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COMPLETION REPORT FOR WELL CLUSTER ER-20-6

DOE Nevada Operations Office
Las Vegas, Nevada

MASTER

February 1998

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COMPLETION REPORT FOR
WELL CLUSTER ER-20-6

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List of Acronyms and Abbreviations

AIN	Annulus Investigation Log
AWS	Atlas Wireline Service
bgs	Below ground surface
BHA	Bottom-hole assembly
BHI	Baker Hughes INTEQ
BN	Bechtel Nevada
BOP	Blow-out prevention system
$CaCl_2$	Calcium chloride
cm	Centimeter(s)
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DOE	U.S. Department of Energy
DOE/ERD	U.S. Department of Energy, Environmental Restoration Division
DRI	Desert Research Institute
EC	Electrical conductivity
FMP	Fluid Management Plan
ft	Foot (feet)
ft/hour	Foot (feet) per hour
ft^3	Cubic feet
gal	Gallon(s)
gpm	Gallon(s) per minute
IDW	Investigation-derived waste
in.	Inch(es)
IT	IT Corporation
LCM	Lost circulation material
LFA	Lava-flow aquifer
Lpm	Liter(s) per minute
m	Meter(s)
m/hour	Meters(s) per hour
m^3	Cubic meter(s)
NTS	Nevada Test Site
od	Outside diameter
pCi	Picocurie(s)

pCi/L	Picocurie(s) per liter
REECo	Reynolds Electrical & Engineering Co. Inc.
RSN	Raytheon Services Nevada
TCU	Tuff confining unit
TD	Total depth
TFM	Thermal flow meter
TWG	Technical Working Group
UGTA	Underground Test Area
USGS	U.S. Geological Survey
WP	Working point

1.0 Introduction

1.1 Project Description

The Well Cluster ER-20-6 drilling and completion project was conducted during February, March, and April of 1996 for the U.S. Department of Energy, Nevada Operations Office (DOE/NV), in support of the Nevada Environmental Restoration Project at the Nevada Test Site (NTS), Nye County, Nevada. This project is part of the DOE's Underground Test Area (UGTA) subproject at the NTS. The primary UGTA tasks include collecting geological, geophysical, and hydrological data from new and existing wells to define groundwater quality as well as pathways and rates of groundwater migration at the NTS. A program of drilling wells near the sites of selected underground nuclear tests (near-field drilling) was implemented as part of the UGTA subproject to obtain site-specific data on the nature and extent of migration of radionuclides produced by an underground nuclear explosion. Well Cluster ER-20-6 is the second UGTA near-field drilling project initiated at the NTS, immediately following the first, Well Cluster ER-20-5.

Well Cluster ER-20-6 is located on Pahute Mesa in Area 20, in the northwestern corner of the NTS (Figure 1-1) near the location of the underground nuclear test (event) code-named BULLION conducted in Emplacement Hole U-20bd (Figure 1-2) on June 13, 1990. The UGTA Technical Working Group (TWG), a group of experts on NTS geology and the weapons testing program (composed of DOE, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and contractor personnel), originally selected the BULLION site for near-field drilling because of the test's yield, its hydrogeologic setting, the relatively short time that had passed since its detonation, and its relatively shallow depth of burial.

The ER-20-6 near-field drilling project was originally planned to be very similar to that recently conducted at Well Cluster ER-20-5, which was designed to obtain data on the existing hydrologic regime near the site of an underground nuclear explosion (IT, 1995; IT, 1996a). However, after further consideration of the goals of the near-field drilling program and the characteristics of the BULLION site, the TWG recommended that the ER-20-6 project be redesigned to accommodate a forced-gradient experiment. This proposed experiment is expected to yield more realistic estimates of transport parameters than can be deduced from sampling and testing natural groundwater flow systems.

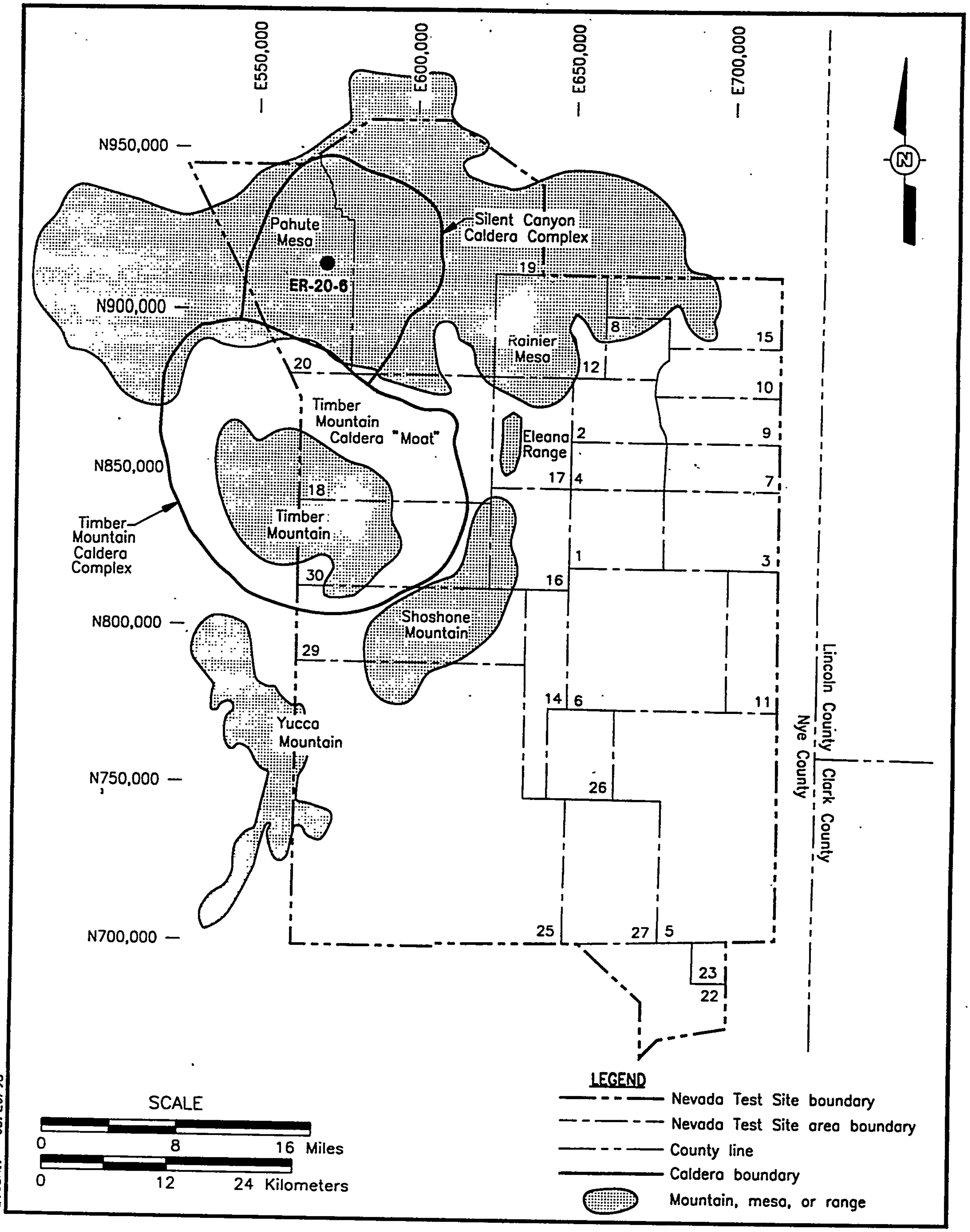


Figure 1-1
Location of Well Cluster ER-20-6

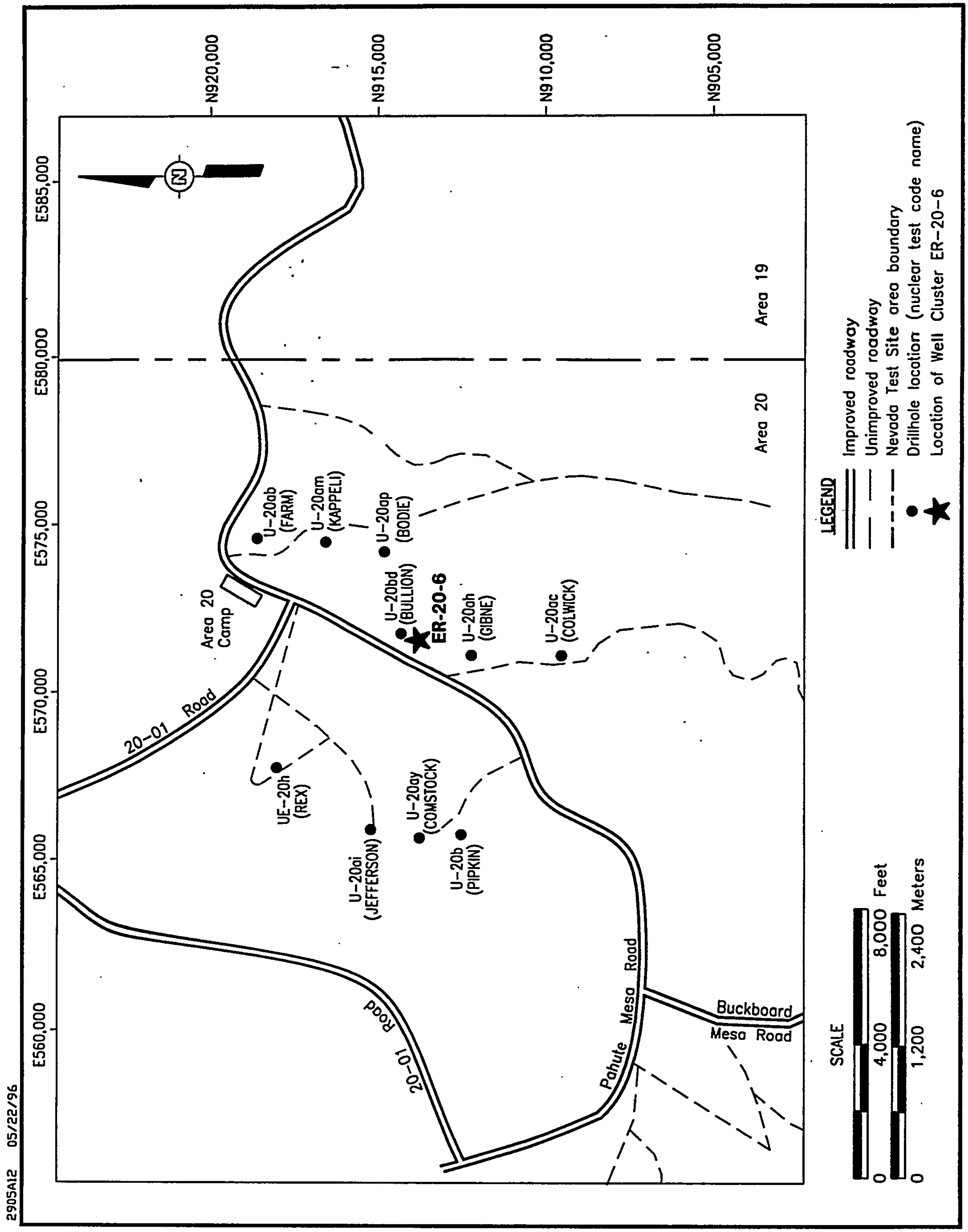


Figure 1-2
Area Map for Well Cluster ER-20-6,
Area 20, Nevada Test Site

The primary change from the original well-cluster design required to accommodate the forced-gradient experiment was placement of one of the three planned wells (the pumping well) at a distance from two monitoring wells (instead of all being placed within one tight cluster). The three holes of Well Cluster ER-20-6 were drilled along an approximate radial from the BULLION surface ground zero, roughly parallel to the local fracture trend, to enhance flow potential between the wells. The first two holes (the monitoring wells) were drilled on the same pad, and Well ER-20-6#3 (the pumping well) was drilled on an adjacent pad (Figure 1-3). As each hole was drilled, data on the geology and radionuclides encountered were evaluated to determine if the site continued to meet the requirements of the forced-gradient experiment and to help locate the subsequent holes. All three wells were drilled to a depth of 975.4 meters (m) (3,200 feet [ft]) and were completed in the lava-flow aquifer that is believed to communicate with the explosion cavity of the BULLION test.

The Nevada State Planar Coordinates and elevation of each well collar are provided in Table 1-1 along with additional site summary and survey information.

Table 1-1
Well Cluster ER-20-6 Site Summary

Hole Designation		ER-20-6#1	ER-20-6#2	ER-20-6#3
Site Coordinates[a]	Central Nevada State Planar (feet)	N913,790.5 E571,558.5	N913,692.3 E571,444.1	N913,420.4 E571,337.1
	Universal Transverse Mercator (Zone 11) (meters)	N4,123,691.8 E551,362.8	N4,123,661.6 E551,328.0	N4,123,578.7 E551,295.7
Surface Elevation[b]		1,973.5 m (6,474.8 ft)	1973.6 m (6,475.1 ft)	1,970.8 m 6,466.0 ft
Drilled Depth		975.4 m (3,200 ft)	975.4 m (3,200 ft)	975.4 m (3,200 ft)
Fluid-Level Depth (Open Borehole)		618.1 m (2,028 ft) (03/03/96)	618.4 m (2,029 ft) (03/26/96)	615.7 m (2,020 ft) (04/11/96)
Fluid-Level Elevation (Open Borehole)		1,355 m (4,447 ft)	1,355 m (4,446 ft)	1,355 m (4,446 ft)

[a]1927 North American Datum. Measurement made by Bechtel Nevada Survey.
[b]1929 North American Vertical Datum. Measurement made by Bechtel Nevada Survey.

IT Corporation (IT) was the principal environmental contractor for the project. The drilling contractor was Welch & Howell Drilling. Engineering, inspection, geotechnical services, and field support were provided by Bechtel Nevada (BN); (formerly Raytheon Services Nevada

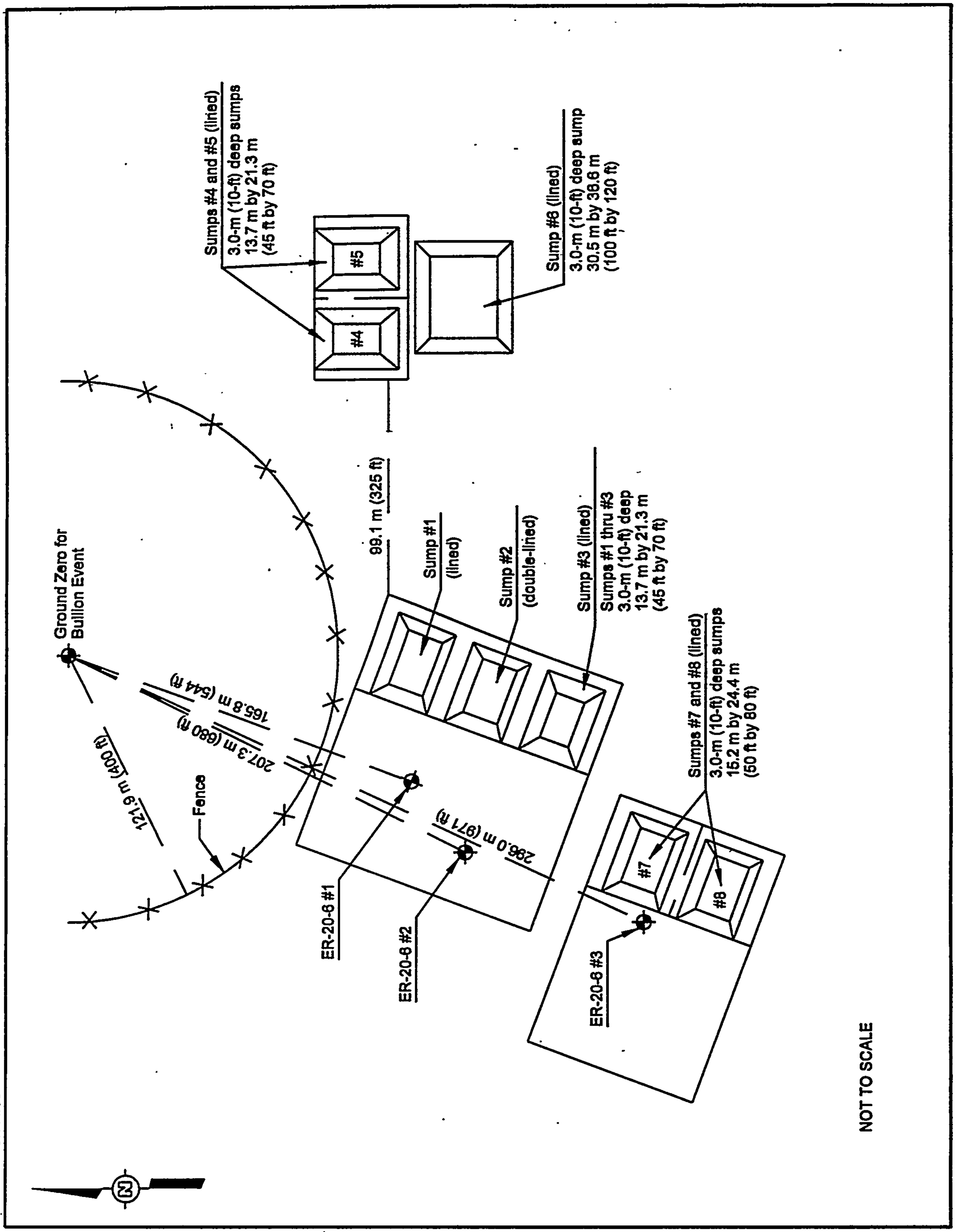


Figure 1-3
Final Drill-Site Configuration for Well Cluster ER-20-6

[RSN] and Reynolds Electrical & Engineering Company [REECo]). The roles and responsibilities of these and other contractors involved in the project are described in Contract DE-RP-08-95NV11808 and in drilling programs prepared for the first and second holes of the cluster (BN, 1996a, b). The TWG provided additional technical advice during the drilling, design, and construction of the wells. See *Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6* and its addendum (IT, 1995, 1996b) for descriptions of the project plans and goals. A fluid management plan (FMP) was developed (in addition to the UGTA FMP [DOE, 1994]) to address the special conditions expected during drilling of a well that could produce radioactive investigation-derived waste (IDW) (IT, 1995).

This document presents construction data and summarizes the scientific data gathered during the drilling and original well-installation phases for all three holes drilled at Well Cluster ER-20-6. Some of this information is preliminary and unprocessed, but it is being released so that drilling, geotechnical, well design, and completion data could be rapidly disseminated. Additional information about water levels, aquifer testing, and groundwater sampling will be reported after work has been performed. The proposed forced-gradient experiment will also be documented separately. Any additional geologic and/or geophysical investigations conducted for this project will be described in one or more analysis and interpretation reports. Lithologic and stratigraphic logs for each well, however, are provided in final form.

1.2 Hydrologic Effects of Nuclear Tests

1.2.1 Phenomenology

Underground nuclear explosions cause physical changes in the near field as a result of cavity growth, ground shock, and chimney formation. Temporary increases in temperature and fluid pressure, and in some cases the groundwater level, have been observed. More permanent changes expected in the near field include enhanced fracture permeability, increased porosity due to bulking of broken material in the cavity/chimney region, and the creation of a potentially permeable vertical conduit between aquifers through the chimney material.

1.2.2 BULLION

The underground nuclear test code-named BULLION was conducted in Emplacement Hole U-20bd in 1990. The reported depth of burial (which corresponds to the location of the Working Point [WP] or explosion point) of the BULLION device was 674 m (2,212 ft), approximately 53 m (175 ft) below the static water level in Emplacement Hole U-20bd (Brikowski, 1992). The

BULLION WP was located in zeolitized, bedded tuff of the Calico Hills Formation, a tuff confining unit. The explosion cavity around the WP (now collapsed) is projected to have been approximately 130 m (426 ft) in diameter (IT, 1995). The collapse chimney, estimated to be approximately cylindrical, is believed to extend approximately 460 m (1,510 ft) above the WP. The explosion cavity is believed to extend down into a lava flow within the Calico Hills Formation, the primary aquifer in the area, which is believed to be the primary conduit for any lateral migration of waterborne radionuclides from the BULLION cavity. Tritium, a mobile byproduct, was expected to be the primary radionuclide encountered at Well Cluster ER-20-6. It was thought that other radionuclides might also be found, but at much lower activities than tritium. Additional information on the phenomenology and expected radionuclides of the BULLION nuclear test is given in the Well Cluster ER-20-6 drilling and completion criteria report (IT, 1995).

The collars of Wells ER-20-6#1, #2, and #3 are located 166, 207, and 296 m (544, 680, and 971 ft) southwest, respectively, of the BULLION surface ground zero (Figure 1-3). At depth, the boreholes are estimated to pass approximately 1.5, 2.2, and 3.6 cavity radii from the edge of the collapse chimney.

1.3 Objectives

The primary purpose of drilling Well Cluster ER-20-6 was to construct a pumping well and two monitoring wells on a line radial to the BULLION WP, parallel to the local fracture trend, within a single aquifer. This well configuration was designed to host a forced-gradient experiment in which data about the transport of radionuclides from the BULLION cavity in the groundwater system would be obtained. The pumping well will induce a gradient from the cavity along a predictable path, and the progress of radionuclides will be determined by sampling the monitoring wells. The purpose of forcing the gradient is to collect data in a relatively short time under well-defined conditions. The data thus obtained can be applied to a simple flow model without requiring extensive characterization of a natural flow field.

The wells in the cluster must meet certain criteria for defining site conditions and for use in the forced-gradient experiment. The location of Well ER-20-6#1, the monitoring well closest to BULLION, was planned to be just within the leading edge of the radioactive groundwater plume from the test cavity. Well ER-20-6#2 was to be located in front of the leading edge of the plume, and Well ER-20-6#3 was planned to be well away from the plume. The general objectives of the Well Cluster ER-20-6 drilling project include the following:

- Define the hydrogeology of the area sufficiently to determine that the wells are completed in an appropriate horizon, located along the appropriate alignment and at appropriate distances from each other and the test cavity and to provide required data to support experiment analysis.

- Determine if the wells are positioned in the contaminant field appropriately for the experiment.

- Provide the required conditions and data collection access to meet experiment requirements.

In addition to providing hydrogeologic data, each well in the cluster will have a distinct role in the planning, construction, and execution of the forced-gradient experiment. Tritium and fracture orientation data from Well ER-20-6#1 were to be used to determine the locations of Wells ER-20-6#2 and #3 (within certain limits, as much of the drill site had already been constructed). Similar data from Well ER-20-6#2 were also to be used to choose a location for Well ER-20-6#3. Aquifer properties obtained from borehole testing in the three wells will determine the operating parameters for the forced-gradient experiment. Analysis of groundwater samples from Wells ER-20-6#1 and #2 will be used to determine the breakthrough curve of contaminants during the experiment.

Initial tritium activities of the three holes were prescribed for the forced-gradient experiment. First, the difference in tritium activity between the two monitoring wells was desired to be such that the shape of the breakthrough curve could be well defined. In Well ER-20-6#1, the maximum estimated tritium activity was 100 million picoCuries per liter (pCi/L), but a level of 25 million pCi/L (or less) was desired. A tritium level of 1 million pCi/L (or less) was desired in Well ER-20-6#2. Second, for the practical disposal of the large amounts of water expected to be produced during the experiment, it was desired that the pumping well not produce water with tritium activities greater than the limit for discharge to an infiltration basin (200,000 pCi/L).

If data from the three wells indicate that the wells are unsuitable for the forced-gradient experiment (i.e., tritium levels are too high or the hydrogeologic setting is too complicated), the well cluster project will revert to its original planned purpose, to serve as nature-and-extent study for monitoring natural transport of radionuclides from BULLION (IT, 1995).

More detailed information on the plans and requirements for constructing Well Cluster ER-20-6 in support of a forced-gradient experiment can be found in the addendum to the original drilling and completion criteria report (IT, 1996b).

1.4 Project Summary

The drill pad for the ER-20-6 drilling project had been constructed previously, when the goal of the project was to install simple monitoring wells, and the first two holes in the project were drilled from the existing pad. To accommodate the pumping well (Well ER-20-6#3) for the forced-gradient experiment, a new pad adjacent to the first was constructed during drilling of Well ER-20-6#2 (Figure 1-3). Immediately after completion of the nearby Well Cluster ER-20-5 drilling project, the Welch and Howell drill rig was moved onto the ER-20-6 site. An exclusion zone, which served as part of the primary contamination control system, was established before drilling of Well ER-20-6#1 began on February 19, 1996. The details of the drilling and completion operations for each hole are presented in Sections 3.0, 4.0, and 5.0 of this report. The following is a summary of these activities.

An effort was made to collect composite drill cuttings at standard 3-m (10-ft) intervals during drilling of all three holes. However, poor returns during drilling of Well ER-20-6#1 prevented sample collection through large intervals of the hole. Rapid drill rates in the other two holes forced reduction of the collection interval to 6 m (20 ft) through some zones. Six 12.7-centimeter (cm) (5-inch [in.]) diameter conventional cores (a total of 39.5 m [129.5 ft] recovered) were cut in Well ER-20-6#1. Sidewall samples were taken from all three holes. Geophysical logging was conducted to aid in construction of the wells, to help verify the geology, and to help characterize the hydrology of the units. Borehole televiewer logs were run in the holes to determine fracture orientations so that the holes could be placed along a line parallel to the local fracture trend.

1.4.1 Well ER-20-6#1

The 102-cm (40-in.) diameter conductor hole for Well ER-20-6#1 was auger-drilled and cased during completion of Well ER-20-5#3 on February 8, 1996. Rotary drilling of the main hole with a 17½-in. bit and mud in conventional circulation began on February 19, 1996. A suitable location for setting casing was reached at 243.8 m (800 ft). After the 13⅜-in. surface casing was set and cemented and the blow-out prevention system (BOP) was installed, rotary drilling of Well ER-20-6#1 continued with a 12¼-in. bit and air-foam. Rotary drilling was halted intermittently for coring operations at six locations between 673.3 and 869.3 m (2,209 to

2,852 ft). The total depth (TD) of 975.4 m (3,200 ft) was reached on March 6, 1996. Despite applications of lost-circulation material (LCM) during drilling of the 17½-in. hole and adjustments of the air injection rate during drilling of the 12¼-in. hole, the drillers could not maintain fluid returns to the surface during drilling of approximately 404 m (1,325 ft) of the hole. This situation made monitoring tritium levels problematical, but the first evidence of tritium was noted at the depth of 577.0 m (1,893 ft), approximately 41 m (135 ft) above the static fluid level. In addition, Cesium-137 was encountered in drill cuttings from the depth of 579.4 m (1,901 ft), which was interpreted as an indication that the hole had crossed a hydrofracture from the BULLION cavity.

The target aquifer, a lava flow within the Calico Hills Formation, was encountered between 765.0 and 897.6 m (2,510 to 2,945 ft). The static, open-hole fluid level prior to completion installation was measured at 618.1 m (2,028 ft) on March 7, 1996. A half-hour of circulation after TD was reached served as precompletion development. The bottom of the hole is plugged with fill to 909.2 m (2,983 ft), and a bottom plug of cement was placed to 898.2 m (2,947 ft).

The monitoring well constructed in Well ER-20-6#1 consists of a 5½-in. completion string and a 2⅞-in. access string. The 5½-in. fiberglass and stainless-steel main string was landed off at 891.2 m (2,924 ft). This bull-nosed string has two screened intervals placed at 764.1 to 835.8 m (2,507 to 2,742 ft) and 863.2 to 881.5 m (2,832 to 2,892 ft). A Moyno® pump was set within the 5½-in. casing on a 2⅞-in. stainless-steel pump string. The pump stator was installed with No-Turn Tools® which, if properly set, would prevent counter-rotation of the stator and allow easy removal of the pump if desired. However, the No-Turn Tools® could not be set in the fiberglass casing, so it is planned to replace them with packers. The pump rotor was installed in the stator on a ⅞-in. drive-rod string, but was removed on April 8, 1996, after the pump string in Well ER-20-6#2 parted. The 2⅞-in. fiberglass access string installed adjacent to the 5½-in. completion string was landed off at 893.1 m (2,930 ft). This string also has two slotted intervals, located at 776.6 to 839.1 m (2,548 to 2,753 ft) and 865.9 to 892.8 m (2,841 to 2,929 ft).

The completion intervals are gravel-packed from 756.8 to 843.4 m (2,483 to 2,767 ft) and from 858.0 to 898.2 m (2,815 to 2,947 ft). A sand pack 14.6 m (48 ft) thick was placed between the two gravel packs, and 14.0 m (46 ft) of sand was placed above the upper gravel pack. The borehole annulus was cemented from the top of the upper sand pack at 742.8 m (2,437 ft) to 181.7 m (595 ft), but gravel and sand layers had to be placed to advance the cementing through three zones which would not hold cement.

Predevelopment, consisting of nine hours of pumping, was successfully conducted immediately after cementing and installation of the pump rotor.

1.4.2 Well ER-20-6#2

The 61-cm (24-in.) conductor hole for Well ER-20-6#2 was auger-drilled and cased during completion of Well ER-20-6#1 on March 13, 1996. Immediately after Well ER-20-6#1 was completed, the drill rig was repositioned and rigged up on Well ER-20-6#2. Drilling of the main hole with a 17½-in. rotary bit and air-foam in conventional circulation began on March 18, 1996. A suitable location for setting casing was reached at 246.0 m (807 ft). After the 13⅜-in. surface casing was set and cemented and the BOP was installed, rotary drilling of Well ER-20-6#2 continued with a 12¼-in. bit and air-foam. Drilling proceeded quickly and smoothly, and the TD of 975.4 m (3,200 ft) was reached on March 25, 1996. The effort was made to clean out fill that accumulated in the hole, but the bottom of the hole remained plugged with fill to 903.1 m (2,963 ft). Tritium was encountered in the fluid returns at the depth of 604.4 m (1,983 ft), approximately 14 m (46 ft) above the static water level.

The targeted lava-flow aquifer within the Calico Hills Formation was encountered between 758.6 and 954.0 m (2,489 to 3,130 ft). The static, open-hole fluid level prior to completion installation was measured at 618.4 m (2,029 ft) on March 26, 1996. An hour of circulation after TD was reached served as precompletion development. A bottom plug of cement was placed to 897.6 m (2,945 ft).

The monitoring well constructed in Well ER-20-6#2 consists of a 5½-in. completion string and a 2⅞-in. access string. The 5½-in. fiberglass and stainless-steel main string was landed off at 893.7 m (2,932 ft). This bull-nosed string has two screened intervals placed at 766.9 to 829.1 m (2,516 to 2,720 ft) and 856.8 to 883.9 m (2,811 to 2,900 ft). A Moyno® pump was set within the 5½-in. casing on a 2⅞-in. stainless-steel pump string. The pump stator was installed with No-Turn Tools®, but the No-Turn Tools® could not be set in the fiberglass casing so it is planned to replace them with packers. The pump rotor was installed in the stator on a ⅞-in. drive-rod string. The 2⅞-in. fiberglass access string installed adjacent to the 5½-in. completion string was landed off at 894.0 m (2,933 ft). This string also has two slotted intervals, located at 768.7 to 831.2 m (2,522 to 2,727 ft) and 858.0 to 884.8 m (2,815 to 2,903 ft).

The completion intervals are gravel-packed from 748.0 to 840.3 m (2,454 to 2,757 ft) and from 851.3 to 897.6 m (2,793 to 2,945 ft). A sand pack 11.0 m (36 ft) thick was placed between the two gravel packs, and 12.2 m (40 ft) of sand was placed above the upper gravel pack. The borehole annulus was cemented from the top of the upper sand pack at 735.8 m (2,414 ft) to 164.3 m (539 ft).

Pumping and predevelopment began immediately after the conclusion of cementing operations and installation of the rotor, but the pump failed after 16 hours. The drive-rod string and rotor were removed on April 7, 1996, and it was found that the rotor had been positioned lower in the stator than intended. On April 10, 1996, it was found that the pump string had unscrewed or parted. It is planned to retrieve the parted string.

1.4.3 Well ER-20-6#3

The drill pad and two new lined sumps for Well ER-20-6#3 were constructed during drilling of Well ER-20-6#2. The 76.2-cm (30-in.) conductor hole was auger-drilled and cased during completion of Well ER-20-6#2 on April 1, 1996. Immediately after Well ER-20-6#2 was completed, the drill rig was repositioned and rigged up on Well ER-20-6#3. Drilling of the main hole with a 17½-in. rotary bit and air-foam in conventional circulation began on April 4, 1996. A suitable location for setting casing was reached at 246.0 m (807 ft). After the 13⅜-in. surface casing was set and cemented, rotary drilling of Well ER-20-6#3 continued with a 12¼-in. bit and air-foam. Drilling proceeded quickly and smoothly, and the TD of 975.4 m (3,200 ft) was reached on April 11, 1996. The drillers did not attempt to clean out fill that accumulated in the hole before geophysical logging, but two shifts were spent trying to clean out the hole after logging was completed. However, the bottom of the hole remained plugged with fill to 856.2 m (2,809 ft). Low levels of tritium were encountered in the fluid returns at the depth of 661.4 m (2,170 ft), approximately 46 m (150 ft) below the static fluid level.

The targeted lava-flow aquifer within the Calico Hills Formation was encountered between 752.9 m and the hole TD at 975.4 m (2,470 to 3,200 ft). The static, open-hole fluid level prior to completion installation was measured at 615.7 m (2,020 ft) on April 11, 1996. A half-hour of circulation after TD was reached served as precompletion development. A bottom plug of cement was placed to 855.6 m (2,807 ft).

The Well ER-20-6#3 completion consists of a 5½-in. pump string and a 2⅞-in. access string. The 5½-in. stainless-steel casing was landed off at 854.9 m (2,804.7 ft). This bull-nosed string has a screened interval at 765.2 to 854.1 m (2,510.4 to 2,802.1 ft) and will house a submersible pump for the forced-gradient experiment. The 2⅞-in. fiberglass access string installed adjacent to the 5½-in. pump string was landed off at 850.3 m (2,789.7 ft). The slotted interval in this string is located at 760.8 to 841.1 m (2,495.9 to 2,759.6 ft).

The completion interval is gravel-packed from 755.9 to 855.6 m (2,480 to 2,807 ft). A sand pack 13.4 m (44 ft) thick was placed above the gravel pack. The borehole annulus was cemented from the top of the sand pack at 742.5 m (2,436 ft) to 166.1 m (545 ft).

Based on tritium levels and hydrogeologic data obtained during drilling and completion of the three holes in Well Cluster ER-20-6, but prior to any hydrologic testing in the wells, this site appears suitable for conducting the proposed forced-gradient experiment.

1.5 Project Manager

Inquiries regarding Well Cluster ER-20-6 should be directed to the UGTA Project Manager:

2.0 Geology and Hydrogeology of Well Cluster ER-20-6

2.1 Introduction

Well Cluster ER-20-6 is located within the Silent Canyon caldera complex (Figure 1-1), one of several calderas and caldera complexes within the southwestern Nevada volcanic field. The Silent Canyon caldera complex has been filled and covered by volcanic rocks up to five kilometers thick, consisting mainly of rhyolitic lavas and ash-flow tuffs with interbedded nonwelded and bedded tuffs (Ferguson et al., 1994). These rocks are cut by north- to north-northeast-trending, mostly down-to-the-west, high-angle normal faults related to Basin and Range extension (Byers et al., 1976). Regional groundwater flow is generally to the south and southwest within aquifers formed by the fractured lava and welded ash-flow tuff units. Zeolitic nonwelded and bedded tuffs act as regional and local confining units (Blankennagel and Weir, 1973). For a more detailed discussion of the regional geology and hydrology of Well Cluster ER-20-6, see the original drilling and completion criteria report (IT, 1995).

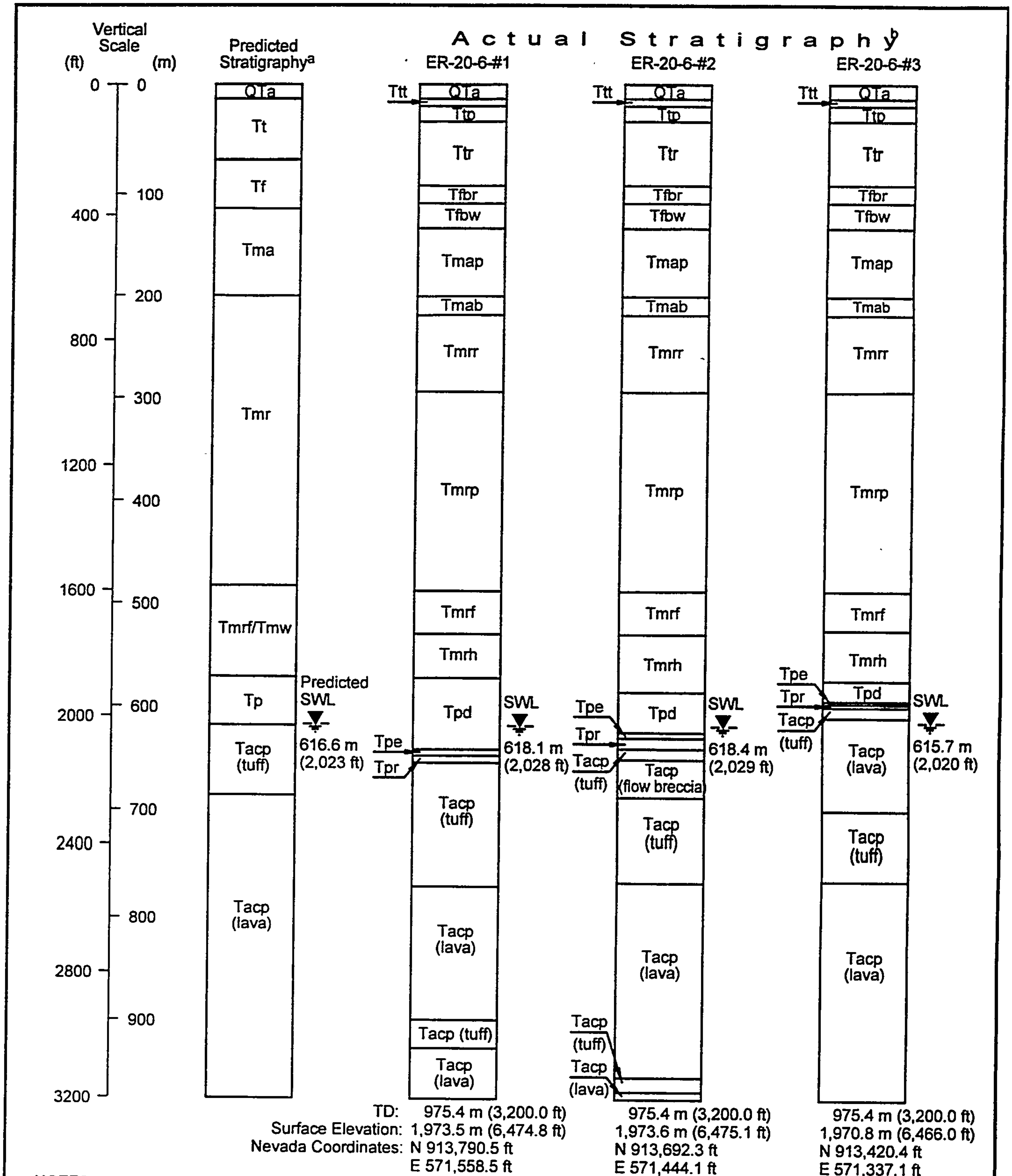
2.2 Geology

The geology encountered at Well Cluster ER-20-6 is generally as predicted prior to drilling and is similar for all three holes of the cluster (Figure 2-1). Stratigraphic and lithologic logs for each borehole of the well cluster are provided in Appendix C. These logs were prepared by BN geologists through examination of the drill cuttings, sidewall core samples, and geophysical logs. A listing of stratigraphic units encountered at Well Cluster ER-20-6, with map symbols, lithology, and hydrogeology, is given in Table 2-1.

2.2.1 Stratigraphy

Except for a thin veneer of alluvium at the surface, the rocks penetrated from the surface to the static water level at approximately 617 m (2,025 ft) consist mainly of welded ash-flow tuff and bedded tuff of the Thirsty Canyon, Volcanics of Fortymile Canyon, and Timber Mountain Groups. These unsaturated rocks are mostly vitric to devitrified to approximately 463 m (1,520 ft), but become progressively more zeolitized below.

Saturated rocks penetrated consist mainly of devitrified to zeolitic rhyolite lava and minor zeolitic bedded tuff of the mafic-poor Calico Hills Formation. However, the distribution of lithologies (and, consequently, hydrogeologic units) differs somewhat from hole to hole as well as from that predicted. This is neither surprising nor anomalous and is due to the presence of



NOTES

See Table 2-1 for definitions of stratigraphic symbols.

[a] IT, 1995.

[b] See Appendix C for lithology and stratigraphy.

Figure 2-1
Predicted and Actual Stratigraphy at Well Cluster ER-20-6

Table 2-1
Stratigraphic, Lithologic, and Hydrogeologic Units Encountered near Well Cluster ER-20-6

Stratigraphic Group	Stratigraphic Unit[a]	Symbol	Typical Lithology	Hydrogeologic Unit[b]
Quaternary/Tertiary Sediments				
Quaternary/Tertiary Sediments		QTa	Gravelly, sandy tuffaceous alluvium	Alluvial aquifer (unsaturated at this location)
Tertiary Volcanic Rocks				
Thirsty Canyon Group (Tt)	Trail Ridge Tuff	Ttt	Nonwelded to partially welded ash-flow tuff	Vitric-tuff aquifer (unsaturated at this location)
	Pahute Mesa Tuff	Ttp		
	Rocket Wash Tuff	Ttr	Nonwelded to moderately welded ash-flow tuff	
Volcanics of Fortymile Canyon (Tf)	Beatty Wash Formation	Tfb	Bedded tuffs, vitric	
	rhyolite of Chukar Canyon	Tfbr		
	rhyolite of Beatty Wash	Tfbw		
Timber Mountain Group (Tm)	Ammonia Tanks Tuff	Tma	Nonwelded to partially welded ash-flow tuff	
	mafic-poor Ammonia Tanks Tuff	Tmap		
	bedded Ammonia Tanks tuff	Tmab	Bedded tuff, vitric	
	Rainier Mesa Tuff	Tmr	Nonwelded to densely welded ash-flow tuff	Welded-tuff aquifer (unsaturated at this location)
	mafic-rich Rainier Mesa Tuff	Tmrr		
	mafic-poor Rainier Mesa Tuff	Tmrp		
	rhyolite of Fluorspar Canyon	Tmrf	Bedded tuffs, zeolitized	Tuff-confining unit (unsaturated at this location)
	tuff of Holmes Road	Tmrh		
	rhyolite of Windy Wash	Tmw		
Paintbrush Group (Tp)	rhyolite of Delirium Canyon	Tpd	Bedded tuffs, zeolitized	Tuff-confining unit (saturated)
	rhyolite of Echo Peak	Tpe		
	rhyolite of Silent Canyon	Tpr		
Volcanics of Area 20 (Ta)	mafic-poor Calico Hills Formation	Tacp(*b*)	Bedded tuff, zeolitized	
		Tacp(L)	Rhyolite lava flow	Lava-flow aquifer (saturated)

[a]Ferguson et al., 1994.
[b]Modified from Winograd and Thordarson (1975) and Laczniak et al. (1996).

rhyolite lava flows which are stratigraphically and hydrogeologically more complex and difficult to predict than the ash-flow tuffs and bedded tuffs of the unsaturated interval.

2.2.2 Structure

The present attitude of geologic units penetrated in the upper part of the holes at Well Cluster ER-20-6 is mainly the result of minor horizontal-axis rotation associated with movement along a nearby fault (located approximately 457.2 m [1,500 ft] east of the well cluster; see IT, 1995). Units above the Paintbrush Group (Table 2-1) generally dip less than ten degrees to the east. However, units of the Paintbrush Group and Calico Hills Formation have dips that are greater and much more variable, reflecting the complex morphology of the lava flows within the Calico Hills Formation (see Section 2.3.1).

Preliminary field analysis of the borehole televiewer log from Well ER-20-6#1 showed fractures that generally trend N35°E above the 667.5-m (2,190-ft) depth and N75°W below (Price, 1996). Based on observations in nearby holes, N35°E is the expected structural trend, while the N75°W trend seems anomalous. The origin of the anomalous fracture trend is currently unknown; data from all three wells are still under evaluation. The N35°E fracture trend was considered to be the more representative of Well Cluster ER-20-6 area and was used to help select the locations of Wells ER-20-6#2 and #3.

2.3 Hydrogeology

The rhyolite lava flows and zeolitic bedded tuffs encountered below the static water table at Well Cluster ER-20-6 form lava-flow aquifers and tuff confining units, respectively (Winograd and Thordarson, 1975). However, as discussed in the following text, the variability in lithology, morphology, and distribution of lava flows has resulted in the development of a somewhat complex hydrogeologic environment.

2.3.1 Hydrogeologic Characteristics of Rhyolite Lava Flows

Rhyolite lava flows beneath Pahute Mesa usually comprise several lithologies with considerably different hydrologic properties. A typical lava flow consists of a stony rhyolite center containing vitrophyric or glassy zones, surrounded by pumiceous lava and flow breccia. Stony lava is usually hard, dense, and devitrified. The brittle nature of stony lava makes it susceptible to fracturing; therefore, this lithology is believed to act as a lava-flow aquifer. Likewise, the vitrophyric zones are also brittle and susceptible to fracturing and are also believed to act as lava-flow aquifers.

In contrast to the stony lava and vitrophyre in the core of the lava flow, the surrounding pumiceous lava is relatively soft and not susceptible to fracturing. In addition, because of its high initial primary porosity, this lithology is usually zeolitized, which greatly reduces its permeability. Consequently, pumiceous lava, where zeolitized, probably acts more as a tuff confining unit than as a lava-flow aquifer.

Flow breccia, which often is present at the top, base, and distal edges of a lava flow, consists of clasts of pumiceous and stony lava with a softer, typically pumiceous matrix. The softer portions of the flow breccia, such as the matrix and pumiceous clasts, are often zeolitized. Because the relative proportions of the various constituents can vary within a flow breccia, the hydrogeologic properties can also vary, resulting in a flow breccia that acts as a lava-flow aquifer at one place in the flow and as a tuff confining unit at another.

Not only are rhyolite lavas at Pahute Mesa lithologically complex, their distribution and morphology are also quite variable. Because of their greater viscosity, rhyolite lava flows are typically much less extensive than ash-flow tuffs, and they form domes, ridges and plateaus in the vicinity of calderas. However, because numerous individual lavas may be extruded in a particular area over a period of time, lava flows tend to coalesce and overlap. Therefore, in some places, rhyolite lava may be the dominant lithology in certain stratigraphic intervals. However, because tephra (ash and pumice) is usually erupted during the extrusion of rhyolite lava, individual flows at Pahute Mesa tend to be separated by zeolitized bedded tuffs of variable thickness that are believed to act as tuff confining units. Consequently, lava-flow aquifers at Pahute Mesa tend to be compartmentalized with thick lenses of transmissive lava surrounded by much less transmissive zeolitic units.

2.3.2 Hydrogeologic Units at Well Cluster ER-20-6

Three lava-flow aquifers separated by tuff confining units were encountered below the static water level at Well Cluster ER-20-6 (Figure 2-2). The uppermost lava-flow aquifer was penetrated from 609.6 to 700.1 m (2,000 to 2,297 ft) in Well ER-20-6 #3 with a flow breccia that probably represents the edge of the lava-flow penetrated between 650.7 and 680.9 m (2,135 and 2,234 ft) in Well ER-20-6#2. However, this lava flow was not encountered in Well ER-20-6#1 or U-20bd and its two instrument holes.

The middle lava-flow aquifer at Well Cluster ER-20-6 was encountered in all three holes, as well as in U-20bd Instrument Hole #1 (Emplacement Hole U-20bd was not drilled deep enough to

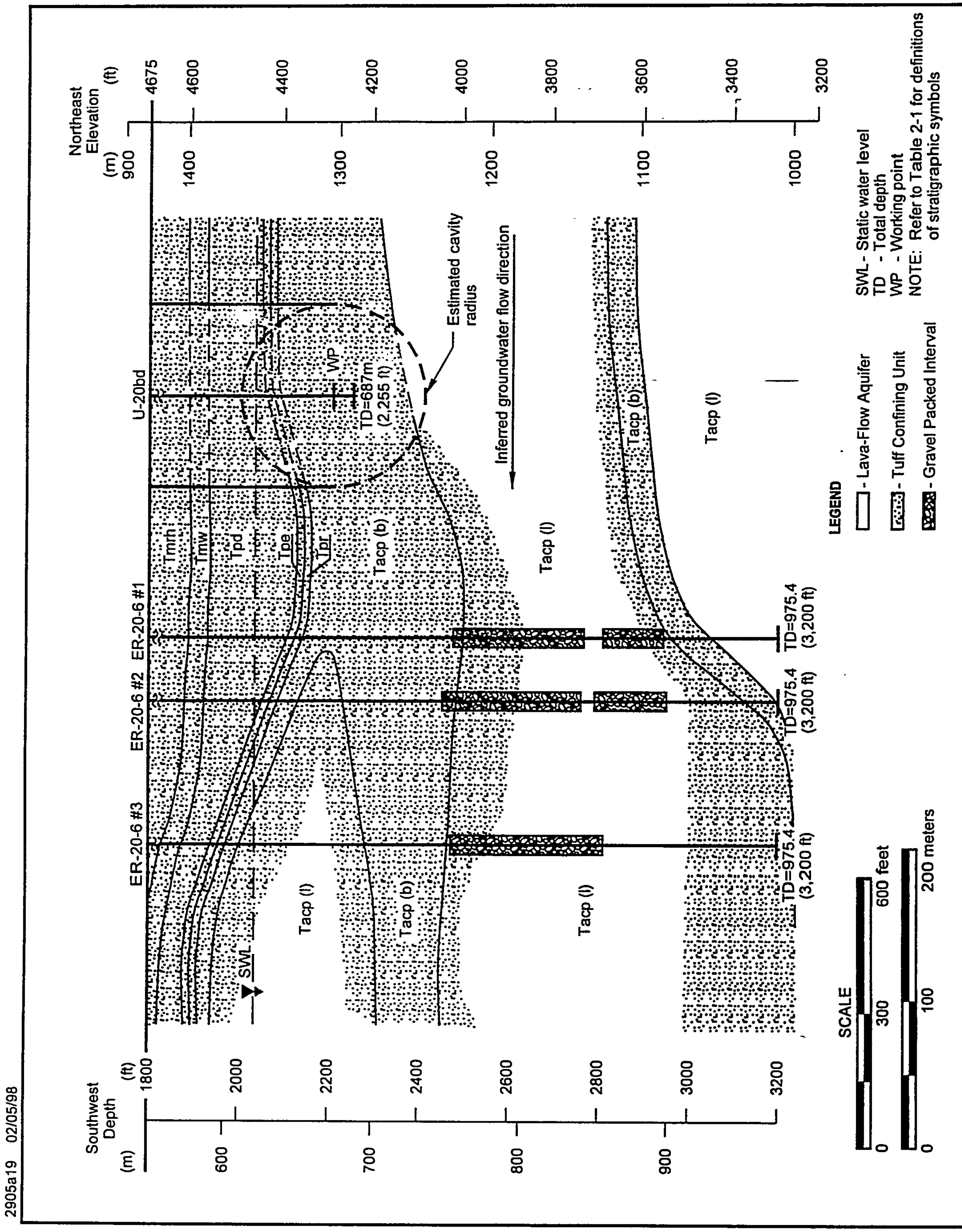


Figure 2-2
Hydrogeologic Cross Section through Wells ER-20-6 #1, ER-20-6 #2, ER-20-6 #3, and Emplacement Hole U-20bd (Southwest - Northeast)

encounter this lava-flow aquifer). However, it is estimated that the BULLION cavity grew downward into this middle aquifer, so this unit was targeted to host the proposed forced-gradient experiment. This middle lava-flow aquifer is separated from the upper aquifer by 57.3 to 77.7 m (188 to 255 ft) of zeolitic bedded tuff.

The lower-most lava-flow aquifer encountered at Well Cluster ER-20-6 was penetrated by Wells ER-20-6#2 and ER-20-6#1 only. This lava-flow aquifer is separated from the middle aquifer by 18.3 to 29.0 m (60 to 95 ft) of zeolitic bedded tuff.

3.0 Well ER-20-6#1

3.1 Drilling Summary

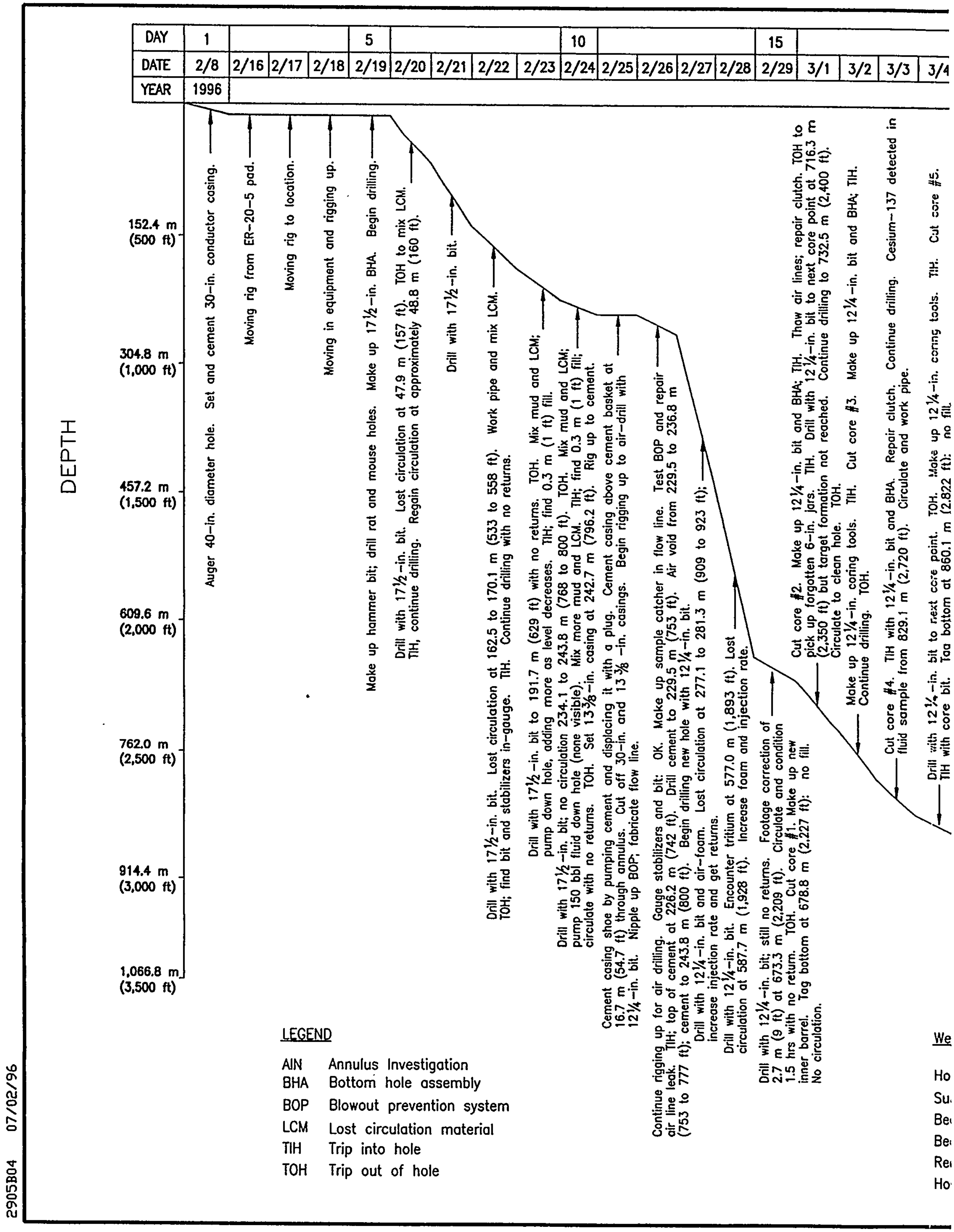
The drilling requirements for Well ER-20-6#1 were outlined in Contract DE-RP-08-95NV11808 and in the BN Drilling and Completion Program D-002-001.96 (BN, 1996a). Changes to these criteria were documented in BN Records of Verbal Communication (Appendix A.1). This summary was compiled from the BN daily rig reports, field notes prepared by the IT Field Representatives, and the BN Well ER-20-6#1 hole history (BN, 1996c), where complete details of drilling activities can be found.

The drill site had previously been prepared with three lined sumps on the drill pad and two lined sumps and an infiltration basin located approximately 100 m east of the pad. Additional sumps for the well-cluster project were constructed later (see Section 5.1 and Figure 1-3). The Welch & Howell rig was moved from the Well Cluster ER-20-5 site and set up on Well ER-20-6#1 on February 16-18, 1996. Welch & Howell Rig #10 was used for this project; the rig consisted of a Pyramid mast with a 176,904-kilogram (390,000-pound) static hook load rating. The exclusion zone was established on February 19, 1996, after drilling of the rat and mouse holes.

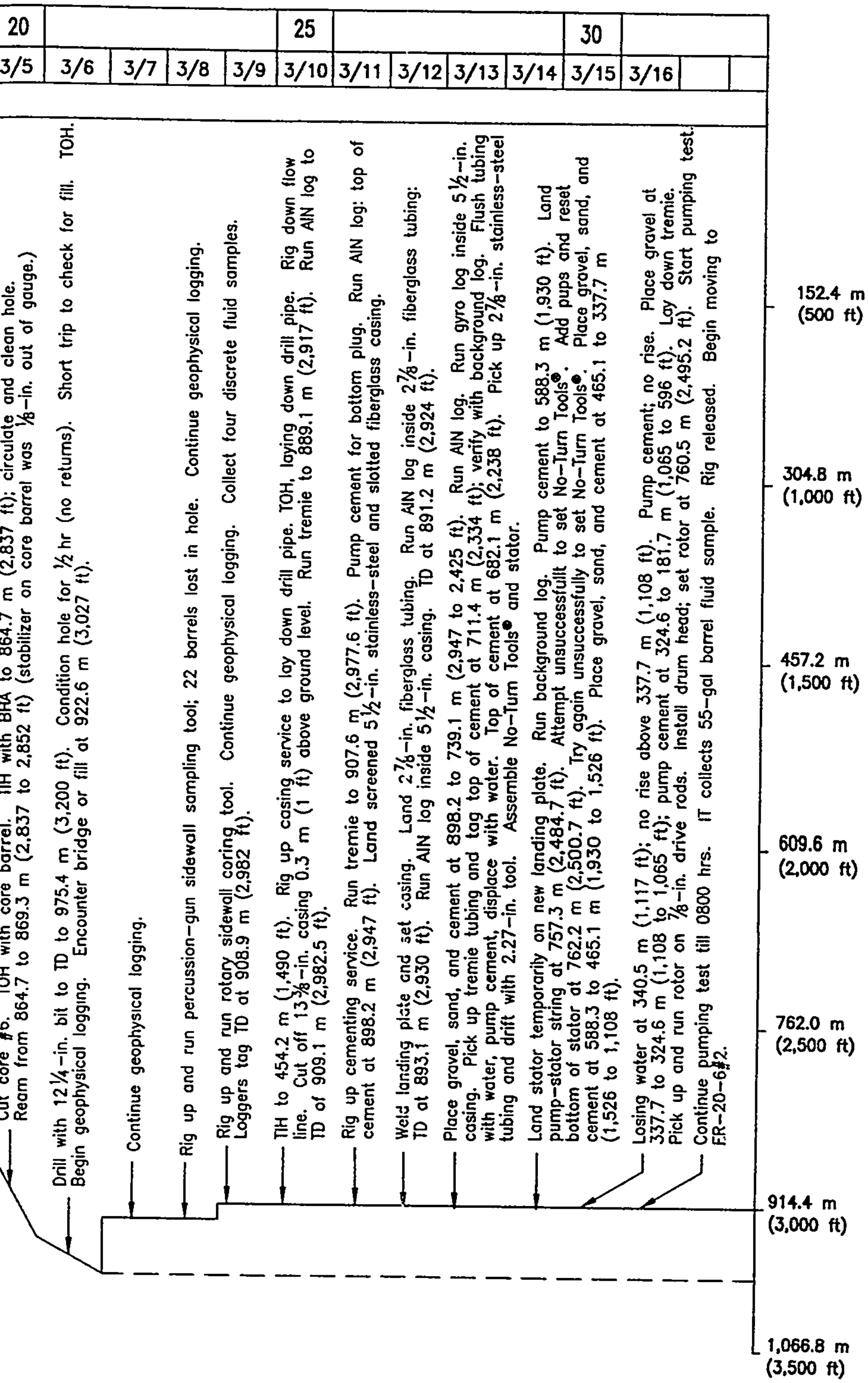
Figure 3-1 is a graphical presentation of the drilling and completion history for Well ER-20-6#1, and Table 3-1 presents abridged drill hole statistics. A graphical depiction of drilling parameters, including penetration rate, revolutions per minute, pump pressure, and weight on the bit is presented in Appendix A.2. Details of the compositions of drill fluid, additives, and cements used are provided in Appendix A.4.

3.1.1 Drilling History

The 101.6-cm (40-in.) diameter conductor hole for Well ER-20-6#1 was dry-augered to the depth of 11.6 m (38 ft) on February 8, 1996, during geophysical logging of Well ER-20-5#3. The 30-in. conductor casing was set at 11.6 m (38 ft) and cemented the same day. After the rig was moved in, the rat and mouse holes were drilled with a hammer bit. Rotary drilling of the Well ER-20-6#1 main hole began on February 19, 1996, with a 17½-in. bit and mud in conventional circulation. Circulation was lost at the depth of 47.9 to 48.8 m (157 to 160 ft) and again at 162.5 to 191.7 m (533 to 629 ft). Lost-circulation material (consisting of cottonseed hulls and cedar fiber) was added to the mud continuously, but as drilling continued to the casing point, circulation was regained only in the interval 191.7 to 234.1 m (629 to 768 ft). The casing



DAY 1 5 10 15
DATE 2/8 2/16 2/17 2/18 2/19 2/20 2/21 2/22 2/23 2/24 2/25 2/26 2/27 2/28 2/29 3/1 3/2 3/3 3/4
YEAR 1996
DEPTH
152.4 m (500 ft)
304.8 m (1,000 ft)
457.2 m (1,500 ft)
609.6 m (2,000 ft)
762.0 m (2,500 ft)
914.4 m (3,000 ft)
1,066.8 m (3,500 ft)
Auger 40–in. diameter hole. Set and cement 30–in. conductor casing.
Moving rig from ER–20–5 pad.
Moving rig to location.
Moving in equipment and rigging up.
Make up hammer bit; drill rat and mouse holes. Make up 17½–in. BHA. Begin drilling.
Drill with 17½–in. bit. Lost circulation at 47.9 m (157 ft). TOH to mix LCM. TIH, continue drilling. Regain circulation at approximately 48.8 m (160 ft).
Drill with 17½–in. bit.
Drill with 17½–in. bit. Lost circulation at 162.5 to 170.1 m (533 to 558 ft). Work pipe and mix LCM. TOH; find bit and stabilizers in–gauge. TIH. Continue drilling with no returns.
Drill with 17½–in. bit to 191.7 m (629 ft) with no returns. TOH. Mix mud and LCM; pump down hole, adding more as level decreases. TIH; find 0.3 m (1 ft) fill.
Drill with 17½–in. bit; no circulation 234.1 to 243.8 m (768 to 800 ft). TOH. Mix mud and LCM; pump 150 bbl fluid down hole (none visible). Mix more mud and LCM. TIH; find 0.3 m (1 ft) fill; circulate with no returns. TOH. Set 13⅜–in. casing at 242.7 m (796.2 ft). Rig up to cement.
Cement casing shoe by pumping cement and displacing it with a plug. Cement casing above cement basket at 16.7 m (54.7 ft) through annulus. Cut off 30–in. and 13⅜–in. casings. Begin rigging up to air–drill with 12¼–in. bit. Nipple up BOP; fabricate flow line.
Continue rigging up for air drilling. Gauge stabilizers and bit: OK. Make up sample catcher in flow line. Test BOP and repair air line leak. TIH; top of cement at 226.2 m (742 ft). Drill cement to 229.5 m (753 ft). Air void from 229.5 to 236.8 m (753 to 777 ft); cement to 243.8 m (800 ft). Begin drilling new hole with 12¼–in. bit.
Drill with 12¼–in. bit and air–foam. Lost circulation at 277.1 to 281.3 m (909 to 923 ft); increase injection rate and get returns.
Drill with 12¼–in. bit. Encounter tritium at 577.0 m (1,893 ft). Lost circulation at 587.7 m (1,928 ft). Increase foam and injection rate.
Drill with 12¼–in. bit; still no returns. Footage correction of 2.7 m (9 ft) at 673.3 m (2,209 ft). Circulate and condition 1.5 hrs with no return. TOH. Cut core #1. Make up new inner barrel. Tag bottom at 678.8 m (2,227 ft): no fill. No circulation.
Cut core #2. Make up 12¼–in. bit and BHA; TIH. Thaw air lines; repair clutch. TOH to pick up forgotten 6–in. jars. TIH. Drill with 12¼–in. bit to next core point at 716.3 m (2,350 ft) but target formation not reached. Continue drilling to 732.5 m (2,400 ft). Circulate to clean hole. TOH.
Make up 12¼–in. coring tools. TIH. Cut core #3. Make up 12¼–in. bit and BHA; TIH. Continue drilling. TOH.
Cut core #4. TIH with 12¼–in. bit and BHA. Repair clutch. Continue drilling. Cesium–137 detected in fluid sample from 829.1 m (2,720 ft). Circulate and work pipe.
Drill with 12¼–in. bit to next core point. TOH. Make up 12¼–in. coring tools. TIH. Cut core #5. TIH with core bit. Tag bottom at 860.1 m (2,822 ft): no fill.
LEGEND
AIN Annulus Investigation
BHA Bottom hole assembly
BOP Blowout prevention system
LCM Lost circulation material
TIH Trip into hole
TOH Trip out of hole
We
Ho
Su
Be
Be
Re
Ho
2905B04 07/02/96



ER-20-6#1 Summary

spudded	02/08/96
ce hole completed and cased	02/08/96
drilling 17½-in. hole	02/19/96
recording tritium in returns	02/28/96
total drilled depth of 975.4 m (3,200 ft)	03/06/96
cemented to 181.7 m (596 ft)	03/15/96

FIGURE 3-1
WELL ER-20-6#1
DRILLING AND COMPLETION HISTORY

Table 3-1
Abridged Drill-Hole Statistics for Well ER-20-6#1

LOCATION DATA: Coordinates: Central Nevada State Planar: N913,790.5, E571,558.5 ft
Universal Transverse Mercator: N4,123,691.8, E551,362.8 m

Ground Elevation: 1,973.5 m (6,474.8 ft)

DRILLING DATA:

Spud Date: 02/19/96
Total Depth (TD): 975.4 m (3,200 ft)
Date TD Reached: 03/06/96
Date Well Completed: 03/15/96
Hole Diameter: 101.6 cm (40 in.) from surface to 11.6 m (38 ft); 44.5 cm (17.5 in.) to 243.8 m (800 ft); 31.1 cm (12.25 in.) to 975.4 m (3,200 ft).

Drilling Techniques: Dry-auger drilling to 11.6 m (38 ft). Rotary drilling with mud (and lost circulation material as needed), using a 17½-in. bit to 243.8 m (800 ft). Rotary drilling using a 12¼-in. bit and air-foam in conventional circulation to the TD, except for a total of 39.9 m (131 ft) cored conventionally in six intermittent intervals between 673.3 and 869.3 m (2,209 to 2,852 ft).

CASING DATA: 30-in. conductor casing from the surface to 11.6 m (38 ft). 13⅜-in. surface casing set at 242.7 m (796.2 ft).

WELL COMPLETION DATA:

The pump string is installed within slotted 14.0-cm (5½-in.) outside diameter (od) casing. The 5½-in. casing consists of fiberglass from the surface to 763.8 m (2,506 ft) and stainless steel from 763.8 to 891.2 m (2,506 to 2,924 ft). A Moyno® pump stator was installed at the bottom of 7.3-cm (2⅞-in.) od stainless-steel tubing, with No-Turn Tools® above and below the stator. The pump rotor was removed from the well on April 8, 1996. A slotted access string consisting of 7.3-cm (2⅞-in.) od fiberglass tubing was landed off at 893.1 m (2,930 ft).

	Completion String	Access String
Total Depth:	891.2 m (2,924 ft)	893.1 m (2,930 ft)
Depth of Screened Sections:	764.1-835.8 m (2,507 to 2,742 ft) 863.2-881.5 m (2,832 to 2,892 ft)	776.6-839.1 m (2,548 to 2,753 ft) 865.9-892.8 m (2,841 to 2,929 ft)
Depth of Sand Pack:	742.8-756.8 m (2,437 to 2,483 ft) 843.4-858.0 m (2,767 to 2,815 ft)	Same as for completion string
Depth of Gravel Pack:	756.8-843.4 m (2,483 to 2,767 ft) 858.0-898.2 m (2,815 to 2,947 ft)	Same as for completion string
Depth of Moyno® Pump:	755.0-761.6 m (2,477.1 to 2,498.8 ft)	Not applicable
Fluid Depth[a]:	618.1 m (2,028 ft)	

DRILLING CONTRACTOR: Welch & Howell Drilling

GEOPHYSICAL LOGS BY: Atlas Wireline Services, Baker Hughes INTEQ, Barbour Well Surveying, Desert Research Institute, Geophysical Engineering Group of the Joint Test Organization, Schlumberger

SURVEYING CONTRACTOR: Bechtel Nevada

[a] Fluid level in the open borehole as of March 7, 1996.

point in the welded Rainier Mesa Tuff was reached at 243.8 m (800 ft) on February 24, 1996. This favorable casing point was determined by analysis of caliper logs from nearby Instrument Holes U-20bd#1 and #2 and the Well ER-20-6#1 penetration rate.

Mud mixed with LCM was pumped down-hole before the surface casing was set in an effort to seal lost-circulation zones prior to cementing. A casing service subcontractor then came on site and set the 13⅜-in. casing at 242.7 m (796.2 ft). The cementing service cemented the bottom of the casing by pumping 11.3 cubic meters (m^3) (400 cubic feet [ft^3]) of cement down the casing and pushing it up into the annulus with water behind a bottom plug. The plug did not reach the bottom, and the casing was shut in under air pressure. The amount of cement rise in the annulus is unknown. To seal the upper part of the casing, a sack of cedar fiber, a sack of barite, and 0.04 m^3 (10 gallons [gal]) of cement were dropped on the cement basket at 16.7 m (54.7 ft). The casing annulus was then cemented from the cement basket to ground level. The casing was still under pressure when the cement job was complete (approximately 5 hours after it was shut in).

The next four shifts were spent rigging up for air-drilling, preparing the 12¼-in. bottom-hole assembly (BHA), testing and repairing the BOP, and making up a sample-port in the flow line. The crew tagged the top of cement inside the surface casing at 226.2 m (742 ft) and began to drill out from under the casing with air-foam on February 26, 1996. A void was encountered from 229.5 to 236.8 m (753 to 777 ft). Drilling then continued through cement to the bottom of the 17½-in. hole at 243.8 m (800 ft) and into the formation.

When circulation was lost at 277.1 to 281.3 m (909 to 923 ft) the air injection rate was increased and circulation resumed. Drilling progressed rapidly, at an average rate of approximately 9 meters per hour (m/hour) (30 feet per hour [ft/hour]) with long intervals of up to 18 m/hour (60 ft/hour). Tritium was encountered in the returns at the depth of 577.0 m (1,893 ft) on February 28, 1996. Circulation was again lost at 587.7 m (1,928 ft) and the injection rate was increased, but the drillers were unable to regain circulation by the time drilling was stopped at the first core point.

The drillers circulated and conditioned the hole, then tripped out before the coring subcontractor arrived and began coring operations. Two cores were cut from 673.3 to 684.0 m (2,209 to 2,244 ft) (see Section 3.2 for a discussion of the coring results). The drillers tripped back in with the 12¼-in. BHA and drilled without returns to the next planned core point at 716.3 m (2,350 ft). The drill rate indicated that the target formation had not been reached, so drilling continued to the depth of 731.5 m (2,400 ft). The drillers circulated to clean the hole and tripped out before the coring crew rigged up to cut the third core from 731.5 to 740.7 m (2,400 to 2,430 ft). The drillers then made up the 12¼-in. BHA and tripped back in to continue drilling to the next core point, again with no fluid returns to the surface. The coring crew cut core #4 from 792.5 to 797.1 m (2,600 to 2,615 ft), and the drillers tripped back in to continue drilling. Circulation was reestablished briefly between 823.0 and 853.4 m (2,700 to 2,800 ft). When Cesium-137 was encountered in the returns at the depth of 829.1 m (2,720 ft) on March 3, 1996, drilling stopped while the radioactive work permit was amended to address this new condition. The drillers circulated and worked the pipe for two hours while waiting on the permit, and then continued drilling to the final core point. Cores #5 and #6 were cut from 853.4 to 869.3 m (2,800 to 2,852 ft), and the coring operation was completed early on March 5, 1996. The drillers tripped in with the 12¼-in. BHA to resume drilling, but had to ream from 864.7 to 869.3 m (2,837 to 2,852 ft) because the stabilizer on the core barrel had been ⅛-in. under gauge.

The TD of 975.4 m (3,200 ft) was reached on March 6, 1996. Circulation was never regained. The drillers conditioned the hole (with no returns) for thirty minutes. A short trip made to check for fill found none, and the drillers tripped the BHA out to prepare for geophysical logging.

The gyroscopic survey run in the well indicates that at the lowest surveyed depth of 888.8 m (2,916 ft), the hole had drifted 20.0 m (65.6 ft) to the west-northwest of the collar location.

3.1.2 Drilling Problems

The primary problem encountered during drilling of Well ER-20-6#1 was lost circulation. Lack of returns to the surface prevents tritium monitoring and timely identification of the well geology and causes increased costs for drilling fluids. Lost circulation occurred in the following intervals:

- 47.9 to 48.8 m (157 to 160 ft)
- 162.5 to 191.7 m (533 to 629 ft)
- 234.1 to 243.8 m (768 to 800 ft)
- 277.1 to 281.3 m (909 to 923 ft)
- no or intermittent returns 587.7 to 823.0 m (1,928 to 2,700 ft)
- 853.4 to 975.4 m (2,800 to 3,200 ft)

Welded ash-flow tuff and lava that may be fractured were present in most of the lost-circulation intervals. However, zeolitized bedded tuff that should be less prone to natural fracturing was present between 576.1 and 765.0 m (1,890 to 2,510 ft). Fractures might be present in this interval as a result of the nearby BULLION explosion.

3.1.3 Fluid Management

A mix of gel (mud) and polymer was used to drill Well ER-20-6#1 to the depth of 243.8 m (800 ft) with applications of cottonseed hulls and cedar fiber LCM as needed. The remainder of the hole was drilled using air-foam, with applications of polymer as needed to condition the hole. The coring operation was also conducted with air-foam. Separate lined sumps were used to hold clean and contaminated discharge fluids.

The drilling effluent was monitored in accordance with the methods prescribed in the *Fluid Management Plan for the Underground Test Area Operable Unit* (DOE, 1994) and the *Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6* (IT, 1995). The results of analyses on samples of drilling fluid collected indicate that all fluids are within the fluid quality objectives established for radiochemical parameters in the Fluid Management Plan.

Appendix B-1 of this report contains the Well ER-20-6#1 Fluid Management Status report. The fluid disposition form lists final volumes and data for drilling and completing the well and for initial well development. The final volumes of fluids imported to and produced at Well ER-20-6#1 were calculated from water-truck delivery tickets and measurements of fluids in the sumps. The solids produced were calculated using the diameter of the borehole and the depth drilled with added volume attributed to rock bulking factors.

3.2 Geologic Data Collection

3.2.1 Collection of Drill Cuttings

The sampling plan for Well ER-20-6#1 called for collection of triplicate sets of composite drill cuttings collected continuously at 3.1-m (10-ft) intervals from the base of the conductor casing to the hole TD (IT, 1995). However, long intervals of the main hole were drilled with no returns to the surface, which precluded sample collection. Samples were not obtained from 109 intervals from 12.2 to 853.4 m (40 to 2,800 ft) due to poor or negligible fluid returns to the surface, and no cuttings were collected from 853.4 m to the TD (2,800 to 3,200 ft). No cuttings were collected during conventional coring. All samples (162 sets of three) collected are stored under secure conditions at the U.S. Geological Survey (USGS) Geologic Data Center and Core

Library in Mercury, Nevada. One of each set of 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 in accordance with standard Core Library procedures.

3.2.2 Conventional Coring

The drilling criteria called for recovery of two 9.1-m (30-ft) conventional cores from Well ER-20-6#1: one from the same depth as the BULLION WP, 670.5 to 679.7 m (2,200 to 2,230 ft) and one from the upper portion of the lava-flow aquifer, predicted to be at approximately 716.2 m (2,350 ft). Analysis of the first core was expected to provide data on any radionuclides present. Study of the second core was expected to provide information about the nature of fractures in the lava-flow aquifer and their influence on groundwater movement. Additional cores were obtained from both target horizons because drill cuttings were lacking due to lost circulation and to ensure that enough material was available for the planned analyses.

Baker Hughes INTEQ (BHI) cut a total of six cores using a 12¼-in. by 5¼-in. bit and 9.1-m (30-ft) aluminum inner barrels. Each recovered core was sawed (still inside the inner barrel) into 0.6-m (2-ft) sections, and the ends were capped at the drill site. Only the exposed ends of the cores were examined at the rig for lithologic information. The cores are stored under secure conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada, pending shipment to project scientists for testing. Core-recovery information is presented in Table 3-2. Additional information about the coring equipment and other data can be found in the BHI coring operations report (BHI, 1996).

3.2.3 Sidewall Samples

After drilling was completed, sidewall samples were collected to verify the stratigraphy and lithology at various locations in the interval 516.9 to 907.7 m (1,696 to 2,978 ft) and to obtain material for rock property tests and analysis of matrix water. Percussion-gun sidewall samples were collected by Atlas Wireline Services who ran a tandem core gun with 50 shots and recovered 16 cores on March 8, 1996. Schlumberger ran a rotary sidewall coring tool on March 9, 1996, and recovered 24 cores out of 30 attempted in the interval 576.1 to 833.9 m (1,890 to 2,736 ft). The sample depths were selected by the IT Field Representative. All samples recovered, the amount of sample recovered, and the geology of the samples are listed in Table 3-3.

Table 3-2
Conventional Cores Taken from Well ER-20-6#1

Core Number	Cored Interval meters (feet)	Core Cut meters (feet)	Core Recovered meters (feet)	Stratigraphic Unit	Hydrogeologic Unit[a]
1	673.3 to 678.8 (2,209 to 2,227)	5.5 (18)	5.0 (16.5)	Tacp[b]	TCU[c]
2	678.8 to 683.7 (2,227 to 2,243)	4.9 (16)	4.9 (16)	Tacp	TCU
3	731.5 to 740.7 (2,400 to 2,430)	9.1 (30)	9.1 (30)	Tacp	TCU
4	792.5 to 797.1 (2,600 to 2,615)	4.6 (15)	4.6 (15)	Tacp	LFA[d]
5	853.4 to 860.1 (2,800 to 2,822)	6.7 (22)	6.7 (22)	Tacp	LFA
6	860.1 to 869.3 (2,822 to 2,852)	9.1 (30)	9.1 (30)	Tacp	LFA

[a]Modified from Winograd and Thordarson (1975) and Laczniak et al. (1996).
[b]Mafic-poor Calico Hills Formation. Stratigraphic nomenclature from Ferguson et al. (1994). See Appendix C-1.
[c]Tuff confining unit
[d]Lava-flow aquifer

Table 3-3
Sidewall Samples Collected from Well ER-20-6#1
(Page 1 of 2)

Core Depth meters (feet)	Tool Used	Recovery centimeters (inches)	Stratigraphic Unit[a]	Hydrogeologic Unit[b]
542.5 (1,780)	Pg[c]	3.2 (1.25)	Tmrh[d]	TCU[e+]
576.1 (1,890)	PG	2.5 (1.0)	Tmrh	TCU
576.1 (1,890)	R[f]	± 2.0 (0.8)	Tmrh	TCU
577.9 (1,896)	R	± 2.0 (0.8)	Tmrh	TCU
577.9 (1,896)	PG	1.9 (0.75)	Tmrh	TCU
581.3 (1,907)	PG	1.9 (0.75)	Tpd[g]	TCU
581.3 (1,907)	PG	1.9 (0.75)	Tpd	TCU
583.7 (1,915)	R	3.5 (1.4)	Tpd	TCU
585.2 (1,920)	PG	1.9 (0.75)	Tpd	TCU
588.3 (1,930)	R	3.0 (1.2)	Tpd	TCU
629.1 (2,064)	R	4.3 (1.7)	Tpd	TCU
630.3 (2,068)	PG	4.4 (1.75)	Tpd	TCU
630.9 (2,070)	PG	3.8 (1.50)	Tpd	TCU
635.2 (2,084)	PG	3.2 (1.25)	Tpd	TCU

Table 3-3
Sidewall Samples Collected from Well ER-20-06#1
(Page 2 of 2)

Core Depth meters (feet)	Tool Used	Recovery centimeters (inches)	Stratigraphic Unit[a]	Hydrogeologic Unit[b]
645.0 (2,116)	PG	3.8 (1.50)	Tpe[h]	TCU
654.7 (2,148)	PG	3.2 (1.25)	Tpe	TCU
656.2 (2,153)	PG	3.8 (1.50)	Tacp[i] (*b*)	TCU
664.5 (2,180)	PG	3.8 (1.50)	Tacp (*b*)	TCU
667.5 (2,190)	R	4.5 (1.8)	Tacp (*b*)	TCU
669.3 (2,196)	R	4.7 (1.9)	Tacp (*b*)	TCU
669.3 (2,196)	PG	3.8 (1.50)	Tacp (*b*)	TCU
670.6 (2,200)	R	4.2 (1.7)	Tacp (*b*)	TCU
672.1 (2,205)	R	4.3 (1.7)	Tacp (*b*)	TCU
705.9 (2,316)	R	3.4 (1.3)	Tacp (*b*)	TCU
707.1 (2,320)	R	4.1 (1.6)	Tacp (*b*)	TCU
709.3 (2,327)	R	1.9 (0.7)	Tacp (*b*)	TCU
719.3 (2,360)	R	1.5 (0.6)	Tacp (*b*)	TCU
753.5 (2,472)	R	2.3 (0.9)	Tacp (L)	TCU*
755.9 (2,480)	R	4.7 (1.9)	Tacp (L)	LFA[j]
773.6 (2,538)	R	2.0 (0.8)	Tacp (L)	LFA
804.7 (2,640)	R	2.2 (0.9)	Tacp (L)	LFA
807.7 (2,650)	R	4.0 (1.6)	Tacp (L)	LFA
814.1 (2,671)	R	±2.2 (0.9)	Tacp (L)	LFA
817.2 (2,681)	R	3.4 (1.3)	Tacp (L)	LFA
823.0 (2,700)	R	4.5 (1.8)	Tacp (L)	LFA
827.8 (2,716)	R	3.0 (1.2)	Tacp (L)	LFA
833.9 (2,736)	R	4.0 (1.6)	Tacp (L)	LFA
881.2 (2,891)	R	±2.5 (1.0)	Tacp (L)	LFA
905.3 (2,970)	PG	1.3 (0.50)	Tacp (*b*)	TCU
907.7 (2,978)	PG	3.8 (1.50)	Tacp (*b*)	TCU

[a]Stratigraphic nomenclature from Ferguson et al. (1994). See Appendix C-1.
[b]Modified from Winograd and Thordarson (1975) and Laczniak et al. (1996).
[c]Percussion-gun Sidewall Core Tool operated by Atlas Wireline Services
[d]Rhyolite of Holmes Road, Timber Mountain Group
[e]Tuff confining unit
[f]Rotary Sidewall Core Tool operated by Schlumberger
[g]Tuff of Delirium Canyon, Paintbrush Group
[h]Rhyolite of Echo Peak, Paintbrush Group
[i]Mafic-poor Calico Hills Formation. (*b*) denotes bedded tuff; (L) denotes lava
[j]Lava-flow aquifer
[+]Sample is weakly zeolitized; this part of unit may not behave as a true TCU.
*Sample is zeolitized pumiceous lava; this part of the unit may behave as a "leaky" TCU.

3.2.4 Geophysical Logging Data

Geophysical logs were run after drilling to characterize the lithology, structure, and hydrogeologic properties of the rocks. In addition, logs were run to check borehole conditions, determine fluid levels and other hydrologic data, identify radionuclides, and monitor the completion process. All geophysical logs run in Well ER-20-6#1 during drilling and completion are listed in Table 3-4. The logs are available from BN in Mercury, Nevada, and copies are on file at the IT office in Las Vegas, Nevada.

Overall, the quality of the geophysical data is acceptable. However, the only geophysical log available for use in correlating geologic units above the casing point at 242.7 m (796.2 ft) was the natural gamma-ray log which was run through the casing. Also, log data are limited for the lower 61 m (200 ft) of the hole due to sloughing. Preliminary data from most of the geophysical logs are presented in Appendix D.

3.3 Hydrology of Well ER-20-6#1

3.3.1 Preliminary Water-Level and Water-Production Information

Most of Well ER-20-6#1 was drilled without fluid returns to the surface or with intermittent returns. However, a small amount of fluid was detected at approximately 577.0 m (1,893 ft). The fluid level in the open borehole (during geophysical logging and prior to installation of the tubing in the well) consistently stabilized at a depth of approximately 618.1 m (2,028 ft) and an elevation of 1,355 m (4,447 ft). The depth to water at Well Cluster ER-20-6 had been projected to be approximately 616.6 m (2,023 ft) at an elevation of approximately 1,355 m (4,447 ft) (IT, 1995).

3.3.2 Radionuclides Encountered

Because much of Well ER-20-6#1 was drilled with little or no fluid returns to the surface, many radiation measurements were made on composite samples made up of small amounts of fluid condensate dripping from the flow line. The cuttings and core samples were scanned for alpha, beta, and gamma radiation, as were dried fluid swipes from the flow line and other surfaces.

Tritium was encountered in the fluid returns when the hole had reached the depth of 577.0 m (1,893 ft), approximately 41 m (135 ft) above the static water level. Cesium-137 activity (1,642 pCi/L) was detected in the cuttings sample from 579.4 m (1,901 ft). The presence of this activity above the water table was interpreted as an indication that the hole had crossed a

Table 3-4
Well ER-20-6#1 Geophysical Log Summary

Geophysical Logs	Log Purpose	Logging Service	Date Logged	Run Number	Top of Logged Interval (bgs)[a] meters (feet)	Bottom of Logged Interval (bgs) meters (feet)
Annulus Investigation Log	Omnidirectional density (check for cement and/or fluid location)	GEG[b]	03/10/96 03/11/96 03/12/96 03/12/96 03/13/96	AIN-1 AIN-2,3 AIN-4,5 AIN-6 AIN-7	868.7 (2,850) 594.4 (1,950) 259.1 (850) 579.1 (1,900) 152.4 (500)	909.5 (2,984) 908.3 (2,980) 893.1 (2,930) 893.1 (2,930) 762.0 (2,500)
4-arm Caliper/Gamma Ray	Borehole conditions/stratigraphic correlation	AWS[c]	03/06/96	CA4-1/GR-1	0	969.0 (3,179)
Borehole Televiewer/Gamma Ray	Borehole examination/stratigraphic correlation	AWS	03/06/96	BHTV-1/GR-2	617.2 (2,025)	921.4 (3,023)
Dual Laterolog/4-arm Caliper/Gamma Ray	Lithology/drill hole conditions/stratigraphic correlation	AWS	03/06/96	DLL-1/CA4-1/ GR-1	618.4 (2,029)	963.2 (3,160)
Epithermal Neutron/Compensated Densilog/Gamma Ray	Porosity/density/stratigraphic correlation	AWS	03/07/96	ENP-1/CDL-1/ GR-3	242.6 (796)	914.4 (3,000)
Spectralog	Stratigraphic correlation, mineralogy, natural radiation, identification of explosion products	AWS	03/07/96	SL-1	231.6 (760)	917.8 (3,011)
Spectralog/Digital Acoustic Televiewer	Stratigraphic correlation, mineralogy, natural radiation, identification of explosion products/borehole examination for fractures	AWS	03/07/96	SL-1/DAC-1	609.6 (2,000)	917.8 (3,011)
Downhole Video	Borehole examination for fractures and lithology	BWS[d]	03/08/96	TV-1	0	617.5 (2,106)
Total Magnetic Intensity	Stratigraphic correlation, lithologic information	GEG	03/08/96 03/09/96	TMI-1 TMI-2	646.5 (2,121) 243.8 (800)	909.5 (2,984) 685.8 (2,250)
Temperature Log	Groundwater temperature	AWS	03/07/96	TL-1	600.5 (1,970)	916.2 (3,006)
Thermal Flow Log (Electrical Conductivity, Temperature)	Determine rate/direction of groundwater flow within the borehole	DRI[e]	03/09/96	HPFLOW-1	624.8 (2,050)	887.0 (2,910)
Differential Temperature Survey	Groundwater temperature	GEG	05/01/96	TLDLT-3	579.1 (1,900)	891.2 (2,924)
Chemistry Log/Temperature Log	Determine pH, electrical conductivity, and temperature of fluid	DRI	03/08/96	CHEM-1/TL-2	624.8 (2,050)	887.0 (2,910)
Percussion-gun Sidewall Sampling/Gamma Ray	Obtain samples for analysis/stratigraphic correlation	AWS	03/07/96	SGUN-1/GR-4	516.9 (1,696)	907.7 (2,978)
Rotary Sidewall Coring/Gamma Ray	Obtain samples for analysis/stratigraphic correlation	SCH[f]	03/08/96	MCT-1/GR-5	576.1 (1,890)	881.2 (2,891)
Directional Gyroscope	Borehole deviation	BHI[g]	03/13/96	DRG-1	0	888.8 (2,916)

Source: BN Logging Department

[a] Below ground surface
[b] Geophysical Engineering Group of the Joint Test Organization
[c] Atlas Wireline Services
[d] Barbour Well Surveying
[e] Desert Research Institute
[f] Schlumberger
[g] Baker Hughes INTEQ

hydrofracture from the BULLION cavity located approximately 100 m (330 ft) from the hole. Cesium-137 activity of approximately 2,600 pCi/L was also recorded in the fluid returns at 829.1 m (2,720 ft).

Reported tritium activities (from the composite fluid samples) were variable throughout the drilling of Well ER-20-6#1 (data from the swipes are not presented in this report). However, after the radiation spike reported above the water table, most of the readings were at background levels from 583.7 to 693.4 m (1,915 to 2,275 ft). Tritium levels varied between approximately 1 million and 3 million pCi/L in the interval 693.4 to 716.3 m (2,275 to 2,350 ft) and then dropped off slightly between 722.4 and 763.5 m (2,370 to 2,505 ft). From approximately 766.6 to 868.1 m (2,515 to 2,848 ft), tritium activities fluctuated between 100,000 and 10 million pCi/L with spikes as high as 68 million pCi/L (at the depth of 823.6 m [2,702 ft]). Below the depth of 868.7 m (2,850 ft), the tritium activity did not rise above a million pCi/L. See Appendix B-2 for a listing of tritium data. See Section 6.1 for a graphic comparison of tritium data for all three holes in the cluster. More data on radionuclides encountered in Well ER-20-6#1 might be obtained through analysis of the spectral log run in the borehole after drilling.

3.3.3 Preliminary Thermal Flow Log Data

Thermal flow meter (TFM) data, in addition to temperature, electrical conductivity (EC), and pH measurements, can characterize borehole fluid variability, which may indicate inflow and outflow zones. Data from the TFM (and other data) were used to help identify intervals for completion in Well ER-20-6#1. Personnel of the Desert Research Institute (DRI) made TFM measurements at the seven locations listed below on March 9, 1996.

- 624.8 m (2,050 ft)
- 670.6 m (2,200 ft)
- 716.3 m (2,350 ft)
- 777.2 m (2,550 ft)
- 813.8 m (2,670 ft)
- 868.7 m (2,850 ft)
- 887.0 m (2,910 ft)

Preliminary field evaluation of the TFM data indicated downward flow at six of the measured stations; upward flow was found at 813.8 m (2,670 ft). The flow rate at the four upper measurement locations was about one liter per minute (Lpm) or less. The flow rate at the three lower stations ranged from approximately 1.7 to 3.7 Lpm. The TFM data were interpreted to indicate that in the interval of interest, two relatively more-transmissive zones are separated by a relatively less-transmissive zone.

3.4 Precompletion and Open-Hole Development

The only precompletion development attempted in Well ER-20-6#1 was circulation and conditioning of the borehole for thirty minutes (with no returns) after TD was reached and prior to geophysical logging.

3.5 Completion

The objective of well completion is to hydraulically isolate one or more water-producing zones in order to test the hydrologic characteristics of selected zone(s). Completion activities at Well ER-20-6#1 began immediately after logging was concluded and a bottom plug had been set on March 11, 1996, and were concluded on March 15, 1996. Figure 3-2 is a schematic of the final well-completion design for Well ER-20-6#1, and Figure 3-3 shows a plan view and profile of the wellhead configuration. Data for this section were obtained from the BN daily rig reports and tubing records for Well ER-20-6#1.

3.5.1 Proposed Completion Design

The original plan for Well Cluster ER-20-6 called for installation of monitoring equipment to obtain data on the characteristics of the existing near-field groundwater regime, but the project was later modified to a forced-gradient experiment (IT, 1995, 1996b). The modification required the redesign of the well cluster configuration (see Section 1.3 of this report), but the target completion interval in Well ER-20-6#1, the middle lava-flow aquifer, was the same as originally planned. The modified completion design for Well ER-20-6#1 was similar to the original design, but with a longer completion interval to maximize access to the formation. The modified design for Well ER-20-6#1 called for the installation of a screened 5½-in. completion string with a pump installed just above the screened interval. A 2⅞-in. fiberglass access string was required adjacent to the completion string with a slotted interval similar to that of the completion string, but longer than originally planned for the well. The plan for the forced-gradient experiment called for one long gravel-packed interval to extend above and below the screened interval.

3.5.2 As-Built Completion Design

The as-built completion design provides access to the two most transmissive portions of the lava-flow aquifer underlying the tuff-confining unit in which the BULLION WP was located.

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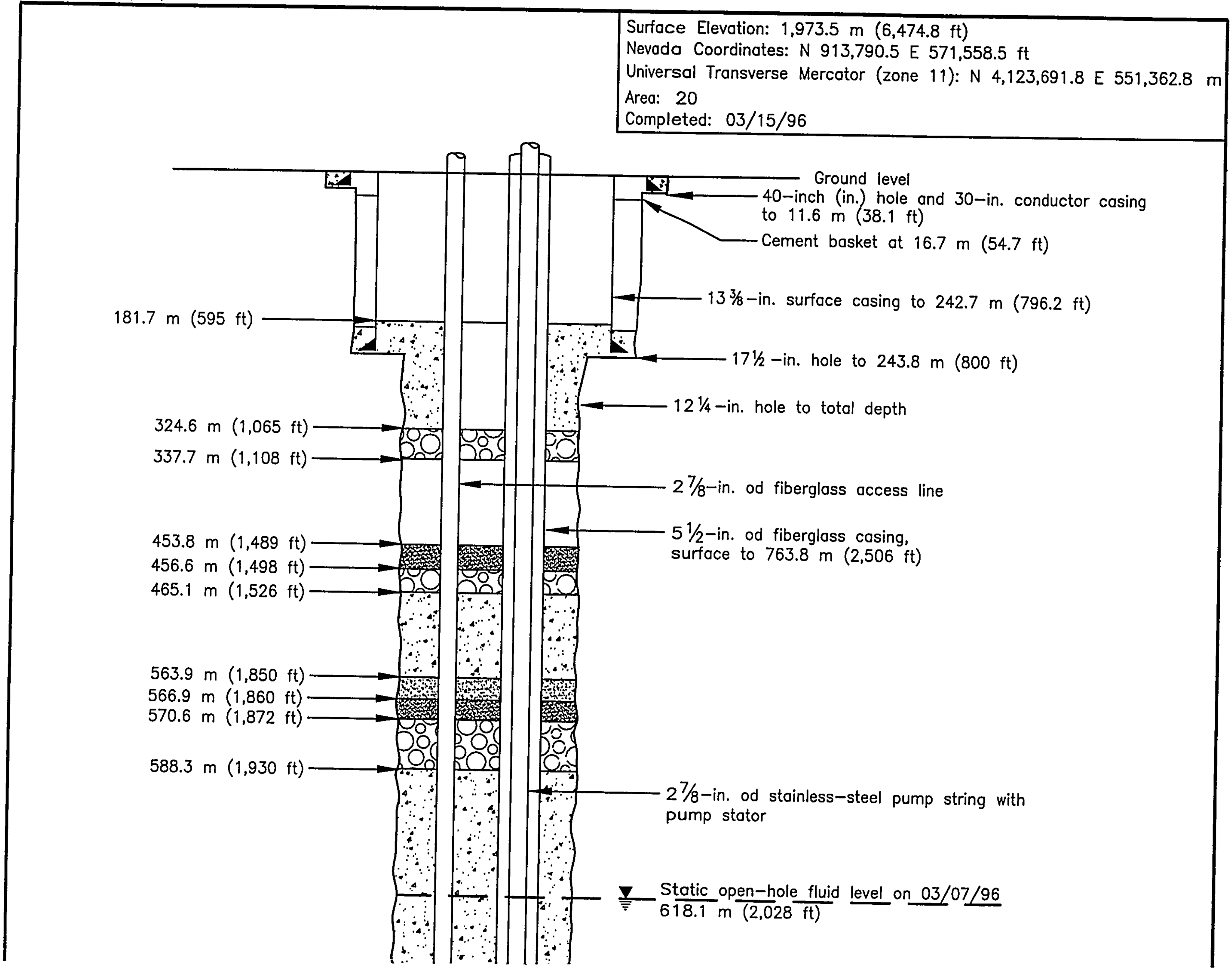


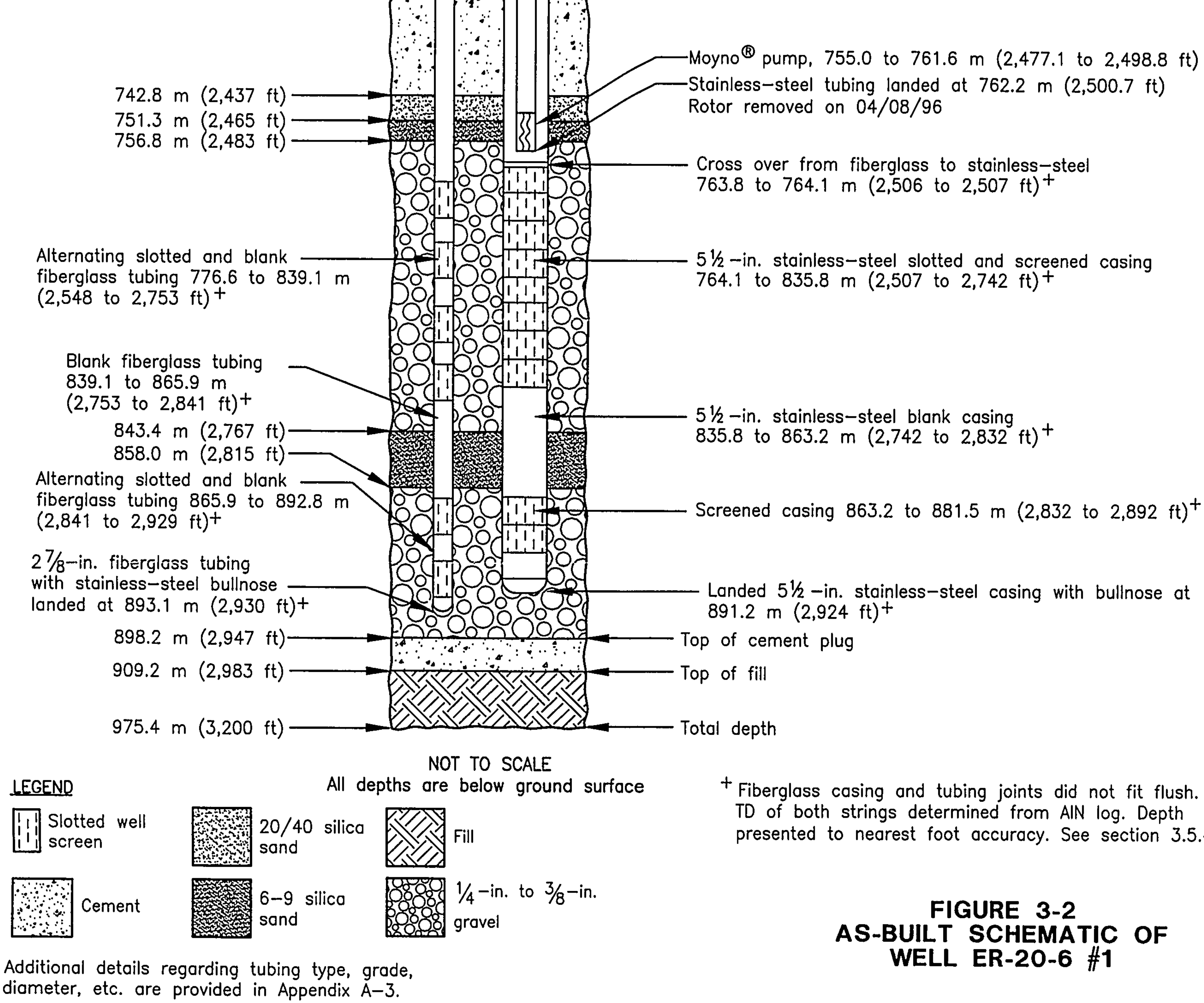


FIGURE 3-2
AS-BUILT SCHEMATIC OF WELL ER-20-6 #1

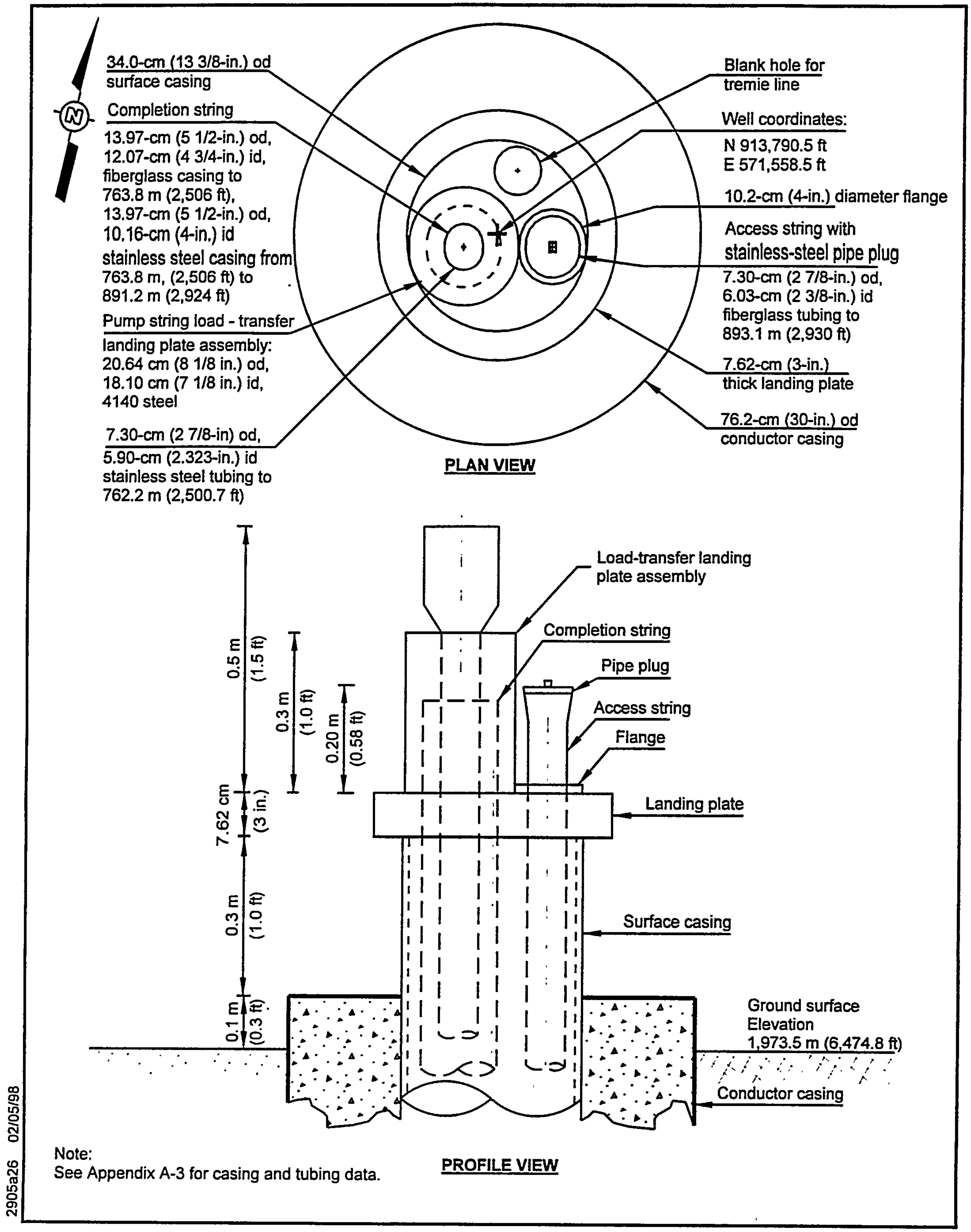


Figure 3-3
Well ER-20-6 #1 Wellhead Diagram

The completion string design has two screened sections with a pump stator positioned on a separate string within the casing just above the screened section. The pump stator was installed with No-Turn Tools® which were expected to prevent counter-rotation of the stator and allow easy removal of the pump if desired. The pump rotor will be installed on a drive-rod string. A separate slotted string was installed adjacent to the completion string for groundwater monitoring. The string compositions are listed on Table 3-5, and tubing materials are listed in Appendix A-3.

The casing for the pump string is 5½-in. od fiberglass to the depth of 763.8 m (2,506 ft) and 5½-in. stainless steel from 763.8 m (2,506 ft) to the bottom of the string at 891.2 m (2,924 ft). The bottom 0.6-m (1.9-ft) joint is bull-nosed with a 0.64-cm (0.25-in.) hole to serve as a fluid drain in the event of excessive drawdown. The first joint above the bull-nose is blank, followed by two screened 9.1-m (29.8-ft) joints. This lower screened section is separated from the upper screened section by a 27.4-m (90.0-ft) blank section. The upper screened section is 71.6 m (234.9 ft) long and consists of eight screened joints. The terminal 0.76 m (2.5 ft) of each stainless-steel screened joint is blank (for strength at the connections), and the middle 7.6 m (25 ft) is perforated with 1.27-cm (0.5-in.) diameter holes at a density of 160 holes per foot. Stainless-steel screen consisting of wire wrapped around wire ribs with 0.20-cm (0.078-in.) openings between wraps was installed within each perforated joint.

The Moyno® pump stator was installed on 2⅞-in. stainless-steel tubing within the 5½-in. casing at 755.0 to 761.6 m (2,477.1-2,498.8 ft) with No-Turn Tools® located above and below the stator. The 2⅞-in. stainless-steel string is unslotted, but open on the bottom (via the pump stator section). The pump rotor was installed in the stator on a string of 7.6-m (25-ft) long, ⅞-in. coated drive rods equipped with spin-through rod guides. The number of guides per rod was determined by computer analysis of side-loading, based on borehole deviation data (Schwichtenburg, 1996). The rotor and drive-rod string were later removed (see Section 3.5.4).

A 2⅞-in. fiberglass tubing string was installed in Well ER-20-6#1 adjacent to the 5½-in. casing string to serve as an access line. The fiberglass tubing was landed off at 893.1 m (2,930 ft). The bottom 0.2-m (0.7-ft) joint is a stainless-steel bull-nose with a 0.64-cm (0.25-in.) hole to serve as a fluid drain. The lower slotted section consists of two slotted, 8.9-m (29.3-m) fiberglass joints separated by a blank joint. This section is separated from the upper slotted section by a 26.8-m (88-ft) long blank section. The upper slotted section is 62.5 m (205 ft) long and consists of four slotted joints alternating with blank joints. The terminal 1.2 m (4 ft) of each fiberglass slotted

Table 3-5
Well ER-20-6#1 Construction Summary

<table>
<tr><th>Completion String</th><th colspan="2">Configuration</th><th>Cement</th><th>Sand/Gravel</th></tr>
<tr><td rowspan="5">5½-inch Completion String</td><td rowspan="5">Fiberglass casing from ground surface to 763.8 m (2,506 ft)

Stainless-steel casing from 763.8 to 891.2 m (2,506-2,924 ft)</td><td>Blank
ground surface to 764.1 m (2,507 ft)</td><td rowspan="13"><u>Type II plus 2% CaCl2</u>

181.7 to 324.6 m (595 to 1,085 ft)

337.7 to 453.8 m (1,108 to 1,489 ft)

(465.1 to 563.9 m (1,526 to 1,850 ft)

588.3 to 742.8 m (1,930 to 2,437 ft)

898.2 to 909.2 m (2,947 to 2,983 ft)</td><td rowspan="13"><u>20/40 Sand</u>

563.9 to 566.9 m (1,850 to 1,860 ft)

742.8 to 751.3 m (2,437 to 2,465 ft)

<u>6-9 Sand</u>

453.8 to 456.6 m 1,489 to 1,498 ft)

588.9 to 570.6 m (1,860 to 1,872 ft)

751.3 to 756.8 m (2,465 to 2,483 ft)

843.4 to 858.0 m (2,767 to 2,815 ft)

<u>1/4- to 3/8-inch Gravel</u>

324.6 to 337.7 m (1,065 to 1,108 ft)

456.6 to 465.1 m (1,498 to 1,526 ft)

570.6 to 588.3 m (1,872 to 1,930 ft)

756.8 to 843.4 m (2,483 to 2,767 ft)

858.0 to 898.2 m (2,815 to 2,947 ft)</td></tr>
<tr><td>Screened
764.1 to 835.8 m (2,507 to 2,742 ft)</td></tr>
<tr><td>Blank
835.8 to 863.2 m (2,742 to 2,832 ft)</td></tr>
<tr><td>Screened
863.2 to 881.5 m (2,832 to 2,892 ft)</td></tr>
<tr><td>Blank and bull-nosed
881.5 to 891.2 m (2,892 to 2,924 ft)</td></tr>
<tr><td rowspan="2">2⅞-inch Stainless-Steel Pump String</td><td rowspan="2">Ground surface to 762.2 m (2,500.7 ft) inside 5½-inch casing</td><td>Moyno® pump stator
755.0 to 761.6 m (2,477.1 to 2,498.8 ft)</td></tr>
<tr><td>No-Turn Tools®
754.5 to 755.0 m (2,475.3 to 2,477.0 ft)

761.7 to 762.3 m (2,499.0 to 2,500.7)</td></tr>
<tr><td>⅞-inch Coated Drive Rod</td><td>Removed from well on April 8, 1996</td><td>Moyno® pump rotor removed from well on April 8, 1996</td></tr>
<tr><td rowspan="5">2⅞-inch Access String</td><td rowspan="5">Smith Fiberglass Products, Inc.

Ground surface to 893.1 m (2,930 ft)</td><td>Blank
Ground surface to 776.6 m (2,548 ft)</td></tr>
<tr><td>4 slotted joints alternating with 3 blank joints
776.6 to 839.1 m (2,548 to 2,753 ft)</td></tr>
<tr><td>Blank
839.1 to 865.9 m (2,753 to 2,841 ft)</td></tr>
<tr><td>2 slotted joints separated by 1 blank joint
865.9 to 892.8 m (2,841 to 2,929 ft)</td></tr>
<tr><td>Blank and bull-nosed
892.8 to 893.1 m (2,929 to 2,930 ft)</td></tr>
</table>

Note: Depth data for strings containing fiberglass components are presented at 1-ft accuracy, corrected from the field records on the basis of AIN logs. See Section 3.5.4.

joint is blank (for strength at the connections), and the middle 6.7 m (22 ft) is slotted. Each slotted joint has eight rows of saw-cut slots, 7.62 cm (3 in.) long by 0.32 cm (0.125 in.) wide on staggered 30.5-cm (12-in.) centers.

3.5.3 Rationale for Differences Between Actual and Proposed Well Design

The as-built design for Well ER-20-6#1 was developed on the basis of geophysical and flow-log data from the borehole. Two gravel-packed zones were installed in the well instead of one as described in the plan for the forced-gradient experiment because the borehole data indicated that the target lava-flow aquifer contains two relatively more-transmissive zones separated by a less-transmissive interval. The blank section of the well completion is located in the less-transmissive portion with sand separating the two gravel packs. This configuration will allow flexibility in test design: the lower slotted interval, placed in a zone of lower tritium levels, can be packed off and tested separately from the upper interval or can be permanently isolated if desired. The difference in permeability between the sand and the gravel is expected to provide an adequate barrier between the two zones.

3.5.4 Completion Method

Standard UGTA decontamination procedures were employed to prevent the introduction of outside contaminants into the well. Well-construction materials were inspected in accordance with 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. A "tremie" line consisting of 2⅞-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 ensure that the line remained clear. The Annulus Investigation log (AIN) was used to monitor the placement of cement, sand and gravel and to verify tubing and casing depths. All casing and tubing were run by a casing installation subcontractor.

Additional borehole sloughing occurred during and after geophysical logging, so that before completion installation began, the bottom of the hole was plugged with fill to 909.2 m (2,983 ft). After the tremie was run into Well ER-20-6#1, its TD was verified with an AIN log at 909.1 m (2,982.5 ft). The hole was cemented from the top of the fill to the depth of 898.2 m (2,947 ft) using Type II cement plus 2-percent calcium chloride ($CaCl_2$). The completion string was landed at 891.2 m (2,924 ft) and the access string was landed at 893.1 m (2,930 ft). During assembly of the strings, it was noticed that the connections between the fiberglass joints in both strings did not fit "flush," so an AIN log was run in each string to verify the string TD. The actual depth of the 5½-in. string (consisting of fiberglass and stainless steel) was found to be 1.9 m (6.3 ft) greater than the sum of the lengths of the joints that make up the string as reported on the BN field records. The actual TD of the 2⅞-in. fiberglass access string was found to be 1.8 m (6.0 ft) longer than the sum of the joint lengths reported in the BN records. Tubing and casing depths listed in all figures and tables in this report have been corrected to match the measured string TDs. The depths of the strings that include fiberglass components are reported only to the nearest foot, reflecting the accuracy of the AIN log used to measure them.

The completion operation continued with the placement of the gravel pack. The lower slotted interval was packed with ¼-in. to ⅜-in. silica gravel from 858.0 to 898.2 m (2,815 to 2,947 ft). The sand pack above the gravel consists of 6/9 Colorado sand placed at 843.4 to 858.0 m (2,767 to 2,815 ft). The upper gravel pack consists of ¼-in. to ⅜-in. gravel from 756.8 to 843.4 m (2,483 to 2,767 ft). The sand pack above this gravel consists of 6/9 Colorado sand placed at 751.3 to 756.8 m (2,465 to 2,483 ft) and 20-40 silica sand placed at 742.8 to 751.3 m (2,437 to 2,465 ft). An initial cement plug consisting of Type II cement plus 2-percent $CaCl_2$ was placed between 739.1 and 742.8 m (2,425 to 2,437 ft). At that point the logging crew arrived and ran a gyroscopic survey inside the 5½-in. casing. Cementing then continued with the placement of Type II cement plus 2-percent $CaCl_2$ to 682.1 m (2,238 ft). The casing crew began running the pump stator inside the 5½-in. casing while waiting on cement. When the next stage of cement was ready for placement, the 2⅞-in. stainless-steel pump string was landed temporarily on the landing plate. Cement was pumped to the depth of 580.6 m (1,905 ft), but loss of cement to the formation caused the level to drop to 588.3 m (1,930 ft). The casing crew completed running the pump string and landed it at 757.3 m (2,484.7 ft), but were unable to set the No-Turn Tools®. The DOE Field Manager ordered the tools set close to the slotted interval, so the bottom of the pump was reset at 762.2 m (2,500.7 ft). The No-Turn Tools® still failed to set properly.

To advance the cementing of the rest of the borehole, a layer of ¼-in. to ⅜-in. gravel was placed at 570.6 to 588.3 m (1,872 to 1,930 ft), with 6/9 sand and 20-40 sand at 563.9 to 570.6 m (1,850 to 1,872 ft). Type II cement plus 2-percent $CaCl_2$ was placed at 465.1 to 563.9 m (1,526 to 1,850 ft), and more gravel was used at 456.6 to 465.1 m (1,498 to 1,526 ft). This was topped with 3.4 m (11 ft) of sand followed by more cement. When cement was lost to the formation at 337.7 m (1,108 ft), an additional 13.1 m (43 ft) of gravel was added. The borehole was then cemented to the depth of 181.7 m (596 ft) from 324.6 m (1,065 ft).

A single, under-sized rotor was installed inside the 2⅞-in. stainless steel pump string, tagging the stop pin at 762.4 m (2,501.2 ft). The rotor was set at 760.5 m (2,495.2 ft), and a nine-hour pumping test was immediately started. The rig was released after the pumping test.

The drive rod string and pump rotor were pulled from the well on April 8, 1996, after the pump string in Well ER-20-6#2 separated (see Section 4.5). The upper 2.0 m (6.5 ft) of the rotor was found to have a 1.9-cm (0.75-in.) flat spiral groove, possibly indicating that the rotor had not been set completely within the stator.

3.6 Actual Versus Planned Costs and Scheduling

The BN cost model for the ER-20-6 well cluster was originally developed on a per-hole basis for generic 914.4-m (3,000-ft) deep holes. In this model, drilling, logging, and completion for a 914.4-m (3,000-ft) deep hole was projected to require 20 days to accomplish. Actual time spent (after rigging up) on drilling and completion of Well ER-20-6#1, with a TD of 975.4 m (3,200 ft), was 27 days.

The cost analysis for Well ER-20-6#1 can be divided into charges by the drilling contractor (including drilling equipment, fluids, and the coring and casing subcontractors) and charges by the support contractors (including radiation technicians, inspection services, geophysical logging, cementing services, and completion materials). The total planned cost of Well ER-20-6#1 was $1,062,143. The actual cost of Well ER-20-6#1 through completion totaled $1,347,541, or approximately 26.9 percent more than the planned cost. Table 3-6 provides a list of the planned and actual costs. Figure 3-4 is a comparison of planned and actual costs, by day, for drilling and completing Well ER-20-6#1.

Table 3-6
Well ER-20-6#1 Actual Versus Planned Costs

Activity	Planned Cost[a]	Actual Cost	Percent Difference Actual versus Planned
Drilling contractor	$339,600	$546,086[b]	60.8
Support contractors	$722,543	$801,455[c]	10.9
Total	$1,062,143	$1,347,541	26.9

[a]Based on BN model for 914.4-m (3,000-ft) hole.
[b]Source: DOE/ERD
[c]Source: BN Drilling

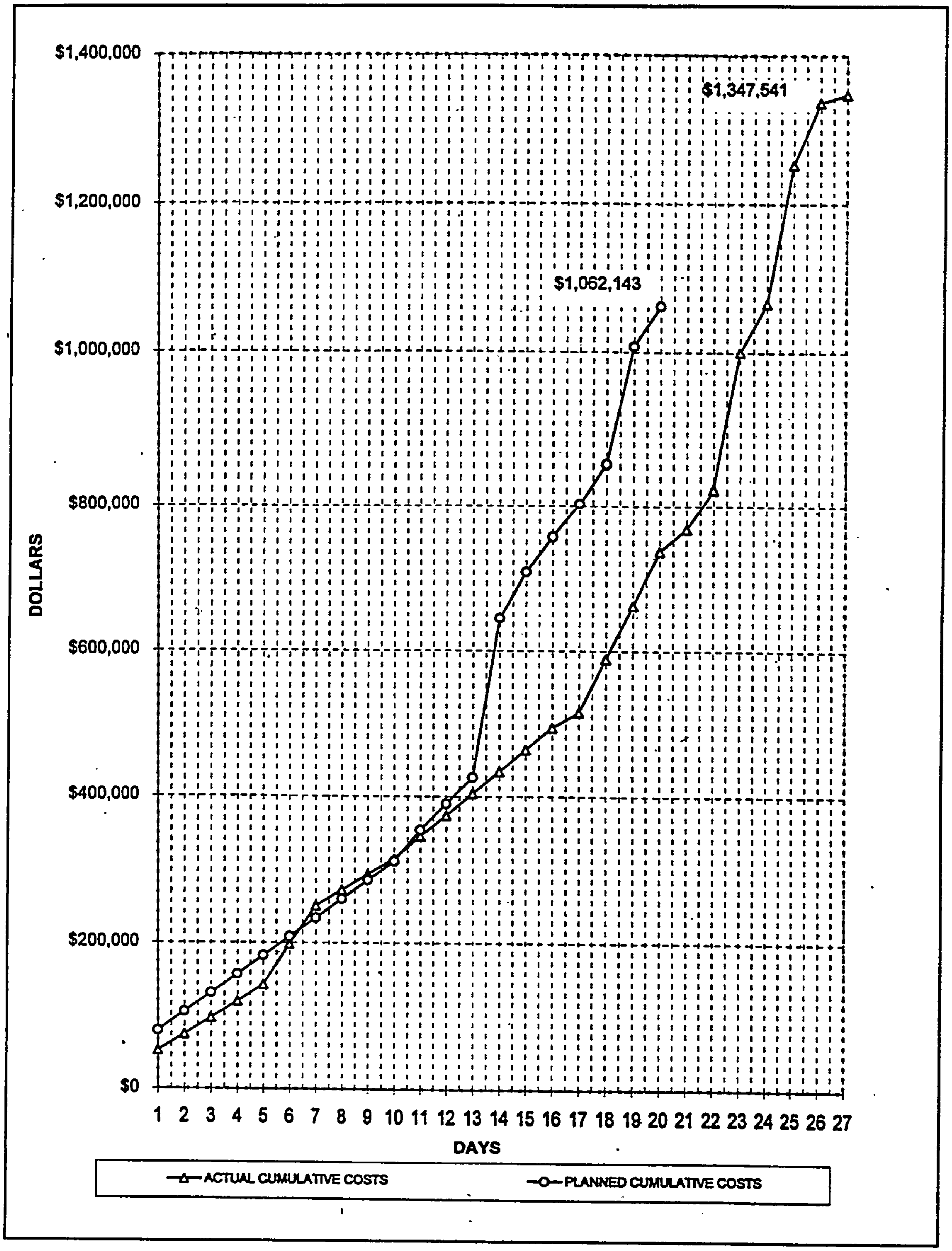


Figure 3-4
Actual Versus Planned Costs for Drilling and Completion of Well ER-20-6#1

3.7 Summary and Lessons Learned

3.7.1 Summary

Drilling commenced at Well ER-20-6#1 on February 19, 1996, and concluded on March 6, 1996, when the TD of 975.4 m (3,200 ft) was reached. The completion was installed and gravel-packed, and the hole cemented to 181.7 m (596 ft) on March 11-15, 1996. Crews worked on a seven-days-per-week, 10-hours-per-day schedule to rig up on the location, and then worked a 24-hours-per-day schedule for the rest of the operation. Thirty-one working days were expended on drilling, logging, and completion activities.

The most significant difficulty encountered in drilling Well ER-20-6#1 was poor or no fluid returns to the surface for much of the operation, which had a negative impact on collection of samples for radionuclide and geologic analysis.

Composite drill cuttings were collected every 3.1 m (10 ft) from 12.2 to 853.4 m (40 to 2,800 ft), but even within this interval, 109 samples were missed because of lack of returns to the surface. No cuttings were collected from 853.4 m (2,800 ft) to the TD. Six conventional cores were cut with a total recovery of 39.5 m (129.5 ft) for a 98.9 percent recovery rate. Forty sidewall samples were collected between 542.5 and 907.7 m (1,780 to 2,978 ft) in the borehole. Geophysical logging was conducted after drilling was finished to aid in construction of the well, to verify the geology, and to help characterize the hydrology of the units penetrated.

One completion string (fiberglass and stainless steel) and one fiberglass access string were successfully installed in the middle lava-flow aquifer. Each string has two screened or slotted intervals separated by a blank. Gravel-packed intervals were placed at 756.8 to 843.4 m (2,483 to 2,767 ft) and 858.0 to 898.2 m (2,815 to 2,947 ft), separated by sand. The Moyno® pump was installed and successfully tested, but the rotor was later removed. It is planned to replace the No Turn Tools® with packers to hold the pump stator in place inside the 5½-in. fiberglass casing.

The total planned cost for Well ER-20-6#1 was $1,062,143. The actual cost of the well was $1,347,541, or 26.9 percent more than the planned cost. Most of the additional cost was incurred as a result of the coring operation, which added the cost of the coring subcontractor and added days to the total drilling time.

The objectives of the BULLION near-field drilling project were advanced through drilling and construction of Well ER-20-6#1 as follows:

- Tritium levels are poorly known, but appear to be within acceptable levels for the forced-gradient experiment.
- Based on borehole imaging data, the fracture direction appeared to change from the expected orientation of N35°E to N75°W at the depth of 667.5 m (2,190 ft) (see Section 2.2.2). The N35°E fracture trend was used to site the other two holes in the cluster, as it was required that all three holes be placed along a bearing parallel to the local fracture trend.
- Geologic data were obtained from examination of drill cuttings and geophysical logs with some additional information gained from a limited examination of the conventional cores and sidewall samples. The interpretation of these data required evaluation of data from the subsequent holes in the cluster and indicated a somewhat more-complicated hydrogeologic setting than was expected due to the complex nature of rhyolite lava flows. See Sections 2.0 and 6.0 for additional discussions of the site geology and its importance to the forced-gradient experiment.
- The completion and access strings required for the forced-gradient experiment were successfully installed.

3.7.2 Lessons Learned

This section describes lessons learned during the drilling and construction of Well ER-20-6#1. Lessons learned from the project as a whole are addressed in Section 6.3.

Completion

It was found that the fiberglass joints of both the 5½-in. casing and the 2⅞-in. tubing did not fit flush, but this was not taken into account when the strings were assembled. Thus, both strings were landed off deeper in the hole than planned.

It was found that No Turn Tools® will not set inside fiberglass casing. Stainless-steel packers were ordered to replace them.

Operational

The distance from Well ER-20-6#1 to the edge of the BULLION chimney, approximately 1.5 cavity radii, may be too close for successful maintenance of drill-fluid circulation due to the potential for explosion-induced fracturing in certain types of lithologies.

Geologic Evaluation

Lack of fluid returns severely limited the "real-time" geologic evaluation of the borehole and made later geologic interpretation of the well geology very difficult. The availability of conventional core and sidewall samples should have alleviated this problem to some degree, but the samples were dedicated to future moisture-sensitive tritium measurements, so geologists were not allowed to open either type of sample for examination.

Lack of geophysical data from the lower 61 m (200 ft) of the hole and limited geophysical data from the upper part of the hole (behind the surface casing) also made it difficult for geologists to interpret the geology in that part of the hole.

4.0 Well ER-20-6#2

4.1 Drilling Summary

The drilling requirements for Well ER-20-6#2 were outlined in Contract DE-RP-08-95NV11808 and BN Drilling Program D-003-001.96 (BN, 1996b); any changes to the program were documented in BN Records of Verbal Communication (Appendix A.1). This summary was compiled from the BN daily rig reports and field notes prepared by the IT Field Representative. Complete details of drilling activities can be found in the BN Well ER-20-6#2 hole history (BN, 1996d). Descriptions of the site and drill rig are given in Paragraphs 1.1 and 3.1 of this report.

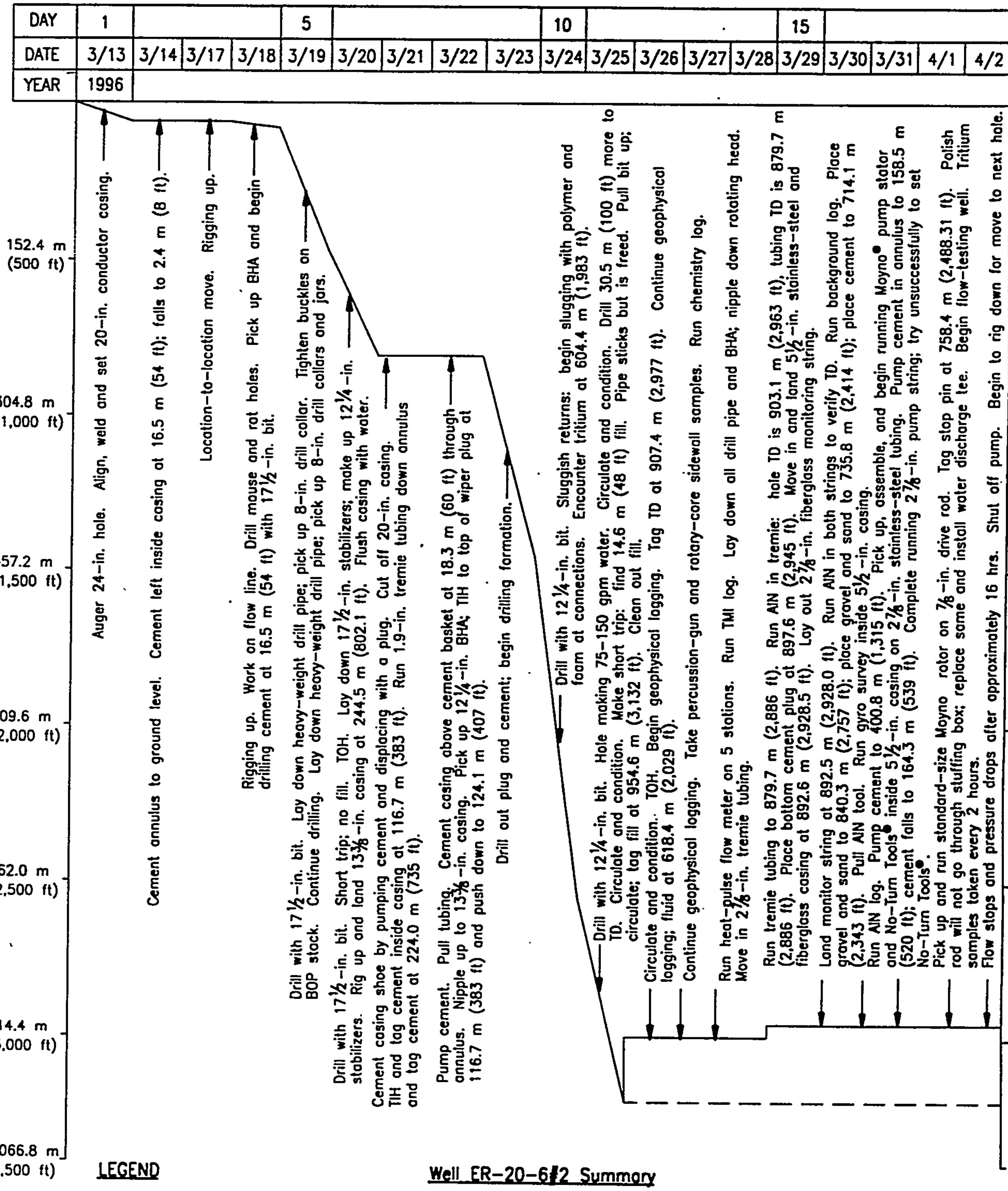
A graphical depiction of drilling parameters, including penetration rate, revolutions per minute, pump pressure, and weight on the bit is presented in Appendix A.2. Details of the composition of drill fluids, additives, and cements used are provided in Appendix A.4. Figure 4-1 is a chart of the drilling history for Well ER-20-6#2. A summary of drilling statistics for Well ER-20-6#2 is given in Table 4-1.

4.1.1 Drilling History

A Welch and Howell crew dry-augured the 61-cm (24-in.) conductor hole for Well ER-20-6#2 to the depth of 18.3 m (60 ft) on March 13, 1996, during completion of Well ER-20-6#1. A 20-in. casing was set at 17.4 m (57 ft). The casing annulus was cemented to the surface and cement was left inside the casing to the depth of 16.5 m (54 ft).

Immediately after completion of Well ER-20-6#1, the drill rig was moved over to Well ER-20-6#2, and three shifts were spent rigging up on the new location. The rat and mouse holes were drilled with a hammer bit first, and drilling of the main hole began on March 18, 1996. A 17½-in. bit and air-foam with polymer in conventional circulation were used to drill through the cement in the conductor casing and then into the formation. Weight on the bit was kept relatively light at first to keep the hole as straight as possible, and drill collars were added when the hole was approximately 123 m (405 ft) deep. Few problems were encountered with lost circulation or sloughing.

A casing point was picked in the welded Rainier Mesa Tuff at the depth of 246.0 m (807 ft), which was reached on March 20, 1996. A 13⅜-in. surface casing was set by the casing subcontractor at the depth of 244.5 m (802.1 ft). The casing was flushed with water to clear



LEGEND

AIN	Annulus Investigation
BHA	Bottom hole assembly
BOP	Blowout prevention system
TIH	Trip into hole
TOH	Trip out of hole

Well ER-20-6#2 Summary

Hole spudded	03/17/96
Surface hole completed and cased	03/20/96
Begin drilling 12¼-in. hole	03/23/96
Begin recording tritium in returns	03/24/96
Reach total drilled depth of 975.4 m (3,200 ft)	03/25/96
Hole cemented to 164.3 m (539 ft)	03/31/96

2905A17 07/10/96

Figure 4-1
Well ER-20-6#2 Drilling and Completion History

Table 4-1
Abridged Drill-Hole Statistics for Well ER-20-6#2

LOCATION DATA:	Coordinates:	Central Nevada State Planar: N913,692.3, E571,444.1 ft Universal Transverse Mercator: N4,123,661.6, E551,328.0 m
	Ground Elevation:	1973.6 m (6,475.1 ft)

DRILLING DATA:

Spud Date:	03/18/96
Total Depth (TD):	975.4 m (3,200 ft)
Date TD Reached:	03/25/96
Date Well Completed:	04/01/96
Hole Diameter:	61.0 cm (24 in.) from surface to 18.3 m (60 ft); 44.5 cm (17.5 in.) to 246.0 m (807 ft); 31.1 cm (12.25 in.) to 975.4 m (3,200 ft).
Drilling Techniques:	Dry-auger drilling to 18.3 m (60 ft). Rotary drilling with air-foam (and polymer as needed) in conventional circulation using a 17½-in. bit to 246.0 m (807 ft). Rotary drilling with air-foam and polymer in conventional circulation using a 12¼-in. bit to TD.

CASING DATA: 20-in. conductor casing from surface to 17.4 m (57 ft). 13⅜-in. surface casing set at 244.5 m (802.1 ft).

WELL COMPLETION DATA:

The pump string is installed within slotted 14.0-cm (5½-in.) od casing. The 5½-in. casing consists of fiberglass from the surface to 764.4 m (2,508 ft) and stainless steel from 764.4 to 893.7 m (2,508-2,932 ft). A Moyno® pump stator was installed at the bottom of 7.3-cm (2⅞-in.) od stainless steel tubing, with No-Turn Tools® above and below the stator. The stop pin below the pump stator is located at the depth of 758.5 m (2,488.6 ft). The pump rotor was installed but removed on April 7, 1996. A slotted access string consisting of 7.3-cm (2⅞-in.) od fiberglass tubing was landed off at 894.0 m (2,933 ft).

	Completion String	Access String
Total Depth:	893.7 m (2,932 ft)	894.0 m (2,933 ft)
Depth of Slotted Sections:	766.9-829.1 m (2,516 to 2,720 ft) 856.8-883.9 m (2,811 to 2,900 ft)	768.7-831.2 m (2,522 to 2,727 ft) 858.0-884.8 m (2,815 to 2,903 ft)
Depth of Sand Packs:	735.8-748.0 m (2,414 to 2,454 ft) 840.3-851.3 m (2,757 to 2,793 ft)	Same as for pump string
Depth of Gravel Packs:	748.0-840.3 m (2,454 to 2,757 ft) 851.3-897.6 m (2,793 to 2,945 ft)	Same as for pump string
Depth of Moyno® Pump:	751.9-758.5 m (2,466.9 to 2,488.6 ft)	Not applicable
Fluid Depth[a]:	618.4 m (2,029 ft)	

DRILLING CONTRACTOR:	Welch & Howell Drilling Company
GEOPHYSICAL LOGS BY:	Atlas Wireline Services, Baker Hughes INTEQ, Desert Research Institute, Geophysical Engineering Group of the Joint Test Organization, Schlumberger
SURVEYING CONTRACTOR:	Bechtel Nevada

[a]Fluid level in the open borehole as of March 26, 1996.

it before cementing the bottom of the casing. To seal the casing shoe, 11.3 m^3 (400 ft^3) of cement was pumped down the casing followed by a wiper plug displaced with water. The plug was not completely displaced, but was pushed down to 124.1 m (407 ft) with the BHA before drilling resumed. After the conductor casing was cut off, 1.9-in. tubing was run down the annulus (without touching the cement basket at 18.3 m [60.2 ft]) and tagged cement in the annulus at 224.0 m (735 ft). A total of 5.7 m^3 (200 ft^3) of additional cement was pumped down the annulus, but the final rise is unknown. To seal the top of the casing, sand bags, dirty gravel, sand, and bags of cedar fiber were dropped on the cement basket, followed by cement to the surface.

After the surface casing was cemented, the drillers picked up the 12¼-in. BHA, pushed down the wiper plug, and began drilling out the plug and cement in the casing; drilling of new hole began on March 23, 1996. Drilling proceeded smoothly with an average penetration rate of 9 to 18 m/hour (30 to 60 ft/hour) through long intervals of the hole. When returns were sluggish a slug of polymer was added at connections, but circulation was periodically lost during drilling of the interval 350.5 to 362.7 m (1,150 to 1,190 ft). The first significant tritium levels were encountered in the returns at the depth of 604.4 m (1,983 ft) on March 24, 1996, approximately 14 m (46 ft) above the static fluid level.

The TD of 975.4 m (3,200 ft) was reached on March 25, 1996. After circulating for an hour to condition the hole, the drillers made a short trip to check for fill and found that approximately 15 m (50 ft) of fill accumulated. The drill pipe stuck briefly but was freed. The drillers circulated for thirty minutes after pulling the bit up to 899.2 m (2,950 ft) and tagged 20.7 m (68 ft) of fill. They cleaned out the fill and circulated for another hour before tripping out for geophysical logging. The caliper log run on March 26, 1996, tagged bottom at 907.4 m (2,977 ft).

The gyroscopic survey run in the 5½-in. casing during completion indicates that at the lowest surveyed depth of 883.9 m (2,900 ft) the hole had drifted 16.7 m (54.8 ft) to the northwest of the collar coordinates.

4.1.2 Drilling Problems

No serious problems were encountered during drilling of Well ER-20-6#2. Borehole sloughing resulted in the loss of approximately 72.2 m (237 ft) of hole, but the hole had been drilled deep enough that this did not prevent or delay the successful completion of the well.

4.1.3 Fluid Management

Air-foam and polymer were used to drill Well ER-20-6#2 from 18.3 m (60 ft) to the total depth of 975.4 m (3,200 ft) with applications of gel (mud) as needed to stiffen the foam. The clean and contaminated fluids produced were stored in separate lined sumps. The drilling effluent was monitored in accordance with the methods prescribed in the *Fluid Management Plan for the Underground Test Area Operable Unit* (DOE, 1994) and the *Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6* (IT, 1995). The results of analyses on samples of drilling fluid collected indicate that all fluids are within the fluid quality objectives established for radiochemical parameters in the Fluid Management Plan.

Appendix B.1 of this report contains the Well ER-20-6#2 Fluid Management Status Report. The fluid disposition form lists final volumes and data for drilling the well. The final volumes of fluids imported to and produced at Well ER-20-6#2 were calculated from water-truck delivery tickets and measurements of fluids in the sumps. The solids produced were calculated using the diameter of the borehole and the depth drilled with the added volume attributed to rock bulking factors.

4.2 Geologic Data Collection

4.2.1 Collection of Drill Cuttings

Triplicate sets of composite drill cuttings were collected continuously from Well ER-20-6#2 at 3.0-m (10-ft) intervals as drilling progressed from the surface to 399.3 m (1,310 ft). Beyond that depth, the effort was made to maintain the 3.0-m (10-ft) sampling interval, but the rapid penetration rate required a 6.1-m (20-ft), and sometimes a 9.1-m (30-ft), collection interval. Samples were obtained from 243 out of a possible 260 intervals. Samples were missed in 14 intervals because of the high penetration rate, and three samples were not collected due to lost circulation.

All samples (243 sets of three) are stored under secure conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada. One of each set of samples was sealed with custody tape at the rig site as an archive sample; one was left unsealed in the original sample containers; and the third was washed in accordance with standard USGS Core Library procedures.

4.2.2 Sidewall Samples

After drilling was completed, sidewall samples were collected to verify the stratigraphy and lithology penetrated in the interval 582.2 to 815.0 m (1,910 to 2,674 ft) and to obtain material for rock properties tests and analysis of matrix fluids. Percussion-gun sidewall samples were collected by Atlas Wireline Services who ran a 25-shot core gun and recovered 15 cores on March 27, 1996. Schlumberger ran a rotary sidewall coring tool the same day and recovered nine cores in nine attempts.. The sample depths were selected by the IT Field Representative. A list of samples, including sample recovery, and the geology of the samples is given in Table 4-2.

4.2.3 Geophysical Logging Data

Geophysical logs were run after drilling to characterize the lithology, structure, and hydrogeologic properties of the rocks. In addition, logs were run to check borehole conditions, determine fluid levels and other hydrologic data, identify radionuclides, and monitor the completion process. All geophysical logs run in Well ER-20-6#2 are listed in Table 4-3. The logs are available from BN in Mercury, Nevada, and copies are on file at the IT office in Las Vegas, Nevada.

Overall, the quality of the geophysical data is acceptable. However, the only geophysical log available for use in correlating geologic units above the casing point at 244.5 m (802.1 ft) is the natural gamma-ray log which was run through the casing. Also, log data are limited for the lower 68.6 m (225 ft) of the hole due to sloughing. Preliminary data from most of the geophysical logs are presented in Appendix D.

4.3 Hydrology

4.3.1 Preliminary Water-Level and Water-Production Information

Groundwater production began at the depth of approximately 610.8 m (2,004 ft), at approximately 95 Lpm (25 gallon(s) per minute [gpm]). Water production increased gradually as the hole was deepened. Production reached 378 Lpm (100 gpm) at the depth of 736.4 m (2,416 ft) in the zeolitized, bedded upper portion of the Calico Hills Formation and 756 Lpm (200 gpm) at the depth of 811.4 m (2,662 ft) in the lava-flow aquifer within the Calico Hills Formation. The maximum production rate was 946 Lpm (250 gpm) encountered at the depth of 944.6 m (3,099 ft) while drilling through the zeolitized, nonwelded lower portion of the Calico Hills Formation, but this may represent increasing production from the overlying lava-flow aquifer.

Table 4-2
Sidewall Samples Collected from Well ER-20-6 #2

Core Depth meters (feet)	Tool Used	Recovery centimeters (inches)	Stratigraphic Unit[a]	Hydrogeologic Unit[b]
582.2 (1,910)	PG[c]	1.9 (0.75)	Tpd[d]	TCU[e]
591.6 (1,941)	PG	1.3 (0.50)	Tpd	TCU
591.9 (1,942)	PG	1.9 (0.75)	Tpd	TCU
592.2 (1,943)	PG	2.5 (1.00)	Tpd	TCU
592.5 (1,944)	R[f]	4.1 (1.63)	Tpd	TCU
596.2 (1,956)	R	4.1 (1.63)	Tpd	TCU
653.5 (2,144)	PG	4.5 (1.75)	Tpr[g]	TCU[+]
676.7 (2,220)	R	2.5 (1.00)	Tpr	TCU[+]
682.1 (2,238)	PG	4.4 (1.75)	Tacp[h]	TCU
682.1 (2,238)	PG	2.9 (1.13)	Tacp	TCU
688.5 (2,259)	PG	3.8 (1.50)	Tacp	TCU
697.7 (2,289)	PG	1.9 (0.75)	Tacp	TCU
698.6 (2,292)	PG	3.8 (1.50)	Tacp	TCU
715.4 (2,347)	PG	3.8 (1.50)	Tacp	TCU
719.0 (2,359)	PG	3.2 (1.25)	Tacp	TCU
734.6 (2,410)	R	4.1 (1.63)	Tacp	TCU
744.3 (2,442)	PG	3.2 (1.25)	Tacp	TCU
758.6 (2,489)	PG	4.4 (1.75)	Tacp	TCU[*]
767.2 (2,517)	PG	3.2 (1.25)	Tacp	TCU[*]
768.1 (2,520)	R	1.6 (0.63)	Tacp	TCU[*]
770.5 (2,528)	R	3.8 (1.50)	Tacp	TCU[*]
771.1 (2,530)	R	1.6 (0.63)	Tacp	TCU[*]
807.4 (2,649)	R	1.0 (0.38)	Tacp	LFA[i]
815.0 (2,674)	R	4.4 (1.75)	Tacp	LFA

[a] Stratigraphic nomenclature from Ferguson et al. (1994). See Appendix C-2.
[b] Modified from Winograd and Thordarson (1975) and Laczniak et al. (1996).
[c] Percussion-gun Sidewall Core Tool operated by Atlas Wireline Services
[d] Tuff of Delirium Canyon, Paintbrush Group
[e] Tuff-confining unit
[f] Rotary Sidewall Core Tool operated by Schlumberger
[g] Rhyolite of Silent Canyon, Paintbrush Group
[h] Mafic-poor Calico Hills Formation
[i] Lava-flow aquifer
[+] Sample is zeolitized, tuffaceous flow breccia; this unit may have hydrologic properties similar to a TCU.
[*] Sample is zeolitized, pumiceous lava; this part of unit may have hydrologic properties similar to a TCU.

Table 4-3
Well ER-20-6#2 Geophysical Log Summary

Geophysical Logs	Log Purpose	Logging Service	Date Logged	Run Number	Top of Logged Interval (bgs)[a] meters (feet)	Bottom of Logged Interval (bgs) meters (feet)
Annular Investigation Log	Omnidirectional density (check for cement and/or fluid location	GEG[b]	03/29/96 03/29/96 03/31/96 03/31/96 04/10/96	AIN-1 AIN-2 AIN-3 AIN-4 AIN-5	594.4 (1,950) 874.8 (2,870) 609.6 (2,000) 152.4 (500) 3.0 (10)	903.1 (2,963) 900.7 (2,955) 894.0 (2,933) 894.0 (2,933) 754.4 (2,475)
Borehole Televiewer/Gamma Ray	Borehole examination/stratigraphic correlation	AWS[c]	03/26/96	BHTV-1/GR-3	618.4 (2,029)	906.8 (2,975)
4-arm Caliper/Gamma Ray	Borehole conditions/stratigraphic correlation	AWS	03/26/96	CA4-1/GR-1	0	907.4 (2,977)
Dual Laterolog/Gamma Ray	Lithology/stratigraphic correlation	AWS	03/26/96	DLL-1/GR-1	542.4 (1,780)	901.0 (2,956)
Epithermal Neutron/ Compensated Density/ Gamma Ray	Water content/density/stratigraphic correlation	AWS	03/26/96	ENP-1/ CDL-1/GR-2	244.4 (802)	905.9 (2,972)
Spectralog	Stratigraphic correlation, mineralogy, natural radiation, identification of explosion products	AWS	03/26/96	SL-1	244.4 (802)	893.7 (2,932)
Spectralog/Digital Acoustic Televiewer	Stratigraphic correlation, mineralogy, natural radiation, identification of explosion products/borehole examination for fractures	AWS	03/26/96	SL-1/DAC-1	609.6 (2,000)	904.0 (2,966)
Total Magnetic Intensity	Stratigraphic correlation, lithologic information	GEG	03/28/96	TMI-1	249.9 (820)	903.4 (2,964)
Chemical Log/Temperature Log	Determine pH, electrical conductivity, and temperature of fluid	DRI[d]	03/27/96	CHEM-1/TL-2	618.7 (2,030)	904.3 (2,967)
Thermal Flow Log (electrical conductivity, temperature)	Determine rate/direction of groundwater flow within the borehole	DRI	03/28/96	HPFLOW-1	624.8 (2,050)	893.1 (2,930)
Temperature Log	Groundwater temperature	AWS	03/26/96	TL-1	595.3 (1,953)	907.4 (2,977)
Differential Temperature Survey	Groundwater temperature	GEG	05/01/96	TLDLT-3	579.1 (1,900)	888.8 (2,916)
Percussion-gun Sidewall Sampling/Gamma Ray	Obtain samples for analysis/stratigraphic correlation	AWS	03/27/96	SGUN-1/GR-4	582.2 (1,910)	815.0 (2,674)
Rotary Sidewall Coring/ Gamma Ray	Obtain samples for analysis/stratigraphic correlation	SCH[e]	03/27/96	MCT-1/GR-5	592.5 (1,944)	815.0 (2,674)
Directional Gyroscope	Borehole Deviation	BHI[f]	03/30/96	DRG-1	0	883.9 (2,900)

Source: Bechtel Logging

[a] Below ground surface
[b] Geophysical Engineering Group of the Joint Test Organization
[c] Atlas Wireline Services
[d] Desert Research Institute
[e] Schlumberger
[f] Baker Hughes INTEQ

The fluid level in the open borehole (measured during geophysical logging and before installation of tubing in the well) consistently stabilized at a depth of 618.4 m (2,029 ft) and an elevation of 1,355.2 m (4,446.1 ft). The open-hole fluid level is very similar to that measured in Well ER-20-6#1, and the fluid-level elevation is very similar to the pre-drill estimate of 1,355 m (4,447 ft) for the water level at Well Cluster ER-20-6.

4.3.2 Radionuclides Encountered

Tritium was first encountered in the fluid returns when the borehole had been drilled to 604.4 m (1,983 ft), approximately 14 m (46 ft) above the static water level. Tritium activities averaged less than 500,000 pCi/L from 608.1 to 670.6 m (1,983 to 2,200 ft) and then jumped to an average of approximately 30 to 50 million pCi/L in the interval 673.6 to 816.9 m (2,210 to 2,680 ft) in the upper lava-flow aquifer; the maximum of 74.5 million pCi/L was measured at 688.8 m (2,260 ft) adjacent to the BULLION WP. Tritium activity dropped by an order of magnitude in the interval 821.4 to 850.4 m (2,695 to 2,790 ft), rose slightly again at 856.5 to 863.2 m (2,810 to 2,832 ft), and then dropped to near the detection limit in all but two samples taken from 863.2 m (2,832 ft) to the TD. See Appendix B.2 for a listing of tritium and water-production data. See Section 6.1 for a graphic comparison of tritium and water-production data for all three holes in the cluster.

4.3.3 Preliminary Thermal Flow Log Data

Thermal flow meter data, along with temperature, electrical conductivity, and pH measurements, can characterize borehole fluid variability, which may indicate inflow and outflow zones. DRI personnel made TFM measurements at five locations in the borehole: 624.8 m (2,050 ft), 646.2 m (2,120 ft), 655.3 m (2,150 ft), 762.0 m (2,500 ft), and 893.1 m (2,930 ft). Preliminary field analysis of the data indicated downward flow of less than a liter per minute at the upper four stations and a downward flow of approximately two liters per minute at 893.1 m (2,930 ft).

4.4 Precompletion and Open-Hole Development

Precompletion development was conducted in Well ER-20-6#2 by circulating and conditioning the borehole for an hour after TD was reached, prior to geophysical logging.

4.5 Completion

The objective of the Well ER-20-6#1 and #2 completions for the forced-gradient experiment was to hydraulically isolate and characterize a transmissive zone in a lava-flow aquifer in which a groundwater gradient will later be induced for the study of contaminant transport from the nearby BULLION cavity. Completion activities at Well ER-20-6#2 began immediately after logging was concluded and a bottom plug set on March 29, 1996. Completion activities were concluded on April 1, 1996. Figure 4-2 is a schematic of the final well completion design for Well ER-20-6#2, and Figure 4-3 shows a plan view and profile of the well-head configuration. Data for this section were obtained from the BN daily rig reports and tubing records for Well ER-20-6#2.

4.5.1 Proposed Completion Design

The original plan for Well Cluster ER-20-6 called for installation of monitoring equipment to obtain data on the characteristics of the existing near-field groundwater regime, but the project was later modified to a force-gradient experiment (IT, 1995, 1996b). The modification required the redesign of the well cluster configuration (see Section 1.3 of this report), but the target completion interval in Well ER-20-6#2, the middle lava-flow aquifer, was the same as originally planned and the same as in Well ER-20-6#1. The modified completion design for Well ER-20-6#2 is identical to that of Well ER-20-6#1 (see Section 3.5.1 of this report) and similar to the original design, but with a longer completion interval to maximize access to the formation. The modified design for Well ER-20-6#2 called for the installation of a screened 5½-in. completion string with a pump installed just above the screened interval. A 2⅞-in. slotted fiberglass access string was required adjacent to the completion string with a slotted interval similar to that of the completion string, but longer than originally planned for the well. The plan for the forced-gradient experiment called for one long, gravel-packed interval to extend above and below the slotted interval.

4.5.2 As-Built Completion Design

The as-built completion design provides access to the two most transmissive portions of the lava-flow aquifer underlying the tuff-confining units in which the BULLION WP was located. The completion string has two screened sections with a pump positioned on a separate string just above the screened section within the casing. The pump stator was installed with No-Turn Tools® which were expected to prevent counter-rotation of the stator and allow easy removal of the pump if desired. The pump rotor will be installed on a drive-rod string. A separate slotted string was installed adjacent to the completion string for groundwater sampling. The string compositions are listed on Table 4-4, and tubing materials are listed in Appendix A.3.

The casing for the pump string is 5½-in. od fiberglass to the depth of 764.4 m (2,508 ft) and stainless steel from 764.4 m (2,508 ft) to the bottom of the string at 893.7 m (2,932 ft). The

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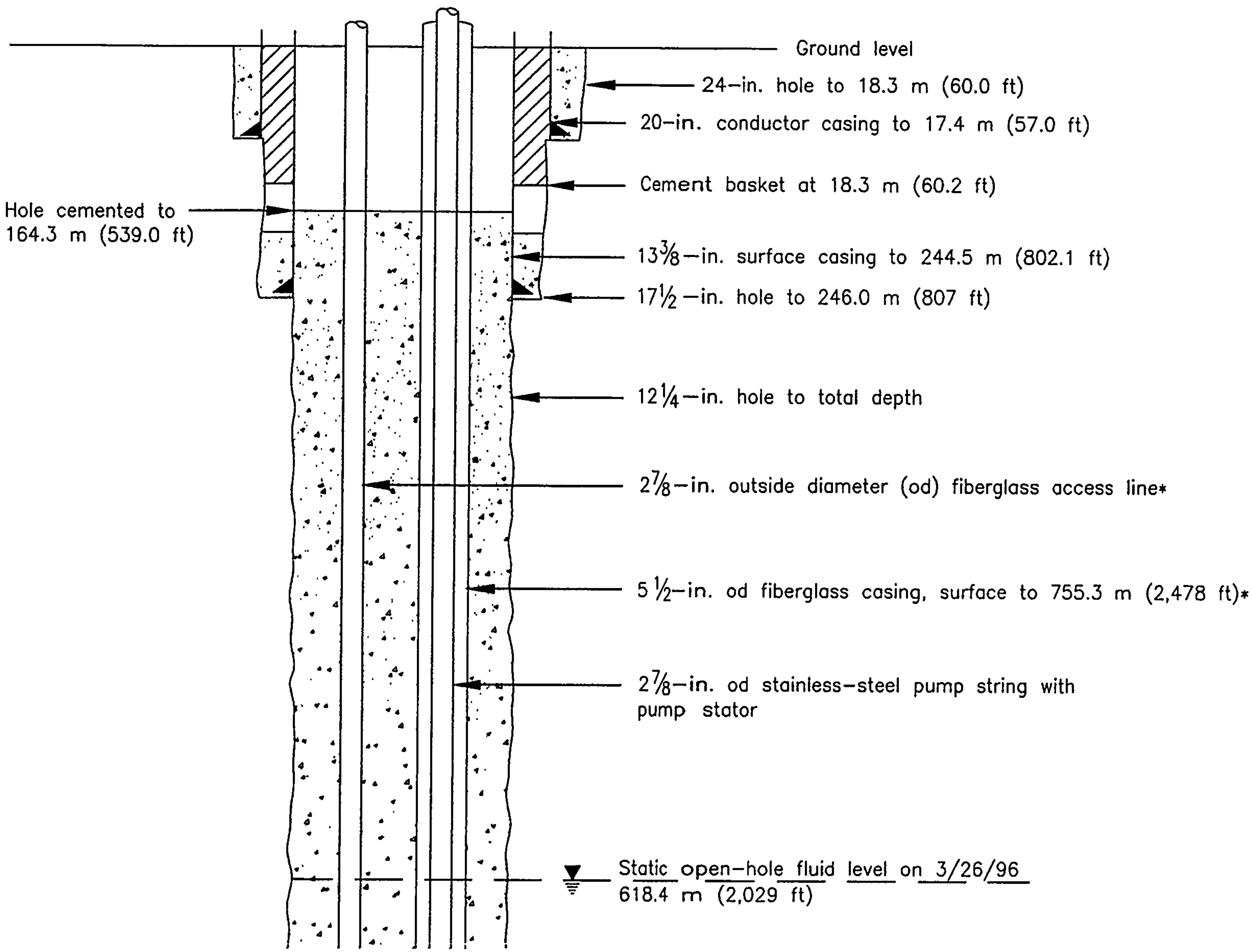
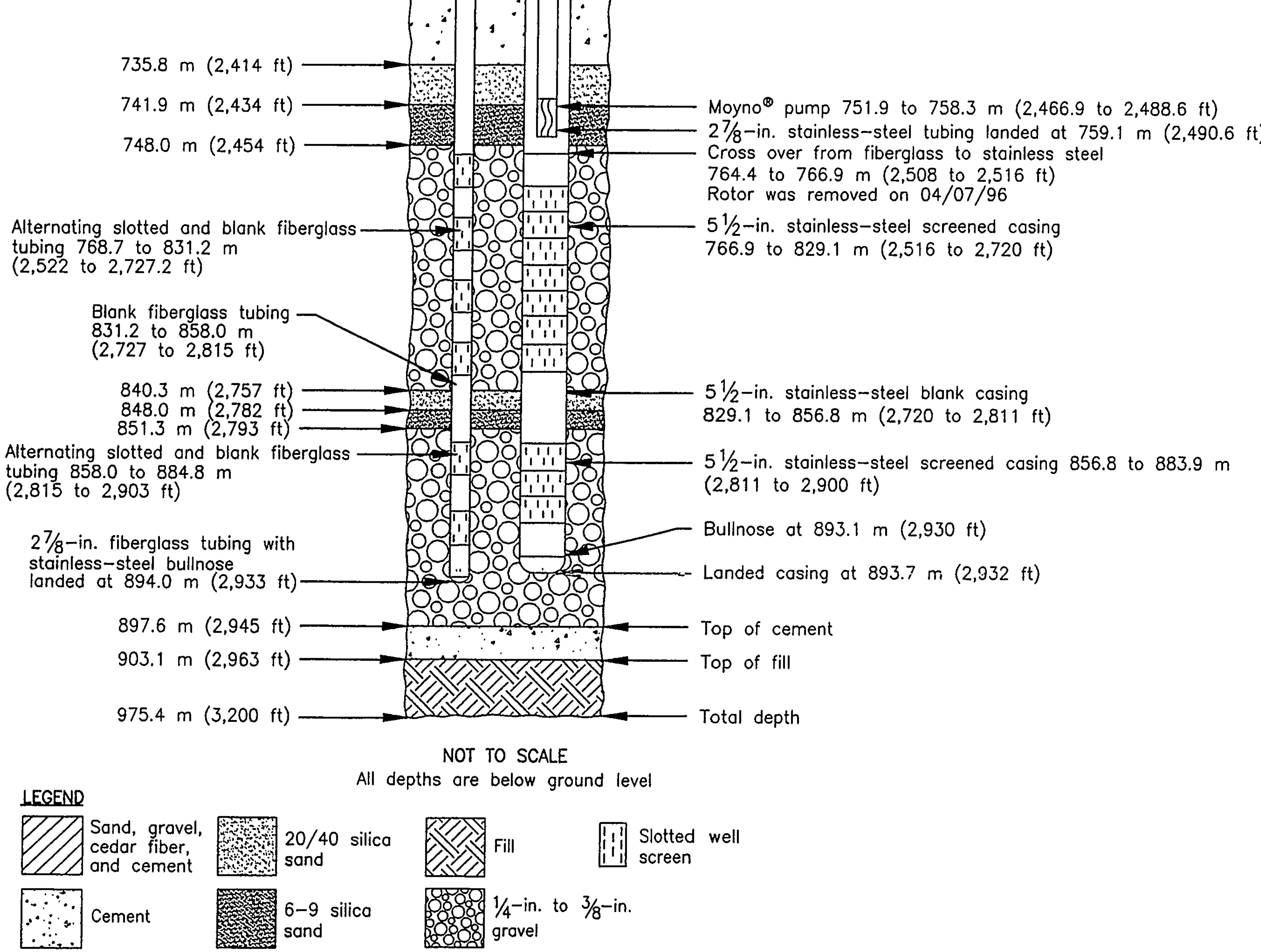
Surface elevation: 1,973.6 m (6,475.1 ft)
Nevada coordinates: N913,692.3 E571,444.1 ft
Universal Transverse Mercator (Zone 11):
Area: 20 N4,123,661.6 E551,328.0 m
Completed: 04/01/96





*Fiberglass casing and tubing joints did not fit flush.
TD of both strings determined from AIN log.
Depths presented to nearest foot accuracy. See Section 4.5.4.

Additional details regarding tubing type, grade, diameter, etc. are provided in Appendix A-3.

FIGURE 4-2
AS-BUILT SCHEMATIC OF WELL ER-20-6#2

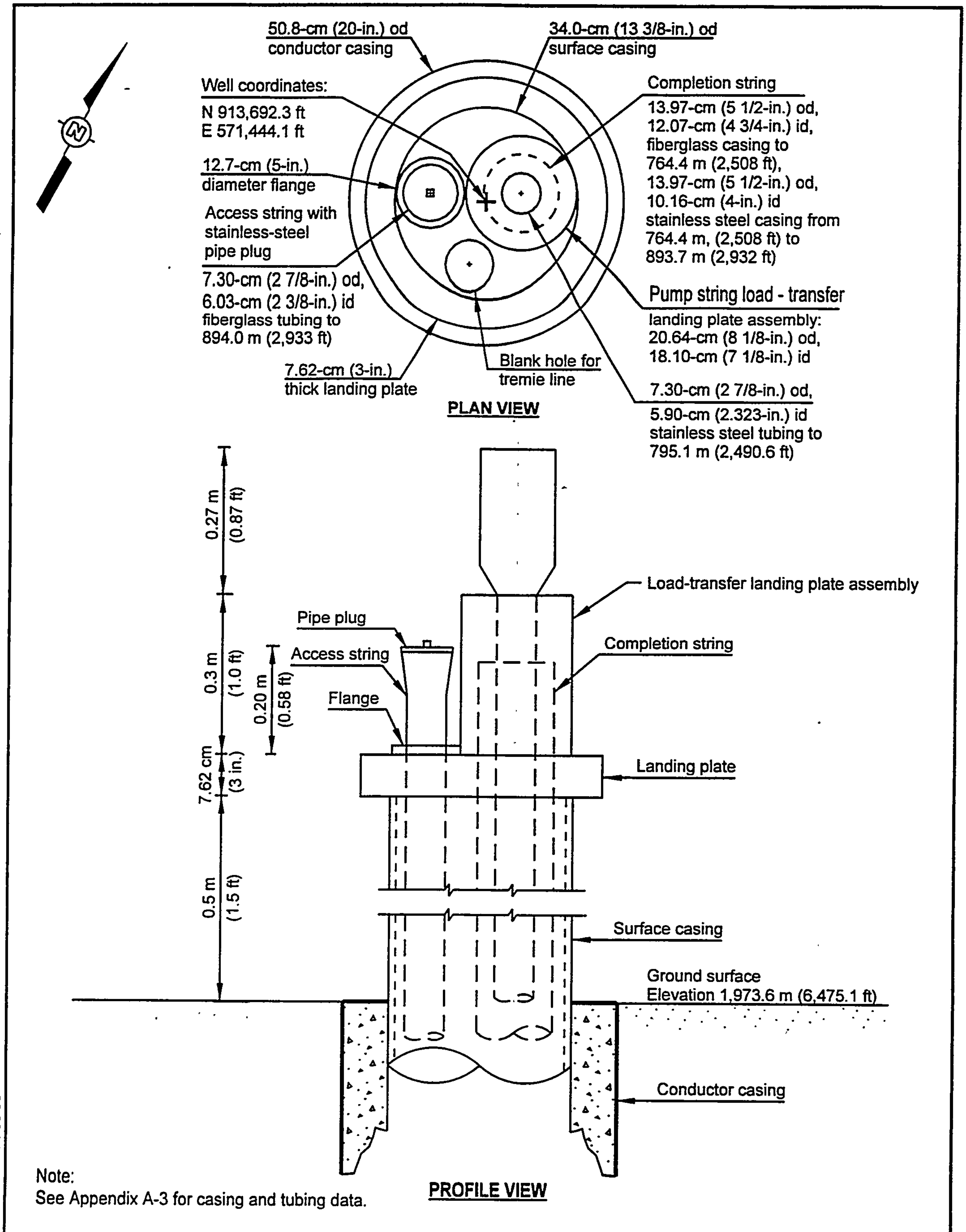


Figure 4-3
Well ER-20-6 #2 Wellhead Diagram

Table 4-4
Well ER-20-6#2 Construction Summary

Completion String	Configuration		Cement	Sand/Gravel
5½-inch Completion String	Fiberglass casing from ground surface to 755.3 m (2,478 ft) Stainless-steel casing from 755.3 to 893.7 m (2,478-2,932 ft)	Blank ground surface to 766.9 m (2,516 ft)	Type II plus 2% $CaCl_2$ 164.3 to 735.8 m (539 to 2,414 ft) 897.6 to 903.1 m (2,945 to 2,963 ft)	20/40 Sand 735.8 to 741.9 m (2,414 to 2,434 ft) 840.3 to 848.0 m (2,757 to 2,782 ft) 6-9 Sand 741.9 to 748.0 m (2,434 to 2,454 ft) 848.0 to 851.3 m (2,782 to 2,793 ft) 1/4 to 3/8-inch Gravel 748.0 to 840.3 m (2,454 to 2,757 ft) 851.3 to 897.6 m (2,793 to 2,945 ft)
		Screened 766.9 to 829.1 m (2,516 to 2,720 ft)		
		Blank 829.1 to 856.8 m (2,720 to 2,811 ft)		
		Screened 856.8 to 883.9 m (2,811 to 2,900 ft)		
		Blank and bull-nosed 883.9 to 893.7 m (2,900 to 2,932 ft)		
2⅞-inch Stainless-steel Tubing	Ground surface to 759.1 m (2,490.6 ft) inside 5½-inch casing	Moyno® pump stator 751.9 to 758.5 m (2,466.9 to 2,488.6 ft)		
		No-Turn Tools® 751.4 to 751.9 m (2,465.3 to 2,466.9 ft) 758.6 to 759.1 m (2,488.9 to 2,490.6 ft)		
⅞-inch Coated Drive Rod	Removed from inside 2⅞-inch tubing on April 7, 1996	Moyno® pump rotor Removed on April 7, 1996		
2⅞-inch Access String	Smith Fiberglass Products, Inc. Ground surface to 894.0 m (2,933 ft)	Blank ground surface to 768.7 m (2,522 ft)		
		4 slotted joints alternating with 3 blank joints 768.7 to 831.2 m (2,522 to 2,727 ft)		
		Blank 831.2 to 858.0 m (2,727 to 2,815 ft)		
		2 slotted joints separated by 1 blank joint 858.0 to 884.8 m (2,815 to 2,903 ft)		
		Blank and bull-nosed 884.8 to 894.0 m (2,903 to 2,933 ft)		

Note Depth data for strings containing fiberglass components are presented at 1-foot accuracy, corrected from the field records on the basis of AIN logs. See Section 4.5.4.

bottom 0.6-m (2.0-ft) joint is bull-nosed with a 0.64-cm (0.25-in.) hole to serve as a fluid drain in the event of excessive drawdown. The first joint above the bull-nose is blank, followed by three screened 9.1-m (29.7-ft) joints. This lower screened section is separated from the upper screened section by a 27.5-m (90.2-ft) blank section. The upper screened section is 62.2 m (204.1 ft) long and consists of seven screened joints. The terminal 0.76 m (2.5 ft) of each stainless-steel screened joint is blank (for strength at the connections), and the middle 7.6 m (25 ft) is perforated with 1.27-cm (0.5-in.) diameter holes at a density of 160 holes per foot. Stainless-steel screen consisting of wire wrapped around wire ribs with 0.20-cm (0.078-in.) openings between wraps was installed within each perforated joint.

The Moyno® pump stator was installed on 2⅞-in. stainless-steel tubing within the 5½-in. casing at 751.9 to 758.5 m (2,466.9 to 2,488.6 ft) with No-Turn Tools ® located above and below the stator. The 2⅞-in. stainless-steel string is unslotted, but open on the bottom (via the pump stator section). The pump rotor was installed in the stator on a string of 7.6-m (25-ft) long, ⅞-in. coated drive rods equipped with spin-through rod guides. The number of guides per rod was determined by computer analysis of side-loading, based on borehole deviation data (Schwichtenburg, 1996). The rotor and drive-rod string were later removed (see Section 4.5.4).

The 2⅞-in. fiberglass tubing string was installed in Well ER-20-6#2 adjacent to the 5½-in. casing string to serve as an access line. The fiberglass tubing was landed off at 894.0 m (2,933 ft). The bottom 0.2-m (0.7-ft) joint is a stainless-steel bull-nose with a 0.64-cm (0.25-in.) hole to serve as a fluid drain. The lower slotted section is 26.8 m (88 ft) long and consists of two slotted, 8.9-m (29.3-ft) fiberglass joints separated from each other and from the bull-nose by a blank joint. This section is separated from the upper slotted section by a 26.8-m (88-ft) long blank section. The upper slotted section is 62.5 m (205 ft) long and consists of four slotted joints alternating with blank joints. The terminal 1.2 m (4 ft) of each fiberglass slotted joint is blank (for strength at the connections), and the middle 6.7 m (22 ft) is slotted. Each slotted joint has eight rows of saw-cut slots 7.62 cm (3 in.) long by 0.32 cm (0.125 in.) wide on staggered 30.5-cm (12-in.) centers.

4.5.3 Rationale for Differences Between Actual and Proposed Well Design

The as-built design for Well ER-20-6#2 was required to be as similar as possible to that of Well ER-20-6#1 to accomplish the goals of the forced-gradient experiment. Thus, the completion interval for Well ER-20-6#2 was picked by comparing the geology, geophysical logs, and flow-log data from the two holes. As in Well ER-20-6#1, two gravel-packed zones were installed instead of one as described in the plan for the forced-gradient experiment because the borehole data indicated that the target lava-flow aquifer contains two more transmissive zones separated by a less transmissive interval. The blank section of the well completion is located in the less transmissive portion with sand separating the two gravel packs. This configuration will allow flexibility in test design; the lower slotted interval, where lower tritium levels were measured, can be packed off and tested separately from the upper interval, or it can be permanently isolated if desired. The difference in permeability between the sand and the gravel is expected to provide an adequate barrier between the two zones.

4.5.4 Completion Method

Standard UGTA decontamination procedures were employed to prevent the introduction of outside contaminants into the well. Well construction materials were inspected in accordance with 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. A "tremie" line consisting of 2⅞-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. The AIN log was used to monitor the placement of cement, sand and gravel, and to verify tubing and casing depths. All casing and tubing were run by a casing installation subcontractor.

Additional borehole sloughing occurred during and after geophysical logging, so that before completion installation began, the bottom of the hole was plugged with fill to 903.1 m (2,963 ft). After the tremie was run into Well ER-20-6#2, its TD was verified with the AIN log at 879.7 m (2,886 ft). The hole was cemented from the top of the fill to the depth of 897.6 m (2,945 ft). The fiberglass and stainless-steel completion string was landed at 893.7 m (2,932 ft), and the fiberglass access string was landed at 894.0 m (2,933 ft). The fiberglass joints did not fit "flush" (see Section 3.5.4 of this report), and the attempt was made to correct for this in the field so that the screened and slotted sections would be placed more precisely in Well ER-20-6#2 than in Well ER-20-6#1. However, the AIN log run in the strings indicated that the actual TD of the 5½-in. casing was 1.1 m (3.5 ft) greater than the sum of the lengths of the joints as reported on the BN field records. The actual TD of the 2⅞-in. fiberglass tubing was found to be 1.5 m (5.0 ft) longer than the sum of the joint lengths reported in the BN records. Fiberglass tubing and casing depths listed in all figures and tables in this report have been corrected to match the measured string TDs.

The completion operation continued with the placement of the lower gravel pack. The lower slotted interval was packed with ¼-in. to ⅜-in. gravel from 851.3 to 897.6 m (2,793 to 2,945 ft). The sand pack above the gravel consists of 6-9 Colorado sand placed at 848.0 to 851.3 m (2,782 to 2,793 ft) and 20/40 silica sand from 840.3 to 848.0 m (2,757 to 2,782 ft). The upper gravel pack consists of ¼-in. to ⅜-in. gravel from 748.0 to 840.3 m (2,454 to 2,757 ft). The sand pack above this gravel consists of 6-9 Colorado sand placed at 741.9 to 748.0 m (2,434 to 2,454 ft) and 20/40 silica sand placed at 735.8 to 741.9 m (2,414 to 2,434 ft). The remainder of the hole from 164.3 to 735.8 m (539 to 2,414 ft) was filled with Type II cement plus 2-percent $CaCl_2$. The final cementing process was interrupted while the gyroscopic survey was run inside the 5½-in. casing. While waiting on cement, the crew began running the Moyno® pump stator on 2⅞-in. stainless-steel tubing inside the 5½-in. casing; this string was landed after cementing was completed. The No-Turn Tools® could not be properly set. A standard-size Moyno® pump rotor was run inside the 2⅞-in. stainless steel tubing on the ⅞-in. drive rod and tagged the stop pin at 758.4 m (2,488.3 ft).

A pumping test was begun immediately after the rotor was set in the well, but on April 2, 1996, after approximately 16 hours of pumping, the flow stopped, and the pressure dropped. When the drive rod and rotor were pulled on April 7, 1996, grease was found on the upper 0.44 m (1.45 ft) of the rotor, indicating that the rotor had been running in the stator 0.27 m (0.9 ft) above the stop pin. This rotor position was 0.6 m (2 ft) lower than intended, which may have been a result of unexpected stretch of the drive rod. It was found by means of an AIN log run on April 10, 1996, that the pump string had unscrewed or parted at the top of the No-Turn Tool® above the stator at 751.3 m (2,465 ft). It is planned to try to retrieve the parted string.

4.6 Actual Versus Planned Costs and Scheduling

The BN cost model for the ER-20-6 well cluster was originally developed on a per-hole basis for generic 914.4-m (3,000-ft) deep holes. In this model, drilling, logging and completion for a 914.4-m (3,000-ft) deep hole was projected to require 20 days to accomplish. Actual time spent (after rigging up) on drilling and completion of Well ER-20-6#2 with a TD of 975.4 m (3,200 ft) was 15 days.

The cost analysis for Well ER-20-6#2 can be divided into charges by the drilling contractor (including drilling equipment, fluids, and the casing subcontractor) and charges by the support contractor (including radiation technicians, inspection services, geophysical logging, and cementing services). The total planned cost of Well ER-20-6#2 was $1,062,143. The actual cost of Well ER-20-6#2 totaled $935,671, 11.9 percent less than the planned cost. Table 4-5 lists the planned and actual costs. Figure 4-4 is a comparison of planned and actual costs by day for drilling and completion of Well ER-20-6#2.

Table 4-5
Well ER-20-6#2 Actual Versus Planned Costs

Activity	Planned Cost[a]	Actual Cost	Percent Difference Actual versus Planned
Drilling contractor	$339,600	$271,130[b]	-20.2
Support contractors	$722,543	$664,541[c]	-8.0
Total	$1,062,143	$935,671	-11.9

[a]Based on BN model for a 914.4-m (3,000-ft) hole.
[b]Source: DOE/ERD
[c]Source: BN Drilling

4.7 *Summary and Lessons Learned*

4.7.1 Summary

Drilling commenced at Well ER-20-6#2 on March 18, 1996, and concluded on March 25, 1996, when the TD of 975.4 m (3,200 ft) was reached. After geophysical logging, the completion strings were installed and gravel-packed, and the hole was cemented to 164.3 m (539 ft) on March 29 through April 1, 1996. Crews worked a seven-day-a-week, 24-hour-a-day schedule for most of the operation. Eighteen working days were expended on drilling, logging, and completion activities.

No serious problems were encountered during drilling of Well ER-20-6#2, but sloughing of borehole material at the bottom of the hole resulted in the loss of approximately 72.2 m (237 ft) of hole.

Composite drill cuttings were collected every 3.0 to 6.1 m (10 to 20 ft), depending on the penetration rate. Twenty-four sidewall samples were collected in the interval 582.2 to 815.0 m (1,910 to 2,674 ft). Geophysical logging was conducted after drilling was finished to aid in

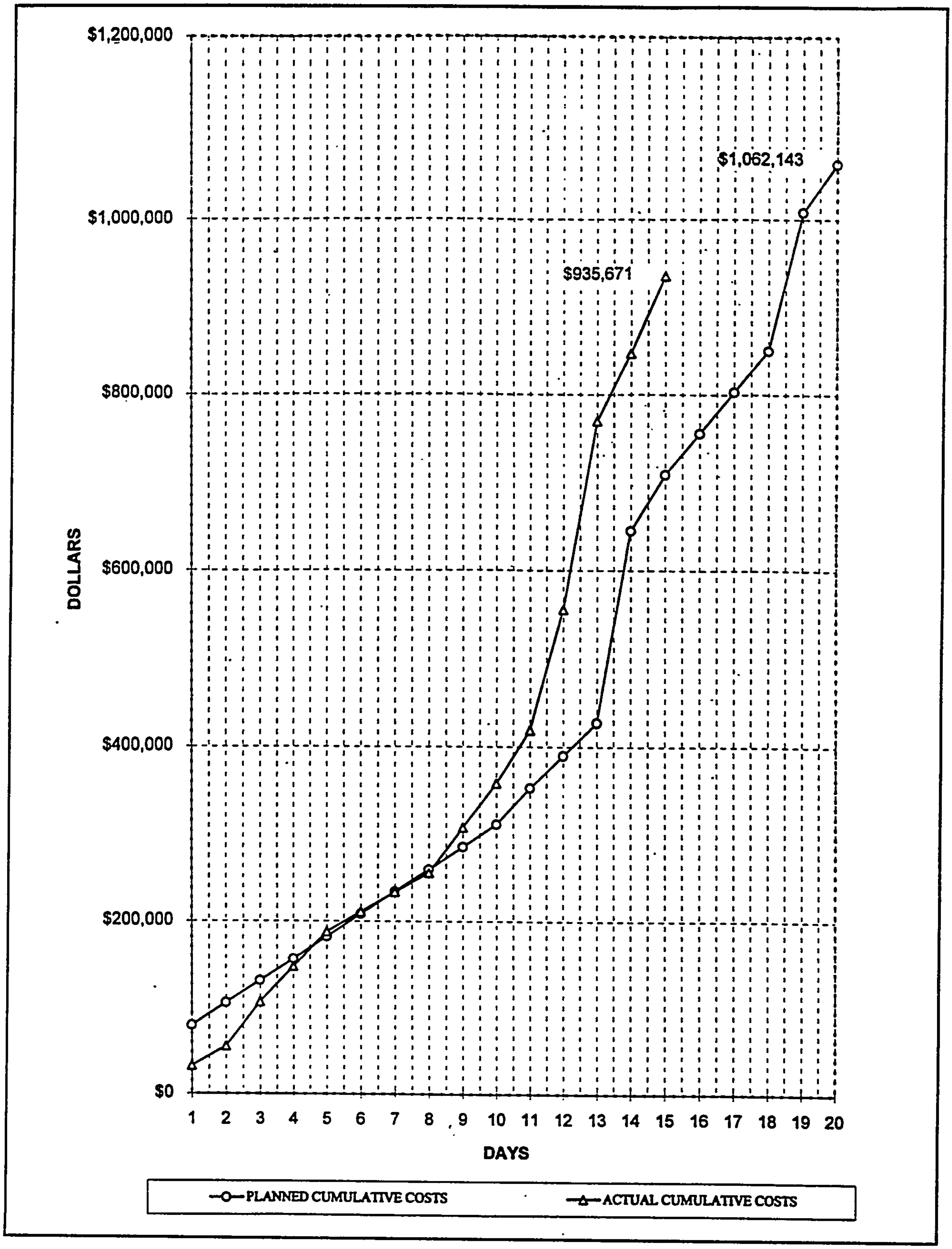


Figure 4-4
Actual Versus Planned Costs for Drilling of Well ER-20-6#2

construction of the well, to help verify the geology, and to help characterize the hydrology of the units penetrated.

One fiberglass access string was successfully installed in the well. The 5½-in. screened casing (fiberglass and stainless steel) was successfully installed, but the 2⅞-in. stainless-steel pump string parted after a short pumping test, and the rotor has been removed from the pump. Each string has two screened or slotted intervals separated by a blank. Gravel-packed intervals were placed at 748.0 to 840.3 m (2,454 to 2,757 ft) and 851.3 to 897.6 m (2,793 to 2,945 ft), separated by sand. The gravel packs coincide with two more transmissive portions of the lava-flow aquifer which was the completion target. It is planned to try to retrieve the parted string and replace the No Turn Tools® with packers to hold the pump stator in place inside the 5½-in. fiberglass casing.

The total planned cost for Well ER-20-6#2 was $1,062,143. The actual cost of the well was $ 935,671, or 11.9 percent less than the planned cost.

The objectives of the BULLION near-field drilling project were advanced through drilling and construction of Well ER-20-6#2 as follows:

- Tritium levels in the completion intervals are within acceptable levels for the forced-gradient experiment, although they were higher in the upper lava-flow aquifer adjacent to the BULLION WP.

- Geologic data were obtained from examination of drill cuttings and geophysical logs. The interpretation of the geology of this hole, in the context of the hole cluster, indicates a somewhat more-complicated hydrogeologic setting than expected due to the complex nature of rhyolite lava flows. See Sections 2.0 and 6.0 for additional discussions of the site geology and its importance to the forced-gradient experiment.

- The access string was successfully installed, and it is expected that the parted pump string will be replaced.

4.7.2 Lessons Learned

This section describes lessons learned during the drilling and construction of Well ER-20-6#2. Lessons learned from the project, as a whole, are addressed in Section 6.3

Completion

The fiberglass joints of both the 5½-in. casing and 2⅞-in. tubing did not fit flush. The correction factor determined after installation of the same type of strings in Well ER-20-6#1 was not adequate for correcting this problem, and both strings were landed off deeper than planned.

It was found that the No Turn Tools® will not set inside fiberglass casing. Stainless-steel packers have been ordered to replace them.

Geologic Evaluation

Lack of geophysical data from the lower 68.6 m (225 ft) of the hole and limited geophysical data in the upper part of the hole (behind the surface casing) made it difficult for geologists to interpret the geology in that part of the hole.

5.0 Well ER-20-6#3

5.1 Drilling Summary

The drilling requirements for Well ER-20-6#3 were outlined in Contract DE-RP-08-95NV11808 (no BN Drilling Program was prepared), and any changes to the program were documented in BN Records of Verbal Communication (Appendix A.1). This summary was compiled from the BN daily rig reports and from field notes prepared by the IT Field Representative. Complete details of drilling activities can be found in the BN Well ER-20-6#3 Hole History (BN, 1996e).

The pad for Well ER-20-6#3, which included two new lined sumps, was constructed during drilling of Well ER-20-6#2 (Figure 1-3). The existing infiltration basin was lined during drilling of Well ER-20-6#3, and a description of the drill rig is given in Section 3.1 of this report. 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. Details of the composition of drill fluids, additives, and cements are provided in Appendix A.4. See Figure 5-1 for a graphical presentation of the drilling and completion history and Table 5-1 for abridged drill-hole statistics.

5.1.1 Drilling History

A Welch & Howell crew dry-augured the 76.2-cm (30-in.) conductor hole for Well ER-20-6#3 to the depth of 19.5 m (64 ft) on April 1, 1996, during completion of Well ER-20-6#2. A 20-in. casing was set at 19.5 m (64 ft). The casing annulus was cemented to the surface with cement left inside the casing to 17.7 m (58 ft). The next two days were spent on moving to the location, rigging up, and completing the liners of the new sumps. The rat and mouse holes were drilled with an air-hammer early on April 4, 1996, and rotary drilling of the main hole began the same day.

A 17½-in. bit and air-foam with polymer in conventional circulation were used to drill the hole, first through the cement in the conductor casing and then into the formation. Weight on the bit was kept relatively light at first to keep the hole as straight as possible, and drill collars were added when the hole was approximately 66 m (216 ft) deep.

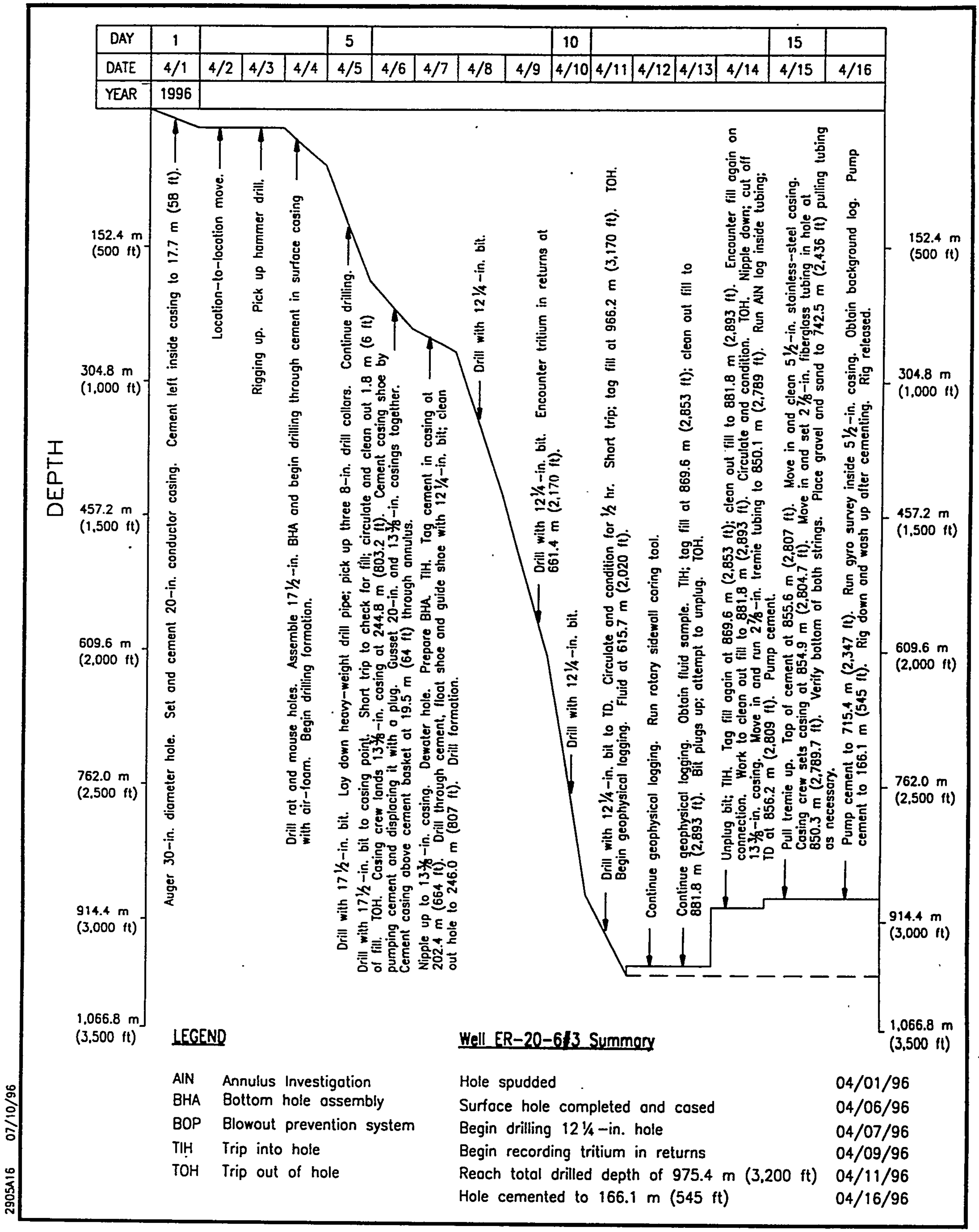


Figure 5-1
Well ER-20-6#3 Drilling and Completion History

Table 5-1
Abridged Drill-Hole Statistics for Well ER-20-6#3

LOCATION DATA: Coordinates: Central Nevada State Planar: N913,420.4, E571,337.1 ft
Universal Transverse Mercator: N4,123,578.7, E551,295.7 m

Ground Elevation: 1,970.8 m (6,466.0 ft)

DRILLING DATA:

Spud Date: 04/04/96
Total Depth (TD): 975.4 m (3,200 ft)
Date TD Reached: 04/11/96
Date Well Completed: 04/16/96
Hole Diameter: 76.2 cm (30 in.) from surface to 19.5 m (64 ft); 44.5 cm (17.5 in.) to 246.0 m (807 ft); 31.1 cm (12.25 in.) to 975.4 m (3,200 ft).

Drilling Techniques: Dry auger drilling to 19.5 m (64 ft). Rotary drilling with air-foam using a 17½-in. bit and conventional-circulation to 246.0 m (807 ft). Rotary drilling with a 12¼-in. bit and air-foam (with polymer as needed) in conventional circulation to TD.

CASING DATA: 20-in. conductor casing from surface to 19.5 m (64 ft); 13⅜-in. surface casing to 244.8 m (803.2 ft).

WELL COMPLETION DATA:

A 14.0-cm (5½-in.) od, perforated stainless-steel casing with internal wire screens planned to house a pump was landed off at 854.9 m (2,804.7 ft). A slotted access string consisting of 7.3-cm (2⅞-in.) od fiberglass tubing was landed off at 850.3 m (2,789.7 ft). No pump has been installed in the well as of July 12, 1996.

	Completion String	Access String
Total Depth:	854.9 m (2,804.7 ft)	850.3 m (2,789.7 ft)
Depth of Slotted Section:	765.2-854.1 m (2,510.4 to 2,802.1 ft)	760.8-849.9 (2,495.9 to 2,788.5 ft)
Depth of Sand Pack:	742.5-755.9 m (2,436 to 2,480 ft)	Same as for completion string
Depth of Gravel Pack:	755.9-855.6 m (2,480 to 2,807 ft)	Same as for completion string
Fluid Depth[a]:	615.7 m (2,020 ft)	Not applicable

DRILLING CONTRACTOR: Welch & Howell Drilling

GEOPHYSICAL LOGS BY: Atlas Wireline Services, Baker Hughes INTEQ, Desert Research Institute, Geophysical Engineering Group

SURVEYING CONTRACTOR Bechtel Nevada

[a]Fluid level in the open borehole as of April 11, 1996.

A casing point was picked in the welded Rainier Mesa Tuff at the depth of 246.0 m (807 ft), which was reached on April 6, 1996. The drillers conditioned the hole for two hours, then cleaned out approximately 1.8 m (6 ft) of fill found after a short trip. A 13⅜-in. surface casing was set by the casing subcontractor at 244.8 m (803.2 ft), and then the cement crew stabbed a 5-in. drill pipe into the casing float collar. Water was pumped down the drill pipe (to make sure it was clear), followed by 11.3 m^3 (400 ft^3) of cement, followed by a plug. The system was then pressurized to force the cement up the annulus. Water remained inside the casing when the drill pipe was removed; the top of the cement inside the casing was tagged at approximately 202.4 m (664 ft). The 20-in. and 13⅜-in. casings were gusseted together at the collar. The top of the casing was sealed by dropping bags of cedar fiber and dirty gravel on top of the cement basket at 18.3 m (60 ft) and then pumping cement down the annulus to seal it to ground level. The drillers then pulled the drill pipe, dewatered the hole, and made minor repairs in preparation for drilling out from under the surface casing.

The drillers picked up the 12¼-in. BHA and began drilling through the cement and casing shoes inside the surface casing. Drilling into the formation began late on April 7, 1996, and progressed very quickly with no problems for the next three days. Tritium was first noted in the fluid returns on April 9, 1996, at the drilled depth of 661.4 m (2,170 ft). The penetration rate averaged 9 to 18 m/hour (30 to 60 ft/hour) through much of the hole, but in some short intervals near the bottom, it reached as high as 52 m/hour (170 ft/hour). Only minor episodes of intermittent poor returns were noted between the depths of 786.4 and 883.9 m (2,580 to 2,900 ft).

After the TD of 975.4 m (3,200 ft) was reached on April 11, 1996, the drillers circulated and conditioned the hole for thirty minutes. Approximately 9.1 m (30 ft) of fill was found after a short trip, but the hole was not cleaned out before geophysical logging began, and the hole continued to slough during logging. After the logging was completed on April 14, 1996, the drillers spent two shifts trying to clean out the fill, but fill accumulated each time the bit was pulled up. By the time the tremie line was installed for completion at the end of the last shift on April 14, 1996, fill had accumulated in the hole to the depth of 856.2 m (2,809 ft).

The gyroscopic survey run inside the 5½-in. completion string in the well indicates that at the lowest surveyed depth of 848.9 m (2,785 ft), the hole had drifted 20.5 m (67.1 ft) west of the collar coordinates.

5.1.2 Drilling Problems

No serious problems were encountered during drilling of Well ER-20-6#3. Borehole sloughing resulted in the loss of approximately 119.2 m (391 ft) of the hole, which delayed completion activities briefly but did not prevent the successful completion of the well.

5.1.3 Fluid Management

Air-foam and polymer were used to drill Well ER-20-6#3 from 19.5 m (64 ft) to the TD of 975.4 m (3,200 ft). The clean and contaminated discharge fluids were held in separate lined sumps. The drilling effluent was monitored in accordance with methods prescribed in the *Fluid Management Plan for the Underground Test Area Operable Unit* (DOE, 1994) and the *Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6* (IT, 1995). The results of analyses on samples of drilling fluid collected indicate that all fluids are within the fluid quality objectives established for radiochemical parameters in the Fluid Management Plan.

Appendix B.1 of this report contains the Well ER-20-6#3 Fluid Management Status Report. The fluid disposition form lists final volumes and data for drilling and completing the well. The final volumes of fluids imported to and produced at Well ER-20-6#3 were calculated from water-truck delivery tickets and measurement of fluids in the sumps. The solids produced were calculated using the diameter of the borehole and depth drilled and included added volume attributed to rock bulking factors.

5.2 Geologic Data Collection

5.2.1 Collection of Drill Cuttings

Triplicate sets of composite drill cuttings were collected continuously from Well ER-20-6#3 at 3-m (10-ft) intervals from the surface to 920.5 m (3,020 ft) and then at 6.1-m (20-ft) intervals to the TD at 975.4 m (3,200 ft). Samples were not obtained from 27 intervals, 22 of which were missed due to intermittent or poor fluid returns to the surface between the depths of 786.4 and 883.9 m (2,580 to 2,900 ft). All samples (275 sets of three) are stored under secure conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada. One of each set of samples was sealed with custody tape at the rig site as an archive sample; one was left unsealed in the original sample containers; and the third was washed in accordance with standard USGS Core Library procedures.

5.2.2 Sidewall Core Samples

After drilling was completed, sidewall core samples were collected to verify the stratigraphy and lithology penetrated in the interval 582.2 to 848.6 m (1,910 to 2,784 ft) and to obtain material for laboratory analysis. Rotary sidewall core samples were collected on April 11, 1996, by Atlas Wireline Services who recovered 28 samples out of 30 attempted. The sample depths were selected by the IT Field Representative. The depths, recovery, and geology of all recovered samples are listed in Table 5-2.

Table 5-2
Rotary Sidewall Core Samples Collected from Well ER-20-6#3

Core Depth meters (feet)	Recovery centimeters (inches)	Stratigraphic Unit[a]	Hydrogeologic Unit[b]
582.2 (1,910.0)	3.0 (1.2)	Tpd[c]	TCU[d]
609.6 (2,000.0)	3.8 (1.5)	Tacp[e]	TCU
631.4 (2,071.5)	4.6 (1.8)	Tacp	TCU[+]
640.1 (2,100.0)	3.6 (1.4)	Tacp	LFA[f]
656.5 (2,154.0)	3.8 (1.5)	Tacp	LFA
667.5 (2,190.0)	3.3 (1.3)	Tacp	LFA
670.6 (2,200.0)	4.6 (1.8)	Tacp	LFA
671.9 (2,204.5)	3.6 (1.4)	Tacp	LFA
672.1 (2,205.0)	4.6 (1.8)	Tacp	LFA
702.0 (2,303.0)	2.0 (0.8)	Tacp	TCU[+]
702.1 (2,303.5)	3.3 (1.3)	Tacp	TCU
711.4 (2,334.0)	3.3 (1.3)	Tacp	TCU
721.8 (2,368.0)	3.8 (1.5)	Tacp	TCU
731.8 (2,401.0)	2.8 (1.1)	Tacp	TCU
745.8 (2,447.0)	3.3 (1.3)	Tacp	TCU
750.7 (2,463.0)	4.3 (1.7)	Tacp	TCU
755.3 (2,478.0)	4.1 (1.6)	Tacp	TCU[+]
765.0 (2,510.0)	4.8 (1.9)	Tacp	LFA
780.3 (2,560.0)	4.6 (1.8)	Tacp	LFA
791.0 (2,595.0)	4.6 (1.8)	Tacp	LFA
794.6 (2,607.0)	1.3 (0.5)	Tacp	LFA
804.4 (2,639.0)	3.3 (1.3)	Tacp	LFA
804.5 (2,639.5)	3.3 (1.3)	Tacp	LFA
804.7 (2,640.0)	2.5 (1.0)	Tacp	LFA
828.4 (2,718.0)	4.3 (1.7)	Tacp	LFA
837.6 (2,748.0)	3.8 (1.5)	Tacp	LFA
848.4 (2,783.5)	1.3 (0.5)	Tacp	LFA
848.6 (2,784.0)	3.6 (1.4)	Tacp	LFA

All samples taken by Atlas Wireline Services
[a]Stratigraphic nomenclature from Ferguson et al. (1994). See Appendix C-3.
[b]Modified from Winograd and Thordarson (1975) and Laczniak et al. (1996).
[c]Tuff of Delirium Canyon, Paintbrush Group
[d]Tuff-confining unit
[e]Mafic-poor Calico Hills Formation
[f]Lava-flow aquifer
[+]Sample is zeolitized, pumiceous lava; this part of unit may have hydrologic properties similar to a TCU.

5.2.3 Geophysical Data

Geophysical logs were run after drilling to characterize the lithology, structure, and hydrogeologic properties of the rocks. In addition, logs were run in Well ER-20-6#3 to check borehole conditions, determine fluid levels and other hydrologic data, identify radionuclides, and monitor the completion process. All geophysical logs run in Well ER-20-6#3 during drilling and completion are listed in Table 5-3. The logs are available from BN in Mercury, Nevada, and copies are on file at the IT office in Las Vegas, Nevada.

Overall, the quality of the geophysical data is acceptable. However, as in Wells ER-20-6#1 and #2, the only geophysical log available for use in correlating geologic units above the casing point at 244.8 m (803.2 ft) was the natural gamma-ray log which was run through the casing. Also, log data are limited for the lower 91 m (300 ft) of the hole due to sloughing. Preliminary data from most of the geophysical logs are presented in Appendix D.

5.3 Hydrology of Well ER-20-6#3

5.3.1 Preliminary Water-Level and Water-Production Information

Production of water from Well ER-20-6#3 began at the depth of approximately 644.0 m (2,113 ft), soon after drilling into a lava of the rhyolite of Silent Canyon. Water production remained at less than 75 Lpm (20 gpm) and then increased to approximately 200 Lpm (53 gpm) by the time the hole depth reached 692.2 m (2,271 ft). Production remained at less than 378 Lpm (100 gpm) to the depth of 785.2 m (2,576 ft) and then increased to 568 Lpm (150 gpm). From that point, production steadily increased to a maximum of about 844 Lpm (223 gpm) at 879.4 m (2,885 ft) in the Calico Hills lava-flow aquifer and remained steady to the TD. See Appendix B.2 for a listing of water-production and tritium data. A comparison of water-production and tritium data for all three holes in the cluster is presented in Section 6.0.

The fluid level in the open borehole (during geophysical logging and before installation of the tubing in the well) consistently stabilized at a depth of approximately 615.7 m (2,020 ft) and an elevation of 1,355.1 m (4,446 ft), very similar to the pre-drill estimate and to the fluid level elevations found in both Wells ER-20-6#1 and #2 (the difference in depth to fluid between Well ER-20-6#3 and the other two wells in the cluster is accounted for by the difference in elevation between the drill pads).

Table 5-3
Well ER-20-6#3 Geophysical Log Summary

Geophysical Logs	Log Purpose	Logging Service	Date Logged	Run Number	Top of Logged Interval (bgs)[a] meters (feet)	Bottom of Logged Interval (bgs) meters (feet)
Annulus Investigation Log	Omnidirectional density (check for cement and/or fluid location)	GEG[b]	04/14/96 04/15/96 04/15/96 04/16/96	AIN-1 AIN-2 AIN-3 AIN-4	609.6 (2,000) 823.0 (2,700) 594.4 (1,950) 30.5 (100)	856.2 (2,809) 856.2 (2,809) 850 1 (2,789) 723.9 (2,375)
Borehole Televiewer/Gamma Ray	Borehole examination/stratigraphic correlation	AWS[c]	04/11/96	BHTV-1/GR-3	615.1 (2,018)	864.1 (2,835)
4-Arm Caliper/Gamma Ray	Borehole conditions/stratigraphic correlation	AWS	04/11/96	CA4-1/GR-1	0	899.2 (2,950)
Dual Laterolog/Gamma Ray	Lithology/stratigraphic correlation	AWS	04/11/96	DLL-1/GR 1	572.7 (1,879)	892.8 (2,929)
Epithermal Neutron/Compensated Density/Gamma Ray	Water content/density/stratigraphic correlation	AWS	04/11/96	ENP-1/CDL-1 GR-2	244.8 (803)	878.1 (2,881)
Spectralog	Stratigraphic correlation, mineralogy, natural radiation, identification of explosion products	AWS	04/12/96	SL-1	244.8 (803)	852.2 (2,796)
Spectralog/Digital Acoustic Log	Stratigraphic correlation, mineralogy, natural radiation, identification of explosion products/borehole examination for fractures	AWS	04/12/96	SL-1/DAC-1	615.7 (2,020)	859.2 (2,819)
Total Magnetic Intensity	Stratigraphic correlation, lithologic information	GEG	04/13/96	TMI-1	248.4 (815)	855.3 (2,806)
Differential Temperature Survey	Groundwater temperature	AWS	04/11/96	TLDLT-1	550.5 (1,806)	885 7 (2,906)
Chemistry Log/Temperature Log	Determine fluid pH, electrical conductivity/temperature	DRI[d]	04/13/96	CHEM-1/TL-2	621.8 (2,040)	855.3 (2,806)
Thermal Flow Log (electrical conductivity, temperature)	Determine rate/direction of groundwater flow within the borehole	DRI	04/13/96	HPFLOW-1	625.4 (2,052)	831.2 (2,727)
Mechanical Coring Tool/Gamma Ray	Obtain samples for analysis/ stratigraphic correlation	AWS	04/12/96	MCT-1/GR-4	582.2 (1,910)	848.6 (2,784)
Directional Gyroscope	Borehole deviation	BHI[e]	04/16/96	DRG-1	0	848.9 (2,785)

Source: Bechtel Logging Department

[a]Below ground surface
[b]Geophysical Engineering Group of the Joint Test Organization
[c]Atlas Wireline Services
[d]Desert Research Institute
[e]Baker Hughes INTEQ

5.3.2 *Radionuclides Encountered*

Tritium activity above background levels was first encountered at a depth of 176.8 m (580 ft). Activity in the fluid sample was measured at 56,073 pCi/L on April 5, 1996. A fluid sample from this same depth was remeasured on April 6, 1996, at 53,400 pCi/L. An explanation for this anomalous reading has not yet been determined. Tritium activity was next encountered in the fluid returns when the borehole had been drilled to 661.4 m (2,170 ft), approximately 45.7 m (150 ft) below the open-hole static water level. The tritium activity never rose above 400,000 pCi/L, and dropped to background levels by the depth of 824.5 m (2,705 ft) near the bottom of the gravel-packed interval.

5.3.3 *Preliminary Thermal Flow Log Data*

As described in Section 3.3.3, flow meter data can be used to characterize fluid flow in boreholes. Data from the TFM obtained by DRI were used in all three holes to help identify completion intervals. Desert Research Institute personnel made TFM measurements at eight locations (listed below) in the Well ER-20-6#3 borehole.

- 625.4 m (2,052 ft)
- 640.1 m (2,100 ft)
- 664.5 m (2,180 ft)
- 685.8 m (2,250 ft)
- 713.2 m (2,340 ft)
- 762.0 m (2,500 ft)
- 786.4 m (2,580 ft)
- 831.2 m (2,727 ft)

Preliminary field evaluation of the data indicated downward flow of approximately two liters per minute or less at all locations.

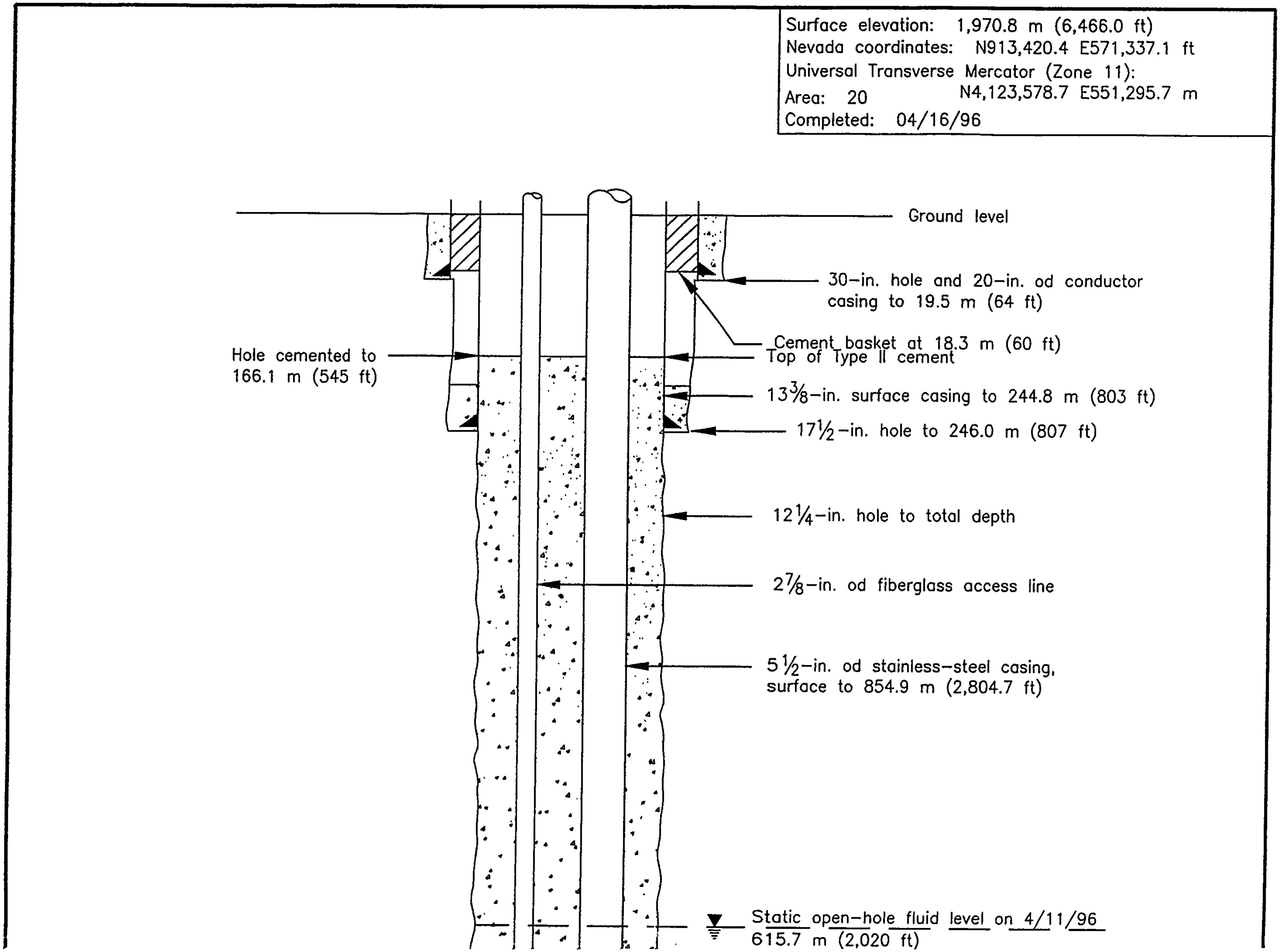
5.4 *Precompletion and Open-Hole Development*

Precompletion development was conducted in Well ER-20-6#3 by circulating and conditioning the borehole. The drillers circulated for thirty minutes after TD was reached, prior to geophysical logging. After logging was completed and efforts to clean out fill were concluded, fluid was again circulated in the hole for an hour before completion activities began.

5.5 *Completion*

The objective of the Well ER-20-6#3 completion was to install a pumping well to induce a gradient from the BULLION cavity through Wells ER-20-6#1 and #2 to study contaminant transport dynamics. Completion activities at Well ER-20-6#3 began immediately after logging was finished and a bottom plug set, on April 15, 1996, and were concluded on April 16, 1996. Figure 5-2 is a schematic of the final well-completion design for Well ER-20-6#3, and Figure 5-3 shows a plan view and profile of the well-head configuration. Data for this section were obtained from the BN daily rig reports and tubing records for Well ER-20-6#3.

2905B06 07/02/96



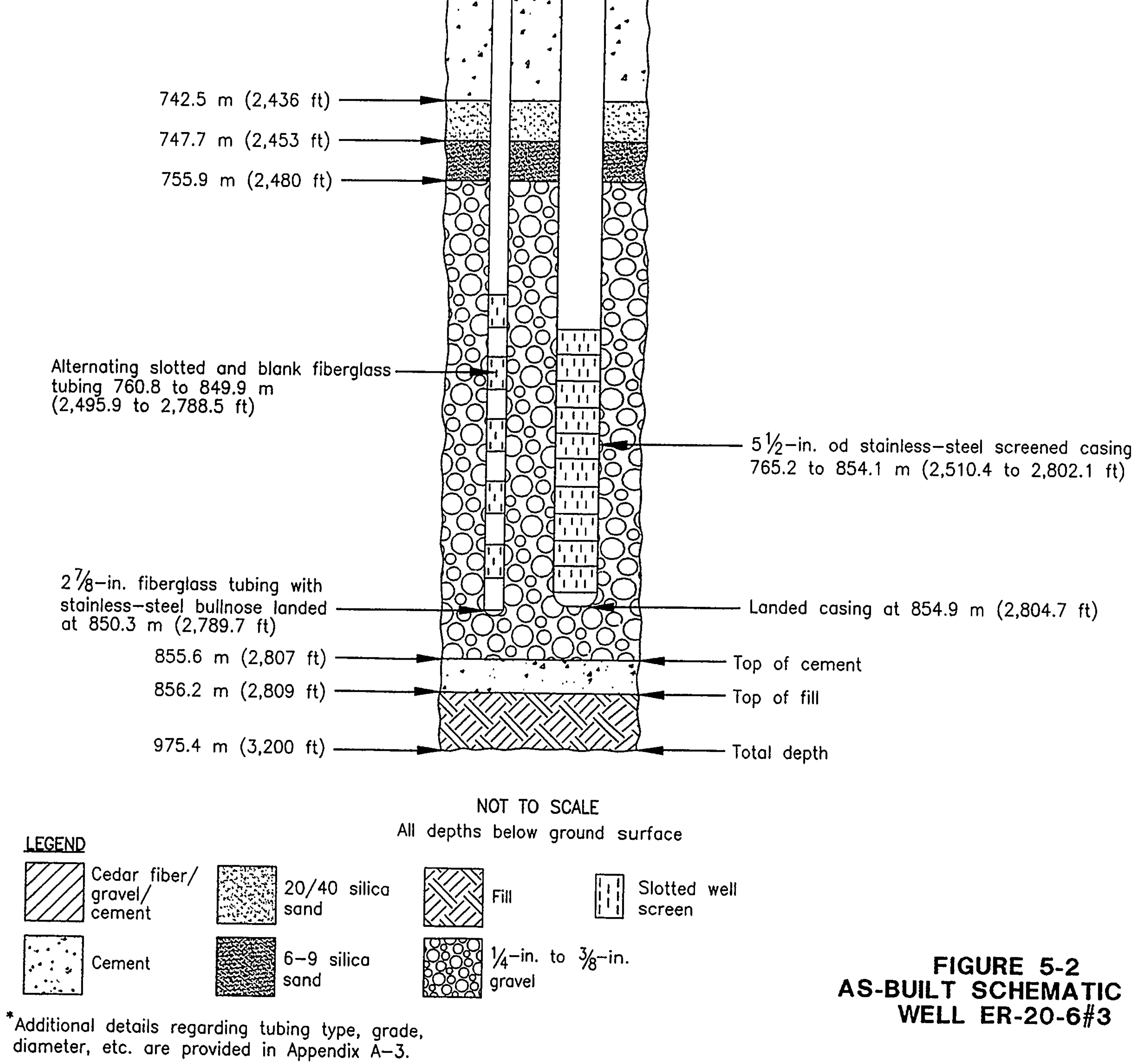


FIGURE 5-2
AS-BUILT SCHEMATIC OF WELL ER-20-6#3

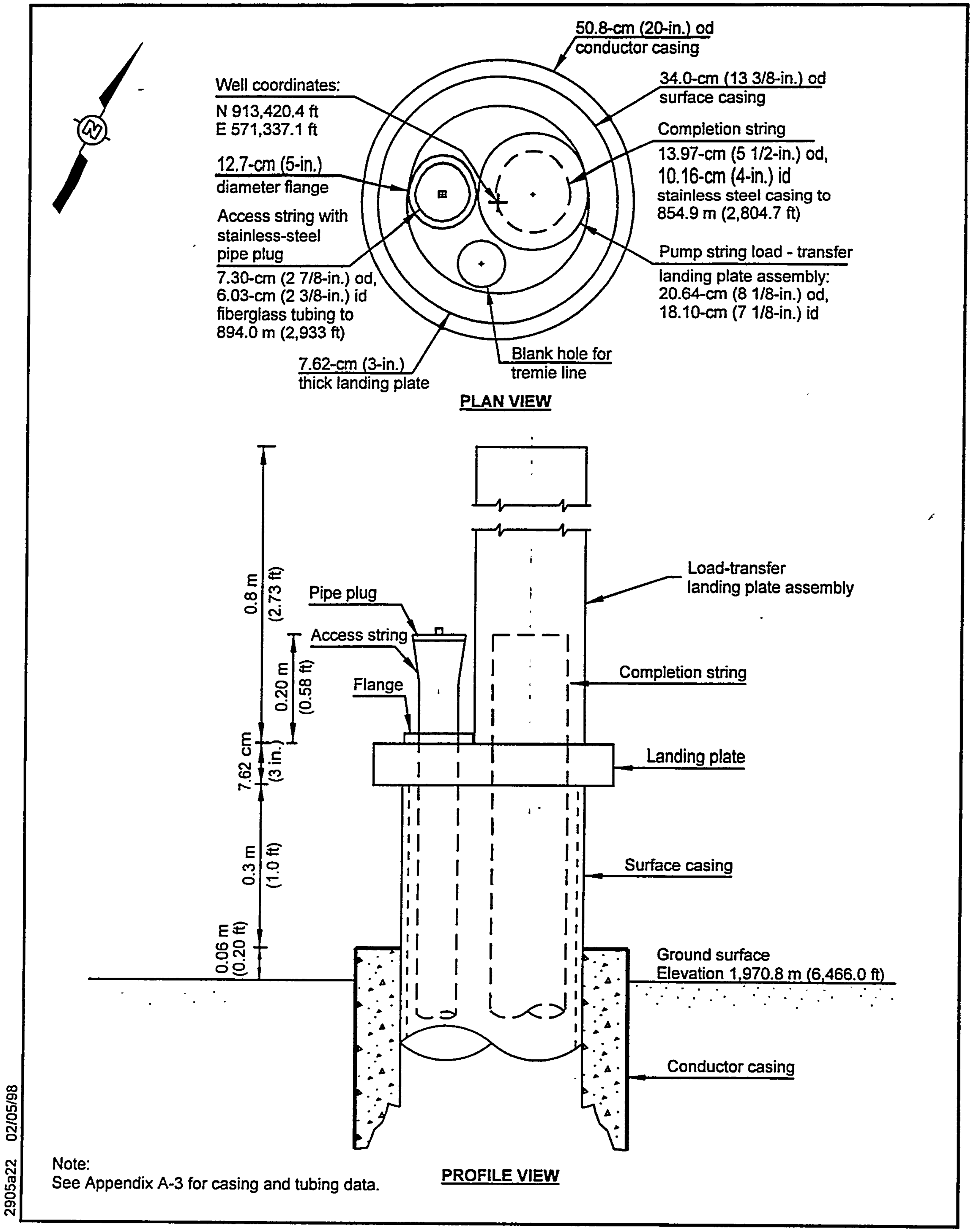


Figure 5-3
Well ER-20-6 #3 Wellhead Diagram

5.5.1 Proposed Completion Design

The modification of the original plan for Well Cluster ER-20-6 from a monitoring well to a forced-gradient experiment required the redesign of the well cluster configuration (see Section 1.3 of this report). Originally, the third well in the cluster was to have been drilled near the first two wells and completed in the tuff-confining unit above the lava-flow aquifer that was completed in Wells ER-20-6#1 and #2. For use as a pumping well, however, the Well ER-20-6#3 completion was required to be constructed in the same hydrogeologic unit as the monitoring wells, at some distance along a radial from the BULLION WP. The modified proposed completion design for Well ER-20-6#3 is, thus, very similar to that of Wells ER-20-6#1 and #2, although the design required a submersible pump with a large production capability (approximately 757 Lpm [200 gpm]) instead of a Moyno® pump (IT, 1996b).

5.5.2 As-Built Completion Design

The as-built completion design of Well ER-20-6#3 provides access to the same lava-flow aquifer (within the Calico Hills Formation) as completed in Wells ER-20-6#1 and #2. The completion string has one screened section placed at a similar depth as the slotted interval of the adjacent access string within the gravel pack. The string compositions are listed on Table 5-4 and tubing materials are listed in Appendix A.3.

The casing for the pump string is 5½-in. stainless steel for its entire length. The bottom 0.8-m (2.6-ft) section is bull-nosed and blank with a 0.64-cm (0.25-in.) hole to serve as a fluid drain in the event of excessive drawdown. The screened interval consists of ten joints, each 8.2 to 9.2 m (26.9 to 30.3 ft) long, located between 765.2 and 854.1 m (2,510.4 and 2,802.1 ft). The terminal 0.76 m (2.5 ft) of each screened joint is blank (for strength at the connection), and the middle 7.6 m (25 ft) is perforated with 1.27-cm (0.5-in.) diameter holes at a density of 160 holes per foot. Screen consisting of wire wrapped around wire ribs was welded inside each perforated joint. The screen inside six of the joints has 0.20-cm (0.078-in.) openings between wraps, and the screen inside four of the joints has 0.10-cm (0.04-in.) openings between wraps.

A 2⅞-in. fiberglass tubing string was installed in Well ER-20-6#3 adjacent to the 5½-in. casing string to serve as an access line. The fiberglass tubing was landed off at 850.3 m (2,789.7 ft). The bottom 0.4-m (1.2-ft) joint is a stainless-steel bull-nose with a 0.64-cm (0.25-in.) hole to serve as a fluid drain. The slotted section is 80.4 m (263.7 ft) long and consists of five slotted 8.9-m (29.3-ft) fiberglass joints alternating with four blank fiberglass joints. The slotted section is separated from the bullnose by a blank joint. The terminal 1.2 m (4 ft) of each fiberglass slotted joint is blank (for strength at the connections) and the middle 6.7 m (22 ft) is slotted. Each slotted joint has eight rows of saw-cut slots 7.62 cm (3 in.) long by 0.32 cm (0.125 in.) wide on staggered 30.5-cm (12-in.) centers.

Table 5-4
Well ER-20-6#3 Construction Summary

Completion String	Configuration		Cement	Sand/Gravel
5½-inch Stainless-Steel Casing	Ground surface to 854.9 meters (m) (2,804.7 feet [ft])	Blank 0 to 765.2 m (0 to 2,510.4 ft)	<u>Type II plus 2% $CaCl_2$</u> 166.1 to 742.5 m (545 to 2,436 ft) 855.6 to 856.2 m (2,807 to 2,809 ft)	<u>20/40 Sand</u> 742.5 to 747.7 m (2,436 to 2,453 ft) <u>6-9 Sand</u> 747.7 to 755.9 m (2,453 to 2,480 ft) <u>1/4 to 3/8-inch Gravel</u> 755.9 to 855.6 m (2,480 to 2,807 ft)
		Screened 765.2 to 854.1 m (2,510.4 to 2,802.1 ft)		
		Blank and bull-nosed 854.1 to 854.9 m (2,802.1 to 2,804.7 ft)		
2⅞-inch Fiberglass Tubing	Ground surface to 850.3 m (2,789.7 ft)	Blank Ground surface to 760.8 m (2,495.9 ft)		
		5 slotted joints alternating with 4 blank joints 760.8 to 841.1 m (2,495.9 to 2,759.6 ft)		
		Blank and bull-nosed 841.1 to 850.3 m (2,759.6 to 2,789.7 ft)		

5.5.3 Rationale for Differences Between Actual and Proposed Well Design

The final design for Well ER-20-6#3 was determined after evaluating radionuclide data, geophysical logs, and the flow log. The completion interval in Well ER-20-6#3 is geologically equivalent to those in Wells ER-20-6#1 and #2. However, only one continuous gravel pack was installed in Well-ER-20-6#3 (instead of two as in the first two holes) because only one transmissive zone was recognized. Thus, the Well ER-20-6#3 completion is very similar to that specified in the revised completion criteria for the forced-gradient experiment (IT, 1996b).

5.5.4 Completion Method

Standard UGTA decontamination procedures were employed to prevent the introduction of outside contaminants into the well. Well-construction materials were inspected in accordance with 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, sand, and gravel needed during well construction. A tremie line consisting of 2⅞-in. Hydril® tubing was used for placing all gravel, sand, and cement; emplacement of these materials was monitored using the AIN log. All casing and tubing were run by a casing installation subcontractor.

The final depth of the hole was shortened to 856.2 m (2,809 ft) due to the accumulation of fill. The hole depth was verified by the AIN log run in the tremie prior to completion, and then the hole was cemented from the top of fill to the depth of 855.6 m (2,807 ft). The completion string was landed at 854.9 m (2,804.7 ft), and the fiberglass access string was landed at 850.3 m (2,789.7 ft). Although the joints of 2⅞-in. fiberglass tubing did not fit "flush" (see Section 3.5.4 of this report), a correction factor determined from experience with Wells ER-20-6#1 and #2 was applied in the field to place the string precisely. The AIN logs run in the strings after emplacement indicated that the actual depths of both strings matched the planned depths.

The completion operation continued with the placement of the gravel pack. The completion interval was packed with ¼-in. to ⅜-in. gravel from 755.9 to 855.6 m (2,480 to 2,807 ft). The sand pack above the gravel consists of 6-9 Colorado sand placed at 747.7 to 755.9 m (2,453 to 2,480 ft) and 20/40 silica sand placed at 742.5 to 747.7 m (2,436 to 2,453 ft). The remainder of the hole from 166.1 to 742.5 m (545 to 2,436 ft) was filled with Type II cement plus 2-percent $CaCl_2$. The final cementing process was interrupted for 6½ hours while the gyroscopic survey was run inside the 5½-in. casing. No pump was installed in the well. The rig was released immediately after cementing.

5.6 Actual Versus Planned Costs and Scheduling

The BN cost model for the ER-20-6 well cluster was originally developed on a per-hole basis for generic 914.4-m (3,000-ft) deep holes. In this model, drilling, logging and completion were projected to require 20 days to accomplish. Actual time spent (after rigging up) on drilling and completion of Well ER-20-6#3, with a TD of 975.4 m (3,200 ft) was 14 days.

The cost analysis for Well ER-20-6#3 can be divided into charges by the drilling contractor (including drilling equipment, fluids, and the casing subcontractor) and charges by the support contractors (including radiation technicians, inspection services, geophysical logging, cementing services, and completion materials). The total planned cost of Well ER-20-6#3 was $1,062,143. The actual cost of the well was $847,881, or 20.2 percent less than the planned cost. Table 5-5 lists the planned and actual costs. Figure 5-4 is a comparison of planned and actual costs by day for drilling Well ER-20-6#3.

Table 5-5
Well ER-20-6#3 Actual Versus Planned Costs

Activity	Planned Cost[a]	Actual Cost	Percent Difference Actual versus Planned
Drilling contractor	$339,600	$333,763[b]	-1.7
Support contractors	$772,543	$514,118[c]	-28.8
Total	$1,062,143	$847,881	-20.2

[a]Based on BN model for 914.4-m (3,000-ft) hole
[b]Source: DOE/ERD
[c]Source: BN Drilling

5.7 Summary and Lessons Learned

5.7.1 Summary

Drilling commenced at Well ER-20-6#3 on April 1, 1996, and concluded on April 11, 1996, when the TD of 975.4 m (3,200 ft) was reached. After geophysical logging, the completion strings were installed and gravel-packed, and the hole was cemented to 166.1 m (545 ft) on April 14-16, 1996. Crews worked on a seven-day-a-week, 24-hour-a-day schedule for most of the operation. Sixteen working days were expended on drilling, logging, and completion activities.

No significant problems were encountered in drilling of Well ER-20-6#3, but sloughing of borehole material at the bottom of the hole resulted in the loss of approximately 119.2 m (391 ft) of hole.

Composite drill cuttings were collected every 3 m (10 ft) from the surface to 920.5 m (3,020 ft) and then every 6 m (20 ft) to TD. Twenty-eight rotary sidewall samples were taken in the interval 582.2 to 848.6 m (1,910 to 2,784 ft). Geophysical logging was conducted after drilling was finished to aid in construction of the well, to help verify the geology, and to help characterize the hydrology of the units.

The 5½-in. stainless-steel casing for the pump was successfully landed in Well ER-20-6#3, but a pump was not installed. The fiberglass access line was also successfully installed in the well adjacent to the 5½-in. casing. Both strings have one screened or slotted interval located near the middle of the gravel pack which is located at 755.9 to 855.6 m (2,480 to 2,807 ft). The completion interval is in the same hydrogeologic unit as the completion intervals of Wells ER-20-6#1 and #2, as required for the forced-gradient experiment.

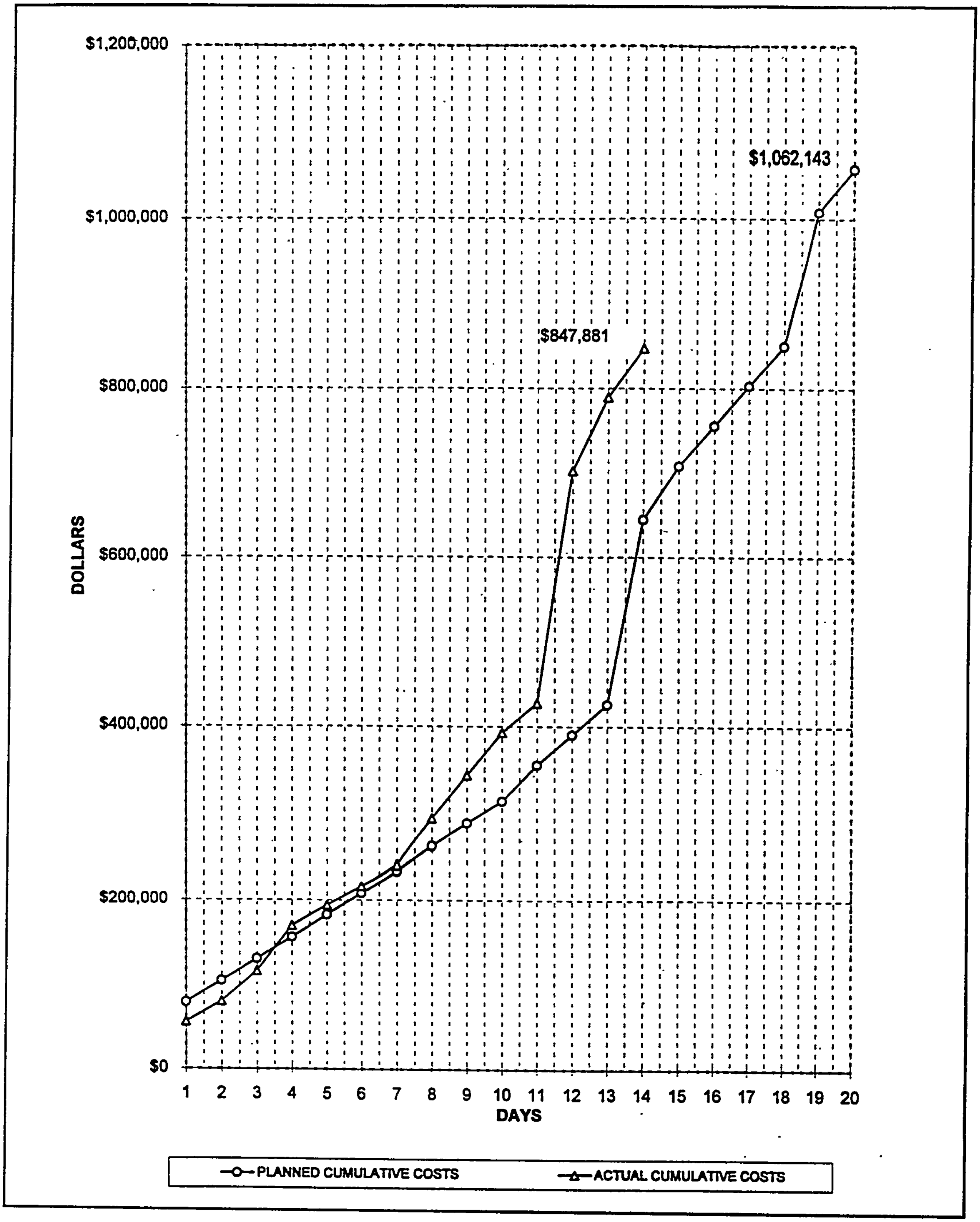


Figure 5-4
Actual Versus Planned Costs for Drilling and Completion of Well ER-20-6#3

The total planned cost for Well ER-20-6#3 was $1,062,143. The actual cost of the well was $847,881 or 20.2 percent less than the planned cost.

The well appears to meet the operational guideline for the forced-gradient experiment, that the pumping well not produce water with tritium activations greater than the limit for discharge to an infiltration basin (200,000 pCi/L) due to the large volume of water that will be produced during the experiment.

5.7.2 Lessons Learned

This section describes lessons learned during the drilling and completion of Well ER-20-6#3. Lessons learned from the project as a whole are addressed in Section 6.3.

Screens of two different sizes were installed in joints of perforated 5½-in. stainless-steel casing used in the completion zone. This was discovered only when the casing was being assembled, and the immediate solution was to alternate the joints with the larger and smaller screen sizes. In the future, joints with screens installed should be inspected when they are delivered at the NTS to avoid surprises in the field.

6.0 Summary, Recommendations, and Lessons Learned from Well Cluster ER-20-6

6.1 Summary

Operations commenced at Well Cluster ER-20-6 when the Welch & Howell drill rig was moved over from the Well Cluster ER-20-5 site on February 16, 1996. Drilling and completion of Well ER-20-6#1 began on February 19, 1996, followed by drilling and completion of Wells ER-20-6#2 and Well ER-20-6#3. Construction of the well cluster was concluded on April 16, 1996. Crews worked on a seven-day-a-week, 24-hour-a-day schedule, and 65 working days were expended on well-drilling, logging, and completion activities. Activities were uninterrupted by holidays or other hiatuses.

Drilling of Well ER-20-6#1 to the TD of 975.4 m (3,200 ft) took place from February 19, 1996, to March 6, 1996. A string of 13⅜-in. surface casing was set at 242.7 m 796.2 ft) in a 44.5-cm (17.5-in.) diameter hole, and a 31.1-cm (12.25-in.) diameter hole was drilled from the bottom of the casing to TD. Despite all efforts, fluid returns to the surface were lacking for long intervals of the drilling, which severely impacted collection of fluid samples for tritium monitoring and drill cuttings for geologic evaluation. Borehole sloughing in the lower part of the hole resulted in a decrease in the accessible depth of the hole by 66.1 m (217 ft) due to accumulation of fill, but the hole had been drilled deep enough that this did not impact well completion. Completion activities took place on March 11-15, 1996. One screened completion string (fiberglass and stainless steel) and one slotted, fiberglass access string were installed as planned in the middle lava-flow aquifer in the Calico Hills Formation, approximately 100 m (330 ft) from the edge of the BULLION collapse chimney. This aquifer is believed to communicate with the BULLION explosion cavity. Each string has two screened or slotted intervals, and there are two corresponding gravel-packed intervals.

Drilling of Well ER-20-6#2 commenced on March 16, 1996, and the TD of 975.4 m (3,200 ft) was reached on March 25, 1996. A string of 13⅜-in. surface casing was set at 244.5 m (802.1 ft) in a 44.5-cm (17.5-in.) diameter hole, and a 31.1-cm (12.25-in.) diameter hole was drilled from the bottom of the casing to TD. No problems were encountered during drilling, though borehole sloughing in the lower part of the hole resulted in a decrease in the accessible depth of the hole by 72.2 m (237 ft). The hole had been drilled deep enough that this did not impact well completion. Completion activities took place on March 29 to April 1, 1996. One screened completion string (fiberglass and stainless steel) and one slotted, fiberglass access string were installed as planned in the middle lava-flow aquifer in the Calico Hills Formation, approximately 142 m (467 ft) from the edge of the BULLION collapse chimney. Each string has two screened or slotted intervals and there are two corresponding gravel-packed intervals.

The No Turn Tools® intended to hold the pump stators in place inside the fiberglass casings of both Wells ER-20-6#1 and #2 could not be properly set and will be replaced with packers. The pump rotors were installed, but later removed from both wells after the pump string in Well ER-20-6#2 parted. It is planned to retrieve the pump string from Well ER-20-6#2.

Drilling of Well ER-20-6#3 to the TD of 975.4 m (3,200 ft) took place from April 4, 1996, to April 11, 1996. A 13⅜-in. surface casing was set at 244.8 m (803.2 ft) in a 44.5-cm (17.5-in.) diameter hole, and a 31.1-cm (12.25-in.) diameter hole was drilled from the bottom of the casing to TD. No difficulties were encountered during drilling. The bottom 119.2 m (391 ft) of the hole was blocked by fill, but this did not prevent the successful completion of the well. Completion activities took place on April 14-16, 1996. A screened, 5½-in. stainless-steel casing for the pump string and a slotted, fiberglass access string were successfully installed in the hole, but the pump was not installed in the casing. The strings in this well have just one screened or slotted interval, and there is one corresponding gravel-packed interval. This well was completed in the same hydrogeologic unit as Wells ER-20-6#1 and #2 and is located 230 m (755 ft) from the edge of the BULLION collapse chimney.

The deviation surveys run inside the 5½-in. casings of the ER-20-6 holes indicated that all three holes remained fairly straight and vertical during drilling. The lateral deviations of the holes are illustrated on Figure 6-1 which is a map that shows the collars and final survey stations of all three holes plotted in true horizontal scale.

The effort was made to collect composite drill cuttings every 3 m (10 ft) in all three holes. However, poor returns during drilling of Well ER-20-6#1 prevented sample collection through large intervals of the hole. Rapid drill rates in the other two holes forced reduction of the collection interval to 6 m (20 ft) through some zones. Six 12.7-cm (5-in.) diameter conventional cores (a total of 39.5 m [129.5 ft] recovered) were cut in Well ER-20-6#1. A total of 92 sidewall samples were collected from the three holes. The sidewall samples, conventional cores, and drill cuttings from all three holes are archived at the USGS Geologic Data Center and Core Library in Mercury, Nevada.

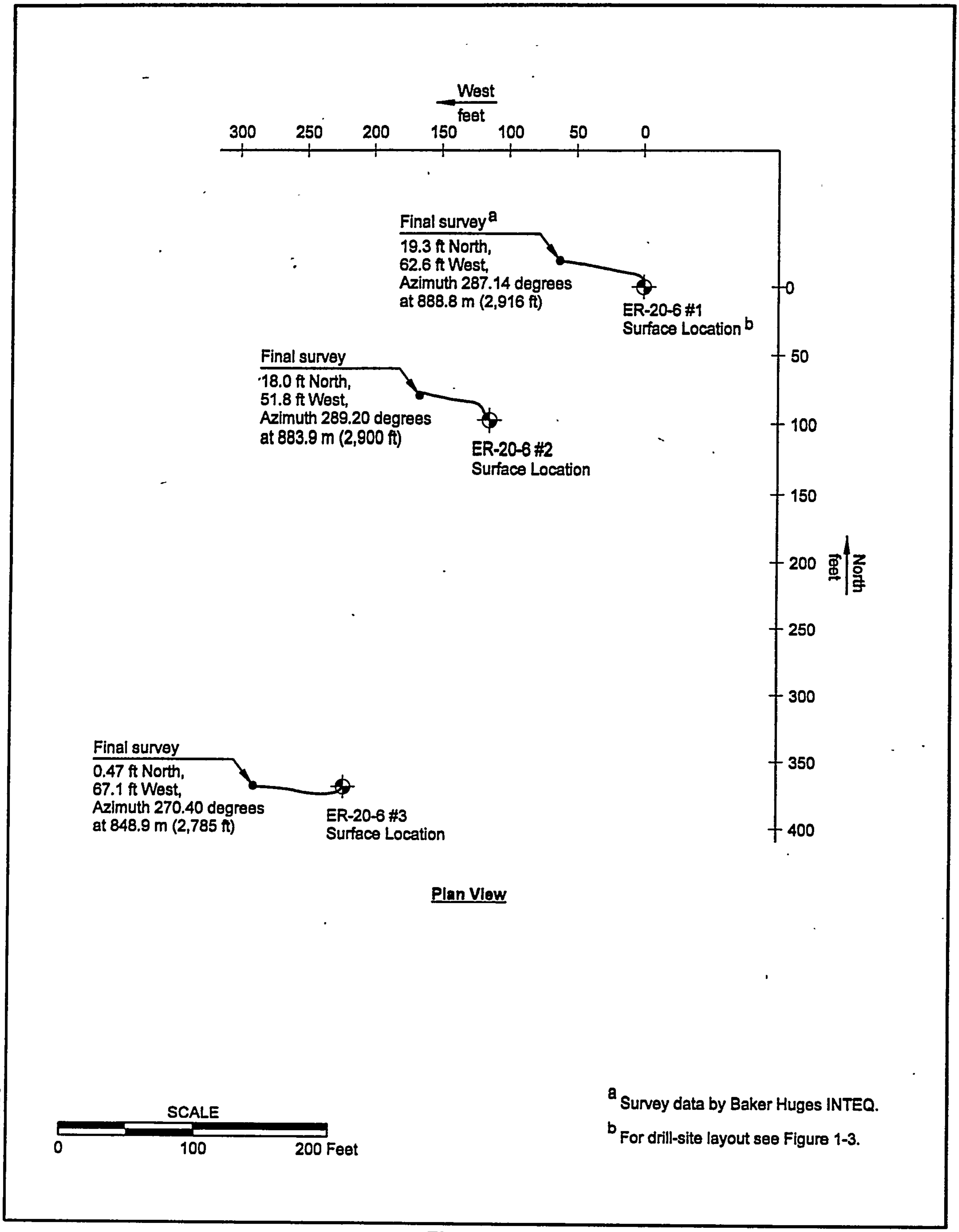


Figure 6-1
Map of Well Cluster ER-20-6 Holes Showing Collars and Measured Borehole Deviations

Geophysical logging was conducted in all three wells 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 IT, Las Vegas, Nevada.

The elevation of the static, open-hole water level in all three wells is approximately 1,355 m (4,447 ft), as predicted prior to drilling. Water production could not be measured during drilling of Well ER-20-6#1. Production reached a maximum of approximately 946 Lpm (250 gpm) in Well ER-20-6#2 and 844 Lpm (223 gpm) in Well ER-20-6#3, but these values probably do not reflect true water-production potential, as they were limited by the amount of air pressure available to lift water to the surface.

Tritium monitoring in Well ER-20-6#1 was greatly inhibited by lack of fluid returns for most of the drilling process. However, tritium (as well as Cesium-137) was encountered above the water table, possibly indicating that a hydrofracture from the BULLION cavity had been encountered. Tritium activity in Well ER-20-6#1 reached a maximum of 68 million pCi/L, but generally averaged less than 10 million pCi/L through most of the hole. Tritium activity in Well ER-20-6#2 reached a maximum of 74.5 million pCi/L in the upper lava-flow aquifer near the elevation of the BULLION WP, but dropped to less than 100,000 pCi/L for the most of the remainder of the hole. Tritium levels in Well ER-20-6#3 peaked at less than 400,000 pCi/L near the elevation of the BULLION WP in the upper lava-flow aquifer and dropped to background levels in the completion interval. Tritium and water-production data for Well Cluster ER-20-6 are presented in Figure 6-2. See Figure 2-2 for an illustration of the completions constructed in Well Cluster ER-20-6 relative to the BULLION explosion cavity and chimney.

The BN cost models for Well Cluster ER-20-6 projected that drilling and completion of three wells would require 60 days to accomplish. The actual time spent to construct the wells was 56 days. The planned cost for three wells was $3,186,429. The actual cost of the well-construction project was $3,131,093, 1.7 percent less than the planned cost. Table 6-1 provides a comparison of the actual and predicted costs.

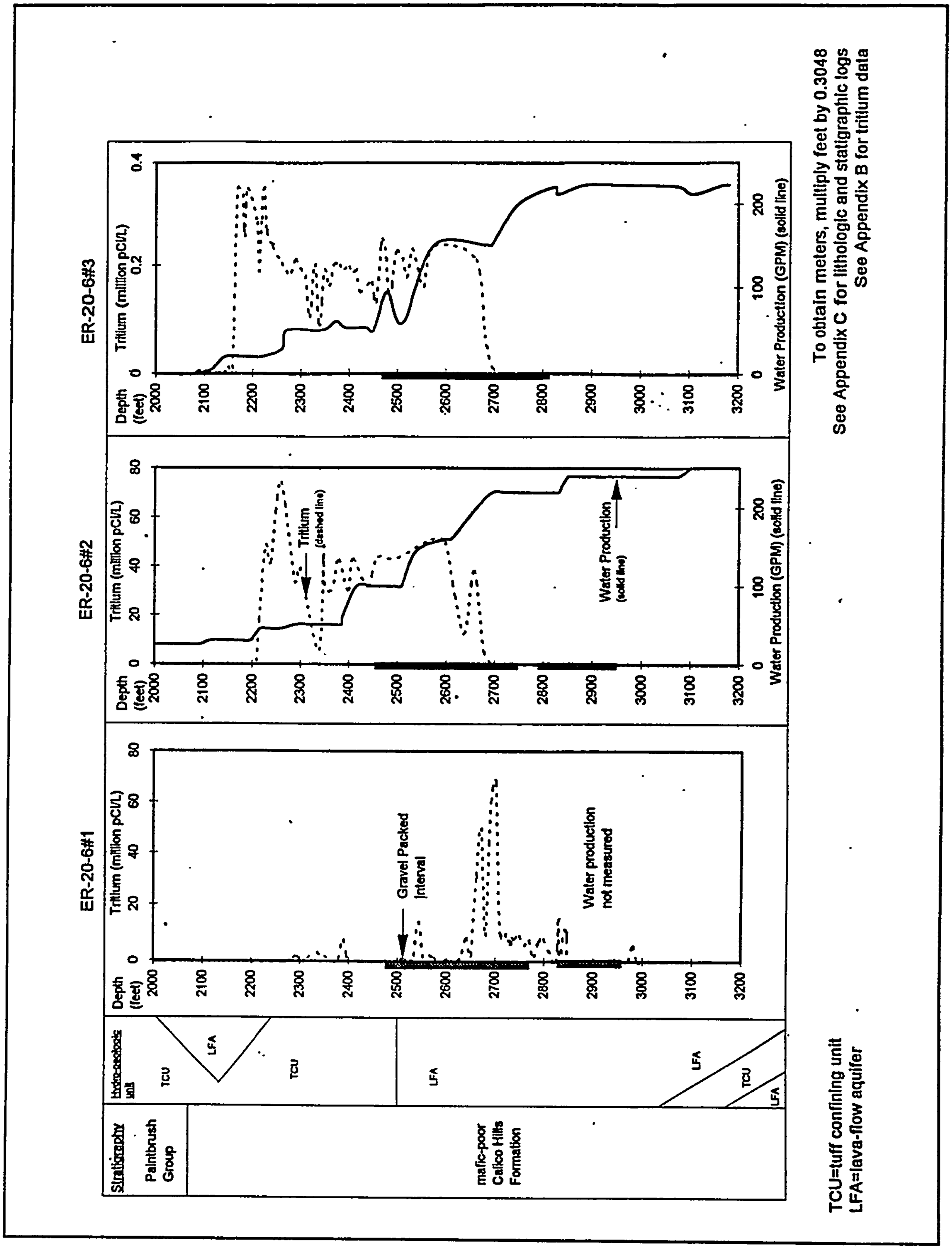


Figure 6-2
Tritium Activity and Water Production Versus Depth for Well Cluster ER-20-6

Table 6-1
Well Cluster ER-20-6 Actual Versus Planned Costs

Activity	Cluster Well ER-20-6	Planned Cost	Actual Cost	Percent Difference Actual versus Planned
Drilling contractor[a]	#1	$ 339,600	$ 546,088	60.8
	#2	$ 339,600	$ 271,130	-20.2
	#3	$ 339,600	$ 333,763	-1.7
Subtotal		*$1,018,800*	*$1,150,979.*	*13.0*
Support contractors[b]	#1	$ 722,543	$ 801,455	10.9
	#2	$ 722,543	$ 664,541	-8.0
	#3	$ 722,543	$ 514,118	-28.8
Subtotal		*$2,167,629*	*$1,980,114*	*-8.7*
Total		**$3,186,429**	**$3,131,093**	**-1.7**

[a]Source: DOE/ERD
[b]Source: BN Drilling Department

6.2 Recommendations for Additional Data Interpretation

Several of the primary requirements that had to be satisfied for the ER-20-6 well cluster to qualify as the host of a forced-gradient experiment have been met (through sampling and geologic interpretation of the site). Hydrologic testing is still required to determine the local hydraulic gradient and to assess monitoring well capability for the forced-gradient experiment.

The following paragraphs describe other work needed to further interpret the geologic, hydrologic, and geophysical data gathered during drilling and completion of Wells ER-20-6#1, #2, and #3 for use in designing and conducting the forced-gradient experiment and interpreting data from the experiment.

Identification of Other Radionuclides

Samples of drilling effluent and spectral gamma logs should be analyzed to determine what radionuclides (in addition to tritium) are present in the groundwater and/or formation at the BULLION site.

Matrix Permeability Studies

Tests on conventional cores and sidewall samples planned by scientists at Los Alamos and Lawrence Livermore National Laboratories should be pursued to provide data on how radionuclides might migrate through or be attenuated by the rock matrix. Radionuclide migration through fractures should also be studied.

Hydrogeologic Characterization of Well Cluster ER-20-6 Area

Additional evaluation of the hydrogeologic character of rhyolite lava flows (alteration and fracturing) would enhance the results of the proposed forced-gradient experiment and the understanding of the hydrogeology of Pahute Mesa.

In addition, geologic and hydrogeologic data from Well Cluster ER-20-6 should be analyzed to further identify and characterize the hydrologic setting of the site, to more precisely define groundwater parameters for the forced-gradient experiment.

6.3 Lessons Learned

Lessons learned during construction of each well are addressed in the appropriate section of this report. This section describes lessons learned during the Well Cluster ER-20-6 operation which may be unique to near-field drilling projects.

General

Significantly fewer problems were encountered during drilling and construction of Well Cluster ER-20-6 than during the Well Cluster ER-20-5 project, conducted directly prior. This apparently reflects improvements in techniques and procedures based on lessons learned during the Well Cluster ER-20-5 project.

Drilling

Problems with lost circulation were encountered while using conventional mud circulation to drill the 17½-in. surface hole to the depth of 243.8 m (800 ft) in Well ER-20-6#1. The lost circulation resulted in considerable lost time for mixing mud and attempting to restore circulation using lost circulation material. This problem was solved by using air/foam circulation for drilling the surface holes for Wells ER-20-6#2 and #3, where circulation could be maintained and penetration rates were much higher. Time required to drill and set surface casing was reduced from seven days on Well ER-20-6#1, to four days on Well ER-20-6#2, and three days on Well ER-20-6#3.

The high penetration rate (usually much greater than the preferred 6 m/hour [20 ft/hour] during most of the drilling process) below the water table impeded the collection and timely analysis of fluid samples for tritium contamination and degraded the quality of the drill cuttings used for geologic interpretation. A slower drilling rate below the water table (6 m/hour [20 ft/hour], based on experience at Well Cluster ER-20-5) would have permitted more satisfactory collection and timely analysis of fluid samples for tritium contamination and would have improved the quantity and quality of the drill cuttings used for geologic interpretation.

Completion

Fiberglass joints in both the 5½-in. casing and 2⅞-in. tubing did not fit flush, causing the strings to make up longer than planned. Proper factors to correct for this problem were required to permit placement of slotted and screened sections at the desired depth. However, the proper factors were determined only on the third hole in the cluster.

Efforts by the casing subcontractor to determine proper torque and tongs for handling fiberglass casing and tubing increased the speed of setting the completion strings.

The No-Turn Tools® with rubber pads (which would have been less abrasive on the fiberglass casing) did not set properly inside the casing and will be replaced with stainless-steel packers.

Correct drive-rod stretch factors must be determined and applied before installation of the pump rotor to avoid misplacement of the rotor. It was found that applying grease to the rotor before installation made installation easier.

Planning

Proper materials and supplies for cementing operations should be on hand before cementing begins.

Given the lead time necessary for some types of training (i.e., Hazardous-Site Worker and RadWorker II), training requirements should be planned in advance for all personnel who might be needed at the site.

The greater lead-time required for procurement orders over $25,000 must be considered when ordering well construction materials.

7.0 References

BHI, see Baker Hughes INTEQ.

Baker Hughes INTEQ. 1996. *Air Coring Completion Report for ERD-DOE ER-20-6#1 Nevada Test Site*. Bakersfield, CA.

Bechtel Nevada. 1996a. *Drilling and Completion Program for Underground Test Area Operable Unit (UGTA (OU) Cluster Well ER-20-6#1*, Drilling Program Number D-002-001.96. Las Vegas, NV.

Bechtel Nevada. 1996b. *Drilling and Completion Program for Underground Test Area Operable Unit (UGTA (OU) Cluster Well ER-20-6#2*, Drilling Program Number D-003-001.96. Las Vegas, NV.

Bechtel Nevada. 1996c (in preparation). ER-20-6#1 Hole History. Las Vegas, NV.

Bechtel Nevada. 1996d (in preparation). ER-20-6#2 Hole History. Las Vegas, NV.

Bechtel Nevada. 1996e (in preparation). ER-20-6#3 Hole History. Las Vegas, NV.

Blankennagel, R.K. and J.E. Weir, Jr. 1973. *Geohydrology of the Eastern Part of Pahute Mesa, Nevada Test Site, Nye County, Nevada*, U.S. Geological Survey Professional Paper 712-B.

BN, see Bechtel Nevada.

Brikowski, T.H., Desert Research Institute. 1992. *Estimates of Potential Radionuclide Migration at the Bullion Site*, Publication #45097. Las Vegas, NV.

Byers, Jr., F.M., W.J. Carr, P.P. Orkild, W.D. Quinlivan, and K.A. Sargent. 1976. *Volcanic Suites and related cauldrons of Timber Mountain-Oasis Valley caldera complex, southern Nevada*, U.S. Geological Survey Professional Paper 919.

DOE, see U.S. Department of Energy.

Ferguson, J.F., A.H. Cogbill, and R.G. Warren. 1994. "A Geophysical-Geological Transect of the Silent Canyon Caldera Complex, Pahute Mesa, Nevada." In *Journal of Geophysical Research*, v. 99, no. 33: 4323-4339.

IT, see IT Corporation.

IT Corporation. 1995. *Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6*, DOE/NV/10972-129. Las Vegas, NV.

IT Corporation. 1996a. Draft, *Completion Report for Well Cluster ER-20-5*. Las Vegas, NV.

IT Corporation. 1996b. *Drilling and Completion Criteria for Underground Test Area Operable Unit Well Cluster ER-20-6,* DOE/NV/10972--129/UC-700 (ADDENDUM).

Laczniak, R.J., J.C. Cole, D.A. Sawyer, and D.A. Trudeau. 1996. *Hydrogeologic Controls on Groundwater Flow at the Nevada Test Site, Nye County, Nevada*, U.S. Geological Survey Water-Resources Investigation Report 96-4109.

Price, E.H. GeoTrans. 1996. Personal communication.

Schwichtenburg, D.R. Bechtel Nevada. 1996. Personal communication.

U.S. Department of Energy. 1994. *Fluid Management Plan for the Underground Test Area Operable Unit*, DOE/NV--370/UC-600.

Winograd, I.J. and William Thordarson. 1975. *Hydrogeologic and Hydrochemical Framework, South-Central Great Basin, Nevada-California, with Special Reference to the Nevada Test Site*, U.S. Geological Survey Professional Paper 712-C.

Appendix A
Drilling Data

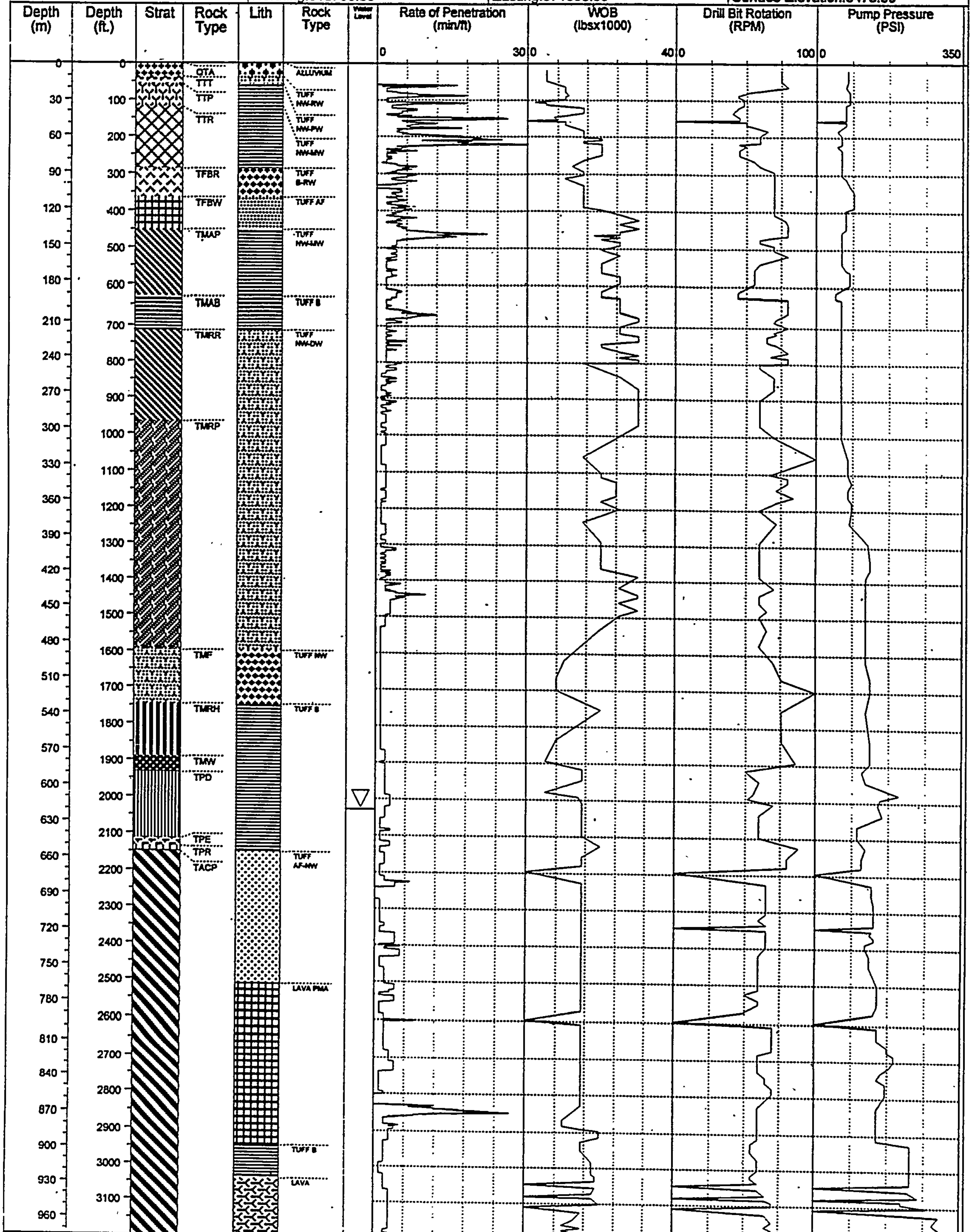
A.1
Records of Verbal Communication for Well Cluster ER-20-6

Table A.1-1
Records of Verbal Communication for Well Cluster ER-20-6 Drilling and Completion

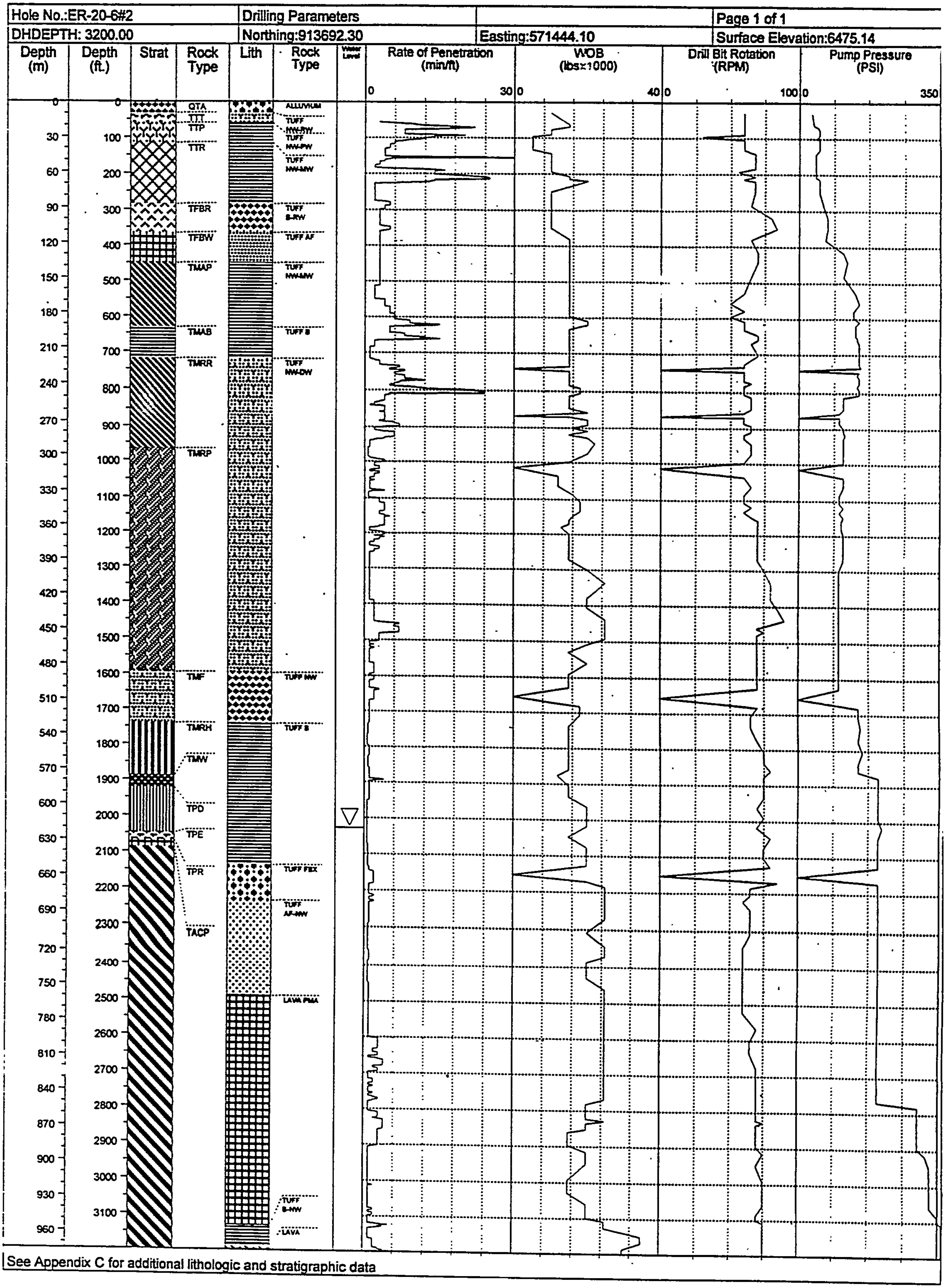
RVC#	Date	Subject
RVC:D:005:96	02/15/96	BN Construction overtime authorization
RVC:D:006:96	02/21/96	Completion tubulars and equipment for ER-20-6#1
RVC:D:008:96	03/19/96	Sandblasting mill varnish off new 2⅞-in. Hydril tubing
RVC:D:009:96	03/20/96	Casing and cementing program for ER-20-6#2 surface hole
RVC:D:010:96	03/26/96	Revisions to drilling program for UGTA Well ER-20-6#2
RVC:D:011:96	04/30/96	Discrete water samples and temp logs at UGTA ER-20-6#1 and #2

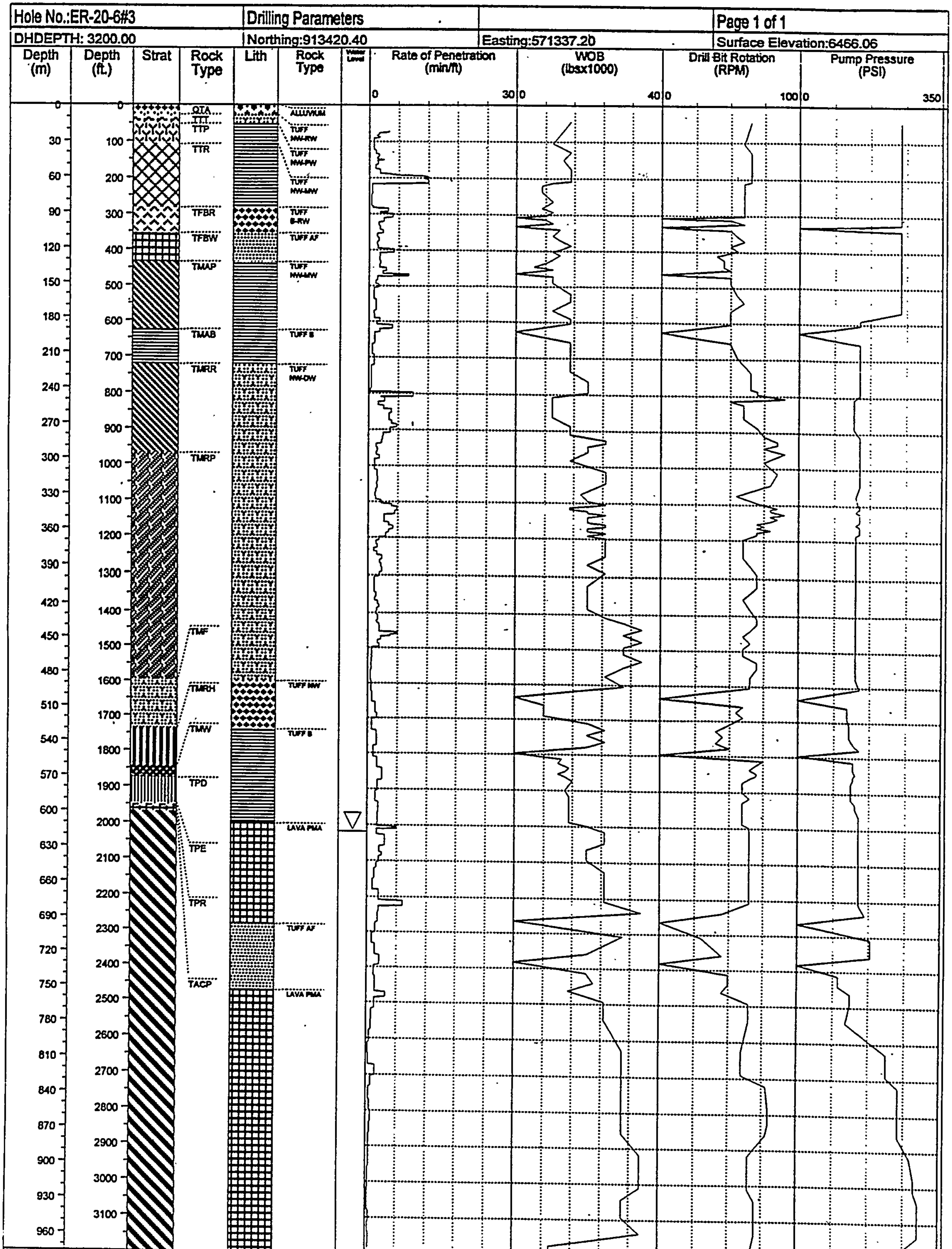
A.2
Drilling Parameter Logs
for Well Cluster ER-20-6

Hole No.:ER-20-6#1	Drilling Parameters		Page 1 of 1
DHDEPTH: 3200.00	Northing:913790.50	Easting:571558.50	Surface Elevation:6475.80



See Appendix C for additional lithologic and stratigraphic data


Hole No.:ER-20-6#2
Drilling Parameters
Page 1 of 1
DHDEPTH: 3200.00
Northing:913692.30
Easting:571444.10
Surface Elevation:6475.14
Depth (m)
Depth (ft.)
Strat
Rock Type
Lith
Rock Type
Water Level
Rate of Penetration (min/ft)
WOB (lbs×1000)
Drill Bit Rotation (RPM)
Pump Pressure (PSI)
QTA
TTT
TTP
TTR
TFBR
TFBW
TMAP
TMAB
TMRR
TMRP
TMF
TMRH
TMW
TPD
TPE
TPR
TACP
ALLUVIUM
TUFF NW-RW
TUFF NW-PW
TUFF NW-MW
TUFF S-RW
TUFF AF
TUFF NW-MW
TUFF S
TUFF NW-DW
TUFF NW
TUFF S
TUFF FBX
TUFF AF-NW
LAVA PMA
TUFF S-NW
LAVA
See Appendix C for additional lithologic and stratigraphic data



See Appendix C for additional lithologic and stratigraphic data

A.3

Casing and Tubing Data for Well Cluster ER-20-6

Table A.3-1
Casing and Tubing Data for Well ER-20-6#1

Casing and Tubing	Depth Interval meters (feet)	Type	Grade	Outside Diameter (inches)	Inside Diameter centimeters (inches)	Wall centimeters (inches)	Weight per foot (pound/foot)
Conductor Casing	0 to 11.6 (0 to 38.1)	Carbon Steel	K-55	30	74.30 (29.25)	0.95 (0.375)	98.93
Surface Casing	0 to 242.7 (0 to 796.2)	Carbon Steel	J-55	13⅜	32.04 (12.615)	0.97 (0.380)	54.5
5½-inch Casing	0 to 763.8 (0 to 2,506)	Fiberglass[a]	Smith Fiberglass Products	5½	12.07 (4.75)	0.95 (0.375)	5.91
5½-inch Casing	763.8 to 891.2 (2,506 to 2,924)	Stainless Steel	T304L	5½	10.16 (4.0)	1.91 (0.75)	14.6
Pump String	0 to 762.2 (0 to 2,500.7)	Stainless Steel	T304	2⅞	5.90 (2.323)	0.70 (0.276)	7.66
Drive Rod String[b] (pump rotor on end of string)	0 to m 760.5 (0 to 2,495.2 ft)	Solid carbon-steel rod	Grade D Coated with 3M Skotchkote® SC-135	⅞	Not applicable	Not applicable	2.2
Access String	0 to 893.1 (0 to 2,930)	Fiberglass[a]	Star Fiberglass Systems	2⅞	6.03 (2.375)	0.64 (0.25)	2.77

[a]The made up lengths of the fiberglass strings were greater than the sums of the individual joints because the connections did not make up flush. The depths of the strings were determined by means of an annulus investigation log. Corrections have been applied to the string depths shown here to match the measured depths of the strings. See Section 3.5.4.
[b]Drive rod and rotor removed from well on April 8, 1996

Table A.3-2
Casing and Tubing Data for Well ER-20-6#2

Casing and Tubing	Depth Interval meters (feet)	Type	Grade	Outside Diameter (inches)	Inside Diameter centimeters (inches)	Wall centimeters (inches)	Weight per foot (pound/foot)
Conductor Casing	0 to 17.4 (0 to 57.0)	Carbon Steel	J-55	20	48.26 (19.0)	1.27 (0.5)	94.0
Surface Casing	0 to 244.5 (0 to 802.1)	Carbon steel	K-55	13⅜	32.04 (12.615)	0.97 (0.38)	54.5
5½ Casing	0 to 755.3 (0 to 2,478)	Fiberglass[a]	Smith Fiberglass Systems	5½	12.07 (4.75)	0.95 (0.375)	5.91
5½ Casing	755.3 to 893.7 (2,478 to 2,932)	Stainless Steel	T304L	5½	10.16 (4.0)	1.91 (0.75)	14.6
Pump String	0 to 759.1 (0 to 2,490.6)	Stainless Steel	T304	2⅞	5.90 (2.323)	0.70 (0.276)	7.66
Drive Rod String[b] (pump rotor on end of string)	0 to 757.9 (0 to 2,486.4)	Solid carbon-steel rod	Grade D Coated with 3M Skotchkote ® SC-135	⅞	Not applicable	Not applicable	2.2
Access String	0 to 894.0 (0 to 2,933)	Fiberglass[a]	Smith Fiberglass Products	2⅞	6.03 (2.375)	0.64 (0.25)	2.77

[a]The made-up lengths of the fiberglass strings were greater than the sums of the individual joints because the connections did not make up flush. The depths of the strings were determined by means of an annulus investigation log. Corrections have been applied to the string depths shown here to match the measured depths of the strings. See Section 4.5.4.
[b]Drive rod and rotor removed from well on April 7, 1996

Table A.3-3
Casing and Tubing Data for Well ER-20-6#3

Casing and Tubing	Depth Interval meters (feet)	Type	Grade	Outside Diameter (inches)	Inside Diameter centimeters (inches)	Wall centimeters (inches)	Weight per foot (pound/foot)
Conductor Casing	0 to 19.5 (0 to 64.0)	Carbon Steel	J-55	20	48.26 (19.0)	1.27 (0.5)	94.0
Surface Casing	0 to 244.8 (0 to 803.2)	Carbon Steel	J-55	13⅜	32.04 (12.615)	0.97 (0.380)	54.5
5½-inch Casing	0 to 854.9 (0 to 2,804.7)	Stainless Steel	T304L	5½	10.16 (4.0)	1.91 (0.75)	14.6
Access String	0 to 850.3) (0 to 2,789.7)	Fiberglass[a]	Blank joints: Smith[b] Slotted joints: Star[c]	2⅞	6.03 (2,375)	0.64 (0.25)	2.77

[a]A correction for the non-flush fit of the fiberglass connections was made prior to installation of the string, and an annulus investigation log verified the depth of the string. No correction has been applied to these depths.
[b]Smith Fiberglass Products
[c]Star Fiberglass Systems

Note: No pump string installed as of July 12, 1996

A.4

Well Cluster ER-20-6 Drilling Fluids and Cement Composition

Table A.4-1
Well ER-20-6#1 Drilling Fluids

Mud/LCM[a] (Typical[b])	Air-Foam (Typical[c])	Air-Foam/Polymer (Typical[d])
1,928 kg[e] (4,250 lb[f]) Quik-Gel® [g] 0.015 m^3 [h] (4 gal[i]) EZ-Mud Plus® [g] Cedar Fiber Cottonseed Hulls	0.019 to 0.038 m^3 (5-10 gal) Quik-Foam® [g] per 7.9 m^3 (50 bbl[j]) water	0.038 m^3 (10 gal) Quik-Foam® and 0.0038 to 0.019 m^3 (1-5 gal) EZ-Mud Plus® per 7.9 m^3 (50 bbl) water

[a] Lost circulation material
[b] Various proportions of viscosifier (gel), polymer, and LCM were used in drilling from 11.6 to 243.8 m (38-800 ft).
[c] Air-foam, made up with various proportions of Quik-Foam®, was used as the drilling fluid from 243.8 m (800 ft) to TD.
[d] Various proportions of polymer were added to suit conditions during air-foam drilling.
[e] Kilograms
[f] Pounds
[g] Quik-Gel®, EZ-Mud Plus®, and Quik-Foam® are products of Baroid Drilling Fluids, Inc.
[h] Cubic meters
[i] Gallons
[j] Barrels

NOTES:
1. All water used to mix drilling fluids for Well ER-20-6#1 came from Water Well 20.
2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of 20 to 40 milligrams per liter.

Table A.4-2
Well ER-20-6#1 Cement Composition

Cement Composition	Conductor Casing	Surface Casing	Bottom Plug	Completion
Type II	Not used	Bottom seal from 243.8 m[a] (800 ft[b])	Not used	Not used
Type II plus 2% $CaCl_2$[c]	In annulus 0 to 11.6 m (38 ft)	Top seal, in annulus above cement basket	898.2 to 909.2 m (2,947 to 2,983 ft)	181.7 to 324.6 m (595 to 1,085 ft) 337.7 to 453.8 m (1,108 to 1,489 ft) 465.1 to 563.9 m (1,526 to 1,850 ft) 588.3 to 742.8 m (1,930 to 2,437 ft) 898.2 to 909.2 m (2,947 to 2,983 ft)
1 sack barite, 1 sack cedar fiber, and 0.038 m^3 [d] (10 gal[e]) cement	Not used	On cement basket at 16.7 m (54.7 ft)	Not used	Not used

[a] Meters
[b] Feet
[c] Calcium chloride
[d] Cubic meters
[e] Gallons

Table A.4-3
Well ER-20-6#2 Drilling Fluids

Air-Foam (Typical[a])	Air-Foam/Polymer (Typical[b])
0.019 to 0.026 m^3 [c] (5-7 gal[d]) Quik-Foam® [e] per 7.9 m^3 (50 bbl[f]) water	0.019 to 0.026 m^3 (5-7 gal) Quik-Foam® and 0.003 m^3 (1 gal) EZ-Mud Plus® [e] per 7.9 m^3 (50 bbl) water

[a]Air-foam, made with various proportions of Quik-Foam®, was used as the drilling fluid from 18.3 m (60 ft) to TD.
[b]Various proportions of polymer were added to suit conditions during air-foam drilling.
[c]Cubic meters
[d]Gallons
[e]Quik-Foam® and EZ-Mud Plus® are products of Baroid Drilling Fluids, Inc.
[f]Barrels

NOTES:
1. All water used to mix drilling fluids for Well ER-20-6#2 came from Water Well 20.
2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of 20 to 40 milligrams per liter.

Table A.4-4
Well ER-20-6#2 Cement Composition

Cement Composition	Conductor Casing	Surface Casing	Bottom Plug	Completion
Type II	Not used	Bottom seal from 246.0 m[a] (807 ft[b])	Not used	Not used
4 sand bags, 227 kg[c] (500 lb[d]) dirty ⅜-in. gravel, 136 kg (300 lb) 6-9 sand, 1 sack cedar fiber	Not used	On cement basket at 18.3 m (60 ft)	Not used	Not used
Type II plus 2% $CaCl_2$[e]	In annulus: 0 to 17.4 m (57 ft)	Bottom seal from 246.0 m (807 ft) Top seal in annulus above cement basket	897.6 to 903.1 m (2,945 to 2,963 ft)	164.3 to 735.8 m (539 to 2,414 ft)

[a]Meters
[b]Feet
[c]Kilograms
[d]Pounds
[e]Calcium chloride

Table A.4-5
Well ER-20-6#3 Drilling Fluids

Air-Foam (Typical[a])	Air-Foam/Polymer (Typical[b])
0.019 to 0.038 m^3[c] (5-10 gal[d]) Quik-Foam®[e] per 7.9 m^3 (50 bbl[f]) water	0.019 to 0.026 m^3 (5-7 gal) Quik-Foam® and 0.003 m^3 (1 gal) EZ-Mud Plus®[e] per 7.9 m^3 (50 bbl) water

[a]Air-foam, made with various proportions of Quik-Foam®, was used as the drilling fluid from 19.5 m (64 ft) to TD.
[b]Various proportions of polymer were added to suit conditions during air-foam drilling.
[c]Cubic meters
[d]Gallons
[e]Quik-Foam® and EZ-Mud Plus® are products of Baroid Drilling Fluids, Inc.
[f]Barrels

NOTES:
1. All water used to mix drilling fluids for Well ER-20-6#3 came from Water Well 20.
2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of 20 to 40 milligrams per liter.

Table A.4-6
Well ER-20-6#3 Cement Composition

Cement Composition	Conductor Casing	Surface Casing	Bottom Plug	Completion
Type II	Not used	Bottom seal from 246.0 m[a] (807 ft[b])	Not used	Not used
Type II plus 2% $CaCl_2$[c]	In annulus 0 to 19.5 m (64 ft)	Top seal, in annulus above cement basket	855.6 to 856.2 m (2,807 to 2,809 ft)	166.1 to 742.5 (545 to 2,436 ft)
2 bags cedar fiber and 91 kg[d] (200 lb[e]) dirty gravel	Not used	On cement basket at 18.3 m (60 ft)	Not used	Not used

[a]Meters
[b]Feet
[c]Calcium chloride
[d]Kilograms
[e]Pounds

B.1
Well Cluster ER-20-6 Fluid Management Status Reports

INTERNATIONAL TECHNOLOGY CORPORATION

April 22, 1996

Project No.: 764029.05.01.03.00

Mr. Robert Bangerter, Project Manager
Underground Test Area Project
DOE/Nevada Operations Office
P.O. Box 98518
Las Vegas, Nevada 89193-8518

Contract No. DE-AC08-92NV10972
ER-20-6 Fluid Management Status Report: Saturated Zone Drilling Completion at Well 3

Dear Mr. Bangerter:

The enclosed information is submitted for your review under the reporting requirements outlined in the Fluid Management Plan (Appendix B) of the *Waste Management Plan for the Underground Test Area Operable Unit*. This submittal for well 3 consists of data collected through saturated zone drilling. Preliminary fluid analytical results indicate that fluid management options implemented for this site are in compliance with the requirements of Appendix B. Final analytical laboratory data documenting fluid quality will be forwarded to your office upon receipt.

The submittal dated March 15, 1996, had a Fluid Disposition Status Reporting Form attached that did not represent data detailed in the letter. Correct data for vadose zone drilling at Cluster Well ER-20-6 for well 1 can be found on the submittal dated April 4, 1996. Please disregard the data on the form for the March 15 submittal.

The enclosed Fluid Disposition Status Reporting Forms summarize fluid production totals and disposition. Only sump #7 was used for holding fluids from this stage, as is detailed on the form. All data supporting this fluid status report are available for your review upon request. If you have any questions or comments, please contact Frank Baird or myself at 794-1700.

Sincerely,

IT CORPORATION

Mark W. Hampton
Project Manager

LV/4-22-96/042296.LET

ER FLUID DISPOSITION STATUS REPORTING FORM

Site Identification: ER20-6#3
Site Location: NTS, Area 20
Site Coordinates: Approx. N913323, E571503
Well Classification: Near Field
IT Project No: 764029.05.02.01.00

Report Date: 04/22/96
DOE/NV Project Manager: B. Bangerter
IT Project Manager: M. Hampton
IT Site Representative: Frank Baird
IT Waste Coordinator: Terre Maize

Well Construction Activity	Activity Duration		#Ops. Days (A)	Well Depth (m)	Sump #7 (m³)		Sump #8 (m³)		
	From	To			Solids (B)	Liquids	Solids	Liquids	
Stage I: Vadose-Zone Drilling	04/04/96	04/09/96	6	628	NA	NA	94	345	
Stage II: Saturated-Zone Drilling	04/09/96	04/11/96	2	975	34	1269	NA	NA	
Stage III: Initial Well Development									
Stage IV: Final Development									
Stage V: Aquifer Testing									
Cumulative Production Totals to Date:			8	975	34	1269	94	345	

(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 volume estimates include calculated added volume attributed to rock bulking factors.
(C) "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.
(D) Optional fluid management devices not installed for this well site.
NA = Not Applicable; m = meters; m^3 = cubic meters; AIP = Analysis In Process

Total Device Capacities: Lined Sump # 7 =2017 m^3 Lined Sump #8 = 2017 m^3

Remaining Device Capacity (Approximate) as of 4/11/96 : Sump #7 = 714 m^3 Sump #8 = 1578 m^3

IT Authorizing Signature/Date: [signature] 4/22/96

INTERNATIONAL TECHNOLOGY CORPORATION

April 4, 1996

Project No.: 764029.05.01.03.00

Mr. Robert Bangerter, Project Manager
Underground Test Area Project
DOE/Nevada Operations Office
P.O. Box 98518
Las Vegas, Nevada 89193-8518

Contract No. DE-AC08-92NV10972
ER-20-6 Fluid Management Status Report: Initial Development Completion at Well 1 and Drilling Completion at Well 2

Dear Mr. Bangerter:

The enclosed information is submitted for your review under the reporting requirements outlined in the Fluid Management Plan (Appendix B) of the *Waste Management Plan for the Underground Test Area Operable Unit*. In addition to previously submitted data for drilling activities, new data are included for initial development at Cluster Well ER-20-6 for well 1. This initial submittal of data for well 2 covers both vadose zone and saturated zone drilling. Preliminary fluid analytical results indicate that fluid management options implemented for this site are in compliance with the requirements of Appendix B. Additionally, field tritium data indicate that fluids are within the fluid quality objectives established for radiochemical parameters. Final analytical laboratory data documenting fluid quality will be forwarded to your office upon receipt.

The enclosed Fluid Disposition Status Reporting Forms summarize fluid production totals and disposition for the respective wells. All data supporting this fluid status report are available for your review upon request. If you have any questions or comments, please contact Frank Baird or me at 794-1700.

Sincerely,

IT CORPORATION

Mark W. Hampton
Project Manager

LV/4-4-96/040496.LET

Regional Office
4330 South Valley View, Suite 114 • Las Vegas, Nevada 89103-4047 • 702-794-1700

ER FLUID DISPOSITION STATUS REPORTING FORM

Site Identification: ER-20-6#1
Site Location: NTS, Area 20
Site Coordinates: Approximately N913790, E571559
Well Classification: Near Field
IT Project No: 764029.05.02.01.00

Report Date: 03/29/96
DOE/NV Project Manager: S. Lawrence
IT Project Manager: M. Hampton
IT Site Representative: Eugene Mullenmeister
IT Waste Coordinator: Terre Maize

Well Construction Activity	Activity Duration		#Ops. Days (A)	Well Depth (m)	Sump #1 (m^3) (lined)		Sump #2 (m^3) (lined)		Sump #3 (m^3) (lined)		Sump #4 (m^3) (lined)		Sump #5 (m^3) (lined)	
	From	To			Solids*	Liquid	Solids*	Liquid	Solids	Liquid	Solids	Liquid	Solids	Liquid
Stage I: Vadose-Zone Drilling	02/19/96	02/28/96	9	816.5	92.2	196	1.0	36	NA	NA	NA	NA	NA	NA
Stage II: Saturated-Zone Drilling	02/28/96	03/06/96	8	975.4	NA	NA	5.3	202	NA	NA	NA	NA	NA	NA
Stage III: Initial Well Development	03/15/96	03/16/96	2	NA	NA	NA	NA	59	NA	NA	NA	NA	NA	NA
Stage IV: Final Development														
Stage V: Aquifer Testing														
Cumulative Production Totals to Date: 3/16/96			19	975.4	92.2	196	6.3	297	NA	NA	NA	NA	NA	

REVISED REPORT BASED ON CORRECTED SUMP DIMENSIONS

(A) Operational days refer to the number of days that the drill rig was in operation during at least part of one shift.
.NA = Not Applicable; m = meters; m^3 = cubic meters; AIP = Analysis in Process

*Volumes are bulk volumes calculated by increasing in-situ rock volumes by 50%.
**Fluid volumes include production water from drilling and snow melt water.

Tritium Curie Inventory: Sump #1 (lined) = 0.005 Sump #2 (lined) = 2.17

Total Device Capacities (m^3): Sump #1 = 2,020.9 Sump #2 = 2,020.9 Sump #3 = 2,020.9 Sump #4 = 1695 Sump #5 = 1695

Remaining Device Capacity (m^3)(Approximate) as of 03/16/96: Sump #1 = 1764 Sump #2 = 1719

Note:
1) Fluid returns to the surface were intermittent from 582 m to 823 m of depth and nonexistant below 853 m of depth.

IT Authorizing Signature/Date: [signature]

ER FLUID DISPOSITION STATUS REPORTING FORM

Site Identification: ER-20-6#2
Site Location: NTS, Area 20
Site Coordinates: Approx N913644, E571505
Well Classification: Near Field
IT Project No: 764029.05.02.01.00

Report Date: 03/29/96
DOE/NV Project Manager: S. Lawrence
IT Project Manager: M. Hampton
IT Site Representative: Eugene Mullenmeister
IT Waste Coordinator: Terre Maize

Well Construction Activity	Activity Duration		#Ops.Days (A)	Well Depth (m)	Sump #1 (m^3) (lined)		Sump #2 (m^3) (double lined)		Sump #3 (m^3) (lined)		Sump #4 and #5(m^3) (lined)		Infiltration Area (m^3)
	From	To			Solids*	Liquid	Solids*	Liquid	Solids	Liquid	Liquid	Liquid	Liquids
Stage I: Vadose-Zone Drilling	03/18/96	03/24/96	6	618	121.8	242	6.17	159	NA	NA	NA	NA	NA
Stage II: Saturated-Zone Drilling	03/24/96	03/25/96	2	975.4	NA	NA	40.65	1043	NA	NA	NA	NA	NA
Stage III: Initial Well Development													
Stage IV: Final Development													
Stage V: Aquifer Testing													
Cumulative Production Totals to Date: 3/27/96			8	975.4	121.8	242	46.83	1202	NA	NA	NA	NA	NA

(A) Operational days refer to the number of days that the drill rig was in operation during at least part of one shift.

* Bulk volumes are calculaed by increasing in-situ rock volumes by 50%.

NA = Not Applicable; m = meters; m^3 = cubic meters; AIP = Analysis In Process

Tritium Curie Inventory: Sump#1 (lined) = 0.005 Ci, Sump#2 (double-lined) = 2.55 Ci.

Total Device Capacities (m^3): Sumps #1, #2, #3 = 2020.9 m^3 each. Sumps #4 and #5 = 1695 m^3 each.

Remaining Device Capacity (m^3) (Approximate) as of 03/27/96: Sump#1 = 1,440 m^3, Sump#2 = 487 m^3, Sump#3 = 1,996.2 m^3, Sump#4 = 1,668 m^3, Sump#5 = 1,668 m^3.

IT Authorizing Signature/Date: [signature]

UGTA Analytical Fluid Sample Results, ER-20-6

				Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver	Fluoride	Nitrate/Nitrite	Alpha (total)	Beta (total)	Antimony 125	Cesium 137	Ruthenium-106	Tritium
SITE	SAMPLE NO	DATE	TIME	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	UG/L	MG/L	UG/L	PCI/L	PCI/L	PCI/L	PCI/L	PCI/L	PCI/L
ER-20-6#1	GCP00366	3/1/96	1500	204	1900	0.7	336	1370	0.64	4.5	0.8	2.49	464	143	143	0	0	0	0
ER-20-6#1	GCP00368	3/1/96	1500	208	1650	0.7	452	1110	0.67	4.5	0.8	4.41	389	124	143	0	0	0	0
ER-20-6#1	GCP00372	2/27/96	900	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2190
ER-20-6#1	GCP00373	2/27/96	1200	4.6	4.8	0.7	3.1	1.7	0.1	4.5	0.8	0.1	50	2.13	0.88	0	0	0	0
ER-20-6#1	GCP00374	2/28/96	1430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	64000
ER-20-6#1	GCP00375	2/29/96	1330	86.6	663.8	2	378.7	309.2	7.97	9	1.6	2.83	758	38.2	40.9	0	0	0	0
ER-20-6#1	GCP00376	2/29/96	1630	6.2	15.9	0.7	3.1	2.5	0.1	4.8	0.8	3.2	410	5.6	5.04	0	0	0	0
ER-20-6#1	GCP00377	3/5/96	945	4.6	2.9	0.7	3.1	1.7	0.1	4.5	0.8	0.1	50	0.24	-0.38	0	0	0	0
ER-20-6#1	GCP00378	3/6/96	1600	36.8	48	1.4	15.3	22.8	0.38	9	1.6	3.99	881	13.2	454	1130	425	3780	7250000
ER-20-6#1	GCP00382	3/15/96	1613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	771
ER-20-6#1	GCP00383	3/15/96	1013	0	0	0	0	3.8	0	0	0	0	0	0	0	0	0	0	0
ER-20-6#2	GCP00384	3/19/96	945	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
ER-20-6#2	GCP00385	3/19/96	915	4.6	3.8	0.7	3.1	1.7	0.42	7.7	0.8	0.1	92.6	-0.07	2.92	0	0	0	0
ER-20-6#2	GCP00386	3/26/96	1500	240	3090	0.7	94	1140	0.16	5.1	0.8	3.27	417	15	22.4	0	0	0	0
ER-20-6#2	GCP00387	3/26/96	1500	110	866	8.7	393	840	0.19	4.5	0.8	3.15	350	238	360	0	0	0	0
ER-20-6#2	GCP00388	3/26/96	1500	98.3	669	2.7	318	716	0.18	4.5	0.8	2.92	327	321	443	0	0	0	0
ER-20-6#2	GCP00389	3/24/96	1630	61.8	580.8	1.4	534	360.7	1.74	11.4	1.6	3.41	349	118	197	0	0	0	0
ER-20-6#2	GCP00390	3/25/96	1200	9.2	91	1.4	434	3.4	0.2	11.7	1.6	1.68	503	-15.5	29.5	0	0	0	0
ER-20-6#2	GCP00391	3/25/96	730	7.6	304	0.7	3.1	12.3	0.1	10.1	0.8	2.78	359	30.4	12.9	0	0	0	0
ER-20-6#2	GCP00392	3/25/96	730	5.8	253	0.7	3.1	11.5	0.1	9.4	0.8	2.8	395	35.9	6.7	0	0	0	0
ER-20-6#2	GCP00393	3/25/96	830	4.6	3	0.7	3.1	1.7	0.1	4.5	0.8	0.1	50	0.17	-1.28	0	0	0	0
ER-20-6#2	GCP00394	3/25/96	1130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3150
ER-20-6#2	GCP00395	3/25/96	730	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
ER-20-6#3	GCP00396	4/12/96	1500	138	4980	0.6	162	224	0.17	5	1.6	3.84	408	14.5	22.1	0	0	0	0
ER-20-6#3	GCP00397	4/12/96	1500	135	1390	0.6	563	322	0.28	3.3	1.6	4.07	448	179.8	161.4	0	0	0	0
ER-20-6#3	GCP00398	4/12/96	1500	136	1280	0.6	519	317	0.32	1.5	1.6	3.93	443	60.6	61.3	0	0	0	0
ER-20-6#3	GCP00399	4/7/96	915	2	3	0.6	2.3	0.73	0.1	1.5	1.6	0.1	50	-0.05	-0.28	0	0	0	0
ER-20-6#3	GCP00417	4/10/96	325	21.2	143.3	1.2	118	77.4	0.36	19.8	3.2	3.06	243	216	28	0	0	0	0
ER-20-6#3	GCP00418	4/10/96	1130	52.1	279	8.6	254	195	1.3	6.4	5.9	3.15	972	11	132	0	0	0	0
ER-20-6#3	GCP00419	4/10/96	1130	55.4	304	8.2	276	208	1.3	5.2	5.9	3.3	1680	11.1	123	0	0	0	0
ER-20-6#3	GCP00420	4/10/96	1130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	88200
ER-20-6#3	GCP00421	4/15/96	100	15.9	37.8	1.2	11.2	31.4	0.22	5.6	3.2	2.42	792	6.72	2.42	0	0	0	0

B.2

Well Cluster ER-20-6 Tritium and Water Production Data

Depth	Depth	Tritium		Depth	Depth	Tritium	
(feet)	(meters)	(pCi/L)		(feet)	(meters	(pCi/L)	
2000	609.6	3140.24		2662	811.4	30323000	
2010	612.6	7621.95		2672	814.4	50075000	
2020	615.7	30.49		2682	817.5	8862727.3	
2051	625.1	1676.83		2692	820.5	60582000	
2075	632.5	1768.29		2702	823.6	68727000	
2090	637.0	11066		2712	826.6	9218242.42	
2100	640.1	6768.29		2740	835.2	7608090.9	
2110	643.1	985.96		2722	829.7	9766181.8	
2120	646.2	6214.57		2732	832.7	6225545.5	
2130	649.2	11174.28		2740	835.2	7608090.9	
2140	652.3	1643.27		2750	838.2	9039575.6	
2150	655.3	3943.86		2760	841.2	5646759.7	
2160	658.4	4481.66		2770	844.3	7571774.4	
2170	661.4	239.02		2780	847.3	1921422.1	
2180	664.5	2210.95		2790	850.4	6828563	
2190	667.5	2599.36		2800	853.4	8133381.7	
2200	670.6	2748.75		2826	861.4	164239.9	
2265	690.4	61718.8		2831	862.9	15218154	
2275	693.4	11687.5		2834	863.8	13899.397	
2285	696.5	1042750		2842	866.2	11176030	
2295	699.5	2045062.5		2845	867.2	11264428	
2305	702.6	11062.5		2848	868.1	10378714	
2315	705.6	1087218.8		2850	868.7	10504	
2335	711.7	3027222		2862	872.3	615440.7	
2350	716.3	2006827.6		2932	893.7	864832.8	
2370	722.4	202783.87		2942	896.7	887872.3	
2380	725.4	723175.13		2952	899.8	682887.5	
2390	728.5	7606899.9		2962	902.8	352735.5	
2400	731.5	70942.86		2972	905.9	397325.2	
2403	732.4	279118.89		2982	908.9	5777203	
2465	751.3	24760.33		2992	912.0	30942.2	
2475	754.4	505276.07		3002	915.0	71276.6	
2495	760.5	68163.3		3012	918.1	128449.8	
2505	763.5	885247.46		3022	921.1	17798	
2515	766.6	1224952.4		3032	924.2	31762.91	
2525	769.6	151006.3					
2535	772.7	2139895.9					
2545	775.7	13997968					
2555	778.8	187111.1					
2565	781.8	2225312.6					
2575	784.9	1727174.6					
2585	787.9	8285.7					
2595	791.0	251777.8					
2600	792.5	880007.6					
2610	795.5	103281.25					
2622	799.2	131121.21					
2632	802.2	2849787.9					
2642	805.3	8412939.4					
2652	808.3	2215669.7					

pCi/L = picocuries per liter
#N/A = no measurement taken

Table derived from IT field data
Total depth = 975.4 meters (3,200 feet)

Depth (feet)	Depth (meters)	Tritium (pCi/L)	Water (GPM)	Depth (feet)	Depth (meters	Tritium (pCi/L)	Water (GPM)	Depth (feet)	Depth (meter	Tritium (pCi/L)	Water (GPM)
1983	604.4	44473	#NA	2460	749.8	43731129	#NA	2974	906.5	#NA	240
1995	608.1	87781	#NA	2477	755.0	#NA	100	2980	908.3	6923	#NA
2004	610.8	#NA	25	2498	761.4	#NA	100	2990	911.4	3272	#NA
2013	613.6	49201	#NA	2500	762.0	43415969	#NA	3000	914.4	3045	#NA
2022	616.3	66489	#NA	2508	764.4	#NA	100	3010	917.4	1859	#NA
2033	619.7	#NA	25	2539	773.9	#NA	145	3012	918.1	#NA	240
2045	623.3	29744	#NA	2570	783.3	51023537	#NA	3020	920.5	1167	#NA
2061	628.2	#NA	25	2600	792.5	#NA	160	3030	923.5	20568	#NA
2072	631.5	134250	#NA	2600	792.5	50149151	#NA	3040	926.6	2208	#NA
2082	634.6	11629	#NA	2610	795.5	#NA	160	3044	927.8	#NA	240
2092	637.6	#NA	25	2620	798.6	27965892	#NA	3050	929.6	4858	#NA
2105	641.6	109625	#NA	2640	804.7	12596686	#NA	3060	932.7	5899	#NA
2115	644.7	#NA	30	2660	810.8	38690864	#NA	3070	935.7	22083	#NA
2135	650.7	301156	#NA	2662	811.4	#NA	200	3076	937.6	#NA	240
2142	652.9	#NA	30	2680	816.9	5299065	#NA	3080	938.8	7319	#NA
2150	655.3	435065	#NA	2695	821.4	#NA	220	3099	944.6	#NA	250
2160	658.4	138871	#NA	2700	823.0	68633	#NA	3100	944.9	#NA	250
2165	659.9	#NA	30	2720	829.1	40073	#NA	3100	944.9	1878	#NA
2170	661.4	185871	#NA	2727	831.2	#NA	220	3110	947.9	2801	#NA
2177	663.5	#NA	30	2740	835.2	51523	#NA	3118	950.4	#NA	250
2180	664.5	158031	#NA	2759	840.9	#NA	220	3120	951.0	3819	#NA
2190	667.5	164875	#NA	2760	841.2	25937	#NA	3130	954.0	1719	#NA
2197	669.6	#NA	30	2778	846.7	#NA	220	3137	956.2	#NA	250
2200	670.6	291969	#NA	2780	847.3	28720	#NA	3140	957.1	2610	#NA
2210	673.6	1148875	#NA	2789	850.1	#NA	220	3150	960.1	5283	#NA
2217	675.7	#NA	45	2790	850.4	26001	#NA	3160	963.2	29373	#NA
2220	676.7	29690613	#NA	2810	856.5	236699	#NA	3164	964.4	#NA	250
2230	679.7	49118781	#NA	2821	859.8	#NA	220	3170	966.2	4869	#NA
2231	680.0	#NA	45	2825	861.1	#NA	220	3177	968.3	#NA	250
2240	682.8	41975969	#NA	2832	863.2	#NA	220	3180	969.3	48277	#NA
2260	688.8	#NA	45	2832	863.2	126667	#NA	3190	972.3	4805	#NA
2260	688.8	74570031	#NA	2840	865.6	#NA	230	3198	974.8	#NA	250
2290	698.0	34170161	#NA	2846	867.5	7115	#NA	3200	975.4	4965	#NA
2291	698.3	#NA	50	2851	869.0	#NA	240				
2300	701.0	39693469	#NA	2854	869.9	7949	#NA				
2323	708.1	#NA	50	2855	870.2	#NA	240				
2340	713.2	5827031	#NA	2864	872.9	3622	#NA				
2350	716.3	48018871	#NA	2866	873.6	#NA	240				
2354	717.5	#NA	50	2875	876.3	4167	#NA				
2360	719.3	30097219	#NA	2887	880.0	#NA	240				
2370	722.4	33194355	#NA	2888	880.3	1839	#NA				
2380	725.4	42975323	#NA	2898	883.3	4263	#NA				
2385	726.9	#NA	50	2907	886.1	#NA	240				
2387	727.6	#NA	60	2923	890.9	#NA	240				
2400	731.5	30600906	#NA	2923	890.9	3333	#NA				
2410	734.6	43417903	#NA	2933	894.0	150000	#NA				
2416	736.4	#NA	100	2950	899.2	7660	#NA				
2440	743.7	31972219	#NA	2960	902.2	3045	#NA				
2447	745.8	#NA	100	2970	905.3	3878	#NA				

pCi/L = picocuries per liter
#N/A = no measurement taken

Table derived from IT field data
Total depth = 975.4 meters (3,200 feet)
GPM = gallons per minute

Depth (feet)	Depth (meters)	Tritium (pCi/L)	Water (GPM)	Depth (feet)	Depth (meters)	Tritium (pCi/L)	Water (GPM)	Depth (feet)	Depth (meters)	Tritium (pCi/L)	Water (GPM)
2020	615.7	0	#NA	2424	738.8	152933	#NA	3160	963.2	167	#NA
2030	618.7	833	#NA	2434	741.9	#NA	56	3169	965.8	#NA	223
2075	632.5	#NA	0	2447	745.8	169033	#NA	3180	969.3	900	#NA
2080	634.0	976	#NA	2449	746.5	#NA	51	3181	969.5	#NA	223
2088	636.4	7908	#NA	2456	748.6	133633	#NA	3200	975.4	733	#NA
2100	640.1	4880	#NA	2469	752.6	250533	#NA				
2110	643.1	6932	#NA	2477	755.0	#NA	94				
2113	644.0	#NA	4	2477	755.0	213500	#NA				
2120	646.2	1514	#NA	2485	757.4	139206	#NA				
2130	649.2	4139	#NA	2498	761.4	227467	#NA				
2140	652.3	875	#NA	2511	765.4	#NA	62				
2143	653.2	#NA	19	2511	765.4	213867	#NA				
2150	655.3	13023	#NA	2521	768.4	178267	#NA				
2160	658.4	8480	#NA	2531	771.4	232933	#NA				
2170	661.4	353008	#NA	2543	775.1	192800	#NA				
2179	664.2	#NA	19	2555	778.8	160000	#NA				
2180	664.5	339447	#NA	2576	785.2	#NA	150				
2185	666.0	256834	#NA	2576	785.2	238167	#NA				
2190	667.5	351494	#NA	2663	811.7	213200	#NA				
2199	670.3	#NA	19	2681	817.1	#NA	150				
2210	673.6	285805	#NA	2685	818.4	53133	#NA				
2215	675.1	188451	#NA	2687	819.0	#NA	150				
2218	676.0	#NA	19	2694	821.3	#NA	150				
2219	676.4	290718	#NA	2705	824.5	2366	#NA				
2225	678.2	353984	#NA	2725	830.6	1100	#NA				
2230	679.7	271333	#NA	2735	833.6	633	#NA				
2240	682.8	244167	#NA	2748	837.6	#NA	200				
2260	688.8	205967	#NA	2775	845.8	767	#NA				
2261	689.2	#NA	29	2790	850.4	133	#NA				
2270	691.9	190767	#NA	2808	855.9	1967	#NA				
2271	692.2	#NA	53	2824	860.8	#NA	221				
2280	694.9	186767	#NA	2831	862.8	#NA	212				
2290	698.0	214000	#NA	2842	866.2	233	#NA				
2300	701.0	196200	#NA	2860	871.7	500	#NA				
2310	704.1	182667	#NA	2885	879.4	#NA	223				
2320	707.1	112200	#NA	2920	890.0	700	#NA				
2330	710.2	204733	#NA	2940	896.1	833	#NA				
2340	713.2	94833	#NA	2950	899.2	#NA	223				
2344	714.5	#NA	53	2960	902.2	667	#NA				
2350	716.3	193167	#NA	3008	916.9	#NA	223				
2360	719.3	164033	#NA	3013	918.4	#NA	223				
2370	722.4	205333	#NA	3040	926.6	533	#NA				
2373	723.3	#NA	65	3077	937.9	#NA	221				
2380	725.4	203067	#NA	3090	941.8	667	#NA				
2390	728.5	194833	#NA	3100	944.9	1000	#NA				
2392	729.1	#NA	56	3108	947.3	#NA	212				
2400	731.5	198933	#NA	3110	947.9	433	#NA				
2410	734.6	188167	#NA	3120	951.0	200	#NA				
2415	736.1	194633	#NA	3140	957.1	667	#NA				

pCi/L = picocuries per liter
#N/A = no measurement taken

Table derived from IT field data
Total depth = 975.4 meters (3,200 feet)
GPM = gallons per minute

Appendix C

Stratigraphic and Lithologic Logs of Well Cluster ER-20-6

C.1

Stratigraphic and Lithologic Logs of Well ER-20-6#1

Stratigraphic Log of Well ER-20-6 #1

Compiled by Sigmund L. Drellack, Jr., Bechtel Nevada, May 1996; updated to incorporate core data, January 1998.

Depth Meters	Depth Feet	Lithology	Stratigraphic Unit[1]	Stratigraphic Symbol[1]	Hydrogeologic Unit[2]	Thickness Meters	Thickness Feet
0 - 11.0	0 - 36	**Pebbly, Silty Sand:** Tuffaceous; calcareous.	Alluvium	QTa	AA	11.0	36
11.0 - 17.1	36 - 56	**Nonwelded Tuff with Underlying Reworked Tuff:** Vitric, peralkaline.	Trail Ridge Tuff, Thirsty Canyon Group	Ttt	VTA	6.1	20
17.1 - 36.3	56 - 119	**Ash-Flow Tuff with Underlying Bedded Tuff:** Nonwelded to partially welded; vitric to devitrified, peralkaline.	Pahute Mesa Tuff, Thirsty Canyon Group	Ttp	VTA	19.2	63
36.3 - 87.8	119 - 288	**Ash-Flow Tuff:** Nonwelded to moderately welded; vitric to devitrified; peralkaline.	Rocket Wash Tuff, Thirsty Canyon Group	Ttr	WTA	51.5	169
87.8 - 110.9	288 - 364	**Bedded Tuff:** Reworked tuffaceous sandstone to shard-rich air-fall; vitric.	rhyolite of Chukar Canyon, Beatty Wash Formation, Volcanics of Fortymile Canyon	Tfbr	VTA	23.2	76
110.9 - 137.8	364 - 452	**Air-Fall Tuff:** Pumice-rich; vitric.	rhyolite of Beatty Wash, Beatty Wash Formation, Volcanics of Fortymile Canyon	Tfbw	VTA	26.8	88

Stratigraphic Log of Well ER-20-6 #1 (continued).

Depth		Lithology	Stratigraphic Unit[1]	Stratigraphic Symbol[1]	Hydrogeologic Unit[2]	Thickness	
Meters	Feet					Meters	Feet
137.8 - 192.3	452 - 631	**Ash-Flow Tuff:** Nonwelded to moderately welded; vitric to devitrified.	mafic-poor Ammonia Tanks Tuff, Timber Mountain Group	Tmap	WTA	54.6	179
192.3 - 218.2	631 - 716	**Bedded Tuff:** Vitric.	bedded Ammonia Tanks Tuff, Timber Mountain Group	Tmab	VTA	25.9	85
218.2 - 294.7	716 - 967	**Ash-Flow Tuff:** Nonwelded to densely welded; vitric to devitrified.	mafic-rich Rainier Mesa Tuff, Timber Mountain Group	Tmrr	WTA	76.5	251
294.7 - 487.1	967 - 1598	**Ash-Flow Tuff:** Nonwelded to densely welded; vitric to devitrified. Zeolitized‡ below 463.3 m (1520 ft).	mafic-poor Rainier Mesa Tuff, Timber Mountain Group	Tmrp	WTA & TCU‡	192.3	631
487.1 - 532.2	1598 - 1746	**Nonwelded Tuff:** Zeolitized.	rhyolite of Fluorspar Canyon, Timber Mountain Group	Tmf	TCU	45.1	148
532.2 - 579.1	1746 - 1900	**Bedded Tuff:** Zeolitized.	tuff of Holmes Road, Timber Mountain Group	Tmrh	TCU	46.9	154
579.1 - 644.3	1900 - 2114	**Bedded Tuff:** Zeolitized.	rhyolite of Delirium Canyon, Paintbrush Group	Tpd	TCU	65.2	214

Stratigraphic Log of Well ER-20-6 #1 (continued).

Depth						Thickness	
Meters	Feet	Lithology	Stratigraphic Unit[1]	Stratigraphic Symbol[1]	Hydrogeologic Unit[2]	Meters	Feet
644.3 - 651.1	2114 - 2136	**Bedded Tuff:** Zeolitized.	rhyolite of Echo Peak, Paintbrush Group	Tpe	TCU	6.7	22
651.1 - 655.3	2136 - 2150	**Bedded Tuff:** Zeolitized.	rhyolite of Silent Canyon, Paintbrush Group	Tpr	TCU	4.3	14
655.3 - 765.0	2150 - 2510	**Air-Fall or Nonwelded Tuff:** Zeolitized.	mafic-poor Calico Hills Formation	Tacp	TCU	109.7	360
765.0 - 897.6	2510 - 2945	**Lava:** Pumiceous and zeolitized (top and bottom portions) to devitrified; minor flow breccia.	mafic-poor Calico Hills Formation	Tacp	LFA*	132.6	435
897.6 - 926.6	2945 - 3040	**Bedded Tuff:** Zeolitized.	mafic-poor Calico Hills Formation	Tacp	TCU	29.0	95
926.6 - 975.4 TD	3040 - 3200 TD	**Lava:** Devitrified.	mafic-poor Calico Hills Formation	Tacp	LFA	48.8	160

1 Stratigraphic nomenclature is from Ferguson et al, 1994.

2 AA - Alluvial aquifer
VTA - Vitric-tuff aquifer
WTA - Welded-tuff aquifer
LFA - Lava-flow aquifer

‡ The bottom, nonwelded portion of the Rainier Mesa Tuff is zeolitized and therefore considered to be hydrologically a TCU.

* Zeolitized lava - hydrologic characteristics may be somewhere between those of TCU And LFA.

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Lithologic Log of Well ER-20-6 #1

Compiled by Sigmund L. Drellack, Jr., Bechtel Nevada, May 1996.
Updated to incorporate conventional core data, January 1998.

Unless otherwise noted, the following descriptions refer to washed cuttings samples at 3.05 m (10 ft) or 6.1 m (20 ft) intervals. The lithologic descriptions follow Bechtel Nevada department procedure NTS-GEO-003. Colors are determined by comparing wet sample color to the Geological Society of America Rock-Color Chart. Stratigraphic contacts and lithologic divisions are tied to geophysical logs whenever possible. Stratigraphic nomenclature is from Ferguson et al., 1994.

Depth Interval meters (feet)	Lithology	Stratigraphy
0 - 11.0 m (0 - 36 ft.)	**Pebbly, Silty Sand:** Grayish-orange to dark-yellowish orange; unconsolidated to poorly indurated; tuffaceous; calcareous. Samples are dominantly sand-sized material consisting of common pumice, minor felsic crystals and common tuff fragments. Well indurated caliche fragments also present in cuttings samples.	Alluvium
11.0 - 15.2 m (36 - 50 ft)	**Nonwelded or Air-Fall Tuff:** Medium-gray to dark-greenish-gray pumice fragments up to 1.5 cm in size with rare reddish-brown iron/manganese stains, some dendritic. Some dusky-yellow pumice with scarce olive-black glass. Both types of pumice are vitric and aphanitic.	Trail Ridge Tuff
15.2 - 17.1 m (50 - 56 ft)	**Reworked Tuff:** Grayish-brown to moderate-brown; loosely consolidated tuffaceous silty sand; calcareous; cuttings sample includes several well indurated moderate-brown welded tuff fragments up to 4 cm in size; minor caliche fragments.	Trail Ridge Tuff
17.1 - 30.2 m (56 - 99 ft)	**Partially Welded Ash-Flow Tuff:** Grayish-brown; well indurated; devitrified; rare brownish-black and mottled brownish-black with medium-light-gray pumice, some with corroded and sucrosic textures, possibly vapor- phase or secondary mineralization; common feldspar phenocrysts; rare clinopyroxene (and trace dark olivine?); scarce lithic fragments.	Pahute Mesa Tuff

Lithologic Log of Well ER-20-6 #1 (cont.)

Depth Interval meters (feet)	Lithology	Stratigraphy
30.2 - 34.1 m (99 - 112 ft)	**Nonwelded Ash-Flow Tuff:** Pale-brown; devitrified; minor feldspar phenocrysts.	Pahute Mesa Tuff
34.1 - 36.3 m (112 - 119 ft)	**Air-Fall/Bedded Tuff:** Dark-yellowish-orange (matrix) to very-pale-orange (pumice) and medium-light-gray to light-olive-gray and yellowish-gray (pumice); vitric, friable; rare felsic phenocrysts.	Pahute Mesa Tuff
36.3 - 40.8 m (119 - 134 ft)	**Nonwelded Ash-Flow Tuff:** Moderate-yellowish-brown; devitrified; common to abundant grayish-orange to dark-yellowish-orange pumice and shard fragments exhibiting vapor-phase mineralization; rare feldspar phenocrysts; scarce mafic minerals (clinopyroxene and lesser olivine); rare lithic fragments.	Rocket Wash Tuff
40.8 - 62.5 m (134 - 205 ft)	**Partially Welded Ash-Flow Tuff:** Brownish-black, devitrified with vapor-phase mineralization; rare grayish-black pumice, many with granular to sucrosic texture; minor feldspar phenocrysts; scarce mafic minerals (clinopyroxene and olivine); scarce lithic fragments.	Rocket Wash Tuff
62.5 - 70.7 m (205 - 232 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-brown; devitrified; rare pumice; rare feldspar phenocrysts; scarce mafic minerals (clinopyroxene and lesser olivine); scarce lithic fragments.	Rocket Wash Tuff
70.7 - 82.9 m (232 - 272 ft)	**Partially Welded Ash-Flow Tuff:** Lithology not distinguishable in cuttings. Lithology inferred from the natural gamma-ray log.	Rocket Wash Tuff
82.9 - 87.8 m (272 - 288 ft)	**Nonwelded (Ash-Flow) Tuff:** Moderate- to dark-yellowish-brown; vitric; moderately indurated; shard-rich; rare feldspar phenocrysts; scarce mafic minerals; minor small lithic fragments.	Rocket Wash Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
87.8 - 110.9 m (288 - 364 ft)	**Bedded Tuff:** Mostly reworked tuffaceous sandstone; moderate- to dark-yellowish-brown; fair induration; weakly calcareous; varying proportions of felsic crystals (sub-rounded in parts), small lithic fragments and glass shards; grades to shard-rich air fall in places.	rhyolite of Chukar Canyon
110.9 - 137.8 m (364 - 452 ft)	**Air-Fall Tuff:** White to yellowish-gray; vitric; pumice rich; friable; pumice contains scarce phenocrysts of feldspar, biotite, magnitite, sphene, and lesser hornblende and clinopyroxene.	rhyolite of Beatty Wash
137.8 - 148.1 m (452 - 486 ft)	**Nonwelded Ash-Flow Tuff:** Moderate-brown to 141.7 m (465 ft) and grayish-black to olive-black below; friable to fairly indurated; vitric, shard-rich; light-gray and brownish-black pumice; common felsic phenocrysts (feldspar and lesser quartz); minor mafic minerals (biotite and lesser clinopyroxene); minor lithic fragments.	mafic-poor Ammonia Tanks Tuff
148.1 - 184.4 m (486 - 605 ft)	**Partially Welded Ash-Flow Tuff:** Light-brown; devitrified, vapor-phase mineralization; moderately indurated; abundant light-brown (5 YR 5/6) glass shards; common grayish-orange-pink to grayish-orange pumice; minor feldspar phenocrysts (including chatoyant sanidine) and lesser quartz; minor mafic minerals (biotite and lesser clinopyroxene); minor lithic fragments commonly 4 to 5 mm in size; becomes pale-brown with only scarce glass shards as base of interval.	mafic-poor Ammonia Tanks Tuff
184.4 - 188.4 m (605 - 618 ft)	**Moderately Welded Ash-Flow Tuff:** Moderate-yellowish-brown with light-brown tint; devitrified; vapor-phase mineralization; minor pale- to dark-yellowish-brown pumice; common felsic phenocrysts; minor mafic minerals; rare lithic fragments.	mafic-poor Ammonia Tanks Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
188.4 - 192.3 m (618 - 631 ft)	**Nonwelded Ash-Flow Tuff:** Pale-reddish-brown; vitric; abundant clear glass shards; common grayish-orange pumice; common felsic phenocrysts; minor mafic minerals.	mafic-poor Ammonia Tanks Tuff
192.3 - 208.8 m (631 - 685 ft)	**Air-Fall Tuff:** Grayish-orange-pink; vitric; friable; abundant clear glass shards; minor very-light gray pumice; rare felsic phenocrysts; rare small lithic fragments.	bedded Ammonia Tanks Tuff
208.8 - 218.2 m (685 - 716 ft)	**Bedded Tuff:** Cuttings samples are enriched in phenocrysts and lithic fragments. Very-light-gray to yellowish-gray; felsic phenocrysts include feldspar and quartz; scarce hornblende and biotite.	bedded Ammonia Tanks Tuff
218.2 - 227.4 m (716 - 746 ft)	**Nonwelded Ash-Flow Tuff:** Cuttings are enriched in phenocrysts and lithic fragments. Moderate-orange-pink groundmass; vitric; friable; feldspar and quartz phenocrysts; biotite.	mafic-rich Rainier Mesa Tuff
227.4 - 234.7 m (746 - 770 ft)	**Partially Welded Ash-Flow Tuff:** Pale-brown to pale-reddish-brown; devitrified; vapor-phase mineralization; common grayish-orange-pink to pale-red pumice; minor to common felsic phenocrysts (feldspar and lesser quartz); minor biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
234.7 - 241.7 m (770 - 793 ft)	**Moderately Welded Ash-Flow Tuff:** Pale-reddish-brown to grayish-red; devitrified, vapor-phase mineralization; minor pale-red pumice; minor feldspar and quartz phenocrysts; minor biotite; scarce clinopyroxene; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
241.7 - 291.1 m (793 - 955 ft)	**Densely Welded Ash-Flow Tuff:** Pale-reddish-brown, finely mottled; devitrified; common pale-red pumice; common felsic phenocrysts; common biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
291.1 - 294.7 m (955 - 967 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-red; devitrified; common light-gray pumice; minor felsic phenocrysts; rare biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
294.7 - 302.7 m (967 - 993 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-red; devitrified; minor felsic phenocrysts; scarce biotite.	mafic-poor Rainier Mesa Tuff
302.7 - 442.0 m (993 - 1450 ft)	**Densely Welded Ash-Flow Tuff:** Grayish-red to grayish-red-purple; devitrified; common light-gray pumice; minor feldspar and quartz phenocrysts; rare biotite. Slightly less dense below about 382.5 m (1255 ft).	mafic-poor Rainier Mesa Tuff
442.0 - 448.1 m (1450 - 1470 ft)	**Densely Welded Ash-Flow Tuff:** Brownish-black; vitric; minor felsic phenocrysts; rare biotite. Geophysical logs imply a vitrophyre at this depth interval, however, this lithology only accounts for 10 percent of the cuttings sample.	mafic-poor Rainier Mesa Tuff
448.1 - 463.3 m (1470 - 1520 ft)	**Moderately Welded Ash-Flow Tuff:** Pale- to moderate-reddish-brown; mottled; vitric to partially devitrified. Becoming partially welded toward base of interval.	mafic-poor Rainier Mesa Tuff
463.3 - 487.1 m (1520 - 1598 ft)	**Nonwelded Ash-Flow Tuff:** Pale-red to pale-reddish-brown; zeolitized; minor felsic phenocrysts; scarce biotite; rare lithic fragments.	mafic-poor Rainier Mesa Tuff
487.1 - 532.2 m (1598 - 1746 ft)	**Nonwelded Tuff:** Grayish-orange- pink; zeolitized; indistinct pumice; rare to minor feldspar and quartz phenocrysts; very scarce biotite; minor small lithic fragments, typically <1 mm in size.	rhyolite of Fluorspar Canyon

Lithologic Log of Well ER-20-6 #1 (cont.)

Depth Interval meters (feet)	Lithology	Stratigraphy
532.2 - 579.1 m 1746 - 1900	**Bedded Tuff:** Moderate-yellowish-brown; zeolitized; well indurated; common very-pale-orange pumice; minor feldspar and quartz phenocrysts; scarce small mafic minerals, including hornblende and biotite; common lithic fragments, some very small. The spectral gamma-ray log shows a locally correlatable marker at 541.9 - 544.1 m (1778 - 1785 ft), which is perhaps a clay-rich paleosol. Petrograohic analyses by R.G. Warren are available for sidewall core samples at 576.1 m and 577.9 m (1890 and 1896 ft).	tuff of Holmes Road
579.1 - 589.5 m (1900 - 1934)	**Bedded Tuff:** Mottled moderate-yellowish-brown and moderate-reddish-brown; well indurated; zeolitized; common feldspar phenocrysts; rare biotite and hornblende, trace sphene; minor to common small lithic fragments. The 588.3 m (1930 ft) cuttings sample consists of cement and moderately welded ash-flow tuff (Rainier Mesa Tuff) from up hole. Lost circulation at 587.7 m (1928 ft). Anomalous radiation levels were also recorded on the spectral gamma log at 577.3 - 590.4 m (1894 - 1937 ft). Petrographic analyses by R.G. Warren (LANL) are available for sidewall core samples at 581.3 m and 583.7 m (1907 and 1915 ft).	rhyolite of Delirium Canyon
589.5 - 644.3 m (1934 - 2114 ft)	**Bedded Tuff:** Grayish-orange to grayish-yellow; well indurated; zeolitized; grayish-yellow pumice; very scarce feldspar phenocrysts; very scarce biotite; common lithic fragments <1 mm in size. No representative cuttings samples due to lost circulation. The 627.9 m (2060 ft) and 634.0 m (2080 ft) cuttings samples consist of cement and rare Rainier Mesa ash-flow tuff from up-hole. Four sidewall samples available.	rhyolite of Delirium Canyon

Depth Interval meters (feet)	Lithology	Stratigraphy
644.3 - 651.1 m (2114 - 2136 ft)	**Bedded Tuff:** Grayish-orange; well indurated; zeolitized; very-pale-orange to grayish-yellow pumice to 5 mm in size; minor feldspar phenocrysts; rare biotite; minor sphene; rare lithic fragments. No cuttings samples available due to lost circulation. Sidewall sample at 645.0 m (2116 ft).	rhyolite of Echo Peak
651.1 - 655.3 m (2136 - 2150 ft)	**Bedded Tuff:** Grayish-yellow; zeolitized. No cuttings samples available; sidewall sample at 654.7 m (2148 ft).	rhyolite of Silent Canyon
655.3 - 674.2 m (2150 - 2212 ft)	**Bedded Tuff:** Grayish-yellow; well indurated; zeolitized; scarce feldspar and quartz phenocrysts; rare lithic fragments. No cuttings samples available; seven sidewall samples available. Petrographic analyses by R.G. Warren (LANL) are available for sidewall cores at 667.5 m and 672.1 m (2190 and 2205 ft).	mafic-poor Calico Hills Formation
674.2 - 765.0 m (2212 - 2510 ft)	**Air-Fall or Nonwelded Tuff:** Grayish-yellow to moderate-yellow; well indurated; zeolitized; grayish-yellow and indistinct pumice; scarce to rare felsic phenocrysts; common lithic fragments, mostly grayish-red devitrified lava. Locally correlatable signature on the resistivity log at 745.2 - 748.3 m (2445 - 2455 ft). Limited samples available: a single cuttings sample at 728.5 - 731.5 m (2390 - 2400 ft), and six sidewall samples. Conventional cores available for 673.3 - 683.7 m (2209 - 2243 ft) and 731.5 - 740.7 m (2400 - 2430 ft). Dip of bedding ranges from 10 to 20 degrees. The sidewall samples at 753.5 m (2360 ft) (a zeolitized lava) and 755.9 m (2480 ft) (a devitrified lava) do not seem to correlate with the geophysical log signatures: suspect the sample depths are deeper than labeled.	mafic-poor Calico Hills Formation
765.0 - 777.2 m (2510 - 2550 ft)	**Lava:** No cuttings samples available. Lithology inferred from geophysical logs and sidewall sample at 773.6 m (2538 ft).	mafic-poor Calico Hills Formation

Lithologic Log of Well ER-20-6 #1 (cont.)

Depth Interval meters (feet)	Lithology	Stratigraphy
777.2 - 781.8 m (2550 - 2565 ft)	**Lava:** No samples available. Lithology inferred from geophysical logs. Low resistivity marker correlatable in vicinity.	mafic-poor Calico Hills Formation
781.8 - 866.9 m (2565 - 2844 ft)	**Lava:** Light-brownish-gray to brownish-gray and pale-red, mottled; devitrified; scarce to rare felsic phenocrysts (feldspar and lesser quartz); rare biotite. Flow banding near vertical at 795 m (2608 ft) and 30 to 60 degrees at 860 m (2822 ft). Vesicles <2 mm to 200 mm in size noted, mostly aligned along fractures and flow bands. Cuttings samples available only for the interval 823.0 - 853.4 m (2700 - 2800 ft). Two conventional cores available at 792.5 - 797.1 m (2600 - 2615 ft) and 853.4 - 866.9 m (2800 - 2844 ft). Seven sidewall cores available.	mafic-poor Calico Hills Formation
866.9 - 876.3 m (2844 - 2875 ft)	**Flow Breccia:** Mottled pale-red, grayish-red, and brownish-gray; devitrified; rare felsic phenocrysts of feldspar and quartz; rare biotite. Clast-supported, with individual clasts of devitrified, flow-banded lava up to 15 cm (6 in.) in size. Conspicuous vesicles up to 5 cm (2 in.) in size, many aligned along fractures and flow bands; particularly prominent where flow banding is more contorted. Conventional core available at 866.9 - 869.3 m (2844 - 2852 ft).	mafic-poor Calico Hills Formation
876.3 - 897.6 m (2875 - 2945 ft)	**Lava:** Medium-gray to light-brownish-gray; devitrified; very scarce phenocrysts. No cuttings samples due to lost circulation. Sidewall core sample at 881.2 m (2891 ft).	mafic-poor Calico Hills Formation
897.6 - 926.6 m (2945 - 3040 ft)	**Bedded Tuff:** Zeolitized. No cuttings samples available. Lithology inferred from geophysical logs and two sidewall samples collected at 905.3 m (2970 ft) and 907.7 m (2978 ft).	mafic-poor Calico Hills Formation

Depth Interval meters (feet)	Lithology	Stratigraphy
926.6 - 975.4 m (3040 - 3200 ft) TD	**Lava:** No samples available. Lithology inferred from geophysical logs.	mafic-poor Calico Hills Formation

Note: The uranium curve on the spectral gamma-ray log shows anomalously high values starting at the water level at 618.4 m (2029 ft), and decreasing to "normal" around 823 m (2700 ft). This anomaly is also present at Well ER-20-6 #2, but not at Well ER-20-6 #3.

C.2

Stratigraphic and Lithologic Logs of Well ER-20-6#2

Stratigraphic Log of Well ER-20-6 #2

Compiled by Sigmund L. Drellack, Jr., Bechtel Nevada, May 1996.

Depth Meters	Depth Feet	Lithology	Stratigraphic Unit [1]	Stratigraphic Symbol [1]	Hydrogeologic Unit [2]	Thickness Meters	Thickness Feet
0 - 9.8	0 - 32	**Pebbly, Silty Sand:** Tuffaceous; calcareous.	Alluvium	Qta	AA	9.8	32
9.8 - 18.3	32 - 60	**Nonwelded Tuff with Underlying Reworked Tuff:** Vitric; peralkaline.	Trail Ridge Tuff, Thirsty Canyon Group	Ttt	VTA	8.5	28
18.3 - 35.4	60 - 116	**Ash-Flow Tuff with Underlying Bedded Tuff:** Nonwelded to partially welded; vitric to devitrified, peralkaline.	Pahute Mesa Tuff, Thirsty Canyon Group	Ttp	VTA	17.1	56
35.4 - 86.9	116 - 285	**Ash-Flow Tuff:** Nonwelded to moderately welded; vitric to devitrified; peralkaline.	Rocket Wash Tuff, Thirsty Canyon Group	Ttr	WTA	51.5	169
86.9 - 111.3	285 - 365	**Bedded Tuff:** Reworked tuffaceous sandstone to shard-rich air fall; vitric.	rhyolite of Chukar Canyon, Beatty Wash Formation, Volcanics of Fortymile Canyon	Tfbr	VTA	24.4	80
111.3 - 137.2	365 - 450	**Air-Fall Tuff:** Pumice rich; vitric.	rhyolite of Beatty Wash, Beatty Wash Formation, Volcanics of Fortymile Canyon	Tfbw	VTA	25.9	85

Stratigraphic Log of Well ER-20-6 #2 (continued).

Depth						Thickness	
Meters	Feet	Lithology	Stratigraphic Unit [1]	Stratigraphic Symbol [1]	Hydrogeologic Unit [2]	Meters	Feet
137.2 - 192.6	450 - 632	**Ash-Flow Tuff:** Nonwelded to moderately welded; vitric to devitrified.	mafic-poor Ammonia Tanks Tuff, Timber Mountain Group	Tmap	WTA	55.5	182
192.6 - 219.5	632 - 720	**Bedded Tuff:** Vitric.	bedded Ammonia Tanks Tuff, Timber Mountain Group	Tmab	VTA	26.8	88
219.5 - 295.0	720 - 968	**Ash-Flow Tuff:** Nonwelded to densely welded; vitric to devitrified.	mafic-rich Rainier Mesa Tuff, Timber Mountain Group	Tmrr	WTA	75.6	248
295.0 - 486.5	968 - 1596	**Ash-Flow Tuff:** Nonwelded to densely welded; vitric to devitrified. Zeolitized below 463.3 m (1520 ft).‡	mafic-poor Rainier Mesa Tuff, Timber Mountain Group	Tmrp	WTA & TCU‡	191.4	628
486.5 - 530.4	1596 - 1740	**Nonwelded Tuff:** Zeolitized.	rhyolite of Fluorspar Canyon, Timber Mountain Group	Tmf	TCU	43.9	144
530.4 - 585.8	1740 - 1922	**Bedded Tuff:** Zeolitized.	tuff of Holmes Road, Timber Mountain Group	Tmrh	TCU	55.4	182
585.8 - 623.9	1922 - 2047	**Bedded Tuff:** Zeolitized.	rhyolite of Delirium Canyon, Paintbrush Group	Tpd	TCU	38.1	125

Stratigraphic Log of Well ER-20-6 #2 (continued).

Depth						Thickness	
Meters	Feet	Lithology	Stratigraphic Unit [1]	Stratigraphic Symbol [1]	Hydrogeologic Unit [2]	Meters	Feet
623.9 - 630.3	2047 - 2068	**Bedded Tuff:** Zeolitized	ryholite of Echo Peak, Paintbrush Group	Tpe	TCU	6.4	21
630.3 - 636.1	2068 - 2087	**Bedded Tuff:** Zeolitized.	rhyolite of Silent Canyon, Paintbrush Group	Tpr	TCU	5.8	19
636.1 - 650.7	2087 - 2135	**Bedded Tuff:** Zeolitized.	mafic-poor Calico Hills Formation	Tacp	TCU	14.6	48
650.7 - 680.9	2135 - 2234	**Flow Breccia:** Tuffaceous; zeolitized to silicified in parts.	mafic-poor Calico Hills Formation	Tacp	TCU*	30.2	99
680.9 - 758.6	2234 - 2489	**Air-Fall or Nonwelded Tuff:** Zeolitized.	mafic-poor Calico Hills Formation	Tacp	TCU	77.7	255
758.6 - 954.0	2489 - 3130	**Lava:** Pumiceous and zeolitized (top and bottom portions) to devitrified.	mafic-poor Calico Hills Formation	Tacp	LFA	195.4	641
954.0 - 972.3	3130 - 3190	**Nonwelded and Bedded Tuff:** Zeolitized.	mafic-poor Calico Hills Formation	Tacp	TCU	18.2	60

Stratigraphic Log of Well ER-20-6 #2 (continued).

Depth				Stratigraphic	Hydrogeologic	Thickness	
Meters	Feet	Lithology	Stratigraphic Unit [1]	Symbol [1]	Unit [2]	Meters	Feet
972.3 - 975.4 TD	3190 - 3200 TD	**Lava:** Devitrified.	mafic-poor Calico Hills Formation	Tacp	LFA	3.0	10

1 Stratigraphic nomenclature is from Ferguson et al., 1994.

2 AA - Alluvial aquifer
VTA - Vitric-tuff aquifer
WTA - Welded-tuff aquifer
LFA - Lava-flow aquifer

‡ The bottom, nonwelded portion of the Rainier Mesa Tuff is zeolitized and therefore considered to be hydrologically a TCU.

* Zeolitized lava and flow breccia - hydrologic characteristics may be somewhere between those of TCU and LFA.

Lithologic Log of Well ER-20-6 #2

Compiled by Sigmund L. Drellack, Jr., Bechtel Nevada, May 1996.

Unless otherwise noted, the following descriptions refer to washed cuttings samples at 3.05 m (10 ft) or 6.1 m (20 ft) intervals. The lithologic descriptions follow Bechtel Nevada department procedure NTS-GEO-003. Colors are determined by comparing wet sample color to the Geological Society of America Rock-Color Chart. Stratigraphic contacts and lithologic divisions are tied to geophysical logs whenever possible. Stratigraphic nomenclature is from Ferguson et al., 1994.

Depth Interval meters (feet)	Lithology	Stratigraphy
0 - 9.8 m (0 - 32 ft.)	**Pebbly, Silty Sand:** Grayish-orange to dark-yellowish orange; unconsolidated to poorly indurated; tuffaceous; calcareous. Samples are dominantly sand-sized material consisting of common pumice, minor free felsic crystals and common tuff fragments. Well indurated caliche fragments present in the 6.1 - 91 m (20 - 30 ft) cuttings samples.	Alluvium
9.8 - 15.2 m (32 - 50 ft)	**Nonwelded or Air-Fall Tuff:** The 9.1 - 12.2 m (30 - 40 ft) sample consists of medium-gray to dark-greenish-gray pumice fragments up to 1.5 cm in size with rare reddish-brown iron/ manganese stains, some dendritic. The 12.2 - 18.3 m (40 - 50 ft) sample consists of dusky-yellow pumice fragments with scarce olive-black glass. The pumice in both samples is vitric and aphanitic.	Trail Ridge Tuff
15.2 - 18.3 m (50 - 60 ft)	**Reworked Tuff:** Grayish-brown to moderate-brown; loosely consolidated tuffaceous silty sand; calcareous; cuttings sample includes several well indurated moderate-brown welded tuff fragments up to 4 cm in size; minor caliche fragments.	Trail Ridge Tuff
18.3 - 29.0 m (60 - 95 ft)	**Partially Welded Ash-Flow Tuff:** Grayish-brown; well indurated; devitrified; rare brownish-black and mottled brownish-black with medium-light-gray pumice, some with corroded and sucrosic textures, possibly vapor-phase or secondary mineralization; common feldspar phenocrysts; rare clinopyroxene (and trace dark olivine?); scarce lithic fragments.	Pahute Mesa Tuff

Lithologic Log of Well ER-20-6 #2 (cont.)

Depth Interval meters (feet)	Lithology	Stratigraphy
29.0 - 33.5 m (95 - 110 ft)	**Nonwelded Ash-Flow Tuff:** Pale-brown; devitrified; minor feldspar phenocrysts.	Pahute Mesa Tuff
33.5 - 35.4 m (110 - 116 ft)	**Air-Fall/Bedded Tuff:** Dark-yellowish-orange (matrix) to very-pale-orange (pumice) and medium-light-gray to light-olive-gray and yellowish-gray (pumice); vitric, friable; rare felsic phenocrysts.	Pahute Mesa Tuff
35.4 - 39.6 m (116 - 130 ft)	**Nonwelded Ash-Flow Tuff:** Moderate-yellowish-brown; devitrified; common to abundant grayish-orange to dark-yellowish-orange pumice and shard fragments exhibiting vapor-phase mineralization; rare feldspar phenocrysts; scarce mafic minerals (clinopyroxene and lesser olivine); rare lithic fragments.	Rocket Wash Tuff
39.6 - 64.0 m (130 - 210 ft)	**Partially Welded Ash-Flow Tuff:** Brownish-black, devitrified with vapor-phase mineralization; rare grayish-black pumice, many with granular to sucrosic texture; minor feldspar phenocrysts; scarce mafic minerals (clinopyroxene and olivine); scarce lithic fragments.	Rocket Wash Tuff
64.0 - 70.1 m (210 - 230 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-brown; devitrified; rare pumice; rare feldspar phenocrysts; scarce mafic minerals (clinopyroxene and lesser olivine); scarce lithic fragments.	Rocket Wash Tuff
70.1 - 82.3 m (230 - 270 ft)	**Partially Welded Ash-Flow Tuff:** Lithology not distinguishable in cuttings. Lithology inferred from the natural gamma-ray log.	Rocket Wash Tuff

Lithologic Log of Well ER-20-6 #2 (cont.)

Depth Interval meters (feet)	Lithology	Stratigraphy
82.3 - 86.9 m (270 - 285 ft)	**Nonwelded (Ash-Flow) Tuff:** Moderate- to dark-yellowish-brown; vitric; moderately indurated; shard-rich; rare feldspar phenocrysts; scarce mafic minerals; minor small lithic fragments.	Rocket Wash Tuff
86.9 - 111.3 m (285 - 365 ft)	**Bedded Tuff:** Mostly reworked tuffaceous sandstone; moderate- to dark-yellowish-brown; fair induration; weakly calcareous; varying proportions of felsic crystals (sub-rounded in parts), small lithic fragments and glass shards; grades to shard-rich air fall in places.	rhyolite of Chukar Canyon
111.3 - 137.2 m (365 - 450 ft)	**Air-Fall Tuff:** White to yellowish-gray; vitric; pumice-rich; friable; pumice contains scarce phenocrysts of feldspar, biotite, magnitite, sphene, and lesser hornblende and clinopyroxene.	rhyolite of Beatty Wash
137.2 - 147.5 m (450 - 484 ft)	**Nonwelded Ash-Flow Tuff:** Moderate-brown to 141.7 m (465 ft) and grayish-black to olive-black below; friable to fair induration; vitric, shard-rich; light-gray and brownish-black pumice; common felsic phenocrysts (feldspar and lesser quartz); minor mafic minerals (biotite and lesser clinopyroxene); minor lithic fragments.	mafic-poor Ammonia Tanks Tuff
147.5 - 186.8 m (484 - 613 ft)	**Partially Welded Ash-Flow Tuff:** Light-brown; devitrified, vapor-phase mineralization; moderately indurated; abundant light-brown (5 YR 5/6) glass shards; common grayish-orange-pink to grayish-orange pumice; minor feldspar phenocrysts (including chatoyant sanidine) and lesser quartz; minor biotite and lesser clinopyroxene; minor lithic fragments commonly 4 to 5 mm in size; becomes pale-brown with only scarce glass shards below about 183 m (600 ft).	mafic-poor Ammonia Tanks Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
186.8 - 190.5 m (613 - 625 ft)	**Moderately Welded Ash-Flow Tuff:** Moderate-yellowish-brown with light-brown tint; devitrified; vapor-phase mineralization; minor pale- to dark-yellowish-brown pumice; common felsic phenocrysts; minor mafic minerals; rare lithic fragments.	mafic-poor Ammonia Tanks Tuff
190.5 - 192.6 m (625 - 632 ft)	**Nonwelded Ash-Flow Tuff:** Pale-reddish-brown; vitric; abundant clear glass shards; common grayish-orange pumice; common felsic phenocrysts; minor mafic minerals.	mafic-poor Ammonia Tanks Tuff
192.6 - 207.3 m (632 - 680 ft)	**Air-Fall Tuff:** Grayish-orange-pink; vitric; friable; abundant clear glass shards; minor very-light gray pumice; rare felsic phenocrysts; rare small lithic fragments.	bedded Ammonia Tanks Tuff
207.3 - 219.5 m (680 - 720 ft)	**Bedded Tuff:** Cuttings samples enriched in phenocrysts and lithic fragments. Very-light-gray to yellowish-gray; felsic phenocrysts include feldspar and quartz; scarce hornblende and biotite.	bedded Ammonia Tanks Tuff
219.5 - 227.1 m (720 - 745 ft)	**Nonwelded Ash-Flow Tuff:** Cuttings are enriched in phenocrysts and lithic fragments. Moderate-orange-pink groundmass; vitric; friable; feldspar and quartz phenocrysts; biotite.	mafic-rich Rainier Mesa Tuff
227.1 - 234.7 m (745 - 770 ft)	**Partially Welded Ash-Flow Tuff:** Pale-brown to pale-reddish-brown; devitrified; vapor-phase mineralization; common grayish-orange-pink to pale-red pumice; minor to common felsic phenocrysts of feldspar and lesser quartz; minor biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
234.7 - 240.8 m (770 - 790 ft)	**Moderately Welded Ash-Flow Tuff:** Pale-reddish-brown to grayish-red; devitrified, vapor-phase mineralization; minor pale-red pumice; minor felsic phenocrysts of feldspar and quartz; minor biotite, scarce clinopyroxene; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
240.8 - 291.1 m (790 - 955 ft)	**Densely Welded Ash-Flow Tuff:** Pale-reddish-brown, finely mottled; devitrified; common pale-red pumice; common felsic phenocrysts; common biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
291.1 - 295.0 m (955 - 968 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-red; devitrified; common light-gray pumice; minor felsic phenocrysts; rare biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
295.0 - 302.7 m (968 - 993 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-red; devitrified; minor felsic phenocrysts; scarce biotite.	mafic-poor Rainier Mesa Tuff
302.7 - 438.9 m (993 - 1440 ft)	**Densely Welded Ash-Flow Tuff:** Grayish-red to grayish-red-purple; devitrified; common light-gray pumice; minor feldspar and quartz phenocrysts; rare biotite. Slightly less dense below about 375.8 m (1233 ft).	mafic-poor Rainier Mesa Tuff
438.9 - 445.0 m (1440 - 1460 ft)	**Densely Welded Ash-Flow Tuff:** Brownish-black; vitric; minor felsic phenocrysts; rare biotite. Geophysical logs imply a vitrophyre at this depth interval, however, this lithology only accounts for 10 percent of the cuttings sample.	mafic-poor Rainier Mesa Tuff
445.0 - 463.3 m (1460 - 1520 ft)	**Moderately Welded Ash-Flow Tuff:** Pale- to moderate-reddish-brown, mottled; vitric to partially devitrified. Becoming partially welded toward base of interval.	mafic-poor Rainier Mesa Tuff

Lithologic Log of Well ER-20-6 #2 (cont.)

Depth Interval meters (feet)	Lithology	Stratigraphy
463.3 - 486.5 m (1520 - 1596 ft)	**Nonwelded Ash-Flow Tuff:** Pale-red to pale-reddish-brown; zeolitized; minor felsic phenocrysts; scarce biotite; rare lithic fragments.	mafic-poor Rainier Mesa Tuff
486.5 - 530.4 m (1596 - 1740 ft)	**Nonwelded Tuff:** Grayish-orange- pink; zeolitized; indistinct pumice; rare to minor feldspar and quartz phenocrysts; very scarce biotite; minor small lithic fragments, typically <1 mm in size.	rhyolite of Fluorspar Canyon
530.4 - 575.5 m (1740 - 1888 ft)	**Bedded Tuff:** Moderate-yellowish-brown; vitric to zeolitized; well indurated; common very-pale-orange pumice; minor felsic phenocrysts of feldspar and quartz; rare biotite and hornblende, lesser clinipyroxene, trace sphene; common lithic fragments, some very small. The spectral gamma-ray log shows a locally useful correlation marker at 539.5 - 541.9 m (1770 - 1778 ft) which is perhaps a clay-rich paleosol.	tuff of Holmes Road
575.5 - 585.8 m (1888 - 1922 ft)	**Bedded Tuff:** Mottled moderate-yellowish-brown and moderate-reddish-brown; well indurated; zeolitized; common feldspar and quartz phenocrysts; common biotite and sphene; minor to common small lithic fragments.	Tuff of Holmes Road
585.8 - 623.9 m (1922 - 2047 ft)	**Bedded Tuff:** Grayish-orange to grayish-yellow; well indurated; zeolitized; grayish-yellow pumice; very scarce feldspar phenocrysts; very scarce biotite; common lithic fragments <1 mm in size.	rhyolite of Delirium Canyon

Depth Interval meters (feet)	Lithology	Stratigraphy
623.9 - 630.3 m (2047 - 2068 ft)	**Bedded Tuff:** Mottled grayish-orange and moderate-reddish-orange; well indurated; zeolitized; silicified in parts; very-pale-orange to grayish-yellow pumice to 5 mm in size; minor feldspar phenocrysts; rare biotite; minor sphene; rare lithic fragments.	rhyolite of Echo Peak
630.3 - 636.1 m (2068 - 2087 ft)	**Bedded Tuff:** Grayish-yellow; zeolitized; minor feldspar phenocrysts; minor to common biotite.	rhyolite of Silent Canyon
636.1 - 650.7 m (2087 - 2135 ft)	**Bedded Tuff:** Grayish-yellow; well indurated; zeolitized; scarce feldspar and quartz phenocrysts; rare lithic fragments.	mafic-poor Calico Hills Formation
650.7 - 680.9 m (2135 - 2234 ft)	**Flow Breccia:** Dusky-yellow to grayish-yellow; tuffaceous; well indurated; zeolitized to silicified in parts; very scarce phenocrysts of feldspar and quartz; scarce to rare biotite.	mafic-poor Calico Hills Formation
680.9 - 758.6 m (2234 - 2489 ft)	**Air-Fall or Nonwelded Tuff:** Grayish-yellow, some grayish-orange-pink mottling around 731.5 - 743.7 m (2400 - 2440 ft); well indurated; zeolitized; grayish-yellow and indistinct pumice; scarce feldspar and quartz phenocrysts; rare biotite; common lithic fragments up to 2.5 cm in size, mostly grayish-red devitrified lava fragments. The specific lithology which produces this locally correlatable signature on the resistivity log at 740.7 - 743.7 m (2430 - 2440 ft) is not recognizable in cuttings samples.	mafic-poor Calico Hills Formation
758.6 - 777.2 m (2489 - 2550 ft)	**Lava:** Yellowish-gray to dusky-yellow; moderate-reddish-brown stain/mottling in parts; pumiceous; zeolitized; very scarce feldspar and quartz phenocrysts; rare biotite.	mafic-poor Calico Hills Formation

Depth Interval meters (feet)	Lithology	Stratigraphy
777.2 - 778.8 m (2550 - 2555 ft)	**Lava:** Light-olive-gray and grayish-orange-pink; strongly silicified. Low-resistivity marker useful for local correlation.	mafic-poor Calico Hills Formation
778.8 - 855.3 m (2555 - 2806 ft)	**Lava:** Light-brownish-gray and pale-red; finely mottled appearance under microscope; devitrified; some flow banding; very scarce felsic phenocrysts (feldspar and lesser quartz); Fe/Mn specks throughout.	mafic-poor Calico Hills Formation
855.3 - 877.8 m (2806 - 2880 ft)	**Lava:** Brownish-gray; partially devitrified; denser than intervals above and below; very scarce feldspar and quartz phenocrysts.	mafic-poor Calico Hills Formation
877.8 - 914.4 m (2880 - 3000 ft)	**Lava:** Medium-gray to light-brownish-gray; devitrified; very scarce feldspar and quartz phenocrysts.	mafic-poor Calico Hills Formation
914.4 - 926.6 m (3000 - 3040 ft)	**Lava:** Moderate-orange-pink to grayish-orange, and grayish-orange-pink; pumiceous; relic perlitic texture in parts; zeolitized; moderately indurated; very scarce feldspar and quartz phenocrysts; scarce biotite; trace MnO_2 spots and dendrites.	mafic-poor Calico Hills Formation
926.6 - 954.0 m (3040 - 3130 ft)	**Lava:** Pale-reddish-brown to light-brown, and pale-red; common moderate-reddish-brown stains, irregular to fibrous streaks; zeolitized; well indurated; scarce feldspar and quartz phenocrysts; scarce biotite; MnO_2 spots and coatings; scarce lithic fragments. Includes rare breccia fragments, particularly below about 941.8 m (3090 ft) depth. There, the base of this interval may be a tuffaceous, zeolitized flow breccia.	mafic-poor Calico Hills Formation

Depth Interval meters (feet)	Lithology	Stratigraphy
954.0 - 963.2 m (3130 - 3160 ft)	**Nonwelded Tuff:** Poor cuttings samples due to cavings from up-hole. Pale- to moderate-yellowish-brown, some grayish-brown reworked tuff at top of interval. Zeolitized; well indurated; common small pale-yellowish-brown pumice; scarce feldspar and quartz phenocrysts; very scarce biotite; rare lithic fragments.	mafic-poor Calico Hills Formation
963.2 - 972.3 m (3160 - 3190 ft)	**Bedded Tuff:** Poor cuttings samples due to cavings from up-hole. Pale-reddish-brown to moderate-reddish-brown, becoming brownish-gray; very well indurated and silicified in parts below 969.3 m (3180 ft); zeolitized; moderately indurated; variable, rare to common very-pale-orange pumice; scarce felsic phenocrysts (feldspar and quartz); very scarce biotite; minor lithic fragments to 10 mm in size.	mafic-poor Calico Hills Formation
972.3 - 975.4 m (3190 - 3200 ft) TD	**Lava:** Mottled, grayish-red; devitrified; minor feldspar and quartz phenocrysts; very scarce biotite.	mafic-poor Calico Hills Formation

Note: The uranium curve on the spectral gamma-ray log shows anomalously high values from the water level at 618.1 m (2028 ft) decreasing to "normal" around 701.0 m (2300 ft) depth. This anomaly is also present at Well ER-20-6#1, but not at Well ER-20-6#3.

C.3

Stratigraphic and Lithologic Logs of Well ER-20-6#3

Stratigraphic Log of Well ER-20-6 #3
Compiled by Sigmund L. Drellack, Jr., Bechtel Nevada, May 1996.

Depth				Stratigraphic	Hydrogeologic	Thickness	
Meters	Feet	Lithology	Stratigraphic Unit [1]	Symbol [1]	Unit [2]	Meters	Feet
0 - 8.2	0 - 27	**Pebbly, Silty Sand:** Tuffaceous; calcareous.	Alluvium	QTa	AA	8.2	27
8.2 - 15.8	27 - 52	**Nonwelded Tuff with Underlying Reworked Tuff:** Vitric, peralkaline.	Trail Ridge Tuff, Thirsty Canyon Group	Ttt	VTA	7.6	25
15.8 - 33.2	52 - 109	**Ash-Flow Tuff with Underlying Bedded Tuff:** Nonwelded to partially welded; vitric to devitrified, peralkaline.	Pahute Mesa Tuff, Thirsty Canyon Group	Ttp	VTA	17.4	57
33.2 - 86.6	109 - 284	**Ash-Flow Tuff:** Nonwelded to moderately welded; vitric to devitrified; peralkaline.	Rocket Wash Tuff, Thirsty Canyon Group	Ttr	WTA	53.3	175
86.6 - 108.2	284 - 355	**Bedded Tuff:** Reworked tuffaceous sandstone to shard-rich air-fall; vitric.	rhyolite of Chukar Canyon, Beatty Wash Formation, Volcanics of Fortymile Canyon	Tfbr	VTA	21.6	71
108.2 - 132.3	355 - 434	**Air-Fall Tuff:** Pumice rich; vitric.	rhyolite of Beatty Wash, Beatty Wash Formation, Volcanics of Fortymile Canyon	Tfbw	VTA	24.1	79

Stratigraphic Log of Well ER-20-6 #3 (continued).

Depth						Thickness	
Meters	Feet	Lithology	Stratigraphic Unit [1]	Stratigraphic Symbol [1]	Hydrogeologic Unit [2]	Meters	Feet
132.3 - 190.8	434 - 626	**Ash-Flow Tuff:** Nonwelded to moderately welded; vitric to devitrified.	mafic-poor, Ammonia Tanks Tuff, Timber Mountain Group	Tmap	WTA	58.5	192
190.8 - 220.1	626 - 722	**Bedded Tuff:** Vitric.	bedded Ammonia Tanks Tuff, Timber Mountain Group	Tmab	VTA	29.3	96
220.1 - 295.7	722 - 970	**Ash-Flow Tuff:** Nonwelded to densely welded; vitric to devitrified.	mafic-rich Rainier Mesa Tuff, Timber Mountain Group	Tmrr	WTA	75.6	248
295.5 - 487.1	970 - 1598	**Ash-Flow Tuff:** Nonwelded to densely welded; vitric to devitrified. Zeolitized below about 463.3 m (1520 ft). ‡	mafic-poor Rainier Mesa Tuff, Timber Mountain Group	Tmrp	WTA & TCU ‡	191.4	628
487.1 - 529.1	1598 - 1736	**Nonwelded Tuff:** Zeolitized.	rhyolite of Fluorspar Canyon, Timber Mountain Group	Tmf	TCU	42.1	138
529.1 - 571.8	1736 - 1876	**Bedded Tuff:** Zeolitized.	tuff of Holmes Road, Timber Mountain Group	Tmrh	TCU	42.7	140
571 .8 - 593.1	1876 - 1946	**Bedded Tuff:** Zeolitized.	rhyolite of Delirium Canyon, Paintbrush Group	Tpd	TCU	21.3	70

Stratigraphic Log of Well ER-20-6 #3 (continued).

Depth		Lithology	Stratigraphic Unit [1]	Stratigraphic Symbol [1]	Hydrogeologic Unit [2]	Thickness	
Meters	Feet					Meters	Feet
593.1 - 596.2	1946 - 1956	**Bedded Tuff:** Zeolitized.	rhyolite of Echo Peak, Paintbrush Group	Tpe	TCU	3.0	10
596.2 - 600.5	1956 - 1970	**Bedded Tuff:** Zeolitized.	rhyolite of Silent Canyon Paintbrush Group	Tpr	TCU	4.3	14
600.5 - 609.6	1970 - 2000	**Bedded Tuff:** Zeolitized.	mafic-poor Calico Hills Formation	Tacp	TCU	9.1	30
609.6 - 695.6	2000 - 2282	**Lava:** Pumiceous and zeolitized to devitrified, with a vitrophyre at 663.9 - 670.6 m (2178 - 2200 ft).	mafic-poor Calico Hills Formation	Tacp	LFA	86.0	282
695.6 - 752.9	2282 - 2470	**Air-Fall Tuff:** Zeolitized.	mafic-poor Calico Hills Formation	Tacp	TCU	57.3	188
752.9 - 975.4 TD	2470 - 3200 TD	**Lava:** Pumiceous and zeolitized (top and bottom portions*) to devitrified, with vitrophyres at 772.7 - 781.8 m (2535 - 2565 ft) and 876.0 - 887.0 m (2874 - 2910 ft).	mafic-poor Calico Hills Formation	Tacp	LFA & TCU*	222.5	730

1 Stratigraphic nomenclature is from Ferguson et al., 1994.

2 AA - Alluvial aquifer; WTA - Welded-tuff aquifer; VTA - Vitric-tuff aquifer; LFA - Lava-flow aquifer

‡ The bottom, nonwelded portion of the Rainier Mesa Tuff is zeolitized and therefore is considered to be hydrologically a TCU.

* Zeolitized lava: hydrologic character may be between those of TCU and LFA.

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Lithologic Log of Well ER-20-6 #3

Compiled by Sigmund L. Drellack, Jr., Bechtel Nevada, May 1996.

Unless otherwise noted, the following descriptions refer to washed cuttings samples at 3.05 m (10 ft) or 6.1 m (20 ft) intervals. The lithologic descriptions follow Bechtel Nevada department procedure NTS-GEO-003. Colors are determined by comparing wet sample color to the Geological Society of America Rock-Color Chart. Stratigraphic contacts and lithologic divisions are tied to geophysical logs whenever possible. Stratigraphic nomenclature is from Ferguson et al., 1994.

Depth Interval meters (feet)	Lithology	Stratigraphy
0 - 8.2 m (0 - 27 ft.)	**Pebbly, Silty Sand:** Grayish-orange to dark-yellowish orange; unconsolidated to poorly indurated; tuffaceous; calcareous. Samples are dominantly sand-sized material consisting of common pumice, minor felsic crystals and common tuff fragments. Well indurated caliche fragments also present in samples.	Alluvium
8.2 - 13.4 m (27 - 44 ft)	**Nonwelded or Air-Fall Tuff:** Medium-gray to dark-greenish-gray pumice fragments up to 1.5 cm in size with rare reddish-brown iron/manganese stains, some dendritic. Some dusky-yellow pumice with scarce olive-black glass. Both types of pumice are vitric and aphanitic.	Trail Ridge Tuff
13.4 - 15.8 m (44 - 52 ft)	**Reworked Tuff:** Grayish-brown to moderate-brown; loosely consolidated tuffaceous silty sand; calcareous; cuttings sample includes several well indurated moderate-brown welded tuff fragments up to 4 cm in size; minor caliche fragments.	Trail Ridge Tuff
15.8 - 27.4 m (52 - 90 ft)	**Partially Welded Ash-Flow Tuff:** Grayish-brown; well indurated; devitrified; rare brownish-black and mottled brownish-black with medium-light-gray pumice, some with corroded and sucrosic textures, possibly vapor-phase or secondary mineralization; common feldspar phenocrysts; rare clinopyroxene (and trace dark olivine?); scarce lithic fragments.	Pahute Mesa Tuff
27.4 - 31.7 m (90 - 104 ft)	**Nonwelded Ash-Flow Tuff:** Pale-brown; devitrified; minor feldspar phenocrysts.	Pahute Mesa Tuff

Lithologic Log of Well ER-20-6 #3 (cont.)

Depth Interval meters (feet)	Lithology	Stratigraphy
31.7 - 33.2 m (104 - 109 ft)	**Air-Fall/Bedded Tuff:** Dark-yellowish-orange (matrix) to very-pale-orange (pumice) and medium-light-gray to light-olive-gray and yellowish-gray (pumice); vitric, friable; rare felsic phenocrysts.	Pahute Mesa Tuff
33.2 - 38.1 m (109 - 125 ft)	**Nonwelded Ash-Flow Tuff:** Moderate-yellowish-brown; devitrified; common to abundant grayish-orange to dark-yellowish-orange pumice and shard fragments exhibiting vapor-phase mineralization; rare feldspar phenocrysts; scarce mafic minerals (clinopyroxene and lesser olivine); rare lithic fragments.	Rocket Wash Tuff
38.1 - 63.1 m (125 - 207 ft)	**Partially Welded Ash-Flow Tuff:** Brownish-black; devitrified with vapor-phase mineralization; rare grayish-black pumice, many with granular to sucrosic texture; minor feldspar phenocrysts; scarce mafic minerals (clinopyroxene and olivine); scarce lithic fragments.	Rocket Wash Tuff
63.1 - 67.7 m (207 - 222 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-brown; devitrified; rare pumice; rare feldspar phenocrysts; scarce mafic minerals (clinopyroxene and lesser olivine); scarce lithic fragments.	Rocket Wash Tuff
67.7 - 80.5 m (222 - 264 ft)	**Partially Welded Ash-Flow Tuff:** Lithology not distinguishable in cuttings. Lithology inferred from the natural gamma-ray log.	Rocket Wash Tuff
80.5 - 86.6 m (264 - 284 ft)	**Nonwelded (Ash-Flow) Tuff:** Moderate- to dark-yellowish-brown; vitric; moderately indurated; shard-rich; rare feldspar phenocrysts; scarce mafic minerals; minor small lithic fragments.	Rocket Wash Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
86.6 - 108.2 m (284 - 355 ft)	**Bedded Tuff:** Mostly reworked tuffaceous sandstone; moderate- to dark-yellowish-brown; fair induration; weakly calcareous; varying proportions of felsic crystals (sub-rounded in parts), small lithic fragments and glass shards; grades to shard-rich air fall in places.	rhyolite of Chukar Canyon
108.2 - 132.3 m (355 - 434 ft)	**Air-Fall Tuff:** White to yellowish-gray; vitric; pumice-rich; friable; pumice contains scarce phenocrysts of feldspar, biotite, magnitite, sphene, and lesser hornblende and clinopyroxene.	rhyolite of Beatty Wash
132.3 - 145.7 m (434 - 478 ft)	**Nonwelded Ash-Flow Tuff:** Moderate-brown at top of interval and grayish-black to olive-black below; friable to fairly indurated; vitric, shard-rich; light-gray and brownish-black pumice; common felsic phenocrysts (feldspar and lesser quartz); minor mafic minerals (biotite and lesser clinopyroxene); minor lithic fragments.	mafic-poor Ammonia Tanks Tuff
145.7 - 184.1 m (478 - 604 ft)	**Partially Welded Ash-Flow Tuff:** Light-brown; devitrified, vapor-phase mineralization; moderately indurated; abundant light-brown glass shards; common grayish-orange-pink to grayish-orange pumice; minor feldspar (including chatoyant sanidine) and lesser quartz; minor mafic minerals (biotite and lesser clinopyroxene); minor lithic fragments commonly 4 to 5 mm in size; becomes pale-brown with only scarce glass shards at base of interval.	mafic-poor Ammonia Tanks Tuff
184.1 - 187.5 m (604 - 615 ft)	**Moderately Welded Ash-Flow Tuff:** Moderate-yellowish-brown with light-brown tint; devitrified; vapor-phase mineralization; minor pale- to dark-yellowish-brown pumice; common felsic phenocrysts; minor mafic minerals; rare lithic fragments.	mafic-poor Ammonia Tanks Tuff
187.5 - 190.8 m (615 - 626 ft)	**Nonwelded Ash-Flow Tuff:** Pale-reddish-brown; vitric; abundant clear glass shards; common grayish-orange pumice; common felsic phenocrysts; minor mafic minerals.	mafic-poor Ammonia Tanks Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
190.8 - 207.3 m (626 - 680 ft)	**Air-Fall Tuff:** Grayish-orange-pink; vitric; friable; abundant clear glass shards; minor very-light gray pumice; rare felsic phenocrysts; rare small lithic fragments.	bedded Ammonia Tanks Tuff
207.3 - 220.1 (680 - 722 ft)	**Bedded Tuff:** Cuttings samples are enriched in phenocrysts and lithic fragments. Very-light-gray to yellowish-gray; felsic phenocrysts include feldspar and quartz; scarce hornblende and biotite.	bedded Ammonia Tanks Tuff
220.1 - 227.1 m (722 - 745 ft)	**Nonwelded Ash-Flow Tuff:** Cuttings samples are enriched in phenocrysts and lithic fragments. Moderate-orange-pink groundmass; vitric; friable; feldspar and quartz phenocrysts; biotite.	mafic-rich Rainier Mesa Tuff
227.1 - 234.7 m (745 - 770 ft)	**Partially Welded Ash-Flow Tuff:** Pale-brown to pale-reddish-brown; devitrified; vapor-phase mineralization; common grayish-orange-pink to pale-red pumice; minor to common felsic phenocrysts (feldspar and lesser quartz); minor biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
234.7 - 240.8 m (770 - 790 ft)	**Moderately Welded Ash-Flow Tuff:** Pale-reddish-brown to grayish-red; devitrified, vapor-phase mineralization; minor pale-red pumice; minor feldspar and quartz phenocrysts; minor biotite; scarce clinopyroxene; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
240.8 - 290.8 m (790 - 954 ft)	**Densely Welded Ash-Flow Tuff:** Pale-reddish-brown, finely mottled; devitrified; common pale-red pumice; common felsic phenocrysts; common biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff
290.8 - 295.7 m (954 - 970 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-red; devitrified; common light-gray pumice; minor felsic phenocrysts; rare biotite; scarce lithic fragments.	mafic-rich Rainier Mesa Tuff

Depth Interval meters (feet)	Lithology	Stratigraphy
295.7 - 302.7 m (970 - 993 ft)	**Moderately Welded Ash-Flow Tuff:** Grayish-red; devitrified; minor felsic phenocrysts; scarce biotite.	mafic-poor Rainier Mesa Tuff
302.7 - 438.9 m (993 - 1440 ft)	**Densely Welded Ash-Flow Tuff:** Grayish-red to grayish-red-purple; devitrified; common light-gray pumice; minor feldspar and quartz phenocrysts; rare biotite. Becoming less dense (moderately welded) below 373.4 m (1225 ft).	mafic-poor Rainier Mesa Tuff
438.9 - 445.0 m (1440 - 1460 ft)	**Densely Welded Ash-Flow Tuff:** Brownish-black; vitric; minor felsic phenocrysts; rare biotite. Geophysical logs imply a vitrophyre at this depth interval, however, this lithology only accounts for 10 percent of the cuttings sample.	mafic-poor Rainier Mesa Tuff
445.0 - 463.3 m (1460 - 1520 ft)	**Moderately Welded Ash-Flow Tuff:** Pale- to moderate-reddish-brown; mottled; vitric to partially devitrified; becoming partially welded toward base of interval.	mafic-poor Rainier Mesa Tuff
463.3 - 487.1 m (1520 - 1598 ft)	**Nonwelded Ash-Flow Tuff:** Pale-red to pale-reddish-brown; zeolitized; minor felsic phenocrysts; scarce biotite; rare lithic fragments.	mafic-poor Rainier Mesa Tuff
487.1 - 529.1 m (1598 - 1736 ft)	**Nonwelded Tuff:** Grayish-orange-pink; zeolitized; indistinct pumice; rare to minor feldspar and quartz phenocrysts; very scarce biotite; minor small lithic fragments, typically <1 mm in size.	rhyolite of Fluorspar Canyon

Depth Interval meters (feet)	Lithology	Stratigraphy
529.1 - 562.1 m (1736 - 1844 ft)	**Bedded Tuff:** Moderate-yellowish-brown; zeolitized; well indurated; common very-pale-orange pumice; minor feldspar and quartz phenocrysts; scarce small mafic minerals; common lithic fragments, some very small. The spectral gamma-ray log shows a locally correlatable marker at 539.5 - 541.3 m (1770 - 1776 ft), which is perhaps a clay-rich paleosol.	tuff of Holmes Road
562.1 - 571.8 m (1844 - 1876 ft)	**Bedded Tuff:** Mottled moderate-yellowish-brown and moderate-reddish-brown; well indurated; zeolitized; common feldspar and quartz phenocrysts; minor biotite and sphene; minor to common small lithic fragments.	tuff of Holmes Road
571.8 - 593.1 m (1876 - 1946 ft)	**Bedded Tuff:** Grayish-orange to grayish-yellow; well indurated; zeolitized; grayish-yellow pumice; very scarce feldspar phenocrysts; very scarce biotite; common lithic fragments, typically <1 mm in size, some 2 - 4 mm in size.	rhyolite of Delirium Canyon
593.1 - 596.2 m (1946 - 1956 ft)	**Bedded Tuff:** Mottled grayish-orange and moderate-reddish-orange; well indurated; zeolitized; very-pale-orange to grayish-yellow pumice to 5 mm in size; minor feldspar phenocrysts; rare biotite and minor sphene; rare lithic fragments.	rhyolite of Echo Peak
596.2 - 600.5 m (1956 - 1970 ft)	**Bedded Tuff:** Yellowish-gray; zeolitized; scarce feldspar phenocrysts; scarce mafic minerals.	rhyolite of Silent Canyon
600.5 - 609.6 m (1970 - 2000 ft)	**Bedded Tuff:** Grayish-orange to grayish-yellow; zeolitized; scarce feldspar and quartz phenocrysts; very scarce biotite.	mafic-poor Calico Hills Formation

Depth Interval meters (feet)	Lithology	Stratigraphy
609.6 - 646.2 m (2000 - 2120 ft)	**Lava:** Generally yellowish-gray, some mottled with pale-red to grayish-orange-pink and grayish-yellow; pumiceous in parts; zeolitized; moderately indurated; very scarce felsic phenocrysts (feldspar and lesser quartz); rare biotite; some MnO_2 spots. Hint of flow banding in parts. Trace chalcedony. Some silicification below 627 m (2060 ft) depth, some medium light-gray, vitric lava also present in cuttings.	mafic-poor Calico Hills Formation
646.2 - 653.8 m (2120 - 2145 ft)	**Lava:** Grayish-red; mottled and flow banded with grayish-yellow and pale-brown; devitrified; very scarce felsic phenocrysts including quartz; rare biotite.	mafic-poor Calico Hills Formation
653.8 - 658.4 m (2145 - 2160 ft)	**Lava:** Mottled moderate-yellowish-brown, grayish-red and moderate-reddish-brown; devitrified; very scarce felsic phenocrysts; rare biotite; chalcedony filled vesicles and spherules up to 5 mm in size.	mafic-poor Calico Hills Formation
658.4 - 663.9 m (2160 - 2178 ft)	**Lava:** Pale-reddish-brown; devitrified; very scarce felsic phenocrysts; rare biotite.	mafic-poor Calico Hills Formation
663.9 - 670.6 m (2178 - 2200 ft)	**Vitrophyric Lava:** Dark-gray, mottled with grayish-brown and pale-reddish-brown; perlitic in parts; very scarce felsic phenocrysts; scarce to rare biotite.	mafic-poor Calico Hills Formation
670.6 - 700.1 m (2200 - 2282 ft)	**Lava:** Generally dusky-yellow; mottled with pale-brown and pale-reddish-brown 670.6 - 688.8 m (2200 - 2260 ft); zeolitized; pumiceous; scarce feldspar phenocrysts; scarce to rare biotite; some MnO_2 spots/stains. Becoming moderate-yellowish-brown at base of interval. Top of interval based on geophysical logs. However, sidewall cores taken at 671.9 m (2204.5 ft) and 672.1 m (2205 ft) are dense, vitrophyric lava implying that this contact may be slightly deeper.	mafic-poor Calico Hills Formation

Depth Interval meters (feet)	Lithology	Stratigraphy
700.1 - 752.9 m (2282 - 2470 ft)	**Air-Fall or Nonwelded Tuff:** Grayish-yellow, some grayish-orange-pink mottling around 731.5 - 743.7 m (2400 - 2440 ft); well indurated; zeolitized; grayish-yellow and indistinct pumice; scarce felsic phenocrysts; common lithic fragments up to 2.5 cm in size, mostly grayish-red devitrified lava fragments. Zone that produces locally correlatable signature on the resistivity log at 740.7 m (2430 ft) not recognizable in cuttings samples; signature may be related to silicified, lithic-rich beds.	mafic-poor Calico Hills Formation
752.9 - 772.7 m (2470 - 2535 ft)	**Lava:** Dusky-yellow to yellowish-gray; moderate-reddish-brown stain/mottling in parts; pumiceous and zeolitized to about 763.8 m (2506 ft), becoming dense and only weakly zeolitized below about 763.8 m (2506 ft). Very scarce phenocrysts.	mafic-poor Calico Hills Formation
772.7 - 781.8 m (2535 - 2565 ft)	**Vitrophyric Lava:** Medium-light-gray to light-olive-gray; vitric to weakly zeolitic in parts; very scarce phenocrysts.	mafic-poor Calico Hills Formation
781.8 - 790.0 m (2565 - 2592 ft)	**Lava:** Light-brownish-gray to pale-red; devitrified; flow banded; very scarce phenocrysts.	mafic-poor Calico Hills Formation
790.0 - 803.1 m (2592 - 2635 ft)	**Lava:** No cuttings samples. This low-resistivity marker horizon is locally correlatable; although it is thicker at this location. Sidewall core samples at 791.0 m (2595 ft) and 794.6 m (2607 ft) are: grayish-red; devitrified; silicified with silica-filled vesicles 5 mm in size.	mafic-poor Calico Hills Formation

Depth Interval meters (feet)	Lithology	Stratigraphy
803.1 - 876.0 m (2635 - 2874 ft)	**Lava:** Generally light-brownish-gray to brownish-gray, some mottled light-brownish-gray and pale-reddish-brown and medium-dark-gray; devitrified; flow banded, becoming pumiceous below 853.4 m (2800 ft); very scarce felsic phenocrysts. No cuttings samples 786.4 - 810.8 m (2580 - 2660 ft); also, the 813.8 m (2670 ft) sample depth appears not to be credible. Three sidewall samples recovered from about 804.5 m (2639 ft).	mafic-poor Calico Hills Formation
876.0 - 887.0 m (2874 - 2910 ft)	**Vitrophyric Lava:** Olive-black; very scarce phenocrysts.	mafic-poor Calico Hills Formation
887.0 - 902.2 m (2910 - 2960 ft)	**Lava:** Light-brownish-gray to mottled pale- and moderate-yellowish-brown; devitrified to weakly zeolitized; becoming light-brown to moderate yellowish-brown 896.1 - 902.2 m (2940 - 2960 ft).	mafic-poor Calico Hills Formation
902.2 - 975.4 m (2960 - 3200 ft) TD	**Lava:** Dusky-yellow to yellowish-gray; zeolitized; pumiceous; very scarce phenocrysts.	mafic-poor Calico Hills Formation

Appendix D
Geophysical Logs for Well Cluster ER-20-6

Appendix D contains unprocessed data from geophysical logs run in the Well Cluster ER-20-6 boreholes. Tables D.1, D.2, and D.3 list the logs presented for Wells ER-20-6#1, #2, and #3, respectively. See Tables 3-4, 4-3, and 5-3 in the report for more information on logs run for these wells.

Table D.1
Geophysical Logs Presented for Well ER-20-6#1

Log Type	Log Interval meters (feet)	Run #	Run Date
Caliper	0 to 969.0 (0 to 3,179)	CA4-1	03/06/96
Compensated Density	242.6 to 914.4 (796 to 3,000)	CDL-1	03/07/96
Digital Acoustic Log	609.6 to 917.8 (2,000 to 3,011)	DAC-1	03/07/96
Dual Laterolog (Resistivity and Spontaneous Potential)	618.4 to 963.2 (2,029 to 3,160)	DLL-1	03/06/96
Gamma Ray	0 to 969.0 (0 to 3,179)	GR-1	03/06/96
Spectralog	231.6 to 917.8 (760 to 3,011)	SL-1	03/07/96
Temperature	600.5 to 916.2 (1,970 to 3,006)	TL-1	03/07/96
Total Magnetic Intensity	646.5 to 824.2 (2,121 to 2,984) 243.8 to 685.8 (800 to 2,250)	TMI-1 TMI-2	03/08/96 03/09/96
Epithermal Neutron Porosity	242.6 to 914.4 (796 to 3,000)	ENP-1	03/07/96
Thermal Flow (Electrical conductivity)	624.8 to 887.0 (2,050 to 2,910)	HPFLOW-1	03/09/96

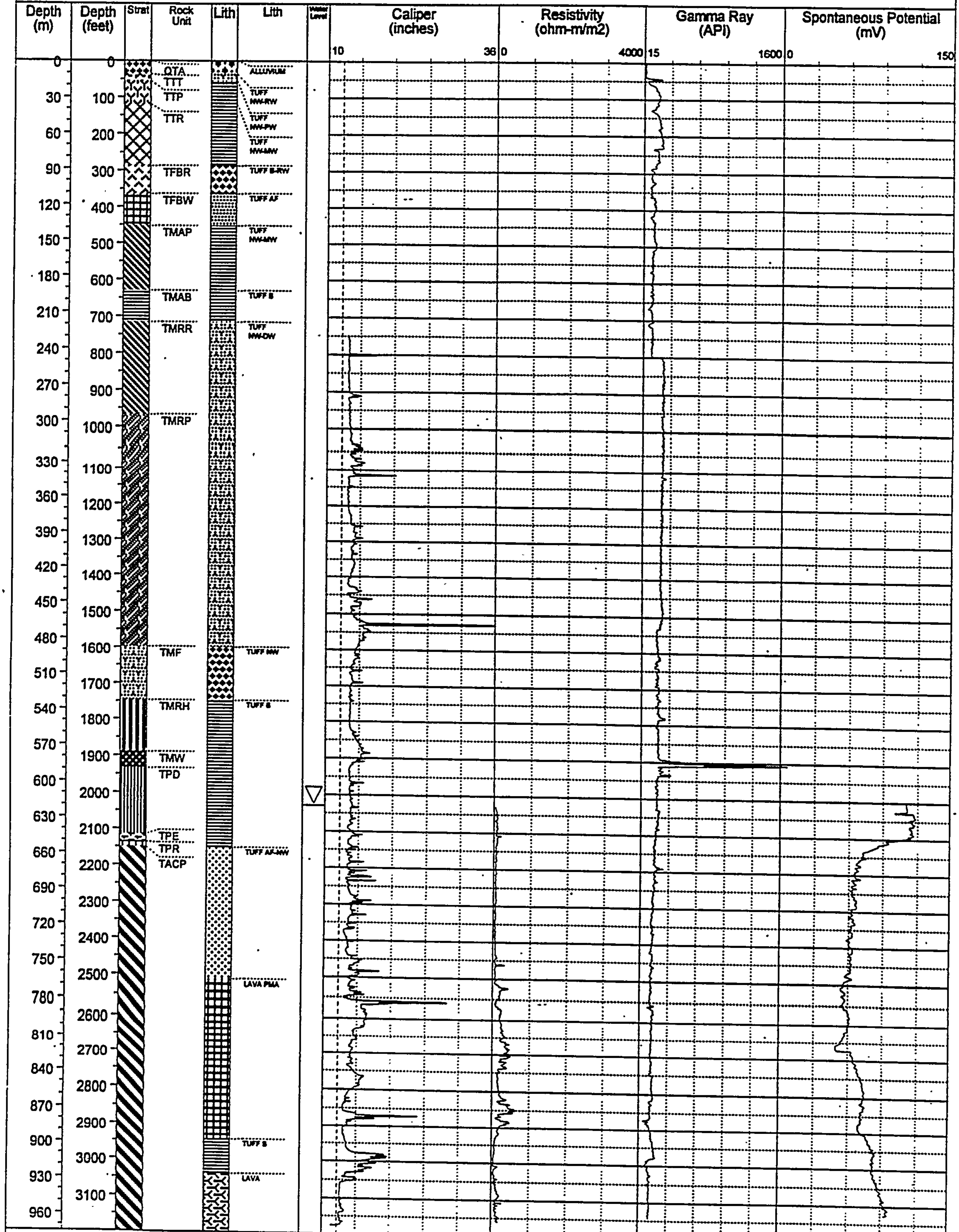
Table D.2
Geophysical Logs Presented for Well ER-20-6#2

Log Type	Log Interval meters (feet)	Run #	Run Date
Caliper	0 to 907.4 (0 to 2,977)	CA4-1	03/26/96
Compensated Density	244.4 to 905.9 (802 to 2,972)	CDL-1	03/26/96
Digital Acoustic Log	609.6 to 904.0 (2,000 to 2,966)	DAC-1	03/26/96
Dual Laterolog (Resistivity and Spontaneous Potential)	542.4 to 901.0 (1,780 to 2,956)	DLL-1	03/26/96
Gamma Ray	0 to 907.4 (0 to 2,977)	GR-1	03/26/96
Spectralog	244.4 to 893.7 (802 to 2,932)	SL-1	03/26/96
Temperature	595.3 to 907.4 (1,953 to 2,977)	TL-1	03/26/96
Total Magnetic Intensity	249.9 to 903.4 (820 to 2,964) 243.8 to 685.8 (800 to 2,250)	TMI-1 TMI-2	03/28/96 03/09/96
Epithermal Neutron Porosity	244.4 to 905.9 (802 to 2,972)	ENP-1	03/26/96
Thermal Flow (Electrical (conductivity)	624.8 to 893.1 (2,050 to 2,930)	HPFLOW-1	03/28/96

Table D.3
Geophysical Log Presented for Well ER-20-6#3

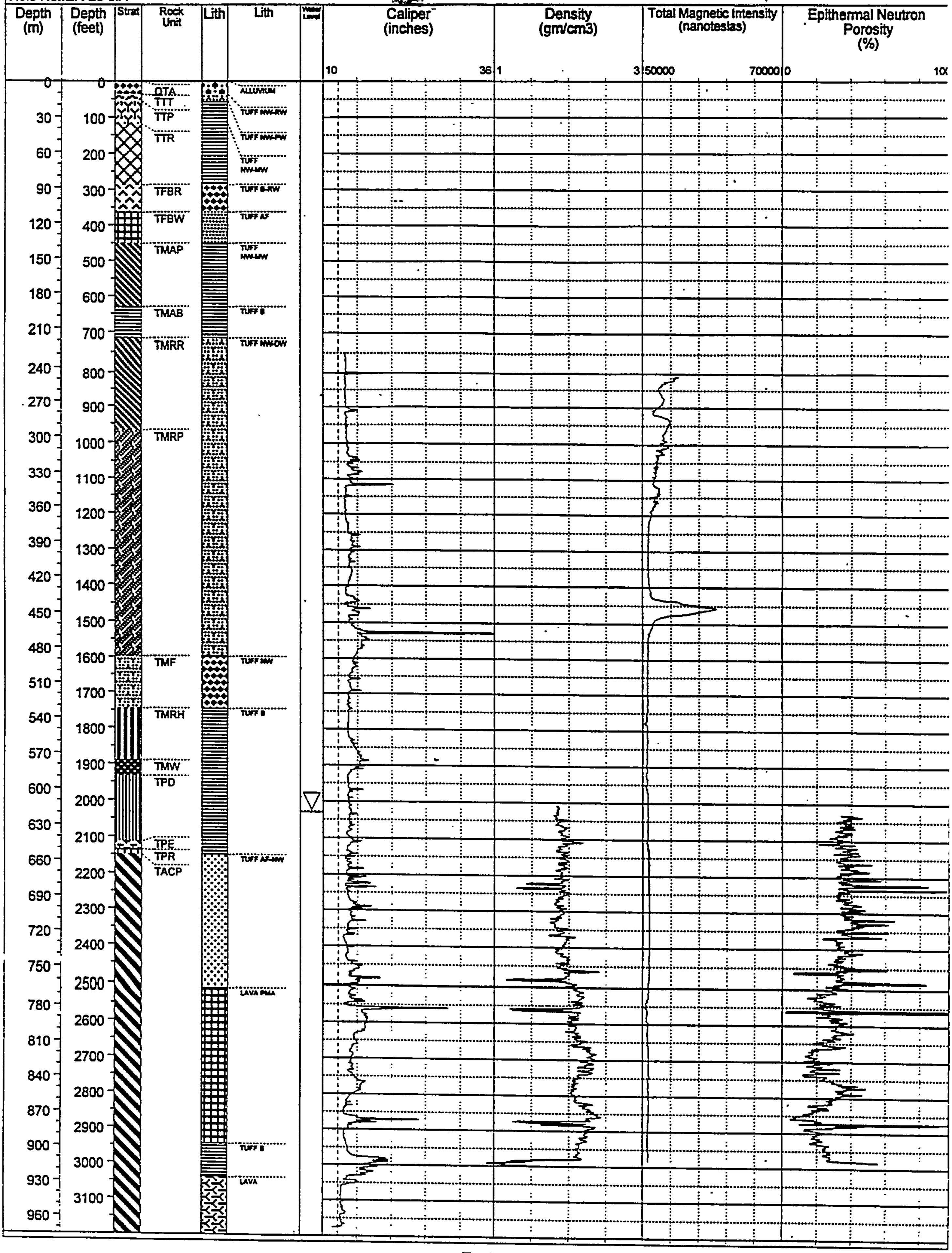
Log Type	Log Interval meters (feet)	Run #	Run Date
Caliper	0 to 899.2 (0 to 2,950)	CA4-1	04/11/96
Compensated Density	244.8 to 878.1 (803 to 2,881)	CDL-1	04/11/96
Digital Acoustic	615.7 to 859.2 (2,020 to 2,819)	DAC-1	04/12/96
Dual Laterolog (Resistivity and Spontaneous Potential)	572.7 to 892.8 (1,879 to 2,929)	DLL-1	04/11/96
Epithermal Neutron Porosity	244.8 to 878.1 (803 to 2,881)	ENP-1	04/11/96
Gamma Ray	0 to 899.2 (0 to 2,950)	GR-1	04/11/96
Spectralog	244.8 to 859.2 (803 to 2,819)	SL-1	04/12/96
Temperature	550.5 to 885.7 (1,806 to 2,906)	TLDLT-1	04/11/96
Chemistry (Electrical conductivity)	621.8 to 855.3 (2,040 to 2,806)	CHEM-1	04/13/96
Total Magnetic Intensity	248.4 to 855.3 (815 to 2,806)	TMI-1	04/13/96

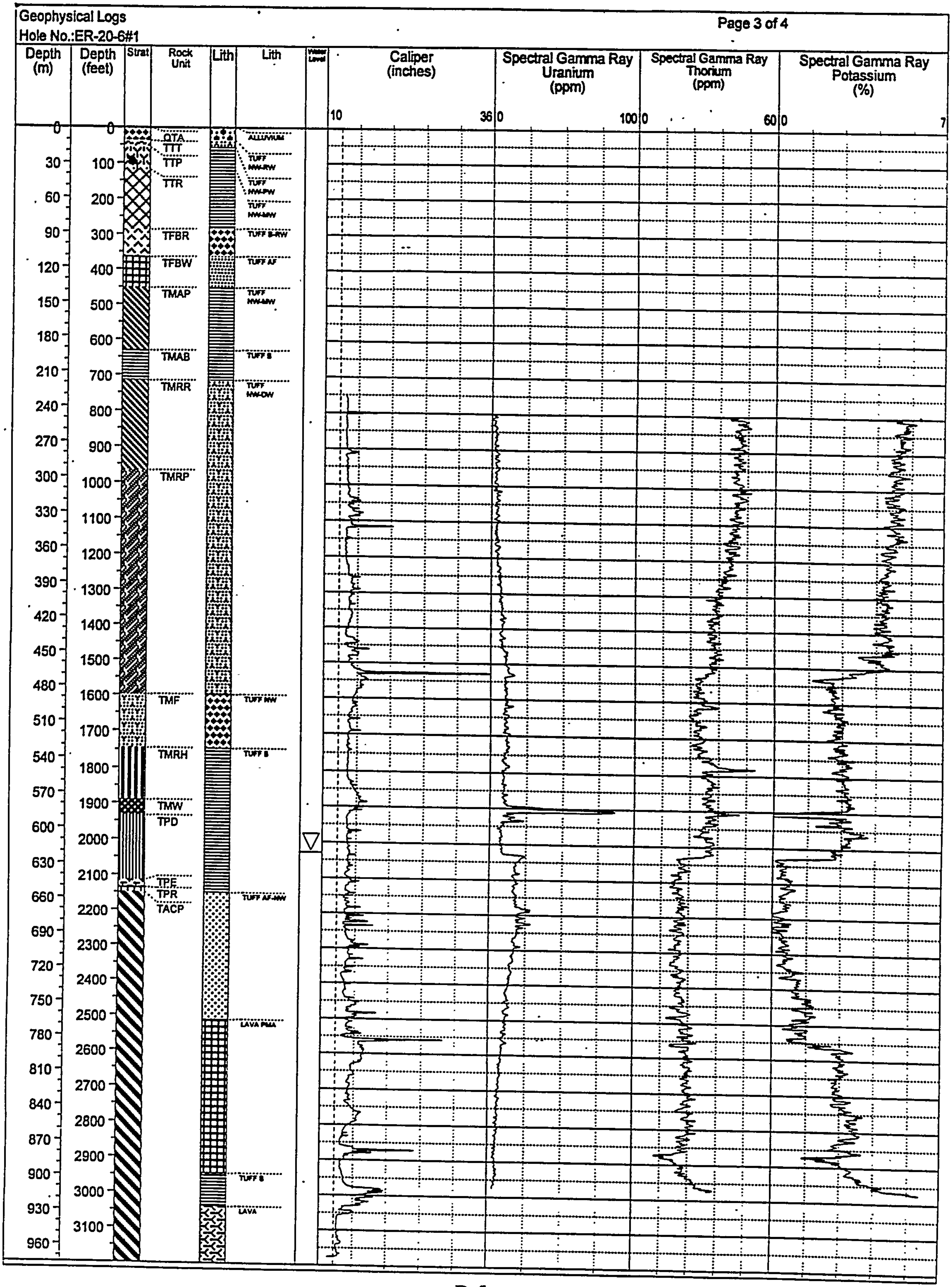
Geophysical Logs
Hole No.:ER-20-6#1



Geophysical Logs

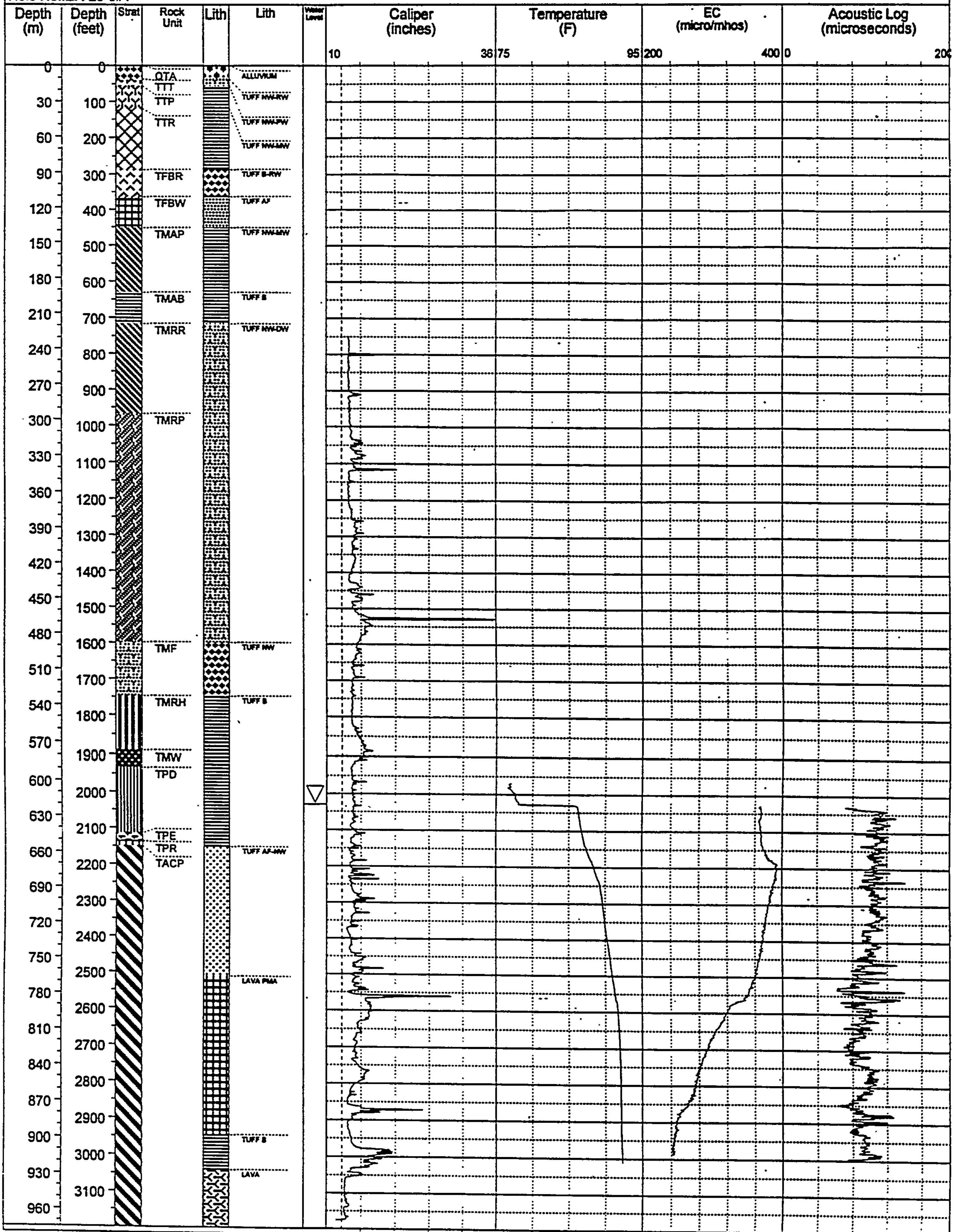
Hole No.:ER-20-6#1

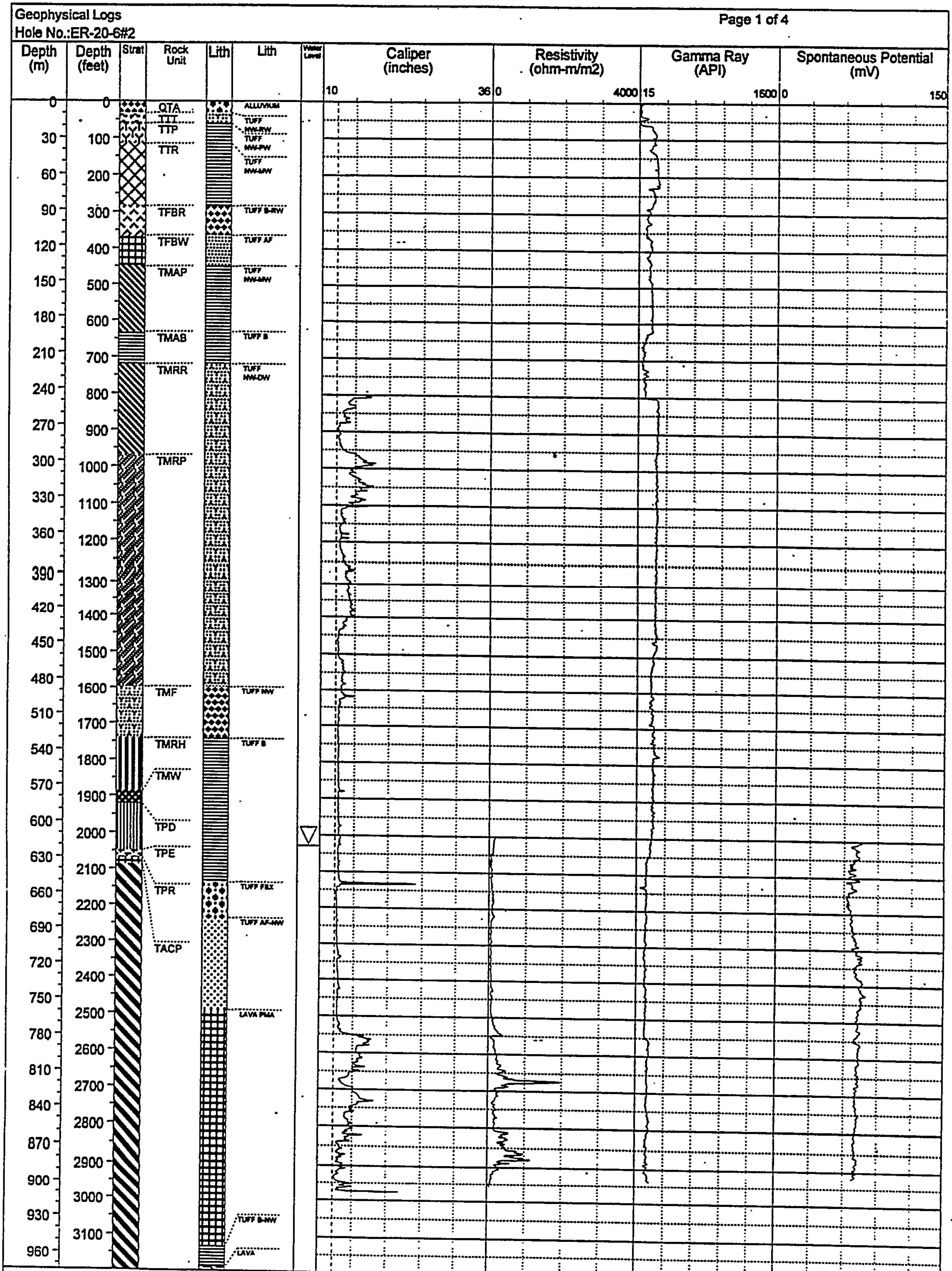




Geophysical Logs
Hole No.:ER-20-6#1
Depth (m)
Depth (feet)
Strat
Rock Unit
Lith
Lith
Water Level
Caliper (inches)
10
36
Spectral Gamma Ray Uranium (ppm)
0
100
Spectral Gamma Ray Thorium (ppm)
0
60
Spectral Gamma Ray Potassium (%)
0
7
QTA
TTT
TTP
TTR
TFBR
TFBW
TMAP
TMAB
TMRR
TMRP
TMF
TMRH
TMW
TPD
TPE
TPR
TACP
ALLUVIUM
TUFF NW-RW
TUFF NW-PW
TUFF NW-MW
TUFF B-RW
TUFF AF
TUFF NW-MW
TUFF B
TUFF NW-DW
TUFF NW
TUFF B
TUFF AF-NW
LAVA PMA
TUFF B
LAVA

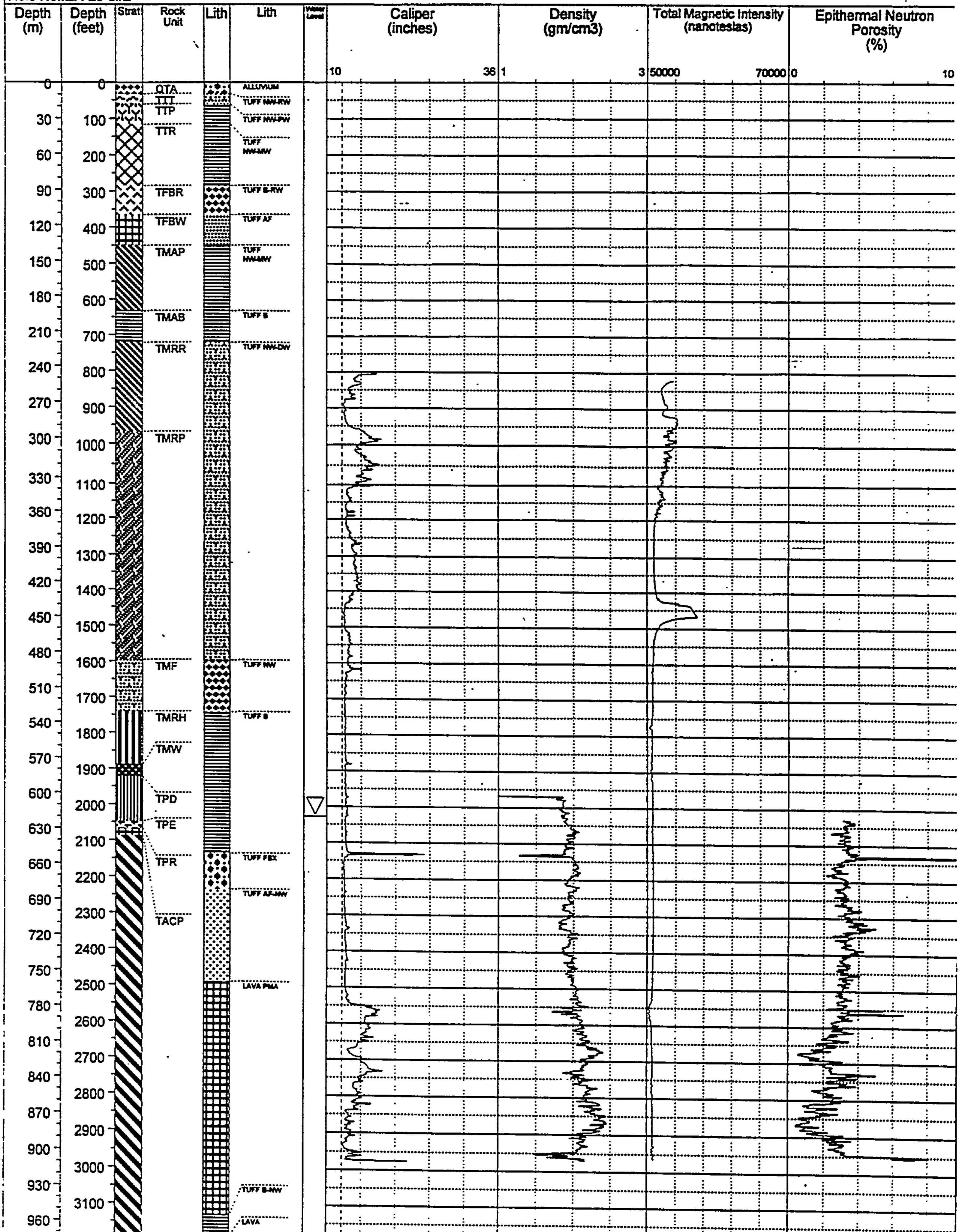
Geophysical Logs
Hole No.:ER-20-6#1



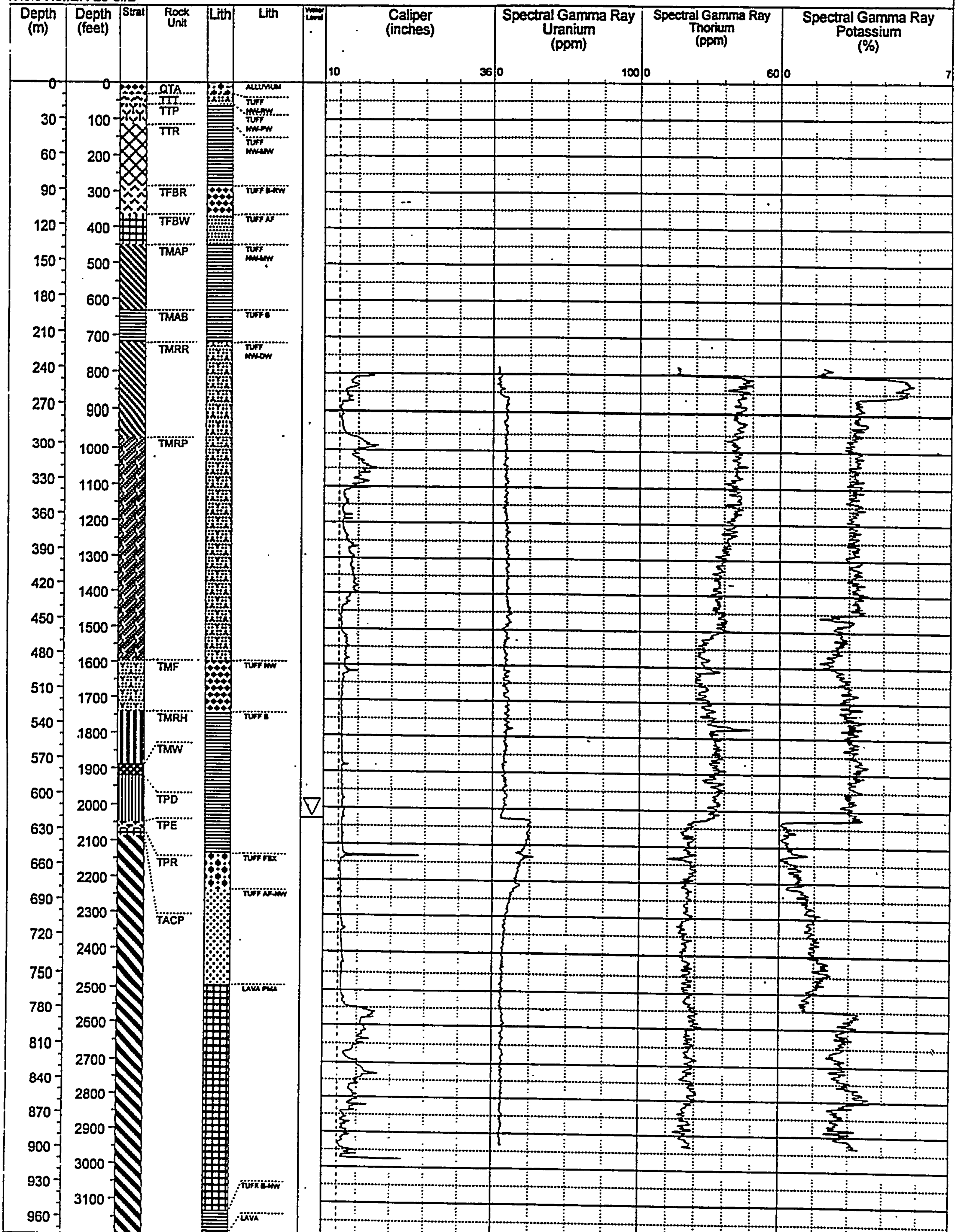

Geophysical Logs
Hole No.:ER-20-6#2
Page 1 of 4
Depth (m)
Depth (feet)
Strat
Rock Unit
Lith
Lith
Water Level
Caliper (inches)
10
36
Resistivity (ohm-m/m2)
0
4000
Gamma Ray (API)
15
1600
Spontaneous Potential (mV)
0
150
QTA
TTT
TTP
TTR
TFBR
TFBW
TMAP
TMAB
TMRR
TMRP
TMF
TMRH
TMW
TPD
TPE
TPR
TACP
ALLUVIUM
TUFF NW-RW
TUFF MW-PW
TUFF NW-MW
TUFF B-RW
TUFF AF
TUFF NW-MW
TUFF B
TUFF NW-DW
TUFF NW
TUFF B
TUFF FBX
TUFF AF-NW
LAVA PMA
TUFF B-NW
LAVA

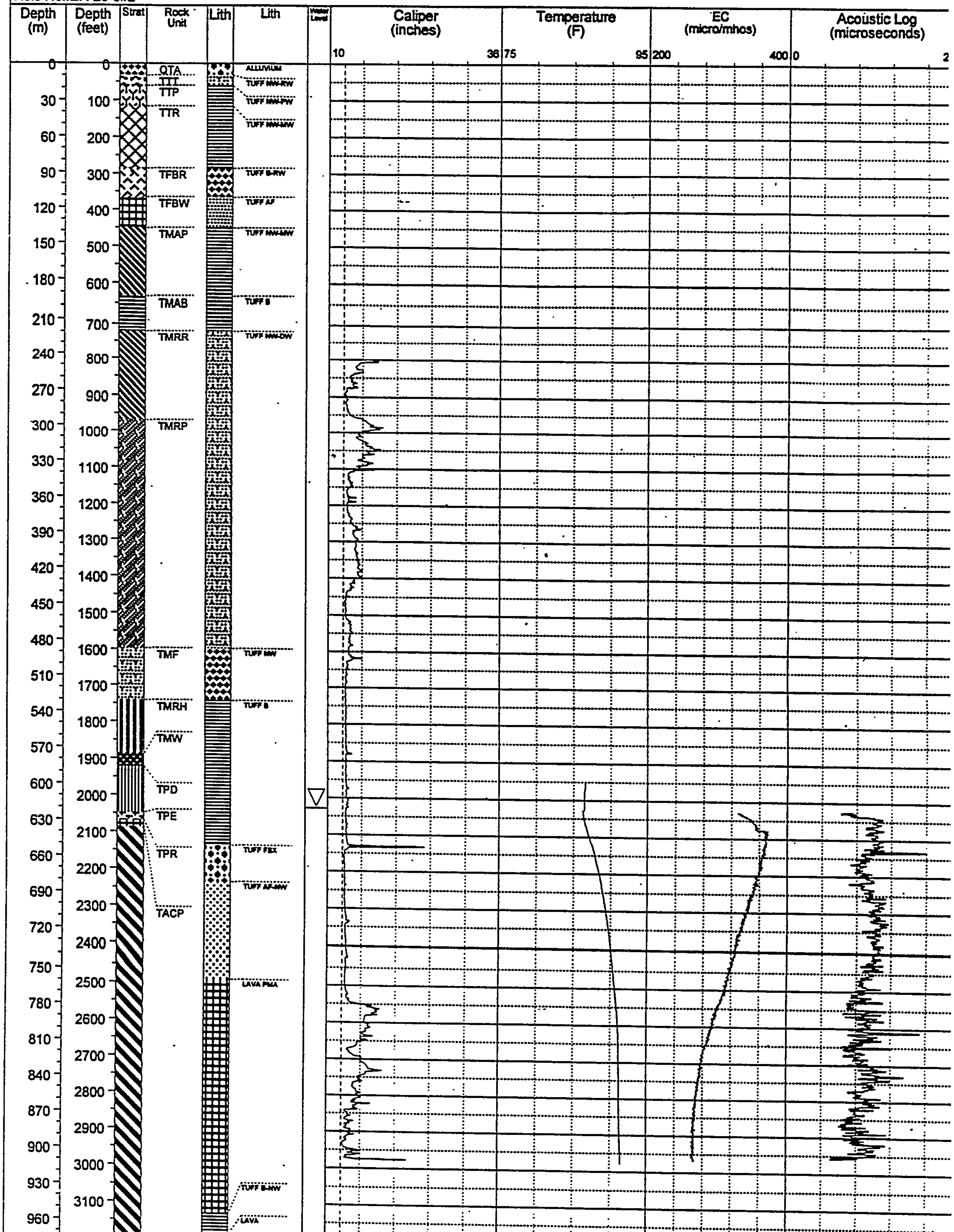
Geophysical Logs

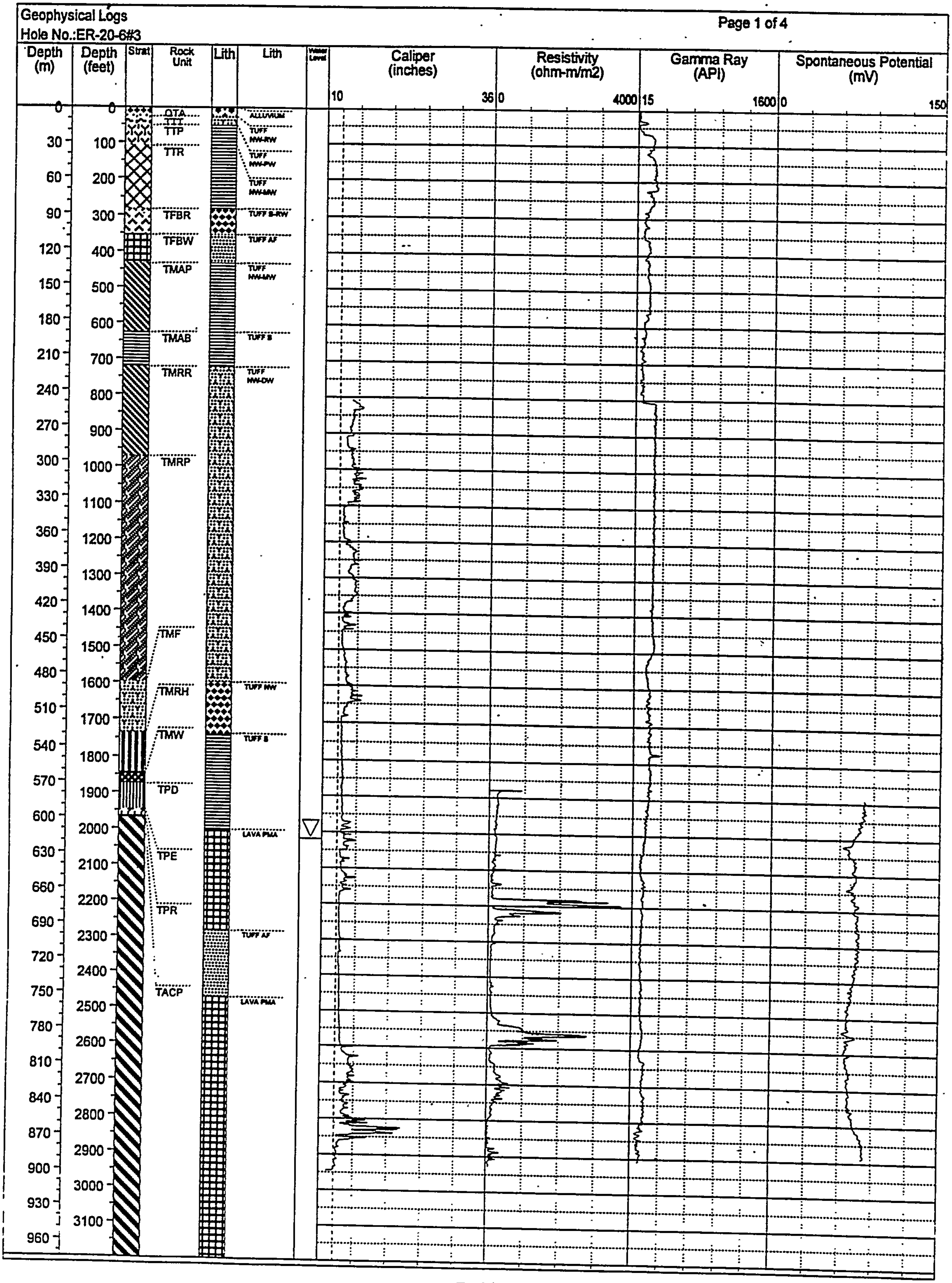
Hole No.:ER-20-6#2



Geophysical Logs
Hole No.:ER-20-6#2

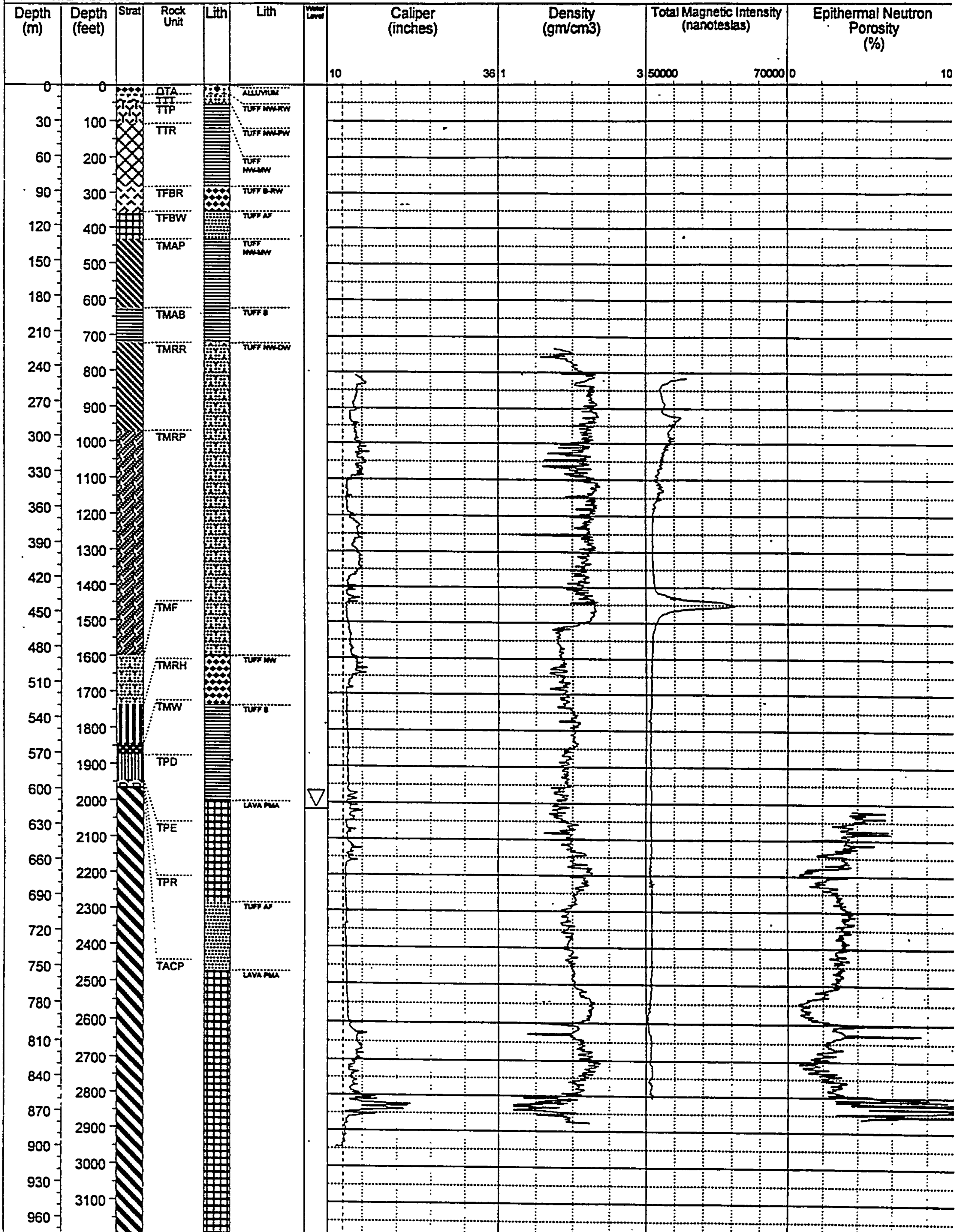


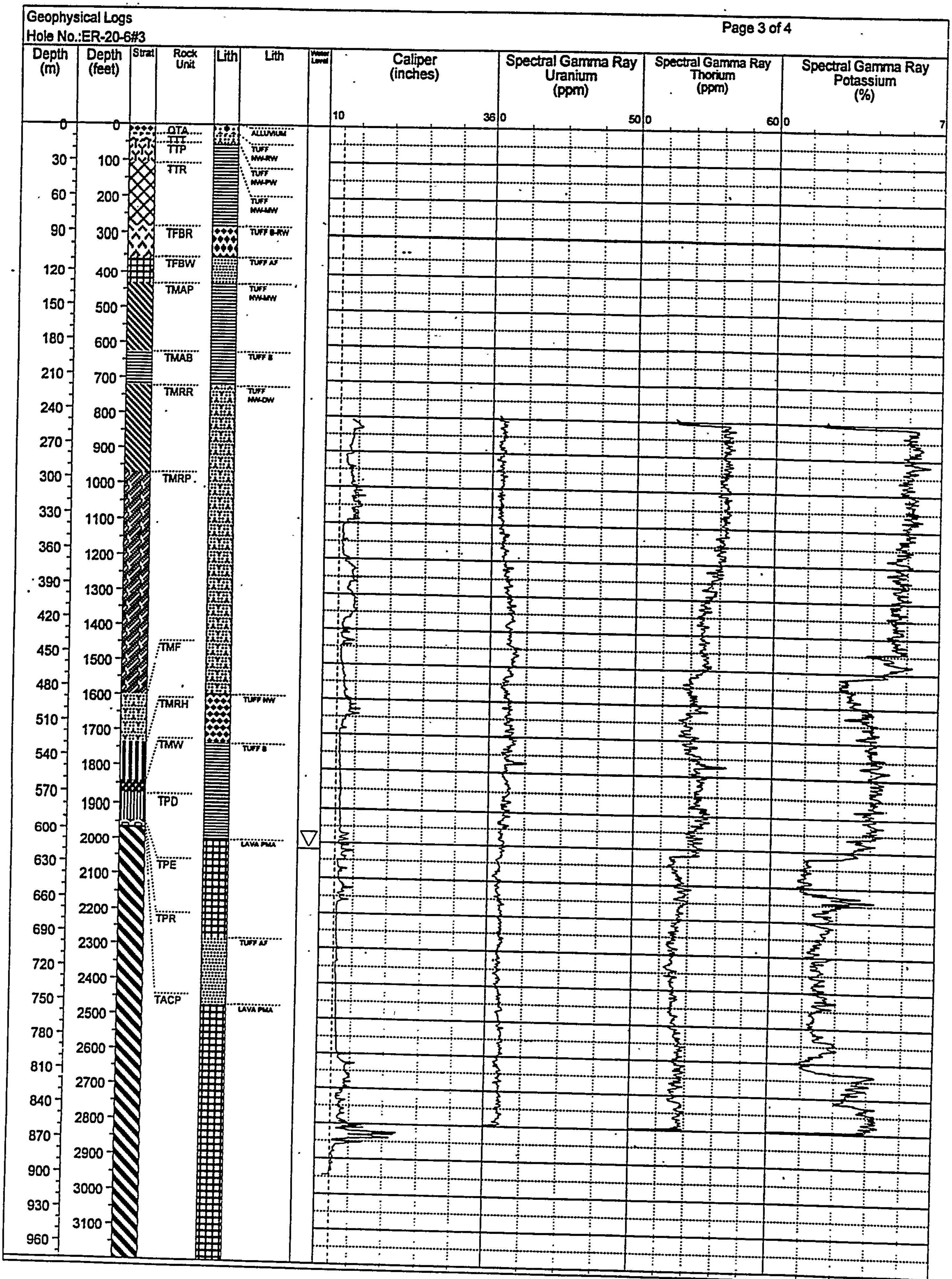

Depth (m)
Depth (feet)
Strat
Rock Unit
Lith
Lith
Water Level
Caliper (inches)
10
36
Temperature (F)
75
95
EC (micro/mhos)
200
400
Acoustic Log (microseconds)
0
QTA
TTT
TTP
TTR
TFBR
TFBW
TMAP
TMAB
TMRR
TMRP
TMF
TMRH
TMW
TPD
TPE
TPR
TACP
ALLUVIUM
TUFF NW-RW
TUFF NW-PW
TUFF NW-MW
TUFF B-RW
TUFF AF
TUFF NW-MW
TUFF B
TUFF NW-DW
TUFF NW
TUFF B
TUFF FBX
TUFF AF-NW
LAVA PMA
TUFF B-NW
LAVA


Geophysical Logs
Hole No.:ER-20-6#3
Page 1 of 4
Depth (m)
Depth (feet)
Strat
Rock Unit
Lith
Lith
Water Level
Caliper (inches)
Resistivity (ohm-m/m2)
Gamma Ray (API)
Spontaneous Potential (mV)
10
36
0
4000
15
1600
0
150
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720
750
780
810
840
870
900
930
960
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
QTA
TTT
TTP
TTR
TFBR
TFBW
TMAP
TMAB
TMRR
TMRP
TMF
TMRH
TMW
TPD
TPE
TPR
TACP
ALLUVIUM
TUFF NW-RW
TUFF NW-PW
TUFF NW-MW
TUFF S-RW
TUFF AF
TUFF NW-MW
TUFF S
TUFF NW-DW
TUFF NW
TUFF S
LAVA PMA
TUFF AF
LAVA PMA

Geophysical Logs

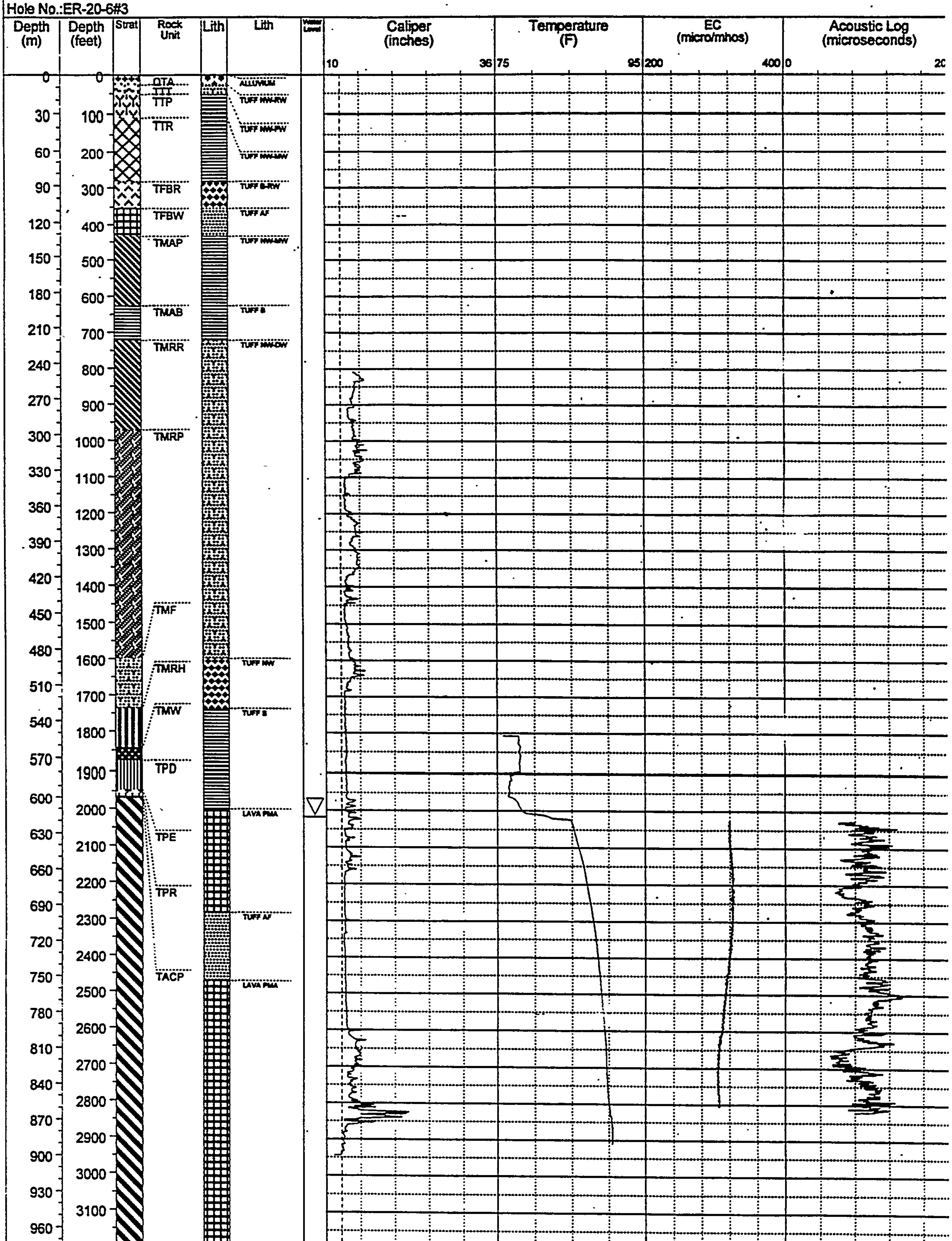
Hole No.:ER-20-6#3




Geophysical Logs
Hole No.:ER-20-6#3
Page 3 of 4
Depth (m)
Depth (feet)
Strat
Rock Unit
Lith
Lith
Water Level
Caliper (inches)
10
36
Spectral Gamma Ray Uranium (ppm)
0
50
Spectral Gamma Ray Thorium (ppm)
0
60
Spectral Gamma Ray Potassium (%)
0
7
QTA
TTP
TTR
TFBR
TFBW
TMAP
TMAB
TMRR
TMRP
TMF
TMRH
TMW
TPD
TPE
TPR
TACP
ALLUVIUM
TUFF NW-RW
TUFF NW-PW
TUFF NW-MW
TUFF B-RW
TUFF AF
TUFF NW-MW
TUFF B
TUFF NW-DW
TUFF NW
TUFF B
LAVA PMA
TUFF AF
LAVA PMA
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720
750
780
810
840
870
900
930
960
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100

Geophysical Logs

Hole No.:ER-20-6#3



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