DOE/NV/11718--862

Nevada
Environmental
Restoration
Project

National Nuclear Security Administration

# Completion Report for Well Cluster ER-6-1

October 2004

Environmental Restoration
Division

U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office

DOE/NV/11718--862

# Completion Report for Well Cluster ER-6-1

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Prepared for:

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National Nuclear Security Administration
Nevada Site Office
Las Vegas, Nevada

October 2004

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DOE/NV/11718--862

# COMPLETION REPORT FOR WELL CLUSTER ER-6-1

Approved by: *Robert M. Bangerter Jr.* for  Date: *12/8/04*
William R. Wilborn, Acting Project Manager,
Underground Test Area Project

Approved by: *Robert M. Bangerter Jr.*  Date: *12/8/04*
Robert M. Bangerter, Acting Director,
Environmental Restoration Division

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**Completion Report for Well Cluster ER-6-1**
DOE/NV/11718--862

## ABSTRACT

Well Cluster ER-6-1 was constructed for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office in support of the Nevada Environmental Restoration Division at the Nevada Test Site, Nye County, Nevada. This work was initiated as part of the Groundwater Characterization Project, now known as the Underground Test Area Project. The well cluster is located in southeastern Yucca Flat.

The first borehole in the cluster, Well ER-6-1, was drilled in 1992. A 50.8-centimeter diameter surface hole was drilled, later reamed to 57.2 centimeters, and cased off to a depth of 547.1 meters below the surface. The hole diameter was then decreased to 31.1 centimeters to a depth of 639.2 meters. The borehole size was further decreased to 22.2 centimeters after coring to a depth of 648.9 meters. A string of 13d-inch casing was set to the depth of 547.1 meters, and a 7.3-centimeter piezometer string with one slotted interval was installed outside the casing. A preliminary composite, static water level was measured at the depth of 470.9 meters shortly after well completion. After a two-year hiatus Well ER-6-1 was deepened by conventional coring to a total depth of 977.3 meters using a 13.97-centimeter bit. In 1995, two temporary bridge plugs were placed in the well to restrict cross flow between two transmissive zones in the lower carbonate aquifer.

A second borehole, Well ER-6-1 Satellite Hole #1, was drilled 15.2 meters south of Well ER-6-1 in 1993. The 25.1-centimeter hole was drilled to the depth of 635.5 meters and a 7.3-centimeter piezometer was installed for measuring water levels.

The third borehole, Well ER-6-1#2, was drilled in 2002 to serve as a pumping well in a planned multi-well tracer experiment, in which the regional aquifer (lower carbonate aquifer) is the target unit. Well ER-6-1#2 is sited down-gradient from Well ER-6-1 and roughly parallel to the local fault/fracture trend. A 47.0-centimeter surface hole was drilled and cased off to a depth of 540.9 meters below the surface. The hole diameter was then decreased to 31.1 centimeters down to a total depth of 975.4 meters. A 6.0-centimeter piezometer string with one slotted interval was installed in the annulus of the surface casing. A preliminary composite water level of 471.2 meters was measured after completion of the well.

Detailed lithologic descriptions with stratigraphic assignments for Well Cluster ER-6-1 are included in this report. These are based on composite drill cuttings collected every 3 meters and conventional core samples taken below 639 meters, supplemented by geophysical log data. Detailed petrographic, chemical, and mineralogical studies of rock samples were conducted on 11 samples to resolve complex interrelationships between several of the Tertiary tuff units. Additionally, paleontological analyses by the U.S. Geological Survey confirmed the stratigraphic assignments below 539 meters within the Paleozoic sedimentary section. All three wells in the Well ER-6-1 cluster were drilled within the Quaternary and Tertiary alluvium section, the Tertiary volcanic section, and into the Paleozoic sedimentary section.

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## *List of Acronyms and Abbreviations*

| | |
|---|---|
| BGL | below ground level |
| BHA | bottom hole assembly |
| BN | Bechtel Nevada |
| C | centigrade |
| $CaCl_2$ | calcium chloride |
| cm | centimeter(s) |
| DOE | U.S. Department of Energy |
| DOE/NV | U.S. Department of Energy, Nevada Operations Office |
| DRI | Desert Research Institute |
| E | east |
| EC | electrical conductivity |
| F | Fahrenheit |
| FMP | Fluid Management Plan |
| ft | foot (feet) |
| gpm | gallons per minute |
| id | inside diameter |
| in. | inch(es) |
| IT | IT Corporation |
| km | kilometer(s) |
| LCA | lower carbonate aquifer |
| LANL | Los Alamos National Laboratory |
| LiBr | lithium bromide |
| LLNL | Lawrence Livermore National Laboratory |
| lpm | liters per minute |
| m | meter(s) |
| mi | mile(s) |
| MSI | Microstrat, Inc. |
| MSL | mean sea level |
| N | north |
| NAD | North American Datum |
| NNSA/NSO | National Nuclear Security Administration Nevada Site Office |
| NTS | Nevada Test Site |
| od | outside diameter |
| REECo | Reynolds Electrical & Engineering Co., Inc. |
| RSN | Raytheon Services Nevada |
| S | south |
| Shaw | Shaw Environmental, Incorporated |
| TCU | tuff confining unit |
| TD | total depth |
| TFM | Thermal Flow Meter |
| UGTA | Underground Test Area |
| UDI | United Drilling, Inc. |
| USGS | U.S. Geological Survey |
| W | west |

# 1.0 Introduction

## 1.1 Project Description

Well Cluster ER-6-1 was drilled for the U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Site Office (NNSA/NSO; formerly Nevada Operations Office [DOE/NV]) in support of the Nevada Environmental Restoration Project at the Nevada Test Site (NTS), Nye County, Nevada. Three wells were constructed as part of the hydrogeologic investigation well program for Yucca Flat. This program is part of the NNSA/NSO Environmental Restoration Division's Underground Test Area (UGTA) project at the NTS. The goals of the UGTA project include evaluating the nature and extent of contamination in groundwater because of underground nuclear testing, and establishing a long-term groundwater monitoring network. As part of the UGTA project, scientists are developing computer models to predict groundwater flow and contaminant migration within and near the NTS. To build and test these models, it is necessary to collect geologic, geophysical, and hydrologic data from new and existing wells to define groundwater migration pathways, migration rates, and quality.

The goal of constructing, sampling, and hydrologic testing at Well Cluster ER-6-1 is to collect subsurface geologic and hydrologic data that will help characterize the hydrogeology of southeastern Yucca Flat. Data from these wells will allow for more accurate modeling of groundwater flow and radionuclide migration in the region. This cluster is planned to be the site of a multi-well tracer test. One of the wells may also function as a long-term monitoring well. Well Cluster ER-6-1 is located in northeastern Area 6 of the NTS (Figure 1-1). The cluster consists of three boreholes drilled on the same pad (Figure 1-2). The elevation of the dirt-fill drill pad averages about 1,199.1 meters (m) (3,934 feet [ft]) above mean sea level (MSL). The Nevada State plane coordinates and elevation at the three wellheads are listed in Table 1-1, along with additional site summary and survey information.

IT Corporation (IT) and Shaw Environmental, Incorporated (Shaw [successor to IT; now replaced by Stoller-Navarro Joint Venture]) were the principal environmental contractors for the project, and their personnel collected geologic and hydrologic data during drilling. Reynolds Engineering and Electric Company (REECo) was the drilling contractor for the first two holes drilled, Wells ER-6-1 and ER-6-1 Satellite Hole #1, and Christensen Boyles was the coring subcontractor for Well ER-6-1. United Drilling, Incorporated (UDI), was the drilling subcontractor for Well ER-6-1#2. Site supervision, engineering, construction, inspection, and geologic support were provided by

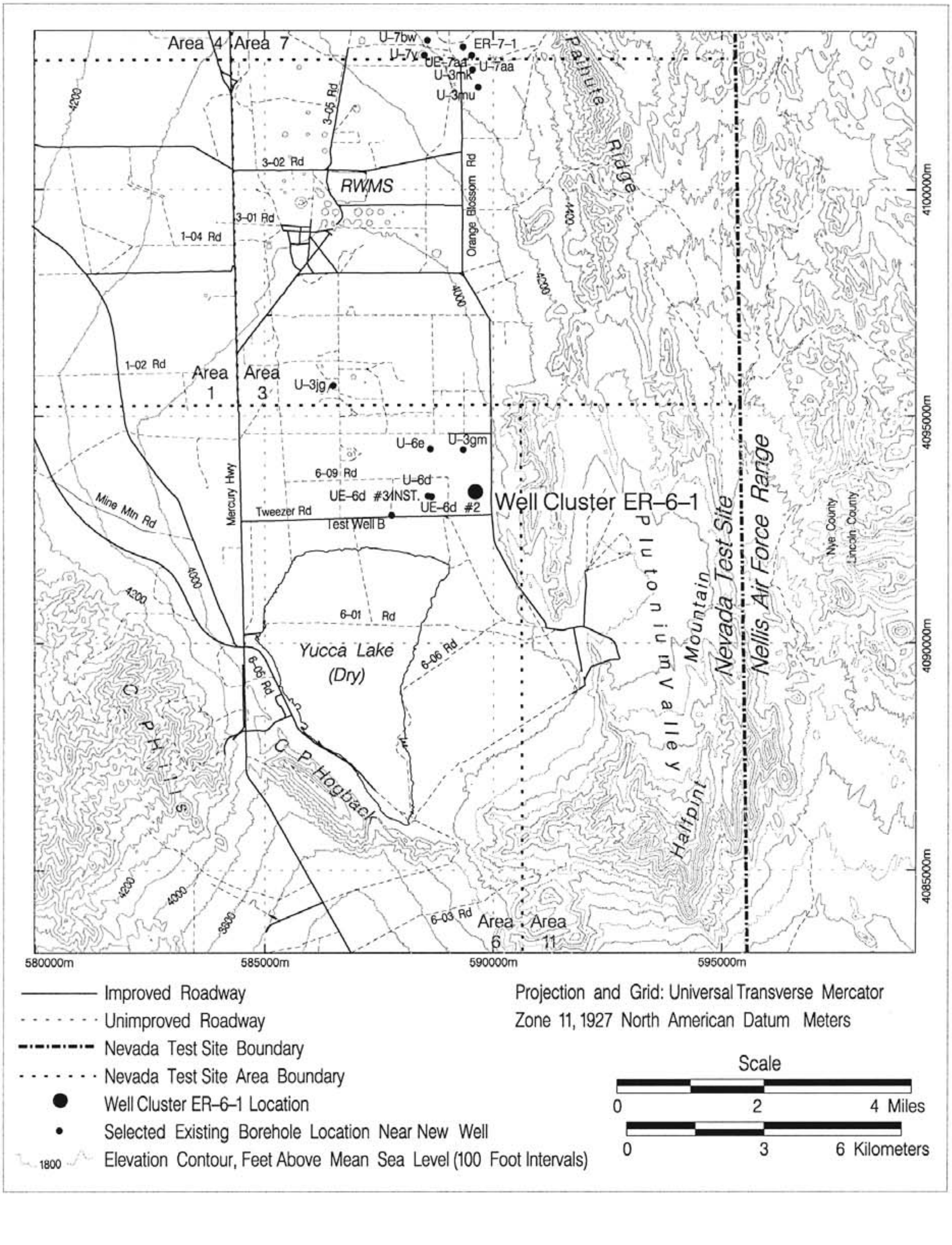


**Figure 1-1**
**Reference Map Showing Location of Well Cluster ER-6-1**

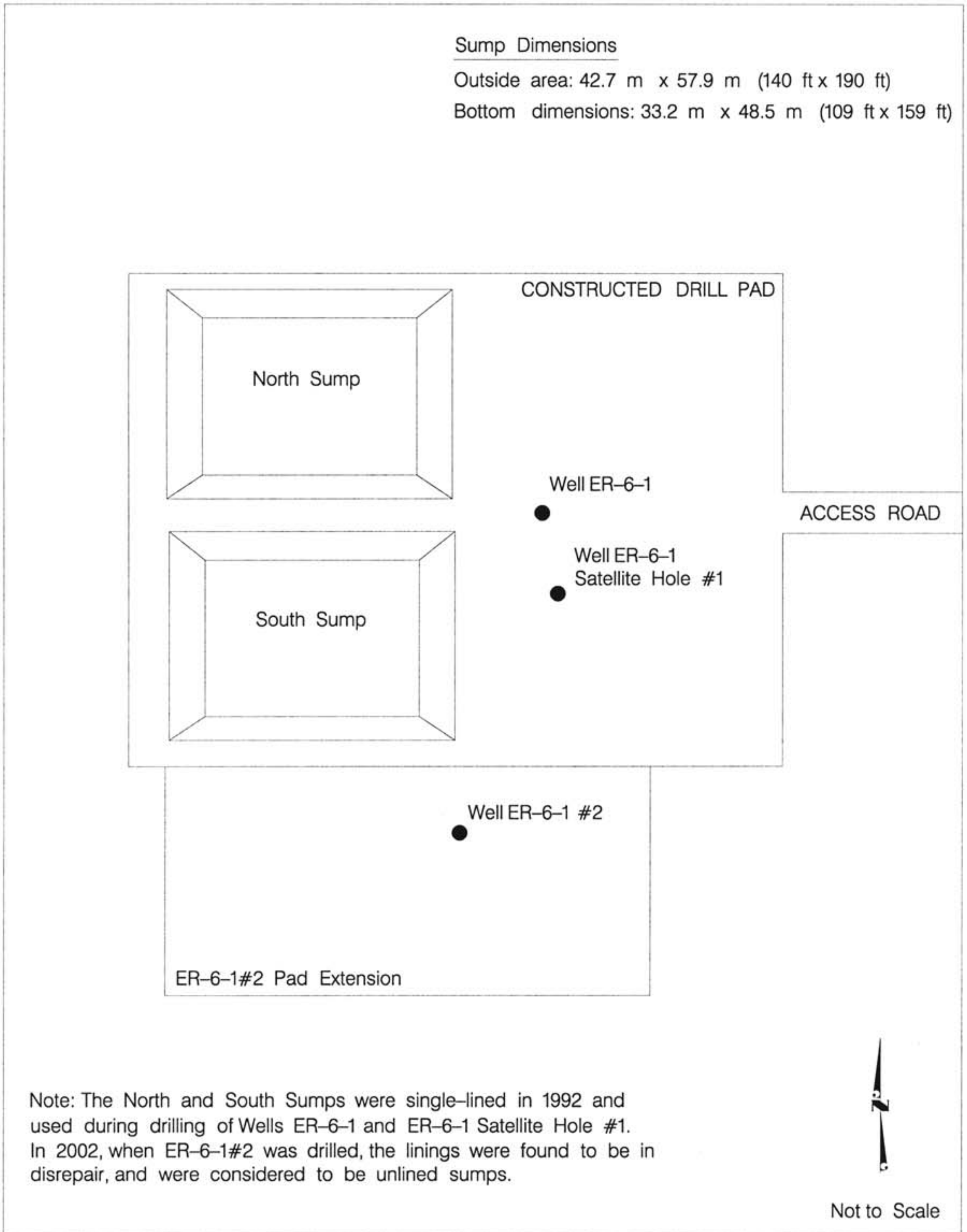


**Figure 1-2**
**Drill Site Configuration for Well Cluster ER-6-1**

**Table 1-1**
**Well Cluster ER-6-1 Site Data Summary**

| **Well Designation** (Date TD Reached) | | **ER-6-1** (October 16, 1994) | **ER-6-1Satellite #1** (July 9, 1993) | **ER-6-1#2** (October 4, 2002) |
|---|---|---|---|---|
| Site Coordinates [a] | Central Nevada State Planar (NAD 83) | N 6,248,108.3 m<br>E 559,906.0 m<br><br>N 20,499,002.1 ft<br>E 1,836,958.3 ft | N 6,248,093.4 m<br>E 559,909.0 m<br><br>N 20,498,953.0 ft<br>E 1,836,968.0 ft | N 6,248,046.4 m<br>E 559,889.4 m<br><br>N 20,498,799.0 ft<br>E 1,836,903.8 ft |
| | Central Nevada State Planar (NAD 27) (feet) | N 814,000.3 ft<br>E 696,799.3 ft | N 813,951.1 ft<br>E 696,809.0 ft | N 813,797.2 ft<br>E 696,744.8 ft |
| | Universal Transverse Mercator (Zone 11) (NAD 83) (meters) | N 4,093,615.0 m<br>E 589,553.7 m | N 4,093,600.1 m<br>E 589,556.7 m | N 4,093,553.1 m<br>E 589,537.3 m |
| Surface Elevation [b] | | 1,199.3 m (3,934.7 ft) | 1,199.2 m (3,934.5 ft) | 1,198.7 m (3,932.7 ft) |
| Drilled Depth | | 977.3 m (3,206.4 ft) | 635.5 m (2,085 ft) | 975.4 m (3,200 ft) |
| Fluid-Level Depth [c] | | 470.9 m (1,545 ft) | 470.9 m (1,545 ft) | 470.9 m (1,545 ft) |
| Fluid-Level Elevation | | 728.4 m (2,390 ft) | 728.4 m (2,390 ft) | 728.4 m (2,390 ft ) |

a Measurement made by BN Survey.
b Measurement made by BN Survey. Elevation at top of construction pad. 1929 National Geodetic Vertical Datum.
c Fluid level depth in Paleozoic rocks (open hole). The fluid level depth in the Tertiary volcanic rocks (piezometer) was 449.3 m (1,474 ft) on 06/07/1996.

Bechtel Nevada (BN; formerly Raytheon Services Nevada [RSN] and REECo). The roles and responsibilities of these and other contractors involved in the project are described in RSN Drilling Work Plan Numbers D-004-002, D-006-002, and D-007-005 (RSN, 1992, 1993a, 1994a), and in BN Drilling Work Plan Number D-009-002.02 (BN, 2002). The UGTA Technical Working Group, a committee of scientists and engineers comprising NNSA/NSO, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), and contractor personnel, provided additional technical advice during drilling, design, and construction of the wells. *Pre-drilling Hydrologic Summary for Characterization Well ER-6-1 (Southeast Yucca Flat)* (U.S. Geological Survey [USGS], 1992) provides the original criteria and objectives for the first of the three wells. The plans and objectives associated with deepening Well ER-6-1 are described in *Coring, Testing, Sampling and Completion Plan for Underground Test Area Operable Unit Well ER-6-1*, (IT, 1994). See *Yucca Flat Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 2002) for descriptions of the specific goals for Well ER-6-1#2; this document also provides the scientific objectives associated with the Yucca Flat CAU Phase I drilling initiative.

During the drilling and coring of Wells ER-6-1 and ER-6-1 Satellite Hole #1, the drilling effluent was monitored according to the methods prescribed in the drilling program (RSN, 1992) and later by the draft fluid management plan (DOE, 1993), which was being developed at the time. Fluids from Well ER-6-1#2 were managed according to the UGTA Fluid Management Plan (FMP) (DOE/NV, 1999), an attachment to the UGTA Waste Management Plan (DOE/NV, 1996). Estimates of expected fluid production and volume of drill cuttings for the first two holes are given in Appendix C of the drilling programs (RSN, 1992, 1993a). Estimates of production of drill fluid and cuttings from Well ER-6-1#2 are given in Appendix F of the drilling and completion criteria document for the Yucca Flat Hydrogeologic Investigation (IT, 2002), along with sampling requirements and contingency plans for management of any hazardous waste produced. All activities were conducted according to the Nevada Environmental Restoration Project Health and Safety Plans in effect at the time of drilling, and the Site-Specific Health and Safety Plans.

This report presents information on drilling and completion operations, and summarizes scientific data collected during construction of Wells ER-6-1, ER-6-1 Satellite Hole #1, and ER-6-1#2. Some of the information in this report is preliminary and unprocessed, but is being released with the drilling and completion data for convenient reference. Well data reports prepared by RSN (Drellack et al., 1992) and by IT (2003) contain additional information on fluid management, waste management, and environmental compliance. Preliminary information on well development, aquifer testing, and groundwater analytical sampling at the first two wells in the cluster were disseminated in Gillespie (1993), Lyles et al. (1995), IT (1996a), Rose et al. (1997), and IT (2000). Data obtained during any future hydrologic work conducted at the well cluster will be compiled and disseminated separately.

## *1.2 Objectives*

The primary purpose of constructing Well Cluster ER-6-1 was to provide hydrogeologic data to help characterize the lower carbonate aquifer (LCA) beneath southern Yucca Flat. The LCA is the primary aquifer through which groundwater flows from the basin beneath Yucca Flat. The primary scientific objectives for these wells, as discussed in their separate drilling criteria documents (USGS, 1992; IT, 1994; and IT, 2002), include the following:

Objectives of drilling Well ER-6-1 were to:

- Determine the hydraulic characteristics of the LCA.
- Measure, if possible, hydraulic characteristics of units above the LCA, specifically the tuff confining unit (TCU).

- Characterize the chemistry of groundwater in the aquifers penetrated.
- A secondary objective was to determine if the welded Topopah Spring Tuff bears perched water at this location.

Objectives of coring (deepening) Well ER-6-1 were to obtain:

- Subsurface geologic information to support development of hydrogeologic models of the LCA.
- Rock samples on which lithologic, petrophysical, and hydrologic laboratory tests could be performed to obtain quantitative data and qualitative information to enhance local and regional transport models.
- Data that can be used to interpret the frequency, orientation, and hydraulic properties of fractures as a function of structure, lithology, and stratigraphy.

Objectives of drilling Well ER-6-1 Satellite Hole #1 were to:

- Obtain additional hydraulic head data.
- Construct a multi-level observation well for full-scale aquifer tests.
- Construct a well into which tracer chemicals can be injected during possible future tests between the ER-6-1 wells.

Objectives of drilling Well ER-6-1#2 were to:

- Construct a pumping well for tracer experiment(s) planned for Well Cluster ER-6-1.
- Construct a multilevel observation well for full-scale aquifer tests.
- Obtain representative aqueous geochemistry samples from the LCA.
- Obtain additional fracture data for the LCA from geophysical logs.
- Obtain hydraulic properties of the hydrostratigraphic units penetrated to determine vertical and horizontal conductivity, and vertical hydraulic gradient.
- Address potential hydrologic "shortcuts" from shallow alluvial and volcanic aquifers to the underlying LCA via documented or inferred faults.

Some of these objectives will not be met until additional work, beyond the scope of this report, is completed, including installing pumps and conducting hydraulic tests (such as the planned multi-well tracer experiment), and analyzing geology and hydrology data from these and other wells in the Yucca Flat area.

### *1.3 Project Summary*

This section summarizes construction operations at Well Cluster ER-6-1; the details are provided in Sections 2.0 through 5.0 of this report.

### *1.3.1 Well ER-6-1*

The surface conductor hole was constructed by augering a 121.9-centimeter (cm) (48-inch [in.]) diameter hole to a depth of 36.6 m (120 ft) and installing a string of 30-in. casing. Drilling of the main hole with a 20-in. rotary bit, using an air-foam fluid in conventional circulation, began on June 30, 1992. A suite of geophysical logs was run when the hole had reached the depth of 554.4 m (1,819 ft), then the hole was opened to 57.2 cm (22.5 in.) in diameter. A string of 13**d**-in. casing was set at the depth of 547.1 m (1,794.8 ft), with a string of 2 **f**-in. slotted tubing attached to the outside of the casing to serve as piezometer. Drilling resumed with air-foam and a 12¼-in. bit to a depth of 639.2 m (2,097 ft), where rotary drilling was halted for coring operations. Two 10.2-cm (4-in.) diameter cores were cut and a temporary total depth (TD) of 648.9 m (2,129 ft) was reached on August 5, 1992.

Well ER-6-1 was deepened by conventional coring in 1994. A diamond core bit with a 5½-in. outside diameter (od) was used to core to a TD of 977.3 m (3,206.4 ft), then geophysical logging was completed in the lower part of the hole.

Composite drill cuttings were collected at 3-m (10-ft) intervals from the ground surface to 637.0 m (2,090 ft), and conventional core samples were taken from 637.0 to 977.3 m (2,090 to 3,206.4 ft). Open-hole geophysical logging of the well was conducted to help verify the geology and characterize the hydrology of the rocks; some logs also aided in the construction of the well by indicating borehole volume and condition, and cement location. The well penetrated Quaternary and Tertiary alluvium, Tertiary volcanic rocks, and Paleozoic-age sedimentary rocks.

The 2 **f**-in. piezometer string (attached to the outside of the 13**d**-in. surface casing) was landed at a depth of 545.5 m (1,794.8 ft). The piezometer string is slotted in the depth interval 450.8 to 460.2 m (1,479.0 to 1,510.0 ft) and provides access to the tuff confining unit. The piezometer string was gravel-packed across the slotted interval, and the remaining annular space was filled with sand and cement to the surface.

On August 20, 1992, a pump was placed in Well ER-6-1 at a depth of 542.0 m (1,778.1 ft), along with an open-ended 2 **f**-in. monitoring line which was landed at 535.4 m (1,756.6 ft), open to the carbonate rocks. Various aquifer tests were conducted in August and October 1992, and geochemical samples were obtained by LANL, LLNL, and Desert Research Institute (DRI) personnel after this phase of testing. No radionuclides above background levels were detected in the borehole. The pump and monitoring line were later removed. During the summer of 1995, two temporary bridge plugs were placed in the well to restrict cross-flow between two transmissive zones in the carbonate rocks.

The static water level in the Tertiary volcanic rocks was measured in the piezometer string in July 1992, at 449.3 m (1,474 ft) below ground level (BGL). Open-hole water-level measurements in September 1992, indicated a water level in the carbonate rocks of 470.9 m (1,545 ft) BGL. Both water levels were found to be unchanged when checked again in 1996.

### *1.3.2 Well ER-6-1 Satellite Hole #1*

The 91.4-cm (36-in.) conductor hole for ER-6-1 Satellite Hole #1 was auger-drilled and a string of 13d-in. casing set was at the depth of 36.2 m (118.6 ft) on July 2, 1993. Drilling of the main hole with a 9f-in. rotary bit and air-foam in conventional circulation began on July 7, 1993. Drilling proceeded quickly and smoothly, and the TD of 636.5 m (2,085 ft) was reached in the carbonate rocks, on July 9, 1993. The effort was made to clean out fill that accumulated in the hole, but the bottom of the hole remains plugged with fill to the depth of 618.1 m (2,028 ft). An access tube consisting of 2f-in. slotted tubing was installed within a sand-and-gravel-packed interval for measuring water levels within the LCA. The bull-nosed piezometer is slotted from 576.5 to 614.8 m (1,891.4 to 2,017.2 ft). No radionuclides were detected in the drill hole.

Composite drill cuttings were collected at 3-m (10-ft) intervals from the ground surface to TD. Limited open-hole geophysical logging of the hole was conducted. The well penetrated the same geological units as Well ER-6-1 within comparable depth intervals.

A static, open-hole fluid level was measured at 462.4 m (1,517 ft) BGL in July 1993. When the fluid level was measured again in 1996, it was found to be 470.9 m (1,545 ft) BGL, the same as measured in the carbonate rocks in nearby Well ER-6-1.

### *1.3.3 Well ER-6-1#2*

The surface conductor hole was constructed by augering a 91.4-cm (36-in.) diameter hole to a depth of 36.6 m (120 ft) and installing a string of 20-in. casing. Drilling of the main hole with an 18½-in. rotary bit, using air-foam in conventional circulation, began on September 24, 2002, and proceeded to a depth of 559.0 m (1,834 ft). The 13d-in. surface casing was set at the depth of 540.9 m (1,774.6 ft), and a string of 2d-in. carbon-steel, slotted tubing was landed at 483.6 m (1,586.6 ft) on September 30, 2002. Drilling resumed with an air-foam/polymer mix and a 12¼-in. bit to a TD of 975.4 m (3,200 ft), which was reached on October 4, 2002.

Composite drill cuttings were collected at 3-m (10-ft) intervals from 36.6 m (120 ft) to TD. Open-hole geophysical logging was completed before the rig was released. Well ER-6-1#2 penetrated the same geologic units as the other two boreholes in the cluster, within comparable depth intervals.

A static, open-hole fluid level was measured at 470.9 m (1,545 ft) BGL in December 2002, the same as measured in the carbonate rocks in the other two wells of the cluster.

## *1.4 Project Manager*

Inquiries concerning Well Cluster ER-6-1 should be directed to the UGTA Project Manager at:

U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office
Environmental Restoration Division
Post Office Box 98518
Las Vegas, Nevada 89193-8518

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# 2.0 Well ER-6-1

## 2.1 Well-Specific Objectives

The scientific objectives for Well ER-6-1 include those listed in Section 1.2. However, the specific goal of this first well in the cluster was to penetrate the LCA and to provide a long-term monitoring point for detecting radionuclides in this aquifer produced by nuclear-testing. The well was planned to reach TD in the LCA.

## 2.2 Drilling Summary

This section contains detailed descriptions of the drilling process and fluid management issues.

### 2.2.1 Introduction

The general drilling requirements for Well ER-6-1 were provided in USGS (1992), and the specific requirements were outlined in Drilling Program Number D-004-002 (RSN, 1992). Changes to these criteria were documented in RSN Records of Verbal Communication (Appendix A-1). Figure 1-2 shows the layout of the drill site. A summary of drilling statistics for the well is given in Table 2-1, and Figure 2-1 is a chart of the drilling and completion history for Well ER-6-1. The following information was compiled primarily from RSN daily drilling reports.

### 2.2.2 Drilling History

Field operations at Well ER-6-1 began on June 10, 1992, when a REECo crew began dry-augering a 121.9-cm (48-in.) diameter conductor hole. The conductor hole was drilled to a depth of 36.6 m (120 ft), and a string of 30-in. conductor casing was set at 35.7 m (117 ft). The bottom of the casing was cemented into place with neat Type II cement, and the annulus of the conductor casing was cemented to ground level. The “rat-hole” and the “mouse-hole” were drilled before the Cardwell 500 drilling rig was moved on-site.

The REECo crew rigged up the Cardwell 500 rig on June 22 to 29, 1992, and tagged cement at the depth of 32.9 m (108 ft). Drilling resumed with a center-punch assembly with a 20-in. rotary bit, to the bottom of the surface hole at 544.4 m (1,819 ft), then the borehole was enlarged to 57.2 cm (22.5 in.) diameter using a hole opener. The “Davis mix” drilling fluid, used in conventional circulation, consisted of air, water, and foam with a bentonite additive (see Appendix A-4). There were no significant drilling or reaming problems, circulation was never lost, and the borehole

## Table 2-1
## Abridged Drill Hole Statistics for Well ER-6-1

**LOCATION DATA:**

Coordinates:

| | | | |
|---|---|---|---|
| Central Nevada State Planar (central zone): | (NAD 27): | N 814,000.3 ft | E 696,799.3 ft |
| | (NAD 83): | N 6,248,108.3 m | E 559,906.0 m |
| Universal Transverse Mercator: | (NAD 83): | N 4,093,615.0 m | E 589,553.7 m |

Ground Elevation [a]: 1,199.3 m (3,934.7 ft)

**DRILLING DATA:**

| | Drill hole | Core hole |
|---|---|---|
| Spud Date: | 06/10/1992 | 08/17/1994 |
| Total Depth (TD): | 648.9 m (2,129 ft) | 977.3 m (3,206.4 ft) |
| Date TD Reached: | 08/05/1992 | 10/16/1994 |
| Date Well Completed: | 09/04/1992 | 11/01/1994 |

Hole Diameter: 218.4-centimeter (cm) (86-inch [in.]) hole to 5.2 m (17 ft); 121.9-cm (48-in.) hole to 36.6 m (120 ft); 57.2-cm (22.5-in.) hole to 544.4 m (1,819 ft); 31.3-cm (12¼-in.) hole to 639.2 m (2,097 ft); 22.2-cm (8¾-in.) core hole to 648.9 m (2,129 ft); 14.0-cm (5½-in.) core hole to the final TD of 977.3 m (3,206.4 ft).

Drilling Techniques: Dry auger drilling from surface to 36.6 m (120 ft). Rotary drilling with 20-in. bit to 544.4 m (1,819 ft) using air-foam with bentonite additive ("Davis mix") in conventional circulation. Reaming with a 22.5-in.-diameter hole opener and Davis mix in conventional circulation to 554.4 m (1,819 ft). Rotary drilling with 12¼-in. bit from 544.5 to 639.2 m (1,819 to 2,097 ft) using air-foam in conventional circulation. Conventional coring from 639.2 m (2,097 ft) to the interim TD of 648.9 m (2,129 ft) using an 8¾-in. outside-diameter (od) by 4-in. inside-diameter (id) diamond core bit, air-foam, and normal circulation. Continuous coring from 648.9 m (2,129 ft) to the final TD of 977.3 m (3,206.4 ft) using a 5½-.in od diamond core bit with polymer mud and normal circulation.

**CASING DATA:** 30-in. conductor casing from surface to 35.7 m (117 ft); 13**d**-in surface casing to 547.1 m (1,794.9 ft).

**WELL COMPLETION DATA:**

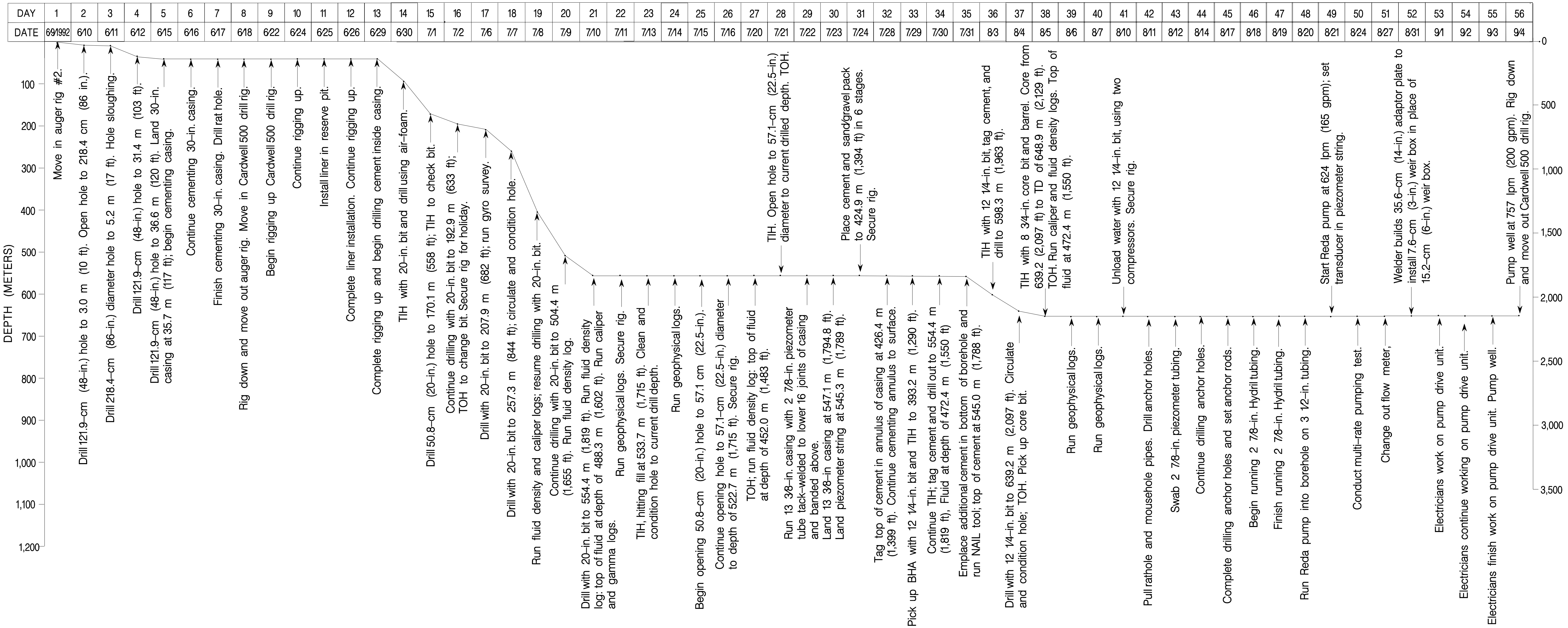
Piezometer tube consisting of 2 **f** -in. tubing tack-welded to the outside of 13**d**-in casing from surface to 545.5 m (1,789.8 ft)

| | Piezometer String |
|---|---|
| Total Depth: | 545.5 m (1,789.8 ft) |
| Depth of Slotted Section: | 450.8 - 460.2 m (1,479.0 - 1,510.0 ft) |
| Depth of 20/40 sand: | 437.4 - 444.4 m (1,435 - 1,458 ft) |
| Depth of 6 - 9 Colorado silica sand: | 444.4 - 448.1 m (1,458 - 1,470 ft) |
| Depth of Gravel Pack: | 448.1 - 470.0 m (1,470 - 1,542 ft) |
| Fluid Depth [b]: | 470.9 m (1,545 ft) |

Temporary bridge plugs were set at 683.7 to 684.0 m (2,243 to 2,244 ft) and 746.8 to 747.1 m (2,450 to 2,451 ft).

| | |
|---|---|
| **DRILLING CONTRACTOR:** | Reynolds Electrical & Engineering Company |
| **CORING CONTRACTOR:** | Christensen Boyles Corporation |
| **GEOPHYSICAL LOGS BY:** | Atlas Wireline Services, Schlumberger, Lawrence Livermore National Laboratory, U.S. Geological Survey, and Westech Engineering |
| **SURVEYING CONTRACTOR:** | Bechtel Nevada |

a Elevation of construction pad at wellhead. 1929 National Geodetic Vertical Datum.
b Fluid level for Paleozoic rocks, measured in the open borehole (RSN, 1992).




## Well ER-6-1 Summary

| | |
|---|---|
| Begin drilling conductor hole: | 06/10/1992 |
| Complete and case conductor hole: | 06/17/1992 |
| Begin drilling 20-in. surface hole: | 06/30/1992 |
| Reach total drilled depth of 648.9 m (2,129 ft): | 08/05/1992 |
| Well completed: | 08/21/1992 |
| Begin pumping test: | 08/21/1992 |
| Complete pumping test: | 09/04/1992 |

LEGEND

| | |
|---|---|
| BHA | Bottom hole assembly |
| cm | centimeter(s) |
| ft | foot (feet) |
| in. | inch(es) |
| m | meter(s) |
| NAIL | Nuclear Annulus Investigation Log |
| TD | Total depth |
| TIH | Trip into hole |
| TOH | Trip out of hole |

FIGURE 2-1
WELL ER-6-1
DRILLING AND COMPLETION HISTORY
SHEET 1 OF 1

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remained in fairly good condition, except for sloughing of the borehole wall during drilling in the argillized older tuffs and the paleocolluvium. See Section 2.2.4 for more details on drilling problems.

A 13d-in. surface casing (with a piezometer string attached; see Section 2.7.2) was set at 547.1 m (1,794.8 ft) on July 23, 1992, after a suite of geophysical logs was run. The original plan for setting the surface casing was based on a requirement to isolate the Topopah Spring Tuff (166.1 to 237.1 m [545 to 778 ft]), potentially a perched aquifer, if it were saturated at this location. However, water was not detected until the underlying tuff confining unit was penetrated, so it was determined to be unnecessary to isolate the Topopah Spring Tuff. The surface casing was landed in the dolomite, sealing off the entire tuff section except where the piezometer is open to the tuff confining unit (Section 2.7.2).

The cementing of the surface casing was completed in 9 stages by pumping a total of 85.1 cubic meters (3,004 cubic feet) of cement, sand and gravel into the annulus through 2 f-in. tubing. The annulus was cemented to the ground surface.

The next several days were spent rigging up for air drilling, preparing the 12¼-in. bit and bottom-hole assembly (BHA), and drilling cement. The crew tagged the top of cement inside the surface casing at 546.8 m (1,794 ft) and began to drill out from under the casing with air-foam on August 3, 1992. Drilling then continued through cement and into the formation to a depth of 639.2 m (2,097 ft).

The drillers circulated, conditioned, and de-watered the hole, then removed the rotary BHA in preparation for coring operations. Two 10.2-cm (4-in.) diameter cores were cut from 639.2 to 648.9 m (2,097 to 2,129 ft) with an 8¾-in. od diamond core bit (see Section 2.3.3 for a discussion of the coring results). The temporary TD of 648.9 m (2,129 ft) was reached on August 5, 1992, and the drillers withdrew the drill string to prepare for geophysical logging.

### *2.2.3 Coring History*

After a two-year hiatus in drilling activities at Well ER-6-1, Christensen Boyles Corporation moved in the CP-50 core rig on August 1, 1994, and started rigging up to deepen the hole by coring. Several days were spent mixing mud, working on mud pumps, pumping polymer mud down-hole, and cleaning out fill. Coring began on August 17, 1994, following the installation of a 6e-in. flush-joint temporary casing set from the surface to the original TD of 648.9 m (2,129 ft). A 5c-in. core bit was used to core to the depth of 659.9 m (2,165 ft), then the hole was reamed with a 5½-in. bit.

Coring continued with a 5½-in. core bit to a TD of 977.3 m (3,206.4 ft) which was reached on October 16, 1994. On October 23, 1994, fill was tagged in the borehole at 972.9 m (3,192 ft). See Figure 2-2 for a graphical presentation of the coring history for Well ER-6-1.

### *2.2.4 Borehole Deviation Surveys*

Borehole deviation surveys were run periodically during drilling to monitor plumbness. The maximum deviation measured was slightly over 0.5 degree from vertical, to the depth of 542.8 m (1,781 ft), which indicates that the hole remained fairly straight and vertical during drilling of the upper part of the hole. A complete gyroscopic survey made on October 22, 1994, showed that at the lowest surveyed depth of 971.4 m (3,187 ft), the hole had drifted 2.8 m (9.1 ft) to the south and 1.5 m (5.0 ft) to the east of the collar location.

### *2.2.5 Drilling and Coring Problems*

The primary problem encountered during the drilling of the upper part of Well ER-6-1 was sloughing of material from the borehole wall. Borehole sloughing from an argillized zone near the base of the Tertiary volcanic rocks and from the contact between the Tertiary and Paleozoic rocks caused some operational problems (Drellack et al., 1992). Fill was repeatedly encountered on drilling breaks between the depths of 533.7 and 539.8 m (1,751 and 1,771 ft). Because of these hole instability problems, geophysical logs were run only to the top of the fill, and thus the bottom 21.3 m (70 ft) was not logged at that time.

Coring activities during deepening of Well ER-6-1 in 1994 were hindered by problems with junk in the hole and with parted casing. After a problem with a mismatched core bit/core barrel assembly was corrected, a coring tube became stuck down-hole, which resulted in most of the ten segments of the core bit being lost in the hole. Attempts were made to drill past the junk, but with no success. A mill-tooth bit had to be brought in from off site to mill through the junk to a depth of 662.0 m (2,172 ft) before coring operations resumed.

On September 6, 1994, it was discovered that the 6e-in. flush-joint temporary casing installed before coring began had parted in several places. Fishing operations over the next several days were successful in retrieving the casing. The crew installed a new string of 6e-in. flush-joint temporary

WELL ER–6–1 COREHOLE SUMMARY

| Activity | Date |
|---|---|
| Begin coring: | 08/17/1994 |
| Reach total cored depth of 977.3 m (3,206.4 ft): | 10/16/1994 |
| Rig off location: | 11/01/1994 |

LEGEND

| | |
|---|---|
| AWS | Atlas Wireline Service |
| BHA | Bottom hole assembly |
| cm | centimeter(s) |
| ft | foot (feet) |
| in. | inch(es) |
| m | meter(s) |
| od | outside diameter |
| REECo | Reynold's Electrical and Engineering Corporation |
| TD | Total depth |
| TIH | Trip into hole |
| TOH | Trip out of hole |

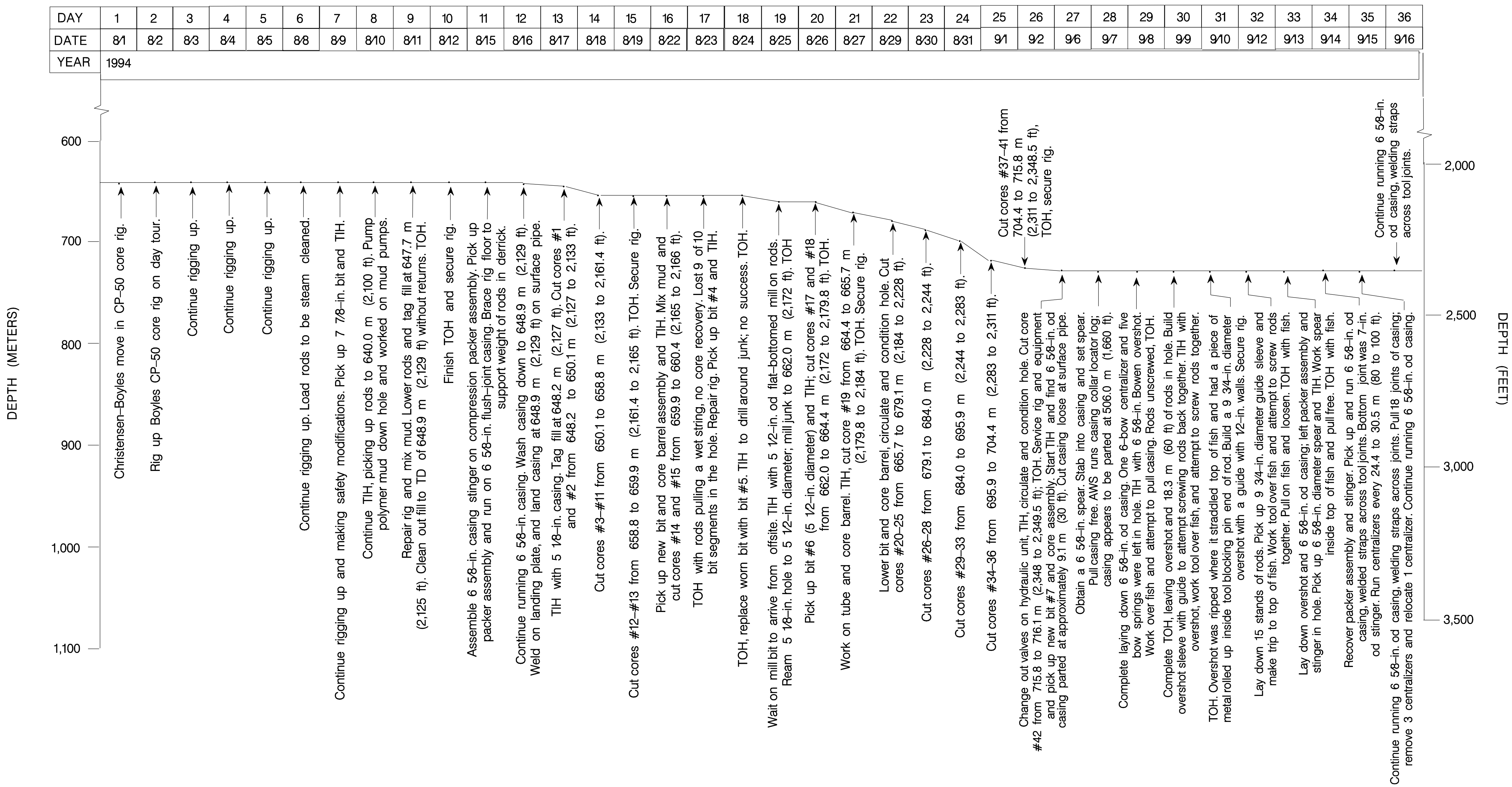



FIGURE 2–2
WELL ER–6–1 COREHOLE
DRILLING AND COMPLETION
HISTORY
SHEET 1 OF 2

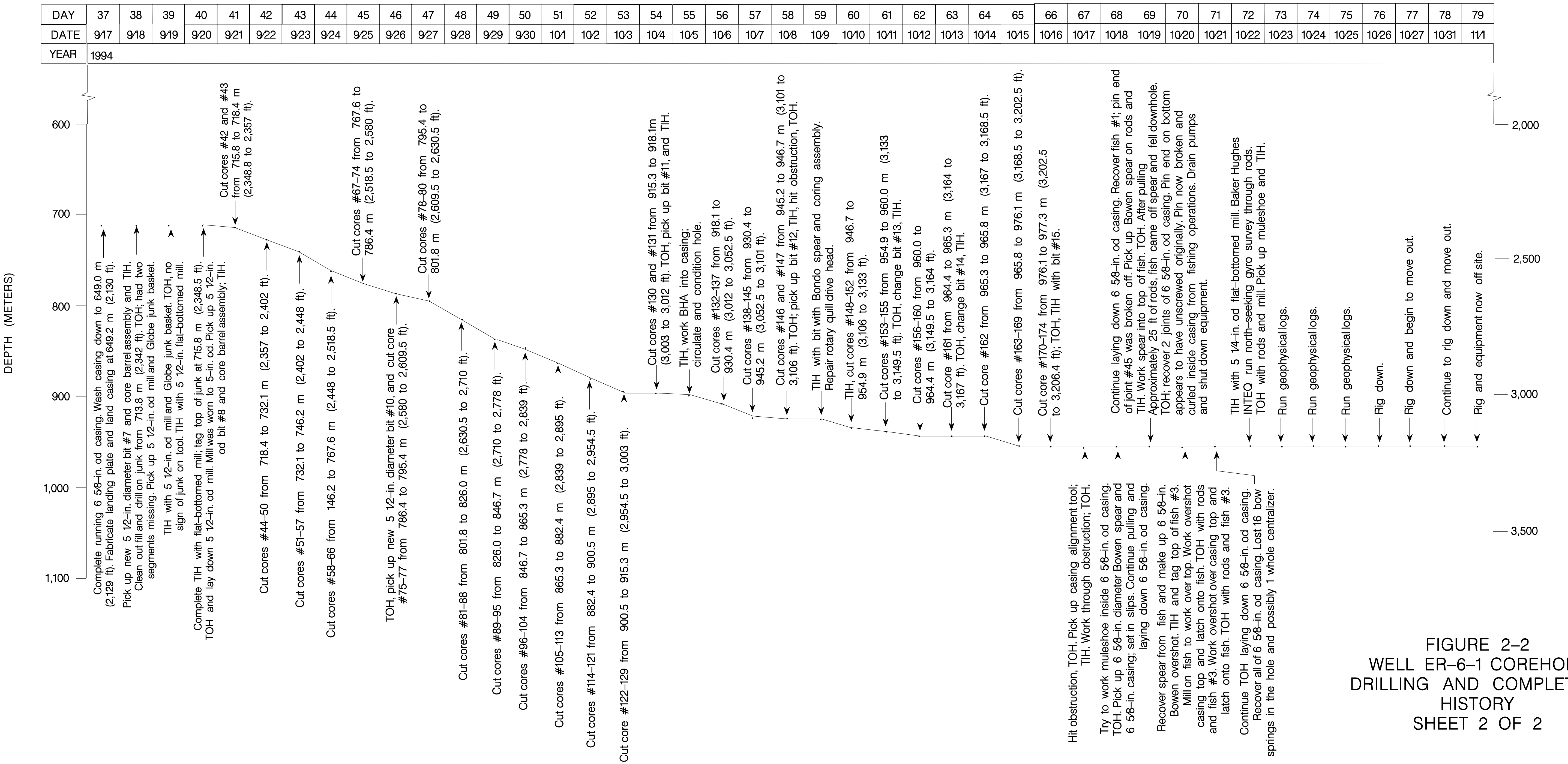



FIGURE 2-2
WELL ER-6-1 COREHOLE
DRILLING AND COMPLETION
HISTORY
SHEET 2 OF 2

casing with straps welded across the joints of the casing in an effort to prevent recurrence of this problem. A 5½-in. flat-bottom mill-tooth bit was then used to grind out junk to 716.6 m (2,351 ft).

Coring resumed on September 20, 1994, and continued to the depth of 977.3 m (3,206.4 ft). While tripping into the hole after a bit change, an obstruction was encountered, and it was discovered that the 6e-in. flush-joint temporary casing had again parted in several places. Fishing attempts over the next several days were successful in retrieving most of the casing; however, 16 bowsprings and a centralizer were lost down hole. A 5¼-in. flat-bottom mill bit was used to push the junk down hole to 973.8 m (3,195 ft) so that a gyro survey and geophysical logs could be run. Because of these problems the hole was terminated 89.5 m (293.6 ft) short of the originally planned cored depth of 1,066.8 m (3,500 ft).

### 2.2.6 Fluid Management

The drilling effluent was monitored according to the methods prescribed in the draft *Fluid Management Plan for the Underground Test Area Operable Unit* (DOE, 1993) and the *Coring, Testing, Sampling and Completion Plan for UGTA Well ER- 6-1* (IT, 1994). The hole was drilled using air-foam (water and detergent) and “Davis Mix,” with applications of polymer as needed. Bentonite and sepiolite muds were used during reaming of the hole, and the coring operation was conducted using a polymer mud. Water used to mix drilling fluids came from Water Well 5B, and lithium bromide (LiBr) was added to the drill fluid as a tracer for future development and testing. See Appendix A-4 for more information on the composition of drilling fluids.

To manage the anticipated water production, two single-lined sumps were constructed prior to drilling (Figure 1-2). The results of analyses on samples of drilling fluid collected indicated that all fluids were within the fluid quality objectives established for radiochemical parameters in the Fluid Management Plan. No fluid management reporting form was produced for activities at Well ER-6-1.

## 2.3 Geologic Data Collection

### 2.3.1 Introduction

This section describes the sources of geologic data obtained from Well ER- 6-1 and the methods of data collection. The primary objective of constructing Well ER- 6-1 was to improve the understanding of the sedimentary rocks of the regional aquifer (LCA) and the overlying volcanic confining units in this part of Yucca Flat, so the proper collection of geologic and hydrogeologic data from Well ER-6-1 was considered fundamental to successful completion of the project.

Geologic data collected at Well ER-6-1 consist of drill cuttings, conventional core samples, and geophysical logs. No sidewall samples were taken from this well. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures.

### *2.3.2 Collection of Drill Cuttings*

Triplicate sets of composite drill cuttings were collected continuously at 3-m (10-ft) intervals from the ground surface to TD (RSN, 1992). No cuttings were collected from the interval 639.2 to 648.9 m (2,097 to 2,129 ft) where bottom-hole cores were taken (see Section 2.3.3). Additional samples were collected at 15.2-m (50-ft) intervals through the Paleozoic section from 548.6 m (1,800 ft) to the original TD of 648.9 m (2,129 ft) for paleontologic studies. These paleontologic studies were completed by Microstrat, Inc. (MSI), of Houston, Texas. No cuttings were collected during coring in 1994. All samples collected, except for the paleontologic samples, are stored under environmentally controlled, secure conditions at the USGS Geological Data Center and Core Library in Mercury, Nevada. One of each set of cuttings samples was sealed with custody tape at the rig site as an archive sample; one set was left unsealed in the original sample containers; and the third was washed and stored according to standard Core Library procedures.

### *2.3.3 Conventional Coring*

The drilling criteria called for recovery of 9.1 m (30 ft) of conventional core from the lowest section of Well ER-6-1, within the carbonate rocks. Two bottom-hole cores were taken from the interval at 639.2 to 648.9 m (2,097 to 2,129 ft) in August 1992. Because of the fractured formation and/or perhaps failure of the core catcher to grab the hard dolomite core, only 0.46 m (1.5 ft) of rubble was recovered from core run #1. Core run #2 recovered 3.4 m (11 ft) of fractured dolomite. Analysis of the core provided data on the age of the carbonate rocks (MSI, 1993) and details about the fractures (IT, 1996a).

When Well ER-6-1 was deepened by means of conventional coring in August-September 1994, it was planned to obtain 8.4-cm (3.3-in.) diameter core from the original TD of 648.9 m (2,129 ft) to depth of approximately 1,066.8 m (3,500 ft). However, drilling was terminated at the depth of 977.3 m (3,206.4 ft) because of operational problems (Section 2.2.5). A total of 325.0 m (1,066 ft) of core was recovered out of 328.3 m (1,077 ft) drilled. The core samples are stored under secure, environmentally controlled conditions at the USGS Geological Data Center and Core Library in Mercury, Nevada. Core recovery information is presented in Table 2-2.

**Table 2-2**
**Summary of Conventional Cores Taken from Well ER-6-1**

| **Core Number** | **Cored Interval** meters (feet) | **Core Cut** meters (feet) | **Core Recovered** meters (feet) | **Stratigraphic Unit** | **Hydrogeologic Unit** [a] |
|---|---|---|---|---|---|
| 1 (August 1992) | 639.2-644.0 (2,097-2,113) | 4.9 (16) | 0.46 (1.5) | Sevy Dolomite [b] | Lower Carbonate Aquifer |
| 2 (August 1992) | 644.0-648.9 (2,113-2,129) | 4.9 (16) | 3.4 (11) | | |
| 1-26 (August 1994) | 648.9-680.9 (2,129-2,234) | 32.0 (105) | 30.8 (101) | Sevy Dolomite | |
| 27-117 (September 1994) | 680.9-890.8 (2,234-2,923) | 209.9 (689) | 208.5 (684) | Laketown Dolomite | |
| 118-142 (September 1994) | 890.8-940.8 (2,923-3,087) | 50.0 (164) | 49.4 (162) | Ely Springs Formation | |
| 143-174 (September 1994) | 940.8-977.3 (3,087-3,206) | 36.3 (119) | 36.3 (119) | Eureka Quartzite | |

a Modified from Winograd and Thordarson, 1975.

b Stratigraphic nomenclature from Cole, 1996.

### 2.3.4 Geophysical Data

Geophysical logs were run in the borehole to further characterize the lithology, structure, and water content of the rocks encountered. In addition, logs were run to evaluate borehole conditions, to determine the fluid levels during the course of drilling, and to monitor completion progress. Geophysical logging was conducted in three stages. Some logs were run in both the saturated and unsaturated sections of the borehole, while others (e.g., spinner flow meter, water-flow log, etc.) were run only in the saturated interval.

The overall quality of the geophysical data collected was good. However, sloughing at the base of the Tertiary volcanic section and the subsequent accumulation of fill in the borehole prevented the logging of the Tertiary/Paleozoic contact below the depth of 538.0 m (1,765 ft). When this phase of logging was completed, the hole was cleaned out to the temporary TD of 554.4 m (1,819 ft) and casing was set at 547.1 m (1,794.8 ft). Consequently, no logs were ever obtained in the interval 533.4 to 547.1 m (1,750 to 1,795 ft).

A complete listing of the logs, dates run, depths, and service companies is provided in Table 2-3. The logs are available from BN in Mercury, Nevada, and copies are on file at the office of Stoller-Navarro Joint Venture (successor to IT and Shaw) in Las Vegas, Nevada.

## 2.4 Hydrology of Well ER-6-1

Well ER-6-1 is located in southeastern Yucca Flat within NTS Area 6. Water-level data from the Tertiary and Paleozoic aquifers are sparse in this part of Yucca Flat, so collection of water-level data at this location has enhanced the current understanding of regional groundwater flow at the NTS.

### 2.4.1 Preliminary Water-Level Information

The elevation of the water table within the Tertiary volcanic rocks at Well ER-6-1 was projected to be approximately 752.9 m (2,470 ft) MSL, based on regional hydrologic data (USGS, 1992). Based on the pre-construction estimate of surface elevation at the site, depth to water was expected at approximately 448.1 m (1,470 ft) BGL.

The static water level in the Tertiary volcanic rocks was determined after installation of the piezometer tube in the well. See Section 2.7.2 for a discussion of this completion. On July 21, 1992, the fluid level in the piezometer tubing was at 449.3 m (1,474 ft) BGL, or 751.6 m (2,466 ft) MSL. This level was found to be unchanged when checked again on June 7, 1996.

## Table 2-3
## Well ER-6-1 Geophysical Log Summary
(Page 1 of 3)

| Geophysical Logs | Log Purpose | Logging Service | Date Logged | Run Number | Top of Logged Interval (BGL) [a] meters (feet) | Bottom of Logged Interval (BGL) meters (feet) |
|---|---|---|---|---|---|---|
| Acoustic Borehole Compensated/ Gamma Ray | Stratigraphic correlation | AWS [b] | 08/06/1992 | AC-1/GR-9 | 527.3 (1,730) | 642.5 (2,108) |
| Annulus Investigation Log | Omnidirectional density (check for cement and/or fluid location) | AWS | 07/24/1992<br>07/24/1992<br><br>07/28/1992<br>07/31/1992 | AIN-1<br>AIN-2<br>AIN-3<br>AIN-4-7<br>AIN-8 | 391.7 (1,285)<br>60.4 (198)<br>392.6 (1,288)<br>1.8 (6)<br>425.2 (1,395) | 544.4 (1,786)<br>544.4 (1,786)<br>479.5 (1,573)<br>456.6 (1,498)<br>545.6 (1,790) |
| Borehole Televiewer | Borehole examination/ stratigraphic correlation, fracture data | Wellenco [c] | 10/23/1994 | BHTV-1 | 650.4 (2,134) | 972.0 (3,189) |
| 6-arm Caliper/Gamma Ray | Borehole conditions/ stratigraphic correlation | AWS | 07/08/1992<br>07/10/1992<br>07/14/1992<br>08/05/1992<br>10/23/1994 | CA6-1/GR-1<br>CA6-2/GR-2<br>CA6-3/GR-4<br>CA6-4/GR-7<br>CA6-5/GR-12 | 11.0 (36)<br>11.0 (36)<br>457.8 (1,502)<br>526.7 (1,728)<br>634.0 (2,080) | 253.3 (831)<br>533.4 (1,750)<br>531.6 (1,744)<br>645.6 (2,118)<br>972.0 (3,189) |
| Compensated Density/ Gamma Ray | Lithologic determination/ stratigraphic correlation | AWS | 07/14/1992 | CDL-1/GR-5 | 21.3 (70) | 531.0 (1,742) |
| Compensated Density/ Compensated Neutron/ Gamma Ray | Lithologic determination/ stratigraphic correlation, alteration | HES [d] | 10/25/1994 | CDL-3/CN-2/ GR-14 | 649.8 (2,132) | 969.9 (3,182) |
| Compensated Z-Density/ Compensated Neutron/ Gamma Ray | Porosity and lithologic determination/ stratigraphic correlation | AWS | 08/06/1992 | ZDL-2/CN-1/ GR-8 | 531.6 (1,744) | 644.7 (2,115) |
| Directional Gyroscope | Borehole deviation | BHI [e] | 07/27/1993<br>10/22/1994 | DRG-1<br>DRG-2 | 526.7 (1,728)<br>0 (0) | 645.6 (2,118)<br>971.4 (3,187) |
| Downhole Video | Borehole examination for fractures, lithology, and fluid flow | Westech | 07/11/1992 | TV-1 | 91.4 (300) | 460.2 (1,510) |

# Table 2-3
## Well ER-6-1 Geophysical Log Summary
(Page 2 of 3)

| Geophysical Logs | Log Purpose | Logging Service | Date Logged | Run Number | Top of Logged Interval (BGL) [a] meters (feet) | Bottom of Logged Interval (BGL) meters (feet) |
|---|---|---|---|---|---|---|
| Dual Induction Focused Log/Gamma Ray | Rock porosity/ stratigraphic correlation | AWS | 07/13/1992 | DIFL-1/GR-3 | 28.7 (94) | 536.8 (1,761) |
| Dual Laterolog/Gamma Ray | Lithology/stratigraphic correlation | AWS | 08/07/1992<br>10/23/1994 | DLL-1/GR-11<br>DLL-2/GR-13 | 515.7 (1,692)<br>650.4 (2,134) | 648.0 (2,126)<br>972.9 (3,192) |
| Downhole Video | Borehole examination for fractures, lithology, and fluid flow | Westech | 07/11/1992 | TV-1 | 91.4 (300) | 460.2 (1,510) |
| Dual Induction Focused Log/Gamma Ray | Rock porosity/ stratigraphic correlation | AWS | 07/13/1992 | DIFL-1/GR-3 | 28.7 (94) | 536.8 (1,761) |
| Dual Laterolog/Gamma Ray | Lithology/stratigraphic correlation | AWS | 08/07/1992<br>10/23/1994 | DLL-1/GR-11<br>DLL-2/GR-13 | 515.7 (1,692)<br>650.4 (2,134) | 648.0 (2,126)<br>972.9 (3,192) |
| Epithermal Neutron Porosity/Gamma Ray | Total water content/ stratigraphic correlation, alteration | AWS | 07/14/1992 | ENP-1/GR-6 | 20.7 (68) | 532.8 (1,748) |
| Fluid Density | Depth to water in borehole | AWS | 07/30/1992<br>07/31/1992<br>08/01/1994 | DF-6<br>DF-7<br>DF-8 | 458.1 (1,503)<br>457.5 (1,501)<br>454.5 (1,491) | 487.7 (1,600)<br>474.3 (1,556)<br>483.1 (1,585) |
| Formation Microscanner | Fracture characterization | SWS [f] | 08/06/1992 | FMS-1 | 547.1 (1,795) | 648.0 (2,126) |
| Fraclog/Gamma Ray | Fracture identification | AWS | 08/05/1992 | FRAC-1/GR-10 | 468.5 (1,537) | 641.6 (2,105) |
| Heat Pulse Flow Meter | Determine rate/direction of groundwater flow within the borehole | GEG/JTO [g] | 08/29/1995<br>09/12/1995 | HPFlow-1<br>HPFlow-2 | 682.8 (2,240)<br>670.6 (2,200) | 960.1 (3,150)<br>743.7 (2,440) |
| Magnetic Susceptibility | Identify mafic-rich volcanic stratigraphy | USGS[h] | 07/11/1992 | MGS-1 | 35.7 (117) | 534.9 (1,755) |
| Seismic Airgun | Lithologic determination | AWS | 08/07/1992 | SGG-1 | 91.4 (300) | 645.6 (2,118) |

**Table 2-3**
**Well ER-6-1 Geophysical Log Summary**
(Page 3 of 3)

| Geophysical Logs | Log Purpose | Logging Service | Date Logged | Run Number | Top of Logged Interval (BGL) [a] meters (feet) | Bottom of Logged Interval (BGL) meters (feet) |
|---|---|---|---|---|---|---|
| Spectral Gamma Ray | Stratigraphic correlation, alteration | AWS | 07/15/1992<br>08/06/1992 | SGR-1<br>SGR-2 | 30.2 (99)<br>527.3 (1,730) | 532.8 (1,748)<br>637.6 (2,092) |
| Spinner Flow Meter | Determine fluid flow | SWS | 10/13/1992 | SPINR-1 | 548.0 (1,798) | 640.1 (2,100) |
| Temperature Log | Groundwater temperature | AWS | 08/06/1992<br>10/13/1992 | TL-1<br>TL-2 | 537.1 (1,762)<br>542.5 (1,780) | 647.7 (2,125)<br>646.2 (2,120) |
| Total Magnetic Intensity | Identify welded ash-flow volcanic stratigraphy | LLNL [i] | 07/15/1992 | MPP-1 | 37.5 (123) | 533.7 (1,751) |
| Waterflow Log | Measure vertical fluid velocities under pumping conditions | SWS | 10/13/1992 | WF-1 | 548.0 (1,798) | 640.1 (2,100) |

Source: BN Logging Services

a Below ground level
b Atlas Wireline Services
c Wellenco, Inc.
d Halliburton Engineering Services
e Baker Hughes INTEQ
f Schlumberger Wireline Services
g Geophysical Engineering Group of the Joint Test Organization
h U.S. Geological Survey
i Lawrence Livermore National Laboratory

A secondary objective of Well ER-6-1 was to determine whether the Topopah Spring Tuff was a perched aquifer at Well ER-6-1. Although no perched water has been found in the Topopah Spring Tuff in other wells in the vicinity of Well ER-6-1, the formation is a significant aquifer where it occurs below the water table. Drilling was halted below the base of the unit and two fluid density logs were run, but perched water was not detected. The epithermal neutron log run on July 14, 1992, did not show the Topopah Spring Tuff to contain significant water.

The pre-drill estimate of the potentiometric surface in the Paleozoic carbonate rocks at Well ER-6-1 was 472.4 m (1,550 ft) BGL, or 728.5 m (2,390 ft) MSL (USGS, 1992). Water- level measurements made in the open borehole on September 7, 1992, indicated a water level of 470.9 m (1,545 ft) BGL, or 730.0 m (2,395 ft) MSL in the Paleozoic carbonate rocks. This level was also found to be unchanged when checked on June 7, 1996.

### *2.4.2 Water Production*

Water production data were not recorded during drilling of Well ER-6-1.

### *2.4.3 Preliminary Flow Meter and Chemistry Log Data*

Flow meter data, along with temperature, electrical conductivity (EC), and pH measurements, can be used to characterize borehole fluid variability, which may indicate inflow and outflow zones. Typically, these measurements are made before the completion string is installed, and the data are consulted during planning of zones to be completed. At Well ER-6-1, these data were first collected by DRI personnel on November 19, 1992, when Well ER-6-1 was at a temporary TD of 648.9 m (2,129 ft). Additional measurements were acquired after the borehole was deepened to a TD of 977.2 m (3,206 ft). Preliminary analysis of the first data set indicated very slow downward flow within the cased portion of the well, upward flow from 611 to 545 m (2,005 to 1,788 ft), and slight downward to zero flow from approximately 611 to 650 m (2,005 to 2,133 ft). In the second set of measurements, increasing downward flow was observed from a low of 3.0 liters per minute (lpm) (0.79 gallons per minute [gpm]) at 683 m (2,240 ft) to a high of 21.5 lpm (5.68 gpm) at 869 m (2,850 ft). Although it was not possible to measure the outflow zones at the bottom of the well, water may be exiting the well near 915 and 950 m (3,000 and 3,117 ft) based on the temperature log (Lyles et al., 1995).

### *2.4.4 Preliminary Groundwater Characterization Samples*

Following aquifer testing (see Section 2.6), DRI collected preliminary groundwater characterization samples from the Well ER-6-1 borehole. These data will provide a basis for comparison with future groundwater chemistry data, and were reported by Rose et al. (1997) and IT (2000).

## *2.5 Precompletion and Open-Hole Development*

Following completion of geophysical logging operations below the 13d-in. surface casing, and after the hole had been drilled to 648.9 m (2,129 ft), the drill string was placed in the hole to a depth of 546.8 m (1,794 ft). Fluid was then air-lifted from the hole for approximately 9½ hours on August 10, 1992. About 170,000 liters (45,000 gallons) of fluid were recovered during air-lifting, at an average rate of about 295 lpm (78 gpm). Dilution of the LiBr tracer in the fluid recovered indicated that sufficient well development had occurred to permit hydrologic testing.

In an attempt to develop the gravel-packed interval surrounding the piezometer tube, several swabbing runs were made. Only a small amount of fluid was recovered, but DRI personnel felt that the swabbing was sufficient for adequate communication between the formation and piezometer tube to permit accurate hydrostatic head measurements (Gillespie, 1993).

## *2.6 Hydrologic Testing*

On August 20, 1992, a Reda® pump was lowered into the hole on 3½-in. tubing, and a transducer was set in the piezometer string. The pump was started the next day for a calibration check, and set at a rate of 625 lpm (165 gpm). Fluid levels were allowed to stabilize until August 24, 1992, when a multi-rate pumping test was started, and conducted in 4 one-hour steps. On October 6, 1992, a long-term aquifer test was begun. Pumping continued at an average rate of 625 lpm (165 gpm) until October 8, 1992, when the test was cut short because of a problem with the electric generator. Groundwater characterization samples were obtained by DRI personnel after this phase of testing. Complete details on these aquifer tests are documented in a data report prepared by DRI (Gillespie, 1993).

## 2.7 Well Completion

### 2.7.1 Introduction

Well completion refers to the installation in a borehole of a string of pipe (casing or tubing) that is slotted or screened at one or more locations along its length. The completion process also typically includes emplacement of backfill materials around the pipe, with coarse fill such as gravel adjacent to the open intervals and impervious materials such as cement between the open intervals to isolate them. The pipe serves as a conduit for insertion of a pump in the well, for inserting devices for measuring fluid level and for sampling, so that accurate potentiometric and water chemistry data can be collected from known portions of the borehole.

Figure 2-3 is a schematic diagram of the final well-completion design for Well ER-6-1, Figure 2-4 shows a plan view and profile of the wellhead surface completion, and Table 2-4 is a construction summary for the well. Data for this section were obtained from daily operations and activity reports, casing records, and cementing records provided by the BN Drilling Department. The RSN well data report (Drellack et al., 1992) was also consulted for preparation of this section.

### 2.7.2 As-Built Completion Design and Installation

The basic design of Well ER-6-1 includes a 2 f -in. piezometer tube that provides access to the tuff confining unit, and open borehole within the underlying carbonate rocks in which pumps and monitoring lines could be installed for future tests.

Initial completion activities at Well ER-6-1 began on July 22, 1992, after logging operations were concluded and the borehole was opened to a diameter of 57.2 cm (22.5 in.) to the temporary TD of 554.4 m (1,819 ft). A string of 13 d -in. casing was installed, with a string of 2 f -in. Hydril® tubing string attached to the outside to serve as an access line. The annulus of the surface casing was cemented to the surface, except for the interval 437.5 to 470.1 m (1,435 to 1,542 ft), which encompasses the slotted section of the piezometer access tube. This interval is open to the tuff confining unit (zeolitized Tunnel Formation).

The lower 16 joints of tubing were tack-welded to the outside of the casing, and the upper part of the tubing was banded to the casing. The tubing is slotted from 450.8 to 460.2 m (1,479.0 to 1,510.0 ft) BGL. Each slotted joint has 6 rows of saw-cut slots 5.1 cm (2 in.) long by 0.5 cm (0.198 in.) wide, placed on staggered 15.2-cm (6-in.) centers.

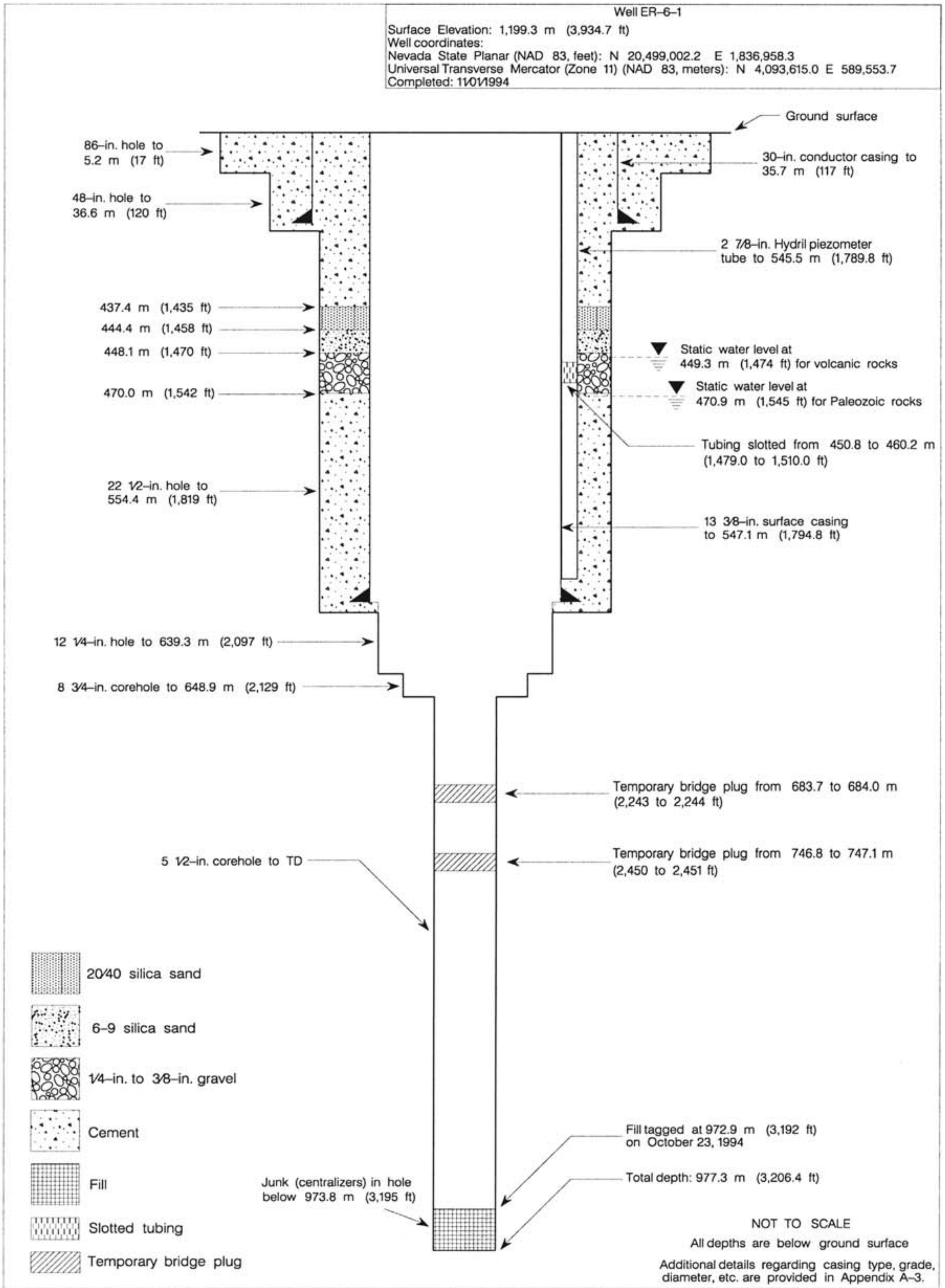



**Figure 2-3**
**Schematic of Final Well-Completion Design for Well ER-6-1**

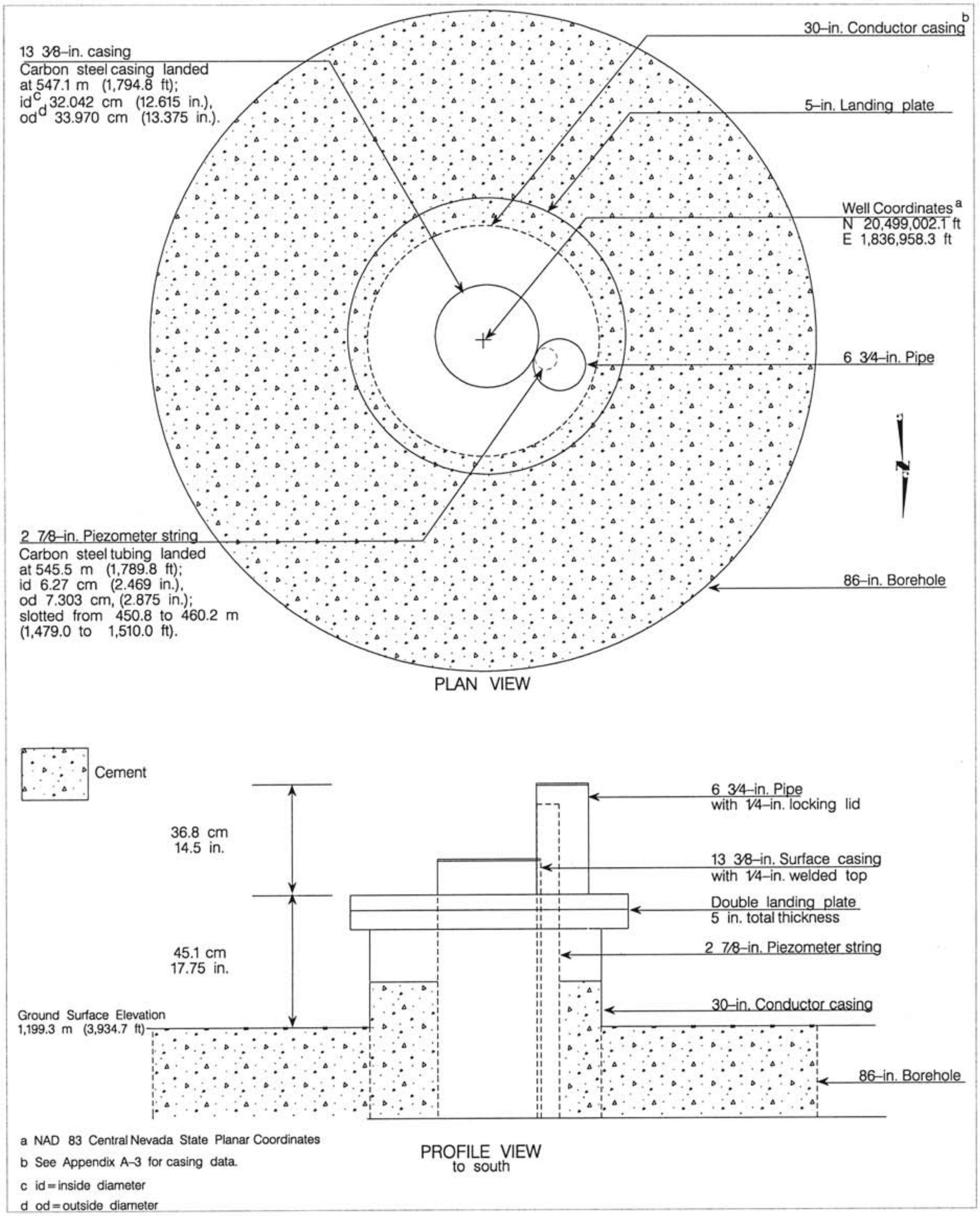



**Figure 2-4**
**Wellhead Diagram for Well ER-6-1**

## Table 2-4
## Well ER-6-1 Completion String Construction Summary

<table>
<tr><th>Tubing Type</th><th colspan="2">Configuration<br>meters (feet)</th><th>Cement</th><th>Sand/Gravel</th></tr>
<tr><td rowspan="3">2 f -in.<br>Carbon-Steel</td><td rowspan="3">Ground Surface<br>to<br>545.5 (1,789.8)</td><td>Blank<br>0 to 450.8<br>(0 to 1,479)</td><td>Type II plus<br>2% $CaCl_2$<br>0 to 437.4<br>(0 to 1,435)</td><td>20/40 Sand<br>437.4 to 444.4<br>(1,435 to 1,458)</td></tr>
<tr><td>Slotted<br>450.8 to 460.2<br>(1,479.0 to 1,510.0)</td><td rowspan="2">470 to 546.8<br>(1,542 to 1,794)</td><td>6-9 Sand<br>444.4 to 448.1<br>(1,458 to 1,470)</td></tr>
<tr><td>Blank<br>460.2 to 545.5<br>(1,510.0 to 1,789.8)</td><td>¼- x d -inch Gravel<br>448.1 to 470.0<br>(1,470 to 4,542)</td></tr>
</table>

The casing/tubing assembly was washed down through fill and set so that the bottom of the surface casing is at 547.1 m (1,794.8 ft), within the Paleozoic rocks. The bottom of the attached piezometer tubing is at 545.5 m (1,789.8 ft). The slotted interval was packed with ¼-in. to d -in. silica gravel from 448.1 to 470.0 m (1,470 to 1,542 ft). The sand pack above the gravel consists of 6-9 Colorado sand placed at 444.4 to 448.1 m (1,458 to 1,470 ft). An interval of 20/40 silica sand was placed above this, at 437.4 to 444.4 m (1,435 to 1,458 ft). Cementing then continued with the placement of Type II cement plus 2 percent calcium chloride ($CaCl_2$) to the ground surface.

The well was left open below 554.4 m (1,819 ft), until during the summer of 1995, two temporary bridge plugs were placed in Well ER-6-1 to restrict cross flow between two transmissive zones within the Laketown Dolomite. These bridge plugs are placed at a depth of 683.7 to 684.0 m (2,243 to 2,244 ft) and 746.8 to 747.1 m (2,450 to 2,451 ft). The well has remained idle since that time.

### *2.8 Actual Versus Planned Costs and Scheduling*

The cost of drilling Well ER-6-1 can be broken down into charges by the NTS drilling and support contractor, REECo, who drilled the main hole in 1992; and charges by the coring subcontractor in 1994. The cost of the geophysical logging subcontractor are included with the REECo costs. The completion cost includes the installation of bridge plugs in 1995.

Work order estimates were prepared for the drilling and original completion of the main hole; the costs of coring activities were estimated from the coring subcontract. RSN tracked drilling and completion costs for Well ER-6-1 on a weekly and monthly basis. The total planned cost of Well ER-6-1 was $2,308,826. The actual cost of the well was $1,951,901, or 15.5 percent less than the planned cost. Table 2-5 presents the planned and actual costs for the drilling, coring, and initial completion of Well ER-6-1.

**Table 2-5**
**Planned and Actual Costs for Drilling, Coring, and Initial Completion of Well ER-6-1**

| Activity | Planned Cost | Actual Cost | Percent Difference Actual Versus Planned |
|---|---|---|---|
| Main hole drilling and geophysical logging | 1,591,000 [a] | 1,000,571 [b] | -37.1 |
| Core hole drilling<br>Coring subcontractor<br>NTS support | <br>448,401 [c]<br>153,325 | <br>581,945<br>110,560 | <br>29.8<br>-27.9 |
| *Subtotal* | *601,726* | *692,505* [d] | *15.1* |
| Well completion (to date) | 116,100 [e] | 258,825[f] | 122.9 |
| **Total** | **2,308,826** | **1,951,901** | **15.5** |

a Source: RSN work order estimates, May 1992.
b Source: RSN monthly cost summary for May 1993.
c Source: Subcontract No. 950-CUC-02(4), Schedule A.
d Source: RSN monthly cost summary for April 1995.
e Source: RSN work order estimate, August 1992.
f Source: RSN monthly cost summary for September and December 1995.

# 3.0 Well ER-6-1 Satellite Hole #1

## 3.1 Well-Specific Objectives

The scientific objectives for Well ER-6-1 Satellite Hole #1 included those listed in Section 1.2. However, the specific goal for this well in the cluster was to obtain additional hydrostatic head data within the LCA.

## 3.2 Drilling Summary

This section contains detailed descriptions of the drilling process and fluid management issues.

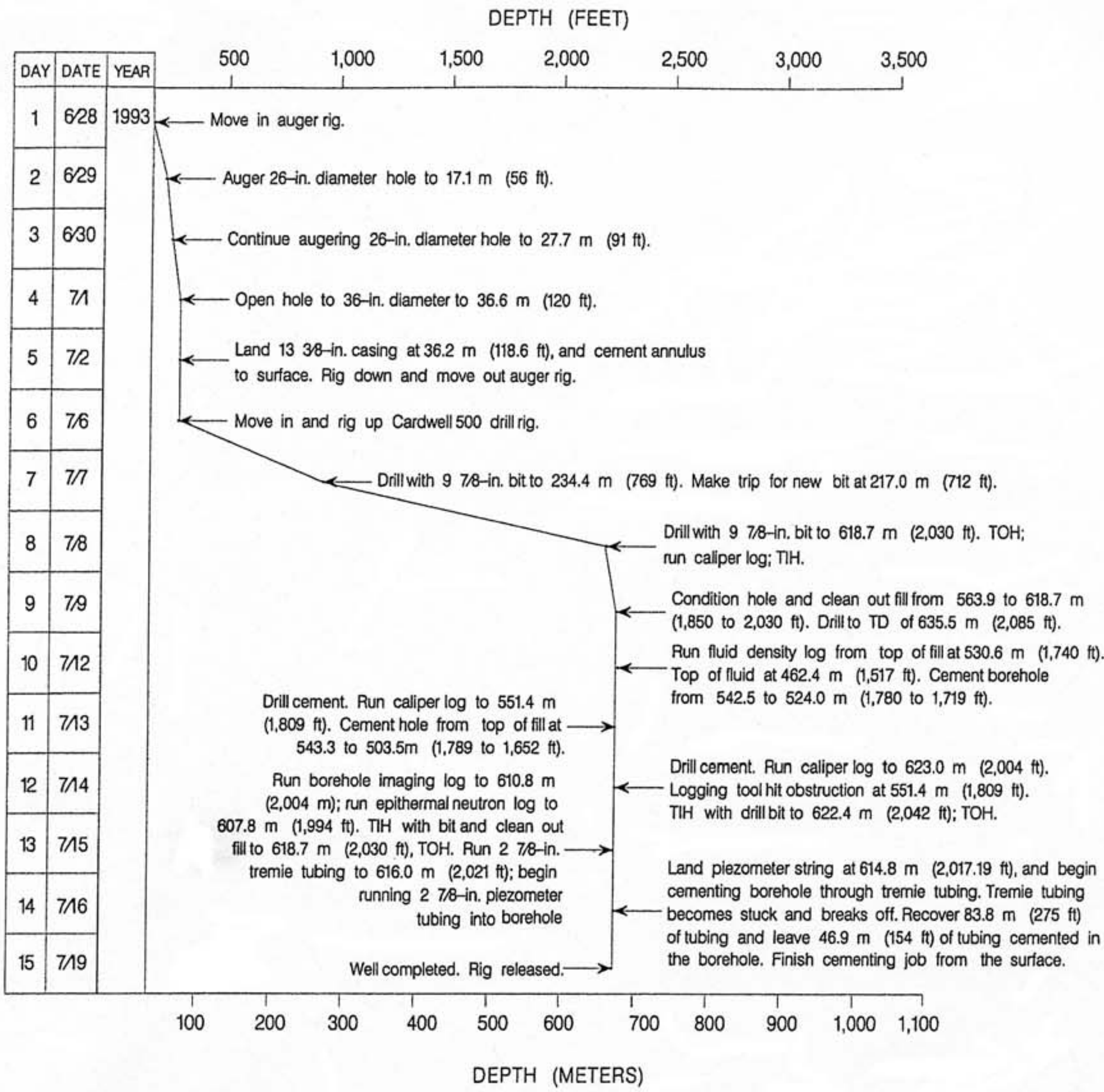
### 3.2.1 Introduction

The drilling requirements for Well ER-6-1 Satellite Hole #1 were outlined in the RSN Drilling and Completion Program D-006-002 (RSN, 1993a), and changes to these criteria were documented in RSN Records of Verbal Communication (Appendix A-1). The drill-site layout is shown on Figure 1-2. Figure 3-1 is a chart of the drilling and completion history for Well ER-6-1 Satellite Hole #1. A summary of drilling statistics for the well is given in Table 3-1. The following information was compiled from the RSN daily rig reports, field notes prepared by the IT Field Representatives, and the RSN Well ER-6-1 Satellite Hole #1 drill-hole history (RSN, 1993c), where complete details of drilling activities can be found.

### 3.2.2 Drilling History

The 91.4-cm- (36-in.) diameter conductor hole for Well ER-6-1 Satellite Hole #1 was dry-augered to the depth of 36.6 m (120 ft) on July 1, 1993. The 13d-in. conductor casing was set at 36.2 m (118.6 ft) and cementing was finished on July 2, 1993. The Cardwell 500 drilling rig was moved to the site and rotary drilling of Well ER-6-1 Satellite Hole #1 began on July 7, 1993, using a 9 f-in. bit, with air-foam and polymer in conventional circulation.

Well ER-6-1 Satellite Hole #1 is located approximately 16.3 m (54 ft) southeast of Well ER-6-1 and consequently penetrated the same geologic units as the main hole. Drilling proceeded very quickly through alluvium and Tertiary volcanic rocks, before tagging Paleozoic carbonate rocks at 539.5 m (1,770 ft) BGL. Circulation was never lost and the TD of 635.5 m (2,085 ft) was reached on July 9, 1993. A limited suite of geophysical logs was run after drilling was completed. During completion activities, on July 16, 1993, fill was tagged in the borehole at the depth of 618.1 m (2,028 ft).




LEGEND

| | |
|---|---|
| cm | centimeter(s) |
| ft | foot (feet) |
| in. | inch(es) |
| m | meter(s) |
| TD | Total depth |
| TIH | Trip into hole |
| TOH | Trip out of hole |

WELL ER-6-1 SATELLITE HOLE#1 SUMMARY

| | |
|---|---|
| Begin drilling surface hole | 06/29/1993 |
| Set 13 3/8-in. surface casing at 36.2 m (118.6 ft) | 07/02/1993 |
| Begin drilling 9 7/8-in. main hole | 07/07/1993 |
| Reach total drilled depth of 635.5 m (2,085 ft) | 07/09/1993 |
| Well completed: | 07/19/1993 |

**Figure 3-1**
**Drilling and Completion History for Well ER-6-1 Satellite Hole #1**

## Table 3-1
## Abridged Drill Hole Statistics for Well ER-6-1 Satellite Hole #1

| | | | | |
|---|---|---|---|---|
| **LOCATION DATA:** | | | | |
| Coordinates: | Nevada State Plane (central zone): | (NAD 27): | N 813,951.1 ft | E 696,809.0 ft |
| | | (NAD 83): | N 6,248,093.4 m | E 559,909.0 m |
| | Universal Transverse Mercator: | (NAD 83): | N 4,093,600.1 | E 589,556.7 m |
| Surface Elevation [a]: | 1,199.2 m (3,934.5 ft) | | | |
| **DRILLING DATA:** | | | | |
| Spud Date: | 06/29/1993 | | | |
| Total Depth (TD): | 635.5 m (2,085 ft) | | | |
| Date TD Reached: | 07/09/1993 | | | |
| Date Well Completed: | 07/16/1993 | | | |
| Hole Diameter: | 91.4 cm (36 in.) from surface to 36.6 m (120 ft); 25.1 cm (9 **f** in.) to 635.5 m (2,085 ft). | | | |
| Drilling Techniques: | Dry auger drilling to 36.6 m (120 ft). Rotary drilling with air-foam and polymer in conventional circulation using a 9 **f** -in.-diameter bit to TD. | | | |
| **CASING DATA:** | 13 **d** -in. conductor casing from surface to 36.2 m (118.6 ft). | | | |
| **WELL COMPLETION DATA:** | | | | |
| A slotted access string consisting of 7.3-cm (2 **f** -in.) od Hydril® tubing was landed at 614.8 m (2,017.2 ft). | | | | |
| | **Access String** | | | |
| Total Depth: | 614.8 m (2,017.2 ft) | | | |
| Depth of Slotted Section: | 576.5 to 614.8 m (1,891.4 to 2,017.2 ft) | | | |
| Depth of Sand Packs: | 559.3 to 568.1 m (1,835 to 1,864 ft) | | | |
| Depth of Gravel Pack: | 568.1 to 618.1 m (1,864 to 2,028 ft) | | | |
| Fluid Depth: [b] | 470.9 m (1,545 ft) | | | |
| **DRILLING CONTRACTOR:** | Reynolds Electrical & Engineering Co., Inc. | | | |
| **GEOPHYSICAL LOGS BY:** | Atlas Wireline Services | | | |
| **SURVEYING CONTRACTOR:** | Bechtel Nevada | | | |

a Elevation of construction pad at wellhead. 1929 National Geodetic Vertical Datum.
b Fluid level as of June 7, 1996.

The gyroscopic survey run in the well on July 27, 1993, indicates that the borehole remained fairly straight during drilling. At the lowest surveyed depth of 609.6 m (2,000 ft), the hole had drifted 4.1 m (13.5 ft) to the north and 6.1 m (20.0 ft) to the east of the collar location.

### *3.2.3 Drilling Problems*

Only minor problems with hole sloughing and tight hole conditions were encountered during drilling of Well ER-6-1 Satellite Hole #1. The sloughing is believed to have occurred in an argillized zone near the base of the Tertiary volcanic rocks and at the contact between the Tertiary and Paleozoic rocks (see geology discussion in Section 5.0). This interval had caused similar problems in the Well-ER-6-1. Fill was repeatedly encountered during drilling breaks below 530.4 m (1,740 ft). Because of these problems, geophysical logs were run only to the top of the fill, and thus the bottom 15.5 m (51 ft) of the borehole was not logged.

### 3.2.4 Fluid Management

Well ER-6-1 Satellite Hole #1 was drilled using air-foam, with the addition of polymer as needed to condition the hole. The two lined sumps that had been built for Well ER-6-1 (Figure 1-2) were used to hold discharge fluids produced while drilling Well ER-6-1 Satellite #1. Water used to mix drilling fluids came from Water Well 5B, and LiBr was added to the drill fluid as a tracer for future development and testing. See Appendix A-4 for more information on the composition of drilling fluids.

The drilling effluent was monitored according to the methods prescribed in the *Fluid Management Plan for the Underground Test Area Operable Unit* (DOE, 1994) and in the drilling program (RSN, 1993b). The results of analyses of samples of drilling fluid collected at Well ER-6-1 Satellite Hole #1 during drilling operations indicate that all fluid quality objectives were met, as shown on the fluid management reporting form dated February 22, 1994 (Appendix B). The form lists volumes of solids (drill cuttings) and fluids produced during well-construction operations, Stage I and II (i.e., vadose-and saturated-zone drilling only; well development and aquifer testing will be conducted at a later date). The volume of solids produced was calculated using the diameter of the borehole (from caliper logs) and the depth drilled, and includes added volume attributed to a rock bulking factor. The volumes of fluids listed on the report are estimates of total fluid production, and do not account for any infiltration or evaporation of fluids from the sumps.

## 3.3 Geologic Data Collection

### 3.3.1 Introduction

This section describes the sources of geologic data obtained from Well ER-6-1 Satellite Hole #1 and the methods of data collection. Improving the understanding of the carbonate sedimentary rocks in this part of Yucca Flat was a primary objective of Well ER-6-1 Satellite Hole #1, so the proper collection of geologic and hydrogeologic data from the well was considered fundamental to successful completion of the project.

Geologic data collected at Well ER-6-1 Satellite Hole #1 consist of drill cuttings and geophysical logs; no sidewall samples or conventional cores were taken. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures.

### 3.3.2 Collection of Drill Cuttings

No samples of drill cuttings were collected from the Well ER-6-1 Satellite Hole #1 conductor hole. Composite drill cuttings were collected at 3-m (10-ft) intervals as drilling of the main hole progressed from 36.6 to 634.0 m (120 to 2,080 ft), just above the hole TD. Two cartons of samples (no sealed samples) were collected at each interval from 36.6 to 201.2 m (120 to 660 ft). Three cartons of cuttings, including a sealed (controlled) sample, were collected from most intervals from the depth of 204.2 to 618.7 m (670 to 2,030 ft). No sealed samples were collected from 621.8 to 634.0 m (2,040 to 2,080 ft). Samples were not obtained from 24 intervals (ranging in length from 3.0 to 18.3 m [10 to 60 ft]) from the ground surface to TD, because of the very fast drilling rate. No samples were collected specifically for paleontologic studies.

All samples collected are stored under secure, environmentally controlled conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada. All controlled samples remain sealed as archive samples. One of each set of uncontrolled samples was left unsealed in the original sample containers, and the other was washed and stored according to standard USGS Core Library procedures.

### 3.3.3 Geophysical Logging Data

A limited suite of geophysical logs was run after drilling to verify the lithology, structure, and hydrogeologic properties of the rocks and compare them with those of Well ER-6-1. In addition, logs were run to evaluate borehole conditions and to monitor completion progress. All geophysical logs run in Well ER-6-1 Satellite Hole #1 are listed in Table 3-2 along with dates run, depths, and service companies. The logs are available from BN in Mercury, Nevada, and copies are on file at the offices of Stoller-Navarro Joint Venture in Las Vegas, Nevada.

## 3.4 Hydrology of Well ER-6-1 Satellite Hole #1

Part of the purpose of constructing Well ER-6-1 Satellite Hole #1 was to obtain additional hydraulic head data for Yucca Flat and to enable measurement of static and dynamic (pumping) water levels during future pumping tests at the well cluster. The satellite hole may also serve as a source well for injection of tracer chemicals for possible future tests between wells in this cluster.

## Table 3-2
## Well ER-6-1 Satellite Hole #1 Geophysical Log Summary

| **Geophysical Logs** | **Log Purpose** | **Logging Service** | **Date Logged** | **Run Number** | **Top of Logged Interval** (BGL) [a] meters (feet) | **Bottom of Logged Interval** (BGL) meters (feet) |
|---|---|---|---|---|---|---|
| Annulus Investigation Log | Omnidirectional density (check for cement or fluid location) | AWS [b] | 07/16/1993 | AIN-1 | 0.9 (3) | 613.3 (2,012) |
| Borehole Televiewer / Gamma Ray | Borehole examination / stratigraphic correlation | AWS | 07/15/1993 | BHTV-1/GR-5 | 512.1 (1,680) | 610.8 (2,004) |
| 6-arm Caliper / Gamma Ray | Borehole conditions / stratigraphic correlation | AWS | 07/08/1993<br>07/12/1993<br>07/13/1993<br>07/14/1993 | CA6-1/GR-1<br>CA6-2/GR-2<br>CA6-3/GR-3<br>CA6-4/GR-4 | 400.2 (1,313)<br>481.0 (1,578)<br>12.5 (41)<br>16.2 (53) | 543.8 (1,784)<br>531.6 (1,744)<br>548.3 (1,799)<br>620.0 (2,034) |
| Directional Gyroscope | Borehole deviation | BHI [c] | 07/27/1993 | DRG-1 | 16.2 (53) | 620.0 (2,034) |
| Epithermal Neutron / Porosity / Gamma Ray | Total water content / stratigraphic correlation, alteration | AWS | 07/15/1993 | ENP-1/GR-6 | 15.2 (50) | 605.0 (1,985) |
| Fluid Density | Depth to water in borehole | AWS | 07/12/1993 | DF-1 | 453.5 (1,488) | 473.4 (1,553) |
| Temperature Log | Groundwater temperature | AWS | 07/21/1993 | TL-1 | 1.8 (6) | 613.3 (2,012) |

Source: BN Logging Section

a Below ground level
b Atlas Wireline Services
c Baker Hughes INTEQ

### 3.4.1 Preliminary Water-Level Data

Drilling proceeded quickly and was not halted to establish the static water level within the Tertiary volcanic rocks. No hole-specific pre-drill estimates of the static water level within the Tertiary volcanic section or the Paleozoic rocks were made; however, the water level was expected to be similar to that of nearby Well ER-6-1. Fluid levels in both holes were measured on June 7, 1996, and found to be identical, at 470.9 m (1,545 ft) depth.

### 3.4.2 Water Production

Water production data were not recorded during drilling of Well ER-6-1 Satellite Hole #1.

## 3.5 Precompletion and Open-Hole Development

The initial precompletion development in Well ER-6-1 Satellite Hole #1 consisted of circulation and conditioning of the borehole after the TD of 635.5 m (2,085 ft) was reached, and prior to geophysical logging and the installation of the piezometer string.

After geophysical logs had been run, hole sloughing became a problem, and the planned air-lift development of the drill hole was not performed prior to the installation of the 2 **f** -in. piezometer string. No development of the gravel pack surrounding the piezometer was performed; nevertheless, it is believed that the gravel pack will allow sufficient communication between the formation and piezometer to permit accurate measurements of hydrostatic head.

## 3.6 Well Completion

### 3.6.1 Introduction

Completion activities at Well ER-6-1 Satellite Hole #1 began on July 15, 1993, after logging operations were concluded. Figure 3-2 is a schematic of the final well-completion design for the well, Figure 3-3 shows a plan view and profile of the wellhead surface completion, and Table 3-3 is a construction summary for the well. Data for this section were obtained from daily operations and activity reports, casing records, and cementing records provided by the BN Drilling Department.

### 3.6.2 Well Completion Design and Installation

A string of 2 **f** -in. Hydril® tubing was run in Well ER-6-1 Satellite Hole #1 to provide access to the carbonate rocks. The Hydril® tubing was landed at a depth of 614.8 m (2,017.2 ft) and is slotted from 576.5 to 614.8 m (1,891.4 to 2,017.2 ft). The lowest 4 joints are slotted, and the bottom

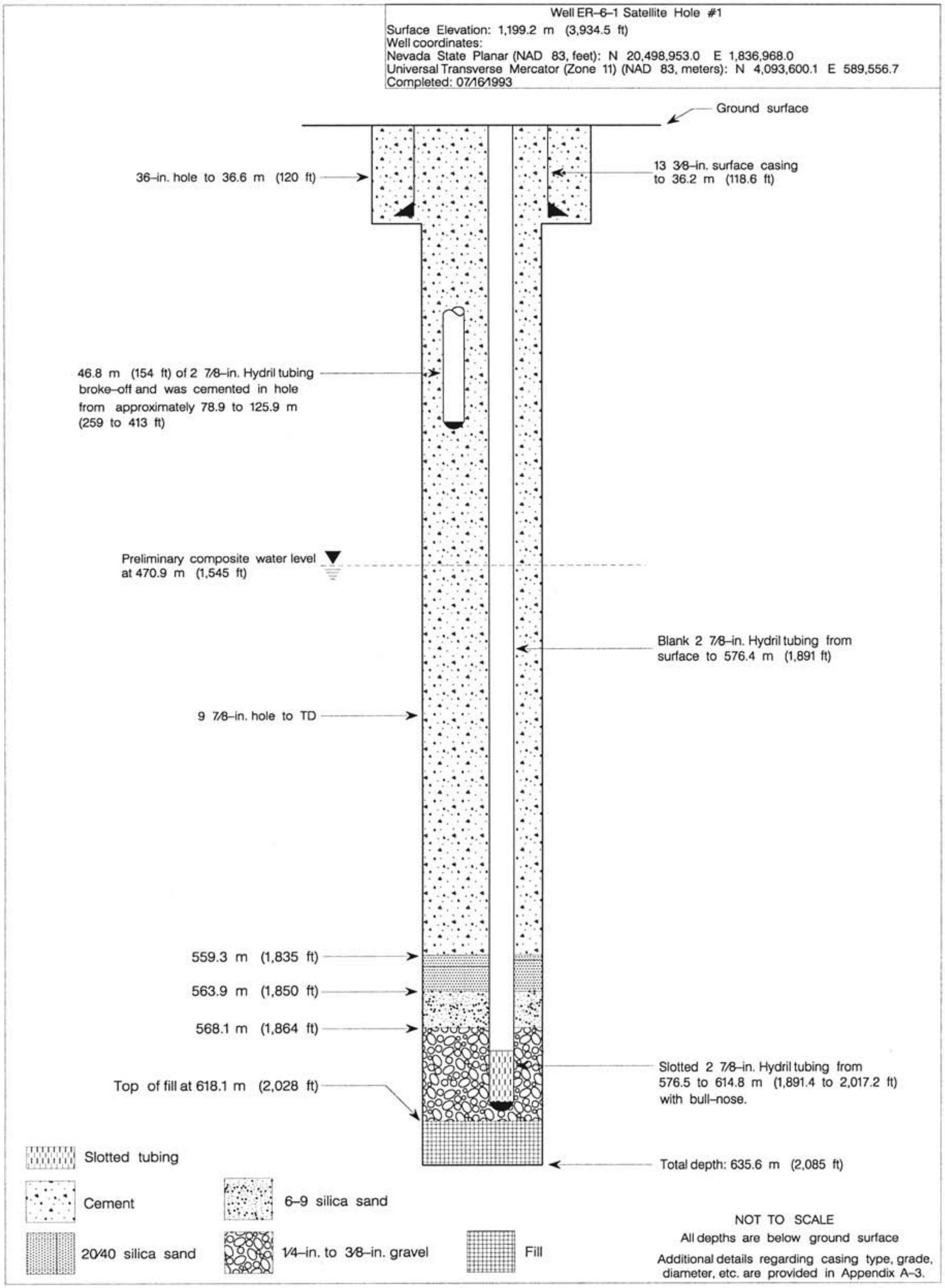
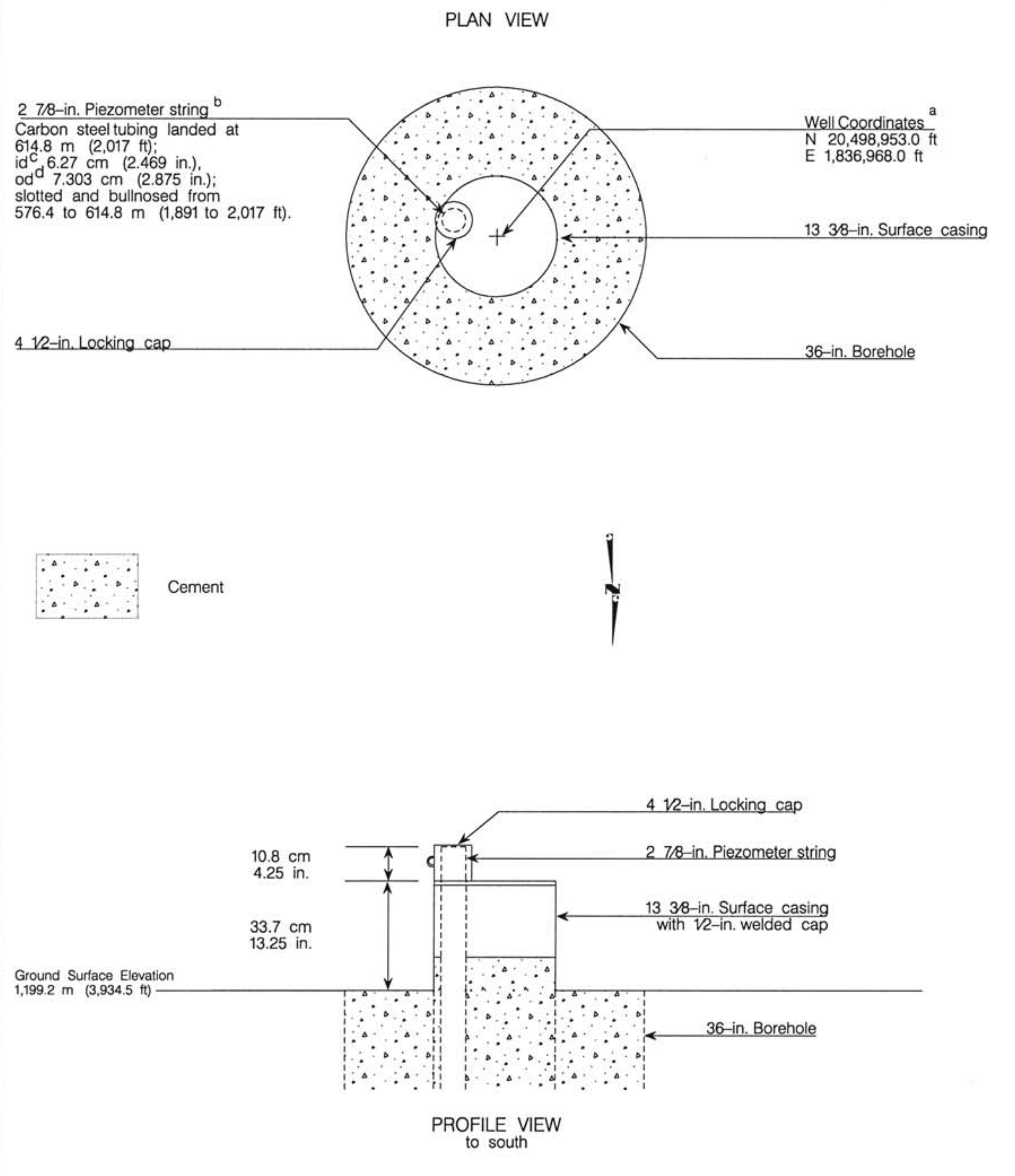



**Figure 3-2**
**Schematic of Final Well Completion Design for Well ER-6-1 Satellite Hole #1**




a NAD 83 Central Nevada State Planar Coordinates
b See Appendix A-3 for casing data.
c id = inside diameter
d od = outside diameter

**Figure 3-3**
**Wellhead Diagram for Well ER-6-1 Satellite Hole #1**

**Table 3-3**
**Well ER-6-1 Satellite Hole #1 Completion String Construction Summary**

| **Tubing Type** | **Configuration**<br>meters (feet) | | **Cement**<br>meters (feet) | **Sand/Gravel**<br>meters (feet) |
|---|---|---|---|---|
| 2 **f** -in.<br>Carbon-Steel | Ground Surface to<br>614.8 (2,017.2) | Blank<br>0 to 576.4<br>(0 to 1,891) | <u>Type II</u><br>0 to 122.5<br>(0 to 402) | <u>20/40 Sand</u><br>559.3 to 563.9<br>(1,835 to 1,850) |
| | | 4 consecutive<br>slotted joints,<br>bull-nosed<br>576.5 to 614.8<br>(1,891.4 to 2,017.2) | <u>Type II plus 2%</u><br><u>$CaCl_2$</u><br>122.5 to 599.3<br>(402 to 1,835) | <u>6-9 Sand</u><br>563.9 to 568.1<br>(1,850 to 1,864)<br><u>¼- x **d** -in. Gravel</u><br>568.1 to 618.1<br>(1,864 to 2,028) |

joint is bull-nosed with a 2.5-cm (1-in.) drain hole. Each slotted joint has 6 rows of saw-cut slots 7.6-cm (3 in.) long by 1.3 cm- (½ in.) wide placed on 15.24-cm (6-in.) centers. Casing and tubing materials in Well ER-6-1 Satellite Hole #1 are listed in Appendix A-3.

The completion operation continued with the placement of the gravel pack. The slotted interval was packed with ¼-in. to **d** -in. silica gravel from 568.1 to 618.1 m (1,864 to 2,028 ft). The sand pack above the gravel consists of 6-9 Colorado silica sand placed at 563.9 to 568.1 m (1,850 to 1,864 ft). A section of 20/40 silica sand was placed above this, at 559.3 to 563.9 m (1,835 to 1,850 ft). Cementing then continued with the placement of Type II cement plus 2 percent $CaCl_2$ to the ground surface.

Standard UGTA decontamination procedures were employed to prevent the introduction of outside contaminants into the well. Well-construction materials were inspected according to relevant procedures before delivery to the drill site, and all tubing installed in the well was recleaned as per standard UGTA practice. Caliper logs were used to calculate the volumes of cement needed during well construction. The annulus investigation log was used to monitor the placement of cement, sand and gravel, and to verify tubing and casing depths.

A "tremie" line consisting of 2 **f** -in. Hydril® tubing was used for emplacement of the cement, gravel, and sand during the completion process. The tremie was flushed with water periodically to assure that the line remained clear. A 46.9-m (154-ft)-long piece of the 2 **f** -in. Hydril® tremie line broke off during cementing operations and was cemented in the hole from approximately 78.9 to 125.9 m (259 to 413 ft) (Figure 3-2). This is not expected to have an adverse effect on the future use of this well.

### *3.7 Actual Versus Planned Costs*

Planned costs for drilling, setting 13d-in. casing, and geophysical logging in Well ER-6-1 Satellite Hole #1 were determined from RSN work order estimates, and actual costs were tracked by RSN on a weekly and monthly basis. The total planned cost of drilling Well ER-6-1 Satellite Hole #1 was $377,961. The actual cost of the hole was $257,559, or 31.9 percent less than the planned cost. The cost of installing the piezometer string was $30,830.

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# 4.0 Well ER-6-1#2

## 4.1 Well-Specific Objectives

The scientific objectives for Well ER-6-1#2 include those listed in Section 1.2. However, the primary purpose of this well will be to serve as a pumping well in a multi-well tracer experiment, in which nearby wells ER-6-1 and ER-6-1 Satellite Hole #1 will function as tracer-injection wells. The target hydrostratigraphic unit for this planned experiment is the LCA. The position of Well ER-6-1#2 was selected to be approximately 91 m (300 ft) south-southwest of Well ER-6-1, parallel to local fracture trends. This position is expected to maximize groundwater flow between these wells during the planned tracer experiment.

## 4.2 Drilling Summary

This section contains detailed descriptions of the drilling process and fluid management issues.

### 4.2.1 Introduction

The general drilling requirements for all Fiscal Year 2003 Yucca Flat hydrogeologic investigation wells were provided in *Yucca Flat Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 2002). Specific requirements for Well ER-6-1#2 were outlined in Drilling Work Plan Number D-009-002.02 (BN, 2002). No changes were made to the criteria during drilling. Figure 1-2 shows the layout of the drill site. A summary of drilling statistics for the well is given in Table 4-1. Figure 4-1 is a chart of the drilling and completion history for Well ER-6-1#2. The following information was compiled primarily from BN daily drilling reports.

### 4.2.2 Drilling History

Field operations at Well ER-6-1#2 began when BN drillers using an auger rig drilled a 91.4-cm (36-in.) diameter conductor hole to 36.6 m (120 ft). A string of 20-in. conductor casing was set at the depth of 36.0 m (118 ft). The bottom of the conductor casing was cemented inside to 32.6 m (107 ft), and the annulus was cemented from the bottom of the casing to ground level on June 7, 2002.

The UDI crew rigged up the Wilson Mogul 42B rig on September 20 to 24, 2002, and tagged cement inside the conductor casing at the depth of 32.6 m (107 ft). The crew drilled through the cement using a BHA with an 18½-in. bit on September 24, 2002, with air-foam and polymer in conventional circulation.

**Table 4-1**
**Abridged Drill Hole Statistics for Well ER-6-1#2**

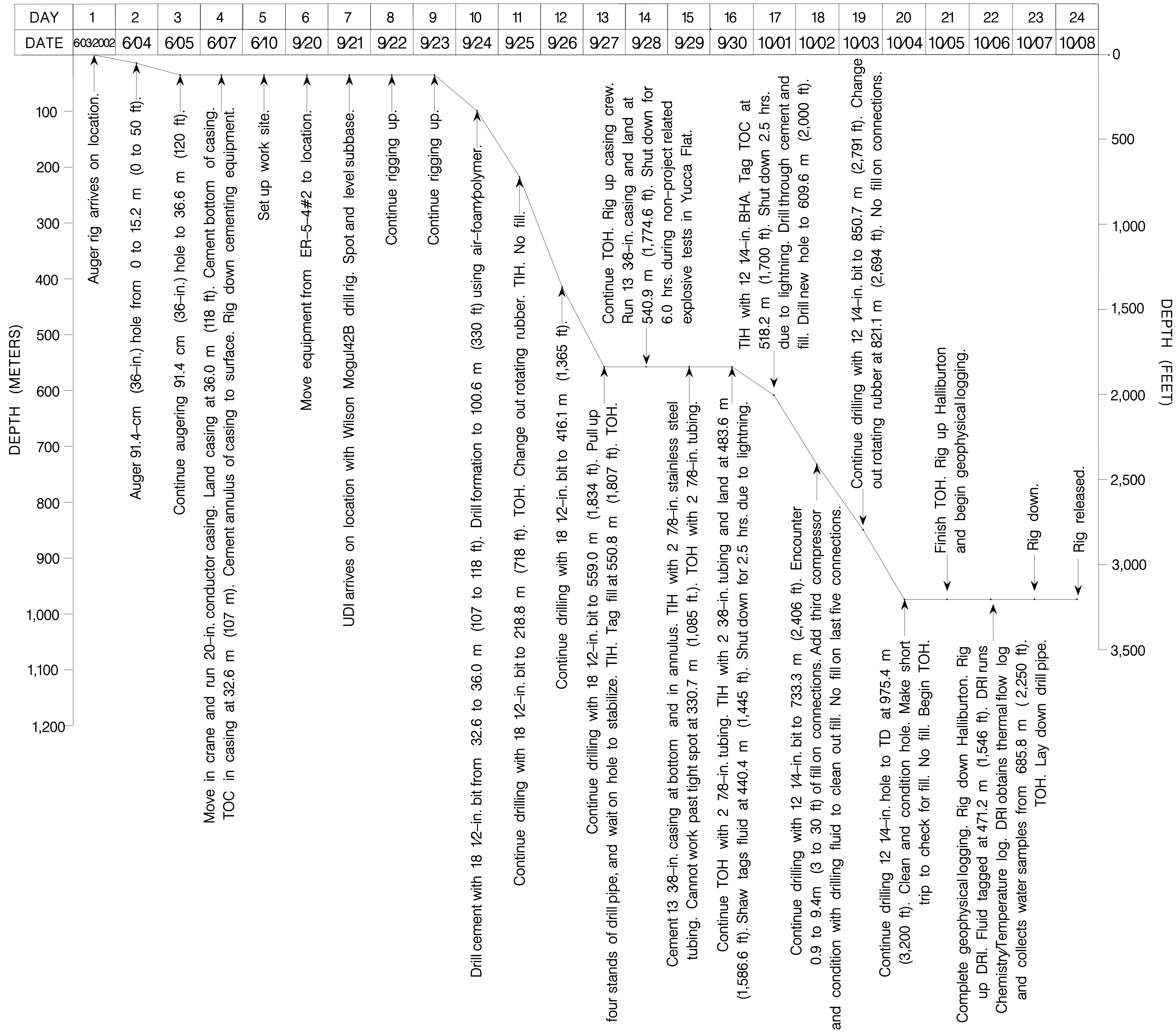
| | | | | |
|---|---|---|---|---|
| **LOCATION DATA:** | | | | |
| Coordinates: | Nevada State Plane (central zone): | (NAD 27): | N 813,797.2 ft | E 696,744.8 ft |
| | | (NAD 83): | N 20,498,799.0 | E 1,836,903.8 m |
| | Universal Transverse Mercator: | (NAD 83): | N4,093,356.0 m | E 589,616.5 m |
| Surface Elevation [a]: | 1,198.7 m (3,934.7 ft) | | | |
| **DRILLING DATA:** | | | | |
| Spud Date: | 09/24/2002 (main hole drilling with Wilson Mogul 42B rig) | | | |
| Total Depth (TD): | 975.4 m (3,200 ft) | | | |
| Date TD Reached: | 10/05/2002 | | | |
| Date Well Completed: | Well is an open hole completion to date. | | | |
| Hole Diameter: | 91.4 cm (36 in.) from surface to 36.6 m (120 ft); 47.0 cm (18.5 in.) from 36.6 m (120 ft) to 559.0 m (1,834 ft); 31.1 cm (12.25 in.) from 559.0 m (1,834 ft) to TD of 975.4 m (3,200 ft). | | | |
| Drilling Techniques: | Dry auger drilling from surface to 36.6 m (120 ft); rotary drilling with 18½-in. bit using air-foam/polymer in direct circulation from 36.6 to 559.0 m (120 to 1,834 ft); rotary drilling with 12¼-in. bit and air-foam/polymer to TD of 975.4 m (3,200 ft). | | | |
| **CASING DATA:** | 20-in. conductor casing, surface to 36.0 m (118 ft); 13**d**-in. surface casing, surface to 540.9 m (1,774.6 ft). | | | |
| **WELL COMPLETION DATA:** | | | | |
| Piezometer tube consisting of 2 **d**-in. od carbon-steel tubing inserted outside of 13**d**-in. casing from surface to 483.6 m (1,586.6 ft). | | | | |
| | **Piezometer Tube** | | | |
| Total Depth: | 483.6 m (1,586.6 ft) | | | |
| Depth of Slotted Section: | 465.2 to 483.6 m (1,526.1 to 1,586.6 ft) | | | |
| Depth of Gravel/Sand Packs: | Annulus was not stemmed. | | | |
| Fluid Depth [b]: | Paleozoic rocks (open borehole): 470.9 m (1,545.1 ft) | | | |
| | Tertiary rocks (piezometer): 448.6 m (1,471.9 ft) | | | |
| **DRILLING CONTRACTOR:** | United Drilling, Inc. | | | |
| **GEOPHYSICAL LOGS BY:** | Halliburton, Desert Research Institute | | | |
| **SURVEYING CONTRACTOR:** | Bechtel Nevada | | | |

a Elevation of construction pad at the wellhead. 1929 National Geodetic Vertical Datum
b Fluid levels measured on December 14, 2002 (IT, 2003).

As a precaution against sloughing of the upper section of the borehole, it was decided to install surface casing when a competent formation was reached. Drilling was stopped to set casing in dolomite on September 27, 2002, at a depth of 559.0 m (1,834 ft); water production had reached an estimated rate of 208 lpm (55 gpm) at this depth. The drillers circulated fluid to clean and condition the hole,

## WELL ER-6-1#2 SUMMARY

| Activity | Date |
|---|---|
| Begin drilling conductor hole: | 06/03/2002 |
| Conductor hole completed and 30-in. casing set to 36.0 m (118 ft): | 06/07/2002 |
| Begin drilling 18 1/2-in. surface hole: | 09/24/2002 |
| Reach total drilled depth of 975.4 m (3,200 ft): | 10/05/2002 |




### LEGEND

| | |
|---|---|
| BHA | Bottom hole assembly |
| cm | centimeter(s) |
| DRI | Desert Research Institute |
| ft | foot (feet) |
| in. | inch(es) |
| m | meter(s) |
| TD | Total depth |
| TIH | Trip into hole |
| TOC | Top of cement |
| TOH | Trip out of hole |
| UDI | United Drillers, Inc. |

FIGURE 4-1
WELL ER-6-1#2
DRILLING AND COMPLETION HISTORY
SHEET 1 OF 1

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pulled the drill string off the bottom twice and waited about an hour before tagging bottom again. No fill was found, and the drillers removed the drill string out of the hole. Drilling activity was suspended for 6 hours during non-project-related operations before installation of the surface casing.

A casing subcontractor landed 13⅜-in. casing that has ribbon stabilizers (centralizers) installed above the guide shoe, at the middle and at the top of the first joint, and at the top of the second joint. The casing was landed at a depth of 540.9 m (1,774.6 ft) on September 29, 2002, above about 18.0 m (59 ft) of fill that had accumulated in the bottom of the surface hole. After the stab-in sub was seated in the float shoe, the seal was checked by pumping air down the drill pipe. Pre-flush clear water was pumped down the casing and the annulus prior to cementing. Type II cement was pumped inside the casing through the stab-in sub, followed by water to displace the cement into the annulus. The casing subcontractor also installed a string of 2⅜-in. carbon-steel tubing to serve as a piezometer. See Section 4.6.2 for information about its installation.

Drilling resumed on October 2, 2002, with air-foam/polymer and a 12¼-in. bit. Cement was drilled from inside the bottom of the casing from 539.5 to 540.7 m (1,770 to 1,774 ft), then drilling continued into fill. Drilling continued uninterrupted to the TD of 975.4 m (3,200 ft), reached on October 5, 2002. Immediately after reaching TD, the drillers circulated fluid to condition the hole before geophysical logging, which took place on October 6, 2002. Demobilization from the Well ER-6-1#2 site began after geophysical logging was completed. The borehole was left open below the 13⅜-in. casing.

The directional survey run in the well on April 16, 2003, indicates that at the lowest surveyed depth of 563.9 m (1,850 ft), the hole had drifted 3.8 m (12.6 ft) to the southeast of the well collar location, and that this part of the borehole is relatively straight (no “dog legs”).

A graphical depiction of drilling parameters including penetration rate, revolutions per minute, pump pressure, and weight on the bit is presented in Appendix A-2. See Appendix A-3 for a list of casing materials. Drilling fluids and cements used in Well ER-6-1#2 are listed in Appendix A-4.

### *4.2.3 Drilling Problems*

No significant drilling problems were encountered at Well ER-6-1#2. The amounts of polymer and foaming agent in the drilling fluid, and the fluid injection rate, were adjusted as necessary during drilling to maintain superior circulation and penetration rate, and to minimize borehole sloughing. Fill of generally less than 3.0 m (10 ft) was encountered periodically throughout drilling but did not result in significant drilling delays.

### 4.2.4 Fluid Management

Drilling effluent was monitored according to the methods prescribed in the UGTA FMP (DOE/NV, 1999). The air-foam/polymer drill fluid was circulated down the inside of the drill string and back up the hole through the annulus (conventional or direct circulation) and then discharged into a sump. Water used to prepare drilling fluids came from water wells 5b and C-1. A LiBr solution was added to the drill fluid as a tracer to provide a means of estimating groundwater production. The rate of water inflow was estimated from the dilution of the tracer in the drill fluid returns.

Well ER-6-1#2 was designated a "far-field" site, so the FMP considered fluids produced from it suitable for discharge to unlined sumps or the ground surface. The two single-lined sumps that had been constructed in 1992 were used to manage the water production from the drilling of the well (Figure 1-2). Although the linings were in poor condition in 2002, no contaminants were expected during drilling of Well ER-6-1#2, so neither sump was relined. Samples of drilling effluent were tested on site hourly for the presence of tritium, and all down-hole tools were tested for lead prior to use. The onsite monitoring results indicate that tritium remained at background levels, ranging from zero to 1,355 picoCuries per liter (IT, 2003). No sump samples were analyzed.

The fluid management reporting form dated December 2, 2002, is reproduced in Appendix B. The form lists volumes of solids (drill cuttings) and fluids produced during well-construction operations, Stages I and II (i.e., vadose-and saturated-zone drilling only; well development and aquifer testing will be conducted at a later date). The volume of solids produced was calculated using the diameter of the borehole (from caliper logs) and the depth drilled, and includes added volume attributed to a rock bulking factor. The volumes of fluids listed on the report are estimates of total fluid production, and do not account for any infiltration or evaporation of fluids from the sumps.

## 4.3 Geologic Data Collection

### 4.3.1 Introduction

This section describes the sources of geologic data obtained from Well ER-6-1#2 and the methods of data collection. Improving the understanding of the carbonate sedimentary rocks in this part of Yucca Flat was one of the primary objective of Well ER-6-1#2, so the proper collection of geologic and hydrogeologic data from the well was considered fundamental to successful completion of the project.

Geologic data collected at Well ER-6-1#2 consist of drill cuttings and geophysical logs; no sidewall samples or conventional cores were taken. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures.

### 4.3.2 Collection of Drill Cuttings

Composite drill cuttings were collected from Well ER-6-1#2 at 3-m (10-ft) intervals as drilling progressed from 48.8 m (160 ft) to 975.4 m (3,200 ft), the hole TD. Triplicate samples were collected from 303 intervals; samples were not collected from 1 interval due to drilling problems. In addition, the IT Field representative collected 2 sets of reference samples from each of the cuttings intervals. One of these sets was examined at the drill site for use in preparing the field lithologic descriptions, and remains in the custody of Stoller-Navarro Joint Venture. The other set was sent to LANL where it remains. All other samples (i.e., 3 sets of 303 samples) are stored under secure, environmentally controlled conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada. One of these sample sets was sealed with custody tape at the rig as an archive sample, one set was left unsealed in the original sample containers, and the third was washed and stored according to standard USGS Core Library procedures.

### 4.3.3 Sample Analyses

Eight samples of drill cuttings from various depths in Well ER-6-1#2 were submitted to the LANL Earth and Environmental Sciences Division Geology and Geochemistry Laboratory for petrographic, mineralogic, and chemical analysis, to aid in stratigraphic identification and for characterization of mineral alteration. All of the analyses have been completed, as shown on Table 4-2.

## Table 4-2
## Status of Rock Sample Analyses for Well ER-6-1#2

| **Depth** [a] meters (feet) | **Analyses Performed** [b] | | | | |
|---|---|---|---|---|---|
| | Petrographic | Mineralogic | | Chemical | |
| | **PTS** | **MP** | **XRD** | **XRF** | **$Fe^{2+}/Fe^{3+}$** |
| 158.5 (520) | QL | C | C | C | N/P |
| 286.5 (940) | QL | C | C | C | N/P |
| 350.5 (1,150) | QL | C | C | C | N/P |
| 432.8 (1,420) | QL | C | C | C | N/P |
| 502.9 (1,650) | QL | C | C | C | N/P |
| 539.5 (1,770) | QL | C | C | C | N/P |
| 682.8 (2,240) | QL | C | C | C | N/P |
| 807.7 (2,650) | QL | C | C | C | N/P |

a Depth represents base of 3-m (10-ft) sample interval for drill cuttings. All samples are drill cuttings that represent the lithologic character of the interval.

b Status of analyses at the time of these writing: **QL** = qualitative analysis complete; **C** = analysis complete; **N/P** = analysis not planned. Analysis type: **PTS** = polished thin section; **MP** = electron microprobe; **XRD** = x-ray diffraction; **XRF** = x-ray fluorescence; **$Fe^{2+}/Fe^{3+}$** = wet chemical analysis for iron.

### *4.3.4 Geophysical Logging Data*

A limited suite of geophysical logs was run after drilling to verify the lithology, structure, and hydrogeologic properties of the rocks and for comparison with those of Well ER-6-1 and Well ER-6-1 Satellite Hole #1. In addition, logs were run to evaluate borehole conditions, to determine the fluid levels during the course of drilling, and to monitor completion progress. Geophysical logs were run only in the saturated interval of the borehole. All geophysical logs run in Well ER-6-1#2 are listed in Table 4-3 along with, dates run, depths, and service companies. The logs are available from BN in Mercury, Nevada, and copies are on file at the offices of Stoller-Navarro Joint Venture in Las Vegas, Nevada. Preliminary geophysical data from the logs are reproduced in Appendix D.

The overall quality of the geophysical data collected was good. However, the pH probe on the DRI chemistry tool was not functional so the log was not run for pH, though EC and temperature data were recorded.

## Table 4-3
## Well ER-6-1#2 Geophysical Log Summary

| Geophysical Logs | Log Purpose | Logging Service | Date Logged | Run Number | Top of Logged Interval (BGL) [a] meters (feet) | Bottom of Logged Interval (BGL) meters (feet) |
|---|---|---|---|---|---|---|
| Natural Gamma Ray Spectroscopy [b] | Stratigraphic correlation, mineralogy, natural and man-made radiation | Halliburton | 10/05/2002 | SGR-1 | 510.5 (1,675) | 969.9 (3,182) |
| Gamma Ray / 6-arm Caliper | Stratigraphic correlation/borehole conditions, cement volume calculation | Halliburton | 10/05/2002 | GR-2/CA6-1 | 510.5 (1,675) | 974.1 (3,196) |
| Temperature / Gamma Ray | Groundwater temperature/ stratigraphic correlation | Halliburton | 10/05/2002 | TL-1/GR-1<br>TL-2/GR-3 | 438.0 (1,437)<br>450.2 (1,477) | 961.3 (3,154)<br>947.6 (3,109) |
| Thermal Flow Log | Rate and direction of groundwater flow in borehole | Desert Research Institute | 10/06/2002 | TFM-1 | 563.9 (1,850) | 951.0 (3,120) |
| Chemistry Log (Temperature and Electrical Conductivity only) | Groundwater chemistry, formation transmissivity | Desert Research Institute | 10/06/2002<br>01/30/2003 | Chem-1<br>Chem-2 | 472.4 (1,550)<br>471.8 (1,548 | 976.6 (3,204)<br>566.9 (1,860) |
| Gamma Ray / Electro Micro Imaging Monitor Log | Stratigraphic correlation, fracture analysis | Halliburton | 10/05/2002 | GR-2/CA6-1<br>EMI-1 | 510.5 (1,675) | 974.1 (3,196) |
| Borehole Televiewer / Gamma Ray | View image of borehole wall for structural data | Halliburton | 10/05/2002 | GR-4/BHTV-1 | 823.0 (2,700) | 969.9 (3,182) |
| Gyroscopic Survey | Borehole deviation | Baker-Hughes Inteq | 04/16/2003 | DRG | 0 | 563.9 (1,850) |

Source: BN Logging Section

a Depth below ground level
b Logs presented in geohysical log summary, Appendix D

### 4.4 Hydrology of Well ER-6-1#2

Well ER-6-1#2 was drilled to provide additional hydraulic head data and to provide a well for collecting static and dynamic (pumping) water levels during a future tracer experiment and hydraulic testing at the well cluster.

#### 4.4.1 Preliminary Water Level Data

Water level measurements in the open borehole on October 7, 2002, based on the DRI temperature log run two days after TD was reached, indicated a water level of 471.2 m (1,545.9 ft) BGL, or approximately 728 m (2,389 ft) MSL for Paleozoic carbonate aquifer. Fluid levels measured by IT on December 14, 2002, approximately two months after well construction indicated a fluid level depth of 470.9 m (1,545.1 ft) in the Paleozoic rocks (open borehole) and 448.6 m (1,471.9 ft) in the Tertiary volcanic rocks (piezometer) (IT, 2003).

#### 4.4.2 Water Production

Water production was estimated during drilling of Well ER-6-1#2 on the basis of LiBr dilution data as measured by IT field personnel. Measurable water production (approximately 38 lpm [10 gpm]) began when the borehole had reached the depth of about 457.2 m (1,500 ft) in Tertiary volcanic rocks. Water production at TD (975.4 m [3,200 ft]), was estimated at 3,028 to 3,407 lpm (800 to 900 gpm). See a plot of water production versus depth on the drilling parameters log in Appendix A-2.

#### 4.4.3 Preliminary Flow Meter and Chemistry Log Data

Flow meter data, along with temperature, EC, and pH measurements, can be used to characterize borehole fluid variability, which may indicate inflow and outflow zones. DRI personnel made measurements in the open hole with their thermal flow meter (TFM) tool and chemistry tool on October 6, 2002.

Measurements were made with the TFM tool at 5 locations between the depths of 609.6 m and 951.0 m (2,000 ft and 3,120 ft). Preliminary analysis of these data indicates a downward flow of water within the borehole at all locations.

DRI ran a chemistry log, which included measurements of temperature and EC, but not pH (the pH probe was not functional), from 472.4 to 976.6 m (1,550 to 3,204 ft). Groundwater temperature gradually increased from the minimum reading of 36.7 degrees Celsius (C) (98.1 degrees Fahrenheit [F]) at the top of the fluid column to the deepest logged depth at the TD of the borehole. The maximum temperature of 38.7 degrees C (101.7 degrees F) was measured at 976.6 m (3,204 ft). A slight perturbation in the temperature curve is apparent near the top of the cement section around the 13d-in. casing. Plots of the TFM and chemistry log data are reproduced in Appendix D.

### 4.4.4 Preliminary Groundwater Characterization Sample

Groundwater characterization samples were not collected during construction of Well ER-6#1, as it was planned to collect samples during later testing. However, after geophysical logging was completed, DRI ran a bailer into the borehole and collected one discrete groundwater sample from a depth of 685.8 m (2,250 ft). Analytical data from this initial sample, collected prior to well development, will provide a basis for comparison with future groundwater chemistry data.

## 4.5 Precompletion and Open-Hole Development

The only precompletion development conducted in Well ER-6-1#2 consisted of circulating fluid for 45 minutes to clean the borehole. This process was conducted immediately after TD was reached and prior to geophysical logging.

## 4.6 Well Completion

The only completion string installed in Well ER-6-1#2 is the piezometer installed outside the 13d-in. casing in the upper part of the hole. Figure 4-2 is a schematic of the final well-completion design for Well ER-6-1#2, Figure 4-3 shows a plan view and profile of the wellhead surface completion, and Table 4-4 is a construction summary for the well. Data for this section were obtained from daily operations and activity reports, casing records, and cementing records provided by the BN Drilling Department. Information from IT's well data report (IT, 2003) was also consulted for preparation of this section.

### 4.6.1 Proposed Completion Design

Well ER-6-1#2 was designed to provide groundwater production from the Paleozoic carbonate rocks of the LCA and had been planned as an open-hole completion if borehole conditions permitted (IT, 2002).

### 4.6.2 As-Built Completion Design

After drilling was completed to the planned TD in carbonate rocks of the LCA, the borehole was considered to be stable within the area of interest, so the 31.1-cm (12.25-in.) borehole below the

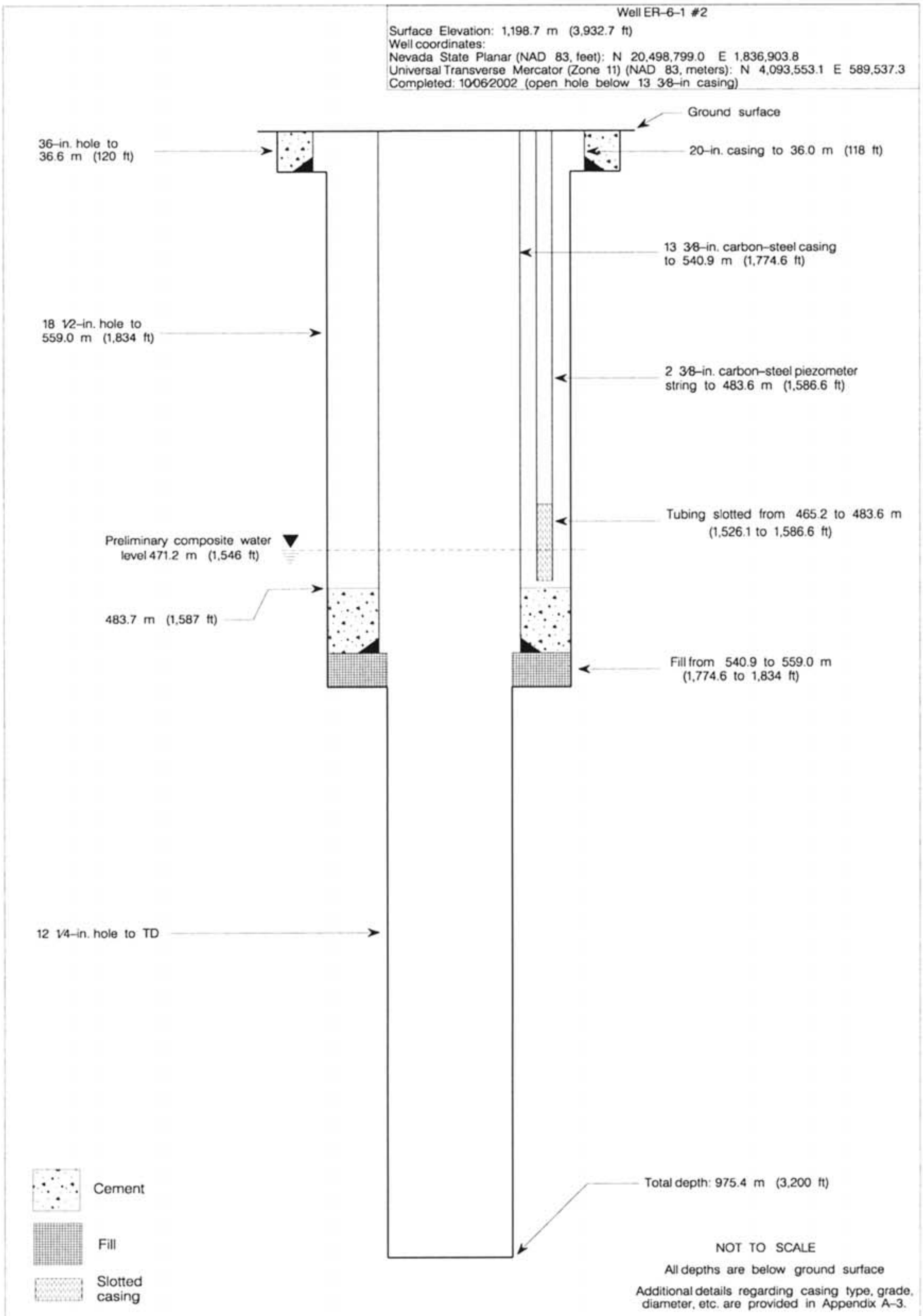


**Figure 4-2**
**Schematic of the Final Well-Completion Design for Well ER-6-1#2**

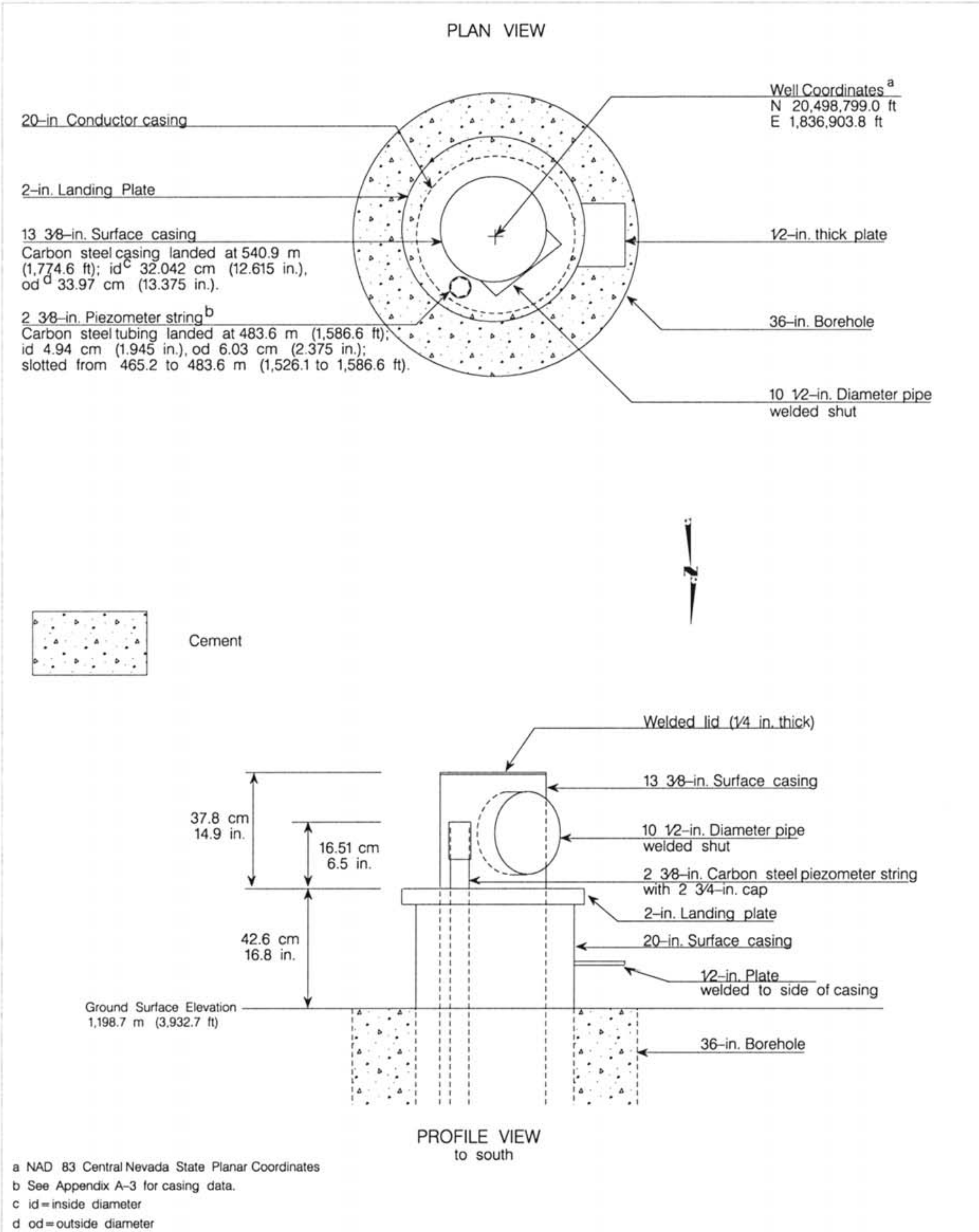


**Figure 4-3**
**Wellhead Diagram for Well ER-6-1#2**

**Table 4-4**
**Well ER-6-1#2 Completion String Construction Summary**

| Tubing Type | Configuration meters (feet) | | Cement | Sand/Gravel |
|---|---|---|---|---|
| 2 **d**-in. Carbon-Steel | Ground Surface to 483.6 (1,586.6) | Blank 0 to 465.2 (0 to 1,526.1) | None | None |
| | | Slotted 465.2 to 483.6 (1,526.1 to 1,486.6) | | |

13**d**-in. casing was left open as planned. In addition, the piezometer tube installed in the annulus of the 13**d**-in. casing will allow measurements of water levels in the upper volcanic rock section.

The piezometer was landed at 483.6 m (1,586.6 ft) and is slotted from 465.2 to 483.6 m (1,526.1 to 1,586.6 ft). Both of the slotted joints have 3 rows of slots, 15.24 cm (6 in.) long by 0.3 cm (0.125 in.) wide on staggered 22.86-cm (9-in.) centers. The slots were cut in the tubing on site by BN welders.

### *4.6.3 Rationale for Differences between Actual and Proposed Completion Design*

Well ER-6-1#2 was completed as planned, except that 2**d**-in. tubing was installed instead of 2 **f**-in. tubing, because of the difficulty in installing the larger size tubing (Section 2.6.4).

### *4.6.4 Completion Method*

Initial completion activities at Well ER-6-1#2 began on September 28, 2002, after the surface casing was set at 540.9 m (1,774.6 ft) and the casing annulus was cemented to approximately 483.7 m (1,587 ft). The casing crew attempted to install a piezometer tube consisting of 2 **f**-in. stainless-steel tubing in the annulus between the 47.0-cm (18½-in.) borehole and the 13**d**-in. casing. However, tight hole conditions were encountered and the 2 **f**-in. tubing could only be lowered to a depth of 330.7 m (1,085 ft), so the decision was made to use 2**d**-in. carbon-steel tubing for the piezometer instead. The 2 **f**-in. tubing was removed from the borehole and the 2**d**-in. tubing was installed. Even though a tight hole was again encountered, the bottom of the 2**d**-in. piezometer was landed at a depth of 483.6 m (1,586.6 ft). The annulus between the borehole and the surface casing was not back-filled or cemented, and remains open from the top of cement at 483.7 m (1,587 ft) to the land surface.

### 4.7 Actual Versus Planned Cost and Scheduling

The BN cost model developed for Well ER-6-1#2 was based on drilling to the planned TD of 975.4 m (3,200 ft). The drilling program baseline projected that it would require 22 days to accomplish drilling of the surface and main holes, logging, and completion for the well, assuming the conductor hole would already have been constructed by BN. The actual time spent to drill the surface and main holes, and install the completion string in Well ER-6-1#2 was 13 days. Drilling of the surface hole and installation of the 13d-in. casing proceeded as expected. However, drilling of the production hole took approximately four days less time than predicted. A graphical comparison (by day) of planned and actual well-construction activities is presented in Figure 4-4.

The cost analysis for Well ER-6-1#2 begins with construction of the conductor hole by BN and the cost of mobilizing the UDI drill rig to the Well ER-6-1#2 site. The cost of building roads, the drill pad, and sumps is not included, and the cost of well-site support by Shaw is not included. The total construction cost for Well ER-6-1#2 includes all drilling costs: charges by the drilling subcontractor; charges by other support subcontractors (including compressor services, drilling fluids, bits, casing services, down-hole tools and, geophysical logging); and charges by BN for mobilization and demobilization of equipment, partial construction of the conductor hole, cementing services, completion materials, radiation technicians, inspection services, and geotechnical consultation.

The total planned cost for constructing Well ER-6-1#2 was $1,262,555. The actual cost was $1,087,622, or 13.9 percent less than the planned cost, which reflects the fact that the well was drilled and completed in significantly less time than predicted. Figure 4-5 presents a comparison of the planned (baseline task plan) and actual cost, by day, for construction Well ER-6-1#2.

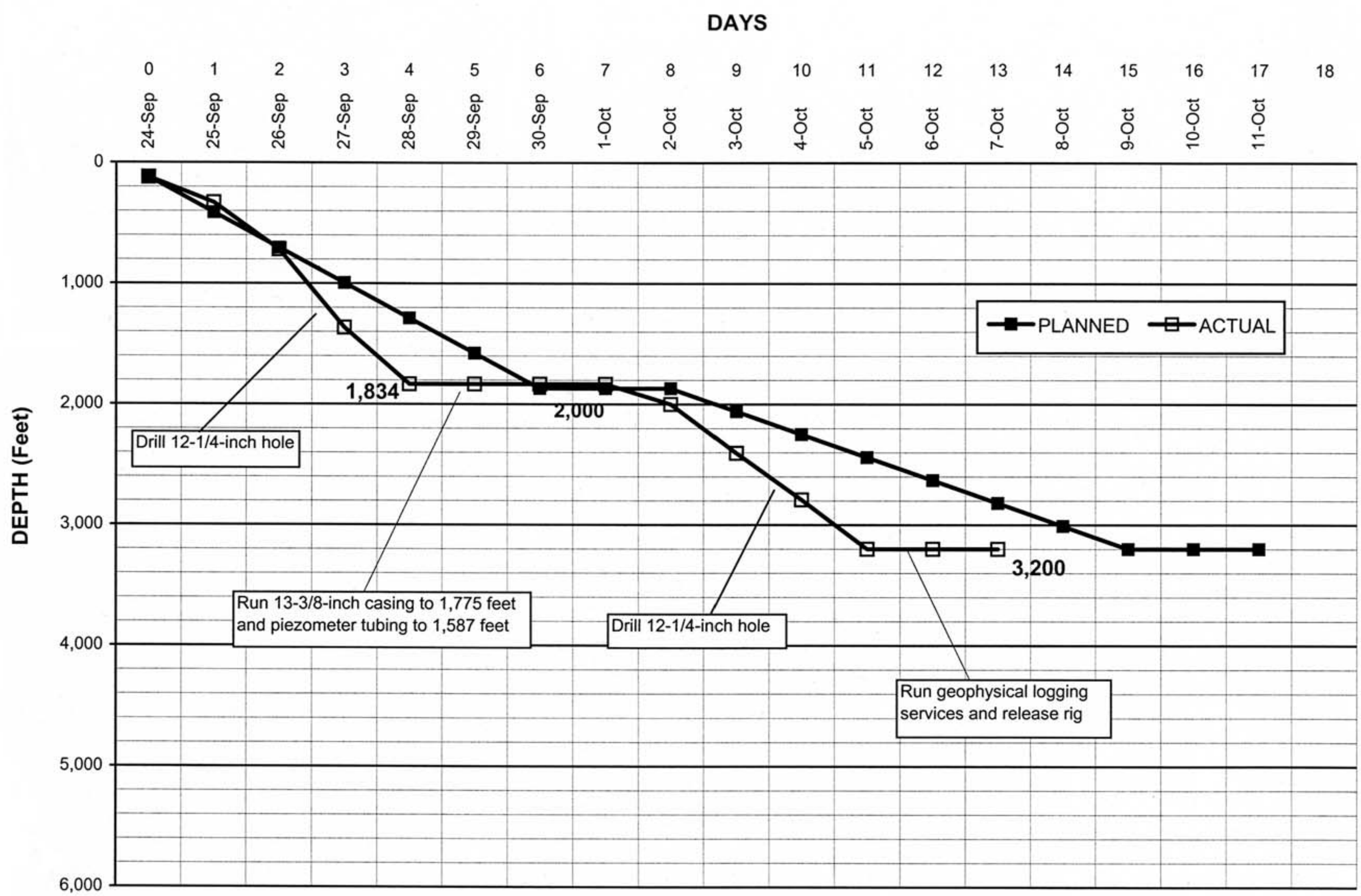


**Figure 4-4**
**Planned versus Actual Construction Progress for Well ER-6-1#2**

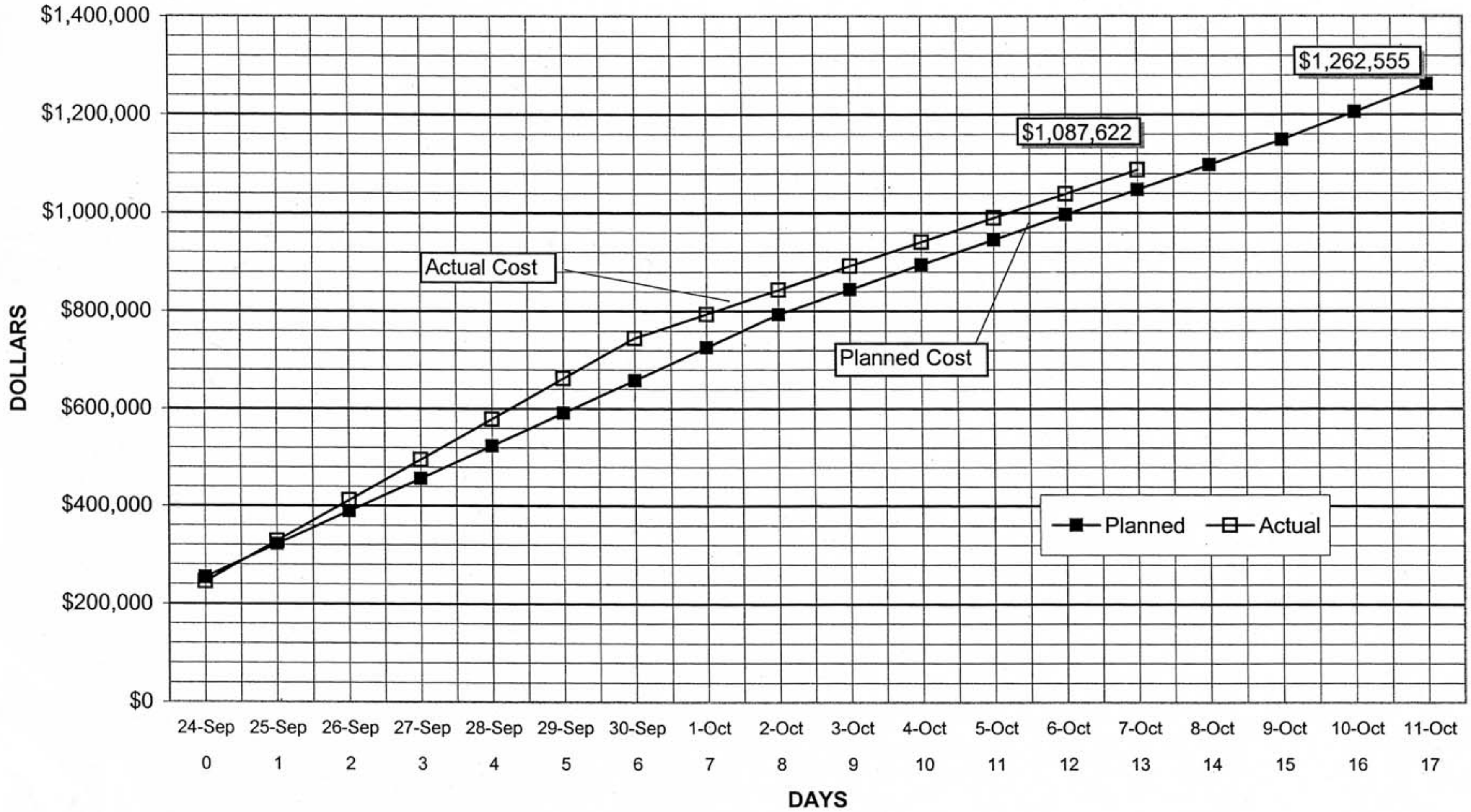


**Figure 4-5**
**Planned versus Actual Cost for Constructing Well ER-6-1#2**

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# 5.0 Geology and Hydrogeology

## 5.1 Introduction

This section summarizes the geology and hydrogeology of Well Cluster ER-6-1. The three wells are located within about 53 m (175 ft) of each other, and Wells ER-6-1 and ER-6-1#2 were drilled to about the same depth (977.3 and 975.4 m [3,206.4 and 3,200 ft], respectively). Well ER-6-1 Satellite Hole #1 is much shallower, at 635.5 m (2,085 ft). Careful examination of the data from the three holes indicates that the geology encountered in all three is very similar, so a composite stratigraphic and lithologic log for was prepared for this site, based primarily on data from Well ER-6-1. Bechtel Nevada geologists prepared the detailed lithologic descriptions presented in Appendix C, incorporating information from Drellack et al. (1992), from descriptions of the Paleozoic sedimentary rocks in the Well ER-6-1 core hole (below 648.9 m [2,129 ft]) presented in IT (1996a), and from geophysical log data. Paleontological analyses of samples from the Paleozoic rocks of Well ER-6-1 by Cole and Harris (1996) were used to confirm the stratigraphic assignments below 539.5 m (1,770 ft). For a more detailed discussion of the regional geology and hydrology of Well Cluster ER-6-1, see the *Yucca Flat Hydrogeologic Investigation Wells and Completion Criteria* (IT, 2002).

## 5.2 Geology

This section is subdivided into discussions of the general geologic setting, stratigraphy and lithology, structural features, and alteration, as interpreted from Well Cluster ER-6-1 data.

Figure 5-1 is a geologic map of the NTS area, showing the location of Well Cluster ER-6-1 in southeastern Yucca Flat. Figure 5-2 shows the surface geology around Well Cluster ER-6-1. The geology and hydrology of Well Cluster ER-6-1 are illustrated in the diagram in Figure 5-3. The discussion below is keyed to the geology of Well ER-6-1, but all three wells in the cluster penetrated the same geologic units with very similar thicknesses. In summary, the boreholes of Well Cluster ER-6-1 penetrated approximately 436.5 m (1,432 ft) of Tertiary volcanic rocks beneath a section of Quaternary and Tertiary alluvial deposits. The alluvium and the upper 347.8 m (1,141 ft) of the volcanic rocks are unsaturated; the underlying volcanic rocks are mostly vitric to devitrified to a depth of approximately 240.2 m (788 ft), but become progressively more zeolitized below. The borehole penetrated approximately 439 m (1,440 ft) of Paleozoic sediments below the Tertiary volcanic rocks.

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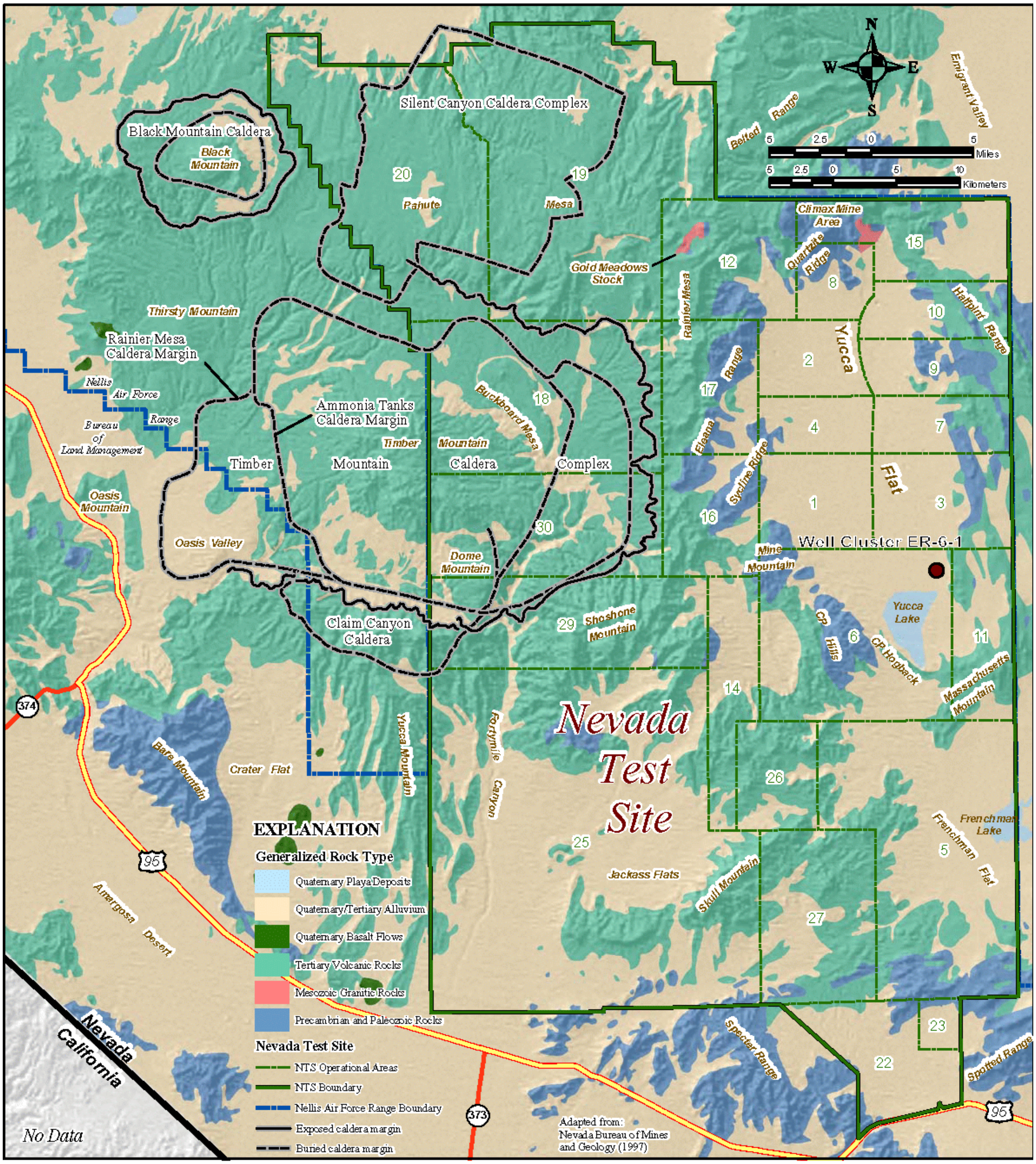


**Figure 5-1**
**Generalized Surface Geologic Map of the Nevada Test Site Area Showing Location of Well Cluster ER-6-1**

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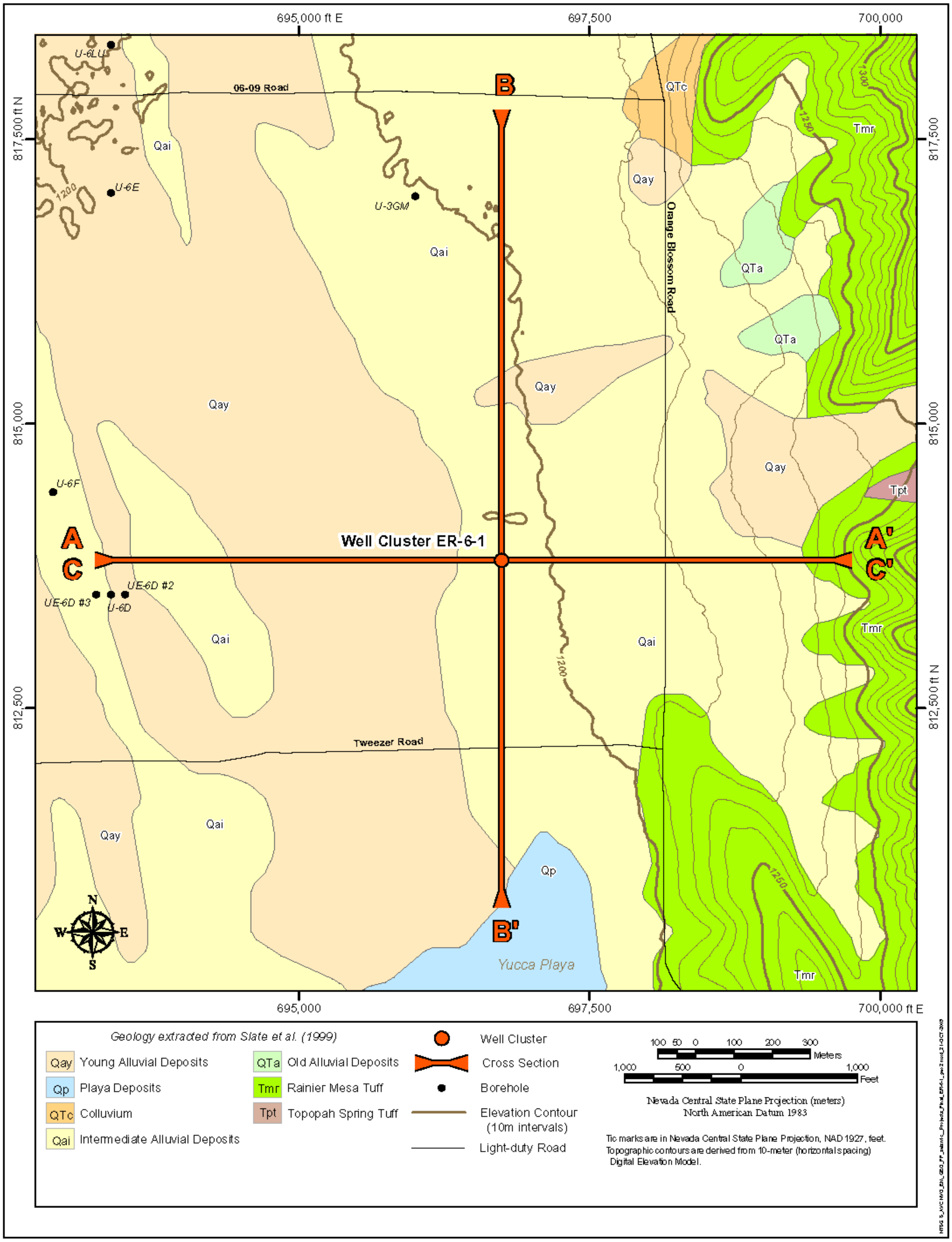


**Figure 5-2**
**Surface Geologic Map of the Well Cluster ER-6-1 Site**

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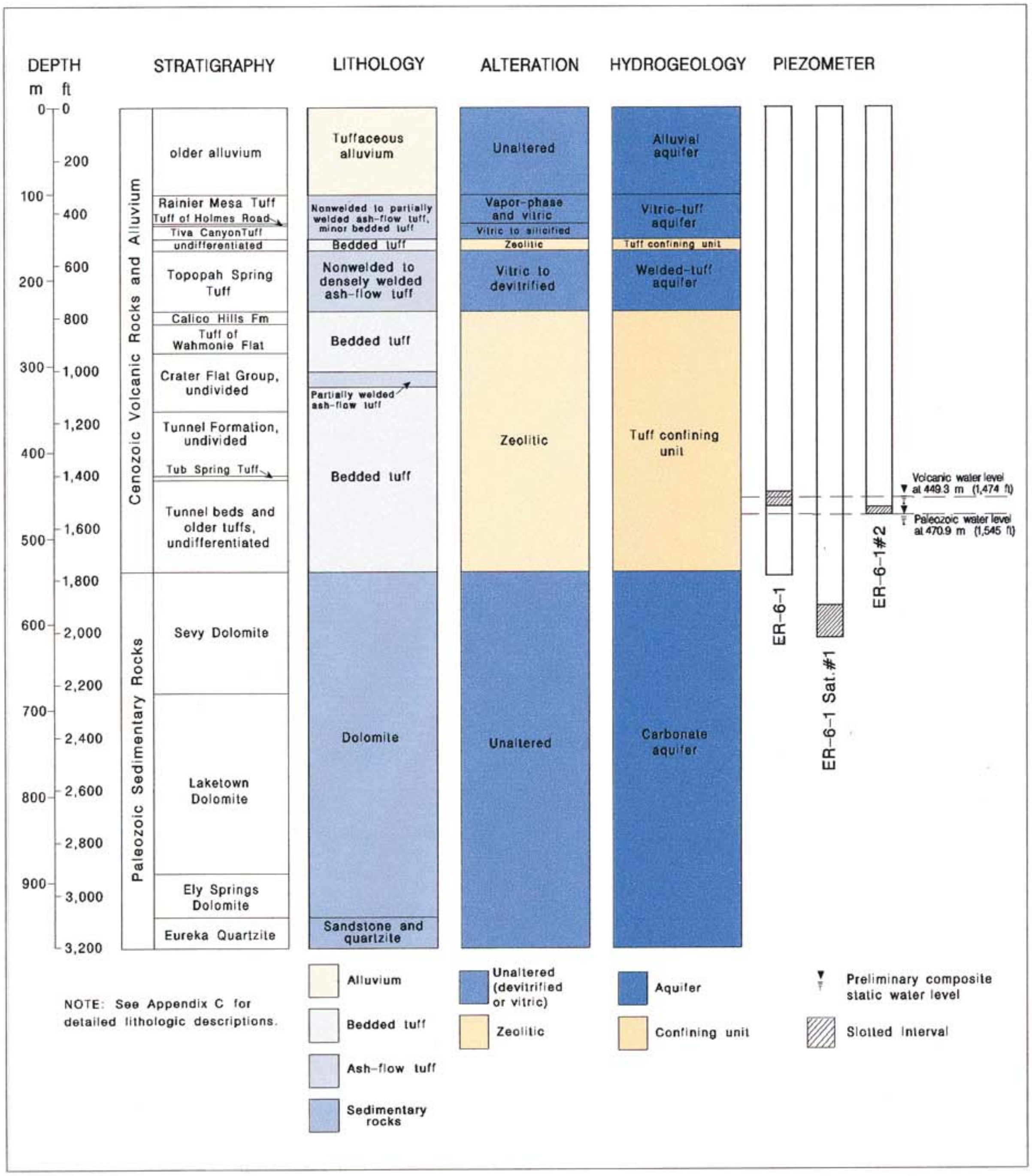


**Figure 5-3**
**Geology and Hydrology of Well Cluster ER-6-1**

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### *5.2.1 Geologic Setting*

Well Cluster ER-6-1 is located in the northeastern corner of NTS Area 6 in southeastern Yucca Flat (Figure 5-1). Yucca Flat is a closed basin typical of the Basin and Range Province, which is characterized by a series of tilted fault blocks resulting in longitudinal mountain ranges and broad intervening basins. In the vicinity of the NTS, the basins and ranges generally trend north-south. Yucca Flat formed as a result of Cenozoic movements and subsequent rotation along mostly normal faults.

The Yucca Flat basin was filled by volcanic deposits consisting mainly of ash-flow tuffs with interbedded nonwelded and bedded tuffs, which are overlain by younger alluvial sediment being eroded from the surrounding mountains. The volcanic rocks are underlain by a thick sequence of Paleozoic miogeosynclinal rocks consisting of mostly carbonate rocks (RSN, 1992). The rocks of this area are cut by north-south-trending, mostly down-to-the-east, high-angle normal faults (Yucca and Topgallant faults) related to Basin and Range extension (Byers et al., 1976). However, in the vicinity of well ER-6-1, most of the faults are down to the west and have less stratigraphic throw than the "valley-forming" down-to-the-east faults.

Regional groundwater flow is generally to the south and southwest within the lower carbonate aquifer and welded-tuff and lava-flow aquifers within the deeper valleys. Zeolitic nonwelded and bedded tuffs act as regional and local confining units (Blankennagel and Weir, 1973).

### *5.2.2 Stratigraphy and Lithology*

As illustrated on Figure 5-3, drilling of Well ER-6-1 began in the Quaternary and Tertiary tuffaceous alluvial deposits, which are 101.5 m (333 ft) thick at the well site. Below the alluvium, the borehole penetrated 35.7 m (117 ft) of mostly poorly welded ash-flow tuff assigned to the Timber Mountain Group. Below the Timber Mountain Group rocks, the well penetrated 100.0 m (328 ft) of mostly nonwelded to densely welded ash-flow tuffs with minor bedded tuff of the Paintbrush Group. Next, the borehole penetrated zeolitized bedded tuffs assigned to the Calico Hills Formation and tuff of Wahmonie Flat. These two units have a combined thickness of only about 48 m (158 ft). Below these bedded tuffs, a very thick sequence of zeolitized bedded, air-fall, and nonwelded to partially welded ash-flow tuff was encountered. These zeolitized units have a combined thickness of 254.2 m (834 ft) and are assigned to the Crater Flat Group, Tunnel Formation, Yucca Flat Tuff, older undifferentiated tuffs, and paleocolluvium. Below the Tertiary volcanic rocks and the paleocolluvium, the borehole penetrated a thick sequence of dolomite of the Sevy Dolomite Formation, Laketown Dolomite, and the Ely Springs Dolomite Formation. These dolomite units have a combined (drilled) thickness of about 401 m (1,316 ft). Drilling of Well ER-6-1 was terminated at a depth of 977.3 m (3,206.4 ft) after penetrating 11.6 m (38 ft) of sandstone and 25.0 m (82 ft) of the Eureka Quartzite.

### *5.2.3 Structural Geology*

The relative position, extent, and thickness of the stratigraphic units near Well Cluster ER-6-1 are illustrated on the west-east and north-south cross sections in Figures 5-4 and 5-5, respectively. As shown on Figure 5-4, Well Cluster ER-6-1 is located on a minor structural block bounded by two north-south trending faults. The western-most fault is inferred from gravity and seismic data (see Figures 23 and 24 in Drellack et al., 1992), while the eastern fault was penetrated by all three wells in the cluster. Both faults dip steeply to the west and produced stratigraphic displacement down to the west.

The eastern fault is estimated to have approximately 73.2 m (240 ft) of normal displacement down to the west (Figure 5-4). This fault is inferred to cross the boreholes of Wells ER-6-1 and ER-6-1 Satellite Hole #1 at the depth of approximately 522.4 m (1,714 ft), based on the presence of an argillized zone and evidence of filled fracture planes in the cuttings samples. The presence of this fault in Well ER-6-1#2 is less clear; if it is present, it may cross the borehole in the Paleozoic rocks.

The Tertiary volcanic units penetrated in Well Cluster ER-6-1 generally dip less than 15 degrees to the west, as determined by abundant data from nearby boreholes, and extrapolation from structural contour and isopach maps of the area (Drellack et al., 1992). The underlying Paleozoic rocks dip more steeply to the west. Analysis of the Formation MicroScanner® log from Well ER-6-1 indicates that the dip of bedding in the Paleozoic rocks averages about 30 degrees to the west (IT, 1996a). However, the upper surface of the Paleozoic section extrapolated from borehole data and structure contour maps for this area averages about 10 degrees to the west.

Several faults were recognized in the cored portion of Well ER-6-1. Formation MicroScanner® log data from Well ER-6-1 indicated that these faults have an average strike direction of N15"E. Fracture orientation is more variable, at N10"E to N55"E (IT, 1996a).

### *5.2.4 Alteration*

Alteration has a significant effect on both the general hydraulic character of volcanic rocks and on how radionuclides migrate through these rocks. The predominant type of mineralogic alteration

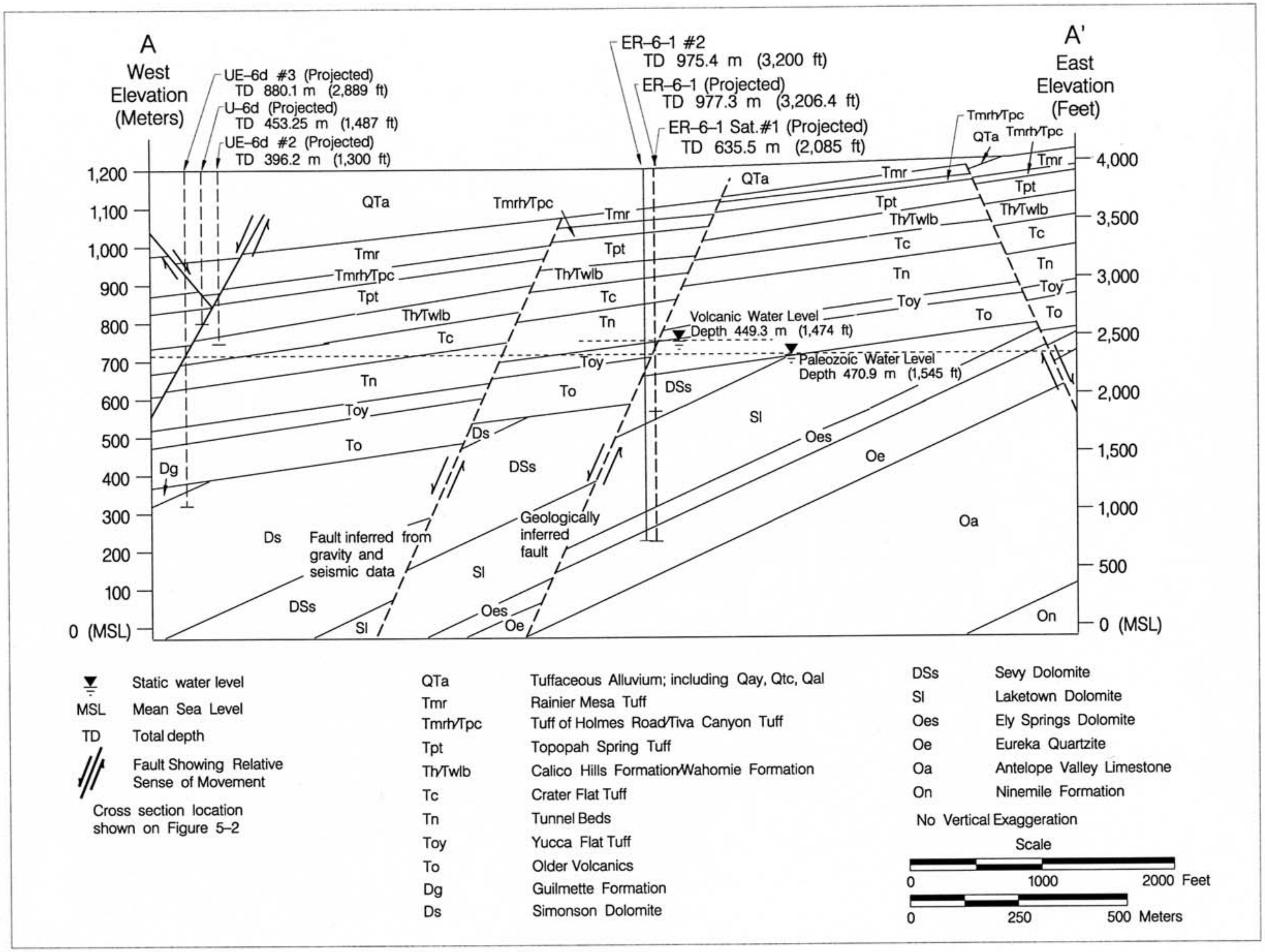


**Figure 5-4**
**West-East Geologic Cross Section A-A′ Through Well Cluster ER-6-1**

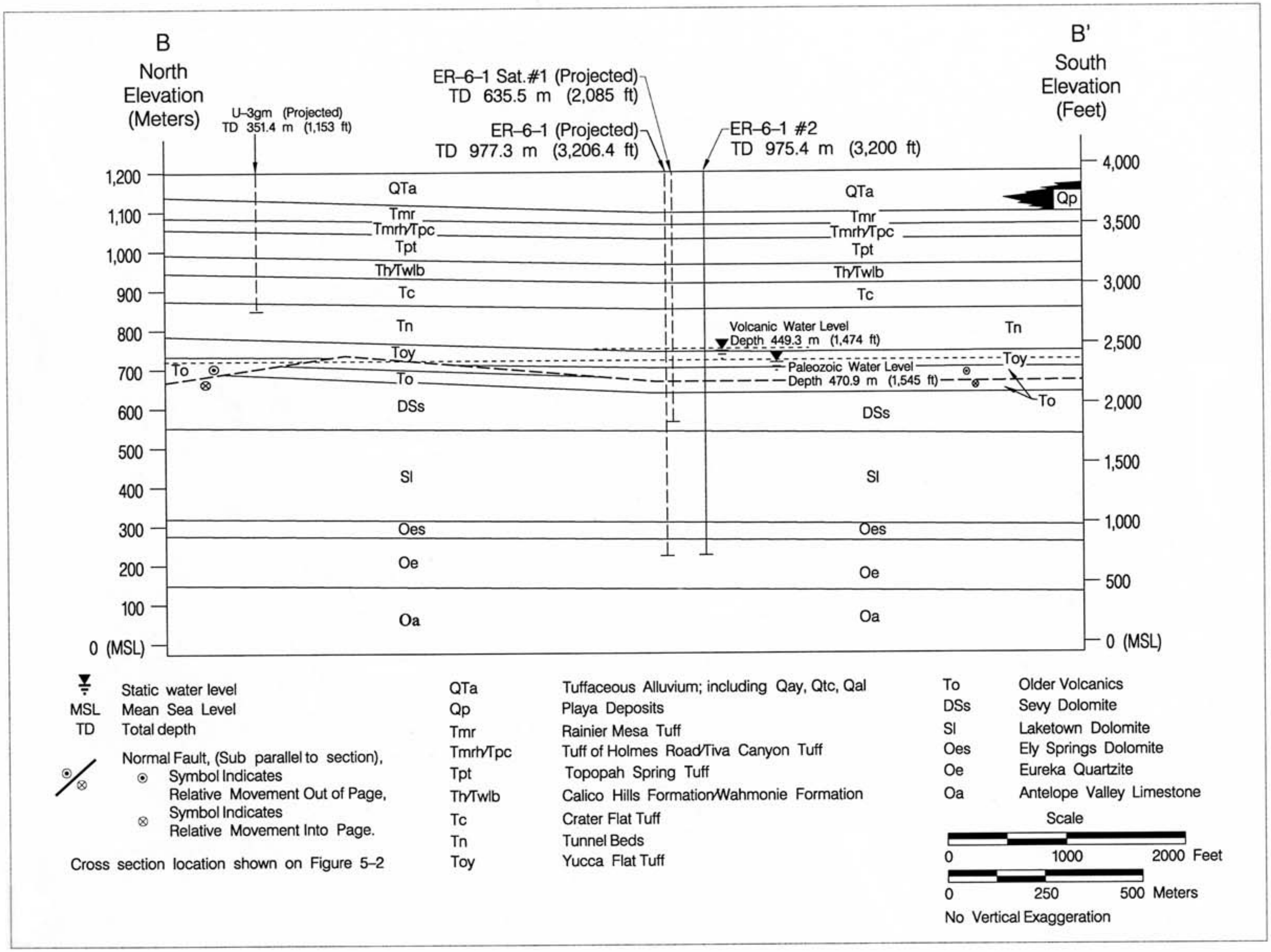


**Figure 5-5**
**North-South Geologic Cross Section B-B′ Through Well Cluster ER-6-1**

observed from visual examination of drill cuttings in each stratigraphic unit encountered in Well Cluster ER-6-1 is illustrated in Figure 5-3. The interval of volcanic rocks above the depth of 237.1 m (778 ft), assigned to the Rainier Mesa Tuff and Paintbrush Group, are mostly unaltered (vitric), with lesser amounts of devitrified, silicic, and zeolitic alteration. The volcanic rocks penetrated below the depth of 237.1 m (778 ft) are mostly bedded tuff, showing zeolitic, silicic, and some argillic alteration. All rocks below 539.5 m (1,770 ft) are unaltered Paleozoic sedimentary rocks consisting mostly of dolomite, with a lesser amount of sandstone and quartzite near the bottom of the boreholes.

## *5.3 Hydrogeology*

The saturated rocks underlying Yucca Flat can be divided into the following hydrogeologic units based in part on their lithologic character: clastic confining unit, carbonate aquifer, tuff confining unit, vitric-tuff aquifer, welded-tuff aquifer, and valley-fill (alluvial) aquifer. These classifications are based on the hydrogeologic framework of the NTS developed by Winograd and Thordarson (1975) and updated by Laczniak et al. (1996). The rocks of Well Cluster ER-6-1 have been subdivided into hydrogeologic units, as illustrated in Figure 5-2. The lowest 68.6 m (225 ft) of the volcanic section (tuff confining unit) and all the Paleozoic sedimentary rocks (carbonate aquifer) are saturated at this location. A preliminary interpretation of the distribution of the hydrogeologic units in the vicinity of Well Cluster ER-6-1 is shown in cross section on Figure 5-6.

Work by Blankennagel and Weir (1973), Winograd and Thordarson (1975), and Laczniak et al. (1996) indicates that the regional groundwater flow is generally to the south and southwest in the Yucca Flat area. Groundwater flow within the carbonate aquifer is assumed to be predominantly through natural fractures. The dominant hydrogeologic unit in Well Cluster ER-6-1 is carbonate aquifer, consisting of mostly dolomite, and comprising approximately 45 percent of the total thickness of rocks penetrated by the wells in the cluster. Thus the detailed fracture analysis of the carbonate section by IT (1996a), which also included comparisons of data from geophysical logs and from core, provides important information concerning the recognition and character of fractures that might transport groundwater.

Analysis of water production data during drilling indicates that the carbonate aquifer rocks produced water at a rate of about 2,270 lpm (600 gpm) to as much as 3,410 lpm (900 gpm). The tuff confining unit present above the Paleozoic carbonate rocks also produces some water in this area. Water production during drilling in this zone was estimated at a rate of about 38 lpm (10 gpm).

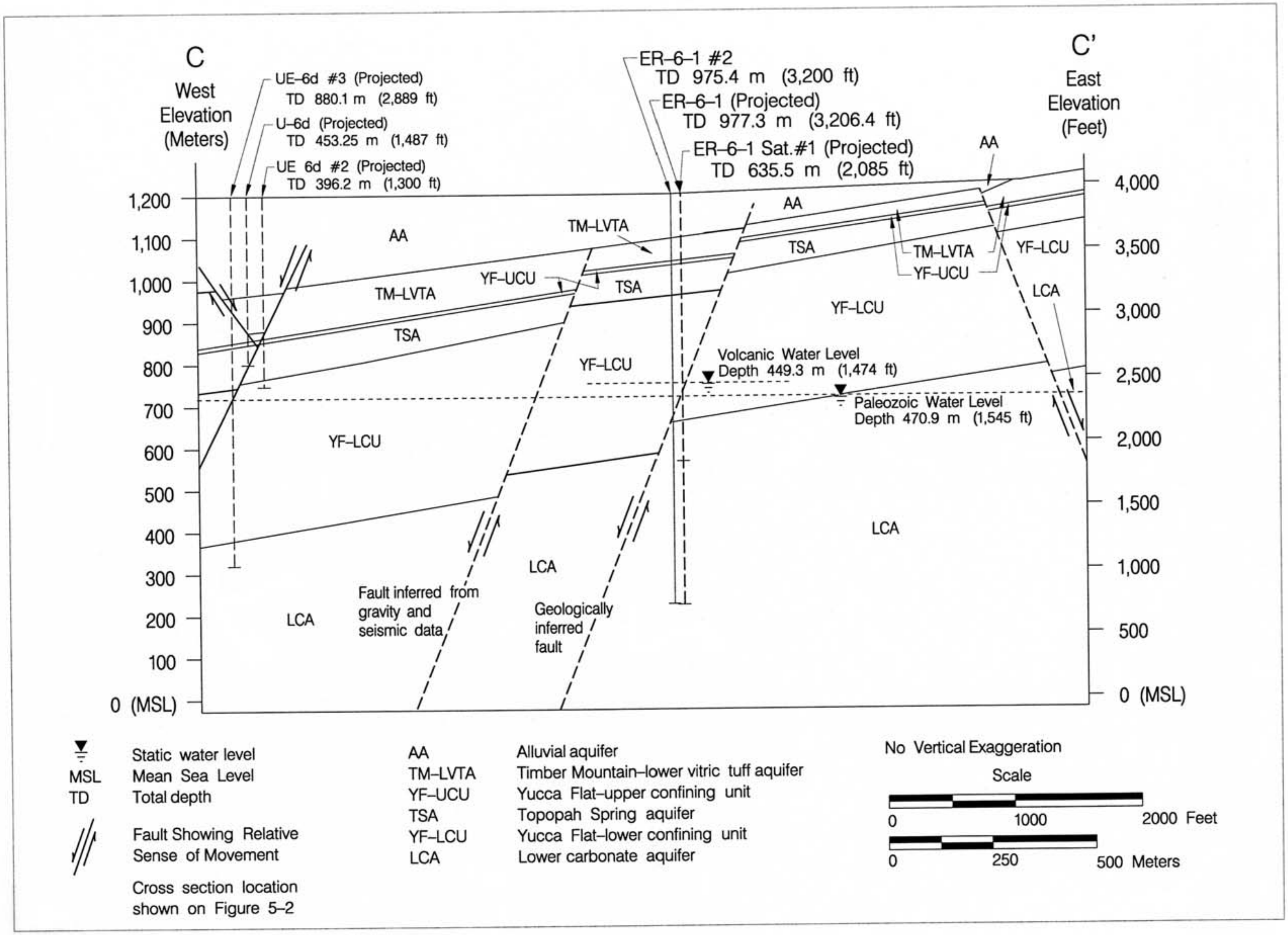


**Figure 5-6**
**Hydrogeologic Cross Section C-C′ Through Well Cluster ER-6-1**

The water level within the Tertiary volcanic section in Well ER-6-1 is approximately 449.3 m (1,474 ft) BGL, and approximately 470.9 m (1,545 ft) BGL in the Paleozoic rocks.  This difference is not unexpected, as fluid levels measured in wells completed in the alluvial aquifer and volcanic units in the eastern two-thirds of Yucca Flat are typically about 20 m (70 ft) higher than in wells completed in the regional carbonate aquifer (Winograd and Thordarson, 1975;  IT, 1996b).  The hydrogeology of these units suggests that the higher elevation of the water table in the overlying Tertiary rocks is related to the presence of low permeability zeolitized tuffs of the tuff confining unit (aquitard) between the Paleozoic and Tertiary aquifers.

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# 6.0 Summary, Recommendations, and Lessons Learned

## 6.1 Summary

Operations commenced at Well Cluster ER-6-1 with the drilling of the conductor hole and setting of the conductor casing for Well ER-6-1 on June 17, 1992. Drilling and completion of Well ER-6-1 began on June 30, 1992, followed by drilling and completion of Well ER-6-1 Satellite Hole #1 in 1993. Well ER-6-1 was deepened by conventional coring in 1994, and a pair of bridge plugs was installed in 1995. After a nine-year hiatus, drilling and completion of Well ER-6-1#2 was accomplished in 2002. Drilling and completion activities at the well cluster were concluded on October 6, 2002.

Crews at Well ER-6-1 worked on a schedule of 5 days per week, 24 hours per day, and 34 working days were expended on well-drilling (to temporary TD of 648.9 m [2,129 ft]), logging, and completion activities. Coring operations at Well ER-6-1 lasted 69 days, during which crews worked on a 7-days-per-week, 24-hours-per-day schedule for most of the operation. Subcontractor activities at Well ER-6-1 Satellite Hole #1 were conducted on a schedule of 5 days per week, 24 hours per day, and 14 working days were expended on well-drilling and logging. Crews worked on a schedule of 7 days per week, 24 hours per day, and 14 working days were expended on drilling, logging, and completion activities at Well ER-6-1#2.

Drilling of the upper 648.9 m (2,129 ft) of Well ER-6-1 took place from June 30 to August 5, 1992. A string of 13d-in. surface casing was set at 547.1 m (1,794.8 ft) in the 57.2-cm (22.5-in.) diameter hole, and a 31.1-cm (12¼-in.) hole was drilled from the bottom of casing to the depth of 639.2 m (2,097 ft). A string of 2 f -in. slotted tubing was installed in the outside of the 13d-in. casing to serve as a piezometer. An 8½-in. diamond core bit was then used to deepen the hole to the TD of 648.9 m (2,129 ft) and obtain two cores. Well ER-6-1 was further deepened by conventional coring beginning on August 17, 1994. A 5½-in. core bit was used to core to a TD of 977.3 m (3,206.4 ft) on October 16, 1994. Geophysical logging was completed prior to rigging down and moving off site. In 1995, two temporary bridge plugs were placed in the borehole to restrict cross flow between two transmissive zones within the lower carbonate aquifer.

Drilling of Well ER-6-1 Satellite Hole #1 to the TD of 636.5 m (2,085 ft) took place July 7-12, 1993. A string of slotted 2 f -in. Hydril® tubing was installed within a gravel-packed interval in the 25.1-cm (9 f -in.) diameter borehole.

Drilling of Well ER-6-1#2 to the TD of 975.4 m (3,200 ft) took place from September 24 to October 4, 2002. A string of 13d-in. surface casing was set at 540.9 m (1,774.6 ft) in dolomite in the 47.0-cm (18½-in.) diameter hole, and a 31.1-cm (12¼-in.) hole was drilled from the bottom of the casing to TD. A string of 2d-in. carbon-steel slotted tubing was landed at 483.6 m (1,586.6 ft) in the annulus between the 13d-in. surface casing and the borehole wall; no gravel packing was installed.

Composite drill cuttings were collected every 3 m (10 ft) in Well ER-6-1 from surface to the drilled depth of 637.0 m (2,090 ft). Additional samples were collected at 15.2-m (50-ft) intervals through the Paleozoic section from 548.6 to 648.9 m (1,800 to 2,129 ft) for paleontologic studies. The remainder of the borehole was continuously cored to the TD of 977.3 m (3,206.4 ft). Cuttings samples were collected from Wells ER-6-1 Satellite Hole #1 and ER-6-1#2 at 3-m (10-ft) intervals from the bottom of the conductor hole to TD. A few intervals were missed due to intermittent or poor fluid returns. The core and cuttings for all three holes are archived at the USGS Geological Data Center and Core Library in Mercury, Nevada.

Geophysical logging was conducted in all three wells in the cluster to aid in construction of the wells, to help verify the geology, and to help characterize the hydrology of the units. Geophysical logs for the holes are on file at BN in Mercury, Nevada, and at the Stoller-Navarro office in Las Vegas, Nevada. Because a very extensive suite of geophysical logs was run in Well ER-6-1, only limited suites of logs were run in Wells ER-6-1 Satellite Hole #1 and ER-6-1#2. However, careful examination of the data indicated that the geology in all three holes is very similar, and the composite stratigraphic log and detailed lithologic log for Well ER-6-1 (the deepest of the three holes) is presented in Appendix C of this report.

The water level within the Tertiary volcanic section in Well ER-6-1 is approximately 449.3 m (1,474 ft) BGL. The fluid level (potentiometric surface for water) within the Paleozoic rocks at this location is 470.9 m (1,545 ft) BGL.

## *6.2 Recommendations*

The planned pump installation in Well ER-6-1#2 and subsequent multi-well tracer experiment must be implemented to accomplish the remaining objectives for this well cluster construction effort.
Well ER-6-1 must also be completed to support the planned tracer experiment; that is, one or more of the temporary bridge plugs placed to prevent in-hole flow between transmissive zones may have to be removed.

In addition, after the planned experiment, data must be evaluated and interpretations of the area hydrology updated and inserted into the UGTA hydrologic model. This process and analysis of the updated model will advance the characterization of groundwater flow direction and velocity in this region of Yucca Flat and the NTS.

### *6.3 Lessons Learned*

This section describes lessons learned during construction of the wells in Well Cluster ER-6-1.

- Air-foam drilling is very erosive, but keeping the penetration rate to no greater than about 6 meters/hour (20 feet/hour) below the water table improves the quality of the drill cuttings used for geologic interpretation.

- Lengthy delays, such as those encountered while drilling Well ER-6-1, could be avoided if certain drilling equipment such as fishing and milling tools were kept on hand.

- It was found that tack-welding straps across temporary casing joints may prevent parting.

- Bridge plugs can be emplaced to isolate transmissive zones if completion of a borehole is delayed.

- The efficiency of drilling and construction to obtain hydrogeologic data in support of the UGTA project continues to improve as experience is gained with each new well.

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# Appendix A
# Drilling Data

- A-1 Well Cluster ER-6-1 Lists of Records of Verbal Communication
- A-2 Well ER-6-1#2 Drilling Parameter Log
- A-3 Well Cluster ER-6-1 Casing and Tubing Data
- A-4 Well Cluster ER-6-1 Drilling Fluids and Cement Composition

# Appendix A-1

## Well Cluster ER-6-1 Lists of Records of Verbal Communication

**Table A-1.1**
**Records of Verbal Communication (RVC) Applicable to Well ER-6-1 Drilling [a]**

| RVC# | Date | Subject |
|---|---|---|
| RVC-0178 | 06/17/1992 | GCP ER-6-1 Program change: Item #1: Cement surface casing |
| RVC-0181 | 06/18/1992 | GCP ER-6-1 Program change: Item #1: Surface casing setting depth |
| RVC-0182 | 06/29/1992 | ER-6-1 Drilling program revisions: Bit program |
| RVC-0183 | 06/30/1992 | ER-6-1 cementing program revisions |
| RVC-0184 and Rev. 1 | 07/01/1992 | Revisions to drilling program for GCP Well ER-6-1: Fluids and logging |
| RVC-0187 | 07/09/1992 | Revision to drilling program for GCP Well ER-6-1: Fluid density log |
| T-92-102 | 07/10/1992 | Logging at ER-6-1 into weekend |
| RVC-0188 | 07/13/1992 | Revision to drilling program for GCP Well ER-6-1: Cleanout |
| T-92-104 | 07/14/1992 | ER-6-1 DIFL Conductivity presentation |
| RVC-0189 | 07/16/1992 | Revision to drilling program for GCP Well ER-6-1: Cleanout, casing, cementing |
| RVC-0192 | 07/16/1992 | Revisions to drilling program for GCP Well ER-6-1: Piezometer & stemming |
| RVC-0193 | 07/17/1992 | Revision to drilling program for GCP Well ER-6-1: Fluid density log |
| RVC-0196 | 07/22/1992 | Revision to drilling program for GCP Well ER-6-1: Tack welding piezo tube |
| RVC-0197 | 07/21/1992 | Revision to drilling program for GCP Well ER-6-1: Mudding up |
| RVC-0202 | 07/30/1992 | Revision to drilling program for GCP Well ER-6-1: Cementing below intermediate casing |
| T-92-116 | 08/03/1992 | Logging in ER-6-1 Saturated interval |
| RVC-0206 | 08/13/1992 | Revision to sampling & test program for GCP Well ER-6-1: Monitoring line size |
| T-92-134 | 09/03/1992 | GZA test |
| T-92-141A | 09/17/1992 | Final prints required urgently |
| RVC-0231 | 09/24/1992 | Revision to drilling program for GCP Well ER-6-1: Construction |
| T-92-150 | 10/07/1992 | Spinner Log in ER-6-1 |
| RVC-0238 | 10/12/1992 | Revision to sampling & test program for GCP Well ER-6-1: 72-hour pumping test |
| RVC-0397 | 07/27/1994 | Coring work schedule for UGTA OU Well ER-6-1 |
| RVC-0409 | 10/25/1994 | Density log at UGTA OU Well ER-6-1 |
| L-95-005 | 05/25/1995 | ER-6-1 and ER-6-2 flow logging and bridge plug setting |
| L-95-006 | 09/11/1995 | Flow logging at ER-6-1 |

a All RVCs are on file at the BN UGTA Project Manager’s office.

**Table A-1.2**
**Records of Verbal Communication (RVC) Applicable to Well ER-6-1 Satellite Hole #1 Drilling and Completion [a]**

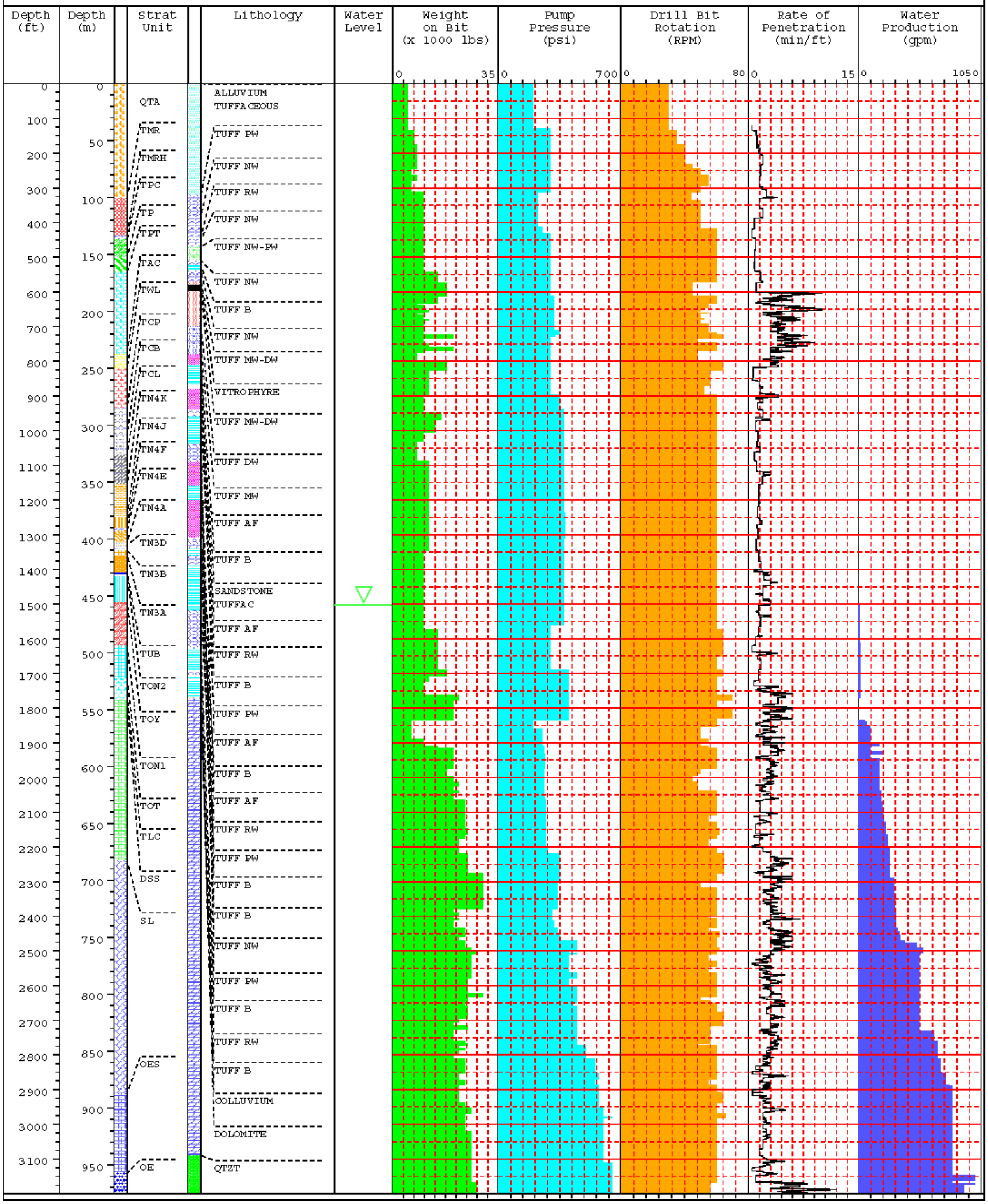
| RVC# | Date | Subject |
|---|---|---|
| RVC-0316 | 07/12/1993 | Revision to drilling program for GCP Well ER-6-1 Satellite#1: Cleanout and logging |
| RVC-0317 | 07/12/1993 | Revision to drilling program for GCP Well ER-6-1 Satellite#1: Cementing |
| L-93-035 | 07/13/1993 | BHTV and directional surveys |
| RVC-0318 | 07/14/1993 | Revision to drilling program for GCP Well ER-6-1 Satellite#1: Completion |
| RVC-0321 | 07/16/1993 | Revision to Drilling Program D-005-002: GCP Well ER-6-1 Satellite #1: Cementing stuck tremie line |
| L-93-036 | 07/20/1993 | Logging at ER-6-1, ER-6-1 Satellite#1, ER-6-2, and ER-19-1 |
| L-94-058 | 02/15/1994 | Analysis of borehole televiewer logs |

a All RVCs are on file at the BN UGTA Project Manager’s office.

# Appendix A-2

## Well ER-6-1#2 Drilling Parameter Log

| | | | |
|---|---|---|---|
| Well:ER-6-1 #2 | Yucca Flat Drilling Program | | Northing: 4093553.1 m |
| Date: 08/29/03 | Start Date: 09/24/02 | Stop Date: 10/07/02 | Easting: 589537.3 m |
| Environmental Contractor: UGTA/Shaw | | Proj No: 840223.03030015 | Surface Elevation:3932.7 ft |
| Drilling Contractor: United | Drilling Method: Air Foam | Geol: J. Wurtz | Drilled Depth: 3200 ft |



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# Appendix A-3

## Well Cluster ER-6-1 Casing and Tubing Data

## Table A-3.1
## Tubing and Casing Data for Well ER-6-1

| **Casing/ Tubing** | **Depth Interval** meters (feet) | **Type** | **Grade** | **Outside Diameter** [a] cm (in.) | **Inside Diameter** cm (in.) | **Wall Thickness** cm (in.) | **Weight per Foot** (pounds) |
|---|---|---|---|---|---|---|---|
| Conductor Casing | 0 to 35.7 (0 to 117.0) | Carbon Steel | K55 | 76.2 (30.0) | 74.30 (29.25) | 0.953 (0.375) | 98.93 |
| Surface Casing | 0 to 546.8 (0 to 1,794.0) | Carbon Steel | J55 | 33.97 (13.375) | 32.042 (12.615) | 0.965 (0.380) | 54.50 |
| Access String | 0 to 545.3 (0 to 1,789.0) | Carbon Steel | N80 | 7.303 (2.875) | 6.27 (2.469) | 0.520 (0.203) | 6.5 |

## Table A-3.2
## Tubing and Casing Data for Well ER-6-1 Satellite Hole #1

| **Casing/ Tubing** | **Depth Interval** meters (feet) | **Type** | **Grade** | **Outside Diameter** [a] cm (in.) | **Inside Diameter** cm (in.) | **Wall Thickness** cm (in.) | **Weight per Foot** (pounds) |
|---|---|---|---|---|---|---|---|
| Conductor Casing | 0 to 36.2 (0 to 118.6) | Carbon Steel | K55 | 33.970 (13.365) | 32.042 (12.6150 | 0.965 (0.380) | 54.5 |
| Access String | 0 to 614.8 (0 to 2,017.2) | Carbon Steel | N80 | 7.303 (2.475) | 6.27 (2.469) | 0.52 (0.203) | 6.5 |

## Table A-3.3
## Tubing and Casing Date for Well ER-6-1#2

| **Casing/ Tubing** | **Depth Interval** meters (feet) | **Type** | **Grade** | **Outside Diameter** [a] cm (in.) | **Inside Diameter** cm (in.) | **Wall Thickness** cm (in.) | **Weight per Foot** (pounds) |
|---|---|---|---|---|---|---|---|
| Conductor Casing | 0 to 36.0 (0 to 118.2) | Carbon Steel | K55 | 50.80 (20.00) | 48.575 (19.124) | 1.113 (0.438) | 94.0 |
| Surface Casing | 0 to 540.9 (0 to 1,774.6) | Carbon Steel | J55 | 33.97 (13.375) | 32.042 (12.615) | 0.965 (0.380) | 54.5 |
| Access String | 0 TO 483.6 (0 to 1,586.6) | Carbon Steel | N/A | 6.03 (2.375) | 4.940 (1.945) | 0.546 (0.215) | 4.67 |

a centimeters (inches)

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# Appendix A-4

## Well Cluster ER-6-1 Drilling Fluids and Cement Composition

## Table A-4.1
## Well ER-6-1 Drilling Fluids

| Typical Air-Foam Mix ("Davis Mix") [a] | Typical Mud Mix [b] |
|---|---|
| 1,814 kilograms (4,000 pounds) bentonite<br><br>530 liters (140 gallons) detergent<br><br>45.4 kilograms (100 pounds) guar gum<br><br>455 kilograms (100 pounds) soda ash | *No. 21 Mud*:<br>1,134 kilograms (2,500 pounds) bentonite or sepiolite<br><br>*No. 24 Mud*:<br>1,497 kilograms (3,300 pounds) bentonite or sepiolite<br><br>*No 25 Mud*:<br>2,495 kilograms (5,500 pounds) bentonite or sepiolite |

a "Davis Mix" air-foam was used as the drilling fluid in Well ER-6-1; proportions listed were added to water to mix 120 barrels of drilling fluid.
b Proportions listed were added to water to mix 120 barrels of drilling fluid.

**NOTES**:
1. All water used to mix drilling fluids for Well ER-6-1 came from Water Well 5B.
2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of 20 milligrams per liter.

## Table A-4.2
## Well ER-6-1 Cement Composition

| Cement Composition | Conductor Casing | Surface Casing | Plugs [a] | Completion |
|---|---|---|---|---|
| Redi-Mix | Inside and outside casing from 32.9 to 36.6 m [b] (108 to 120 ft [c])<br><br>In annulus 0 to 32.9 m (108 ft) | Not used | Not used | Not used |
| Type II plus 2% $CaCl_2$ [d] | Not used | In annulus 0 to 437.4 m (1,435 ft) and 470.0 to 546.8 m (1,542 to 1,794 ft) | 546.8 to 554.4 m (1,794 to 1,819 ft) | Same as surface casing |

a Cement plugs used to emplace cement into borehole to stabilize sloughing intervals; cemented interval was then redrilled.
b Meter(s)
c Feet
d Calcium chloride

## Table A-4.3
## Well ER-6-1 Satellite Hole #1 Drilling Fluids

| Typical Air-Foam/Polymer Mix [a] |
|---|
| 0.22 cubic meters (58 gallons) detergent<br>and<br>13.6 kilograms (30 pounds) Baroid EZ-Mud DP®<br>per<br>19.1 cubic meters (120 barrels) water |

a An air-foam ("soap")/polymer mix was used as the drilling fluid in Well ER-6-1 Satellite Hole #1. Various proportions of polymer were added to the air-foam to suit conditions during drilling.

b EZ-Mud DP® polymer is a product of Baroid Drilling Fluids, Inc.

**NOTES:**

1. All water used to mix drilling fluids for Well ER-6-1 Satellite Hole #1 came from Water Well 5B.

2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of 0.7 to 173 milligrams per liter.

## Table A-4.4
## Well ER-6-1 Satellite Hole #1 Cement Composition

| Cement Composition | Conductor Casing | Plugs [a] | Completion |
|---|---|---|---|
| Type II plus 3% $CaCl_2$ [b] | Inside and outside casing from 33.5 to 36.6 m [c] (110 to 120 ft [d]) | 524.0 to 542.8 m (1,719 to 1,781 ft) | Not used |
| 75% neat and 25% gypsum | In annulus 0 to 33.5 m (110 ft) | Not used | Not used |
| Type II and Type II plus 3% $CaCl_2$ | Not used | 499.9 to 545.3 m (1,640 to 1,789 ft) | Not used |
| Type II plus 2% $CaCl_2$ | Not used | Not used | 1,22.5 to 559.3 (402 to 1,835 ft) |
| Type II | Not used | Not used | 0 to 122.5 m (402 ft) |

a Cement plugs were used to emplace cement into borehole to stabilize sloughing intervals; cemented interval was then redrilled.
b Calcium chloride
c Meter(s)
d Feet

## Table A-4.5
## Well ER-6-1#2 Drilling Fluids

| Typical Air-Foam/Polymer Mix [a] |
|---|
| 11.4 to 37.9 liters (3 to 10 gallons) Geofoam® [b]<br>and<br>7.6 liters (2 gallons) LP701®<br>per<br>7,949 liters (50 barrels) water |

a An air-foam (“soap”)/polymer mix was used as the drilling fluid in Well ER-6-1#2. Various proportions of polymer were added to the air-foam to suit conditions during drilling.

b Geofoam® and LP701® polymer are products of Geo Drilling Fluids, Inc.

**NOTES:**
1. All water used to mix drilling fluids for Well ER-6-1#2 came from Water Well 5B.

2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of 0.7 to 173 milligrams per liter.

## Table A-4.6
## Well ER-6-1#2 Cement Composition

| Cement Composition | 20-inch Conductor Casing | 13 d -inch Surface Casing | Completion 2 d -inch Tubing |
|---|---|---|---|
| 75/25 [a] | 32.9 to 36.0 m [b]<br>(1107 to 118 ft [c]) | Not used | Not used |
| 75/25 and Type II Neat | 13.4 to 32.9<br>(44 to 108 ft) | Not used | Not used |
| Type II Neat | 0 to 13.4<br>(0 to 44 ft) | 483.7 to 540.9 m<br>(1,587 [d] to 1,774.6 ft) | No used |

a 75% neat cement and 25% gypsum
b Meter(s)
c Foot (feet)
d Estimated

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# Appendix B

# Well Cluster ER-6-1 Fluid Management Data

# ER FLUID MANAGEMENT REPORTING FORM

**Site Identification:** ER-6-1 Satellite Hole #1
**Site Location:** Area 6 - NTS
**Site Coordinates:** N 813,951/E 696,759
**Well Classification:** Satellite Observation Hole
**IT Project No:** 301957.116.XX

**Report Date:** 02/22/94
**DOE/NV Project Manager:** S. Lawrence
**IT Project Manager:** J. Eberlin
**IT Site Representative:** F. Baird
**IT Waste Coordinator:** L. Cardenas *lc*

| Well Construction Activity | Activity Duration | | #Ops. Days (A) | Well Depth (m) | Import Fluid ($m^3$) | (SOUTH) Lined Sump #1 ($m^3$) | | (NORTH) Lined Sump #2 ($m^3$) | | Infiltration Area ($m^3$) | Other (C) | Fluid Quality Objectives Met? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | From | To | | | | Solids (B) | Liquids | Solids | Liquids | Liquids | | |
| **Stage I:** Vadose-Zone Drilling | 07/07/93 | 07/08/93 | 2 | 449 | 200 | 22 | 200 | -0- | -0- | -0- | -0- | YES |
| **Stage II:** Saturated-Zone Drilling | 07/08/93 | 07/15/93 | 6 | 625 | 86 | 13 | 100 | -0- | -0- | -0- | -0- | YES |
| **Stage III:** Initial Well Development | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Stage IV:** Aquifer Testing | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Stage V:** Well Completion/Final Development | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Cumulative Production Totals to Date:** | | | 8 | 625 | 286 | 35 | 300 | -0- | -0- | -0- | -0- | YES |

(A) Operational days refer to the number of days that the drill rig was in operation during at least part of one shift.
(B) Solids refer to the drill volume estimates include added volume attributed to interstitial spaces.
(C) "Other" refers to fluid conveyance to other locations or facilities away from the well site, such as vacuum truck transport to another location.
m = Meters; $m^3$ = cubic meters; NA = not applicable
**Total Sump Capacity:** Lined Sump #1 = 7500 $m^3$ Lined Sump #2 = 7500 $m^3$
**Remaining Sump Capacity (Approximate) as of 08/04/93:** Sump #1 = 7135 $m^3$ (95 %) Sump #2 = 7500 $m^3$ (100 %)

IT Authorizing Signature/Date: *John Eberlin*

Well ER-6-1 #2 Fluid Disposition Reporting Form

**Site Identification:** ER-6-1 #2
**Site Location:** Nevada Test Site
**Site Coordinates:** N: 4,093,330 ft E: 589,609 ft
**Well Classification:** ER Hydrogeologic Investigation Well
**Project Number:** 840223-03030015

**Report Date:** 12/02/02
**DOE/NV Project Manager:** Bob Bangerter
**IT Project Manager:** Janet Wille
**IT Site Representative:** Jeff Wurtz
**IT Waste Coordinator:** Patty Gallo

| Well Activity | Activity Duration | | #Ops Days[a] | Well Depth (m) | Import Fluid ($m^3$) | Sump #1 Volumes ($m^3$) | | Sump #2 Volumes ($m^3$) | | Infiltration Area ($m^3$)[c] | Other[d] ($m^3$) | Fluid Quality Objectives Met? |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | From | To | | | | Solids[b] | Liquids | Solids | Liquids | Liquids | | |
| **Phase I:** Vadose-Zone Drilling | 9/24/02 | 9/28/2002 | 5 | 471.2 | 548 | 341.2 | 404.3 | NA | NA | NA | NA | Yes |
| **Phase I:** Saturated-Zone Drilling | 10/1/02 | 10/05/2002 | 5 | 975.4 | 310 | 245.2 | 5,243.2 | NA | NA | NA | NA | Yes |
| **Phase II:** Initial Well Development | Pending | Pending | - | - | - | - | - | - | - | - | - | - |
| **Phase II:** Aquifer Testing | Pending | Pending | - | - | - | - | - | - | - | - | - | - |
| **Phase II:** Final Development | Pending | Pending | - | - | - | - | - | - | - | - | - | - |
| **Cumulative Production Totals to Date:** | | | 10 | 975.4 | 858 | 586.4 | 5,647.5 | NA | NA | NA | NA | Yes |

[a]Operational days refer to the number of days that fluids were produced during at least part (>3 hours) of one shift.
[b]Solids volume estimates include calculated added volume attributed to rock bulking factor.
[c]Ground surface discharge and infiltration within the unlined sump.
[d]Other refers to fluid conveyance to other fluid management locations or facilities away from the well site, such as vacuum truck transport to another well site.

NA = Not applicable m = Meters $m^3$ = Cubic meters

**Total Facility Capacities (at an 15.5 ft fluid level):** Sump #1 = 9,473.8 $m^3$ Sump #2 = 9,473.8 $m^3$
Infiltration Area (assuming very low/no infiltration) = NA $m^3$

**Remaining Facility Capacity (Approximate) as of** 10/05/02 : Sump #1 = 3,239.9 $m^3$ (34%) Sump #2 = 8,980.6 $m^3$ (95%)

Current Average Tritium = (Natural Background) pCi/L

IT Authorizing Signature/Date Janet Wille 3-11-03

# Appendix C

# Well Cluster ER-6-1
# Detailed Lithologic Log

# Detailed Lithologic Log for Well ER-6-1

Compiled by Lance Prothro, Bechtel Nevada

June 1996

Lithologic descriptions for the interval from the surface to 648.9 in (2,129 ft) are from Drellack and others (1992) and were compiled by Sigmund L. Drellack, Jr. and Robert L. McCall of Raytheon Services Nevada. These descriptions are from drill cuttings samples at 3.0-meter (m) (10-foot [ft]) intervals. Descriptions below 648.9 m (2,129 ft) are from IT Corporation (1995a) and were compiled by Lance B. Prothro of Raytheon Services Nevada. These descriptions are from 8.4-centimeter (3.3-inch) conventional core. Only minor modifications for consistency and continuity were made to the original logs. The lithologic descriptions follow Bechtel Nevada Operations Instruction OI-2152.203. Stratigraphic contacts and lithologic divisions are tied to geophysical logs whenever possible. Stratigraphic nomenclature is generally from Ferguson and others (1994). Paleontological analyses by J. C. Cole and A. G. Harris of the U.S. Geological Survey confirmed most of the original stratigraphic assignments below 648.9 m (2,129 ft) (Cole and Harris, 1996 [a]). The analyses indicate that the original assignment of Laketown Dolomite for the interval 648.9 - 680.9 in (2,129 - 2,234 ft) is incorrect. The interval is actually Sevy Dolomite and has been reassigned accordingly. Based on this reassignment and previous paleontological work by Harris on drill cuttings from the overlying interval of dolostone (Cole and Harris, 1996 [a]), the interval 539.5 - 648.9 in (1,770 - 2,129 ft) has also been reassigned to the Sevy Dolomite.

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 0 - 101.5 (0 - 333) | 101.5 (333) | **Tuffaceous Alluvium:** Light-brown to moderate-brown (5 YR 3/4) and moderate-yellowish-brown; non-indurated to poorly indurated, rare fairly indurated caliche-cemented aggregates; poorly sorted, silt to pebble sizes; tuffaceous with less than 2% Paleozoic rock fragments; less than 1% total carbonate fragments; subrounded to subangular; calcareous. Sandy in parts, particularly above 61 m (200 ft). Granule and larger sized pieces are largely Rainier Mesa Tuff (Tmr) lithology with lesser Topopah Spring Tuff (Tpt) and other pre-Rainier units. Tpt constituent increasing in the interval 67 to 88 m (220 to 290 ft). | Alluvium |
| 101.5 - 111.3 (333 - 365) | 9.8 (32) | **Partially Welded Ash-Flow Tuff:** Light-gray with purplish tint; devitrified; strong vapor-phase mineralization; fair induration; minor light-brownish-gray to moderate-yellowish-brown pumice; minor dipyramidal quartz and feldspar phenocrysts; scarce mafic minerals; scarce lithic fragments. | mafic-poor Rainier Mesa Tuff |
| 111.3 - 117.3 (365 - 385) | 6.1 (20) | **Partially Welded Ash-Flow Tuff:** Grayish-red to moderate-brown; well indurated; becoming moderate-reddish-brown and less indurated below 113 m (370 ft); vitric; common pale-red pumice; abundant clear glass shards. | |

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 117.3 - 128.0 (385 - 420) | 10.7 (35) | **Nonwelded Ash-Flow Tuff:** Pale-reddish-brown to moderate-reddish-brown; friable; vitric; common pumice, sizes to greater than 1 cm in diameter; common quartz and feldspar phenocrysts; scarce to rare mafic minerals; rare lithic fragments; very abundant clear glass shards. | mafic-poor Rainier Mesa Tuff |
| 128.0 - 134.1 (420 - 440) | 6.1 (20) | **Nonwelded Ash-Flow Tuff:** Pale-reddish-brown to moderate-orange-pink; fair induration to friable; vitric; common grayish-orange-pink to pinkish-gray pumice; minor to common quartz and feldspar phenocrysts; scarce mafic minerals; rare lithic fragments. | |
| 134.1 - 137.1 (440 - 450) | 3.0 (10) | **Reworked Tuff:** Light-brown to moderate-brown; well indurated; vitric to devitrified; calcareous to weakly silicified; rare pumice; common to abundant feldspar and quartz phenocrysts; rare small mafic minerals of hornblende, biotite, and magnetite; rare lithic fragments. | tuff of Holmes Road |
| 137.1 - 143.2 (450 - 470) | 6.1 (20) | **Nonwelded Ash-Flow Tuff:** Moderate-yellowish-brown; moderate induration; vitric; dark-yellowish-orange to dark-yellowish-brown pumice to > 2 cm in diameter; shard rich; scarce feldspar phenocrysts; very scarce mafic minerals, including biotite and clinopyroxene; very scarce lithic fragments. | Tiva Canyon Tuff |
| 143.2 - 149.3 (470 - 490) | 6.1 (20) | **Nonwelded to Partially Welded Ash-Flow Tuff:** Dark-yellowish-brown; well indurated; vitric (glass shards) to devitrified (matrix) to silicified, some sucrosic secondary mineralization, possibly weakly zeolitized; minor moderate-brown pumice; phenocryst poor; porous texture, 0.1-mm voids. | |
| 149.3 - 152.7 (490 - 501) | 3.4 (11) | **Nonwelded Ash-Flow Tuff:** Moderate to dark-yellowish-brown; poorly indurated, friable; vitric; shard rich; very (shard-rich base) scarce pumice; phenocryst poor; trace biotite; trace lithic fragments. | |
| 152.7 - 166.1 (501 - 545) | 13.4 (44) | **Bedded Tuff:** Grayish-orange and moderate-yellowish-brown to yellowish-gray to pale-greenish-yellow; moderately to well indurated; zeolitized; some sucrosic secondary mineralization; common pale-greenish-yellow pumice to 1 cm in diameter; scarce feldspar phenocrysts; scarce to rare mafic minerals including clinopyroxene, including distinct small $MnO_2$ stains, an increase in mafic minerals around 160-163 m (525-535 ft), rare to minor lithic fragments. | Paintbrush Group, undifferentiated |

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 166.1 - 169.1 (545 - 555) | 3.0 (10) | **Nonwelded Ash-Flow Tuff:** Moderate-yellowish-brown; moderately indurated to friable; zeolitized; possibly sucrosic secondary mineralization; common light-olive-gray to dark-yellowish-brown pumice; rare felsic phenocrysts; scarce mafic minerals; very scarce lithic fragments. | Topopah Spring Tuff |
| 169.1 - 170.6 (555 - 560) | 1.5 (5) | **Moderately to Densely Welded Ash-Flow Tuff:** Moderate-brown; very hard and dense; devitrified; minor feldspar phenocrysts. | |
| 170.6 - 175.2 (560 - 575) | 4.6 (15) | **Densely Welded Ash-Flow Tuff:** Black; vitrohyre; perlitic glass texture; minor to common black flattened pumice; minor feldspar phenocrysts. Some mottled with moderate-brown, densely welded, and devitrified. | Topopah Spring Tuff (vitrophyre) |
| 175.2 - 184.0 (575 - 604) | 8.8 (29) | **Moderately to Densely Welded Ash-Flow Tuff:** Mottled moderate-brown and grayish-red; devitrified; minor pumice; minor feldspar phenocrysts; very scarce mafic (minerals, including clinopyroxene and biotite; scarce lithic fragments. Conspicuous lithophysae cavities to 5 cm in diameter noted in down-hole camera video. Euhedral quartz clusters with individual crystals <1 mm to 3 mm in length present in cuttings samples. | Topopah Spring Tuff (lithophysal zone) |
| 184.0 - 213.3 (604 - 700) | 29.3 (96) | **Moderately to Densely Welded Ash-Flow Tuff:** Pale-brown; very hard and dense; devitrified; rare pumice with some vapor-phase mineralization; rare feldspar phenocrysts; scarce mafic minerals (bronze biotite); very scarce lithic fragments. | Topopah Spring Tuff |
| 213.3 - 225.5 (700 - 740) | 12.2 (40) | **Densely Welded Ash-Flow Tuff:** Moderate-brown; very hard and dense; vitric to partially devitrified; some anastomosing devitrification (“leopard spots”), dark-grayish-red and moderate-brown; phenocryst poor; very scarce mafic minerals; very scarce lithic fragments. | |
| 225.5 - 231.6 (740 - 760) | 6.1 (20) | **Moderately Welded Ash-Flow Tuff:** Olive-black glass shards in a moderate- brown matrix; well indurated; vitric; “basal vitrophyre;” very abundant translucent olive-black glass shards; phenocryst poor. | Topopah Spring Tuff (“basal vitrophyre”) |
| 231.6 - 237.1 (760 - 778) | 5.5 (18) | **Nonwelded to Partially Welded Ash-Flow Tuff:** Moderate-yellowish-brown; moderate- to dark-yellowish-brown matrix and very abundant olive-black glass shards; well indurated; vitric; phenocryst poor. | Topopah Spring Tuff |

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 237.1 - 240.2 (778 - 788) | 3.05 (10) | **Air-Fall Tuff:** Pale-yellow-brown; vitric; moderate induration; abundant clear to translucent very-light-gray glass shards; minor to common light-gray pumice, 3 mm to several centimeters in diameter, and light-brown pumice, 1 to 6 mm in diameter; minor felsic phenocrysts; scarce mafic minerals; rare lithic fragments. | mafic-poor Calico Hills Formation |
| 240.2 - 251.8 (788 - 826) | 11.6 (38) | **Bedded Tuff:** Grayish-orange to moderate-yellowish-brown; moderately to well indurated; zeolitized; generally common to abundant very-pale-orange pumice, common feldspar and quartz phenocrysts; rare mafic minerals; rare to minor lithic fragments. | |
| 251.8 - 254.5 (826 - 835) | 2.7 (9) | **Bedded Tuff:** Moderate-yellowish-brown; moderate induration; zeolitized; minor pumice; mafic rich, mostly biotite, some hornblende; minor lithic fragments. | tuff of Wahmonie Flat |
| 254.5 - 257.6 (835 - 845) | 3.05 (10) | **Bedded Tuff:** Pale-greenish-yellow to grayish-yellow; good induration; zeolitized; mafic rich, mostly biotite and magnetite, some hornblende, trace clinopyroxene; common to indistinct pale-greenish-yellow pumice; abundant feldspar phenocrysts; rare lithic fragments; possibly interbedded with dark-yellowish-brown reworked tuff and tuffaceous sandstone described below. | |
| 257.6 - 260.6 (845 - 855) | 3.05 (10) | **Tuffaceous Sandstone:** Dark-yellowish-brown; moderate induration; zeolitized; fine grained; bedded; mafic rich, mostly biotite; common small lithic fragments. NOTE: The 259-m (850-ft) cuttings sample is contaminated with cavings from up-hole. | |
| 260.6 - 269.4 (855 - 884) | 8.8 (29) | **Air-Fall Tuff:** Pale-greenish-yellow; good induration; zeolitized; mafic-rich, mostly biotite; minor feldspar phenocrysts; rare lithic fragments. Possibly some tuffaceous sandstone as above. | |
| 269.4 - 279.8 (884 - 918) | 10.4 (34) | **Air-Fall Tuff:** Grayish-yellow; good induration; zeolitized; abundant to indistinct pale-greenish-yellow pumice; scarce quartz and feldspar phenocrysts; scarce mafic minerals, rare $MnO_2$ stains; minor lithic fragments 0.5 to 2 mm in diameter. Trace botryoidal chalcedony vein material in the 277.4-m (910-ft) sample. | Crater Flat Group, undifferentiated or Calico Hills Formation |
| 279.8 - 285.3 (918 - 936) | 5.5 (18) | **Reworked Tuff grading to Tuffaceous Sandstone:** Dark-yellowish-brown; good induration; zeolitized; minor small, very-pale-orange pumice; mafic-rich; common feldspar phenocrysts; minor small lithic fragments. This lithology is represented in cuttings samples from 286.5 and 289.6 m (940 and 950 ft). | tuff of Wahmonie Flat |

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 285.3 - 300.5 (936 - 986) | 15.2 (50) | **Bedded Tuff:** Grayish-orange; well indurated; zeolitized; common pale-greenish-yellow pumice to 1 cm in diameter; minor to common feldspar and quartz phenocrysts; common small lithic fragments 0.25 to 1 mm in diameter; rare mafic minerals of biotite, magnetite, trace hornblende. | Prow Pass Tuff |
| 300.5 - 307.2 (986 - 1,008 | 6.7 (22) | **Bedded Tuff:** Grayish-yellow; well indurated; zeolitized; small to indistinct pale-greenish-yellow pumice; abundant feldspar and quartz phenocrysts; minor mafic minerals, biotite dominant, magnetite, trace hornblende; minor lithic fragments, typically 0.5 to 1 mm in diameter. Grades to tuffaceous sandstone in parts. | |
| 307.2 - 324.9 (1,008 - 1,066 | 17.7 (58) | **Partially Welded Ash-Flow Tuff:** Grayish-orange; well indurated; zeolitized; minor to common pumice; rare felsic phenocrysts; rare mafic minerals, mostly biotite, some hornblende; rare lithic fragments; trace silicified in upper 3 m (10 ft). | Bullfrog Tuff |
| 324.9 - 333.7 (1,066 - 1,095) | 8.8 (29) | **Air-Fall Tuff:** Grayish-yellow; fairly indurated; zeolitized; common grayish-yellow to pale-greenish-yellow pumice; minor feldspar and quartz phenocrysts; rare mafic minerals of biotite, hornblende, and magnetite; scarce moderate-brown (5 YR 4/4) lithic fragments up to 10 mm in diameter. | Tram Tuff |
| 333.7 - 352.9 (1,095 - 1,158) | 19.2 (63) | **Air-Fall Tuff:** Moderate-yellowish-brown; well indurated; zeolitized; abundant very pale-orange to pale-greenish-yellow pumice 0.5 to 2 mm in diameter; minor felsic phenocrysts; minor mafic minerals; rare lithic fragments. | Crater Flat Group lower tuff (informal unit) |
| 352.9 - 364.5 (1,158 - 1,196) | 11.6 (38) | **Bedded Tuff:** Moderate-yellowish-brown, some mottled with moderate-reddish-brown; moderately indurated; zeolitized; common very-pale-orange pumice; minor felsic phenocrysts; minor to common mafic minerals including biotite, trace pyroxene; rare lithic fragments. | Tunnel Formation, Tunnel 4 Member, bed 4K |
| 364.5 - 377.3 (1,196 - 1,238) | 12.8 (42) | **Air-Fall Tuff:** Moderate-reddish-brown; well indurated; zeolitized; abundant grayish-orange-pink pumice, 0.5 to 3 mm in diameter, some with mafic minerals; minor felsic phenocrysts; common mafic minerals, mostly biotite with lesser hornblende; rare lithic fragments. | |
| 377.3 - 381.0 (1,238 - 1,250) | 3.7 (12) | **Air-Fall Tuff:** Yellowish-gray to very-light-gray; fair induration; zeolitized; mafic-rich, mostly biotite and hornblende; common felsic phenocrysts; indistinct very-light-gray pumice; scarce lithic fragments. | |

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 381.0 - 390.1 (1,250 - 1,280) | 9.1 (30) | **Air-Fall Tuff:** Moderate-reddish-brown; moderately to well indurated; zeolitized to argillized; common very-pale-orange pumice; rare felsic phenocrysts, feldspar and lesser quartz; rare mafic minerals (biotite, magnetite, clinopyroxene); scarce lithic fragments. | Tunnel Formation, Tunnel 4 Member, bed 4J |
| 390.1 - 392.6 (1,280 - 1,288) | 2.5 (8) | **Reworked Tuff:** Grayish-orange to pale-yellowish-orange to moderate-reddish-orange; moderately indurated; zeolitized to weakly argillized; minor very-pale-orange pumice; rare felsic phenocrysts; scarce mafic minerals (biotite); rare lithic fragments. | Tunnel Formation, Tunnel 4 Member, beds 4FGH, undifferentiated |
| 392.6 - 401.7 (1,288 - 1,318) | 9.1 (30) | **Partially Welded Ash-Flow Tuff:** Mottled grayish-orange and moderate-reddish-brown; moderately indurated; zeolitized; minor pale-yellowish-orange to grayish-yellow pumice to 8 mm in diameter; rare felsic phenocrysts, generally feldspar with lesser quartz; rare mafic minerals (biotite and magnetite); rare to minor lithic fragments to 7 mm in diameter. | Tunnel Formation, Tunnel 4 Member, bed 4E (equivalent) |
| 401.7 - 405.4 (1,318 - 1,330) | 3.7 (12) | **Bedded Tuff:** Grayish-orange to moderate-yellowish-brown; moderately indurated; zeolitized; common grayish-orange pumice; common felsic phenocrysts; scarce mafic minerals; rare lithic fragments. | Tunnel Formation, Tunnel 4 Member, beds 4ABCD, undifferentiated |
| 405.4 - 409.7 (1,330 - 1,344) | 4.3 (14) | **Bedded Tuff:** Moderate-reddish-brown; well indurated; zeolitized to weakly argillized; abundant very-pale-orange pumice up to 2 mm in diameter; minor felsic phenocrysts; rare mafic minerals, rare lithic fragments. | Tunnel Formation, Tunnel 3 Member, bed 3D |
| 409.7 - 414.6 (1,344 - 1,360) | 4.9 (16) | **Nonwelded Ash-Flow Tuff:** Mottled with grayish-yellow and moderate-reddish-orange; moderately indurated; rare grayish-yellow to very-pale-orange pumice; very scarce felsic phenocrysts; very scarce mafic minerals; scarce lithic fragments. Abundant glass shard molds. | Tunnel Formation, Tunnel 3 Member, beds 3BC (equivalent) |
| 414.6 - 429.2 (1,360 - 1,408) | 14.6 (48) | **Bedded Tuff:** Moderate-reddish-brown; well indurated; zeolitized to argillized; minor very-pale-orange pumice; rare to scarce felsic phenocrysts; rare mafic minerals (biotite, magnetite); very scarce lithic fragments. | Tunnel Formation, Tunnel 3 Member, bed 3A |
| 429.2 - 432.2 (1,408 - 1,418) | 3.05 (10) | **Bedded Tuff:** Dusky-yellow; peralkaline; well indurated; zeolitized; indistinct pumice; common felsic phenocrysts including dipyramidal quartz; scarce magnetite; rare lithic fragments. | Tub Spring Tuff |

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 432.2 - 440.4 (1,418 - 1,445) | 8.2 (27) | **Bedded Tuff:** Grayish-yellow; well indurated; zeolitized; common pale-greenish-yellow pumice; common felsic phenocrysts; rare to minor mafic minerals (biotite, magnetite); minor lithic fragments. | Tunnel Bed 2 |
| 440.4 - 446.5 (1,445 - 1,465) | 6.1 (20) | **Bedded Tuff:** Grayish-yellow to pale-greenish-yellow, some mottled with grayish-orange-pink; moderately indurated; zeolitized; minor pale-greenish-yellow to grayish-orange- pink pumice to 15 mm in diameter; minor felsic phenocrysts; minor mafic minerals (magnetite, biotite); very scarce lithic fragments. | |
| 446.5 - 455.7 (1,465 - 1,495) | 9.1 (30) | **Bedded Tuff:** Moderate-reddish-brown; well indurated; zeolitized, possibly weakly argillized in some intervals; abundant very-pale-orange pumice up to 2 mm in diameter; rare felsic phenocrysts; rare mafic minerals and lithic fragments. | |
| 455.7 - 492.9 (1,495 - 1,617) | 37.2 (122) | **Partially Welded Ash-Flow Tuff:** Yellowish-gray; well indurated; zeolitized; minor grayish-yellow to pale-greenish-yellow pumice, some with sucrosic secondary mineralization; common felsic phenocrysts of feldspar and quartz, decreasing to minor with depth; common mafic minerals, biotite dominant; minor lithic fragments to 20 mm in diameter. | Yucca Flat Tuff |
| 492.9 - 506.0 (1,617 - 1,660) | 13.1 (43) | **Bedded Tuff:** Grayish-yellow; well indurated; zeolitized; common to indistinct grayish-yellow pumice to 5 mm in diameter; felsic phenocrysts variable from rare to abundant; minor mafic minerals, mostly biotite and magnetite; rare lithic fragments. | Tunnel Bed 1 |
| 506.0 - 510.6 (1,660 - 1,675) | 4.6 (15) | **Bedded Tuff:** Dark-reddish-brown; well indurated; zeolitized to weakly argillized; common pale-red pumice exhibiting corroded texture; minor felsic phenocrysts; minor mafic minerals; scarce lithic fragments; sucrosic texture. | |
| 510.6 - 513.6 (1,675 - 1,685) | 3.05 (10) | **Bedded Tuff:** Grayish-yellow; well indurated; zeolitized; common to indistinct grayish-yellow pumice; abundant large felsic phenocrysts, including some quartz; common biotite; rare lithic fragments. | |
| 513.6 - 516.6 (1,685 - 1,695) | 3.05 (10) | **Reworked Tuff:** Moderate-reddish-brown; well indurated; zeolitized to weakly argillized; common very-pale-orange pumice, becoming rare in lower half of interval; abundant felsic phenocrysts; rare mafic minerals of biotite and magnetite; rare small lithic fragments. | |

| Depth Interval meters (feet) | Thickness meters (feet) | Lithologic Description | Stratigraphic Unit |
|---|---|---|---|
| 516.6 - 522.4 (1,695 - 1,714) | 5.8 (19) | **Bedded Tuff:** Moderate- to dark-reddish-brown; poorly to fairly indurated; zeolitized to strongly argillized; scarce to rare pumice; common felsic phenocrysts; rare mafic minerals; lithic fragments vary from rare to common in reworked zones. Lower contact is probable fault zone. | Tunnel Bed 1 |
| 522.4 - 526.7 (1,714 - 1,728) | 4.3 (14) | **Bedded Tuff:** Grayish-orange-pink to moderate-orange-pink; fair to moderate induration; zeolitized; rare grayish-yellow pumice up to 4 mm in diameter; rare to minor felsic phenocrysts; rare mafic minerals; rare lithic fragments. | Older tuffs, undifferentiated |
| 526.7 - 530.4 (1,728 - 1,740) | 3.7 (12) | **Bedded Tuff:** Moderate- to dark-reddish-brown; poor to fair induration; zeolitized and argillized; generally common very-pale-orange pumice. Some argillized reworked lithologies with rare pumice; minor felsic phenocrysts; rare mafic minerals and lithic fragments. | |
| 530.4 - 538.0 (1,740 - 1,765) | 7.6 (25) | **Bedded Tuff (?):** Grayish-orange, delicately mottled with moderate-reddish-brown; fairly indurated; zeolitized to weakly argillized; minor very-pale-orange pumice; minor felsic phenocrysts; minor mafic minerals (biotite and magnetite); rare lithic fragments. Thin calcite filled fractures. | |
| 538.0 - 539.5 (1,765 - 1,770) | 1.5 (5) | **Paleocolluvium:** Moderate to dark-reddish-brown: poorly indurated to friable; argillized; tuffaceous; minor grayish-orange-pink pumice; minor felsic phenocrysts; scarce small Paleozoic rock fragments. | tuffaceous Paleocolluvium |
| 539.5 - 648.9 (1,770.- 2,129) Temporary TD | 109.4 (359) | **Dolostone:** Light-olive-gray; fine to medium crystalline; dense; hard; trace vuggy porosity with subhedral dolomite crystals. Some sucrosic texture (on fracture surfaces), trace calcareous; trace moderate-reddish-orange argillaceous fracture fill/coatings. Trace grayish-red to moderate-reddish-brown iron-oxide stain on some fracture surfaces. Moderate-reddish-brown finely laminated/fissile clay fracture fill in the cuttings sample from 612.6 m (2,010 ft). | Sevy Dolomite |
| 648.9 - 680.9 (2,129 - 2,234) | 32.0 (105) | **Dolostone:** Light-brownish-gray; cryptocrystalline to medium crystalline; vuggy, with less than 5% vuggy porosity. Vugs are less than 10 mm in size and lined in part with subhedral dolomite crystals. | |
| 680.9 - 701.0 (2,234 - 2,300) | 20.1 (66) | **Dolostone:** Medium-dark-gray to dark-gray; medium crystalline; vuggy in part; scattered nodules and lenses of pale-reddish-brown, black, and very-pale-orange chert; brecciated in part. | Laketown Dolomite |

| **Depth Interval** meters (feet) | **Thickness** meters (feet) | **Lithologic Description** | **Stratigraphic Unit** |
|---|---|---|---|
| 701.0 - 724.2 (2,300 - 2,376) | 23.2 (76) | **Dolostone:** Light-brownish-gray; finely crystalline; vuggy, with less than 5% vuggy porosity. Vugs are less than 10 mm in size and lined in part with subhedral dolomite crystals. Brecciated from approximately 712.9 to 713.5 m (2,339 to 2,341 ft). | Laketown Dolomite |
| 724.2 - 748.9 (2,376 - 2,457) | 24.7 (81) | **Dolostone:** Medium-gray to medium-dark-gray; finely to medium crystalline. Abundant dark-yellowish-orange clay occurs as fracture fillings from approximately 730.6 to 742.2 m (2,397 to 2,435 ft). | |
| 748.9 - 890.0 (2,457 - 2,920) | 141.1 (463) | **Dolostone:** Light-brownish-gray to brownish-gray; finely crystalline; vuggy, with <5% vuggy porosity. Vugs are less than I0 mm in size and lined in part with subhedral calcite and dolomite crystals. Fossiliferous from approximately 800.1 to 809.2 in (2,625 to 2,655 ft) consisting of relict shell fragments. Brecciated in part to 823.0 m (2,700 ft) with conspicuous moderate-reddish-brown clay as fracture fillings | |
| 890.0 - 940.6 (2,920 - 3,086) | 50.6 (166) | **Dolostone:** Medium-gray to medium-dark-gray to 906.2 in (2973 ft), pale- yellowish-brown from 906.2 to 915.0 m (2,973 to 3,002 ft), and medium-dark-gray to dark gray below 915.0 m (3,002 ft); medium crystalline; abundant lenses of pale-yellowish-brown to dark-yellowish-brown chert from 918.4 to 936.7 m (3,013 to 3,073 ft). | Ely Springs Dolomite |
| 940.6 - 952.2 (3,086 - 3,124) | 11.6 (38) | **Sandstone:** Light-brownish-gray to brownish-gray, mottled in part; well indurated; 70% fine- to medium-grained, well sorted, subrounded quartz sand; 30% dolomite cement becoming mostly silica-cemented near base of interval. | Eureka Quartzite |
| 952.2 - 977.2 (3,124 - 3,206) Final TD | 25.0 (82) | **Quartzite:** Light-brownish-gray to pale-yellowish-brown to 965.9 m (3,169 ft); very-pale-orange to grayish-orange below; very well indurated; 85% medium-grained, very well sorted, subrounded to rounded quartz sand; 15% silica cement. | |

a Cole, J. C., and A. G. Harris, 1996. Written communication. Subject: *Stratigraphic and Structural Interpretation of Paleontologic Studies and Core Logging, ER-6-1 and ER-6-2 Wells, Nevada Test Site*. U.S. Geological Survey Assessment Task WBS 1.4.1.2.1.02.01.06. Las Vegas, NV.

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# Appendix D

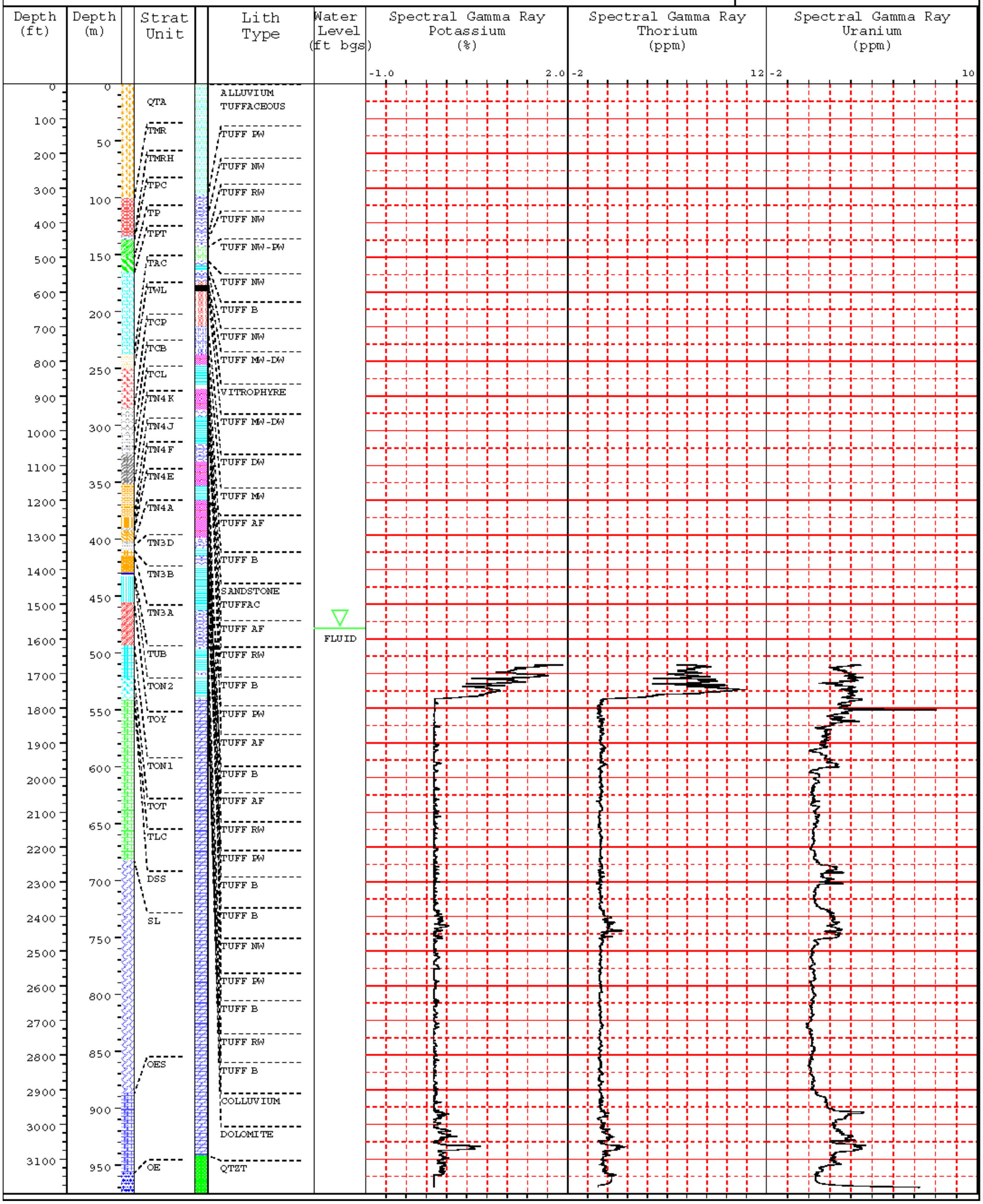
# Well ER-6-1#2
# Geophysical Logs

Appendix D contains unprocessed data presentations of selected geophysical logs run in Well ER-6-1#2. Table D-1 summarizes the logs presented. See Table 4-3 for more information.

**Table D-1**
**Geophysical Log Summary for Well ER-6-1#2**

| Log Type | Run Number | Date | Log Interval meters | Log Interval feet |
|---|---|---|---|---|
| Spectral Gamma Ray (potassium, thorium, uranium) | SGR-1 | 10/05/2002 | 510.5 - 969.9 | 1,675 - 3,182 |

| | | | |
|---|---|---|---|
| Well Name: ER-6-1 #2 | Yucca Flat Drilling Program | | Northing: 4093553.1 m |
| Date: 08/29/03 | Start Date: 09/24/02 | Stop Date: 10/07/02 | Easting: 589537.3 m |
| Environmental Contractor: UGTA/Shaw | | Proj No: 840223.03030015 | Surface Elevation:3932.7 ft |
| Drilling Contractor: United | Drilling Method: Air Foam | Geol: J. Wurtz | Drilled Depth: 3200 ft |



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