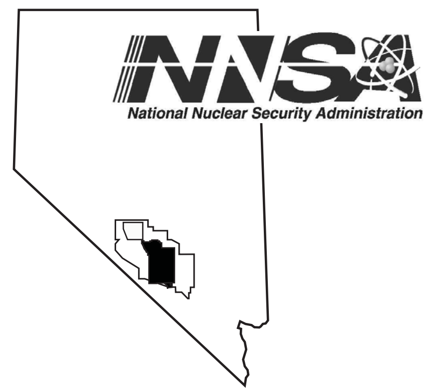
DOE/NV--1447

Nevada Environmental Restoration Project



Completion Report for Well ER-20-4

Corrective Action Units 101 and 102: Central and Western Pahute Mesa

April 2011

Environmental Restoration Project

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

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Completion Report for Well ER-20-4

Corrective Action Units 101 and 102: Central and Western Pahute Mesa

Prepared for:
U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office
Las Vegas, Nevada

Prepared by:
Underground Test Area and Boreholes Programs and Operations
National Security Technologies, LLC
Las Vegas, Nevada

April 2011

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DOE/NV--1447

Completion Report for Well ER-20-4

Corrective Action Units 101 and 102: Central and Western Pahute Mesa

Approved by: ______________________ Date: 5/2/2011

Bill R. Wilborn
Federal Sub-Project Director
Underground Test Area Project

Approved by: ______________________ Date: 5/2/11

Robert F. Boehlecke
Federal Project Director
Environmental Restoration Project

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Abstract

Well ER-20-4 was drilled for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office in support of the Nevada Environmental Restoration Project at the Nevada National Security Site, Nye County, Nevada. The well was drilled in August and September 2010 as part of the Pahute Mesa Phase II drilling program. The primary purpose of the well was to investigate the possibility of radionuclide transport from up-gradient underground nuclear tests conducted in central Pahute Mesa. This well also provided detailed hydrogeologic information in the Tertiary volcanic section that will help reduce uncertainties within the Pahute Mesa-Oasis Valley hydrostratigraphic framework model.

The main 44.5-centimeter (cm) hole was drilled to a depth of 467.9 meters (m) and cased with 34.0-cm casing to 461.9 m. The hole diameter was then decreased to 31.1 cm, and the well was drilled to a total depth of 1,066.5 m. The completion string, set to the depth of 927.7 m, consists of 16.8-cm stainless-steel casing hanging from 19.4-cm carbon-steel casing. The 16.8-cm stainless-steel casing has one continuous slotted interval that accesses a lava-flow aquifer within the lower portion of the Calico Hills zeolitic composite unit and the upper portion of the Crater Flat confining unit.

Two piezometer strings were installed in Well ER-20-4. A string consisting of 7.3-cm stainless-steel tubing was hung on 6.0-cm carbon-steel tubing via a crossover sub. This string was landed at 488.2 m to monitor groundwater within a lava-flow aquifer within the upper part of the Calico Hills zeolitic composite unit. A second string of 7.3-cm stainless-steel tubing hung on 6.0-cm carbon-steel tubing via a crossover sub was landed at 951.8 m. This deeper piezometer string was installed to monitor groundwater in the lower lava-flow aquifer within the Calico Hills zeolitic composite unit and the upper portion of the Crater Flat confining unit.

Data collected during and shortly after hole construction include composite drill cuttings samples collected every 3.0 m, sidewall core samples from 50 depth intervals, various geophysical logs, water quality (primarily tritium) measurements, and water level measurements. The well penetrated 10.7 m of Quaternary/Tertiary alluvium and 1,055.8 m of Tertiary volcanic rock, including three saturated lava-flow aquifers.

A fluid level measurement was obtained during open-hole geophysical well logging for the upper Calico Hills lava-flow aquifer at the depth of 462.1 m on August 26, 2010, after the borehole had

penetrated only a short distance into the water table. The fluid level measured in the open hole on September 20, 2010, after the total depth was reached, was measured at the depth of 463.8 m. On October 25, 2010, a fluid level of 463.6 m was measured in both the shallow and deep piezometer strings. Preliminary field measurements indicated that tritium values were less than the minimum detectable concentration during the drilling of the borehole. Laboratory analyses on depth-discrete samples confirm that tritium is not present in the target aquifers encountered in this well.

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List of Tables

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List of Acronyms and Abbreviations

BN	Bechtel Nevada
BRA	Belted Range aquifer
CAIP	Corrective Action Investigation Plan
CAU	Corrective Action Unit
CBIL	Circumferential Borehole Imaging Log
CFCM	Crater Flat composite unit
CFCU	Crater Flat confining unit
CHZCM	Calico Hills zeolitic composite unit
cm	centimeter(s)
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DRI	Desert Research Institute
FAWP	Field Activity Work Package
FFACO	Federal Facility Agreement and Consent Order
FMP	Fluid Management Plan
ft	foot (feet)
HFM	hydrostratigraphic framework model
HSU	hydrostratigraphic unit
id	inside diameter
in.	inch(es)
km	kilometer(s)
LANL	Los Alamos National Laboratory
LFA	lava-flow aquifer
LLNL	Lawrence Livermore National Laboratory
m	meter(s)
Ma	million years ago
mi	mile(s)
NAD	North American Datum
NAIL	nuclear annular investigation log
NARA	National Archives and Records Administration
NNES	Navarro Nevada Environmental Services, LLC
N-I	Navarro-Intera, LLC

List of Acronyms and Abbreviations (continued)

NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NNSS	Nevada National Security Site
NSTec	National Security Technologies, LLC
NTMMSZ	northern Timber Mountain moat structural zone
od	outside diameter
PM–OV	Pahute Mesa–Oasis Valley
SCCC	Silent Canyon caldera complex
SNJV	Stoller-Navarro Joint Venture
TD	total depth
TMCC	Timber Mountain caldera complex
TWG	Technical Working Group
UDI	United Drilling, Incorporated
UGT	underground nuclear test
UGTA	Underground Test Area
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

1.0 Introduction

1.1 Project Description

Well ER-20-4 was drilled for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office (NNSA/NSO) in support of the Nevada Environmental Restoration Project at the Nevada National Security Site (NNSS; formerly the Nevada Test Site), Nye County, Nevada. Well ER-20-4 was the sixth well to be drilled as part of the Underground Test Area (UGTA) Sub-Project Phase II hydrogeologic investigation well-drilling program in the southwestern Pahute Mesa area. It was the second well of the second drilling campaign of the Phase II drilling program, and was constructed in the spring of 2010.

The Pahute Mesa Phase II drilling program is part of the Corrective Action Investigation Plan (CAIP) for the Central and Western Pahute Mesa Corrective Action Units (CAUs) 101 and 102 (NNSA/NSO, 2009a). The CAIP is a requirement of the *Federal Facility Agreement and Consent Order* (FFACO) (1996, as amended March 2010).

The Central and Western Pahute Mesa CAUs and the associated well drilling program are part of the NNSA/NSO Environmental Restoration Project's UGTA Sub-Project at the NNSS. Two of the goals of the UGTA Sub-Project are to evaluate the nature and extent of contamination in groundwater due to historic underground nuclear testing and to establish a long-term groundwater monitoring network. As part of the UGTA Sub-Project, scientists are developing computer models to predict groundwater flow and contaminant migration within and near the NNSS. To build and test these models, it is necessary to collect geologic, geophysical, and hydrologic data from new and existing wells to define groundwater quality, migration pathways, and migration rates. Data from these wells will allow for more accurate modeling of groundwater flow and radionuclide migration in the region. Some of the wells may be used as long-term monitoring wells.

Well ER-20-4 is located in southern Area 20 of the NNSS (Figure 1-1). The primary purpose of this well was to investigate transport pathways from central Pahute Mesa along the West Greeley fault and off Pahute Mesa (Figure 1-2). Detailed hydrogeologic information for the Tertiary volcanic section obtained from this well will help address uncertainties within the Phase I Pahute Mesa–Oasis Valley (PM–OV) hydrostratigraphic framework model (HFM) (Bechtel Nevada [BN], 2002) and aid the planned revision of the model. These data will also improve subsequent flow and transport modeling efforts for Phase II.

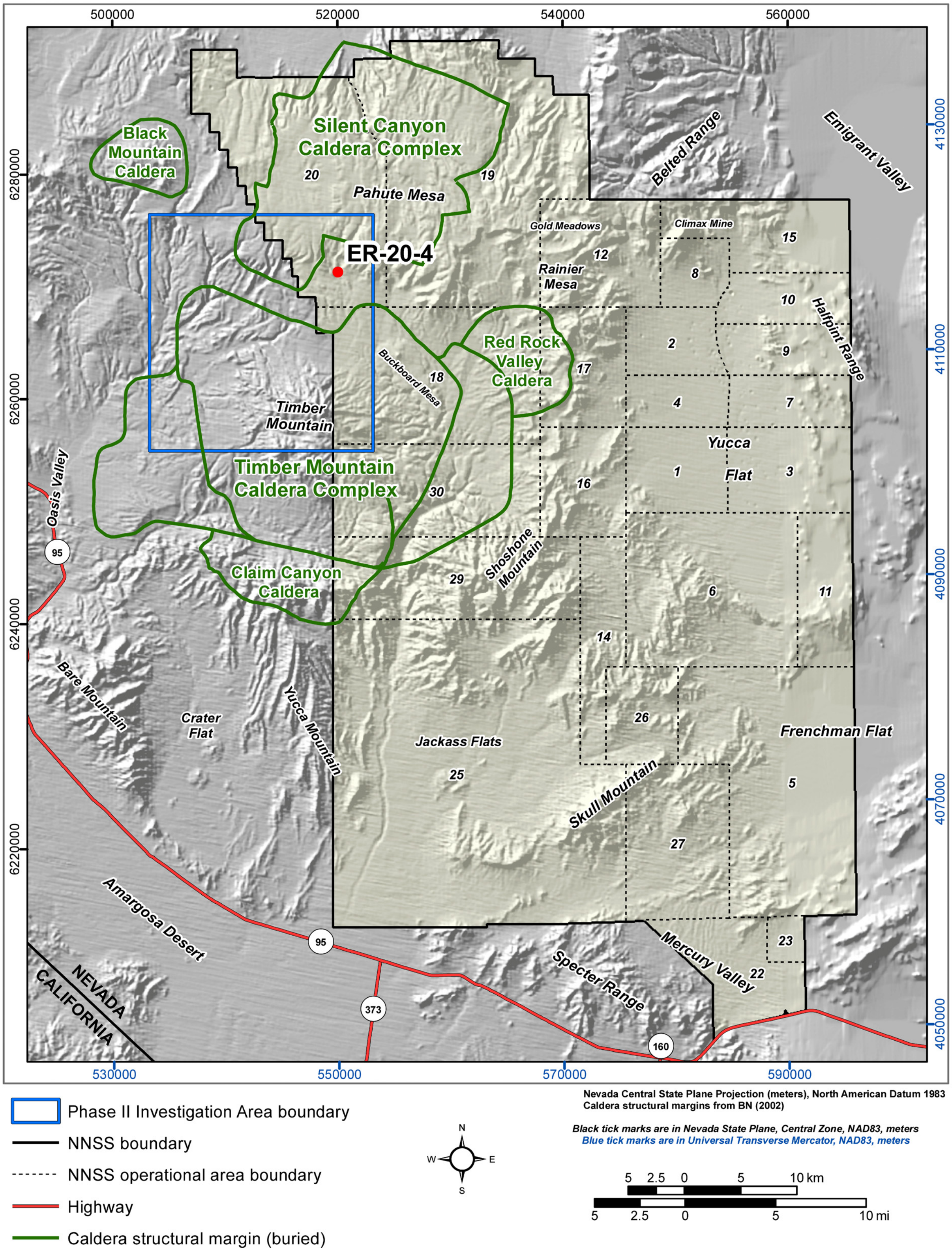


Figure 1-1
Reference Map Showing the Location of Well ER-20-4

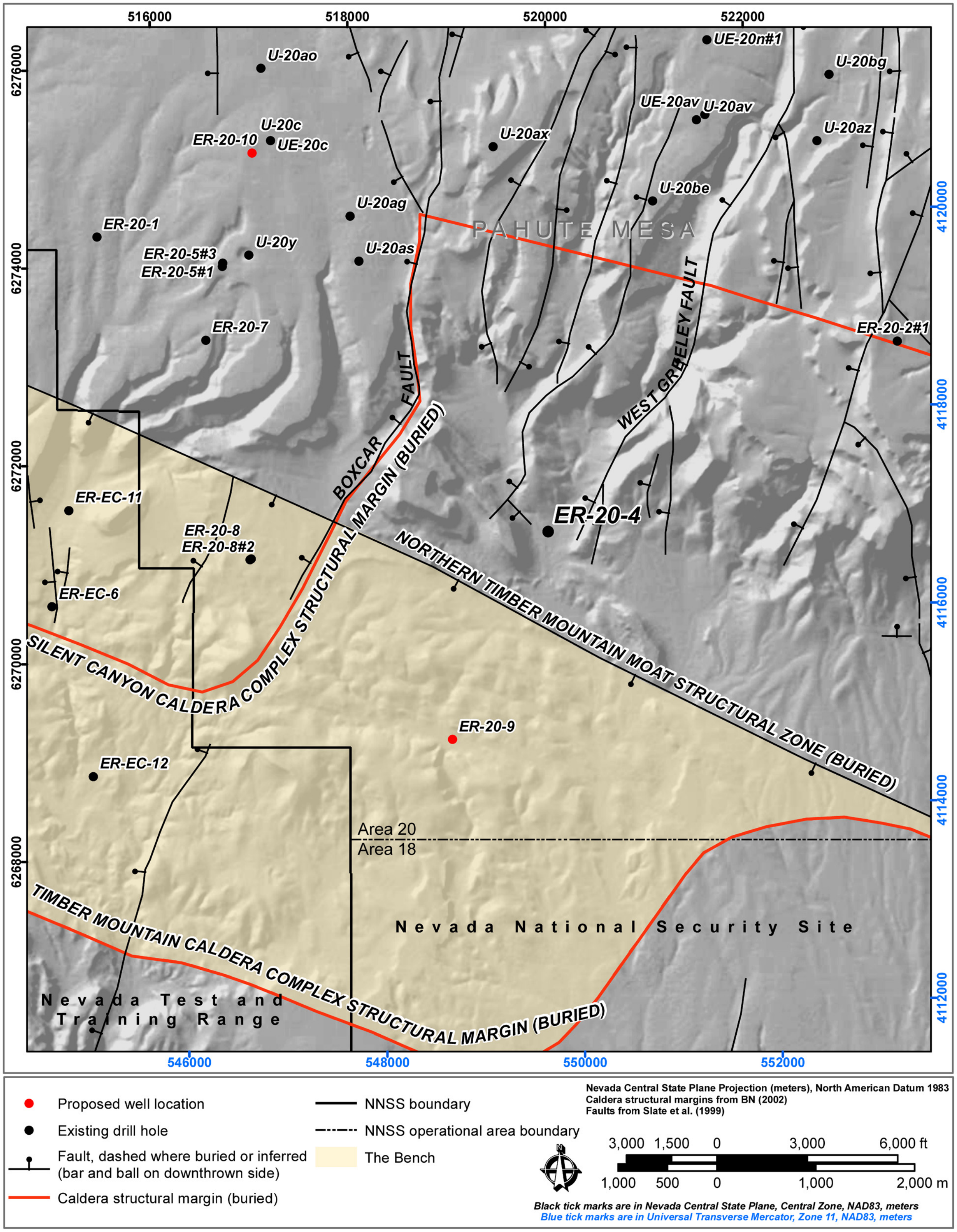


Figure 1-2
Shaded Relief Map of the Well ER-20-4 Location Showing Important Geologic Features

1.2 Project Organization

The construction of Well ER-20-4 was intended to help fulfill the goals of the UGTA Sub-Project. Several groups function within the sub-project, whose responsibilities include ensuring that the sub-project goals are properly planned and achieved. The roles of these groups regarding successful construction of Well ER-20-4 are described in this section.

The UGTA Technical Working Group (TWG) is a committee of scientists and engineers from NNSA/NSO, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), the Nevada Division of Environmental Protection, the Desert Research Institute (DRI), the U.S. Geological Survey (USGS), Navarro-Intera, LLC (N-I) (formerly Stoller-Navarro Joint Venture [SNJV] and, most recently, Navarro Nevada Environmental Services, LLC [NNES]), and National Security Technologies, LLC (NSTec). The TWG has responsibility for providing technical advice and recommendations to the UGTA Sub-Project manager to promote the effective closure of UGTA CAUs on the NNSS and ensure the continuing protection of the public health. The TWG's Pahute Mesa CAU Guidance Team and the TWG CAIP subcommittee assisted NNSA/NSO in developing the CAIP for the Pahute Mesa CAUs. The TWG's Well ER-20-4 Drilling Advisory Team, which included the NNSA/NSO UGTA Sub-Project manager, the N-I (environmental contractor) field manager, the NSTec (NNSS management and operating contractor) UGTA manager/drilling engineer, a hydrologist, a geologist, and a radio-chemist, provided technical advice during drilling, design, and construction of the well to ensure that Well ER-20-4 was constructed to meet scientific objectives identified in the CAIP and the drilling criteria. See *Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria* (SNJV, 2009a) for descriptions of the general plan and goals of the Pahute Mesa Phase II drilling initiative project, as well as specific goals for each well.

N-I was the principal environmental contractor for the project, and N-I personnel collected geologic and hydrologic data during drilling. Site supervision, engineering, construction, inspection, and geologic support were provided by NSTec. The drilling company was United Drilling, Incorporated (UDI), a subcontractor to NSTec. The roles and responsibilities of these and other contractors involved in the project are described in NSTec subcontract number 107553 and in field activity work packages (FAWPs) number D-003-001.10 and number D-007-001.10 (NSTec, 2010a; 2010b).

General guidelines for managing fluids used and generated during drilling, completion, and testing of UGTA wells are provided in the UGTA Fluid Management Plan (FMP)

(NNSA/NSO, 2009b). Estimates of expected production of fluid and drill cuttings for the Pahute Mesa holes are given in Appendix O of the drilling and completion criteria document for the drilling project (SNJV, 2009a), along with sampling requirements and contingency plans for management of any hazardous waste produced. All activities were conducted according to specific FAWPs (e.g., NSTec, 2010a and 2010b; NNES, 2010a]) and the UGTA Project Health and Safety Plan, Revision 2 (NSTec, 2008).

This report presents construction data and summarizes scientific data gathered during the drilling of Well ER-20-4. Some of the information in this report is preliminary and unprocessed, but is being released with the drilling and completion data for convenient reference. A well data report prepared by N-I contains additional information on fluid management, waste management, and environmental compliance for the project (N-I, 2011). Hydrogeologic information for this area is presented in the data documentation package for the PM–OV HFM prepared by BN (2002). Documentation for Phase I flow and transport modeling, which guided this Phase II data collection activity, can be found in SNJV (2006, 2007, and 2009b). Pre-drilling geologic information for this area (including any changes in the geologic interpretation since completion of the PM–OV HFM [BN, 2002]) is compiled in the Phase II drilling criteria document (SNJV, 2009a). Information on well development, aquifer testing, and groundwater analytical sampling (which are outside the scope of this report) are typically compiled and disseminated separately.

1.3 Location and Significant Nearby Features

Well ER-20-4 is located in NNSS Area 20 at an elevation of 1,748.3 meters (m) (5,736 feet [ft]). It is located just south of the southern edge of Pahute Mesa, approximately 4.0 kilometers (km) (2.5 miles [mi]) east-southeast of Well ER-20-7 (NNSA/NSO, 2010a), 4.3 km (2.7 mi) southeast of Well Cluster ER-20-5 (U.S. Department of Energy, Nevada Operations Office [DOE/NV], 1997), 4.0 km (2.5 mi) southwest of Well ER-20-2#1 (BN, 1997), and 3.1 km (1.9 mi) east-northeast of Well ER 20-8 (NNSA/NSO, 2011a). The locations of these features in relation to Well ER-20-4 are shown in Figures 1-2 and 1-3. Additional information about Well ER-20-4 is provided in Table 1-1.

Well ER-20-4 is located along the eroded and dissected south face of Pahute Mesa, though the immediate area is relatively flat. Drainage is generally to the south into Fortymile Canyon (Figures 1-2 and 1-3).

Table 1-1
Well ER-20-4 Site Data Summary

Site Coordinates [a]	**Nevada State Plane (Central Zone) (NAD 27)** N 890,183.2 ft E 565,940.3 ft **Nevada State Plane (Central Zone) (NAD 83)** N 6,271,329.1 m E 520,019.2 m **UTM (Zone 11) (NAD 83)** N 4,116, 689.7 m E 549,596.1 m **UTM (Zone 11) (NAD 27)** N 4,116,492.5 m E 549,676.2 m **Geographic (NAD 83)** (degrees, minutes, seconds) Latitude: 37° 11' 43" Longitude: 116° 26' 28" **Township and Range** Southwest ¼ of Southwest ¼ of Section 31, Township 8 South, Range 50 East
Surface Elevation [a, b]	1,748.4 m (5,736.1 ft)
Drilled Depth	1,066.5 m (3,499 ft)
Fluid-Level Depth [c]	463.6 m (1,521.1 ft)
Fluid-Level Elevation	1,284.7 m (4,215.0 ft)
Surface Geology	Alluvium (young alluvial deposits [Qay])

a Measurements made by NSTec Survey using NAD 27 Nevada State Plane coordinates in feet. All other coordinates listed were calculated from NAD 27 feet using Corpscon (U.S. Army Corps of Engineers, 2004). NAD = North American Datum (National Archives and Records Administration [NARA], 1989; U.S. Coast and Geodetic Survey, 1927). UTM = Universal Transverse Mercator.

b Measurement made by NSTec Survey. Elevation above mean sea level at top of construction pad. National Geodetic Vertical Datum, 1929 (NARA, 1973).

c Measured in the shallow and deep piezometer strings by N-I on October 25, 2010.

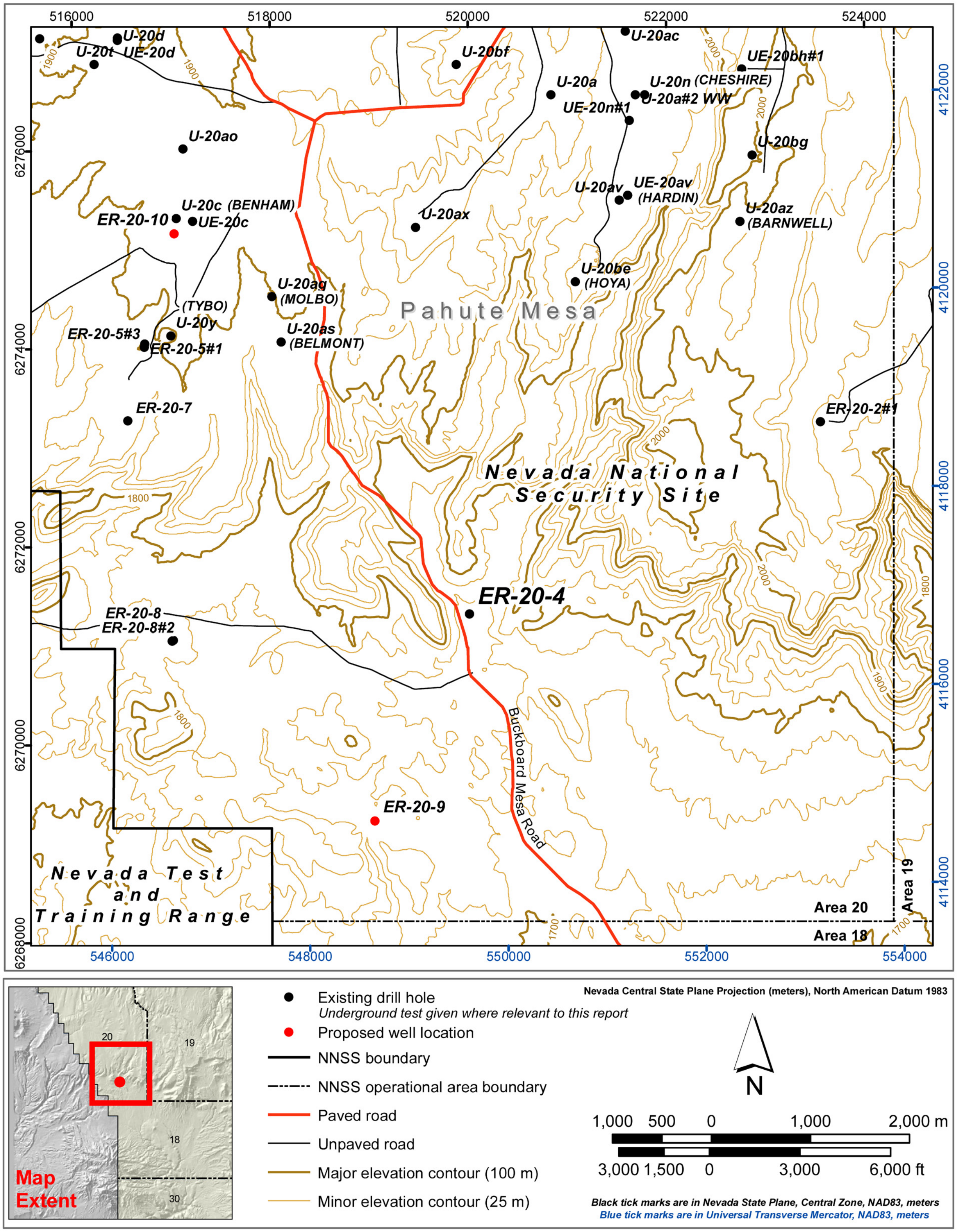


Figure 1-3
Topographic Map of the Well ER-20-4 Area Showing the Locations of Roads and Nearby Drill Holes

The closest underground nuclear tests (UGTs) to Well ER-20-4 are BELMONT (U-20as), HOYA (U 20be), MOLBO (U-20ag), and TYBO (U-20y) (Figure 1-3). Three of these tests were conducted below the water table, and BELMONT was conducted approximately 8.8 m (29 ft) above the water table. Well ER-20-4 is sited approximately 3,322.3 m (10,900 ft) southeast of the BELMONT test location and approximately 3,505.2 m (11,500 ft) southwest of the HOYA UGT. Table 1-2 provides information pertaining to these tests.

1.4 Objectives

The primary purpose for Well ER-20-4 is to investigate transport paths from central Pahute Mesa along the West Greeley fault and off of Pahute Mesa.

An important secondary objective is to obtain information that will help characterize the hydrogeology of southern Pahute Mesa (SNJV, 2009a; NNES, 2010b). Well ER-20-4 was expected to produce data that will improve flow and transport modeling within CAUs 101 and 102. The Well ER-20-4 location may be a favorable location for a long-term monitoring well.

The objectives for Well ER-20-4, as described in Appendix K of the addendum to the drilling and completion criteria document for the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells (NNES, 2010b), are listed below, along with well-specific activities necessary to accomplish the objectives:

1. Investigate the possibility that contaminants have been transported down-gradient from UGTs in central Pahute Mesa and possibly along the West Greeley fault.

2. Characterize the hydrogeology of southern Pahute Mesa to reduce uncertainties within the southern Pahute Mesa area of the PM–OV HFM. In particular, data from the well are expected to aid in accomplishing the following specific goals:

   – Refine the location of the northern Timber Mountain moat structural zone (NTMMSZ) and characterize the West Greeley fault.

   – Provide detailed hydrogeologic information for the shallow- to moderate-depth Tertiary volcanic section.

   – Provide detailed geology and configuration of aquifer units in the upper portion of the saturated section where contaminant transport is most likely.

3. Obtain hydraulic properties such as detailed fracture data and hydrologic information for the saturated units encountered, to improve subsequent flow and transport modeling for the area between the former test areas at Pahute Mesa and the Timber Mountain caldera complex (TMCC).

Table 1-2
Information for Underground Nuclear Tests Relevant to Well ER-20-4

Emplacement Hole Name	Test Name [a]	Test Date [a]	Surface Elevation [b] meters (feet)	Working Point		Regional Water Level		Announced Yield [a] (kilotons)	Working Point Formation [c, d]	Working Point HSU [c, e]
				Depth [b] meters (feet)	Elevation meters (feet)	Depth [b] meters (feet)	Elevation meters (feet)			
U-20as	BELMONT	10/16/1986	1,898 (6,227)	605 (1,985)	1,293 (4,242)	614 (2,014)	1,284 (4,213)	20–150	Tpb(b)	UPCU
U-20be	HOYA	9/11/1991	1,951 (6,401)	658 (2,159)	1,293 (4,242)	657 (2,156)	1,294 (4,245)	150	Th	CHZCM
U-20ag	MOLBO	2/12/1982	1,900 (6,234)	638 (2,093)	1,262 (4,141)	619 (2,031)	1,281 (4,203)	20–150	Tpb	BA
U-20y	TYBO	5/14/1975	1,907 (6,257)	765 (2,510)	1,142 (3,747)	630 (2,067)	1,277 (4,190)	200–1,000	Tpt	TSA

a DOE/NV, 2000a
b NNSA/NSO, 2009a
c BN, 2002

d Stratigraphic nomenclature:
- **Tpt** = Topopah Spring Tuff
- **Tpb(b)** = rhyolite of Benham, bedded
- **Tpb** = rhyolite of Benham
- **Th** = Calico Hills Formation

e HSU = Hydrostratigraphic unit
HSU nomenclature:
- **TSA** = Topopah Spring aquifer
- **UPCU** = upper Paintbrush confining unit
- **BA** = Benham aquifer
- **CHZCM** = Calico Hills zeolitic composite unit

The following activities are necessary to accomplish these goals:

- Collect drill cuttings and other geologic samples for geologic evaluation and for detailed mineralogic analysis. The mineralogic data will help define the vertical distribution of reactive minerals such as clays, zeolites, and iron oxides in the Tertiary volcanic section.
- Obtain geophysical log data from the borehole, including image logs for fracture identification and other logs for lithologic and stratigraphic identification and interpretation of rock properties.
- Collect aqueous geochemistry samples for analysis to determine whether tritium and other radionuclides have migrated to the well location. These analyses will also make it possible to better define potential groundwater flow paths based on water chemistry.
- Obtain detailed water-level data to determine the regional water level and investigate potential local groundwater flow down-gradient from central Pahute Mesa UGTs.

Additional data that will help characterize the hydrology in southern Pahute Mesa will be obtained during later hydraulic testing at this well. Specific criteria for these later tests will be provided elsewhere (e.g., FAWPs and the Well Development and Testing Plan), but, ultimately, Well ER-20-4 is expected to provide data for determination of horizontal and vertical conductivity and hydraulic properties of saturated hydrostratigraphic units (HSUs) penetrated.

The completed well will accommodate single-well hydraulic testing and will be used as a water-level observation well for future multiple-well aquifer tests.

1.5 Project Summary

This section summarizes Well ER-20-4 construction operations; the details are provided in Sections 2.0 through 7.0 of this report.

A 91.4-centimeter (cm) (36-inch [in.]) diameter surface conductor hole was constructed by drilling to a depth of 17.7 m (58 ft) and installing a string of 20-in. conductor casing to the depth of 17.4 m (57 ft). Drilling of the main hole with a 17½-in. tricone bit, using an air-foam/polymer drill fluid in conventional circulation, began on August 21, 2010. The stratigraphic units encountered in the upper part of the drill hole were thicker than expected and an unexpected lava-flow aquifer (LFA) was encountered within the upper part of the Calico Hills Formation. About 140.2 m (460 ft) of this lava flow is saturated. The surface casing was set as planned, slightly above the static water level. The 13⅜-in. surface casing was set at 461.9 m (1,515.5 ft) on August 27, 2010, after geophysical logging was completed.

The main hole was drilled with a 12¼-in. bit using air-foam to a total depth (TD) of 1,066.5 m (3,499 ft), which was reached on September 3, 2010. The target aquifer, the welded Grouse Canyon Tuff, was not encountered, but a second lava flow was penetrated within the Calico Hills Formation, and it was decided to set the main completion string in this aquifer. The static water level was measured at 463.8 m (1,521.5 ft) after installation of the main completion casing.

The open-hole fluid level was measured at the depth of 463.6 m (1,521 ft) on September 5, 2010, during geophysical logging conducted prior to installation of the completion string.

Composite drill cuttings were collected every 3.0 m (10 ft) from the depth of 18.3 m (60 ft) to TD, and 50 sidewall core samples were recovered at various depths between 76.2 and 1,063.8 m (250 and 3,490 ft). Open-hole geophysical logging of the well was conducted in two stages to help verify the geology and characterize the hydrologic properties of the rocks; some logs also aided in the construction of the well by indicating borehole volume and condition. The well was drilled entirely within Tertiary volcanic rocks.

The well was completed with a string of 6⅝-in. stainless-steel casing suspended from 7⅝-in. carbon-steel casing, which terminated 11.9 m (39 ft) above the water level. The completion casing was landed at 927.7 m (3,043.5 ft). The 6⅝-in. casing is slotted in the interval 755.6 to 914.9 m (2,479.0 to 3,001.5 ft) to allow access to a LFA within the Calico Hills zeolitic composite unit (CHZCM) and the Crater Flat confining unit (CFCU).

Two 2⅞-in. piezometer strings were installed in the Well ER-20-4 borehole to monitor the water level in two LFAs within the Calico Hills Formation and the upper portion of the Crater Flat Group during hydraulic testing. Both 2⅞-in. tubing strings were hung from strings of 2⅜-in. carbon-steel tubing, and have one slotted interval each. The deep piezometer string was set at 951.8 m (3,122.8 ft). The shallow piezometer string was set at 488.2 m (1,601.6 ft), just below the static water level. The shallow string is bullnosed and slotted from 463.5 to 488.2 m (1,520.6 to 1,601.6 ft). The deep piezometer string is slotted from 757.3 to 914.9 m (2,484.7 to 3,001.7 ft).

1.6 Contact Information

Inquiries concerning Well ER-20-4 should be directed to the UGTA Federal Project Director at:

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

2.0 Drilling Summary

2.1 Introduction

This section contains detailed descriptions of the drilling process and fluid management issues. The general drilling requirements for all the Pahute Mesa Phase II wells were provided in *Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria* (SNJV, 2009a) and its addendum (NNES, 2010b). Specific requirements for Well ER-20-4 were outlined in FAWP numbers D-003-001.10 and number D-007-001.10 (NSTec, 2010a; 2010b). Figure 2-1 shows the layout of the drill site. Figure 2-2 is a chart of the drilling and completion history for Well ER-20-4. A summary of drilling statistics for the well is given in Table 2-1. The following information was compiled primarily from NSTec daily drilling reports.

2.2 Drilling History

The Well ER-20-4 location originally had been prepared for drilling in 1994, when two unlined sumps were built and a 66.0-cm (26-in.) conductor hole was drilled with an auger rig to the depth of 17.7 m (58 ft). A 20-in. conductor casing was set at a depth of 17.4 m (57 ft) and the annulus was cemented to the surface. However, UGTA drilling priorities changed and Well ER-20-4 was not constructed at that time. In March 2010, repairs were made to the existing pad and sumps at the Well ER-20-4 site, and the location was prepared for drilling.

The UDI crews arrived on July 27, 2010, and began rigging up the Wilson Mogul 42B drill rig. They finished rigging up on August 21, 2010, after a flow line was installed and secured with 152-cm (60-in.) weights along its length. The UDI crew began drilling from the top of cement inside the 20-in. casing at 15.2 m (50 ft), working through the cement and into the formation using a 17½-in. rotary bit. The drilling fluid was an air/water/soap mix with a polymer additive (when necessary) in conventional circulation. Drilling proceeded with little or no fill noted during connections.

On August 24, 2010, at the depth of 467.9 m (1,535 ft), the target casing point near the water table within the Calico Hills Formation was reached. Drilling was stopped to perform geophysical logging and install casing. After the drillers pulled up six stands of drill pipe, 0.3 m (1 ft) of fill was detected. The drill crew then removed the drill pipe from the hole in preparation for logging.

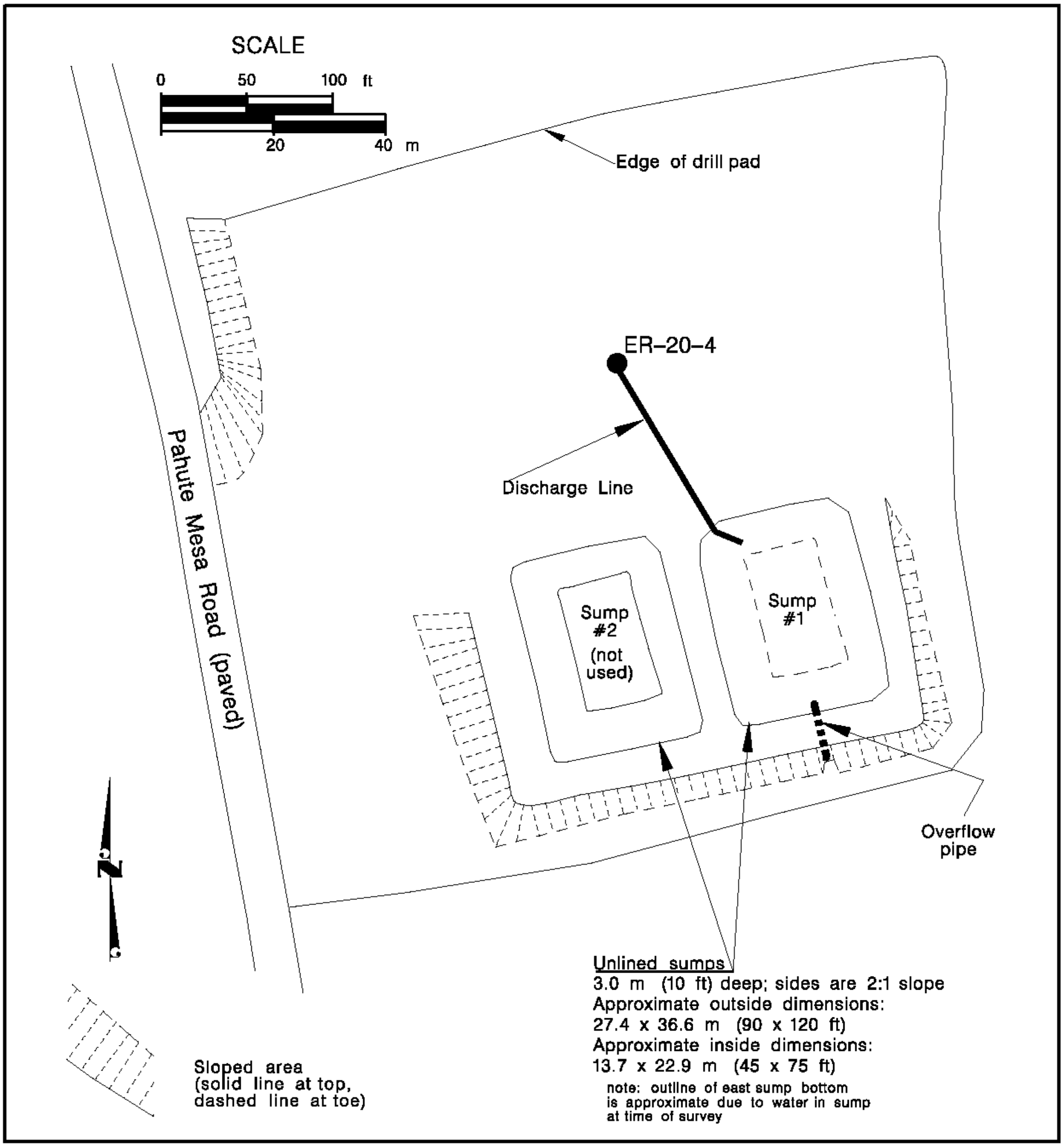
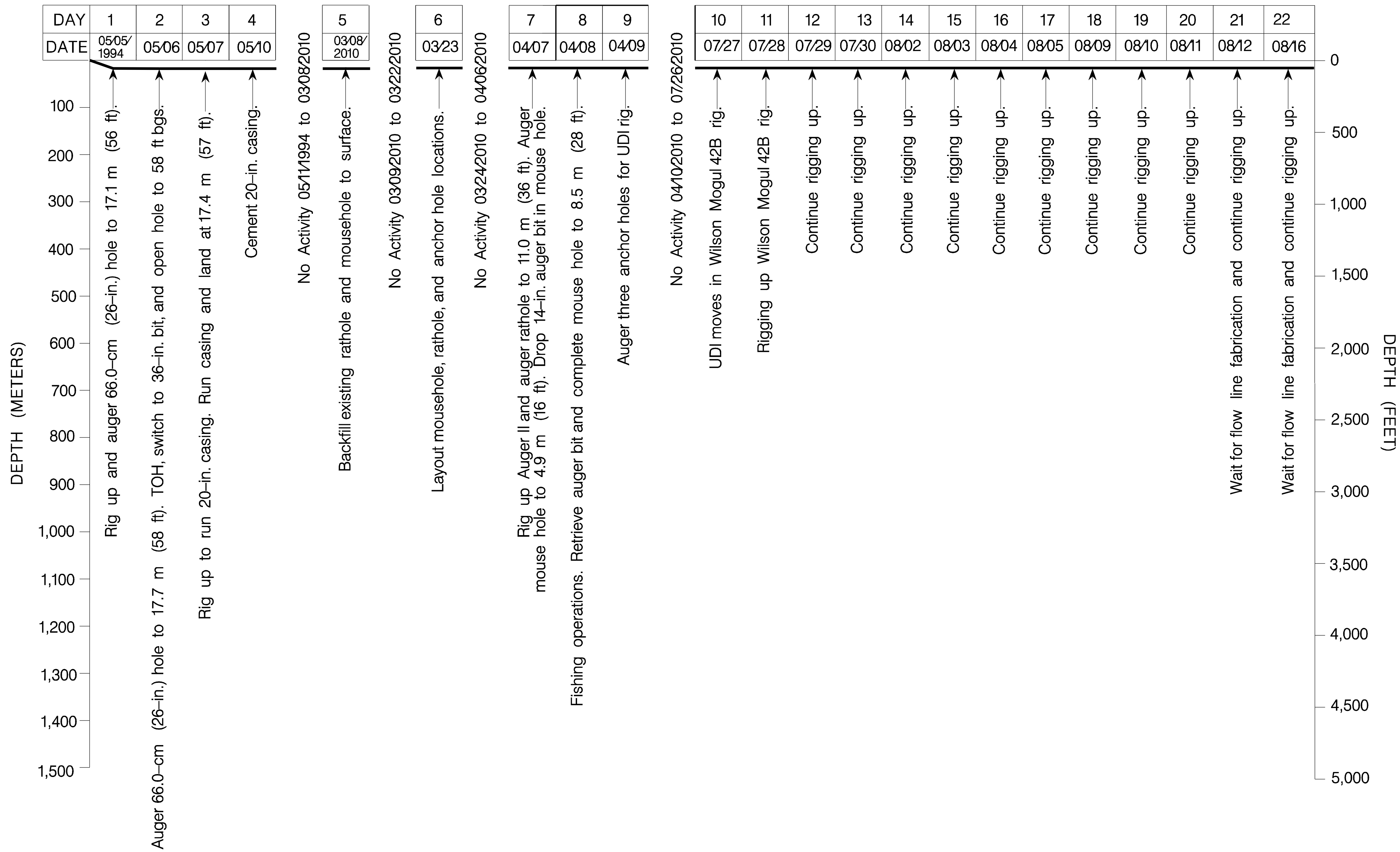


Figure 2-1
Drill Site Configuration for Well ER-20-4



LEGEND

BA	Baker Atlas
bgs	below ground surface
BHA	bottom hole assembly
cm	centimeters
DPS	deep piezometer string
DRI	Desert Research Institute
ft	foot (feet)
HWDP	heavy-weight drill pipe
in.	inch(es)
m	meter(s)
min	minute(s)
NAIL	nuclear annular investigation log
NSTec	National Security Technologies, LLC
P-SWC	percussion sidewall core
RIH	run in hole
R-SWC	rotary sidewall core
SLM	steel line measurement
SPS	shallow piezometer string
TD	total depth
TFL	thermal flow log
TIH	trip into hole
TL	temperature log
TOC	top of cement
TOF	top of fluid
TOH	trip out of hole
UDI	United Drilling Inc.

WELL ER-20-4 SUMMARY

Activity	Date
Begin drilling for conductor hole:	05/05/1994
Conductor hole completed and 20-in. casing set at 17.4 m (57 ft):	05/10/1994
Begin drilling 44.5-cm (17.5-in.) surface hole:	08/21/2010
Set 13 3/8-in. surface casing at 461.9 m (1,515.5 ft):	08/27/2010
Begin drilling 31.1-cm (12.25-in.) hole:	08/31/2010
Reach total drilled depth of 1,066.5 m (3,499 ft):	09/04/2010
Well completed:	09/12/2010

FIGURE 2-2

WELL ER-20-4
DRILLING AND COMPLETION HISTORY
SHEET 1 OF 2

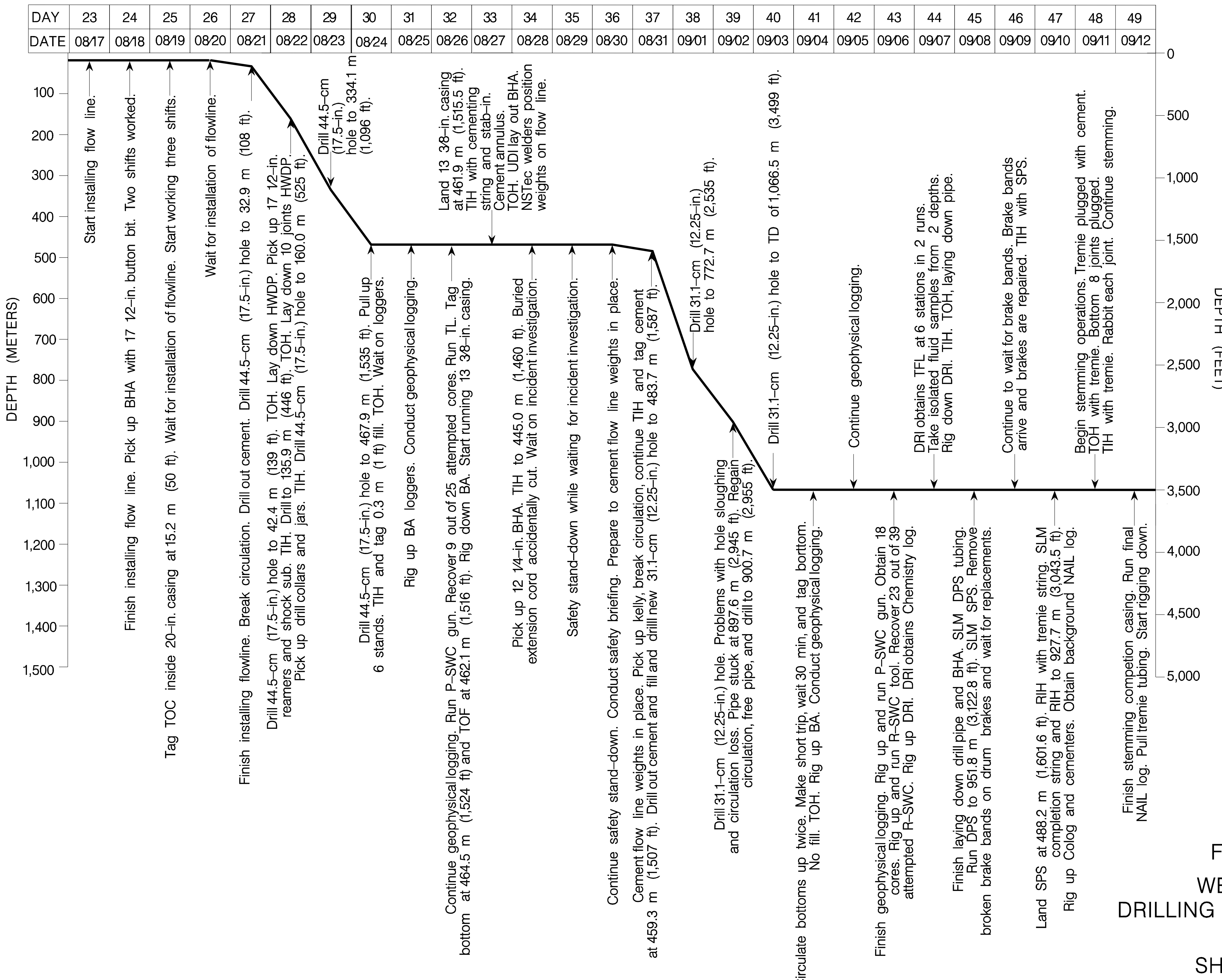


FIGURE 2-2

WELL ER-20-4

DRILLING AND COMPLETION HISTORY

SHEET 2 OF 2

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

LOCATION DATA:	
Coordinates:	Nevada State Plane (Central Zone) (NAD 27): N 890,183.2 ft E 565,940.3 ft Nevada State Plane (Central Zone) (NAD 83): N 6,271,329.1 m E 520,019.2 m Universal Transverse Mercator (Zone 11) (NAD 83): N 4,116,689.7 m E 549,596.1 m Universal Transverse Mercator (Zone 11) (NAD 27): N 4,116,492.5 m E 549,676.2 m
Surface Elevation [a]:	1,748.4 m (5,736.1 ft)
DRILLING DATA:	
Spud Date:	08/21/2010 (main hole drilling with Wilson Mogul 42B rig)
Total Depth (TD):	1,066.5 m (3,499 ft)
Date TD Reached:	09/03/2010
Date Well Completed:	09/12/2010 (date completion string was cemented in place)
Hole Diameter:	91.4 cm (36 in.) from surface to 17.7 m (58 ft); 44.5 cm (17.5 in.) from 17.7 to 467.9 m (58 to 1,535 ft); 31.1 cm (12.25 in.) from 467.9 m (1,535 ft) to TD of 1,066.5 m (3,499 ft).
Drilling Techniques:	Dry-hole auger from surface to 17.7 m (58 ft.); rotary drill with $17\frac{1}{2}$-in. tricone bit, using air-foam and polymer in direct circulation, from 17.7 to 467.9 m (58 to 1,535 ft); rotary drill with $12\frac{1}{4}$-in. tricone bit to TD of 1,066.5 m (3,499 ft).
CASING DATA:	20-in. conductor casing to 17.4 m (57 ft); $13\frac{3}{8}$-in. surface casing to 461.9 m (1,515.5 ft); $7\frac{5}{8}$-in. casing to 451.9 m (1,482.5 ft); cross-over sub at 451.9 to 452.1 m (1,482.5 to 1,483.4 ft); $6\frac{5}{8}$-in. casing from 927.7 to 755.6 m (1,483.4 to 3,043.5 ft).
WELL COMPLETION DATA [b]:	A string of $7\frac{5}{8}$-in. carbon-steel casing, connected to $6\frac{5}{8}$-in. stainless-steel casing via a crossover sub, was installed in Well ER-20-4 after drilling. The carbon-steel casing terminates within the unsaturated zone approximately 11.9 m (39 ft) above the water table. The $7\frac{5}{8}$-in. outside-diameter casing has an inside diameter (id) of 17.701 cm (6.969 in.). The $6\frac{5}{8}$-in. casing has an id of 15.5 cm (6.104 in.). The completion string was landed at 927.7 m (3,043.5 ft). Two $2\frac{7}{8}$-in. piezometers were also installed. Both stainless-steel tubing strings hang from strings of $2\frac{3}{8}$-in. carbon-steel tubing (id of 5.067 cm [1.995 in.]), connected via crossover subs. The shallow piezometer was landed at 488.2 m (1,601.6 ft) and the deep piezometer was landed at 951.8 m (3,122.8 ft).
Depth of Slotted Section:	$6\frac{5}{8}$-in. completion casing: 755.6 to 914.9 m (2,479.0 to 3,001.5 ft) Shallow $2\frac{7}{8}$-in. piezometer string (CHZCM): 463.5 to 488.2 m (1,520.6 to 1,601.6 ft) Deep $2\frac{7}{8}$-in. piezometer string (CFCU): 757.3 to 914.9 m (2,484.7 to 3,001.7 ft)
Depth of Sand Packs:	736.1 to 746.8 m (2,415 to 2,450 ft) and 944.9 to 951.9 m (3,100 to 3,123 ft)
Depth of Gravel Packs:	746.8 to 930.6 m (2,450 to 3,053 ft) and 951.9 to 1,066.5 m (3,123 to 3,499 ft)
Depth of Pump:	Not installed at the time of completion
Water Depth [c]:	Fluid level depth measured on September 20, 2010: 463.8 m (1,521.5 ft) measured in the main casing string. Fluid level depths measured on October 25, 2010: 463.6 m (1,521.1 ft) measured in the shallow $2\frac{7}{8}$-in. piezometer string; 463.6 m (1,521.1 ft) measured in the deep $2\frac{7}{8}$-in. piezometer string.
DRILLING CONTRACTOR:	United Drilling, Inc.
GEOPHYSICAL LOGS BY:	Baker Atlas, DRI, Colog
SURVEYING CONTRACTOR:	National Security Technologies, LLC

a Elevation of ground level at wellhead. National Geodetic Vertical Datum, 1929 (NARA, 1973).

b See Section 7.0 of this report for more detailed data on completion intervals. See Table A-2-1 of this report for more details about the casing and tubing materials. CHZCM = Calico Hills zeolitic composite unit; CFCU = Crater Flat confining unit

c Fluid level tags by Navarro-Intera, LLC (N-I).

Geophysical logging and sidewall sampling began on August 25, 2010. A water level of 462.1 m (1,516 ft) was measured on August 26, 2010. After logging and sampling operations were completed on August 26, 2010, the Baker Atlas logging crew rigged down and departed the location.

The casing subcontractor installed a string of 13⅜-in casing, which was set at the depth of 461.9 m (1,515.5 ft). The bottom of the casing was cemented with 7.8 cubic meters (10.2 cubic yards) of Type II neat cement on August 27, 2010. The top of cement in the annulus was estimated to be at the depth of 394.7 m (1,295 ft), based on geophysical log data.

A newly engineered flow line was installed prior to drilling in the saturated zone at Well ER-20-4. The design of the flow line was based on lessons learned while drilling Well ER-EC-12, where the flow line separated due to a high-pressure fluid surge, and impacted nearby equipment (NNSA/NSO, 2011b). Though no injuries resulted from the incident, the design of flow lines for future UGTA wells was altered to prevent similar problems. The new flow line design includes the use of 16-in. casing for the entire length of the line, with no gate valves. The line is secured by chains and binders to large weights. At Well ER-20-4 one of the two existing 152-cm (60-in.) weights (5,443.1 kilograms [12,000 pounds] each) was replaced with four 229-cm (90-in.) weights (11,385.2 kilograms [25,100 pounds] each), so that a total of five weights were installed to hold the flow line in place. The 229-cm (90-in) weights were stacked two high, and the weights on the bottom of the stack were partially buried and cemented into the ground.

During installation of the new flow system, on August 28, 2011, a laborer accidentally cut a buried extension cord that was unplugged. Drilling operations were suspended to investigate the incident (NSTec Case # 2010-144) and resumed on August 31, 2010.

The drill crew lowered the drill string with a 12¼-in. bit into the hole to drill out the cement and cleaned out the hole. They tagged the top of cement inside the 13⅜-in casing at 459.3 m (1,507 ft). They drilled cement from 459.3 to 463.3 m (1,507 to 1,520 ft) and cleaned out fill from 463.3 to 467.9 m (1,520 to 1,535 ft). Drilling with the 12¼-in. bit continued uneventfully to the depth of 897.6 m (2,945 ft), though fluid circulation was lost intermittently and material sloughed from the borehole wall at 865.9 m (2,841 ft). On September 3, 2010, at 897.6 m (2,945 ft), the hole sloughed in, circulation was lost, and the drill pipe became stuck. The drillers worked about an hour to free the pipe and regain circulation, then drilling continued to the TD of 1,066.5 m (3,499 ft), which was reached later that day.

The drillers cleaned and conditioned the borehole by circulating the borehole volume twice, then pulled up four stands of drill pipe, and waited thirty minutes before tagging bottom. No fill was encountered and the crew began removing the drill string from the borehole in preparation for geophysical logging.

Geophysical logging and sidewall sampling operations were conducted with no problems by Baker Atlas crews from September 4 to 6, 2010. After completion of sidewall sampling the Baker Atlas logging crew pulled out of the hole in preparation for logging and water sampling by DRI personnel. DRI operations were completed on September 7, 2010.

Commencing on September 8, 2010, the drill crew began running the lower of two 2⅞-in. stainless-steel piezometer strings. Both of the 2⅞-in. piezometer strings were hung from strings of 2⅜-in. carbon-steel tubing and have one slotted interval each. The deep piezometer string was set at 951.8 m (3,122.8 ft). The shallow piezometer string was set at 488.2 m (1,601.6 ft), just below the static water level. The upper piezometer string is bullnosed and slotted from 463.5 to 488.2 m (1,520.6 to 1,601.6 ft), and provides access to a lava in the upper part of the Calico Hills Formation. The deep piezometer string is slotted from 757.3 to 914.9 m (2,484.7 to 3,001.7 ft), and provides access to a lava in the upper part of the Crater Flat Group. See more information about the completion design and installation in Section 7.0.

A 6⅝-in. stainless-steel completion string with one slotted interval was inserted into the hole on September 10, 2010, and landed at a depth of 927.7 m (3,043.5 ft). The completion casing, along with the two piezometer strings, were stemmed with sand, gravel, and cement (see Section 7.0). Stemming operations were completed on September 12, 2010. The drillers started demobilizing the rig and drilling equipment on the same day, and crews worked one shift per day after that until demobilization to the Well ER-EC-13 site was completed on September 22, 2010.

The inclination of the borehole was determined from borehole orientation logs run by Baker Atlas on August 25 and September 4, 2010, within the interval 21.3 to 1,061.9 m (70 to 3,484 ft). Within this interval the borehole drifted approximately 17.4 m (57.0 ft) to the northeast (on a bearing of 45.3 degrees). No abrupt changes in the borehole orientation ("doglegs") were apparent. At the lowest logged depth of 1,061.9 m (3,484 ft), the true vertical depth is calculated to be 1,061.7 m (3,483.31 ft), a difference of 0.2 m (0.7 ft).

A graphical depiction of drilling parameters, including penetration rate, rotary revolutions per minute, pump pressure, and weight on the bit, is presented in Appendix A-1. See Appendix A-2 for a listing of tubing and casing materials. Drilling fluids and cements used in Well ER-20-4 are listed in Appendix A-3.

2.3 Drilling Problems

Drilling delays at Well ER-20-4 were mainly due to operational problems (safety stand-down and delay for fabrication of a newly-designed flow line) rather than drilling problems. Borehole sloughing was not a major problem during drilling of the 44.5-cm (17.5-in.) diameter main hole. However, during the drilling of the 31.1-cm (12.25-in.) diameter hole, borehole instability issues were encountered, culminating in loss of circulation and sticking of the drill pipe for a brief time at the depth of 897.6 m (2,945 ft). Examination of drill cuttings samples and the caliper log in this interval indicate that the interval where sloughing occurred is a pumiceous lava that was penetrated in the interval 696.5 to 730.0 m (2,285 to 2,395 ft). No further drilling problems were encountered below 897.6 m (2,945 ft).

2.4 Fluid Management

During drilling, the drilling effluent was monitored according to the methods prescribed in the UGTA Project FMP (NNSA/NSO, 2009b) and the associated state-approved, well-specific, fluid management strategy letter (N-I, 2010). The air-foam/polymer drilling fluid was circulated down the inside of the drill string and back up the hole through the annulus (conventional or direct circulation) and then discharged into a sump. Water used to prepare drilling fluids came from Area 20 Water Well (U-20WW). A concentrated lithium bromide solution was added to the drilling fluid as a tracer to provide a means of estimating groundwater production. The rate of water production was estimated from the dilution of the tracer in the drilling fluid returns.

Radionuclides exceeding fluid quality objectives were not expected at Well ER-20-4, based on Phase I flow and transport modeling (SNJV, 2006; 2007; 2009b). To manage the anticipated water production, two unlined sumps were constructed prior to drilling (Figure 2-1).

Samples of drilling effluent were collected hourly by N-I and analyzed on site by radiological control technicians for the presence of tritium. As detailed in the N-I data report (N-I, 2011) and summarized in Appendix B of this report, the onsite monitoring results for the drilling indicated that tritium levels measured in the drilling fluid were less than the minimum detectable concentration and well below drinking water standards, as measured by field instruments.

No lead monitoring was performed. Lead monitoring is not initiated until discharge fluids exceed the UGTA Fluid Management Criteria for tritium (200,000 picocuries per liter), as specified in the Well ER-20-4 Fluid Management Strategy Letter (N-I, 2010) approved by the Nevada Division of Environmental Protection. N-I personnel checked all equipment for lead before it was inserted in the borehole and none was found.

All fluid quality objectives were met, as shown on the fluid management reporting form (Appendix B). The form lists volumes of solids (drill cuttings) and fluids produced during well-construction operations (vadose-zone drilling and saturated-zone drilling; well development and aquifer testing are not addressed in this report). The volume of solids produced was calculated using the diameter of the borehole (from caliper logs) and the depth drilled, and includes added volume attributed to a rock bulking factor. The volumes of fluids listed on the form are estimates of total fluid production, and do not account for any infiltration or evaporation of fluids from the sumps.

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3.0 Geologic Data Collection

3.1 Introduction

This section describes the sources of geologic data obtained from Well ER-20-4 and the methods of data collection. Improving the understanding of the subsurface structure, stratigraphy, and hydrogeology in the southern portion of Pahute Mesa was among the primary objectives of Well ER-20-4, so the proper collection of geologic and hydrogeologic data from the borehole was considered fundamental to successful completion of the drilling project.

Geologic data collected at Well ER-20-4 consist of drill cuttings, sidewall core samples, and geophysical logs. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures, as listed in the NNES FAWP (NNES, 2010a).

3.2 Drill Cuttings

Raytheon Services Nevada personnel (predecessor to NSTec) collected 12 samples between the depths of 1.5 and 17.7 m (5 and 58 ft) during construction of the conductor hole in 1994. During drilling of the main hole, N-I personnel collected composite drill cuttings at 3.0-m (10-ft) intervals. Triplicate samples, each consisting of approximately 550 cubic centimeters of material, were collected from 343 intervals from 18.3 m (60 ft) to TD. These samples are stored under environmentally controlled, secure conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada. One of each triplicate sample set was sealed with custody tape at the rig site and remains sealed as an archive sample, one set was left unsealed in the original sample containers, and the third set was washed and stored according to standard USGS Core Library procedures. The washed set was used by NSTec geologists to construct the detailed lithologic log presented in Appendix C. The N-I field representative collected an additional set of reference drill cuttings samples from each of the cuttings intervals. This set was examined at the drill site for use in preparing field lithologic descriptions, and remains in the custody of N-I.

3.3 Sidewall Core Samples

Sidewall core samples were collected at selected depths in Well ER-20-4 to verify the stratigraphy and lithology and for special analytical tests. Sample locations were selected by NSTec geologists and the N-I field representative on the basis of field lithologic logs, with consideration of borehole conditions determined from caliper logs. Baker Atlas used a percussion-gun sidewall coring tool to collect samples between the depths of 76.2 and 1,063.8 m

(250 and 3,490 ft). A total of 50 sample depths were attempted, with 27 cores recovered. Baker Atlas used a rotary sidewall coring tool to obtain sidewall samples between the depths of 485.9 and 1,063.8 m (1,594 and 3,490 ft). A total of 39 rotary samples were attempted, with 23 cores recovered. Table 3-1 summarizes the results of sidewall coring operations at Well ER-20-4.

3.4 Sample Analysis

Eleven sidewall cores and sixteen samples of drill cuttings from various depths in Well ER-20-4 were submitted to Comprehensive Volcanic Petrographics, LLC, for petrographic analysis. A split of the same sidewall cores and the samples of drill cuttings from the same depths were submitted to the Hydrology, Geochemistry, and Geology Group of the Earth and Environmental Sciences Division at LANL for mineralogic (x-ray diffraction) and chemical (x-ray fluorescence) analyses. The samples were selected after initial geologic evaluation of the cuttings and core samples and geophysical logs. The primary purpose of the analytical data is to confirm stratigraphic identification and to characterize mineral alteration. In addition, the data provide detailed information on mineralogic composition for transport modeling, and will aid in evaluation of geophysical log signatures. Table 3-2 lists all samples analyzed. The results of the petrographic analyses are reported in Warren (2011), and the results of the mineralogic and chemical analyses are reported in WoldeGabriel et al. (2011).

3.5 Geophysical Log Data

Geophysical logs were run in the borehole to further characterize the lithology, structure, and hydrologic properties of the rocks encountered, and to evaluate borehole conditions. Geophysical logging was conducted in two stages during drilling: prior to installation of the 13⅜-in. casing at 461.9 m (1,515.5 ft) and after the TD was reached at 1,066.5 m (3,499 ft). A complete listing of the logs, dates run, depths, and service companies is provided in Table 3-3. Note that a gamma-ray log is typically included on each logging run to aid in depth control. The logs are available from NSTec in Mercury, Nevada, and copies are on file at the office of N-I in Las Vegas, Nevada, and at the USGS Geologic Data Center and Core Library in Mercury, Nevada. Plots of selected geophysical log data are provided in Appendix D.

The overall quality of the geophysical log data collected was good.

Table 3-1
Sidewall Samples from Well ER-20-4

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
76.2	250	SWC	E	mafic-poor Ammonia Tanks Tuff	Ash-flow tuff, moderately welded
76.2	250	SWC[d]	E	mafic-poor Ammonia Tanks Tuff	Ash-flow tuff, moderately welded
129.5	425	SWC	L	rhyolite of Tannenbaum Hill	Bedded tuff, zeolitic
250.0	820	SWC	E	rhyolite of Tannenbaum Hill	Stoney rhyolite lava
250.0	820	SWC[d]	E	rhyolite of Tannenbaum Hill	Stoney rhyolite lava
286.5	940	SWC	M	rhyolite of Delirium Canyon	Flow-breccia
286.5	940	SWC[d]	E	rhyolite of Delirium Canyon	Flow-breccia
298.7	980	SWC	M	rhyolite of Delirium Canyon	Ash-flow tuff, nonwelded, zeolitic
298.7	980	SWC[d]	M	rhyolite of Delirium Canyon	Ash-flow tuff, nonwelded, zeolitic
298.7	980	SWC[e]	1.91 (0.75)	rhyolite of Delirium Canyon	Ash-flow tuff, nonwelded, zeolitic
306.3	1,005	SWC	M	rhyolite of Delirium Canyon	Ash-flow tuff, nonwelded, zeolitic
306.3	1,005	SWC[d]	3.81 (1.50)	rhyolite of Delirium Canyon	Ash-flow tuff, nonwelded, zeolitic
320.0	1,050	SWC	3.81 (1.50)	Pahute Mesa lobe of Topopah Spring Tuff	Ash-flow tuff, nonwelded, zeolitic
329.2	1,080	SWC	M	Pahute Mesa lobe of Topopah Spring Tuff	Ash-flow tuff, nonwelded, zeolitic
335.3	1,100	SWC	3.18 (1.25)	Pahute Mesa lobe of Topopah Spring Tuff	Ash-flow tuff, nonwelded, zeolitic
344.4	1,130	SWC	M	Pahute Mesa lobe of Topopah Spring Tuff	Ash-flow tuff, nonwelded, zeolitic
365.8	1,200	SWC	5.08 (2.00)	Pahute Mesa lobe of Topopah Spring Tuff	Ash-flow tuff, nonwelded, zeolitic
365.8	1,200	SWC[d]	5.08 (2.00)	Pahute Mesa lobe of Topopah Spring Tuff	Ash-flow tuff, nonwelded, zeolitic
374.9	1,230	SWC	1.91 (0.75)	Pahute Mesa lobe of Topopah Spring Tuff	Bedded tuff, zeolitic
379.5	1,245	SWC	3.81 (1.50)	Pahute Mesa lobe of Topopah Spring Tuff	Bedded tuff, zeolitic
393.2	1,290	SWC	M	mafic-poor Calico Hills Formation	Pumiceous rhyolite lava
399.3	1,310	SWC	E	mafic-poor Calico Hills Formation	Pumiceous rhyolite lava
420.6	1,380	SWC	M	mafic-poor Calico Hills Formation	Vitrophyric rhyolite lava

Table 3-1
Sidewall Samples from Well ER-20-4 (continued)

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
442.0	1,450	SWC	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava
457.2	1,500	SWC	1.91 (0.75)	mafic-poor Calico Hills Formation	Stoney rhyolite lava
485.9	1,594	RS	2.54 (1.00)	mafic-poor Calico Hills Formation	Stoney rhyolite lava
527.3	1,730	RS	3.81 (1.50)	mafic-poor Calico Hills Formation	Flow-breccia
533.4	1,750	SWC	M	mafic-poor Calico Hills Formation	Flow-breccia
563.9	1,850	RS	3.18 (1.25)	mafic-poor Calico Hills Formation	Pumiceous rhyolite lava
597.4	1,960	RS	E	mafic-poor Calico Hills Formation	Pumiceous rhyolite lava
597.4	1,960	RS[d]	4.45 (1.75)	mafic-poor Calico Hills Formation	Pumiceous rhyolite lava
609.6	2,000	RS	3.05 (1.20)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
612.7	2,010	SWC	3.81 (1.50)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
627.9	2,060	SWC	3.81 (1.50)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
640.1	2,100	SWC	3.51 (1.38)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
649.2	2,130	RS	4.32 (1.70)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
664.5	2,180	SWC	4.40 (1.63)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
679.7	2,230	RS	2.54 (1.00)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
679.7	2,230	SWC	M	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
688.9	2,260	SWC	3.18 (1.25)	mafic-poor Calico Hills Formation	Bedded tuff, zeolitic
698.0	2,290	RS	4.32 (1.70)	mafic-poor Calico Hills Formation	Pumiceous rhyolite lava, zeolitic
716.3	2,350	RS	3.18 (1.25)	mafic-poor Calico Hills Formation	Pumiceous rhyolite lava, zeolitic and devitrified
734.6	2,410	RS	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
741.9	2,434	RS	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
768.1	2,520	RS	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
780.3	2,560	RS	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
780.3	2,560	RS[d]	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
794.3	2,606	RS	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
794.3	2,606	RS[d]	E	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
818.7	2,686	RS	3.30 (1.30)	mafic-poor Calico Hills Formation	Stoney rhyolite lava, devitrified
842.5	2,764	RS	2.54 (1.00)	tuff of Jorum, Crater Flat Group	Flow breccia, quartzo-feldspathic
856.5	2,810	RS	E	tuff of Jorum, Crater Flat Group	Flow breccia, quartzo-feldspathic

Table 3-1
Sidewall Samples from Well ER-20-4 (continued)

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
868.7	2,850	RS	E	tuff of Jorum, Crater Flat Group	Flow breccia, quartzo-feldspathic
877.2	2,878	RS	3.05 (1.20)	tuff of Jorum, Crater Flat Group	Flow breccia, quartzo-feldspathic
885.8	2,906	RS	3.05 (1.20)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
887.0	2,910	SWC	M	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
888.8	2,916	RS	3.05 (1.20)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
899.2	2,950	SWC	3.81 (1.50)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
907.1	2,976	SWC	3.81 (1.50)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
920.5	3,020	SWC	3.81 (1.50)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
932.7	3,060	SWC	3.81 (1.50)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
940.6	3,086	SWC	L	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
940.9	3,087	RS	4.32 (1.70)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
944.9	3,100	SWC	3.81 (1.50)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
958.9	3,146	RS	3.05 (1.20)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
963.2	3,160	SWC	3.18 (1.25)	tuff of Jorum, Crater Flat Group	Nonwelded and bedded tuff, quartzo-feldspathic
984.5	3,230	RS	2.54 (1.00)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
990.6	3,250	RS	3.05 (1.20)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
990.6	3,250	SWC	M	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,002.8	3,290	SWC	3.81 (1.50)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,011.9	3,320	SWC	2.87 (1.13)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic

Table 3-1
Sidewall Samples from Well ER-20-4 (continued)

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
1,012.6	3,322	RS	1.91 (0.75)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,018.0	3,340	SWC	3.81 (1.50)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,021.1	3,350	RS	E	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,021.1	3,350	RS[d]	2.54 (1.00)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,028.4	3,374	RS	2.54 (1.00)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,038.8	3,408	RS	E	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,038.8	3,408	RS[d]	3.05 (1.20)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,039.4	3,410	SWC	E	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,048.5	3,440	SWC	3.18 (1.25)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,048.5	3,440	SWC[d]	3.81 (1.50)	rhyolite of Sled, Crater Flat Group	Pumiceous rhyolite lava, quartzo-feldspathic
1,057.7	3,470	SWC	3.18 (1.25)	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic
1,057.7	3,470	SWC[d]	3.18 (1.25)	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic
1,062.2	3,485	RS	3.81 (1.50)	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic
1,062.8	3,487	RS	E	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic
1,063.1	3,488	RS	E	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic
1,063.8	3,490	SWC	E	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic
1,063.8	3,490	RS	E	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic
1,063.8	3,490	RS[d]	E	rhyolite of Sled, Crater Flat Group	Nonwelded tuff, quartzo-feldspathic

Table 3-1
Sidewall Samples from Well ER-20-4 (continued)

Notes:

a All depths are drilled depths.

b SWC = percussion-gun sidewall coring tool; core diameter: 17.3 millimeters (0.68 in.)
RS = rotary sidewall coring tool; core diameter: 25.4 millimeters (1 in.)

c Shaded rows indicate samples attempted but not recovered. E = empty barrel; L = lost barrel; M = misfire.

d Second attempt.

e Third attempt.

Table 3-2
Rock Samples from Well ER-20-4 Selected for Petrographic, Mineralogic, and Chemical Analysis [a]

Depth [b, c]		Sample Identifier [d]
meters	feet	
24.4	80	ER20/4–80D
39.6	130	ER20/4–130D
79.3	260	ER20/4–260D
125.0	410	ER20/4–410D
225.6	740	ER20/4–740D
271.3	890	ER20/4–890D
313.9	1,030	ER20/4–1,030D
368.8	1,210	ER20/4–1,210D
387.1	1,270	ER20/4–1,270D
411.5	1,350	ER20/4–1,350D
478.5	1,570	ER20/4–1,570D
509.0	1,670	ER20/4–1,670D
524.3	1,720	ER20/4–1,720D
560.8	1,840	ER20/4–1,840D

Depth [b, c]		Sample Identifier [d]
meters	feet	
597.4	1,960	ER20/4–1,960RS
649.2	2,130	ER20/4–2,130RS
670.6	2,200	ER20/4–2,200D
698.0	2,290	ER20/4–2,290RS
786.4	2,580	ER20/4–2,580D
842.5	2,764	ER20/4–2,764RS
877.2	2,878	ER20/4–2,878RS
888.8	2,916	ER20/4–2,916RS
940.9	3,087	ER20/4–3,087RS
990.6	3,250	ER20/4–3,250RS
1,021.1	3,350	ER20/4–3,350RS
1,038.8	3,408	ER20/4–3,408RS
1,062.2	3,485	ER20/4–3,485RS

a Mineralogic analysis by x-ray diffraction; chemical analysis by x-ray fluorescence.

b All depths are drilled depths.

c Depths for petrographic, mineralogic, and chemical analyses represent base of 3.0-m (10-ft) sample interval for drill cuttings samples.

d “D” in sample identifier indicates drill cuttings sample. “RS” indicates rotary sidewall core sample.

Table 3-3
Well ER-20-4 Geophysical Log Summary

Geophysical Log Type [a]	Log Purpose	Logging Service [b]	Date Logged	Run Number	Bottom of Logged Interval [c] meters (feet)	Top of Logged Interval [c] meters (feet)
Differential Temperature / Gamma Ray [d]	Saturated zone: groundwater temperature; stratigraphic and depth correlation	BA	9/4/2010	TL-1 / GR-5	1,066.3 (3,498.5)	373.1 (1,224)
Aligned Borehole Profile (i.e., oriented * 6-Arm Caliper) / * Gamma Ray	Borehole conditions, cement volume calculation, lithologic features, borehole orientation, stratigraphic and depth correlation	BA	8/25/2010 9/4/2010	CA6-1 / ORIT-1 / GR-1 CA6-2 / ORIT-2 / GR-6	462.1 (1,516) 1,063.5 (3,489)	0 (0) 461.8 (1,515)
* Digital Spectralog / * Gamma Ray	Stratigraphy, mineralogy, and natural and man-made radiation determination	BA	8/25/2010 9/4/2010	SGR-1 / GR-1 SGR-2 / GR-6	454.5 (1,491) 1,063.5 (3,489)	0 (0) 461.8 (1,515)
* High Definition Induction / Gamma Ray	Lithologic determination; saturation of formations; stratigraphic and depth correlation	BA	8/25/2010	HDIL-1 / GR-2	460.2 (1,510)	17.4 (57)
* Compensated Z-Densilog / * Compensated Neutron / Gamma Ray / Caliper	Stratigraphic and lithologic determination; identification of welding, alteration, rock porosity, and water content	BA	8/25/2010 9/5/2010	ZDL-1 / CN-1 / GR-3 / CAL-1 ZDL-2 / CN-2 / GR-8 / CAL-2	464.5 (1,524) 1,065.3 (3,495)	17.4 (57) 365.8 (1,200)
Circumferential Borehole Imaging / Gamma Ray	Structural analysis, including fracture characterization; recognition of lithologic features	BA	9/5/2010	CBIL-1 / ORIT-5 / GR-11	1,064.7 (3,493)	463.3 (1,520)
* X-Multipole Array Acoustilog / Gamma Ray	Primary matrix porosity	BA	9/5/2010	XMAC-1 / ORIT-3 / GR-9	1,061.0 (3,481)	461.8 (1,515)
Resistivity Imaging / Gamma Ray	Saturated zone: lithologic characterization, bedding dip, fracture and void analysis	BA	9/5/2010	STAR-1 / ORIT-4 / GR-10	1,064.5 (3,492.5)	469.4 (1,540)
Percussion Gun Sidewall Tool / Gamma Ray	Geologic samples	BA	8/26/2010 9/6/2010	SWC-1 / GR-4 SWC-2 / GR-12	457.2 (1,500) 1,063.8 (3,490)	76.2 (250) 533.4 (1,750)
* R_t Explorer / Gamma Ray	Lithologic determinations; saturation of formations; stratigraphic and depth correlation	BA	9/4/2010	RTEX-1 / GR-7 / SP-1	1,063.5 (3,489)	461.8 (1,515)

Table 3-3
Well ER-20-4 Geophysical Log Summary (continued)

Geophysical Log Type [a]	Log Purpose	Logging Service [b]	Date Logged	Run Number	Bottom of Logged Interval [c] meters (feet)	Top of Logged Interval [c] meters (feet)
Rotary Sidewall Coring Tool / Gamma Ray	Geologic samples	BA	9/6/2010	RCOR-1 / GR-13	1,062.2 (3,485)	485.9 (1,594)
* Chemistry / * Temperature	Groundwater chemistry and temperature	DRI	9/6/2010	Chem-1 / TL-2	1,067.7 (3,503)	464.2 (1,523)
* Heat Pulse Flow Log	Groundwater flow rate and direction	DRI	9/7/2010	HPFlow-1	1,051.6 (3,450)	478.5 (1,570)

a Logs presented in geophysical log summary, Appendix D, are indicated by *.

b BA = Baker Atlas DRI = Desert Research Institute.

c Drilled depth.

d A gamma-ray log is included on each logging run to aid in depth control.

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4.0 Geology and Hydrogeology

4.1 Introduction

This section describes the geology and hydrogeology of Well ER-20-4. The basis for the discussions here is the detailed geologic characterization of Well ER-20-4 presented as a lithologic log in Appendix C. The detailed lithologic log was developed using drill cuttings and sidewall core samples, geophysical logs, and drilling characteristics. Information from petrographic, mineralogic, and chemical analyses on selected lithologic samples (listed in Table 3-2) was incorporated into the detailed lithologic log.

4.2 Geology

This section is divided into three discussions relating to the geology of Well ER-20-4. Section 4.2.1 briefly describes the geologic setting of the Pahute Mesa area and Well ER-20-4. The stratigraphic and lithologic units penetrated at the well are discussed in Section 4.2.2. Because of the significant influence some alteration products have on the hydraulic properties of certain rocks, alteration of the rocks encountered at the well is discussed separately in Section 4.2.3. Detailed descriptions of the stratigraphy, lithology, and alteration of the rocks encountered are provided in the lithologic log presented in Appendix C. Tables 4-1 and 4-2 provide the definitions of stratigraphic and HSUs used in various figures in this report.

4.2.1 Geologic Setting

Well ER-20-4 was drilled at the base of the southern topographic edge of Pahute Mesa, which is a high volcanic plateau located within the southwestern Nevada volcanic field (Byers et al., 1976). Much of Pahute Mesa overlies the buried Silent Canyon caldera complex (SCCC) (Figure 1-1), which consists of two overlapping calderas—the Grouse Canyon caldera and the younger Area 20 caldera (Sawyer and Sargent, 1989). These calderas were formed by voluminous eruptions of ash-flow tuffs of generally rhyolitic composition, between approximately 14 and 13 million years ago (Ma) (Sawyer et al., 1994). The SCCC was eventually filled and buried by younger tuff and lava erupted from nearby vents and calderas between approximately 13 and 9 Ma. In the vicinity of Well ER-20-4, these caldera-filling and burying volcanic units, from oldest to youngest, include tuff and lava of the Crater Flat Group, the Calico Hills Formation, and the Paintbrush Group, and an overlying series of mostly welded ash-flow tuffs and a few lavas. These units include the Rainier Mesa Tuff, rhyolite of Tannenbaum Hill, Ammonia Tanks Tuff, Rocket Wash Tuff, Pahute Mesa Tuff, and Trail Ridge Tuff, which cap much of Pahute Mesa

Table 4-1
Key to Stratigraphic Units of the Well ER-20-4 Area

Stratigraphic Unit	Map Symbol
Quaternary and Tertiary Alluvial Deposits	**QTa**
Young alluvial deposits	Qay
Colluvium	QTc
Intermediate alluvial deposits	Qai
Caldera moat-filling sediments	Tgc
Thirsty Canyon Group	**Tt**
Trail Ridge Tuff	Ttt
Pahute Mesa Tuff	Ttp
Rocket Wash Tuff	Ttr
Volcanics of Fortymile Canyon	**Tf**
Beatty Wash Formation	Tfb
Timber Mountain Group	**Tm**
Ammonia Tanks Tuff	Tma
mafic-rich Ammonia Tanks Tuff	Tmar
mafic-poor Ammonia Tanks Tuff	Tmap
bedded Ammonia Tanks Tuff	Tmab
rhyolite of Tannenbaum Hill	Tmat
landslide breccia	Tmatx
Rainier Mesa Tuff	Tmr
mafic-rich Rainier Mesa Tuff	Tmrr
mafic-poor Rainier Mesa Tuff	Tmrp
rhyolite of Fluorspar Canyon	Tmrf
Paintbrush Group	**Tp**
rhyolite of Benham	Tpb
rhyolite of Scrugham Peak	Tps
tuff of Pinyon Pass	Tpcy
crystal-poor tuff of Pinyon Pass	Tpcyp
Tiva Canyon Tuff	Tpc
Pahute Mesa lobe of Tiva Canyon Tuff	Tpcm
rhyolite of Delirium Canyon	Tpd
Topopah Spring Tuff	Tpt
Pahute Mesa lobe of Topopah Spring Tuff	Tptm
Calico Hills Formation	**Th**
mafic-poor Calico Hills Formation	Thp
mafic-rich Calico Hills Formation	Thr

Table 4-1
Key to Stratigraphic Units and Symbols for the Well ER-20-4 Area (continued)

Stratigraphic Unit	Map Symbol
Crater Flat Group	**Tc**
rhyolite of Inlet	Tci
rhyolite of Jorum	Tcpj
rhyolite of Sled	Tcps
Bullfrog Tuff	Tcb
Belted Range Group	**Tb**
Dead Horse Flat Formation	Tbd
Grouse Canyon Tuff	Tbg
pre-Grouse Canyon caldera units	**To**
Paleozoic sedimentary rocks	**Pz**

Table 4-2
Key to Hydrostratigraphic Units and Symbols Used in This Report

Hydrostratigraphic Unit	Symbol
Alluvial aquifer	AA
Thirsty Canyon volcanic aquifer	TCVA
Tannenbaum Hill lava-flow aquifer	THLFA
Tannenbaum Hill composite unit	THCM
Timber Mountain aquifer	TMA
upper Paintbrush confining unit	UPCU
Scrugham Peak aquifer	SPA
Tiva Canyon aquifer	TCA
lower Paintbrush confining unit	LPCU
Paintbrush lava-flow aquifer	PLFA
Calico Hills zeolitic composite unit	CHZCM
Crater Flat confining unit	CFCU
Bullfrog confining unit	BFCU
pre-Belted Range composite unit	PBRCM
Lower carbonate aquifer	LCA

(Slate et al., 1999). The Rainier Mesa and Ammonia Tanks Tuffs were erupted 11.6 and 11.45 Ma, respectively, from the Rainier Mesa and Ammonia Tanks calderas (Sawyer et al., 1994), both of which are part of the TMCC, located just south of Well ER-20-4. The Rocket Wash Tuff, Pahute Mesa Tuff, and Trail Ridge Tuff were erupted between 9.4 and 9.3 Ma, from the Black Mountain caldera (Slate et al., 1999) located northwest of Well ER-20-4. A thin deposit of Quaternary alluvium forms the ground surface at the well site (Figure 4-1).

Major structural features in the vicinity of Well ER-20-4 are associated in some degree with caldera formation. Most of these structural features are completely buried by younger volcanic rocks and alluvial material, and thus their locations and characteristics can only approximately be determined. Well ER-20-4 is located just outside the southern portion of the Area 20 caldera (BN, 2002) (Figure 4-1). The faults bounding the caldera and forming the structural margins of the Area 20 caldera, however, are well below the bottom of the Well ER-20-4 borehole. The northern structural margin of the TMCC is located approximately 3,600 m (12,000 ft) southeast of Well ER-20-4. At this location the structural margin of the TMCC is interpreted to represent the northern structural boundaries of both the Rainier Mesa and Ammonia Tanks calderas (BN, 2002).

Approximately 820 m (2,700 ft) southwest of Well ER-20-4 is a west-northwest trending structural zone called the northern Timber Mountain moat structural zone (NTMMSZ). This buried structural zone was first recognized through geophysical methods (Mankinen et al., 1999, Grauch et al., 1999), and subsequently was confirmed by data from PM–OV Phase I drilling (DOE/NV, 2000b). The latest Phase II drilling campaign (especially Wells ER-20-7, ER-20-8, and ER-EC-11) has provided additional details regarding the NTMMSZ west of the Boxcar fault (NNSA/NSO, 2010a, 2011, and 2010b). The NTMMSZ is a down-on-the-southwest fault (or fault zone) that displaces rock units as young as the Rainier Mesa Tuff by more than 300 m (1,000 ft). The NTMMSZ appears to be related to the formation of the TMCC, with major movement occurring between the eruptions of the Rainier Mesa and Ammonia Tanks Tuffs (DOE/NV, 2000b).

Movement along the NTMMSZ resulted in the formation of a structural bench on the down-thrown side of the NTMMSZ and a collapse collar on the adjacent up-thrown side. This structural bench, designated the Northwestern Timber Mountain Bench by Warren et al. (2000), is referred to simply as the Bench in this and other Phase II documents (e.g., SNJV, 2009a; NNSA/NSO, 2010a; 2010b) (see Figure 1-2). The associated collapse collar, a feature that is commonly associated with calderas (Lipman, 2000) and indicative of rapid fault movement,

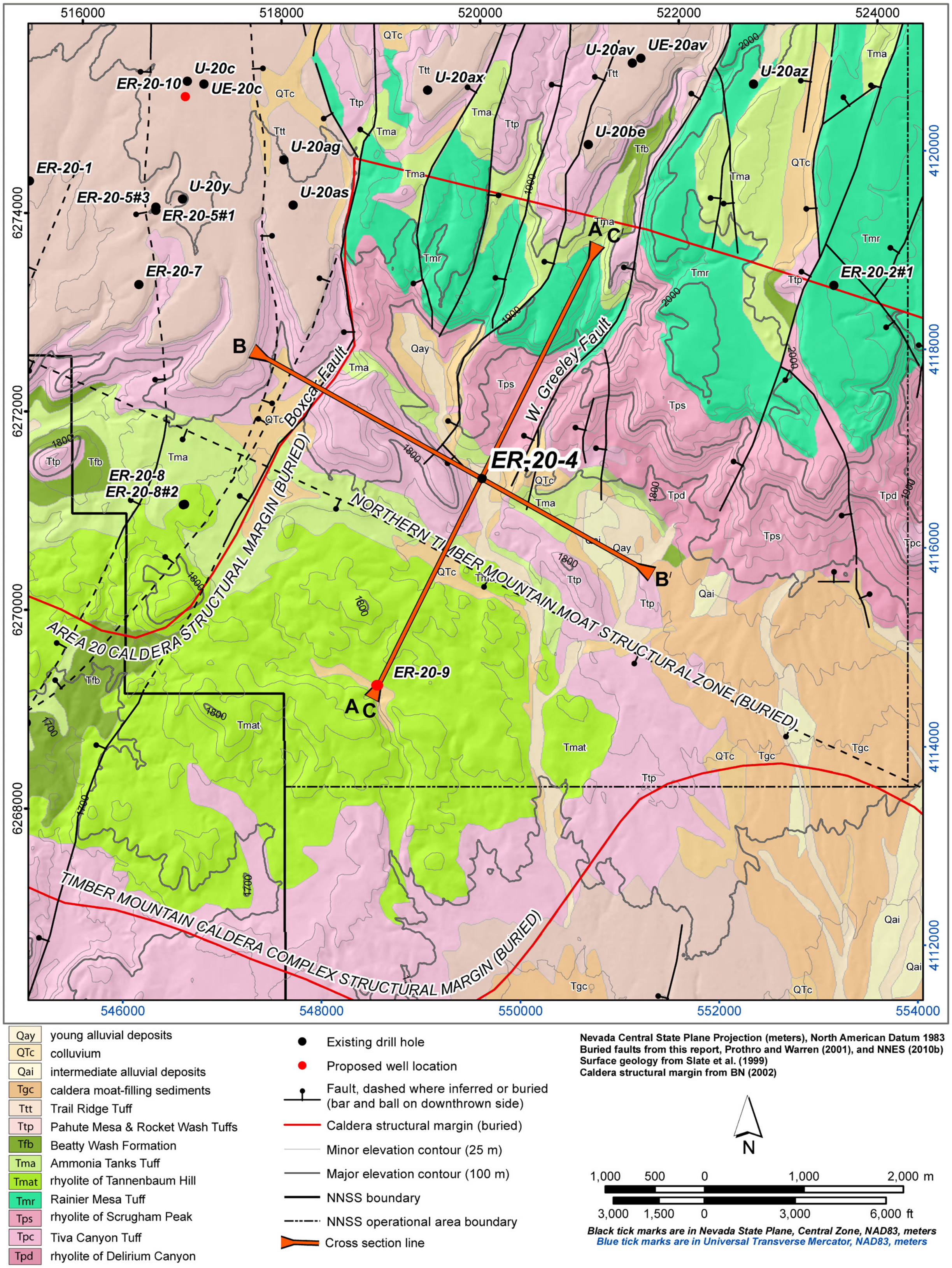

Figure 4-1
Surface Geologic Map of the Well ER-20-4 Area

formed by the catastrophic failure and collapse of the over-steepened fault scarp that developed on the up-thrown side of the NTMMSZ during rapid displacement along the NTMMSZ and the formation of the Bench. The eroded remnant of this collapse collar forms the south face of Pahute Mesa north of the well site. Thick rhyolite of Tannenbaum Hill lava ("Tmat" on Figure 4-1) flowed onto the downward-displaced Bench area after the eruption of the Rainier Mesa Tuff. Detailed stratigraphic information indicates that Well ER-20-4 crossed the collapse collar of the NTMMSZ at the depth of about 259 m (850 ft) depth. At this contact the rhyolite of Tannenbaum Hill rests directly upon the rhyolite of Delirium Canyon.

Well ER-20-4 is located just northeast of the Bench, on the up-thrown side of the NTMMSZ and within the collapse collar of the NTMMSZ (Figure 4-1). Stratigraphic units that occur between the rhyolite of Delirium Canyon and the rhyolite of Tannenbaum Hill (exposed along the south face of Pahute Mesa just north of Well ER-20-4) were removed at the Well ER-20-4 location by mass wasting processes.

Numerous normal faults have been mapped at the surface on Pahute Mesa (Slate et al., 1999). These faults generally strike in a northerly direction and dip to the west. Seismic refraction and subsurface mapping suggest that some of these faults are related at depth to the SCCC (Ferguson et al., 1994).

The surface trace of one such fault, the West Greeley fault, is located approximately 366 m (1,200 ft) east of the collar of Well ER-20-4 (Figure 4-1). Beneath Pahute Mesa, the West Greeley fault appears to be closely associated with the eruption and deposition of the Calico Hills Formation. The Calico Hills Formation thickens substantially west of the West Greeley fault, indicating movement along the West Greeley fault prior to (as in Ferguson et al., 1994), and probably during the eruption of the Calico Hills Formation. Many of the intercalated lava flows within the Calico Hills Formation probably erupted from vents along the West Greeley and other major basin-and-range faults at Pahute Mesa (Warren et al., 1989).

4.2.2 Stratigraphy and Lithology

The stratigraphic and lithologic units penetrated at Well ER-20-4 are illustrated in Figure 4-2, and the distribution of stratigraphic units in the vicinity of the well is shown in cross section in Figures 4-3 and 4-4. The determination of the volcanic stratigraphic and lithologic units penetrated by Well ER-20-4 was aided by correlation with the geology of nearby emplacement holes to the north, nearby outcrops, Well ER-20-7 (NNSA/NSO, 2010a) to the west, and the PM–OV HFM (BN, 2002).

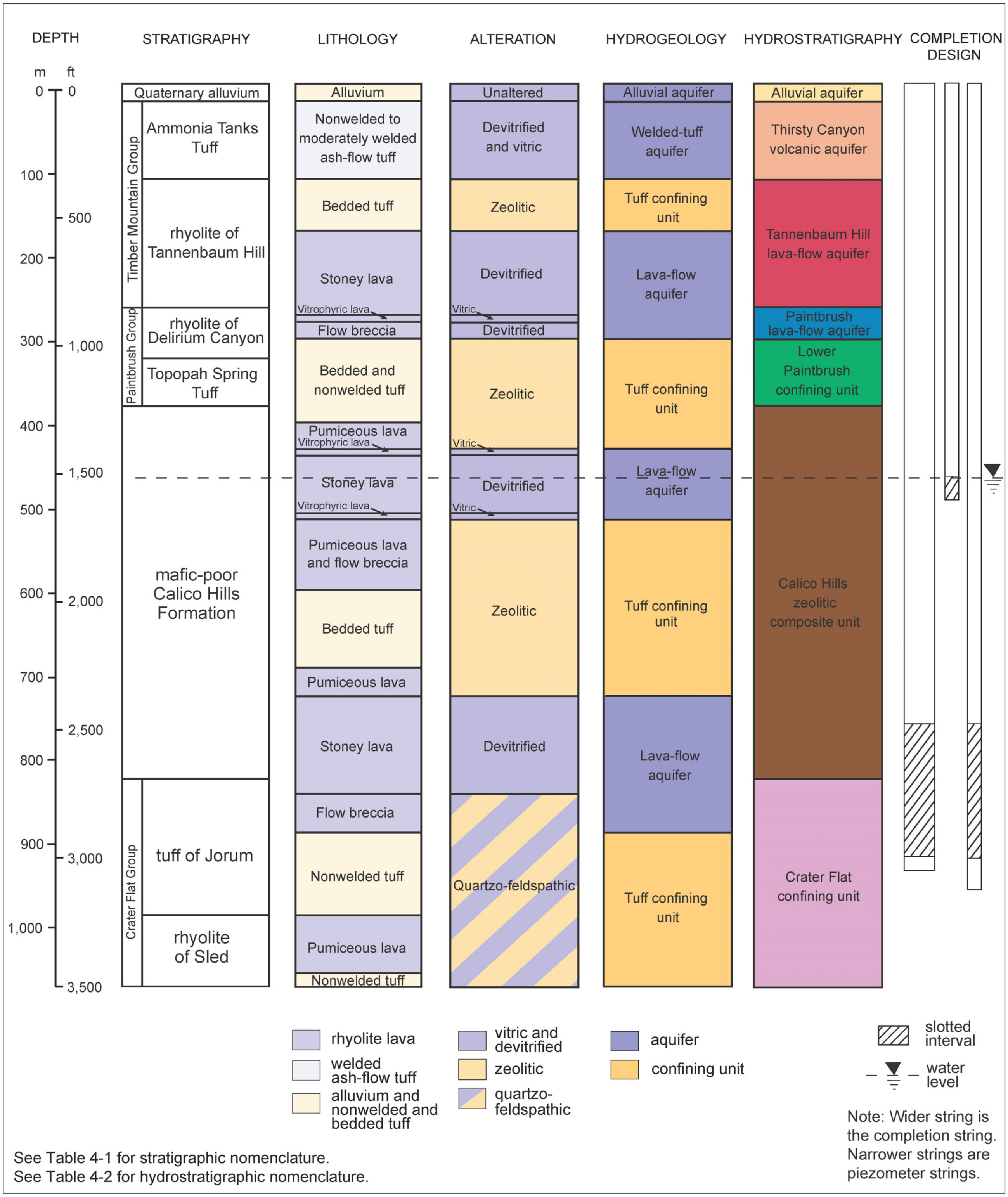

Figure 4-2
Graphical Presentation Showing Geology and Hydrogeology for Well ER-20-4

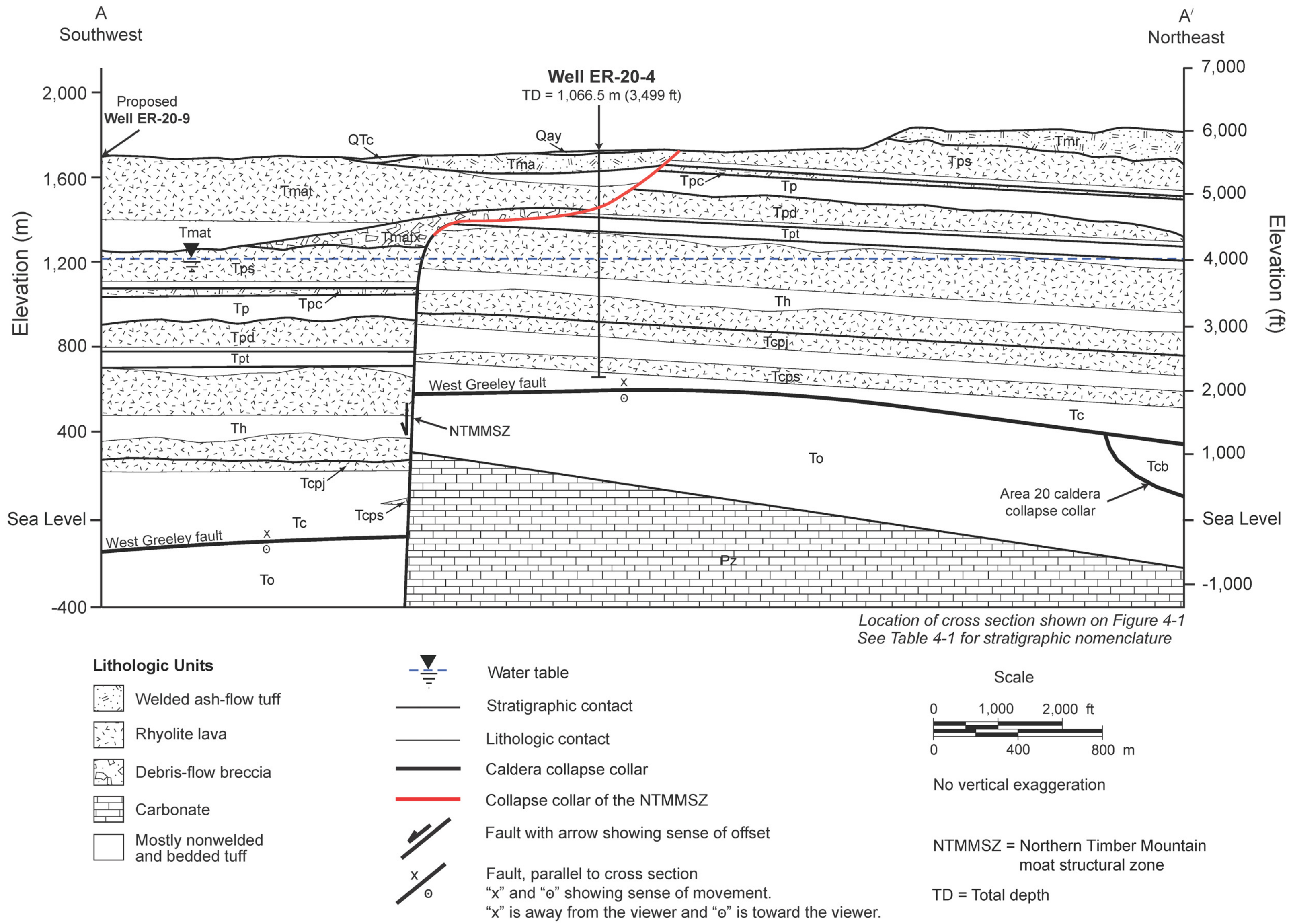

Figure 4-3
Southwest–Northeast Geologic Cross Section A–A’ through Well ER-20-4

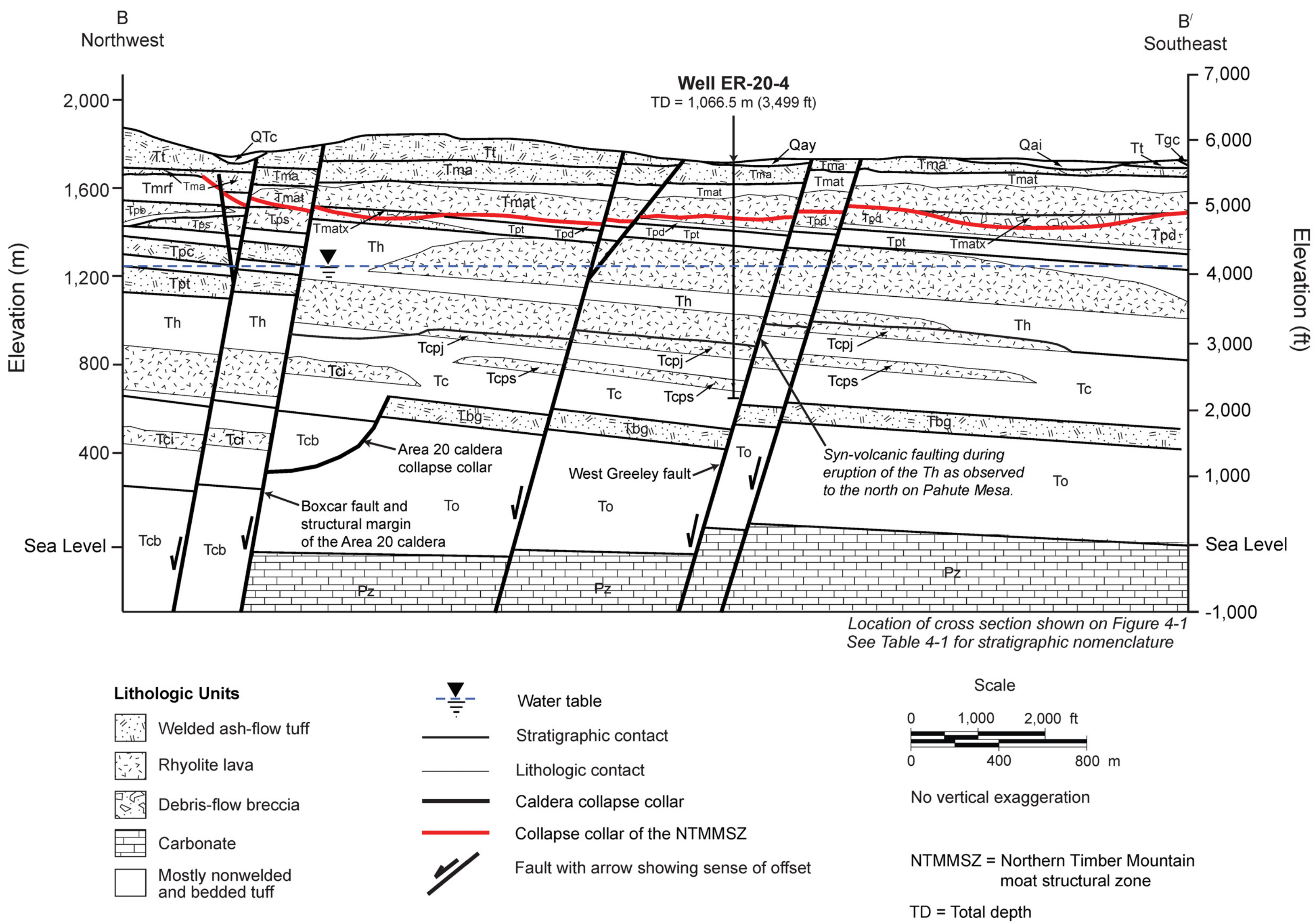

Figure 4-4
Northwest–Southeast Geologic Cross Section B–B’ through Well ER-20-4

Drilling at Well ER-20-4 began in Quaternary alluvial deposits that form the ground surface in the vicinity of the well (Figure 4-1). The next major stratigraphic interval in Well ER-20-4 is the Timber Mountain Group, consisting of the Ammonia Tanks Tuff, erupted 11.45 Ma from the TMCC (Sawyer et al., 1994) located about 7 km (4.3 mi) to the south, and the rhyolite of Tannenbaum Hill, erupted 11.55 Ma from local source(s) on the Bench.

The Ammonia Tanks Tuff was encountered in the interval 10.7 to 103.6 m (35 to 340 ft). At Well ER-20-4 this unit consists of 93.0 m (305 ft) of nonwelded to moderately welded ash-flow tuff. Both the mafic-rich and mafic-poor members of the Ammonia Tanks Tuff were recognized in the well. The stratigraphic assignment of the Ammonia Tanks Tuff is based on surface geology in the vicinity of the well, ash-flow tuff lithology, and mineralogic assemblage, including the presence of quartz phenocrysts, biotite, sphene, and sanidine showing blue iridescence.

Below the Ammonia Tanks Tuff, Well ER-20-4 penetrated 64.0 m (210 ft) of bedded tuff of the rhyolite of Tannenbaum Hill, from 103.6 to 167.6 m (340 to 550 ft), and a thick section of rhyolitic lava of the rhyolite of Tannenbaum Hill from 167.6 to 259.1 m (550 to 850 ft). The rhyolite of Tannenbaum Hill was identified on the basis of its lava-flow lithology and mineralogic assemblage including sphene, quartz phenocrysts, and biotite. As is characteristic of lava, lithic and pumice fragments (i.e., pyroclasts) were noticeably absent from the lava interval.

Below the rhyolite of Tannenbaum Hill, the borehole penetrated a 59.7-m (196-ft) thick interval of rhyolitic stoney lava, vitrophyric lava, basal flow breccia, and nonwelded tuff from 259.1 to 318.8 m (850 to 1,046 ft). The interval's lava-flow lithology, absence of quartz phenocrysts, and stratigraphic position between the rhyolite of Tannenbaum Hill and the underlying Topopah Spring Tuff indicate that the lava belongs to the Paintbrush Group. Detailed petrographic analyses indicate that this unit can be more precisely assigned to the rhyolite of Delirium Canyon (Warren, 2011). The Paintbrush Group was erupted from calderas and related vents that are approximately spatially coincident with the TMCC, between 12.7 and 12.8 Ma (Sawyer et al., 1994). As mentioned in Subsection 4.2.1, the contact between the rhyolite of Tannenbaum Hill and the rhyolite of Delirium Canyon is interpreted to be a collapse collar related to the NTMMSZ scarp to the south.

The Topopah Spring Tuff encountered at 318.8 m (1,046 ft) represents the base of the Paintbrush Group in Well ER-20-4. This unit consists of about 66.8 m (219 ft) of nonwelded and bedded tuff. Detailed petrographic analyses indicate that the Topopah Spring Tuff in Well ER-20-4 is the Pahute Mesa lobe member of the formation (Warren, 2011). The Topopah Spring Tuff is identified by its pyroclastic lithology, the absence of quartz phenocrysts, and its stratigraphic position at the base of the Paintbrush Group section.

Below the Paintbrush Group, Well ER-20-4 encountered rhyolite lavas and zeolitic to quartzo-feldspathic bedded and nonwelded tuff of the Calico Hills Formation. The Calico Hills Formation in Well ER-20-4 is dominated by thick rhyolite lava flows penetrated in the intervals from 392.3 to 605.0 m (1,287 to 1,985 ft) and from 695.9 to 821.4 m (2,283 to 2,695 ft). Detailed petrographic analyses indicate that theses rocks are part of the mafic-poor member of the Calico Hills Formation (Warren, 2011). The Calico Hills Formation was identified by its stratigraphic position and the presence of quartz phenocrysts.

Well ER-20-4 reached TD at 1,066.5 m (3,499 ft), within the Crater Flat Group, consisting of rhyolite lava and nonwelded tuff. Detailed petrographic analyses indicate that rocks of the Crater Flat Group encountered in Well ER-20-4 consist of the tuff of Jorum from 821.4 to 981.8 m (2,695 to 3,221 ft), and the rhyolite of Sled, from 981.8 m (3,221 ft) to TD (Warren, 2011). The absence of quartz phenocrysts as observed in microscopic examination of drill cuttings samples and thin sections is diagnostic of this quartz-poor formation (Warren et al.,1989).

4.2.3 Alteration

The volcanic rocks penetrated at Well ER-20-4 are generally unaltered above 103.6 m (340 ft). Unaltered rocks include nonwelded and bedded tuffs that have retained their original vitric (i.e., glassy) character. The welded portions of the ash-flow tuffs are mostly devitrified as a result of recrystallization of the original glass matrix to microcrystalline quartz and feldspar during cooling and degassing as the welding process proceeded. Below 103.6 m (340 ft), and to the depth of 841.2 m (2,760 ft), the original glass matrix of the nonwelded and bedded tuffs has been altered mainly to the zeolite minerals clinoptilolite and mordenite. Rhyolite lavas within this interval are devitrified in their stoney interiors, vitric within vitrophyric intervals, and zeolitic where pumiceous. Below 841.2 m (2,760 ft), higher temperature quartzo-feldspathic alteration is pervasive, and is characterized by microcrystalline quartz and feldspar as the main alteration products, even within typically zeolitic rocks such as nonwelded tuff and pumiceous lava.

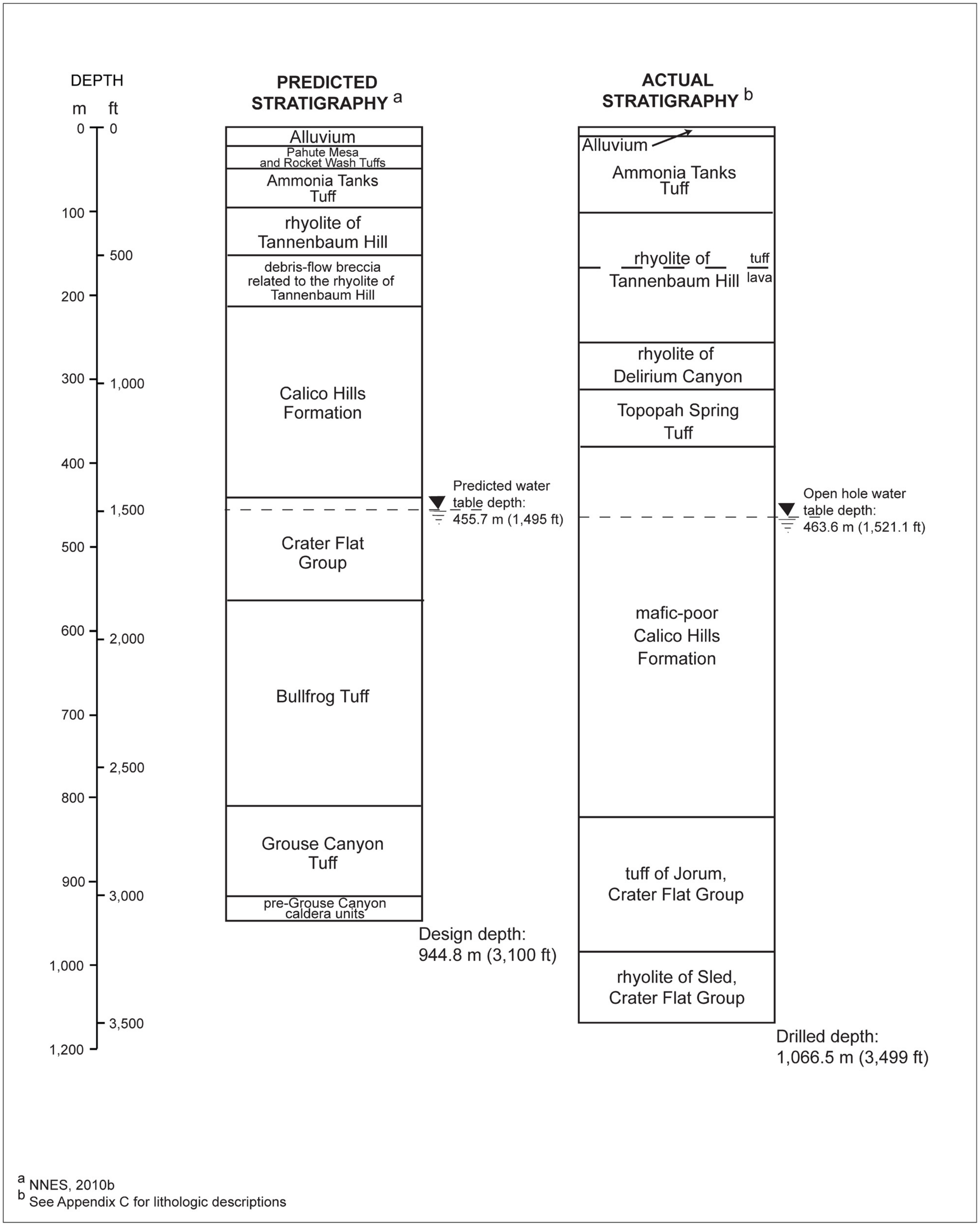

Figure 4-5
Predicted and Actual Stratigraphy at Well ER-20-4

4.3 Predicted and Actual Geology

The geology encountered at Well ER-20-4 is different than predicted prior to drilling (Figure 4-5). Most of the differences within the upper unsaturated portion of the volcanic section penetrated involve units associated with the Timber Mountain Group and units associated with the Paintbrush Group, particularly the presence of the rhyolite of Delirium Canyon and the Topopah Spring Tuff. The uppermost volcanic units penetrated in Well ER-20-4 consist of ash-flow tuffs of the Ammonia Tanks Formation of the Timber Mountain Group and a pre-Ammonia Tanks rhyolite lava, the rhyolite of Tannenbaum Hill. Both of these units are slightly thicker than predicted. Below the Timber Mountain Group, however, the geology encountered is significantly different than predicted. The differences observed in the shallow units (post-rhyolite of Delirium Canyon) are related to the position of the well relative to the buried fault scarp and collapse collar of the NTMMSZ.

The saturated stratigraphic sequence penetrated in the lower portion of Well ER-20-4 is very different in thickness and composition from that predicted prior to drilling. This interval includes units of the Calico Hills Formation and the Crater Flat Group. The Calico Hills Formation, encountered below the Paintbrush Group units, is much thicker and lower in elevation than expected. The Calico Hills Formation was expected to include only unsaturated bedded tuffs of intermediate thickness, but the unit is of substantial thickness (435.9 m [1,430 ft]) and includes two thick lava flows along with intervening bedded tuffs.

Crater Flat Group rocks were encountered in the lower portion of the borehole, indicating that the older units associated with the Crater Flat Group and underlying Belted Range Group, which were expected, are below the bottom of the well. The predicted geology for the deeper units at Well ER-20-4 was based heavily on gravity data (interpretation of a gravity high, as shown in Figure 3-2 in BN, 2002). The presence of a substantial thickness of Calico Hills Formation here suggests that this structural block may represent an outer collapse of the Area 20 caldera. Alternatively, the thick section of Calico Hills Formation at Well ER-20-4 might be due to movement along the West Greeley fault.

4.4 Hydrogeology

The saturated portion of Well ER-20-4 consists of an alternating sequence of LFAs and tuff confining units. Rhyolite lava flows within the Calico Hills Formation and tuff of Jorum form LFAs in the well, while the zeolitic bedded and nonwelded tuffs that occur between and below the LFAs are categorized as tuff confining units. The lava flow within the rhyolite of Sled is pumiceous and altered, and thus is not designated an LFA. An interpretation of the possible distribution of the HSUs in the vicinity of Well ER-20-4 is shown in cross section in Figure 4-6.

Prior to drilling, it was predicted that the water table would be encountered at a depth of 455.7 m (1,495 ft), within zeolitic bedded tuffs of the Crater Flat Group. The actual water table depth on October 25, 2010, was 463.6 m (1,521.1 ft), but because the stratigraphic units in the lower portion of the well are deeper than predicted, this depth is within the upper portion of the Calico Hills Formation.

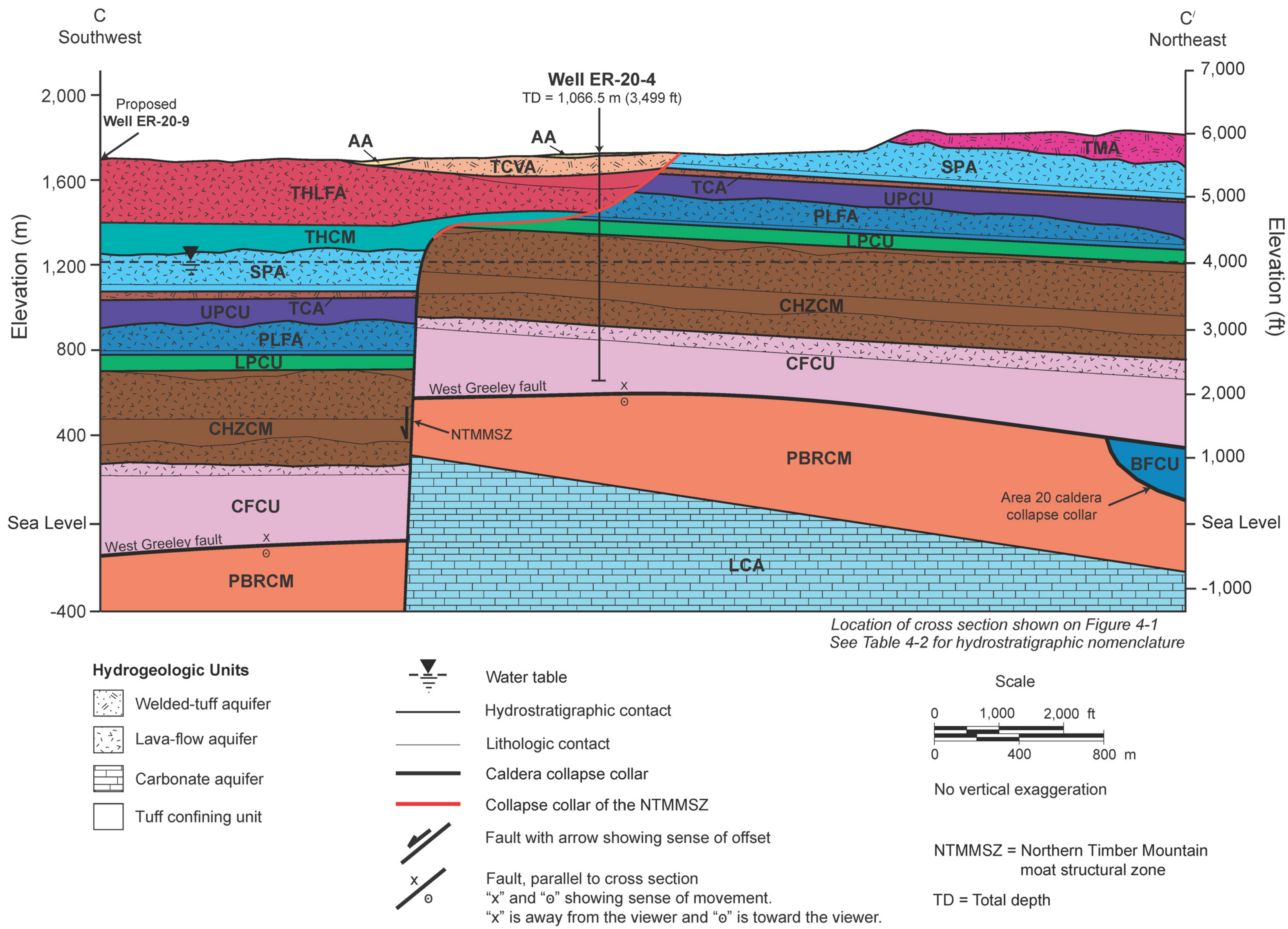

Figure 4-6
Southwest–Northeast Hydrostratigraphic Cross Section C–C' through Well ER-20-4

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5.0 Hydrology

5.1 Water-Level Information

Prior to drilling, the water level at Well ER-20-4 was estimated to be 455.7 m (1,495 ft) below ground surface, within the Crater Flat confining unit. During open-hole geophysical logging operations on August 26, 2010, after the borehole had penetrated a short distance below the water table near the CHZCM, a fluid level depth of 462.1 m (1,516 ft) (elevation of 1,286.3 m [4,220 ft]) was measured. On September 20, 2010, after the borehole had reached TD and the upper aquifer was cased off, a fluid level depth for the lower LFA within the CHZCM was measured at the depth of 463.8 m (1,521.5 ft). On October 25, 2010, a fluid level depth of 463.6 m (1,521.1 ft) was measured in both the shallow and deep piezometer strings (installed within the upper and lower CHZCM LFAs, respectively), indicating that the fluid level had probably reached equilibrium.

5.2 Water Production

Water production was estimated during drilling of Well ER-20-4 on the basis of dilution of a lithium-bromide tracer, as measured by N-I field personnel. The first observation of water in returns was reported on August 31, 2010, at the depth of 483.7 m (1,587 ft). Estimated water production ranged from zero in the unsaturated zone to approximately 1,514 liters per minute (400 gallons per minute) while drilling in the CHZCM and the CFCU.

Estimated water production rates during drilling are presented graphically in Appendix A-1. More accurate water production will be available after hydraulic testing is conducted following completion and development of the well.

5.3 Flow Meter Data

Flow meter data, along with temperature, electrical conductivity, and pH measurements, are typically used in UGTA wells to characterize borehole fluid variability, which may indicate inflow and outflow zones. DRI personnel ran their chemistry log to obtain temperature, electrical conductivity, and pH measurements, and their Heat Pulse Flow log to obtain flow direction within the saturated portion of the borehole, shortly after the TD was reached. The DRI flow log indicated gradually increasing downward flow from 478.5 m (1,570 ft), just below the water table, to 930.2 m (3,052 ft). An outflow zone was measured between 930.2 and 1,022.0 m (3,052 and 3,353 ft). Flow data below 1,022.0 m (3,353 ft) indicated an upward flow.

5.4 Groundwater Characterization Samples

Following geophysical logging on September 7, 2010, and prior to well completion and development, DRI collected groundwater characterization samples within the open borehole at the depths of 570.0 and 914.4 m (1,870 and 3,000 ft). These water samples were sent to LLNL and LANL for analysis, and the results will be reported in data reports prepared by the analyzing laboratories and in UGTA project reports (e.g., the water chemistry database and the transport data document).

6.0 Precompletion and Open-Hole Development

Initial open-hole well development conducted in Well ER-20-4 consisted of using the drill string to air-lift groundwater to remove residual cuttings and drilling fluids from the borehole, prior to the final logging operation, after the TD was reached.

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7.0 Well Completion

7.1 Introduction

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

The proposed design for Well ER-20-4 was presented in NNES (2010b) and in the NSTec FAWP (NSTec, 2010b). The completion plans are summarized in Section 7.2.1 of this report, and the actual well completion design, based on the hydrogeology encountered in the borehole, is presented in Section 7.2.2. The rationale for differences between the planned and actual design is discussed in Section 7.2.3, and the completion methods are presented in Section 7.3. Figure 7-1 is a schematic diagram of the well completion design. Figure 7-2 shows a plan view and profile of the final wellhead surface completion. Table 7-1 is a construction summary for the completion strings.

7.2 Well Completion Design

The final completion design differs from the proposed design, as described in the following sections.

7.2.1 Proposed Completion Design

The original completion design (presented in NNES, 2010b) was based on the assumption that Well ER-20-4 would penetrate the water table within zeolitic bedded tuff of the Crater Flat Group and reach TD within the upper portion of the pre-Grouse Canyon caldera units. The primary goal of the proposed completion design was to provide groundwater production data from the Belted Range aquifer (BRA) and to provide access to groundwater for monitoring and sampling. The 13⅜-in. casing was intended to extend to the depth of approximately 449.6 m (1,475 ft) to isolate and stabilize the unsaturated portion of the borehole while drilling the saturated section.

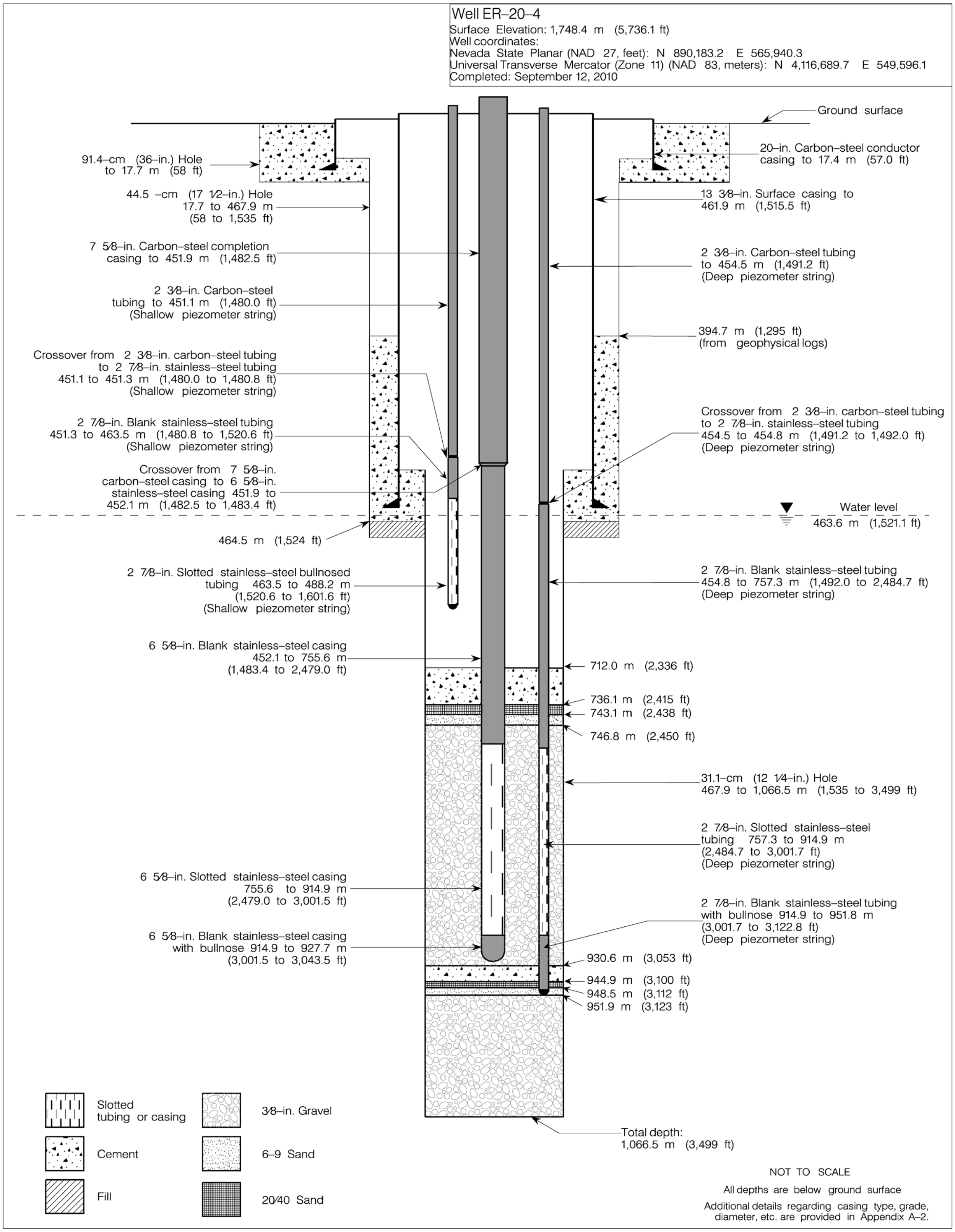

Figure 7-1
As-Built Completion Schematic for Well ER-20-4

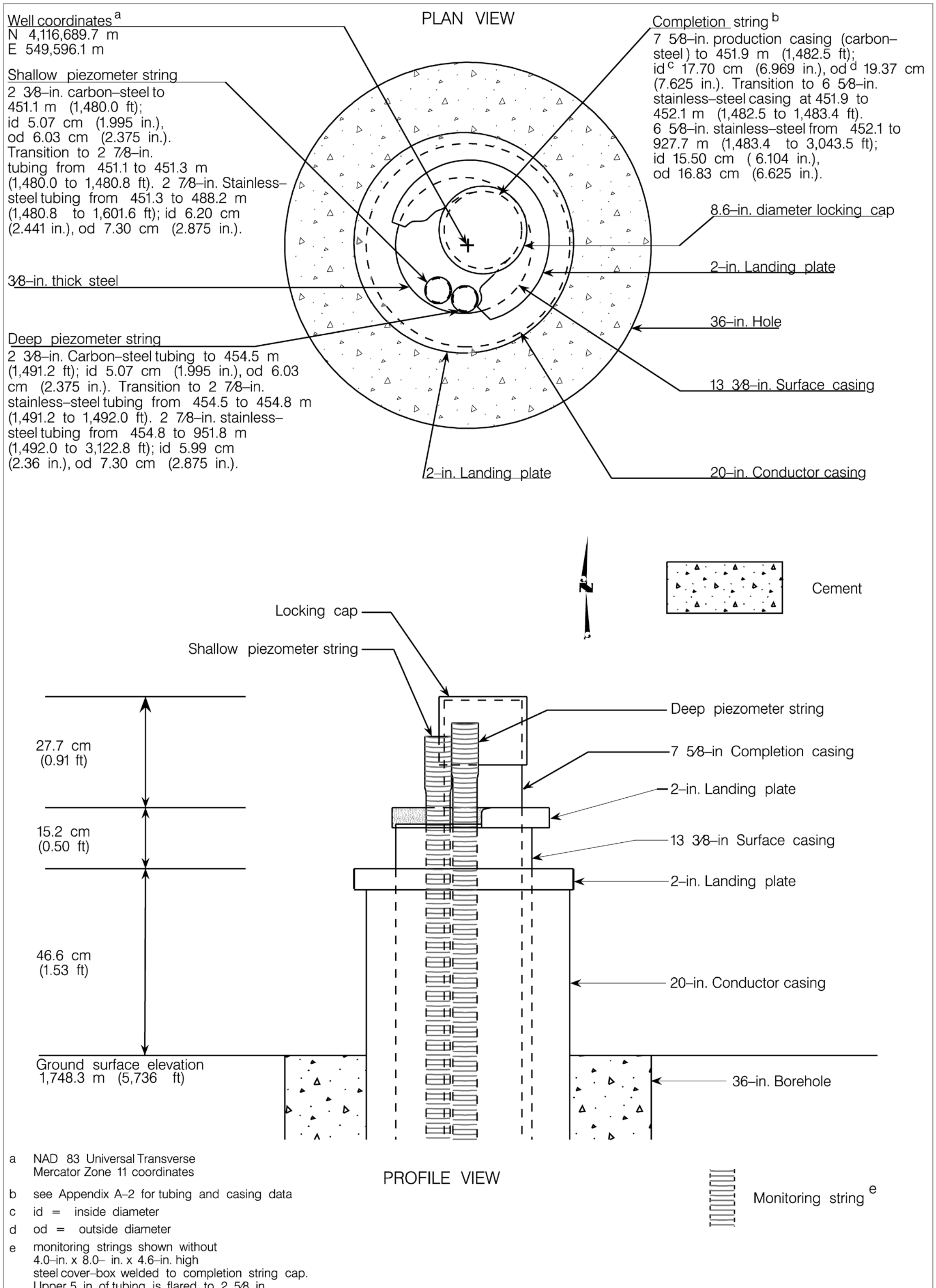

Figure 7-2
Wellhead Diagram for Well ER-20-4

Table 7-1
Well ER-20-4 Completion String Construction Summary

String	Casing and Tubing	Configuration meters (feet)		Cement meters (feet)	Sand/Gravel meters (feet)
Shallow Piezometer String	2⅜-in. carbon-steel tubing with cross-over sub	0 to 451.3 (0 to 1,480.8)	**Blank**	None	
	2⅞-in. stainless-steel tubing	451.3 to 488.2 (1,480.8 to 1,601.6	**Blank** 451.3 to 463.5 (1,480.8 to 1,520.6)	None	
			2 Slotted Joints [a] (lowest is bullnosed) 463.5 to 488.2 (1,520.6 to 1,601.6)	None	
Deep Piezometer String	2⅜-in. carbon-steel tubing with cross-over sub	0 to 454.8 (0 to 1,492.0)	**Blank**	None	
	2⅞-in. stainless-steel tubing	454.8 to 951.8 (1,492.0 to 3,122.8)	**Blank** 454.8 to 757.3 (1,492.0 to 2,484.7)	**Type II Neat Cement** 712.0 to 736.1 (2,336 to 2,415)	**20/40 Sand** 736.1 to 743.1 (2,415 to 2,438) **6–9 Sand** 743.1 to 746.8 (2,438 to 2,450) **⅜-in. Washed Gravel** 746.8 to 930.6 (2,450 to 3,053)
			13 Consecutive Slotted Joints [a] 757.3 to 914.9 (2,484.7 to 3,001.7)	None	**20/40 Sand** 944.9 to 948.5 (3,100 to 3,112) **6–9 Sand** 948.5 to 951.9 (3,112 to 3,123) **⅜-in. Washed Gravel** 951.9 to 1,066.5 (3,123 to 3,499)
			Blank and Bullnosed 914.9 to 951.8 (3,001.7 to 3,122.8)	**Type II Neat Cement** 930.6 to 944.9 (3,053 to 3,100)	

Table 7-1
Well ER-20-4 Completion String Construction Summary (continued)

String	Casing and Tubing	Configuration meters (feet)		Cement meters (feet)	Sand/Gravel meters (feet)
Completion Casing	7⅝-in. carbon-steel completion casing with cross-over sub	0 to 452.1 (0 to 1,483.4)	**Blank**	None	
	6⅝-in. stainless-steel completion casing	452.1 to 927.7 (1,483.4 to 3,043.5)	**Blank** 452.1 to 755.6 (1,483.4 to 2,479.0)	Same as for Deep Piezometer String	Same as for Deep Piezometer String
			25 Consecutive Slotted Joints [b] 755.6 to 914.9 (2,479.0 to 3,001.5)	None	
			Blank and Bullnosed 914.9 to 927.7 (3,001.5 to 3,043.5)		

a Slots are 0.159 cm (0.0625 in.) wide and 5.715 cm (2.25 in.) long, arranged in 8 rows, 72 slots per row, 45 degrees apart.

b Slots are 0.159 cm (0.0625 in.) wide and 6.985 cm (2.75 in.) long, arranged in 12 rows on staggered 15.2-cm (6.0-in.) centers.

The well was planned to be completed with a single string of casing. This completion string was to consist of 7⅝-in. internally epoxy-coated carbon steel casing from the surface to within 10.7 m (35 ft) above the water table, and 6⅝-in. stainless-steel casing hanging from the carbon-steel casing and extending through the target aquifer, the BRA. This casing string was to be slotted and gravel-packed at the BRA. Since only one saturated aquifer was expected, cement isolation above the gravel pack was not planned.

A piezometer string was to be positioned inside the 13⅜-in. surface casing, between the borehole wall and the well-completion string, to monitor the water level during testing and for collecting water samples directly from the developed interval. The slotted portion of this tubing string was to be positioned within the gravel-packed interval at the BRA, adjacent to the slotted portion of the completion casing.

7.2.2 As-Built Completion Design

Changes to the design of Well ER-20-4 were initially considered due to penetration of two saturated lavas within the CHZCM and a lava within the CFCU. The final design of the Well ER-20-4 completion was determined after the TD of 1,066.5 m (3,499 ft) was reached, through consultation with members of the UGTA Well ER-20-4 Drilling Advisory Team, on the basis of onsite evaluation of data such as lithology and water production, drilling data, tritium levels, and data from various geophysical logs. As shown in Figure 7-1, the main completion string and two piezometer strings were installed in Well ER-20-4.

The main completion string consists of a section of 6⅝-in. stainless-steel casing suspended from 7⅝-in. carbon-steel casing, and was set at the depth of 927.7 m (3,043.5 ft). The 7⅝-in. carbon-steel casing extends from the surface to the depth of 451.9 m (1,482.5 ft), which is 11.9 m (39 ft) above the water table. The stainless-steel 6⅝-in. casing is slotted in the interval from 755.6 to 914.9 m (2,479.0 to 3,001.5 ft) within the lower LFA of the CHZCM and the upper CFCU. The slotted section consisted of 25 consecutive slotted joints, and was terminated with 12.1 m (39.6 ft) of blank stainless-steel casing and a 0.73-m (2.4-ft) stainless-steel bullnose to function as a sediment sump. The openings in each slotted casing joint are 0.159 cm (0.0625 in.) wide and 6.99 cm (2.75 in.) long. The slots are arranged in rows of 12, with rows staggered 30 degrees on 15.2-cm (6.0-in.) centers.

The slotted interval accesses the borehole from the top of the san/gravel pack, at the depth of 736.1 m (2,415 ft), to the top of cement, at 930.6 m (3,053 ft). This interval encompasses all the lower lava in the CHZCM, a lava within the upper part of the CFCU, and approximately 29.6 m

(97 ft) of the underlying tuff confining unit. The slotted interval is isolated by cement from all formations above the gravel pack.

The shallow piezometer string was installed to provide access to the upper LFA within the CHCZM. It consists of a section of 2⅞-in. stainless-steel tubing suspended from 2⅜-in. carbon-steel tubing, and was set at the depth of 488.2 m (1,601.6 ft) in the annulus between the completion casing and the 13⅜-in. surface casing. The 2⅞-in. tubing is slotted in the interval 463.5 to 488.2 m (1,520.6 to 1,601.6 ft). The slots are 0.159 cm (0.0625 in.) wide and 5.715 cm (2.25 in.) long, arranged in 8 rows, 72 slots per row, 45 degrees apart. No stemming was placed around the shallow piezometer string.

The deep piezometer string was installed to provide access to the lower LFA within the CHCZM and the upper part of the CFCU. It consists of a section of 2⅞-in. stainless-steel tubing suspended from 2⅜-in. carbon-steel tubing, and was set at the depth of 951.8 m (3,122.8 ft) in the annulus between the completion casing and the 13⅜-in. surface casing. The 2⅞-in. tubing is slotted in the interval 757.3 to 914.9 m (2,484.7 to 3,001.7 ft). The slots are the same size and arrangement as on the shallow piezometer string: 0.159 cm (0.0625 in.) wide and 5.715 cm (2.25 in.) long, arranged in 8 rows, 72 slots per row, 45 degrees apart. The slotted section of this string is embedded within the same gravel section as the completion casing, and is isolated from units above and below by the same sand and cement sections described above for the completion casing (Table 7-1).

7.2.3 Rationale for Differences between Planned and Actual Well Design

The original proposed well completion design for Well ER-20-4 was based on the expectation that the only aquifer encountered in the well would be saturated BRA in the depth interval of 807.7 to 914.4 m (2,650 to 3,000 ft). The BRA was not encountered in the borehole and is presumably deeper than the TD of the borehole. Two saturated lavas within the CHZCM and one lava within the CFCU were encountered. These aquifers had to be isolated from each other to avoid possible cross-communication. Therefore, adjustments to the original completion were made, as described above.

7.3 Well Completion Method

As described in Sections 2.2 and 7.2.2, two piezometer strings were installed by the drill crew prior to installation of the completion casing.

Prior to installation of the main completion string, the UDI drill crew inserted a string of 2⅞-in. Hydril tremie line to be used as a conduit during emplacement of stemming materials (the tremie line was pulled up as stemming progressed). The casing crew began running the main completion string on September 10, 2010, and landed it at 927.7 m (3,043.5 ft) on the same day. Colog, Inc. ran a nuclear annular investigation log (NAIL) tool inside the completion string to monitor placement of stemming materials. A layer of ⅜-in. washed gravel 114.6 m (376 ft) thick was emplaced at the bottom of the borehole below the completion string. Next, a 3.4-m (11.0-ft) layer of 6–9 coarse silica sand and a 3.7-m (12.0-ft) layer of 20/40 fine silica sand were placed above the gravel to prevent cement from infiltrating the gravel pack. Cement was placed above the sand to a depth of 930.6 m (3,053 ft), which is 2.9 m (9.5 ft) below the bottom of the completion string. Next, another layer of ⅜-in. washed gravel was emplaced around the slotted interval, to a depth of 746.8 m (2,450 ft). Then, a 3.7-m (12.0-ft) layer of 6–9 coarse silica sand and a 7.0-m (23.0-ft) layer of 20/40 fine silica sand were placed above the gravel to prevent cement infiltration. Cement was placed above the sand to a depth of 712.0 m (2,336 ft) to isolate the upper Calico Hills LFA from the two lower lavas (one within the Calico Hills Formation and one within the Crater Flat Group) (Figure 7-1).

The UDI drill rig was released after the completion casing was installed. Hydrologic testing is planned as a separate effort, so a pump was not installed in the well, and no well-development or pumping tests were conducted immediately after completion.

All well construction materials used for the completion were inspected according to relevant procedures, as listed in SNJV (2009a). Standard decontamination procedures were employed to prevent the introduction of contaminants into the well.

8.0 Planned and Actual Costs and Scheduling

The original NSTec-approved baseline task plan cost estimate for drilling and completing Well ER-20-4 was based on drilling to a planned TD of 944.9 m (3,100 ft) from the surface. Based on the geology encountered in the borehole, it was decided that the borehole would need to be drilled deeper than planned in order to fully penetrate the Calico Hills Formation and to confirm the thicker and deeper stratigraphic assemblages. The final TD of Well ER-20-4 is 1,066.5 m (3,499 ft), which is 121.6 m (399 ft) deeper than planned. However, due to favorable drilling conditions the drilling operation remained several days ahead of schedule, so changes to the baseline were deemed unnecessary.

It took 22 days to construct Well ER-20-4, starting with the drilling of the 44.5-cm (17.5-in.) hole. This includes a drilling hiatus of three days for the investigation related to a safety incident, and one day during installation of a new flow line. However, the drilling rate was faster than initially planned, and was more than enough to compensate for the unanticipated delays and additional hole depth. A graphical comparison, by day, of planned and actual well-construction activities is presented in Figure 8-1.

The cost analysis for Well ER-20-4 begins with the mobilization of the UDI drill rig to the drill site, where the conductor hole had already been constructed. The total construction cost for Well ER-20-4 includes all drilling costs: charges by the drilling subcontractor, charges by other support subcontractors (including compressor services, drilling fluids, casing services, down-hole tools, and geophysical logging), and charges by NSTec for mobilization and demobilization of equipment, cementing services, radiological control technician services, inspection services, site supervision, and geotechnical consultation. The cost of building the roads, drill pad, sumps, and conductor hole is not included, nor is the cost of well-site support by N-I personnel.

The total planned cost for constructing Well ER-20-4 was $3,746,951. The actual cost was $3,162,307, or 15.6 percent less than the planned cost. Additional costs were incurred prior to the start of drilling operations due to the fabrication of a new flow line and subsequent rig standby time. Because drilling proceeded smoothly and Well ER-20-4 took two fewer days to drill than planned, the initial overrun costs were offset by the savings of a shortened drilling period. Figure 8-2 presents a comparison of the planned and actual costs, by day, for construction of Well ER-20-4.

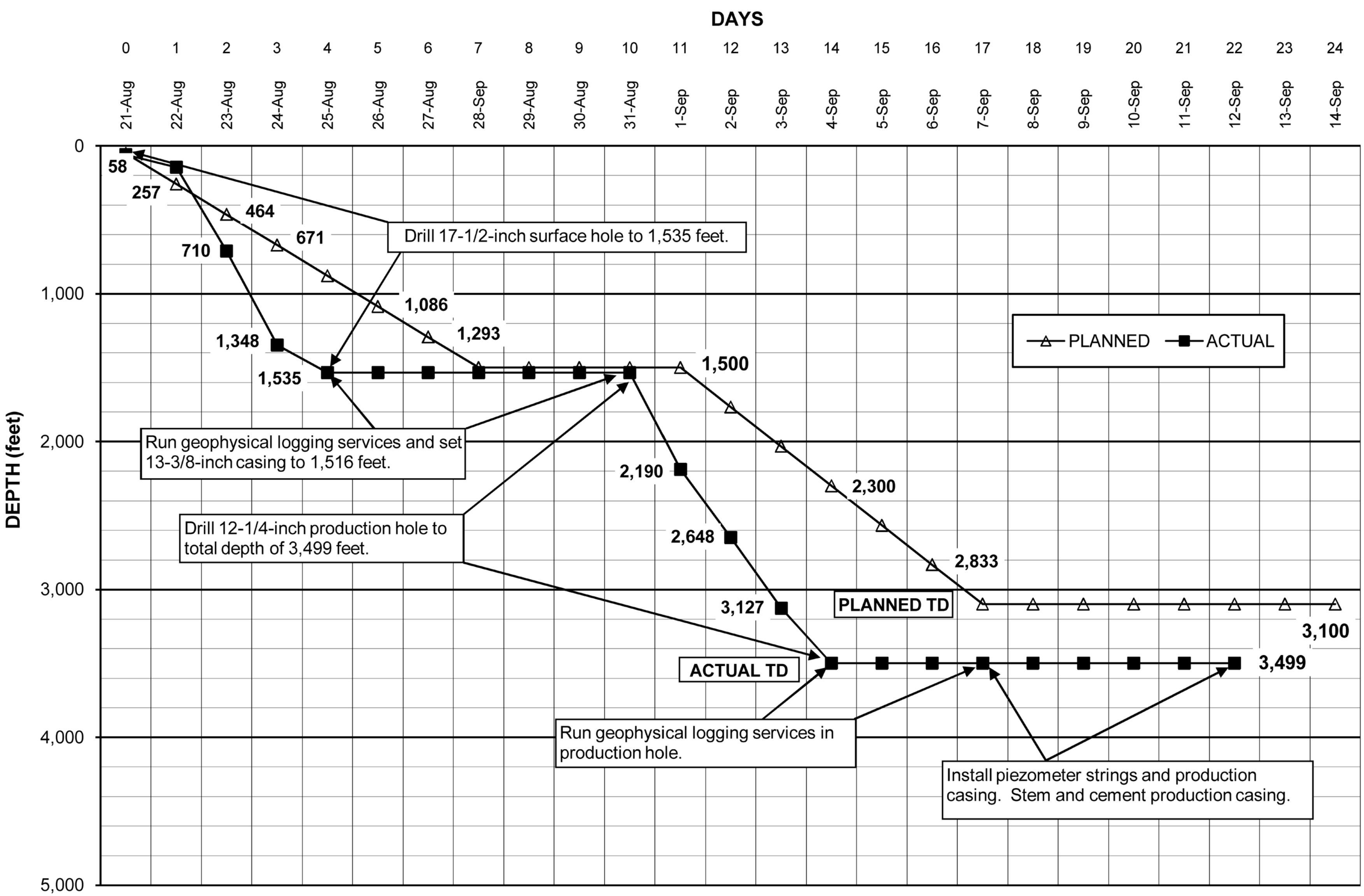

Figure 8-1
Planned and Actual Construction Progress for Well ER-20-4

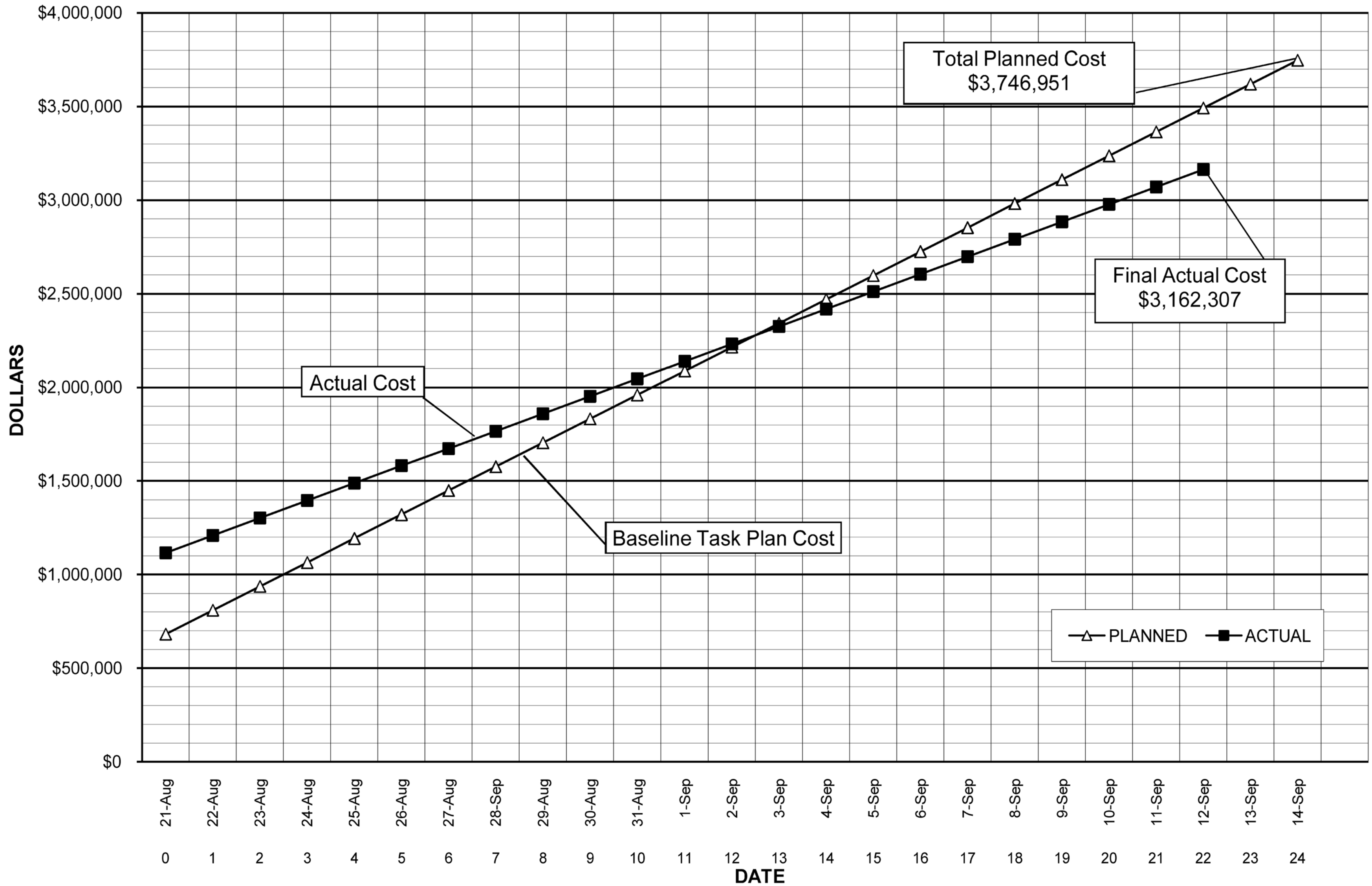

Figure 8-2
Planned and Actual Cost of Constructing Well ER-20-4

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9.0 Summary, Recommendations, and Lessons Learned

9.1 Summary

Main hole drilling at Well ER-20-4 commenced on August 21, 2010, and concluded on September 3, 2010, at a total drilled depth of 1,066.5 m (3,499 ft). Few problems were encountered during drilling. The borehole was completed within the CHZCM and the CFCU, which were encountered in the lower portion of the drill hole.

The completion string consists of 6⅝-in. stainless-steel casing suspended from 7⅝-in. carbon-steel casing. The carbon-steel casing extends to a depth that is 11.9 m (39 ft) above the water table. The 6⅝-in. casing is slotted in the interval 755.6 to 914.9 m (2,479.0 to 3,001.5 ft), providing access to LFAs within the CHZCM and the CFCU for monitoring and sampling. The slotted section consists of 25 consecutive stainless-steel slotted joints and is gravel-packed.

Two piezometer strings were installed that will provide access to the three saturated LFAs encountered in the borehole within the CHZCM and the CHCU. Both 2⅞-in. tubing strings hang from strings of 2⅜-in. carbon-steel tubing, and have one slotted interval each. The deep piezometer string was set at 951.8 m (3,122.8 ft). The shallow piezometer string was set at 488.2 m (1,601.6 ft), just below the static water level. The shallow string is bullnosed and slotted from 463.5 to 488.2 m (1,520.6 to 1,601.6 ft). The deep piezometer string is slotted from 757.3 to 914.9 m (2,484.7 to 3,001.7 ft).

Geologic data collected during drilling included composite drill cuttings samples collected every 3.0 m (10 ft) from 18.3 m (60 ft) to TD. In addition, 50 sidewall core samples were collected in the interval 76.2 to 1,063.8 m (250 to 3,490 ft). Open-hole geophysical logging was conducted in the upper portion of the borehole before installation of the surface casing and in the lower portion after the TD of the well was reached. Some of these logs were used to aid in construction of the well, while others help to verify the geology and determine the hydrologic characteristics of the rocks.

Well ER-20-4 is collared in Quaternary alluvium, and penetrated 10.7 m (35 ft) of alluvium and 1,055.8 m (3,464 ft) of Tertiary volcanic rocks, consisting of bedded and nonwelded to moderately welded ash-flow tuffs, rhyolitic lavas, and zeolitic to quartzo-feldspathic nonwelded tuffs. The water level was measured in the well within the CHZCM at 463.6 m (1,521.1 ft) on October 25, 2010. This equates to an elevation of 1,284.7 m (4,215.0 ft).

Tritium levels in the drilling fluid were below the minimum detectable concentration (as measured by field instruments) while drilling the Well ER-20-4 borehole.

9.2 Recommendations

All the geologic and hydrologic data and interpretations from Well ER-20-4 should be integrated into the PM–OV Phase II HFM. This will allow for more precise characterization of groundwater flow direction and velocity in the Pahute Mesa area. Updating the HFM will also allow better predictions for drilling, well development and testing, and aquifer testing.

The water level in Well ER-20-4 should be monitored during the drilling and testing of nearby wells. Groundwater chemistry, particularly with respect to radionuclides, should be monitored on a routine basis to look for any indication of contaminants from up-gradient UGTs. These data will also improve the understanding of aquifer connectivity.

9.3 Lessons Learned

The efficiency of drilling and constructing wells to obtain hydrogeologic data in support of the UGTA project continues to improve as experience is gained with each new well. Sometimes difficult drilling conditions are encountered and challenges are confronted. Several new lessons were learned during the construction of Well ER-20-4, the sixth well in the Pahute Mesa Phase II drilling initiative:

- In special situations where the bottom open-hole section of the borehole below the deepest completion zone is to be stemmed (as at Well ER-20-4), it is advantageous to extend the lower access line with blank tubing joints into the stemming column. This allows monitoring of the rise of stemming material (using a NAIL tool) as it approaches the target completion interval.

- A buried electrical cord was accidently cut while installing a new flow line. No one was injured and an incident report was filed (NSTec Case # 2010-144). The location of temporary buried power cords on drill pads should be recorded/mapped, then checked prior to any excavations.

- Predicting the geology in a structurally complex caldera setting is associated with considerable uncertainty. Sometimes the target geologic units are deeper than expected. It is prudent, therefore, to have extra casing and stemming materials on-hand to allow for deepening the well and avoid delays waiting on material deliveries.

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Appendix A
Drilling Data

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Appendix A-1
Drilling Parameter Log for Well ER-20-4

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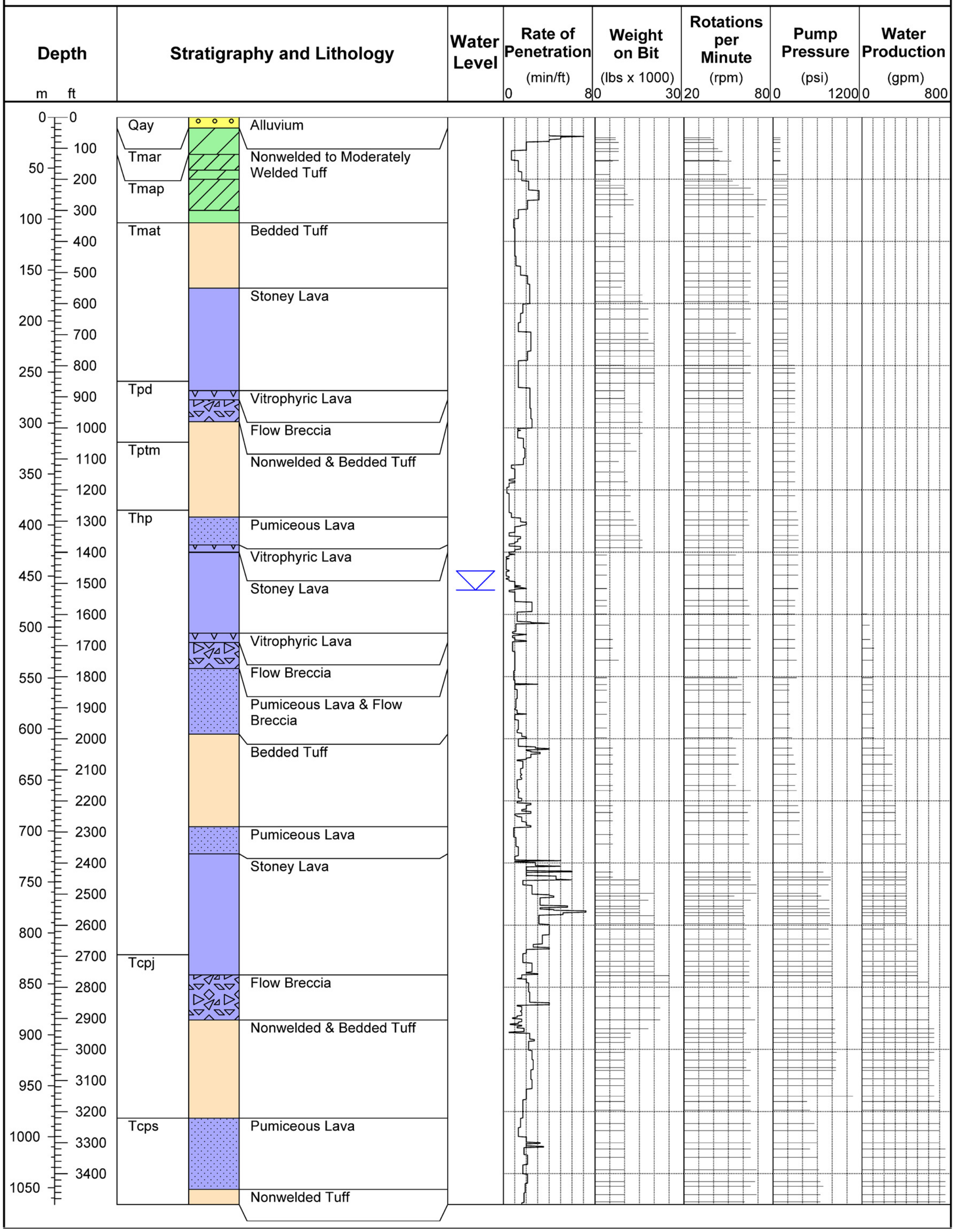
Well ER-20-4

Logging Company: Baker Atlas
Drilled Depth: 1,066.5 m (3,499 ft)
Date TD Reached: September 3, 2010
Drill Method: Rotary/Air foam

Surface Elevation: 1,748.4 m (5,736.1 ft)
Coordinates (UTM [NAD 83]): 4,116,689.7 m
549,596.1 m
Water Level: 463.6 m (1,521.1 ft) on October 25, 2010



See legend for lithology symbols on Page D-2.

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Appendix A-2
Tubing and Casing Data for Well ER-20-4

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Table A-2-1
Tubing and Casing Data for Well ER-20-4

Casing and Tubing	**Depth Interval** meters (feet)	**Type**	**Grade**	**Outside Diameter** centimeters (inches)	**Inside Diameter** centimeters (inches)	**Wall Thickness** centimeters (inches)	**Weight per foot** (pounds)
Conductor Casing	0 to 17.4 (0 to 57.0)	Carbon Steel	B	50.80 (20)	49.53 (19.5)	0.635 (0.250)	52.73
Surface Casing	0 to 461.9 (0 to 1,515.5)	Carbon Steel	K55	33.97 (13.374)	31.788 (12.515)	1.092 (0.430)	54.5
Completion Casing with Crossover	0 to 452.1 (0 to 1,483.4)	Carbon Steel	J55	19.37 (7.625)	17.701 (6.969)	0.834 (0.328)	26.4
Completion Casing	452.1 to 927.7 (1,483.4 to 3,043.5)	Stainless Steel	304L	16.83 (6.625)	15.504 (6.104)	0.663 (0.261)	17.02
Shallow Piezometer Tubing with Crossover	0 to 451.3 (0 to 1,480.8)	Carbon Steel	N80	6.03 (2.375)	5.067 (1.995)	0.483 (0.190)	4.7
Shallow Piezometer Tubing	451.4 to 488.2 (1,480.8 to 1,601.6)	Stainless Steel	SS	7.303 (2.875)	6.200 (2.441)	0.551 (0.217)	7.66
Deep Piezometer Tubing with Crossover	0 to 454.8 (0 to 1,492.0)	Carbon Steel	N80	6.03 (2.375)	5.067 (1.995)	0.483 (0.190)	4.7
Deep Piezometer Tubing	454.8 to 951.8 (1,492.0 to 3,122.8)	Stainless Steel	SS	7.303 (2.875)	5.994 (2.36)	0.655 (0.258)	7.66

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Appendix A-3
Well ER-20-4 Drilling Fluids and Cement Composition

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Table A-3-1
Drilling Fluids Used in Well ER-20-4

Typical Air-Foam/Polymer Mix
37.9 to 56.8 liters (10 to 15 gallons) Geofoam® [a]
0 to 5.7 liters (0 to 1.5 gallons) LP701® [a]
per
7,949 liters (50 barrels) water

a Geofoam® foaming agent and LP701® polymer additive are products of Geo Drilling Fluids, Inc.

NOTES:

1. All water used to mix drilling fluids for Well ER-20-4 came from Area 20 Water Well (U-20WW).

2. A concentrated lithium bromide (LiBr) solution was added to all introduced fluids to make up a final concentration of approximately 20 to 30 parts per million. The concentration was increased in zones of higher water production to make up a solution of 50 to 60 parts per million LiBr.

Table A-3-2
Well ER-20-4 Cement Composition

Cement Composition	20-inch Conductor Casing	13⅜-inch Surface Casing	6⅝-inch Completion Casing
Portland Type II neat	0 to 17.7 m [a] (0 to 58 ft) [b]	In annulus: 394.7 to 464.5 m (1,295 to 1,524 ft) Inside casing: 459.3 to 464.5 m (1,507 to 1,524 ft)	712.0 to 736.1 m (2,336 to 2,415 ft)

a meter(s)
b foot (feet)

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Appendix B
Well ER-20-4 Fluid Management Data

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Table B-1
Well ER-20-4 Fluid Disposition Reporting Form

Site Identification: ER-20-4
Site Location: Nevada Test Site, Area 20
Site Coordinates: (UTM NAD 27, Zone 11): N 4,116,492.42 m E 549,676.17 m
Well Classification: ER Hydrogeologic Investigation Well
N-I Project No: UG10-437

Report Date: 02-01-2011
NNSA/NSO Federal Sub-Project Director: Bill Wilborn
N-I Project Manager: Sam Marutzky
N-I Site Representative: Steven Hopkins
N-I Field Environmental Specialist: Mark Heser

Well Construction Activity	Activity Duration		#Ops. Days [a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes (m^3)		Infiltration Area [c] (m^3)	Other [d] (m^3)	Fluid Quality Objective Met?
	From	To				Solids [b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	08/21/10	08/24/10	4	463.6	330	108	136	N/A	N/A	N/A	N/A	yes
Phase I: Saturated-Zone Drilling	08/31/10	09/03/10	4	1,066.5	186	100	1,281	N/A	N/A	8,313	N/A	yes
Phase II: Initial Well Development	-	-	-	-	-	-	-	-	-	-	-	-
Phase II: Aquifer Testing	-	-	-	-	-	-	-	-	-	-	-	-
Phase II: Final Development	-	-	-	-	-	-	-	-	-	-	-	-
Cumulative Production Totals to Date:			8	1,066.5	516	208	1,417	N/A	N/A	8,313	N/A	yes

[a] Operational days refer to the number of days that fluids were produced during at least part (>3 hours) of one shift.

[b] Solids volume estimates include calculated added volume attributed to rock bulking factor.

[c] Ground surface discharge.

[d] Other refers to fluid conveyance to other fluid management devices or facilities: e.g., baker tank or transported to another well site for storage.

N/A = Not Applicable; m = meters; m^3 = cubic meters.
Total Facility Capacities (at 8 ft fluid level): Sump #1 = 1,547 m^3 Sump #2 = 1,547 m^3
Infiltration Area (assuming very low/no infiltration) = N/A
Remaining Facility Capacity (Approximate) as of 09/15/2010: Sump #1 = 206 m^3 (13 %) Sump #2 = 1,547 m^3 (100 %)
Current Average Tritium = -100 (less than minimum detectable concentration) pCi/L
Notes: None

N-I Authorizing Signature/Date: 2-14-11

Table B-2
Analytical Results for Fluid Management Samples for Well ER-20-4

Sample Number	Date Collected	Comment		*Resource Conservation Recovery Act (RCRA)* Metals (mg/L)							
				Arsenic	Barium	Cadmium	Chromium	Lead	Selenium	Silver	Mercury
20-4-090710-4	09/07/2010	Sample from Sump #1	Total	0.005	0.034 J-	0.005 U	0.01 U	0.013	0.005 U	0.01 U	0.0002 U
			Dissolved	0.0058	0.00065 J-	0.005 U	0.01 U	0.0025 J-	0.005 U	0.01 U	0.0002 U
20-4-090710-5	09/07/2010	Duplicate sample from Sump #1	Total	0.0053	0.034 J-	0.00037	0.01 U	0.015	0.005 U	0.01 U	0.0002 U
			Dissolved	0.0061	0.1 J	0.005 U	0.01 U	0.0015 J-	0.005 U	0.01 U	0.0002 U
Detection Limit				0.01	0.1	0.005	0.01	0.003	0.005	0.01	0.0002
Nevada Drinking Water Standard				0.05	2.0	0.005	0.1	0.015	0.05	0.1	0.002

Sample Number	Date Collected	Comment		Radiological Indicator Parameters (pCi/L)		
				Tritium	Gross Alpha	Gross Beta
20-4-090710-4	09/07/2010	Sample from Sump #1	Result	-100	1.6 U	4.4
			Error	200	1.6	1.8
			MDC	350	2.3	2.5
20-4-090710-5	09/07/2010	Duplicate sample from Sump #1	Result	-100 U	3 U	2.7 U
			Error	200	1.7	1.6
			MDC	350	2	2.3
Nevada Drinking Water Standard				15	50	20,000

Analyses for metals and radionuclides performed by ALS Laboratory Group.
Data provided by Navarro Intera, LLC (N-I, 2011)

Sump #1 is an unlined sump located on the Well ER-20-4 drill pad.

Notes: U = Compound analyzed for but not detected ("nondetect").
J = Result is estimated
J- = Result is estimated bias low.
MDC (minimum detectable concentration) varies by matrix, instrument, and count rates.
mg/L = milligrams per liter pCi/L = picocuries per liter

Analytical methods: All metals except mercury: Environmental Protection Agency (EPA) *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, Method 6010 (SW-846, 6010)
Mercury: EPA SW-846, 7470
Tritium: EPA Method 906.0
Gross alpha and gross beta: EPA Method 900.0

Appendix C
Detailed Lithologic Log for Well ER-20-4

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Table C-1
Detailed Lithologic Log for Well ER-20-4

Logged by Jose Gonzales and Lance Prothro, National Security Technologies, LLC

February 2011

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
0–10.7 (0–35)	10.7 (35)	AC	None	**Gravelly, Silty Sand:** Moderate pink (5R 7/4) to grayish-orange-pink (5YR 7/2); unconsolidated to poorly cemented; tuffaceous; calcareous. Clasts are sub-rounded and up to 1 centimeter (cm) in diameter consisting of tuff fragments and felsic crystals. A few large black vitrophyric fragments observed at base of unit.	Alluvium (Qay)
10.7–15.2 (35–50)	4.6 (15)	AC	None	**Partially Welded Ash-Flow Tuff:** Pale yellowish brown (10YR 6/2) and light brown (5YR 6/4); vitric to partially devitrified; minor light pink vitric pumice; minor phenocrysts of quartz and feldspar; common biotite; rare lithic fragments; rare black glassy lenses.	mafic-rich Ammonia Tanks Tuff (Tmar)
15.2–17.7 (50–58)	2.4 (8)	AC	None	**Partially Welded Ash-Flow Tuff:** Light brown (5YR 5/6); devitrified with some vapor-phase mineralization; minor grayish orange pink (10R 8/2) pumice; minor phenocrysts of quartz and feldspar; minor to common biotite; rare to minor lithic fragments; common black glassy lenses. Some dark yellowish orange (10YR 6/6) alteration and grayish pink (5R 8/2) botryoidal chalcedony.	
17.7–24.4 (58–80)	6.7 (22)	DA	24.4 (80)	**Partially Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4); devitrified to partially vitric; minor pale pink (5RP 8/2) pumice and rare black glass shards; minor felsic phenocrysts of quartz and feldspar; common mafic minerals of mostly black and bronze biotite, with some magnetite; rare lithic fragments.	
24.4–36.6 (80–120)	12.2 (40)	DA	None	**Partially Welded Ash-Flow Tuff:** Medium light gray (N6) to light brownish gray (5YR 6/1); devitrified; minor pink to white pumice; rare to minor felsic phenocrysts of feldspar and quartz including sanidine with a blue iridescence and dipyramidal quartz; rare to minor biotite; trace sphene; minor pale red lithic fragments.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
36.6 -51.8 (120–170)	15.2 (50)	DA	39.6 (130)	**Moderately Welded Ash-Flow Tuff:** Pale red (5R 6/2); devitrified; some vapor phase mineralization; minor grayish pink (5R 8/2) pumice; minor phenocrysts of quartz and feldspar; rare mafic minerals of mostly black and bronze biotite; rare sphene; rare pale reddish brown (10R 5/4) and light gray (N7) lithic fragments.	mafic-poor Ammonia Tanks Tuff (Tmap)
51.8–61.0 (170–200)	9.1 (30)	DA	None	**Partially Welded Ash-Flow Tuff:** Pale red (10R 6/2) to light gray (N7); devitrified; rare pale pink pumice; rare to minor felsic phenocrysts of quartz and feldspar including rare sanidine with a blue iridescence; minor biotite; trace medium gray (N5) lithic fragments.	
61.0–91.4 (200–300)	30.5 (100)	DA	79.2 (260)	**Moderately Welded Ash-Flow Tuff:** Light brownish gray (5YR 6/1); devitrified with some vapor-phase mineralization; minor pumice; rare to minor phenocrysts of quartz and feldspar; conspicuous sanidine with a blue iridescence; minor bronze biotite; trace sphene; rare medium gray (N5) lithic fragments.	
91.4–103.6 (300–340)	12.2 (40)	DA	None	**Nonwelded Ash-Flow Tuff:** Moderate reddish brown (10R 4/6); vitric; minor to common pumice; minor felsic phenocrysts of quartz and feldspar; minor black and bronze biotite; sphene is present; minor lithic fragments.	
103.6–167.6 (340–550)	64.0 (210)	DA	125.0 (410)	**Bedded Tuff:** Grayish yellow (5Y 8/4), moderate yellowish brown (10YR 5/4) to dusky yellow (5Y 6/4); zeolitic; minor to common moderate orange pink (5YR 8/4) pumice; rare to minor quartz and feldspar phenocrysts; rare biotite and other dark altered mafic minerals; minor grayish red and brownish gray lithic fragments (up to 8 millimeters [mm]). Interval with abundant to very abundant grayish red purple (5RP 4/2) to medium dark gray (N4) and medium gray (N5) lithic fragments (most between 5 to 8 mm in size) below 146.3 meters (m) (480 feet [ft]).	rhyolite of Tannenbaum Hill (Tmat)

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
167.6–259.1 (550–850)	91.4 (300)	DB4	225.6 (740)	**Stoney Rhyolite Lava:** Mottled light brownish gray (5YR 6/1) and grayish red (5R 4/2); devitrified; spherulitic; minor felsic phenocrysts of quartz and feldspar; rare biotite (black and bronze), and other dark, altered small mafic minerals; trace of sphene. Note: From 237.7 to 268.2 m (780–880 ft) cuttings contain material, including cement from the conductor casing, sloughed from the borehole wall above this interval.	rhyolite of Tannenbaum Hill (Tmat)
259.1–268.2 (850–880)	9.1 (30)	DA	None	**Stoney Rhyolite Lava:** Medium gray (N5); spherulitic; devitrified; rare feldspar phenocrysts; scarce black biotite; few small quartz-lined vugs.	rhyolite of Delirium Canyon (Tpd)
268.2–277.4 (880–910)	9.1 (30)	DA	271.3 (890)	**Vitrophyric Rhyolite Lava:** Medium dark gray (N4) to grayish black (N2) with some moderate yellowish brown (10YR 5/4); vitric; rare felsic phenocrysts of feldspar and quartz; common unaltered hornblende and biotite and rare magnetite observed in thin section; unaltered accessory minerals also observed in thin section are common sphene and perrierite/chevkinite, rare zircon, and apatite.	
277.4–298.7 (910–980)	21.3 (70)	DA	None	**Basal Flow Breccia:** Moderate yellowish brown, pale yellowish brown (10YR 6/2), and light brown (5YR 6/4); devitrified; minor feldspar phenocrysts; rare biotite; minor to common medium gray (N5) breccia clasts.	
298.7–318.8 (980–1,046)	20.1 (66)	DA PSWC	313.9 (1,030)	**Nonwelded Tuff:** Dusky yellow (5Y 6/4) and grayish orange (10YR 7/4); zeolitic; minor pale brown pumice; minor feldspar and quartz phenocrysts (common phenocrysts of sanidine, plagioclase, and quartz observed in thin section); common lithic fragments; trace sphene. Also observed in thin section are unaltered biotite, altered hornblende and magnetite. Accessory minerals observed in thin section are common sphene and zircon, and rare pyrrhotite and apatite.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
318.8–339.9 (1,046–1,115)	21.0 (69)	DA	None	**Nonwelded Tuff:** Dusky yellow (5Y 6/4) and grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6); zeolitic; grayish orange and white pumice; minor phenocrysts of felspar; trace biotite; rare small medium gray (N5) lithic fragments.	Pahute Mesa lobe of Topopah Spring Tuff (Tptm)
339.9–368.8 (1,115–1,210)	29.0 (95)	DA PSWC	368.8 (1,210)	**Nonwelded Tuff:** Light brown (5YR 6/4); zeolitic; common pumice; minor to common feldspar, no quartz; common biotite; rare lithic fragments.	
368.8–385.6 (1,210–1,265)	16.8 (55)	DA PSWC	None	**Bedded Tuff:** Light olive brown (5Y 5/6); zeolitic, slightly silicified in parts; minor to common pumice is mostly white; minor to common feldspar phenocrysts; minor to common biotite; trace lithic fragments.	
385.6–392.3 (1,265–1,287)	6.7 (22)	DA	387.1 (1,270)	**Bedded Tuff:** Dusky yellow (5Y 6/4); zeolitic; minor to common pumice; rare to minor very small felsic phenocrysts of feldspar and lesser quartz; minor mafic minerals (including biotite); common lithic fragments.	mafic-poor Calico Hills Formation (Thp)
392.3–402.3 (1,287–1,320)	10.1 (33)	DA	None	**Pumiceous Rhyolite Lava:** Moderate yellow (5Y7/6); zeolitic; rare felsic phenocrysts of quartz and feldspar; rare to minor biotite and other small, dark, indistinct mafic minerals.	
402.3–419.7 (1,320–1,377)	17.4 (57)	DA	411.5 (1,350)	**Pumiceous Rhyolite Lava:** Dusky yellow (5Y 6/4); mostly zeolitic, lesser devitrified; rare feldspar and quartz phenocrysts; rare to minor black biotite.	
419.7–426.7 (1,377–1,400)	7.0 (23)	DA	None	**Vitrophyric Rhyolite Lava:** Medium dark gray (N4) with some moderate red (5R 4/6) mottling; vitric, perlitic; rare felsic phenocrysts of feldspar and quartz; rare black biotite.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
426.7–506.0 (1,400–1,660)	79.2 (260)	DA PSWC	478.5 (1,570)	**Stoney Rhyolite Lava:** Pale reddish brown (10R 5/4) to grayish red (10R 4/2); devitrified and quartzo-feldspathic; flow banded; spherulitic and lithophysal; rare to minor felsic phenocrysts of quartz and feldspar, with lesser plagioclase; minor bronze biotite. Flow foliation dipping approximately 30 degrees east-southeast observed on borehole image log.	mafic-poor Calico Hills Formation (Thp)
506.0–515.1 (1,660–1,690)	9.1 (30)	DA	509.0 (1,670)	**Vitrophyric Rhyolite Lava:** Moderate brown (5YR 4/4) to olive black (5Y 2/1); vitric and devitrified, perlitic; rare felsic phenocrysts of quartz and feldspar; rare small biotite.	
515.1–540.7 (1,690–1,774)	25.6 (84)	DA	524.3 (1,720)	**Basal Flow Breccia:** Pale yellowish green (10GY 7/2), moderate red (5R 5/4), and pale yellowish brown (10YR 6/2); zeolitic; slightly pumiceous; rare to minor felsic phenocrysts of quartz and feldspar; minor biotite, some magnesium dioxide (MnO_2) staining.	
540.7–605.0 (1,774–1,985)	64.3 (211)	DA RSWC	560.8 (1,840) 597.4 (1,960)	**Pumiceous Rhyolite Lava:** Grayish orange (10YR 7/4) some dusky yellow (5Y 6/4); zeolitic; rare felsic phenocrysts of feldspar and quartz; minor biotite; some MnO_2 dendrites. Interval marked by a decrease in density and resistivity as observed on geophysical logs. Flow brecciated in parts.	
605.0–695.9 (1,985–2,283)	90.8 (298)	DA RSWC PSWC	649.2 (2,130) 670.6 (2,200)	**Bedded Tuff:** Grayish yellow (5Y 8/4) to grayish orange (10YR 7/4); zeolitic and quartzo-feldspathic; common to abundant pumice; rare to minor felsic phenocrysts of feldspar and quartz; rare to minor biotite; rare to common grayish red (10R 4/2) and medium to dark gray lithic fragments; some MnO_2. Possible intercalated pumiceous lava and flow breccia from 635.5 to 646.5 m (2,085–2,121 ft) based on the borehole image log.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
695.9–722.4 (2,283–2,370)	26.5 (87)	DA RSWC	698.0 (2,290)	**Pumiceous Rhyolite Lava:** Grayish yellow (5Y 8/4) to moderate greenish yellow (10Y 7/4); zeolitic and devitrified; rare felsic phenocrysts of quartz and feldspar; rare to minor mafic minerals including biotite. Upper contact dips 45 degrees to the south-southwest based on the borehole image log.	mafic-poor Calico Hills Formation (Thp)
722.4–821.4 (2,370–2,695)	99.0 (325)	DA	786.4 (2,580)	**Stoney Rhyolite Lava:** Medium gray to medium bluish gray (5B 5/1) mottled in part with moderate reddish brown (10R 4/6); devitrified; weakly spherulitic; rare felsic phenocrysts of quartz and feldspar; rare very small biotite.	
821.4-841.2 (2,695 - 2,760)	19.8 (65)	DA	None	**Stoney Rhyolite Lava:** Medium gray to medium bluish gray (5B 5/1) mottled in part with moderate reddish brown (10R 4/6); devitrified; weakly spherulitic; rare felsic phenocrysts, mostly feldspar; rare biotite.	tuff of Jorum (Tcpj)
841.2–885.4 (2,760–2,905)	44.2 (145)	DA RSWC	842.5 (2,764) 877.2 (2,878)	**Flow Breccia:** Mottled moderate brown (5YR 4/4) and medium dark gray (N4); quartzo-feldspathic matrix with devitrified clasts; minor felsic phenocrysts, mostly feldspar; rare biotite; silicic in parts; some MnO_2 stains.	
885.4–981.8 (2,905–3,221)	96.3 (316)	DA RSWC PSWC	888.8 (2,916) 940.9 (3,087)	**Nonwelded and Bedded Tuff:** Light brown (5YR 5/6); quartzo-feldspathic; minor to common moderate yellow (5Y 7/6) pumice; rare felsic phenocrysts of feldspar and quartz; rare to minor biotite; rare small lithic fragments. Becomes more bedded below 956.2 m (3,137 ft). Upper contact dips 8 degrees to the northeast, based on borehole image log.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
981.8–1,015.0 (3,221–3,330)	33.2 (109)	DA RSWC PSWC	990.6 (3,250)	**Pumiceous Rhyolite Lava:** Dusky yellow (5Y 6/4), lesser dusky red (5R 3/4); quartzo-feldspathic; rare feldspar phenocrysts, no quartz phenocrysts observed; no identifiable mafic minerals observed (pseudomorphic hornblende, pyroxene, and biotite observed in thin section).	rhyolite of Sled (Tcps)
1,015.0–1,051.6 (3,330–3,450)	36.6 (120)	DA RSWC PSWC	1,021.1 (3,350) 1,038.8 (3,408)	**Pumiceous Rhyolite Lava:** Light brown (5YR 5/6) and moderate dark gray (N4); quartzo-feldspathic; rare feldspar phenocrysts; rare black altered mafic minerals. Upper contact dips 24 degrees east-southeast, based on borehole image log.	rhyolite of Sled (Tcps)
1,051.6–1,066.5 (3,450–3,499) Total Depth	14.9 (49)	DA RSWC PSWC	1,062.2 (3,485)	**Nonwelded Tuff:** Pale reddish brown (10R 5/4) mottled with grayish orange pink (5YR 7/2); quartzo-feldspathic; rare feldspar phenocrysts; no quartz or biotite observed.	

a Lithologic samples collected from interval during drilling and logging operations and utilized for lithological interpretation. **AC** = auger cuttings; **DA** = drill cuttings that represent lithologic character of interval. Note: The upper 3.0 to 6.1 m (10 to 20 ft) of most intervals contain cuttings from the overlying interval, particularly in the bottom half of the hole, due to drilling lag time. **DB4** = cuttings that are intimate mixtures of units; generally less than 50% of drill cuttings represent lithologic character of interval; **PSWC** = percussion-gun sidewall core; **RSWC** = rotary sidewall core. See Table 3-1 in this report for more information about sidewall samples.

b Depths of lithologic samples selected for laboratory analyses. Laboratory analyses typically include when appropriate, petrography (polished thin section), mineralogy (electron microprobe and x-ray diffraction), and chemistry (x-ray fluorescence and wet chemical analysis for iron). See Table 3-2 of this report for additional information on laboratory analyses.

c Descriptions are based mainly on visual examination of lithologic samples using a 10x- to 40x-zoom binocular microscope, and incorporating observations from geophysical logs and results of laboratory analyses. Colors describe wet sample color.
Abundances for felsic phenocrysts, pumice fragments, and lithic fragments: **trace** = only one or two individuals observed; **rare** = $\leq$ 1%; **minor** = 5%; **common** = 10%; **abundant** = 15%; **very abundant** $\geq$ 20%.
Abundances for mafic minerals: **trace** = only one or two individuals observed; **rare** = $\leq$ 0.05%; **minor** = 0.2%; **common** = 0.5%; **abundant** = 1%; **very abundant** = $\geq$ 2%.

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Appendix D
Geophysical Logs Run in Well ER-20-4

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Appendix D contains plots of selected geophysical logs run in Well ER-20-4. Table D-1 summarizes the logs presented. See Table 3-3 for more information.

Table D-1
Well ER-20-4 Geophysical Logs Presented

Log Type	Run Number	Date	Log Interval meters	Log Interval feet
Caliper	CA6-1 CA6-2	8/25/2010 9/4/2010	0–462.1 461.8–1,063.5	0–1,516 1,515–3,489
X-Multipole Array Acoustilog (sonic)	XMAC-1	9/5/2010	461.8–1,061.0	1,515–3,481
Gamma Ray	GR-1 GR-6	8/25/2010 9/4/2010	0–454.4 461.8–1,063.5	0–1,491 1,515–3,489
Spectral Gamma Ray (potassium, thorium, uranium)	SGR-1 SGR-2	8/25/2010 9/4/2010	0–454.4 461.8–1,063.5	0–1,491 1,515–3,489
High Definition Induction and R_t Explorer (resistivity)	HDIL-1 RTEX-1	8/25/2010 9/4/2010	17.4–460.2 461.8–1,063.5	57–1,510 1,515–3,489
Density	ZDL-1 ZDL-2	8/25/2010 9/5/2010	17.4–464.5 365.8–1,065.3	57–1,524 1,200–3,495
Compensated Neutron	CN-2	9/5/2010	365.8–1,065.3	1,200–3,495
Chemistry (pH and conductivity) Temperature	Chem-1 TL-2	9/6/2010	464.2–1,067.7	1,523–3,503
Heat Pulse Flow Log	HPFlow-1	9/7/2010	478.5–1,051.6	1,570–3,450

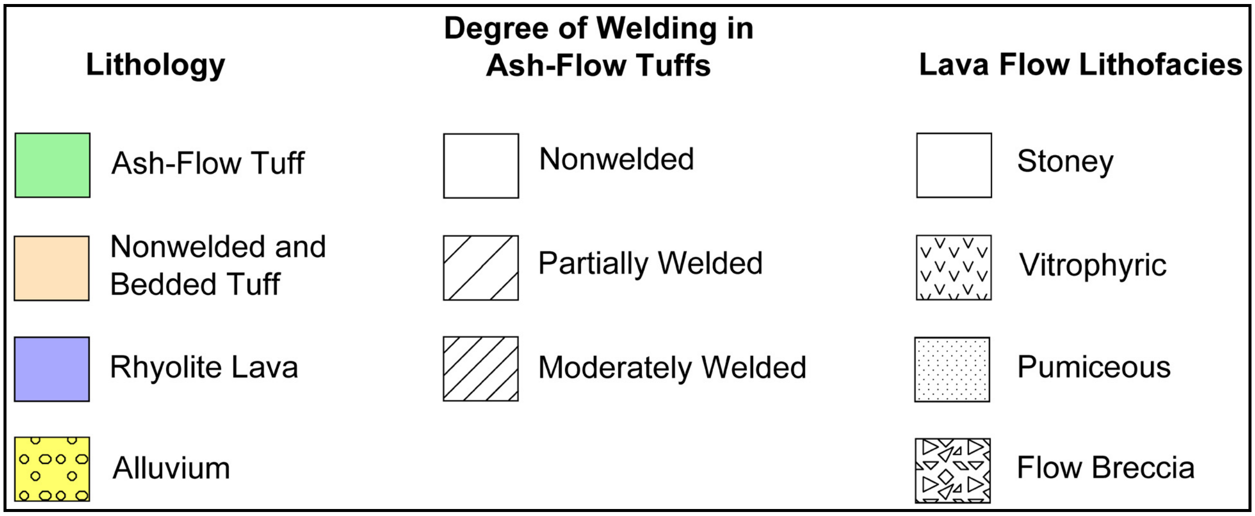
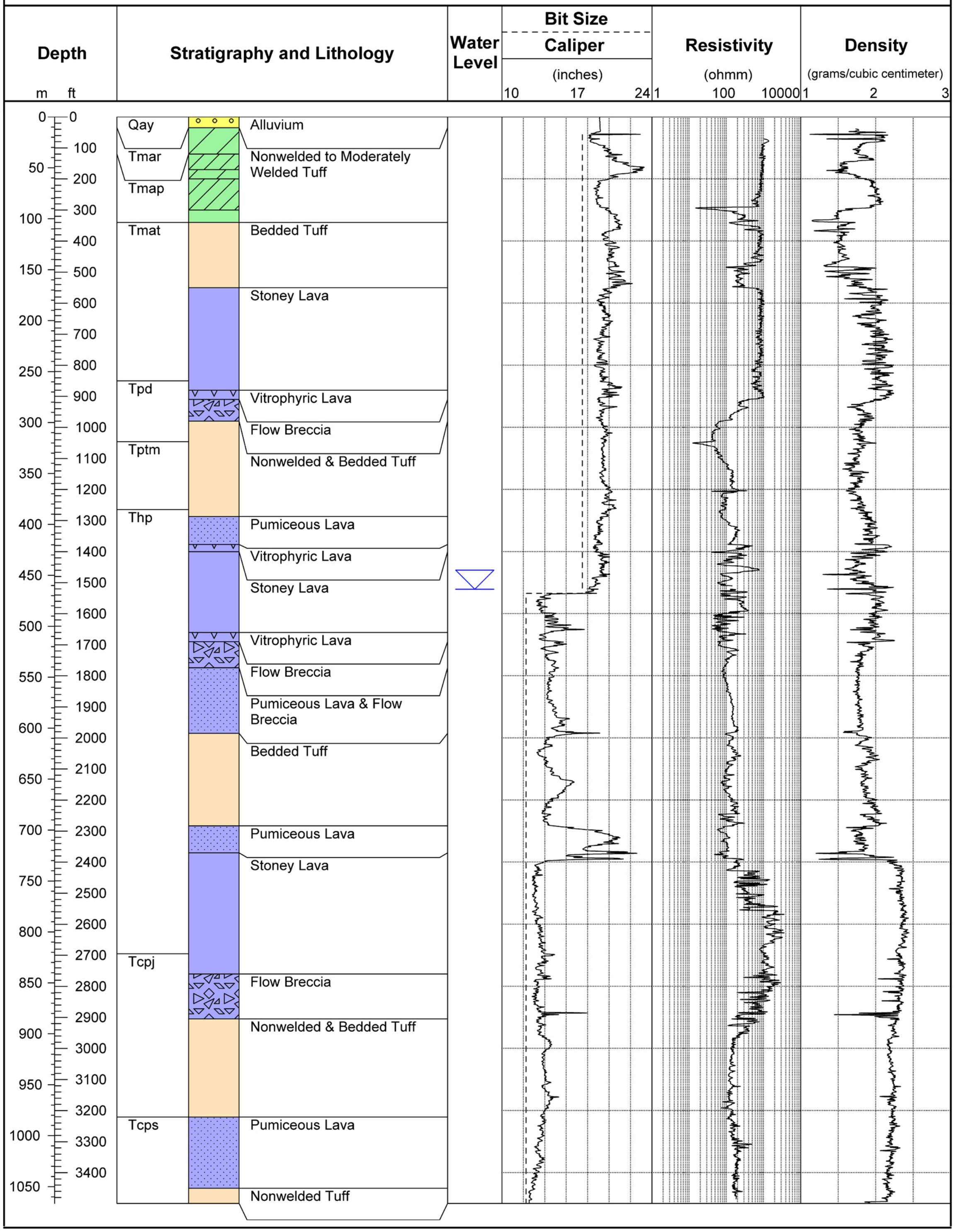


Figure D-1
Legend for Lithology Symbols Used on Log Plots

Well ER-20-4

Logging Company: Baker Atlas
Date Logged: August 25 & 26 and September 4 & 5, 2010
Drilled Depth: 1,066.5 m (3,499 ft)
Date TD Reached: September 3, 2010
Drill Method: Rotary/Air foam

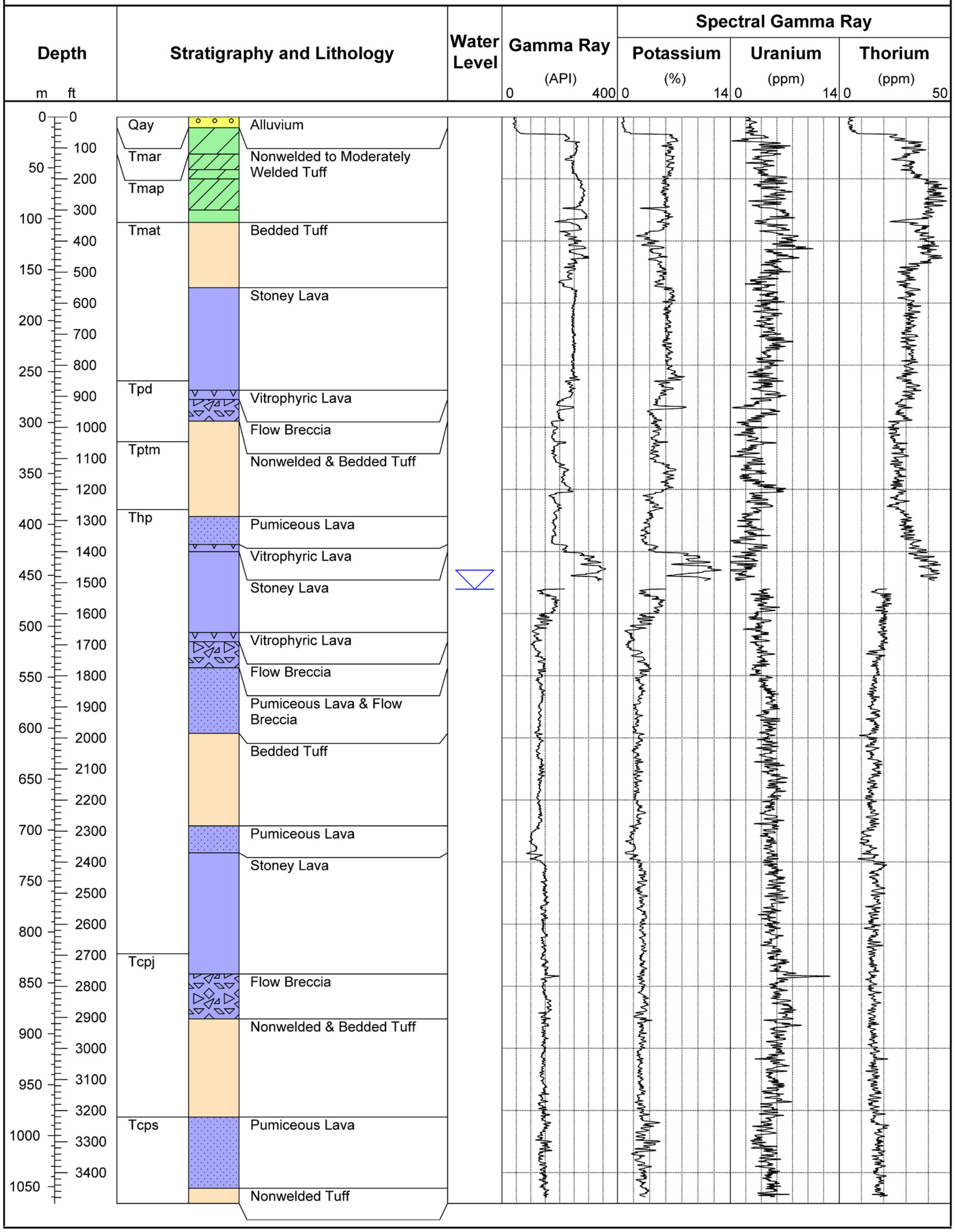
Surface Elevation: 1,748.4 m (5,736.1 ft)
Coordinates (UTM [NAD 83]): 4,116,689.7 m
549,596.1 m
Water Level: 463.6 m (1,521.1 ft) on October 25, 2010



Well ER-20-4

Logging Company: Baker Atlas
Date Logged: August 25 and September 4, 2010
Drilled Depth: 1,066.5 m (3,499 ft)
Date TD Reached: September 3, 2010
Drill Method: Rotary/Air foam

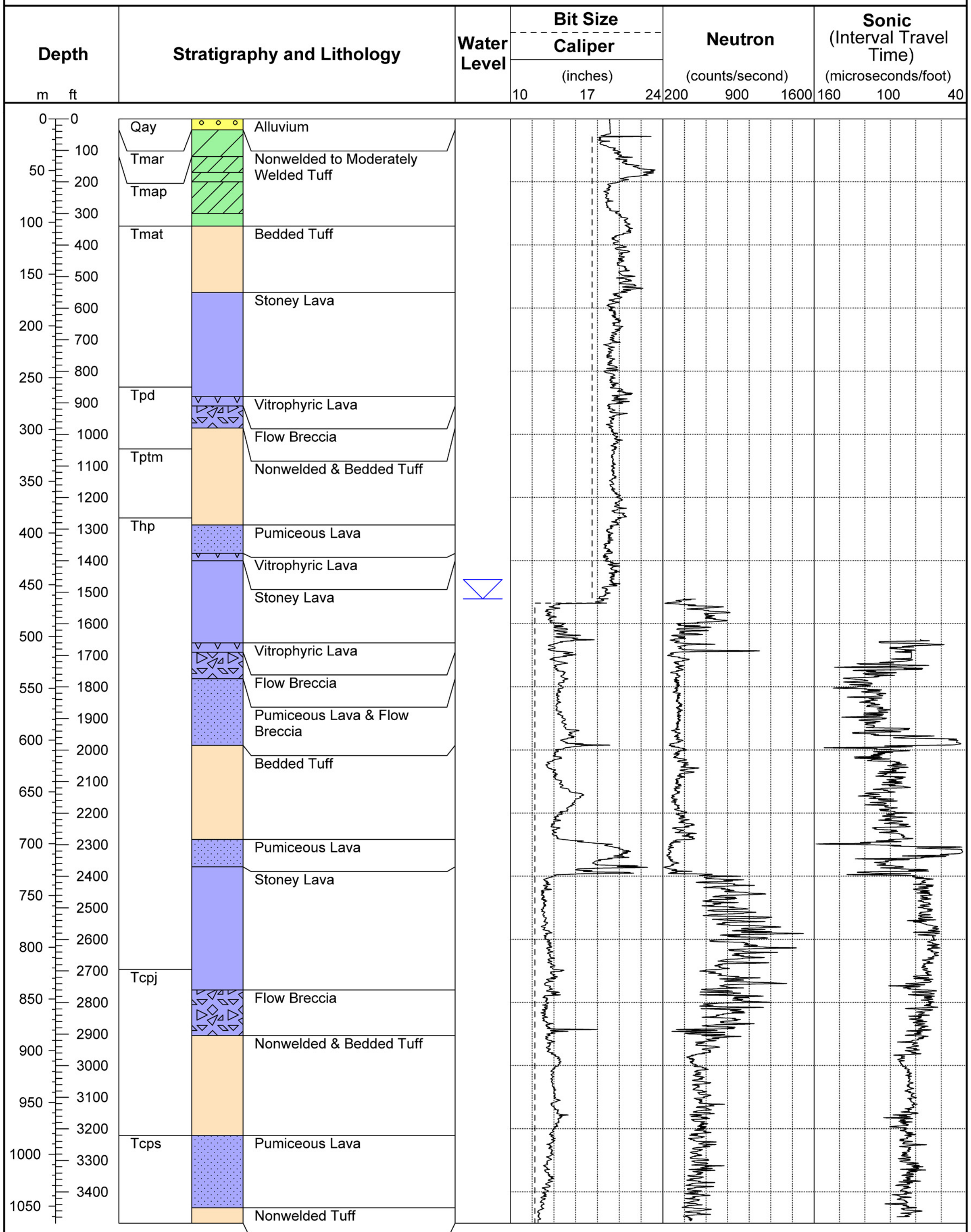
Surface Elevation: 1,748.4 m (5,736.1 ft)
Coordinates (UTM [NAD 83]): 4,116,689.7 m
549,596.1 m
Water Level: 463.6 m (1,521.1 ft) on October 25, 2010



Well ER-20-4

Logging Company: Baker Atlas
Date Logged: August 25 and September 4 and 5, 2010
Drilled Depth: 1,066.5 m (3,499 ft)
Date TD Reached: September 3, 2010
Drill Method: Rotary/Air foam

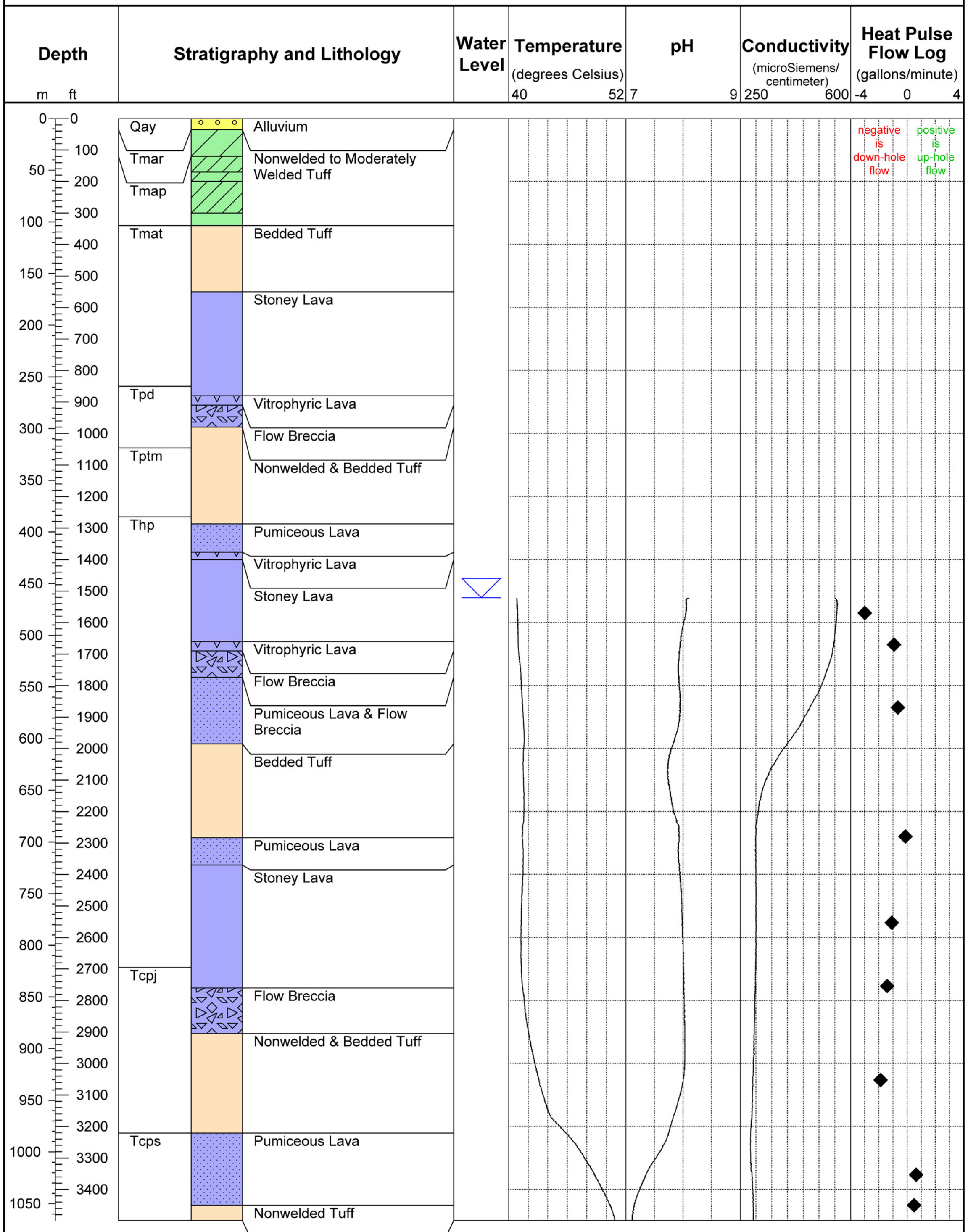
Surface Elevation: 1,748.4 m (5,736.1 ft)
Coordinates (UTM [NAD 83]): 4,116,689.7 m
549,596.1 m
Water Level: 463.6 m (1,521.1 ft) on October 25, 2010



Well ER-20-4

Logging Company: Desert Research Institute
Date Logged: September 6 and 7, 2010
Drilled Depth: 1,066.5 m (3,499 ft)
Date TD Reached: September 3, 2010
Drill Method: Rotary/Air foam

Surface Elevation: 1,748.4 m (5,736.1 ft)
Coordinates (UTM [NAD 83]): 4,116,689.7 m
549,596.1 m
Water Level: 463.6 m (1,521.1 ft) on October 25, 2010



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