6,920	823.3	-
		shut in		

Table 11.--Liquid-level recovery data, well H-3 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 675-703 ft below land surface]

Method of testing: The casing was perforated, the hole was bailed dry, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3- 7-77	-	-	-	-	Perforated
3- 9-77	0700	0	-	-	Bailed 480 gallons 40 runs
	0947	167	0	-	-
	0955	175	8	549.9	-
	0957	177	10	545.3	-
	0958	178	11	541.8	-
	0959	179	12	539.8	-
	1000	180	13	536.8	-
	1005	185	18	523.5	-
	1010	190	23	511.6	-
	1015	195	28	500.8	-
	1020	200	33	491.0	-
	1030	210	43	473.7	-
	1040	220	53	458.6	-
	1050	230	63	446.9	-
	1100	240	73	437.1	-
	1120	260	93	425.3	-
	1141	281	114	419.4	-
	1201	301	134	417.7	-
	1234	334	167	417.1	-
	1318	378	211	416.8	-
	1413	433	266	416.4	-
	1952	772	605	415.6	-
3-10-77	0935	1,595	1,428	414.5	-
	1105	1,685	1,518	414.4	-
3-11-77	1258	3,238	3,071	411.2	-
3-12-77	1022	4,522	4,355	411.4	-
3-13-77	1218	6,078	5,911	411.7	-
3-14-77	1642	7,782	7,615	411.3	-
3-15-77	1712	9,252	9,085	410.0	-
3-17-77	1204	11,824	11,657	409.8	-

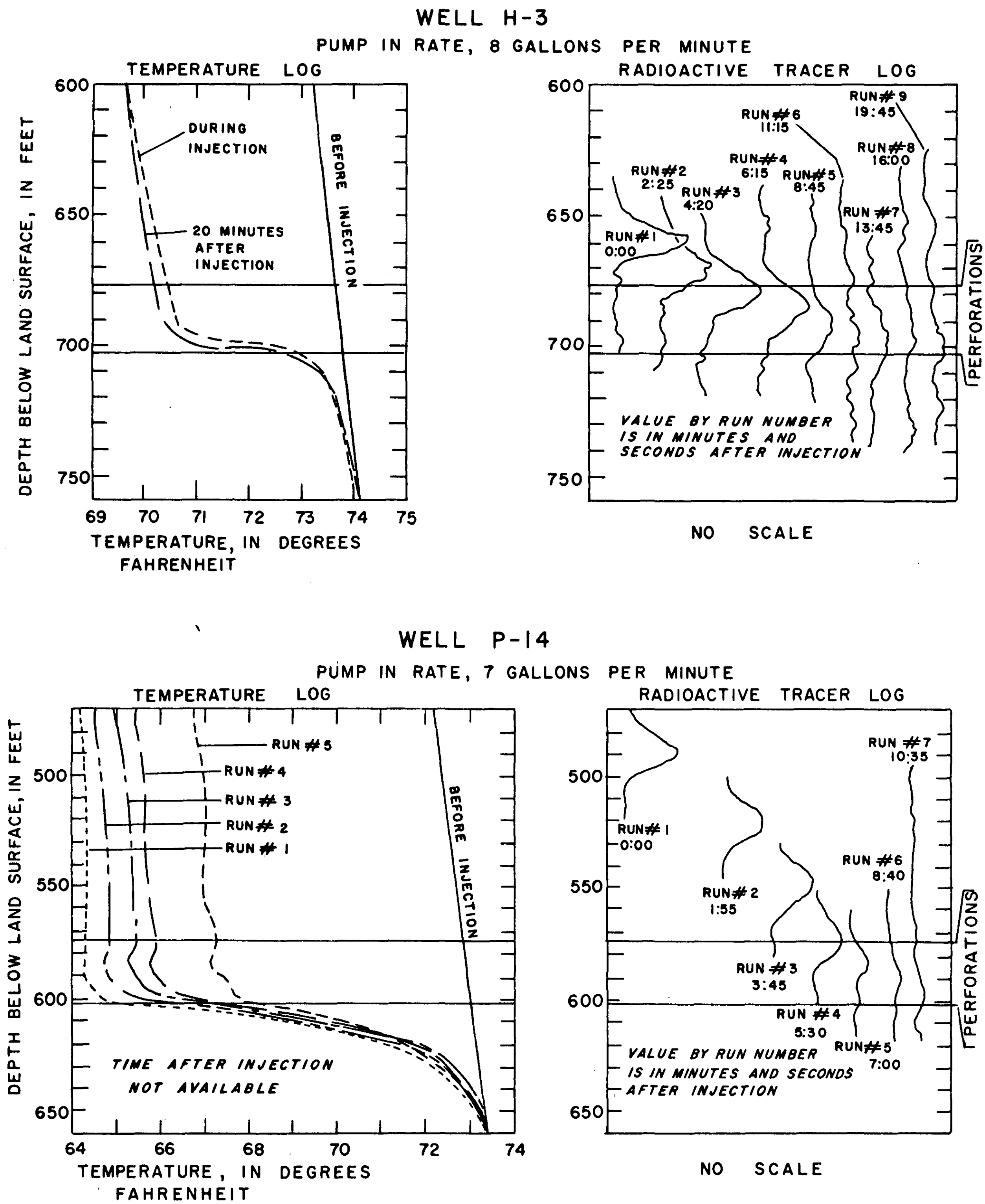


Figure 10.--Radioactive tracer (tracejector) and temperature logs in the Culebra Dolomite Member of Rustler Formation for wells H-3 and P-14.

An inflatable-retrievable bridge packer was set at 652.6 feet, sealing the Culebra from the rest of the hole. The tubing was pulled on April 6, 1977; the zone opposite to the Magenta was then perforated from 564 to 592 feet (fig. 8). The hole was bailed on April 6 to develop the test zone. On April 7, 360 gallons of liquid were bailed from the hole in 1 hour with a resultant drop of only 6 feet in the liquid level. Liquid levels were monitored for 33 days in which time the liquid recovered from 405 to 401 feet (table 12). The well was bailed on May 10 (624 gallons) and a sample was collected for chemical analyses (table 2). On May 25 the liquid level was 299 feet, which was 102 feet higher than the measurement made prior to bailing on May 10 (table 12). This difference probably resulted from blocked perforations on the early tests. Tests indicated that the zone was productive and may lend itself to pump testing at a later time.

Tubing with a latch-on tool was run to the bridge packer on May 13. The Culebra was then reopened to the tubing and the test hole was put into a long-term dual-completion phase (fig. 8). The Culebra was monitored through the tubing and the Magenta in the annulus. As of October 1977 periodic measurements indicate that liquid levels were becoming stabilized. The Culebra liquid level was at about 405 feet (table 13) and the Magenta liquid level at about 245 feet (table 14).

Well complex H-2

Drilling program.--Modified open-hole drill-stem tests in H-1 and H-3 required long-term testing and monitoring because of the low permeabilities. For this reason, the H-2 drilling program was altered. The alternative program was to drill a closely spaced nest of three holes (fig. 1), one for each potential liquid-bearing zone. The individual holes were drilled to a point above the zone, and casing was run and cemented to the surface. The zone was then cored and prepared for open-hole testing (table 15). The zones tested included the Rustler-Salado contact and the Culebra and Magenta Dolomite Members of the Rustler Formation.

Drilling history.--The H-2 complex (H-2a, H-2b, and H-2c) consists of three closely spaced holes around a point 720 feet FNL and 3,584 feet FEL, sec. 29, T.22 S., R.31 E. The ground level at the drill site is 3,377.1 feet above mean sea level. The three holes were located in a close triangular array (fig. 1) which provided an opportunity for later interference testing between holes and for evaluation of possible vertical hydraulic connection between zones. An abbreviated well chronology is included in table 15.

Table 12.--Liquid-level recovery data, well H-3 (Magenta Dolomite Member of Rustler Formation)

[Perforated interval 564-592 ft below land surface]

Method of testing: The casing was perforated, the hole was bailed, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
4- 6-77	-	-	-	-	Perforated zone
4- 7-77	0955	-	-	405.1	Bailed 30 runs (360 gallons)
	1000	0	-	-	
	1100	-	0	-	-
	1110	-	10	411.1	-
	1120	-	20	410.8	-
	1130	-	30	409.6	-
	1145	-	45	409.1	-
	1200	-	60	408.8	-
	1210	-	70	408.6	-
	1755	-	415	408.4	-
4- 8-77	1130	-	1,470	404.1	-
4-11-77	1839	-	6,219	402.0	-
4-12-77	1156	-	7,256	402.7	-
4-13-77	1342	-	8,802	402.7	-
4-14-77	1125	-	10,105	402.4	-
4-15-77	1202	-	11,582	401.5	-
4-22-77	1010	-	21,550	401.1	-
5- 6-77	1022	-	41,722	401.0	-
5-10-77	0855	-	47,395	401.3	-

End test - bailed

Table 13.--Long-term liquid level recovery data, well H-3 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 675-703 ft below land surface]

Method of testing: The tubing was reopened to zone for long-term monitoring.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-12-77	1200	0	-	-
5-13-77	1536	1,656	403.7	Sheared plug in inflatable-packer to open zone to tubing
5-25-77	1225	18,745	405.1	-
6-23-77	1245	60,525	405.2	-
8- 4-77	1320	121,040	404.8	-
9- 4-77	1229	165,629	404	-
9-28-77	1200	200,160	407	-

Table 14.--Long-term liquid-level recovery data, well H-3 (Magenta Dolomite Member of Rustler Formation)

[Perforated interval 564-592 ft below land surface]

Method of testing: Tubing was opened to the Culebra interval, and liquid levels were monitored on a long-term basis.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-10-77	1300	0	-	Bailed 52 bailers = 624 gallons
5-25-77	1230	21,570	299	-
6-23-77	1312	63,372	249.7	-
8- 4-77	1340	79,240	250.0	-
9- 3-77	1159	122,339	249	-
10- 3-77	1305	210,245	248.0	-

Table 15.--Chronology of well complex H-2

[All depth measurements adjusted to ground level, 3,377 ft above mean sea level]

Well H-2a Date 1977	
Jan. 24-25	Surface pipe set.
Feb. 14	Hole spudded.
Feb. 15	Open hole tested (0-188 ft) 5 hours; no appreciable liquid.
Feb. 16	Rotary drilled to 513 ft.
Feb. 17	USGS ran caliper log; casing landed at 511 ft and cemented.
Feb. 19	Magenta cored (513-563 ft); hole bailed dry.
Feb. 22	Hole cleaned up, bailed, and liquid sampled.
Feb.22- Apr. 6	Liquid levels monitored.
Apr. 6- Oct. 1	Monthly measurements.

Table 15.--Chronology of well complex H-2 - Continued

Well H-2b

Date	
1977	
Jan. 24-25	Surface pipe set.
Feb. 7	Hole spudded; moist cuttings 185 ft.
Feb. 10	Rotary drilled to 611 ft; casing landed at 609 ft and cemented.
Feb. 12	Culebra cored (611-661 ft).
Feb. 13	Hole bailed dry.
Feb. 13-21	Liquid levels monitored.
Feb. 22	Hole bailed dry and sampled.
Feb.22-Apr. 1	Liquid levels monitored.
Apr. 4	Inflatable packer set at 585.9 ft and tubing pulled.
Apr. 6	Perforated casing (Magenta 510-538 ft).
Apr. 8	Hole bailed dry.
Apr. 8-May 13	Liquid levels monitored.
May 13	Packer released and pulled; Sentry device set below inflatable packer at 578 ft; tubing opened to Culebra.
May 13-Oct. 1	Monthly measurements.

Table 15.--Chronology of well complex H-2 - Concluded

Well H-2c

Date 1977	
Jan. 24-25	Surface pipe set.
Jan. 27	Hole spudded; moist zone at 181 ft; first liquid at 515 ft.
Jan. 31	Rotary drilled to 743 ft.
Feb. 1	USGS geophysical logs.
Feb. 2	Dresser Atlas geophysical logs; casing landed at 742 ft; cement.
Feb. 4-5	Rustler-Salado contact cored (743-795 ft).
Mar. 3	Set inflatable packer at 731.9 ft; pulled tubing; bailed dry.
Mar. 7	Perforated casing, (Culebra, 624-652 ft).
Mar. 8	Bailed hole.
Mar. 8-16	Liquid levels monitored.
Mar. 16	Hole bailed and sampled (Culebra).
Mar. 21	Ran radioactive tracer survey (^{131}I) and temperature log.
Mar. 23	Bailed hole dry.
Mar. 25	Reran tubing; reopened Rustler-Salado zone to tubing.
Mar. 25-May 25	Liquid levels monitored.
May 25-Oct. 1	Monthly measurements.

Hole H-2c was spudded on January 27, 1977 and moisture was detected in the drill cuttings at 181 feet. Drilling continued from 181 to 188 feet with no cutting returns; at this time the circulating medium was changed to air mist. Drilling continued with air mist to a depth of 615 feet where liquid was encountered. After the depth of liquid entry was noted, drilling continued to a total depth of 743 feet. Geophysical logs were run by the U.S. Geological Survey after drilling was completed. The hole was then conditioned, loaded with mud gel, and logged by Dresser Atlas (fig. 11).

Hole H-2c was designed to test the Rustler-Salado contact. Casing was set and cemented on February 2 to a depth of 741.6 feet below land surface. After waiting 36 hours for the cement to set, the casing was blown dry and the interval from 743 to 795 feet was cored with air mist, with 100 percent core recovery. A lithologic description of the core, the final hole configuration, and well-construction specifications are included in figure 12.

Hole H-2b was spudded on February 7, 1977. At 185 feet, moisture was detected in the cuttings and partial loss of drill cuttings occurred. The circulating medium was changed to air mist (3 gal/min with soap). No additional liquid was detected and the hole was drilled to 611 feet below land surface. After the hole was loaded with mud gel, casing was set and cemented on February 10 to 609 feet below land surface. After the cement had set for 36 hours, the casing was blown dry. The interval from 611 to 661 feet was cored using air mist, with 100 percent core recovery. A lithologic description of the core, final hole configuration, and well-construction specifications are included in figure 13.

Hole H-2a was spudded on February 14, 1977. At 185 feet, moisture was detected in the cuttings, and drilling continued to 188 feet with no return of cuttings. The drill pipe was removed and the hole was monitored for five hours. During monitoring, very little liquid was detected in the hole. After the test was completed, drilling continued with air mist to a casing depth of 513 feet below land surface. The hole was loaded with mud gel and casing was set and cemented to a depth of 511 feet. After the cement had set for 36 hours, the casing was blown dry. The interval from 513 feet to 563 feet was cored using air mist, with 100 percent core recovery. A lithologic description of the core, final hole configuration, and well-construction specifications are included in figure 14.

Hydrologic testing.--Hydrologic testing on H-2c began February 5, 1977 with monitoring of liquid produced from the Rustler-Salado cored interval, and continued through February 23, 1977. The test interval produced only 14 gallons of liquid, raising the water level 15 feet. On February 23, 1977, the hole was bailed dry and samples were recovered for chemical analyses (table 2).

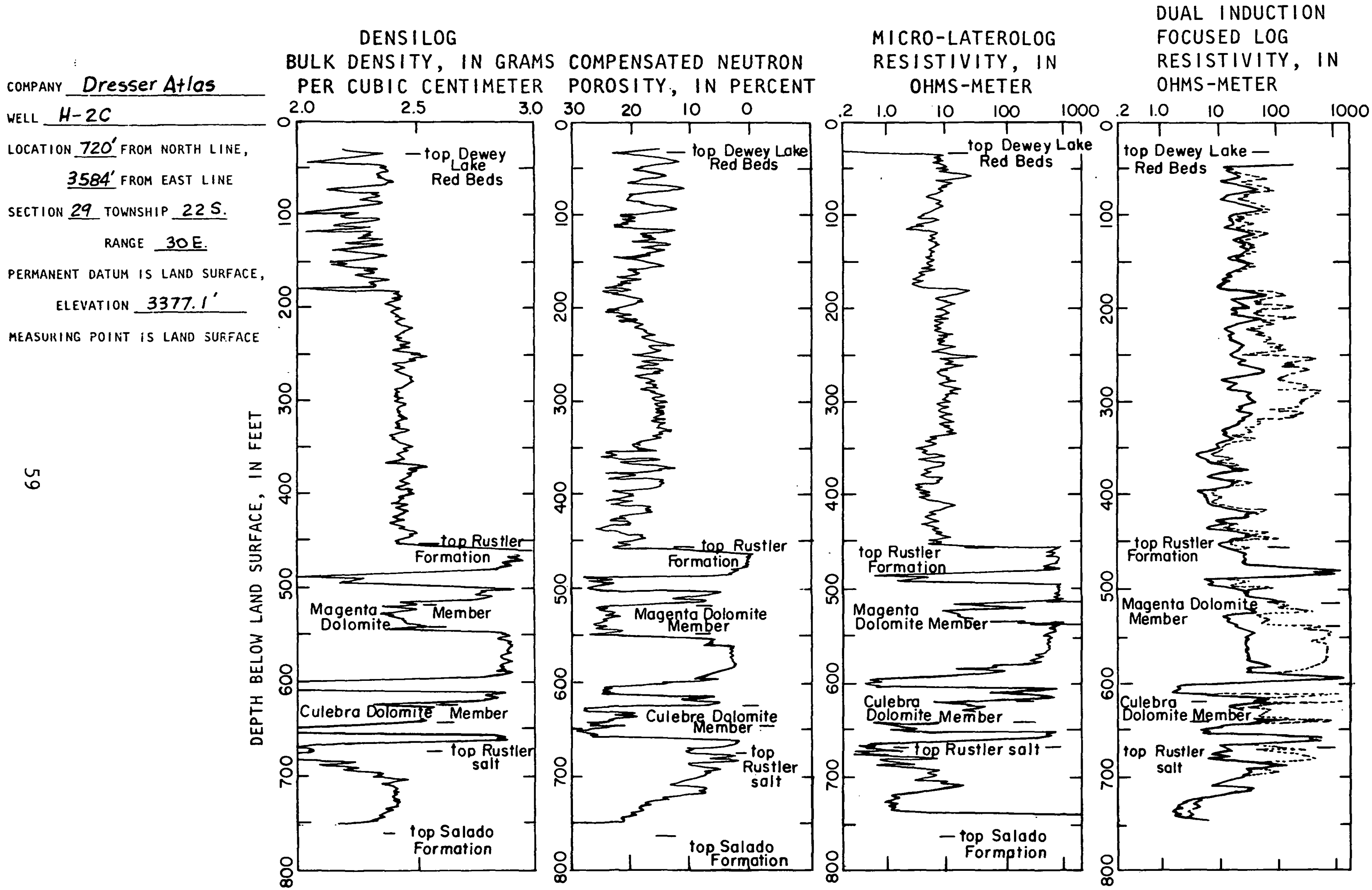
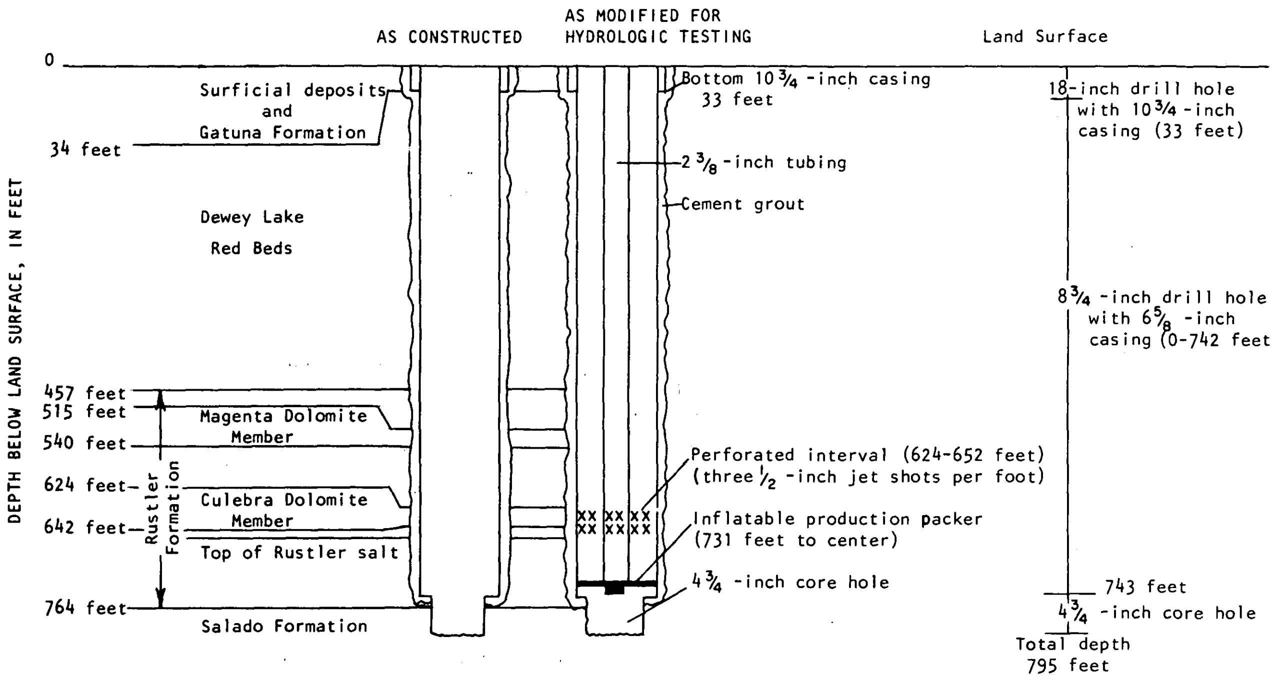


Figure 11. Selected geophysical logs for well H-2c.



LOCATION: 720 feet from north line, 3,584 feet from east line, section 29, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 795 feet

DATE COMPLETED: February 5, 1977

DRILLING CONTRACTOR: Pennsylvania Drilling Company, Carlsbad, New Mexico

DRILLING METHOD: Auger 18-inch hole (0-33 feet), Rotary 8 3/4-inch hole with air and air mist (33-743 feet), Core 4 3/4-inch hole with air mist (743-795 feet) (cut 2 1/4-inch diameter core)

WELL CASING RECORD: 10 3/4-inch steel casing (0-33 feet) cemented to surface; 6 5/8-inch outside diameter steel casing; 24 pounds; 1.43 gallons per foot (0-742 feet); centralizers at 260 feet, 460 feet, 580 feet and 700 feet; cemented to surface

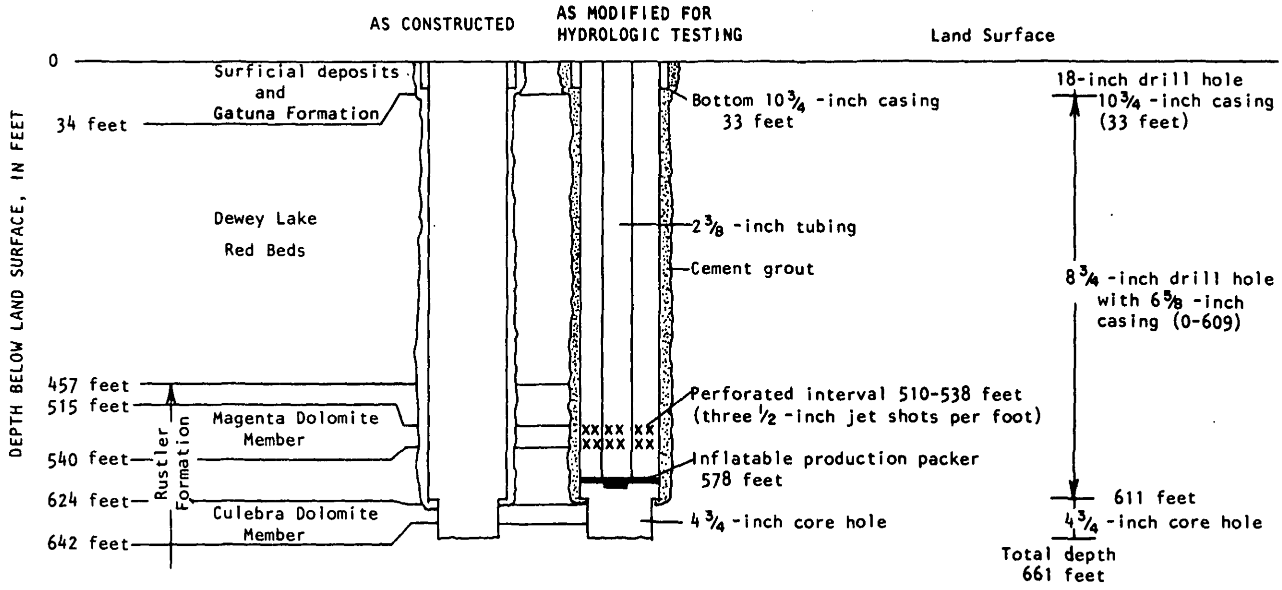
GEOPHYSICAL LOGS:

Shown in figure 11: Compensated Densilog, Dual Laterolog, Microlaterolog, Compensated Neutron
Not shown inuigure 11: BHC Acoustilog, 4-Arm Caliper, USGS Lithologic log, Gamma

CORE DESCRIPTION: Rustler-Salado cored interval (743-795 feet)

Depth (feet)	Description
743 - 762.2	Gray mudstone with pink halite vugs and clear halitic fracture fillings, gradational downward to banded, red, halitic mudstone.
762.2 - 764.1	Red-brown halitic mudstone.
764.1 - 767.3	Red-brown, argillaceous halite.
767.3 - 772.5	Red-orange polyhalitic halite with polyhalite blebs and bands.
772.5 - 773.5	Red-brown halitic clay and red-brown argillaceous halite.
773.5 - 795.6	Light pink to light red-orange polyhalitic halite, minor clay partins, with brown halitic clay at base.

Figure 12.--Well H-2c construction, completion, and specifications.



LOCATION: 720 feet from north line, 3,584 feet from east line, section 29, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 795 feet

DATE COMPLETED: February 5, 1977

DRILLING CONTRACTOR: Pennsylvania Drilling Company, Carlsbad, New Mexico

DRILLING METHOD: Auger 18-inch hole (0-33 feet); Rotary 8 3/4-inch hole with air and air mist (33-611 feet); Core 4 3/4-inch hole with air mist (611-661 feet) (cut 2 1/4-inch diameter core)

WELL CASING RECORD: 10 3/4-inch outside diameter casing (0-33 feet) cemented to surface; 6 5/8-inch outside diameter steel casing, 24 pounds, 1.43 gallons per foot (0-609 feet), centralizers at 406 feet and 568 feet, cemented to surface

GEOPHYSICAL LOGS: (See H-2C)

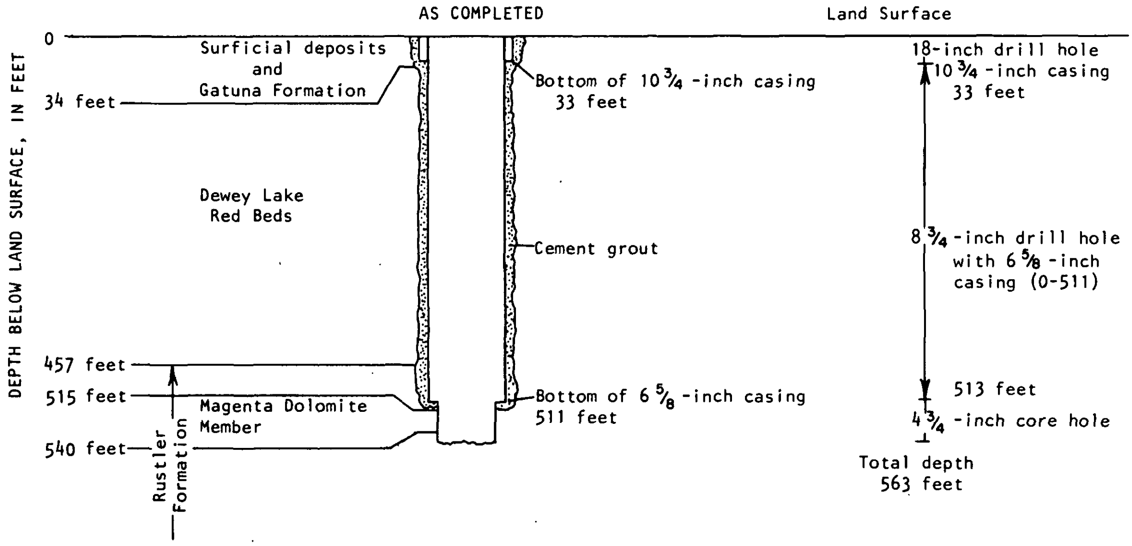
CORE DESCRIPTION:

Culebra Dolomite cored interval (611-661 feet)

Depth (feet)	Description
611 - 624.2	Dense gray anhydrite, massive to banded
624.2 - 642.0	Brown silty dolomite with selenitic fracture fillings and crystals, pitted and fractured from 629.5 to 642.0 feet
642.0 - 644.0	Gray mudstone
644.0 - 652.0	Red-brown selenitic siltstone
652.0 - 660.7	Dense gray anhydrite

Figure 13.--Well H-2b construction, completion, and specifications.

Figure 13.--Well H-2b construction, completion, and specifications.



LOCATION: 720 feet from north line, 3,584 feet from east line, section 29, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,377.1 feet (ground level)

DEPTH DRILLED: 563 feet

DATE COMPLETED: February 19, 1977

DRILLING CONTRACTOR: Pennsylvania Drilling Company, Carlsbad, New Mexico

DRILLING METHOD: Auger 18-inch hole (0-33 feet); Rotary 8 3/4-inch hole with air and air mist (33-513 feet); Core 4 3/4-inch hole with air mist (513-563 feet) (cut 2 1/4-inch diameter core)

WELL CASING RECORD: 10 3/4-inch outside diameter steel casing (0-33 feet) cemented to surface
6 5/8-inch outside diameter steel casing; 24 pounds; 1.43 gallons per foot (0-511 feet); centralizers at 270 feet, 350 feet, and 469 feet; cemented to surface

GEOPHYSICAL LOGS: (See H-2C)

CORE DESCRIPTION:

Magenta Dolomite cored interval (513-563 feet)

Depth (feet)	Description
511.7 - 513	Cement
513.0 - 514.6	Dense gray anhydrite
514.6 - 539.6	Gray-brown silty dolomite with some fractures in the interval 537.5-539.6 feet
539.6 - 563	Brown-gray banded anhydrite

Figure 14.--Well H-2a construction, completion, and specifications.

An inflatable-retrievable production packer was set at 731.9 feet on March 3, 1977, sealing off the Rustler-Salado cored interval from the rest of the hole, and the tubing was pulled.

On March 7, 1977, the casing was perforated from 624 feet to 652 feet (fig. 12). The hole was bailed March 8, and Culebra zone fluid levels were monitored until March 16, at which time the water level had risen to 352.4 feet below land surface (table 16). On March 16 the hole was bailed and samples were taken for chemical analyses (table 2).

A tracer (^{131}I) and temperature survey made on March 21, 1977, in H-2c indicated no significant upward or downward movement within the cemented annulus. Movement of the radioactive tracer outward from the borehole occurred from 631 to 644 feet; the majority of this liquid loss occurred from 640 to 644 feet (fig. 6). This coincides with the core description from H-2b (fig. 13) which indicated the occurrence of pitted dolomite from 629.5 feet to 642 feet, and with significant fracturing from 635 to 642 feet. No flow was indicated within the casing below 644 feet. The survey was run down the casing with a fluid pump-in rate of approximately 8 gal/min for a total of 697 gallons injected into the test interval. On March 23 the hole was bailed to remove contaminants.

On March 25, a latch-on tool was run on tubing to the packer and the tubing was opened to the Rustler-Salado interval. The well was placed into a long-term dual-completion monitoring phase, with Rustler-Salado water-level measurements being made in the tubing and Culebra water-level measurements being made in the annulus (fig. 12). As of October 1, 1977, the Culebra water level was approaching prepumping levels at 355 feet (table 17) and the Rustler-Salado zone was still recovering, with a change in water levels of 34 feet from September to October (table 18).

Hydrologic testing of H-2b began on February 13, 1977 by bailing liquid from the Culebra cored interval (611 to 661 feet). The hole was bailed nearly dry and liquid levels were monitored from February 13 to February 21, 1977, at which time the liquid level stood at 352 feet below land surface (table 19). On February 22, 1977, the hole was again bailed dry and water samples were taken for chemical analyses (table 2). After liquid levels were monitored from February 22, 1977 to March 7, 1977, the Culebra zone in H-2c was again bailed and the response was noted in H-2b. On March 16, 1977, the test was repeated with close monitoring of H-2b liquid levels (table 19). The first response was detected 54 minutes after bailing commenced.

Table 16.--Liquid-level recovery data, well H-2c (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 624-648 ft below land surface]

Method of testing: Casing was perforated, the hole was bailed, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3- 8-77	1020	0	-	-	22 bailers, 264 gallons
	1122	62	0	-	-
	1143	83	21	656.4	-
	1146	86	24	655.0	-
	1150	90	28	654.7	-
	1155	95	33	653.6	-
	1200	100	38	652.4	-
	1210	110	48	650.0	-
	1220	120	58	647.5	-
	1230	130	68	645.4	-
	1245	145	83	643.2	-
	1300	160	98	639.2	-
	1315	175	113	635.2	-
	1330	190	128	631.8	-
	1345	205	143	628.9	-
	1400	220	158	625.4	-
	1415	235	173	622.5	-
	1430	250	188	619.2	-
	1445	265	203	616.5	-
	1500	280	218	613.4	-
	1625	365	303	596.5	-
	1840	500	438	571.8	-
	1935	555	493	563.0	-
3- 9-77	0730	1,270	1,208	474.6	-
	1255	1,595	1,533	446.6	-
3-10-77	0905	2,805	2,743	392.6	-
3-11-77	1156	4,416	4,354	367.2	-
3-12-77	1053	5,793	5,731	360.7	-
3-13-77	1247	7,347	7,285	355.5	-
3-14-77	1242	8,782	8,720	353.0	-

Table 16.--Liquid level recovery data, well H-2c (Culebra Dolomite Member of Rustler Formation) - Concluded

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3-15-77	1603	10,423	10,361	354.0	-
3-16-77	1200	11,620	11,558	352.4	-

Bailed - end of test

Table 17.--Long-term liquid-level recovery data, well H-2c (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 624-648 ft below land surface]

Method of testing: Long-term monitoring began following dual completion of the well.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
3-25-77	1100	0	-	Ran tubing in hole
3-27-77	1006	2,826	352.5	-
3-28-77	1348	4,488	352.6	-
3-29-77	1024	5,724	352.2	-
4- 7-77	1030	18,690	348.2	-
4-12-77	1126	25,946	353.8	-
4-14-77	1227	28,887	353.5	-
4-15-77	1251	30,351	352.7	-
4-22-77	0950	40,250	351.7	-
5- 6-77	1045	60,465	351.7	-
5-25-77	1000	87,780	348.8	-
6-23-77	1415	129,795	354.2	-
8- 4-77	1230	190,170	354	-
9- 4-77	1921	233,781	350	-
10- 6-77	1020	280,760	355.9	-

Table 18.--Long-term liquid-level recovery data, well H-2c

(Rustler-Salado contact)

[Perforated interval 743-795 ft below land surface]

Method of testing: The packer plug was sheared to open the zone to the tubing and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)
3-25-77	1133	0	-
	1143	10	753.4
3-26-77	1032	1,379	768.1
	1135	1,442	768.7
3-27-77	0954	2,781	768.4
3-28-77	1330	4,437	769.4
3-29-77	1008	5,675	769.6
4- 1-77	1555	10,342	767.6
4- 4-77	1100	14,367	767.3
4- 7-77	1020	18,647	765.4
4-12-77	1115	25,902	761.3
4-14-77	1218	28,845	759.4
4-15-77	1244	30,311	759.2
4-22-77	0945	40,212	757.1
5- 6-77	1040	60,427	751.1
5-25-77	1006	87,753	746
8- 4-77	1300	190,167	689
9- 4-77	1915	235,182	640
10- 2-77	1015	274,962	606

Table 19.--Liquid-level recovery data, well H-2b (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 611-661 ft below land surface]

Method of testing: H-2b was bailed dry and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
2-13-77	0600	0	-	-	10 bailers = 70 gallons
	0630	30	0	-	-
	0724	84	54	636.9	-
	0736	96	66	632.9	-
	0748	108	78	628.9	-
	0758	118	88	625.8	-
	0830	150	120	616.7	-
	0900	180	150	607.4	-
	0930	210	180	602.1	-
	1000	240	210	596.6	-
	1045	285	255	589.9	-
	1130	330	300	580.9	-
	1200	360	330	578.6	-
	1230	390	360	572.4	-
	1920	800	770	516.5	-
2-14-77	0815	1,575	1,545	458.0	-
	1545	2,025	1,995	423.3	-
2-15-77	0820	3,020	2,990	389.1	-
	1355	3,355	3,325	380.6	-
2-16-77	1145	4,665	4,635	364.9	-
2-17-77	0200	5,520	5,490	359.7	-
	1120	6,080	6,050	358.8	-
2-21-77	1527	12,087	12,057	352.1	-

Bailed end of test

Table 19.--Liquid-level recovery data, well H-2b (Culebra Dolomite Member of Rustler Formation) - Continued

Method of testing: The hole was bailed and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
2-22-77	1315	0	-	-	38 bailers = 470 gallons
	1520	125	0	-	-
	1528	133	8	630.6	-
	1715	240	115	600.0	-
2-23-77	1535	1,580	1,455	462.0	-
2-24-77	0933	2,658	2,533	421.5	-
2-25-77	1220	4,265	4,140	398.2	-
2-26-77	1128	5,653	5,528	358.4	-
2-27-77	1158	7,123	6,998	354.8	-
2-28-77	1523	8,768	8,643	352.7	-
3- 1-77	1435	10,160	10,035	352.6	-
3- 4-77	1150	14,315	14,190	351.6	-
3- 7-77	1310	18,715	18,590	351.4	-
3- 8-77	-	-	-	-	Bailed H-2c

Method of testing: H-2c was bailed and liquid levels in H-2b were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3-16-77	1310	0	-	353.0	Commenced bailing H-2c, 1 run every 4 minutes, 12 gallons per bailer
	1320	10	-	353.0	-
	1325	15	-	353.0	-
	1340	30	-	353.0	-
	1351	41	-	353.0	-
	1400	50	-	353.1	-
	1405	55	-	353.1	-
	1415	65	-	353.1	-

Table 19.--Liquid-level recovery data, well H-2b (Culebra Dolomite Member of Rustler Formation) - Concluded

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3-16-77	1422	72	-	353.1	-
	1430	80	-	353.2	-
	1453	103	-	353.2	-
	1520	130	-	353.3	-
	1524	134	-	353.4	-
	1542	152	-	353.5	-
	1559	169	-	353.6	-
	1612	182	-	353.7	-
	1635	205	-	353.9	-
	1645	215	-	354.0	-
	1656	226	-	354.1	-
	1719	249	-	354.4	-
	1740	270	-	354.6	-
	1800	290	-	354.9	-
	2224	554	-	358.0	-
	2235	565	-	358.1	-
3-17-77	0850	1,180	-	362.7	-
	1300	1,430	-	361.1	-
3-25-77	0943	12,753	-	351.2	trace injector test conducted on H-2c, 3-22-77
3-26-77	1153	14,323	-	352.6	-
3-28-77	1407	17,337	-	351.9	-
3-29-77	0948	18,518	-	351.6	-
4- 1-77	1510	23,160	-	350.1	-

Shut in

An inflatable production packer was set at a depth of 585.9 feet on April 4, 1977. On April 6, the casing was perforated from 510 to 538 feet for testing the Magenta (fig. 13). The hole was bailed to develop the perforated interval, after which the Magenta zone liquid levels were monitored from April 8, 1977 to May 6, 1977 (table 20). These test data, when compared with the H-2a open-hole Magenta test, indicate that liquid communication between the formation and the cased hole is not as efficient as in an open borehole in which the maximum surface area of the formation is exposed to the borehole.

On May 13, 1977, a latch-on tool was run on tubing to the packer in H-2b and the packer was then released and pulled from the hole. A Lynes Sentry pressure-monitoring system was placed beneath the packer, and the packer was rerun on tubing to 578 feet. The packer was inflated, tubing was swabbed, and the Culebra was opened to the tubing. Long-term dual-completion monitoring began in H-2b with the Culebra liquid levels being measured through the tubing and the Magenta liquid levels being measured in the annulus. The final hole configuration and well-construction specifications are included in figure 13. On October 1, 1977, the Culebra liquid level was approaching prepumping levels at 351 feet (table 21) and the Magenta liquid level was slowly recovering 47 feet below Magenta liquid levels in H-2a (tables 22 and 23).

Testing on the Magenta cored interval in H-2a began February 22, 1977, when the hole was bailed and a water sample was taken for chemical analyses (table 2). Liquid levels were monitored throughout the rest of the year (table 23). On April 9, 1977, the Magenta interval was bailed in H-2b and a slight effect was noted in the Magenta in H-2a. By October 1, 1977, a liquid level in H-2a was at about 249 feet below land surface (table 23).

Well P-14

Drilling history.--P-14 is located 312 feet from the south line (FSL) and 613 feet from the west line (FWL) of sec. 24, T.22 S., R.30 E., in Eddy County, New Mexico. The elevation of the ground surface at the drill site is 3,358.1 feet above mean sea level.

Table 20.--Liquid-level recovery data, well H-2b (Magenta Dolomite Member of Rustler Formation)

[Perforated interval 510-538 ft below land surface]

Method of testing: The zone was perforated, the hole was bailed dry, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
4- 8-77	0903	0	-	-	-
	0950	47	0	-	Bailed 33 runs = 396 gallons
	0957	54	7	559.9	-
	1000	57	10	559.1	-
	1005	62	15	557.0	-
	1010	67	20	556.7	-
	1020	77	30	556.1	-
	1035	92	45	552.1	-
	1045	102	55	550.2	-
	1055	112	65	548.4	-
	1105	122	75	547.9	-
4- 9-77	0945	1,482	1,435	419.7	-
4-11-77	1814	4,871	4,824	358.1	-
4-12-77	1053	5,870	5,823	355.4	-
4-13-77	1235	7,412	7,365	352.7	-
4-14-77	1150	8,807	8,760	352.7	-
4-15-77	1223	10,280	10,233	351.4	-
4-22-77	0935	20,192	20,145	350.7	-
5- 6-77	1050	40,427	40,380	349.5	-

End of test

Table 21.--Long-term liquid-level recovery data, well H-2b (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 611-661 ft below land surface]

Method of testing: The tubing was opened to the Culebra zone and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-13-77	1900	0	-	Ran sentry and packer opened packer to tubing
5-25-77	1028	18,208	350.8	-
6-23-77	1425	60,205	350.7	-
8- 4-77	1225	120,565	353	-
10- 2-77	1025	203,965	351	-

Table 22.--Long-term liquid-level recovery data, well H-2b (Magenta Dolomite Member of Rustler Formation)

[Perforated interval 510-538 ft below land surface]

Method of testing: The liquid levels were monitored on a long-term basis.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-13-77	1900 (est.)	0	-	Ran tubing to inflatable packer
5-25-77	1045	16,785	291	-
6-23-77	1430	58,770	283.4	-
8- 4-77	1220	119,110	286	-
9- 4-77	1312	163,812	291	-
10- 3-77	1455	205,675	295.7	-

Table 23.--Long-term liquid-level recovery data, well H-2a (Magenta Dolomite Member of Rustler Formation)

[Perforated interval 513-563 ft below land surface]

Method of testing: The hole was bailed dry and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
2-22-77	0950-1215			Bailed and cleaned oil from hole
	1215	0	-	-
	1226	11	556.8	-
	1730	315	552.8	-
2-23-77	1548	1,653	538.7	-
2-24-77	0922	2,707	531.3	-
2-25-77	1240	4,345	506.8	-
2-26-77	1110	5,695	500.0	-
2-27-77	1215	7,200	487.8	-
2-28-77	1510	8,815	481.4	-
3- 1-77	1415	10,200	475.5	-
3- 4-77	1210	14,395	456.2	-
3- 7-77	1300	18,765	437.4	-
3-10-77	0920	22,865	423.3	-
3-11-77	1228	24,493	415.7	-
3-12-77	1120	25,865	411.4	-
3-13-77	1309	27,414	407.4	-
3-14-77	1717	29,102	401.2	-
3-15-77	1533	30,438	397.8	-
3-17-77	1312	33,177	388.1	-

Table 23.--Long-term liquid-level recovery data, well H-2a (Magenta Dolomite Member of Rustler Formation) - Concluded

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
3-26-77	1201	46,066	358.7	-
3-28-77	1357	49,062	353.3	-
3-29-77	0941	50,246	350.6	-
4- 1-77	1520	54,905	339.8	-
4- 4-77	1045	58,950	335.6	-
4- 7-77	1015	63,240	327.0	-
4- 9-77	0950	66,095	323.8	H-2b bailed in Magenta
4-11-77	1820	69,485	324.8	H-2b bailed in Magenta
4-12-77	1059	70,484	323.5	-
4-13-77	1242	72,027	321.7	-
4-14-77	1155	73,420	320.4	-
	1206	73,431	318.2	-
4-15-77	1232	74,897	316.0	-
4-22-77	0930	84,795	307.2	-
5- 6-77	1057	105,042	293.8	-
5-25-77	1055	132,400	279.76	-
6-23-77	1450	174,395	263.36	-
8- 4-77	1324	234,875	252.53	-
9- 4-77	1259	279,515	249	-
10- 3-77	1352	321,275	248.73	-

Surface casing was set to a depth of 20 feet and the test hole was spudded on September 24, 1976 (table 24). The hole was drilled with air and air mist as a circulating medium. No liquid was encountered in the hole until 455 feet, at which time soap was added to the circulatory system to assist in removal of cuttings. Drilling continued to a casing depth of 784 feet. Geophysical logs were run by the U.S. Geological Survey after drilling was completed (fig. 15). After the hole was conditioned and loaded with mud gel, casing was set and cemented on September 29 to a depth of 775 feet.

After cement had set, a 4-inch hole was drilled to the core depth of 1,188 feet. The potash zone was cored from 1,188 feet to a total depth of 1,545 feet. On October 3, 1976, the hole was logged by the U.S. Geological Survey and was then plugged back to 759 feet with cement. The final hole configuration and well-construction specifications are included in figure 16.

Hydrologic testing.--P-14 hydrologic testing began on January 19, 1977, when the hole was bailed dry and U.S. Geological Survey geophysical logs were rerun to pick perforation intervals. On January 21, the casing was perforated across the Rustler-Salado contact interval (676 to 700 feet) (fig. 16). Liquid produced from the Rustler-Salado contact was monitored from January 21 to February 24, during which time the liquid level rose from 730 to 417 feet below land surface (table 25). Later tests indicated that the perforations had plugged during the test. On February 24, 250 gallons of liquid were bailed from the hole and samples were taken for chemical analyses. Water levels were then monitored until February 26 when the Rustler-Salado zone was temporarily shut in (table 25). The final hole configuration and well-construction specifications are included in figure 16.

On March 2, 1977, an inflatable production packer was run into the hole and set at 663.2 feet. The casing was perforated in a dry hole across the Culebra interval (573 to 601 feet) on March 7. On March 8, 720 gallons of liquid were bailed with no noticeable change in water levels. Liquid levels were monitored until March 14 (table 26)

On March 15, 1977, a latch-on tool on tubing was run to the packer, the tubing was opened to the Rustler-Salado interval, and the zone was swabbed. Liquid levels were monitored until March 18 when tubing was again swabbed to check the packer seat. After the Rustler-Salado interval was shut in and the tubing was pulled, liquid levels were monitored in the Culebra until March 21 (table 25) when the packer at 663.2 feet was released because of possible communication with the Rustler-Salado interval. The packer was then rerun to 656.5 feet and set.

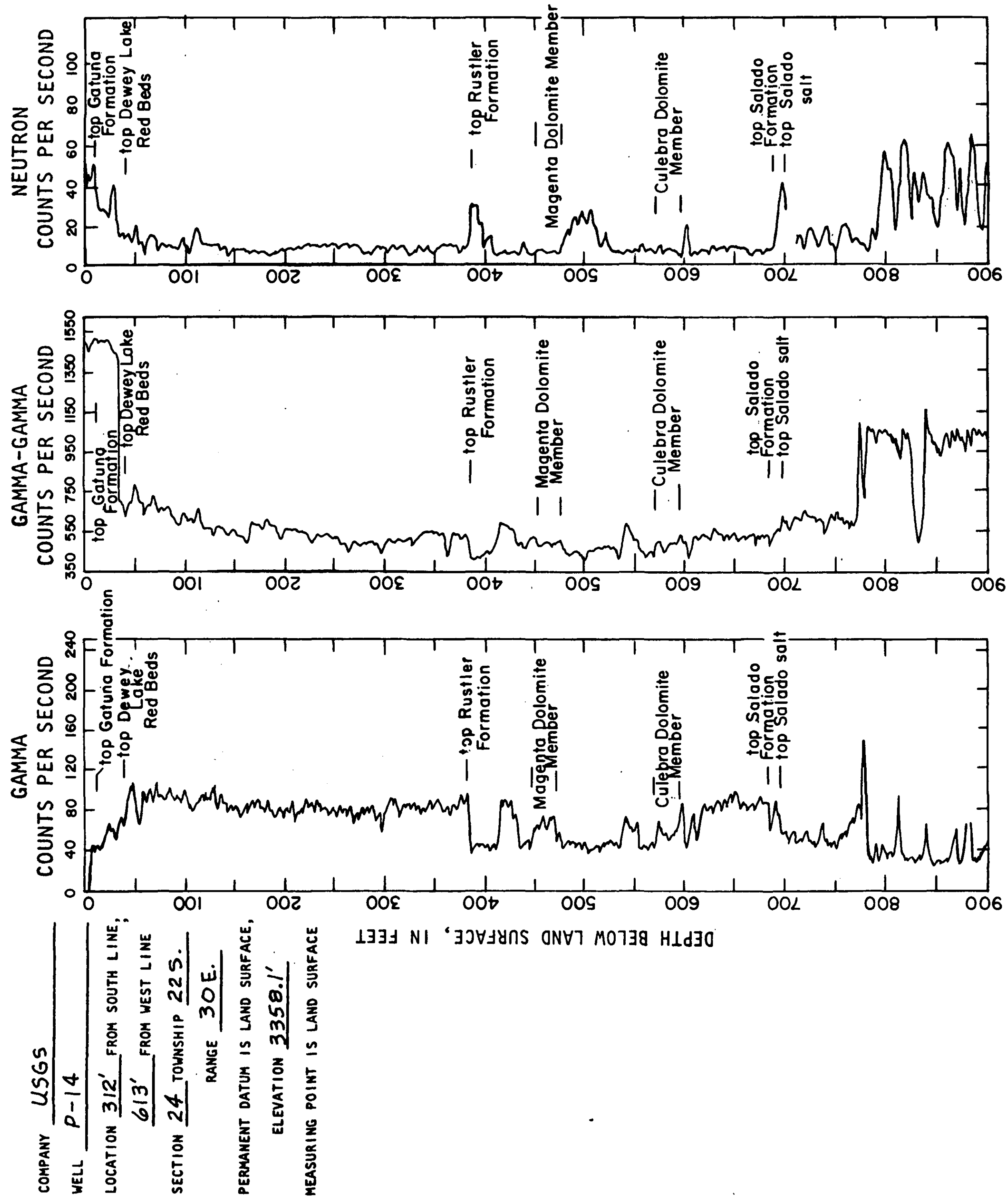
Table 24.--Chronology of well P-14

[All depth measurements adjusted to ground level, 3,358.1 ft above mean sea level]

Date	
1976	
Sept. 24	Set surface pipe; hole spudded.
Sept. 27	Reran larger diameter surface pipe; continued drilling.
Sept. 28	Rotary drilled to 635 ft; liquid encountered at 589 ft.
Sept. 29	Rotary drilled to 784 ft; USGS geophysical logs; casing landed at 775 ft; cemented.
Sept. 30-Oct. 1	Rotary drilled to core point (1,188 ft).
Oct. 1-3	Cored to 1,545 ft.
Oct. 3	USGS geophysical logs.
Oct. 4	Hole plugged back to 759 ft.
Oct. 25	Rigged up; ran drill pipe and bit; tagged cement at 775 ft; hole temporarily abandoned.
1977	
Jan. 19	Hole bailed dry; USGS logs.
Jan. 21	Perforated casing (Rustler-Salado contact, 676-700 ft).
Jan. 21-Feb. 24	Liquid levels monitored.
Feb. 24	Bailed hole and sampled (Rustler-Salado).
Feb. 24-26	Liquid levels monitored.
Mar. 2	Set inflatable packer (663.2 ft); pulled tubing; bailed hole dry.
Mar. 7	Perforated casing (Culebra, 573-601 ft).
Mar. 8	Bailed hole.

Table 24.--Chronology of well P-14 - Concluded

Date	
1977	
Mar. 8-14	Liquid levels monitored.
Mar. 14	Bailed hole and sampled (Culebra).
Mar. 15	Reran tubing to packer; reopened Rustler-Salado zone.
Mar. 15-18	Liquid levels monitored.
Mar. 18	Swabbed tubing to check packer seal; shut in Rustler-Salado zone; pulled tubing.
Mar. 18-21	Liquid levels monitored.
Mar. 21	Pulled packer; reset packer at 656.5; pulled tubing.
Mar. 22	Ran radioactive tracer survey (^{131}I) on Culebra zone.
Mar. 23	Bailed hole (1,440 gallons).
Mar. 24	Reran tubing; swabbed tubing dry; reopened packer to Rustler-Salado zone.
Mar. 24-May 25	Monitored liquid levels.
May 25-Oct 1.	Monthly measurements.


NEUTRON
COUNTS PER SECOND
GAMMA-GAMMA
COUNTS PER SECOND
GAMMA
COUNTS PER SECOND
top Gatuña Formation
top Dewey Lake Red Beds
top Rustler Formation
Magenta Dolomite Member
Culebra Dolomite Member
top Salado Formation
top Salado salt
DEPTH BELOW LAND SURFACE, IN FEET
COMPANY USGS
WELL P-14
LOCATION 312' FROM SOUTH LINE,
613' FROM WEST LINE
SECTION 24 TOWNSHIP 22S.
RANGE 30E.
PERMANENT DATUM IS LAND SURFACE,
ELEVATION 3358.1'
MEASURING POINT IS LAND SURFACE

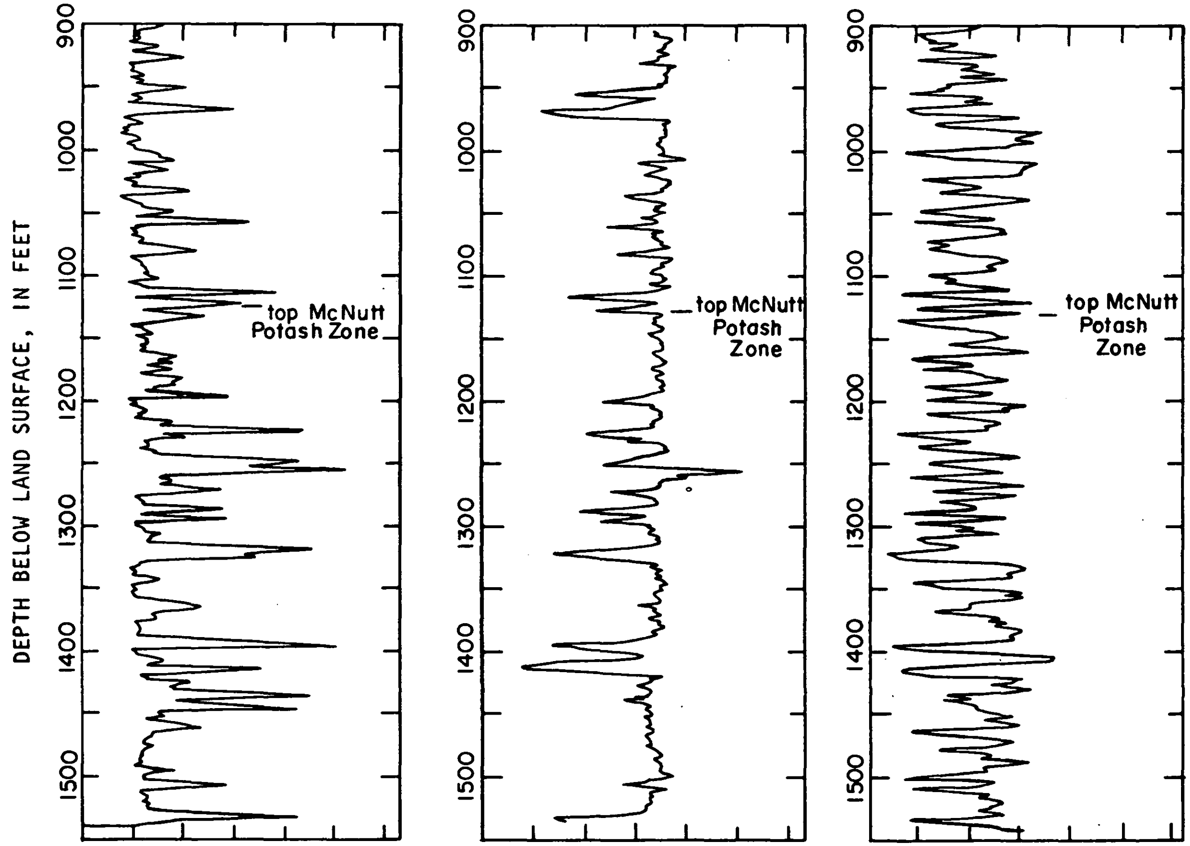
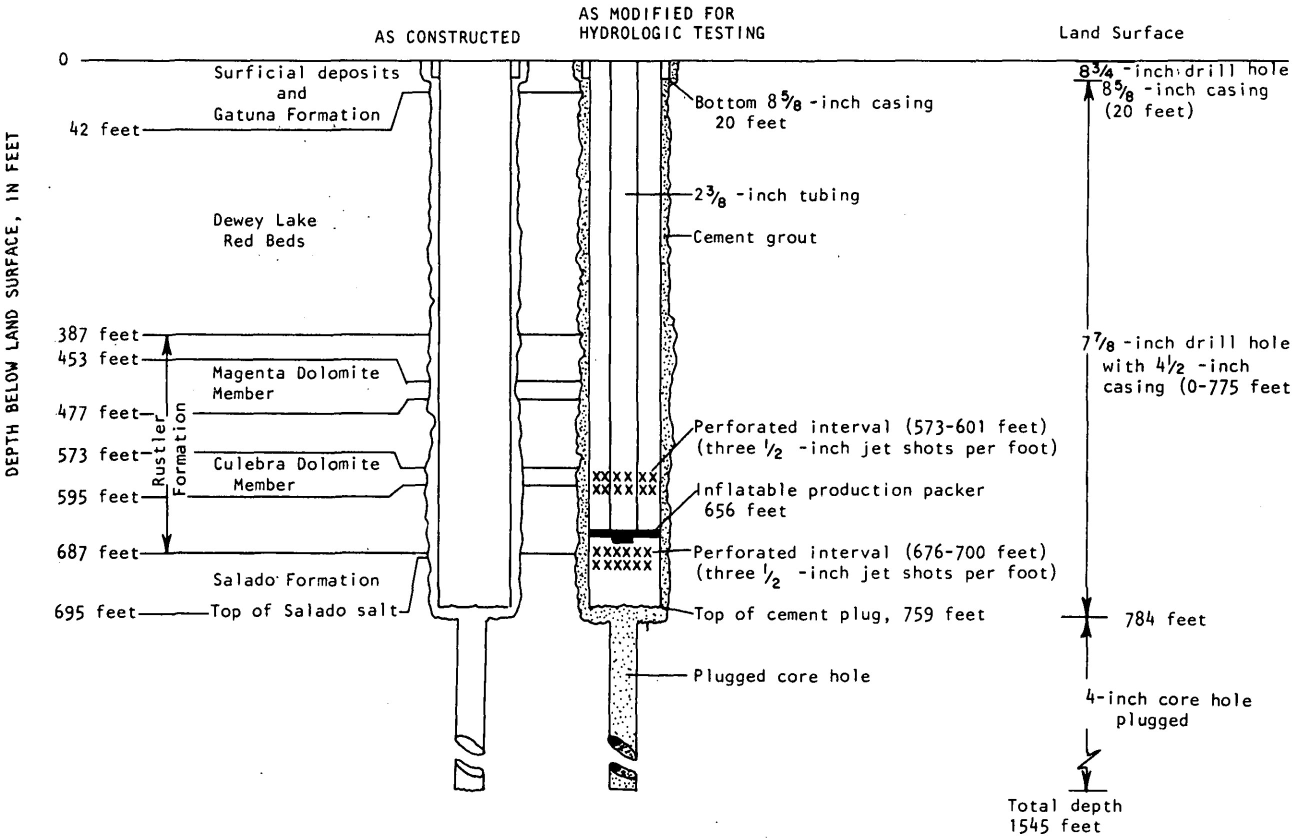


Figure 15.--Selected geophysical logs for well P-14.



LOCATION: 312 feet from south line, 613 feet from west line, section 24, Township 22 South, Range 30 East, Eddy County, New Mexico

ELEVATION: 3,358.1 feet (ground level)

DEPTH DRILLED: 1,545 feet (plugged back to 759 feet)

DATE COMPLETED: October 3, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Company, Las Cruces, New Mexico

DRILLING METHOD: Rotary 8 3/4-inch hole with air (0-20 feet); Rotary 7 7/8-inch hole with air and air mist (20-784 feet); Rotary 4-inch hole with air mist (784-1,188 feet); Core 4-inch hole with brine mud (1,188-1,545 feet)

WELL CASING RECORD: 8 5/8-inch outside diameter steel casing (0-20 feet); 4 1/2-inch outside diameter steel casing; 9.5 pounds; 0.68 gallons per foot (0-775 feet); centralizers at 326 feet, 371 feet, 574 feet and 765 feet; cemented to surface; hole plugged back from 1,545 feet to 759 feet with cement

GEOPHYSICAL LOGS:

Shown in figure 15: Gamma, Gamma-Gamma, Neutron

Not shown in figure 15: Caliper

Figure 16.--Well P-14 construction, completion, and specifications.

Table 25.--Liquid-level recovery data, well P-14 (Rustler-Salado contact)

[Perforated interval 676-700 ft below land surface]

Method of testing: The casing was bailed dry and perforated, and liquid levels were monitored with a recorder.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
1-21-77	0947	0	-	-	Perforated zone
	1019	32	-	729.7	-
	1028	41	-	728.2	-
	1039	52	-	726.8	-
	1056	69	-	724.7	-
	1500	313	-	696.8	-
	1535	348	-	693.2	-
	1555	368	-	691.2	-
	1618	391	-	689.2	-
	1820	513	-	678.2	-
	1900	553	-	675.8	-
	1930	583	-	672.4	-
	2000	613	-	669.6	-
	2030	643	-	667.3	-
	2100	673	-	665.7	-
	2330	823	-	655.5	-
	2400	853	-	654.2	-
1-22-77	0830	1,363	-	623.1	-
	1240	1,613	-	608.1	-
	1430	1,723	-	605.0	-
	1445	1,738	-	605.3	-
	1800	1,933	-	596.0	-
	1900	1,993	-	593.3	-
	2400	2,293	-	580.9	-
1-23-77	0600	2,653	-	567.8	-
	0925	2,858	-	560.8	-
	1200	3,013	-	555.8	-
	1428	3,161	-	551.1	-
	1800	3,373	-	544.5	-
	2400	3,733	-	534.4	-
1-24-77	0600	4,093	-	524.8	-
	1037	4,370	-	518.1	-
	1200	4,453	-	516.1	-
	1441	4,614	-	512.4	-
	1800	4,813	-	508.1	-
	2400	5,173	-	500.8	-

Table 25.--Liquid-level recovery data, well P-14 (Rustler-Salado contact) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
1-25-77	0600	5,533	-	494.1	-
	0830	5,683	-	491.5	-
	1200	5,893	-	488.0	-
	1500	6,073	-	485.1	-
	1800	6,253	-	482.3	-
	2400	6,613	-	477.2	-
1-26-77	0600	6,973	-	472.5	-
	1200	7,333	-	468.1	-
	1630	7,603	-	464.9	-
	1800	7,693	-	464.0	-
	2400	8,053	-	460.2	-
1-27-77	0600	8,413	-	456.6	-
	1200	8,773	-	453.5	-
	1230	8,803	-	453.1	-
	1800	9,133	-	450.4	-
	2400	9,493	-	447.5	-
1-28-77	0600	9,853	-	445.0	-
	0920	10,053	-	443.7	-
	1200	10,213	-	442.6	-
	1800	10,573	-	440.5	-
	2400	10,933	-	438.6	-
1-29-77	0600	11,293	-	436.8	-
	1200	11,653	-	435.1	-
	1800	12,013	-	433.7	-
	2025	12,158	-	433.1	-
	2400	12,373	-	432.4	-
1-30-77	0600	12,733	-	431.1	-
	1200	13,093	-	430.1	-
	1800	13,453	-	429.1	-
1-31-77	0600	14,173	-	427.4	-
	0815	14,308	-	427.1	-
	1200	14,533	-	426.6	-
	1800	14,893	-	426.0	-
	2400	15,253	-	425.4	-

Table 25.--Liquid-level recovery data, well P-14 (Rustler-Salado contact) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
1-31-77	0600	14,173	-	427.4	-
	0815	14,308	-	427.1	-
	1200	14,533	-	426.6	-
	1800	14,893	-	426.0	-
	2400	15,253	-	425.4	-
2- 1-77	0600	15,613	-	424.9	-
	1200	15,973	-	424.4	-
	1800	16,333	-	423.9	-
	2400	16,693	-	423.5	-
2- 2-77	0600	17,053	-	423.1	-
	0820	17,193	-	423.0	-
	1200	17,413	-	422.8	-
	1800	17,773	-	422.5	-
	2400	18,133	-	422.1	-
2- 3-77	0600	18,493	-	421.9	-
	1200	18,853	-	421.6	-
	1800	19,213	-	421.4	-
	2400	19,573	-	421.2	-
2- 4-77	0600	19,933	-	420.9	-
	1200	20,293	-	420.8	-
	1710	20,603	-	420.6	-
	1800	20,653	-	420.6	-
	2400	21,013	-	420.5	-
2- 5-77	0600	21,373	-	420.4	-
	1200	21,733	-	420.2	-
	1230	21,763	-	420.1	-
	1800	22,093	-	420.1	-
	2400	22,453	-	420.0	-
2- 6-77	0600	22,813	-	419.9	-
	1200	23,173	-	419.7	-
	1800	23,533	-	419.6	-
	2400	23,893	-	419.5	-
2- 7-77	0600	24,253	-	419.4	-
	1200	24,613	-	419.4	-
	1415	24,748	-	419.3	-
	1800	24,973	-	419.3	-
	2400	25,333	-	419.2	-

Table 25.--Liquid-level recovery data, well P-14 (Rustler-Salado contact) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
2- 8-77	0600	25,693	-	419.2	-
	1200	26,053	-	419.1	-
	1800	26,413	-	419.0	-
	2400	26,773	-	419.0	-
2- 9-77	0600	27,133	-	418.9	-
	1200	27,493	-	418.9	-
	1540	27,713	-	418.8	-
	1800	27,853	-	418.7	-
	2400	28,213	-	418.7	-
2-10-77	0600	28,573	-	418.6	-
	1200	28,933	-	418.6	-
	1300	28,993	-	418.6	-
2-11-77	0830	30,163	-	418.4	-
2-14-77	1420	34,833	-	418.0	-
2-17-77	1358	39,131	-	417.7	-
2-23-77	1715	-	-	417.3	-
2-24-77	1019	-	-	417.6	-

End of test - bailed

Method of testing: Fluid was bailed from the casing and the fluid level recovery was monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
2-24-77	1025	0	-	-	25 bailers = 250 gallons
	1207	102	0	-	-
	1710	405	303	692.7	-
	1715	410	308	692.1	-
	1722	417	315	690.5	-
	1734	429	327	688.5	-
	1749	444	342	685.7	-
	1803	458	356	683.2	-
	1814	469	367	681.2	-
	1827	482	380	682.2	-
	1838	493	391	679.4	-

Table 25.--Liquid-level recovery data, well P-14 (Rustler-Salado contact) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
2-24-77	1850	505	403	677.7	-
	1900	515	413	675.9	-
	1910	525	423	673.9	-
	1916	531	429	672.4	-
	1932	547	445	670.2	-
2-25-77	1100	1,475	1,373	561.7	-
	1112	1,487	1,385	560.6	-
	1120	1,495	1,393	559.6	-
	1503	1,718	1,616	539.9	-
2-26-77	0935	2,830	2,728	509.5	-
	1430	3,125	3,023	448.5	-
	1607	3,222	3,120	434.0	-
Shut in					

Method of testing: The packer plug was sheared to open the zone to the tubing.

3-15-77	1430 (est.)	0	-	-	-
	1455	25	-	495.5	-
	1505	35	-	493.3	-
3-16-77	1059	1,229	-	384.6	-
	1111	1,241	-	385.2	-
3-17-77	0927	2,577	-	378.1	-
	1411	2,861	-	374.5	-
3-18-77	1005	4,055	-	373.8	-

Method of testing: The tubing was swabbed and liquid levels were monitored.

3-18-77	1208	0	-	-	Last swab ≅ 40 gallons total
	1215	7	-	545.4	-
	1225	17	-	535.4	-
	1234	26	-	537.4	-

Table 25.--Liquid-level recovery data, well P-14 (Rustler-Salado contact) - Concluded

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3-19-77	0913	1,265	-	391.6	-
3-20-77	0852	2,684	-	381.5	-
3-21-77	0815	4,087	-	383.4	-

Shut in

Table 26.--Liquid-level recovery data, well P-14 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 573-601 ft below land surface]

Method of testing: The casing was perforated, the hole was bailed, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
3- 8-77	0630	0	-	-	60 bailers 720 gallons
	0932	182	0	-	-
	0938	188	6	328.4	-
	0939	189	7	328.1	-
	0940	190	8	328.1	-
	0943	193	11	328.0	-
	0945	195	13	327.9	-
	0950	200	18	327.7	-
	0955	205	23	327.6	-
	1000	210	28	327.6	-
	1010	220	38	327.5	-
	1020	230	48	327.4	-
	1040	250	68	327.4	-
	1100	270	88	327.3	-
	1115	285	103	327.3	-
	1705	635	453	328.6	-
3- 9-77	0700	1,470	1,288	328.2	-
3-10-77	0825	2,995	2,813	327.3	-
3-11-77	1331	4,741	4,559	327.3	-
3-12-77	1203	6,093	5,911	327.4	-
3-14-77	1144	8,954	8,772	326.9	-

Bailed, ran tubing to Rustler-Salado contact

A tracer (^{131}I) and temperature survey (fig. 10) was conducted on the Culebra zone perforated interval on March 22, 1977, to determine the interval of liquid loss and to detect possible up-hole or down-hole communication. The gamma trace and temperature profile indicated that most of the liquid (63 percent) was lost to the formation across the interval from 583 to 590 feet with the remainder lost from 573 to 583 feet. No flow was detected in the casing below 590 feet. No communication was detected in the cemented annulus. The survey was conducted down the casing at a liquid-injection rate of 7 gal/min with a total of 1,634 gallons being injected during the survey. The high permeability of the zone allowed the injection of liquid to take place under gravity feed. On March 23, contaminated liquid was bailed from the hole.

On March 24, 1977, a latch-on tool on tubing was run to the packer, the tubing was swabbed dry, and the packer was opened allowing liquid from the Rustler-Salado zone to rise into the tubing. The hole was placed into a long-term dual-completion phase, with the Rustler-Salado water levels being monitored in the tubing (table 27) and the Culebra water levels being monitored in the annulus (table 28) and (fig. 16). As of October 1, 1977, the Rustler-Salado liquid level had risen to about 389 feet below land surface (table 27) and the Culebra liquid level had risen to about 324 feet (table 28).

Well P-15

Drilling history.--P-15 is located 398 feet FSL and 184 feet FWL of sec. 31, T.22 S., R.31 E., in Eddy County, New Mexico. The elevation of the land surface at the drill site is 3,309.7 feet above mean sea level.

Surface casing was set to a depth of 20 feet and the test hole was spudded on October 4, 1976 (table 29). The hole was drilled with air and air mist as a circulating medium. Moist cuttings were first observed at a depth of 225 feet at which time soap was added to assist in cuttings removal. The hole was drilled to a depth of 405 feet and U.S. Geological Survey geophysical logs were run because drill cuttings indicated that the top of the Rustler Formation was higher than expected. Drilling was resumed after the geophysical logs showed stratigraphic markers to be at the projected depths. The interval across the Rustler-Salado contact, from 515 to 600 feet, was cored and the hole was reamed to the casing depth of 635 feet. Geophysical logs were run by the U.S. Geological Survey after drilling was completed (fig. 17). The hole was then conditioned and loaded with mud gel in preparation for running casing.

Table 27.--Long-term liquid-level recovery data, well P-14 (Rustler-Salado contact)

[Perforated interval 676-700 ft below land surface]

Method of testing: The packer plug was sheared, opening the tubing to zone, and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)
3-24-77	1017	0	-
	1033	16	577.7
	1035	18	576.0
	1037	20	574.3
	1039	22	571.4
	1041	24	569.8
	1043	26	568.9
	1045	28	567.5
	1047	30	565.8
	1059	42	554.7
	1105	48	551.3
	1110	53	548.2
	1115	58	546.3
	1748	451	457.1
3-25-77	0853	1,356	406.5
	1526	1,749	402.7
3-26-77	1342	3,085	389.1
3-27-77	1134	4,397	386.5
3-28-77	1100	5,803	385.6
3-29-77	1255	7,358	385.5
3-30-77	1236	8,779	385.5
4- 5-77	0915	17,218	385.4
4-12-77	1515	27,658	384.4
4-14-77	1605	30,588	385.0
4-15-77	0951	31,654	386.0
5- 6-77	0903	61,846	386.1

Table 27.--Long-term liquid-level recovery data, well P-14 (Rustler-Salado contact) - Concluded

Date	Clock time	Time since test began (min)	Water level (ft below land surface)
5-25-77	1515	89,578	386.4
6-23-77	1530	131,353	386.2
8- 4-77	1530	191,833	389
9- 5-77	0958	237,581	383
10- 6-77	1055	282,278	388.7

Table 28.--Long-term liquid-level recovery data, well P-14 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 573-601 ft below land surface]

Method of testing: A radioactive tracer (^{131}I) injection test was conducted, the well was bailed, and long-term liquid-level monitoring was begun.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
3-22-77	0947	-	-	0835-0947 injected 38.9 barrels into zone (1,634 gallons)
3-23-77	-	-	-	Bailed 1,440 gallons
3-27-77	1148	-	324.6	-
3-29-77	1310	-	325.4	-
3-30-77	1246	-	325.6	-
4- 5-77	0930	-	325.8	-
4-14-77	1619	-	324.6	-
4-15-77	1002	-	324.6	-
5- 6-77	0910	-	324.7	-
5-25-77	1525	-	322.2	-
6-23-77	1600	-	325.9	-
8- 4-77	1535	-	326	-
9- 5-77	1005	-	326	-
10- 6-77	1104	-	324.3	-

Table 29.--Chronology of well P-15

[All depth measurements adjusted to ground level, 3,309.7 ft above mean sea level]

Date	
1976	
Oct. 4	Set surface pipe; hole spudded; damp cuttings at 225 ft.
Oct. 6	Rotary drilled to 515 ft.
Oct. 6-8	Cored Rustler-Salado contact (515-600 ft).
Oct. 8	USGS geophysical logs; rotary drilled to 637 ft; casing landed at 635 ft.
Oct. 8-9	Casing cemented.
Oct. 10-12	Rotary drilled to core point (1,038 ft).
Oct. 12-14	Cored to 1,465 ft.
Oct. 14-15	USGS geophysical logs.
Oct. 15	Plugged back to 600 ft.
Oct. 26	Drilled out cement plug to 620 ft.
Oct. 29	Dresser Atlas Spectralog; hole temporarily abandoned.
1977	
Jan. 19	Hole bailed dry.
Jan. 21	Perforated casing (Rustler-Salado contact, 532-560 ft).
Jan. 21-Apr. 4	Liquid levels monitored.
Apr. 4	Set inflatable packer (511.6); pulled tubing.
Apr. 6	Perforated casing (Culebra, 410-438 ft).
Apr. 7	Hole bailed (156 gallons).
Apr. 7-May 10	Liquid levels monitored.

Table 29.--Chronology of well P-15 - Concluded

Date	
1977	
May 10	Bailed hole and sampled.
May 11	Reran tubing and airline.
May 14- Oct 1	Reopened the Rustler-Salado to tubing; commenced long-term monitoring of Rustler-Salado contact and Culebra.

COMPANY USGS

WELL P-15

LOCATION 398' FROM SOUTH LINE,

184' FROM WEST LINE

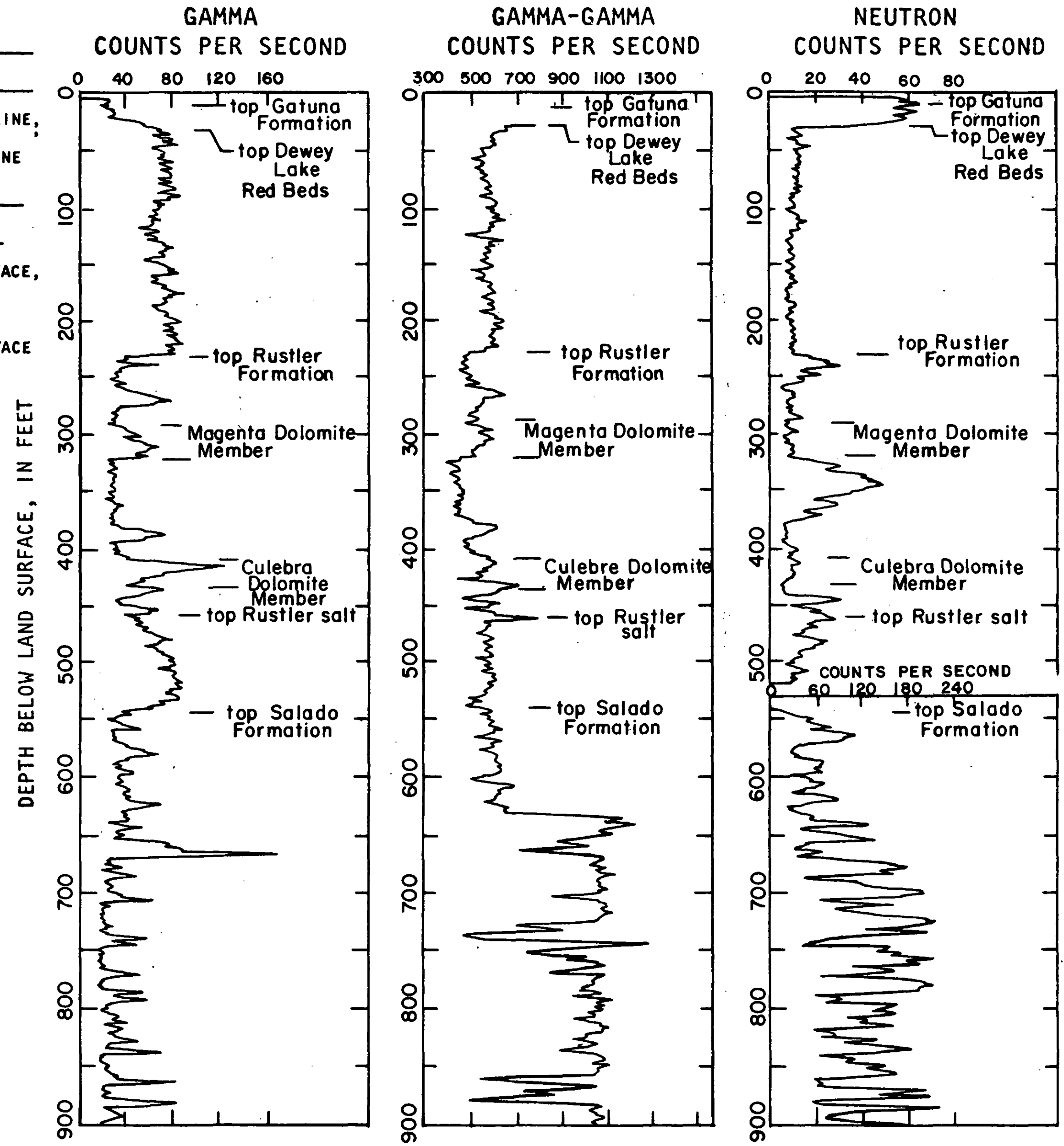
SECTION 31 TOWNSHIP 22S.

RANGE 31 E.

PERMANENT DATUM IS LAND SURFACE,

ELEVATION 3309.7'

MEASURING POINT IS LAND SURFACE



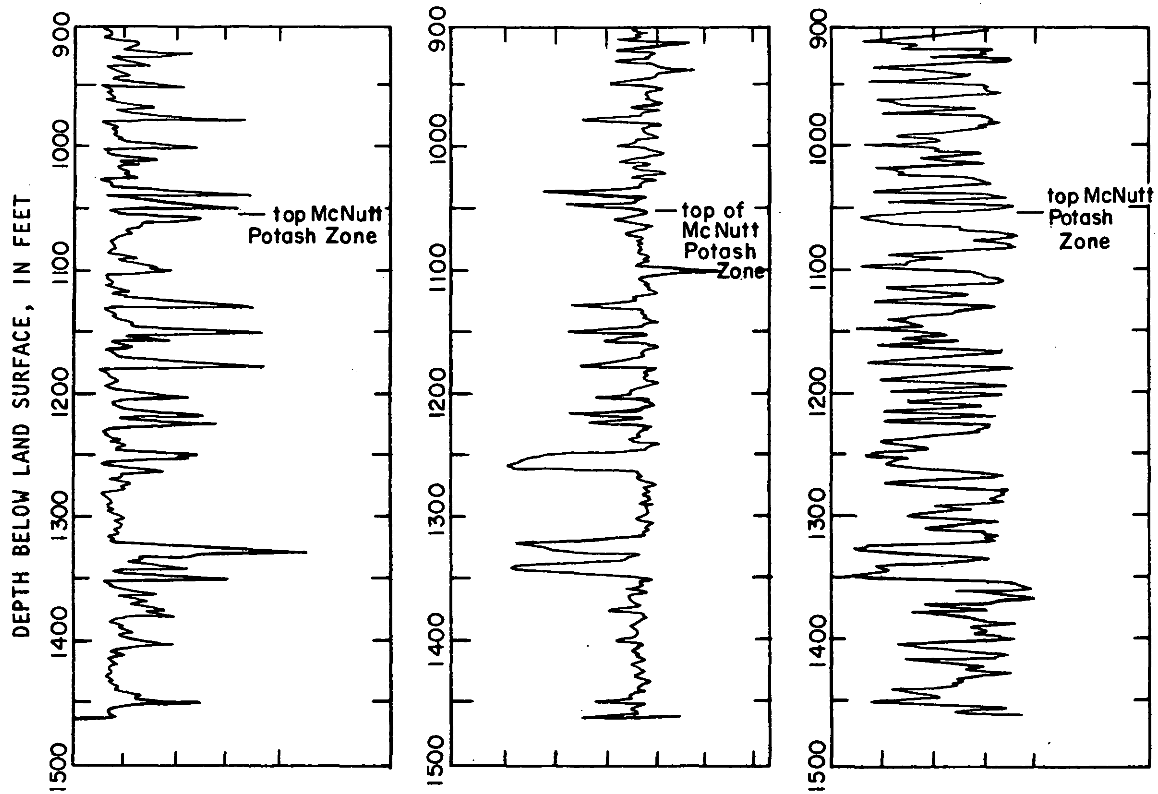


Figure 17.--Selected geophysical logs for well P-15.

Casing was set and cemented on October 8 to a depth of 635 feet below land surface. After the cement had set, a 5-inch hole was drilled to a core depth of 1,038 feet. The potential potash zone was cored from 1,038 to a total depth of 1,465 feet. On October 14, 1976, the hole was logged and plugged back to 600 feet with cement.

On October 26, 1976, the cement was drilled out from 600 to 620 feet. A Dresser Atlas spectralog was run on October 29 because the Culebra had shown a high gamma count during initial logging. The spectralog indicated the anomolous zone to be an interval of naturally deposited uranium. Following the logging, the well was temporarily abandoned pending later hydrologic tests. The final hole configuration and well-construction specifications are included in figure 18.

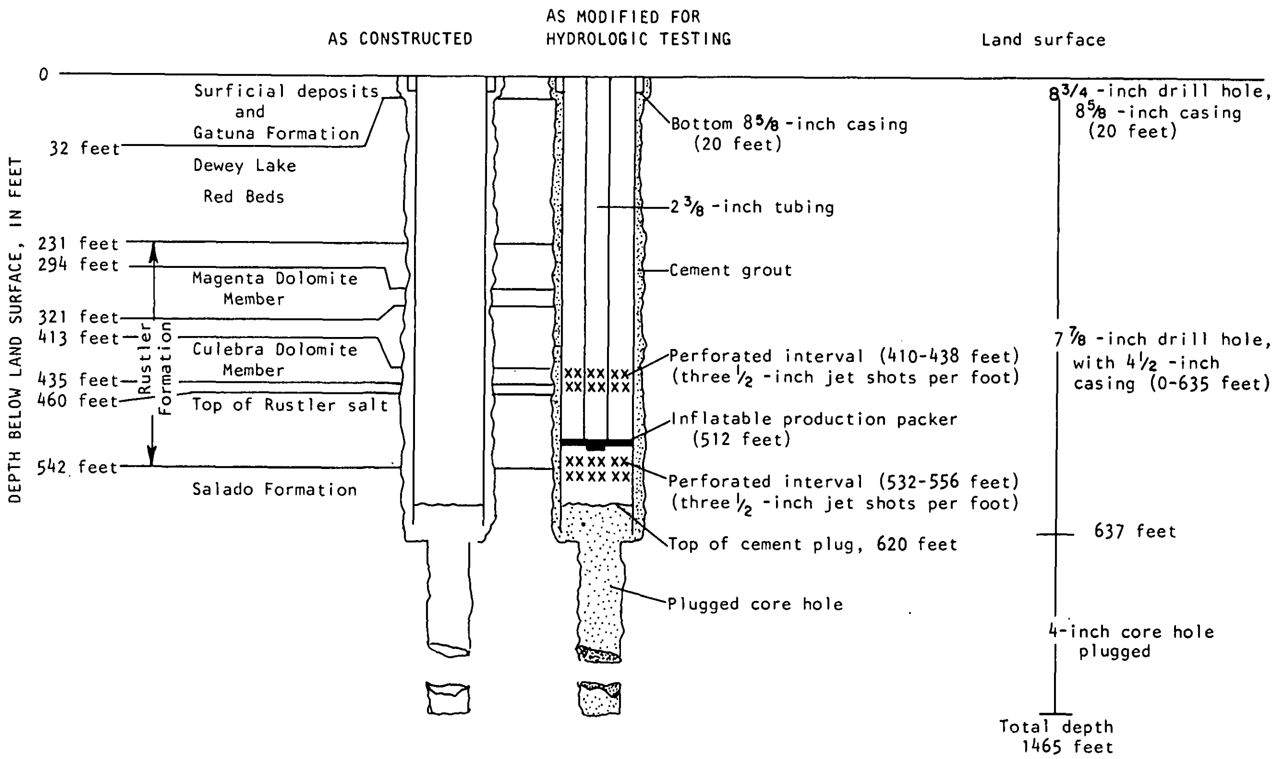
Hydrologic testing.--P-15 hydrologic testing began on January 19, 1977, when the hole was bailed dry. The casing was perforated January 21 from 532 to 560 feet below land surface (fig. 18). Liquid produced from the Rustler-Salado contact was monitored from January 21 to April 4, 1977, at which time liquid levels had risen from 618 to 497 feet (table 30). On April 4, an inflatable-retrievable bridge packer was run on tubing and was set at 511.6 feet to shut in the Rustler-Salado perforations below. Tubing was then pulled.

The interval from 410 to 438 feet was perforated on April 6, 1977 (fig. 18). Liquid produced from the Culebra was monitored from April 7 to May 10, 1977, during which time the liquid level had risen from 496 to 312 feet below land surface and the zone had yielded 125 gallons (table 31).

On May 10, 1977, the hole was bailed and samples were taken for chemical analyses (table 2). On May 11, a latch-on tool on tubing was run to the packer and the tubing was opened to the Rustler-Salado. The hole was placed into a long-term dual-completion monitoring phase, with the Rustler-Salado liquid levels being monitored in the tubing and Culebra liquid levels being monitored in the annulus (fig. 18). By October 1, 1977, the Rustler-Salado was approaching prepumping levels at 324 feet (table 32) and the Culebra was approaching prepumping levels at 308 feet (table 33).

Well P-17

Drilling history.--P-17 is located 1,351 feet FSL and 395 feet FWL of sec. 4, T.23 S., R.31 E., in Eddy County, New Mexico. The elevation of the ground surface at the drill site is 3,339.5 feet above mean sea level.



LOCATION: 398 feet from south line, 184 feet from west line, section 31, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,309.7 feet (ground level)

DEPTH DRILLED: 1,465 feet (plugged back to 620 feet)

DATE COMPLETED: October 14, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Company, Las Cruces, New Mexico

DRILLING METHOD: Rotary 8 3/4-inch hole with air (0-20 feet); Rotary 7 7/8-inch hole with air and air mist (20-515 feet); Core 4-inch hole with air mist (515-600 feet) (cut 2 1/4-inch diameter core); Ream 7 7/8-inch hole with air mist (515-637 feet) Rotary 4-inch hole with air mist (600-1,038 feet); Core 4-inch hole with brine mud (1,038-1,465 feet)

WELL CASING RECORD: 8 5/8-inch outside diameter steel casing (0-20 feet); 4 1/2-inch outside diameter steel casing, 9.5 pounds, 0.68 gallons per foot (0-635 feet), cemented to surface, hole plugged back from 1,465 feet to 600 feet with cement, cement drilled out to 620 feet

GEOPHYSICAL LOGS:

Shown in figure 19: Gamma, Gamma-Gamma, Neutron

Not shown in figure 19: Caliper, Spectralog

Figure 18.--Well P-15 construction, completion, and specifications.

Table 30.--Liquid-level recovery data, well P-15 (Rustler-Salado contact)

[Perforated interval 532-560 ft below land surface]

Method of testing: The casing was perforated and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
1-21-77	1109	0	-	Perforated zone
	1147	38	618	-
	1157	48	618	-
	1207	58	618	-
	2225	676	618.4	-
1-23-77	0950	2,801	614.1	-
1-24-77	1205	4,376	611.4	-
1-27-77	1000	8,571	605.5	-
2- 2-77	1115	17,286	597.2	-
2- 6-77	1145	23,076	580.6	-
2-12-77	1425	31,876	572.0	-
2-15-77	1740	36,391	566.6	-
2-17-77	1650	39,221	563.2	-
2-27-77	1356	53,447	544.4	-
3- 4-77	0935	60,386	539.7	-
3- 7-77	1535	65,066	534.9	-
3-10-77	0952	69,043	529.4	-
3-13-77	1332	73,583	524.9	-
3-19-77	1140	82,111	513.9	-
3-29-77	1225	96,556	505.2	-
4- 4-77 Shut in	1005	105,056	496.6	-

Table 31.--Liquid-level recovery data, well P-15 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 410-438 ft below land surface]

Method of testing: The casing was perforated, the hole was bailed.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
4- 7-77	1530	0	-	-	Bailed 13 runs (156 gallons)
	1600	30	0	-	
	1655	85	55	496.4	-
	1705	95	65	495.4	-
	1715	105	75	494.6	-
4- 8-77	1143	1,213	1,183	424.4	-
4-11-77	1854	5,964	5,934	330.8	-
4-12-77	1215	7,005	6,975	326.6	-
4-13-77	1406	8,556	8,526	320.1	-
4-14-77	1106	9,816	9,786	318.5	-
4-15-77	1143	11,293	11,263	315.6	-
4-22-77	1030	21,300	21,270	314.1	-
5- 6-77	1010	41,440	41,410	311.8	-
5-10-77	1636	47,586	47,556	312.1	-

bailed--end of test

Table 32.--Long-term liquid-level recovery data, well P-15

(Rustler-Salado contact)

[Perforated interval 532-560 ft below land surface]

Method of testing: The packer plug was sheared to open the zone to the tubing and long-term monitoring began.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)
5-11-77	1430	0	-
5-25-77	1300	20,070	341.7
6-23-77	1210	61,780	328.5
8- 4-77	1405	122,375	328
9- 4-77	1213	166,903	325
10-11-77	1110	220,120	324.4

Table 33.--Long-term liquid-level recovery data, well P-15 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 410-438 ft below land surface]

Method of testing: The hole was bailed and liquid levels were monitored on long-term basis.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-10-77	1700	0	-	Last bailer (commenced 1640)
5-25-77	1305	21,365	307.8	-
6-23-77	1200	63,060	307.4	-
8- 4-77	1405	79,025	307	-
9- 3-77	1135	122,075	308	-
10- 3-77	1225	165,325	307.7	-

Surface casing was set on October 18, 1976, to a depth of 20 feet (table 34). The test hole was spudded on October 18 and was drilled using air and air mist as a circulating medium. Liquid was encountered in the hole at 425 feet, at which time soap and water were injected to assist in removal of cuttings. Drilling continued to a casing depth of 755 feet. Geophysical logs were run by the U.S. Geological Survey after drilling was completed. The hole was then conditioned and loaded with mud gel prior to running casing.

Casing was set on October 19 and 20 to a depth of 751 feet. Lost circulation occurred during cementing and additional cement had to be added. After the cement had set, a 4-inch hole was drilled to a coring depth of 1,220 feet below land surface. The potash zone was cored from 1,220 feet to a total depth of 1,660 feet. The hole was logged on October 26 by the U.S. Geological Survey (fig. 19) and was then plugged back to 720 feet with cement. The cement plug was drilled to a depth of 731 feet and the hole was temporarily abandoned pending later hydrologic testing. The final hole configuration and well-construction specifications are included in figure 20.

Hydrologic testing.--The Rustler-Salado contact in P-17 was perforated on January 20, 1977, in an interval of cased hole from 702 to 726 feet (fig. 20). After 73 days of monitoring, the liquid level had risen from 726 feet to 622 feet (table 35), representing 71 gallons of liquid produced from the interval. An inflatable-retrievable bridge packer was set on April 5 at 682.5 feet to seal off the Rustler-Salado perforations from the rest of the hole. Tubing was then pulled and the casing adjacent to the Culebra was perforated from 558 to 586 feet (fig. 20). Following perforation, 324 gallons of liquid used to cushion the perforating gun was bailed from the hole. Liquid levels were monitored for 29 days, in which the liquid level rose from 622 to 372 feet (table 36). On May 10, 1977, 288 gallons of liquid was bailed from the hole and a sample was taken for chemical analyses (table 2). Bailing indicated the zone to be fairly productive. Tubing with a latch-on tool was run and connected to the bridge packer that had been set at 682.5 feet. The Rustler-Salado zone was opened to the tubing and the test hole was put into a long-term dual-completion phase in which the Rustler-Salado contact was monitored through the tubing and the Culebra monitored in the annulus (fig. 20). The Rustler-Salado liquid level has fluctuated very little (table 37) since the tubing was opened to the zone on May 14, 1977. In fact, the liquid level approximates the Culebra liquid level which was at 371.9 feet in October 1977 (table 38). The data might suggest that either the bridge packer is leaking or there is communication in the cemented annulus. Water-level data collected from January to May 1977 from the Rustler-Salado zone (table 35) would probably eliminate the possibility of communication within the cemented annulus. The connection between the tubing and the packer may have been leaking. Swabbing and liquid level monitoring will be conducted to determine whether there is communication between the annulus and tubing.

Table 34.--Chronology of well P-17

[All depth measurements adjusted to ground level, 3,339.5 ft above mean sea level]

Date	
1976	
Oct. 18	Set surface pipe; hole spudded.
Oct. 20	Rotary drilled to 755 ft; USGS geophysical logs; casing landed at 751 ft; cemented.
Oct. 21-22	Rotary drilled to core point (1,220 ft).
Oct. 22-26	Cored to 1,660 ft.
Oct. 26	USGS geophysical logs; plugged back to 720 ft.
Oct. 28	Drilled and washed back to 731 ft; hole temporarily abandoned.
1977	
Jan. 20	Hole bailed dry; perforated casing (Rustler-Salado contact, 702-726 ft).
Jan. 20-Apr. 4	Liquid levels monitored.
Apr. 5	Set inflatable packer (682.5); pulled tubing; perforated casing (Culebra, 558-586 ft).
Apr. 7	Hole bailed dry.
Apr. 7-May 10	Liquid levels monitored.
May 10-12	Liquid levels monitored.
May 12	Reran tubing to packer.
May 14-Oct. 1	Reopened packer to Rustler-Salado zone; monthly measurements.

COMPANY USGS

WELL P-17

LOCATION 1351' FROM SOUTH LINE,

395' FROM WEST LINE

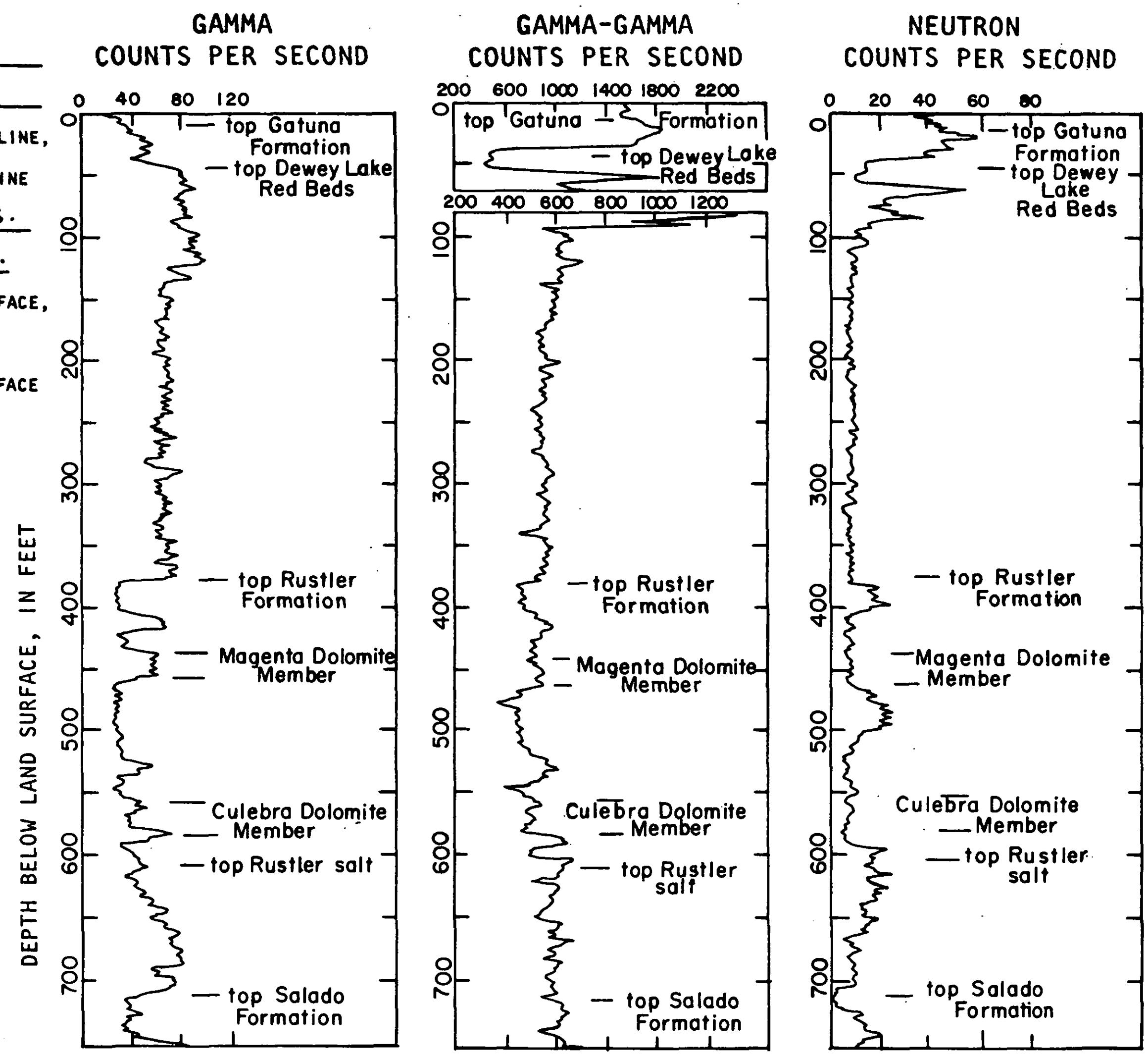
SECTION 4 TOWNSHIP 23 S.

RANGE 31 W.

PERMANENT DATUM IS LAND SURFACE,

ELEVATION 3339.5'

MEASURING POINT IS LAND SURFACE



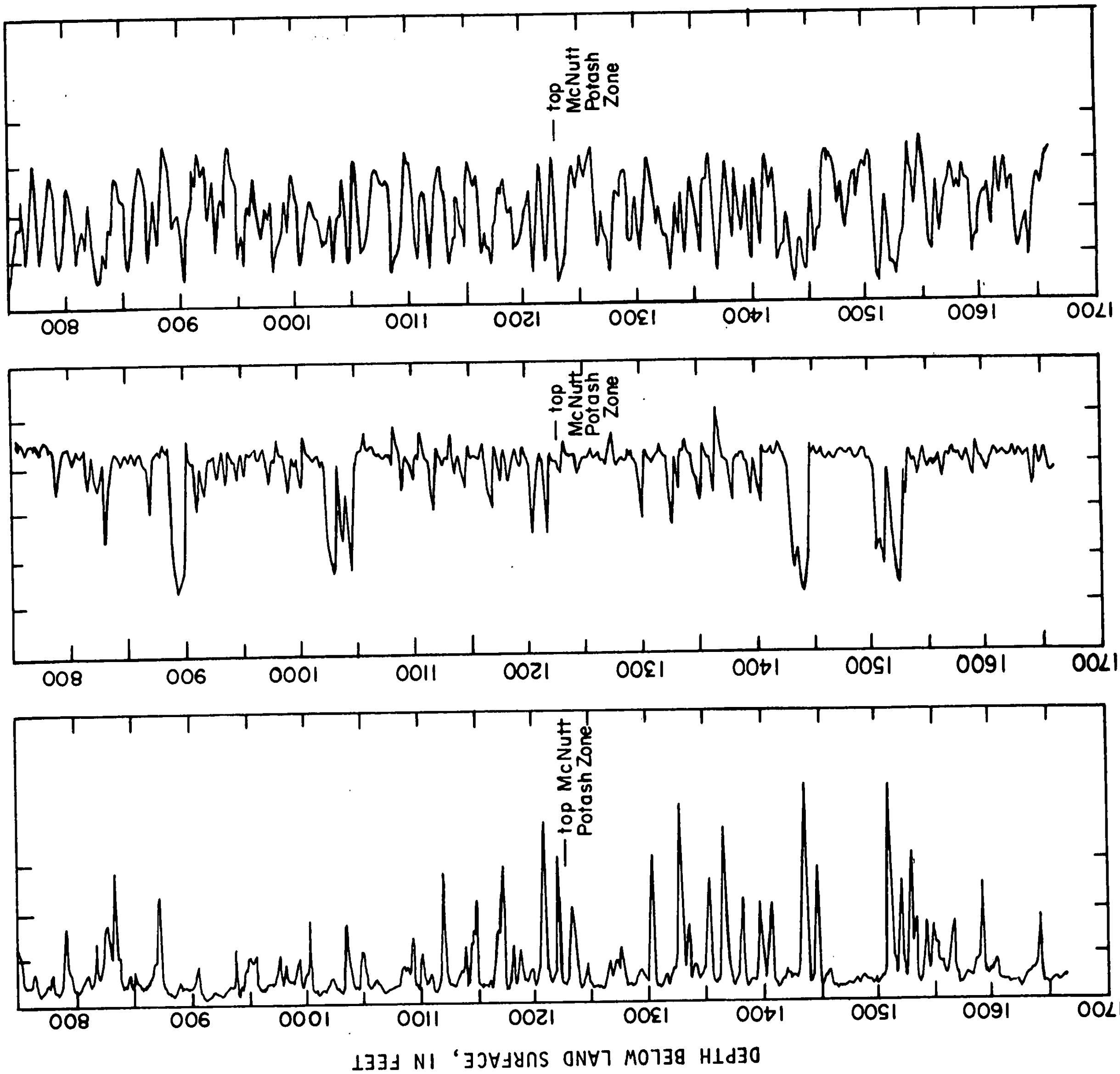
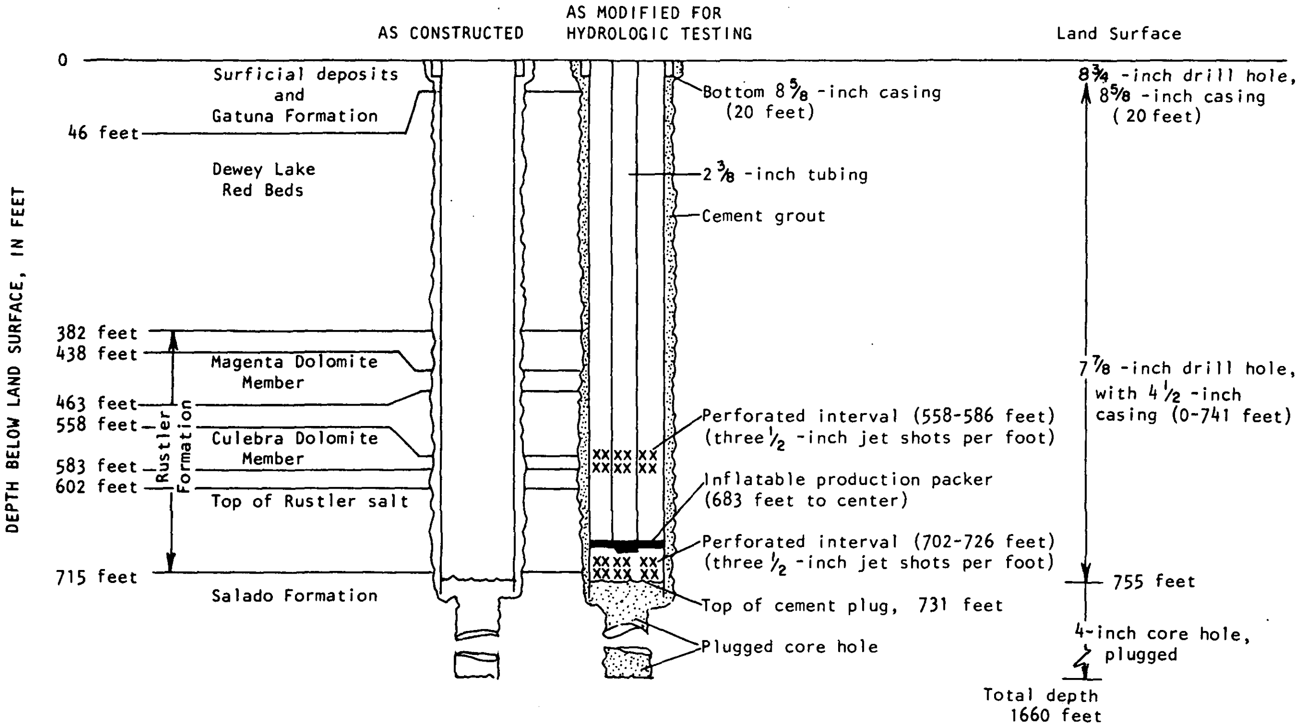


Figure 19.--Selected geophysical logs for well P-17.



LOCATION: 1,351 feet from south line, 395 feet from west line, section 4, Township 23 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,339.5 feet (ground level)

DEPTH DRILLED: 1,660 feet (plugged back to 731 feet)

DATE COMPLETED: October 26, 1976

DRILLING CONTRACTOR: Boyles Brothers Drilling Company, Las Cruces, New Mexico

DRILLING METHOD: Rotary 8 3/4-inch hole with air (0-20 feet); Rotary 7 7/8-inch hole with air and air mist (20-755 feet); Rotary 4-inch hole with air mist (755-1,220 feet); Core 4-inch hole with brine mud (1,220-1,660 feet); Rotary cement plug (720-731 feet)

WELL CASING: 8 5/8-inch outside diameter steel casing (0-20 feet); 4 1/2-inch outside diameter steel casing, 9.5 pounds, 0.68 gallons per foot (0-741 feet), cemented to surface, hole plugged back from 1,660 feet to 720 feet with cement, cement drilled out to 731 feet

GEOPHYSICAL LOGS:

Shown in figure 19: Gamma, Gamma-Gamma, Neutron

Not shown in figure 19: Caliper

Figure 20.--Well P-17 construction, completion, and specifications.

Table 35.--Liquid-level recovery data, well P-17 (Rustler-Salado contact)

[Perforated interval 702-726 ft below land surface]

Method of testing: The casing was perforated and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)
1-21-77	1715	0	-
1-22-77	1647	1,412	725.9
1-24-77	1330	4,095	722.0
1-26-77	1230	6,915	717.2
1-28-77	1215	9,780	715.0
2- 1-77	1345	15,630	708.2
2-12-77	1105	31,310	685.5
2-15-77	1112	35,637	681.5
2-19-77	1340	41,545	674.0
3- 4-77	1005	60,050	660.0
3- 7-77	1110	64,435	656.0
3-10-77	1050	68,735	650.9
3-13-77	1356	73,241	646.0
3-26-77	1504	92,029	634.2
3-30-77	1205	97,610	628.4
4- 4-77	1645	105,090	622.0
Shut in			

Table 36.--Liquid-level recovery data, well P-17 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 558-586 ft below land surface]

Method of testing: The casing was perforated, the hole was bailed, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
4- 7-77	1415	0	-	-	28 bailers = 324 gallons
	1505	50	0	-	-
	1515	60	10	622.0	-
	1530	75	25	602.0	-
	1535	80	30	595.0	-
	1540	85	35	585.7	-
	1545	90	40	575.4	-
	1550	95	45	566.3	-
	1555	100	50	557.0	-
	1600	105	55	547.3	-
	1605	110	60	540.0	-
	1615	120	70	523.5	-
	1625	130	80	511.0	-
	1635	140	90	499.0	-
4- 8-77	1200	1,305	1,255	374.5	-
4-11-77	1920	6,065	6,015	373.3	-
4-12-77	1241	7,106	7,056	373.3	-
4-13-77	1118	8,463	8,413	372.7	-
4-14-77	1424	10,089	10,039	371.3	-
4-15-77	1040	11,305	11,255	371.4	-
5- 6-77	0955	41,500	41,450	372.0	-

Table 37.--Long-term liquid-level recovery data, well P-17

(Rustler-Salado contact)

[Perforated interval 702-726 ft below land surface]

Method of testing: The packer plug was sheared to open the zone to the tubing and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-14-77	1430	0	-	Reopened zone
5-25-77	1335	15,785	371	-
6-23-77	1055	57,385	373.9	-
8- 4-77	1425	118,075	376	-
9- 4-77	1154	162,564	370	-
10- 1-77	0920	201,290	370	-
11- 4-77	0830	250,200	368.8	-

Table 38.--Long-term liquid-level recovery data, well P-17 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 558-586 ft below land surface]

Method of testing: The hole was bailed prior to long-term monitoring.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-10-77	1615	0	-	1500 - 1615 hrs, 24 runs, 288 gallons
5-25-77	1340	22,360	372	-
6-23-77	1112	63,972	373.4	-
8- 4-77	1420	124,640	372	-
9- 3-77	1104	167,644	373	-
10- 3-77	1210	210,910	371.9	-
11- 3-77	1240	255,580	372.1	-

Well P-18

Drilling history.--P-18 is located 134 feet FSL and 797 feet FEL of sec. 26, T.22 S., R.31 E., in Eddy County, New Mexico. The elevation of the ground surface at the drill site is 3,478.7 feet above mean sea level.

Surface casing was set on October 19, 1976, to a depth of 18 feet. The test hole was spudded in on October 19 and was drilled using salt-water gel as a circulating medium (table 39). Because the hole was drilled with mud, no liquid entry was detected during drilling. Drilling continued to a casing depth of 1,139 feet where geophysical logs were run on the hole by the U.S. Geological Survey.

The hole was conditioned and casing was set and cemented to a depth of 1,138 feet. After the cement had set, a 4-inch hole was drilled to the coring depth of 1,630 feet below land surface. The potash zone was cored from 1,630 feet to a total depth of 1,998 feet. The hole was logged by the U.S. Geological Survey on November 5 (fig. 21). The drill hole was then plugged back to 1,125 feet with cement and was temporarily abandoned pending later hydrologic testing. The final hole configuration and well-construction specifications are included in figure 22.

Hydrologic testing.--The casing opposite the Rustler-Salado contact in P-18 was perforated on January 21, 1977, from 1,076 to 1,100 feet (fig. 22). The zone was perforated in a dry hole and after 73 days of monitoring, the liquid level had risen from 1,123.1 to 1,073.2 feet (table 40), only 3 feet above the top perforations. This liquid level rise represents a total production of 34 gallons of liquid from the test interval.

Table 39.--Chronology of well P-18

[All depth measurements adjusted to ground level, 3,478.7 ft above mean sea level]

Date	
1976	
Oct. 19	Set surface pipe; hole spudded.
Oct. 21	Rotary drilling; lost circulation at 349 ft; regained ground-level circulation after conditioning mud.
Oct. 27	Rotary drilled to 1,139 ft; USGS geophysical logs; casing landed at 1,138 ft.
Oct. 28	Casing cemented.
Oct. 29-31	Rotary drilled to core point (1,630 ft).
Nov. 1-5	Cored to 1,998 ft.
Nov. 5	USGS geophysical logs.
Nov. 6	Plugged back to 1,125 ft; hole temporarily abandoned.
1977	
Jan. 19-20	Hole bailed dry.
Jan. 21	Perforated casing (Rustler-Salado contact, 1,076-1,100 ft).
Jan. 21-Apr. 4	Liquid levels monitored.
Apr. 4	Set inflatable packer (1,061 ft); pulled tubing.
Apr. 6	Perforated casing (Culebra, 912-940 ft).
Apr. 7	Hole bailed dry.
Apr. 7-May 10	Liquid levels monitored.
May 10	Hole bailed and sampled (Culebra).
May 14-Oct. 1	Reran tubing with air line; reopened to Rustler-Salado; monthly measurements.

Blank Page

COMPANY USGS

WELL P-18

LOCATION 134' FROM SOUTH LINE,

797' FROM EAST LINE

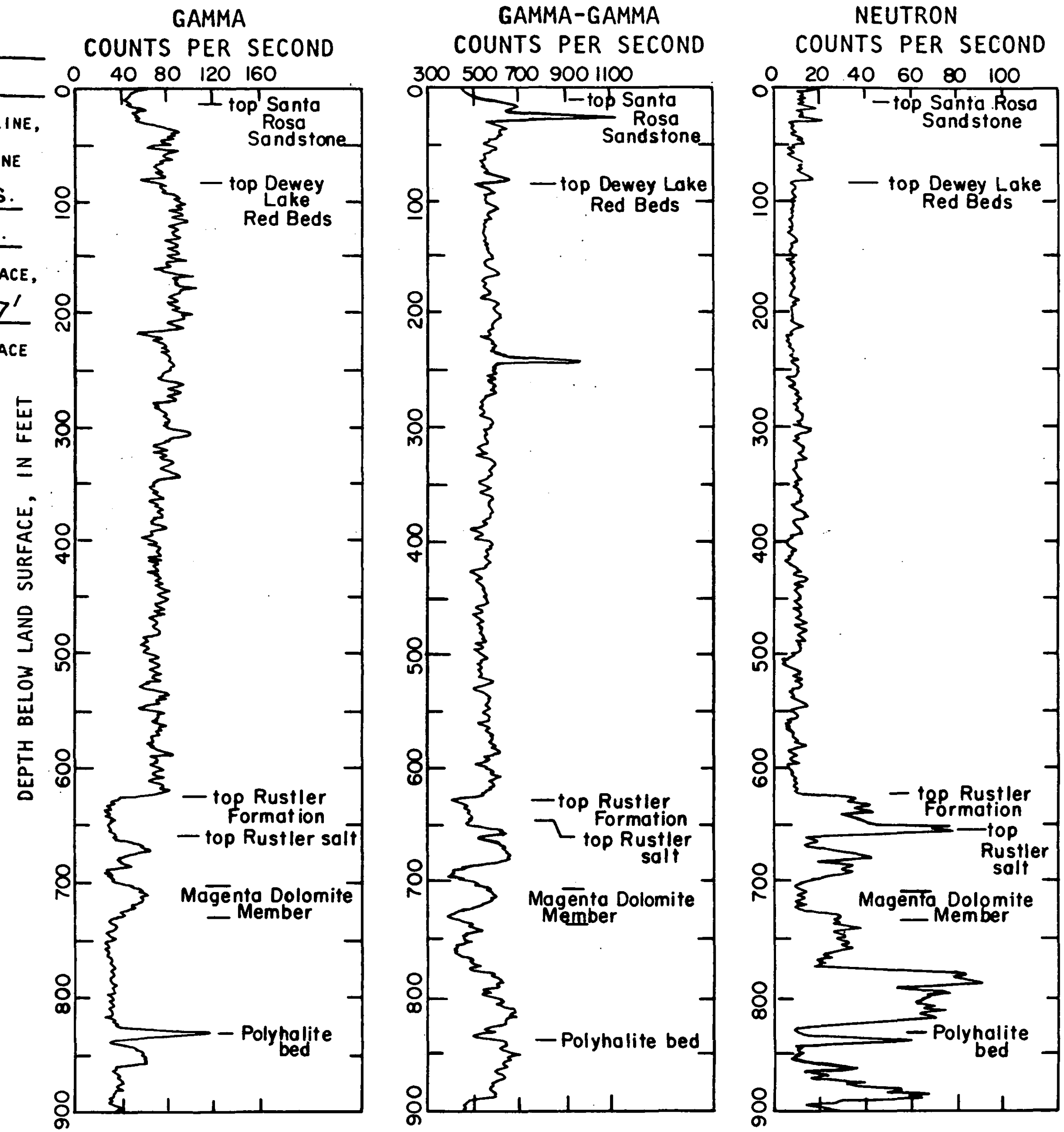
SECTION 26 TOWNSHIP 22S.

RANGE 31E.

PERMANENT DATUM IS LAND SURFACE,

ELEVATION 3478.7'

MEASURING POINT IS LAND SURFACE



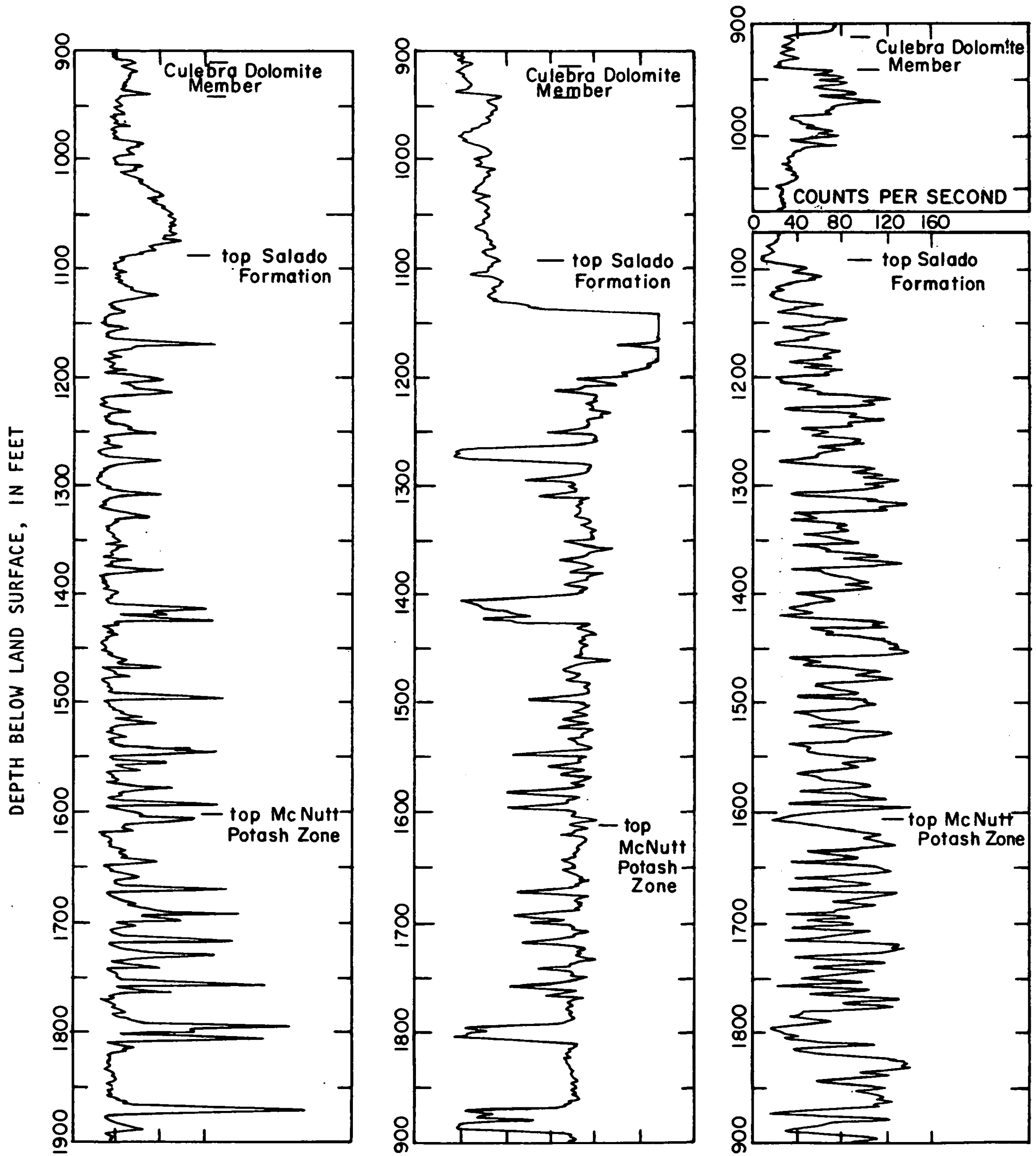
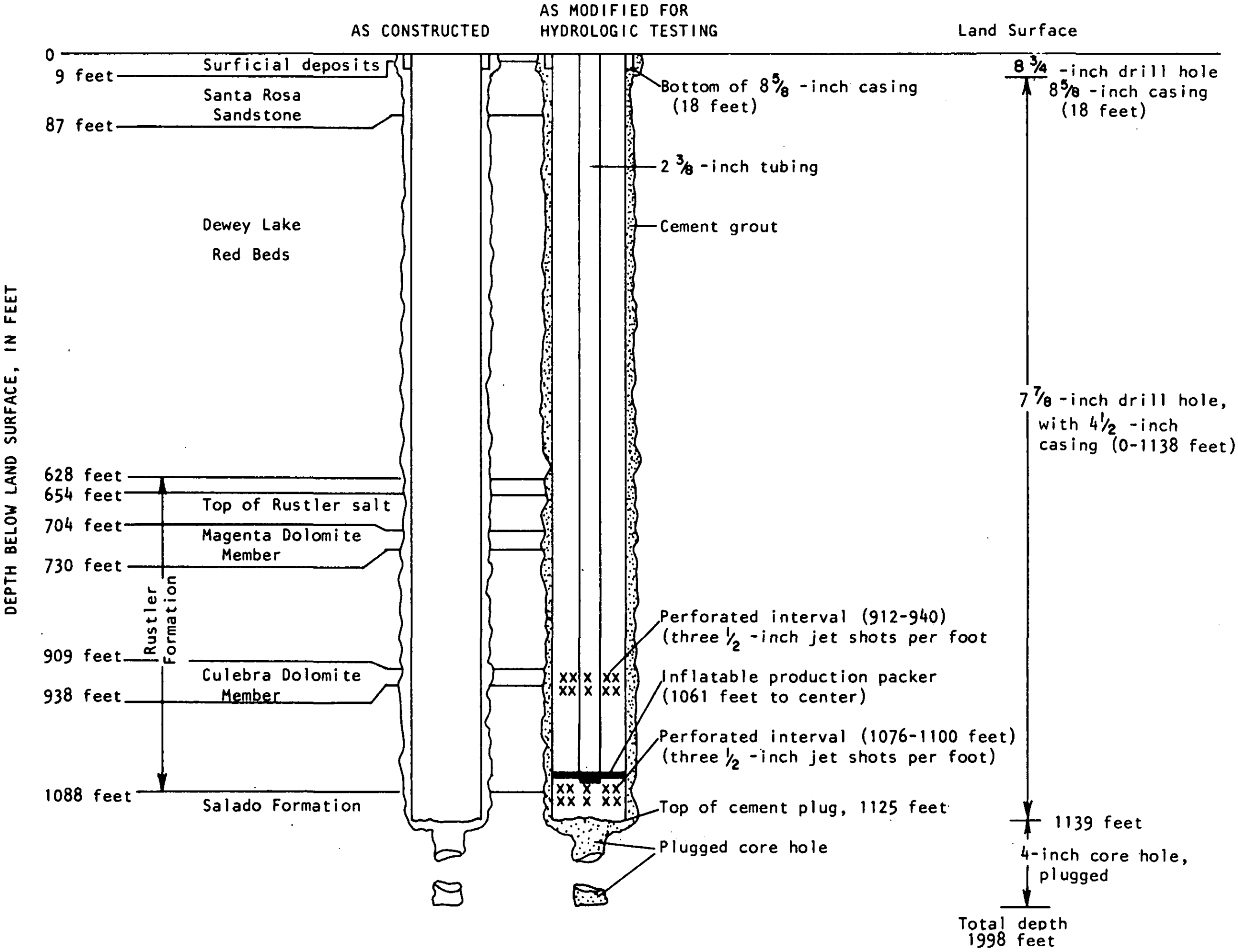


Figure 21.--Selected geophysical logs for well P-18.



LOCATION: 134 feet from south line, 797 feet from east line, section 26, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,478.7 feet (ground level)

DEPTH DRILLED: 1,998 feet (plugged back to 1,125 feet)

DATE COMPLETED: November 5, 1976

DRILLING CONTRACTOR: Pennsylvania Drilling Company, Carlsbad, New Mexico

DRILLING METHOD: Rotary 8 3/4-inch hole with brine mud (0-18 feet); Rotary 7 7/8-inch hole with brine mud (18-1,139 feet); Rotary 4-inch hole with brine mud (1,139-1,630 feet); Core 4-inch hole with brine mud (1,630-1,998 feet)

WELL CASING RECORD: 8 5/8-inch outside diameter steel casing (0-18 feet); 4 1/2-inch outside diameter steel casing, 9.5 pounds, 0.68 gallons per foot (0-1,138 feet), cemented to surface, hole plugged back from 1,998 feet to 1,125 feet with cement

GEOPHYSICAL LOGS:

Shown in figure 21: Gamma, Gamma-Gamma, Neutron

Not shown in figure 21: Caliper

Figure 22.--Well P-18 construction, completion, and specifications.

Table 40.--Liquid-level recovery data, well P-18 (Rustler-Salado contact)

[Perforated interval 1,076-1,100 ft below land surface]

Method of testing: The casing was perforated and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
1-21-77	1730	0	-	Perforated zone
1-22-77	1755	1,465	1,123.1	-
1-24-77	1250	4,040	1,121.4	-
1-26-77	1345	6,975	1,119.4	-
1-28-77	1125	9,715	1,117.3	-
2- 2-77	1000	16,830	1,111.5	-
2-12-77	1140	31,330	1,097.9	-
2-15-77	1040	35,590	1,096.6	-
2-19-77	1235	41,465	1,095.2	-
3- 4-77	1035	60,065	1,091.7	-
3- 7-77	1040	64,390	1,090.7	-
3-10-77	1025	68,695	1,086.0	-
3-13-77	1432	73,262	1,083.5	-
3-19-77	1245	81,795	1,082.5	-
3-26-77	1433	91,983	1,079.4	-
3-30-77	1125	97,555	1,077.4	-
4- 4-77	1450	104,960	1,073.2	-
		Shut in		

A bridge packer was set on April 4 at 1,061 feet to seal off the Rustler-Salado perforations. Tubing was then pulled and the casing next to the Culebra was perforated in a liquid-filled hole from 912 to 940 feet (fig. 22). After perforating, the liquid used to cushion the perforating gun was bailed from the hole. Liquid levels were monitored for 33 days, in which time the liquid level rose from 1,045 to 1,022 feet (table 41). This represents 16 gallons of liquid produced from the interval. The liquid entry into the hole was very slow and at the end of the first test the liquid level was still 82 feet below the bottom of the perforations. The hole was bailed on May 10, 1977 (14 gallons), and a liquid sample was collected for chemical analyses (table 2). Tubing with a latch-on tool was run and connected to the bridge packer that was set at 1,061 feet. The lower zone (Rustler-Salado contact) was opened to the tubing on May 14 and the hole was placed into a long-term monitoring phase (fig. 22). Periodic measurements as of October 1977, indicated the liquid level of the Rustler-Salado contact (monitored in the tubing) was at 801 feet and still recovering (table 42). The liquid level in the annulus (Culebra) was at 998.9 feet and also still rising (table 43). The long-term Rustler-Salado recovery rate was much faster than the Culebra recovery rate. This might be attributed to several factors. The Rustler-Salado contact may indeed be more permeable, resulting in greater production and faster recovery rates or fractures contributing to the Culebra permeability may have been sealed off during cementing or missed completely during perforation.

Well AEC-8

Drilling history.--AEC-8 is located 937 feet FNL and 1,980 feet FWL of sec. 11, T.22 S., R.31 E., in Eddy County, New Mexico. The elevation of the land surface at the drill site is 3,531.9 feet above mean sea level.

Surface casing was set and the hole was spudded on April 24, 1974 (table 44). Core drilling continued to a depth of 1,027 feet during which time drill-stem tests were performed on rock units within the Rustler Formation. Casing was set and cemented to 1,027 feet and core drilling continued to a total depth of 3,019 feet. The hole was then temporarily abandoned.

Table 41.--Liquid-level recovery data, well P-18 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 912-940 ft below land surface]

Method of testing: The casing was perforated, the hole was bailed, and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Remarks
4- 7-77	1215	0	-	-	13 bailers, 135 gallons
	1300	45	0	-	-
	1308	53	8	No liquid detected	-
	1330	75	30	No liquid detected	-
	1345	90	45	1,045.4	-
	1400	105	60	1,045.2	-
	1415	120	75	1,045.0	-
	1430	135	90	1,045.0	-
4- 8-77	1220	1,445	1,400	1,047.4	-
4-12-77	1315	7,260	7,215	1,041.2	-
4-13-77	1150	8,615	8,570	1,040.8	-
4-14-77	1350	10,175	10,130	1,040.0	-
4-15-77	1108	11,453	11,408	1,039.2	-
5-10-77	1336	47,601	47,556	1,022.0	-

Bailed

Table 42.--Long-term liquid-level recovery data, well P-18

(Rustler-Salado contact)

[Perforated interval 1,076-1,100 ft below land surface]

Method of testing: The packer plug was sheared, opening tubing to zone, and liquid levels were monitored.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-14-77	1300	0	-	-
5-25-77	1410	15,910	1,011	-
8- 4-77	1450	118,190	882	-
9- 4-77	1122	162,622	836	-
10- 1-77	0830	201,330	801	-

Table 43.--Long-term liquid-level recovery data, well P-18 (Culebra Dolomite Member of Rustler Formation)

[Perforated interval 912-940 ft below land surface]

Method of testing: The hole was bailed and liquid levels were monitored on a long-term basis.

Date	Clock time	Time since test began (min)	Water level (ft below land surface)	Remarks
5-10-77	1430	-	-	Bailed one run
5-14-77	1000-1300 hours (use 1300 hours as 0)			Ran tubing to Rustler-Salado airline measurements; uncorrected for density
5-25-77	1430	16,020	1,033.7	-
8- 4-77	1445	73,635	1,015	-
9- 3-77	1028	116,578	1,016	-
10- 3-77	1130	159,840	998.9	-

Table 44.--Chronology of well AEC-8

[All depth measurements adjusted to ground level, 3,531.9 ft above mean sea level]

Date	
1974	
Apr. 24	Surface pipe set; hole spudded; cored interval 31-768 ft.
Apr. 30	Set single-inflatable packer, drill-stem test no. 1, Magenta (678-768 ft); cored interval 768-922 ft.
May 2	Set single-inflatable packer, drill-stem test no. 2, Culebra (768-922 ft); cored interval 922-1,027 ft.
May 3	Set single-inflatable packer, drill stem test no. 3, Rustler-Salado contact (922-1,027 ft).
May 3	Welex geophysical logs; reamed hole to 875 ft; casing landed at 874 ft; cemented; cored interval 1,027-3,019 ft.
May 19	Welex geophysical logs to total depth.
May 23	Hole loaded with brine-based mud; temporarily abandoned.
1975	
June 18	Bailed hole to ± 700 ft.
June 19	Set retrievable plug at 944 ft; bailed hole; perforated casing (Culebra, 850-860 ft); acidized perforations; set inflatable packer at 767 ft; squeezed; formation broke at 400 lbs/in^2; pulled tubing and packer.
June 26	Swabbed 100 ft of liquid from hole; latched on to bridge plug; hole made gas; blew tubing and packer out of hole; pressure head and gages installed; hole temporarily abandoned.
1976 (under WIPP Program)	
June 28	Moved in rig to deepen hole.
June 28-July 7	Washed and reamed hole to 3,018.5 ft.
July 7-11	Drilled and milled junk from hole to 3,050.5 ft.

Table 44.--Chronology of well AEC-8 - Continued

Date	
1976	
July 11-27	Cored and drilled interval 3,050.5-4,862.5 ft; ran Salado drill-stem tests.
July 28	Reamed core hole and rotary drilled to 4,910.5 ft.
July 28-Aug. 2	Dresser Atlas geophysical logs.
Aug. 2-3	Casing landed at 4,907 ft; cemented.
Aug. 5	Hole recompleted and temporarily abandoned.
1977	
Aug. 8-9	Moved in pulling unit and blowout preventor; drilled out cement plug (4,858-4,878.6 ft).
Aug. 10	Swabbed hole.
Aug. 11-12	Perforated casing (lower sand in Bell Canyon Formation, 4832.5-4,845.5 ft): monitored liquid levels; drill-stem test single-inflatable packer (4,832.3 ft) with Sentry pressure device.
Aug. 12-15	Monitored shut-in pressure recovery.
Aug. 15	Opened packer; swabbed tubing.
Aug. 15-17	Monitored liquid levels.
Aug. 17-19	Pulled tubing and packer; bailed for sample; reran packer; attempted to open packer.
Aug. 20-21	Monitored liquid levels; packer not open to tubing.
Aug. 22	Pulled tubing and packer; bailed for samples.
Aug. 22-23	Monitored liquid levels.
Aug. 24	McCullough ran radioactive tracer log (131I).
Aug. 25	Swabbed hole.

Table 44.--Chronology of well AEC-8 - Concluded

Date 1977	
Aug. 26- Sept. 19	Monitored liquid levels.
Sept. 19-21	Ran tubing to swab; swabbed hole; monitored liquid levels.
Sept. 21	Perforated casing (upper sand in Bell Canyon Formation, 4,809.5-4,815.5 ft); ran inflatable-bridge plug (4,835 ft); pulled one joint tubing.
Sept. 22	Swabbed hole; pulled tubing.
Sept. 23	Ran single-inflatable packer (4,805 ft) with Sentry pressure device.
Sept. 22-26	Monitored shut-in pressures.
Sept. 26	Opened packer; monitored liquid levels.
Sept. 27	Swabbed hole and sampled.
Sept. 27-28	Monitored liquid levels.
Sept. 28- Oct. 3	Shut in packer and monitored pressures.
Oct. 3	Pulled packer and Sentry; attempted to run radioactive tracer log; formation would not take liquid.
Oct. 4-6	Ran tubing; swabbed; pulled tubing; monitored liquid levels.
Oct. 7	McCullough ran radioactive tracer log (^{131}I).
Oct. 10	Ran tubing; swabbed hole; latched on to bridge plug; pulled tubing and bridge plug.
Oct. 11	Single-inflatable packer (4,836.5) with Sentry pressure devices mounted above and below for dual completion; opened packer to tubing.
Oct. 12	Swabbed tubing; demobilized pulling unit; hole in long-term dual-monitoring phase.

Drilling commenced under the WIPP program on June 28, 1976, and AEC-8 was rotary drilled and cored to 4,910.5 feet and geophysically logged (fig. 23). Casing was set and cemented on August 2-3, 1976, and the hole was temporarily abandoned pending later hydrologic testing. The final hole configuration and well-construction specifications are included in figure 24. Hydrologic testing by the U.S. Geological Survey began August 8, 1977 when the cement plug was drilled out to 4,878.6 feet.

Hydrologic testing.--This report presents AEC-8 data collected in 1977 from tests performed on rock units in the Bell Canyon Formation of the Delaware Mountain Group. AEC-8 drill-stem test data from the Salado and Castile Formations are available in Lambert (1977).

Analyses of geophysical logs taken from selected zones of the Bell Canyon Formation indicated that two units, designated in this report as the lower sand (4,832.5 to 4,848.5 feet), and the upper sand (4,809.5 to 4,815.5 feet), potentially would yield liquid (fig. 25). The natural gamma log indicated that the two units were predominantly sandstone and the porosity log indicated that they had greater porosities than other Bell Canyon sand units. Porosity is expressed quantitatively as the ratio of the total volume of interstices or voids to the total rock volume.

Prior to perforating, the liquid level in the casing was lowered by swabbing to approximately 4,200 feet. The casing adjacent to the lower sand was perforated August 11, 1977 (fig. 24). The zone yielded 31 gallons in the 166-minute test, at an average rate of 0.19 gal/min, raising the liquid level to 4,095 feet (table 45). The zone was then shut in with a production packer set at 4,832.3 feet to allow recovery to static formation pressure. A Sentry monitoring device mounted beneath the packer was used to record pressure buildup. A stabilized pressure of 2,037 lbs/in^2 was reached in 44.5 hours of testing (table 45). Later samples indicated a liquid density of 1.11 g/cm^3. Head calculations, uncorrected to fresh-water densities, were made using this liquid density. The following equation was used to calculate brine levels from pressure and density measurements:

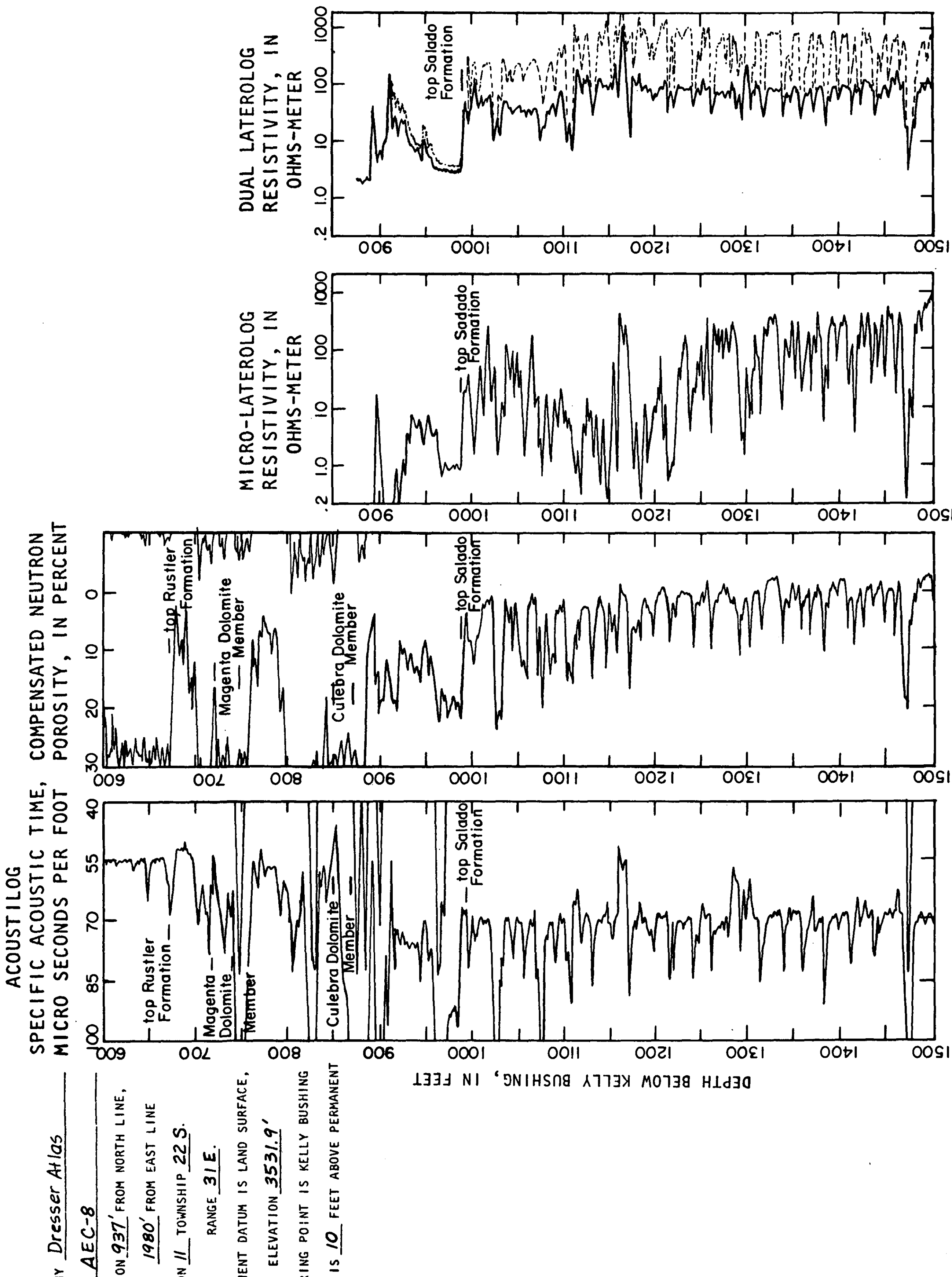
$$H_b = \text{depth to Sentry device} - \frac{(P)(144\ \text{in}^2/\text{ft}^2)}{(\rho)(62.4\ \text{lb}/\text{ft}^3)}$$

where H_b = brine liquid level in feet

P = pressure at Sentry instrument in lb/in^2

ρ = specific gravity of borehole liquid

At 2,037 lbs/in^2 the actual liquid level would be about 600 feet below land surface. On August 17, 1977, the packer was released, pulled, and 850 gallons of liquid were bailed.


COMPANY Dresser Atlas
WELL AEC-8
LOCATION 937' FROM NORTH LINE,
1980' FROM EAST LINE
SECTION 11 TOWNSHIP 22 S.
RANGE 31 E.
PERMANENT DATUM IS LAND SURFACE,
ELEVATION 3531.9'
MEASURING POINT IS KELLY BUSHING
WHICH IS 10 FEET ABOVE PERMANENT
DATUM
ACOUSTILOG
SPECIFIC ACOUSTIC TIME,
MICRO SECONDS PER FOOT
COMPENSATED NEUTRON
POROSITY, IN PERCENT
MICRO-LATEROLOG
RESISTIVITY, IN
OHMS-METER
DUAL LATEROLOG
RESISTIVITY, IN
OHMS-METER
DEPTH BELOW KELLY BUSHING, IN FEET
top Rustler Formation
Magenta Dolomite Member
Culebra Dolomite Member
top Salado Formation
top Sadado Formation

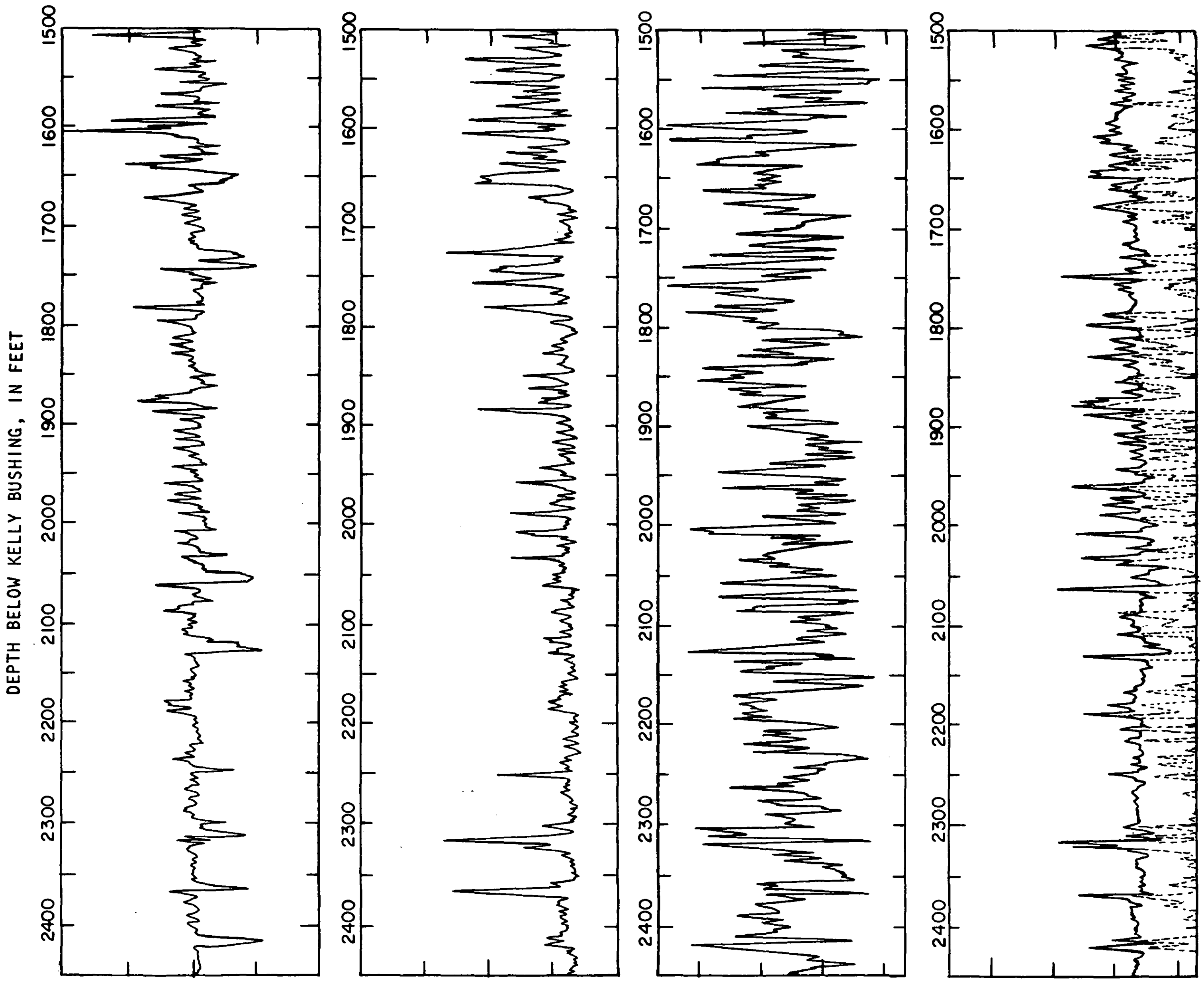
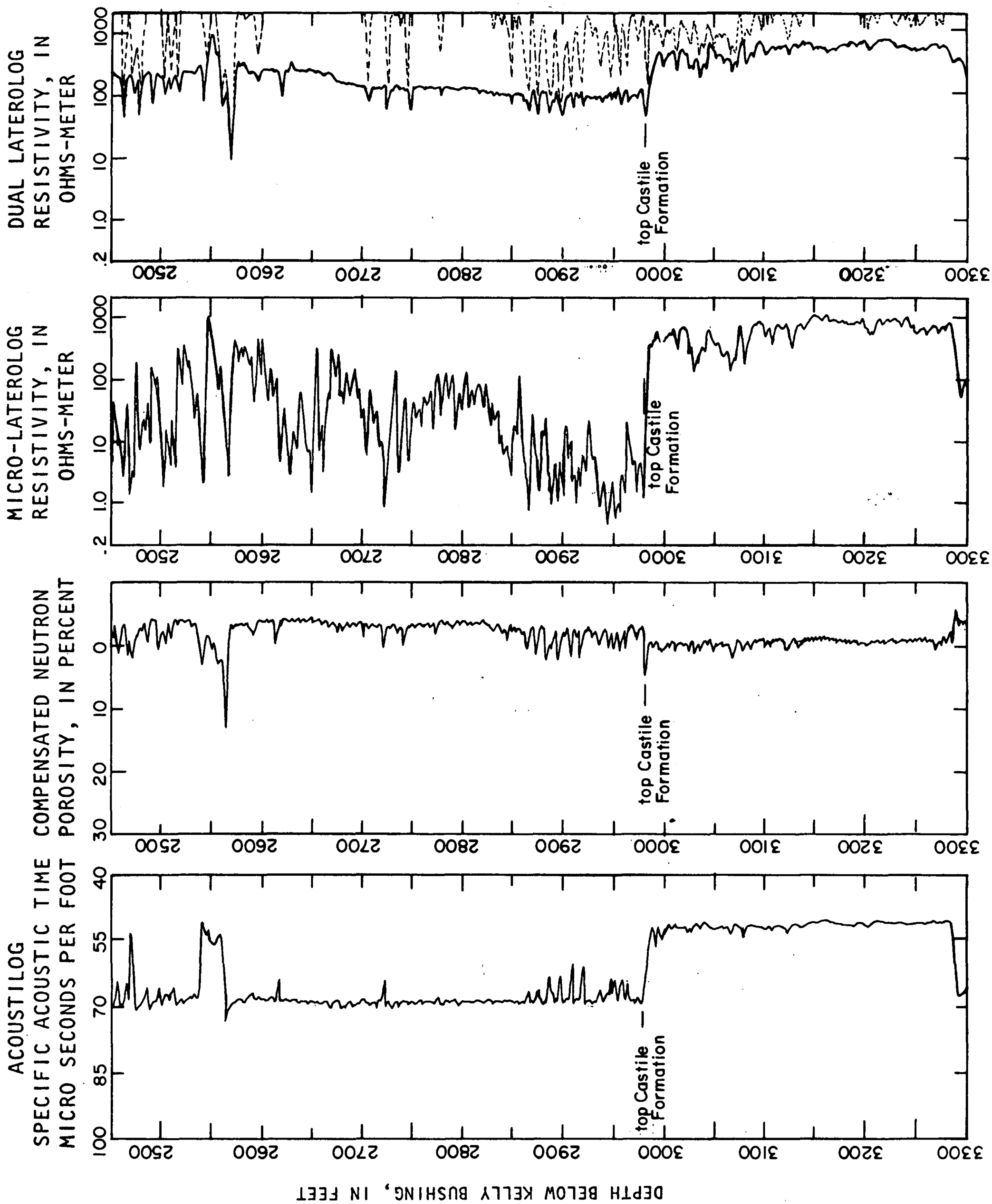


Figure 23.--Selected geophysical logs for well AEC-8.


DUAL LATEROLOG RESISTIVITY, IN OHMS-METER
MICRO-LATEROLOG RESISTIVITY, IN OHMS-METER
COMPENSATED NEUTRON POROSITY, IN PERCENT
ACOUSTILOG SPECIFIC ACOUSTIC TIME MICRO SECONDS PER FOOT
top Castile Formation
DEPTH BELOW KELLY BUSHING, IN FEET
2500
2600
2700
2800
2900
3000
3100
3200
3300

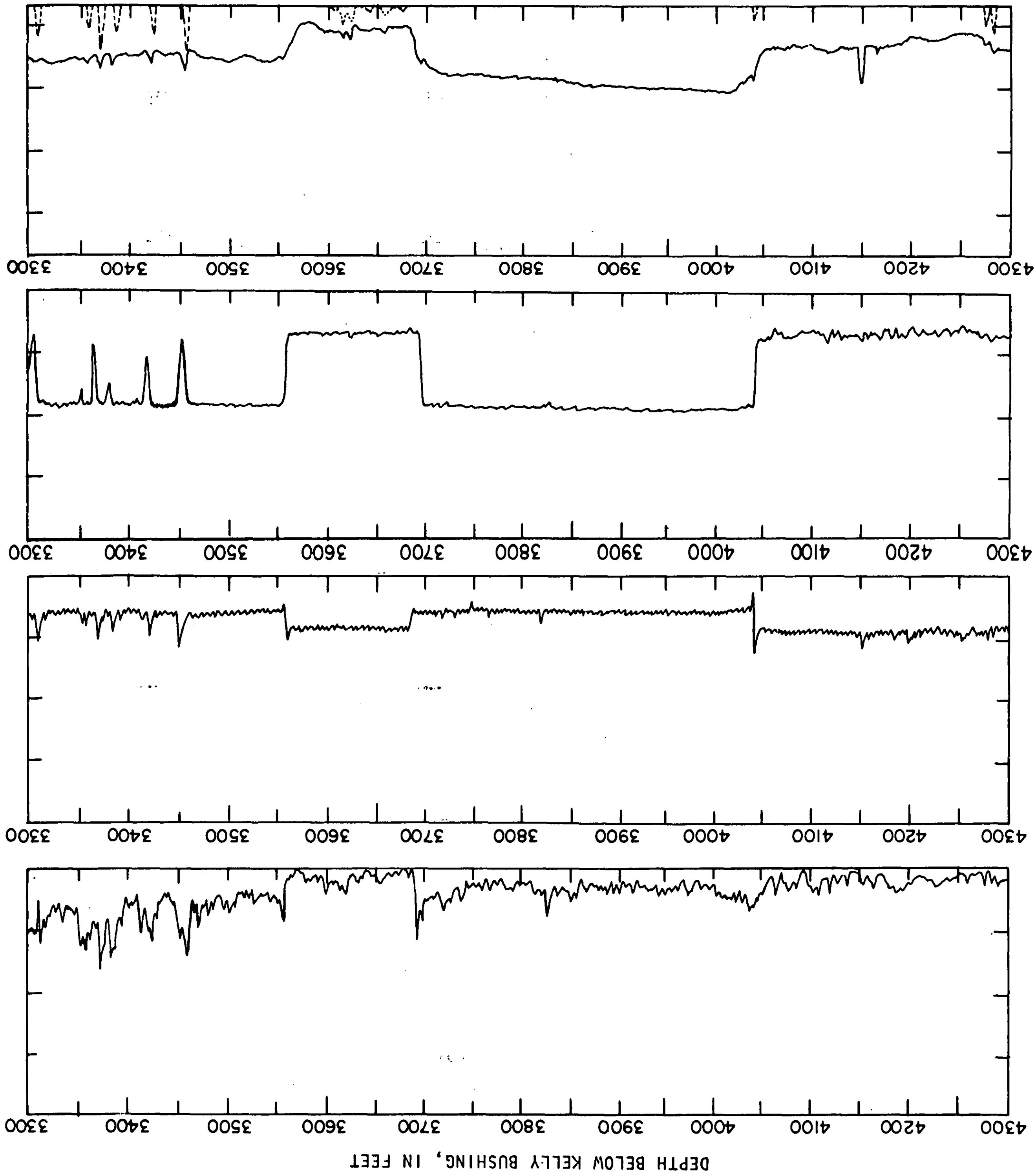


Figure 23.--Selected geophysical logs for well AEC-8 - Continued.

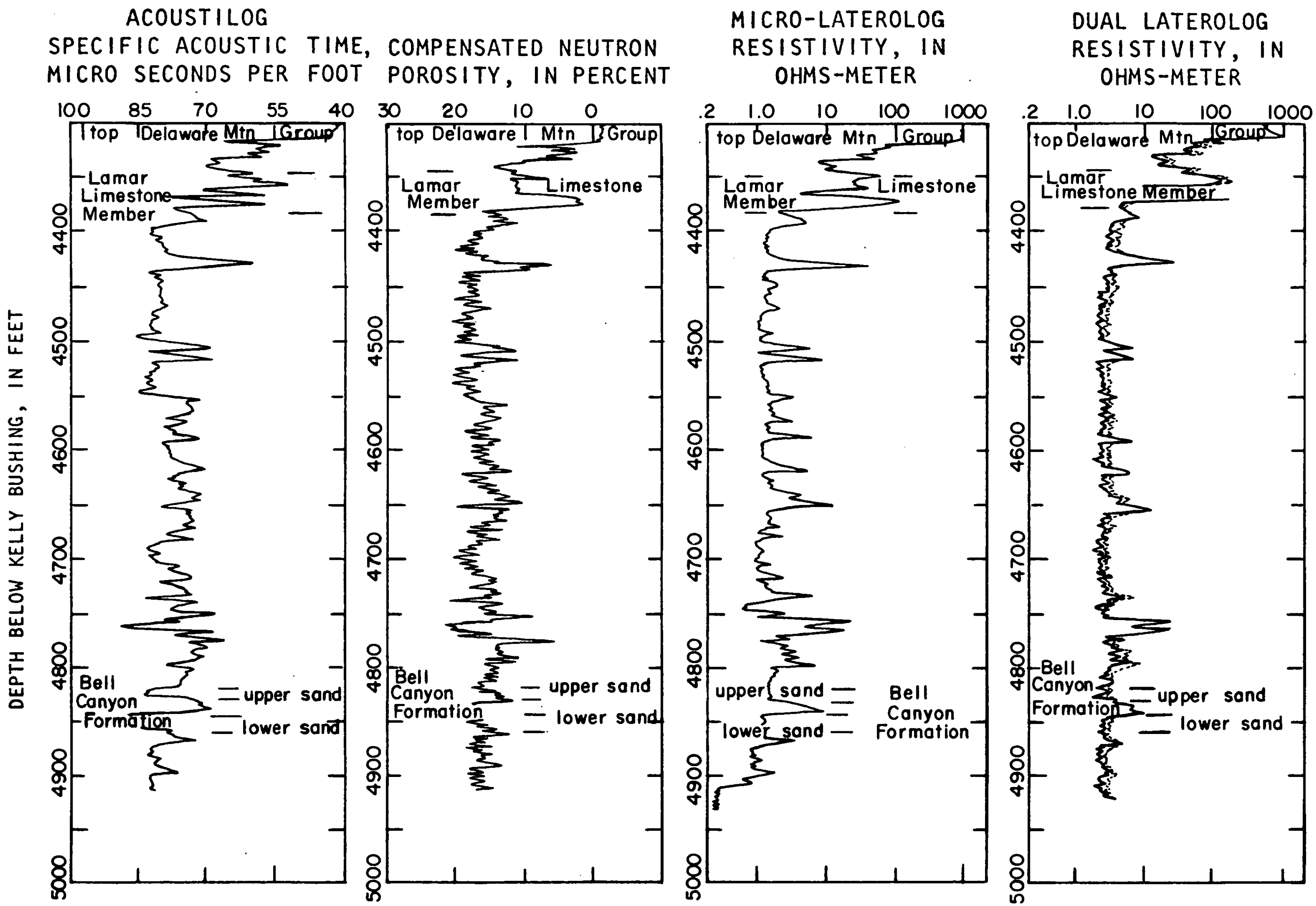
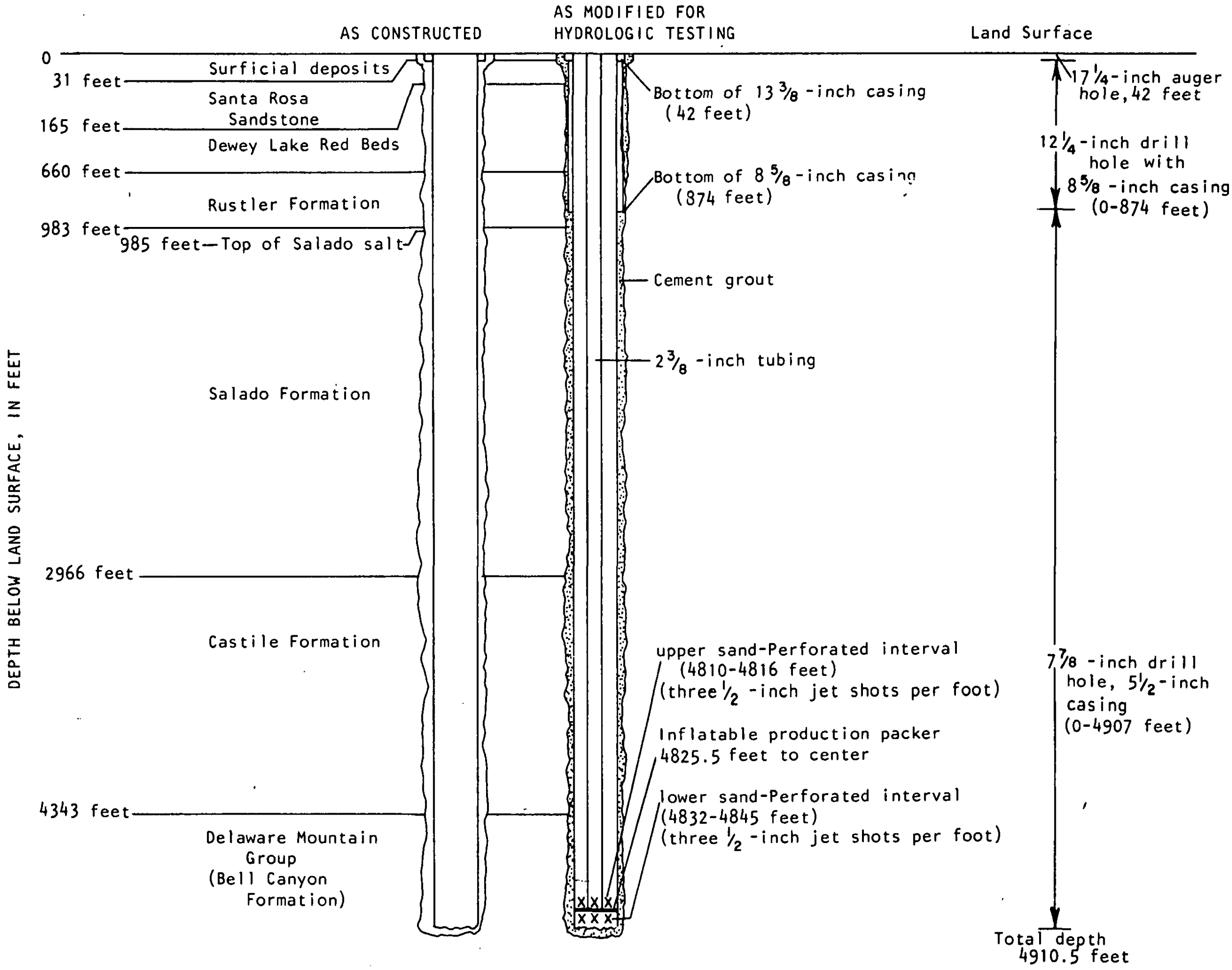


Figure 23.--Selected geophysical logs for well AEC-8 -Concluded.



LOCATION: 937 feet from north line, 1,980 feet from west line, section 11, Township 22 South, Range 31 East, Eddy County, New Mexico

ELEVATION: 3,531.9 feet (ground level)

DEPTH DRILLED: 3,019 feet (1974), deepened to 4,910.5 feet (1976)

DATE COMPLETED: August 5, 1976

DRILLING CONTRACTOR: Sonora Drilling Company, Carlsbad, New Mexico

DRILLING METHOD: Auger 17¼-inch hole (0-42 feet); Core, ream, rotary 12¼-inch hole with brine mud (44-874 feet); Core, ream, rotary 7 7/8-inch hole with brine mud (874-4,910.5 feet)

WELL CASING RECORD: 13 3/8-inch outside diameter steel casing(0-42 feet), 8 5/8-inch outside diameter steel casing, 28 pounds, 2.62 gallons per foot (0-874 feet), cemented to surface; 5 1/2-inch outside diameter steel casing, 15.5 pounds, 1 gallon per foot (0-4,907 feet), cemented to 880 feet

GEOPHYSICAL LOGS:

Shown in figure 23: Compensated Neutron, Microlaterlog, Dual Laterolog, Acoustilog

Figure 24.--Well AEC-8 construction, completion, and specifications.

COMPANY *Dresser Atlas*
WELL *AEC-8*
LOCATION *937'* FROM NORTH LINE, *1980'* FEET FROM EAST LINE
SECTION *11* TOWNSHIP *22S.* RANGE *31E*
PERMANENT DATUM IS LAND SURFACE.
ELEVATION *3531.91*
MEASURING POINT IS KELLY BUSHING WHICH IS *11.5* FEET ABOVE PERMANENT DATUM

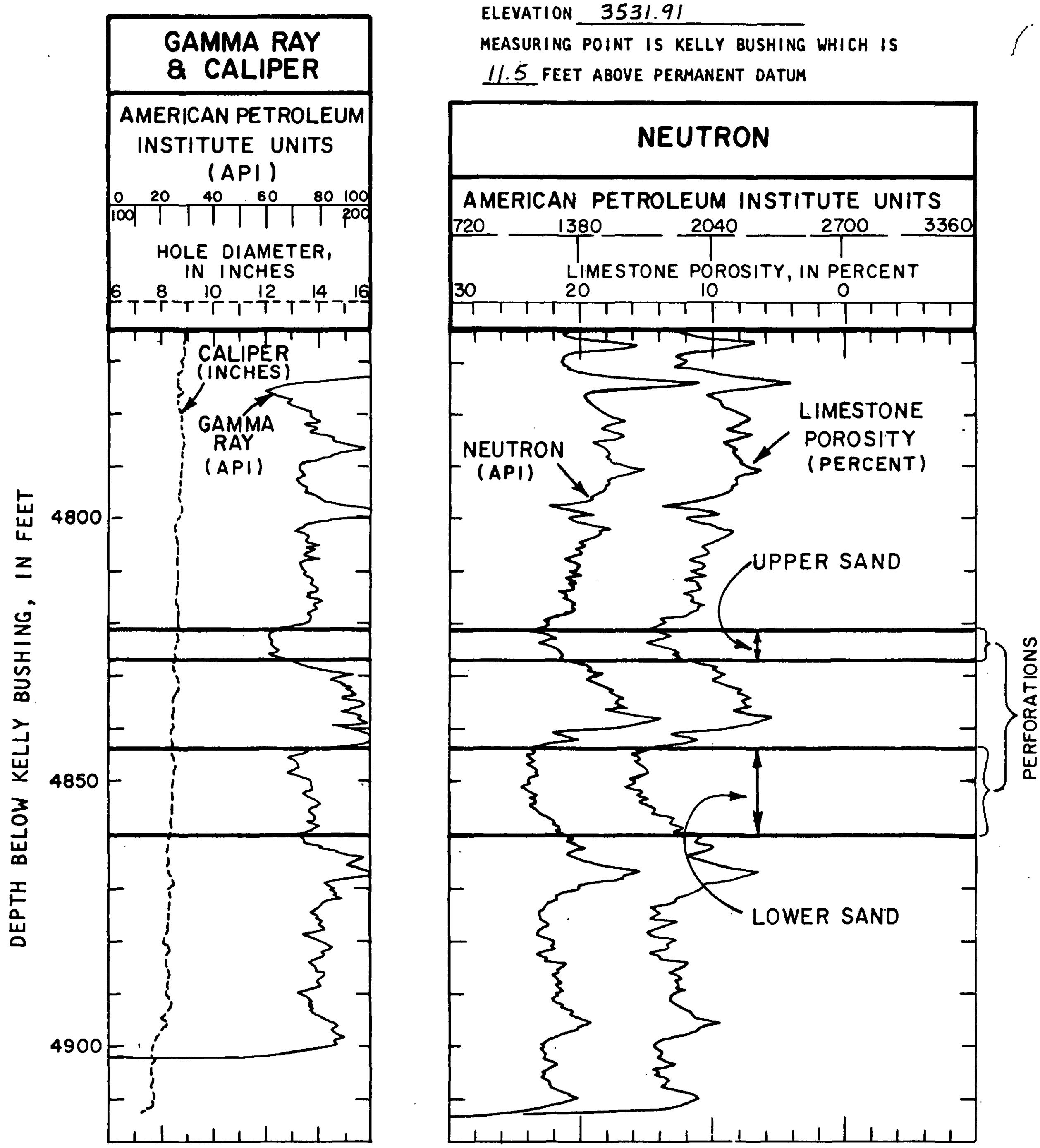


Figure 25.--Gamma, caliper, and neutron logs of the perforated intervals in the Bell Canyon Formation - well AEC 8.

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group)

[Perforated interval 4,832.5-4,848.5 ft below land surface]

Method of testing: The casing was perforated and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
8-11-77	1045	0	-	≅4,126±	-	Perforated zone
	1214	89	-	4,110.5	-	-
	1220	95	-	4,109.5	-	-
	1225	100	-	4,108.5	-	-
	1235	110	-	4,106.6	-	-
	1242	117	-	4,105.3	-	-
	1250	125	-	4,103.7	-	-
	1306	141	-	4,100.3	-	-
	1331	166	-	4,095.4	-	-
End test - run Sentry packer						
Method of testing: Shut in, Sentry pressure monitoring.						
8-12-77	1300	0	-	541	2,065	Shut in
	1305	5	-	761	1,981	Brine liquid levels calculated using specific gravity of 1.11, temperature 27°C
	1320	20	-	891	1,897	-
	1330	30	-	935	1,876	-
	1345	45	-	1,008	1,841	-
	1350	50	-	1,008	1,841	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
8-12-77	1405	65	-	1,008	1,841	-
	1430	90	-	964	1,862	-
	1500	120	-	935	1,876	-
	1530	150	-	906	1,890	-
	1600	180	-	891	1,897	-
	1630	210	-	877	1,904	-
	1700	240	-	862	1,911	-
	1730	270	-	833	1,925	-
8-13-77	0800	1,140	-	672	2,002	-
	0830	1,170	-	672	2,002	-
	0900	1,200	-	672	2,002	-
	0930	1,230	-	658	2,009	-
	1430	1,530	-	658	2,009	-
	1500	1,600	-	658	2,009	-
	1530	1,630	-	658	2,009	-
8-14-77	0900	2,640	-	614	2,030	-
	0930	2,670	-	599	2,037	-
	2000	3,300	-	599	2,037	-
	2030	3,330	-	599	2,037	-
8-15-77	0800	4,020	-	599	2,037	-
	0830	4,050	-	599	2,037	-
	0840	4,060	-	599	-	

End test - open packer to tubing

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Method of testing: The well was swabbed for two days and liquid levels were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
8-25-77	1142	0	-	-	-	21 swab runs (4,300 gallons)
8-26-77	1038	1,376	0	-	-	-
	1634	1,732	356	4,177.5	-	-
	1640	1,738	362	4,174.5	-	-
	1646	1,744	368	4,171.7	-	-
	1700	1,758	382	4,165.6	-	-
	1730	1,788	412	4,152.1	-	-
	1745	1,803	427	4,145.3	-	-
	1800	1,818	442	4,138.8	-	-
	2303	2,121	745	4,010.6	-	-
	2322	2,140	764	4,002.9	-	-
	2340	2,158	782	3,995.7	-	-
	2355	2,173	797	3,988.4	-	-
8-27-77	0800	2,658	1,282	3,800.0	-	-
	0815	2,673	1,297	3,794.0	-	-
	0845	2,703	1,327	3,783.0	-	-
	0900	2,718	1,342	3,777.7	-	-
	1000	2,778	1,402	3,755.7	-	-
	1100	2,838	1,462	3,733.3	-	-
	1130	2,868	1,492	3,723.0	-	-
	1345	3,003	1,627	3,674.7	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
8-27-77	1400	3,018	1,642	3,669.4	-	-
	1500	3,078	1,702	3,648.0	-	-
	1506	3,084	1,708	3,646.0	-	-
	1510	3,088	1,712	3,644.0	-	-
	1515	3,093	1,717	3,642.0	-	-
	1521	3,099	1,723	3,640.0	-	-
	1527	3,105	1,729	3,638.0	-	-
	1532	3,110	1,734	3,636.0	-	-
	1538	3,116	1,740	3,634.0	-	-
	1543	3,121	1,745	3,632.0	-	-
	1549	3,127	1,751	3,630.0	-	-
	1556	3,134	1,758	3,628.0	-	-
	1601	3,139	1,763	3,626.0	-	-
	2315	3,573	2,197	3,480.9	-	-
	2319	3,577	2,201	3,479.0	-	-
	2325	3,583	2,207	3,477.0	-	-
	2331	3,589	2,213	3,475.0	-	-
	2337	3,595	2,219	3,473.0	-	-
	2343	3,601	2,225	3,471.0	-	-
8-28-77	0856	4,154	2,778	3,300.0	-	-
	0902	4,160	2,784	3,298.0	-	-
	0908	4,166	2,790	3,296.0	-	-
	0929	4,187	2,811	3,290	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
8-28-77	0935	4,193	2,817	3,288.0	-	-
	0941	4,199	2,823	3,286.0	-	-
	0948	4,206	2,830	3,284.0	-	-
	0954	4,212	2,836	3,282.0	-	-
	1001	4,219	2,843	3,280.0	-	-
	1018	4,236	2,860	3,275.0	-	-
	1529	4,547	3,171	3,185.4	-	-
	1533	4,551	3,175	3,184.0	-	-
	1540	4,558	3,182	3,182.0	-	-
	1547	4,565	3,189	3,180.0	-	-
	1554	4,572	3,196	3,178.0	-	-
	1601	4,579	3,203	3,176.0	-	-
	1607	4,585	3,209	3,174.0	-	-
8-29-77	0615	5,433	4,057	2,949.7	-	-
	0619	5,437	4,061	2,948.0	-	-
	0627	5,445	4,069	2,946.0	-	-
	0635	5,453	4,077	2,944.0	-	-
	0643	5,461	4,085	2,942.0	-	-
	0651	5,469	4,093	2,940.0	-	-
	0659	5,477	4,101	2,938.0	-	-
	0707	5,485	4,109	2,936.0	-	-
	0715	5,493	4,117	2,934.0	-	-
	1630	6,048	4,672	2,781.4	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
8-29-77	1634	6,052	4,676	2,780.0	-	-
	1642	6,060	4,684	2,778.0	-	-
	1651	6,069	4,693	2,776.0	-	-
	1659	6,077	4,701	2,774.0	-	-
	1707	6,085	4,709	2,772.0	-	-
	1715	6,093	4,717	2,770.0	-	-
	1726	6,104	4,728	2,768.0	-	-
	1732	6,110	4,734	2,766.0	-	-
8-30-77	0620	6,878	5,502	2,596.5	-	-
	0627	6,885	5,509	2,595.0	-	-
	0635	6,893	5,517	2,593.0	-	-
	0644	6,902	5,526	2,591.0	-	-
	0654	6,912	5,536	2,589.0	-	-
	0703	6,921	5,545	2,587.0	-	-
	0713	6,931	5,555	2,585.0	-	-
	0722	6,940	5,564	2,583.0	-	-
	1745	7,563	6,187	2,456.9	-	-
	1752	7,570	6,194	2,455.0	-	-
	1801	7,579	6,203	2,453.0	-	-
	1810	7,588	6,212	2,451.0	-	-
	1821	7,599	6,223	2,449.0	-	-
	1832	7,610	6,234	2,447.0	-	-
	1842	7,620	6,244	2,445.0	-	-
	1853	7,631	6,255	2,443.0	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
8-31-77	0830	8,448	7,072	2,295.0	-	-
	0840	8,458	7,082	2,293.0	-	-
	0849	8,467	7,091	2,291.0	-	-
	0900	8,478	7,102	2,289.0	-	-
	0912	8,490	7,114	2,287.0	-	-
	0924	8,502	7,126	2,285.0	-	-
	0947	8,525	7,149	2,281.0	-	-
	0959	8,537	7,161	2,279.0	-	-
	1710	8,968	7,592	2,207.0	-	-
	1720	8,978	7,602	2,205.0	-	-
	1732	8,990	7,614	2,203.0	-	-
	1744	9,002	7,626	2,201.0	-	-
	1758	9,016	7,640	2,199.0	-	-
	1810	9,028	7,652	2,197.0	-	-
9- 1-77	0845	9,903	8,527	2,064.8	-	-
	0854	9,912	8,536	2,063.0	-	-
	0906	9,924	8,548	2,061.0	-	-
	0920	9,938	8,562	2,059.0	-	-
	0930	9,948	8,572	2,058.0	-	-
	0938	9,956	8,580	2,057.0	-	-
	0944	9,962	8,586	2,056.0	-	-
	0955	9,973	8,597	2,054.0	-	-
	1008	9,986	8,610	2,052.0	-	-
	1353	10,211	8,835	2,020.0	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9- 1-77	1409	10,227	8,851	2,017.8	-	-
	1644	10,382	9,006	1,996.0	-	-
	1657	10,395	9,019	1,994.0	-	-
	1712	10,410	9,034	1,992.0	-	-
	1726	10,424	9,048	1,990.0	-	-
	1741	10,439	9,063	1,988.0	-	-
	1755	10,453	9,077	1,986.0	-	-
9- 2-77	0757	11,295	9,919	1,876.6	-	-
	0815	11,313	9,937	1,874.0	-	-
	0831	11,329	9,953	1,872.0	-	-
	0848	11,346	9,970	1,870.0	-	-
	0906	11,364	9,988	1,868.0	-	-
	1720	11,858	10,482	1,808.9	-	-
	1741	11,879	10,503	1,806.0	-	-
	1758	11,896	10,520	1,804.0	-	-
	1815	11,913	10,537	1,802.0	-	-
	1831	11,929	10,553	1,800.0	-	-
9- 3-77	0841	12,779	11,403	1,706.5	-	-
	0903	12,801	11,425	1,704.0	-	-
	0922	12,820	11,444	1,702.0	-	-
	0941	12,839	11,463	1,700.0	-	-
	1927	13,425	12,049	1,641.1	-	-
	1936	13,434	12,058	1,640.0	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9- 3-77	1946	13,444	12,068	1,639.0	-	-
	1956	13,454	12,078	1,638.0	-	-
9- 4-77	1010	14,308	12,932	1,558.5	-	-
	1025	14,323	12,947	1,557.0	-	-
	1035	14,333	12,957	1,556.0	-	-
	1047	14,345	12,969	1,555.0	-	-
	1058	14,356	12,980	1,554.0	-	-
	1805	14,783	13,407	1,517.2	-	-
	1817	14,795	13,419	1,516.0	-	-
	1828	14,806	13,430	1,515.0	-	-
	1840	14,818	13,442	1,514.0	-	-
	1852	14,830	13,454	1,513.0	-	-
9- 5-77	0935	15,713	14,337	1,442.4	-	-
	0950	15,728	14,352	1,441.0	-	-
	1003	15,741	14,365	1,440.0	-	-
	1015	15,753	14,377	1,439.0	-	-
	1029	15,767	14,391	1,438.0	-	-
	1042	15,780	14,404	1,437.0	-	-
	1615	16,113	14,737	1,412.3	-	-
	1631	16,129	14,753	1,411.0	-	-
	1644	16,142	14,766	1,410.0	-	-
	1658	16,156	14,780	1,409.0	-	-
	1711	16,169	14,793	1,408.0	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9- 6-77	0834	17,092	15,716	1,343.9	-	-
	0846	17,104	15,728	1,343.0	-	-
	0903	17,121	15,745	1,342.0	-	-
	0917	17,135	15,759	1,341.0	-	-
	0931	17,149	15,773	1,340.0	-	-
	1241	17,339	15,963	1,327.7	-	-
	1252	17,350	15,974	1,327.0	-	-
	1357	17,415	16,039	1,322.8	-	-
	1427	17,445	16,069	1,320.9	-	-
	1455	17,473	16,097	1,319.0	-	-
	1511	17,489	16,113	1,318.0	-	-
	1522	17,500	16,124	1,317.3	-	-
	1715	17,613	16,237	1,310.0	-	-
	1731	17,629	16,253	1,309.0	-	-
	1746	17,644	16,268	1,308.0	-	-
	1801	17,659	16,283	1,307.0	-	-
9- 7-77	0753	18,491	17,115	1,254.7	-	-
	0807	18,505	17,129	1,253.8	-	-
	0824	18,522	17,146	1,252.9	-	-
	0839	18,537	17,161	1,252.0	-	-
	0901	18,559	17,183	1,250.9	-	-
	1640	19,018	17,642	1,223.4	-	-
	1718	19,056	17,680	1,221.4	-	-
	1747	19,085	17,709	1,220.1	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9- 7-77	1800	19,098	17,722	1,219.2	-	-
	1817	19,115	17,739	1,218.2	-	-
9- 8-77	0837	19,975	18,599	1,171.5	-	-
	0847	19,985	18,609	1,171.0	-	-
	0910	20,008	18,632	1,169.8	-	-
	0928	20,026	18,650	1,169.1	-	-
	0943	20,041	18,665	1,168.3	-	-
	1544	20,402	19,026	1,148.9	-	-
	1703	20,481	19,105	1,145.1	-	-
	1715	20,493	19,117	1,144.5	-	-
	1723	20,501	19,125	1,144.0	-	-
	1738	20,516	19,140	1,143.4	-	-
	1750	20,528	19,152	1,142.8	-	-
9- 9-77	0706	21,324	19,948	1,105.0	-	-
	0722	21,340	19,964	1,104.4	-	-
	0742	21,360	19,984	1,103.4	-	-
	0755	21,373	19,997	1,103.0	-	-
	1725	21,943	20,567	1,077.1	-	-
	1746	21,964	20,588	1,076.8	-	-
	1809	21,987	20,611	1,075.1	-	-
9-10-77	1305	23,123	21,747	1,027.9	-	-
	1335	23,153	21,777	1,026.9	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-11-77	1340	24,598	23,222	973.8	-	-
	1405	24,623	23,247	973.6	-	-
	1432	24,650	23,274	972.6	-	-
	1501	24,679	23,303	971.6	-	-
9-12-77	1305	26,003	24,627	963.8	-	-
	1336	26,034	24,658	962.8	-	-
	1607	26,185	24,809	958.5	-	-
9-13-77	0830	27,168	25,792	935.7	-	-
9-14-77	0845	28,623	27,247	900.2	-	-
	1335	28,913	27,537	895.3	-	-
	1345	28,923	27,547	895.0	-	-
	1355	28,933	27,557	894.7	-	-
	1405	28,943	27,567	894.5	-	-
9-15-77	0837	30,055	28,679	869.0	-	-
	0854	30,072	28,696	868.7	-	-
	0910	30,088	28,712	868.4	-	-
	0925	30,103	28,727	868.1	-	-
9-16-77	0800	31,458	30,082	842.5	-	-
	1000	31,578	30,202	840.7	-	-
	1030	31,609	30,232	840.2	-	-

Table 45.--Liquid-level recovery data, well AEC-8 (lower sand, Bell Canyon Formation, Delaware Mountain Group) - Concluded

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-16-77	1200	31,698	30,322	838.8	-	-
	1400	31,818	30,442	836.8	-	-
	1600	31,938	30,562	834.8	-	-
9-17-77	0800	32,898	31,522	819.4	-	-
9-18-77	0905	34,403	33,027	798.7	-	-
9-19-77	0905	35,843	34,467	781.4	-	-
End of test						
Method of testing: Long-term monitoring						
11- 7-77	-	-	-	615.0	-	-

On August 24, 1977, a tracer (^{131}I) and temperature survey was run on the lower sand perforations (fig. 26) to determine the interval of liquid loss and to detect possible communication or channeling within the cemented annulus. The tracer and temperature logs indicated major liquid loss occurring in the interval from 4,827.5 to 4,848.5 feet. Very minor communication was observed down casing to 4,858.5 feet. The survey was run down the casing with liquid injection rates of 14 gal/min with a total of 2,289 gallons injected into the formation. On August 25-26, 1977, 4,300 gallons of liquid were swabbed to remove injected liquid from the formation.

Liquid levels were monitored from August 26 to September 19 during which time the liquid level rose from 4,178 to 781 feet (table 45). At the end of the test, the water-level recovery rate was 17 feet per day.

The casing next to the upper sand (4,809.5 to 4,815.5 feet) was perforated on September 21, 1977. A packer was set between the two perforated zones at 4,835 feet and liquid in the upper zone was swabbed to a depth of 2,600 feet. On September 23, an inflatable production packer with a Sentry pressure monitoring device mounted beneath it was run on tubing and set at 4,805 feet. Shut-in pressures recovered to 2,037 lbs/in^2 in 57 hours (table 46). Liquid density was measured to be 1.12 g/cm^3. Using this density, the static head, uncorrected to fresh water, was calculated to be 608 feet below land surface.

The packer was opened on September 26, 1977, allowing liquid from the upper sand to rise in the tubing. Liquid levels were then monitored in the tubing and pressures were monitored with the sentry pressure device (table 46). Because fresh water was in the tubing at the time the packer was opened, measurements showed liquid levels to be higher than those calculated for corresponding pressures at the brine density of 1.12 g/cm^3. On September 27, 3,800 gallons of liquid from the zone were swabbed, lowering the water level to 2,800 feet, and samples were taken for chemical analyses (table 2). Calculated water levels from pressure readings and actual water-level recovery measurements corresponded after fresh water had been removed from the tubing (table 46). Liquid levels rose from 2,771 to 767 feet in 17 hours at which time the zone was shut in. A longer shut-in drill-stem test was run from September 28 to October 2, 1977 (table 46). At this time, pressures appeared to have stabilized at 2,044 lbs/in^2 or at a brine level of 593 feet below land surface.

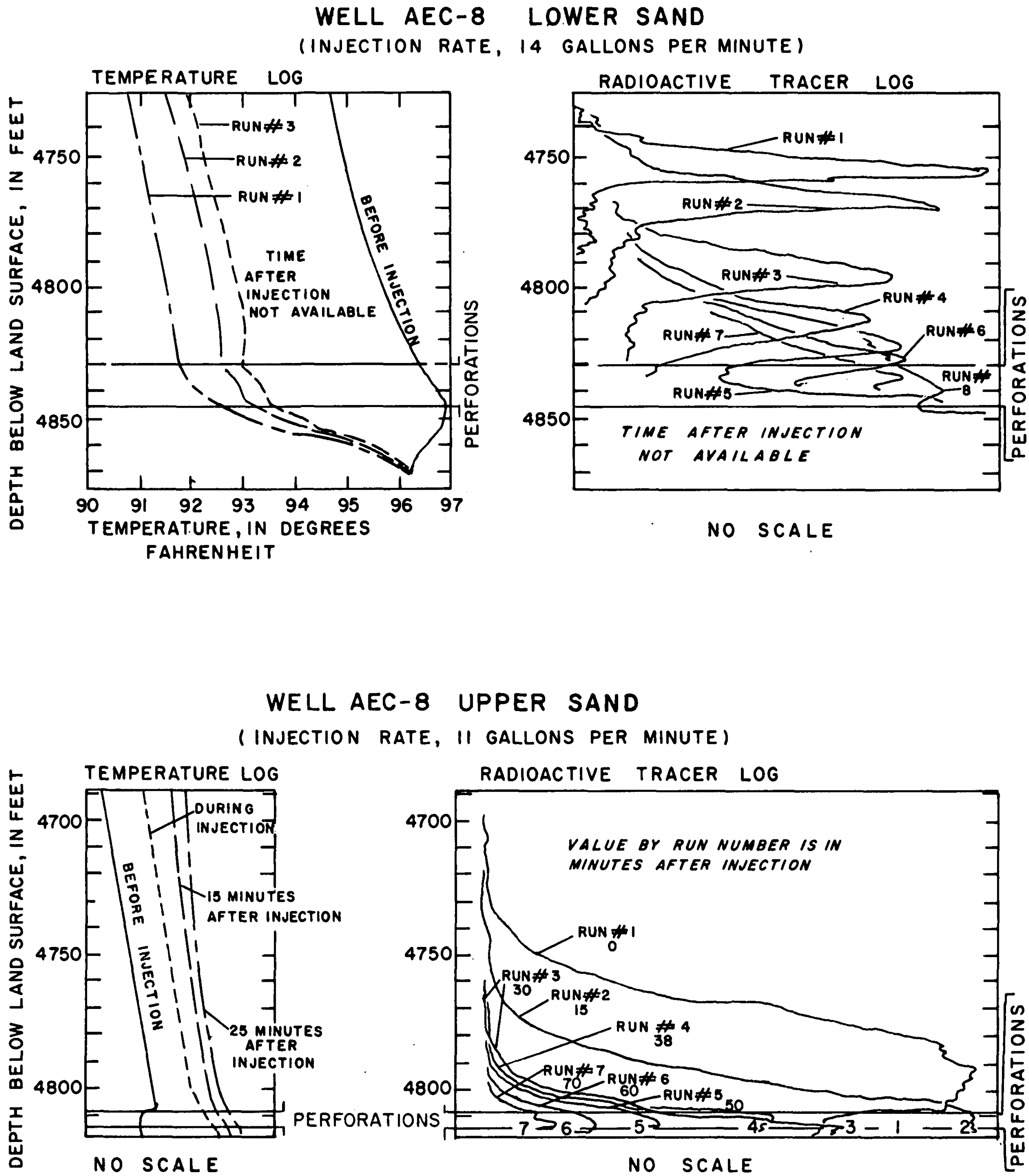


Figure 26.--Radioactive tracer (tracejector) and temperature logs in the Bell Canyon Formation for well AEC-8.

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group)

[Perforated interval 4,809.5-4,815.5 ft below land surface]

Method of testing: The zone was perforated, an inflatable bridge plug was set below the zone to isolate it from the lower sand, the Sentry packer was set above the perforations, and shut in pressures were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-23-77	1420	0	-	233	2,219	Inflating packer
	1425	5	-	377	2,149	-
	1428	8	-	499	2,114	-
	1432	12	-	478	2,100	Brine liquid levels calculated using specific gravity of 1.12 and liquid temperature of 27.0°C
	1448	28	-	550	2,065	-
	1500	40	-	593	2,044	-
	1507	47	-	608	2,037	-
	1527	67	-	637	2,023	-
	1533	73	-	651	2,016	-
	1630	130	-	666	2,009	-
	1730	190	-	680	2,002	-
	1830	250	-	694	1,995	-
	1930	310	-	694	1,995	-
	2030	370	-	694	1,995	-
	2130	430	-	694	1,995	-
	2230	490	-	694	1,995	-
	2330	550	-	680	2,002	-

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-24-77	0030	610	-	680	2,002	-
	0130	670	-	680	2,002	-
	0230	730	-	680	2,002	-
	0330	790	-	680	2,002	-
	0430	850	-	666	2,009	-
	0530	910	-	666	2,009	-
	0630	970	-	666	2,009	-
	0638	978	-	666	2,009	-
	0730	1,030	-	666	2,009	-
	0830	1,090	-	666	2,009	-
	0930	1,150	-	666	2,009	-
	1030	1,210	-	666	2,009	-
	1130	1,270	-	666	2,009	-
	1230	1,330	-	666	2,009	-
	1330	1,390	-	666	2,009	-
	1430	1,450	-	666	2,009	-
	1452	1,472	-	666	2,009	-
	1510	1,490	-	666	2,009	-
	1610	1,550	-	666	2,009	-
	1710	1,610	-	651	2,016	-
	1810	1,670	-	651	2,016	-
	1910	1,730	-	651	2,016	-
	2010	1,790	-	651	2,016	-

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-24-77	2110	1,850	-	651	2,016	-
	2210	1,910	-	651	2,016	-
	2310	1,970	-	651	2,016	-
9-25-77	0010	2,030	-	651	2,016	-
	0110	2,090	-	651	2,016	-
	0210	2,150	-	651	2,016	-
	0310	2,210	-	651	2,016	-
	0410	2,270	-	637	2,023	-
	0510	2,330	-	637	2,023	-
	0610	2,390	-	637	2,023	-
	0710	2,450	-	637	2,023	-
	0810	2,510	-	637	2,023	-
	0910	2,570	-	637	2,023	-
	0940	2,600	-	637	2,023	-
	1010	2,630	-	637	2,023	-
	1110	2,690	-	637	2,023	-
	1210	2,750	-	637	2,023	-
	1310	2,810	-	637	2,023	-
	1410	2,870	-	637	2,023	-
	1510	2,930	-	622	2,030	-
	1610	2,990	-	622	2,030	-
	1710	3,050	-	622	2,030	-

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-25-77	1810	3,110	-	622	2,020	-
	1910	3,170	-	622	2,030	-
	1950	3,210	-	622	2,030	-
	2010	3,230	-	622	2,030	-
	2110	3,290	-	622	2,030	-
	2210	3,350	-	622	2,030	-
	2310	3,410	-	608	2,037	-
9-26-77	0010	3,470	-	608	2,037	-
	0110	3,530	-	608	2,037	-
	0210	3,590	-	608	2,037	-
	0310	3,650	-	608	2,037	-
	0410	3,710	-	608	2,037	-
	0510	3,770	-	608	2,037	-
	0610	3,830	-	608	2,037	-
	0710	3,890	-	608	2,037	-
	0810	3,950	-	608	2,037	-
	0838	3,978	-	608	2,037	-
	0926	4,026	-	608	2,037	-
	0935	4,035	-	608	2,037	-

End of test

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Method of testing: The packer plug was sheared and pressures were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-26-77	0940	0	-	882	1,904	-
	1000	20	-	839	1,925	Note: tubing contained 18 barrels of fresh water at time of opening
	1002	22	-	839	1,925	-
	1004	24	-	839	1,925	-
	1009	29	-	824	1,932	-
	1020	40	-	781	1,953	-
	1024	44	-	-	1,953	-
	1025	45	-	767	1,960	-
	1030	50	-	752	1,967	-
	1035	55	-	738	1,974	-
	1040	60	-	723	1,981	-
	1050	70	-	272	-	Wireline measurement*
	1057	77	-	709	1,988	-
	1112	92	-	694	1,995	-
	1127	107	-	666	2,009	-
	1142	122	-	666	2,009	-
	1157	137	-	666	2,009	-
	1212	152	-	666	2,009	-
	1227	167	-	666	2,009	-
	1242	182	-	666	2,009	-
	1259	199	-	651	2,016	-
	1310	210	-	651	2,016	-

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-26-77	1356	256	-	210.0	-	Wireline measurement*
	1410	270	-	651	2,016	-
	1510	330	-	651	2,016	-
	1610	390	-	637	2,023	-
	1710	450	-	637	2,023	-
	1810	510	-	637	2,023	-
	1855	555	-	183.2	-	Wireline measurement*
	1906	566	-	637	2,023	-
9-27-77	0750	1,330	-	190.4	-	Wireline measurement*
	0756	1,336	-	608	2,037	-
	0815	1,355	-	190.1	-	Wireline measurement*
	0823	1,363	-	608	2,037	-

End of test - swabbing

Method of testing: The tubing was swabbed and liquid levels and pressure recovery were monitored.

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-27-77	0344	0	-	-	-	25 swab runs (3800 gallons) Note: If no pressure is noted, measurement is of actual liquid level
	1550	426	0	2,771	987	-
	1624	460	34	1,978	1,372	-
	1626	462	36	1,949	1,386	-
	1628	464	38	1,935	1,393	-
	1635	471	45	1,863	1,428	(1890) actual liquid level measurement
	1636	472	46	1,820	-	-

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-27-77	1637	473	47	1,815	-	-
	1639	475	49	1,805	-	-
	1640	476	50	1,800	-	-
	1651	487	61	1,706	-	-
	1653	489	63	1,690	-	-
	1654.5	490.5	64.5	1,680	-	-
	1655.5	491.5	65.5	1,670	-	-
	1658.5	494.5	68.5	1,650	-	-
	1700	496	70	1,646	1,533	-
	1702	498	72	1,625	-	-
	1706	502	76	1,600	-	-
	1710	506	80	1,575	-	-
	1714	510	84	1,550	-	-
	1718.5	514.5	88.5	1,525	-	-
	1723	519	93	1,500	-	-
	1728	524	98	1,475	-	-
	1730	526	100	1,432	1,637	-
	1738.5	534.5	108.5	1,425	-	-
	1744.5	540.5	114.5	1,400	-	-
	1751	547	121	1,375	-	-
	1757.5	553.5	127.5	1,350	-	-
	1800	556	130	1,358	1,673	-
	1811	567	141	1,300	-	-
	2119	755	329	972	-	-
	2121	757	331	970	-	-
	2127	763	337	965	-	-

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Continued

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-27-77	2130	766	340	968	1,862	-
	2133	769	343	960	-	-
	2146	782	356	950	-	-
	2200	796	370	940	1,876	-
	2206	802	376	935	-	-
	2230	826	400	925	1,883	-
	2245	841	415	910	-	-
9-28-77	0810	1,406	980	755	-	-
	0830	1,426	1,000	767	1,960	-
	0847	1,443	1,017	750	-	-
	0900	1,456	1,030	767	1,960	-
End of test - shut in						
Method of testing: Shut in inflatable packer, monitored stabilization to formational pressure.						
9-28-77	0910	0	-	-	-	-
	0920	10	-	132	2,268	-
	0925	15	-	204	2,233	-
	0940	30	-	363	2,156	-
	1004	54	-	464	2,107	-
	1110	120	-	595	2,044	-
	1200	170	-	622	2,030	-
	1300	230	-	651	2,016	-
	1400	290	-	666	2,009	-

Table 46.--Liquid-level recovery data, well AEC-8 (upper sand, Bell Canyon Formation, Delaware Mountain Group) - Concluded

Date	Clock time	Time since pumping started (min)	Time since pumping stopped (min)	Water level (ft below land surface)	Pressure (lb/in^2)	Remarks
9-28-77	1500	350	-	666	2,009	-
	1600	410	-	666	2,009	-
	1700	470	-	666	2,009	-
	1800	530	-	666	2,009	-
	1900	590	-	666	2,009	-
	1930	620	-	666	2,009	-
9-29-77	0750	1,360	-	651	2,016	-
	1630	1,880	-	637	2,023	-
	1800	1,970	-	637	2,023	-
	2400	2,330	-	651	2,016	-
9-30-77	0600	2,690	-	608	2,037	-
	0931	2,901	-	608	2,037	-
10- 1-77	0800	4,250	-	608	2,037	-
10- 2-77	1050	5,860	-	593	2,044	-
	2315	6,605	-	593	2,044	-
10- 3-77	0810	7,140	-	593	2,044	-
End of test - ran packer						
Method of testing: Long-term monitoring.						
11- 7-77	-	-	-	559.7	-	-

The packer was released and pulled October 3, 1977, prior to running a radioactive tracer survey on the upper sand (4,809.5 to 4,815.5 feet). The test was aborted due to an apparent blockage of perforations, preventing injection of liquid into the formation. Tubing was run and the well was swabbed October 4-6, 1977, to reopen the perforations. The tracer (^{131}I) and temperature survey was successfully run October 7 (fig. 26). The survey indicated that liquid injection was occurring evenly over the bottom 4 feet of perforations. No communication upward or downward was detected. The survey was run down the casing at a liquid injection rate of 11 gal/min, with a total of 300 gallons injected into the zone. On October 10, 1977, 1,300 gallons were swabbed from the hole to remove contaminated liquid, and the packer separating the two perforated zones was released and pulled. On October 11, a single inflatable production packer, with Sentry pressure monitoring devices mounted above and below the element, was run on tubing and inflated at 4,836.5 feet. The tubing was opened to the lower sand and was swabbed October 12, 1977. AEC-8 was then placed in a dual-completion long-term monitoring phase with the lower zone (4,832.5 to 4,848.5 feet) pressure head being monitored in the tubing and the upper zone (4,809.5 to 4,815.5 feet) being monitored in the annulus (fig. 24). Sentry pressure devices are being used to monitor formation pressures and verify liquid-level measurements. As of November 1977, the liquid level from the lower zone was approaching prepumping levels at 615 feet (table 45) and the upper zone at 560 feet (table 46).

Data interpretation

Shallow hydrologic testing

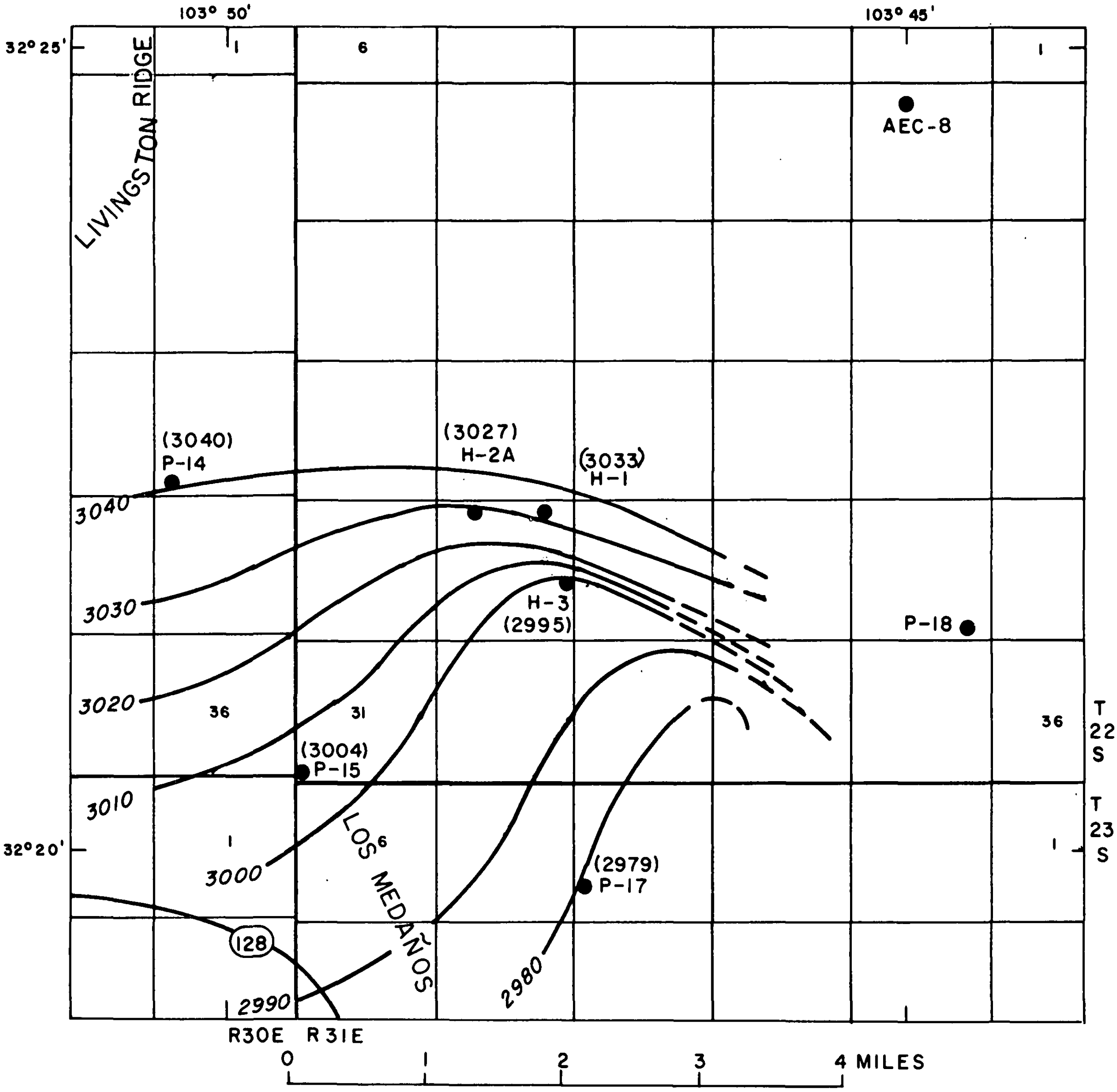
At the WIPP site, modified open-hole drill-stem tests in H-1, the H-2 complex, and H-3 were used in the initial investigations to gain preliminary hydrologic information on which to base decisions for subsequent hydraulic testing. Data from these tests indicated that there were three potential liquid-bearing zones above the salt. These zones in ascending order are as follows: (1) The Rustler Formation-Salado Formation contact, (2) the Culebra Dolomite Member of the Rustler Formation, and (3) the Magenta Dolomite Member of the Rustler Formation. Drilling also indicated that these zones are laterally continuous under the site area. Salt-residue zones were also tested in the Rustler Formation in H-1 and H-3, and were found to contain no significant liquid. Air drilling and subsequent geophysical logging of the zones above the Rustler Formation indicated that the formations did not yield water with the exception of a thin sandy unit in the Dewey Lake Red Beds. This unit was tested in H-2a and yielded very little water. After open-hole testing, the hydrologic test holes were cased to provide long-term static-head data for the liquid-bearing zones.

Testing of liquid-bearing zones in the Rustler Formation showed that static heads are highest in the Magenta, lower in the Culebra, and lowest at the Rustler-Salado contact. Over 100 feet of head difference exists between the Magenta and Culebra Dolomite Members at the H-2 complex, with a static water level of 249 feet in the Magenta (table 23) and a static water level of 351 feet for the Culebra (table 21). Approximately 60 feet of head difference exists between the Culebra and Rustler-Salado at P-14, with a static water level of 324 feet in the Culebra (table 28) and a static water level of 386 feet at the Rustler-Salado contact (table 27). Approximately 19 feet of head difference exists between the Culebra and Rustler-Salado heads in P-15, with a static water level of 308 feet in the Culebra (table 33) and a static water level of 327 feet at the Rustler-Salado contact (table 32). The low hydraulic conductivities of the thick anhydrite, siltstone, and mudstone units separating the three liquid-bearing units probably restricts vertical liquid movement significantly despite differences in head between zones.

Head distribution (liquid-level elevations in the test holes), as described by a potentiometric surface map, is useful in determining the direction of flow, hydraulic gradient, and changes in hydraulic conductivity. A potentiometric surface is the surface defined by the level to which water will rise in a tightly cased well. Hydraulic gradient is the change in static head per unit of distance in a given direction and hydraulic conductivity is a measure of the ability of the formation to transmit liquid under a hydraulic gradient at prevailing field conditions.

Rustler-Salado static heads are available only in P-14 and P-15 because of the very slow recovery rates in other wells. The P-15 liquid level is at an elevation of 2,985 feet, and the P-14 liquid level is at an elevation of 2,969 feet. Brine-density differences and the very low hydraulic conductivity of the Rustler-Salado contact hinders current analyses of direction of flow and gradient calculations. Further definition of hydrologic conditions at the Rustler-Salado contact will require long-term head stabilization and accurate liquid-density measurements.

The Culebra was tested in all shallow hydrologic holes at the site. Head distribution, corrected to fresh-water density, as shown in the potentiometric surface map (fig. 27) indicates movement of liquid to the south and southeast across the site. The hydraulic gradient ranges from 7 ft/mi (between P-15 and P-17) to 120 ft/mi (between H-1 and H-3). The wide variations in gradient on the Culebra potentiometric surface may be attributed to lateral variations in hydraulic conductivity.



EXPLANATION

● P-17 (2979) WELL--P-17 is well identification. (2979) is altitude of water level, in feet (expressed as freshwater with a density of 1.00 gram per centimeter). Datum is mean sea level

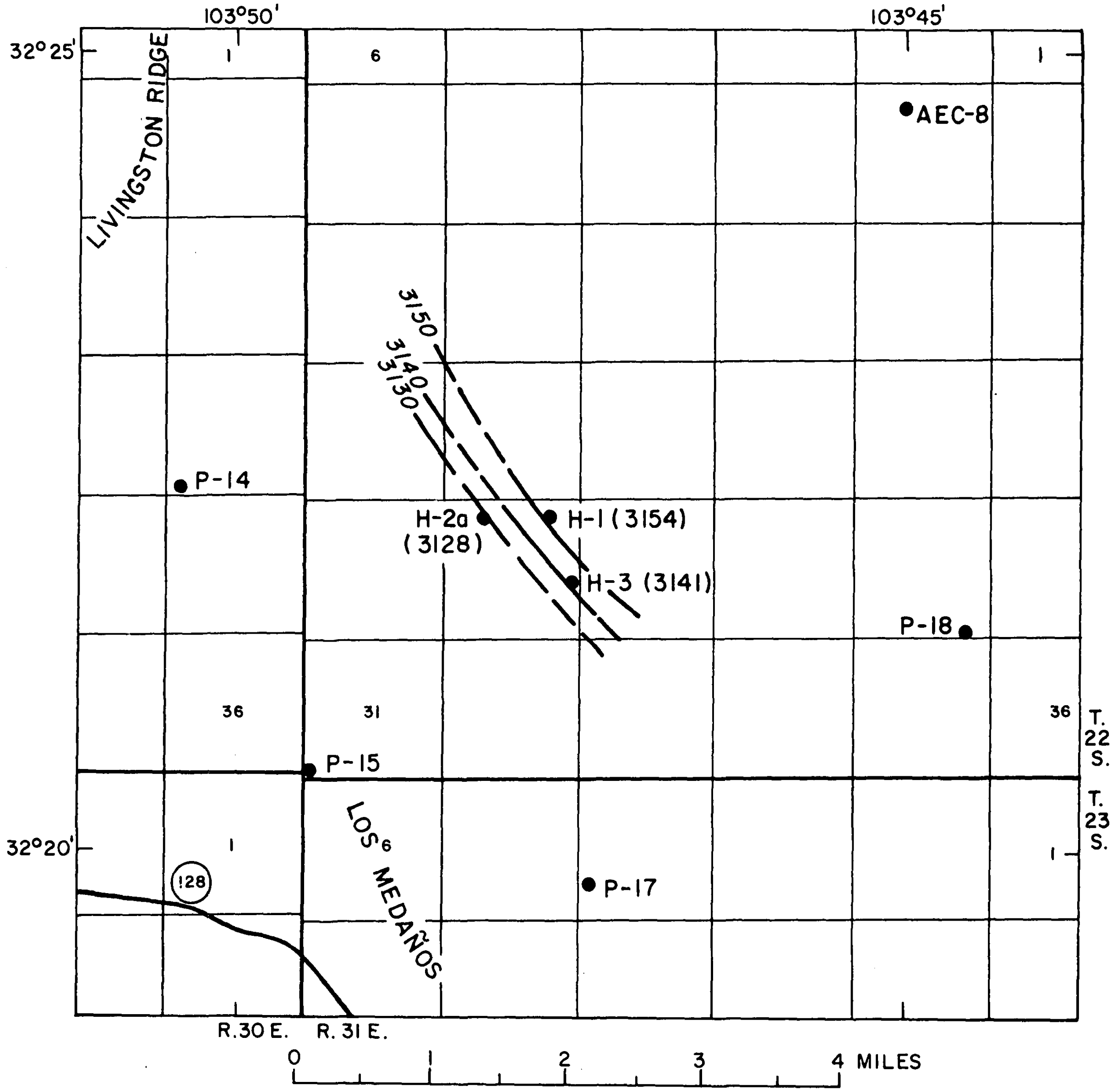
—— 2990 — — POTENTIOMETRIC CONTOUR--Shows altitude at which fresh water having a density of 1.00 gram per centimeter would have stood in a tightly cased well, October 1977. Dashed where approximately located. Contour interval 10 feet. Datum is mean sea level

Figure 27.--Potentiometric surface of the Culebra Dolomite Member of Rustler Formation.

Heads in the Magenta have been determined in only three wells (H-1, H-2b, and H-3). The potentiometric surface suggests that liquid moves to the southwest beneath sec. 29, T.22 S., R.31 E., at a gradient of about 50 ft/mi (fig. 28). Testing in the adjacent hydrologic holes is needed to better define distribution of heads in the Magenta.

Preliminary transmissivity values calculated for the Rustler-Salado contact range from $10^{-1}ft^2/d$ (P-14) west of the site, to $10^{-4}ft^2/d$ (P-18) east of the site. Preliminary transmissivity values calculated for the Culebra range from 140 ft^2/d, on the flanks of Nash Draw (P-14), to $10^{-1}ft^2/d$, at the site center (H-1), to $10^{-4}ft^2/d$, on the Divide to the east of the site (P-18). The standard techniques used in this phase of the hydrologic testing were suitable for calculating preliminary values of transmissivity. New methods need to be developed that will compensate for the effects of well-bore storage and well efficiency. These standard methods used did indicate, however, that transmissivities of all rock units were low and that the Culebra to the west of the site on the flanks of Nash Draw (P-14) would be the transmissive zone. Drilling and hydrologic testing have indicated minor salt solution at the top of the Salado Formation along the western margin of the WIPP site (fig. 2). Solution of salt within the Rustler Formation ranges from complete removal in P-14 to little or no removal in P-18 (fig. 2). Drill-stem tests were conducted in H-1 and H-3 across residue zones in the Rustler left by salt removal. Results indicated that very little fluid now occurs in these zones. Salt dissolution in the Rustler and Salado Formations followed by subsidence and an accompanying increase in fracture porosity within the Culebra most likely contributes to the higher values of transmissivity to the west. Conversely, thick intact salt sections, to the east of the site approaching the divide, indicate little to no dissolution.

The Magenta has been tested only in the hydrologic test holes in section 29. Preliminary values of transmissivity calculated for the Magenta are less than 1 ft^2/d except for H-3, in which a transmissivity of 2 ft^2/d was calculated. Additional tests, specifically designed for very low-permeability rocks, are planned for the near future.



EXPLANATION

● H-3 (3141) WELL--H-3 is well identification. (3141) is altitude of water level, in feet (expressed as fresh water with a density of 1.00 gram per centimeter). Datum is mean sea level.

3130 ——— — — POTENTIOMETRIC CONTOUR--Shows altitude at which fresh water having a density of 1.00 gram per centimeter would have stood in a tightly cased well, October 1977. Dashed where approximately located. Contour interval 10 feet. Datum is mean sea level.

Figure 28.--Potentiometric surface of the Magenta Dolomite Member of Rustler Formation.

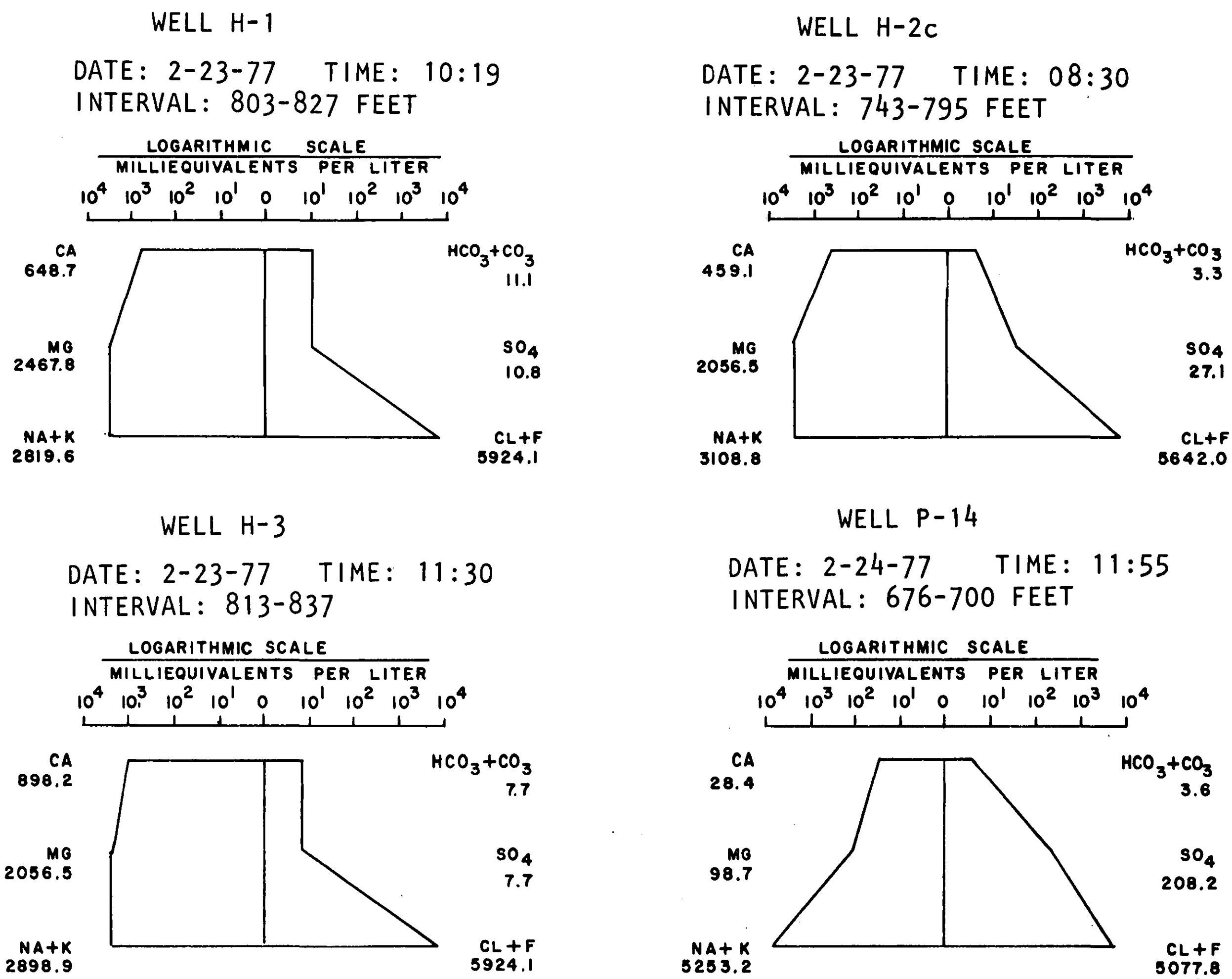
Shallow-water quality

High concentrations of dissolved solids have been found in waters moving through the Rustler Formation overlying the proposed repository area (table 2). The Rustler-Salado contact, Culebra and Magenta Dolomite Members comprise the liquid-bearing rocks of the Rustler Formation. Concentrations of major chemical constituents are directly related to the interaction between host rocks and the liquid moving slowly through them as a function of residence time. Interpretation of water-chemistry analyses from these rocks will aid in the understanding of hydrologic mechanisms at work in the evaporite rocks above the WIPP horizons.

Comparisons between chemical analyses of water samples are facilitated by graphical representations known as Stiff diagrams (Stiff, 1951, p. 15). The chemical equivalent concentrations of the cations, calcium, magnesium, and sodium (plus potassium), are plotted as proportionate line segments on equally spaced parallel lines to the left of a central axis and the equivalent concentrations of the anions, bicarbonate (plus carbonate), sulfate, and chloride (plus any nitrate), are plotted on the same lines extended to the right of the axis (Metzger and others, 1973, p. 76). In WIPP hydrochemical analyses, a modified Stiff diagram (Hiss, 1975) was used in which milliequivalent concentrations of cations and anions were plotted on a logarithmic scale to allow for the wide variations in concentrations. Interpretations should be treated as preliminary, pending later sampling programs.

The contact between the Rustler and Salado Formations is known to carry liquid in Nash Draw. This zone yielded moderate amounts of liquid to P-14. However, extremely low yields from other hydrologic holes hindered the collection of representative liquid samples. The moderate recovery rate and higher yield observed in P-14 contrasts sharply to the slower recovery rates and lower yields observed in H-1, H-2c, and H-3. These data, in combination with chemical-quality data, suggest that greater liquid movement is occurring to the west of the WIPP site at the Rustler-Salado contact.

Stiff diagrams were plotted from analyses of water from the Rustler-Salado contact (fig. 29). These graphic representations portray similarities in the chemical composition of samples from H-1, H-2c, and H-3. The presence of large quantities of calcium and magnesium in these waters suggests longer liquid residence times in the host rock, and subsequently greater liquid-rock interaction. On the other hand, the Stiff diagram for P-14 shows significantly less calcium and magnesium, suggesting shorter residence time and subsequently less liquid-rock interaction.



EXPLANATION

CA 898.2	Calcium	HCO_3+CO_3 7.7	Bicarbonate plus carbonate
MG 2056.5	Magnesium	SO_4 7.7	Sulfate
NA+K 2898.9	Sodium plus potassium	CL+F 5924.1	Chloride plus fluoride

NOTE: Number beneath chemical symbol is value in milliequivalents per liter.

Figure 29.--Stiff diagrams of chemical characteristics of liquid from the Rustler-Salado contact.

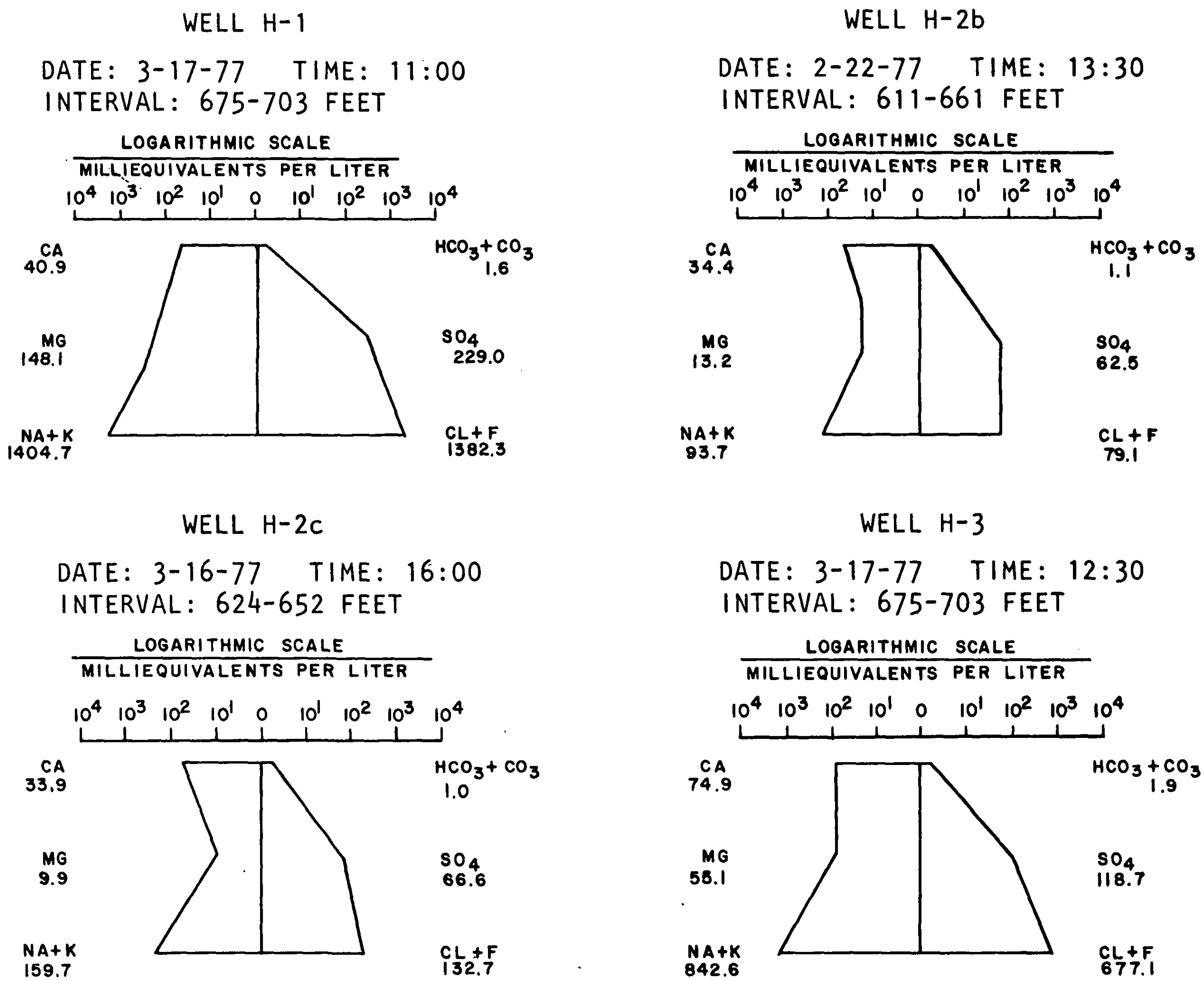
Water saturated with pure sodium chloride at 25°C contains 318,000 mg/L dissolved sodium chloride. The point of sodium chloride saturation will be raised slightly by the addition of other dissolved minerals and will be lowered by a decrease in brine temperature. Rustler-Salado brines at the WIPP site contain from 266,000 to 300,000 mg/L dissolved chloride and from 311,000 to 327,000 mg/L dissolved solids (table 2). These brines, although high in dissolved materials, appear to be unsaturated with respect to sodium chloride. The presence of salt in the Rustler-Salado brines is probably the result of salt removal from the top of the Salado Formation and from the lower section of the Rustler Formation. Other major constituents, calcium and magnesium cations and sulfate anions, may be attributed to rock dissolution and ion exchange within the predominately calcium sulfate and clayey lithology of the lower part of the Rustler Formation.

Dissolved solids in waters sampled from the Culebra tend to increase from the west to the east across the WIPP site, ranging from 23,700 mg/L in P-15 to 118,000 mg/L in P-18. Samples from other WIPP wells fall within this range except for H-2b which contains 8,890 mg/L dissolved solids. The halite, calcium sulfate, and clayey lithologies of rocks adjacent to and within the Culebra are reflected by the chemical composition of Culebra waters as is indicated by Stiff diagrams plotted from sample analyses (fig. 30). Lateral distribution of the major chemical constituents differs considerably from well to well probably as a function of water velocity and residence time as controlled by fracture permeabilities.

Sodium chloride concentrations, although high in comparison to fresh water, lie well below saturation limits in all sampled Culebra liquids. They range from 4,900 to 89,200 mg/L. This contrasts to the near saturation levels of liquids occurring at the Rustler-Salado contact.

Culebra water samples from P-17 are of dubious value because of the possibility of liquid communication between zones. Samples from P-18 were found to contain high amounts of potassium (table 2) relative to other wells completed in the Culebra . Additional tests are planned for P-17 and P-18 in order to resolve these questions.

The Magenta waters have been chemically analyzed in H-1, H-2a, and H-3 only. Liquid sampled from the Magenta is significantly lower in dissolved solids than it is in underlying liquid-bearing rocks. Dissolved solids vary widely within the Magenta, ranging from 10,300 mg/L in H-2a to 22,200 mg/L in H-1 and 29,700 mg/L in H-3. Sodium chloride concentrations range from 6,800 to 24,300 mg/L. Differences in sodium chloride concentrations account for these wide variations in dissolved solids (fig. 31).

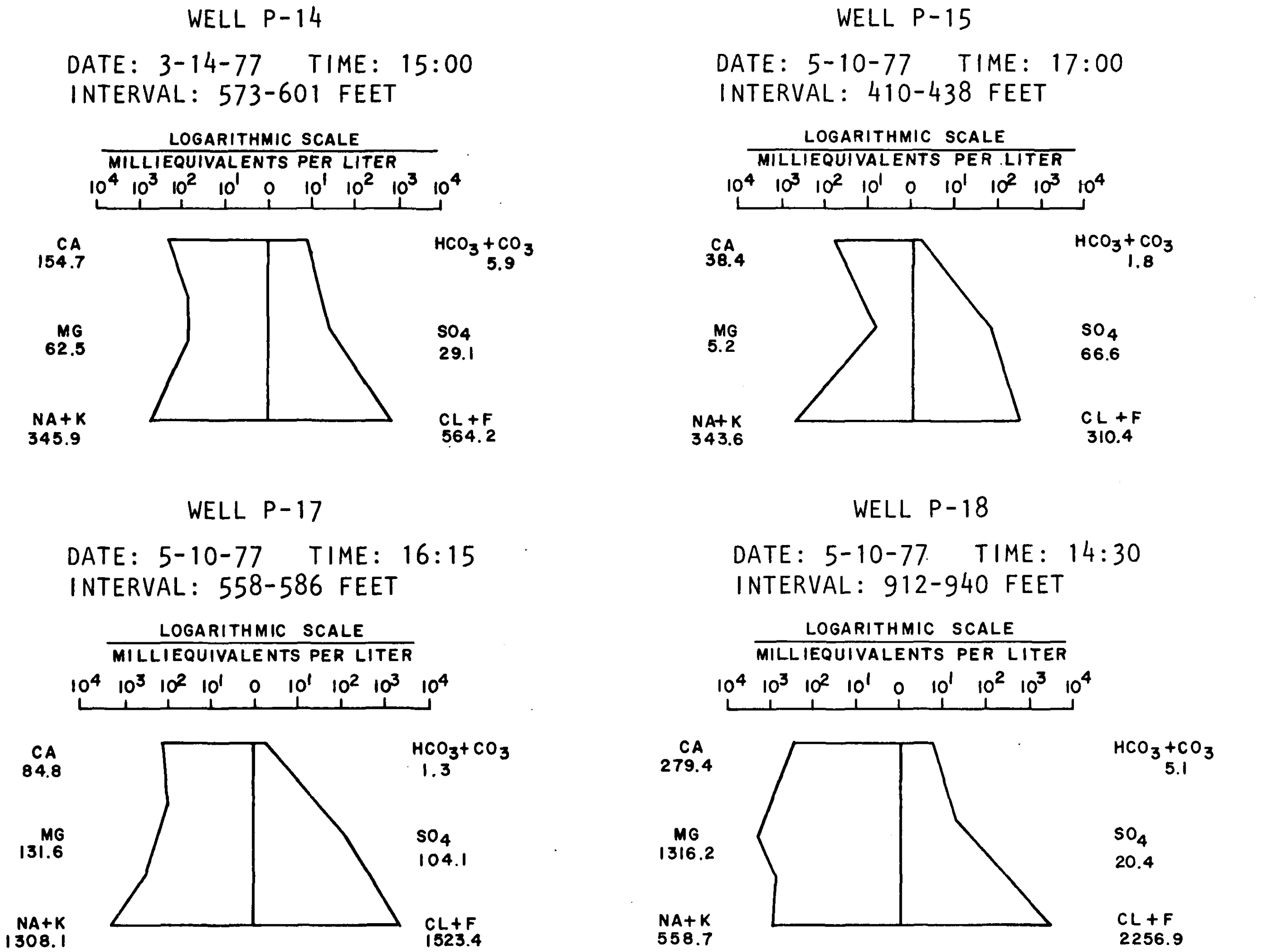


EXPLANATION

CA 33.9	Calcium	HCO_3+CO_3 1.0	Bicarbonate plus carbonate
MG 9.9	Magnesium	SO_4 66.6	Sulfate
NA+K 159.7	Sodium plus potassium	CL+F 132.7	Chloride plus fluoride

NOTE: Number beneath chemical symbol is value in milliequivalents per liter

Figure 30.--Stiff diagrams of chemical characteristics of liquid from the Culebra Dolomite Member of the Rustler Formation



EXPLANATION

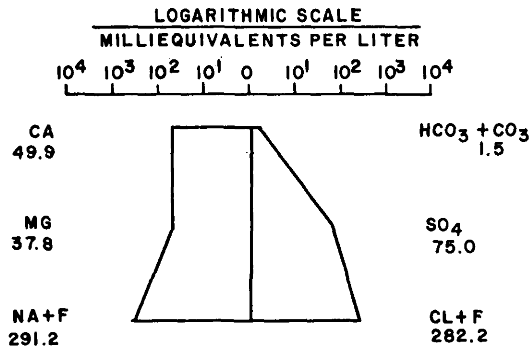
CA 84.8	Calcium	HCO_3+CO_3 1.3	Bicarbonate plus carbonate
MG 131.6	Magnesium	SO_4 104.1	Sulfate
NA+K 1308.1	Sodium plus potassium	CL+F 1523.4	Chloride plus fluoride

NOTE: Number beneath chemical symbol is value in milliequivalents per liter

Figure 30.--Stiff diagrams of chemical characteristics of liquid from the Culebra Dolomite Member of the Rustler Formation - Concluded

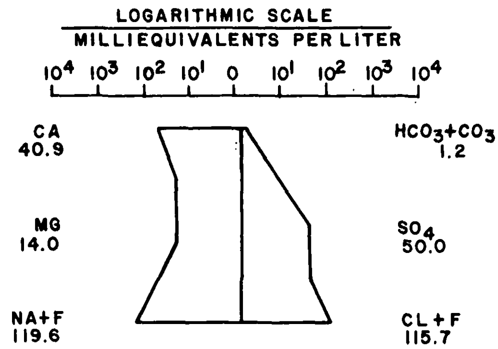
WELL H-1

DATE: 5-10-77 TIME: 11:00
INTERVAL: 562-590 FEET



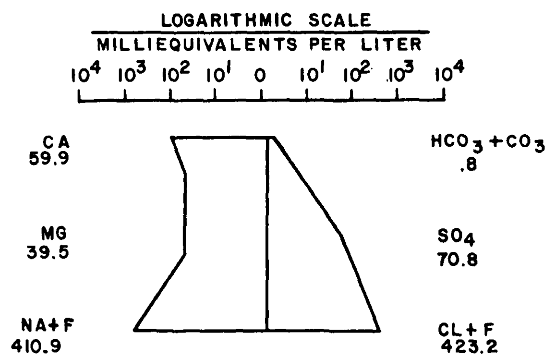
WELL H-2a

DATE: 2-22-77 TIME: 10:00
INTERVAL: 513-563 FEET



WELL H-3

DATE: 5-10-77 TIME: 13:00
INTERVAL: 564-592 FEET



EXPLANATION

CA 59.9	Calcium	HCO_3+CO_3 .8	Bicarbonate plus carbonate
MG 39.5	Magnesium	SO_4 70.8	Sulfate
NA+K 410.9	Sodium plus potassium	CL+F 423.2	Chloride plus fluoride

NOTE: Number beneath chemical symbol is value in milliequivalents per liter

Figure 31.--Stiff diagrams of chemical characteristics of liquid from the Magenta Dolomite Member of the Rustler Formation

Deep hydrologic testing

Data collected from AEC-8 hydrologic tests was in the preliminary stage of interpretation at the time this report was being prepared because testing was not completed until October 1977. Formational pressures were measured during shut-in phases of testing and liquid-level calculations have been made from these pressures. A measured pressure of 2,037 lbs/in^2 in the lower sand (4,832.5 to 4,848.5 feet) of the Bell Canyon Formation was approaching formational pressure (table 45). This pressure can be converted to a brine liquid level of about 600 feet below land surface by using a measured liquid density of 1.11 g/cm^3. A pressure of 2,044 lbs/in^2 was observed in the upper sand (4,809.5 to 4,815.5 feet) and this pressure can be converted to a brine liquid level of 605 feet below land surface by using a measured liquid density of 1.12 g/cm^3. These calculated liquid levels are in close agreement with liquid levels measured in November 1977, after the hole had been placed into a long-term dual configuration (fig. 24). These November measurements were 615 feet and 560 feet for the lower and upper zones respectively.

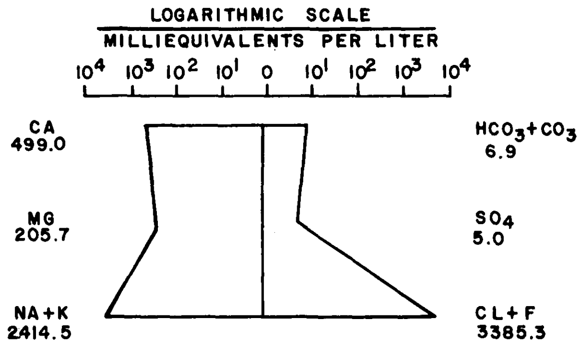
In AEC-8, the measured pressure of 2,037 lbs/in^2 in the lower sand is converted to an equivalent fresh-water head which agrees with the potentiometric surface of the Delaware Mountain Group as constructed by Hiss (1976).

Deep-water quality

Liquid samples were collected from the lower sand and the upper sand of the Bell Canyon Formation. Dense brines occur in these intervals as is indicated by the Stiff diagram (fig. 32). Preliminary evaluation of these brines suggests that a significant amount of liquid-rock interaction has taken place which would be expected from a deep-seated, slowly moving hydrologic system. Liquid sampled from the upper sand contains 189,000 mg/L dissolved solids and 175,000 mg/L sodium chloride. The abundance of calcium, magnesium, sodium, and potassium cations supports the concept of extensive liquid-rock interaction as a result of long liquid residence times in rocks of the Bell Canyon Formation.

WELL AEC-8

DATE: 9-22-77 TIME: 14:55
INTERVAL: 4809.5-4815.5 FEET



EXPLANATION

CA 499.0	Calcium	HCO_3+CO_3 6.9	Bicarbonate plus carbonate
MG 205.7	Magnesium	SO_4 5.0	Sulfate
NA+K 2414.5	Sodium plus potassium	CL+F 3385.3	Chloride plus fluoride

NOTE: Number beneath chemical symbol is value in milliequivalents per liter.

Figure 32.--Stiff diagram of chemical characteristics of liquid from the Bell Canyon Formation.

Summary and conclusions

Hydrologic tests were made in 11 exploratory test holes at the WIPP site. Of these 11 holes, five (H-1, H-2 complex, and H-3) were specifically designed for hydrologic testing of liquid-bearing zones above the salt. Additionally, four potash test holes (P-14, P-15, P-17, and P-18) were constructed to allow static-head determination and hydrologic testing to be conducted in the liquid-bearing zones above the salt near the outer boundary of the WIPP site. The two remaining holes (AEC-8 and ERDA-10) were deep geologic test holes acquired for testing of liquid-bearing zones below the salt section. ERDA-10 testing was not completed by the time of the cutoff date for this report.

Sedimentary rocks exposed at the WIPP site range in age from Early Permian to Quaternary with the oldest rocks lying to the west and progressively younger rocks to the east. The rocks penetrated by drilling consist mainly of Permian sandstones, evaporites, and red beds, but do include some Triassic sandstone and Pleistocene bolson-type deposits. Most of the older consolidated rocks are blanketed by Quaternary caliche and semistabilized and active dune sands.

Few rock units penetrated at the WIPP site were found to yield liquids. Brines were found in AEC-8 in the sandstones of the Bell Canyon Formation, which directly underlies the evaporite section. Above the Salado Formation, liquids were found only in the Magenta and Culebra Dolomite Members of the Permian Rustler Formation, and along the contact of the Rustler and Salado Formations. Rocks in which previous halite leaching had occurred within the Rustler yielded no liquid. Although zones of lost circulation have previously been encountered in the Dewey Lake Red Beds, testing of these zones indicated minimal amounts of liquid.

At the WIPP site, the liquid-bearing rocks of the Rustler Formation have been the primary study zones because they directly overlie the salt and offer a potential avenue for salt dissolution and radionuclide transport.

The drilling and hydrologic testing of these holes at the WIPP site support the following conclusions.

Testing procedures

Liquid-bearing rocks at the WIPP site are low yielding and are difficult to test by standard methods. Modified open-hole drill-stem tests can be used to obtain preliminary hydrologic parameters which can be used to design later long-term tests. Cased-hole testing is not as desirable as open-hole tests of low-yielding rocks found at the test site. The H-2 complex of three wells was found to be the best design for long-term open-hole testing. Determinations of hydraulic conductivity and effective porosity are very difficult to obtain from low-yielding fractured rocks. A better understanding of the hydraulic parameters of these fractured rocks requires the development of specialized testing techniques.

Shallow-zone hydrology

Hydrologic tests of liquid-bearing zones in the Rustler Formation indicate that heads decrease with depth; consequently, potential liquid movement would be downward in rocks above the salt. The degree to which ground water can move toward the Salado, however, is controlled by the very low vertical hydraulic conductivity of the Rustler.

Minor solution of salt has occurred along the western margin of the site at the top of the Salado Formation. Solution of salt in the Rustler ranges from complete removal in the west to little or no removal in the east.

High concentrations of dissolved solids, particularly sodium chloride, occur in liquids above the salt, and chemical composition of these liquids is dependent upon extensive interaction with the evaporite host rocks resulting from long residence times.

Rustler-Salado contact.--Brines are found along the Rustler-Salado contact, but extremely low yields require long-term testing to establish reliable heads. Preliminary values of transmissivity of the Rustler-Salado contact range from $10^{-1}ft^2/day$ in P-14 to $10^{-4}ft^2/day$ in P-18. Water from the Rustler-Salado contact contains from 311,000 mg/L to 327,000 mg/L dissolved solids. Sodium chloride ranges from 266,000 mg/L to 300,000 mg/L.

Culebra Dolomite Member of the Rustler Formation.--Head distribution determined for the Culebra Dolomite Member indicates liquid movement to the southeast beneath the site. Gradients range from 7 to 120 ft/mi and vary as a function of hydraulic conductivity.

Salt dissolution in the Rustler and Salado Formations, with accompanying subsidence of the Rustler, causes an increase in fracture porosity of the Culebra and contributes to variabilities in transmissivities.

Preliminary values of transmissivity for the Culebra range from 140 ft^2/day in P-14 on the flanks of Nash Draw, to $10^{-1} ft^2$/day in H-1 near the site center, to 10^{-4} ft^2/day in P-18 to the east. Culebra liquids range from 8,890 mg/L to 118,000 mg/L dissolved solids. Sodium chloride ranges from 4,900 mg/L to 89,200 mg/L.

Magenta Dolomite Member of the Rustler Formation.--Head distribution within the Magenta Dolomite Member has only been determined in three holes (H-1, H-2a, and H-3) and suggests fluid movement to the southwest. The hydraulic gradient in the vicinity of these three holes is 50 ft/mi.

Preliminary values of transmissivity for the Magenta range from 2 ft^2/day in H-3 to less than 1 ft^2/day in H-1. Magenta liquids range from 10,300 mg/L to 29,700 mg/L dissolved solids. Sodium chloride ranges from 6,800 mg/L to 24,300 mg/L.

Deep-zone hydrology

Tests conducted in AEC-8 were still being evaluated at the time of the writing of this report. Measured pressures from the Bell Canyon Formation were approaching reservoir pressures and ranged from 2,037 lb/in^2 in the lower sand to 2,044 lb/in^2 in the upper sand. These pressures are equivalent to brine liquid levels of about 600 and 593 feet below land surface, respectively.

Brines in the upper sand of the Bell Canyon Formation contain 189,000 mg/L dissolved solids and 175,000 mg/L dissolved sodium chloride. This brine chemistry within the Bell Canyon Formation is probably dependent upon extensive liquid-rock interaction.

Future testing

Future testing is needed to estimate hydraulic conductivity, transmissivity, and effective porosity of the liquid-bearing rocks. However, accuracy in these estimates will be difficult to achieve because of very low permeabilities of the rock units and the uncertainties associated with fracture permeabilities. Consequently, future programs will require the development of specialized testing techniques.

References

Adams, J. E., 1944, Upper Permian Ochoan series of Delaware Basin, West Texas and southeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 11, p. 1596-1625.

______1965, Stratigraphic-tectonic development of the Delaware Basin: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 2140-2142.

Bachman, G. O., 1973, Surficial features and late Cenozoic history in southeastern New Mexico: U.S. Geological Survey Open-File Report, 32 p.

______1974, Geologic processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geological Survey Open-File Report 74-194, 31 p.

Bjorklund, L. J., and Motts, W. S., 1959, Geology and water resources of the Carlsbad area, New Mexico: U.S. Geological Survey Open-File Report, 322 p., 14 pls., 54 figs.

Blankennagel, R. K., 1967, Hydraulic testing techniques of deep drill holes at Pahute Mesa, Nevada Test Site: U.S. Geological Survey Open-File Report, 50 p.

Bretz, J. H., and Horberg, C. L., 1949a, Caliche in southeastern New Mexico: Journal of Geology, v. 57, no. 5, p. 491-511.

Brokaw, A. L., Jones, C. L., Cooley, M. E., and Hays, W. H., 1972, Geology and hydrology of the Carlsbad potash area, Eddy and Lea Counties, New Mexico: U.S. Geological Survey Open-File Report, 86 p.

Cooper, J. B., 1962, Ground-water investigations of the Project Gnome area, Eddy and Lea Counties, New Mexico: U.S. Geological Survey TEI-802, 67 p., 17 figs.

______1971, Geohydrology of Project Gnome Site, Eddy County, New Mexico: U.S. Geological Survey Professional Paper 712-A, 24 p.

Cox, E. R., 1967, Geology and hydrology between Lake McMillan and Carlsbad springs, Eddy County, New Mexico: U.S. Geological Survey Water-Supply Paper 1828, 48 p.

Cox, E. R., and Kunkler, J. L., 1962, Feasibility of injecting brine from Malaga Bend into the Delaware Mountain Group, Eddy County, New Mexico: U.S. Geological Survey Open-File Report, 69 p., 5 figs.

Darton, N. H., 1922, Geologic structure of parts of New Mexico: U.S. Geological Survey Bulletin 726-E, 275 p.

Gard, L. M. Jr., 1968, Geologic studies, Project Gnome, Eddy County, New Mexico: U.S. Geological Survey Professional Paper 589, 33 p.

Hale, W. E., 1945a, Ground-water conditions in the vicinity of Carlsbad, New Mexico: New Mexico State Engineer 16th and 17th Biennial Report, p. 195-260.

______1945b, Ground-water conditions in the vicinity of Rattlesnake Springs, Eddy County, New Mexico: New Mexico State Engineer Technical Report 3, 54 p.

______1961, Availability of ground water in New Mexico, in Sixth Annual New Mexico Water Conference, November 1-2, 1961, New Mexico State University, New Mexico: p. 11-22.

Hale, W. E., and Clebsch, Alfred Jr., 1958, Preliminary appraisal of ground-water conditions in southeastern Eddy County and southwestern Lea County, New Mexico: U.S. Geological Survey TEM-1045, 23 p.

Hale, W. E., Hughes, L. S., and Cox, E. R., 1954, Possible improvement of quality of water of the Pecos River by diversion of brine at Malaga Bend, Eddy County, New Mexico: Pecos River Commission, New Mexico and Texas, 43 p.

Halpenny, L. C., and Greene, D. K., 1966, Water rights and water supply, city of Carlsbad, investigation of present situation and future requirements: Water Development Corp., Tucson, Arizona, 85 p.

Hendrickson, G. E., and Jones, R. S., 1952, Geology and ground-water resources of Eddy County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Ground-Water Report 3, 169 p.

Hiss, W. L., 1971, Capitan aquifer observation-well network, Carlsbad to Jal, New Mexico: New Mexico State Engineer Technical Report 38, 76 p.

______1975, Water quality data from oil and gas wells in part of the Permian basin, southeastern New Mexico and western Texas, U.S. Geological Survey Open-File Report, p. 75-579.

______1976, Stratigraphy and ground-water hydrology of the Capitan aquifer, southeastern New Mexico and western Texas: University of Colorado, Boulder, Ph.D. thesis, 374 p., 34 figs.

Jones, C. L., 1954, The occurrence and distribution of potassium minerals in southwestern New Mexico, in Stiff, T. F., ed, Southeastern New Mexico: New Mexico Geological Society Guidebook, 5th Field Conference, p. 107-112.

______1973, Salt deposits of Los Medanos area, Eddy and Lea Counties, New Mexico, with sections on Ground-water hydrology, by M. E. Cooley, and Surficial geology, by G. O. Bachman: U.S. Geological Survey Open-File Report, 67 p.

Keys, W. Scott, and MacCary, L. M., 1971, Application of borehole geophysics to water-resources investigation: U.S. Geological Survey Techniques of Water-Resources Investigation Book 2, chap. E-1, 126 p.

King, P. B., 1942, Permian of West Texas and southeastern New Mexico, Part 2 of DeFord, R. K., and Lloyd, E. R., eds., West Texas-New Mexico--a symposium: American Association of Petroleum Geologists Bulletin, v. 26, no. 4, p. 535-763.

Lambert, S. J. and Mercer, J.W., 1977, Hydrologic Investigations of the Los Medanos area, southeast New Mexico, 1977: Sandia Laboratories SAND 77-1401.

Lang, W. B., 1935, Upper Permian formations of Delaware Basin of Texas and New Mexico: American Association of Petroleum Geologists Bulletin, v. 19, no. 2, p. 262-270.

Lang, W. B., 1938, Geology of the Pecos River between Laguna Grande De La Sal and Pierce Canyon, in Robinson, T. W., and Lang, W. B., Geology and ground-water conditions of the Pecos River Valley in the vicinity of Laguna Grande De La Sal, New Mexico with special reference to the salt water content of the river water: New Mexico State Engineer 12th and 13th Biennial Reports, p. 77-100.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Maley, V. C., and Huffington, R. M., 1953, Cenozoic fill and evaporite solution in Delaware Basin, Texas and New Mexico: Geological Society of America Bulletin, v. 64, no. 5, p. 539-546.

Mercer, J. W., and Orr, B. O., 1977, Review and analysis of hydrogeologic conditions near the site of a potential nuclear-waste repository, Eddy and Lea Counties, New Mexico: U.S. Geological Survey Open-File Report 77-123, 35 p., 7 figs.

Metzger, D. G., Loeltz, O. J., and Irelan, B., 1973, Geohydrology of the Parker-Blythe-Cibola Area, Arizona and California: U.S. Geological Survey Professional Paper 486-G, 130 p.

Nicholson, Alexander Jr., and Clebsch, Alfred Jr., 1961, Geology and ground-water conditions in southern Lea County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Ground-Water Report 6, 120 p.

Page, L. R., and Adams, J. E., 1940, Stratigraphy, eastern Midland Basin, Texas, in Deford, R. K., and Lloyd, E. R., eds., West-Texas-New Mexico symposium, part 1: American Association of Petroleum Geologists Bulletin, v. 24, no. 1, p. 52-64.

Richardson, G. B., 1904, Report of a reconnaissance in Trans-Pecos Texas, north of Texas and Pacific Railway: Texas University Mineralogical Survey Bulletin 9, and Texas University Bulletin 23, 119 p.

Robinson, T. W., and Lang, W. B., 1938, Geology and ground-water conditions of the Pecos River valley in the vicinity of Laguna Grande de la Sal, with special reference to the salt content of the river water: New Mexico State Engineer 12th and 13th Biennial Reports, p. 77-100.

Stiff, H. A., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, Technical Note 84, sec. 1, p. 15-17.

Theis, C. V., and Sayre, A. N., 1942, Geology and ground water, in U.S. National Resources Planning Board, 1942, Pecos River Joint Investigation - Reports of the participating agencies: Washington, U.S. Government Printing Office, p. 27-38.

Uren, L. C., 1946, Petroleum production engineering-oil field development, 3rd edition: New York, McGraw-Hill Book Co., Inc., 764 p.

Vine, J. D., 1960, Recent domal structures in southeastern New Mexico: American Association of Petroleum Geologists Bulletin, v. 44, no. 12, p. 1903-1911.

_______1963, Surface geology of the Nash Draw quadrangle, Eddy County, New Mexico: U.S. Geological Survey Bulletin 1141-B, p. B1-B46.

☆ U. S. GOVERNMENT PRINTING OFFICE 1979 - 681-809/120 Reg. 8

Please return to -- DRAFTING