Nevada
Environmental
Restoration
Project

DOE/NV--1386

Completion Report for Well ER-20-7

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

April 2010

Environmental Restoration Project

U.S. Department of Energy
National Nuclear Security Administration
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Completion Report for Well ER-20-7

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 2010

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DOE/NV--1386

COMPLETION REPORT FOR WELL ER-20-7

CORRECTIVE ACTION UNITS 101 AND 102: CENTRAL AND WESTERN PAHUTE MESA, NEVADA

Approved by: ______________________________ Date: 4/19/2010
Wilhelm R. Wilborn
Federal Sub-Project Director
Underground Test Area Project

Approved by: ______________________________ Date: 4/19/2010
Robert F. Boehlecke
Federal Project Director
Environmental Restoration Project

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Abstract

Well ER-20-7 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 Test Site, Nye County, Nevada. The well was drilled in June 2009 as part of the Pahute Mesa Phase II drilling program. The primary purpose of the well was to further investigate migration of radionuclides from the nearby, up-gradient TYBO and BENHAM underground nuclear tests, which originally was discovered at Well Cluster ER-20-5. This well also provided detailed hydrogeologic information in the Tertiary volcanic section that will reduce uncertainties within the Pahute Mesa-Oasis Valley hydrostratigraphic framework model.

The main 44.45-centimeter hole was drilled to a depth of 681.8 meters and cased with 33.97-centimeter casing to 671.7 meters. The hole diameter was then decreased to 31.12 centimeters, and the well was drilled to total depth of 894.9 meters. The completion string, set to the depth of 890.0 meters, consists of 14.13-centimeter stainless-steel casing hanging from 19.37-centimeter carbon-steel casing. The 14.13-centimeter stainless-steel casing has one continuous slotted interval open to the Topopah Spring aquifer.

Data collected during and shortly after hole construction include composite drill cuttings samples collected every 3.0 meters, sidewall core samples from 20 depth intervals, various geophysical logs, water quality (primarily tritium) measurements, and water level measurements. The well penetrated 894.9 meters of Tertiary volcanic rock, including two saturated welded-tuff aquifers.

A fluid level measurement was obtained during open-hole geophysical well logging for the upper, Tiva Canyon, aquifer at the depth of 615.7 meters on June 19, 2009. The fluid level measured in the open hole on June 27, 2009,after the total depth was reached and the upper aquifer was cased off, was also at the depth of 615.7 meters. Preliminary field measurements indicated 1.5 to 4.5 million picocuries per liter of tritium in the Tiva Canyon aquifer and 20 to 61 million picocuries per liter in the underlying Topopah Spring aquifer.

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List of Acronyms and Abbreviations

BN	Bechtel Nevada
CA	contamination area
CAIP	Corrective Action Investigation Plan
CAU	Corrective Action Unit
CBIL	Circumferential Borehole Imaging Log
CHZCM	Calico Hills zeolitic composite unit
cm	centimeter(s)
DOE	U.S. Department of Energy
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
in.	inch(es)
km	kilometer(s)
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
m	meter(s)
ma	million years ago
mi	mile(s)
mm	millimeter(s)
NAD	North American Datum
NARA	National Archives and Records Administration
NNES	Navarro Nevada Environmental Services, LLC

List of Acronyms and Abbreviations (continued)

NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NSTec	National Security Technologies, LLC
NTMMSZ	Northern Timber Mountain moat structural zone
NTS	Nevada Test Site
PM-OV	Pahute Mesa–Oasis Valley
pCi/L	picocuries per liter
RCT	radiological control technician
SCCC	Silent Canyon Caldera Complex
SNJV	Stoller-Navarro Joint Venture
TD	total depth
TCA	Tiva Canyon aquifer
TMCC	Timber Mountain caldera complex
TSA	Topopah Spring aquifer
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
WP	working point

1.0 Introduction

1.1 Project Description

Well ER-20-7 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 Test Site (NTS), Nye County, Nevada. Well ER-20-7 was the first well drilled as part of the Phase II hydrogeologic investigation well drilling program in the Central and Western Pahute Mesa area of Nye County, Nevada.

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 February 2008).

The Central and Western Pahute Mesa CAUs and the associated well drilling program are part of the NNSA/NSO Environmental Restoration Project's Underground Test Area (UGTA) Sub-Project at the NTS. Two of the goals of the UGTA Sub-Project are to evaluate the nature and extent of contamination in groundwater due to 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 NTS. To build and test these models, it is necessary to collect geologic, geophysical, and hydrologic data from new and existing wells to define groundwater 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-20-7 is located near the northwest boundary of the NTS (Figure 1-1). The primary purpose of this well was to further investigate migration of radionuclides from the nearby up-gradient TYBO (U-20y) and BENHAM (U-20c) underground nuclear tests (UGTs) (Figure 1-2), which was originally discovered at Well Cluster ER-20-5 (U.S. Department of Energy, Nevada Operations Office [DOE/NV], 1997). Detailed hydrogeologic information for the Tertiary volcanic section obtained from this well will reduce uncertainties within the Pahute Mesa–Oasis Valley (PM-OV) hydrostratigraphic framework model (HFM) (Bechtel Nevada [BN], 2002) and subsequent flow and transport modeling.

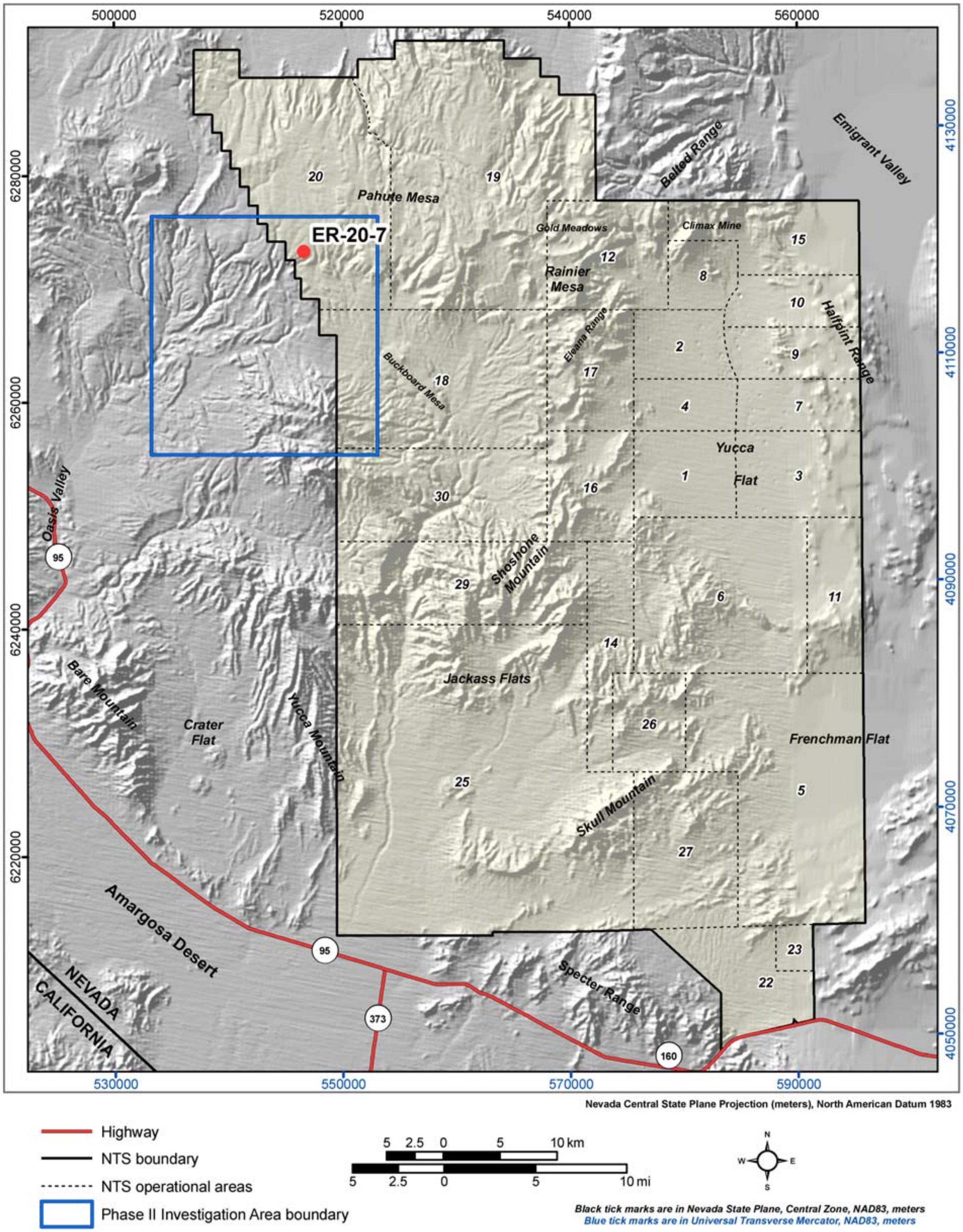

Figure 1-1
Reference Map Showing Location of Well ER-20-7

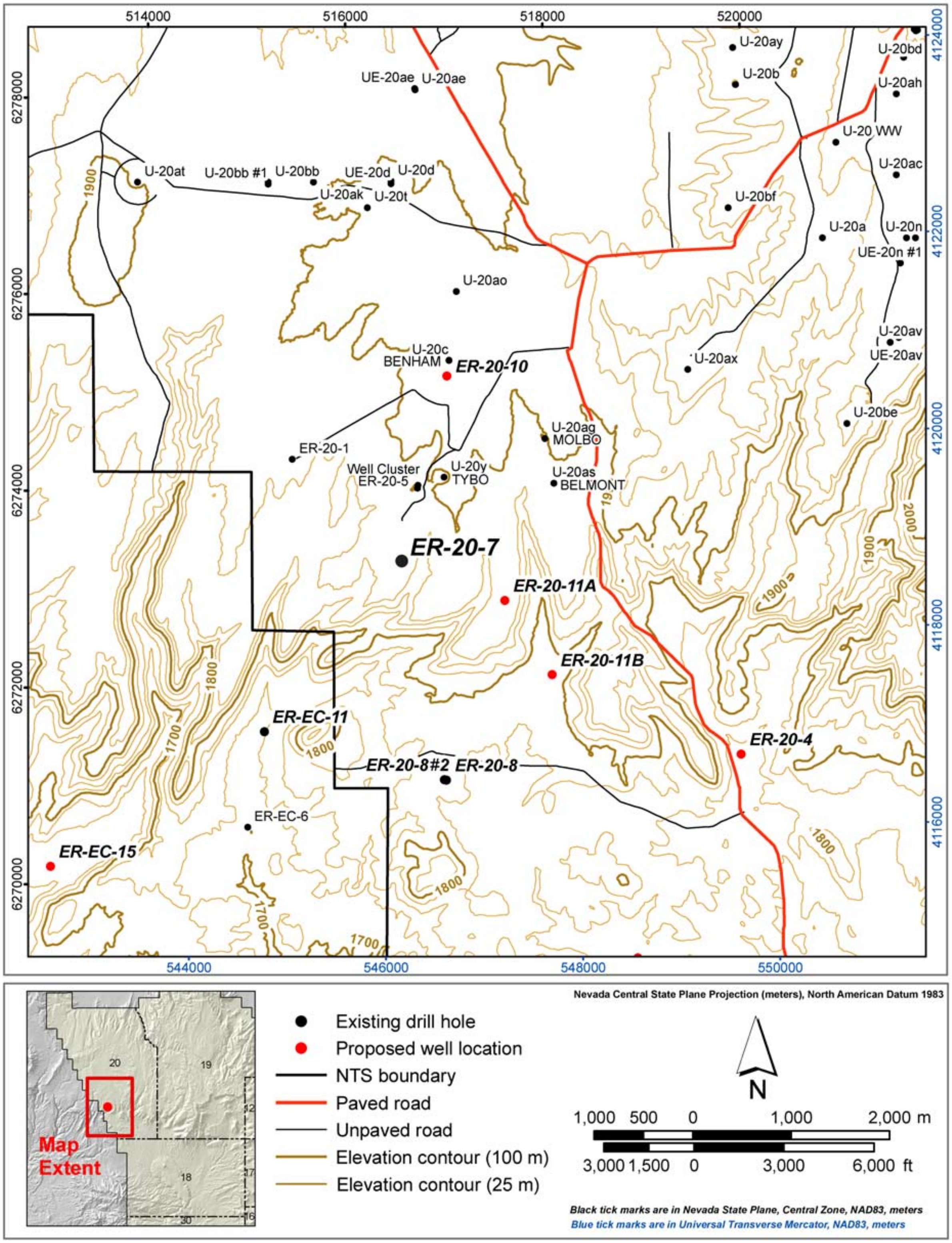

Figure 1-2
Topographic Map of the Well ER-20-7 Area Showing the Locations of Roads and Nearby Drill Holes

1.2 Project Organization

The construction of Well ER-20-7 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-20-7 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), Stoller-Navarro Joint Venture (SNJV), 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 NTS 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-20-7 Drilling Advisory Team, which included the NNSA/NSO UGTA Sub-Project manager, the SNJV (environmental contractor) field manager, the NSTec (NTS 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-20-7 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.

SNJV was the principal environmental contractor for the project, and SNJV personnel collected geologic and hydrologic data during drilling. (SNJV's name was changed to Navarro Nevada Environmental Services, LLC [NNES], effective October 1, 2009; all subsequent references to the activities of this entity in this report will be NNES.) 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) numbers D-005-001.09 and D-006-001.09 (NSTec, 2009a and b).

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, 2009a and b; SNJV, 2009b) 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-20-7. 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 NNES contains additional information on fluid management, waste management, and environmental compliance for the project (NNES, 2010). 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 2009c). 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) will be compiled and disseminated separately.

1.3 Location and Significant Nearby Features

Well ER-20-7 is located in NTS Area 20 at an elevation of 1,892.5 meters (m) (6,208.9 feet [ft]). It is located near the southern edge of Pahute Mesa, 766 m (2,512 ft) south of Well ER-20-5#3 and 797 m (2,616 ft) south of Well ER-20-5#1. The locations of these features in relation to Well ER-20-7 are shown in Figure 1-2. Additional information about Well ER-20-7 is provided in Table 1-1.

Well ER-20-7 is located on a highly dissected volcanic plateau known as Pahute Mesa near the southwestern edge of the mesa. The surface topography at the wellhead is relatively flat, with drainage to the southwest.

The closest UGTs to Well ER-20-7 are TYBO (U-20y), BELMONT (U-20as), MOLBO (U-20ag), and BENHAM (U-20c) (Figure 1-2). Three of the tests were conducted below the water table, and BELMONT was conducted approximately 9 m (29 ft) above the water table.

Table 1-1
Well ER-20-7 Site Data Summary

Site Coordinates [a]	UTM (Zone 11) (NAD 83): N 4,118, 626.9 m E 546,138.4 m Nevada State Plane (Central Zone) (NAD 27): N 896,580.93 ft E 554,615.39 ft Nevada State Plane (Central Zone) (NAD 83): N 6,273,279.1 m N 20,581,583.0 ft E 516,567.3 m E 1,694,771.1 ft
Surface Elevation [a, b]	1,892.5 m (6,208.9 ft)
Drilled Depth	894.9 m (2,936 ft)
Fluid-Level Depth [c]	615.7 m (2,020 ft) for the Tiva Canyon aquifer (measured on June 19, 2009) 615.7 m (2,020 ft) for the Topopah Spring aquifer (measured on June 27, 2009, after the Tiva Canyon aquifer was cased off)
Fluid-Level Elevation	1,276.8 m (4,189 ft)
Surface Geology	Moderately welded tuff (Trail Ridge Tuff)

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 at top of construction pad. National Geodetic Vertical Datum, 1929 (NARA, 1973).

c Measured during open hole geophysical well logging.

Well ER-20-7 was sited approximately 964 m (3,163 ft) south-southwest of the TYBO test location and approximately 2,104 m (6,903 ft) south of the BENHAM UGT. Table 1-2 provides additional information regarding these nearby tests.

1.3.1 TYBO

The TYBO UGT was conducted in Emplacement Hole U-20y in 1975 (DOE/NV, 2000a). The reported depth of burial (which corresponds to the location of the working point [WP] or detonation point) of the TYBO device was 765 m (2,510 ft), which was approximately 135 m (443 ft) below the static water level in Emplacement Hole U-20y. The TYBO WP was located in zeolitic, nonwelded tuff near the bottom of the welded portion of the Topopah Spring Tuff, the principal aquifer penetrated by Emplacement Hole U-20y. The cavity around the WP (now collapsed) is projected to have a radius of approximately 100 m (328 ft) (International Technologies Corporation, 1995). The collapse chimney, estimated to be approximately cylindrical, extends to the ground surface above the WP. The Topopah Spring welded-tuff aquifer (Topopah Spring aquifer [TSA] hydrostratigraphic unit [HSU]) is believed to be the primary conduit for any lateral migration of waterborne radionuclides from the TYBO cavity.

1.3.2 BENHAM

The BENHAM underground nuclear test was conducted in Emplacement Hole U-20c in 1968 (DOE/NV, 2000a). The reported depth of burial (WP) of the BENHAM device was 1,402 m (4,600 ft), which was approximately 763 m (2,504 ft) below the static water level in Emplacement Hole U-20c. The BENHAM WP was located in zeolitic, bedded tuff of the Calico Hills Formation, approximately 64 m (210 ft) below a lava-flow aquifer within the Calico Hills zeolitic composite unit. The cavity around the WP is projected to have a radius of approximately 100 m (328 ft) (International Technologies Corporation, 1995). The cavity is believed to have collapsed, forming a collapse chimney that is approximately cylindrical; however, the chimney did not propagate to the ground surface. Under certain thermal and hydraulic conditions, radionuclides may have been able to migrate upward into the TSA, approximately 168 m (550 ft) above the BENHAM WP, and thus migrate laterally from the BENHAM cavity (Brikowski, 1991; Wolfsberg et al., 2002).

1.4 Objectives

The primary purpose for Well ER-20-7 is to investigate migration of contaminant plumes down-gradient from the TYBO and BENHAM UGTs executed in U-20y and U-20c, respectively, as

Table 1-2
Selected Information for Underground Nuclear Tests Relevant to Well ER-20-7

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-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
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-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-20c	BENHAM	12/19/1968	1,914 (6,281)	1,402 (4,600)	512 (1,681)	639 (2,096)	1,275 (4,185)	1,150	Th	CHZCM

a DOE/NV, 2000a
b DOE/NV, 1999
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 Hydrostratigraphic nomenclature:
- **TSA** = Topopah Spring aquifer
- **UPCU** = upper Paintbrush confining unit
- **BA** = Benham aquifer
- **CHZCM** = Calico Hills zeolitic composite unit

first identified at Well Cluster ER-20-5 (DOE/NV, 1997). An important secondary objective is to obtain information that will help characterize the hydrogeology of southwestern Pahute Mesa (NNSA/NSO, 2009a). Well ER-20-7 is expected to produce data that will improve flow and transport modeling within CAUs 101 and 102. The Well ER-20-7 location may be a favorable location for a long-term monitoring well.

The objectives for Well ER-20-7, as described in Appendix A of the drilling and completion criteria document for the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells (SNJV, 2009a), are listed below, along with well-specific activities necessary to accomplish the objectives:

1. Investigate radionuclide migration down-gradient from the TYBO and BENHAM UGTs.

2. Characterize the hydrogeology of southwestern 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).

   – 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 TSA, 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).

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 possible 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 the TYBO UGT.

Additional data that will help characterize the hydrology in southwestern 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 [SNJV, 2009d]), but, ultimately, Well ER-20-7 is expected to provide data for determination of horizontal and vertical conductivity and hydraulic properties of saturated HSUs penetrated.

The completed well will accommodate single-well hydraulic testing, though pumping tests may need to be limited due to the potential for production of large volumes of contaminated water from the TSA compared to available sump capacity. This well could be an observation well for future multiple-well aquifer tests.

1.5 Project Summary

This section summarizes Well ER-20-7 construction operations; the details are provided in Sections 2.0 through 7.0 of this report.

A 106.7-centimeter (cm) (42-inch [in.]) diameter surface conductor hole was constructed by drilling to a depth of 36.6 m (120 ft), and installing a string of 30-in. conductor casing to the depth of 35.2 m (115.4 ft). Drilling of the main hole with a 17½-in. tri-cone bit, using a air-foam/polymer fluid in conventional circulation, began on June 6, 2009. An upper aquifer, the Tiva Canyon aquifer (TCA), was encountered deeper than predicted (see Section 4.4); consequently, the lower portion of the TCA was saturated. Also unexpected were high levels of tritium (up to 4,500,000 picocuries per liter [pCi/L]) in the TCA. Tritium was encountered at a depth of approximately 628.8 m (2,063 ft), approximately 13.1 m (43 ft) below the static water level. The decision was made by NNSA/NSO and the Pahute Mesa CAU Guidance Team to case off this upper aquifer and proceed as planned to the target aquifer, the TSA. The casing point was reached at the depth of 673.0 m (2,208 ft); geophysical logging was then completed prior to installing the casing. The 13⅜-in. surface casing was set at 671.7 m (2,203.9 ft) on June 22, 2009.

A string of 2⅜-in. carbon-steel tubing was planned to be set within the TCA to permit monitoring of the water level during hydraulic testing. However, during operations to set the tubing in the annulus outside of the 13⅜-in. surface casing, it became stuck at 117.0 m (384 ft). The tubing was left in the hole, possibly to be removed at a later date.

The main hole was drilled with a 12¼-in. bit using air-foam to a total depth (TD) of 894.9 m (2,936 ft), which was reached on June 27, 2009. The target aquifer, the welded Topopah Spring Tuff, was encountered between 707.1 and 868.7 m (2,320 to 2,850 ft). The static, open-hole water level prior to installation of the completion string was measured at the depth of 615.7 m (2,020 ft) on June 27, 2009, during geophysical logging.

Composite drill cuttings were collected every 3.0 m (10 ft) from the depth of 36.6 m (120 ft) to TD, and 20 sidewall core samples were recovered at various depths between 43.0 and 887.0 m (141 and 2,910 ft). Open-hole geophysical logging of the well was conducted 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 5½-in. stainless-steel casing suspended from 7⅝-in. epoxy-coated carbon-steel casing (which extended 76.8 m [252 ft] below the water level). The completion casing was landed at 890.0 m (2,920 ft). The 5½-in. casing was slotted in the interval 719.3 to 876.3 m (2,360.0 to 2,874.9 ft) to allow access to the TSA.

1.6 Project Director

Inquiries concerning Well ER-20-7 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

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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 2009 Pahute Mesa Phase II wells were provided in *Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria* (SNJV, 2009a). Specific requirements for Well ER-20-7 were outlined in FAWP number D-005-001.09 (NSTec, 2009a). Figure 2-1 shows the layout of the drill site. Figure 2-2 shows the location of Well Cluster ER-20-5, including the sumps there that were used for Well ER-20-7. Figure 2-3 is a chart of the drilling and completion history for Well ER-20-7. 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

Field operations at Well ER-20-7 began on April 28, 2009, when an NSTec crew set up a Failing 1500 drill rig and began to drill two concentric rings of five blast holes through the hard welded-tuff cap rock. The holes were 12.1 cm (4.75 in.) in diameter and were drilled an average of 10.7 m (35 ft) deep. The crew installed plastic pipe in each hole after it was drilled, and lastly drilled a 31.3-cm (12.25-in.) diameter “relief” hole in the center of the rings of blast holes. Drilling was completed on May 7, 2009. On May 14, 2009, the ten blast holes were loaded with explosive, which was detonated to facilitate construction of the conductor hole. On May 15, 2009, NSTec drillers used the Auger II drill rig to remove rubble from the hole, and continued to auger the 106.7-cm (42-in.) conductor hole to the depth of 36.6 m (120 ft). A string of 30-in. conductor casing was set at the depth of 35.2 m (115.4 ft). The conductor casing was cemented in place on May 19, 2009, using 29.8 cubic meters (39.0 cubic yards) of Redi-Mix Formula 400 (see cement composition in Appendix A-3). The cement was pumped into the annulus between the casing and the formation, with a rise inside the casing to the depth of 31.4 m (103 ft).

The UDI crews arrived on May 23, 2009, and began rigging up the Wilson Mogul 42B drill rig. They finished rigging up on June 6, 2009, and began drilling from the top of cement inside the 30-in. casing at 31.4 m (103 ft). The drill crew worked through the cement at the bottom of the 30-in. casing with a center-punch assembly consisting of a 17½-in. rotary bit mounted 3.2 m (10.5 ft) below a 26-in. hole opener. The drilling fluid was an air/water/soap mix with a polymer additive (when necessary) in conventional circulation. The hole opener was removed when the hole reached the depth of 39.0 m (128 ft).

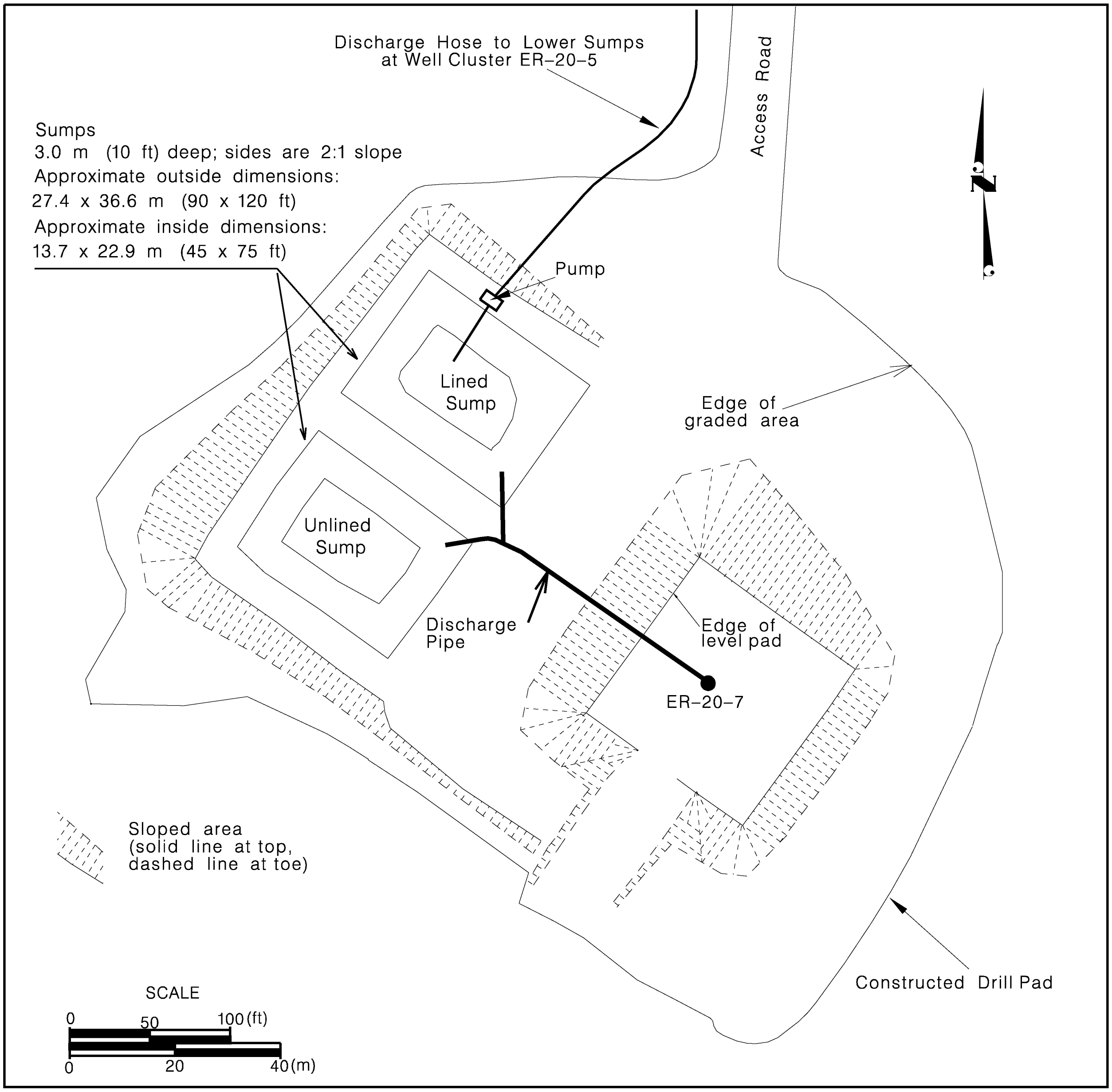

Figure 2-1
Drill Site Configuration for Well ER-20-7

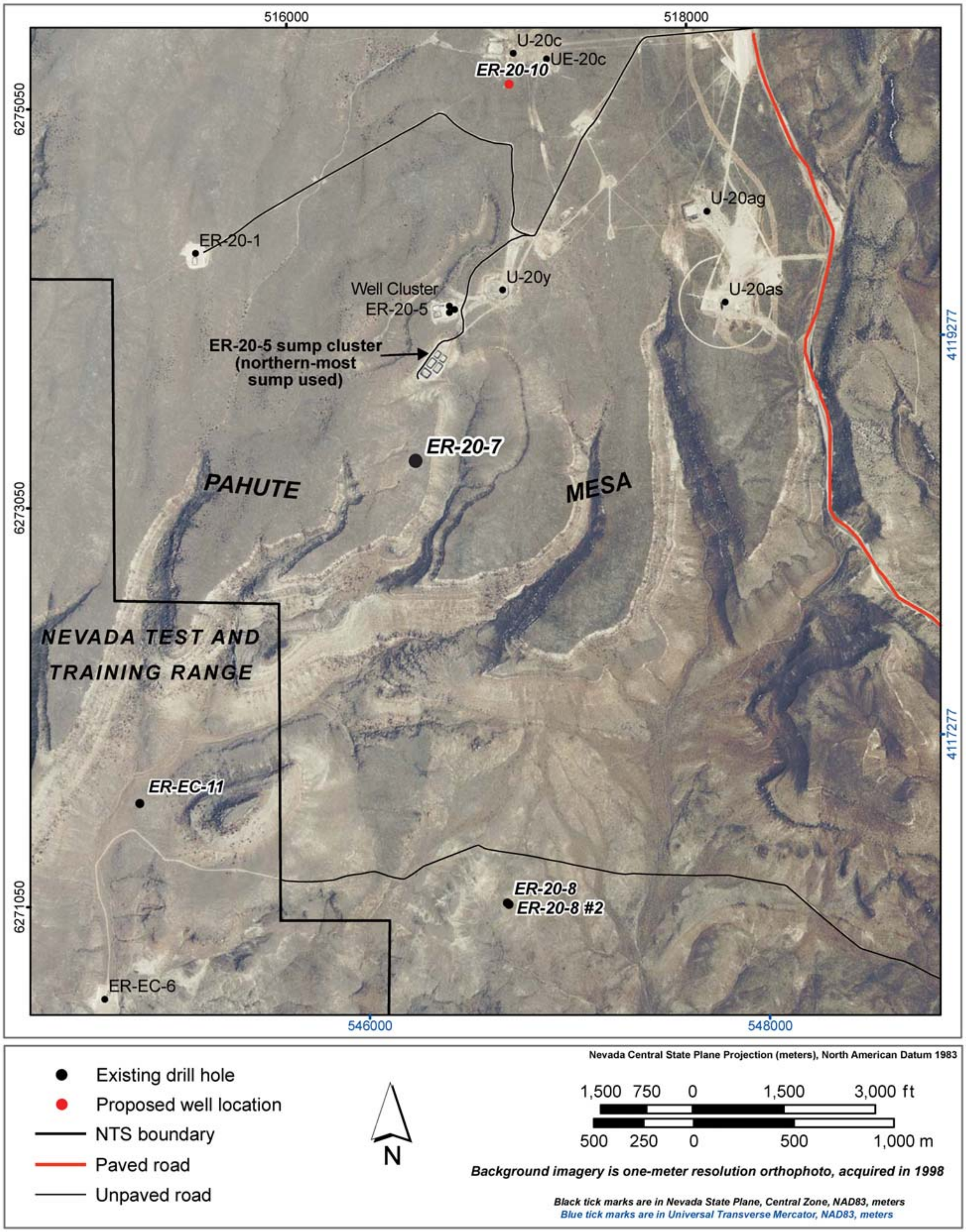

Figure 2-2
Orthophoto of the Well ER-20-7 Location Showing Well Cluster ER-20-5 Sumps Used for Well ER-20-7 Fluids

WELL ER-20-7 SUMMARY

Activity	Date
Begin drilling for conductor hole:	05/15/2009
Conductor hole completed and 30-in. casing set at 35.2 m (115.4 ft):	05/19/2009
Begin drilling 17 1/2-in. surface hole	06/08/2009
Set 13 3/8-in. surface casing at 671.7 m (2203.9 ft):	06/22/2009
Land 2 3/8-in. piezometer at 117.0 m (384.0 ft):	06/23/2009
Begin drilling 12 1/4-in. hole:	06/24/2009
Reach total drilled depth of 894.9 m (2,936 ft):	06/27/2009
Well completed	07/06/2009

LEGEND

BHA	bottom hole assembly
cm	centimeter(s)
CA	Contamination area
CN	Compensated neutron
CBIL	Circumferential borehole imaging log
cu ft	cubic feet
DRI	Desert Research Institute
EC	Electrical Conductivity
ft	foot (feet)
GR	gamma ray
HO	hole opener
in.	inch(es)
lpm	liters per minute
m	meter(s)
NAIL	nuclear annulus investigation log
NSTec	National Security Technologies
PVC	polyvinyl chloride
SGR	spectral gamma ray
SLM	steel line measurement
SNJV	Stoller Navarro Joint Venture
SWC	sidewall core
TD	total depth
TIH	trip into hole
TOC	top of cement
TOH	trip out of hole
UDI	United Drilling Inc.
WOC	wait on cement
XMAC	cross-multipole array acoustilog
ZDL	Z-densilog

FIGURE 2-3

WELL ER-20-7
DRILLING AND COMPLETION
HISTORY
SHEET 1 OF 2

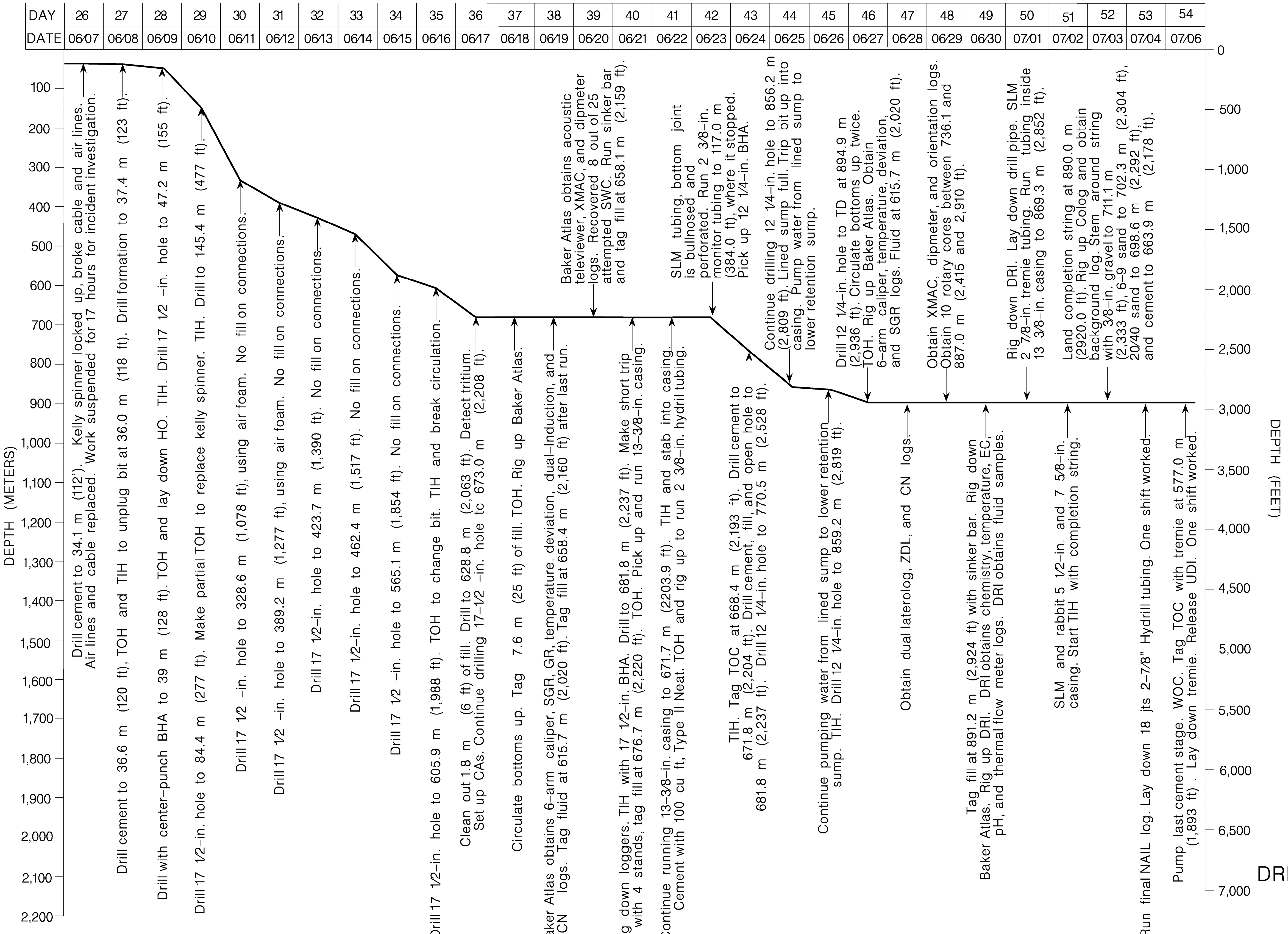

FIGURE 2-3
WELL ER-20-7
DRILLING AND COMPLETION HISTORY
SHEET 2 OF 2

Table 2-1
Abridged Drill Hole Statistics for Well ER-20-7

LOCATION DATA:

Coordinates:
- Nevada State Plane (Central Zone) (NAD 27): N 896,580.93 ft E 554,615.39 ft
- Nevada State Plane (Central Zone) (NAD 83): N 6,273,279.1 m E 516,567.3 m
- Universal Transverse Mercator (Zone 11) (NAD 83): N 4,118,626.9 m E 546,138.4 m

Surface Elevation [a]: 1,892.5 m (6,208.9 ft)

DRILLING DATA:

Spud Date: 06/6/2009 (main hole drilling with Wilson Mogul 42B rig)

Total Depth (TD): 894.9 m (2,936 ft)

Date TD Reached: 06/27/2009

Date Well Completed: 07/06/2009 (date completion string was cemented in place)

Hole Diameter: 106.7 cm (42 in.) from surface to 36.6 m (120 ft); 44.5 cm (17.5 in.) from 36.6 to 681.8 m (120 to 2,237 ft); 31.1 cm (12.25 in.) from 681.8 m (2,237 ft) to TD of 894.9 m (2,936 ft).

Drilling Techniques: Drill and blast; 10 blast holes with an average depth of 10.7 m (35 ft); then dry-hole auger from surface to 36.6 m (120 ft.); center-punch with 17½-in. tricone bit mounted below a 26-in. hole opener to 39.0 m (128 ft); rotary drill with 17½-in. tricone bit, using air-foam and polymer in direct circulation from 39.0 to 681.8 m (128 to 2,237 ft); rotary drill with 12¼-in. tricone bit to TD of 894.9 m (2,936 ft).

CASING DATA: 30-in. conductor casing to 35.2 m (115.4 ft); 13⅜-in. surface casing to 671.7 m (2,203.9 ft); 7⅝-in. casing to 692.4 m (2,271.6 ft); cross-over sub at 692.4 to 693.2 m (2,271.6 to 2,274.2 ft); 5½-in. casing 693.2 to 890.0 m (2,274.2 to 2,920.0 ft).

WELL COMPLETION DATA:

A string of 7⅝-in. epoxy-coated carbon-steel casing, connected to 5½-in. stainless-steel casing via a crossover sub was installed in Well ER-20-7 after drilling. The carbon-steel casing extends through the unsaturated zone and approximately 77 m (252 ft) below the water table. The 7⅝-in. outside-diameter casing has an inside diameter of 17.701 cm (6.969 in.). The 5½-in. casing has an inside diameter of 12.82 cm (5.047 in.). The completion string was landed at 890.0 m (2,920 ft). A string of carbon-steel 2⅜-in. tubing with one slotted interval was inserted outside the 13⅜-in. casing within the 44.5-cm (17.5-in.) hole, intended as a monitoring string, but became stuck at 117.0 m (384 ft). This tubing may be removed, and/or replaced at a later date. Detailed data for the completion interval are provided in Section 7.0 of this report.

Depth of Slotted Section: 719.3 to 876.3 m (2360.0 to 2,874.9 ft)

Depth of Gravel Pack: 711.1 to 891.2 m (2,333 to 2,924 ft); sand from 698.6 to 711.1 m (2,292 to 2,333 ft)

Depth of Pump: Not installed at the time of completion

Water Depth [b]: A fluid level of 615.7 m (2,020 ft) for the TCA measured inside the 44.5-cm (17.5-in.) hole, June 19, 2009, during geophysical logging, and 615.7 m (2,020 ft) for the TSA measured inside the 31.1-cm (12.25-in.) hole on June 27, 2009, during geophysical logging, for the TSA.

DRILLING CONTRACTOR: United Drilling, Inc.

GEOPHYSICAL LOGS BY: Baker Atlas

SURVEYING CONTRACTOR: National Security Technologies, LLC

a Elevation of ground level at wellhead. National Geodetic Vertical Datum, 1929 (NARA, 1973).
b Fluid level tag by Baker Atlas. TSA = Topopah Spring aquifer.

Drilling of the surface hole with a 17½-in. rotary tricone bit and air-foam began June 6, 2009. Drilling was suspended on June 7, 2009, due to a near-miss safety incident, but resumed on June 8, 2009, upon completion of the investigation of the incident. Drilling continued uneventfully with little or no fill accumulating when drilling was stopped to add pipe (make a connection). After a bit change on June 16, 2009, 1.8 m (6 ft) of fill was encountered. Drilling resumed with little to no fill on connections.

The first observation of water in the returns was reported in the TCA at the depth of 634.6 m (2,082 ft) on June 17, 2009. Tritium was initially detected on June 17, 2009, at the depth of 628.8 m (2,063 ft), approximately 13.1 m (43 ft) below the water table, and reached 1,500,000 pCi/L at 634.3 m (2,081 ft). Drilling was suspended for 3.5 hours while radiological control technicians (RCTs) set up contamination area (CA) zones and held briefings on safety and requirements for radiological work. When drilling resumed, approximately 4.6 m (15 ft) of fill was encountered.

On June 17, 2009, at the depth of 673.0 m (2,208 ft), the onsite geologist requested that drilling be stopped to evaluate cuttings and circulate the hole. He made a preliminary pick of the base of the Tiva Canyon Tuff, the target casing point, at approximately 655.3 m (2,150 ft). This was approximately 17.7 m (58 ft) above the current drilled depth, so drilling was stopped to perform geophysical logging and install casing. The RCTs also set up a CA zone around the rig floor, catwalk, and subbase. After this 6-hour break in drilling, 7.6 m (25 ft) of fill was found to have accumulated to a depth of 665.4 m (2,183 ft); the crew removed the drill pipe from the hole in preparation for logging.

Geophysical logging and sidewall sampling began on June 19, 2009, and a water level of 615.7 m (2,020 ft) was measured the same day. After logging operations were completed on June 20, 2009, fill was tagged at a depth of 658.1 m (2,159 ft), for a total accumulation of 7.3 m (24 ft) during logging. The Baker Atlas logging crew completed the required geophysical logs, then rigged down and departed the location. The drillers lowered the drill string and bit back into the borehole to clean and condition the hole, and then deepened it an additional 8.8 m (29 ft) to 681.8 m (2,237 ft) to assure that the casing could be set deep enough to fully isolate the TCA.

After the hole was cleaned out and deepened, the casing subcontractor installed a string of 13⅜-in. casing, which was set at the depth of 671.7 m (2,203.9 ft). The bottom of the casing was cemented with 2.8 cubic meters (3.7 cubic yards) of Type II neat cement on June 22, 2009. The top of cement in the annulus is estimated to be at the depth of 635.2 m (2,084 ft), based on geophysical log data.

After installation of the casing, the drill crew attempted to install a piezometer string of 2⅜-in. Hydril® steel tubing to a point beneath the fluid level (deeper than 615.7 m [2,020 ft]) to permit monitoring within the TCA. However, the crew could not advance the string any deeper than 117.0 m (384 ft) after several attempts. The decision was made to abandon the tubing string, though it may be removed and replaced at a later date.

After the unsuccessful installation of the tubing, the drill crew lowered the drill string with a 12¼-in. bit into the hole to drill out the cement and clean out the hole. On June 24, 2009, they tagged the top of cement inside the 13⅜-in. casing at 668.4 m (2,193 ft). They drilled cement and the casing shoe from 668.4 to 672.1 m (2,193 to 2,205 ft), cement and fill from 672.1 to 673.9 m (2,205 to 2,211 ft), and open hole (no fill) from 673.9 to 681.8 m (2,211 to 2,237 ft).

Drilling with the 12¼-in. bit commenced on June 24, 2009. A 24-hour drilling hiatus occurred, starting late on June 25, 2009, when the lined sump at Well ER-20-7 filled to capacity and water had to be pumped to a lined sump at the nearby Well ER-20-5 site (see Section 2.4). Drilling then continued uneventfully to the TD of 894.9 m (2,936 ft), which was reached on June 27, 2009. Up to 1.8 m (6 ft) of fill was encountered at some connections. The drillers then cleaned and conditioned the borehole by circulating the borehole volume twice, then pulled up four stands of drill pipe, and waited 30 minutes before tagging bottom. The depth check tagged approximately 0.3 m (1 ft) of fill and the crew then began removing the drill string from the hole for geophysical logging.

Geophysical logging and sidewall sampling operations were conducted with no problems by Baker Atlas crews from June 27 to 30, 2009. After completion of sidewall sampling, the logging crew conducted a depth check with a sinker bar, tagging fill at 891.2 m (2,924 ft), then pulled out of the hole in preparation for logging and water sampling by DRI personnel. DRI operations were completed on July 1, 2009.

A completion string with one slotted interval was inserted into the hole on July 2, 2009, and landed on July 3, 2009, at a depth of 890.0 m (2,920.0 ft). The string was gravel-packed and cemented (see Section 7.0). The drillers started demobilizing the rig and drilling equipment on July 6, 2009, and crews worked one shift per day after that until demobilization was completed on July 13, 2009.

The inclination of the borehole was determined from Directional Survey logs run by Baker Atlas on June 19 and June 27, 2009, within the interval 39.6 to 890.0 m (130 to 2,920 ft). Within this interval the borehole drifted approximately 3.4 m (11.3 ft) to the southwest (on a bearing of 237.04 degrees). No abrupt changes in the borehole orientation ("doglegs") were apparent. At the lowest logged depth of 890.0 m (2,920 ft), the true vertical depth is calculated to be 890.0 m (2,919.86 ft). Thus, no depth corrections are deemed to be necessary.

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-20-7 are listed in Appendix A-3.

2.3 Drilling Problems

Drilling delays at Well ER-20-7 were mainly due to operational problems (safety stand-down; delay for transferring drilling fluid returns containing radiological contaminants), 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, the 13⅜-in. surface casing installed to isolate the upper aquifer (TCA) from the TSA (the target aquifer) also mitigated potential hole instability issues.

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 (SNJV, 2009e). 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). Lithium bromide 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 expected at Well ER-20-7, based on the results of analysis of groundwater from Well ER-20-5#1, located 797 m (2,616 ft) north of Well ER-20-7 (Figure 2-2) (DOE/NV, 1997) and on Phase I flow and transport modeling. To manage the anticipated water production, one unlined sump (sump #1) and one lined sump (sump #2) were constructed prior to drilling (Figure 2-1). Additional fluid storage capacity was available through the use of existing lined sumps at Well Cluster ER-20-5 located approximately 766 m (2,512 ft) north of Well ER-20-7 (Figures 2-2 and 2-4). A transfer line was installed from the Well ER-20-7 well site to the northwest Well Cluster ER-20-5 sump (designated as sump #3). When the fluid level in sump #2 reached the level of 2.9 m (9.5 ft) on the staff gauge

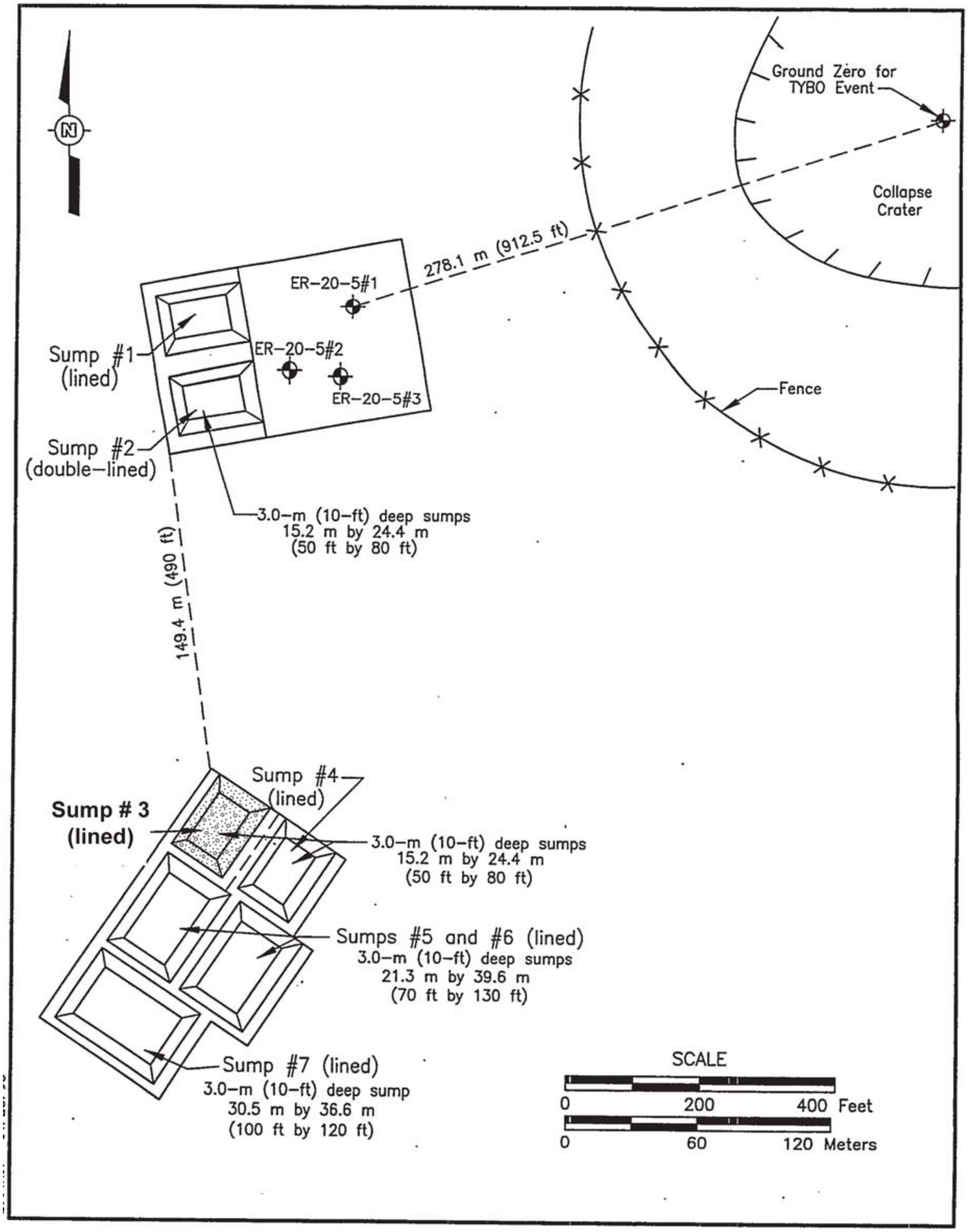

Figure 2-4
Well Cluster ER-20-5 Site Showing Location of Lined Sump #3 Used for Excess Fluids from Sump #2 at Well ER-20-7

in the sump on June 25, 2009, excess fluid was pumped through the transfer line to sump #3. The transfer line was pressure tested prior to pumping, and the line was checked for leaks, with none found. Drilling was stopped until the fluid in sump #2 was pumped to the level of about 1.8 m (6 ft). NNES personnel monitored the transfer line periodically during pumping to check for leaks.

Samples of drilling effluent were collected hourly by NNES and analyzed on site by RCTs for the presence of tritium. As detailed in the NNES data report (NNES, 2010) and summarized in Appendix B of this report, the onsite monitoring results for the drilling indicated that tritium levels measured in the drilling fluid exceeded background levels, as measured by field instruments, starting at the depth of approximately 628.8 m (2,063 ft), and ranging from 47,000 to 1,5000,000 pCi/L. During circulation at a depth of 673 m (2,208 ft), tritium levels in the drilling effluent rose to 4,500,000 pCi/L, which was presumed to represent fluids from the TCA. After the TCA was cased off, and as drilling progressed through the underlying TSA, tritium levels rose to an average of about 20,000,000 pCi/L, with a maximum of over 61,000,000 pCi/L at the depth of 806.2 m (2,645 ft).

On the evening of June 25, 2009, while the crew was re-establishing circulation down hole, pressures increased as the water column was lifted. Water was ejected out of the discharge pipe under high pressure and caused fluid from lined sump #2 to splash across the berm between the two sumps and into unlined sump #1. The volume of fluid that infiltrated sump #1 was estimated by NNES to be between 379 and 1,136 liters (100 and 300 gallons). NSTec RCTs posted the entire area as a CA. A sample collected from sump #1 was found to contain levels of tritium at 1,600,000 pCi/L. NNES collected additional fluid samples from sump #1 while drilling was suspended during transfer of fluid from sump #2 to sump #3. The water sample collected from sump #1 on the morning of June 26, 2009, had a reported tritium value of 214,260 pCi/L. This reduction is likely due to evaporation and mixing with fluids in sump #1. Drilling operations resumed on the night of June 26, 2009, and the TD of 894.9 m (2,936 ft) was reached the morning of June 27, 2009. Sump #1 was de-posted on July 6, 2009, and is no longer a CA.

Lead monitoring was not initiated until discharge fluids exceeded the UGTA Fluid Management Criteria for tritium (400,000 pCi/L), as specified in the Well ER-20-7 Fluid Management Strategy Letter (SNJV, 2009e) approved by the Nevada Division of Environmental Protection. When fluids did exceed the criteria, one sample was then taken for lead analysis every eight hours of drilling until the TD was reached. Lead values did not exceed the minimum detectable concentration (NNES, 2010). NNES personnel also checked all down-hole equipment for lead; 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 report are estimates of total fluid production, and do not account for any infiltration or evaporation of fluids from the sumps.

3.0 Geologic Data Collection

3.1 Introduction

This section describes the sources of geologic data obtained from Well ER-20-7 and the methods of data collection. Improving the understanding of the subsurface structure, stratigraphy, and hydrogeology in the southern portion of PM-OV CAU was among the primary objectives of Well ER-20-7, 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-20-7 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 SNJV FAWP (2009b).

3.2 Collection of Drill Cuttings

Composite drill cuttings were collected at 3-m (10-ft) intervals as drilling progressed. NSTec geologists collected 21 samples during construction of the conductor hole, between the depths of 6.1 and 36.6 m (20 and 120 ft). Below that depth, NNES personnel collected triplicate samples, each consisting of approximately 550 cubic centimeters of material, from 280 intervals from 36.6 m (120 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 NNES 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 NNES.

3.3 Sidewall Core Samples

Sidewall core samples were collected at selected depths in Well ER-20-7 to verify the stratigraphy and lithology and for special analytical tests. Sample locations were selected by NSTec geologists and the NNES 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 43.0 and 563.9 m (141 and 1,850 ft). A total of 25 sample depths was attempted, with 8 cores recovered. Baker Atlas used a rotary sidewall coring tool to obtain sidewall samples between the depths of

736.1 and 887.0 m (2,415 and 2,910 ft), within a section of densely welded ash-flow tuff. All 12 rotary samples attempted were successfully recovered. Table 3-1 summarizes the results of sidewall coring operations at Well ER-20-7.

3.4 Sample Analysis

One sidewall core and 21 samples of drill cuttings from various depths in Well ER-20-7 were submitted to Comprehensive Volcanic Petrographics, LLC, for petrographic analysis. A split of the same sidewall core and 21 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 (2010), and the results of the mineralogic and chemical analyses are reported in WoldeGabriel et al. (2009).

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 671.7 m (2,203.9 ft) and after the TD was reached at 894.9 m (2,936 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 NNES 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. The borehole resistivity imaging tool ("STAR") was not functioning properly during logging, but the data were adequate to produce a Dipmeter Log for use in determining bedding dips. Where the circumferential borehole acoustic imaging tool ("CBIL") was run within the welded Tiva Canyon Tuff, scarring of the borehole wall due to drilling obscured fracturing on the image.

Table 3-1
Sidewall Samples from Well ER-20-7

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
43.0	141	SWC	Empty barrel	Pahute Mesa Tuff	Bedded tuff, vitric
49.1	161	SWC	Lost barrel	Pahute Mesa Tuff	Ash-flow tuff, vitric, nonwelded
62.5	205	SWC	3.18 (1.25)	Rocket Wash Tuff	Ash-flow tuff, vitric, nonwelded
96.0	315	SWC	Empty barrel	Rocket Wash Tuff	Ash-flow tuff, welded
105.5	346	SWC	2.84 (1.12)	Ammonia Tanks Tuff (mafic-rich)	Ash-flow tuff, partially welded, partially devitrified
116.4	382	SWC	Misfire	Ammonia Tanks Tuff (mafic-rich)	Ash-flow tuff, nonwelded
139.0	456	SWC	Empty barrel	Ammonia Tanks Tuff (mafic-poor)	Ash-flow tuff, partially welded
163.4	536	SWC	3.18 (1.25)	Ammonia Tanks Tuff (mafic-poor)	Ash-flow tuff, nonwelded, vitric
169.8	557	SWC	Empty barrel	Ammonia Tanks Tuff (mafic-poor)	Ash-flow tuff, nonwelded, vitric
181.4	595	SWC	3.56 (1.40)	Ammonia Tanks Tuff (bedded)	Bedded tuff, vitric
190.5	625	SWC	2.84 (1.12)	Ammonia Tanks Tuff (bedded)	Bedded tuff, vitric
205.7	675	SWC	Empty barrel	Rainier Mesa Tuff (mafic-rich)	Ash-flow tuff, partially welded
239.0	784	SWC	3.81 (1.50)	rhyolite of Fluorspar Canyon	Bedded tuff, vitric
248.4	815	SWC	3.18 (1.25)	rhyolite of Fluorspar Canyon	Bedded tuff, vitric
262.1	860	SWC	3.56 (1.40)	rhyolite of Fluorspar Canyon	Bedded tuff, vitric
269.7	885	SWC	Lost barrel	rhyolite of Fluorspar Canyon	Bedded tuff, vitric
275.2	903	SWC	Empty barrel	rhyolite of Fluorspar Canyon	Bedded tuff, vitric
295.0	968	SWC	Empty barrel	rhyolite of Benham	Flow breccia
483.1	1,585	SWC	Empty barrel	rhyolite of Benham	Rhyolitic lava
492.3	1,615	SWC	Empty barrel	rhyolite of Benham (bedded)	Bedded tuff, partially vitric
506.0	1,660	SWC	Empty barrel	rhyolite of Benham (bedded)	Bedded tuff, partially vitric
538.9	1,768	SWC	Empty barrel	rhyolite of Benham (bedded)	Bedded tuff, zeolitic
549.2	1,802	SWC	Empty barrel	tuff of Pinyon Pass	Bedded tuff, zeolitic
559.0	1,834	SWC	Empty barrel	Tiva Canyon Tuff	Ash-flow tuff, partially welded
563.9	1,850	SWC	Empty barrel	Tiva Canyon Tuff	Ash-flow tuff, moderately welded
736.1	2,415	RS	2.03 (0.80)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
739.1	2,425	RS	2.03 (0.80)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
752.9	2,470	RS	4.57 (1.80)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified

Table 3-1
Sidewall Samples from Well ER-20-7 (continued)

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
760.5	2,495	RS	4.32 (1.70)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
774.2	2,540	RS	2.29 (0.90)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
774.2	2,540	RS [d]	4.57 (1.80)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
789.4	2,590	RS	3.05 (1.20)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
808.9	2,654	RS	3.56 (1.40)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
842.8	2,765	RS	4.06 (1.60)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
843.1	2,766	RS	3.43 (1.35)	Topopah Spring Tuff	Ash-flow tuff, densely welded, devitrified
873.3	2,865	RS	4.57 (1.80)	Topopah Spring Tuff	Ash-flow tuff, nonwelded, zeolitic
887.0	2,910	RS	3.18 (1.25)	Calico Hills Formation (mafic-poor)	Bedded tuff, zeolitic

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.

d Second attempt

Table 3-2
Rock Samples from Well ER-20-7 Selected for Petrographic, Mineralogic, and Chemical Analysis [a]

Depth [b, c]		Sample Identifier [d]
meters	feet	
94.5	310	ER20/7–310D
158.5	520	ER20/7–520D
234.7	770	ER20/7–770D
262.1	860	ER20/7–860D
286.5	940	ER20/7–940D
323.1	1,060	ER20/7–1,060D
417.6	1,370	ER20/7–1,370D
472.4	1,550	ER20/7–1,550D
499.9	1,640	ER20/7–1,640D
530.4	1,740	ER20/7–1,740D
551.7	1,810	ER20/7–1,810D
606.6	1,990	ER20/7–1,990D
634.0	2,080	ER20/7–2,080D
707.1	2,320	ER20/7–2,320D
713.2	2,340	ER20/7–2,340D
722.4	2,370	ER20/7–2,370D
752.9	2,470	ER20/7–2,470D
777.2	2,550	ER20/7–2,550D
810.8	2,660	ER20/7–2,660D
842.8	2,765	ER/20/7–2,765RS
874.8	2,870	ER20/7–2,870D
894.9	2,936	ER20/7–2,936D

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-20-7 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	Saturated zone: groundwater temperature / stratigraphic and depth correlation	BA	6/19/2009 6/27/2009	TL-1 / GR-1 TL-2 / GR-9	662.6 (2,174) 893.1 (2,930)	528.5 (1,734) 545.6 (1,790)
* 6-Arm Caliper / Aligned Borehole Profile / Gamma Ray	Borehole conditions, cement volume calculation / lithologic and stratigraphic correlation	BA	6/19/2009	CA6-1 / ORIT-1 / GR-2	659.0 (2,162)	0 (0)
* Digital Spectralog / * Gamma Ray / * 6-Arm Caliper	Stratigraphy, mineralogy, and natural and man-made radiation determination	BA	6/19/2009 6/27/2009	SGR-1 / GR-3 SGR-2 / GR-10 / CA6-2 / ORIT-5	658.1 (2,159) 883.9 (2,900)	0 (0) 609.6 (2,000)
* High Definition Induction / * Gamma Ray	Lithologic determination; saturation of formations; stratigraphic and depth correlation	BA	6/19/2009	HDIL-1 / GR-3	658.1 (2,159)	0 (0)
* Compensated Z-Densilog / * Compensated Neutron / Gamma Ray / Caliper	Stratigraphic and lithologic determination / identification of welding, alteration, rock porosity, and water content	BA	6/19/2009 6/28/2009	CAL-1 / ZDL-1 / CN-1 / GR-4 CAL-2 / ZDL-2 / CN-2 / GR-12	657.5 (2,157) 890.6 (2,922)	35.1 (115) 594.4 (1,950)
Circumferential Borehole Imaging / Gamma Ray	Structural analysis, including fracture characterization. Recognition of lithologic features	BA	6/19/2009 6/29/2009	CBIL-1 / ORIT-2 / GR-5 CBIL-2 / ORIT-7 / GR-14	657.8 (2,158) 891.2 (2,924)	615.7 (2,020) 664.5 (2,180)
* X-Multipole Array Acoustilog / Gamma Ray	Primary matrix porosity	BA	6/19/2009 6/28/2009	XMAC-1 / ORIT-3 / GR-6 XMAC-2 / ORIT-6 / GR-13	652.3 (2,140) 885.7 (2,906)	615.7 (2,020) 609.6 (2,000)
Resistivity Imaging / Gamma Ray	Saturated zone: lithologic characterization, bedding dip, fracture and void analysis.	BA	6/20/2009 6/29/2009	STAR-1 / ORIT-4 / GR-7 STAR-2 / ORIT-8 / GR-15	657.1 (2,156) 890.6 (2,922)	615.7 (2,020) 673.6 (2,210)
Percussion Gun Sidewall Tool / * Gamma Ray	Geologic samples	BA	6/20/2009	SWC-1 / GR-8	563.9 (1,850)	43.0 (141)
* Dual Laterolog / Gamma Ray	Lithologic determinations, identification of alteration, recognition of welding; distinguishing low versus high porosity	BA	6/28/2009	DLL-1 / GR-11 / SP-1	887.9 (2,913)	671.8 (2,204)

Table 3-3
Well ER-20-7 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	6/29/2009	RCOR-1 / GR-16	887.0 (2,910)	736.1 (2,415)
* Chemistry / * Temperature	Groundwater chemistry and temperature	DRI	6/30/2009	Chem-1 / TL-3	891.2 (2,924)	615.7 (2,020)
* Heat Pulse Flow Log	Groundwater flow rate and direction	DRI	6/30/2009	HPFlow-1	815.3 (2,675)	678.2 (2,225)

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

b BA = Baker Atlas DRI = Desert Research Institute.

c Drilled depth.

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4.0 Geology and Hydrogeology

4.1 Introduction

This section describes the geology and hydrogeology of Well ER-20-7. The basis for the discussions here is the detailed geologic characterization of Well ER-20-7 presented as a detailed lithologic log in Appendix C. The detailed lithologic log was developed using drill cuttings and sidewall core samples, geophysical logs, and drilling parameters. Information from petrographic, mineralogic, and chemical analyses on select lithologic samples (listed in Table 3-2) were incorporated into the detailed lithologic log. Information on fractures was obtained from the interpretation of borehole image logs.

4.2 Geology

This section is divided into three discussions relating to the geology of Well ER-20-7. Section 4.2.1 briefly describes the geologic setting of the Pahute Mesa area and Well ER-20-7. The stratigraphic and lithologic units penetrated at the well are discussed in detail 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 detailed lithologic log presented in Appendix C. Tables 4-1 and 4-2 provide the definitions of stratigraphic and hydrostratigraphic units used in various figures in this report.

4.2.1 Geologic Setting

Well ER-20-7 was drilled near the southern 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), 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-20-7, 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. Overlying these units is a series of welded ash-flow tuffs, including the Rainier Mesa Tuff,

Table 4-1
Key to Stratigraphic Units and Symbols Used in This Report

Stratigraphic Unit	Map Symbol
Thirsty Canyon Group, undivided	Tt
Trail Ridge Tuff	Ttt
Pahute Mesa Tuff	Ttp
Rocket Wash Tuff	Ttr
Volcanics of Fortymile Canyon, undivided	Tf
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
debris-flow 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, undivided	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
Topopah Spring Tuff	Tpt
Pahute Mesa lobe of the Topopah Spring Tuff	Tptm
Calico Hills Formation	Th
mafic-poor Calico Hills Formation	Thp
Crater Flat Group	Tc
rhyolite of Inlet	Tci
rhyolite of EC-1	Tcpe
rhyolite of Kearsarge	Tcpk
Bullfrog Tuff	Tcb
Grouse Canyon Tuff	Tbg
Volcanics of Oak Spring Butte	To

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

Hydrostratigraphic Unit	Symbol
Thirsty Canyon volcanic aquifer	TCVA
Tannenbaum Hill lava-flow aquifer	THLFA
Tannenbaum Hill composite unit	THCM
Timber Mountain aquifer	TMA
Fluorspar Canyon confining unit	FCCU
Paintbrush vitric-tuff aquifer	PVTA
Benham aquifer	BA
upper Paintbrush confining unit	UPCU
Tiva Canyon aquifer	TCA
lower Paintbrush confining unit	LPCU
Topopah Spring aquifer	TSA
Calico Hills zeolitic composite unit	CHZCM
Inlet aquifer	IA
Crater Flat composite unit	CFCM
Bullfrog confining unit	BFCU

Ammonia Tanks Tuff, Rocket Wash Tuff, Pahute Mesa Tuff, and Trail Ridge Tuff, which cap much of Pahute Mesa (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-20-7. The Pahute Mesa Tuff and Trail Ridge Tuff were erupted 9.4 and 9.3 Ma, respectively, from the Black Mountain caldera (Slate et al., 1999) located northwest of Well ER-20-7. The Trail Ridge Tuff forms the ground surface at the well site (Figure 4-1).

Major structural features in the vicinity of Well ER-20-7 are related in some degree to caldera formation. Most of the structural features are completely buried by younger volcanic rocks and alluvial material, and thus their locations and characteristics can only be approximately determined. Well ER-20-7 is located within the southern portion of the Area 20 caldera. 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-20-7 borehole. The northern structural margin of the TMCC is located approximately 6,100 m (20,000 ft) southwest of Well ER-20-7. 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 1,200 m (4,000 ft) southwest of Well ER-20-7 is a north-northwest trending structural zone called the NTMMSZ. This buried structural zone was first recognized geophysically (Mankinen et al., 1999, Grauch et al., 1999), and subsequently confirmed by data from PM–OV Phase I drilling (U.S. Department of Energy [DOE], 2000b). 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, 2000b).

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). One such fault, the Boxcar fault, is located approximately 2,100 m (7,000 ft) east of Well ER-20-7. A buried normal fault, generally parallel to, but smaller than, the Boxcar fault, is postulated to be present between Well ER-20-7 and Well Cluster ER-20-5 (see Section 4.3).

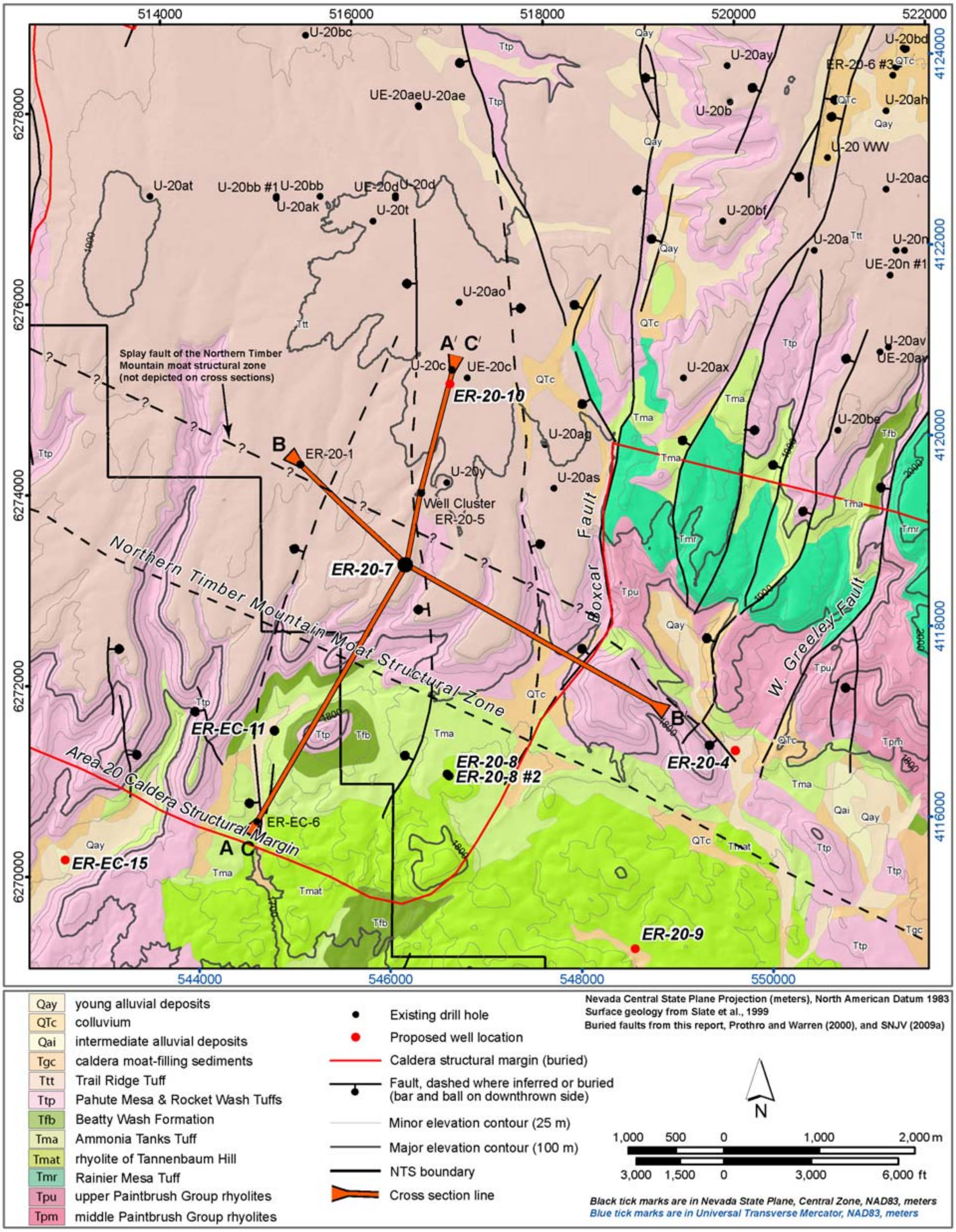

Figure 4-1
Surface Geologic Map of the Well ER-20-7 Area

4.2.2 Stratigraphy and Lithology

The stratigraphic and lithologic units penetrated at Well ER-20-7 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-20-7 was aided by examination of, and correlation with, nearby Well Cluster ER-20-5, which was drilled in 1995/96 to explore geologic conditions down-gradient of the TYBO and BENHAM UGTs (DOE/NV, 1997). Wells ER-20-5#3 and ER-20-5#1 are located approximately 766 and 797 m (2,512 and 2,616 ft), respectively, to the north of Well ER-20-7.

Drilling at Well ER-20-7 began in the moderately welded Trail Ridge Tuff of the Thirsty Canyon Group, which forms the ground surface in the vicinity of the well (Figure 4-1). The Thirsty Canyon Group erupted between 9.15 and 9.4 Ma from the Black Mountain caldera (Sawyer et al., 1994), located 12 kilometers (km) (7.5 miles [mi]) to the northwest. The Thirsty Canyon Group in the vicinity of Well ER-20-7 typically consists of three welded ash-flow tuffs separated by vitric bedded ash-fall deposits. All three ash-flow tuffs (Trail Ridge Tuff, Pahute Mesa Tuff, and the Rocket Wash Tuff) were encountered in the upper 99.1 m (325 ft) of Well ER-20-7. The stratigraphic assignment of the Thirsty Canyon Group is based on surface mapping (Byers and Cummings, 1967) and the rock's peralkaline character, evidenced mainly by the absence of biotite and quartz phenocrysts. A thin bedded tuff related to the Volcanics of Fortymile Canyon underlies the Rocket Wash Tuff.

The next major stratigraphic interval in Well ER-20-7 is the Timber Mountain Group, consisting of the Ammonia Tanks Tuff, erupted 11.45 Ma, and the Rainier Mesa Tuff, erupted 11.6 Ma, from the TMCC (Sawyer et al., 1994), located about 7 km (4.3 mi) to the south.

The Ammonia Tanks Tuff was encountered in the interval 102.4 to 196.6 m (336 to 645 ft). The Ammonia Tanks Tuff at Well ER-20-7 consists of 76.2 m (250 ft) of nonwelded to partially welded ash-flow tuff overlying 18.0 m (59 ft) of bedded tuff. Both the mafic-rich and mafic-poor member of the Ammonia Tanks Tuff were recognized in the well. The stratigraphic assignment of the Ammonia Tanks Tuff is based on stratigraphic position below the Thirsty Canyon Group, ash-flow tuff lithology, and mineralogic assemblage, including the presence of quartz phenocrysts, minor to common biotite, and chatoyant sanidine.

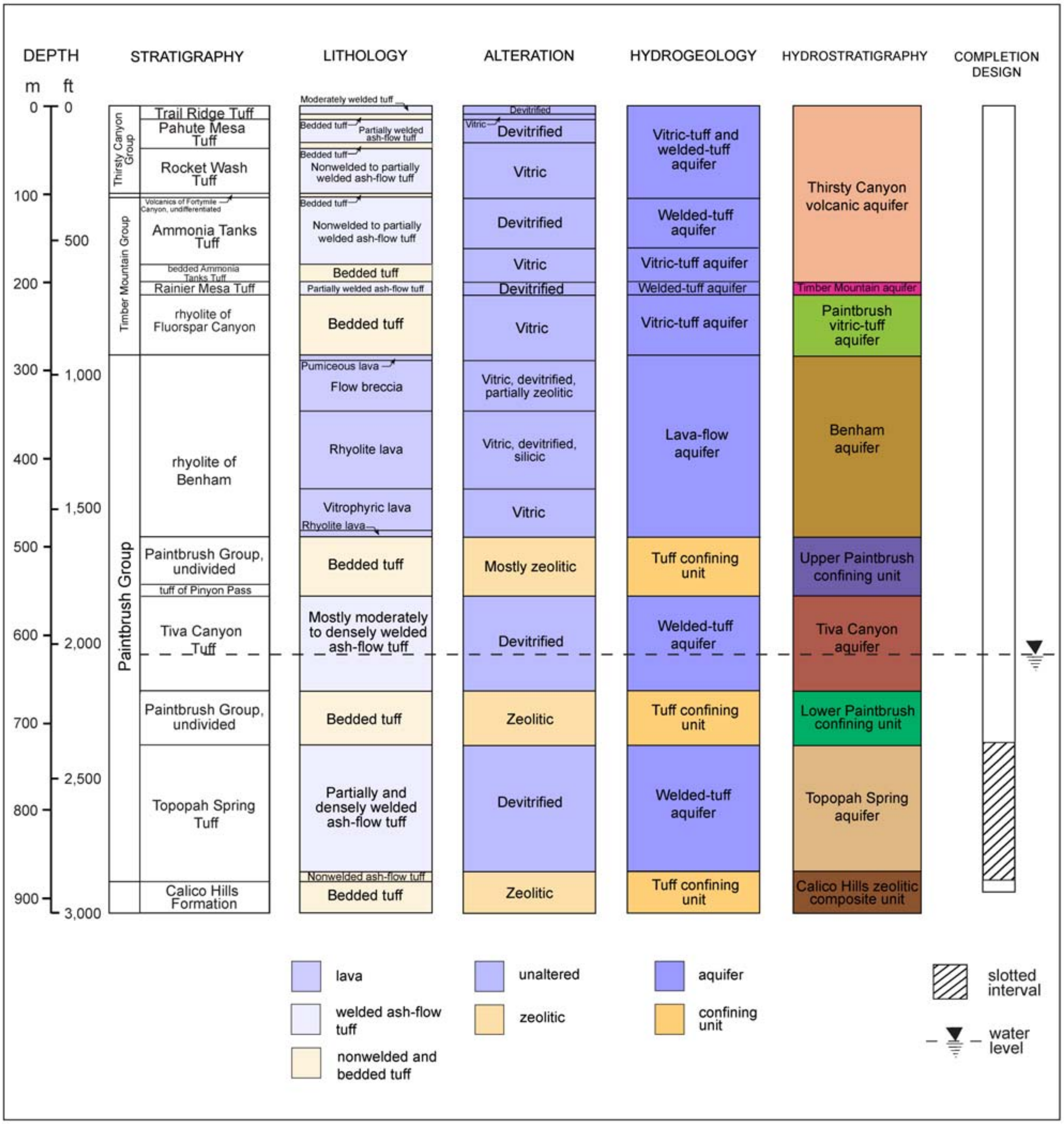

Figure 4-2
Geology and Hydrogeology of Well ER-20-7

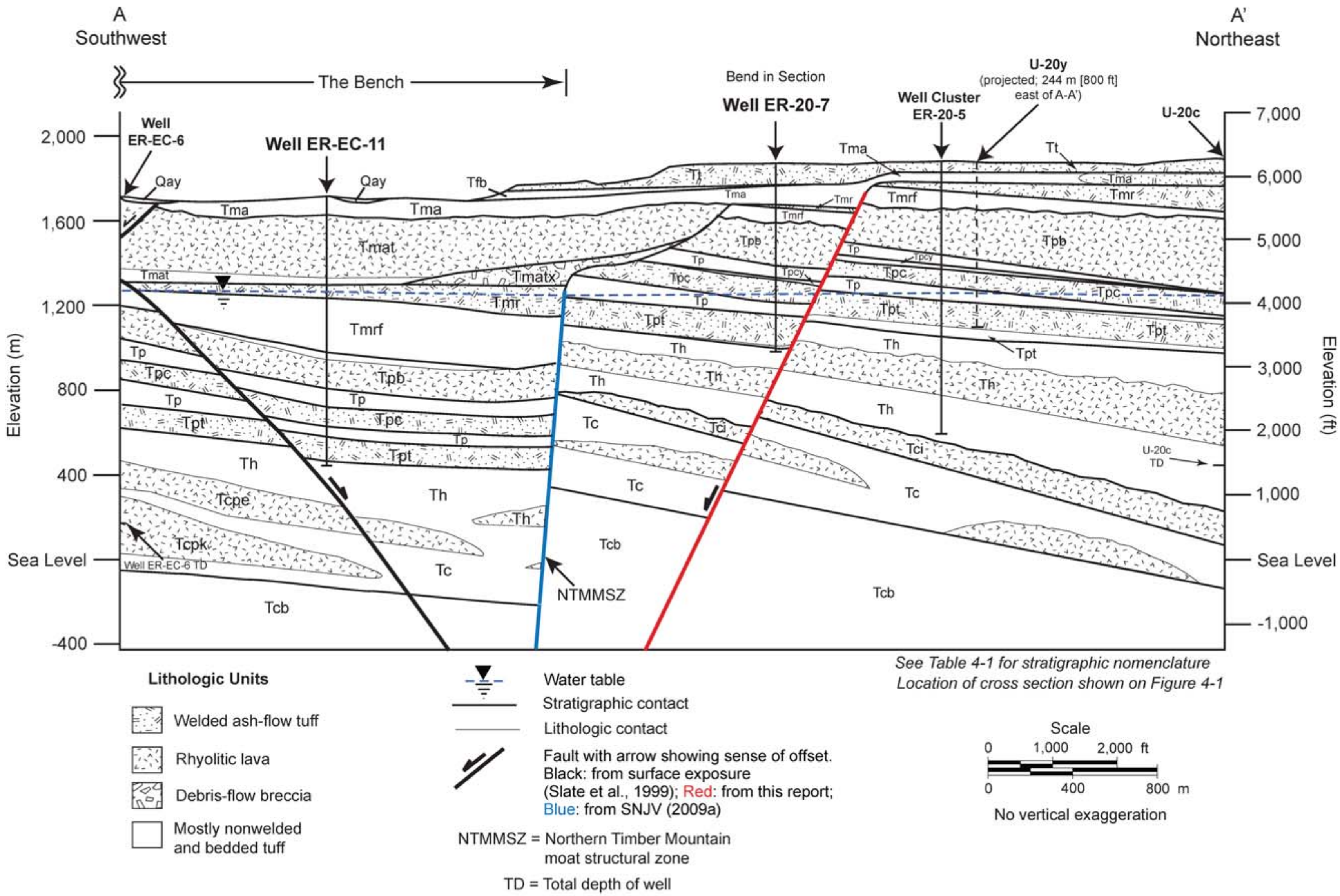

Figure 4-3
Southwest–Northeast Geologic Cross Section A–A' through Well ER-20-7

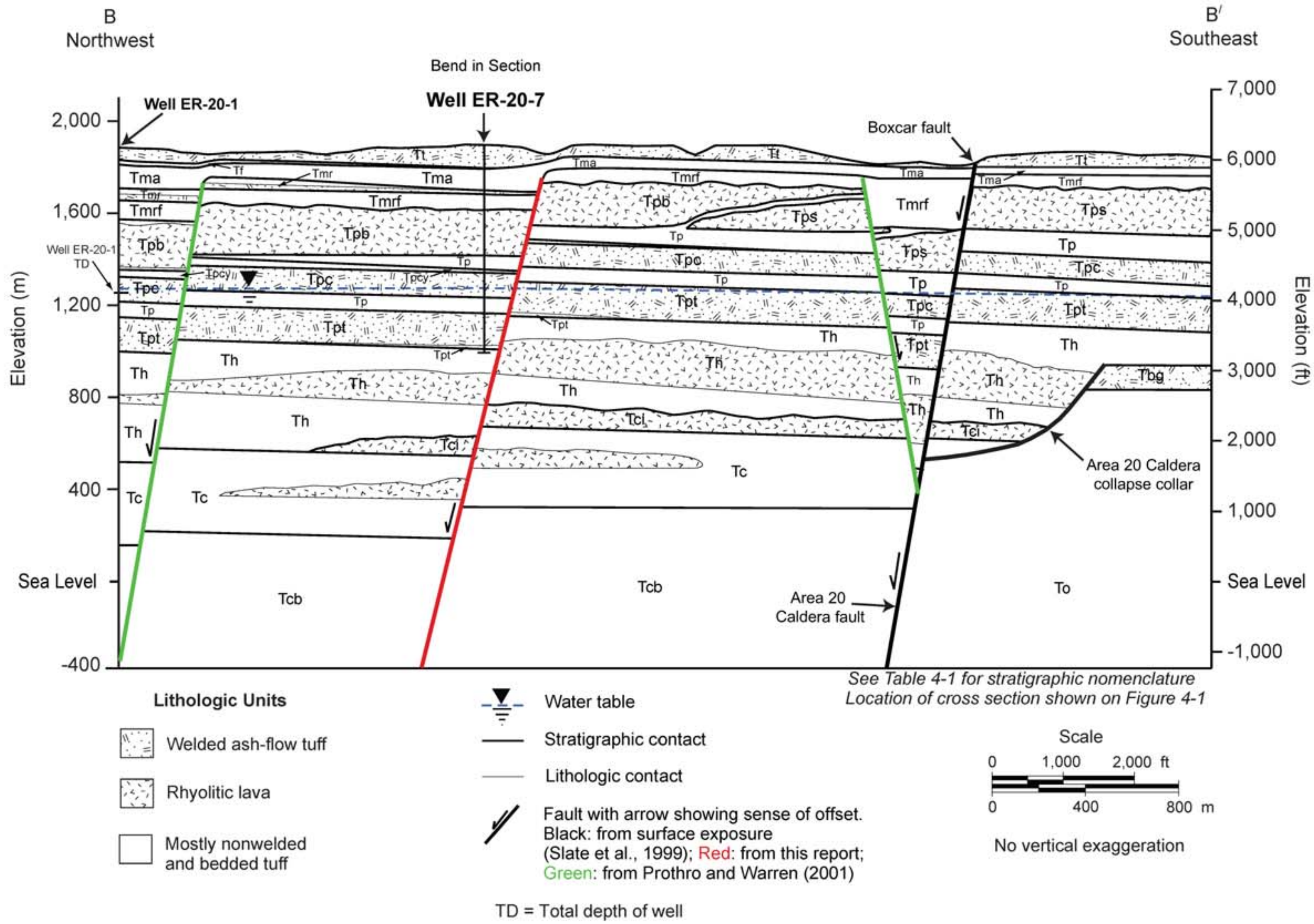

Figure 4-4
Northwest–Southeast Geologic Cross Section B–B' through Well ER-20-7

Below the Ammonia Tanks Tuff, Well ER-20-7 penetrated 15.8 m (52 ft) of partially welded Rainier Mesa Tuff, from 196.6 to 212.4 m (645 to 697 ft). Based on the abundance of biotite, the well likely encountered the mafic-rich member of the formation. The Rainier Mesa Tuff is identified by its stratigraphic position, ash-flow tuff lithology, and mineralogic assemblage.

The rhyolite of Fluorspar Canyon was encountered below the Rainier Mesa Tuff. It consists of bedded tuff with a thickness of 70.4 m (231 ft), and was identified by the presence of quartz phenocrysts and biotite, and through an excellent correlation with Well ER-20-5, using the thorium curve on spectral gamma ray logs.

The next major stratigraphic interval in Well ER-20-7 is the Paintbrush Group, which consists of the rhyolite of Benham, the Tiva Canyon Tuff, and the Topopah Spring Tuff. 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). Well ER-20-7 encountered a thick section of rhyolitic lava of the rhyolite of Benham from 282.9 to 486.2 m (928 to 1,595 ft). The rhyolite of Benham was identified on the basis of its lava-flow lithology and mineralogic assemblage (conspicuous sphene, no quartz phenocrysts). Characteristics typical of NTS rhyolitic lavas were observed, including intervals of pumiceous lava, flow breccia, and vitrophyre. Spherulites, perlite, and flow banding were also observed. Lithic and pumice fragments (i.e., pyroclasts) were noticeably absent from the lava interval.

Below the rhyolite of Benham lava, the well penetrated a 68.6-m (225-ft) thick interval of zeolitic bedded tuff, from 486.2 to 554.7 m (1,595 to 1,820 ft). The absence of quartz phenocrysts and the interval's stratigraphic position between two Paintbrush Group units (rhyolite of Benham and the underlying Tiva Canyon Tuff) indicate that the bedded tuffs belong to the Paintbrush Group. Detailed petrographic analyses indicate that the units above 539.5 m (1,770 ft) can probably be more precisely assigned to the rhyolite of Benham. The units below 539.5 m (1,770 ft) are tentatively assigned to the crystal-poor tuff of Pinyon Pass.

Well ER-20-7 encountered ash-flow tuff of the Tiva Canyon Tuff, in the interval from 554.7 to 661.4 m (1,820 to 2,170 ft). A thin, partially welded zone was encountered at the top of the Tiva Canyon Tuff, and below this, the well penetrated 91.4 m (300 ft) of more welded ash-flow tuff. This zone is moderately welded at the top and bottom, and densely welded to vitrophyric in the middle. At its base, the Tiva Canyon Tuff grades from moderately welded to nonwelded within a zone 12.2 m (40 ft) thick. Detailed petrographic analyses indicate that both the Pahute Mesa lobe and crystal-poor members are present. The Tiva Canyon Tuff was identified by the relatively thick ash-flow tuff lithology, stratigraphic position between the rhyolite of Benham and the underlying Topopah Spring Tuff, and its mineralogic assemblage, which includes sphene and hornblende, but no quartz phenocrysts. Beneath the Tiva Canyon Tuff, 45.7 m (150 ft) of bedded and reworked tuff and 12.8 m (42 ft) of nonwelded tuff was penetrated in Well ER-20-7. Detailed petrographic analyses indicate that these intervals include the Paintbrush Group formations rhyolite of Delirium Canyon, rhyolite of Echo Peak, and bedded Topopah Spring Tuff.

The Topopah Spring Tuff was encountered at the base of the Paintbrush Group at 722.4 m (2,362 ft). This unit consists of about 148.7 m (488 ft) of partially to densely welded ash-flow tuff, with 11 m (36 ft) of zeolitic, nonwelded tuff at the base. Borehole image logs show that the densely welded portion is fractured, especially between 783.3 and 801.6 m (2,570 and 2,630 ft), and contains lithophysae. Detailed petrographic analyses indicate that the Topopah Spring Tuff in Well ER-20-7 consists of the Pahute Mesa lobe member of the formation. The Topopah Spring Tuff was identified by its thick ash-flow tuff lithology, the absence of quartz phenocrysts, and its stratigraphic position at the base of the Paintbrush Group section.

Well ER-20-7 reached TD at 894.9 m (2,936 ft), within the Calico Hills Formation, consisting of zeolitized bedded tuffs. Detailed petrographic analyses indicate that the mafic-poor member of the Calico Hills Formation was encountered. The Calico Hills Formation is recognized by stratigraphic position and the presence of quartz phenocrysts.

4.2.3 Alteration

The volcanic rocks penetrated at Well ER-20-7 are generally unaltered above 530.4 m (1,740 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. Parts of the rhyolitic lava are also devitrified. Below 530.4 m (1,740 ft), the original glass matrix of the nonwelded and bedded tuffs has been altered mainly to zeolite. The intensity of secondary alteration increases below approximately 707.1 m (2,320 ft). Higher temperature hydrothermal alteration is observed within the interval of bedded and nonwelded tuffs between the Tiva Canyon Tuff and the Topopah Spring Tuff at approximately 707.1 m (2,320 ft). This alteration is characterized by the presence of a quartzo-feldspathic mineral assemblage and higher temperature zeolites such as mordenite and analcime. Although the bedded tuffs of the Calico Hills Formation at the bottom of the well are also quartzo-feldspathic, the welded tuffs of the overlying Topopah Spring Tuff show typical devitrification.

4.3 Predicted and Actual Geology

The geology encountered at Well ER-20-7 is different than that predicted prior to drilling (Figure 4-5). This may seem surprising, considering the proximity of UGTA Well Cluster ER-20-5 and the relatively well characterized TYBO-BENHAM area (e.g., Prothro and Warren, 2001). Much of the difference, however, can be attributed to a previously unknown fault between Well Cluster ER-20-5 and Well ER-20-7, and to the poorly constrained NTMMSZ. These faults appear to be partly associated with an episode of complex faulting that was generally coincident with eruption of the Timber Mountain Group. Consequently, most of the differences, particularly with regards to the occurrence and thickness of stratigraphic units, are confined to the upper unsaturated portion of the volcanic section penetrated, and mainly involve units associated with the Timber Mountain Group such as the rhyolite of Fluorspar Canyon, Rainier Mesa Tuff, and the Ammonia Tanks Tuff, all of which are unsaturated in Well ER-20-7. The saturated stratigraphic sequence penetrated in the lower half of Well ER-20-7, however, is very similar to that predicted prior to drilling but is considerably lower in elevation than predicted.

The uppermost units penetrated in Well ER-20-7 consist of a series of welded ash-flow tuffs and intervening bedded tuffs of the Thirsty Canyon Group. The thickness and composition of these rocks are very similar to that predicted prior to drilling. Below the Thirsty Canyon Group, however, the geology encountered is significantly different than predicted. All the differences observed from the base of the Thirsty Canyon Group down to, and including, the upper portion of the rhyolite of Benham are related to the position of Well ER-20-7 relative to the poorly characterized buried fault scarp of the NTMMSZ. Although recognizing that the location of the scarp was not well constrained, it was predicted prior to drilling that Well ER-20-7 was located just inside the scarp, and that the upper portion of the well would encounter geologic relationships associated with the NTMMSZ and its related scarp. Based on the actual geology encountered in the upper portion of Well ER-20-7, particularly the occurrence of the Rainier Mesa Tuff, it is clear that the well is located north of the scarp.

The saturated stratigraphic sequence penetrated in the lower portion of Well ER-20-7 is very similar in thickness and composition to that predicted prior to drilling. The elevations of the

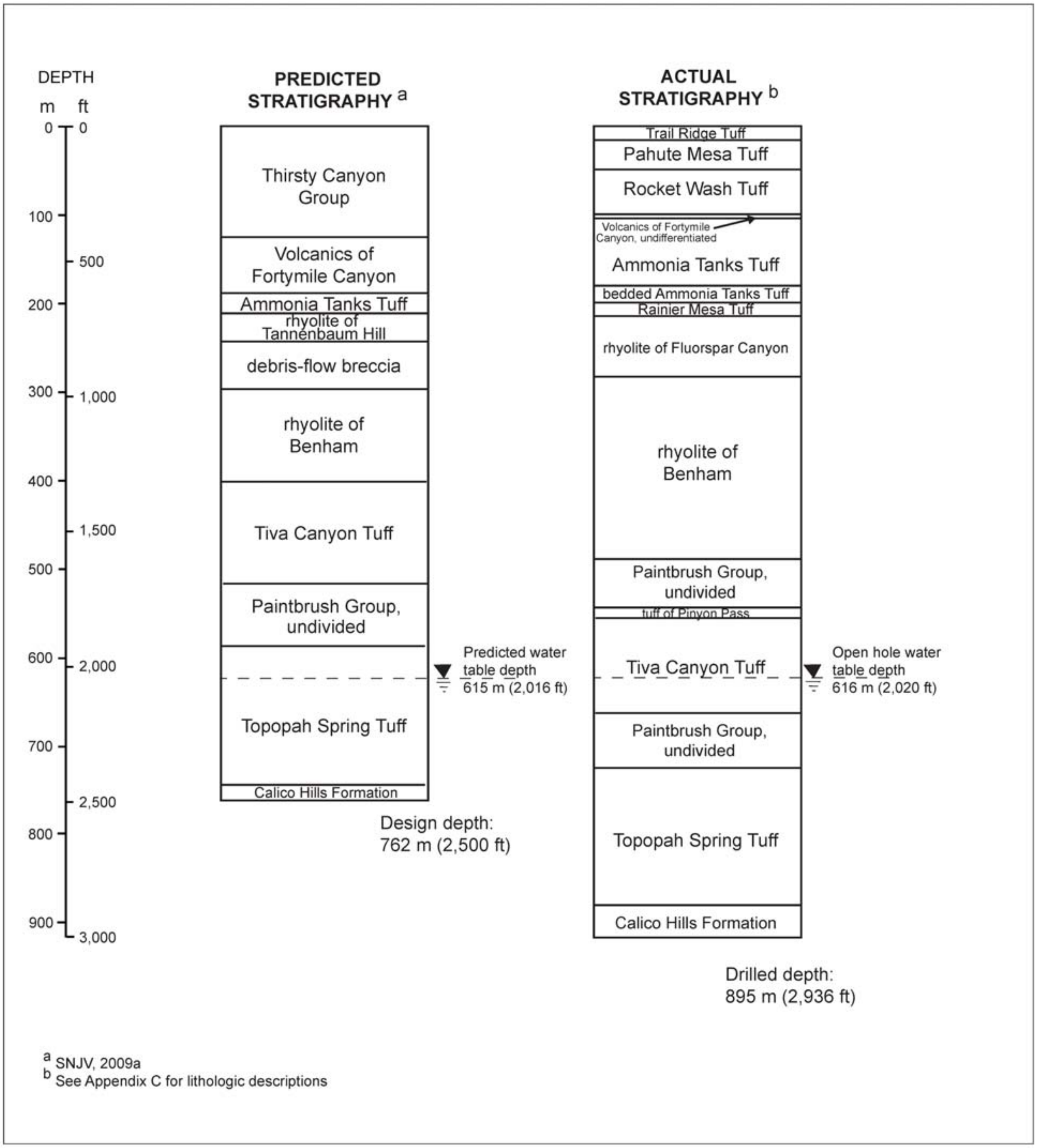

Figure 4-5
Predicted and Actual Stratigraphy at Well ER-20-7

units, however, are more than 122 m (400 ft) lower than predicted. This difference in elevation is most likely the result of a previously undocumented buried fault located between Well ER-20-7 and Well Cluster ER-20-5 (Figures 4-1, 4-3, and 4-4). Pre-drill cross sections (SNJV, 2009a) and structure maps (Warren et al., 2000) in the vicinity of Well ER-20-7 indicated a significant northward component of dip between Well Cluster ER-20-5 and holes to the north (e.g., U-20c).

Because of the relatively close proximity of Well ER-20-7 to Well Cluster ER-20-5, and because no structural features were documented between the two well locations, this northward component of dip was maintained for estimating formation tops in proposed Well ER-20-7 (located approximately 760 m [2,500 ft] south of Well Cluster ER-20-5). As a result, most formation tops in Well ER-20-7, particularly those in the saturated portion of the well, were predicted to be higher in elevation than in Well Cluster ER-20-5. However, the actual formation tops (e.g., Tiva Canyon and Topopah Spring Tuffs) are significantly lower than predicted, and even lower in elevation than corresponding units in Well Cluster ER-20-5. This indicates that some type of buried structural feature, most likely a fault, is present between Well ER-20-7 and Well Cluster ER-20-5.

The orientations of surface cracks from UGTs (Grasso, 2003) and mapped normal faults (Byers and Cummings, 1967) indicate a north-south structural grain in the Well ER-20-7 vicinity. This would suggest that displacement along a previously undocumented buried northward-striking, down-on-the-west normal fault between Well ER-20-7 and Well Cluster ER-20-5 is responsible for the lower elevations observed for units in Well ER-20-7. The postulated buried fault may connect with similarly oriented normal faults mapped at the surface south and north of Well ER-20-7 (Figure 4-1). Structural information based on the interpretation of limited borehole image data from the lower portion of the bedded tuff interval between the Tiva Canyon Tuff and Topopah Spring Tuff in Well ER-20-7 indicate an eastward component of tilt that may be associated with a nearby down-on-the-west normal fault. Similar buried normal faults have been postulated in the area (Prothro and Warren, 2001) (Figures 4-1, 4-3, and 4-4).

The structural scenario described above is depicted in the cross sections in Figures 4-3, 4-4, and 4-6 (see Section 4.4). However, other structural scenarios are still possible. For example, the fault between Well ER-20-7 and Well Cluster ER-20-5 could be a west-northwest-striking splay of the NTMMSZ (Figure 4-1). A similarly oriented fault is mapped at the surface east of the Boxcar fault and east-southeast of Well ER-20-7 (Byers and Cummings, 1967) (Figure 4-1).

4.4 Hydrogeology

The saturated portion of Well ER-20-7 consists of an alternating sequence of welded-tuff aquifers and tuff confining units. Welded ash-flow tuffs of the Tiva Canyon Tuff and Topopah Spring Tuff form two distinct welded-tuff aquifers in the well, while the zeolitic bedded and nonwelded tuffs that occur between the two welded-tuff aquifers and below the welded Topopah Spring Tuff are categorized as tuff confining units. An interpretation of the possible distribution of the hydrostratigraphic units in the vicinity of Well ER-20-7 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 614.5 m (2,016 ft) and within welded-tuff aquifer of the Topopah Spring Tuff. The actual water table depth on June 27, 2009 was 615.7 m (2,020 ft), but because the stratigraphic units in the lower portion of the well are deeper than predicted, this depth is within the lower portion of the welded Tiva Canyon Tuff. Consequently, the welded-tuff aquifer composed of the Topopah Spring Tuff is fully saturated, while only the lower portion of the Tiva Canyon welded-tuff aquifer is saturated.

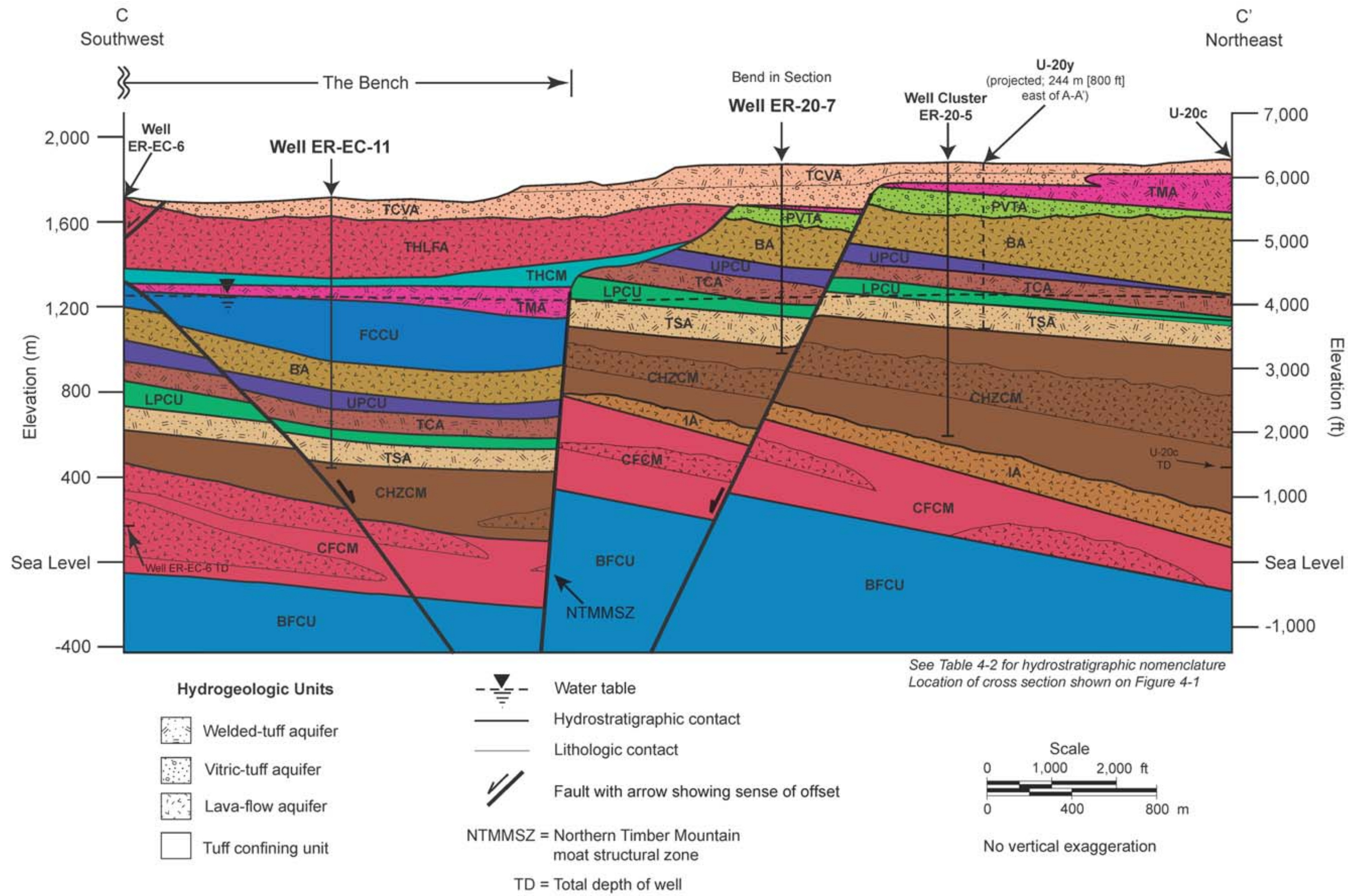

Figure 4-6
Southwest–Northeast Hydrostratigraphic Cross Section C–C' through Well ER-20-7

5.0 Hydrology

5.1 Preliminary Water-Level Information

Prior to drilling, the water level at Well ER-20-7 was estimated to be 614.5 m (2,016 ft) below ground surface, within the TSA. During open-hole geophysical logging operations on June 19, 2009, after the borehole had penetrated the TCA but not the TSA, a fluid level depth of 615.7 m (2,020 ft) or 1,276.8 m (4,189 ft) elevation was measured. After the TCA was isolated behind casing and the borehole had reached TD (June 27, 2009), a fluid level depth for the TSA was measured at the same depth, 615.7 m (2,020 ft).

5.2 Water Production

Water production was estimated during drilling of Well ER-20-7 on the basis of dilution of a lithium-bromide tracer, as measured by NNES field personnel. The first observation of water in returns was reported on June 17, 2009, at the depth of 634.6 m (2,082 ft). Estimated water production ranged from 0 to 189.3 liters per minute (0 to 50 gallons per minute) while drilling the TCA. These numbers should be used cautiously as only the lower 36.6 m (120 ft) of the aquifer is saturated and production rates may not be representative. Water production through the TSA ranged from 0 to 2,461 liters per minute (0 to 650 gallons per minute). Estimated water production rates during drilling are presented graphically in Appendix A-1.

5.3 Preliminary 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 TSA, shortly after the TD was reached. The DRI flow log indicated downward flow above 795.5 m (2,610 ft) and upward flow below this depth. The 795.5-m (2,610-ft) depth corresponds to a drilling break (where the drilling penetration rate increased dramatically for 3.0 m [10 ft]) and to borehole breakout on the caliper log within the TSA, which may indicate fracturing.

5.4 Preliminary Groundwater Characterization Samples

Following geophysical logging on June 30, 2009, DRI collected preliminary groundwater characterization samples within the open borehole at the depths of 772.7 and 807.7 m (2,535 and 2,650 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).

Water samples approximately 3.8 liters (1 gallon) in volume were collected by NNES during drilling of the well and shipped to LANL for radiological analysis. See the list of sample numbers and depths in Table 5-1.

Table 5-1
Fluid Samples Collected During Drilling of Well ER-20-7

Sample Number [a]	Depth or Depth Interval meters (feet)
ER-20-7-061709-1-DL	644.7 (2,115)
ER-20-7-061709-2-DL	673.0 (2,208)
ER-20-7-061709-3-DL	673.9 (2,211)
ER-20-7-061709-4-DL	681.8 (2,237)
ER-20-7-061709-5-DL [b]	668.4–769.9 (2,193–2,526)
ER-20-7-061709-6-DL [b]	774.2–856.2 (2,540–2,809)
ER-20-7-061709-7-DL [b]	866.2–893.1 (2,842–2,930)

a Samples collected by NNES personnel from fluid discharge line are approximately 3.8 liters (1 gallon) in volume.

b Samples are composites of samples collected over a 24-hour period during drilling through the indicated depth interval.

6.0 Precompletion and Open-Hole Development

Initial well development conducted in Well ER-20-7 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 a string of tubing or casing that is slotted or screened at one or more locations along its length. The completion process also typically includes emplacement of backfill materials around the casing, 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 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-20-7 was presented in SNJV (2009a) and in the NSTec FAWPs (NSTec, 2009a and b). 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 SNJV, 2009a) was based on the assumption that Well ER-20-7 would penetrate the water table near the top of the TSA and reach TD just below the TSA within the Calico Hills zeolitic composite unit (CHZCM). The primary goal of the proposed completion design was to provide groundwater production data from the TSA and to provide access to groundwater for monitoring and sampling. The 13⅜-in. casing was intended to extend to the depth of approximately 614.5 m (2,016 ft) and isolate the TSA from the overlying rocks.

The well was planned to be completed with a single casing string of 7⅝-in. casing extending through the TSA. This casing string would be slotted, and gravel-packed throughout the slotted sections. Since only one saturated aquifer was expected, no cement isolation intervals were

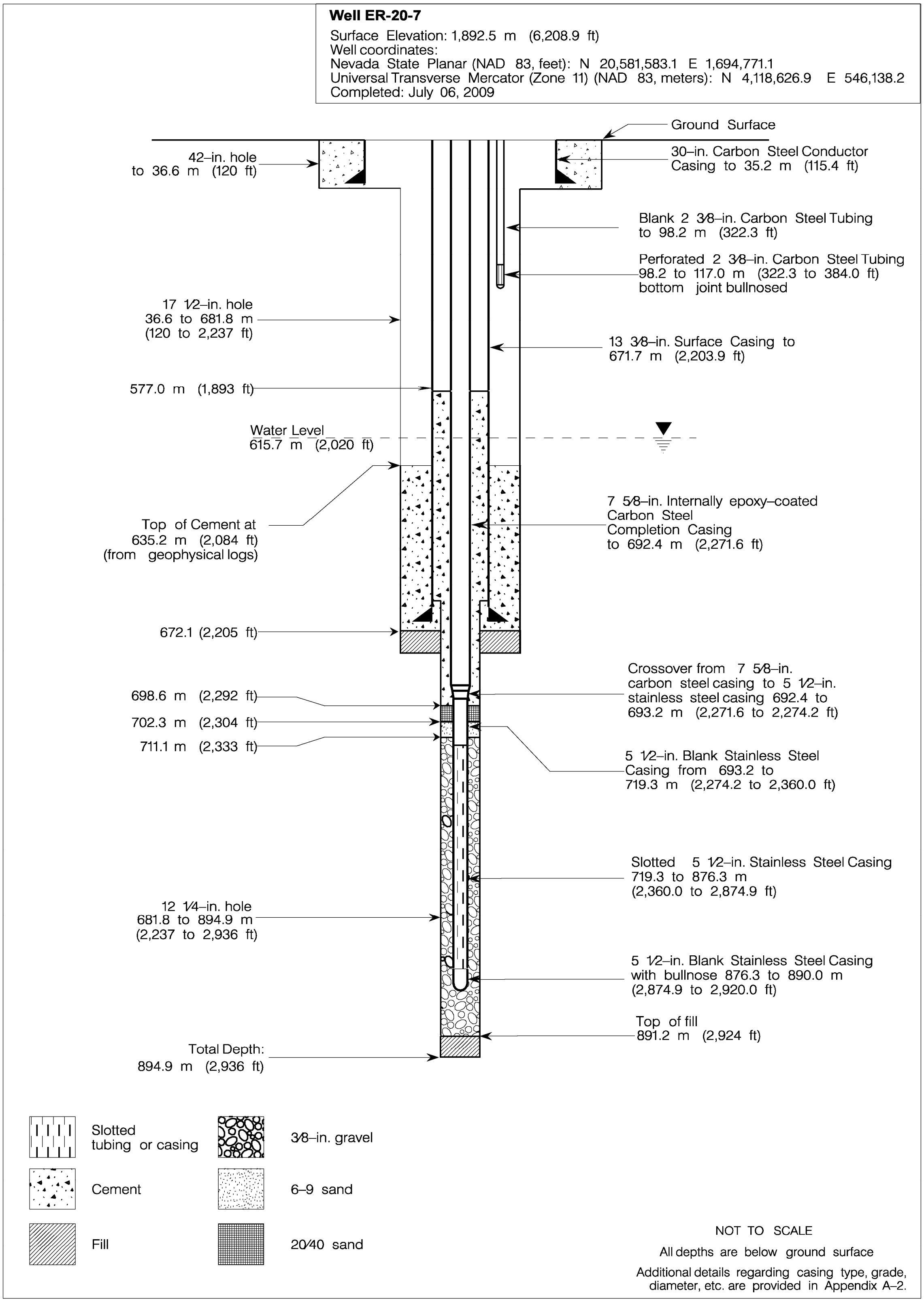

Figure 7-1
As-Built Completion Schematic for Well ER-20-7

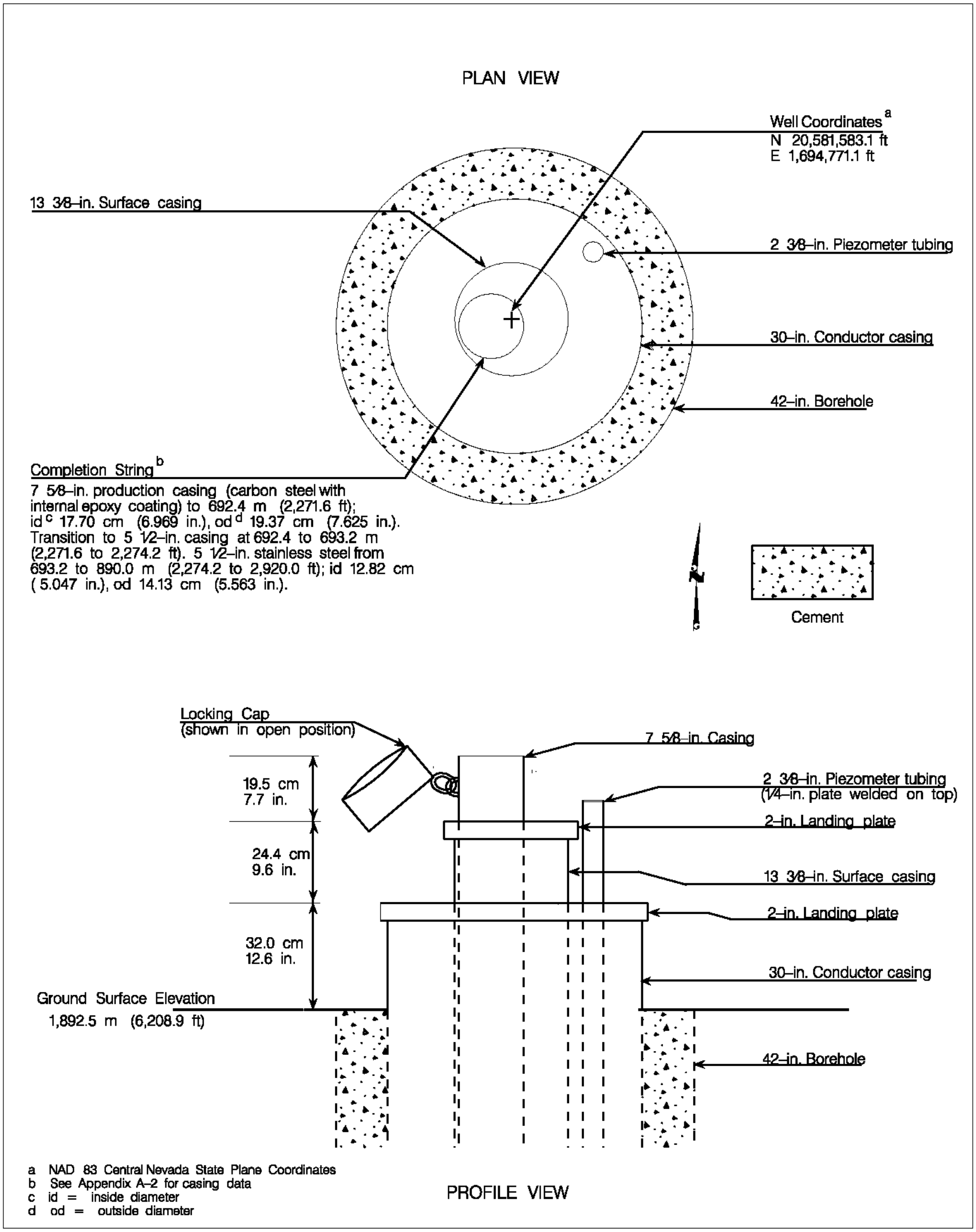

Figure 7-2
Wellhead Diagram for Well ER-20-7

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

<table>
<tr><th>Casing and Tubing</th><th colspan="2">Configuration
meters (feet)</th><th>Cement
meters (feet)</th><th>Sand/Gravel
meters (feet)</th></tr>
<tr><td rowspan="2">2⅜-in. carbon-steel tubing [a]</td><td rowspan="2">0 to 117.0
(0 to 384.0)</td><td>Blank
0 to 98.2
(0 to 322.3)</td><td rowspan="2">None</td><td rowspan="5">None</td></tr>
<tr><td>Slotted and bull-nosed
98.2 to 117.0
(322.3 to 384.0)</td></tr>
<tr><td>7⅝-in. epoxy-coated carbon-steel production casing</td><td>0 to 692.4
(0 to 2,271.6)</td><td>Blank</td><td rowspan="3">Type II neat cement
577.0 to 698.6
(1,893.0 to 2,292.0)</td></tr>
<tr><td>7⅝-in. to 5½-in. cross-over sub, carbon steel, with stainless-steel double pin</td><td>692.4 to 693.2
(2,271.6 to 2,274.2)</td><td>Blank</td></tr>
<tr><td rowspan="3">5½-in. stainless-steel production casing (below the static water level)</td><td rowspan="3">693.2 to 890.0
(2,274.2 to 2,920.0)</td><td>Blank
693.2 to 719.3
(2,274.2 to 2,360.0)</td></tr>
<tr><td>12 consecutive slotted joints [b]
719.3 to 876.3
(2,360.0 to 2,874.9)</td><td rowspan="2">None</td><td rowspan="2">20/40 sand
698.6 to 702.3
(2,292.0 to 2,304.0)

6-9 sand
702.3 to 711.1
(2,304.0 to 2,333.0)

3/8-inch washed gravel
711.1 to 891.2
(2,333.0 to 2,924.0)</td></tr>
<tr><td>Blank and bull-nosed
876.3 to 890.0
(2,874.9 to 2,920.0)</td></tr>
</table>

a This piezometer string became stuck during emplacement and may be retrieved at a later date.

b Slots are 0.159 cm (0.0625 in.) wide and 5.1 cm (2.0 in.) long, arranged in 18 rows, on staggered 15.2-cm (6.0-in.) centers.

planned. The completion string would consist of epoxy-coated carbon steel to within 25 m (82 ft) above the water table and stainless-steel casing below the water table.

A piezometer tube was to be positioned inside the 13⅜-in. intermediate 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 bottom portion of this tubing string would be positioned within the gravel-packed interval. No cement was planned, as the 13⅜-in. casing would provide isolation.

7.2.2 As-Built Completion Design

Changes to the design of Well ER-20-7 were initially considered due to penetration of saturated TCA containing tritium activities greater than 1,000,000 pCi/L. The final design of the Well ER-20-7 completion was determined after the initial TD of 894.9 m (2,936 ft) was reached, through consultation with members of the UGTA Well ER-20-7 Drilling Advisory Team, on the basis of onsite evaluation of data such as lithology and water production, drilling data, tritium activities, and data from various geophysical logs.

As shown in Figure 7-1, only the main completion string was installed in Well ER-20-7. An attempt was made to install a piezometer tube in the annular space between the 13⅜-in. surface casing and the borehole wall to monitor the TCA. However, this tubing became stuck at the depth of 117.0 m (384.0 ft). It is likely that this tubing will be removed, and another attempt to place a piezometer line to the TCA may be made at a later date.

The main completion string consists of a section of 5½-in. stainless-steel casing suspended from 7⅝-in. internally epoxy-coated carbon-steel casing, and was set at the depth of 890.0 m (2,920 ft). The 7⅝-in. epoxy-coated carbon-steel casing extends from the surface to the depth of 692.4 m (2,271.6 ft), which is 76.8 m (252 ft) below the water table. The portion of the 7⅝-in. epoxy-coated carbon steel casing below the water level is encapsulated within cement. The stainless-steel 5½-in. casing is slotted in the interval from 719.3 to 876.3 m (2,360.0 to 2,874.9 ft) within the TSA. The slotted section consisted of 12 consecutive slotted joints, and was terminated with 13.1 m (42.9 ft) of blank stainless-steel casing and a 0.67 m (2.2 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 5.08 cm (2.0 in.) long. The slots are arranged in rows of 18, with rows staggered 20 degrees on 15.2-cm (6-in.) centers.

The slotted interval accesses the borehole from the top of the gravel pack at the depth of 711.1 m (2,333 ft) to the bottom of the hole at 894.9 m (2,936 ft). The slotted interval is isolated by cement from all formations above the gravel pack. This interval encompasses all the TSA and approximately 14.3 m (47 ft) of the overlying tuff confining unit.

7.2.3 Rationale for Differences between Planned and Actual Well Design

The original proposed well completion design for Well ER-20-7 was based on the expectation that the first and only aquifer encountered in the well would be saturated TSA in the depth interval of 614.5 to 716.3 m (2,016 to 2,350 ft). The TSA was encountered deeper than expected because of presumed faulting, and the Tiva Canyon Tuff (another Paintbrush aquifer) was the first saturated aquifer encountered. Both of these aquifers contained high levels of tritium and had to be isolated from each other to avoid cross-contamination. 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, an unsuccessful attempt was made to install a $2\frac{3}{8}$-in. piezometer string in the annular space between the $13\frac{3}{8}$-in. surface casing and the borehole wall. This tubing string was left in the borehole, but may be replaced at a later date.

Prior to installation of the main completion string, the UDI drill crew inserted a string of $2\frac{7}{8}$-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 July 2, 2009, and landed it at 890.0 m (2,920.0 ft) on July 3, 2009. Colog, Inc. ran a NAIL tool inside the completion string to monitor placement of stemming materials. A layer of $\frac{3}{8}$-in. washed gravel 189.0 m (620 ft) thick was emplaced around the slotted interval, to a depth of 711.1 m (2,333 ft). Next, a 8.8-m (29-ft) layer of 6-9 coarse silica sand and a 3.7-m (12-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 position above the water table to isolate the carbon-steel $7\frac{5}{8}$-in. casing from groundwater (Figure 7-1).

The UDI drill rig was released after the production 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-20-7 was based on drilling to a planned TD of 792.5 m (2,600 ft) from the surface. A baseline change was later approved that adjusted the baseline depth from 792.5 m (2,600 ft) to 895.1 m (2,936 ft) and increased the number of construction days from 22 days to 26 days.

It took 31 days to construct Well ER-20-7, starting with the drilling of the 44.5-cm (17.5-in.) hole. This includes drilling hiatuses of two days for investigations related to safety incidents, one day during installation of a liner in a sump, and two holidays. Additional drilling time was needed to drill the production hole 102.4 m (336 ft) deeper than planned, which was necessary to ensure that the target aquifer was completely penetrated. A graphical comparison, by day, of planned and actual well-construction activities is presented in Figure 8-1.

The cost analysis for Well ER-20-7 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-20-7 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, RCT 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 NNES personnel.

The total planned cost for constructing Well ER-20-7 was \$3,872,017. The actual cost was \$3,909,940, or 1.0 percent more than the planned cost. Figure 8-2 presents a comparison of the planned and actual costs, by day, for construction of Well ER-20-7.

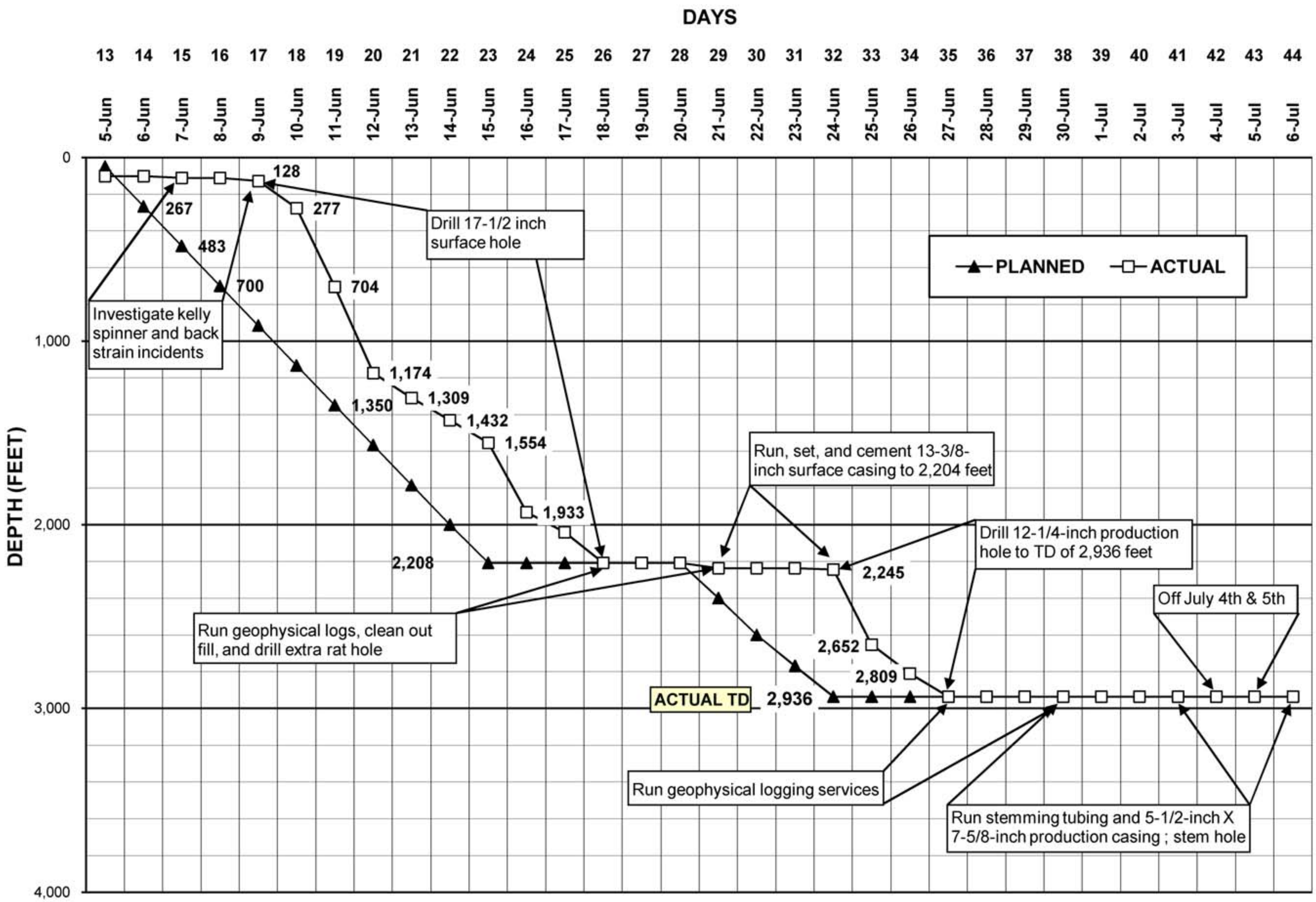

Figure 8-1
Planned and Actual Construction Progress for Well ER-20-7

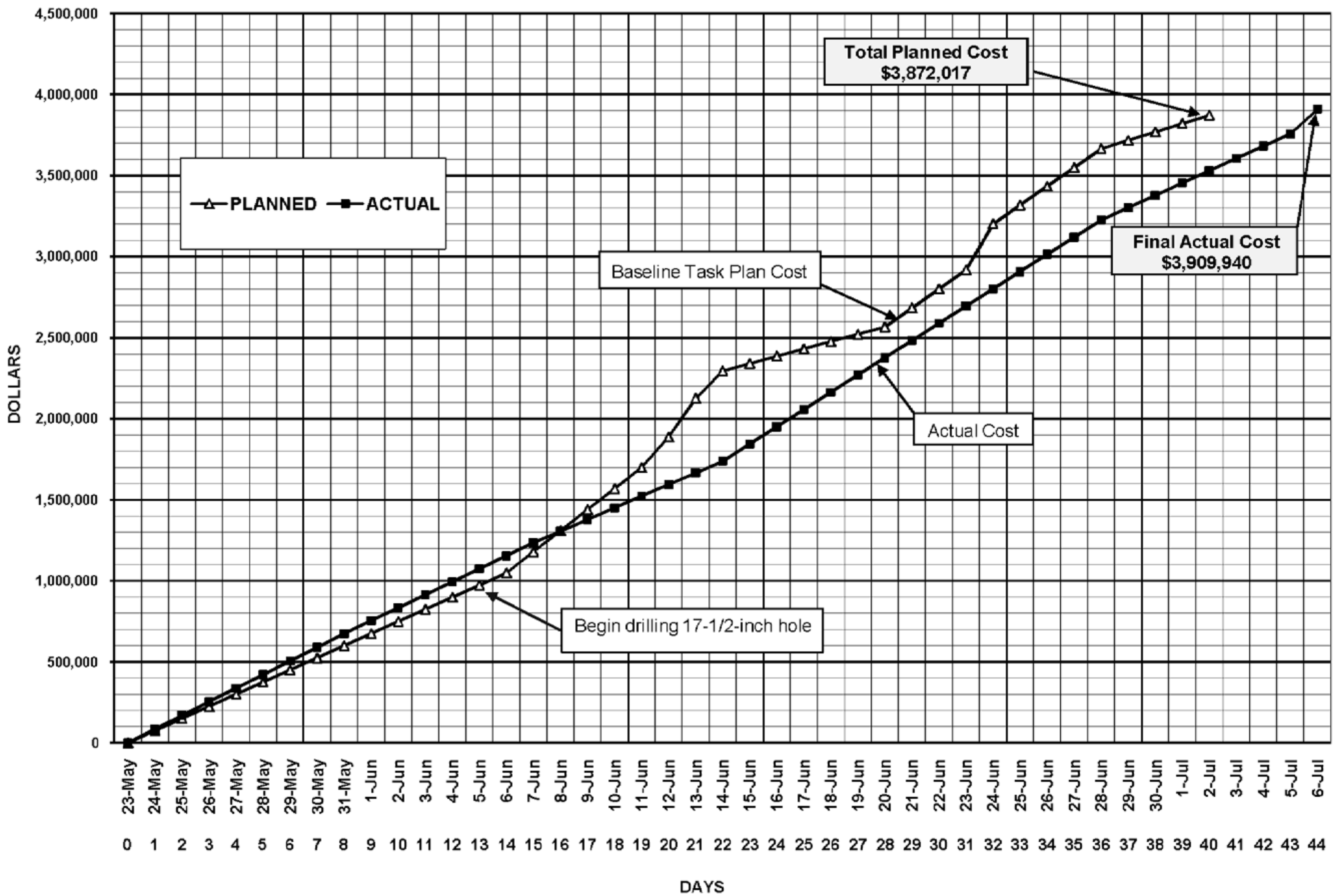

Figure 8-2
Planned and Actual Cost of Constructing Well ER-20-7

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9.0 Summary, Recommendations, and Lessons Learned

9.1 Summary

Main hole drilling at Well ER-20-7 commenced on June 6, 2009, and concluded on June 27, 2009, at a total drilled depth of 894.9 m (2,936 ft). Few problems were encountered during drilling, though the borehole had to be cleaned and deepened after the last geophysical logging series and prior to installation of the surface casing. The borehole was completed within the TSA encountered in the bottom portion of the drill hole.

The completion string consists of 5½-in. stainless-steel casing suspended from 7⅝-in. carbon-steel casing. The carbon-steel casing is internally epoxy-coated and extends to a depth that is 76.8 m (252 ft) below the water table. The outside of the carbon-steel casing is isolated from groundwater by cement. The 5½-in. casing is slotted in the interval 719.3 to 876.3 m (2,360.0 to 2,874.9 ft), providing access to the TSA for monitoring and sampling. The slotted section consists of 12 consecutive stainless-steel slotted joints and is gravel packed.

The effort was made to install a piezometer tube in the annulus between the 13⅜-in. surface casing and the borehole wall to provide access to the saturated portion of the upper aquifer (TCA), which is now cased off from the lower aquifer (TSA). However, the tubing became stuck at the depth of 117.0 (384 ft), well above the desired depth. This partial string may be removed or replaced at a later date.

Geologic data collected during drilling included composite drill cuttings samples collected every 3.0 m (10 ft) from 36.6 m (120 ft) to TD. In addition, 20 sidewall core samples were collected in the interval 43.0 to 887.0 m (141 to 2,910 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-20-7 is collared in welded Trail Ridge Tuff of the Thirsty Canyon Group, and penetrated 894.9 m (2,936 ft) of Tertiary volcanic rocks, consisting largely of bedded and nonwelded to densely welded ash-flow tuffs, rhyolitic lavas, and zeolitic nonwelded tuffs. The water level was measured in the well within the TCA at 615.7 m (2,020 ft) on June 19, 2009, and within the TSA also at 615.7 m (2,020 ft) on June 27, 2009. This equates to an elevation of 1,276.8 m (4,189 ft).

Tritium levels in the drilling fluid were at or below background levels (as measured by field instruments) while drilling the surface hole to a depth approximately 13.1 m (43 ft) below the water table. At and below the depth of 628.8 m (2,063 ft), tritium activity concentration above background levels was encountered in drilling fluids removed from Well ER-20-7. Preliminary field values of up to 4,500,000 pCi/L were measured in the TCA and values of up to 61,000,000 pCi/L were measured with the TSA.

9.2 Recommendations

All the geologic and hydrologic data and interpretations from Well ER-20-7 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-20-7 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 learn more about the nature and extent of the contaminants from the TYBO and BENHAM UGTs. These data will also improve the understanding of aquifer connectivity.

The 2⅜-in. tubing string should be removed and a slimmer piezometer string (e.g., 1.9-in. flush-joint tubing) should be inserted to allow access to the saturated portion of the TCA. If insertion of a new string is successful, fluid level and water chemistry, particularly radionuclides, should be monitored regularly.

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-20-7, the first well in the 2009 Pahute Mesa Phase II drilling initiative:

- CAU guidance teams and hole-specific drilling advisory teams formed by the UGTA TWG can provide timely assistance and guidance for addressing “surprises” and assessing their impacts on the overall program.

- Communication at these remote sites is important. It was found that the satellite phone was unreliable. The radio phones used by the NSTec Site Supervisors worked well.

- Initial confusion regarding the roles of the various state regulatory agencies in determining procedures for isolation of multiple aquifers caused several delays. As these issues were addressed during drilling of Well ER-20-7, guidelines were established that can be applied to future wells to prevent such delays.

- The development of drilling criteria should be started further in advance of actual drilling operations. This would allow the timely procurement of the appropriate size and amount of casing and tubing, based on final approved criteria.

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Appendix A
Drilling Data

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Appendix A-1
Drilling Parameter Log for Well ER-20-7

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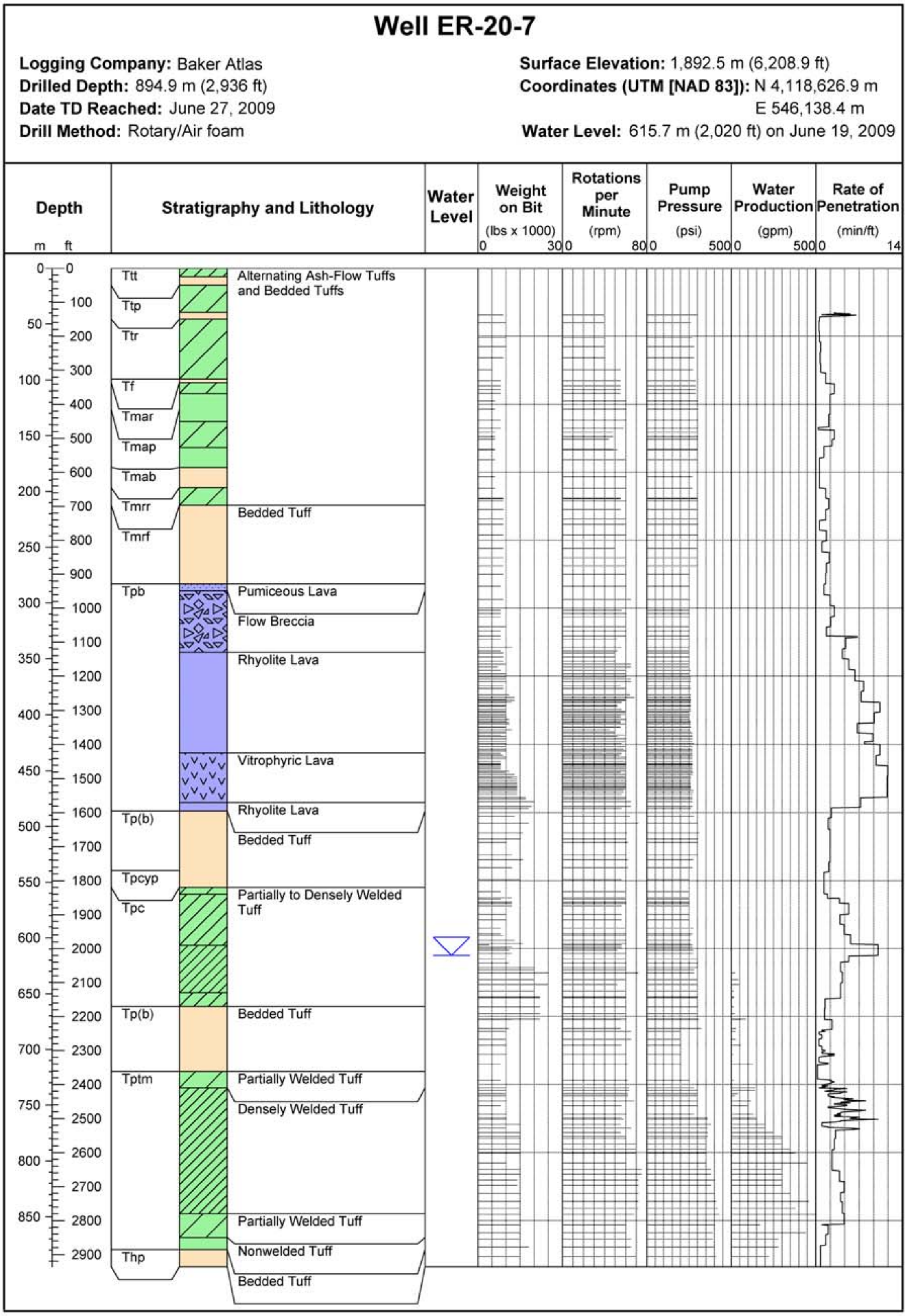

See legend for lithology symbols on Page D-1

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Appendix A-2
Tubing and Casing Data for Well ER-20-7

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Table A-2-1
Tubing and Casing Data for Well ER-20-7

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 35.2 (0 to 115.4)	Carbon Steel	B	76.20 (30)	73.66 (29.0)	1.27 (0.50)	158.0
Surface Casing	0 to 671.7 (0 to 2,203.9)	Carbon Steel	K55	33.97 (13.374)	31.788 (12.515)	1.092 (0.430)	61.0
Completion Casing with Crossover	0 to 693.2 (0 to 2,274.2)	Epoxy Coated Carbon Steel	N80	19.37 (7.625)	17.701 (6.969)	0.834 (0.328)	26.4
Completion Casing	693.2 to 890.0 (2,274.2 to 2,920.0)	Stainless Steel	SSTP304	14.13 (5.563)	12.819 (5.047)	0.655 (0.258)	14.6
Piezometer Tubing [a]	0 to 117.0 (0 to 384.0)	Carbon Steel	N80	6.03 (2.375)	5.067 (1.995)	0.483 (0.190)	4.7

a This tubing became stuck at 117.0 m (384 ft) and may be removed at a later date.

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Appendix A-3
Well ER-20-7 Drilling Fluids and Cement Composition

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Table A-3-1
Drilling Fluids Used in Well ER-20-7

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] 0.05 to 1.5 liters of lithium bromide 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-20-7 came from Area 20 Water Well (U-20WW).

2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of approximately 10 to 40 milligrams per liter.

Table A-3-2
Well ER-20-7 Cement Composition

Cement Composition	30-inch Conductor Casing	13⅜-inch Surface Casing	7⅝-inch Completion Casing
Redi-Mix Formula 400: 998 kilograms (2,200 pounds) sand, 326 kilograms (719 pounds) Portland cement, and 232 liters (61 gallons) water per cubic yard	0 to 36.6 m [a] (0 to 120 ft) [b]	N/A	N/A
Type II neat	N/A	In annulus: 635.2 to 681.1 m (2, 084 to 2,237 ft) Inside casing: 668.4 to 681.1 m (2,193 to 2,237) ft	577.0 to 698.6 m (1,893 to 2,292 ft)

a meter(s)
b foot (feet)

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Appendix B
Well ER-20-7 Fluid Management Data

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Table B-1
Well ER-20-7 Fluid Disposition Reporting Form

FLUID DISPOSITION REPORTING FORM

Site Identification: ER-20-7
Site Location: NTS Area
Site Coordinates (UTM, NAD 27, Zone 11): N: 4,118,429.7 m E: 546,218.6 m
Well Classification: ER Hydrologic Investigation Well
Project No: UG09-223

Report Date: January 2010
NNSA/NSO Federal Sub-Project Director: Bill Wilborn
SNJV Project Manager: Sam Marutzky
SNJV Site Representative: Steven Hopkins
SNJV 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[c] (m^3)		Volume of Infiltration Area (m^3)	Other[d] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids[b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	6/06/09	6/17/09	11	616	889	181	581	2	28[1]	N/A	N/A	Yes
Phase I: Saturated-Zone Drilling	6/17/09	6/27/09	5	895	191	N/A	N/A	40	1,096	N/A	1,547	Yes
Phase II: Initial Well Development	-	-	-	-	-	-	-	-	-	-	-	-
Phase II: Aquifer Testing	-	-	-	-	-	-	-	-	-	-	-	-
Phase II: Final Development	-	-	-	-	-	-	-	-	-	-	-	-
Cumulative Production Totals to Date:			**16**	**895**	**1,080**	**181**	**581**	**42**	**1,124**	**N/A**	**1,547**	**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 (150%).
[c] Optional fluid management devices not installed for this well site.
[d] Other refers to fluid conveyance to other fluid management locations or facilities away from the well site, such as vacuum truck transport to another well site.
N/A = Not Applicable; m^3 = cubic meters.

Total Facility Capacities (at 8 ft fluid level): Sump #1 = 1,547 m^3 Sump #2 = 1,547 m^3 Sump #3 = 1,547 m^3 Sump #4 = 1,547 m^3

Infiltration Area (assuming negligible infiltration) = N/A m^3

Remaining Facility Capacity (approximate) as of 7/11/09: Sump #1 = 1,178 m^3 (76 %) Sump #2 = 559 m^3 (36 %) Sump #3 = 256 m^3 (16 %) Sump #4 = 1,547 m^3 (100 %)

[2] Current Average Tritium Sump #1 (unlined) = 119,500 pCi/L

[3] Current Average Tritium Sump #2 and #3 (lined) = 18,934,820 pCi/L

Notes: [1]Fluid was pumped from Sump #2 (lined) to Sump #3 (lined) for additional storage. Approximately 28 m^3 of fluid from the unsaturated zone was discharged into Sump #2 (lined).
[2]Tritium result from two sump samples.
[3]Tritium result from on-site monitoring.

Authorizing Signature/Date: ____________

Table B-2
Analytical Results for Fluid Management Sample for Well ER-20-7

Sample Number	Date Collected	Comment		*Resource Conservation Recovery Act* Metals (mg/L)							
				Arsenic	Barium	Cadmium	Chromium	Lead	Selenium	Silver	Mercury
20-7-070709-5	07/07/2009	Sample from Sump #1	Total	0.013	0.1	0.005 U	0.029	0.04	0.014	0.01	0.0002 U
			Dissolved	0.0051	0.1 U	0.005 U	0.02	0.0061 U	0.012	0.01	0.0002 U
20-7-070709-6	07/07/2009	Duplicate sample from Sump #1	Total	0.013	0.1	0.005 U	0.029	0.039	0.013	0.01	0.0002 U
			Dissolved	0.0068	0.11	0.005 U	0.02	0.0068 U	0.011	0.01	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
20-7-070709-5	07/07/2009	Sample from Sump #1	Result	124,000	15.2	28.2
			Error	19,000	3.5	5.8
			MDC	1,000	2.6	5.4
20-7-070709-6	07/07/2009	Duplicate sample from Sump #1	Result	115,000	14.7	30.7
			Error	18,000	3.5	6.1
			MDC	1,000	2.8	5.3
Nevada Drinking Water Standard				15	50	20,000

Data provided by Navarro Nevada Environmental Services (NNES, 2010)

Analyses for metals and radionuclides (filtered prior to analysis) performed by Paragon Analytics, Inc.
Sump #1 is the unlined sump located on the Well ER-20-7 drill pad.

Notes: U = Result less than the instrument detection limit or the MDC (Minimum Detectable Concentration).
mg/L = milligrams per liter pCi/L = picocuries per liter

Analytical methods: All metals except mercury: Environmental Protection Agency (EPA) 6010
Mercury: EPA 7470
Tritium: EPA 906.0

Appendix C
Detailed Geologic Characterization for Well ER-20-7

Table C-1
Detailed Lithologic Log for Well ER-20-7
Logged by Heather Gang, Sigmund Drellack, and Lance Prothro, NSTec, August 2009
Updated to incorporate analytical data, February 2010

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
0–7.6 (0–25)	7.6 (25)	AC	None	**Moderately Welded Ash-Flow Tuff:** Grayish brown (5YR 3/2); partially devitrified; minor olive gray (5Y 4/1) to olive black (5Y 2/1), devitrified, vesicular pumice; common feldspar phenocrysts; minor mafic minerals (clinopyroxene and olivine); rare grayish black (N2) lithic fragments to 1 centimeter (cm) in size; also white speckled and moderate reddish brown (10R 4/6) lithic fragments. Becomes partially welded and light brown (5YR 6/4) with dark yellowish orange (10YR 6/6) argillized pumice near base. The interval 0–3.1 m (0–10 ft) is fill resulting from construction of drill pad.	Trail Ridge Tuff (Ttt)
7.6–5.2 (25–50)	7.6 (25)	AC	None	**Bedded Tuff:** Unconsolidated lapilli tuff consisting of medium light gray (N6), vitric, vesicular pumice fragments up to 2.5 cm, which float on water; rare feldspar phenocrysts; minor mafic minerals (clinopyroxene and olivine); very rare lithic fragments up to 1 millimeter (mm) in size. Includes beds of white (N9) to very light gray (N8) lapilli tuff with grayish black (N2) and dark reddish brown (10R 3/4) lithic fragments. At the base of this interval is a pale yellowish brown (10YR 6/2), moderately indurated, vitric bedded tuff with pieces of medium gray (N5) vitric pumice, minor feldspar phenocrysts, minor mafic minerals including clinopyroxene, and minor sand-sized 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)
15.2–39.6 (50–130)	24.4 (80)	DA	None	**Partially Welded Ash-Flow Tuff:** Grayish brown (5YR 3/2); partially devitrified; common very dusky red (10R 2/2), vitric pumice, with minor vapor-phase mineralization; abundant euhedral feldspar phenocrysts up to 3 mm in size; rare mafic minerals; minor lithic fragments. Below 27.4 m (90 ft), grades into a dark yellowish brown (10YR 4/2), partially welded, devitrified tuff with minor moderate brown (5YR 3/4) pumice with vapor-phase mineralization, common euhedral feldspar phenocrysts, rare mafic minerals, and minor small lithic fragments.	Pahute Mesa Tuff (Ttp)
39.6–45.7 (130–150)	6.1 (20)	DB1	None	**Bedded tuff:** Cuttings are a concentration of lithic fragments and feldspar phenocrysts similar to the hard components of the tuff described in the interval above. Interval includes moderate yellowish brown (10YR5/4) and moderate brown (5YR3/4) bedded tuff; vitric with cuspate black glass shards; vitric, fibrous, dark yellowish orange (10 YR6/6) pumice, minor feldspar phenocrysts, rare mafic minerals, and common lithic fragments.	
45.7–99.1 (150–325)	53.3 (175)	DB1/DA PSWC	94.5 (310)	**Nonwelded to Partially Welded Ash-Flow Tuff:** Dark yellowish brown (10YR 4/2); vitric, nonwelded tuff grading into devitrified, partially welded tuff below 91.4 m (300 ft); minor light brown (5YR 5/6) fibrous pumice with vapor-phase mineralization; minor large tabular feldspar phenocrysts; minor mafic minerals, including clinopyroxene. Lithic fragments in tuff cuttings are minor; however, loose lithic fragments are abundant in samples.	Rocket Wash Tuff (Ttr)

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type [a]	Depth of Analytical Samples [b] meters (feet)	Lithologic Description [c]	Stratigraphic Unit (map symbol)
99.1–102.4 (325–336)	3.4 (11)	DB4	None	**Bedded Tuff:** Yellowish gray (5Y 8/1); vitric; minor fibrous, white, vitric pumice; minor felsic phenocrysts; common mafic minerals including clinopyroxene, lesser bronze biotite.	Volcanics of Fortymile Canyon, undifferentiated (Tf)
102.4–112.2 (336–368)	9.8 (32)	DA PSWC	None	**Partially Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4); partially devitrified; common pumice that is white and dark yellowish orange (10YR 6/6), vitric, and fibrous; also black and vitrophyric (fiamme). Minor felsic phenocrysts including quartz and feldspar; common mafic minerals including black biotite in “books” up to 3 mm in size, and lesser clinopyroxene; rare sand-sized lithic fragments.	mafic-rich Ammonia Tanks Tuff (Tmar)
112.2–126.5 (368–415)	14.3 (47)	DA	None	**Nonwelded Ash-Flow Tuff:** Light brownish gray (5YR 6/1); devitrified; rare light brown (5YR 5/6) devitrified pumice; common felsic phenocrysts, including quartz and feldspar; common black biotite. Lithic fragments are rare in tuff, but are commonly found loose in cuttings box.	
126.5–137.2 (415–450)	10.7 (35)	DA	None	**Nonwelded Ash-Flow Tuff:** Light brownish gray (5YR 6/1); devitrified; minor light brown (5YR 5/6) devitrified pumice; minor felsic phenocrysts, including quartz and chatoyant sanidine; minor black biotite.	mafic-poor Ammonia Tanks Tuff (Tmap)
137.2–160.6 (450–527)	23.5 (77)	DA	158.5 (520)	**Partially Welded Ash-Flow Tuff:** Grayish red (10R 4/2); devitrified; vapor-phase mineralization; minor white to grayish red (10R 4/2) pumice; common felsic phenocrysts, including quartz and feldspar; minor mafic minerals including small bronze biotite; minor sand-sized grayish red (10R 4/2) 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)
160.6–178.6 (527–586)	18.0 (59)	DA PSWC	None	**Nonwelded Ash-Flow Tuff:** Moderate brown (5YR 4/4); vitric, with dark yellowish orange (10YR 6/6) glass shards; common white, fibrous, vitric pumice; minor felsic phenocrysts (quartz and feldspar); minor mafic minerals (clinopyroxene and lesser biotite); minor grayish red (10R 4/2) sand-sized lithic fragments.	mafic-poor Ammonia Tanks Tuff (Tmap)
178.6–196.6 (586–645)	18.0 (59)	DB1 PSWC	None	**Bedded Tuff:** Grayish orange (10YR 7/4) to light brown (5YR 6/4); vitric; minor, white vitric pumice; rare felsic phenocrysts; minor tiny altered mafic minerals and rare tiny lithic fragments. Sample is dominated by white, vitric pumice up to 2.5 cm. Pumice contains rare felsic phenocrysts, including quartz, and minor mafic minerals (black biotite and clinopyroxene).	bedded Ammonia Tanks Tuff (Tmab)
196.6–212.4 (645–697)	15.8 (52)	DA	None	**Partially Welded Ash-Flow Tuff:** Grayish red (10R 4/2); largely devitrified (some parts contain glass shards and vitric pumice), vuggy, with vapor-phase mineralization; silicified in places; minor grayish orange pink (5YR 7/2) pumice, some vitric, some with vapor-phase mineralization; common felsic phenocrysts (feldspar and quartz); minor mafic minerals, including black biotite; rare sand-sized lithic fragments. Geophysical logs indicate tuff may be moderately welded between 203.0 and 209.4 m (666 and 687 ft) and nonwelded between 210.3 and 212.4 m (690 and 697 ft).	mafic-rich Rainier Mesa Tuff (Tmrr)
212.4–274.3 (697–900)	61.9 (203)	DA PSWC	234.7 (770) 262.1 (860)	**Bedded Tuff:** Very pale orange (10YR 8/2); vitric; common white vitric, fibrous, pumice; minor felsic phenocrysts, including quartz; minor mafic minerals, mostly small black biotite, increasing in abundance toward base of interval; minor sand-sized lithic fragments, increasing in size (up to 1 cm) and abundance toward base of interval. Includes greenish silicified beds below 221.0 m (725 ft).	rhyolite of Fluorspar Canyon (Tmrf)

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
274.3–282.9 (900–928)	8.5 (28)	DA	286.5 (940) [d]	**Bedded Tuff:** Yellowish gray (5Y 7/2); mostly zeolitic, partially vitric in some beds, with small silicified patches; rare pumice; minor felsic phenocrysts, including quartz; common biotite; minor to common lithic fragments, varying in abundance with bedding.	rhyolite of Fluorspar Canyon (Tmrf)
282.9–289.3 (928–949)	6.4 (21)	DA	None	**Pumiceous Lava:** Light brownish gray (5YR 6/1) to pale yellowish brown (10YR 6/2); vitric; rare feldspar phenocrysts; common black biotite, conspicuous sphene; lithic fragments not seen in definite association with this lithology.	rhyolite of Benham (Tpb)
289.3–344.4 (949-1,130)	55.2 (181)	DA	323.1 (1,060)	**Flow Breccia:** Medium dark gray (N3); vitric, perlitic; and pale yellowish brown (10YR 6/2), devitrified, partially zeolitic; contains large pale yellowish brown (10YR 6/2) spherulites, some of which are hollow and lined with secondary chalcedony and drusy quartz; minor feldspar phenocrysts; common black biotite, rare sphene; no lithic fragments observed.	
344.4–434.0 (1,130–1,424)	89.6 (294)	DA	417.6 (1,370)	**Rhyolitic Lava:** Mottled with medium light gray (N6) vitric, grayish red (10R 4/2), and devitrified pale reddish brown (10R 5/4); silicified; common feldspar phenocrysts; common biotite; no lithic fragments observed. Interval also contains grayish brown (5YR 3/2) finely flow-banded lava. Below 414.5 m (1,360 ft), light gray (N7) with a "salt and pepper" look due to tiny mafic minerals; partially devitrified with small areas of pink zeolitization; minor feldspar phenocrysts; common bronze biotite, trace sphene; no lithic fragments observed. Silica-filled fractures and evidence of quartz-lined vugs are present.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type [a]	Depth of Analytical Samples [b] meters (feet)	Lithologic Description [c]	Stratigraphic Unit (map symbol)
434.0–478.5 (1,424–1,570)	44.5 (146)	DA	472.4 (1,550)	**Rhyolitic Lava:** Brownish black (5YR 2/1); vitrophyric, perlitic; common feldspar phenocrysts; common black and bronze biotite, conspicuous sphene near top of interval. Phenocryst content decreases with depth.	rhyolite of Benham (Tpb)
478.5–486.2 (1,570–1,595)	7.6 (25)	DA	None	**Rhyolitic Lava:** Grayish red (10R 4/2); vitric, perlitic in places, becoming partially devitrified near base of interval; minor feldspar phenocrysts; common biotite, conspicuous sphene; rare silica-filled fractures. No lithic fragments observed.	
486.2–539.5 (1,595–1,770)	53.3 (175)	DA	499.9 (1,640) 530.4 (1,740) 551.7 (1,810) [d]	**Bedded Tuff:** Pale red (10R 6/2), light brown (5YR 6/4), and pale yellowish brown (10YR 6/2); zeolitic; minor to common moderate yellow (5Y 7/6) pumice. Minor to common feldspar phenocrysts (abundance varies from bed to bed); common mafic minerals, including black biotite, magnetite, and sphene; common manganese oxide stains; minor lithic fragments. Sample at 499.9 m (1,640 ft) is a partially welded block-and-ash-flow tuff that is zeolitic to devitrified. Sample analyses indicate interval is probably related to the rhyolite of Benham.	Paintbrush Group, undivided (Tp)
539.5–554.7 (1,770–1,820)	15.2 (50)	DA	None	**Bedded tuff:** Grayish orange pink (5YR 7/2); zeolitic; common grayish yellow (5Y 8/4) and moderate orange pink (5YR 7/2) zeolitic pumice; rare feldspar phenocrysts; minor mafic minerals including small biotite, hornblende; rare lithic fragments. Below 545.6 m (1,790 ft), unit is very pale orange (10YR 8/2) to moderate reddish orange (10R 6/6); abundant moderate yellow (5Y 7/6) and moderate reddish orange (10R 6/6) to moderate pink (5R 7/4), and very pale orange (10YR 8/2) zeolitic pumice; minor felsic phenocrysts, including trace of quartz; abundant mafic minerals, including black biotite; minor lithic fragments up to 7mm in size.	crystal-poor tuff of Pinyon Pass (Tpcyp)

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
554.7–560.8 (1,820–1,840)	6.1 (20)	DA	None	**Partially Welded Ash-Flow Tuff:** Light gray (N7) to light brownish gray (5YR 6/1); devitrified; minor medium gray (N5) pumice with vapor-phase mineralization; minor feldspar phenocrysts; minor mafic minerals, including biotite and hornblende.	Tiva Canyon Tuff (Tpc)
560.8–606.6 (1,840–1,990)	45.7 (150)	DA	606.6 (1,990)	**Moderately Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4) in the upper 6.1 to 9.1 m (20 to 30 ft) of unit, grayish red (5R 4/2) below; devitrified; rare medium gray (N5) pumice with vapor-phase mineralization; minor feldspar phenocrysts; minor bronze biotite, trace sphene; rare lithic fragments.	
606.6–637.0 (1,990–2,090)	30.5 (100)	DA	634.0 (2,080)	**Densely Welded Ash-Flow Tuff:** Grayish red (10R 4/2); devitrified; minor light brownish gray (5YR 6/1) pumice; rare feldspar phenocrysts; minor mafic minerals, including black biotite. Rare lithic fragments. Below 630.9 m (2,070 ft), becomes mottled grayish brown (5YR 3/2) and light brown (5YR 5/6) with minor light gray (N6) pumice.	
637.0–649.2 (2,090–2,130)	12.2 (40)	DA	None	**Densely Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4); vitrophyric, with black perlitic inclusions (some intervals contain black cuspate shards); rare pumice, phenocrysts, and lithic fragments; silica and manganese oxide-filled fractures observed. Gradational contact with the unit below.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
649.2–661.4 (2,130–2,170)	12.2 (40)	DA DB4	None	**Moderately Welded Ash-Flow Tuff grading downward to Nonwelded Tuff:** Light brown (5YR 5/6) becoming light brown (5YR 6/4) and partially welded below 652.3 m (2,140 ft); devitrified. Remnant perlitic structure in places; rare grayish to yellowish pumice with vapor-phase mineralization; rare feldspar phenocrysts; minor small mafic minerals; trace sphene; rare lithic fragments up to 1 mm in size. Nonwelded tuff below 655.3 m (2,150 ft) is poorly represented in cuttings, but may be moderate brown (5YR 4/4), zeolitic (?), porous tuff with abundant felsic phenocrysts and minor mafic minerals. Also nonwelded tuff with spherulites, pink pumice, minor biotite, and small black lithic fragments.	Tiva Canyon Tuff (Tpc)
661.4–707.1 (2,170–2,320)	45.7 (150)	DA	707.1 (2,320)	**Bedded and Reworked Tuff:** Grayish orange (10YR 7/4) with lesser beds of moderate reddish orange (10R 6/6), dark yellowish orange (10YR 6/6), moderate orange pink (10R 7/4), and dusky yellow (5Y 6/4); zeolitic. Minor to common moderate reddish orange (10R 6/6) and moderate yellow (5Y 7/6), with lesser grayish orange (10YR 7/4) pumice; rare to minor feldspar phenocrysts; rare to minor mafic minerals (biotite and hornblende). Minor to common lithic fragments, varying with bedding, mostly small, but some up to 5 mm in size. Detailed petrographic analysis of sample at 707.1 m (2,320 ft) indicates it is rhyolite of Delirium Canyon, a formation of the Paintbrush Group. Analysis of dip-meter log data shows that bedding in the lower portion of this interval strikes north-northeast and dips 16 degrees to the east-southeast. No cuttings samples from 685.8–691.9 m (2,250–2,270 ft) due to poor returns.	Paintbrush Group, undivided (Tp)

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
707.1–712.0 (2,320–2,336)	4.9 (16)	DA	713.2 (2,340) [d]	**Nonwelded Tuff:** Moderate reddish orange (10R 6/6); zeolitic and quartzo-feldspathic; minor very pale orange (10YR 8/2) pumice. In places, tuff is grayish orange (10YR 7/4) with light brown (5YR 5/6) pumice; minor feldspar phenocrysts; abundant mafic minerals (mostly black biotite); rare small lithic fragments.	Paintbrush Group, undivided (Tp)
712.0–719.9 (2,336–2,362)	7.9 (26)	DA	722.4 (2,370) [d]	**Nonwelded Tuff:** Light brown (5YR 6/4); quartzo-feldspathic, lesser zeolitic; minor pale yellowish brown (10YR 6/2) pumice and lesser white zeolitic pumice; rare feldspar phenocrysts, common black biotite, minor lithic fragments.	
719.9–734.6 (2,362–2,410)	14.6 (48)	DA	None	**Partially Welded Ash-Flow Tuff:** Light gray (N7); devitrified; minor light brown (5YR 5/6) devitrified pumice and medium gray (N5) pumice with vapor-phase mineralization; minor feldspar phenocrysts; minor mafic minerals (bronze and black biotite); rare lithic fragments.	Pahute Mesa lobe of Topopah Spring Tuff (Tptm)
734.6–749.8 (2,410–2,460)	15.2 (50)	DA RSWC	752.9 (2,470) [d]	**Densely Welded Ash-Flow Tuff:** Dusky brown (5YR 2/2); devitrified; common small pale brown (5YR 5/2) devitrified pumice; abundant feldspar phenocrysts; common black biotite; rare lithic fragments. Analysis of Circumferential Borehole Imaging Log (CBIL) data indicates a concentration of mostly west-dipping high angle fractures in the interval 731.5–762.0 m (2,400–2,500 ft).	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type [a]	Depth of Analytical Samples [b] meters (feet)	Lithologic Description [c]	Stratigraphic Unit (map symbol)
749.8–832.1 (2,460–2,730)	82.3 (270)	DA RSWC	777.2 (2,550) 810.8 (2,660)	**Densely Welded Ash-Flow Tuff:** Moderate brown (5YR 3/4); mostly devitrified; spherulitic in part; minor light brown (5YR 6/4) devitrified pumice; minor feldspar phenocrysts, some altered; minor mafic minerals, including biotite; minor lithic fragments. Fractures coated with iron oxides and silica observed. Gradational contact with unit below. Analysis of CIBL data indicates a concentration of mostly west-dipping, high angle fractures in the interval 783.3– 801.6 m (2,570–2,630 ft).	Pahute Mesa lobe of Topopah Spring Tuff (Tptm)
832.1–847.3 (2,730–2,780)	15.2 (50)	DA RSWC	842.8 (2,765)	**Densely Welded Ash-Flow Tuff:** Light brown (5YR 5/6), mottled dark yellowish orange (10YR 6/6) and dusky yellowish brown (10YR 2/2); devitrified; minor light brown (5YR 6/4) pumice; minor felsic phenocrysts, including rare quartz; minor black biotite; minor lithic fragments. Fractures filled with silica and manganese oxide observed, hairline to 1 mm wide.	
847.3–868.7 (2,780–2,850)	21.3 (70)	DA	none	**Partially Welded Ash-Flow Tuff:** Pale brown (5YR 5/2); devitrified with mild quartzo-feldspathic alteration; minor light brown (5YR 6/4) zeolitic pumice; minor feldspar phenocrysts; common mafic minerals including black biotite; minor lithic fragments. Interval above 853.4 m (2,800 ft) is transitional from moderately to partially welded.	
868.7–879.7 (2,850–2,886)	11.0 (36)	DB4 RSWC	874.8 (2,870)	**Nonwelded Ash-Flow Tuff**: Pale reddish brown (10R 5/4); zeolitic. abundant pale red (10R 6/2) zeolitic pumice; rare felsic phenocrysts; minor biotite; rare lithic fragments up to 4 mm in size. Poorly represented in cuttings; described from sidewall core.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
879.7–894.9 (2,886–2,936) Total Depth	>15.2 (>50)	DA RSWC	894.9 (2,936)	**Bedded Tuff:** Moderate reddish orange (10R 6/6); zeolitic and quartzo-feldspathic; abundant yellowish gray (5Y 7/2) pumice; rare felsic phenocrysts, including quartz; rare mafic minerals, including biotite and lesser hornblende; minor lithic fragments up to 2 mm in size.	mafic-poor Calico Hills Formation (Thp)

a **AC** = auger cuttings; **DA** = drill cuttings that represent lithologic character of interval; **DB1** = drill cuttings enriched in hard components; **DB4** = cuttings that are intimate mixtures of units; generally less than 50% of drill cuttings represent lithologic character of interval; **PSWC** = percussion sidewall core; **RSWC** = rotary sidewall core. See Table 3-1 in this report for more information about sidewall samples.

b Depth of lithologic samples selected for mineralogical and petrographic analyses. Laboratory analyses, reported in WoldeGabriel et al. (2009), include mineralogy (x-ray diffraction) and chemistry (x-ray fluorescence). Petrography from analysis of polished thin sections is reported in Warren (2010). See Table 3-2 in this report for a complete list of 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. Information from laboratory analyses will be incorporated when they are received.
Colors describe wet sample color.
Abundances for felsic phenocrysts, pumice fragments, and lithic fragments: **trace** = only one or two individuals observed; **rare** = ≤ 1%; **minor** = 5%; **common** = 10%; **abundant** = 15%; **very abundant** ≥ 20%.
Abundances for mafic minerals: **trace** = only one or two individuals observed; **rare** = ≤ 0.05%; **minor** = 0.2%; **common** = 0.5%; **abundant** = 1%; **very abundant** = ≥ 2%.

d Sample is representative of the indicated unit rather than the underlying unit due to drilling lag time.

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Appendix D
Geophysical Logs Run in Well ER-20-7

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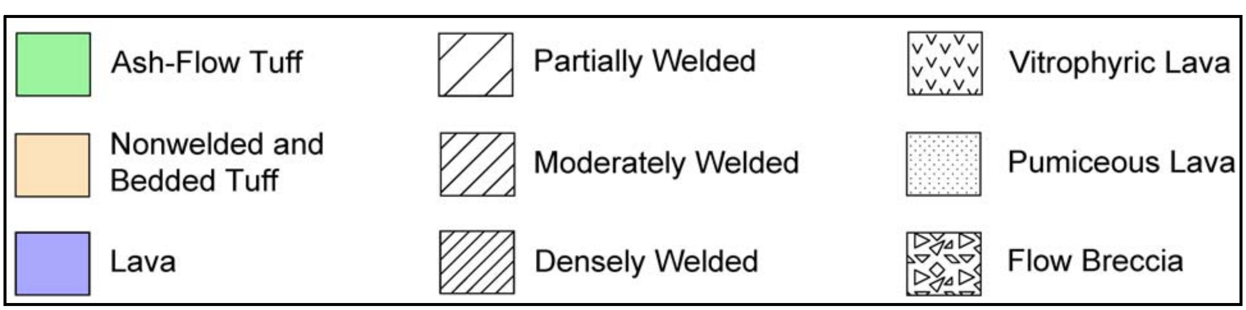
Appendix D contains plots of selected geophysical logs run in Well ER-20-7. Table D-1 summarizes the logs presented. See Table 3-3 for more information.

Table D-1
Well ER-20-7 Geophysical Logs Presented

Log Type	Run Number	Date	Log Interval meters	Log Interval feet
Caliper	CA6-1 CA6-2	06/19/2009 06/27/2009	0–659.0 609.6– 883.4	0–2,162 2,000–2,900
X-Multipole Array Acoustilog (sonic)	XMAC-2	6/27/2009	609.6–885.7	2,000–2,906
Gamma Ray	GR-3 GR-10	6/19/2009 6/27/2009	0–658.1 609.6–883.9	0–2,159 2,000–2,900
Spectral Gamma Ray (potassium, thorium, uranium)	SGR-1 SGR-2	6/19/2009 6/27/2009	0–658.1 609.6–883.9	0–2,159 2,000–2,900
High Definition Induction and Dual Laterolog (resistivity)	HDIL-1 DLL-1	6/19/2009 6/28/2009	0–658.1 671.8–887.9	0–2,159 2,204–2,913
Density	ZDL-1 ZDL-2	6/19/2009 6/28/2009	35.1–657.5 594.4–890.6	115–2,157 1,950–2,922
Compensated Neutron	CN-2	6/28/2009	594.4–890.6	1,950–2,922
Chemistry (temperature, pH, and conductivity)	Chem-1	6/30/2009	615.7–891.2	2,020–2,924
Heat Pulse Flow Log	HPFlow-1	6/30/2009	678.2–815.3	2,225–2,675

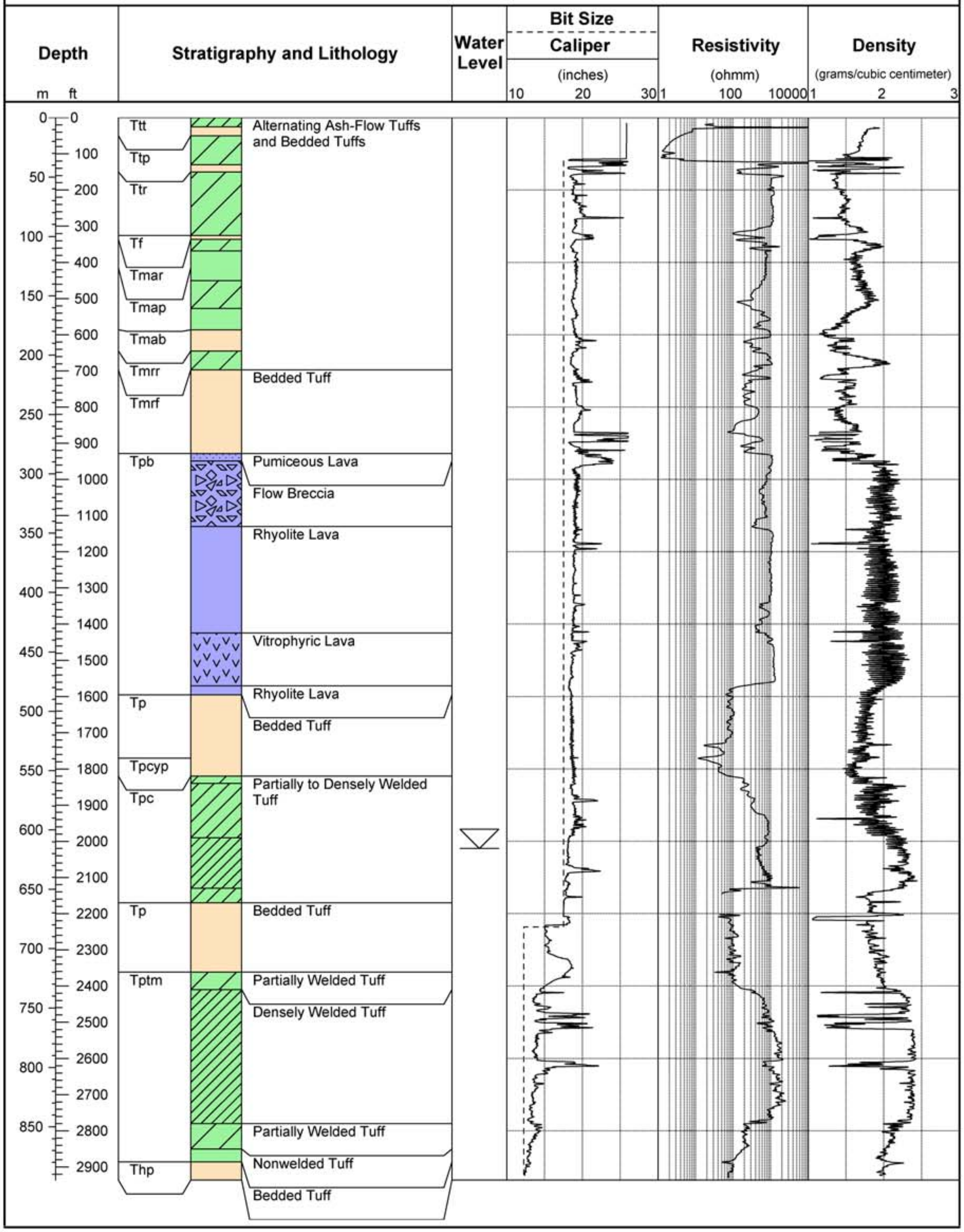
Figure D-1
Legend for Lithology Symbols Used on Log Plots

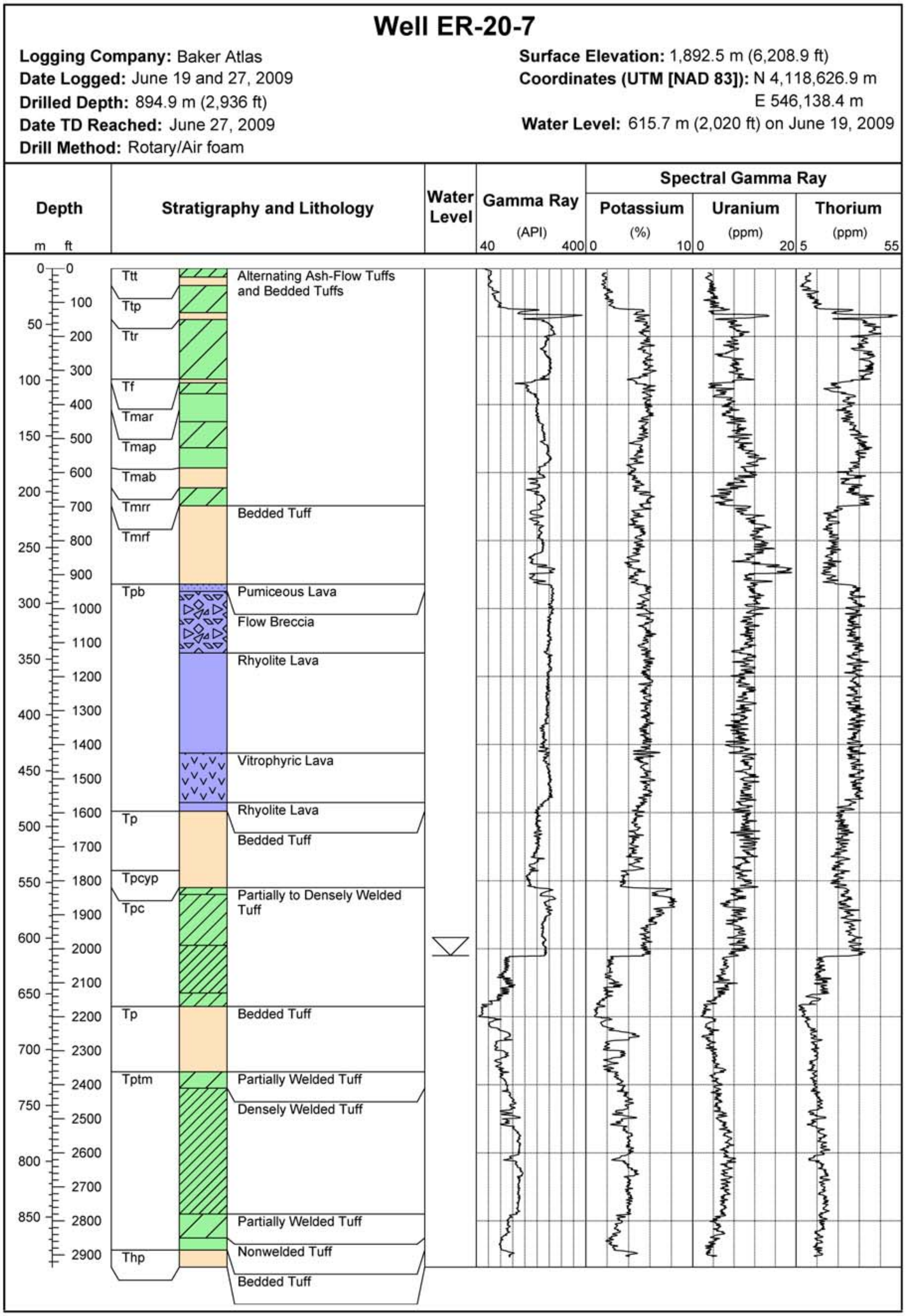


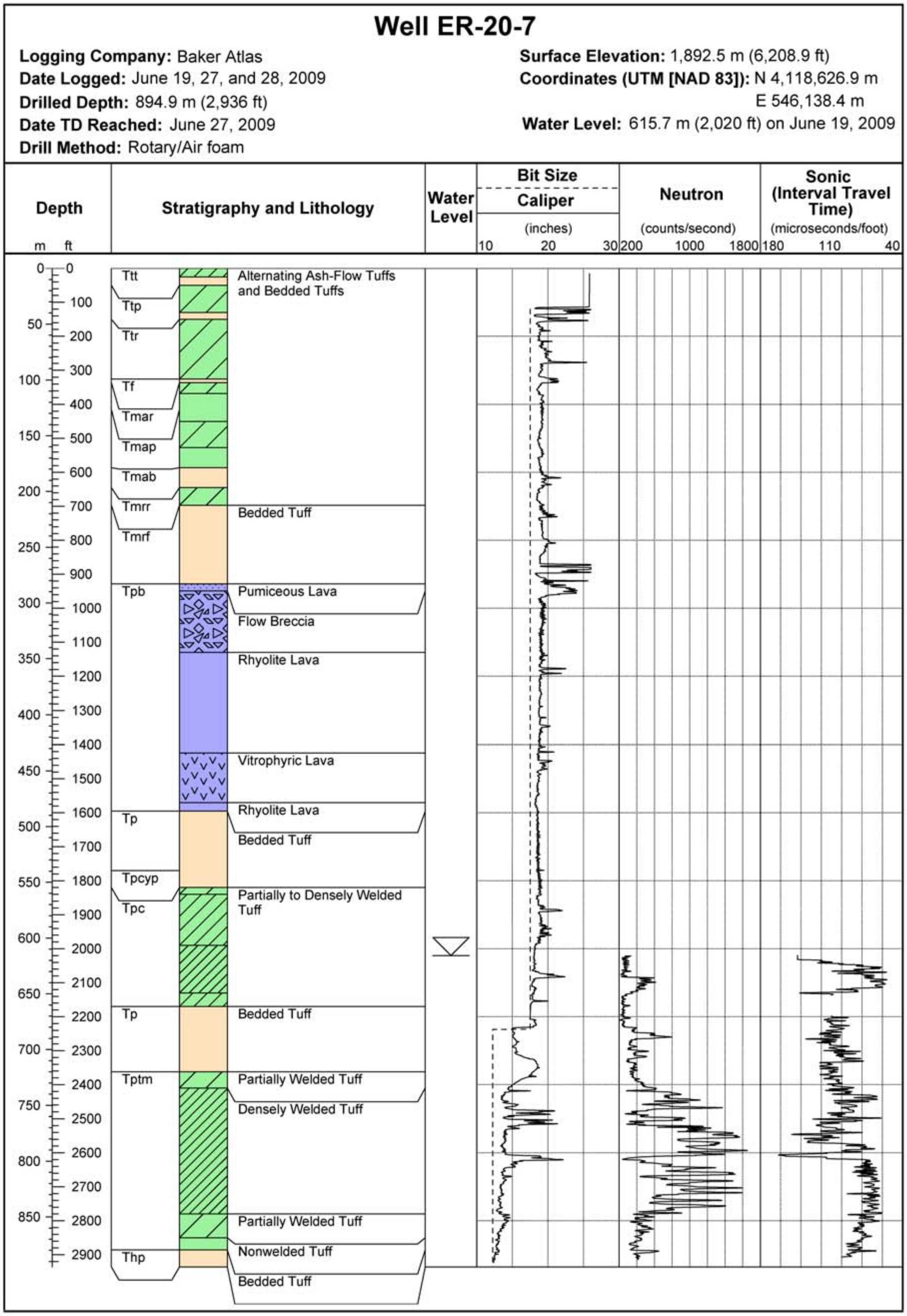
Well ER-20-7

Logging Company: Baker Atlas
Date Logged: June 19, 27, and 28, 2009
Drilled Depth: 894.9 m (2,936 ft)
Date TD Reached: June 27, 2009
Drill Method: Rotary/Air foam

Surface Elevation: 1,892.5 m (6,208.9 ft)
Coordinates (UTM [NAD 83]): N 4,118,626.9 m
E 546,138.4 m
Water Level: 615.7 m (2,020 ft) on June 19, 2009



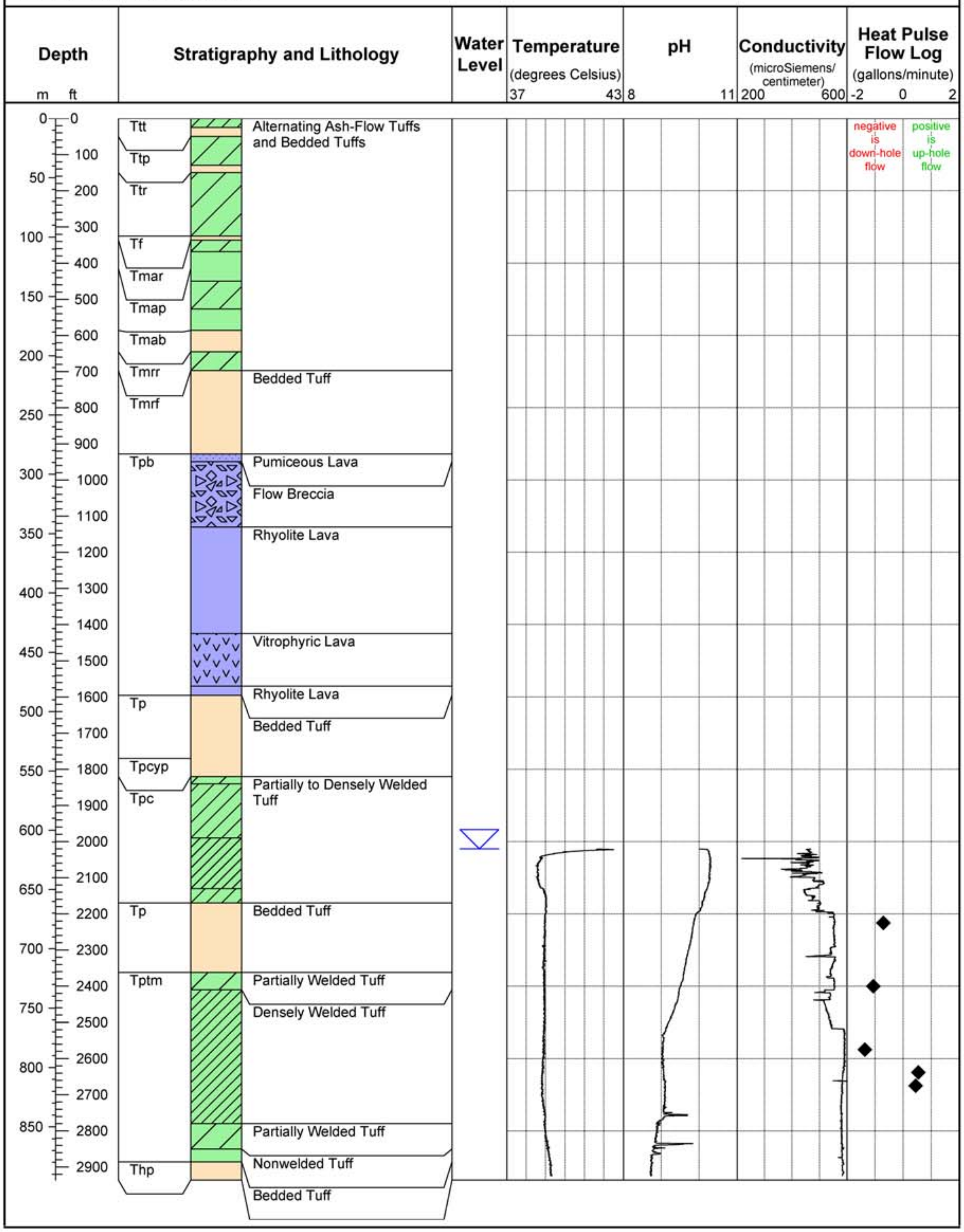

Well ER-20-7
Logging Company: Baker Atlas
Date Logged: June 19 and 27, 2009
Drilled Depth: 894.9 m (2,936 ft)
Date TD Reached: June 27, 2009
Drill Method: Rotary/Air foam
Surface Elevation: 1,892.5 m (6,208.9 ft)
Coordinates (UTM [NAD 83]): N 4,118,626.9 m
E 546,138.4 m
Water Level: 615.7 m (2,020 ft) on June 19, 2009
Depth
m ft
Stratigraphy and Lithology
Water Level
Gamma Ray
(API)
40 400
Spectral Gamma Ray
Potassium
(%)
0 10
Uranium
(ppm)
0 20
Thorium
(ppm)
5 55
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900
Ttt
Ttp
Ttr
Tf
Tmar
Tmap
Tmab
Tmrr
Tmrf
Tpb
Tp
Tpcyp
Tpc
Tp
Tptm
Thp
Alternating Ash-Flow Tuffs and Bedded Tuffs
Bedded Tuff
Pumiceous Lava
Flow Breccia
Rhyolite Lava
Vitrophyric Lava
Rhyolite Lava
Bedded Tuff
Partially to Densely Welded Tuff
Bedded Tuff
Partially Welded Tuff
Densely Welded Tuff
Partially Welded Tuff
Nonwelded Tuff
Bedded Tuff


Well ER-20-7
Logging Company: Baker Atlas
Date Logged: June 19, 27, and 28, 2009
Drilled Depth: 894.9 m (2,936 ft)
Date TD Reached: June 27, 2009
Drill Method: Rotary/Air foam
Surface Elevation: 1,892.5 m (6,208.9 ft)
Coordinates (UTM [NAD 83]): N 4,118,626.9 m
E 546,138.4 m
Water Level: 615.7 m (2,020 ft) on June 19, 2009
Depth
m ft
Stratigraphy and Lithology
Water Level
Bit Size
Caliper
(inches)
10 20 30
Neutron
(counts/second)
200 1000 1800
Sonic (Interval Travel Time)
(microseconds/foot)
180 110 40
Ttt
Ttp
Ttr
Tf
Tmar
Tmap
Tmab
Tmrr
Tmrf
Tpb
Tp
Tpcyp
Tpc
Tp
Tptm
Thp
Alternating Ash-Flow Tuffs and Bedded Tuffs
Bedded Tuff
Pumiceous Lava
Flow Breccia
Rhyolite Lava
Vitrophyric Lava
Rhyolite Lava
Bedded Tuff
Partially to Densely Welded Tuff
Bedded Tuff
Partially Welded Tuff
Densely Welded Tuff
Partially Welded Tuff
Nonwelded Tuff
Bedded Tuff

Well ER-20-7

Logging Company: Desert Research Institute
Date Logged: June 30, 2009
Drilled Depth: 894.9 m (2,936 ft)
Date TD Reached: June 27, 2009
Drill Method: Rotary/Air foam

Surface Elevation: 1,892.5 m (6,208.9 ft)
Coordinates (UTM [NAD 83]): N 4,118,626.9 m
E 546,138.4 m
Water Level: 615.7 m (2,020 ft) on June 19, 2009



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