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TEI-803

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GROUND WATER TEST WELL D, NEVADA TEST SITE,
NYE COUNTY, NEVADA*

By

William Thordarson, Murray S. Garber, and George E. Walker

February 1962

Report TEI-803

This report is preliminary
and has not been edited for
conformity with Geological
Survey format.

*Prepared on behalf of the
U. S. Atomic Energy Commission.

metadc502010

February 9, 1962

AEC--137/2

Mr. James E. Reeves
Assistant Manager for Test Operations
Albuquerque Operations Office
U. S. Atomic Energy Commission
P. O. Box 5400
Albuquerque, New Mexico

Dear Mr. Reeves:

Transmitted herewith are ten copies of TEI-803, "Ground water test well D, Nevada Test Site, Nye County, Nevada," by William Thordarson, Murray S. Garber, and George E. Walker, February 1962.

We plan to release this report to the public in the open files.

Sincerely yours,

A handwritten signature in cursive script, appearing to read "V. E. McKelvey", followed by a flourish.

V. E. McKelvey
Assistant Chief Geologist
Interagency Programs and
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GROUND WATER TEST WELL D, NEVADA TEST SITE,
NYE COUNTY, NEVADA

By William Thordarson, Murray S. Garber, and George E. Walker

ABSTRACT

Ground-water test well D was drilled to a depth of 1,950 feet with rotary and cable-tool drilling rigs. It penetrated alluvium from 0 to 1,505 feet; tuff of Tertiary age from 1,505 to 1,730 feet; talus (?) breccia from 1,730 to 1,750 feet; and rocks of Mississippian to Pennsylvanian age from 1,750 to 1,950 feet. The Paleozoic bedrock in the depth interval from about 1,750 to 1,840 feet is composed mainly of interbedded dolomite and limestone; in the interval 1,840 to 1,950 feet it consists of argillite. The static water level is about 1,733 feet below the land surface (altitude, 2,417 feet).

The aquifer in test well D comprises the talus (?) breccia and the carbonate rocks in the interval from 1,730 to 1,840 feet. Tests by bailing indicate that the minimum transmissibility of the aquifer is about 90 gallons per day per foot. The specific capacity was less than 0.3 gallons per minute per foot after 3 1/4 hours of bailing at a rate of 18 gallons per minute. These tests also indicate that the transmissibility of the argillite stratum underlying the aquifer is extremely low.

A suite of geophysical logs, a summary of contract costs, and detailed descriptions of the drilling machines, drilling operations, and the casing and cementing operations are presented.

INTRODUCTION

The U.S. Geological Survey is appraising the possibility, however slight, that the ground water beneath the Nevada Test Site, possibly contaminated by nuclear detonations, may carry radioactive fission products to places where they may constitute a public hazard. The U.S. Atomic Energy Commission is sponsoring this work, which deals with the ground-water hydrology of the Nevada Test Site, and especially the hydrology beneath Yucca Flat. Test wells penetrating 100 feet or more below the water table provide a major part of the information needed for the study and also yield much information that cannot be incorporated in the final report. This information, however, can be recorded and preserved in interim reports, of which this report is one of a series.

Purpose and scope

In detail, the objectives sought through the drilling of test wells are:

1. To determine the lithology, distribution, structure, and water-bearing properties of the rocks and sediments from the surface downward into the zone of saturation.
2. To sample these rocks and sediments for laboratory analysis and study.

3. To determine the location, depth below the surface, quantity, temperature, and chemical and radiochemical quality of the ground water.

4. To determine the configuration and slope of the piezometric surface as one step in ascertaining the direction and rate of movement of the ground water.

5. To establish a network of wells in which observation of water-level fluctuations can be made and from which samples can be taken for chemical and radiochemical monitoring.

Specifically, test well D is one of six wells that were drilled to find the direction and rate of ground-water movement beneath Yucca Flat. This report describes the drilling, casing, the geophysical logging, the sediments and rocks penetrated, the bailing tests that were made in the well, and the chemical quality of the water. The report is largely a compilation of data. Little interpretation of data is given because valid interpretations must await the accumulation of data from other test wells.

Location

Ground-water test well D is on the Nevada Test Site, which is about 70 miles northwest of Las Vegas, Nev. The well is in the Central part of Yucca Flat, an enclosed intermontane valley that is about 20 miles long and 7 miles wide. The well is about 1.5 miles west-northwest of the B-J Junction of the Mercury Highway, and it is at Nevada State coordinates N 846,600, E 672,600 (fig. 1). The altitude of the land surface at the well is about 4,150 feet.

General geology

The rocks exposed in the Nevada Test Site consist of varied sedimentary rocks of Paleozoic age, volcanic and sedimentary rocks of Tertiary age, and alluvial and playa deposits of Quaternary age (Johnson and Hibbard, 1957; Hansen and Lemke, 1958). The Paleozoic rocks have a total thickness of about 22,000 feet and are dominantly limestone and dolomite, together with marble, quartzite, argillite, shale, and conglomerate. The Paleozoic rocks have been intruded at a few places by a granodiorite stock and by sills of Cretaceous or Tertiary age. The overlying Tertiary rocks consist principally of welded, vitric, and zeolitic tuffs of the Oak Spring Formation of Miocene(?) or younger age. The alluvium of Tertiary and Quaternary age consists principally of detritus deposited in the intermontane basins, much of it as fan deposits.

Methods of investigation

Field work for this report consisted principally of observations of drilling operations, and hydraulic testing by bailing. Bruce Blackerly and Robert B. Scott, both formerly with the U.S. Geological Survey, collected much of the field data and helped in preparing the well log. Samples of cuttings were collected

Coordinates: Nevada State
System, central zone.

FIGURE 1.--MAP SHOWING LOCATION OF TEST WELL DESCRIBED IN
THIS REPORT

by the drill crews according to instructions of the contracting officer. They were washed and examined by standard methods in the laboratory.

All measurements to determine the depth to static water-level and the rate of recovery of water level after bailing were made by the use of a water-level measuring device consisting of a bronze-magnesium "potential" cell suspended on a steel-sheathed coaxial wire. The sheath serves as a ground conductor; the length of cable in the hole is measured by a productimeter wheel; and the presence of water is indicated by a voltmeter recording in the range up to 1 volt. All components are mounted on one frame. The periodic checks against a steel tape show that the instrument error usually is no greater than 0.002 foot per foot. The human error introduced by different operators usually has not been more than 0.5 foot at the maximum depths that are measured. The indicated errors are so small that the water-level measurements in this report have not been adjusted for them.

Acknowledgments

The writers are grateful for the cooperation and assistance given by James L. McBride and W. Raymond McNinch of the Mac Exploration Company, Kyle Cheney of the Layne-Franklin Company, and H. G. Woodworth of Holmes and Narver, Inc.

CONSTRUCTION RECORD

Work on test well D began on June 28, 1960, and was completed on January 8, 1961. Details of the work follow.

Specifications and contract

The specifications for hole D were presented in AEC invitation 292-60-21, February, 1960. The work was performed under contract No. AT(29-2) 989, which was awarded to the Mac Exploration Company, Milford, Utah. This company did the rotary-hydraulic drilling but subcontracted the cable-tool work to the Layne-Franklin Company, Houston, Texas. Engineering inspection was provided by Holmes and Narver, Inc., Los Angeles, California.

General construction plans

Plans specified that the hole would be drilled by the rotary-hydraulic method from the surface to a point just above the zone of saturation, and would be completed by the cable-tool method.

The cable-tool method was specified for use in the zone of saturation in order to avoid the possibility of plugging the aquifer with drilling fluid and cuttings; in order to obtain water samples uncontaminated by drilling fluid; and in order to facilitate the identification of zones of differing head or permeability.

Drilling equipment

The drilling equipment comprised two rotary-drilling rigs and one cable-tool drilling rig. The two rotary-drilling rigs were a Failing 1500 Holemaster combination machine, and a custom-made rig built from parts manufactured by several companies and assembled by the Cardwell Manufacturing Co., Wichita, Kan. The custom-made machine was capable of drilling deeper than the Failing machine. The cable-tool rig was a Bucyrus Erie 36-L machine. Details on this drilling equipment, records of drilling speed, and records of drilling fluid and other materials used in drilling are summarized in appendices II to VI.

Drilling operations

Drilling was started with the Failing 1500 rotary-hydraulic machine, and a pilot hole 1,744 feet deep was completed in 23 days. Bits 6 inches in diameter were used for most of this drilling. A total of 37,450 gallons of water was used.

Reaming of the pilot hole with bits having diameters of 12 to 15 inches was begun with the Failing 1500 rotary machine, continued with the custom-built rotary machine, and completed with the Bucyrus Erie cable-tool machine. The bits used for this purpose were 15 inches in diameter from the land surface to 1,700 feet and 12 inches in diameter from 1,700-1,744 feet. The reaming required 162 days.

The rate of penetration during rotary-hydraulic drilling was recorded by a geolograph. For the drilling of the pilot hole the rate ranged from 1.8 to 13.0 minutes per foot and averaged 5.2 minutes per foot (fig. 2); for the reaming by the Failing Holemaster, the rate ranged from 1.6 to 85.6, and averaged 9.8 minutes per foot; and for reaming by the custom-made machine it ranged from 1.6 to 25.6, and averaged 9.7 minutes per foot. The rate of penetration depended principally, but not entirely, on the character of the strata being penetrated. It also depended on the size and sharpness of bits, on the weight of the tools, and on the rotary speed. The drillers reduced the rate when penetrating soft beds so as to minimize the likelihood of making the hole crooked and to ensure flushing of cuttings from the hole.

The rate of penetration for the cable-tool drilling was determined from the drillers' records, which showed the time required for drilling intervals of about 5 feet. The rate of penetration during reaming ranged from 6 to 30 minutes per foot, and averaged about 14.7 minutes per foot; and during deepening from 1,744 to 1,950 feet it ranged from 10 to 40 minutes per foot and averaged about 17.2 minutes per foot (fig. 2).

After reaming had been completed to a depth of 1,700 feet, casing was installed to that depth, and the hole was deepened to 1,950 feet. The first 44 feet of the deepening can be regarded as reaming because the pilot hole had been drilled to that depth. A 12-inch bit was used for drilling in the depth interval from 1,700 to 1,900 feet, and a 9-inch bit was used from 1,900 to 1,950 feet. The walls of the hole caved so badly in the interval from 1,860 to 1,900 feet that a second string of casing was installed to control the caving. The deepening and the installation of casing required 11 days. The rates of penetration during this phase of the work (fig. 2) are only approximations because depths as recorded by the drillers are accurate only to 10 or 20 feet.

Casing operations

Test well D contains two strings of casing, which overlap by 50 feet. As a preliminary to their installation, short sections of the casing were lowered to the bottom of the hole, to show whether the hole was unobstructed and was straight enough to accept the full string. After reaming to a depth of 1,700 feet had been completed, a 12 3/4-inch OD seamless steel pipe was installed to that depth. This pipe was cemented in place at both the top and the bottom. Drilling by cable-tool machine then was resumed, but as the depth approached 1,800 feet, caving of tuff slowed progress and threatened sticking of the bit or the bailer. In order to control caving, therefore, the hole was cased with 10 3/4-inch OD seamless pipe in the interval from 1,650 to 1,900 feet, and was swaged out against the larger casing. The 10 3/4-inch casing is slotted from about 1,772 to 1,882 feet. The interval from 1,900 to 1,950 feet is uncased.

The sections of both the 12 3/4-inch and the 10 3/4-inch pipe are each about 20 feet long. The sections were butt welded together as the casing was lowered into the hole. The 12 3/4-inch casing was landed on tuff; and the 10 3/4-inch casing was landed on argillite, which subsequently became a shoulder when drilling was continued with a smaller bit. However, the swaged coupling at the top of the 10 3/4-inch casing is believed to provide the main support for the string. Further details of the casing and cementing in the well are given in appendix VII.

Interruptions of work

Two major interruptions and several minor ones delayed the work in the well. The first major delay lasted 31 days (August 14 to September 13, 1960) and was due to lack of a drilling rig; the custom-built machine, needed for reaming, had not arrived at the Test Site.

The second major delay lasted 59 days (September 29 to November 26, 1960) and was due to the drilling tools being stuck in the hole at a depth of 1,361 feet. Attempts to pull these tools were made intermittently for about a month. About 10,700 gallons of water and 3,600 pounds of bentonite were used in the attempts. On October 28, 1960, by means of a free-point indicator owned and operated by the Ford Alexander Corp., Whittier, Calif., the point below which

the tools were stuck (the "free point") was determined to be a tool joint at 1,347 feet. A "string shot" bracketing a tool joint at about 1,319 feet was discharged, while at the surface a reverse torque was applied to the drill pipe. By this method the tool joint was loosened enough to be unscrewed and pulled out of the hole, leaving behind 42 feet of collars and the bit. The custom-made rotary machine then was used in attempts to fish the remaining tools from the hole but without success. Finally, the cable-tool drilling rig was moved over the hole and with it the tools were recovered in 1 day.

Minor interruptions totaling several days delayed the cable-tool operations. They were due to caving in of the lower 30 feet of tuff, which was below the bottom of the casing. Blocks of tuff as much as 1.5 feet long fell into the bailer and were recovered when it was brought to the land surface. The caving was most serious during the drilling of the depth intervals from 1,780 to 1,785 feet and from 1,860 to 1,900 feet.

Cost

The contractor was paid \$38,367 for the materials and labor required to drill and case the hole, for obtaining geophysical logs, for making bailing tests, and for obtaining other information (appendix I). The average cost is slightly less than \$20.00 per foot.

LITHOLOGY OF STRATA PENETRATED

Test well D penetrated four stratigraphic formations, which are described from youngest to oldest in this report. From 0 to 1,505 feet the well penetrated alluvium of Tertiary(?) and Quaternary age, which consists predominantly of unconsolidated alluvial-fan deposits comprising poorly sorted silt, sand, and gravel. From 1,505 to 1,730 feet, it penetrated pumiceous-crystal tuff altered to zeolite and clay, which is similar to tuff in the Oak Spring Formation of Tertiary age. From 1,730 to 1,750 feet, the well penetrated talus(?) breccia, presumably of Tertiary age, which is composed of angular dolomite fragments in a silty-sand matrix. From 1,750 to 1,950 feet, it penetrated Paleozoic strata similar to rocks in the Eleana Formation of Late(?) Mississippian to Early Pennsylvanian age. These Paleozoic rocks comprise interbedded dolomite, dolomitic limestone, limestone, argillaceous limestone, limey argillite, argillite, and siltstone. A lithologic log (table 1) shows the character of the rocks and summarizes those of the alluvium. The detailed character of the alluvium is given in table 2.

Table 1.--Lithologic log of test well D

	Thickness (feet)	Depth to bottom of bed (feet)
ALLUVIUM		
Sand and gravel, silty, very pale orange; thin calcium-carbonate coatings on some gravel cuttings. Cuttings do not show bedding. Principal subdivisions based on proportions of different rock types in gravel, as follows:		
Gravel consisting predominantly of zeolitized pumiceous tuff, quartzite, and chert; with minor amounts of welded tuff, argillite, limy siltstone, silty limestone, sandy limestone, and limestone	600	600
Gravel consisting predominantly of welded tuff and zeolitized pumiceous tuff; with minor amounts of quartzite, chert, argillite, limy siltstone, silty limestone, sandy limestone, and limestone	350	950
Gravel consisting predominantly of limy siltstone, silty limestone, sandy limestone, and limestone; with minor amounts of welded tuff, zeolitized pumiceous tuff, quartzite, chert, and argillite.	555	1,505
OAK SPRING FORMATION		
Tuff, crystal zeolitized; very pale orange crystals of quartz and feldspar, 20 to 40 percent; pumice fragments difficult to distinguish from matrix, 20(?) percent; biotite, 1 to 3 percent; magnetite, 2 percent; trace of dusky yellowish-green clayey mineral (altered hornblende(?); lithic fragments as much as 10 percent	145	1,650
Tuff, clayey, pumiceous, crystal; light gray; white pumice fragments altered to clay (mostly 4 mm across, 5 percent as much as 8 mm across), 35 percent; quartz and feldspar crystals as much as 2 mm across, 7 percent; magnetite, 2 percent; trace of greenish-black hornblende(?); lithic fragments, including pale-red, light-gray, and		

Table 1.--Lithologic logs of test well D - Continued

	Thickness (feet)	Depth to bottom of bed (feet)
OAK SPRING FORMATION (Cont'd)		
grayish-red quartzite(?) and volcanic rock fragments as much as 5 mm across, 10 percent; slickensides abundant. (Described from large block that fell into bailer from 1,700 to 1,730 foot interval; see pages 14 and 43.)	80	1,730
TALUS(?) BRECCIA		
Siltstone and breccia, interbedded; grayish-orange to dark yellowish orange. Siltstone is hard, firm, indurated(?) and possibly laminated. Breccia contains fragments of whitish and grayish orange to dark yellowish-orange altered angular dolomite(?) as much as 2.5 mm across in an indurated silty matrix. Both breccia and siltstone can be scratched by steel knife; neither reacts to acid	5	1,735
Breccia and siltstone, interbedded. Breccia contains angular fragments of medium dark-gray dolomite in a dark yellowish-gray to light olive-gray matrix of silty sand that is well cemented with calcium-magnesium carbonate(?). The silt and fine sand fraction is largely made up of quartz and feldspar; the medium-- to coarse-sand fraction is predominantly composed dolomite. Siltstone is white to very pale orange; very fine-grained silt is laminated(?) with some slightly calcareous laminae, soft	15	1,750
PALEOZOIC BEDROCK		
Eleana(?) Formation.		
Dolomite; mostly medium dark gray, but varies between medium dark gray and brownish gray; in basal 5 feet is dark gray; dense, very fine grained, partly silicified; sparse chert; a few veinlets less than 0.5 mm wide of clear quartz or whitish dolomite.	37	1,787

Table 1.--Lithologic log of test well D - Continued

	Thickness (feet)	Depth to bottom of bed (feet)
PALEOZOIC BEDROCK (Cont'd)		
Siltstone; grayish orange to pale yellowish brown; very fine grained, calcareous . . .	4	1,791
Limestone and dolomitic limestone; containing some chert and some interbedded calcareous siltstone. Limestone and dolomitic limestone are light olive gray to medium gray, light brownish gray, and medium gray; dense, mostly fine grained; contains some olive-gray chalcedonic chert cuttings in 1,780 to 1,790-foot interval; also sparse moderate red calcite veinlets less than 0.5 mm wide; fractures abundant and stained red. Siltstone makes up less than 5 percent of cuttings, grayish orange to pale yellowish brown, very fine grained, laminated	19	1,810
Interbedded dolomitic limestone and argillite; limestone is medium dark gray, grayish red, and brownish gray; dense, mostly very fine grained, but a small amount is coarse grained and contains sparse small fossils. Argillite is between pale reddish brown and dark reddish brown; laminated, shaley; moderately calcareous; muscovite, 1 to 2 percent.	7	1,817
Interbedded siltstone (possibly cave-in from 1,735 to 1,750-foot interval and limestone; siltstone, between white and very pale orange; laminated, very fine-grained, soft, slightly calcareous, with some calcareous laminae < 0.5 mm thick. Limestone, medium-gray; dense, mostly very fine-grained, but a small amount is coarse-grained and contains moderately abundant fossils	5	1,821
Interbedded limestone, limy argillite, and argillaceous limestone, limestone, light brownish gray and medium light gray; dense, mostly fine-grained, but		

Table 1.--Lithologic log of test well D - Continued

	Thickness (feet)	Depth to bottom of bed (feet)
PALEOZOIC BEDROCK (Cont'd)		
a small amount is medium to coarse grained (from 1,817 to 1,825 feet) and contains moderately abundant fossils; white calcite veinlets less than 0.5 mm wide; several fractures have red coatings. Limy argillite and argillaceous limestone totaling 10 percent of cuttings are grayish red to pale red; some shaly, some laminated, some clayey(?); trace muscovite.	19	1,840
Argillite; mostly moderate brown to grayish brown; upper 20 feet pale brown and more silty than that below; shaly, laminated, clayey(?) and silty; slightly calcareous, less calcareous with depth; muscovite 1 percent; small amount of manganese(?) oxide stains, 1 percent; abundant white calcite veinlets about 0.1 mm wide	110	1,950

Collection and analysis of samples

The drillers collected 1-pint samples of the drill cuttings at 5-foot intervals during the rotary drilling and at 5- to 15-foot intervals during the cable-tool drilling. They took the rotary-drilled cuttings from the shale shaker and the cable tool cuttings from the bottom of a halved oil drum into which they emptied the bailer.

Survey geologists then washed the samples in the laboratory to free them of drilling mud, and examined them by means of a binocular microscope. They compared the colors of the samples with the standard colors of the National Research Council rock color chart (Goddard and others, 1951). The footages logged by the several geologists follow: 0 to 290, 395 to 690, and 800 to 1,005 feet by William Thordarson; 290 to 395 and 690 to 800 feet by George E. Walker; 1,005 to 1,730 feet by Robert B. Scott, Bruce Blackerby, and William Thordarson; 1,730 to 1,950 feet by William Thordarson, Murray S. Garber, and Lewis R. West. The procedures used in logging are described below.

In logging the alluvium, estimates were made of the percentages of the rock types that comprise the gravel (table 2). Then, an examination was made of the silt- and sand-sized particles, herein termed the sandy matrix. The error in estimating the percentages of gravel rock types and composition of the sandy matrix is 5 to 15 percent.

In logging the bedrock, two procedures were followed. One was the use of the first appearance of cuttings of a different lithology, even though in small proportion, to delimit the top of a different bed, and the other was the visual elimination of extraneous cuttings derived from strata higher in the hole.

Many factors influence the quality of drill-hole samples. The cuttings from test well D were described with these factors in mind. For example, samples of alluvium obtained by rotary drilling are subject to contamination by the caving in of the upper part of the hole; to crushing and disaggregation by the bit; to inaccuracy caused by increasing delay in arrival of cuttings at the surface as the hole is deepened; to settling and sorting of grains caused by variations in velocity and viscosity of the drilling fluid; and to excessive grinding as bits become dulled. Although these same factors adversely affect the cuttings obtained from rotary drilling in bedrock, they do so to a lesser degree and good samples from bedrock are more easily obtained. The cable-tool cuttings from test well D are of better quality than the rotary-hydraulic cuttings; first, because the upper 1,700 feet of the hole had been cased which lessened contamination by caving from above; and second, because there was no drilling fluid of the type used in rotary-hydraulic drilling to interfere with the quality of the sample.

Alluvium

The alluvium consists mostly of fan deposits of poorly sorted silt, sand, and gravel. Lake beds may be included but none were identifiable in the cuttings. At most, lake beds probably make up only a small part of the alluvium. The samples of the alluvium do not show enough changes in composition or texture to permit their use in delimiting beds in a conventional log. Therefore, only the major rock types of the gravel are shown in table 2 and figure 2. The constituents of the alluvium are described separately below, beginning with the rock types in the gravel.

Gravel rock types

The gravel comprises pebbles, cobbles, and boulders of many rock types, which are variegated in color. The gravel rock types are welded tuff, pumiceous tuff, quartzite, chert, argillite, limy siltstone, silty limestone, sandy limestone, and limestone, which occur in diverse percentages in the different samples (table 2, figure 2). These rock types correspond to those of the formations of the nearby mountains from which they were derived. The rock types in the gravel are probably derived as follows: tuff from the Oak Spring Formation of Tertiary age; and limy siltstone, silty limestone, sandy limestone, and limestone from the Tappahannock Limestone of Pennsylvanian to Permian(?) age; quartzite, chert, and argillite from the Eleona Formation of Mississippian to Pennsylvanian age. Calcium-carbonate coatings are common on the gravel cuttings.

A few small unbroken pebbles were recovered. Most of these were sub-angular to sub-rounded, but the argillite pebbles were rounded to well-rounded

and also were flat.

Welded tuff gravel.--The welded tuff in the gravel is mostly pale red to grayish-orange pink. It contains flattened pumice; clear, euhedral quartz and feldspar crystals as much as 2 millimeters across 25 percent; and biotite, less than 1 percent; all are embedded in an aphanitic matrix. Less than 1 percent of the welded tuff is black vitrophyre or olive-gray glass.

Pumiceous tuff gravel.--The pumiceous tuff in the gravel is yellowish-gray to very pale orange, 60 to 90 percent of the total, or various shades of pink and red, 10 to 40 percent. Tuffs of these colors are grouped together in table 2.

The pumiceous tuff contains as much as 30 to 50 percent zeolitized pumice fragments as much as 3 millimeters in maximum dimension, 10 to 20 percent clear, euhedral quartz and feldspar crystals, and less than 2 percent biotite and black opaque minerals. The matrix of the pumiceous tuff is zeolitized and is generally hard and dense, but some of it is relatively soft. Less than 1 percent of the pumiceous tuff is silicified.

Quartzite gravel.--The quartzite is mottled light gray and light brown, grayish red, pale brown, grayish brown, medium-light gray, and light gray. The quartzite is made up of sand grains of clear quartz and feldspar, which are subrounded to rounded and generally are very fine to fine grained. Some of the quartzite, however, is medium to very coarse grained, and granule sized. Many of the very coarse grains and granules in the quartzite are subangular to rounded chert grains.

Chert gravel.--The chert gravel was mostly derived from chert-pebble conglomerates, and is grayish black to dark gray. Other common chert colors are medium gray and shades of red and brown.

Argillite gravel.--Most of the argillite gravel is pale yellowish brown, but minor amounts are light olive gray. Very small amounts are medium gray, dark gray, and grayish red.

Limy-siltstone gravel.--The limy siltstone in the gravel is mostly pale yellowish brown to moderate yellowish brown, but a very small amount is grayish orange. Some of the limy siltstone may be limy argillite.

Silty-limestone gravel.--The silty limestone in the gravel is medium gray, medium dark gray, and olive gray. It is partly silicified, and contains abundant fine silt and fusulinids. Some of the fusulinids are silicified.

Sandy-Limestone gravel.--The sandy limestone gravel is medium dark gray, dark gray, and olive gray. It contains abundant sand composed of quartz and rock fragments, which are possibly chert, argillite, or quartzite. The quartz sand is fine- to medium-grained and is rounded to well rounded. The sand-sized rock fragments attain larger size and are more angular than the quartz sand.

Limestone gravel.--The limestone gravel is medium gray to dark gray and olive gray. It is fine grained and contains small to moderate amounts of fine-textured material that may be silt or possibly fine-grained secondary silica. Fusulinida are abundant in the limestone.

FIGURE 2. -- PERCENTAGES OF MAJOR GRAVEL ROCK TYPES, MAXIMUM SIZE OF CUTTINGS, BIT RECORD, AND DRILLING PENETRATION RATES

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D

Bottom depth (feet)	Percentages of major gravel rock types ^{1/}							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
5	10	25	25	5	35		Tr	Tr
15	5	35	20	10	30		Tr	5
25	10	35	25	10	20		Tr	
35	10	56	15	8	11			10
45	5	55	20	10	10		Tr	30
55	10	60	10	5	15			5
65	10	70	5	5	10			
75	5	70	10	5	10			10
85	10	50	15	15	10			20
95	5	45	20	10	20			20
105	5	25	30	25	15			30
115	5	30	25	25	15			30
120	10	20	30	20	15		< 5	30
130	5	20	35	25	15		Tr	30

^{1/} Trace (tr) equals 1 percent or less.

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
140	5	20	40	25	10	Tr		30
150	5	30	35	20	10			
160	5	35	30	20	5	< 5		20
170	5	30	25	25	10	< 5		< 5
180	5	20	35	25	10	5		5
190	5	25	25	25	15	5		10
200	5	35	20	25	15	< 5		10
210	5	30	25	25	12	< 5		10
220	5	40	30	20	5	< 5		5
230	5	25	30	25	12	< 5		5
240	5	22	35	30	7	< 5		5
250	5	22	40	25	6	< 5		10
260	5	30	30	25	5	5		
270	10	55	15	15	5	< 5		
280	< 5	17	30	25	10	15		
290	< 5	32	25	25	11	< 5		

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
300	5	30	10	35	10		10	Tr
310	5	35	10	35	10		5	Tr
320	5	25	15	45	5		5	Tr
330	5	25	15	45	5		5	Tr
340	5	30	10	40	5		10	Tr
350	5	25	15	35	10		10	Tr
360	5	30	20	30	5		10	
370	5	30	20	25	15		5	
380	60	10	10	10	5		5	
390	5	25	25	15	25		5	Tr
400	10	5	40	25	10		10	< 5
410	10	15	30	15	15		15	
420	< 5	5	65	15	10		5	Tr
430	< 5	30	35	20	13		< 5	Tr
440	< 5	15	40	25	8		10	
450	5	30	30	15	17		< 5	
460	5	17	40	20	18		< 5	

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
470	10	25	25	20	15	5		
480	15	17	20	20	23	5		
490	5	20	30	25	10	10		
500	5	35	25	15	16	< 5		
510	5	25	25	15	5	25		< 5
520	5	5	50	15	10	15		
530	5	15	45	15	10	10		
540	5	15	40	35	5	< 5		
550	5	30	30	15	10	10		
560	5	15	35	20	15	10		
570	< 5	8	45	10	15	20		
580	< 5	13	25	10	5	45		< 5
590	< 5	< 5	5	< 5	< 5	90		
600	5	20	20	15	10	30		
610	< 5	13	30	10	10	35		< 5
620	30	27	15	5	20	< 5		
635	35	40	15	5	5	< 5		

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
640	35	30	10	< 5	20	< 5		
650	5	25	30	5	15	20		< 5
660	30	35	15	5	5	10		15
670	10	75	5	< 5	< 5	< 5		
680	15	65	5	< 5	10	5		
690	40	35	10	< 5	10	< 5		
700	60	25	< 5	< 5	10	< 5		Tr
710	75	15	Tr	Tr	10	Tr		Tr
720	35	35	5	5	20	Tr		Tr
730	40	35	< 5	< 5	20	Tr		
740	35	45	5	5	10	Tr		
750	40	30	< 5	< 5	20	5		Tr
760	40	30	5	5	10	10		Tr
770	40	35	< 5	< 5	5	15		Tr
780	30	50	< 5	< 5	5	10		Tr
790	30	45	< 5	5	5	10		Tr
800	30	50	< 5	< 5	5	10		Tr

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
810	35	35	5	< 5	25	< 5		Tr
820	35	30	< 5	< 5	30	< 5		
830	30	35	5	< 5	25	5		20
840	40	40	5	< 5	10	< 5		
850	50	30	5	< 5	10	< 5		
860	35	45	< 5	< 5	15	0		Tr
870	40	43	< 5	< 5	15	0		
880	40	40	< 5	< 5	15	0		10
890	80	15	0	0	5	0		
900	80	15	0	0	5	0		
910	80	15	0	0	5	0		
920	35	35	0	0	30	0		
930	35	35	0	0	30	0		
940	35	35	0	0	30	0		
950	35	35	10	5	5	10		
960	10	35	20	Tr	< 5	35		
970	25	10	15	< 5	10	35		

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
980	Tr	< 5	Tr	Tr	0	95		< 5
990	30	20	< 5	< 5	5	40		
1,000	60	15	0	0	0	25		
1,005	10	10	0	0	0	80		
1,020	20	5	10	0	10	40	15	5
1,030	30	15	5	< 5	10	20	20	5
1,040	60	< 5	10	0	5	25	< 5	
1,050	60	< 5	10	0	5	20	5	Tr
1,060	5	Tr	10	0	75	5	< 5	5
1,070	15	55	10	0	5	10	< 5	25
1,080	30	30	5	0	10	20	5	20
1,090	15	< 5	< 5	0	25	50	10	20
1,100	10	< 5	< 5	0	20	30	35	10
1,110	5	5	< 5	0	15	40	30	15
1,120	10	10	< 5	Tr	20	30	25	10
1,130	5	5	< 5	5	20	30	30	5
1,140	25	35	5	0	5	15	15	30

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	Cuttings with calcium-carbonate coatings (percent)
1,150	10	8	7	5	10	20	40	
1,160	10	5	5	0	15	35	30	5
1,170	10	5	10	0	10	35	30	10
1,180	35	Tr	15	0	25	10	15	5
1,190	5	Tr	20	0	10	25	40	5
1,200	5	5	20	0	10	30	30	15
1,210	Tr	5	70	0	5	15	< 5	< 5
1,220	5	5	15	0	5	45	25	< 5
1,230	7	< 5	10	Tr	10	30	40	< 5
1,240	10	5	10	Tr	10	35	30	Tr
1,250	10	20	5	< 5	15	20	30	< 5
1,260	40	25	Tr	Tr	10	10	15	< 5
1,270	10	< 5	5	Tr	10	30	40	Tr
1,280	< 5	< 5	5	Tr	25	35	30	5
1,290	5	< 5	< 5	Tr	10	30	50	5
1,300	40	30	Tr	0	5	20	< 5	Tr
1,310	10	10	5	Tr	5	35	35	Tr

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
1,320	10	10	Tr	0	5	30	45	< 5
1,330	10	Tr	10	0	10	35	35	Tr
1,340	7	8	5	Tr	15	30	35	
1,350	10	5	10	0	20	25	30	5
1,360	7	5	15	0	8	35	30	5
1,370	5	7	10	0	8	45	25	
1,380	5	Tr	10	Tr	5	25	55	10
1,390	5	Tr	5	5	5	30	50	15
1,400	15	5	5	16	Tr	35	25	20
1,410	50	10	Tr	25	Tr	15	Tr	8
1,420	65	10	5	10	Tr	10	< 5	35
1,425	30	35	< 5	< 5	< 5	15	15	15
1,435	5	5	10	5	5	25	45	8
1,445	5	5	10	5	10	30	35	5
1,455	5	5	5	5	10	45	25	10
1,465	Tr	< 5	5	Tr	10	40	40	5
1,475	Tr	< 5	5	Tr	10	40	40	5

Table 2.--Major gravel rock types in alluvial sediments penetrated in test well D - Continued

Bottom depth (feet)	Percentages of major gravel rock types							Cuttings with calcium-carbonate coatings (percent)
	Welded tuff	Pumiceous tuff	Quartzite	Chert	Argillite	Limy siltstone, silty and sandy limestone	Limestone	
1,480	Tr	0	10	10	5	40	35	8
1,490	< 5	Tr	10	10	5	40	35	5
1,500	< 5	Tr	10	10	5	45	25	5
1,505	---	----	----	----	----	----	----	----

Calcium-carbonate coatings

Calcium-carbonate coatings remain on some of the gravel cuttings that contain surfaces not obliterated or destroyed by drilling, and a few discrete chips of calcium carbonate also are found in the cuttings (table 1). These coatings and chips are white to very pale orange, and most of them are more than 0.5 millimeter thick. The greatest percentages of calcium-carbonate coatings are at depths of 35 to 160 feet, 1,070 to 1,140 feet, and 1,380 to 1,425 feet.

The calcium-carbonate coatings may represent caliche. If a caliche bed is penetrated in drilling, most of the calcium carbonate in it is crushed and disintegrated by the bit and its relation to the other components of the bed is destroyed. It is suggested, therefore, that the strata having the more abundant calcium-carbonate coatings may be caliche.

Changes in gravel rock types with depth

The percentages of each of the rock types in the gravel are plotted against depth in several graphs of figure 2. These graphs show three large depth intervals that are delimited by abrupt changes in gravel rock types as follows: from 0 to 600 feet, pumiceous tuff, quartzite, and chert predominate; from 600 to 950 feet, welded tuff and pumiceous tuff predominate; and from 950 to 1,505 feet, limy siltstone, silty limestone, sandy limestone, and limestone predominate. Irregular gradual changes in rock types also are illustrated by the graphs.

The changes in rock types in the gravel should be interpreted with the following facts in mind:

1. Only the cuttings larger than 1 millimeter were considered because they are much easier to identify than the smaller ones. Among these cuttings the more resistant rock types such as chert, quartzite, welded tuff, and limestone may be more concentrated than in the undisturbed gravel.
2. Resistant rocks are likely to be relatively more abundant in coarse than in fine gravel. For instance, a boulder gravel may contain proportionately more resistant limestone and less non-resistant pumiceous tuff than a pebble stratum.
3. Drilling through a large boulder will produce an abrupt increase in the percentage of the rock type represented by the boulder.
4. The drilling equipment affects the distribution of different rock types in the cuttings. For instance, the condition of the bit partly controls the size of the cuttings. Sharp bits generally produce larger cuttings than dull bits. For example, the cuttings become larger at a depth of 1,011 feet, at which point a sharp bit was substituted for a dull one.

Sandy matrix

The character of the sandy matrix of the alluvium is shown, at least in part, by natural clusters of grains recovered in the cuttings. These clusters are predominately very pale orange; but minor amounts are grayish orange or pale yellowish brown. These colors are probably the same as the gross colors of the alluvium. The grains in the clusters range in size from clay to very coarse sand and they are cemented by calcium carbonate or clay. Those of silt and sand size consist of quartz, feldspar, and rock fragments.

Bedrock

Three formations of stratified bedrock were penetrated in test well D. From youngest to oldest, they are tuff, talus (?) breccia, and interbedded carbonate rocks and argillite. Unconformities probably separate these formations.

Tuff

The first bedrock penetrated in test well D was tuff, similar to the tuff in the Oak Spring Formation of Tertiary age. The tuff was penetrated from 1,505 to 1,730 feet, a total of 225 feet. Abrupt changes in the drilling penetration rate were recorded at the top and bottom of this interval and were confirmed by changes in character of the geophysical logs (fig. 3).

A two-fold division of the tuff is recognized. The upper part, from 1,505 to about 1,650 feet, is a very pale orange, zeolitized, crystal tuff. The lower part, from about 1,650 to 1,730 feet, is a light gray, clayey, zeolitized, pumiceous crystal tuff.

The basal 30 feet of the tuff caved badly. (See section on interruptions of work.) Locally the caving is estimated to have increased the diameter of the hole 4 feet or more, judged from the size of the blocks (as much as 1.5 feet long) that fell into the bailer, and from the volume of caved material which fell to the bottom of the hole. The tuff probably caved so much during the drilling operations because of structural weakness of the clayey tuff and because of many slickensided fractures.

The slickensides in the largest blocks of caved tuff consists of three main sets which are spaced 1 to several inches apart, and which intersect at right and acute angles, thereby nearly forming parallelopipeds. Several other minor slickensides also were found in this block.

Five X-ray analyses of samples from the tuff were made by John E. Moore. These samples first were gently sieved through a screen having 0.074-millimeter openings in order to remove most of the phenocrysts. Then the finer fraction was X-rayed on a goniometer diffractometer, and semi-quantitative estimates based on peak heights of the resulting curves were made of the percentages of clay (montmorillonite), mica (biotite), zeolite (heulandite and clinoptilolite),

quartz, feldspar (sanidine and minor amounts of albite), and calcite (table 3). The X-ray analyses showed, further, that no beta-cristobalite, dolomite, or glass were included.

Table 3.--X-ray mineralogic analyses of tuff from test well D, by John E. Moore (Samples were taken from rotary-hydraulic cuttings, except the sample from a chunk of tuff recovered in the bailer).

Depth interval (feet)	Percentage of minerals					
	Clay	Mica	Zeolite	Quartz	Feldspar	Calcite
1,515-1,520	----	----	55	5	10	30
1,595-1,600	----	----	40	16	12	32
1,670-1,695	38	----	11	8	4	39
1,700-1,730	70	9	----	11	10	----
1,710-1,716	84	----	6	4	6	----

Talus(?) breccia

A talus(?) breccia composed of broken dolomite with a few layers of siltstone was penetrated from 1,730 to 1,750 feet. The upper 5 feet consists of altered or indurated(?) siltstone and breccia. The lower 15 feet consists of angular dolomite fragments in a matrix of detrital silty sand that is well cemented by calcium-magnesium carbonate, and it also contains some interbedded soft siltstone.

Both the matrix of the breccia and the interbedded layers of siltstone probably are of sedimentary origin. Traces of vein calcite, gouge, or other features characteristic of faulting were not found in the matrix. The breccia was probably deposited as talus on a Tertiary erosion surface, but other parts of the unit, notably the layers of siltstone, may have been breccia that were reworked by streams. Breccias of this type are common at the contact between the Tertiary tuff and the Paleozoic rocks at the Nevada Test Site. If, as hinted above, the breccia accumulated on an erosion surface developed during Tertiary time, it is of Tertiary age.

Paleozoic bedrock

Paleozoic bedrock similar to rocks in the Eleana Formation of Mississippian and Pennsylvanian age was penetrated from 1,730 to 1,950 feet. Two subdivisions

are recognized. The upper subdivision, from 1,750 to 1,840 feet, consists of interbedded fine-grained dolomite, dolomitic limestone, and limestone; coarse-grained fossiliferous limestone; argillaceous limestone; limy argillite, argillite, and siltstone. The argillaceous content of these rocks increases irregularly downward. The lower subdivision, from 1,840 to 1,950 feet, consists of clayey, shaly argillite.

Fossils were found in cuttings of the coarse-grained limestone in the depth interval of 1,817 to 1,825 feet. The residues obtained after digestion of some of this material in acetic acid were examined by J. T. Dutro, Jr. He identified several fragments of inarticulate brachiopods probably referable to *Orbiculoidea*, and siliceous hexactine sponge spicules not identifiable as to genus. *Orbiculoidea* ranges in age from Ordovician through the Permian (personal communication, June 15, 1961).

GEOPHYSICAL LOGS

Geophysical logs made to depths of about 1,735 feet in test well D on July 21, 1960, by the Schlumberger Well Surveying Corp. included electrical, laterolog, gamma ray-neutron, and sonic logs. A section-gage log also was made. A comparison of the geophysical logs and lithologic log is shown in figure 3. At the time of logging the hole was 1,744 feet deep, was uncased, and was filled with drilling fluid. The logs showed several pronounced changes at various depths which are believed to be related to the lithologic character of the rocks below them. The depths at which the more significant changes were noted are as follows:

(Figures are depth, in feet, below land surface)

Electric logs	Laterolog	Gamma ray-neutron log	Sonic log	Section-gage log	Rock type underlying
950	940	----	----	----	Alluvium with much limestone
1,510	1,510	1,530	1,520	1,550	Zeolitized tuff
1,630	1,630	----	1,600	1,630	Clayey and zeolitized tuff
1,732	1,732	1,732	----	----	Talus(?) breccia

FIGURE 3. - LOGS OF TEST WELL D

GROUND-WATER HYDROLOGY

The static water level in test well D is about 1,733 feet below the land surface, or at altitude 2,417 feet, and is approximately at the contact between the tuff and the underlying talus(?) breccia.

It is not known if artesian conditions exist at the well. The drillers first suspected the presence of ground water while reaming the hole at a depth of 1,735 feet. However, just above this depth they had injected 300 gallons of water into the hole to facilitate the removal of cuttings, thereby preventing the positive recognition of ground water until much additional drilling had been done. The presence of ground water was not definitely established until the bottom of the hole was about 53 feet below the present static water level. Once the position of the water table had been ascertained, no rise or decline in head was observed as the hole was deepened through the saturated zone.

No perched ground water was found in the hole when it was being reamed by the cable-tool method.

Description of the aquifer

The aquifer in test well D comprises 90 feet of chiefly carbonate strata that are interbedded with argillite and siltstone in the depth interval from 1,750 to 1,840 feet and the overlying 20 feet of talus(?) breccia from 1,730 to 1,750 feet. The underlying 110 feet of argillite in the interval from 1,840 to 1,950 feet is relatively impermeable, as shown by the fact that in tests by bailing the well yielded no more water after having been deepened through this interval than it had yielded previously.

Presumably the argillite and siltstone interbedded with the carbonate rocks also are relatively impermeable, so the carbonate rocks probably yield most of the water. The carbonate rocks are believed to contain water chiefly in fractures, which in surface outcrops are numerous. Other openings such as solution channels and vugs are rare at the surface and drillers have not, as a rule, reported a free fall of the drill string while drilling in the carbonate rocks, which would occur if a sizeable solution cavity were penetrated.

Aquifer tests

Three tests by bailing were made in test well D in order to determine the hydraulic characteristics of the water-bearing strata, principally the coefficient of transmissibility and the specific capacity. Each test began with a series of water-level measurements to determine the static water level. Next, one or more bailerfuls of water were removed from the well. If the bailer came to the surface only partly full, the height of the water column in it was measured and noted. When several bailerfuls were being withdrawn, an effort was made to maintain a uniform rate of withdrawal. After bailing was stopped,

the recovery of the water level was measured, the measurements being continued if possible until the water had returned to its static level.

Measurements of water level could not be started until the last bailerful had reached the land surface and the measuring probe could be lowered to the water. Because of the considerable depth to water, this procedure took 6 or 7 minutes, during which time some water could have entered the bore. The first water-level measurement after bailing, therefore, indicates somewhat less than the maximum drawdown.

The data from all three tests were analyzed to determine the coefficient of transmissibility by a method suggested by Skibitzke (personal communication); and the data from the second and third tests were further analyzed by the method of Cooper and Jacob (1946). In both methods it is assumed as one of several limiting conditions that the aquifer is isotropic, whereas the aquifer in test well D probably contains water principally in fractures and thus may be far from isotropic. Divergent results from the two methods of interpretation therefore may be expected. From the data obtained in the bailing tests in well D it is possible to calculate values for the coefficient of transmissibility that span a rather wide range. To be conservative, only minimum values are given in this report, pending synthesis of results of similar tests in other wells. Although the coefficients of transmissibility determined for this well may be at best no more than indications of the true values, they nevertheless are useful for comparing the hydraulic properties of different intervals in the well and for comparing water-bearing strata in different wells.

Bailing test 1 was made December 31, 1960, when the hole was about 1,786 feet deep and was uncased below 1,700 feet. The static water level before testing was 1,732.6 feet below the land surface. One bailerful of water, about 57 gallons, was removed. The first measurement of water level after bailing was made 7 minutes after the bailer started to the surface, and showed the residual drawdown to be 3 feet; 8 minutes later the drawdown was still 3 feet indicating that the actual conditions were quite dissimilar from the conditions that must exist if the equation used for computing coefficients of transmissibility is to be applicable within a narrow range. The minimum indicated coefficient of transmissibility based on this test is about 55 gallons per day per foot. Further details, including the water-level measurements, are given in table 9.

Bailing test 2 was made January 7, 1961, when the hole was about 1,900 feet deep and was cased to the bottom. The casing in the 110-foot interval from 1,772 to 1,882 feet was slotted. The static water level at the time of the test was 1,732.2 feet below the land surface. The well was bailed with a 98-gallon bailer for 1 hour and 29 minutes. A total of 1,960 gallons of water was withdrawn, and the average rate of withdrawal was 22 gallons per minute. Thereafter the first measurement of water level was made 6 minutes after bailing stopped, showed the residual drawdown to be 48.3 feet. The specific capacity after 89 minutes of bailing was less than 0.4 gallon per minute per foot of drawdown. The minimum coefficient of transmissibility computed by the Skibitzke method is 95 gallons per day per foot; and by the Cooper-Jacob method, 80 gallons per day per foot. Details of the test are given in table 10 and a semi-logarithmic plot of the recovery of water level is illustrated in figure 4.

FIGURE 4. --GRAPH OF WATER-LEVEL RECOVERY DURING THE SECOND BAILING TEST

The third bailing test was made January 9, 1961, when the well was 1,950 feet deep and was cased the same as it was at the time of the second test. The static water level also was the same as at the time of the second test, and the same bailer was used. As planned, the test was to consist of 8 hours of continuous bailing, but the bailing lasted less than half this long because the drill rig could not be operated continuously for a longer period of time at the high rates that were necessary. The well was bailed at an average rate of 18 gallons per minute for 3 hours and 14 minutes, during which period about 3,480 gallons of water was removed. Then there was an interruption of 25 minutes, between the 30th and 31st bailerfuls, when the drilling rig had to be shut down because the brake lining of the bailing drum had become overheated. The greatest drawdown recorded for the test was observed during this interruption. From it and from the average bailing rate to the time of the interruption, 22.5 gallons per minute, it is estimated that the specific capacity is less than 0.27 gallon per minute per foot of drawdown. The minimum coefficient of transmissibility based on the full period of bailing and computed by the Cooper-Jacob method is 55 gallons per day per foot; and by the Skibitzke method, 90 gallons per day per foot.

The value of the coefficient of transmissibility determined by the Cooper-Jacob method in the third test is only slightly more than half that obtained by the Skibitzke method, although values determined by the two methods should be comparable. The difference may be partly or entirely due to the interruption in bailing. This would affect the Cooper-Jacob method because a basic assumption of the method is that withdrawal be uniform. The Skibitzke method, on the other hand, takes account of the time each bailerful is removed and thereby adjusts for the irregularity of bailing operations.

Details of test 3 are given in table 2, and a semi-logarithmic plot of the recovery of water is illustrated in figure 5. Results of all three bailing tests are summarized in table 4.

Table 4.--Summary of bailing tests in test well D

Test number	Hole depth (feet)	Casing (feet)	Number of bailerfuls	Specific capacity (gallons per minute per foot of drawdown)	Coefficient of transmissibility	
					Cooper-Jacob method	Skibitzke method
1	1,786	0-1,700	1			55
2	1,900	^a 0-1,900	20	0.45	80	95
3	1,950	^a 0-,900	36	.27	50	90
^a Slotted, 1,772-1,882 feet

FIGURE 5. --GRAPH OF WATER-LEVEL RECOVERY DURING THE THIRD BAILING TEST

CHEMICAL QUALITY OF WATER

A water sample collected from test well D after about 3 hours of nearly continuous bailing and analyzed in the Geological Survey laboratory, Denver, Colo., contained relatively high concentrations of sodium, bicarbonate, and sulfate ions, and had a hardness explained as calcium carbonate of 84 parts per million. No bentonite or chemicals that might have contaminated the water sample were put in the well while it was being drilled in the zone of saturation. Table 5 gives the detailed chemical and radiochemical analyses for the water sample.

CONCLUSIONS

Test well D penetrated alluvium to a depth of 1,505 feet; tuff between 1,505 and 1,730 feet; a talus(?) breccia between 1,730 and 1,750 feet; dolomite, limestone, and argillite between 1,750 and 1,840 feet and argillite between 1,840 and 1,950 feet.

The aquifer in test well D comprises the talus(?) breccia and the carbonate rocks in the interval from 1,730 to 1,840 feet. The lower limit of the aquifer is defined by the limestone-argillite contact.

During two tests by bailing, the well yielded 18 and 22 gallons per minute. The specific capacity is less than 0.27 gallon per minute per foot of drawdown, and the coefficient of transmissibility is about 90 gallons per day per foot.

Water from test well D contains relatively high concentrations of sodium bicarbonate, and sulfate ions, but dissolved solids of only 343 parts per million.

Table 5.--Chemical and radiochemical analyses of water from test well D, by the U.S. Geological Survey (water from bailer after about 3,100 gallons had been bailed out).

Date collected: January 9, 1960.		Temperature: 78°F.	
Collected by: Murray S. Garber.		Appearance: very muddy.	
Chemical components, Parts per million (ppm)		Physical characteristics and computed values	
Silica (SiO ₂)	18	Dissolved solids (ppm)	
Aluminum (Al)	.4	Res. on evap. at 180°C	343
Iron (Fe)	.03	Calculated	398
Manganese (Mn)	0.00	Hardness as CaCO ₃	
Calcium (Ca)	17	Total	84
Magnesium (Mg)	10	Non-carbonate	0
Sodium (Na)	107	Specific conductance (μmhos at 25°C)	486
Potassium (K)	14	pH	7.8
Bicarbonate (HCO ₃)	274	Color	1
Carbonate (CO ₃)	0	Radiochemical data	
Sulfate (SO ₄)	71	Alpha activity (μg/l as uranium equivalent) as of 2/10/61	5.5 ±4.7
Chloride (Cl)	20	Beta activity (pc/l) as of 2/6/61	58 ±9
Flouride (F)	1.6	Radium (Ra) (pc/l)	0.9 ±0.2
Nitrate (NO ₃)	4.2	Uranium (U) (μg/l)	14 ±1
Phosphate (PO ₄)	.38	Extractable alpha activity (net) (pc/l)	12 ±6
		Strontium 90 (pc/l)	^{a/} < 1.2

^{a/} None found down to this value.

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Appendix I.--Payments to contractor

Payments made to the contractor for the construction of test well D are itemized in the following summary prepared by George Willson of Holmes and Narver, Inc. The summary is divided into two parts.

Payments for rotary hydraulic drilling

Description	Quantity	Amount
1. Dismantle and set up drilling rig	1 each	\$ 300.00
2. Drill pilot hole in alluvium and Oak Spring Formation	1,730 feet	8,650.00
3. Reaming pilot hole	1,361 feet	6,805.00
4. Drill pilot hole in bedrock	14 feet	98.00
5. Logging-truck mileage	1 each	300.00
6. Electric log	1 each	300.00
7. Section guage log	1 each	250.00
8. Gamma-neutron log	1 each	250.00
9. Sonic log	1 each	250.00
10. Laterolog	1 each	250.00
11. Standby-ready for geophysical logging	15 hours	<u>240.00</u>
	Sub total	\$17,693.00

Appendix I.--Payments to contractor - Continued

Payments for work with cable-tool drilling rig

Description	Quantity	Amount
1. Dismantle and set up drilling rig	1 each	\$ 300.00
2. Moving in drilling rig	19 miles	95.00
3. Reaming pilot hole	383 feet	2,393.75
4. Drilling in bedrock	206 feet	2,781.00
5. Furnish and install 12 3/4-in OD plain casing	1,700 feet	12,325.00
6. Cementing 12 3/4-in. OD casing	1 job	700.00
7. Furnish and install 10 3/4-in. OD slotted casing	111 feet	749.25
8. Furnish and install 10 3/4-in OD plain casing	139 feet	834.00
9. Bailing	6 hours	96.00
10. Standby-ready for water-level measurements	25 hours	<u>400.00</u>
	Sub total	\$20,674.00
	Grand total	<u>\$38,367.00</u>

Appendix II.--Drilling equipment

The equipment used in drilling and reaming test well D is itemized in three tabulations: (A) Failing 1500 holemaster combination drilling rig, (B) Custom made rotary hydraulic drilling rig, and (C) Bucyrus 36-L cable tool drilling rig.

A. Failing 1500 Holemaster combination drilling rig.

Rotary drilling rig: Failing 1500 Holemaster combination rig (shop number 915), mounted on General Motors truck.

Owner: Mac Exploration Company, Milford, Utah.

Power: Truck engine, 154 hp.

Mast: 42 ft long, rated at 70,000 lbs.

Sand reel: 16-in. diameter, friction clutch.

Drill head: Hydraulic feed, for 2 7/8-in. kelly.

Kelly: 2 7/8-in. diameter, round fluted.

Drill pipe and tool joints: Failing Exploration Full Hole drill pipe, 2 3/8 in. OD and 1 1/2 in. ID; in 15.1-ft lengths weighing about 133 lb per length, having API Full Hole tool joints, 3 in. OD and 1 1/2 in. ID.

Drill collar: 22 ft long; weight, 800 lb.

Core barrel: Drilling and Service, Inc.; double-tube, swivel type, inner tube 2 1/4 in. ID, 18 ft 11 3/4 in. long.

Mud pump: Gardner-Denver reciprocating, 5-in. piston, 6-in. stroke.

Two were used: Model FG-FXG from surface to 1501 ft; model FG-FXGP from 1501 to 1744 ft.

Mechanical well logger: Geolograph model G3 recorder.

Water swivel: Failing S-1025, rated capacity 25,000 lbs.

Shale shaker: Link Belt Co., NRM-145-S, 30-mesh screen, depth interval from 0-875 ft; Overstrom M.S. 20-B, 30-mesh screen, depth interval from 875-1744 ft.

Bits: The record of bits is summarized in appendix III.

Appendix II.--Drilling equipment - Continued

B. Custom made rotary hydraulic drilling rig

Rotary drilling rig: Custom made, parts assembled by Cardwell Manufacturing Company, Wichita, Kan.; mounted on a semi-trailer.

Owner: Mac Exploration Company, Milford, Utah.

Power: Cummings NHRS diesel, 320 hp.

Mast: 80-ft long, Joy Manufacturing Co., rated at 100,000 lb.

Sand reel: 15-in. diameter, friction clutch.

Drawworks: Cardwell HR-71.

Traveling block: Byron Jackson, 3-sheave, 150,000 lbs capacity.

Hook: Byron Jackson, 100,000 lbs capacity.

Rotary table: Brewster, OB-12-S.

Kelly: 3 in. square, 36 ft long.

Drill pipe and tool joints: 3 1/2-in. diameter external-upset drill pipe in 30-ft lengths, weighing about 400 lbs per length; having A.P.I. internal flush joints with 4 threads per inch.

Drill collar: Two, each collar 23-ft long; 5 1/2 in. OD, 2 3/4 in. ID, weighing about 1,400 lb each.

Mud pump: Wilson-Snyder 612 P reciprocating 6-in. piston, 12-in. stroke, powered by a Buda Model K428 engine.

Water swivel: Brewster 6-SX, capacity 420,000 lb.

Mechanical well logger: Geolograph model G3 recorder.

Bits: The record of bits is summarized in appendix III.

Appendix II.--Drilling equipment - Continued

C. Bucyrus Erie 36-L cable-tool drilling rig.

Cable-tool drilling rig: Bucyrus-Erie 36-L, mounted on a semitrailer.

Owner: Layne-Franklin Company, Houston, Tex.

Power: Cummins diesel engine.

Derrick: height, 54 ft, rated capacity, 120,000 lb.

Wire rope: drill line, 1 in.; sand line 5/8 in; casing line, 7/8 in.

Rope socket: Prosser wire-line, swivel socket.

Drilling jars: diameter, 5 3/4 in; stroke, 8 in.; weight, 400 lb.

Drill stem: diameter, 6 in.; length, 23.5 ft; weight, 2,400 lb.

Bailers: Dart valve, (a) 0.82 ft ID x 15 ft long, capacity, 59 gals;
(b) 0.72 ft ID x 32-ft long, capacity, 98 gals.

Bits: The record of bits is summarized in appendix III.

Appendix III.--Record of bits used to drill and ream test well D

The bits used in test well D are classified as follows: (A) those used in the drilling operations, and (B) those used in reaming operations.

A. Bits used in drilling test well D

Depth interval (feet)	Diameter (inches)	Type	Manufacturer
0- 21	7 7/8	---	Hughes
21- 381	6	---	Chicago Pneumatic
381- 508	4 3/4	OW	Hughes
508- 886	4 3/4	---	(?)
886-1,011	4 3/4	---	Gunner
1,011-1,057	6	---	Chicago Pneumatic
1,057-1,172	6	K2P	Smith
1,172-1,373	6	---	Security
1,373-1,501	6	DL2G	Gunner
1,501-1,601	6	Sr	Security
1,601-1,744	5 5/8	---	Smith
1,744-1,900	12	(a)	---
1,900-1,950	9	(a)	---

(a) Twisted-blade, California paddle

Appendix III.--Record of bits used to drill and ream test
well D - Continued

B. Bits used in reaming test well D

Depth interval (feet)	Diameter (inches)	Type	Manufacturer
381-1,011	6	---	Chicago Pneumatic
0- 600	15	---	Custom made
600-1,326	8 3/4	---	Security
500-1,361	15	---	Reed
1,361-1,700	15	(a)	-----
1,700-1,744	12	(a)	-----

(a) Twisted-blade California paddle

Appendix IV.--Viscosity of drilling fluid

The viscosity of the drilling fluid was measured using a Marsh funnel, graduated cup, and stopwatch. The figures reported are number of seconds that elapsed during the discharge of 1,000 cc of drilling fluid. The viscosities are relative and not absolute in value.

Table 6.--Viscosity of drilling fluid in test well D

Depth interval (feet)	Viscosity (Sec. per 1000 cc)	Drilling Machine	Operation
0- 615	30- 90	Failing 1500	Drilling
615- 870	60-155	Failing 1500	Drilling
870-1,010	40-100	Failing 1500	Drilling
1,010-1,075	58-200	Failing 1500	Drilling
1,075-1,475	47-120	Failing 1500	Drilling
1,475-1,744	70-300	Failing 1500	Drilling
0- 424	35-115	Failing 1500	Reaming
424-1,326	64-175	Failing 1500	Reaming
500-1,023	42- 46	Custom-made	Reaming
1,023-1,234	45- 80	Custom-made	Reaming
1,234-1,361	36- 60	Custom-made	Reaming

Appendix V.--Rotary speeds maintained while drilling
and reaming test well D

The depth interval, rotary speed, drilling machine used, and drilling operation being performed at test well D are listed below.

Table 7.--Rotary speeds maintained while drilling
and reaming test well D

Depth interval (feet)	Rotary Speed (Revolutions per min.)	Drilling Machine	Operation
0-1,288	100-150	Failing 1500	Drilling
1,288-1,744	80-120	Failing 1500	Drilling
0- 327	50- 70	Failing 1500	Reaming
327-1,186	85-120	Failing 1500	Reaming
1,186-1,326	50-100	Failing 1500	Reaming
500-1,361	50- 70	Custom-made	Reaming

Appendix VI.--Record of water, bentonite, and other materials used for test hole D

The record of water, bentonite and other materials used in drilling well D has been broken into two sections. Section A shows the rate of water consumption, in gallons per foot drilled, for the pilot hole; and section B, is an itemized account of the water, bentonite and other materials used to drill and ream the well.

Table 8

A. Rate of water consumption in gallons per foot of penetration in drilling the pilot hole at test hole D

Depth interval (feet)	Gallons per foot	Depth interval (feet)	Gallons per foot
0- 50	No record	1,172-1,183	22
50- 285	4-14	1,183-1,270	7-10
285- 315	No record	1,270-1,290	21
315- 380	12-28	1,290-1,315	89
380- 455	No record	1,315-1,362	11
455- 590	4-12	1,362-1,415	24-45
590- 613	18	1,415-1,460	7
613- 743	10-14	1,460-1,475	31
743- 870	4	1,475-1,500	No record
870-1,010	10-12	1,500-1,525	41
1,010-1,045	21-29	1,525-1,592	6- 7
1,045-1,056	5	1,592-1,601	80
1,056-1,110	21-29	1,601-1,677	6- 7
1,110-1,172	7-10	1,677-1,740	24

Appendix VI.--Record of water, bentonite, and other materials used
for test hole D - Continued

Table 8 - Continued

B. Record of water, bentonite, and other materials used to
drill and ream test well D

Material	Failing 1500 rig	Custom- made rig	Bucyrus-Erie 36-L rig		Total
			Reaming	Crilling	
Water (gal)	61,350	25,100	8,800	0	95,250
Bentonite (lb)	18,000	2,500	0	0	20,500
Quicklime (lb)	169	0	0	0	169
Sodium hexameta- phosphate (lb)	25	0	0	0	25
Caustic soda (lb)	43	75	0	0	118
Lignite (lb)	26	0	0	0	26
Barium sulfate (lb)	0	2,200	0	0	2,200
Quebracho (lb)	0	750	0	0	750
Ligno-sulfanate (lb)	0	50	0	0	50

Appendix VII.--Casing record

Following is the record of blank casing, slotted casing, and cementing in test well D. All casing has a wall thickness of 0.375 in., is electric-welded seamless steel pipe (ASTM-A 139-58, grade B) of about 20-ft. lengths. Joints were butt-welded with a minimum of two passes of an electric arc from a welding machine (Fleetweld 5P 3/16 in.). The 12 3/4-in. OD casing weighs 49.65 lb per ft, and the 10 3/4-in OD casing weighs 40 lb per ft. The ends of the pipe were factory beveled to a 30° angle.

Depth interval (feet)	Casing and cement
0-1,700	12 3/4-in. OD with casing shoe consisting of split piece of 12 3/4-in. OD casing 4-in. long welded around its bottom. Casing landed on tuff shoulder; bottom cemented with 17 sacks type II Monolith Portland-Regular cement, squeezed into annular space with 4- by 6- in. board and a burlap plug (squeezing pressure applied by cable-tool bit and 1,000 gal of water); after squeezing, casing lowered into cement from 1,695 to 1,700 ft; upper 10 ft also cemented.
1,650-1,771.5	10 3/4-in. OD; upper 10 ft annealed and swaged out against 12 3/4-in. OD, forming main support for 10 3/4-in. OD.
1,771.5-1,791.5	10 3/4-in. OD with vertical slots cut by acetylene torch 0.125 to 0.25 in. wide by 12 in. long, circumferentially arranged in rows of 6 slots each, about 6-in. separation between rows; slots staggered so that those in alternate rows are vertically in line.
1,791.5-1,811.5	10 3/4-in. OD with machine-cut vertical slots, 0.125-in. wide by 3 in. long, circumferentially arranged in rows of 16 slots each, 3-in. separation between rows; slots staggered so that those in alternate rows are vertically in line.
1,811.5-1,832.5	10 3/4-in. OD; slotted same as in depth interval from 1,771.5-1,791.5 ft.
1,832.5-1,882.5	10 3/4-in. OD; slotted same as in depth interval from 1,791.5-1,811.5 ft.
1,882.5-1,900	10 3/4-in. OD with casing shoe consisting of 1-ft piece of 12 3/4-in. OD casing welded around bottom of 10 3/4-in. OD and extending 0.5 in. below it.
1,900 -1,950	Uncased.

Appendix VIII.--Bailing tests

Records of the hydraulic tests performed in test well D are given below. All water-level measurements were made electrically with a two-conductor cable and bronze-magnesium probe. All depths reported in this appendix are depths below measuring point and have not been adjusted to the land surface. Other conditions and circumstances differed from test to test, and accordingly are itemized separately for each test, together with the measurements of water level, in tables, 9, 10, and 11.

Table 9.--Record of first bailing test

Date: December 31, 1960.

Observer: I. J. Winograd.

Bailerfuls removed: 1.

Water removed: 57 gal.

Measuring point: top of 12 3/4-in. OD casing which was 2.07 ft above land surface.

Static water level before test: 1,734.7 ft.

Time since bailing stopped (minutes)	Depth to water (feet)	Time since bailing stopped (minutes)	Depth to water (feet)
7	1,737.7	65	1,736.1
8	1,737.6	70	1,735.8
9	1,737.7	75	1,735.6
11	1,737.7	80	1,735.4
15	1,737.7	85	1,735.3
34	1,737.3	95	1,735.1
45	1,737.2	105	1,734.9
55	1,736.9	120	1,734.8

Appendix VIII.--Bailing tests - Continued

Table 10.--Record of second bailing test

Date: January 7, 1961. Observer: I. J. Winograd.
 Bailing started: 12:52 p.m. Bailing stopped: 2:21 p.m.
 Bailerfulls removed: 20. Water removed: 1,960 gal.
 Average bailing rate: 22 gpm. Water temperature: 78-79°F.
 Measuring point: Top of 12 3/4-in. OD casing, which is 1.4 ft above
 land surface.
 Static water level before test: 1733.6 ft.

Time since bailing stopped (minutes)	Depth to water (feet)	Time since bailing stopped (minutes)	Depth to water (feet)
6	1,781.9	25	1,771.0
7	1,781.5	27	1,770.7
8	1,781.0	29	1,770.2
9	1,780.3	31	1,768.9
10	1,779.6	33	1,768.0
11	1,778.9	35	1,766.9
13	1,777.7	37	1,765.3
14	1,777.1	39	1,764.3
15	1,776.4	41	1,763.2
17	1,775.4	44	1,761.4
19	1,774.3	47	1,759.6
21	1,773.1	50	1,758.2
23	1,772.0	55	1,755.3

Appendix VIII.--Bailing tests - Continued

Table 10.--Record of second bailing test - Continued

Time since bailing stopped (minutes)	Depth to water (feet)	Time since bailing stopped (minutes)	Depth to water (feet)
60	1,752.6	115	1,733.8
65	1,750.0	120	1,733.5
70	1,747.6	130	1,732.9
75	1,745.4	140	1,732.3
80	1,743.4	150	1,731.7
85	1,741.2	160	1,731.1
90	1,739.3	170	1,730.5
95	1,737.5	180	1,730.2
100	1,736.1	190	1,730.0
105	1,735.2	200	1,729.7
110	1,734.4	210	1,729.6

Appendix VIII.--Bailing tests - Continued

Table 11.--Record of third bailing test

Date: January 9, 1961.

Observer: M. S. Garber.

Bailing started: 8:40 a.m.

Bailing stopped: 11:54 a.m.

Bailerfuls removed: 35.5.

Water removed: 3,480 gal.

Average bailing rate: 18 gpm.

Measuring point: Top of 12 3/4-in. OD casing which is 1.4 ft above land surface.

Static water level before test: 1,733.6 ft.

Time since bailing stopped (minutes)	Depth of water (feet)	Time since Bailing stopped (minutes)	Depth to water (feet)
7	1,798.4	22	1,781.0
8	1,796.6	23	1,780.3
9	1,795.6	25	1,770.8
10	1,794.7	27	1,777.8
11	1,793.4	29	1,775.6
12	1,791.8	32	1,772.7
13	1,790.7	34	1,770.5
14	1,789.6	36	1,768.4
15	1,788.5	38	1,766.4
16	1,787.4	40	1,764.4
18	1,785.0	42	1,762.6
19	1,784.1	44	1,760.3
20	1,783.2	46	1,758.7
21	1,782.1	48	1,756.8

Appendix VIII.--Bailing tests - Continued

Table 11.--Record of third bailing test - Continued

Time since bailing stopped (minutes)	Depth of water (feet)	Time since bailing stopped (minutes)	Depth to water (feet)
50	1,755.3	70	1,743.4
52	1,753.8	73	1,742.5
54	1,752.2	78	1,742.5
56	1,750.7	83	1,741.6
58	1,749.0	102	1,739.5
62	1,746.5	110	1,738.9
64	1,745.3	116	1,738.7
66	1,744.6	125	1,738.3
68	1,743.9	138	1,737.9