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NATIONAL LABORATORY

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Date: June 13, 2003
Refer to: RRES-GPP-03-060

Mr. Mat Johansen
National Nuclear Security Administration
Department of Energy, MS A316
Los Alamos Site Operations
Los Alamos, NM 87545

SUBJECT: **CHARACTERIZATION WELL R-5 COMPLETION REPORTS**

Dear Mat:

Enclosed are two copies of the Characterization Well R-5 Completion Report. This report documents work completed under the Hydrological Work Plan.

If you have questions, please call me at (505) 665-4681.

Sincerely,

Charles L. Nylander

Charles Nylander, Program Manager
Groundwater Protection Program

CN/th

Enclosure: Characterization Well R-5 Completion Report (ER2003-0184/GPP-03-028)

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RPF, MS M707 (ER2003-0376)

TA-00

Remediation Program

RRES

LA-UR-03-1600
June 2003
ER2003-0148
GPP-03-028

Characterization Well R-5 Completion Report

Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

Produced by the Groundwater Protection Program, Risk Reduction & Environmental Stewardship Division

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List of Acronyms and Abbreviations

AITH	Array Induction Tool, version H
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMP	best management practice
CMR	Combinable Magnetic Resonance
CNTG	Compensated Neutron Tool, model G
CVAA	cold vapor atomic absorption
DH	down hole
DOE	Department of Energy (US)
DR	dual rotary
DTH	down-the-hole
ECS	Elemental Capture Spectroscopy
EES	Earth and Environment Sciences (Laboratory division)
EPA	Environmental Protection Agency (US)
ER	Environmental Restoration (Project)
ESH	Environment, Safety and Health
FIP	field implementation plan
FMI	Formation Micro-Imager
FMU	facility management unit
FSF	Field Support Facility (now part of Risk Reduction and Environmental Stewardship)
GPIT	General Purpose Inclinometry Tool
GPS	global positioning system
GR	gamma ray
HASL	Health and Safety Laboratory (US Department of Energy)

HNGS	Hostile Natural Gamma Spectroscopy
hp	horsepower
HSA	hollow-stem auger
IC	ion chromatography
ICPES	inductively coupled plasma emission spectroscopy
ICPMS	inductively coupled plasma mass spectrometry
ID	inner diameter
ISE	ion selective electrode
LANL	Los Alamos National Laboratory
MCFL	Micro Cylindrically Focused Log
MS	mass spectroscopy
msl	mean sea level
NGS	Natural Gamma Spectroscopy
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
OD	outer diameter
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RC	reverse circulation
RRES	Risk Reduction and Environmental Stewardship (Laboratory division)
SGWCC	S. G. Western Construction Company
SSHASP	site-specific health and safety plan
TD	total depth
TLD	Triple detector Litho-Density
UR-DTH	under-reaming down-the-hole (hammer)
WCSF	waste characterization strategy form
WGII	Washington Group International, Inc.
XRD	x-ray diffraction
XRF	x-ray fluorescence

Metric to US Customary Unit Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

CHARACTERIZATION WELL R-5 COMPLETION REPORT

ABSTRACT

Characterization well R-5 was installed by the Los Alamos National Laboratory (LANL or the Laboratory) under implementation of its hydrogeologic work plan, is located on the southern side of lower Pueblo Canyon, about 3000 ft west-northwest of water supply well Otowi-1 and about 4700 ft southeast of the Bayo Canyon Sewage Treatment Plant. The primary purpose of this well is provide water-quality, geochemical, hydrologic, and geologic information that would contribute to understanding the hydrogeologic setting beneath the Laboratory. In addition, the well was designed to help determine whether Laboratory releases and sewage plant effluents may be present in the regional aquifer beneath lower Pueblo Canyon and, if so, the extent to which contaminants may have affected groundwater quality.

In addition, hydrologic, geologic, geochemical, and geophysical information obtained during completion and subsequent sampling of well R-5 will provide data to evaluate the hydrologic setting in this part of Pueblo Canyon and contribute to implementing a Laboratory-wide groundwater monitoring network. Data from R-5 and similar wells support the Laboratory's Groundwater Protection Management Program Plan.

Borehole R-5 was drilled to a total depth of 902 ft using air-rotary drilling methods. No core drilling was conducted. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis. Geologic strata encountered during drilling operations included, in descending order, alluvial sediments, the Guaje Pumice Bed, upper Puye Formation sediments, the Cerros del Rio basalt, the lower section of the Puye Formation, and the intercalcated Santa Fe Group basalts and sediments.

Three possible perched zones were encountered during drilling and geophysical logging. Two possible perched zones above the zone of regional saturation were selected for screen placement. The regional zone of groundwater saturation was encountered at a depth of 685 ft bgs in Santa Fe Group sediments. Water samples for contaminant analysis were collected from the regional aquifer as well as from the upper zones of saturation. Based on the analytical results for five samples taken, it appears that contamination from Laboratory discharges is not present in the regional aquifer at this well site.

Well installation, including four screened intervals, was completed on May 31, 2001. The completed well was equipped with a Westbay™ multiport sampling system

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, and site completion activities conducted from April 24, to June 21, 2001, at characterization well R-5. The well was installed by the Los Alamos National Laboratory (LANL or the Laboratory) under implementation of its "Hydrogeologic Workplan" (LANL 1998, 59599), is located at the southern end of lower Pueblo Canyon, approximately 3000 ft west-northwest of water supply well Otowi-1 and about 4700 ft southeast of the Bayo Sewage Treatment Plant (Figure 1.0-1). Well R-5 supports the Laboratory's "Groundwater Protection Management Program Plan" (LANL 1996, 70215.1) and was drilled in accordance with the "Task/Site Work Plan for Operable Unit 1049 Los Alamos Canyon and Pueblo Canyon, November 1995" (LANL 1995, 50290.1).

Well R-5 was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program and installed by the Laboratory's former Environmental Restoration (ER) Project, now part of Risk Reduction and Environmental Stewardship (RRES) Division. Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for executing the drilling activities.

This well completion report focuses on operational activities associated with the drilling, sampling, and completion of well R-5. The information presented here was compiled from field reports and activity summaries generated by the Laboratory and the drilling subcontractor. Geophysical data and geodetic survey information are also included. Data from R-5 and similar wells support the Laboratory's Groundwater Protection Management Program Plan.

The primary purpose of this well is to provide water-quality, geochemical, hydrologic, and geologic information that would contribute to understanding the hydrogeologic setting beneath the Laboratory. In addition, the well was designed to help determine whether Laboratory releases and sewage plant effluents may be present in the regional aquifer beneath lower Pueblo Canyon and, if so, the extent to which contaminants may have affected groundwater quality. This well will function primarily to investigate the nature and extent of potential impacts to regional groundwater resulting from Laboratory activities in the Pueblo Canyon watershed. Water-quality, geochemical, hydrologic, and geologic information gathered during drilling and well completion will augment knowledge of regional subsurface characteristics and distribution of any contaminants downgradient of Laboratory releases and sewage plant effluent. These data will be used to update sitewide hydrologic and geologic conceptual models for the Laboratory.

This well completion report focuses on operational activities associated with the drilling, sampling, and completion of well R-5. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data, included as part of previous well completion reports, will be discussed in technical documents to be prepared by the Laboratory.

2.0 PRELIMINARY ACTIVITIES

WGII received contractual authorization to start administrative preparation tasks on January 18, 2001. As part of these tasks, WGII modified existing site-specific health and safety plan (SSHASP) No. 273 to include well R-5 and prepared the R-5 waste characterization strategy form (WCSF). The Laboratory prepared the field implementation plan (FIP), entitled "The Drilling and Testing of LANL Regional Aquifer Characterization Well R-5" (LANL 2001, 71453.1). The FIP specified drilling and sampling plans to guide site personnel in executing R-5 field activities. The host facility, Facility Management Unit (FMU) 80, signed a Facility Tenant Agreement to provide for site access and security control, health and safety, and regulatory and other requirements for drilling and completion activities.

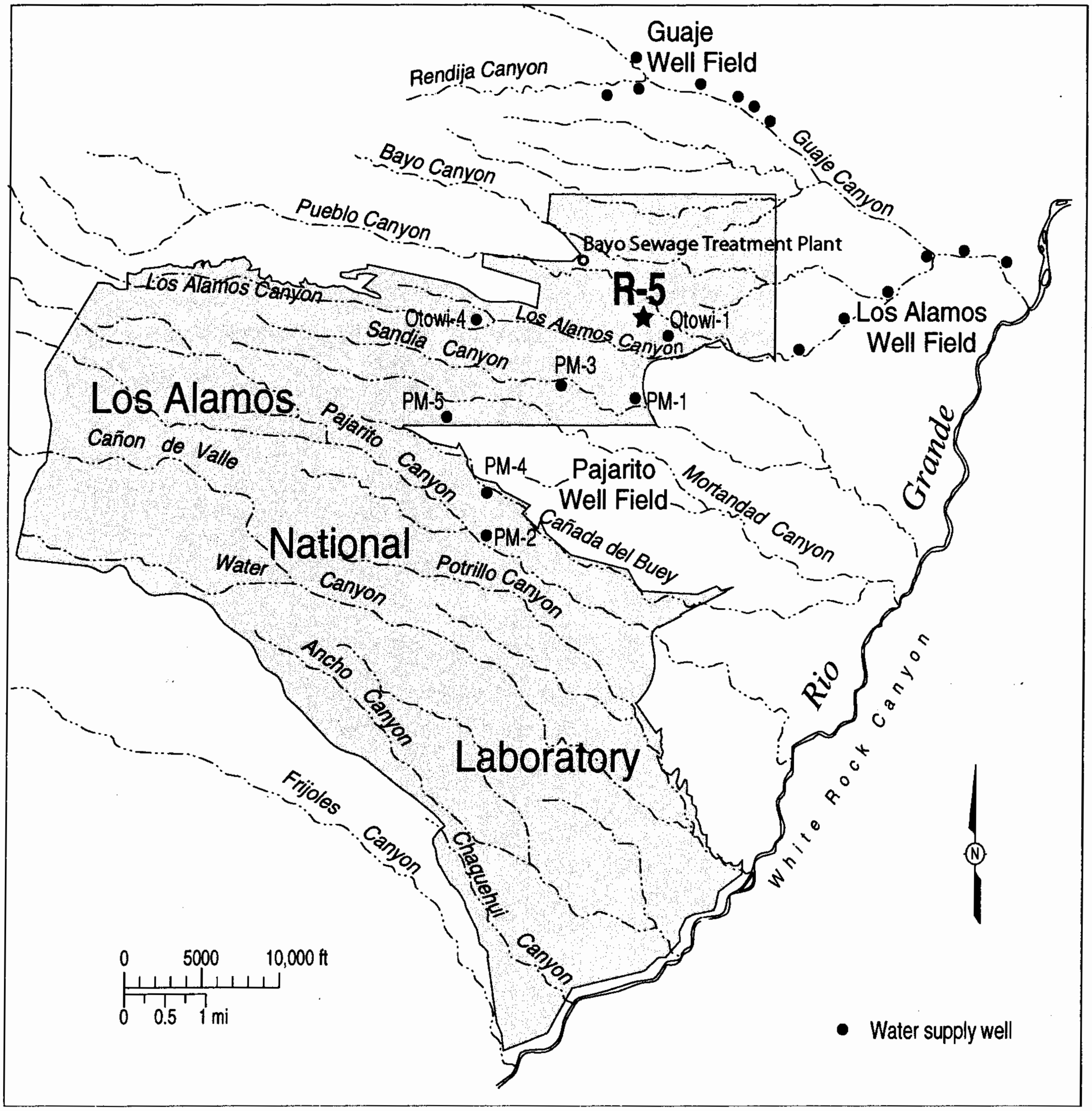


Figure 1.0-1. Location map, characterization well R-5

A readiness review meeting was held on February 2, 2001, to discuss administrative documents, permits, agreements, and plans pertaining to the R-5 project. The Groundwater Investigations Focus Area project leader signed the Phase I readiness review checklist on February 5, 2001, giving authorization to begin fieldwork. The readiness review checklist for Phase II (drilling) was signed on May 5, 2001.

S. G. Western Construction Company (SGWCC) was subcontracted by WGII to perform pre-drilling site preparation. Activities included site clearing, access road construction, drill pad leveling and construction, and excavation for a lined cuttings-containment area. Site preparation, including Phase I drilling, was completed from April 17 through May 1, 2001.

The site initially was cleared of small trees and stumps. An access road was constructed to facilitate mobilization to the well location from the Pueblo Canyon road. The drill pad was constructed by leveling the area with a grader and was completed by grading and compacting several layers (2 to 4 in. each) of base-course gravel. A containment area 6-ft-deep by 20-ft-wide by 60-ft-long was excavated at the south end of the pad to store drilling fluids and cuttings. The containment area was surrounded by a 3-ft-high berm, and the entire excavation was lined with 6-mil polyethylene sheeting. An 80-ft by 25-ft secondary fluids-containment area was constructed to accommodate twelve 3000-gal. polyethylene tanks that would hold drilling fluids pumped from the cuttings-containment area. A berm was constructed around this containment area perimeter and then lined with 6-mil polyethylene sheeting. Safety barriers and signs were installed around the cuttings-containment area and at the site entrance. On April 26, 2001, SGWCC began installation of a jack cellar to assist the dual rotary (DR)-24 rig during drill-casing retraction. The installation was completed on April 27, 2001. Office and supply trailers, safety lighting equipment, and a generator were also set up on the site.

3.0 SUMMARY OF DRILLING ACTIVITIES

Drilling activities were conducted in two phases during April and May 2001. Phase I drilling performed by Stewart Brothers Drilling, Inc., involved installing 18-in.-diameter surface casing. Phase II drilling, performed by Dynatec Drilling Company, Inc. (Dynatec), involved installing a jack cellar and drilling a borehole to a total depth (TD) of 902 ft below ground surface (bgs).

Sections 3.1 and 3.2 below discuss Phase I and II drilling activities, respectively. Figure 3.0-1 summarizes well data and depicts groundwater and geologic conditions encountered in well R-5. Figure 3.0-2 summarizes the chronology of drilling and other related on-site activities.

3.1 Phase I Drilling

Phase I drilling was conducted by Stewart Brothers Drilling on April 24 and 25, 2001. A Central Mining Equipment 750 drill rig, owned and operated by Stewart Brothers Drilling and equipped with 20-in. outside diameter (OD) hollow-stem augers (HSA), was used to install 18-in.-diameter surface casing to ensure stability in the upper portion of the borehole. The hole was advanced 36 ft into the upper portion of the Puye fanglomerate. During borehole advancement, auger cuttings were sampled at 5-ft intervals for logging purposes.

Upon removal of the augers, the open-hole depth was measured at 22 ft bgs, indicating 14 ft of slough at the bottom. The surface casing was installed down to 22 ft within the Guaje Pumice Bed. The 18-in.-diameter steel casing was lowered into the borehole and landed at 23 ft bgs. A cement/bentonite grout mixture was pumped into the annulus to form a seal between the borehole and the casing wall from 23 ft to the surface.

3.2 Phase II Drilling

Construction of a jack cellar was completed on April 30,2001, prior to commencement of Phase II drilling. The jack cellar was constructed by excavating an 8-ft by 10-ft by 5-ft-deep pit around the surface casing, placing a 6-ft by 8-ft by 1-ft-thick steel reinforced concrete pad in the bottom of the excavation, placing a temporary steel box (6-ft by 6-ft by 4-ft) on the concrete, and backfilling around the outside of the box. In the event that hydraulic casing jacks would have been needed, the reinforced concrete floor would have provided a solid surface to support the pullback weight of the casing. Upon well completion, the concrete floor was buried in place.

Location: TA-74, Pueblo Canyon

Survey coordinates (brass marker in NW corner of cement pad):
x = 1646707 E y = 1773063 N (NAD 83)
z = 6472.6 ft asl (NGVD 29)

Drilling: hollow stem auger and fluid-assist air rotary reverse circulation with casing advance
- Phase 1 Start date: 4/24/01
- Phase 1 End date: 4/25/01
- Phase 2 Start date: 5/5/01
- Phase 2 End date: 5/20/01

Borehole R-5 drilled to 902 ft. bgs. (T.D.)

Data collection:
- Hydrologic properties: N/A
- Cores/cuttings submitted for geochemical and contaminant characterization: (0)
- Groundwater samples submitted for geochem. and cont. characterization: (4)
- Geologic properties:
  - Mineralogy, petrography, and chemistry (38)
- Borehole logs:
  - Lithologic: 0-902 ft.
  - Video (LANL tool): 570-685 ft
  - Natural gamma (LANL tool): 0-851 ft. (cased), 851-902 ft. (open hole)
  - Schlumberger Logs: 0-851 ft.(cased), 851-898 ft. (open hole): Compensated Thermal and Epithermal Neutron, Spectral Gamma, and Litho-Density

Contaminants Detected in Borehole Samples:
- Regional groundwater: nitrate

Well construction:
- Drilling Completed: 5/20/01
- Contract Geophysics: 5/21/01
- Well Constructed: 5/22/01-5/31/01
- Well Developed: 6/2/01 - 6/21/01
- Westbay Installed: 7/13/01 - 7/19/01

Casing: 4.5-in I.D. stainless steel with external couplings

Number of Screens: 4
- 4.5-in I.D. pipe based, s.s. wire-wrapped; 0.010-in slot

Screen (perforated pipe interval):
- Screen #1 - 326.4 - 331.5 ft
- Screen #2 - 372.8 - 388.8 ft
- Screen #3 - 676.9 - 720.3 ft
- Screen #4 - 858.7 - 863.7 ft

Well development consisted of brushing, bailing, and pumping.

Groundwater occurrence was determined by recognition of first water produced while drilling. Static water levels were determined after the borehole was rested.

Geologic contacts determined by examination of cuttings, petrography, rock chemistry and interpretation of natural gamma logs.

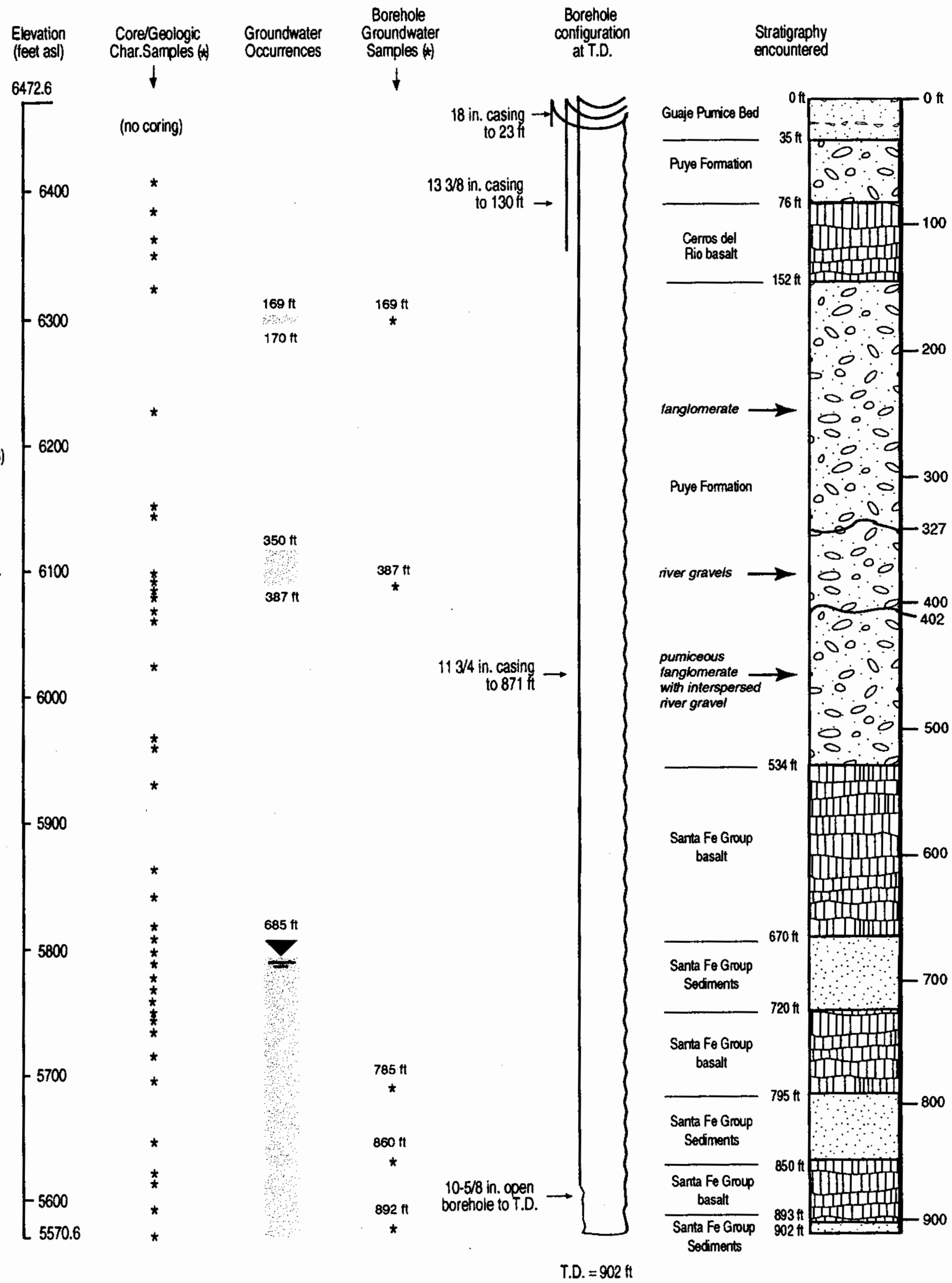


Figure 3.0-1. Well summary data sheet, characterization well R-5

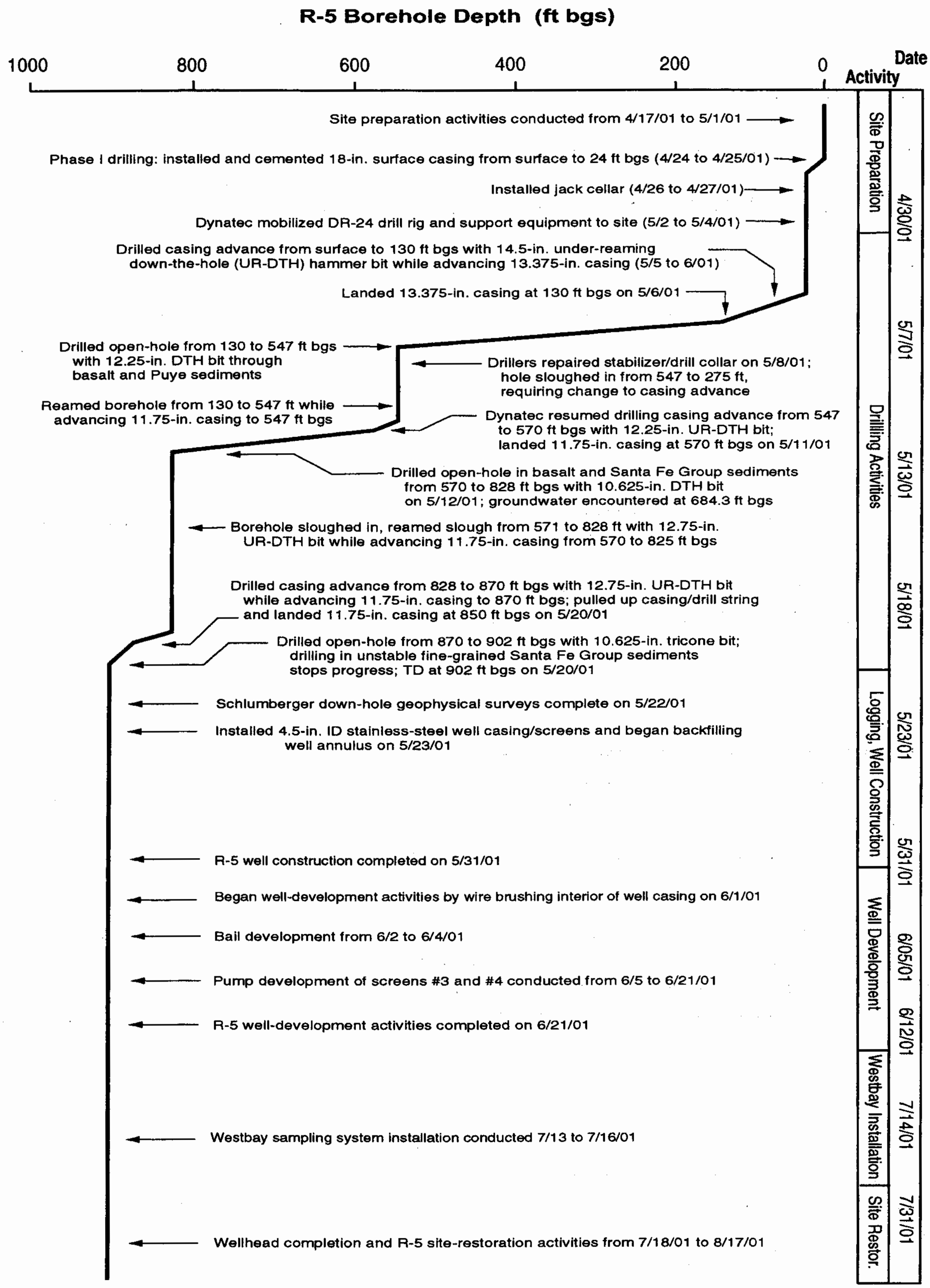


Figure 3.0-2. Operations chronology diagram, characterization well R-5

Phase II drilling was completed between May 2 and May 20, 2001 (Figure 3.0-2), using fluid-assisted reverse-circulation air-rotary drilling methods. Dynatec Drilling Company mobilized a Foremost™ DR-24 drill rig and essential support equipment to the site for Phase II drilling.

Drilling objectives for Phase II were to collect drill cuttings for geologic characterization, collect groundwater samples for contaminant analysis, and provide a deep borehole for geophysical logging and installing of a well in the regional aquifer. Drilling was performed using open-hole and casing-advance methods, as dictated by changing geologic and drilling conditions. Air-rotary drilling was assisted at times with municipal water mixed with polymer additives, such as EZ-MUD™ and QUIK-FOAM™, to improve drilling lubrication and to facilitate cuttings removal from the borehole.

Casing-advance drilling commenced on May 5, 2001, through the Guaje Pumice Bed, the Puye Formation, and into the Cerros del Rio basalt, from approximately 23 to 130 ft bgs using 13.375-in. drill casing with a 14.5-in. under-reaming down-the-hole (UR-DTH) hammer bit. The drill casing was landed in basalt at 130 ft bgs. Open-hole drilling with a 12.25-in. down-the-whole (DTH) bit continued from 130 to 547 ft bgs through Puye fanglomerates and river gravels into Santa Fe Group basalts. Formation instability prompted Dynatec to switch back to casing-advance drilling at 547 ft bgs.

On May 9, 2001, Dynatec tripped in 11.75-in. drill casing to 150 ft bgs, where it encountered slough. The borehole was reamed back down to 547 ft bgs, then drilled to 570 ft bgs with a 12.25-in. DTH bit, where the 11.75-in. casing was landed on May 11, 2001. Dynatec then switched to open-hole drilling using a 10.625-in. DTH bit and advanced the borehole from 570 to 828 ft bgs through basalts and sediments of the Santa Fe Group. Drilling was suspended briefly at a depth of 785 ft bgs to monitor for groundwater.

Unstable borehole conditions were encountered within the Santa Fe deposits, resulting in sloughing of the borehole. Measurements indicated that the borehole depth was 570 ft bgs. Casing-advance drilling resumed on May 15, 2001, by reaming while advancing 11.75-in. drill casing with a 12.25-in. UR-DTH bit from approximately 570 ft. The borehole was re-opened to the previous depth of 828 ft bgs on May 19, 2001. Casing-advance continued to 870 ft bgs. In preparation for a possible call to stop drilling, the 11.75-in. casing was then retracted and landed at 850 ft bgs on May 20, 2001. To provide a viable depth for well sump length relative to desired screen placement, open-hole drilling continued from 870 ft bgs with a 10.625-in. tricone bit. Wet sand and gravel conditions were encountered at 902 ft bgs, and TD of the borehole was called on May 20, 2001.

4.0 SAMPLING AND ANALYSIS OF DRILL CUTTINGS AND GROUNDWATER

During drilling operations at R-5, drill cuttings were collected according to the R-5 FIP. Borehole material was collected as drilling conditions permitted. A portion of the cuttings was sieved (at >#10 and >#35 mesh) and placed in chip-tray bins along with an unsieved portion. These chip trays were studied to determine lithological characteristics and were used to prepare the lithologic logs. The remaining cuttings were sealed in ziplock bags and set in core boxes for curation. No cuttings samples were submitted for contaminant analysis. Prior to curation of the chip trays and cuttings, 38 samples were removed for mineralogic, petrographic, and geochemical analyses. Samples of core were not collected from R-5 and, therefore, not analyzed for contaminants.

During drilling operations, groundwater was encountered in two perched zones and the regional aquifer. Perched groundwater was encountered at approximately 169 ft bgs and between 350 and 387 ft bgs; regional groundwater was first encountered at 685 ft bgs. Groundwater samples were collected from each perched zone (169 and 387 ft bgs) and at three depths in the regional aquifer (785, 860, and 892 ft bgs) and submitted for analysis.

Geochemistry of Sampled Waters

Groundwater samples were collected from the undeveloped borehole during drilling and were analyzed for a limited suite of constituents to investigate the presence of constituents from Laboratory releases and sewage plant discharges (see Appendix A). Major potential contaminants of concern at R-5 include mobile constituents such as perchlorate, nitrate, and tritium. These samples contain residual drilling fluids (EZ-MUD® and other additives) used in the drilling process.

Groundwater samples analyzed for inorganic and radionuclide constituents were collected by air lifting groundwater through the drill stem. Filtered and nonfiltered water samples were collected to analyze metals, trace elements, major cations, and major anion analysis. Nonfiltered water was collected for tritium and radiochemical analyses. Filtered samples were passed through a 0.45-µm Gelman cartridge filter. Samples were acidified as needed with analytical-grade nitric acid to a pH of 2.0 or less for metal and major cation analyses. All groundwater samples collected in the field were stored at 4°C until they were analyzed.

Groundwater samples were analyzed by laboratories under contract to the Laboratory using the ER Project statement of work for analytical laboratories (LANL 2000, 71233.1) and at the laboratory of the Earth and Environmental Sciences Division's Hydrology, Geochemistry, and Geology Group (EES-6; within the Laboratory), using techniques specified in the US Environmental Protection Agency (EPA) SW-846 manual. Ion chromatography (IC) was the analytical method for bromide, chloride, fluoride, nitrate + nitrite, oxalate, perchlorate, phosphate, and sulfate. Ammonium was analyzed by ion selective electrode (ISE), whereas mercury was analyzed by cold vapor atomic absorption (CVAA). Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used for aluminum, arsenic, barium, chromium, cobalt, copper, iron, manganese, nickel, selenium, silver, calcium, magnesium, potassium, silica, sodium, and zinc. Antimony, beryllium, cadmium, lead, thallium, vanadium, and uranium, were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS). Tritium activity in a groundwater sample was determined by electrolytic enrichment at the University of Miami. Americium-241 was analyzed according to Health and Safety Laboratory-300, cesium-137 by generic gamma spectroscopy, plutonium-238 and plutonium-239 by isotopic plutonium (HASL-300), strontium-90 by beta counting, and uranium-234, uranium-235, and uranium–238 by isotopic uranium (HASL-300). The precision limits (analytical error) for major ions and trace elements were generally less than ±10% using ICPES and ICPMS.

Results of screening analyses for groundwater samples collected from the Puye Formation and Santa Fe Group in R-5 are provided in Table 4.1-1. Based on the analytical results for the five samples, it appears that contamination from Laboratory discharges is not present in the regional aquifer at this well site.

Table 4.1-1
Hydrochemistry of Regional Aquifer Samples, Characterization Well R-5

Analysis	Sample from Puye Formation, 169-ft Depth, May 6, 2001, Filtered	Sample from Puye Formation, 387-ft Depth, May 7, 2001, Filtered	Sample from Santa Fe Group Basalt, 785-ft Depth, May 12, 2003, Nonfiltered with Nitric Acid Digestion	Sample from Santa Fe Group Basalt, 860-ft Depth, May 19, 2003, Filtered	Sample from Santa Fe Group Sediments, 892-ft Depth, May 19, 2003, Filtered
Inorganic Constituents					
pH (field)	—[a]	—	—	—	7.54
Alkalinity (laboratory; mg $CaCO_3$/L)	—	—	—	—	—
Al (mg/L)	—	0.062, J[b]	194	—	—
NH_4 (as N) (mg/L)	0.42	0.90	0.69	—	—
Sb (mg/L)	—	0.0002, J	0.0003, J	—	—
As (mg/L)	—	0.002, J	0.0095	—	—
B (mg/L)	—	0.034, J	0.046	—	—
Ba (mg/L)	—	0.170	1.840	—	—
Be (mg/L)	—	[0.000012], U[c]	0.003	—	—
Br (mg/L)	0.04	[0.02], U	[0.02], U	0.04	0.03
Cd (mg/L)	—	[0.00037], U	0.0012	—	—
Ca (mg/L)	—	28	143	—	—
Cl (mg/L)	5.0	3.3	12.3	5.80	6.17
ClO_4 (mg/L)	0.002	[0.000958], U	[1.6], U	[0.002], U	[0.002], U
Cr (mg/L)	—	0.0018, J	0.151	—	—
Co (mg/L)	—	0.00042, J	0.158	—	—
Cu (mg/L)	—	0.022	0.213	—	—
F (mg/L)	0.71	0.51	0.344	0.21	0.21
Fe (mg/L)	—	0.14, U	268	—	—
Pb (mg/L)	[0.001], U	0.00045, J	0.031	[0.001], U	[0.001], U
Mg (mg/L)	—	3.3	173	—	—
Mn (mg/L)	—	0.012	4.23	—	—
Mo (mg/L)	—	0.0052, J	0.0297, J	—	—
Hg (mg/L)	—	[0.000033], U	[0.0001], U	—	—
Ni (mg/L)	—	0.0055, J	0.577	—	—
NO_3-NO_2 (mg/L) (as N)	0.52	0.48	[0.05], U	0.51	0.48
C_2O_4 (mg/L) (oxalate)	0.64	[0.19], U	0.543, J	[0.02], U	0.72
P (mg/L)	[0.06], U	0.066	—	[0.06], U	[0.06], U
K (mg/L)	—	4.2	16.6	—	—
Se (mg/L)	—	[0.0019], U	0.0045, J	—	—
Ag (mg/L)	—	[0.00057], U	0.0013, UJ	—	—
Na (mg/L)	16.7	13	29.1	—	—
SiO_2 (mg/L)	39.2	64.2	77.9	—	—

Table 4.1-1 (continued)

Analysis	Sample from Puye Formation, 169-ft Depth, May 6, 2001, Filtered	Sample from Puye Formation, 387-ft Depth, May 7, 2001, Filtered	Sample from Santa Fe Group Basalt, 785-ft Depth, May 12, 2003, Nonfiltered with Nitric Acid Digestion	Sample from Santa Fe Group Basalt, 860-ft Depth, May 19, 2003, Filtered	Sample from Santa Fe Group Sediments, 902-ft Depth, May 19, 2003, Filtered
SO_4 (mg/L)	6.17	3.2	11.4	5.18	5.62
Tl (mg/L)	—	[0.00008], U	0.108, J	—	—
U (mg/L)	0.0012	0.004	0.0016	0.0031	0.0023
V (mg/L)	—	0.006, J	0.154	—	—
Zn (mg/L)	—	0.009	0.363	—	—
δD (permil)	—	-76	-66	—	—
D15N (permil)	—	—	—	—	—
D18O (permil)	—	-10.7	-9.9	—	—
Radiological Constituents					
Am^{241} (pCi/L) (nonfiltered)	—	[-0.017], U	[0.0], U	—	—
Cs^{137} (pCi/L) (nonfiltered)	—	[-2.4], U	[0.788], U	—	—
Gross alpha (pCi/L) (nonfiltered)	—	4.1	32	—	—
Gross beta (pCi/L) (nonfiltered)	—	11	57.2	—	—
Gross gamma (pCi/L) (nonfiltered)	—	150	—	—	—
Pu^{238} (pCi/L) (nonfiltered)	—	[0.022], U	[0.009], U	—	—
Pu^{239} (pCi/L) (nonfiltered)	—	[-0.005], U	[-0.0015], U	—	—
Sr^{90} (pCi/L) (nonfiltered)	—	[0.3], U	[0.519], U	—	—
Tritium (pCi/L) (nonfiltered)	—	4.29	—	—	—
U^{234} (pCi/L) (nonfiltered)	—	0.44	19.3	—	—
U^{235} (pCi/L) (nonfiltered)	—	[0.018], U	0.699, J	—	—
U^{238} (pCi/L) (nonfiltered)	—	0.281	16.1	—	—

[a] Dash = not analyzed.

[b] J = the analyte is classified as "detected" but the reported concentration value is expected to be more uncertain then usual.

[c] U = not detected.

5.0 BOREHOLE GEOPHYSICS

The Laboratory and Schlumberger geophysical logging services (Schlumberger) performed borehole logging operations at well R-5. Table 5.0-1 summarizes these surveys.

Table 5.0-1
Borehole and Well Logging Surveys, Characterization Well R-5

Surveyor	Date	Method	Cased Footage	Open-hole Interval (ft bgs)	Remarks
LANL/WGII	May 14, 2001	Video	0–570	570–685	Conducted to evaluate borehole conditions and lithologies.
LANL/WGII	May 20, 2001	Natural gamma	0–850	850–898	Conducted to evaluate borehole conditions and gather data after drilling to 902 ft bgs, prior to well installation.
Schlumberger	May 21, 2001	Logging suite [a]	0–850	850–898	Conducted borehole logging at TD prior to well design and installation.
LANL/WGII	May 23, 2001	Video, caliper	0–884	NA[b]	Conducted in the well casing to assess well construction quality prior to annular backfilling activities.
LANL/WGII	June 1, 2001	Video, natural gamma	0–884	NA	Conducted in the well casing after well construction was completed.

[a] Schlumberger's suite of borehole logging surveys includes lithodensity, spectral gamma, compensated neutron, and natural gamma tool.

[b] NA = Not applicable.

5.1 Geophysical Logging Using Laboratory Tools

Between May 20 and June 1, 2001, natural gamma and video logs were performed in the borehole using Laboratory-provided down-hole tools. The first natural gamma log was collected to obtain lithologic and stratigraphic information that complemented data gathered from cuttings. The first video log was used to assess borehole conditions in the interval from 850 to 898 ft depth. WGII personnel trained to use the down-hole tools performed the logging.

Natural gamma logs have proven successful in discriminating between geologic units that contain varying concentrations of uranium, thorium, and potassium. One natural gamma log was run on May 20, 2001, shortly after drilling to a depth of 902 ft bgs and prior to well installation. Three casing strings lined most of the borehole at that time. The casing in place consisted of an 18-in.-diameter surface casing from ground surface to 24 ft bgs, 13.375-in. drill casing to a depth of 130 ft bgs, and 11.75-in. drill casing to a depth of 850 ft bgs. Open-hole conditions extended from 850 to 898 ft bgs. Slough filled the bottom 4 ft of the borehole. Measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised upward in the hole at a rate of approximately 15 ft/min.

Video logs were run in the borehole to observe sidewall features and assess the stability of the borehole prior to deploying the natural gamma tool, and to evaluate the open portion of the borehole prior to well installation. The video log of open borehole (Appendix B) appears on a CD attached to the inside back cover of this report. Natural gamma, video, and caliper logging surveys were also performed after R-5 construction activities were completed and run inside the well casing for quality control (QC) purposes to verify proper well construction. Video logs run during well development functioned as a QC procedure to inspect the condition of casing and screens.

5.2 Schlumberger Geophysical Logging

Schlumberger conducted borehole geophysical logging in the borehole on May 21, 2001. A suite of logging surveys was performed after achieving the TD of the borehole and prior to well construction. At that time, an 18-in. surface casing extended from ground surface to 24 ft bgs, 13.375-in. drill casing extended from ground surface to 130 ft bgs, and 11.75-in. drill casing was installed inside the outer drill casing from ground surface to 850 ft bgs. The interval between 850 and 898 ft bgs constituted the open portion of the borehole.

The primary purpose of the geophysical logging was to characterize the conditions in the geologic units penetrated by the borehole, with an emphasis on determining moisture distribution, identifying perched groundwater and regional water table zones, and obtaining lithologic and stratigraphic data.

The Schlumberger suite of geophysical logging tools included the following tools:

- Triple detector Litho-Density (TLD™) measures total porosity and bulk density of a formation, photoelectric effects, and borehole diameter and characterizes lithology.
- Natural Gamma Spectroscopy (NGS™) measures overall and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, thus evaluating geology and lithology; and
- Compensated Neutron Tool, model G (CNTG™) measures volumetric water content beyond the casing to evaluate formation moisture content and porosity.

Additionally, a calibrated natural gamma tool was used, and gross natural gamma-ray activity was recorded with every logging method (except NGS™) to correlate depth runs between the surveys conducted. The Schlumberger logging summary report, and the geophysical logs compiled as a montage, can be found in Appendix C on a CD attached to the inside back cover of this report.

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered during borehole drilling is presented below. Included is a brief description of the geologic units identified from characterization of cuttings. Groundwater occurrences are discussed based on drilling evidence and geophysical logging data.

6.1 Stratigraphy and Lithologic Logging

A generalized stratigraphic column is shown in the well summary sheet (Figure 3.0-1). Rock units and stratigraphic relationships were determined primarily through visual examination of drill cuttings and analysis of borehole geophysical data logging and should be considered preliminary. These interpretations may be refined upon future detailed analysis of petrographic, geochemical, mineralogical, and geophysical logging data. Appendix D contains a lithology log.

Alluvium and Soil (0 to 20 ft bgs)

Unconsolidated detrital sediments, derived from the Bandelier Tuff, were encountered from the surface to a depth of 20 ft. These pumice-rich sediments represent Quaternary alluvium in the inactive stream channel of Pueblo Canyon. A 1-ft-thick layer of poorly developed soil occurs at the surface. The interval is otherwise made up of abundant vitric pumice fragments, quartz and sanidine crystals, and minor dacite lithics.

Guaje Pumice Bed of the Bandelier Tuff (20 to 35 ft bgs)

The Guaje Pumice Bed of the Otowi member of the Bandelier Tuff is the first bedrock unit penetrated in the interval from 20 to 35 ft bgs. This pumiceous fall deposit forms the basal unit of the Otowi Member of the Quaternary-age Bandelier Tuff. Drill cuttings indicate that the Guaje Pumice Bed is made up almost entirely of nonwelded, vitric rhyolite pumice lapilli that essentially are unaltered. Trace amounts of dacitic lithic fragments also are present.

Upper Puye Formation (35 to 76 ft bgs)

The Pliocene Puye Formation occurs in the interval from 35 to 76 ft bgs. The upper subunit of the Puye Formation is made up of volcaniclastic sand and gravel deposits. The cuttings from this unit are predominantly composed of hornblende- and pyroxene-bearing dacitic clasts that are enclosed in a matrix of silty sand containing grains of volcanic lithics, quartz and sanidine crystals, and local minor occurrences of pumice.

Cerros del Rio Basalt (76 to 152 ft bgs)

The Pliocene Cerros del Rio basalt occurs at 76 to 152 ft bgs. The basalt is sparsely porphyritic with fine-grained olivine phenocrysts in an aphanitic groundmass, with a wide range of vesicularity. Overall, the basalt throughout this interval displays slight alteration represented by local iron-oxide staining and the presence of clay on fracture surfaces and as amygdaloidal fill. A thin layer of glassy basaltic scoria occurs at the base of the basalt.

Lower Puye Formation (152 to 534 ft bgs)

A 382-ft-thick sequence of clastic sediments that form a stratigraphically lower section of the Puye Formation occurs from 152 to 534 ft bgs. These alluvial-fan deposits are dominantly coarse gravels and interlayered sands that are slightly to moderately indurated. Volcaniclastic materials dominate the interval from 152 to 327 ft bgs. The middle half of the section (327 to 402 ft bgs) also contains significant quartzite and plutonic lithologies derived from Precambrian sources. Pumiceous sediments occur in the basal 130 ft of the lower Puye section (approximately 402 to 534 ft bgs).

Upper Santa Fe Group Basalt (534 to 670 ft bgs)

Well R-5 intersected Santa Fe Group basalt flows and scoriaceous breccias from 534 to 670 ft bgs. At least three flow events are evident, each with a basal interval of highly oxidized scoria or basalt cinders. Basalts in this upper sequence of older basalts are aphyric to slightly porphyritic, with phenocrysts of olivine, pyroxene, and minor plagioclase in an aphanitic groundmass. In general, these basalt flows are more altered than those of the younger Cerros del Rio sequence. Evidence of alteration includes reddish iddingsite replacement of olivine phenocrysts, presence of green epidote and/or chlorite, and of green- and orange-colored clay as fragments or as amygdaloidal vesicle fill. The base of the section is marked by the presence of basaltic scoria and pyroclastic cinder clasts.

Santa Fe Group Sediments and Deeper Basalts (670 to 902 ft bgs)

A sequence of Santa Fe Group sedimentary rocks with intercalated basalt flows was encountered from 670 ft bgs to the bottom of the borehole at 902 ft bgs. Characteristics of these units are discussed in the following sections.

Santa Fe Group Sediments

Miocene sandstone of the Santa Fe Group immediately underlies the upper Santa Fe Group basalt, described above, from 670 to 720 ft bgs. Santa Fe gravel and sand deposits, separated by two additional basalt sequences (see below), also are recognized in the intervals from 795 to 850 ft bgs and from 893 to 902 ft bgs. In general, the sedimentary rocks are moderately to well-indurated and contain an abundance of volcanic detritus (dacite, basalt, and pumice) as well as rounded, locally frosted quartz clasts.

Santa Fe Group Basalts

Two additional Miocene basalt units are present in two intervals, from 720 to 795 ft bgs and from 850 to 892 ft bgs. These apparent volcanic flows are intercalated with Santa Fe Group sediments. Both units are porphyritic olivine-bearing basalts that exhibit moderate to very strong secondary alteration. Evidence for rock alteration includes the presence of iddingsite after olivine; amygdaloidal clay, calcite, and zeolite; manganese oxides; chlorite; and local chalcedony. Locally, phenocrysts and groundmass feldspars in these basalts are entirely vacated, resulting in a pitted and vuggy texture evident in chip samples.

6.2 Groundwater Occurrence and Characteristics

Because of its depth and location in Pueblo Canyon, the R-5 borehole was expected to encounter both perched and regional zones of saturation. Two potential perched zones were encountered during drilling in the lower part of the Puye Formation: one at a depth of 169 ft bgs (thickness uncertain) and one between the depths of 373 and 389 ft bgs. A third potential perched zone, between the depths of 325 and 331 ft bgs, was identified through analysis of Schlumberger geophysical data. The regional water table was intersected in sediments of the Santa Fe Group at a depth of approximately 685 ft bgs. The most productive interval in the regional zone of saturation was encountered immediately below a basalt unit in the Santa Fe Group, between a depth of 897 and 902 ft bgs.

Because R-5 was drilled by fluid-assisted methods from 36 ft bgs to TD, saturation was recognized only when highly productive zones were penetrated.

7.0 WELL DESIGN AND CONSTRUCTION

The R-5 well was intended to provide hydrogeologic, geochemical, and water-quality data for the regional groundwater aquifer and for any significant zones of perched water. Sections 7.1 and 7.2 describe the well design and construction, respectively.

7.1 Well Design

The Laboratory, US Department of Energy (DOE), New Mexico Environmental Department (NMED) and WGII participated in the well design. Geophysical logs, video logs, borehole geologic samples, water-level data, field water-quality data, and drillers' observations were reviewed by the Groundwater Investigations Team to plan screen placement intervals for the well. The number and placement of screens were designed to meet the following criteria:

- to monitor intermediate perched zone(s) of saturation,
- to monitor the top of the regional zone of saturation, and
- to monitor a deeper, more productive zone within the regional aquifer.

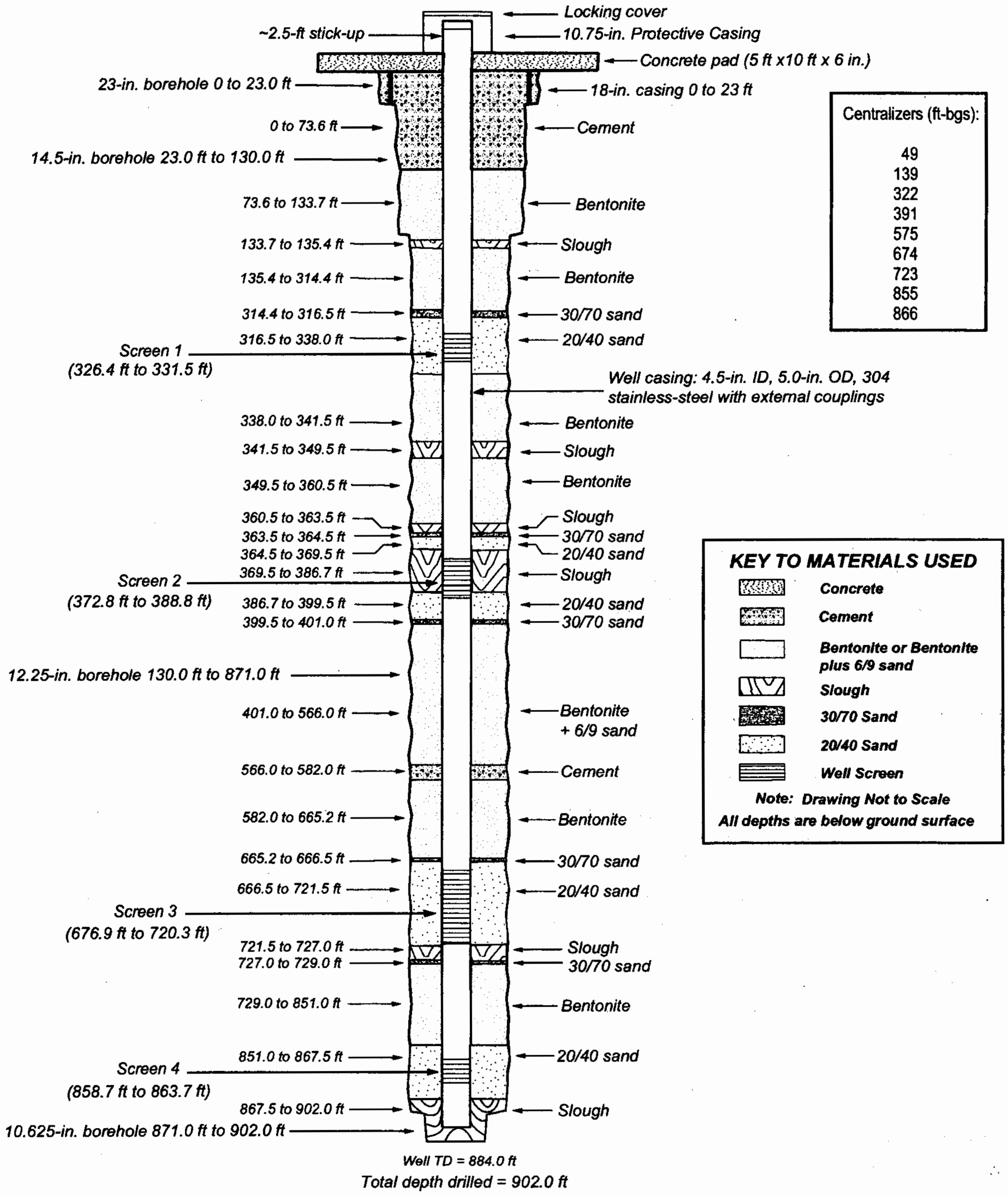
The final design specified four screens for well R-5, consisting of one screen each of the two suspected perched zones in the Puye Formation and two screens in the regional aquifer. The planned and actual screen locations are given in Table 7.1-1. A Westbay™ multiport groundwater sampling system was installed after completion and development of the well.

Table 7.1-1
Summary of Well Screen Information, Characterization Well R-5

Screen	Planned Depth (ft)	Actual Depth (ft)	Geologic/Hydrologic Setting
1	329.1–334.1	326.4–331.5	Possible perched saturation zone in the Puye Formation identified from geophysics
2	375.4–391.3	372.8–388.8	Possible saturation zone in the Puye Formation
3	678.9–722.4	676.9–720.3	Top of regional zone of saturation in the Santa Fe Group sediments
4	860.7–865.7	858.7–863.7	Deeper part of regional zone of saturation in Santa Fe Group basalt

7.2 Well Construction

The well casing and pipe-based screens were manufactured using 4.5-in. inner diameter (ID)/ 5.0-in. OD-type 304 stainless-steel fabricated to American Society for Testing and Materials (ASTM) Standard A554. The external couplings used were also type 304 stainless steel fabricated to ASTM Standard A312, which exceed the tensile strength of the threaded casing ends. The pipe-based screens were modified from 10-ft sections of blank well casing by drilling a series of 0.5-in.-diameter holes and then welding a stainless-steel wire-wrap (0.010-in. gap) over the perforated interval. The final well screen OD was 5.56 in. The stainless-steel well components were cleaned at the well site using a high-pressure steam cleaner and scrub brushes. The bottom of the well was set at 884.0 ft bgs. All annular fill materials were placed in the borehole well casing annulus through a tremie pipe. Figure 7.2-1 shows the as-built well casing configuration and indicates the depths of the various well components from ground surface.



Notes: 1. The screen interval lists the footage of the pipe perforations, not the top and bottom of screen joints.
2. Pipe-based screen: 4.5-in. ID, 5.563-in. OD, 304 stainless-steel with s.s. wire wrap; 0.010-in. slots.
3. The top interval of slough consists of Cerros del Rio sediments. The intervals of slough around screen 2 consist of Puye river gravels. The slough intervals below screens 3 and 4 consist of Santa Fe Group sediments and/or basalt.
4. Westbay multiport sampling system (MP-55) casing not shown.

Figure 7.2-1. As-built configuration diagram, characterization well R-5

7.2.1 Well Installation

Well installation consisted of connecting joints of stainless steel well casing and screen sections by means of threaded couplings in preparation for the installation of the multiport Westbay™ sampling system. Stainless-steel centralizers were installed above and below each screen and in several locations above the zone of regional saturation to enhance positional stability during and after backfill placement operations. Dynatec installed the well casing and screen from May 22 to May 23, 2001.

7.2.2 Annular Fill Placement

Placement of annular fill was accomplished by using a steel tremie pipe to deliver annular materials to the specified design depths. Dynatec installed the annular fill material from May 23 to May 31, 2001. Filter packs across screened intervals consisted of silica sand materials mixed with municipal water and placed in the annulus as a fluid slurry. Bentonite materials were placed between screened intervals to seal the annular space and prevent interaction between water-bearing zones. Bentonite products also were mixed with municipal water as a fluid slurry. Portland cement (mixed at a ratio of 5 gal. of water per bag of cement) was used to provide foundations for the annular fill (566 to 582 ft) and for wellhead protection in the annular space in the upper 73.6 ft of the borehole.

Table 7.2-1 summarizes the annular fill materials installed during the construction of R-5. The final configuration of the annular materials is also illustrated in Figure 7.2-1.

Table 7.2-1
Annular Fill Materials, Characterization Well R-5

Material	Use/Function	Amount	Unit*
20/40 sand (medium-grained)	To pack screen intervals	527	bags
30/70 sand (fine-grained)	To separate filter packs from bentonite seals	15	bags
6/9 sand (coarse)	To bridge formation fractures and matrix pores	256	bags
Benseal® (bentonite)	As a high-solids, multipurpose grout	2	bags
Holeplug® (.375-in. angular and unrefined bentonite chips)	To provide a borehole annular seal	354	bags
Pelplug® bentonite (.25 in. by .375 in., refined elliptical pellets)	To provide a borehole annular seal below the water table	229	buckets
Portland® cement (mixed with municipal water at a ratio of 5 gal. water to 1 bag)	To provide annular support and surface seal on the upper 100 ft of the borehole	54	bags

*Sand bag = 45 lb ea, bentonite bag/bucket = 50 lb ea, cement bag = 94 lb ea.

8.0 WELL DEVELOPMENT AND HYDROLOGIC TESTING

Well development and hydrologic testing were conducted from June 1 to June 21, 2001. Dynatec performed development procedures, under the supervision of WGII. Activities included wire brushing, well screen swabbing, bailing, and pumping.

8.1 Well Development

Well development was performed in two stages. The initial stage consisted of wire-brushing the well interior, swabbing and surging the screen intervals to draw fine sediment from the constructed filter pack, and bailing to remove unwanted solid materials from the well. In the second stage, a submersible pump was lowered in succession to screens 3 and 4 and on/off cyclic pumping from each water-bearing zone was performed to remove any remaining fines from the filter pack and formation.

Criteria for well development were based on selected field water quality parameters (turbidity, specific conductance, pH, and temperature). To monitor progress during each development stage, groundwater samples were collected periodically and parameter measurements were recorded. One objective of well development was to remove suspended sediment from the water until turbidity, recorded in nephelometric turbidity units (NTU), was measured at a value less than 5 NTU for three consecutive samples. Similarly, the other measured parameters were required to stabilize before development procedures could be terminated. The well was declared sufficiently developed when the above criteria were met, or could not be improved with continued pumping. Table 8.1-1 presents water-quality parameter data measured at the beginning and end of each stage of development method.

Table 8.1-1
Water-Quality Parameter Data, Characterization Well R-5

Method	Water Removed (gal.)	Range of Parameters[a]			
		pH	Temperature (°C)	Specific Conductance (µS/cm)[b]	Turbidity (NTU)
Bailing screen	3020	6.12–8.00	21.6–19.0	236–216	9.6–482
Pump–screen 3	1095	6.87–8.62	25.5–21.7	235–200	34.2–15.5
Pump–screen 4[c]	985	8.3–8.5	23.4–22.7	230–232	32.7–8.8
Pump–sump	9130	NM[d]	21.5–23.2	130–258	6.7–5.8
Total	**14,230**				

[a] Range is made up of value at beginning, followed by value at end, of the development method; higher and lower values may have been attained during development.
[b] Specific conductance reported in microsiemens per centimeter.
[c] Pumping from screen 4 using 10-hp pump (single packer deployed).

To remove any materials that may have been introduced into the well interior during construction, the casing and screens first were cleaned thoroughly using a wire brush. Preliminary bailing using a 12-gal. steel bailer was performed to remove debris and sediment from the sump. A total of 3020 gal. of water was withdrawn from the well and turbidity was recorded at 482 NTU at the end of bailing (Table 8.1-1).

Pump development procedures were applied to screens 3 and 4 by deploying a single inflatable packer. Complete development procedures were not applied to screens 1 and 2 because of insufficient water production. A 10-horsepower (hp) submersible pump was lowered to each screen and the packer installed above the screen interval. Attempts to develop the screens individually were unsuccessful because the water-bearing zones failed to produce sufficient flow. Then the pump was lowered to the bottom of screen 3, without deploying the packer. A pressure transducer and data logger were installed to continuously measure and record water levels during pumping. The pump was cycled on at a rate of approximately 1 gallon per minute (gpm) withdrawing 1095 gal. of groundwater from the position of the bottom of screen 3. Water samples were collected at regular intervals for parameter measurements. A similar procedure was conducted at screen 4; however, drillers experienced mechanical difficulties with the 10-hp pump that had been positioned below the bottom of the screen. The pumping rate could not be throttled to less than 14 gpm without overloading the circuit breaker, which caused the pump to shutdown. Cyclic pumping was initiated with intermittent periods of down time of up to one hour to allow water level recovery. A total of 985 gal. of water was purged, and turbidity was recorded at 8.8 NTU by the end of the pumping period (Table 8.1-1).

Pump development was resumed after a 7.5-hp submersible pump was installed below screen 4. Three periods of on/off cyclic pumping were performed with a pressure transducer and data logger installed to measure the water-level response. Pumping was conducted at flow rates that varied from 10.5 to 2.8 gpm. Two additional pumping periods were performed without the transducer/data logger system. Turbidity was less than 6 NTU at this final stage of well development (Table 8.1-1).

Figure 8.1-1 compares the variation in measured field parameters with gallons of water purged during pump development. The graph shows that specific conductance and temperature were reasonably stable during the latter period of pumping and that turbidity had fallen below 6 NTU when R-5 was declared fully developed.

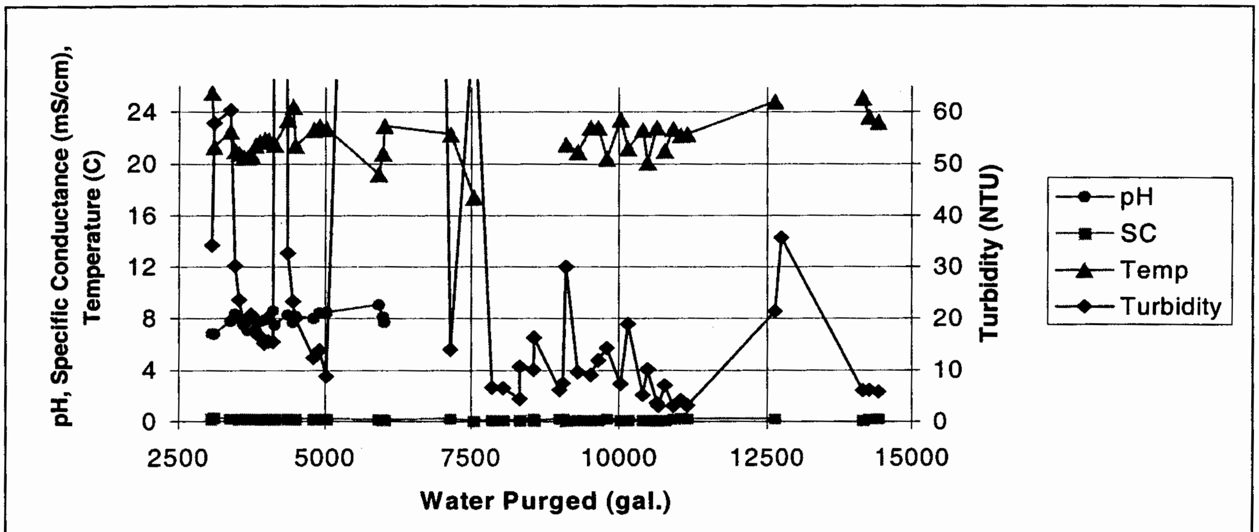


Figure 8.1-1. Effects of pump development on water-quality parameters, characterization well R-5

8.2 Hydrologic Testing

Hydraulic properties of saturated materials in multiscreened R-wells normally are evaluated by straddle-packer/injection tests. However, such testing was not appropriate for two of the four screens in R-5. Material behind screen 1, targeting a suspected perched zone of saturation, was dry, and screen 3 straddles the regional water table. The method cannot be used in these conditions because injected water would drain quickly from the well into the unsaturated geologic media, leading to an overestimate of permeability (Fetter 1994, 70942). Although materials behind screens 2 and 4 were wet, they were not productive. In view of the fact that the pump in the straddle-packer/pump assembly used for development of these intervals kept shutting off because of a lack of water, they were not tested.

8.3 Installation of Westbay™ Monitoring System

After development procedures in well R-5 were completed, a Westbay™ multiport sampling system was installed inside the stainless steel well casing. The Westbay™ multilevel sampling diagram provides construction details of the installed system (Appendix E).

9.0 WELLHEAD COMPLETION AND SITE RESTORATION

When operational tests were completed on the installed sampling system, the protective casing height was adjusted to accommodate a locking cap over the Westbay™ installation. Finish work commenced on the wellhead area, well components were surveyed, and the site underwent final clean up and restoration.

9.1 Wellhead Completion

The surface completion involved placement of a reinforced (5000 pounds per square inch [psi]) concrete pad, 5-ft by 10-ft by 12-in. thick, around the well casing to ensure the long-term structural integrity of the well (Figure 9.1-1). The concrete pad was placed on August 15, 2001. A 3-in.-diameter threaded galvanized-steel conduit approximately 18 in. long with a 12-in. stickup was embedded vertically through the pad to allow for future installation of a solar-power energy supply. A 10.0-in. steel protective casing with a mushroom cap protects the well riser. Four 4-in.-diameter concrete-filled steel bollards were placed at each side of the pad boundary. One bollard is removable to allow access to the well for sampling and maintenance activities. A brass survey pin was installed in the northwest corner of the concrete pad.

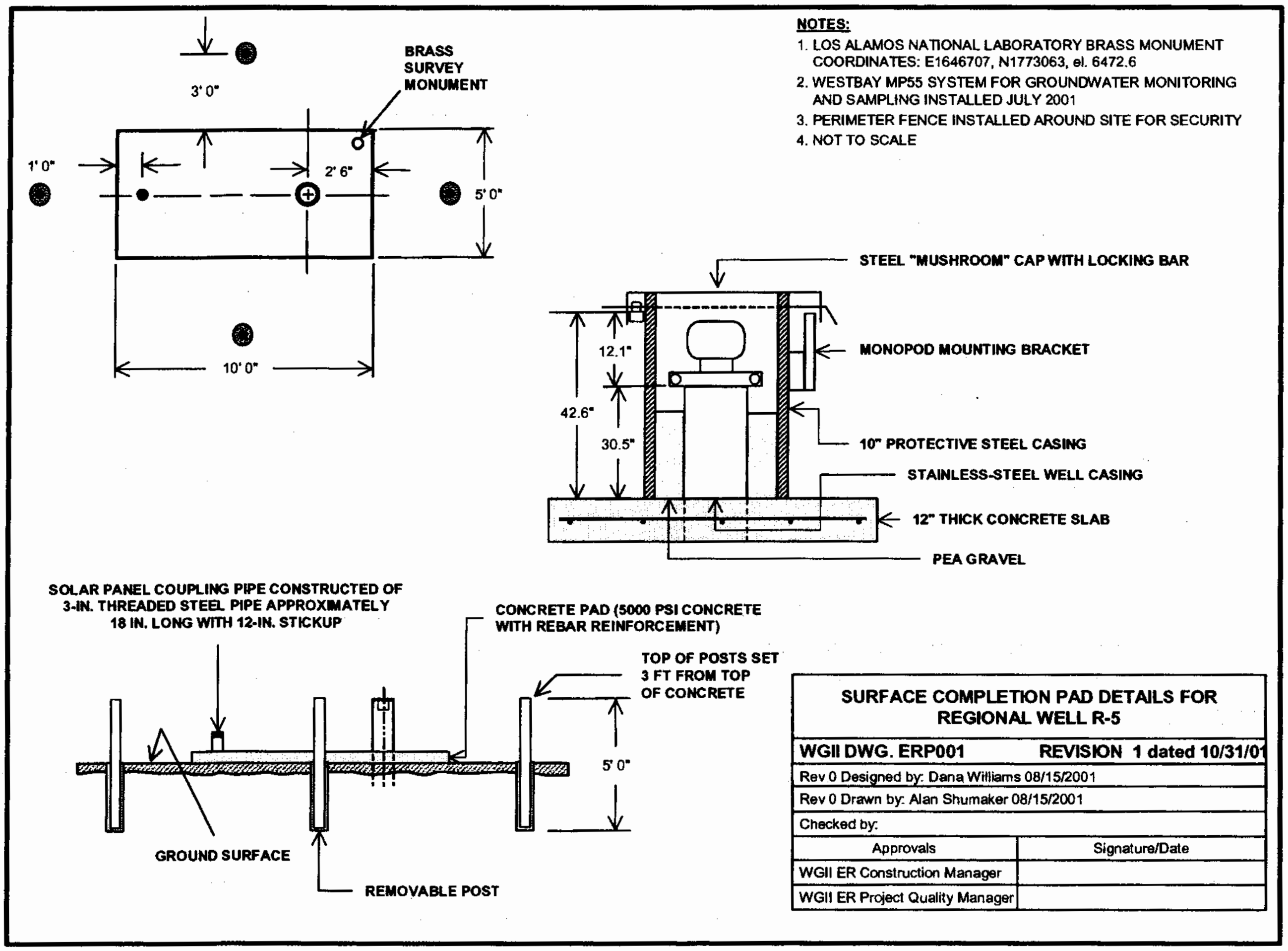


Figure 9.1-1. Surface completion configuration diagram, characterization well R-5

9.2 Geodetic Survey

The location of R-5 was determined by geodetic survey on September 5, 2001, using a Wild/Lesca TC 1000, 3-Second Theodolite total station. Control for the survey was provided by control points B0001 and 74-16 from the 1992 Laboratory-wide control network. Field measurements were reduced using LisCad Plus® surveying software.

The survey located the brass cap monument in the northwest corner of the concrete pad and measured elevations to the top of the steel protective casing, top of the Westbay™ collar, and top of the Westbay™ plate at R-5 (Table 9.2-1). Horizontal well coordinates are in the New Mexico State Plane Coordinate System, Central Zone (North American Datum, 1983 [NAD 83]), expressed in ft. Elevation is expressed in ft above mean sea level relative to the National Geodetic Vertical Datum of 1929.

Table 9.2-1
Geodetic Data, Characterization Well R-5

Description	East Coordinate	North Coordinate	Elevation ft*
Top of steel protective casing (north edge)	1646709	1773061	6475.7
Top of Westbay™ Collar	1646709	1773061	6475.5
Top of Westbay™ Plate	1646709	1773061	6475.0
Brass cap in R-5 pad	1646707	1773063	6472.6

* Measured in ft above mean sea level relative to the National Geodetic Vertical Datum of 1929.

The Facility for Information Management, Analysis and Display (FIMAD) location identification number for the R-5 well is PU-10177.

9.3 Site Restoration

From July 18 to August 17, 2001, site restoration activities were completed. Prior to recontouring, the cuttings-containment area was excavated and the plastic lining removed. Then the containment area was backfilled with dirt that had been bermed during pad construction. The water storage tank trailers were removed, and the secondary containment area was cleaned up, and the drill site area was recontoured to conform to the surrounding topography. The base-course area was reduced in size and regraded up to and around the concrete wellhead pad to promote drainage. In addition, the site was cleared of the brush piles that had accumulated during tree removal activities related to drill pad construction.

The straw wattles and silt fences that are part of the R-5 site best management practices (BMPs) remain in place as needed. The site was re-seeded with a Laboratory-provided blend of native grasses mixed with straw mulch to facilitate reintroduction of ground cover. Site restoration activities after drilling was completed were conducted.

10.0 DEVIATIONS FROM THE R-5 FIP

Appendix A compares the actual characterization activities performed at R-5 with the planned activities in the hydrogeologic work plan and the R-5 FIP. Significant deviations are discussed below:

- *Planned depth.* The FIP stated that the approximate depth of the boring would be 1200 ft bgs. The actual depth of the borehole was terminated at a depth of 902 ft bgs because unstable Santa

Fe Group sediments were encountered. The boring had been advanced 217 ft into the regional aquifer, which was consistent with the work plan.

- *Number of core/cuttings samples collected for contaminant analysis.* Collection of sidewall cores was not possible because 11.75-in. casing was advanced during drilling to a depth of 870 ft. Additionally, the lack of any contaminants of concern in the screening water samples collected from the perched zone and regional aquifer precluded the usefulness of submitting cuttings samples for contaminant analyses.

- *Field hydraulic property tests.* Straddle-packer/injection tests were not conducted at this location because the screen intervals were dry or nonproductive or a screen interval straddled the water table.

11.0 ACKNOWLEDGEMENTS

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D. Broxton, A. Groffman, S. Pearson, W. Stone, and D. Vaniman, of Los Alamos National Laboratory, prepared this report.

R. Bohn and E. Louderbough, of Los Alamos National Laboratory, reviewed this report for classification and legal purposes, respectively.

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LANL (Los Alamos National Laboratory), March 2001. "Field Implementation Plan for the Drilling and Testing of LANL Regional Aquifer Characterization Well R-5," Los Alamos, New Mexico. (LANL 2001, 71453.1)

Appendix A

Activities Planned for R-5 Compared with Work Performed

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Planned Depth	100 to 500 ft bgs into the regional aquifer	Approximately 1200 ft bgs	Total drill depth 902 ft bgs, approximately 217 ft bgs below the regional water table
Drilling Method	Methods may include, but are not limited to hollow-stem auger (HSA), air-rotary/Odex/Stratex, air rotary/Barber rig, and mud-rotary drilling	HSA and casing-advance/open-hole, air-rotary equipment	HSA and casing-advance/open-hole, air-rotary equipment
Amount of Core	10% of the borehole	No core planned	No core attempted
Lithologic Log	Log to be prepared from core, cuttings, and drilling performance	Log to be prepared from cuttings, geophysical logs and drilling performance	Log prepared from cuttings, geophysical logs, and drilling performance
Number of Water Samples Collected for Contaminant Analysis	A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified.	Up to three water samples will be collected and will target perched zones and the regional aquifer. The geochemistry project leader and technical team will determine the number and locations of samples based on conditions encountered. The number of sampling events after well completion is not specified.	Four water samples were obtained. Water was collected from two perched zones at 169 ft bgs and 387 ft bgs. Water from the regional aquifer was sampled at 860 ft bgs and 892 ft bgs.
Water Sample Analysis	Initial sampling: Radiochemistry I, II, and III, tritium, general inorganics, stable isotopes, VOCs, and metals. Saturated zones: radionuclides (tritium, ^{90}Sr, ^{137}Cs, ^{241}Am, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements.	Anions (dissolved), major cations, trace elements and metals (dissolved), ^{90}Sr (dissolved), tritium (low level or direct counting), RVGross alpha, beta and RVGross gamma, NH_4, NO_3, NO_2, Br^1, Cl^{-1}, PO_4, F^1, SO_4, Stable isotopes ($^{18}O/^{16}O$, D/H, $^{15}N/^{14}N$, CLO_4^-)	^{241}AM, Gamma spec, isotopic Pu, isotopic U, ^{90}Sr, stable isotopes (deuterium, $^{18}O/^{16}O$), total uranium by ICPMS, cation by MS, anions, gross alpha, beta, and gamma, low-lev tritium, TAL-metals +Fr +B+Mo+Si+Sr, NO_3, NO_2, NH_4, anions, Radvan, and Semi VOAGCMS
Water Sample Field Measurements	Alkalinity, pH, specific conductance, temperature, turbidity	pH, specific conductance, temperature, turbidity	pH, specific conductance, temperature, turbidity
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole	Up to two cuttings samples will be selected for geochemical and contaminant characterization by the geochemistry task leader during drilling operations.	No core or cuttings samples submitted for contaminant analysis. Collection of sidewall core was not possible because of drill casing in the hole from 0 to 870 ft.

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Cuttings/Core Sample Analytes	Upper-most sample to be analyzed for a full range of compounds; deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low- and high-detection levels), and metals. Four samples to be analyzed for VOCs.	Cuttings analyses may include radionuclides, metals, and anions. Each sidewall core sample shall be analyzed for the following anions: boron, bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate.	No core obtained
Laboratory Hydraulic-Property Tests	Physical properties analyses will be conducted on 5 core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	No laboratory hydraulic property tests planned	No samples submitted
Geology	Ten samples of core or cuttings will be collected for petrographic, X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses.	The geology task leader will determine the number of samples analyzed for characterization. Testing of samples may include mineralogy by XRD, petrography by modal analysis of thin sections, by electron microprobe, by scanning electron microscope, and geochemistry by XRF.	Thirty-eight samples were characterized for mineralogy, petrography, and rock chemistry.
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	In general, open-hole geophysics includes caliper, array induction imager, triple lithodensity, full-bore formation microimager, combinable magnetic resonance tool, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron log, mechanical sidewall coring, and elemental capture spectrometer. In general, cased-hole geophysics includes: triple lithodensity, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron and elemental capture spectrometer	Video (LANL tool): 570 – 685 ft bgs, natural gamma (LANL tool): cased 0–851 ft bgs, and open hole 851–898 ft bgs, Schlumberger geophysics (0-851 ft bgs cased, 851–898 ft bgs open hole): lithodensity, spectral gamma, compensated thermal/epithermal neutron
Water-Level Measurements	Procedures and methods not specified in hydrogeologic work plan	When the regional aquifer is first encountered, a static water level shall be measured by the FTL, using a dedicated water-level meter and/or a pressure transducer system.	Water level measurements were obtained during drilling using a water-level meter.
Field Hydraulic-Property Tests	Not specified in hydrogeologic work plan	The hydrology task leader shall design and conduct slug or pumping tests once the well is completed.	None conducted

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Surface Casing	Approximately 20-in. OD, extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	18-in.-OD steel casing will be installed and cemented in place to isolate the borehole from surface water and possible alluvial groundwater and to stabilize the upper part of the borehole from caving and collapse.	18-in.-OD steel casing set at 23 ft bgs and cemented in place.
Minimum Well Casing Size	6.625-in.-OD	5-in-OD by 4.5-in.-ID	5.5-in.-OD (4.5-in-ID) stainless steel casing w/ external couplings.
Well Screen	Machine-slotted (0.01-in.) stainless-steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED	Well screen shall be constructed with multiple sections of 5.56-in OD pipe based stainless-steel screen, with a 0.010-in slot size	Screened intervals constructed of 5.56-in OD (4.5-in ID) pipe based, stainless steel, wire wrapped, 0.010-in slotted screen.
Filter Material	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	Primary filter pack shall consist of round, clean, washed and resieved silica sand with a uniformity coefficient of 2.0 or less, placed 10 ft above and 5 ft below the well screen. The size of the filter pack shall be selected based on the characteristics of the formation to be screened. Secondary filter pack is finer, clean, washed silica sand emplaced a minimum of 2 ft below and above the primary pack.	Screen 1: Primary filter pack consists of 6.5 ft of 20/40 sand below screen, 20/40 sand and 6/9 sand (50/50 mix) across screen and 4.3 ft of 20/40 sand above mix. Secondary filter pack constructed of 2.1 ft of 30/70 sand above 20/40 sand. Screen 2: Primary filter pack consists of 20/40 silica sand 10.7 ft below screen and 2.1 ft up into the screen, slough across the remainder of the screen and 3.3 ft above with 5 ft of 20/40 silica sand above slough. Secondary filter pack of 30/70 silica s and constructed in a 1-ft-thick layer above and a 1.5-ft-thick layer below the primary filter pack. Screen 3: Primary filter pack constructed of 20/40 silica sand placed 1.2 ft below and 10.4 ft above screen. Secondary filter pack constructed of 5.5 ft slough below screen and 2.0 ft of 30/70 ft below slough and 1.3 ft above 20/40 sand. Screen 4: Primary filter pack constructed of 20/40 silica sand placed 3.8 ft below and 7.7 ft above the screen. No secondary filter pack.

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"R-5 Field Implementation Plan (FIP)" (LANL 2001, 71453.1)	R-5 Actual Work
Backfill Material (exclusive of filter materials)	Uncontaminated drill cuttings below sump and bentonite above sump	The annular space in the blank zones between filter packs associated with screens and above the top-most secondary filter pack shall be sealed with a mixture of approximately 50% bentonite (chips or pellets) and 50% gravel or sand. As necessary, 5- to 10-ft cement plugs may be placed within the bentonite and gravel/sand intervals to provide stable floors for the placement of annular fill. The annular space fro a depth of approximately 75-ft to land surface shall be sealed with cement grout.	Bentonite pellets, bentonite chips, and bentonite chips and 6/9 or 8/12 sand mixture between filter packs. One cement grout plug and cement from surface to 73.6 ft bgs.
Sump	Stainless-steel casing, approximately 10 ft, with an end cap	A capped 30-ft section of stainless-steel casing	5.0-in diameter stainless-steel casing 20 ft long
Bottom Seal	Bentonite	Bentonite	No bottom seal constructed due to sloughing and unstable formation at the bottom of the borehole.

Appendix B

Lithology Log

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qal, Alluvium	Unconsoilidated sediments, grayish-orange (10YR 7/4) to yellowish-gray (5YR 8/1), pumiceous, vitric. +10F: upper 1 ft consists of poorly developed soil; remainder made up of glassy to sugar-textured pumice (0.5 to 1.0 cm), minor quartz and sanidine crystals, rare dacite lithics; trace clay.	0–20	6472.6–6452.6
Qbog, Guaje Pumice Bed	Tephra deposit, yellowish-gray (5YR 8/1), pumiceous, vitric, nonwelded. +10F: (i.e., plus No.10 sieve sample fraction) 98–99% coarse pumice fragments (0.5 to 3.0 cm) that are uniformly vitric, 1–2% dacite lithics.	20–25	6452.6–6447.6
	Tephra deposit, grayish-orange (10YR 7/4) pumiceous, vitric, nonwelded. +10F: 99% glassy pumice (0.5 to 1.0 cm), fragments rounded with local rinds of clay; very slight local Fe-oxide staining; trace dacite lithics.	25–35	6447.6–6437.6
Tpf, Puye Formation	No sample collected. Basal Qbog contact with underlying Tpf estimated at 35 ft bgs.	35–36	6437.6–6436.6
	Volcaniclastic sediments, gravel (GW) with sand, light brown (5YR 4/1), coarse pebbles (up to 4.0 cm) are angular to subrounded. +10F: clasts composed of 80–95% dacite and hornblende-dacite; 5–20% andesite, basalt, and vitrophyre; matrix of silty sand, sanidine, quartz, and mafic minerals.	36–46	6436.6–6426.6
	Volcaniclastic sediments, silty sandy gravel (GM), light brownish-gray (5YR 6/1), pebbles (0.5–3.0 cm) mostly subrounded. +10F: clasts composed of 98% light and dark gray hornblende-dacite, pinkish dacite, slight Fe-oxide staining; 2% other volcanic lithics, sanidine, and quartz crystals.	46–61	6426.6–6411.6
	Volcaniclastic sediments, silty sandy gravel (GM), grayish-orange (10YR 7/4), pebbles (up to 2.0 cm) are subrounded to rounded. +10F: clasts composed of 95–98% light gray pyroxene- and hornblende-bearing dacites, clasts commonly have clay coatings; 2–5% pumice, quartz, sanidine and mafic minerals.	61–71	6411.6–6401.6
	Clastic sediments (30% by volume) represented by silty, sandy gravel (GM), grayish-orange (10YR 7/4), pebbles (up to 2.0 cm) are subrounded made up mostly of subrounded clasts porphyritic dacite. Remaining 70% of +10F sample consists of broken fragments of vesicular, oxidized basalt with abundant amygdaloidal clay. Basal Tpf contact with underlying Tb4 lava is estimated at approximately 76 ft bgs.	71–76	6401.6–6396.6
Tb 4, Cerros del Rio Basalt	Basalt, pale yellowish-brown (10YR 6/2), highly vesicular. WR/+10F: 85–90% broken fragments of oxidized, vesicular basalt, abundant clay-filled vesicles; 10–15% rounded granules of dacitic volcanics.	76–81	6396.6–6391.6
	Basalt, pale yellowish-brown (10YR 6/2), highly vesicular to scoriaceous, altered. WR/+10F: 95–98% broken fragments of oxidized, vesicular and scoriaceous basalt, abundant clay-filled vesicles; trace dacitic volcanics and siltstone.	81–91	6391.6–6381.6
	Basalt, medium-dark gray (N4), vesicular. WR/+10F: 95–98% broken fragments of vesicular basalt, slight oxidation, minor clay in vesicles; 2–5% tan-colored siltstone fragments.	91–101	6381.6–6371.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb 4, Cerros del Rio Basalt	Basalt, medium-dark gray (N4), vesicular. WR/+10F: 100% broken fragments of vesicular basalt, slight oxidation, moderate to abundant white clay in vesicles.	101–111	6371.6–6361.6
	Basalt, medium-dark gray (N4), fine-grained, slightly vesicular. WR/+10F: 98–99% broken fragments fine-grained basalt, moderate to abundant clay; 1–2% siltstone.	111–121	6361.6–6351.6
	Basalt, pale yellowish-brown (10YR 6/2), highly vesicular, fine-grained. WR/+10F: 95–98% broken fragments fine-grained basalt, slightly oxidized, moderate amygdaloidal clay; 3–5% fragments of pale tan colored clay and siltstone.	121–132	6351.6–6340.6
	Basalt, medium-dark gray (N4), massive, fine grained. WR/+10F: 100% broken fragments fine-grained basalt, slightly porphyritic with aphanitic groundmass, olivine phenocrysts up to 2 mm, minor Fe-oxides and clay.	132–142	6340.6–6330.6
	Basalt, medium-dark (N4) to dark gray (N3), highly vesicular, slightly porphyritic with fine-grained groundmass. WR/+10F: 97% broken chips of fine-grained olivine basalt, Fe-oxides and clay coatings on fragments, locally reddish (oxidized) coloration; 2–3% siltstone and/or clay fragments.	142–147	6330.6–6325.6
	Basalt, dark gray (N3) to locally dark reddish-brown (10R 3/4), vesicular to scoriaceous, slightly porphyritic with fine-grained groundmass. WR/+10F: 75% broken chips of fine-grained olivine basalt, highly oxidized, moderate white to tannish clay coatings on fragments; 20–25% glassy black scoria commonly with bluish silica veinlets or coatings; 2–3% siltstone or clay fragments. +35F: (i.e., plus No. 35 sieve sample fraction) 65% vitric scoriaceous basalt. Basal Tb4 contact with underlying Tpf estimated at 152 ft bgs.	147–152	6325.6–6320.6
Tpf, Puye Formation	Volcaniclastic sediments, silty sandy gravel (GM), dark yellowish-brown (10YR 4/2), pebbles (up to 1.5 cm) mostly subangular. +10F: 100% dacitic lithic clasts that are subangular; trace clay.	152–157	6320.6–6315.6
	Volcaniclastic sediments, sand (SW) with gravel and clay, dark yellowish-brown (10YR 4/2), pebbles (up to 0.5 cm) are angular. +10F: 100% lithic clasts made up of light gray to pinkish hornblende-biotite dacite.	157–162	6315.6–6310.6
	Volcaniclastic sediments, silty sandy gravel (GM), pale yellowish-brown (10YR 6/2), angular to subangular pebbles (up to 2.0 cm). +10F: 98–99% clasts made up of light gray to pinkish hornblende- and biotite-dacites; 1–2% clasts of vitric dacite, variolitic rhyodacite, and latite.	162–172	6310.6–6300.6
	Volcaniclastic sediments, sandy gravel (GW) with clay, medium-light gray (N6), subrounded pebbles (up to 2.0 cm). +10F: 100% lithic clasts made up of light gray hornblende- and pyroxene-bearing dacites.	172–177	6300.6–6295.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravel (GW) with sand and clay, medium gray (N5), subangular to subrounded pebbles (up to 1.3 cm). +10F: 100% lithic clasts made up of light gray porphyritic dacites; dacites locally glassy, sugary surface texture at 177–182 ft bgs.	177–192	6295.6–6280.6
	Volcaniclastic sediments, sandy gravel (GW), light brownish-gray (5YR 6/1), subangular to subrounded pebbles (up to 1.3 cm). +10F: 100% lithic clasts made up of light gray porphyritic dacites, locally quartz-bearing dacite.	192–202	6280.6–6270.6
	Volcaniclastic sediments, sandy gravel (GW), light brownish-gray (5YR 6/1), coarse subangular to subrounded pebbles (up to 3.0 cm). +10F: 100% lithic clasts made up of mixed reddish and light-gray hornblende-bearing dacite and other porphyritic dacites.	202–212	6270.6–6260.6
	Volcaniclastic sediments, sandy gravel (GW), light brownish-gray (5YR 6/1), coarse subangular to subrounded pebbles (up to 3.0 cm). +10F: 100% clasts of mixed reddish, tan, and light-gray hornblende-bearing dacites, trace quartzite present.	212–222	6260.6–6250.6
	Volcaniclastic sediments, gravel (GW) with sand, grayish-orange pink (5YR 7/2), subangular to subrounded pebbles (up to 1.0 cm). +10F: 100% lithic clasts made up of mixed pinkish and light-gray hornblende-bearing dacites.	222–232	6250.6–6240.6
	Volcaniclastic sediments, gravel (GW) with silt and sand, grayish-orange pink (5YR 7/2), subangular to subrounded pebbles (up to 1.0 cm). +10F: 95–97% mixed clasts of pinkish, light-gray, and bleached hornblende-, biotite-, and quartz-bearing dacites, local clay and calcium carbonate coatings; 3–5% clasts of volcaniclastic sandstone.	232–242	6240.6–6230.6
	Volcaniclastic sediments, silty gravel (GM) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 1.0 cm). +10F: 95–99% mixed clasts of light gray and bleached hornblende- and biotite-bearing dacites; 1–3% clasts of volcaniclastic sandstone, quartz grains.	242–252	6230.6–6220.6
	Volcaniclastic sediments, gravel (GW) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 2.0 cm). +10F: 100% mixed light gray and bleached hornblende- and quartz-bearing dacites.	252–257	6220.6–6215.6
	Volcaniclastic sediments, silty gravel (GM) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 1.8 cm). +10F: 100% mixed dacite clasts including light gray and bleached biotite-, hornblende-bearing dacites; trace quartzite.	257–277	6215.6–6195.6
	Volcaniclastic sediments, silty gravel (GM) with sand, grayish-orange pink (5YR 7/2), angular to subrounded pebbles (up to 1.5 cm). +10F: 100% mixed dacite clasts that are generally bleached, including biotite- and hornblende-bearing dacites.	277–287	6195.6–6185.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6), angular to subrounded pebbles (up to 1.0 cm). +10F: 100% mixed dacite clasts that are generally bleached, including biotite- and hornblende-bearing dacites.	287–292	6185.6–6180.6
	Volcaniclastic sediments, silty gravel (GM) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 2.0 cm). +10F: 100% monolithologic light gray dacite clasts that are generally bleached.	292–302	6180.6–6170.6
	Volcaniclastic sediments, gravel (GW) with silt and sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 1.5 cm). +10F: 100% monolithologic light gray to bleached dacite clasts; trace quartzites.	302–312	6170.6–6160.6
	Volcaniclastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 1.0 cm). +10F: 100% monolithologic light gray to bleached dacite clasts; trace grains of quartz.	312–317	6160.6–6155.6
	Volcaniclastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 1.5 cm). +10F: 100% mixed porphyritic dacite clasts including light gray, reddish, and bleached; trace grains of quartz.	317–327	6155.6–6145.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), angular to rounded pebbles (up to 1.5 cm). +10F: 90–95% mixed light gray and pinkish dacites; 5–10% rounded quartzite and meta-granitic clasts. Note: first appearance of significant percentages of Precambrian lithologies denotes the stratigraphic top of axial river gravels within the Puye Formation in the interval 327 to 402 ft bgs.	327–332	6145.6–6140.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.5 cm). +10F: 80–85% mixed light gray and pinkish dacites; 15–20% rounded quartzite, metamorphic rocks, and pink potash feldspar (microcline).	332–342	6140.6–6130.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.5 cm). +10F: 93–95% mixed light gray and pinkish dacite clasts; 5–7% rounded quartzite, pink microcline, and granitic clasts.	342–357	6130.6–6115.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.0 cm). +10F: 85% mixed dacite and silicified dacites; 15% rounded quartzite and meta-granitic clasts.	357–362	6115.6–6110.6
	Clastic sediments, silty gravel with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 95–97% mixed variety of dacite, flow-banded rhyodacite, and silicified dacites; 3–5% rounded quartzite and meta-granitic clasts.	362–372	6110.6–6100.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 80–85% mixed light gray and bleached dacites; 10–15% rounded quartzite and Precambrian granite clasts. Note: significant reduction in percentage of Precambrian clasts below 377 ft bgs.	372–377	6100.6–6095.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 0.5 cm). +10F: 100% mixed varieties of light gray fresh dacite and earthy-textured, clay-altered bleached dacite; trace pumice.	377–382	6095.6–6090.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subangular to subrounded pebbles (up to 2.0 cm). +10F: 98% mixed varieties of dacite; 2% clay-altered vesicular basalt, andesite and earthy-textured, clay-altered bleached dacite. +35F: contains trace pumice.	382–387	6090.6–6085.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 1.0 cm). +10F: 97–99% mixed varieties of light gray, pink, and white (bleached) dacite; 1–3% quartzites. +35F: contains 10–15% clay-altered pumices in the interval 292 to 297 ft bgs.	387–397	6085.6–6075.6
	Clastic sediments, silty gravel (GM) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 95% mixed light gray and bleached dacite; 3–5% quartzites. +35F: contains 10–15% clay-altered pumices. Note: the interval 402 to 534 contains significant amounts of pumice with interspersed lenses of river gravel.	397–402	6075.6–6070.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 50–85% mixed pinkish and gray dacites; 15–30% white altered pumice; up to 20% pumiceous clay-cemented sandstone. +35F: contains >50% clay-altered pumices.	402–412	6070.6–6060.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 15% mixed dacites; 30% white altered (waxy luster) pumice; up to 55% pumiceous clay-cemented sandstone; 1–2% quartzite.	412–417	6060.6–6055.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: 60–70% mixed light gray and bleached dacites; 5–10% white altered hornblende-bearing pumice; 20–25% pumiceous clay-cemented sandstone; 1–2% quartzite.	417–422	6055.6–6050.6
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subrounded to rounded pebbles (up to 2.0 cm). +10F: dominantly mixed dacites and white altered pumice; 1–2% quartzite. +35F: contains 10% pumice.	422–432	6050.6–6040.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 2.0 cm). +10F: dominantly mixed dacites; 5% white altered pumice; <1% quartzite and plutonic lithologies.	432–442	6040.6–6030.6
	Clastic sediments, gravel (GW) with silt and sand, light gray (N6), angular to subrounded pebbles (up to 2.0 cm). +10F: dominantly mixed dacites; minor pumiceous sandstone; trace quartzite.	442–447	6030.6–6025.6
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to rounded pebbles (up to 2.0 cm). +10F: mostly mixed dacites; minor pumiceous sandstone; 1–2% quartzite and plutonic rocks.	447–452	6025.6–6020.6
	Clastic sediments, gravel (GW) with sand and silt, light brownish-gray (5YR 6/1), angular to rounded pebbles (up to 2.5 cm). +10F: mostly mixed dacites; minor hornblende-bearing pumice; 2% quartzite and plutonic rocks.	452–462	6020.6–6010.6
	Clastic sediments, silty gravel (GM) with sand, light brownish-gray (5YR 6/1), angular to subrounded pebbles (up to 2.2 cm). +10F: 90% mixed dacites; 2–4% pumice; 4–5% quartzite and plutonic rocks.	462–472	6010.6–6000.6
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange (10YR 7/4), angular to subrounded pebbles (up to 2.5 cm). +10F: dominantly mixed varieties of dacite; 10% amphibole-bearing pumice; 10% quartzite. +35F: contains 5% pumice.	472–477	6000.6–5995.6
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange (10YR 7/4), angular to subrounded pebbles (up to 2.5 cm). +10F: dominantly mixed varieties of dacite; 30% pumice; 1% quartzite. +35F: contains 60% pumice.	477–482	5995.6–5990.6
	Clastic sediments, clayey sand (SC) with gravel, light brown (5YR 6/4), angular to subrounded pebbles (up to 1.0 cm). +10F: dominantly mixed varieties of dacite and pumiceous clay-cemented sandstone; 1% quartzite. +35F: contains 40% pumice.	482–487	5990.6–5985.6
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange (10YR 7/4), angular to rounded pebbles (up to 2.0 cm). +10F: dominantly mixed varieties of dacite; 5% quartzite; some carbonate nodules (up to 1.0 cm). +35F: contains 20% pumice.	487–492	5985.6–5980.6
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2), angular to subrounded clasts. +10F: 80–95% pumice and clay-cemented pumiceous sandstone; 15–20% dacite clasts. +35F: contains 10–50% amphibole-bearing pumice.	492–507	5980.6–5965.6
	Clastic sediments, gravel (GW) with clay and sand, grayish-orange pink (5YR 7/2), angular to subrounded clasts (up to 2.0 cm). +10F: dominantly mixed varieties of dacite; 10% quartzite. +35F: contains 10% pumice.	507–512	5965.6–5960.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, silty sand with gravel (SM), pale yellowish-brown (10YR 6/2), angular to subangular clasts (up to 2.2 cm). +10F: dominantly dacite and silicified dacite; 1–3% quartzite. +35F: contains 10–60% pumice.	512–527	5960.6–5945.6
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded clasts (up to 1.7 cm). +10F: mostly dacite clasts, lesser amounts of pumice, 10% quartzite clasts. +35F: contains 5% pumice.	527–532	5945.6–5940.6
	Transitional Tpf/Tb2 interval. Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), angular to subrounded clasts (up to 1.7 cm). +10F: 30–35% dacite volcanic clasts; 65–70% altered basalt fragments; 3–5% quartzite clasts. Basal Tpf contact with underlying Tb2 estimated at 534 ft bgs	532–537	5940.6–5935.6
Tb 2, Santa Fe Group Basalt	Basalt, light brownish-gray (5Y 6/1), altered. +10F: highly altered basalt fragments; trace quartzite.	537–542	5935.6–5930.6
	Basalt, pale yellowish-brown (10YR 6/2), microcrystalline. +10F: fragments highly altered. +35F: contains abundant quartz sand (probably slough).	542–547	5930.6–5925.6
	Basalt, pale yellowish-brown (10YR 6/2), microcrystalline. +10F: 90% fine-grained basalt fragments that are highly altered and with green clay alteration. +35F: contains 50% pumice fragments (probably slough).	547–552	5925.6–5920.6
	Basalt, light olive-gray (5YR 6/1), microcrystalline, massive. +10F: fine-grained basalt fragments that are highly altered.	552–562	5920.6–5910.6
	Basalt, medium-dark gray (N4), microcrystalline, massive. +10F: fine-grained basalt, slightly vesicular.	562–570	5910.6–5902.6
	Basalt, pale brown (5YR 5/2), microcrystalline. +10F: fine-grained basalt scoria.	570–575	5902.6–5897.6
	Basalt, pale brown (5YR 6/2) to medium-dark gray (5G 4/1), porphyritic with aphanitic groundmass, vesicular. +10F: olivine phenocrysts mostly altered to iddingsite.	575–585	5897.6–5887.6
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. +10F: phenocrysts of olivine, plagioclase, and pyroxene; olivines partly altered or replaced by iddingsite; some calcite in-filling of vesicles.	585–595	5887.6–5877.6
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. +10F: olivines partly altered or replaced by iddingsite; some calcite in-filling of vesicles; yellowish clay present at 605–610 ft bgs.	595–610	5877.6–5862.6
	Basalt, reddish-brown (5YR 5/4), porphyritic with aphanitic groundmass, scoriaceous. +10F: basaltic scoria; olivines replaced by bright red-orange iddingsite, pyroxene and feldspar phenocrysts generally unaltered; groundmass moderately to highly altered; calcite filling vesicles common; orange-red clay present. WR sample clay rich.	610–615	5862.6–5857.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb 2, Santa Fe Group Basalt	Basalt, dark gray (N5), porphyritic with aphanitic groundmass, vesicular. +10F: altered phenocrysts of olivine, pyroxene, and plagioclase; white silica on some fractures; abundant calcite filling vugs and vesicles. WR sample clay rich.	615–625	5857.6–5847.6
	Basalt, gray (N6), porphyritic with aphanitic groundmass, vesicular. +10F: altered phenocrysts of olivine are yellow-brown with dark rinds; pyroxene and plagioclase phenocrysts mostly altered; calcite filling vugs and vesicles common.	625–635	5847.6–5837.6
	Basalt, greenish-black (5GY 2/1), porphyritic with aphanitic groundmass, massive. +10F: altered phenocrysts of olivine, pyroxene, and plagioclase; greenish powdery mineral locally lining vugs and vesicles.	635–650	5837.6–5822.6
	Basalt, greenish-black (5GY 2/1), porphyritic with aphanitic groundmass, massive. +10F: altered phenocrysts of olivine replaced by honey-colored iddingsite; pyroxene and plagioclase phenocrysts moderately fresh.	650–665	5822.6–5807.6
	Basalt, pale yellowish-brown (10YR 6/2) to moderate orange-pink (10r 7/4), porphyritic with aphanitic groundmass, scoriaceous. +10F: basalt scoria and cinders marking the base of Tb2; vesicles in-filled with calcite, white powdery mineral, and red-orange clay.	665–670	5807.6–5802.6
Tsf, Santa Fe Group Sediments	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2), fine to very coarse sand, angular to rounded grains. +10F: sand grains of basalt, quartz, and pumice; clay-cemented orange fragments present.	670–675	5802.6–5797.6
	Clastic sediments, clayey sand (SC), pale yellowish-brown (10YR 6/2), mostly coarse-grained sand in a clayey matrix, subrounded to rounded grains. +10F: sand grains of quartz with lesser amounts of basalt and pumice; gray and orange clay present.	675–680	5797.6–5792.6
	Clastic sediments, sand (SW) with clay and gravel (SW), grayish-orange pink (5YR 7/2), fine to coarse-grained sand and gravel (up to 1.0 cm), subrounded grains. +10F: gravel clasts of dacite, pumice, basalt, quartz.	680–685	5792.6–5787.6
	Clastic sediments, sand (SW) with clay, grayish-orange pink (5YR 7/2), clay to coarse sand grains that are subrounded. +10F: grains composed of dacite quartz, and pumice, commonly clay-cemented.	685–690	5787.6–5782.6
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2), rounded pebbles (up to 2.0 cm). +10F: clasts composed of dacite, quartz, pumice, and clay-cemented sandstone.	690–695	5782.6–5777.6
	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2). +10F: sand grains composed of dacite, quartz, basalt, and clay-cemented sandstone.	695–700	5777.6–5772.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group Sediments	Clastic sediments, sand (SW) with gravel, grayish-orange pink (5YR 7/2), pebbles (up to 2.2 cm) are subrounded to rounded. +10F: clasts composed of dacite, silicified dacite, plus minor quartz and basalt.	700–705	5772.6–5767.6
	Clastic sediments, gravel (GW) with sand, grayish-orange pink (5YR 7/2), pebbles (up to 2.0 cm) are subrounded to rounded. +10F: clasts composed of abundant intermediate volcanics (dacite, silicified dacite) and clay-cemented sandstone.	705–715	5767.6–5757.6
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2), pebbles (up to 2.0 cm) are subrounded to rounded. +10F: clasts composed of a variety of volcanic rocks (andesite, basalt, pumice) and minor quartzite; earth-brown clay fragments present.	715–720	5757.6–5752.6
Tb 2, Santa Fe Group Basalt	Basalt, medium gray (N4), porphyritic with aphanitic groundmass, slightly vesicular, highly altered. +10F: altered phenocrysts of olivine (red orange iddingsite) and plagioclase; vesicles commonly filled with calcite, zeolite, and Mn-oxides. WR sample clay rich.	720–735	5752.6–5737.6
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, massive, slightly altered. +10F: phenocrysts of olivine (greenish iddingsite); calcite on some fracture surfaces.	735–745	5737.6–5727.6
	Basalt, medium gray (N4), porphyritic with aphanitic groundmass, massive to vesicular, moderately altered. +10F: massive and vesicular basalt present, phenocrysts of olivine (reddish iddingsite); calcite, clay, and zeolite on fracture surfaces and filling vesicles; groundmass feldspars argillized.	745–755	5727.6–5717.6
	Basalt, medium gray (N4) to dark gray (N3), porphyritic with aphanitic groundmass, massive, moderately altered. +10F: olivine phenocrysts replaced by reddish iddingsite; alteration includes calcite, clay, and chlorite on fracture surfaces and filling vesicles; some clay-cemented fine sandstone and quartz sand present.	755–765	5717.6–5707.6
	Basalt, medium gray (N4) to dark gray (N3), porphyritic with aphanitic groundmass, massive to vesicular, moderately altered. +10F: massive and vesicular basalt present, ferromagnesian phenocrysts are oxidized, feldspar phenocrysts argillized; groundmass affected by sericite-chlorite and calcite alteration.	765–785	5707.6–5687.6
	Transitional Tb2/Tsf interval. Light gray (N6) basalt and pale brown (5YR 7/2) volcaniclastic sediments. +10F: 5–10% basalt, highly altered, some pale bluish chalcedony filling vesicles; 90–95% rounded, highly altered volcaniclastic gravel and clay-cemented sand.	785–790	5687.6–5682.6
	Basalt, medium gray (N4) to light gray (N5), porphyritic with aphanitic groundmass, vesicular, highly altered. +10F: ferromagnesian phenocrysts are oxidized with distinctive Fe-oxide rinds, feldspar phenocrysts argillized; amygdaloidal clay and calcite. WR sample clay rich.	790–795	5682.6–5677.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group Sediments	Clastic sediments, sandy clay (CH) with gravel, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 2.5 cm). +10F: variety of altered, silicified volcanic lithologies, rare basalt, minor quartzite.	795–805	5677.6–5667.6
	Clastic sediments, sand (SW) with gravel and clay, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 1.5 cm). +10F: 90% volcanic lithologies of felsic to intermediate composition; 10% sandstone fragments. +35F: abundant quartz sand grains present. WR: sample clay rich.	805–815	5667.6–5657.6
	Clastic sediments, gravel (GW) with sand, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 2.0 cm). +10F: dominantly volcanic lithologies similar to interval 805–815 ft, abundant indurated sandstone fragments.	815–820	5657.6–5652.6
	Clastic sediments, gravel (GW) with sand, pale yellowish-brown (10YR 6/2), rounded pebbles (up to 2.0 cm). +10F: dominantly volcanic lithologies similar to 805–815, abundant indurated sandstone fragments.	820–841	5652.6–5631.6
	Clastic sediments, clay (CH) with sand and gravel, grayish-orange pink (5YR 7/2), subrounded pebbles (up to 2.0 cm). +10F: dominantly intermediate and lesser felsic volcanic lithologies, local clay and Mn-oxide clasts present. +35F: fine to medium sand made up of quartz and diverse volcanic lithologies. WR sample clay-rich.	841–850	5631.6–5622.6
Tb 2, Santa Fe Group Basalt	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, vesicular to massive, highly altered. +10F: basalt is intensely altered; olivine phenocrysts are distinctively greenish in color with iddingsite rims; phenocryst and groundmass feldspars completely argillized, or vacated, resulting in a pitted and vuggy surface texture; abundant amygdaloidal calcite.	850–865	5622.6–5607.6
	Basalt, dark gray (N3), porphyritic with aphanitic groundmass, massive, highly altered. +10F: continued intense rock alteration with vuggy textured appearance; altered olivine phenocrysts pale greenish with opaque rims; small amount of rounded pebbles (up to 1.5 cm) made up of basalt and intermediate porhyritic volcanic rocks. Note: thin interlayer (1 to 2 ft thick) of volcaniclastic sediments possibly present.	865–870	5607.6–5602.6
	Basalt, dark gray (N3), slightly porphyritic with aphanitic groundmass, massive, moderately altered. +10F: rock alteration considerably diminished, groundmass minerals distinguishable. WR sample clay-rich in lower 5 ft.	870–887	5602.6–5585.6
	Transitional Tb 2/Tsf interval. WR sample contains 50% basalt as described in interval 870 to 887 ft that is partly scoriaceous; 50% granules and pebbles of basalt and other diverse volcanic lithologies; clayey matrix.	887–892	5585.6–5580.6

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group Sediments	Clastic sediments, gravel (GW) with sand, pale brown (5YR 5/2), subangular to rounded pebbles (up to 2.0 cm). +10F: 10–20% carbonate altered basalt and intermediate to felsic volcanic rocks, 80–90% fragments of indurated fine-grained sandstone. Basal Tb 2 contact with underlying Tsf sediments estimated at 893 ft bgs.	892–897	5580.6–5575.6
	Clastic sediments, clayey sand (SC) with gravel, pale brown (5YR 5/2), subrounded pebbles (up to 2.0 cm). +10F: pebbles of indurated fine-grained sandstone and of a variety to intermediate to felsic volcanic rocks. +35F: contains abundant volcanic rocks and frosted sand grains of quartz and quartzite.	897–902	5575.6–5570.6
R-5 BOREHOLE COMPLETED AT 902 FT BGS TOTAL DEPTH (TD)			

Notes:

1. American Society for Testing and Materials ([ASTM] D 2488-90. Standard Practice and Identification of Soils [Visual-Manual Procedure]) standards were used in describing the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Formation. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following is a glossary of standard USCS symbols used in the R-5 lithologic log:.

SW = Well-graded sand	SM = Silty gravel	CH = Clay, high plasticity
GW = Well-graded gravel	GM = Silty gravel	SC = Clayey sand
GP = Poorly graded gravel	GC = Clayey gravel	

2. Cuttings at R-5 were collected from ground surface to 902 ft bgs at nominal 5-ft intervals. Each sample was divided into three sample splits: (1) unsieved, or whole rock (WR), sample; (2) +10F sieved fraction (No. 10 sieve equivalent to 2.0 mm); and (3) +35F sieved fraction (No. 35 sieve equivalent to 0.50 mm).
3. The term *percent*, as used in the above descriptions, refers to percent by volume for a given sample component.
4. Color designations such as hue, value, and chroma (e.g., 5YR 5/2) are from "The Geological Society of America Rock-Color Chart."

Appendix C

LANL Borehole Video Log
(CD attached to inside back cover)

TO VIEW THE VIDEO THAT ACCOMPANIES THIS DOCUMENT, PLEASE CALL THE HAZARDOUS WASTE BUREAU AT 505-476-6000 TO MAKE AN APPOINTMENT

Appendix D

Schlumberger Geophysical Report and Montage
(CD attached to inside back cover)

GEOFRAME
PROCESSED
INTERPRETATION

Integrated Log Well Montage

Processed Wireline Geophysics Data

*A Mark of Schlumberger

Using the following logs: CNTG*, LDTD*
NGT

COMPANY:	Washington Group / LANL
WELL:	Characterization Well R-5
FIELD:	LANL Characterization and Monitoring Well Network
COUNTY:	Santa Fe
STATE:	New Mexico
COUNTRY:	U.S.
Date Logged:	21-May-2001 Date Processed: 13-Feb-2003
Well Location:	Lower Pueblo Canyon

Elevations: KB: DF: GL:

API Number: Job Number:

FOLD HERE The well name, location, borehole reference data were furnished by the customer.

Field Recording:	Location:	Farmington	Software Version:	9C2-303	Engineer:	Hudson
Office Recording:	ICS Center:	SKS Sacramento	Baseline:	GF3.8.1	Log Analyst:	N. Clayton

Mud and Borehole Measurements:

Rm @ Measured temperature:	@	BHT:	Bitsize: 12.2 in
Rmf @ Measured temperature:	@	Type Fluid in Hole	Water / Air
Rmc @ Measured temperature:	@	Mud Density: 8.30 lbm/gal	

Remarks:

NGT run used as primary depth reference.
Thick steel casing present in borehole except at very bottom.
Neutron and density logs adversely affected by air/water/mud-filled annulus between casing and formation.
Logs are corrected for casing and fluid in casing, but not the annulus.

Geophysical Logging Report

Schlumberger Water Services
February 2003

TABLE OF CONTENTS

1.**0** **ABSTRACT**

This report describes the borehole geophysical logging measurements acquired in characterization well R-5 by Schlumberger, logged in May 2001 just prior to well completion. It also presents the final processed results from these measurements and discusses the interpretation of these results. The logs were acquired through 11.75 in. outer diameter steel casing, used in casing-advance drilling with 12.25 in. diameter bit size, except for a very short open hole section at the bottom of the borehole. The primary purpose of the geophysical logging was to characterize the geologic/hydrogeologic section intersected by the well with emphasis on determining moisture content, perched groundwater zones, capacity for flow, and the stratigraphy/mineralogy of geologic units. These objectives were accomplished by measuring, nearly continuously, along the length of the well: (1) water-filled porosity, (2) bulk density (sensitive to total water- plus air-filled porosity), and (3) spectral natural gamma ray, including potassium, thorium, and uranium concentrations.

Preliminary results of these measurements were generated in the logging truck at the time the geophysical services were performed and are documented in field logs provided on-site. However, the measurements presented in the field results are not corrected for borehole casing and fluid conditions and are provided as separate, individual logs. The field results were reprocessed by Schlumberger to (1) correct/improve the measurements, as best as possible, for borehole/formation environmental conditions, (2) perform an integrated analysis of the log measurements so that they are all coherent, and (3) combine the logs in a single presentation, enabling integrated interpretation. The reprocessed log results provide better quantitative property estimates that are consistent for all applicable measurements, as well as estimates of properties that otherwise could not be reliably estimated from the single measurements alone (e.g. total porosity inclusive of all water and air present, water saturation, grain density).

Overall the geophysical log measurements from Well R-5 provide good quality results that are consistent with each other through most of the borehole, although the quality of the porosity and bulk density measurements was degraded in certain sections where the borehole contains large washouts behind the free-standing casing. The measurement most affected by the adverse borehole conditions was the bulk density because it has a shallow depth of investigation and requires close contact to the borehole wall; instead of measuring formation properties it at least partially measures borehole fluid properties. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements are reduced. Thus, the integrated log analysis results (e.g. the optimized water-filled porosity log) are the most robust single representation of the geophysical log results—providing valuable high resolution information on the geologic and hydrogeologic environment of the R-5 locale.

Important results from the processed geophysical logs in R-5 include the following.

1. Above 534 ft the estimated water saturation is consistently below 50%, indicating that there are no significant perched water zones above this depth and the regional aquifer groundwater level lies below. The water level in the borehole, both inside and outside the free-standing casing, was 711 ft at the time the geophysical logs were acquired. The estimated water saturation is 100% or quite high through much of the section below this depth. However, there are also zones showing full saturation above 711 ft and below 534 ft. These results, interpreted independent of other data sources, suggest that the regional aquifer groundwater level may lie at 711 ft, or their could be saturated conditions as high as 534 ft.

2. The highest water-filled porosities are near the bottom of the log interval from 711–850 ft., varying from about 25-45% with the highest values at the top and bottom of the zone.

3. The lowest water-filled porosities (5-10%) are at the top of the log interval (39–120 ft) and in the zone 560–670 ft. The total and air-filled porosity is high in the top zone and low in the bottom zone.

- 4. Significant geologic contacts appear to be present at 73 ft, 152 ft, 338 ft, 534 ft, 612 ft, 723 ft, 790 ft, 849 ft, and 860 ft—marked by changes in the lithology/mineralogy of the optimized mineral-fluid model that is estimated from the integrated log analysis.

2.0 INTRODUCTION

Geophysical logging services were performed in characterization well R-5 by Schlumberger in May 2001, prior to initial well completion. The purpose of these services was to acquire in situ measurements that help characterize the borehole, near-borehole, and abutting geologic formation environment. The primary objective of the geophysical logging was to provide in situ evaluation of formation properties (hydrogeology and geology) intersected by the well. This information was (and is) used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to design the well completion, better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging services performed by Schlumberger in well R-5 were the

- Compensated Neutron Tool, model G (CNTG*) to measure volumetric water content of the formation, which is used to evaluate moist/porous zones;
- Litho-Density Tool (LDT) to measure formation bulk density , which is used to estimate total porosity;
- Natural Gamma Spectroscopy (NGS) tool to measure gross natural gamma and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, which is used to evaluate geology, including stratigraphic contacts and lithology.

In addition, calibrated gross gamma ray (GR) was recorded with every service except the NGS, for the purpose of depth matching the logging runs to each other. Table 2.1 summarizes the geophysical logging runs performed in R-5.

Table 2.1
Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in Borehole R-5

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Depth Interval (ft)
21-May-2001	Steel casing without any emplaced annular material above 850 ft. Casing OD of 11.75 in. Bit size of 12.25 in. Open hole below 850 ft. Bitsize of 12.25 in.	1	NGS		14–866 ft
Same	Same	2	CNTG	GR	46–866 ft
Same	Same	2	LDT	GR	92–874 ft

* Mark of Schlumberger

2.1 Technology Description

Geophysical logging represents mature, yet constantly evolving, technologies employed as the principal methods of borehole analysis in subsurface characterization. Geophysical logs have a long history of use in the groundwater industry for aquifer delineation and basic characterization. More recently, advanced logging technologies, developed for the petroleum industry, are being applied for characterizing a wide range of groundwater-related physical properties.

Wireline geophysical logging systems consist of three components (Figure 2.1):

1. downhole instrument (or sonde) introduced into a borehole that measures one or more physical properties of the formation (a logging “tool” is usually defined as the sonde plus required accompanying electronic cartridges;
2. cable that connects the sonde to the surface, conducting power downhole and transmitting data uphole; and
3. logging truck that controls sonde location, provides power and houses a computer that controls sonde operation, as well as processes and displays data in real time. The resulting data are shown on a continuous strip chart commonly called a log.

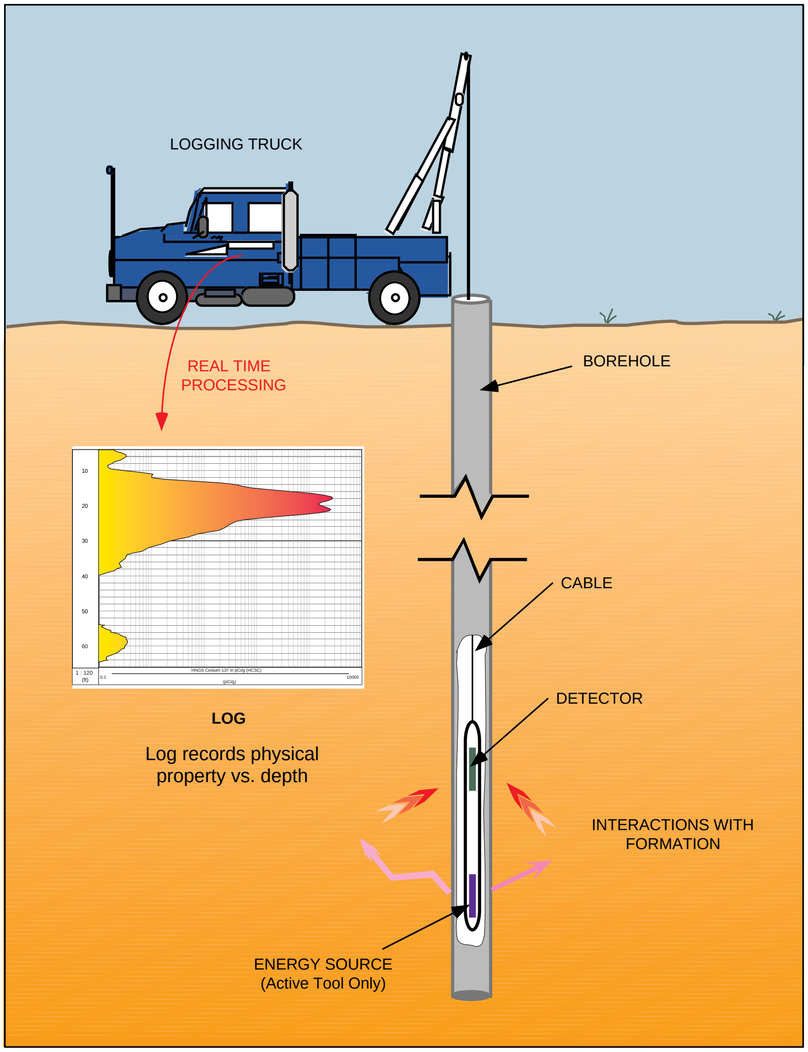

Figure 2.1: Schematic diagram of a wireline logging system in operation.

Geophysical logging systems are designed to give an accurate and precise in situ measurement of formation properties. Formation parameters commonly measured include porosity, moisture content, bulk geochemistry, hydraulic conductivity, orientation of bedding and fractures, identification and quantification of specific radionuclides and other elements, and many others. Similarly, logging systems provide accurate and precise measurements of completed well parameters, such as casing geometry, casing thickness, cement bond, and annular fill composition. Logging systems can also be used for downhole sampling and testing.

The integration of multiple logging technologies plus other data types (e.g., geologist's log, core analyses, surface geophysics, hydrologic test analyses) can lead to a fairly comprehensive picture of the subsurface. The precision of the measurements, in concert with the potential to measure the same volume repeatedly (i.e., re-enter the same borehole), enhances the use of logging systems for monitoring.

2.1.1 Compensated Neutron Tool, Model G (CNTG)

The CNTG tool measures the hydrogen index (HI), which is usually closely related to hydrogen concentration and water volume and can be employed in either open or cased, water or air filled boreholes. The HI measurement is made by emitting high-energy neutrons from a 16-Ci Americium-Beryllium neutron source, which collide with atoms in the volume surrounding the tool and are slowed to epithermal and thermal energy levels. The number of slowed neutrons returning to a set of detectors is then measured. The CNTG contains two He-3 thermal detectors, spaced 37.8 cm (15 in.) and 62 cm (24.7 in.) above the neutron source, as well as two He-3 epithermal neutron detectors spaced 11.6 in. and 20.5 in. below the source. This model of the CNT makes an HI measurement from epithermal neutrons in addition to one from thermal neutrons. The detectors count the neutrons that have been reduced to thermal/epithermal energy level. Measured count rates from the detectors are used to compute a ratio that varies primarily with the hydrogen concentration, or HI, of the media, and is related to formation water-filled porosity. Environmental effects are reduced using the ratio of the two count rates from the two detectors, which are affected in a similar manner by the environment. Residual environmental effects can be corrected with offsite processing. While the HI measurement is calibrated to provide a volumetric water content estimate, it is affected by lithology; it measures all hydrogen in clays, including that in hydroxyl molecules, as well as other oddball neutron absorbers, typically resulting in an elevated porosity in clays.

The CNTG provides two different porosity measurements, thermal and epithermal. The advantage of the epithermal measurement is that it provides a measurement in air-filled boreholes (not possible with the thermal measurement) and is relatively insensitive to thermal neutron absorbers (such as chlorine in salt water and the rare earth elements in shale). However, because of less efficient detection and of the relatively brief time spent by the neutrons in the epithermal energy band, epithermal count rates are lower than thermal count rates, under identical conditions in water-filled boreholes, by a factor of ten.

The measurements are calibrated in open and cased boreholes, albeit the measurement will be affected by the annular fill between the casing and the formation. The median depth of investigation is approximately 7 in. and vertical resolution approximately 18 in., although the thermal measurement can be resolution-enhanced to 8 in.

Basic measurement specifications for the CNTG are shown below.

Range of Measurement (water content):	0 to 60 %
Repeatability (Precision) (1 standard deviation or σ):	0– 20% = <1% porosity 20 to 30% = ± 2% porosity above 45% = ± 5% porosity

2.1.2 Litho-Density Tool (LDT)

The LDT is a dual-detector gamma-gamma (gamma ray source and gamma ray detectors) system for measuring compensated bulk density and formation photoelectric factor (P_e). Formation bulk density is a function of porosity, rock matrix density, and pore fluid density and P_e is a measure of the average atomic number of the formation, which is correlated to formation chemistry and lithology. The tool uses a focused gamma source (1.5-curie 137Cs) to emit a large flux of gamma rays into the formation and measures the resulting gamma intensity in dual near and far detectors. From these spectral measurements, a robust, environmentally corrected calculation of bulk density is made. True matrix porosity can be calculated based on bulk density, an estimation of matrix grain density (aided by the P_e measurement) and fluid densities. This porosity is unaffected by bound hydrogen in clays, as is porosity from neutron devices. The detectors, like the source, are highly focused due to their small size and heavy shielding—producing a high resolution measurement.

The LDT has a vertical resolution as high as 1.2 in. (3 cm) and a depth of investigation of 4 in. (10 cm). The tool is sensitive to changes in bulk density down to 0.01 g/cm^3 and can be run in open hole and certain types of cased hole completions, and in both saturated and unsaturated formations.

The LDT uses a pad-like skid that is pressed against the borehole wall. Because the tool has a relatively shallow depth of investigation it can be severely affected by borehole washouts and rugosity, especially behind casing.

Basic measurement specifications for the LDT measurements are shown below and a schematic diagram of a LDT-type sensor system is shown in Figure 2.2. Further technical information can be found in [Scott 1995].

Range of Measurement (bulk density):	1 to 3 g/cc
Range of Measurement (P_e):	0.6 to 10
Repeatability (Precision) (1 standard deviation or σ):	± 0.015 g/cc
Total Error (bulk density):	1.0 to 1.6 g/cc = ±0.02 g/c 1.6 to 3 g/cc = ±0.01 g/cc
Accuracy (P_e):	10% of measurement

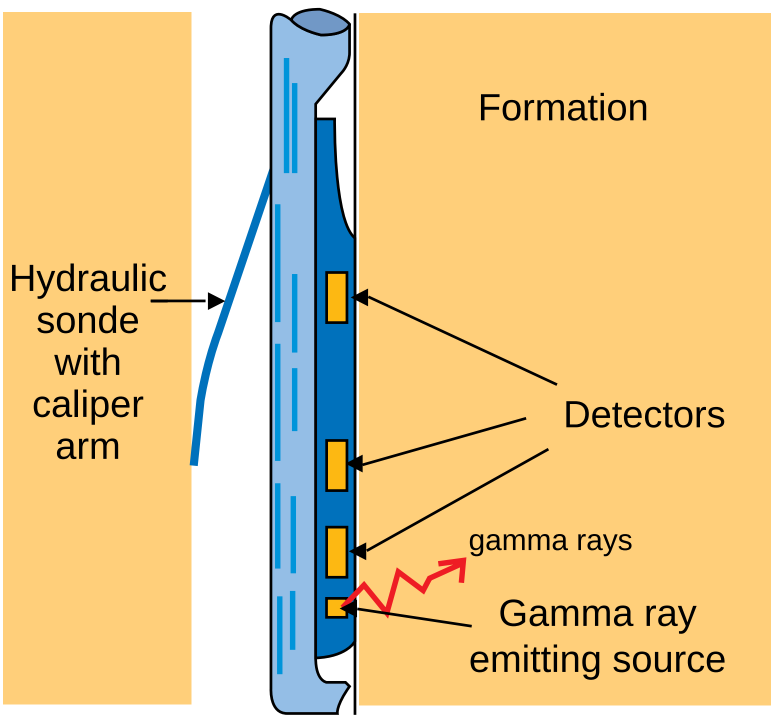

Figure 2.2. Schematic diagram of LDT-type density logging system.

2.1.3 Natural Gamma Ray Spectroscopy (NGS) tool

The NGS tool is a passive gamma ray measuring sonde that can be used in either open or cased boreholes. The tool measures the natural gamma activity energy spectrum with two sodium-iodide crystal detectors, and uses a spectral weighted-least squares processing algorithm to resolve the three most common components of naturally occurring radiation — potassium, thorium, and uranium. The tool is designed for continuous logging and provides a depth/time averaged continuous log of the three elemental components in relative weight %. In addition, the standard gamma ray, and gamma ray minus uranium, are computed. The spectral gamma measurements are useful for analyzing and correlating geologic/lithologic stratigraphy, as well as evaluating clay type and clay content, especially when integrated with other types of log measurements.

Basic measurement specifications are shown below.

Basic specifications for the NGS and a schematic diagram of the measurement sensor are shown below and in Figure 2.3, respectively.

Range of measurement:	GR	0 to >750 API units;
	K	0 to ~50%;
	Th	0 to ~10,000 ppm;
	U	0 to ~10,000 ppm
Statistical precision (σ):	Th–1.5 ppm; U–0.9 ppm; K–0.25%	
Min./Max. hole size:	4.5 in. / 24 in.	
Depth of Investigation:	9.5 in (24 cm)	

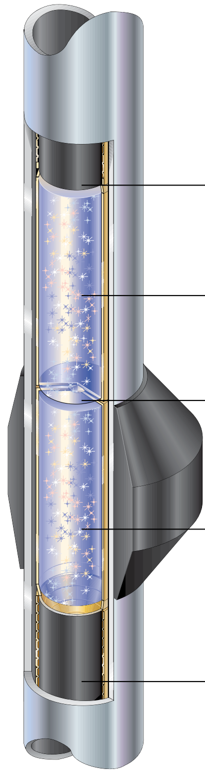

Figure 2.3. Schematic diagram of NGS-type sensor

3.0 METHODOLOGY

This section describes the methods employed by Schlumberger for performed geophysical logging services in Well R-5, including the following stages/tasks:

- Measurement acquisition at the well site
- Quality assessment of logs
- Reprocessing of field data

3.1 Acquisition procedure

Once the well drilling project team notified Schlumberger that each well was ready for geophysical well logging, the Schlumberger district in Farmington, NM, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the LANL site, the crew completed site entry paperwork and received site-specific safety training.

After arriving at the well site, the crew proceeded to rig up the wireline logging system, including

1. parking and stabilizing the logging truck in a position relative to the borehole that is best for performing the surveys;
2. performing any required environmental protection procedures (e.g., covering the ground with plastic liner, where the tools will be assembled, and around the well) as specified in the work order;
3. setting up a lower and an upper sheave wheel (the latter attached to, and hanging above, the borehole from the drilling rig/mast truck);
4. threading the wireline cable through the sheaves; and
5. attaching the appropriate sonde(s) for the first run to the end of the cable.

Next, pre-logging checks and any required calibrations were performed on the logging sondes and the tool string was lowered into the borehole. If any of the tools required active radioactive sources (in this case a neutron and gamma source for the CNTG and LDTD, respectively) just prior to lowering the tool string, the sources were taken out of their carrying shields and placed in the appropriate tool source-holding locations using special source handling tools. The tool string was lowered to the bottom of the borehole and brought up at the appropriate logging speed as measurements were made. At least two logging runs (one main and one repeat) were made with each tool string.

Upon reaching the surface any radioactive sources were removed from the tools and returned to their appropriate storage shields, thus eliminating any radiation hazards. The tool string was cleaned as it was pulled out of the hole.

The second tool string was attached to the cable for another suite of logging runs.

After completion of the surveys, any post-logging measurement checks were performed. Before departure, the engineer printed the field logs (including calibration summaries) for on site distribution and sent the data via satellite to the Schlumberger data archiving center in Sedalia, CO. The Schlumberger data processing center was alerted that the data were ready for initial post-acquisition processing.

3.2 Log Quality Control and Assessment

Schlumberger has a thorough set of procedures and protocols for ensuring that the geophysical logging measurements are of very high quality. This includes careful calibration of tools when they are first built, regular recalibrations and tool measurement/maintenance checks, and real-time monitoring of log quality as measurements are made. Indeed, one of the primary responsibilities of the logging engineer is to ensure, before and during acquisition, that the log measurements meet prescribed quality criteria.

CNTG

The calibration and verification methodology for the CNTG consists of an initial base calibration and verification, monthly shop verification, and a wellsite before and after verification. The initial base calibration constitutes the development of a measurement to moisture content algorithm for a certain set of environmental conditions. The calibration is based on Monte Carlo computer modeling and measurements in the Schlumberger EECF calibration models in Houston, TX. This initial base calibration only has to be performed once for a certain set of conditions.

Schlumberger also performs what is called a “master calibration,” which is actually a verification of water-filled borehole conditions where the CNTG measurements are checked in a water tank with known saturated porosity. In addition, detector and neutron generator electronics are checked, and detector plateau voltages are set.

Detector electronics verifications are also performed before and after every logging run of the CNTG, constituting the well site before and after verifications.

NGS

The Schlumberger calibration and verification methodology for the NGS, similar to the CNTG, consists of an initial base calibration and verification, routine shop verification, and a wellsite before and after verification. The initial base calibration constitutes the development of measurement to gross gamma activity and spectral gamma activity algorithms, accounting for environmental conditions that influence the measurements. The initial base calibration only has to be performed once for a certain set of conditions.

The NGS gross gamma measurement in API units is made by taking a linear combination of U, Th, and K gamma activity yields to determine total count rates and then converting total count rates to API units. The coefficients of the linear combination and the API conversion are determined from the NGS response in the API test pits at the University of Houston (the API calibration standard) and calibration facilities at the Schlumberger Environmental Effects Calibration Facility (EECF) in Houston, which are tied to the API test pits.

In order to calibrate the spectral gamma activity measurements the response function of the NGS to each radioactive isotope of interest must be determined. The response function is the spectrum that would be observed by the tool for a given detector resolution and gain if just the one element were present and evenly distributed in the formation in a certain concentration. Such a spectrum is called a spectral standard. For natural gamma ray logging Th, U and K standards are used. Test formations with known concentrations of radionuclides at the API test pits and EECF are used to determine the NGS spectral standards.

The routine shop verification, referred to as a “master calibration” by Schlumberger, consists of measuring the NGS response to a thorium blanket with known Th activity and a background check. During the background check the detector response to an internal ^{22}Na stabilization source is measured. In addition, detector electronics checks are performed. The primary task of the shop verification is to set the electronic gain ratios properly so that the Th and ^{22}Na gamma peaks occur at the correct energy levels.

NGS response to the stabilization source and detector electronics verifications are also performed before and after every logging run of the NGS, constituting the wellsite before and after verifications.

LDT

Similar to the CNTG and NGS, the calibration and verification methodology for the LDT consists of an initial base calibration and verification, monthly shop verification, and a well site before and after verification. The initial base calibration constitutes the development of a measurement to bulk density algorithm for a certain set of environmental conditions. The calibration is based on Monte Carlo computer modeling and measurements in the Schlumberger EECF calibration models. This initial base calibration only has to be performed once for a certain set of conditions.

The routine shop verification consists of checking the LDT bulk density measurement for uncased borehole conditions by making the measurement in materials with known densities. In addition, a background check with the gamma source removed from the tool is performed to verify that the system response to the 622 keV ^{137}Cs stabilization source located on each of the two detectors is accurate.

The background check is also performed before and after every logging run of the LDT, constituting the well site before and after verifications.

3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data archived, the data were downloaded to the Schlumberger processing center. There the data were processed, in the stated order to (1) correct the measurements for near-wellbore environmental conditions and redo the raw measurement field processing for certain tools using better processing algorithms, (2) depth match and merge the log curves from different logging runs, and (3) model the near-wellbore substrate lithology/mineralogy and pore fluids through integrated log analysis. Afterwards an integrated log montage was built to combine and compile all the processed log results.

Environmental Corrections and Raw Measurement Reprocessing

If required, the field log measurements were processed to correct for conditions in the well, including fluid type (water or air), presence of steel casing, and (to a much lesser extent) pressure and temperature. Basically these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In R-5 the log measurements requiring these corrections are the CNTG porosity, LDT density, and NGS spectral gamma ray logs.

The CNTG epithermal neutron moisture content measurement in air-filled hole is derived using an entirely different processing algorithm than applied in water-filled hole; this processing is performed in the field.

The standard open hole processing algorithm used for the LDT density measurement is influenced by the steel density in cased hole. A cased hole density algorithm was applied to the raw LDT field measurements to try to eliminate the casing response. While the algorithm can account for the casing per say, it can not account for air- or water-filled gaps in the annulus between the casing and the formation—that cause erroneously low bulk density readings.

The NGS spectral gamma ray are affected by the material (fluid, air, casing) in the borehole because different types and amounts of these materials have different gamma ray shielding properties; the NGS measures incoming gamma rays emitted by radioactive elements in the formation surrounding the borehole. The processing algorithms try to correct for the damping influence of the borehole material.

All the measurements cannot be corrected for borehole washouts, rugosity, and the annulus material (if any) between casing and the formation; thus, the effects of these conditions should be accounted for in the interpretation of the log results.

Depth-Matching

Once the logs were environmentally corrected for the conditions in the wellbore and the raw measurement reprocessing was completed, the logs from different logging runs were depth-matched to each other using the NGS tool run as the base reference. Gamma ray was used as the common correlation log measurement for depth-matching the different runs.

Integrated Log Analysis

This analysis was performed using the Elemental Log Analysis (ELAN*) program. ELAN is a petrophysical interpretation program (Mayer and Sibbit, 1980; Quieren et al, 1986) designed for quantitative formation evaluation of cased and open-hole logs level by level. Evaluation is done by optimizing simultaneous equations described by one or more interpretation models.

The primary purpose of ELAN is solving the inverse problem in which log measurements, or tools, and response parameters are used together in response equations to compute volumetric results for formation components. This relationship is often presented in the triangular diagram below (Figure 3.1).

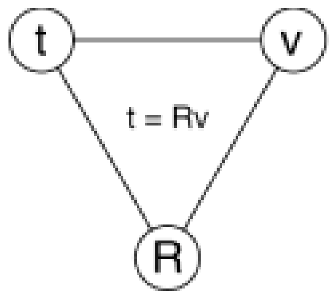

Figure 3.1. Schematic diagram of ELAN mathematical model

In this figure, t represents the tool vector—all logging instrument data and synthetic curves. The v is the volume vector, the volumes of formation components. R is the response matrix, containing the parameter values for what each tool would read, given 100% of each formation component. Given the data represented by any two corners of the triangle, ELAN can determine the third.

Additionally, ELAN includes methods by which individual models can be mixed and spliced to provide a combined model for more complex environments and large borehole extents. Each individual model is specified in a separate “Solve” process. The final result is produced by mixing and splicing the results from individual models in a “Combine” process.

The quality of the ELAN results can be assessed by reconstructing the individual geophysical logging curves from the solution and comparing them to the original data. However, a “good” fit does not necessarily mean the correct ELAN, as the answer is non-unique. The degree of match between input and output curves is summarized as an error curve.

ELAN requires an a priori specification of the volume components present within the formation—fluids, minerals, and rocks. For each component, the relevant parameters for each tool are also required. For example, if one assumes that quartz is a volume component and the bulk density tool is used, then the bulk density parameter for this mineral is usually assumed to be 2.65 g/cc.

A key point in properly using ELAN is the input of the most representative parameter values possible. For certain minerals (e.g., quartz) most parameter values are fairly constant and easy to select; other

* Mark of Schlumberger

minerals (e.g., clays) present the potential for wide variability in many parameters due to compaction (sonic slowness, bulk density) and minor changes in chemistry (Th, K, Fe, Al, H). Estimation of parameters, or their changes with depth, can be a major limitation to ELAN. Geochemical logs (one of which, NGS, was acquired in R-5) are particularly helpful measurements for ELAN since they provide abundances of a number of important mineral forming elements.

ELAN simultaneously solves for multiple volume components using different tools. Some tools are highly influenced by parameters other than mineralogy and pore fluid (e.g., sonic), including geomechanical properties and borehole environmental conditions that cannot be corrected for in pre-processing. The dependency of the tool measurements on these conditions depends on the specific tool type and measurement. Including log measurements that are being highly influenced by these properties in the ELAN can significantly affect the solution, since variations in the logs are not only due to changes in mineralogy or pore fluid—what ELAN is trying to estimate. For example, if some of the logs are sensitive to washouts ELAN will try to match the log response in washed out zones by increasing the amount of porosity in the model, possibly at the expense of matching other log measurements used in the analysis that are not as sensitive to washouts (although the latter can be rectified by assigning more weight to the better logs). If some of the logs are affected by borehole conditions, or other properties not explicitly accounted for in the model (e.g. formation water salinity), while the others are not, often there is a poor match between modeled and actual log measurements in intervals where there are variations in these unaccounted for properties. Sometimes the solution can also become unstable—the model results change significantly due to only minor variations in log responses. In such cases it may be better to not include such measurements in the ELAN. In short, ELAN results are only as accurate at depicting true formation mineralogy and fluid content as the input logs are sensitive to the formation components included in the model—and insensitive to components/properties not included.

The tool measurements, volume components and parameters used in the ELAN analysis for R-5 are provided in Table 3.1. To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (39–869 ft.), as many as possible of the processed logs were included in the analysis, with less weighting applied to less robust logs. Unfortunately, only a limited suite of logs were run in R-5, allowing only a limited number of possible mineral/rock constituents to be included in the ELAN analysis. Many of the minerals likely present in the logged section could not be included. Thus, the mineral model resulting from the ELAN analysis does not represent a full representation of the actual mineral makeup, but still provides the best estimate of porosity (air and water filled) and water saturation, as well as matrix grain density and qualitative information about the types of minerals present.

The ELAN analysis was performed with as few constraints or prior assumptions as possible. A considerable effort was made to choose a set of minerals or mineral types for the model that is representative of Los Alamos area's geology and it's volcanic origins. No prior assumption is made about water saturation—where the boundary between saturated (if any) and unsaturated zones lies (e.g. the depth to the top of the regional aquifer or perched zones). Thus, the presence and amount of air in the pore space is unconstrained. Total porosity and water-filled porosity are also left unconstrained throughout the analysis interval. There are many places where bulk density is very low and/or neutron porosity is very high—likely due to air- and/or water-filled voids behind the casing—resulting in very high, physically impossible, air- and/or water-filled porosity in the ELAN solution. (The bulk density and neutron porosity drive the ELAN total porosity and water-filled porosity, respectively, since bulk density is the only measurement directly sensitive to total porosity, while neutron porosity is the most sensitive measurement to water-filled porosity.) It was felt that the ELAN analysis should be performed with as few constraints as possible—even though the resulting model shows the effects of washouts and annular voids behind the casing (as elevated porosity)—in order to guard against presumptions that the results are conclusive when in fact they may not be. Thus, interpretations should be made from the ELAN results with the understanding that the mineral-fluid model represents a mathematically optimized solution that is not necessarily a physically accurate representation of the native geologic formation. Within this context, the ELAN model is a robust estimate of the bulk mineral-fluid composition that accounts for the combined response from all the geophysical measurements.

Table 3.1
Tool measurements, volumes, and respective parameters used in the R-5 ELAN analysis .

Volume / Tool Measurement	Air	Water	Hypersthene	Labradorite	Silica Glass	Heavy Mafic Minerals	Orthoclase
Bulk density (g/cc)	–0.19	1.00	3.55	2.65	2.2	4.0	2.58
Thermal neutron porosity (ft^3/ ft^3)	–0.05	1.00	0.04	-0.01	0.0	0.07	-0.01
Epithermal neutron porosity (ft^3/ ft^3)	-0.02	1.00	0.01	-0.01	0.0	0.02	-0.01
Volumetric Photoelectric Effect	0.0	0.40	20.2	7.0	4.2	65	7.3
Wet weight potassium (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.102
Wet weight thorium (ppm)	0.0	0.0	25	3	2	4	5.5

4.0 RESULTS

This section describes the final log results from the borehole geophysical logging performed by Schlumberger in R-5. These results have been processed, if required, to correct for the well environment and depth-match the logs from different tool runs in the well. Also, some of the results are not directly measured logs but are instead logs generated from integrated analysis of measured logs. In the following description of the results, an attempt is made to organize the discussion based on the evaluation needs addressed by the logs instead of describing each log independently.

The log results are presented as continuous curves of the processed measurement versus depth and are displayed as (1) summary log displays for selected directly related sets of measurements and (2) an integrated log montage that contains all the final log curves, on depth and side by side. The summary log displays address specific characterization needs, such as moisture content. The purpose of the integrated log montage is to present, side by side, all the most salient reprocessed logs and log-derived models, depth-matched to each other, so that correlations and relationships between the logs can be identified.

First the R-5 final processed log results are presented as a number of useful summary logs and described according to specific evaluation needs addressed by the geophysical logs. Next, the integrated log montage is described track by track.

4.1 Water-Filled Porosity

One of the primary objectives of the geophysical logging was to evaluate volumetric water content (water-filled porosity) to identify wet and porous water-producing zones. The CNTG neutron porosity, which measures water content in both open and cased hole above and below the borehole water level, was the primary service run for this purpose. The LDT bulk density measurement provides useful information about total porosity—the sum of water-filled and air-filled porosity. In Well R-5 the CNTG neutron porosity and LDT bulk density appear to be adversely impacted by fluid-filled voids behind the free-standing casing that was present throughout the well at the time of logging—yielding unrealistically high water content and total porosity values in some places. The LDT bulk density appears to be much worse affected by this condition, probably due to it's shallow depth of investigation (approximately 2 in) compared to the CNTG neutron porosity (approximately 9 in).

To provide accurate quantitative measurements of total volumetric water fraction behind the casing, the CNTG and LDT field measurements had to be corrected for borehole environmental conditions, primarily the casing and borehole fluid type. The CNTG neutron porosity field measurements did not require any additional environmental corrections beyond those applied at the time of the measurement. The LDT field measurements required reprocessing for casing. As noted above, the measurements cannot be corrected for the effects of enlarged casing-to-formation annulus due to borehole washouts and rugosity (causing an increased borehole fluid response), since the specific characteristics of the annular voids (e.g., geometry) are unknown and their effects on the measurements too complex to account for. Thus, it should be understood that the porosity measurements are highly influenced by borehole diameter variations, especially when there are large washouts behind the casing that are filled with drilling mud or water.

The best estimate of true water content is obtained from the ELAN integrated log analysis, since none of these measurements actually directly measures volumetric water content. This analysis accounts for the individual measurement response to each matrix and pore volume constituent, as well as the relative uncertainty in the measurements, in solving for a single matrix-pore volume model at each depth that best accounts for the processed measurements results. The limited number of log measurements in R-5 necessitated that the ELAN analysis rely predominantly on the CNTG neutron porosity to estimate water-filled porosity.

The ELAN water-filled porosity results for R-5 are shown as part of the summary logs in Figure 4.1 (solid dark blue curve and blue shading in the second track from the right), and in expanded form, as part of the integrated log montage provided in Appendix C of the LANL R-5 Well Completion Report (compressed form shown in Figure 4.7). The summary log also displays

- ELAN total (water- and air-filled) porosity (red hashed curve in track furthest to the right);
- Air-filled porosity (dotted red shading in track furthest to the right);
- ELAN water saturation (dotted light blue curve in track furthest to the right);
- Gross gamma ray (solid brown curve in first track from left); and
- Caliper with measured washouts (dashed black curve with washouts shown by pink shading).

Borehole water level in R-5 at the time of the May 2001 geophysical logging was 711 ft (depth referenced to the NGS log). There is significant uncertainty in defining where true 100% saturation of the virgin geologic formation occurs from the geophysical logs (corresponding to conditions within the regional aquifer or in perched zones above, where the entire pore space is filled with water)—due to the unknown condition of the borehole beyond the casing and it's effects on the log measurements. The measurements are detrimentally affected by the existence of an annulus and voids between the free-standing casing and borehole wall (resulting in elevated water content and water saturation if the annulus is filled with water or drilling fluid, and lowered water content/saturation if filled with air), as well as drilling damage to the formation. Even without such borehole conditions, the water saturation estimate from the geophysical logs is very sensitive to the matrix grain density.

The processed log results do indicate a significant, overall shift in water saturation at 534 ft—decreasing from intermittently 100% saturation below to 10–50% saturation above—associated with a shift in overall total porosity (see Figure 4.1). However, there are a number of zones below this depth where water saturation drops well below full saturation due to increases in total porosity; the total porosity in these zones could be elevated due to the presence of an air-filled annulus behind the casing that erroneously lowers the bulk density measurement. At the well water level (711 ft) the logs show a very large void and the water level behind casing is very evident by a sudden drop in water content above, while the total porosity remains very high; a plausible interpretation is that the void is filled with water below and air above. Whether this water-air contact behind casing represents the regional aquifer static groundwater level is questionable; it could well be an artifact of the drilling operation and borehole condition. In addition, above 668 ft the total porosity decreases substantially, with many zones showing full saturation—extending up to 534 ft where the water saturation drops to a low level for much of the above section. Thus, it is very difficult to determine the true regional aquifer groundwater level independently from the geophysical log results, although it is almost definitely below 534 ft, possibly at 534 ft or at the depth of the borehole water level (711 ft).

There are a few zones above 534 ft where the processed log results sporadically peak at or near 100% water saturation: 39–86 ft, 105 ft, 120 ft, and 125 ft. The top zone is simply an artifact of the ELAN analysis; bulk density was not available above this depth so air had to be removed from the suite of possible constituents in the model. The other sudden increases in water saturation are largely the result of large decreases in total porosity and relatively constant water content across the zones—corresponding to a net decrease in air content and, thus, more of the pore space being occupied by water. However, none of these zones clearly exhibit perched water, especially considering the uncertainty in the total and water-filled porosity estimates from the logs.

Other significant features of the R-5 porosity summary log are as follows:

- Zones with apparent water content of 30% or greater by volume:
  - 711–726 ft, the top 8 ft of which likely corresponds with a large water-filled void behind the casing
  - 730–736 ft
  - 757–760 ft
  - 789–849 ft
  - Extremely high total porosity (100%) and low water content (0%) anomalies in the zones 330–338 ft and 473–482 ft, probably corresponding to large air-filled voids behind the casing

Overall trends in the water content log results are as follow, from top to bottom:

- A general trend of increasing water content from the top of the log interval (39 ft) to 340 ft, starting at 5% and increasing to 20
- Generally constant water content (20%) from 340–532 ft

- Generally low water content (10–15%) from 532–672 ft
- Constant water content of 20% from 672–711 ft
- Decreasing water content from 90% at 711 ft (see explanation in above discussion) to 12% at 749 ft
- Widely varying water content (15–35%) from 749–782 ft
- High, generally increasing water content (30–55%) from 782–849 ft
- Much lower water content (15 – 20%) at the bottom of the log interval (849–866 ft)

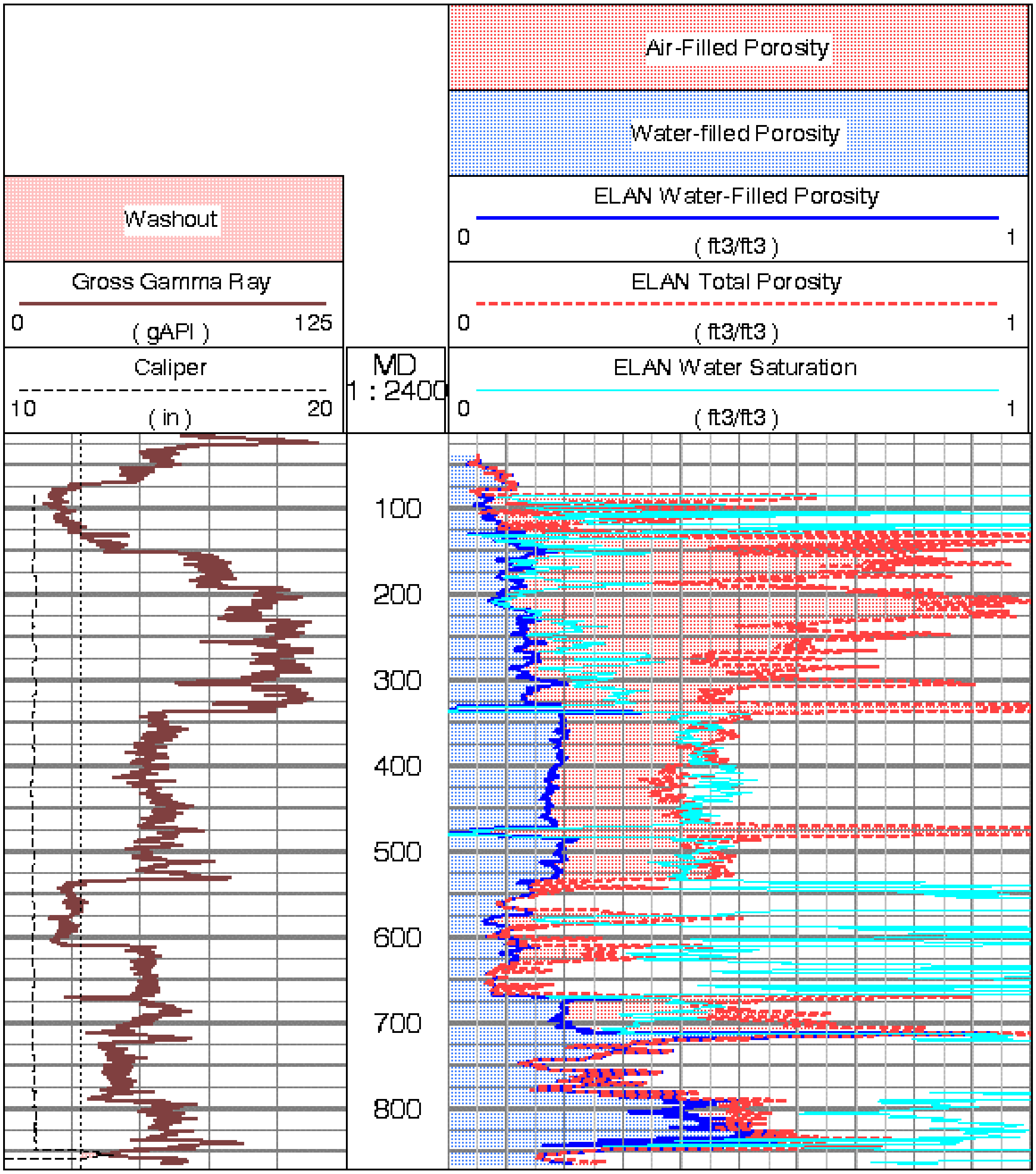

Figure 4.1. Summary porosity logs in R-5 borehole from processed geophysical logs, interval 39–866 ft, with caliper, gross gamma, and water saturation logs. Porosity and water saturation logs are derived from the ELAN integrated log analysis.

4.2 Density

Bulk density and P_e log measurements, obtained from the LDT geophysical tool in R-5, provide information about the formation total porosity (water plus air) and lithology, respectively. The LDT measurements are typically only valid in open borehole, but there is a cased hole bulk density algorithm that has been adapted and implemented at Los Alamos. This algorithm was used in R-5 since almost the entire log interval contained free-standing casing at the time of logging. There is no way to rectify the P_e measurement in casing; thus, P_e could only be utilized in the very short open hole section at the bottom of R-5 (850–874 ft). The bulk density is the only measurement in the suite of logs run in R-5 (and most geophysical log measurements) that is directly sensitive to all formation components: air-filled porosity, water-filled porosity, and rock matrix. Total air plus water-filled porosity in the vadose zone can be estimated from density porosity when it is computed in conjunction with a water content measurement (e.g., neutron porosity) and an independent measurement/assumption of grain density. The processed bulk density and P_e curves (the latter referred to as "Pef" for photoelectric effect), as well as the apparent grain density derived from the ELAN analysis, are displayed as part of the summary logs (third track from left) for R-14 in Figure 4.2. Other applicable curves in the summary log are gross gamma ray (for stratigraphic correlation) and caliper (for identifying borehole washouts, although most of well contained casing), shown in the farthest left track.

The bulk density and P_e measurements have a shallow depth of investigation and, thus, the measurements can be severely affected by borehole washouts and standoff from the formation (i.e. when measuring through casing where there is an annulus between the casing and formation)—measuring the density and P_e of water/air instead of the formation. The LDT has a strong caliper arm to push the sensor pad against the borehole wall, but, with casing in the well, the pad can only be pushed as far as the inner wall of the casing and, thus, cannot compensate for any annulus between the casing and formation. The bulk density measurement is made using three detectors; the tool tries to compensate for differences in the near and far detector response by performing an internal processing correction, which is shown on logs as a density correction curve, flagged when it goes above/below quality cutoff thresholds. This flag is used as an indication when the LDT measurement quality may be compromised. However, the density correction cannot be computed for cased hole.

The cased hole bulk density measurement in R-5 is much less robust than if the logs were run in open hole, since the casing in place at the time of logging was emplaced as freestanding pipe to support the borehole while drilling progressed. If the formation did not collapse around the casing a water, drilling fluid, or air filled annulus would remain between the casing and the formation. In such a scenario the bulk density measurement, which is very sensitive to standoff from the borehole wall, would be heavily influenced by the water/air in the annulus—biasing the measurement towards the density of water (1 g/cc) or air (close to 0 g/cc). Unfortunately, there is no automatic internal processing flag to indicate when the casing-to-formation standoff is problematic to the measurement. However, there are zones in the R-5 log interval were the bulk density and total porosity (derived from bulk density) are unreasonably low and high, respectively, for natural geologic formations—indicating the likelihood of problematic standoff. Intervals where density porosity is above 60% and/or bulk density is below 1.5 g/cc include (from bottom to top): 840–848 ft, 836–838 ft, 699–718 ft, 690–693 ft, 670–674 ft, 471–483 ft, 329–340 ft, 301–308 ft, 284–290 ft, 266–268 ft, 192–246 ft, 156–182 ft, 136–152 ft, and 130–134 ft. In these intervals the bulk density measurement likely is not representative of true formation bulk density and, consequently, the total porosity estimate may not be valid due to fluid- or air-filled annulus behind casing. Even in these intervals it is not certain that the bulk density is unrepresentative since certain volcanic tuff lithology types in the Los Alamos area are known to have very high porosity and low bulk density; conversely the measurement may be affected to a lesser degree by annular voids in other zones.

Total porosity was computed from the ELAN integrated analysis of all the log measurements, including bulk density as a crucial input, as displayed in the first track from the right on the summary log (Figure 4.2) and the second track from the right on the integrated log montage (inclusive of the depth track). In this analysis no constraints were placed on air or water-filled porosity through the entire depth section. As can be seen on the summary logs, the ELAN total porosity mimics bulk density since bulk density is the primary measurement providing information on air-filled porosity. As mentioned above, where the bulk density measurement is of questionable quality, due to possible voids behind the casing, so is the total porosity estimate. While there are many zones where the total porosity is adversely affected by annular voids, the total porosity appears to be valid through much of the depth section.

The P_e measurement is a good indicator of lithologic changes. In this geologic setting, an increase in P_e above 3 is a good indicator of the presence of heavy, probably mafic, minerals; an increase to 5 is an indicator of a very heavy mineral-rich bed ("heavy" most likely corresponding to iron), such as a massive basalt lava flow. However, P_e is valid only in open hole and, thus, only the bottom 24 ft in R-5. Across the interval 850–860 ft P_e averages 3.75, indicating the likely presence of heavy mafic minerals. Across the interval 860–874 ft P_e averages much lower (2.5), indicating a lower concentration of heavy minerals.

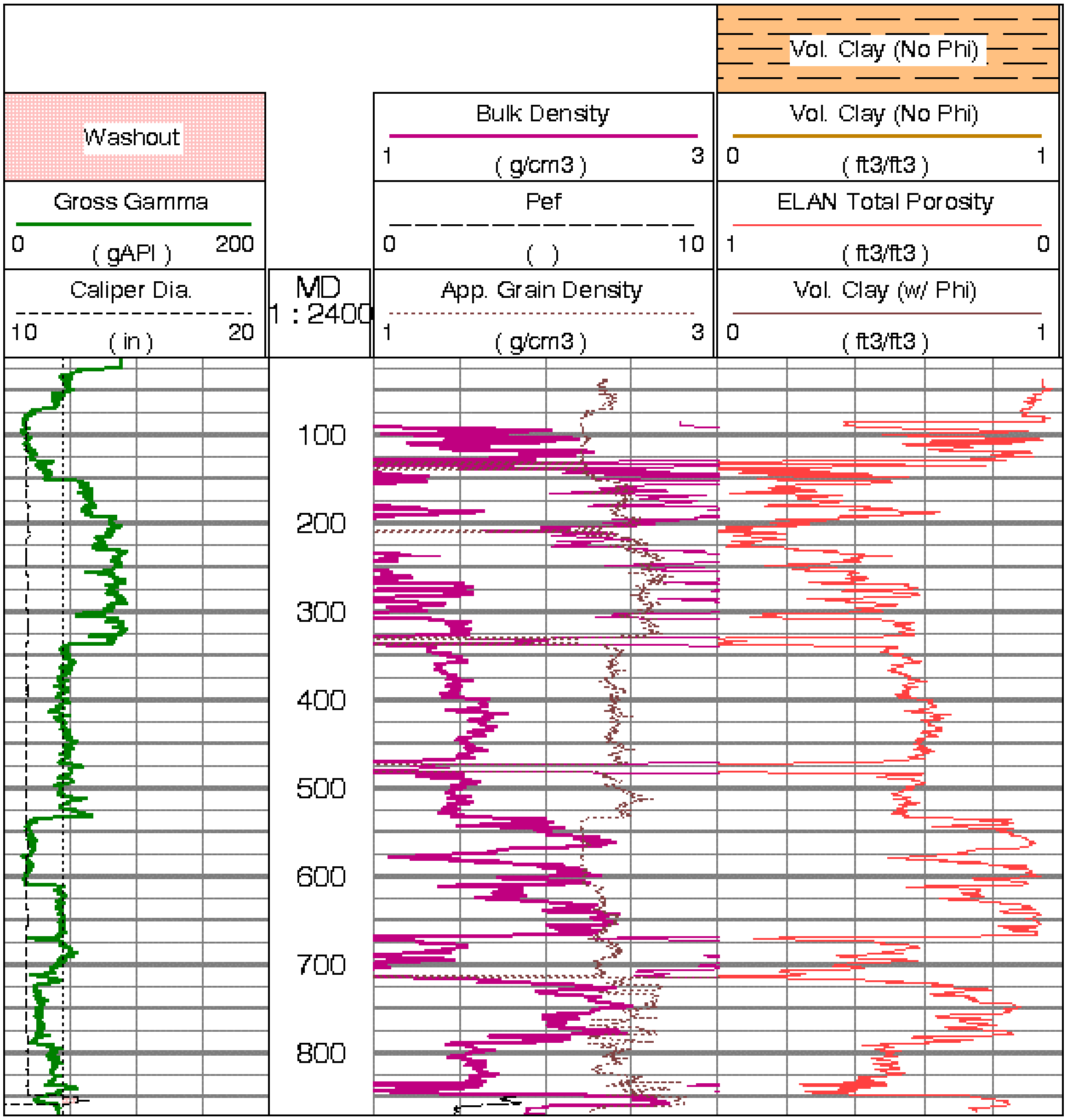

Figure 4.2. Summary bulk density and volume clay logs in R-5 borehole from processed geophysical logs, interval 96–874 ft. Also shown– caliper, gross gamma, apparent grain density, P_e, and total porosity logs.

4.3 Volume of Clay

Volume of clay is of interest particularly because clay can have a large influence on hydraulic conductivity as well as the groundwater geochemistry. Unfortunately, there is no way to directly measure volume of clay from geophysical logging. It can only be derived indirectly from other log measurements, preferably a combination of measurements. Of the logging services run in R-5, the one that provides the most information about clay content is the NGS spectral gamma ray, since thorium and potassium are often associated with clays. However, because of the complex geologic history of the Los Alamos area, including many periods of volcanic activity, the geologic section contains numerous minerals other than clays that produce similar spectral gamma (and gross gamma) responses. This fact greatly complicates the estimate of clay volume directly from gamma ray measurements.

Considering the above-mentioned circumstances, the most robust way to estimate clay volume from the geophysical logs is to use all the logs together to solve for the full mineral and fluid volumetric composition of the formation. This type of analysis constitutes an inverse problem and can be performed using the ELAN program. However, because of the limited geophysical logging suite acquired in R-5 only a limited number of mineral/rock constituents could be included in the ELAN analysis in order for the model to be constrained. Clay could not be included in the model without the results becoming very unrealistic. Thus, a quantitative analysis of clay volume could not be performed.

4.4 Spectral Natural Gamma Ray

Natural gamma ray spectroscopy logs were acquired in R-5 for the purpose of

- identifying geologic/lithologic layer boundaries,
- correlating geologic/lithologic units with other wells, and
- helping in the evaluation of mineralogy.

The processed spectral gamma log results are shown as summary logs in Figure 4.3 and in expanded form as part of the integrated log montage in Appendix C of the LANL R-5 Well Completion Report (shown compressed in Figure 4.4). On the summary log, gross gamma and gross gamma minus the uranium contribution are displayed in the first track (from left), useful radioisotope ratios are displayed in the third track, and the individual radioisotope concentrations–potassium (K), thorium (Th), and uranium (U)–are displayed in the fourth track.

The NGS spectral gamma measurements are of good quality throughout the log interval, valid for the purpose of quantitative interpretation. The raw field measurements were preprocessed to correct for borehole environmental conditions–mainly the presence of air (as opposed to water) and the presence of steel casing across most of the well. There is some uncertainty in the casing correction, particularly the precise amount of amplification to apply to the recorded gamma ray signal in order to account for the suppressing effect of the thick steel casing. Also the unknown size and presence of material (e.g. bentonite drilling mud) in the annulus cannot be corrected for; thus the processed measurements include any gamma ray contribution/suppression from annular material. Nonetheless, the K and Th spectral components were used as valuable input to the ELAN analysis in R-5. If possible, it is not recommended to use U as an input to the ELAN model, because it can vary significantly for a particular mineral component due to independent processes (e.g. water flow, geochemical conditions); U was not used in the R-5 ELAN.

The R-5 spectral gamma ray logs have a number of distinct characteristics, which are described below:

- A thick zone from 73–152 ft with the highest gamma activity in the section (2 to 3% K, 6 to 11 ppm Th, and 2 to 4 ppm U). The higher K and Th are reflected in the ELAN analysis results as an increase in orthoclase and hypersthene dry weight %.
- Two zones with low gamma activity, 152–338 ft and 534–612 ft (0.5 to 0.7% K, 1 to 3 ppm Th, and 0.5 to 1.5 ppm U). The low K and Th are reflected in the ELAN analysis results as a substantial decrease in orthoclase and hypersthene dry weight % and corresponding increase in silica glass.

- The overall trend in the Th/K ratio is fairly constant, except for a slight drop across the 534–612 ft low gamma activity zone.
- There is a lot of high depth frequency variations in the spectral gamma components, suggesting there is a high degree of small scale lithologic heterogeneity across the section.

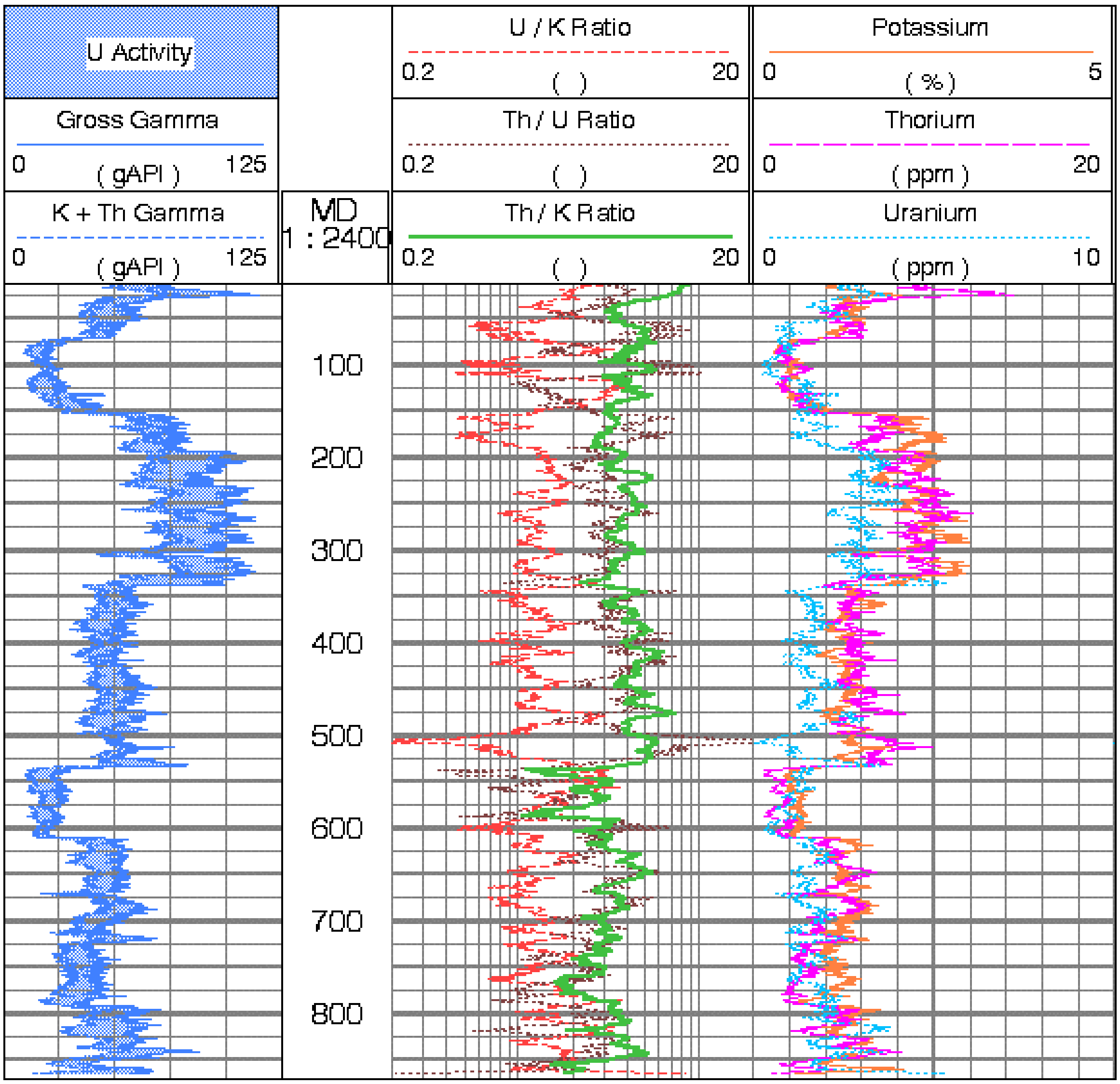

Figure 4.3. Summary spectral natural gamma ray logs from R-5 borehole, interval 14-867 ft

4.5 Integrated Log Montage

This section describes the integrated geophysical log montage for R-5: It includes a discussion of (1) what each log curve represents and how it was derived and (2) what are some of the most notable features in the displayed logs. The montage is provided in Appendix C of the LANL R-5 Well Completion

Report and is shown compressed in Figure 4.4. A description of each log curve in the montage follows—organized under the heading of each track, starting from track 1 on the left-hand side of the montage. Note that the descriptions in this section focus on what the curves are and how they are displayed; the specific characteristics and interpretations of the R-5 geophysical logs are provided in the previous section.

Track 1–Depth

The first track on the left contains the depth below ground surface in units of feet, as measured by the geophysical logging system during the NGS logging run. All the geophysical logs are depth-matched to the NGS gross gamma measurement.

Track 2–Basic Logs

The second track on the left (inclusive of the depth track) presents basic curves:

- gamma ray (thick black), recorded in API units and displayed on a scale of 0 to 150 API units;
- caliper (thin solid black) with bit size as a reference (dashed black) to show washout (pink shading, but none exist because the well was cased), recorded in inches and displayed on a scale of 11 to 21 in.

Two gamma ray curves from the NGS are presented:

- total gross gamma (thick solid black curve) and
- gross gamma minus the contribution of uranium (dashed black).

The gross gamma curve from the NGS is used as the depth reference for all other logs. Gross gamma measurements are sensitive to radioactive elements in the near wellbore environment, which are potassium, thorium, and uranium—assuming the gamma activity is from naturally occurring sources. The response of the gross gamma curves is the result of the formation chemical makeup, including lithology/mineralogy.

The caliper curve is from the LDT tool, the single arm that is used to press the tool sensor against the borehole wall. It has been depth-matched to the NGS tool run using gross gamma ray as a reference. The caliper is constant in most of R-5 since the well was cased for casing-advance drilling at the time of logging. However, washouts could have been present behind the casing and likely were, as evidenced by very high porosity measurements.

Track 3–Porosity

The fourth track displays the primary porosity log results. All the porosity logs are recorded in units of volumetric fraction and displayed on a linear scale of 0.75 (left side) to negative 0.1 (right side). Specifically, these logs consist of

- CNTG water-filled epithermal neutron porosity (solid sky blue curve)–a merged log of epithermal neutron porosity processed for water-filled borehole and epithermal neutron porosity processed for air-filled hole;
- CNTG water-filled thermal neutron porosity (dashed light blue curve)–thermal neutron porosity valid only in the water-filled borehole (below 711 ft)

- Total porosity derived from bulk density and neutron porosity using 2.65 g/cc grain density (thick long dashed red), 2.25 g/cc (thin dashed red), and 3.05 g/cc (thin dotted red)–with red shading between the 2.25 g/cc and 3.05 g/cc curves; and
- ELAN total water and air-filled porosity (dashed-dotted cyan)–derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

The CNTG logs are environmentally corrected for borehole conditions–particularly casing and borehole fluid (water or air)–as is the bulk density (used for density porosity) for casing correction. The ELAN results are based on fully corrected logs. All the porosity logs are depth matched to the NGS log using the gross gamma ray measurement obtained in every logging run.

Track 4–Density

The fifth track displays the:

- bulk density (thick solid maroon curve) on a scale of 1 to 3 grams per cubic centimeter (g/cc);
- P_e (long-dashed black curve at bottom) on a scale of 0 to 10 non-dimensional units;
- density correction (dashed orange curve at bottom) on a scale of -0.75 to 0.25 g/cc; and
- apparent grain density (dashed-dotted brown curve), derived from the ELAN analysis, on a scale of 2 to 4 g/cc.

Grey area shading is shown where the P_e increases above 3 (indicating the presence of heavy, possibly mafic, minerals) and orange shading is shown where the density correction is greater than the absolute value of 0.25 (indicating the density processing algorithm had to perform a major correction to the bulk density calculation). P_e and density correction are shown only in the open hole section at the bottom because this is the only place where they are valid. The bulk density log is environmentally corrected for casing, but cannot be corrected for any annulus. All logs have been depth matched to the NGS using gross gamma ray.

Track 5–NGS Spectral Gamma

The sixth track from the left displays the spectral components of the NGS measurement results as wet weight concentrations:

- potassium (solid green curve) in units of percent and on a scale of –5 to 5 percent;
- thorium (dashed brown) in units of parts per million (ppm) and on a scale of 25 to –25 ppm; and
- uranium (dotted blue) in units of parts per million (ppm) and on a scale of 10 to 0 ppm.

The log results are environmentally corrected for borehole conditions (particularly presence of casing and fluid properties). Potassium and thorium are presented in such a way that they increase to the right and the left from the center of the track, respectively, with gray shading between the two curves to qualitatively show changes in both concentration values. Uranium is plotted increasing from the right boundary.

Tracks 6–ELAN Intrinsic Hydraulic Conductivity

Track 6 displays an estimate of intrinsic hydraulic conductivity (K) from the ELAN analysis, presented on a logarithmic scale of 10^{-3} to 10^{7} centimeters per second (cm/s) multiplied by 10^{6}: The estimate is derived strictly from the optimized ELAN mineral-fluid model and assumes full saturation. The hydraulic conductivity values have been multiplied by 10^{6} to reduce the number of significant figures, since in cm/s the values are very small. Thus, when using these hydraulic conductivity estimates for quantitative analysis, the values should be divided by10^{6} or converted to other units. The estimate is derived from processed logs that are depth matched to the NGS.

Track 7–ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 7 displays the results from the ELAN integrated log analysis (the matrix portion)–presented as dry weight fraction of mineral types chosen in the model:

- Silica glass (orange)
- Orthoclase or other potassium feldspar (lavender)
- Labradorite or other plagioclase feldspar (pink)
- Hypersthene (purple)
- Heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green).

Track 8–ELAN Mineralogy-Pore Space Model Results (Wet Volume Fraction)

Track 8 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- Silica glass (yellow with large black dots)
- Orthoclase or other potassium feldspar (lavender)
- Labradorite or other plagioclase feldspar (pink)
- Hypersthene (purple)
- Heavy mafic minerals, such as magnetite (dark army green)
- Air (red)
- Water (white)

Track 9–Summary Logs

Track 9, the second track from the right, displays several summary logs that describe the fluid and air-filled volume measured by the geophysical tools, including water saturation:

- Optimized estimate of total volume fraction water from the ELAN analysis (solid dark blue curve and area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);
- Optimized estimate of water saturation (percentage of pore space filled with water) from the ELAN analysis (dashed-dotted purple curve);

- Water saturation as calculated directly from the bulk density and geochemical estimated porosity using a grain density of 3.05 g/cc (dotted light blue curve), 2.65 g/cc (long-dashed light blue curve), and 2.25 g/cc (dashed light blue curve)–with light blue shading between the 2.25 and 3.05 g/cc saturation curves to show the range;

The water and porosity curves scale from 0 to 1 volume fraction, left to right; the water saturation scales from 0 to 1, from left to right.

Track 10–Depth

The final track on the right, same as the first track on the left, displays the depth below ground surface in units of feet, as measured by the geophysical logging system during the NGS logging run.

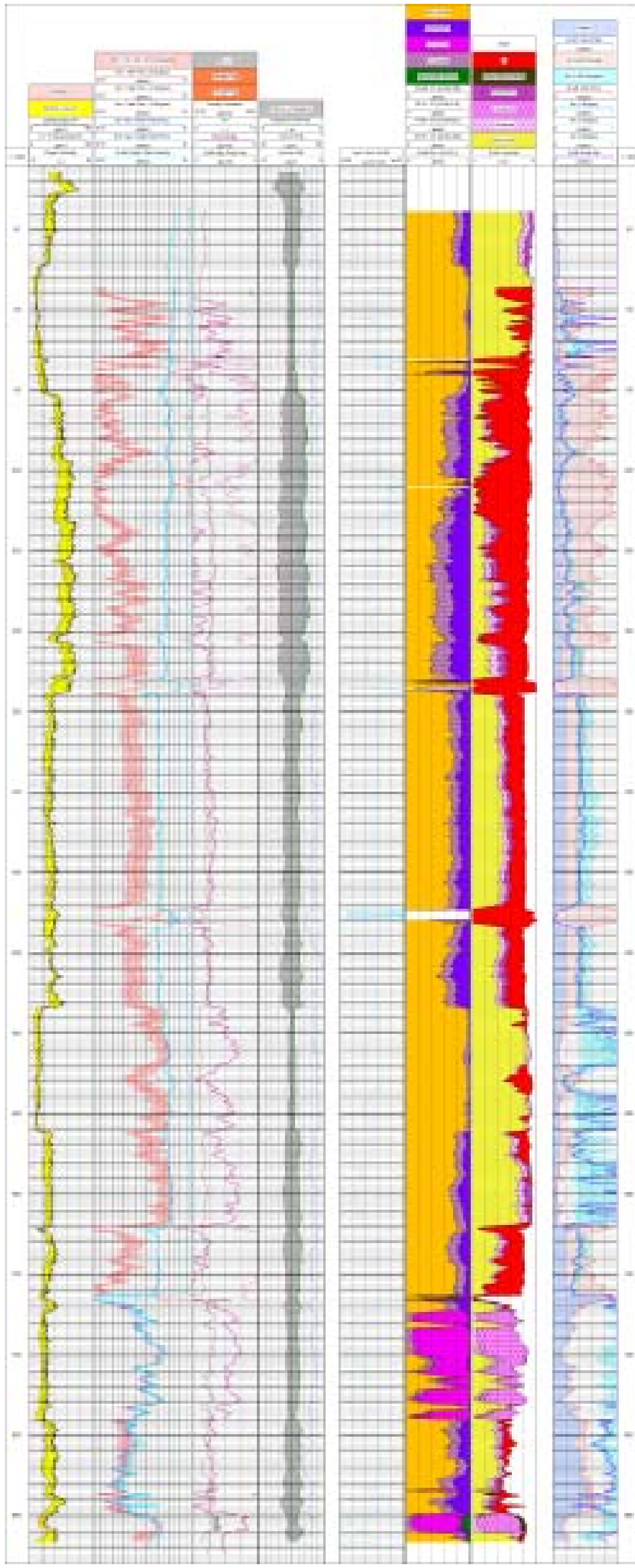

Figure 4.4. Geophysical log montage showing a compressed composite of all processed logs, including ELAN models, from borehole R-5.

5.0 REFERENCES

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~VERSION INFORMATION

VERS	.2.0		:CWLS LOG ASCII STANDARD-VERSION 2.0
WRAP	.NO		:ONE LINE PER DEPTH STEP

~WELL INFORMATION

STRT	.FT	2.75588	:START DEPTH
STOP	.FT	-0.524929	:STOP DEPTH
STEP	.FT	0	:STEP
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COMP	.	WGII	:COMPANY
WELL	.		:WELL
FLD	.		:FIELD
LOC	.	Pueblo Canyon	:LOCATION
PROV	.	N/A	:PROVINCE
SRVC	.	N/A	:SERVICE COMPANY
DATE	.	5/20/2001	:DATE
UWI	.	N/A	:UNIQUE WELL ID

~CURVE INFORMATION

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GAMM	.CPS		:Gamma

~PARAMETER INFORMATION

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DENS	.		:DENSITY
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OPER	.		:OPERATING RIG TIME
WGT1	.		:WGT1
CASI	.	18" OD	:CASING SIZE1
CASI	.	130'	:CASING TO2
WGT2	.		:WGT2
CASI	.	13 3/8" OD	:CASING SIZE2
WELL	.	R-5	:WELL ID
CASI	.	850'	:CASING TO3
K.B.	.		:K.B.
WGT3	.		:WGT3
TYPE	.		:TYPE LOG
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CASI	.		:CASING TO4
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CASI	.		:CASING TO5
DRIL	.		:DRILLING MEAS. FROM
WGT5	.		:WGT5
CASI	.		:CASING SIZE5
CTY	.		:CTY
WGT6	.		:WGT6
CASI	.		:CASING SIZE6
MAX.	.		:MAX. REC. TEMP.
D.F.	.		:D.F.
CASI	.		:CASING TO6
OTHE	.		:OTHER SERVICES
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DEPT	.	902'	:DEPTH-DRILLER
BIT2	.	14.5"	:BIT2
RUN	.		:RUN No
RUN1	.		:RUN1
BIT3	.	12.25"	:BIT3
RUN2	.		:RUN2
PERM	.		:PERMANENT DATUM
TWP	.		:TWP
BIT4	.	10 5/8"	:BIT4
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BIT	.	0	:BIT FROM1
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BIT5	.		:BIT5
CASI	.	0	:CASING FROM1
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RUN4	.		:RUN4
FLD	.		:FLD
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BIT	.		:BIT FROM6
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FILI	.		:FILING No
BIT	.		:BIT TO6

~OTHER

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34.2516	43.2598
34.4156	39.4863
34.5797	32.3457
34.7437	39.7051
34.9078	28.5654
35.0718	42.793
35.2359	17.9766
35.3999	39.5352
35.5639	25.4268
35.728	25.2549
35.892	36.084
36.0561	57.6953
36.2201	18.2393
36.3841	36.0703
36.5482	57.9453
36.7122	32.6406
36.8763	40.0527
37.0403	40.293
37.2043	29.4414
37.3684	18.4229
37.5324	44.4785
37.6965	44.4395
37.8605	40.752
38.0245	18.6738
38.1886	26.0137
38.3526	51.6836
38.5167	40.4375
38.6807	32.4902
38.8447	57.4414
39.0088	54.0684
39.1728	36.0781
39.3369	35.9805
39.5009	46.5527
39.6649	21.5645
39.829	25.291
39.993	28.9775
40.1571	28.8311
40.3211	46.8945
40.4851	36.2773
40.6492	47.1836
40.8132	25.3359
40.9773	54.2363
41.1413	50.8359
41.3053	29.0137
41.4694	47.2637
41.6334	69.4414
41.7975	40.5137
41.9615	36.9355
42.1255	55.3594
42.2896	44.2793
42.4536	44.5625
42.6177	55.1816
42.7817	55.3652
42.9457	44.1797
43.1098	43.9102
43.2738	43.7402
43.4379	43.1191
43.6019	49.998
43.7659	50.166
43.93	46.7402
44.094	39.4512
44.2581	43.1719
44.4221	50.4121
44.5861	39.6504
44.7502	21.7207
44.9142	83.6094
45.0783	18.1416
45.2423	54.6465
45.4063	39.9336
45.5704	61.5039
45.7344	28.9941
45.8985	46.8945
46.0625	43.6387
46.2265	54.6895
46.3906	25.9053

46.5546	59.0313
46.7187	67.0781
46.8827	48.791
47.0468	36.959
47.2108	66.5703
47.3748	44.6523
47.5389	29.752
47.7029	33.334
47.867	47.2793
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48.5231	36.2676
48.6872	72.1172
48.8512	47.8242
49.0152	29.1035
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49.6714	51.2969
49.8354	29.1719
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50.4916	74.4492
50.6556	52.3809
50.8197	22.5889
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51.4758	42.1367
51.6399	56.6035
51.8039	83.2617
51.968	37.8359
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52.296	30.2773
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52.6241	40.9922
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52.9522	37.707
53.1162	55.6777
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53.4443	55.584
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53.9364	59.082
54.1005	14.7544
54.2645	36.5605
54.4286	22.4082
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55.5768	29.9307
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56.069	49.3477
56.233	34.2227
56.397	30.292
56.5611	26.6963
56.7251	22.8193
56.8892	18.9668
57.0532	30.2695
57.2172	30.0244
57.3813	33.4512
57.5453	22.1719
57.7094	18.4824
57.8734	25.9697
58.0374	29.9443
58.2015	30.375
58.3655	41.8691
58.5296	11.6445
58.6936	19.5771
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59.0217	35.8848
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59.8419	40.3262
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60.334	34.6699
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60.6621	30.5313
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61.1542	43.3633
61.3183	40.5039
61.4823	41.5625
61.6463	23.2588
61.8104	52.0547
61.9744	56.9609
62.1385	29.0195
62.3025	64.3789
62.4665	39.7539
62.6306	35.4199
62.7946	35.6348
62.9587	25.9355
63.1227	31.2031
63.2867	26.0508
63.4508	26.3164
63.6148	21.2793
63.7789	15.8281
63.9429	31.875
64.1069	21.4482
64.271	32.457
64.435	27.3506
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67.0597	11.6089
67.2237	42.207
67.3877	42.2891
67.5518	30.6191
67.7158	55.791
67.8799	24.6162
68.0439	37.375
68.2079	18.6523
68.372	44.2656
68.536	25.498
68.7001	25.709
68.8641	57.5625
69.0281	38.8281
69.1922	32.3711
69.3562	26.0605
69.5203	32.6191
69.6843	26.3936
69.8483	32.8828
70.0124	33.0879
70.1764	39.8145
70.3405	6.67749
70.5045	33.6035
70.6686	33.9121
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70.9966	6.71924
71.1607	59.8477
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71.4888	39.1836
71.6528	13.2412
71.8168	26.4521
71.9809	26.3193
72.1449	19.7256
72.309	13.2393
72.473	19.8574
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73.2932	20.3623
73.4572	47.6406
73.6213	27.4717
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73.9494	6.9187
74.1134	20.6162
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74.7696	41.3906
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75.2617	34.6426
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75.5898	27.7041
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75.9178	27.2471
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76.2459	13.5132
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77.8863	20.1582
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96.751	48.7539
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97.2431	14.1787
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99.0475	0
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174.67	90.4297
174.834	41.7891
174.998	69.3047
175.162	61.5742
175.326	42.2676
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175.654	90.5508
175.818	69.4453
175.982	47.9648
176.146	67.6797
176.31	74.4102
176.475	60.8281
176.639	40.8809
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176.967	67.5664
177.131	26.9912
177.295	74.1094
177.459	40.5215
177.623	47.4492
177.787	54.7285
177.951	54.4609
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178.771	69.2305
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179.099	69.1055
179.263	41.7305
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179.755	20.7988
179.919	34.9629
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302.95	67.7969
302.786	96.0859
302.621	68.9688
302.457	63.5469
302.293	71.6172
302.129	76.293
301.965	68.1758
301.801	81.0859
301.637	56.0059
301.473	62.8398
301.309	54.1953
301.145	52.3867
300.981	49.2969
300.817	51.0039
300.653	55.6504
300.489	53.8203
300.325	56.502
300.161	83.6523
299.997	68.5469
299.833	84.8633
299.669	84.5586
299.505	68.4141
299.341	47.5781
299.177	59.0234
299.013	76.0625
298.849	63.1445
298.685	80.043
298.52	72.4023
298.356	71.125
298.192	69.4219
298.028	82.2227
297.864	78.6211
297.7	51.873
297.536	79.6602
297.372	86.2969

297.208	64.457
297.044	69.1875
296.88	62.4004
296.716	57.5254
296.552	50.9961
296.388	49.2246
296.224	57.6504
296.06	67.375
295.896	35.8984
295.732	66.8984
295.568	66.7578
295.404	70.207
295.24	69.9492
295.076	78.4219
294.912	73.5586
294.748	72.082
294.584	65.7656
294.419	59.8359
294.255	84.8086
294.091	53.834
293.927	77.9297
293.763	53.9609
293.599	80.5469
293.435	68.6602
293.271	66.5117
293.107	66.6563
292.943	74.8945
292.779	72.8672
292.615	69.4961
292.451	79.4297
292.287	71.0703
292.123	57.6816
291.959	69.3945
291.795	77.2031
291.631	57.5527
291.467	68.9453
291.303	73.7422
291.139	83.543
290.975	63.7148
290.811	70.5156
290.647	72.3867
290.483	93.5742
290.318	70.7656
290.154	63.9395
289.99	56.2148
289.826	74.8047
289.662	55.3516
289.498	91.0625
289.334	59.2695
289.17	78.7578
289.006	55.0469
288.842	76.832
288.678	73.4453
288.514	72.1094
288.35	69.7383
288.186	72.5234
288.022	69.5664
287.858	79.2773
287.694	72.3672
287.53	60.8809
287.366	68.5313
287.202	73.8516
287.038	62.2188
286.874	78.2852
286.71	68.3711
286.546	84.5859
286.382	45.8711
286.217	71.8008
286.053	78.5977
285.889	72.3203
285.725	68.7656
285.561	62.3418
285.397	61.1465
285.233	73.2695
285.069	53.6367
284.905	57.1035
284.741	75.7617
284.577	70.543
284.413	65.1992
284.249	43.6426
284.085	88.5703
283.921	60.0781
283.757	81.0938
283.593	44.7461
283.429	72.4766
283.265	66.1289
283.101	62.5273
282.937	70.6445
282.773	68.8125
282.609	83.3672
282.445	63.7637
282.281	56.9746
282.116	60.5234
281.952	75.0273
281.788	65.2539
281.624	80.2773
281.46	57.5176
281.296	65.7734
281.132	76.9688
280.968	73.9805
280.804	69.5586
280.64	38.4492
280.476	57.2461
280.312	79.2656
280.148	55.3848
279.984	53.3457
279.82	71.8984
279.656	72.1523
279.492	63.6133
279.328	70.0195
279.164	61.1543
279	79.168
278.836	67.8438
278.672	67.2344
278.508	60.5313
278.344	75.2734
278.179	53.9297
278.015	43.9219
277.851	68.3281
277.687	45.7578
277.523	70.5547
277.359	98.3711
277.195	75.6172
277.031	72.4766
276.867	80.3789
276.703	62.3457
276.539	80.5078
276.375	82.625
276.211	73.0469
276.047	68.8047
275.883	69.2266
275.719	59.2695
275.555	50.3867
275.391	71.8984
275.227	77.0313
275.063	58.9004
274.899	61.791
274.735	69.793
274.571	49.4121
274.407	52.5039
274.243	46.0391
274.078	70.375
273.914	65.5898
273.75	70.2305
273.586	63.6992
273.422	49.1992
273.258	70.4727
273.094	81.8789
272.93	85.1523
272.766	70.7813
272.602	80.4063
272.438	50.7832
272.274	66.8945
272.11	62.2031
271.946	74.1602
271.782	64.8828
271.618	75.0195
271.454	72.1641
271.29	52.3984
271.126	65.75
270.962	50.2305
270.798	41.8945
270.634	68.8281
270.47	64.9063
270.306	66.4414
270.142	82.543
269.977	75.5039
269.813	65.668
269.649	72.1719
269.485	80.4219
269.321	88.5
269.157	78.5703
268.993	75.332
268.829	65.6641
268.665	70.4063
268.501	68.9844
268.337	72.7305
268.173	60.7129
268.009	75.1992
267.845	73.7734
267.681	75.125
267.517	78.6523
267.353	57.8047
267.189	68.5117
267.025	87.2656
266.861	79.1602
266.697	67.6289
266.533	70.4648
266.369	73.9063
266.205	85.7813
266.041	66.9766
265.876	56.5391
265.712	62.7871
265.548	75.4609
265.384	58.9707
265.22	80.3281
265.056	72.125
264.892	72.3984
264.728	67.2695
264.564	68.6992
264.4	55.5527
264.236	57.5664
264.072	83.6211
263.908	55.9336
263.744	81.7227
263.58	70.2734
263.416	73.4297
263.252	81.375
263.088	62.0117
262.924	79.0039
262.76	60.0762
262.596	62.25
262.432	80.8828
262.268	72.8672
262.104	63.8789
261.94	60.7051
261.775	80.707
261.611	70.3164
261.447	84.9688
261.283	69.4453
261.119	93.8008
260.955	72.2109
260.791	82.2422
260.627	65.7266
260.463	70.5234
260.299	65.5625
260.135	45.9336
259.971	60.6426
259.807	47.6934
259.643	65.6289
259.479	49.0039
259.315	57.0977
259.151	53.7754
258.987	47.3496
258.823	50.6777
258.659	52.3145
258.495	52.7891
258.331	46.5117
258.167	51.8672
258.003	70.7188
257.838	52.3477
257.674	49.0488
257.51	53.9316
257.346	63.8516
257.182	59.9707
257.018	64.8125
256.854	71.375
256.69	67.582
256.526	74.1875
256.362	63.9961
256.198	77.2188
256.034	65.7148
255.87	68.7891
255.706	75.4766
255.542	57.498
255.378	58.9473
255.214	60.8613
255.05	53.9746
254.886	57.3457
254.722	75.3516
254.558	63.7227
254.394	83.625
254.23	70.1641
254.066	82.3086
253.902	96.2227
253.737	56.4922
253.573	62.2285
253.409	62.8984
253.245	86.3906
253.081	43.8984
252.917	62.1836
252.753	83.5313
252.589	76.7656
252.425	74.5508
252.261	67.7813
252.097	90.4727
251.933	100.254
251.769	70.8203
251.605	86.5586
251.441	69.0547
251.277	72.3711
251.113	69.1367
250.949	62.373
250.785	49.0488
250.621	62.1641
250.457	69.9336
250.293	71.793
250.129	70.4688
249.965	48.9316
249.801	57.2578
249.636	65.5117
249.472	49.3496
249.308	61.6719
249.144	60.5391
248.98	72.4492
248.816	79.2305
248.652	62.3281
248.488	58.875
248.324	68.2344
248.16	70.0234
247.996	71.2266
247.832	76.1289
247.668	71.1914
247.504	62.5859
247.34	77.3125
247.176	69.2266
247.012	70.7891
246.848	70.957
246.684	72.4063
246.52	64.1328
246.356	91.6211
246.192	68.4844
246.028	81.6797
245.864	70.4258
245.7	65.3555
245.535	71.9141
245.371	72.1523
245.207	65.7266
245.043	82.0313
244.879	84.5156
244.715	68.6484
244.551	59
244.387	77.4375
244.223	80.9805
244.059	78.8711
243.895	51.8457
243.731	61.9707
243.567	66.6953
243.403	48.0879
243.239	69.6797
243.075	79.1992
242.911	72.6602
242.747	77.3945
242.583	54.3438
242.419	47.8496
242.255	62.3457
242.091	52.5039
241.927	83.6875
241.763	60.207
241.599	50.5176
241.434	71.7695
241.27	61.998
241.106	70.0703
240.942	93.25
240.778	65.4063
240.614	75.2031
240.45	59.3184
240.286	68.2656
240.122	57.332
239.958	87.5742
239.794	65.9922
239.63	62.043
239.466	85.3633
239.302	75.2969
239.138	69.8633
238.974	64.8828
238.81	92.7148
238.646	68.125
238.482	47.8379
238.318	84.4414
238.154	88.9023
237.99	82.1523
237.826	66.0977
237.662	65.5977
237.498	66.8477
237.333	60.4473
237.169	82.8594
237.005	89.3281
236.841	80
236.677	78.4258
236.513	86.9023

236.349	68.4336
236.185	68.6289
236.021	84.125
235.857	86.0977
235.693	72.0859
235.529	57.3203
235.365	72.3672
235.201	72.1445
235.037	66.9023
234.873	91.8359
234.709	68.3516
234.545	71.6836
234.381	81.293
234.217	71.0469
234.053	87.2813
233.889	70.8359
233.725	76.1133
233.561	52.6543
233.396	60.6602
233.232	57.1934
233.068	57
232.904	63.5859
232.74	65.1289
232.576	55.2676
232.412	55.5859
232.248	72.0508
232.084	52.3477
231.92	47.5273
231.756	63.9316
231.592	54.2754
231.428	64.2656
231.264	54.9434
231.1	45.3398
230.936	64
230.772	53.7793
230.608	61.9238
230.444	50.1406
230.28	63.4375
230.116	80.2305
229.952	64.8516
229.788	64.793
229.624	56.2949
229.46	61.0703
229.295	57.7441
229.131	65.7891
228.967	64.1133
228.803	69.2148
228.639	80.1758
228.475	66.8438
228.311	47.0566
228.147	71.582
227.983	63.873
227.819	62.2832
227.655	58.9355
227.491	60.6484
227.327	52.4766
227.163	47.3418
226.999	78.9688
226.835	53.002
226.671	54.9688
226.507	73.6016
226.343	73.9297
226.179	67.0352
226.015	70.2422
225.851	61.6992
225.687	95.3398
225.523	56.8457
225.359	63.1934
225.194	61.4336
225.03	61.1406
224.866	57.8379
224.702	64.4414
224.538	64.0977
224.374	60.6328
224.21	62.2109
224.046	50.834
223.882	50.5352
223.718	68.7148
223.554	70.7188
223.39	64.1641
223.226	75.4453
223.062	50.9902
222.898	70.5625
222.734	62.2891
222.57	47.4414
222.406	56.123
222.242	56.4434
222.078	76.707
221.914	41.875
221.75	46.8223
221.586	66.8945
221.422	60.5547
221.258	50.5879
221.093	70.1445
220.929	51.7715
220.765	67.875
220.601	74.8203
220.437	56.2422
220.273	63.9883
220.109	67.2227
219.945	65.4648
219.781	76.9102
219.617	52.4238
219.453	47.375
219.289	55.6113
219.125	68.8242
218.961	70.5742
218.797	66.9922
218.633	70.4922
218.469	70.6445
218.305	71.918
218.141	75.2344
217.977	57.2129
217.813	74.3867
217.649	63.3125
217.485	65.2461
217.321	79.1836
217.157	89.1484
216.992	67.4609
216.828	65.7344
216.664	83.4961
216.5	68.6719
216.336	71.5156
216.172	76.4492
216.008	72.9688
215.844	61.1523
215.68	60.5547
215.516	72.2383
215.352	49.1797
215.188	85.2188
215.024	64.0078
214.86	85.1719
214.696	71.9609
214.532	70.2891
214.368	66.9961
214.204	60.6777
214.04	70.2969
213.876	47.5508
213.712	57.2207
213.548	85
213.384	59.0508
213.22	83.1328
213.055	68.4648
212.891	70.7188
212.727	53.9941
212.563	52.1836
212.399	75.832
212.235	58.543
212.071	69.8789
211.907	68.5156
211.743	71.2891
211.579	66.2305
211.415	67.5508
211.251	78.8828
211.087	54.0527
210.923	60.3359
210.759	60.5957
210.595	70.5625
210.431	65.4883
210.267	59.0762
210.103	88.4219
209.939	57.4043
209.775	70.4023
209.611	82.0234
209.447	65.5898
209.283	60.4023
209.119	79.7852
208.954	53.7227
208.79	67.7031
208.626	76.9531
208.462	70.8672
208.298	81.25
208.134	53.9375
207.97	68.8516
207.806	57.2422
207.642	43.4805
207.478	66.8906
207.314	71.332
207.15	57.8555
206.986	80.4922
206.822	80.3281
206.658	73.5625
206.494	85.0742
206.33	62.6836
206.166	75.543
206.002	75.7617
205.838	67.4297
205.674	68.6992
205.51	67.0898
205.346	67.1289
205.182	65.2031
205.018	57.0957
204.853	48.9453
204.689	84.7656
204.525	73.1953
204.361	65.707
204.197	74.9023
204.033	80.582
203.869	57.3652
203.705	84.5586
203.541	52.0352
203.377	82.1719
203.213	65.2969
203.049	49.9063
202.885	68.2695
202.721	71.4531
202.557	80.6953
202.393	68.8516
202.229	68.957
202.065	52.7422
201.901	69.3672
201.737	72.1523
201.573	65.707
201.409	75.4648
201.245	70.7422
201.081	62.3105
200.917	31.1533
200.752	72.1523
200.588	53.9297
200.424	53.9824
200.26	76.7227
200.096	58.2969
199.932	68.7813
199.768	66.3945
199.604	73.7031
199.44	58.9082
199.276	95.793
199.112	85.5508
198.948	70.6367
198.784	68.7891
198.62	63.5566
198.456	68.3672
198.292	73.1602
198.128	67.7227
197.964	65.8281
197.8	57.4023
197.636	65.7695
197.472	60.75
197.308	62.5273
197.144	78.7461
196.98	75.3008
196.816	73.3164
196.651	73.5352
196.487	70.043
196.323	56.9785
196.159	75.0703
195.995	55.3203
195.831	55.3457
195.667	73.0195
195.503	61.7871
195.339	47.8301
195.175	64.7734
195.011	64.0195
194.847	60.8984
194.683	57.0254
194.519	52.1074
194.355	42.0918
194.191	50.1523
194.027	56.6641
193.863	41.5254
193.699	77.3984
193.535	56.2793
193.371	62.5488
193.207	74.0313
193.043	57.7676
192.879	55.918
192.715	59.3613
192.55	52.4766
192.386	54.1523
192.222	47.2539
192.058	47.1699
191.894	39.0488
191.73	57.0469
191.566	50.4199
191.402	48.9785
191.238	53.7695
191.074	63.6055
190.91	37.8086
190.746	49.7656
190.582	50.4004
190.418	55.623
190.254	48.7988
190.09	43.3555
189.926	43.4766
189.762	58.5273
189.598	53.5859
189.434	61.5156
189.27	32.9824
189.106	46.2188
188.942	52.7871
188.778	52.6406
188.614	51.0703
188.449	42.7676
188.285	50.9063
188.121	50.623
187.957	52.332
187.793	62.1797
187.629	55.5352
187.465	47.2148
187.301	38.9863
187.137	48.7402
186.973	61.8301
186.809	58.9277
186.645	39.1484
186.481	42.5684
186.317	34.7227
186.153	56.6836
185.989	53.8477
185.825	57.2871
185.661	61.8613
185.497	60.3164
185.333	72.0938
185.169	53.4258
185.005	66.5547
184.841	48.082
184.677	42.9434
184.513	41.3867
184.348	54.332
184.184	61.084
184.02	59.207
183.856	51.0996
183.692	55.9473
183.528	63.832
183.364	55.5137
183.2	37.5352
183.036	55.2754
182.872	69.6211
182.708	53.6641
182.544	57.1152
182.38	60.2305
182.216	61.7969
182.052	42.4043
181.888	41.0273
181.724	39.9219
181.56	78.8008
181.396	45.3457
181.232	73.9727
181.068	46.584
180.904	38.3301
180.74	53.3262
180.576	53.0996
180.411	56.6172
180.247	46.5059
180.083	52.9199
179.919	44.5938
179.755	42.9219
179.591	54.5605
179.427	46.1094
179.263	47.4668
179.099	55.6387
178.935	45.8047
178.771	42.5391
178.607	49.0391
178.443	60.2793
178.279	48.6152
178.115	44.1074
177.951	53.9297
177.787	55.5195
177.623	52.334
177.459	44.1094
177.295	52.6055
177.131	49.8223
176.967	48.7988
176.803	50.1816
176.639	36.7676
176.475	56.6641
176.31	65.2656
176.146	46.8047
175.982	38.291
175.818	46.584
175.654	38.0723

175.49	53.1172
175.326	56.2754
175.162	70.7813
174.998	52.6836
174.834	58.9277
174.67	35.9238
174.506	63.8281
174.342	50.5938
174.178	45.9082
174.014	61.7773
173.85	34.918
173.686	66.4883
173.522	46.0273
173.358	53.9941
173.194	52.3398
173.03	52.4375
172.866	49.4785
172.702	51.5098
172.538	52.2422
172.374	57.0898
172.209	58.7539
172.045	43.8047
171.881	42.2969
171.717	68.582
171.553	50.4199
171.389	51.8945
171.225	42.0664
171.061	61.7813
170.897	48.4395
170.733	63.8203
170.569	60.2188
170.405	50.6719
170.241	40.9883
170.077	50.4395
169.913	55.1113
169.749	48.6211
169.585	45.1191
169.421	62.7773
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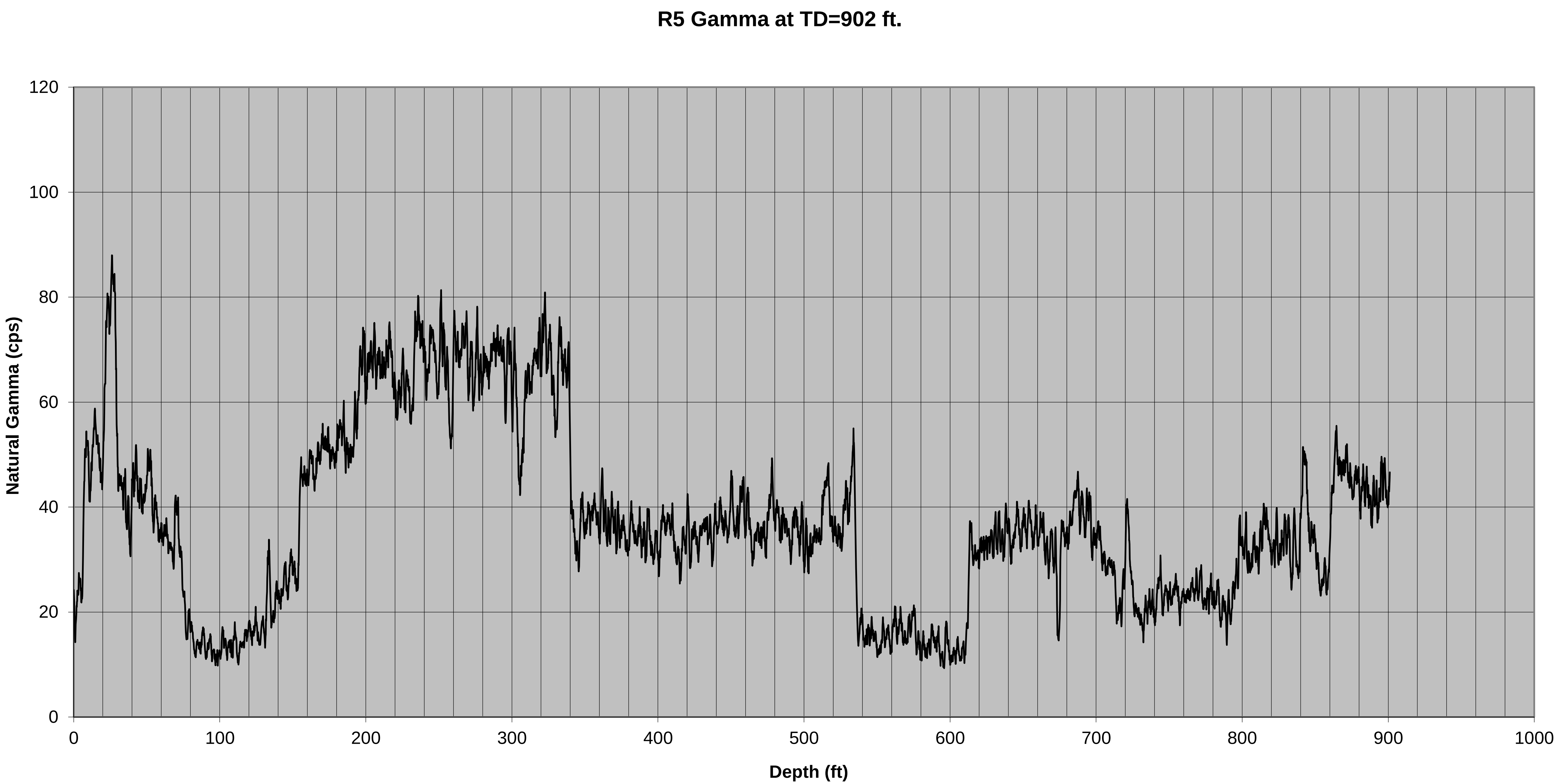
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Natural Gamma (cps)
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80
60
40
20
0
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100
200
300
400
500
600
700
800
900
1000
Depth (ft)


FOREMOST


FOREMOST


REX
NAPA
RESTRICTED AREA—AUTHORIZED PERSONNEL ONLY
RESTRICTED AREA—AUTHORIZED PERSONNEL ONLY
RESTRICTED AREA—AUTHORIZED PERSONNEL ONLY

Appendix E

Westbay™ Multi-Level Sampling Diagram
(CD attached to inside back cover)

Summary MP Casing Log

Company: Los Alamos National Lab
Well: R-5
Site: LANL
Project: Hydrogeology Study

Job No: WB777
Author: GG/DL

Well Information

Reference Datum: Ground Level
Elevation of Datum: 0.00 ft.
MP Casing Top: 0.00 ft.
MP Casing Length: 881.75 ft.
Depth Adjusted For:
  Field De-Stressing
Well Description:
  Plastic MP55
Other References:
  Pipe-based wire-wrapped screens.
  BF and screens after LANL 02/08/01
  Magnetic Collars 2.5 ft below MPorts

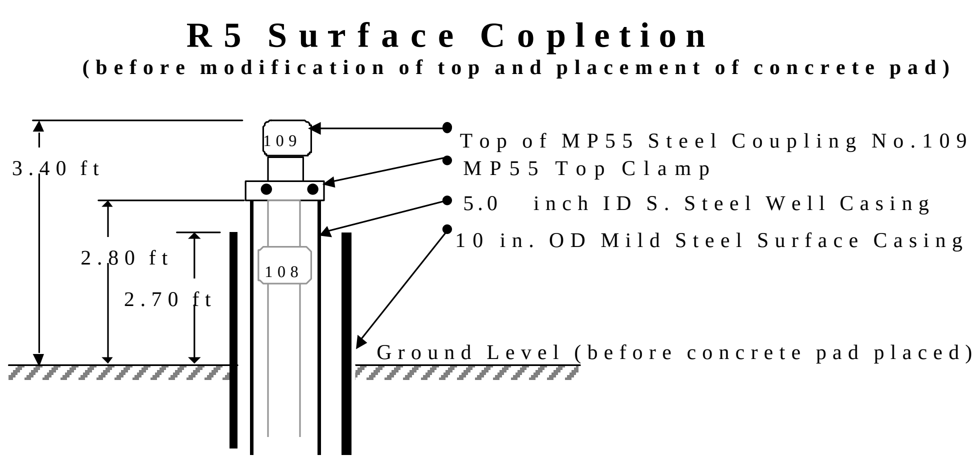
Borehole Depth: 883.00 ft.
Borehole Inclination: vertical
Borehole Diameter: 4.50 in.

File Information

File Name: 777_R5.WWD
Report Date: Thu Jul 19 18:01:42 2001

File Date: Jul 19 13:44:04 2001

Sketch of Wellhead Completion



Legend

(Qty) MP Components

(Library - WD Library 7/27/00)

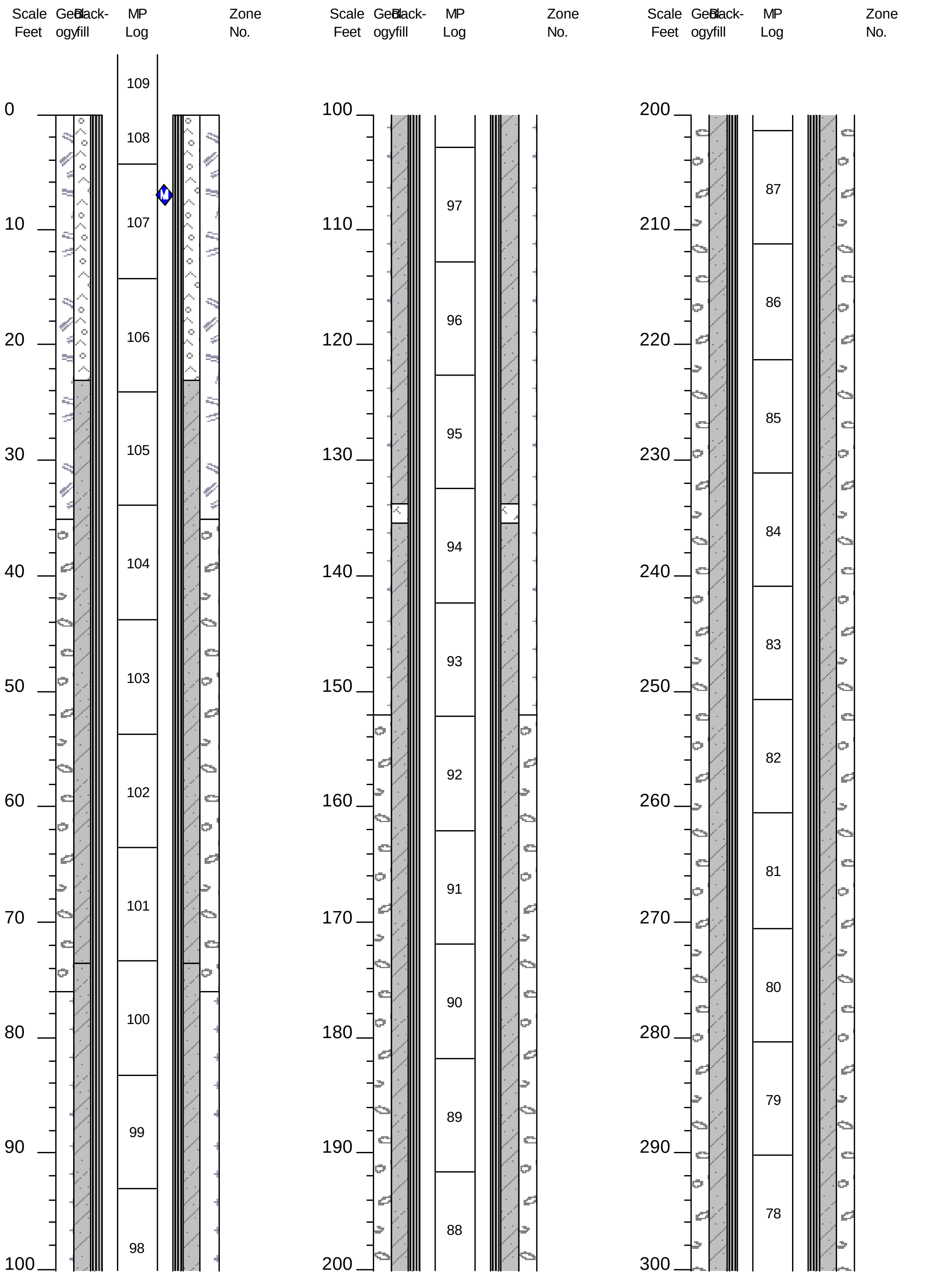
(20)	0601M15 - MP55 Casing, 1.5 m, PVC
(72)	0601M30 - MP55 Casing, 3.0 m, PVC
(10)	0612 - MP55 Packer, Stiffened, SS
(7)	0601M10 - MP55 Casing, 1.0 m, PVC
(1)	0603 - MP55 End Plug
(92)	0602 - MP55 Regular Coupling
(14)	0605 - MP55 Measurement Port
(4)	0607 - MP55 Hydraulic Pumping Port
(6)	0608 - MP55 Magnetic Location Collar

Geology

Rock, Porphyritic
Conglomerate
Rock, Igneous 2
Rock, Igneous
Shale, Sandy

Backfill/Casing

Concrete
Bentonite, Sand
Native / Cave
Sand Coarse
Sand Fine
Grout
Stainless Steel
Well Screen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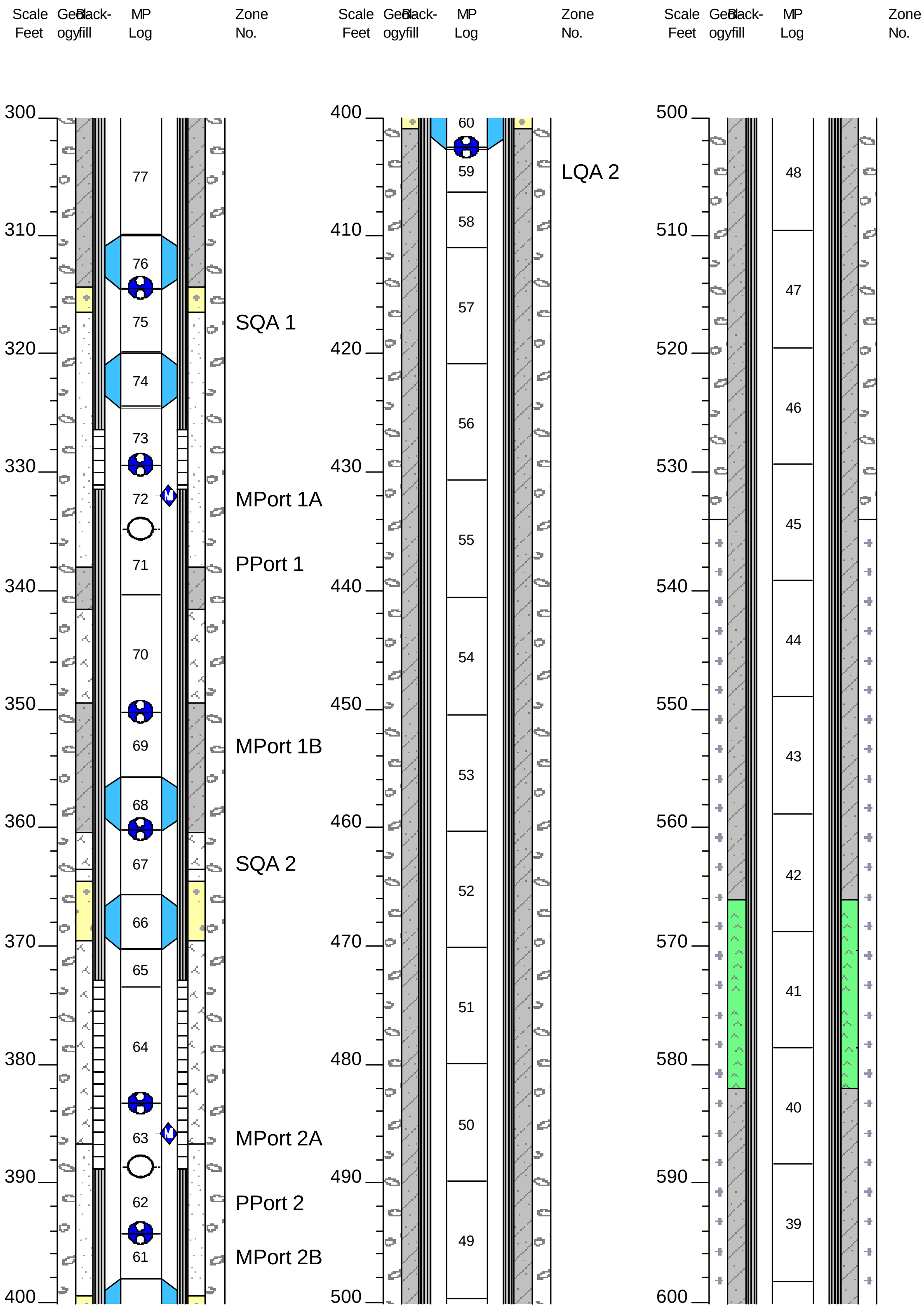
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74
73
72
71
70
69
68
67
66
65
64
63
62
61
SQA 1
MPort 1A
PPort 1
MPort 1B
SQA 2
MPort 2A
PPort 2
MPort 2B
400
410
420
430
440
450
460
470
480
490
500
60
59
58
57
56
55
54
53
52
51
50
49
LQA 2
500
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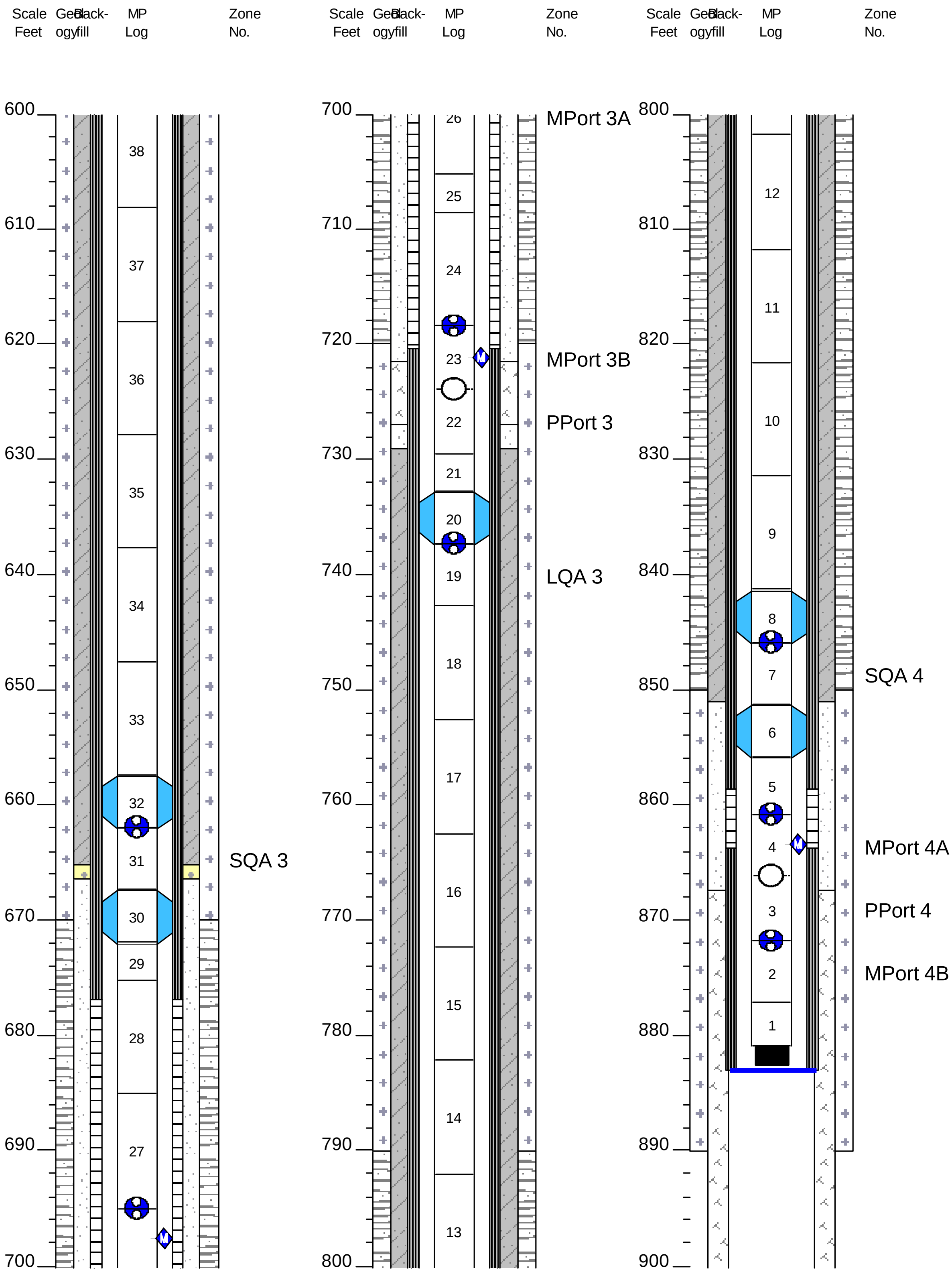
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34
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32
31
30
29
28
27
SQA 3
710
720
730
740
750
760
770
780
790
800
26
25
24
23
22
21
20
19
18
17
16
15
14
13
MPort 3A
MPort 3B
PPort 3
LQA 3
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820
830
840
850
860
870
880
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900
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11
10
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3
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