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Characterization Well R-19 Completion Report

Los Alamos
NATIONAL LABORATORY

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Cover photo shows a modified Foremost Dual Rotary (DR-24) drill rig. The DR-24 is one of several drill-rig types being used for drilling, well installation, and well development in support of the Los Alamos National Laboratory Hydrogeologic Workplan. The Hydrogeologic Workplan is jointly funded by the Environmental Restoration Project and Defense Programs to characterize groundwater flow beneath the 43-square-mile area of the Laboratory and to assess the impact of Laboratory activities on groundwater quality. The centerpiece of the Hydrogeologic Workplan is the installation of up to 32 deep wells in the regional aquifer.

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List of Acronyms and Abbreviations

AIT-H	array induction tool
API	American Petroleum Institute
APS	accelerator porosity sonde
APT	accelerator porosity tool
bgs	below ground surface
CMR	combinable magnetic resonance
cps	counts per second
DR	dual rotation
DX	Dynamic Experimentation (Division)
ER	environmental restoration
FMI	formation microimager
ft MSL	feet above mean sea level
GPIT	general purpose inclinometry tool
GPS	Global Positioning System
GR	gross gamma radiation
HE	high explosive
HGNS	highly integrated gamma ray neutron sonde
HNGS	hostile natural gamma ray sonde
HPLC	high-performance liquid chromatography
HSA	hollow-stem auger
I.D.	inner diameter
LATA	Los Alamos Technical Associates, Inc.
LANL	Los Alamos National Laboratory
MCFL	micro-cylindrically focused log
NMED	New Mexico Environment Department
NMR	nuclear magnetic resonance
NTU	nephelometric turbidity unit
O.D.	outer diameter
PPE	personal protection equipment
QA	quality assurance
RC	reverse circulation
RCT	radiological control technician
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine (research department explosive)
SAIC	Science Applications International Corporation
SP	spontaneous potential
TA	technical area
TD	total depth

3-D	three-dimensional
TLD	three-detector lithology density tool
TOC	total organic carbon
TNT	2,4,6-trinitrotoluene
WCSF	waste characterization strategy form

Metric to English 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-19 REPORT

by

David Broxton, David Vaniman, William Stone, Steve McLin, Jon Marin, Richard Koch, Rick Warren, Patrick Longmire, David Rogers, Neal Tapia

ABSTRACT

Characterization well R-19 is located atop the mesa separating Threemile and Potrillo Canyons, east of firing site IJ at Technical Area (TA)-36, Los Alamos National Laboratory (the Laboratory). This characterization well is the sixth of approximately 32 wells being installed in the regional aquifer as part of the Laboratory's "Hydrogeologic Workplan" (LANL 1998, 59599). R-19 was funded by the Laboratory's Environmental Restoration Project and is primarily designed to provide water-quality and water-level data for potential intermediate-depth perched zones and for the regional aquifer downgradient of high-explosive contaminant-release sites at TA-16. The installation schedule for R-19 was accelerated after high-explosive contamination was found in groundwater from characterization well R-25, located 2 mi west of R-19. Data collected from R-19, in conjunction with data from other planned characterization boreholes and from other data sources, are being used to evaluate the nature and extent of high-explosive contamination originating at TA-16. Data from R-19 are also being used to increase understanding of the hydrogeology of a little-studied part of the Laboratory and to update the sitewide conceptual hydrogeologic model.

R-19 was drilled in two phases. Phase I was conducted during January 2000 and consisted of using a hollow-stem-auger method to drill to a depth of 126.5 ft within the Tshirege Member of the Bandelier Tuff. Phase II of drilling was conducted from January through April 2000 using rotary methods that involved a combination of casing-advance and open-hole techniques. During Phase II, R-19 was drilled to a depth of 1902.5 ft, and a multiscreen well containing seven screened intervals was installed.

Geologic units encountered in R-19 consisted of, in descending order, soil, the Tshirege Member of the Bandelier Tuff including the basal Tsankawi Pumice Bed; tephras and volcaniclastic sediments of the Cerro Toledo interval; the Otowi Member of the Bandelier Tuff, including the basal Guaje Pumice Bed; an upper subunit of the Puye Formation fanglomerate facies; basaltic rocks of the Cerros del Rio volcanic field; a lower subunit of Puye Formation fanglomerates; and a thick sequence of pumice-rich sedimentary deposits that are currently not assigned to a specific stratigraphic unit.

Three zones of saturation were anticipated at R-19; two were perched zones and one was the regional zone of saturation. However, the presence or absence of perched water at R-19 is unclear because drilling fluids masked any saturation above the regional water table. Two well screens were placed opposite possible perched zones based on indications of increased moisture content on geophysical logs. The regional water table was found at a depth of 1178 ft, 60 ft deeper than expected. This water appeared to be unconfined and saturation continued to total depth of the borehole (1902.5 ft). Five well screens were distributed through the regional zone of saturation. Straddle-packer/injection testing of materials in the lower two screens in unassigned pre-Puye Formation deposits yielded hydraulic conductivity values of 17.5 (screen #6) and 19.6 (screen #7) ft/day.

Extensive borehole geophysical data were obtained from support subcontractor personnel who conducted borehole video and natural gamma radiation surveys using the Laboratory's logging trailer and from Schlumberger, Inc., who obtained a suite of borehole geophysical logs. These surveys were conducted in cased hole from the surface to a depth of 211 ft and in open hole below 211 ft. Open-hole geophysical logging included caliper, resistivity, natural gamma radiation, spontaneous potential, lithodensity,

magnetic resonance, borehole color video, epithermal neutron, neutron porosity, spectral natural radiation (K, U, Th), formation microimager, and hole deviation.

Well R-19 will provide long-term data on the groundwater system. However, the installation of R-19 has already provided new knowledge on existing water levels, water composition, and hydrogeology. In addition, the unexpected thickness of the Cerro Toledo interval and the occurrence of a deep sequence of pumiceous sediments, where Santa Fe Group sediments were anticipated, add to the understanding of hydrogeologic units at the Laboratory.

1.0 INTRODUCTION

This report describes the drilling, well construction and development, and testing activities for characterization well R-19. R-19 is located atop the mesa separating Threemile and Potrillo Canyons, east of firing site IJ at Technical Area (TA) 36. R-19 was drilled to a depth of 1902.5 ft, and it was completed as a multiscreen well containing seven screened intervals that can be sampled individually. This well was installed for the Environmental Restoration (ER) Project by the Groundwater Investigations Focus Area. It is the sixth characterization well drilled to the regional aquifer as part of the "Hydrogeologic Workplan"(LANL 1998, 59599) in support of Los Alamos National Laboratory's (the Laboratory's) "Groundwater Protection Management Program Plan" (LANL 1995, 50124).

R-19 is primarily designed to provide water quality and water-level data for potential intermediate-depth perched zones and for the regional aquifer downgradient of high-explosive (HE)-contaminant release sites at TA-16. The schedule for installation of R-19 was accelerated after HE was found in groundwater during drilling of characterization well R-25, located 2 mi to the west of R-19. In the hydrogeologic work plan, R-19 was originally planned for installation in Pajarito Canyon, but its location was moved to the mesa top south of Threemile Canyon to provide early warning of contaminants approaching supply well PM-2, located about 1 mi to the east (Figure 1.0-1). The location for R-19 also provides new hydrologic and geologic data that contribute to the understanding of the vadose zone and regional aquifer in a little-studied part of the Laboratory. Data collected from R-19 will be used in conjunction with data from other planned characterization boreholes as well as from other data sources to evaluate and update the sitewide hydrologic conceptual model.

Preliminary interpretations are presented for some of the data collected, but discussion of other data is deferred until they can be evaluated in the context of sitewide information collected from other ER Project and hydrogeologic work plan wells. A future report will provide an integrated human health and ecological risk assessment and will include groundwater data from other nearby ER Project wells.

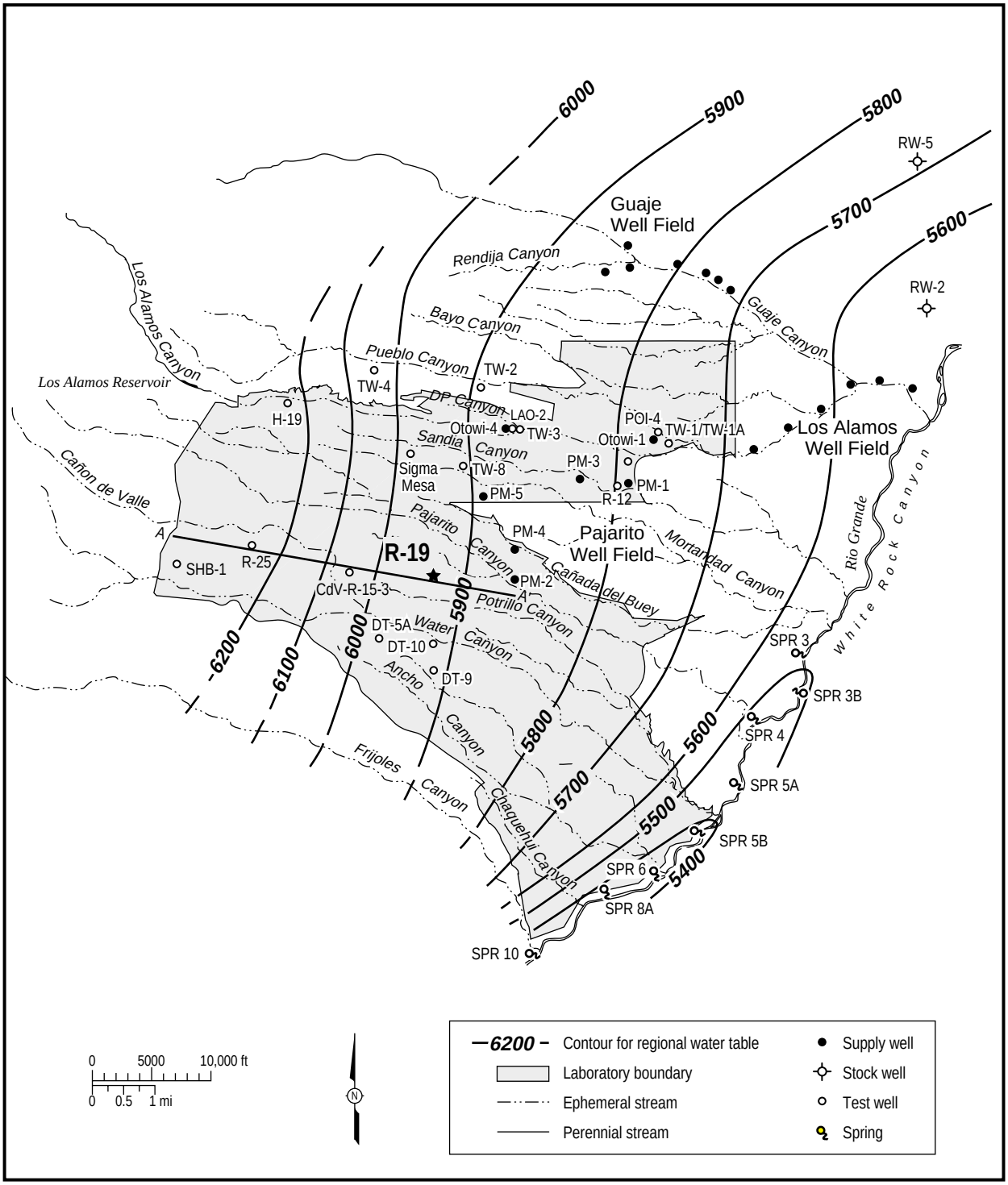
Although R-19 is primarily a characterization well, its design also meets the requirements of a monitoring well as defined in Module VIII of the Laboratory's Hazardous Waste Facility Permit. Incorporation of this well into a Laboratory-wide groundwater monitoring program will be evaluated at a later date when the results of this characterization activity are integrated with groundwater investigations in the hydrogeologic work plan (LANL 1998, 59599).

2.0 SUMMARY OF DRILLING ACTIVITIES

Drilling activities at R-19 are divided into the following categories: site preparation and Phase I drilling, Phase II drilling, well installation, and well development/testing. Los Alamos Technical Associates, Inc. (LATA) and Science Applications International Corporation (SAIC) provided field support during both phases of drilling. Table 2.0-1 compares the actual number of shifts for each category with the number of shifts projected for R-19 operations in the field implementation plan.

Phase I drilling at R-19 utilized the hollow-stem auger (HSA) drilling technique to drill to a depth of 126.5 ft below ground surface (bgs) and to install 18-in. steel surface conductor casing to 19.5 ft bgs. The HSA borehole below the surface casing was back-filled with cuttings and the 18-in. surface casing was cemented in place.

Phase II drilling at R-19 utilized an air-rotary drilling technique to drill to a depth of 1902.5 ft. A diagram showing the configuration of the R-19 borehole at total depth (TD) is shown in Figure 2.0-1. Following Phase II drilling, a permanent monitoring well was installed and completed with seven screened intervals.



Source: Purtymun 1984, 6513.

F1.0-1 / R-19 WELL COMPLETION RPT / 081200 / PTM

Figure 1.0-1. Locations of well R-19 and line of section for Figure 3.0-2

Table 2.0-1
Drilling Shift Information

Operations Category	Field Implementation Plan Number of Shifts	Actual Number of Shifts
Phase I drilling/site preparation	8 10-hr	5 10-hr
Phase II drilling	90 12-hr	77 12-hr
Well installation	55 12-hr	62 12-hr
Well development/testing	5 12-hr	39 12-hr
Total Shifts	8 10-hr and 150 12-hr	5 10-hr and 178 12-hr

Note: Shifts averaged 10 to 12 hr each, depending on production needs.

2.1 Equipment

2.1.1 Phase I

Phase I drilling at R-19 was conducted by Stewart Brothers Drilling Company using a CME-750 HSA drill rig with 4.25-in.-inside diameter (I.D.) Truspin™ HSAs to a depth of 126.5 ft bgs. The hole was overreamed using an 11-in.-I.D. HSA to a depth of 20 ft. A Moss™ wire line continuous-core retrieval system was used to core from the surface to 126.5 ft bgs.

2.1.2 Phase II

Phase II of R-19 was drilled by Dynatec Drilling Company, Inc. (formerly Tonto Drilling Company) using Foremost™ dual rotation (DR)-24 drill rigs. Dynatec provided a drilling supervisor, drilling crews, crew vehicles including 1-ton flatbed trucks, drilling rods, hammers, bits, 5000-gal. water truck, fuel truck, construction lights, auxiliary air compressor, and a 5-ton boom truck for handling casing, drill rods, and heavy support apparatus such as casing jacks.

The ER Project's field support facility provided drill casings, drilling bits, a small front-end loader (Bobcat™), dust suppression system, water containment tanks, depth-to-water meters, water sampling bailers, sample filtration trailer, diesel-powered electric generator, core boxes, chip trays, and an industrial sink for borehole material washing. The Sample Management Office provided sample and sample shipping containers. The ER Project provided escort vehicles, a laptop computer, cellular telephone, equipment to measure water sample field parameters, filtering apparatus, and a core-logging microscope. ESH-18 provided the borehole geophysics trailer and a downhole pressure transducer and electronic data logger.

The facility host (the Dynamic Experimentation Division [DX]) provided radio communication.

LATA/SAIC, as subcontractors to the ER Project, provided field team leaders, geologists, and site safety officers; rented a portable toilet and a combination sampling/office trailer; and procured field support supplies including deionized water for small-scale decontamination.

2.2 Schedule

2.2.1 Phase I

During Phase I, the CME-750 drill rig was mobilized to R-19 on January 7, 2000, and it was demobilized on January 13, 2000. Drilling operations required 5 drilling shifts, including equipment mobilization and demobilization. Operations were conducted in one 10-hr shift per day, Monday through Friday.

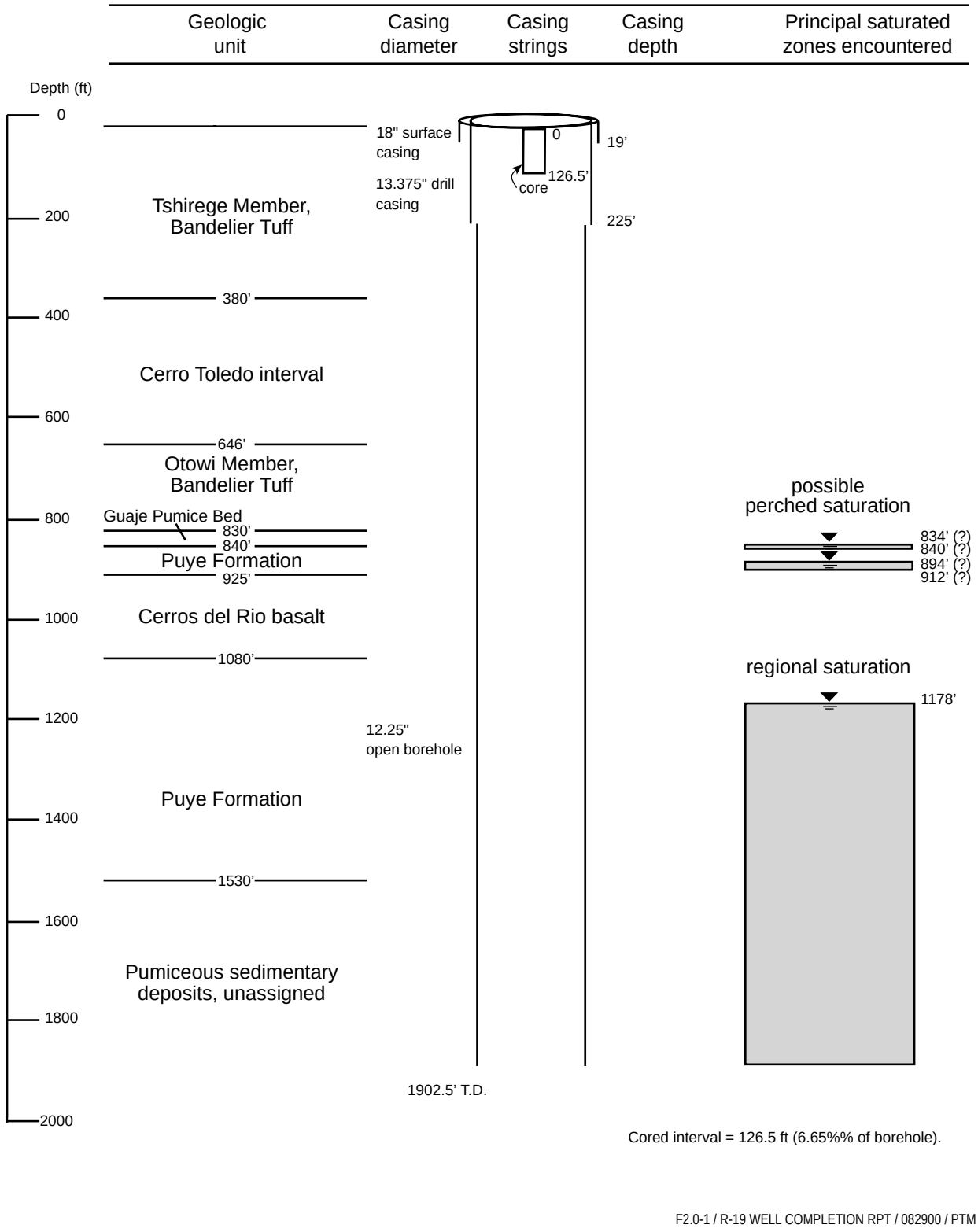


Figure 2.0-1. R-19 borehole configuration at total depth

Table 2.0-1 compares the actual number of shifts with the number of shifts projected for R-19 Phase I in the field implementation plan.

2.2.2 Phase II

During Phase II, the DR-24 drill rig was mobilized to R-19 on January 25, 2000 and demobilized on April 28, 2000. Drilling production at another deep borehole/well (CdV-R-15-3) required the switch out of the leased DR-24 drill rig at that site with the DR rig from R-19. Phase II drilling operations at R-19, including well development and testing, required 139.0 total shifts. Drilling and well-installation operations were typically conducted in two 12-hr shifts, seven days per week, but were periodically suspended due to facility work restrictions. Well development and testing activities were typically conducted during one 12-hr shift per day, five to seven days per week. Table 2.0-1 compares the actual number of shifts with the number of shifts projected for R-19 Phase II in the field implementation plan.

2.3 Production

2.3.1 Phase I

During Phase I, R-19 was continuously cored from the surface to refusal at 126.5 ft using 4.25-in.-I.D. Truspin™ HSAs with a Moss™ wire line continuous-core retrieval system. Using the in-place 4.25-in. HSA string as a guide, the borehole was reamed by 11-in.-I.D. HSAs from the surface to 20 ft. As the 4.25-in. auger string was withdrawn, the borehole was backfilled with cuttings from 126.5 to 19 ft.

The 11-in. HSAs were removed and one 18-in.-diameter, 20-ft-long steel casing joint was lowered to a depth of 19 ft bgs and a stickup of 1 ft above the ground surface. A cement slurry was tremied to 19 ft and rose approximately 3 ft inside and outside the casing. The casing was repeatedly raised and lowered to achieve a homogeneous cement seal. After curing overnight, the cement plug was a barrier to prevent more cement from flowing into the casing from below while the borehole annular space around the casing was cemented to approximately six ft below the ground surface.

The total footage drilled in Phase I by the HSA drilling technique was 146.5 ft. Phase I production statistics are summarized in Table 2.3-1.

2.3.2 Phase II

Drilling techniques used in Phase II of R-19 consisted of air-rotary under-reamer advance of one retractable casing string (13.375-in.) and open-borehole drilling using a 12.25-in. tricone carbide button bit. Phase II footage drilled by the 13.375-in. casing was 211 ft (does not include 16 ft of open hole inside 18-in. surface casing at that time); footage drilled by the open-borehole drilling system was 1695 ft. Implementing the open-borehole drilling technique to advance approximately 95% of the Phase II borehole footage was a significant operational modification. The total Phase II footage drilled by the different drilling techniques and casing sizes was 1906 ft. The total footage drilled does not include regular conditioning of the borehole or tripping drill systems to regain circulation and/or change bits. The total trip-in footage was 27,275.5 ft at an average rate of 520.7 ft/hr, and the total trip-out footage was 28,034.7 ft at an average rate of 310.7 ft/hr. Phase II production statistics are also summarized in Table 2.3-1.

Table 2.3-1
Preliminary Performance Statistics, Characterization Well R-19

Drilling Types	Phase I			Phase II		Total
	4.25-in.-I.D. HSA Core	11-in.-I.D. HSA	18-in. Surface Casing	12.25-in. Open-Hole System	13.375-in. Casing[a,f]	
Total footage drilled (ft)[b]	126.5	20		1676	211	2052.5
Total footage rate (ft/hr)[b]						18.3
Bandelier Tuff footage (ft)[c]	126.5	20.0		620	211.0	977.5
Bandelier Tuff rate (ft/hr)[c]	18.5	26.7		21.2	20.4	20.8
Basalt footage (ft)[d]				150.0		150.0
Basalt rate (ft/hr)[d]				7.5		7.5
Puye clastics footage (ft)[e]				925		925
Puye clastics rate (ft/hr)[e]				17.5		17.5
Trip-in footage (ft)						27,275.5
Trip-in rate (ft/hr)						520.7
Trip-out footage (ft)						28,034.7
Trip-out rate (ft/hr)						310.7
Life-of-hole casing TD (ft)			19		227.0	

[a] Holte 3-wing under-reamer for 13.375-in. casing use SD-12 hammer and 7-in. reverse circulation (RC) rods.
[b] Borehole TD is 1902.5 ft. Total cored footage (126.5 ft) is 6.6% of total borehole depth.
[c] Bandelier Tuff footage and rate include Tshirege Member, Cerro Toledo interval, and Otowi Member.
[d] Basalt footage and rate include various subunits of Cerros del Rio basalt (massive, vesicular, and scoriaceous).
[e] Puye footage and rate include various subunits of the fanglomerate facies (upper, lower, and unassigned pumiceous).
[f] First 16 ft of 13.375-in. casing was lowered into hole; not drilled.

TORKease® polymer, EZ-MUD® (polyacrylamide-polyacrylate copolymer), and QUIK-FOAM® slurries, mixed with community water obtained at the standpipe located adjacent to the Los Alamos County landfill, were utilized during drilling to lubricate the casing and open-borehole drill systems. Footage intervals for which lubricating slurry was used are indicated in Table 2.3-2.

Table 2.3-2
Footage Intervals Drilled with Lubrication Slurry, Characterization Well R-19

Drilling Technique/Tools	Dry Footage Intervals (ft)	Footage Intervals with Lubrication Slurry (ft)
HSA/4.25-in. I.D.	0–126.5	
HSA/11-in. I.D.	0–20	
Air rotary/13.375-in. casing	16–143	143–227
Air rotary/open-hole 12.25-in. Tricone		225–1902.5

2.3.3 Casing Advancement

During Phase II, 13.375-in. retractable casing was initially advanced using air as the drilling fluid. At 134 ft bgs, slow production prompted the use of lubrication slurries. Advancement of the 13.375-in. retractable casing was terminated at 227 ft bgs due to getting stuck in Qbt 2 of the Tshirege Member. Several drilling shifts were expended to free the casing using various extraction techniques. Dynatec had slowly pulled back the casing from 227 ft to 205 ft, at which depth the casing separated at 113 ft. The 13.375-in. casing from 113 ft to 205 ft was abandoned in the borehole prior to well installation. At R-19, the 13.375-in. retractable casing was used only within the Bandelier Tuff, at an average rate of 20.4 ft/hr (Table 2.3-1).

2.3.4 Open-Borehole Drilling

Open-borehole drilling using a 12.25-in. tricone bit was used to drill from 225 ft to TD at 1902.5 ft. Dynatec drilled 620 ft of open borehole in the Bandelier Tuff and volcaniclastic sediments of the Cerro Toledo interval at an average rate of 21.2 ft/hr; 150 ft of Cerros del Rio basalt at an average rate of 7.5 ft/hr; and 905 ft of the fanglomerate facies of the Puye Formation at an average rate of 17.5 ft/hr (Table 2.3-1).

2.3.5 Core Drilling

During Phase I, coring was accomplished using the Moss™ wire line retrieval system with the HSA drilling method. HSA core was attempted from the surface to auger refusal at 126.5 ft. Average recovery was 94.2%.

During Phase II, no coring was attempted.

2.3.6 Other Drilling Activities

Other drilling activities included conditioning and reaming the borehole wall to maintain fluid circulation and prevent locking the drill strings in place. Miscellaneous activities such as cleaning clay cake from drill bits, casing, and air-circulation equipment were minimized by injecting TORKease polymer, EZ-MUD, and QUIK-FOAM slurries during drilling.

3.0 GEOLOGY

Geologic units encountered in R-19 consist of, in descending order, soil, Tshirege Member of the Bandelier Tuff including the basal Tsankawi Pumice Bed, tephras and volcaniclastic sediments of the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff including the basal Guaje Pumice Bed, an upper subunit of the Puye Formation fanglomerate facies, basaltic rocks of the Cerros del Rio volcanic field, a lower subunit of Puye Formation fanglomerates, and pumice-rich sedimentary deposits of a yet unassigned stratigraphic association. Depths and elevations of the contacts between these units are shown in Figure 3.0-1, with a comparison to the predicted stratigraphy based on the three-dimensional (3-D) geologic model available at the time drilling began. Notable differences between the predicted and as-drilled stratigraphy are the greater thickness of the Cerro Toledo interval, the lesser thickness of the Otowi Member of the Bandelier Tuff, the thinner sequence of Cerros del Rio basalts, the absence of axial facies river gravels (Totavi) at the base of the Puye Formation, and the occurrence of unassigned pumiceous sedimentary deposits in lieu of Santa Fe Group sedimentary deposits.

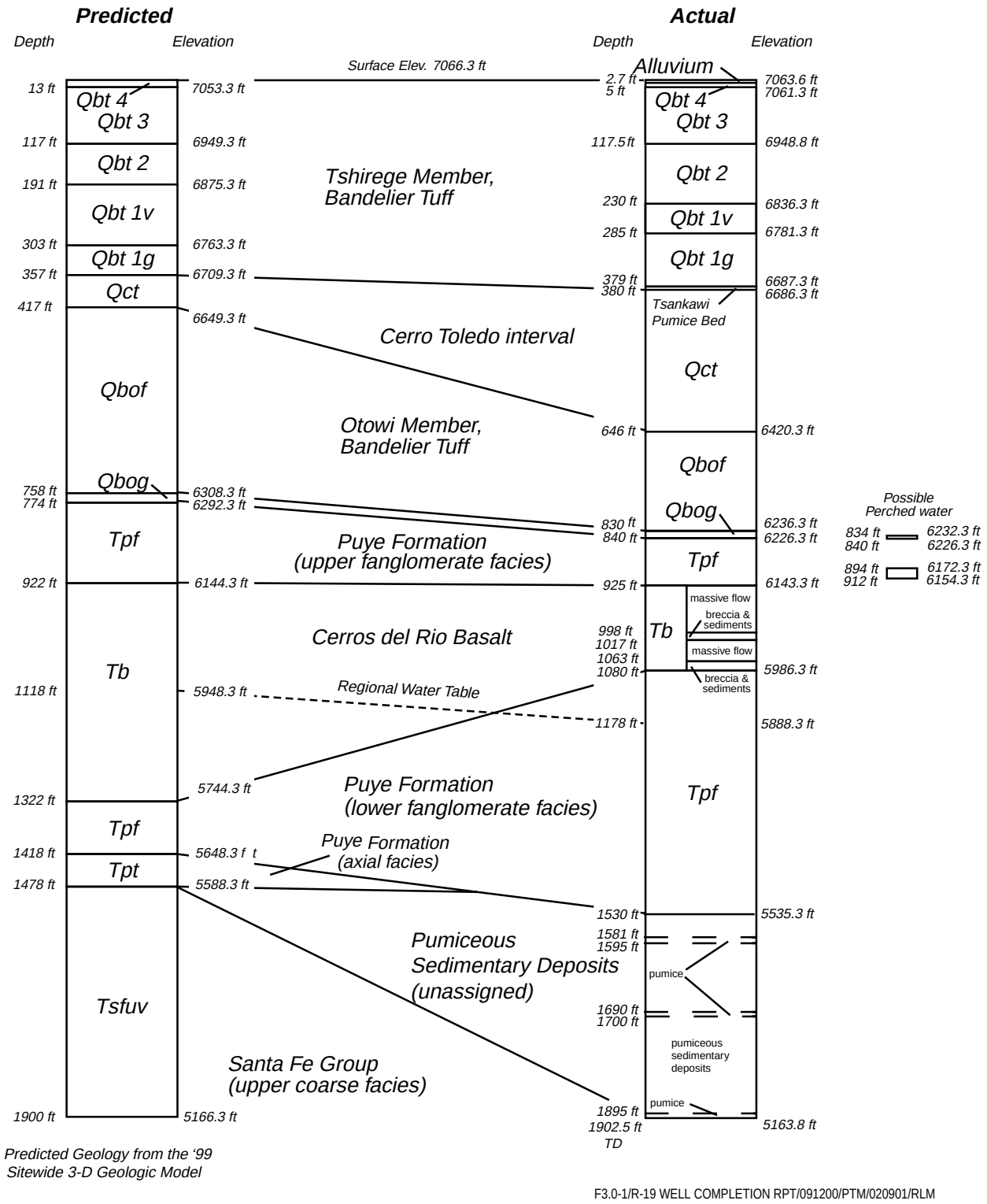


Figure 3.0-1. Comparison of actual and predicted geologic contacts in R-19

A brief summary of unit characteristics is given in the following sections, and a lithologic log is provided in Appendix A. An interpretive east-west cross section incorporating results from recent drilling at CdV-R-15-3 is given in Figure 3.0-2. Descriptions of geologic units are based on examination of cuttings, geophysical logs, drilling information, and laboratory examination of borehole materials. All studies of deeper borehole materials for petrography, mineralogy, and geochemistry were based on cuttings. Cuttings were collected by reverse circulation, minimizing the admixture of materials from upper portions of the borehole. Table 3.0-1 summarizes the weight proportions of different-sized-fractions for cuttings representative of several stratigraphic units in R-19. Disaggregation during drilling and concentration of lithic fragments was particularly prominent in nonwelded portions of the Bandelier Tuff. However, fragments of the basalt flows were collected unmixed with other lithologies from higher units, providing an indication of how effective the reverse-circulation system is in lifting cuttings solely from the zone where the bit is active. In the sedimentary units (Cerro Toledo, Puye, and unassigned pumiceous sedimentary deposits) the analysis of size fractions in Table 3.0-1 provides information related to in situ grain sizes, with the caveats that cobbles significantly larger than the inner diameter of the drill rods must be disaggregated to be carried to the surface and the fine-sand to clay fraction may be largely lost when cuttings are caught at the surface.

Table 3.0-1 also shows the locations of well screens at R-19 in relation to the intervals sampled for lithologic analysis. These samples are particularly important for relating geochemistry, petrology, mineralogy, and sedimentology to the interpretation of waters sampled in long-term monitoring. The preliminary data for evaluating these relations are provided in this report; other analyses may be appropriate in evaluating data to be obtained in the future under the long-term monitoring program.

3.1 Stratigraphy and Lithology

3.1.1 Mesa-Top Soil (0- to 2.7-ft depth)

Mesa-top soil was penetrated from the surface to a depth of 2.7 ft (Appendix A). The soil is sandy, dry, and contains abundant 1- to 2-mm crystals of quartz and chatoyant sanidine derived principally from Qbt 4 of the Tshirege Member of the Bandelier Tuff.

3.1.2 Tshirege Member of the Bandelier Tuff

The Pleistocene Tshirege Member of the Bandelier Tuff consists of multiple cooling units, designated downsection as units Qbt 4, 3, 2, 1v, and 1g. Nomenclature and definition of these units follows the usage of Broxton and Reneau (1995, 49726).

Qbt 4 (2.7- to 5-ft depth)

A thin sequence of Qbt 4 of the Tshirege Member was encountered below the soil. Qbt 4 consists of massive, moderately welded, devitrified, ash-flow tuff. Compared to the underlying units of the Tshirege Member, Qbt 4 is poorer in silica and more Ti, Fe, and Ba-rich (Broxton et al. 1995, 54709).

Qbt 3 (5- to 117.5-ft depth)

Qbt 3 of the Tshirege Member was encountered between the depths of 5 and 117. 5 ft. Qbt 3 consists of massive, poorly consolidated, vitric, nonwelded ash-flow tuff. This unit is more typical in composition of the lower Tshirege ash flows, which are distinctly less mafic than Qbt 4.

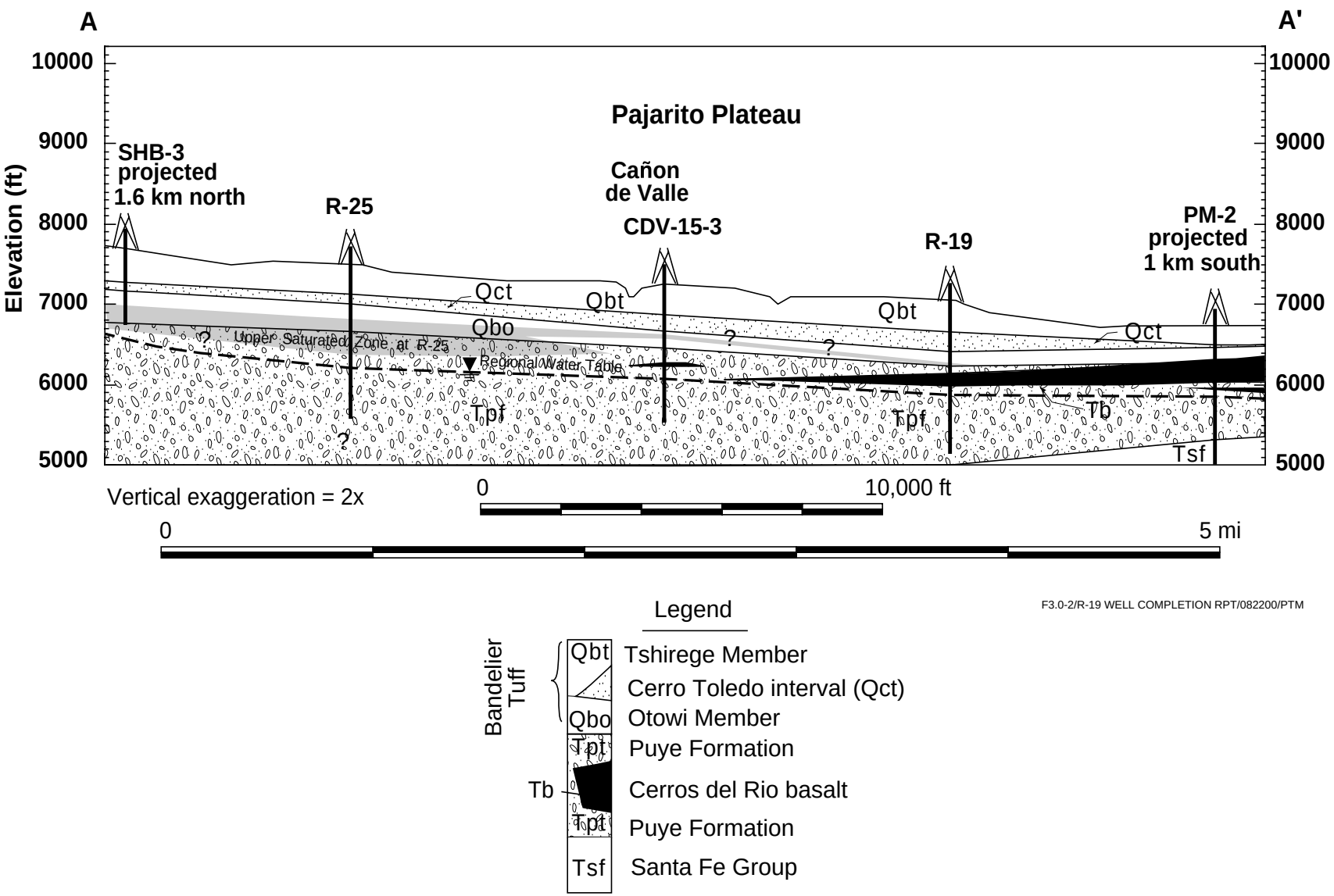


Figure 3.0-2. WNW-ESE cross-section through the southern part of the Laboratory showing geology in the vicinity of R-19 (see Figure 1.0-1 for location of cross-section)

Table 3.0-1
Weight Percentages of Size Fractions in Representative Cuttings from Drill Hole R-19

Sample Top (Depth in ft)	Sample Bottom (Depth in ft)	Screen Locations	Unit	Notes	% >4 mm	% 2–4 mm	% 1–2 mm	% <1 mm
380	382		Cerro Toledo		69.3	29.1	1.3	0.2
510	515		Cerro Toledo		29.4	34.1	19.9	16.7
635	640		Cerro Toledo		19.0	12.5	13.4	55.1
834	835	screen #1	Guaje		9.2	11.9	32.7	46.1
900	905	screen #2	Puye		25.6	25.3	21.6	27.5
960	965		Cerros del Rio	tholeiitic flow	42.5	48.8	6.2	2.5
995	1000		Cerros del Rio	tholeiitic flow	39.2	16.0	13.3	31.5
1025	1030		Cerros del Rio	alkalic flow	7.9	1.7	28.6	61.8
1055	1060		Cerros del Rio	alkalic flow	11.0	19.6	32.1	37.3
1075	1080		basaltic sand		12.9	34.6	18.2	34.3
1095	1100		Puye		11.6	22.0	22.6	43.7
1170	1175	screen #3	Puye		19.9	39.2	19.1	21.8
1205	1210	screen #3	Puye	clay/gravel	40.9	22.8	8.6	27.7
1330	1335		Puye	rounded cobbles	83.9	15.4	0.4	0.3
1380	1385		Puye	clay/sand	7.4	5.0	8.3	79.4
1410	1415	screen #4	Puye		51.7	21.5	11.8	15.0
1515	1520		Puye		42.3	29.9	8.1	19.6
1555	1560		unassigned		1.9	4.0	6.1	88.0
1585	1590	screen #5	unassigned	pumice bed	22.4	54.5	0.7	22.4
1590	1595		unassigned	pumice bed	35.7	59.7	0.6	4.1
1720	1725		unassigned	clay/sand	0.6	4.1	15.7	79.6
1730	1735	screen #6	unassigned		10.6	28.0	14.6	46.7
1735	1740		unassigned		14.0	20.2	15.2	50.5
1830	1835		unassigned		83.3	10.1	3.4	3.2
1835	1840	screen #7	unassigned		22.2	31.6	12.7	33.5
1895	1900		unassigned	pumice bed	87.3	7.1	0.1	5.5

Qbt 2 (117.5- to 230-ft depth)

Qbt 2 of the Tshirege Member was encountered between depths of 117.5 and 230 ft. This unit consists of massive, slightly to moderately welded, devitrified, ash-flow tuff. Even though completely vapor-phase altered, in most locales Qbt 2 differs from the upper parts of the Tshirege in having a silica-phase assemblage of mostly tridymite and phenocrystic quartz that is common in the higher zones of vapor-phase alteration (Broxton et al. 1995, 54709).

Caliper logging of the open borehole at R-19 indicates significant washout near the base of Qbt 2, to ~226 ft depth. This zone of washout may correspond to a decrease in welding at the Qbt 2/Qbt 1v contact.

Qbt 1v (230- to 285-ft depth)

Qbt 1v of the Tshirege Member was encountered between depths of 230 and 285 ft. This unit consists of massive, poorly consolidated, devitrified, nonwelded ash-flow tuff. The use of “v” in the unit symbol refers to the extensive vapor-phase alteration in this upper part of Qbt 1, in contrast to the lower part, Qbt 1g, in which primary glass is largely preserved with little vapor-phase alteration.

Geophysical logs indicate a steady rise in the abundance of bound water and particularly in capillary water from top to bottom in Qbt 1v. This increase in water content, most notably in capillary water, may reflect increasing matrix porosity of Qbt 1v with depth.

Qbt 1g (285- to 379-ft depth) and Tsankawi Pumice Bed (379- to 380-ft depth)

Qbt 1g of the Tshirege Member, including the basal Tsankawi Pumice Bed, was encountered between depths of 285 and 380 ft. This unit consists of massive, poorly consolidated, vitric, nonwelded ash-flow tuff. A thin deposit of the Tsankawi Pumice Bed occurs from 379 to 380 ft.

At ~300-ft depth the abundance of capillary water in Qbt 1g begins to rise above the highest value measured in Qbt 1v, and the content of capillary water in Qbt 1g continues to rise to the base of the unit. The values of capillary water content attained are comparable to those in the Otowi Member and may reflect the high matrix porosity typical of vitric nonwelded tuff.

3.1.3 Tephras and Volcaniclastic Sediments of the Cerro Toledo Interval (380- to 646-ft depth)

The Pleistocene Cerro Toledo interval is exceptionally thick at R-19, extending from depths of 380 to 646 ft (Appendix A). The thickness of this unit, 266 ft, is much greater than the thickness predicted from the 3-D geologic model at the time of drilling (60 ft; Figure 3.0-1). Revisions to the 3-D geologic model are needed in view of the unexpected magnitude of Cerro Toledo deposition in this part of the Laboratory site. The correspondingly less-than-expected thickness of the Otowi Member indicates an erosional low, developed on the Otowi Member, in which Cerro Toledo sedimentary deposits accumulated. The thickness of the Cerro Toledo deposits and the erosional thinning of the Otowi Member at R-19 are consistent with the SSW-draining pre-Tshirege valley proposed in this area by Broxton and Reneau (1996, 55429). Further drilling in the central, southern, and southwestern parts of the Laboratory site should provide the information necessary to revise the geometry of the erosional and depositional relations between the Cerro Toledo and the underlying Otowi Member.

The Cerro Toledo interval at R-19 consists predominantly of moist red-brown clayey silt and moist fine- to medium-grained, well sorted, clean sand. Somewhat coarser sandy gravels are also present at the top of the sequence (380 to 390 ft) and in the lower sedimentary deposits (520 to 646 ft). Grain-size analysis of representative cuttings (Table 3.0-1) indicates considerable variability in sediment size, ranging from gravels composed of >98 wt % clasts >2 mm (380- to 382-ft depth), to fine sands with >55 wt % clasts of <1 mm (510- to 515-ft depth), to deposits with fine sand (<1 mm), coarse sand (1 to 2 mm), fine gravel (2 to 4 mm), and coarser clasts (>4 mm) in subequal abundance (635- to 640-ft depth).

Petrographic analysis of the 2- to 4-mm clasts from three Cerro Toledo horizons (380 to 382 ft, 510 to 515 ft, and 635 to 640 ft) shows a common occurrence of aphyric vitric pumice related to rhyolitic sources active between the two episodes of Bandelier ash-flow eruption. However, the abundance of these pumices is greatest in the sample from the central portion of the Cerro Toledo interval and relatively minor in the samples from near the top and the bottom of the sequence. In these latter samples, clasts derived from the Tschicoma Formation predominate. The uppermost sample includes one clast of meta-arkose, probably a trace xenolith reworked from a deposit of rhyolitic tephra.

Chemical data for splits of the 2- to 4-mm clasts from the same three representative horizons in the Cerro Toledo are provided in Table 3.1-1. The higher silica content of the 2- to 4-mm clasts at 510- to 515-ft depth reflects the greater abundance of rhyolitic pumice in this sample, compared to the 2-4 mm clasts from the top and bottom of the Cerro Toledo unit. The data in Table 3.1-1 include analyses of <1-mm clasts from the horizons at 510- to 515-ft and 635- to 640-ft depth. Compared to the 2- to 4-mm fractions from the same horizons, the finer fractions are significantly higher in SiO_2 and lower in most other constituents, suggesting concentration of detrital silica minerals (probably quartz) in the sand fraction. Further analysis of Cerro Toledo samples from this and future boreholes in the region will help in interpreting the sedimentology of this unit. These interpretations can be used to construct a more realistic representation of the Cerro Toledo deposits in the 3-D geologic model.

Table 3.1-1
Chemical Analyses of the Cerro Toledo Deposits
and of the Guaje Pumice Bed from Drill Hole R-19 by Size Fractions

Sample Number[a]	R-19 380–382	R-19 510–515	R-19 510–515	R-19 635–640	R-19 635–640	R-19 834–835	R-19 834–835	R-19 834–835
Stratigraphic Unit	Cerro Toledo	Cerro Toledo	Cerro Toledo	Cerro Toledo	Cerro Toledo	Guaje Pumice Bed	Guaje Pumice Bed	Guaje Pumice Bed
Sample type	Cuttings (2–4 mm)	Cuttings (2–4 mm)	Cuttings (<1 mm)	Cuttings (2–4 mm)	Cuttings (<1 mm)	Cuttings (2–4 mm)	Cuttings (1–2 mm)	Cuttings (<1 mm)
SiO_2 %	68.95	70.26	77.49	64.15	74.87	70.85	88.95	80.39
TiO_2 %	0.49	0.28	0.11	0.72	0.23	0.47	0.10	0.11
Al_2O_3 %	16.22	15.41	12.74	17.08	13.42	13.97	6.01	10.80
Fe_2O_3 %	3.58	2.74	1.15	4.39	1.84	2.97	0.74	1.37
MnO %	0.07	0.08	0.03	0.09	0.05	0.09	0.02	0.05
MgO %	1.27	0.69	0.17	1.45	0.40	0.85	0.17	0.14
CaO %	2.46	1.49	0.52	3.00	0.83	1.83	0.33	0.43
Na_2O %	3.63	4.16	3.59	4.51	3.63	3.47	1.39	2.69
K_2O %	2.92	3.38	3.51	2.39	3.15	3.12	1.35	2.66
P_2O_5 %	0.14	0.08	0.02	0.23	0.06	0.15	0.03	0.02
Total %	99.73	98.57	99.33	98.02	98.47	97.76	99.08	98.66
LOI[b] %	1.32	1.40	0.64	1.28	0.68	1.14	0.46	0.55
V ppm	49	19	<10	52	24	35	<10	<10
Cr ppm	37	26	<8	29	21	23	22	10
Ni ppm	14	11	<11	<12	<11	14	<12	<11
Zn ppm	89	57	23	187	38	75	24	49
Rb ppm	74	80	48	54	57	110	51	89
Sr ppm	393	206	63	477	124	269	42	29
Y ppm	29	27	<7	35	<7	29	<7	26
Zr ppm	187	167	86	217	99	211	59	84
Nb ppm	34	46	20	35	22	55	22	28
Ba ppm	902	593	154	1170	219	629	143	62

Note: Values reported in percent or parts per million by weight. Analytical errors (2σ) are SiO_2, 0.7; TiO_2, 0.01; Al_2O_3, 0.2; Fe_2O_3, 0.06; MnO, 0.01; MgO, 0.08; CaO, 0.1; Na_2O, 0.1; K_2O, 0.05; P_2O_5, 0.01; V, 10; Cr, 8; Ni, 10; Zn, 12, Rb, 5, Sr, 25; Y, 6; Zr, 30; Nb, 7; and Ba, 50.

[a] Number ranges indicate depth ranges of cuttings in ft.

[b] LOI = loss on ignition.

Despite the variability in clast sizes and clast lithologies, the deposits of the Cerro Toledo interval in R-19 show little variability in properties measured by borehole logging. Caliper-measured borehole dimensions, gamma signals, capillary and bound water, and neutron measures of water residence environment are all strikingly homogeneous. This homogeneity contrasts with the highly heterogeneous nature of all of these properties within the deeper Puye sedimentary deposits.

There is a modest but measurable rise in capillary water content within the lower Cerro Toledo sedimentary deposits (520- to 646-ft depth). This rise is likely associated with a small increase in porosity. The most significant differences between the Cerro Toledo sedimentary deposits and the bounding tuffs are a lower gamma signal (attributable principally to lower U and Th content) and much lower abundances of capillary water (less available porosity).

3.1.4 Otowi Member of the Bandelier Tuff (646- to 830-ft depth) and Guaje Pumice Bed (830- to 840-ft depth)

Tuffs of the Pleistocene Otowi Member, including ash flows (Qbof) and the basal Guaje Pumice Bed (Qbog), were encountered between depths of 645 and 840 ft. At R-19, the Otowi Member consists of massive, poorly consolidated, vitric, nonwelded ash-flow tuff. The Guaje Pumice Bed occurs from 830 to 840 ft.

Petrographic analysis of the 2- to 4-mm clasts from the Guaje Pumice Bed at 834- to 835-ft depth shows that this size fraction consists mostly of dacitic lithic fragments. Pumices in this size range from the Guaje have been almost completely crushed during drilling. The chemical data from the 2- to 4-mm, 1- to 2-mm, and <1-mm-sized fractions of the Guaje Pumice Bed (Table 3.1-1) indicate significant chemical fractionation with grain size. The 2- to 4-mm-sized fraction is dominated by dacitic lithic fragments and thus has relatively low SiO_2 content (~71%); the 1- to 2-mm-sized fraction has anomalously high SiO_2 content (~89%) reflecting concentration of quartz grains; and the <1-mm-sized fraction has more ash and comes closer to the composition of the Bandelier ash flows. The large compositional differences between grain sizes, with the likelihood of ash loss when cuttings are collected, make reconstruction of reliable bulk composition from cuttings difficult in this unit.

Borehole logs for the Otowi Member indicate properties comparable to Qbt 1g of the Tshirege Member, which is also a vitric nonwelded tuff. The Guaje Pumice Bed is an interval with considerably larger pore structure and greater water content than the overlying ash flows.

Drill hole R-19 was located in a portion of the Laboratory where the Bandelier Tuff is postulated to fill a SSW draining paleovalley (Broxton and Reneau 1996, 55429). In their approximation of the paleovalley topography, the base of the Otowi Member in the vicinity of R-19 was placed at approximately 6350 ft elevation. This is 130 ft higher than this contact was encountered. The predicted contact in the 1999 3-D sitewide geologic model is also higher than the actual contact (Figure 3.0-1). The new information from R-19 reinforces the concept of the paleovalley and helps to define the topology of this feature.

3.1.5 Puye Formation (upper fanglomerate facies; 840- to 925-ft depth)

A subunit of the Pliocene fanglomerate facies of the Puye Formation extends from depths of 840 to 925 ft (Appendix A). This unit consists of coarse volcaniclastic sedimentary deposits as described by Griggs (1964, 8795) and by Waresback (1986, 58715). The volcaniclastic sedimentary deposits are dominated by rounded clasts of various lavas. Size analysis of cuttings from 900- to 905-ft depth, representative of the sedimentary deposits at screen #2, indicates a distribution of fine sand (<1 mm), coarse sand (1 to 2 mm), fine gravel (2 to 4 mm), and coarser clasts (>4 mm) in subequal abundance (Table 3.0-1). Clasts

in the 2- to 4-mm-sized fraction consist predominantly of Tschicoma Formation dacites and rhyodacites with lesser amounts of basalt. Chemical analyses of the 2- to 4-mm, 1- to 2-mm, and <1-mm-sized fractions of the 900- to 905-ft sample show a strong similarity to the upper section of the lower Puye deposits, beneath the Cerros del Rio basalts (see discussion of Puye chemical analyses, Section 3.1.7 of this document). This similarity in Puye composition above and below the basalt unit indicates continuity in Puye sources across the episode of basalt emplacement, although the occurrence of basalt detritus in the upper fanglomerate is distinctive.

Borehole logs indicate that the sedimentary deposits from 900- to 912-ft depth, in the vicinity of screen #2, are of relatively high porosity and lower in bulk density, and contain more mobile water than other sedimentary deposits in this portion of the Puye Formation at R-19 (see Section 3.2 of this document).

3.1.6 Cerros del Rio Basalt (925- to 1080-ft depth)

Late Pliocene basaltic rocks of the Cerros del Rio volcanic field occur from a depth of 925 to 1088 ft (Appendix A). The basaltic rocks consist of vesicular to massive flows with intercalated scoriaceous and clay-rich intervals. Drilling properties of lavas in this interval vary considerably; an upper lava, 925- to 998-ft depth, produces mostly coarse fragments of >4 mm whereas a lower lava (1017- to 1063-ft depth) produces finer fragments (Table 3.0-1). The easier fragmentation of the lower lava may be composition-related, since similar fine fragmentation was observed in a lower alkalic basalt, relative to upper tholeiitic basalt, in a similar association at drill hole R-9i (Broxton et al. 2000, 66600).

Cuttings and borehole logs indicate two principal basalt flows in R-19. The upper flow (925- to 998-ft depth) is uniformly dense with essentially no available porosity. Two samples from this flow were collected for more detailed analysis, one sample from 960- to 965-ft depth and another from 995- to 1000-ft depth. This flow is tholeiitic with abundant olivine phenocrysts; the sample from 995 to 1000 ft includes less abundant glomerocrystic associations of plagioclase and clinopyroxene. Results of chemical analyses are summarized in Table 3.1-2. Based on these data, Figure 3.1-1 compares four parameters of basalt composition for the upper and lower Cerros del Rio basaltic lavas at R-19: parameters of silica content, K_2O/P_2O_5 ratio, Mg# [representing the cation ratio Mg/(Mg+Fe)], and Sr content. Increasing SiO_2 content and decreasing Mg# are indices of magma evolution through olivine fractionation. Higher K_2O/P_2O_5 values reflect increasing basalt contamination by assimilation of high-K, low-P crustal rocks. Higher Sr contents are characteristic of more alkalic basalt compositions. All four of these parameters are smaller in the tholeiitic upper flow than they are in the alkalic lower flow. In borehole logging, the tholeiitic upper flow also has a gamma signal indicating significantly lower K abundance than the lower basalt flow; this is corroborated by the difference in K_2O content measured by XRF (~0.9% K_2O in the upper flow versus 2.3% K_2O in the lower flow; Table 3.1-2). The samples analyzed from the tholeiitic flow were hand-picked and unaltered, but there is a zone of flow-base rubble (998- to 1006-ft depth) below the upper flow, overlying massive poorly-bedded scoria (1006- to 1017-ft depth). Borehole logging indicates abundant bound water in the rubble and scoria, a sign of significant clay alteration (see Section 3.2).

The lower basalt flow (1017- to 1063-ft depth) is highly vesicular with relatively low density, determined by borehole logging, in the upper portion (1017 to 1040 ft). As noted above, this lower basalt flow is more fragmented throughout than is the upper flow, producing generally finer cuttings and providing evidence in borehole logging of small but measurable porosity. Two samples were collected from the lower flow for more detailed analysis, one sample from 1025- to 1030-ft depth and another from 1055- to 1060-ft depth. Both samples have abundant fresh olivine phenocrysts; the lower sample (1055- to 1060-ft depth) also contains phenocrysts of corroded and sieved plagioclase. The high K_2O content (Table 3.1-2) and in particular the high Sr content (Table 3.1-2 and Figure 3.1-1) of this lower flow distinguish it as part of the Cerros del Rio alkalic series.

Table 3.1-2
Chemical Analyses of Cerros del Rio Basalts and of Pumice Beds and Hand-Picked Pumice from Drill Hole R-19

Sample Number[a]	R-19 960–965	R-19 995–1000	R-19 1025–1030	R-19 1055–1060	R-19 1585–1590	R-19 1585–1590	R-19 1590–1595	R-19 1895–1900
Stratigraphic Unit	Cerros del Rio	Cerros del Rio	Cerros del Rio	Cerros del Rio	Unassigned pumice bed	Unassigned pumice bed	Unassigned pumice	Unassigned pumice
Sample Type	Hand-picked	Hand-picked	Hand-picked	Hand-picked	Cuttings (2–4 mm)	Cuttings (<1 mm)	Hand-picked (>2 mm)	Hand-picked (>2 mm)
SiO_2 %	49.04	49.49	51.82	52.01	69.62	65.85	69.63	69.07
TiO_2 %	1.43	1.41	1.33	1.36	0.14	0.36	0.13	0.113
Al_2O_3 %	16.71	16.73	17.87	17.22	16.71	18.53	19.07	17.10
FeO %[b]	6.05	6.47	2.20	4.55	NA[c]	NA	NA	NA
Fe_2O_3 %[b]	4.42	4.08	5.47	2.98	0.82	2.56	0.73	0.78
MnO %	0.15	0.15	0.14	0.14	0.058	0.046	0.056	0.076
MgO %	6.61	6.88	5.94	6.37	0.15	1.09	<0.11	0.14
CaO %	8.78	8.79	7.23	7.21	0.44	2.40	0.36	0.50
Na_2O %	3.29	3.26	3.94	4.18	2.54	3.60	2.47	2.33
K_2O %	0.89	0.91	2.28	2.29	5.18	3.33	5.04	5.19
P_2O_5 %	0.35	0.34	0.65	0.68	0.02	0.11	0.01	0.016
Total %	97.72	98.50	98.87	98.99	95.66	97.87	97.49	95.32
LOI %[d]	0.91	0.52	0.20	-0.15	3.60	1.03	3.46	4.32
V ppm	184	173	149	138	<10	40	<10	<10
Cr ppm	183	207	179	168	<8	30	<8	13
Ni ppm	74	88	105	119	<11	<11	<11	<11
Zn ppm	94	92	63	67	<13	39	22	19
Rb ppm	14	11	39	46	128	68	125	102
Sr ppm	470	456	890	893	39	354	25	49
Y ppm	25	27	26	12	19	9	23	28
Zr ppm	144	145	219	213	88	143	87	103
Nb ppm	10	19	28	39	23	18	27	32
Ba ppm	419	450	1207	1231	453	1094	461	578

Note: Values reported in percent or parts per million by weight. Analytical errors (2σ) are SiO_2, 0.7; TiO_2, 0.01; Al_2O_3, 0.2; Fe_2O_3, 0.06; MnO, 0.01; MgO, 0.08; CaO, 0.1; Na_2O, 0.1; K_2O, 0.05; P_2O_5, 0.01; V, 10; Cr, 8; Ni, 10; Zn, 12, Rb, 5, Sr, 25; Y, 6; Zr, 30; Nb, 7; and Ba, 50.

[a] Number ranges indicate depth ranges of cuttings in ft.

[b] All iron reported as Fe_2O_3 unless ferrous/ferric ratio was determined by digestion/titration.

[c] NA = not analyzed.

[d] LOI = loss on ignition; negative values indicate oxidation of ferrous iron during ignition.

The base of the lower basalt flow, at 1063- to 1067-ft depth, is a zone of flow-base rubble overlying a zone of scoria and layered basaltic sedimentary deposits from 1067- to 1074-ft depth and basaltic sands from 1074- to 1080-ft depth. A sample from the basaltic sands (1075- to 1080-ft depth) contains grains of olivine, sieved clinopyroxene, and plagioclase derived from basaltic sources, as well as quartz from other sources. The interval of flow-base scoria and basaltic sedimentary deposits has a high clay content, similar to the zone of rubble and scoria between the flows at 998- to 1017-ft depth.

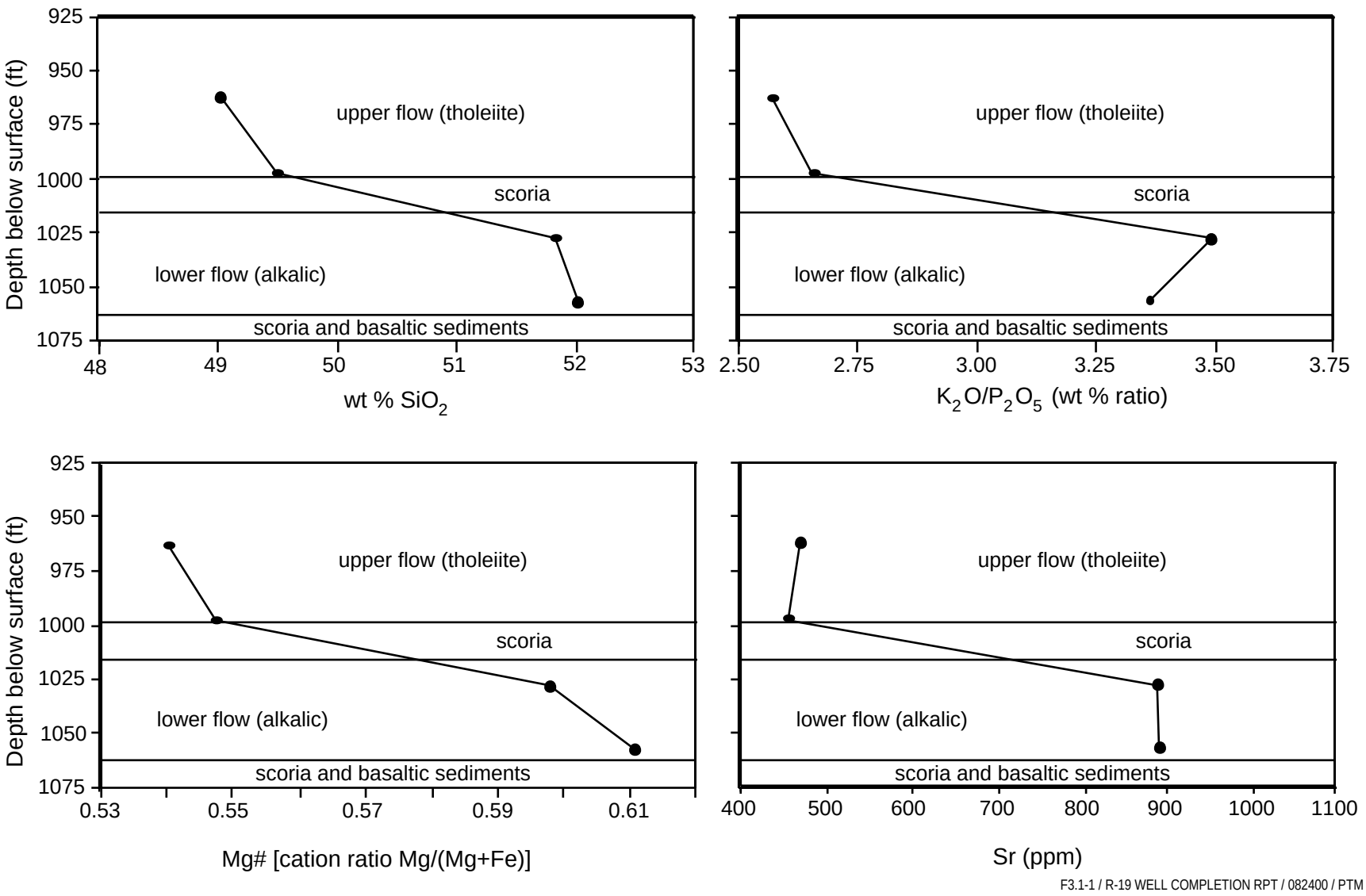


Figure 3.1-1. **Variations in SiO_2, K_2O/P_2O_5, Sr, and Mg# [cation ratio of Mg/(Mg+Fe)] with stratigraphic depth in the sequence of Cerros del Rio basalts sampled at R-19 (data from Table 3.1-2)**

The occurrence of tholeiitic lava overlying an alkalic lava in the Cerros del Rio basalts of R-19 is superficially similar to the tholeiitic-over-alkalic flow series documented in drill holes to the northeast (R-15, R-12, R-9, and R-9i). However, the trends shown in Figure 3.1-1 differ in two respects from the compositions of Cerros del Rio basalts in these drill holes to the northeast. The Cerros del Rio basalts in these other drill holes have higher SiO_2 and higher K_2O/P_2O_5 ratios in the upper, tholeiitic lavas, whereas these parameters are both lower in the tholeiitic lava at R-19. The decline in silica content and in K_2O/P_2O_5 in the younger lava at R-19 makes it less likely that the lava series at R-19 is derived by olivine fractionation and increased crustal assimilation with evolution in a single magma chamber, a scenario that is plausible for the lavas to the northeast. The differences at R-19 also make it unlikely that the same Cerros del Rio lava flows found beneath the midreaches of Los Alamos, Sandia, and Mortandad Canyons extend as far to the southwest as R-19.

3.1.7 Puye Formation (lower fanglomerate facies; 1080- to 1530-ft depth)

Beneath the basalts, a lower sequence of Pliocene fanglomerates of the Puye Formation extends from 1080 to 1530 ft (Appendix A) and consists of coarse volcaniclastic sedimentary deposits. Grain-size analysis of cuttings within this interval indicates great variability in clast-size distributions (Table 3.0-1); this is supported by borehole neutron data indicating polymodal distribution of pore size, although the pore sizes are generally smaller than in the underlying pumiceous sedimentary deposits. There are exceptions to this distinction, however, particularly in the vicinity of the water-table screen (screen #3). Sedimentary deposits at 1330- to 1335-ft depth, just below screen #3, are among the coarsest of the fanglomerates in this unit, containing 84 wt % of clasts >4 mm in size. These clasts consist of varied dacites and are more rounded than typical for this section of fanglomerate. This sample has <1 wt % sand component (<2-mm clasts). More typical fanglomerates in this section have ~40 wt % clasts >4 mm and 20 to 50 wt % sand particles of <2 mm.

Petrographic analysis shows that most of the clastic materials in the 2- to 4-mm-sized range are derived from intermediate-composition volcanic rocks, dacites and rhyodacites typical of the Tschicoma Formation. However, the deepest sample analyzed from the fanglomerate (1515- to 1520-ft depth) includes some clasts of well-cemented sandstone and coarse quartz grains. Chemical data for size fractions from the Puye fanglomerates, both the upper fanglomerate (above the Cerros del Rio basalt) and the lower fanglomerate (below the Cerros del Rio basalt), are summarized in Table 3.1-3. Analyses of the 2- to 4-mm, 1- to 2-mm, and <1-mm-sized fractions were collected for samples from 900- to 905-ft depth (upper fanglomerate) and from 1170 to 1175 ft, 1205 to 1210 ft, and 1410 to 1415 ft (lower fanglomerate). Three defining constituents (SiO_2, Fe_2O_3, and Sr) and one ratio (Sr/Rb) are plotted against depth in Figure 3.1-2. The data indicate coherence between the upper and lower fanglomerates, with systematic increase in SiO_2 and decrease in Fe_2O_3 and Sr with depth. Gamma logs indicate a relatively abrupt transition to higher K plus Th content at ~1360 ft depth within the lower fanglomerate. The K_2O values for the 2- to 4-mm and 1- to 2-mm-sized fractions of the sample at 1410- to 1415-ft depth are higher than those in the samples above 1360 ft, but the principle cause of the higher gamma signal may be in Th content, which was not determined by XRF analysis.

Differences between the 2- to 4-mm, 1- to 2-mm, and <1-mm-sized fractions at each horizon in the fanglomerates are minimal, a strong indication that selective disaggregation or borehole mixing of finer fragments is not a concern in Puye deposits with the drilling method used at R-19. In terms of source detritus, the similarity between all three size fractions also indicates a single or well-mixed source for all deposits within the fanglomerates, without significant contributions from other sources in the finer detritus. This contrasts markedly with the situation in the Cerro Toledo deposits, where admixture of coarse Tschicoma detritus and finer Otowi detritus leads to significant chemical differences between the 2- to 4-mm and <1-mm-sized fractions (Table 3.1-1 and Figure 3.1-2).

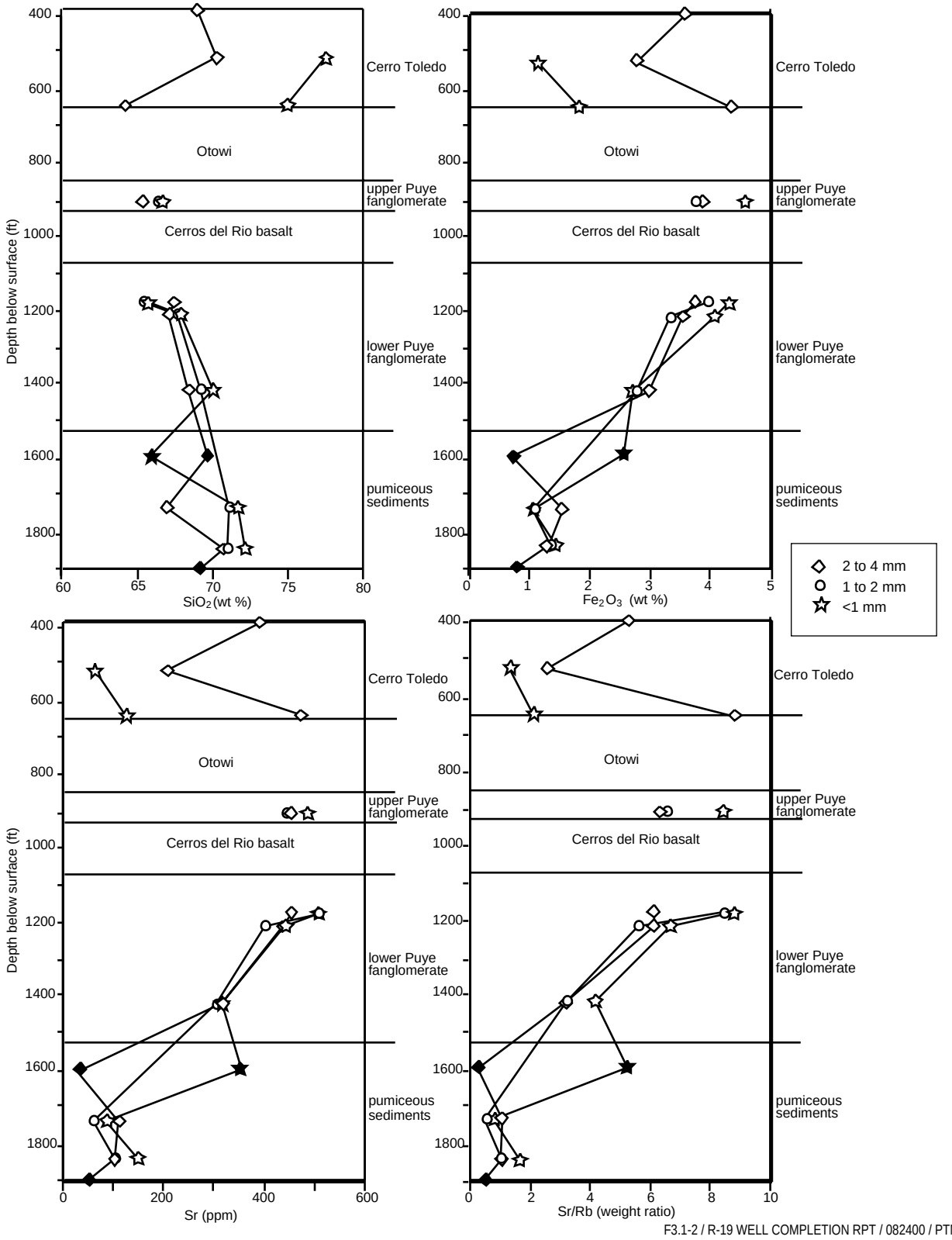
Table 3.1-3
Chemical Analyses of the Puye Fanglomerates from Drill Hole R-19 by Size Fractions

Sample Number[a]	R-19 900–905	R-19 900–905	R-19 900–905	R-19 1170–1175	R-19 1170–1175	R-19 1170–1175	R-19 1205–1210	R-19 1205–1210	R-19 1205–1210	R-19 1410–1415	R-19 1410–1415	R-19 1410–1415
Stratigraphic Unit	Guaje	Guaje	Guaje	Guaje	Guaje	Guaje	Guaje	Guaje	Guaje	Guaje	Guaje	Guaje
Sample Type	Cuttings (2–4 mm)	Cuttings (1–2 mm)	Cuttings (<1 mm)	Cuttings (2–4 mm)	Cuttings (1–2 mm)	Cuttings (<1 mm)	Cuttings (2–4 mm)	Cuttings (1–2 mm)	Cuttings (<1 mm)	Cuttings (2–4 mm)	Cuttings (1–2 mm)	Cuttings (<1 mm)
SiO_2 %	66.60	66.26	65.29	67.42	65.33	65.66	67.08	67.64	67.85	68.41	69.17	70.07
TiO_2 %	0.53	0.52	0.61	0.50	0.53	0.55	0.48	0.46	0.51	0.41	0.38	0.39
Al_2O_3 %	15.63	15.91	15.66	15.33	16.41	15.82	15.98	15.58	15.01	15.63	16.10	15.54
Fe_2O_3 %	3.89	3.78	4.57	3.74	3.96	4.33	3.55	3.33	4.09	2.98	2.77	2.73
MnO %	0.06	0.05	0.07	0.06	0.07	0.07	0.06	0.05	0.07	0.05	0.05	0.05
MgO %	1.37	1.28	1.76	1.59	1.69	2.04	1.62	1.43	1.88	1.22	1.19	1.12
CaO %	3.01	2.92	3.09	3.10	3.27	3.36	2.99	2.79	3.21	2.21	2.09	2.12
Na_2O %	3.93	3.95	3.85	3.90	3.77	3.72	3.90	3.80	3.79	3.89	3.79	3.34
K_2O %	3.28	3.21	2.95	3.37	3.23	3.09	3.30	3.40	3.10	3.83	3.69	3.15
P_2O_5 %	0.20	0.20	0.17	0.22	0.25	0.22	0.20	0.17	0.17	0.11	0.10	0.08
Total %	98.50	98.06	98.03	99.22	98.50	98.87	99.18	98.64	99.68	98.73	99.33	98.58
LOI %[b]	0.72	0.72	0.67	0.59	0.55	0.54	0.49	0.55	0.70	0.70	0.68	0.98
V ppm	52	55	65	49	61	63	53	47	55	35	30	31
Cr ppm	46	39	62	29	36	59	34	33	48	39	42	46
Ni ppm	25	29	30	27	15	21	24	15	34	32	29	27
Zn ppm	51	47	64	51	47	47	52	39	63	48	32	35
Rb ppm	72	68	58	74	61	58	72	72	67	99	95	75
Sr ppm	455	444	487	455	513	509	437	402	444	315	305	317
Y ppm	21	16	12	20	24	17	<7	15	<7	29	20	17
Zr ppm	179	174	178	169	171	172	165	172	167	154	147	188
Nb ppm	14	30	16	28	24	30	23	24	15	34	15	15
Ba ppm	1200	1141	1069	1169	1114	1128	1149	1152	1093	786	776	763

Note: Values reported in percent or parts per million by weight. Analytical errors (2σ) are SiO_2, 0.7; TiO_2, 0.01; Al_2O_3, 0.2; Fe_2O_3, 0.06; MnO, 0.01; MgO, 0.08; CaO, 0.1; Na_2O, 0.1; K_2O, 0.05; P_2O_5, 0.01; V, 10; Cr, 8; Ni, 10; Zn, 12, Rb, 5, Sr, 25; Y, 6; Zr, 30; Nb, 7; and Ba, 50.

[a] Number ranges indicate depth ranges of cuttings in ft.

[b] LOI = loss on ignition.



F3.1-2 / R-19 WELL COMPLETION RPT / 082400 / PTM

Figure 3.1-2. Variation in SiO_2, Fe_2O_3, Sr, and Sr/Rb with depth by size fractions from Cerro Toledo, Puye, and unassigned pumiceous sedimentary deposits in drill hole R-19. Filled symbols indicate data from pumice beds; open symbols indicate all other deposits.

Quantitative XRD data from 2- to 4-mm-sized fractions of other representative samples from the Puye fanglomerates are summarized in Table 3.1-4. Some clay alteration occurs, but is limited to ~1% to 2% smectite. Appreciable amounts of glass (~13% to 14%) remain in all of the fanglomerate samples, evidence of only limited alteration. Clays were separated from fanglomerate samples at 1205- to 1210-ft depth and 1380- to 1385-ft depth. These clays are poorly ordered smectites with ~4% to 6% kaolinite, common to most alteration typical of the Puye Formation. The significant amounts of remnant glass attest to the very incomplete alteration of these sedimentary deposits.

Table 3.1-4
Quantitative X-Ray Diffraction Analyses of 2- to 4-mm-Sized Fractions from the Puye Fanglomerate and from Unassigned Pumiceous Sedimentary Deposits in Drill Hole R-19

Sample[a]	Smectite	Mica	Quartz	Cristobalite	Tridymite	Opal-CT	Feldspar	Glass	Hematite	Magnetite	Total
R-19 1095–1100 Puye fanglomerate	3.6	0.1	0.9	7.1	10.9	—[b]	60.3	13.2	0.3	—	96.4
R-19 1330–1335 Puye fanglomerate	—	—	—	5.0	18.1	—	58.7	12.6	—	3.1	97.5
R-19 1380–1385 Puye fanglomerate	2.9	3.0	2.6	9.1	9.0	—	52.6	14.2	0.8	2.1	96.3
R-19 1515–1520 Puye fanglomerate	0.9	3.0	1.2	12.3	8.9	—	53.8	13.2	0.8	2.2	96.3
R-19 1555–1560 Unassigned pumiceous sedimentary deposit	1.3	0.8	—	6.5	3.7	12.1	46.4	26.2	0.6	2.3	99.9
R-19 1735–1740 Unassigned pumiceous sedimentary deposit	1.8	0.5	0.6	2.0	1.1	—	15.3	78.1	—	—	99.4
R-19 1830–1835 Unassigned pumiceous sedimentary deposit	0.6	0.8	3.1	5.5	4.1	—	45.2	37.6	0.7	2.3	100.1

Notes: 1. Analytical errors (2σ) are ~5% of the amount reported for abundances >10% and ~10% of the amount reported for abundances <10%.

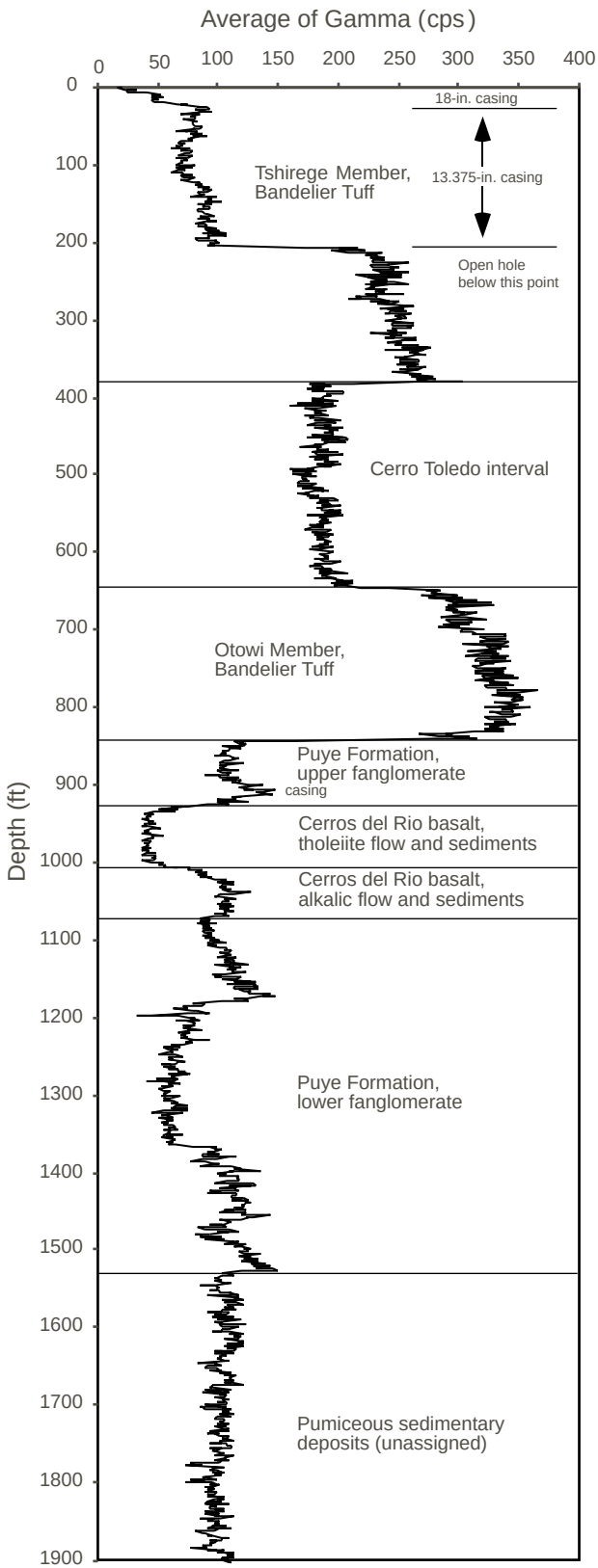
2. All values reported in weight percent.

[a] Number ranges indicate depth ranges of cuttings in ft.

[b] A dash in the table indicates that the phase was not detected; detection limits ~0.1%.

3.1.8 Pumiceous Sedimentary Deposits, Unassigned (1530-ft depth to TD at 1902.5 ft)

From the depth of 1530 ft to TD at 1902.5 ft, the sedimentary deposits are distinctively pumice-rich, in contrast to the overlying fanglomerates. The transition into this unit from the fanglomerate is marked by a notable decrease in the natural gamma signal recorded with the Laboratory GR tool (Figure 3.1-3). In general the pumiceous sedimentary deposits are finer-grained than the fanglomerates, with <25 wt % clasts of >4 mm and >60 wt % sands of <2 mm (Table 3.0-1). However, an exception to this occurs above screen #7, where >4-mm clasts comprise >80 wt % of the deposit at 1830- to 1835-ft depth. The typical pumiceous sedimentary deposits of this interval contain variable clast admixtures of mostly aphyric to poorly porphyritic pumice plus intermediate volcanic rocks, with rare fragments of lavas with andesitic to basaltic composition.



F3.1-3 / R-19 WELL COMPLETION RPT / 082400 / PTM

Figure 3.1-3. Results of natural gamma radiation survey obtained March 14, 2000

Chemical data from the 2- to 4-mm, 1- to 2-mm, and <1-mm-sized fractions were collected for two representative samples of the unassigned pumiceous sedimentary deposits, at 1730- to 1735-ft depth and 1835- to 1840-ft depth (Table 3.1-5). Data for these deposits are also plotted in Figure 3.1-2, for comparison with the overlying Puye fanglomerates. The pumiceous deposits have geochemical indicators of rhyolitic sources, unlike the intermediate-composition Tschicoma sources that characterize the Puye fanglomerates. The differences between the Puye fanglomerates and the underlying pumiceous deposits are clearly seen in Figure 3.1-4, where a plot of Sr versus Rb content defines a distinctive high Sr, low Rb field for the fanglomerates and a low Sr, high Rb field for the unassigned pumiceous sedimentary deposits. Also shown on this plot is the very distinctive low-Rb, low-Sr field for the <1-mm-sized fraction from the Cerro Toledo deposits, contrasted with the Tschicoma-like compositions for the 2- to 4-mm-sized fractions in the Cerro Toledo.

Table 3.1-5
Chemical Analyses of Unassigned Pumiceous Sedimentary Deposits from Drill Hole R-19

Sample Number[a]	R-19 1730–1735	R-19 1730–1735	R-19 1730–1735	R-19 1835–1840	R-19 1835–1840	R-19 1835–1840
Stratigraphic Unit	Unassigned pumiceous sedimentary deposits	Unassigned pumiceous sedimentary deposits	Unassigned pumiceous sedimentary deposits	Unassigned pumiceous sedimentary deposits	Unassigned pumiceous sedimentary deposits	Unassigned pumiceous sedimentary deposits
Sample Type	Cuttings (2–4 mm)	Cuttings (1–2 mm)	Cuttings (<1 mm)	Cuttings (2–4 mm)	Cuttings (1–2 mm)	Cuttings (<1 mm)
SiO_2 %	66.87	71.07	71.69	70.68	70.93	72.16
TiO_2 %	0.25	0.17	0.17	0.21	0.22	0.23
Al_2O_3 %	19.10	14.48	13.79	15.21	13.84	13.88
Fe_2O_3 %	1.56	1.06	1.04	1.31	1.34	1.43
MnO %	0.06	0.06	0.07	0.07	0.07	0.06
MgO %	0.59	0.35	0.26	0.43	0.43	0.38
CaO %	1.07	0.63	0.65	0.81	0.84	0.90
Na_2O %	2.57	2.49	3.01	2.97	2.83	2.96
K_2O %	4.40	4.89	4.59	4.53	4.61	4.19
P_2O_5 %	0.06	0.02	0.02	0.05	0.05	0.04
Total %	96.53	95.24	95.29	96.26	95.15	96.23
LOI %[b]	3.25	4.30	3.75	3.13	3.63	3.53
V ppm	23	26	<10	13	18	21
Cr ppm	16	<8	10	15	14	18
Ni ppm	<11	<11	<11	<11	<11	<12
Zn ppm	33	27	40	33	33	34
Rb ppm	106	113	106	103	98	91
Sr ppm	114	58	86	105	106	152
Y ppm	20	24	30	28	27	18
Zr ppm	97	97	99	103	100	145
Nb ppm	28	26	26	36	32	24
Ba ppm	545	519	702	982	943	1008

Note: Values reported in percent or parts per million by weight. Analytical errors (2σ) are SiO_2, 0.7; TiO_2, 0.01; Al_2O_3, 0.2; Fe_2O_3, 0.06; MnO, 0.01; MgO, 0.08; CaO, 0.1; Na_2O, 0.1; K_2O, 0.05; P_2O_5, 0.01; V, 10; Cr, 8; Ni, 10; Zn, 12, Rb, 5, Sr, 25; Y, 6; Zr, 30; Nb, 7; and Ba, 50.

[a] Number ranges indicate depth ranges of cuttings in ft.

[b] LOI = loss on ignition.

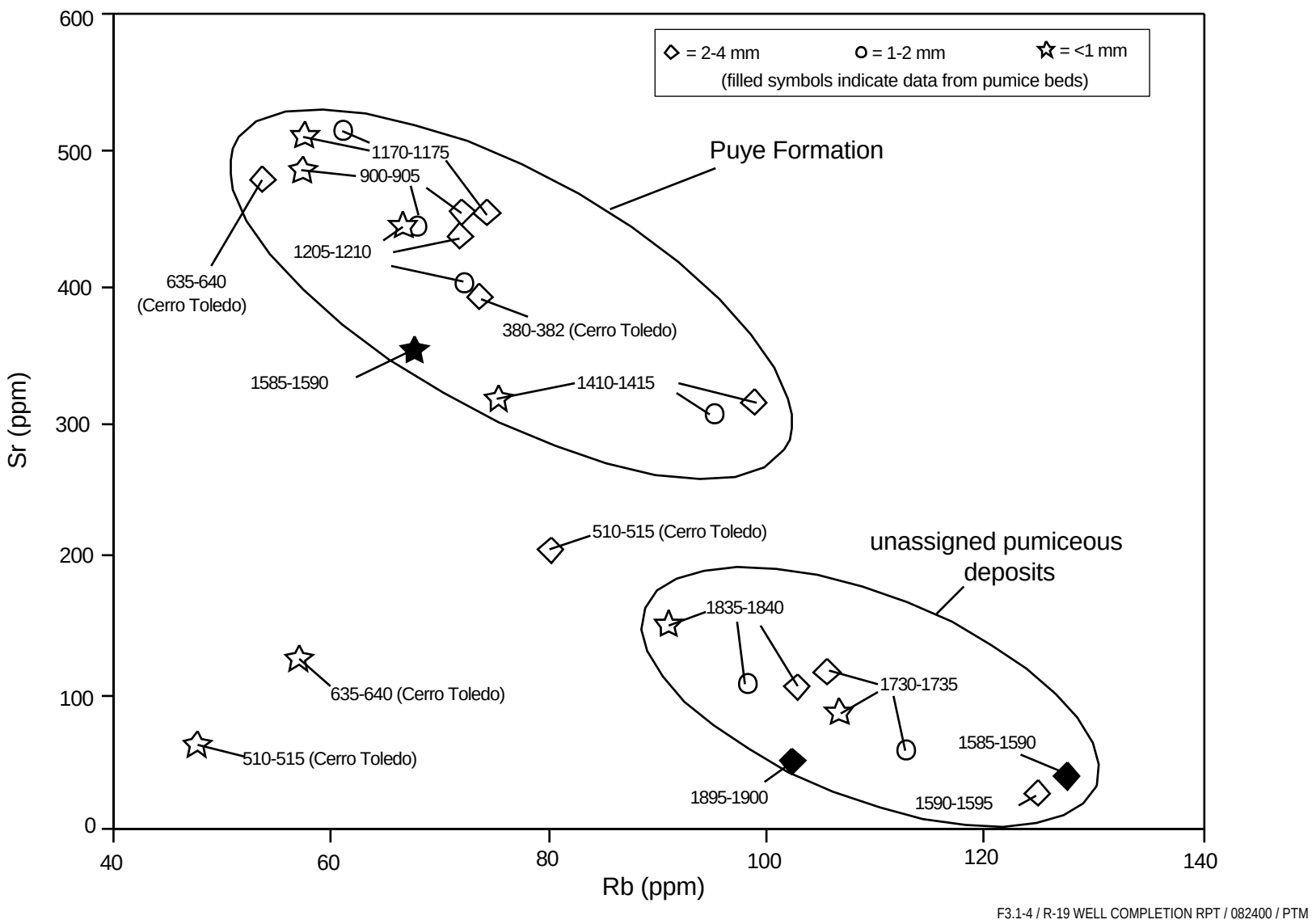


Figure 3.1-4. **Sr versus Rb systematics, defining fields of high Sr, low Rb for Puye deposits, low Sr, high Rb for the unassigned pumiceous deposits, and a distinctive low-Sr, low-Rb field for the <1-mm-sized fraction of the Cerro Toledo deposits**

Quantitative XRD data from 2- to 4-mm-sized fractions of other representative samples from the unassigned sedimentary deposits are summarized in Table 3.1-4. As in the Puye fanglomerates, some clay alteration occurs but is limited to ~1% to 2% smectite. Greater amounts of glass occur in the pumiceous deposits than in the fanglomerates (~26% to 78%, versus ~13% to 14%). The almost complete preservation of all glass to maximum borehole depth at R-19 is evidence of very limited alteration. Clay was separated from the pumiceous sediment at 1720- to 1725-ft depth and analyzed by XRD. As in the Puye deposits, this clay is a poorly ordered smectite with ~1% kaolinite.

Intercalated within the pumiceous sedimentary deposits are relatively homogeneous pumice beds at 1581- to 1595-ft depth, 1690- to 1700-ft depth, and 1895- to 1902.5-ft depth. The pumices in these deposits are poorly porphyritic, with <1% quartz, sanidine, and albite phenocrysts. Pumices in the upper two beds are mostly 2 to 4 mm in diameter, but the deepest bed contains 87 wt % of pumices >4 mm in size. Chemical compositions for samples from the pumice beds are listed in Table 3.1-2, including the 2- to 4-mm-sized fraction and the <1-mm-sized fraction of the pumice bed at 1585- to 1590-ft depth, a hand-picked sample of pure pumice from the lower part of that pumice bed (1590- to 1595-ft depth), and a hand-picked sample of pure pumice from the lowest pumice bed (1895- to 1900-ft depth). The composition of the <1-mm-sized fraction of the pumice bed at 1585- to 1590-ft depth is considerably more mafic than the coarser (2 to 4 mm) pumice-dominated size fraction. The finer fraction has lower SiO_2 and higher Fe_2O_3, MgO, V, Cr, Sr, and Ba. The differences in SiO_2, Fe_2O_3, Sr, and Sr/Rb in the two size fractions from this pumice bed are illustrated in Figure 3.1-2. These differences may indicate a fine-sand source with different origins than the pumices that comprise the bulk of the deposit. In terms of potential water-rock interactions, the higher surface area of the finer fraction and its higher Fe content may dictate interactions with contaminants that are very different from those that would occur if the coarser pumices alone comprised the deposit. The pumices in all beds are slightly rounded and slightly to moderately clay-coated, indicating minor amounts of reworking. None of the pumice beds appear to be undisturbed primary falls. However, the preservation of original glass is extensive. Screen #5 is located within the pumice bed at 1581- to 1595-ft depth and is thus situated to sample waters from an exceptionally glass-rich horizon with Fe-rich fines.

3.2 Borehole Geophysics

Borehole geophysical logs were obtained from the R-19 borehole after completion of drilling activities. This section describes the borehole geophysical methods that were employed and describes the results obtained from the borehole geophysical logging.

3.2.1 Description of Borehole Logging Activities

Borehole geophysical data were obtained from two sources: (1) Laboratory and support subcontractor personnel obtained borehole video and GR surveys using Laboratory geophysical logging equipment, and (2) Schlumberger, Inc., personnel obtained a suite of borehole geophysical logs. Table 3.2-1 lists the borehole video and geophysical surveys that were obtained from each source. Borehole geophysical surveys were obtained from the open borehole that extended from the base of drill casing which was located at about 205 ft bgs to near the total depth of the well, which was found to be at 1886 bgs at the time of the Schlumberger borehole surveys.

On March 13, 2000, after completion of drilling the borehole to a total depth of 1902.5 ft, two borehole video log surveys were obtained of the open borehole from 205 ft downward. On March 14, 2000, a GR survey was obtained to total depth. Laboratory borehole logging equipment was used to obtain the video and GR surveys. Initially, the 1 3/4-in.-diameter slim-hole borehole video log was used to obtain the video survey to a depth of approximately 1600 ft where the water in the borehole became too cloudy to see the

walls of the borehole. The slim-hole camera was used initially because the condition of the borehole walls was not known and there existed the possibility of collapse of the open borehole and potential loss of the video equipment. The slim-hole camera showed that the walls of the borehole appeared to be stable throughout the borehole to at least the 1600-ft depth.

Table 3.2-1
Borehole Geophysics Surveys at R-19

Operator	Date	Depth (ft)[a]	Survey
Laboratory and support contract personnel using Laboratory equipment	03/13/2000	0–1600	Borehole video survey (slim hole)
	03/13/2000	0–1400	Borehole video survey (side-looking)
	03/14/2000	0–1900	Gross gamma radiation (GR)
Schlumberger, Inc.	03/16/2000	204–1886	Survey #1:
			Array induction tool (AIT-H) (Resistivity), 10, 20, 30, 60, 90-inch array induction, spontaneous potential (SP)
			Highly integrated gamma ray neutron sonde (HGNS; combination of thermal neutron porosity and gross gamma tools)
			Three-detector lithology density (TLD) tool and micro-cylindrically focused log (MCFL; includes caliper, bulk density, photoelectric effect, and micro-resistivity)
	03/16/2000	130–1886	Survey #2:
			Accelerator porosity sonde (APS; for epithermal neutron measure of porosity in the saturated zone, moisture content in the unsaturated zone, and macroscopic thermal neutron absorption cross-section) and the hostile natural gamma ray sonde (HNGS; for spectral gamma logging)
	03/16/2000	230–1886	Survey #3:
			Combinable magnetic resonance (CMR)
			Gross gamma radiation (GR)
			Caliper–1-arm
	03/16/2000	110–1886	Survey #4:
			Fullbore formation microimager (FMI)–16-button
			Caliper–4-arm
			General purpose inclinometry tool (GPIT)
			Gross gamma radiation (GR)

[a] Depth range for logging run.

Subsequently, the 4-in.-diameter side-looking video camera was used to obtain a supplemental video log survey to thoroughly document the walls of the borehole. The second video log survey was obtained to a depth of 1400 ft where the water in the borehole became too cloudy to see details of the borehole walls. The borehole walls were observed to be dry from surface to 900 ft and damp-to-wet from 900 ft to the water level. The second borehole video survey provided an excellent video log of Puye Formation fanglomerate to the 1400-ft depth.

On March 14, 2000, a GR survey was obtained of the open borehole from surface to total depth at 1902.5 ft. The tool was run into the borehole to total depth of 1900 ft. GR data were obtained while logging the tool up-hole at 20 ft/min except at times when the wireline fouled on the draw-works and the tool had to be lowered into the borehole to fix the cable problems. This occurred at 1870 ft, 1865 ft, 1705 ft, 1469 ft, 1433 ft, 1147 ft, 827 ft, and 818 ft. Figure 3.1-3 shows the results of the open-borehole GR survey obtained on March 14, 2000.

Schlumberger, Inc., obtained geophysical logs at R-19 on March 16, 2000, finishing early in the morning on March 17, 2000. Four separate logging runs through the borehole were obtained; the geophysical logs obtained during each run are listed in Table 3.2-1. The Schlumberger logging tools tagged the bottom of the borehole at 1885 to 1886 ft bgs and the water level in the borehole was at 1178 ft. The following section describes the different borehole geophysical surveys that were obtained.

3.2.2 Borehole Geophysical Methods

3.2.2.1 Gross Gamma Radiation

The GR survey employs a scintillation detector to measure the gross gamma radiation activity of the formation; the information is used for determination of lithology and for depth correlation between different geophysical surveys. Naturally occurring gamma radiation comes from the decay of ^{40}K plus the U and Th decay series. Typically, these elements occur in higher concentrations within clay minerals; hence, GR is used to estimate lithology. The gross gamma signatures of each formation are also used for depth correlation between geophysical logging runs to ensure proper depth profiles for each geophysical log.

3.2.2.2 Array Induction Tool

The induction logging tool is used to measure formation resistivity. The array induction tool (AIT) measures formation resistivity at five depths of investigation simultaneously, at 10, 20, 30, 60, and 90 in., with a vertical resolution of 1, 2, and 4 ft. These measurements permit the quantification of invasion of borehole fluids, including water and associated drilling fluids, into the formation, from which permeability and lithology can be inferred. The results are useful for stratigraphic correlation and in unsaturated formations may provide an estimate of invasion by borehole fluids.

3.2.2.3 Lithodensity Tool

The lithodensity tool (TLD) measures formation bulk density from which porosity in both the unsaturated zone and the saturated zone can be calculated. The TLD is a gamma-gamma density log that is primarily used to provide a measure of formation electron density. A 1.5-Ci cesium-137 gamma source is used to provide the excitation energy for the tool, which is calibrated to provide measurements in an air- or liquid-filled open hole and also in an uncemented steel casing. In addition to providing density measurements, the tool also measures the photoelectric absorption index of the formation in open boreholes. Photoelectric absorption is a measure of the average atomic number of the formation, which corresponds to formation chemistry and lithology. The electron density measurement is converted to formation bulk density, which corresponds primarily to porosity and secondarily to rock matrix and water saturation in the unsaturated zone.

In the unsaturated zone the TLD will provide a continuous log of formation porosity (liquid- and air-filled porosity). This measurement requires an estimation of formation grain density to provide accurate porosity estimates. The porosity estimate from the TLD is used with moisture content data (from the

combinable magnetic resonance [CMR] and neutron surveys) to provide a continuous log of water saturation. The TLD has a 2.5-in. depth of investigation and a 6-in. vertical resolution.

3.2.2.4 Epithermal Neutron (CNT-G or APT)

The epithermal neutron tool provides information about moisture content in the unsaturated zone and porosity in the saturated zone. The epithermal neutron-neutron logging tool measures the amount of hydrogen in the formation in either a water- or air-filled borehole. The hydrogen content typically provides a good measure of moisture content in the unsaturated zone and porosity in the saturated zone. However the tool can overestimate either value if there is a significant amount of hydrogen in the matrix minerals (e.g., clay).

The CNT-G neutron tool uses a 16-Ci source of americium-beryllium to generate neutrons and has a lateral depth of investigation of 9 in. with a vertical resolution of 18 in. The accelerator porosity tool (APT) uses thermal excitation of tritium as an neutron source and provides a calibrated moisture content with similar parameters as those for the CNT-G tool. In addition the APT tool provides uncalibrated moisture measurement (slowing-down time) with both a 3-in. vertical resolution and depth of investigation. Due to problems associated with transporting a 16-Ci source of the CNT-G neutron tool onto Laboratory property, the APT tool was used at R-19 to obtain the neutron geophysical survey.

3.2.2.5 Combinable Magnetic Resonance (CMR)

The nuclear magnetic resonance (NMR) data are obtained to determine the porosity, pore size distribution and in situ hydraulic conductivity properties of the formations. The CMR makes pulse-echo NMR measurements that are sensitive to the hydrogen nuclei (protons) contained in the pore space of the formation and within interlayers of clay minerals. These measurements contain information relating to both pore volume and pore size in a saturated formation. The pore size information is used to partition the formation porosity into (1) capillary-bound water fractions, (2) free-fluid fractions, and (3) clay-bound fractions. In saturated formations, this information is used to estimate the hydraulic conductivity of the formation. The pore size information is unique to NMR logging devices.

In the unsaturated zone, the CMR provides a volumetric moisture content of the formation, independent of lithology, and provides an estimate of the amount of water that binds to the pore walls (e.g., capillary bound vs. producible water). This tool has a very shallow lateral depth of investigation (approximately 1 in.) and a 6-in. vertical resolution.

3.2.2.6 Fullbore Formation MicroImager (FMI)

The fullbore formation microimager (FMI) tool collects electrical conductivity data from 92 buttons placed on 4 pads and 4 flaps. The orientation of the tool in the borehole is recorded, enabling the individual conductivity curves to be combined, forming an image of the borehole wall. The tool also includes an accelerometer and 3 magnetometers that record the absolute position of the tool while logging. This permits an oriented borehole image and measurement of borehole deviation. The orientation of borehole structures (i.e., bedding, fractures, and faults) can either be calculated automatically or interpreted manually. The FMI has a vertical and horizontal resolution of 0.2 in. and a depth of investigation of approximately 2 in.

3.2.2.7 Hostile Natural Gamma Ray Sonde

The hostile natural gamma ray sonde (HNGS) uses two bismuth germanate scintillation detectors to measure the natural gamma ray radiation of the formation. The HNGS makes similar measurements to the GR tool (section 3.2.2.1), but the HNGS is capable of gamma ray energy discrimination. Gamma ray spectra recorded on both detectors are analyzed with a full-spectrum procedure based on a least-squares fitting technique. The procedure uses a set of standard responses for each contributor to the gamma ray signal—K, U, and Th—and converts the signal to concentrations of each element based on their isotopic abundance and assuming secular equilibria for U and Th.

Filtering techniques are used to reduce the statistical noise by comparing and averaging counts at a certain depth with counts sampled just before and after. The final outputs are the total gamma ray; a uranium-free gamma-ray measurement; and the concentrations of potassium, thorium, and uranium. The radius of investigation depends on several factors: hole size, mud density, formation bulk density (denser formations display a slightly lower radioactivity), and on the energy of the gamma rays (a higher energy gamma ray can reach the detector from deeper in the formation). For a gamma ray of 1.46 MeV (^{40}K), 90% of the signal is from a shell 7-in. thick.

3.2.3 Results of Borehole Geophysical Surveys

3.2.3.1 GR Obtained Using Laboratory Borehole Survey Tools

Figure 3.1-3 shows the results of the GR survey obtained by support contractor personnel on March 14, 2000, using Laboratory survey equipment. Stratigraphic information is also shown on the figure. The data were collected for each 0.1 ft throughout the borehole; these data were averaged for each 1-ft interval for display on the figure. At the time of the survey, heavy-walled drill casing (13.375-in. diameter) extended to a depth of 205 ft bgs; the borehole was open from 205 to 1902.5 ft.

Table 3.2-2 summarizes the GR measured for each major stratigraphic unit encountered in the borehole and for the cased portion of the borehole. In general, the highest GR occurs in the Guaje Pumice Bed and the Otowi Member, which contain a mean rate of 324 and 317 cps, respectively. The Cerro Toledo interval between the Otowi and Tshirege Member contains a mean natural gamma rate of 187 cps, which is lower than the surrounding Bandelier Tuff Members. The lowest natural gamma radiation occurs in the massive Cerros del Rio basalt flow, which contains a mean rate of 45 cps. The lower Puye Formation contains varying lithologies that exhibit characteristic natural gamma radiation (see Section 3.1 of this document).

Table 3.2-2
Summary of Natural Gamma Radiation at R-19 on March 14, 2000

Rock Unit	Depth (ft)	Natural Gamma (cps)				
		Min	Max	Mean	Median	Std. Deviation
Tshirege Member, cased hole	0–205	15	107	78	81	16
Tshirege Member, open hole	205–377	172	281	245	246	18
Tsankawi Pumice Bed	377–380	269	303	282	274	18
Cerro Toledo interval	380–645	159	212	187	186	10
Otowi Member	645–808	217	366	317	322	24
Guaje Pumice Bed	808–840	267	352	324	326	20
Puye Formation upper	840–925	89	280	116	111	22

Table 3.2-2 (continued)

Rock Unit	Depth (ft)	Natural Gamma (cps)				
		Min	Max	Mean	Median	Std. Deviation
Basalt, massive	925–1000	36	92	45	43	10
Volcaniclastics	1000–1176	45	147	102	103	17
Puye Formation, Lower A	1176–1365	32	124	66	63	13
Puye Formation, Lower B	1365–1528	77	150	112	113	15
Puye Formation, Lower C	1528–1902	72	122	102	103	9

3.2.3.2 Results of Schlumberger Geophysical Logging

The results of the geophysical surveys obtained by Schlumberger, Inc., on March 16, 2000, are shown in the plate on the CD included with this document. This plate, Open Hole Formation Evaluation Well Montage, is a montage of processed and interpreted information about geology, hydrology, and rock structure parameters. Gamma radiation measurements obtained by Schlumberger Wireline Services Company are recorded in American Petroleum Institute (API) units.

Summary statistics of the Schlumberger geophysical data obtained for each formation encountered at R-19 are shown in Tables 3.2-3 and 3.2-4. The results of the geophysical logging were averaged over the thickness of each formation; both geologic data and hydrologic data summaries are shown in Tables 3.2-3 and 3.2-4. In general, the formation containing the greatest amount of porosity as shown by the density porosity is the Guaje Pumice Bed from 808 to 840 ft. The formation containing the least porosity is the massive Cerros del Rio basalt unit from 925 to 1000 ft. Formations containing the highest amount of permeability are the Guaje Pumice Bed and the lower Puye Formation.

Table 3.2-3
Average Borehole Geophysical Data for Each Formation, Geologic Summary

Rock Unit	Geologic Parameters										
	Natural Gamma[a] (API)	Neutron Moisture/ Porosity[b,c] (%)	Density Porosity[d] (%)	Total Porosity[e] (%)	Shallow Porosity[b] (%)	Bulk Density[d] (g/cc)	Grain Density[d] (g/cc)	Thorium[f] (ppm)	Uranium[f] (ppm)	Potassium (wt %)	Deep Resistivity[a] (ohm-m)
Tshirege Member Cased Hole	134	NR[g]	NR	NR	NR	1.91	2.65	26.7	8.3	2.61	1950
Tshirege Member Open Hole	299	NR	49.4	13.5	25.5	1.43	2.65	49.3	13.5	4.40	1454
Tsankawi Pumice Bed	286	5.7	50.9	18.7	23.3	1.36	2.65	45.7	13.0	4.17	830
Cerro Toledo interval	232	7.1	45.6	12.0	26.8	1.51	2.65	36.5	10.4	4.28	703
Otowi Member	380	8.7	44.4	18.5	31.9	1.56	2.65	55.2	18.2	4.08	569
Guaje Pumice Bed	379	8.2	47.2	26.7	33.5	1.49	2.66	58.6	19.9	3.69	736
Puye Formation Upper	148	4.3	34.9	11.3	19.1	2.03	3.05	27.1	7.9	3.21	138

Table 3.2-3 (continued)

Rock Unit	Geologic Parameters										
	Natural Gamma[a] (API)	Neutron Moisture/ Porosity[b,c] (%)	Density Porosity[d] (%)	Total Porosity[e] (%)	Shallow Porosity[b] (%)	Bulk Density[d] (g/cc)	Grain Density[d] (g/cc)	Thorium[f] (ppm)	Uranium[f] (ppm)	Potassium (wt %)	Deep Resistivity[a] (ohm-m)
Basalt, massive	62	<0.1	19.8	4.5	8.1	2.50	3.10	24.9	5.2	0.80	156
Volcaniclastics	136	2.8	22.8	11.5	13.3	2.14	2.73	32.3	6.1	2.49	268
Puye Formation Lower A	104	24.8	21.7	19.3	27.4	2.06	2.35	9.3	2.5	2.24	108
Puye Formation Lower B	121	34.3	31.1	31.1	NR	1.91	2.32	9.9	2.7	2.86	74

[a] Source data tool is array induction.

[b] Source data tool is APT neutron.

[c] Neutron porosity data measure moisture content in the unsaturated portion of the borehole above 1176-ft depth in the Puye Formation, Lower A.

[d] Source data tool is lithodensity. Density porosity was calculated with a matrix density of 2.65 g/cm^3.

[e] Source data tool is CMR.

[f] Source data tool is hostile environment natural gamma ray sonde (HNGS).

[g] NR = not reported.

Porosity Zones

Formation porosity zones were identified from the geophysical surveys, which are shown on the montage plate. Notable porosity zones are discussed below.

830- to 840-ft Interval

This interval from about 830 to 840 ft within the Guaje Pumice Bed exhibits a lower formation density than the overlying Otowi Member and an elevated density porosity up to 20%. The neutron porosity curve through this zone is tracking moisture content and exhibits a slightly increased moisture content in this interval over the Otowi section above and the Puye Formation below. The CMR log data indicate total porosity up to 40% in this interval, a free fluid porosity of up to 28%, and a calculated permeability up to 1000 millidarcies (md). However, flowing water was not encountered in this zone and the increased moisture content may be unsaturated moisture contained within the formation, which may have been introduced during drilling. Nonetheless, well screen #1 was targeted for this interval of possible perched groundwater based on the interpretation of higher moisture from the geophysical logs. The deep resistivity curves show higher resistivity and separation from the shallow curves from 834 to 838 ft, which indicates some near-borehole formational changes possibly caused by drilling.

Table 3.2-4
Average Borehole Geophysical Data for Each Formation, Hydrologic Summary

Rock Unit	Hydrologic Parameters					
	Bound Fluid Volume (%)	Capillary Bound Fluid (%)	Free Fluid Porosity (%)	Total Porosity (%)	Calculated Permeability (SDR method) (md)[a]	Calculated Permeability (Timor taper method) (md)
Tshirege Member, cased hole	NR[b]	NR	NR	NR	NR	NR
Tshirege Member, open hole	12.9	7.2	0.6	13.5	0.1	0.1
Tsankawi Pumice Bed	17.8	16.3	0.8	18.7	0.4	0.4
Cerro Toledo interval	11.3	3.8	0.7	12.0	1.1	0.1
Otowi Member	16.4	11.1	2.1	18.5	0.1	0.3
Guaje Pumice Bed	14.9	22.8	11.8	26.7	177.8	484.9
Puye Formation Upper	9.1	6.3	2.2	11.3	36.5	1.3
Basalt, massive	1.7	3.1	2.7	4.5	125.0	2.1
Volcaniclastics	8.5	6.9	3.0	11.5	43.3	2.6
Puye Formation Lower A	13.2	14.3	7.2	19.3	57.5	48.4
Puye Formation Lower B	14.0	26.6	17.2	31.1	142.5	307.9

Note: Source data tool is CMR.
[a] md = millidarcies.
[b] NR = not reported.

896- to 912-ft Interval

A 16-ft interval from 896 to 912 ft in the upper Puye Formation above the Cerros del Rio basalt also exhibits higher porosity values. The average grain density recorded through the Puye is about 2.2 g/cc but the grain density in this interval is significantly below 2.0 g/cc and the density porosity ranges from 30% to 60%. The relative neutron moisture content increases by a factor of about 3 compared with the adjacent zones within the Puye Formation. The open-hole video log shows an increase in moisture on the walls of the borehole between 900 and 910 ft. The total CMR porosity increases from an average in the formation of 6% to 20% with a high of about 35%. The calculated permeability from 906 to 910 ft is from 1 to 10 md. Below 912 ft the porosity curves return to 4% to 6% with no detectable calculated permeability. Well screen #2 was targeted for this interval to sample possible perched water based on the interpretation of geophysical data of increased moisture and from observations of increased moisture from the borehole video log.

There is no separation of the resistivity curves through this interval, indicating that the formation was not significantly affected by drilling. Formation water moving from the formation into the borehole would exhibit similar resistivity values at both the deep and shallow depths of investigation; therefore the resistivity curves would not be expected to exhibit separation. The natural gamma curve in the upper Puye Formation averages about 140 API units, but from 896 to 912 ft bgs the gamma values are 170 to 180 API units, suggesting a lithologic change through this part of the Puye Formation, probably with a higher content of finer-grained materials. The higher gamma values correspond to the zone of higher porosity and moisture content. The CMR pore water data show that the majority of the water in this interval is bound to fine-grained sediments, small-pore, micro-pore, and clay-bound.

998- to 1030-ft Interval

A 32-ft interval corresponds to the zone of volcaniclastic sediments between two massive basalt flows in the Cerros del Rio basalt. The red scoria zone from 1018 to 1030 ft is differentiated from the breccia zone above by a higher gamma value of 140 API units compared to about 100 API units in the breccia zone. The lower part of the breccia zone from 1006 to 1018 ft contains density porosity of 50% to 60% and corresponding CMR total porosity of 17% to 25%. The scoria zone contains density porosity of 20% to 30% and CMR total porosity of 10% to 20%. However, the CMR free fluid porosity in the breccia zone is about 5%, which increases up to 15% in the scoria zone. The neutron log indicates some level of elevated moisture content in the breccia zone, which decreases downward in the scoria zone. The CMR log shows limited permeability in the breccia zone but permeability ranging from 1 to 10 md in the scoria zone. The CMR bound water data indicate that moisture in this zone is primarily bound up in clay-sized pores.

1064- to 1072-ft Interval

This 8-ft interval is present directly beneath the lower massive basalt flow and may represent a basalt breccia zone similar to the breccia zone from 998 to 1018 ft described above. This zone exhibits increased moisture content on the neutron log, density porosity of 35% to 40%, CMR total porosity of 16% to 20%. However the CMR log does not indicate the presence of significant free-fluid porosity, nor does the CMR log indicate the presence of significant calculated permeability. There is some separation in the resistivity curve, indicating that the formation contains low permeability.

Regional Aquifer

The water level of the regional aquifer was encountered at 1178 ft at the time of the Schlumberger logging. The neutron moisture and CMR data indicate less than 1 ft of capillary fringe above the water level. The permeability, as interpreted from the geophysical logs, at the top of the water table, is very low (1 to 10 md).

1178- to 1530-ft Interval

The upper part of the regional saturation from 1178 to about 1550 ft exhibits 24% to 30% porosity on the neutron log and 30% to 40% porosity on the density log with the highest porosity zone at 1242 to 1246 ft. The total porosity shown on the CMR averages about 20% with 2% to 8% free fluid porosity. The porosity through this zone is generally from smaller pore sizes from clay to micro-pore size. Calculated permeability shown on the CMR log varies generally from 1 to 10 md. The resistivity curves track very closely showing the saturated nature of the formation; the only separation is in the deep resistivity in zones of less porosity where some higher resistivity values are present at deeper distances from the borehole.

1530- to 1900-ft Interval

The deeper part of the regional saturation from 1530 to 1900 ft exhibits higher porosity values than the zone described above. The neutron log shows average porosity values of approximately 35% to 40% and the density log shows 40% to 50% average porosity. The CMR log shows 24% to 40% total porosity with an average of 4% to 20% free fluid porosity. Average calculated permeability shown on the CMR log varies generally from 0.1 to 177.8 md (Table 3.2-4), with the highest porosity and permeability zones at 1634 to 1638 ft and 1733 to 1736 ft. The resistivity curves track very close to showing the saturated nature of the formation; the only separation is in the deep resistivity in zones of less porosity where some higher resistivity values are present. This lower zone appears to be a more transmissive part of the regional aquifer in R-19.

Screen Intervals

Average summary statistics of the Schlumberger geophysical data obtained for each screened interval in R-19 are shown in Tables 3.2-5 and 3.2-6. The results of the geophysical logging were averaged over the length of each screened interval; both geologic data and hydrologic data summaries are shown in Tables 3.2-3 and 3.2-4. In general, the screen interval with the highest average permeability and porosity as shown by the density porosity log and the CMR log is screen #1 in the Guaje Pumice Bed. Within the regional zone of saturation, screen #6 has the highest average amount of porosity and screen #5 has the highest average permeability.

Borehole Washout Zones

The open portion of the borehole from 205-ft to 1886-ft depth remained stable during drilling. The top of the open borehole from 205 to about 350 ft in the Tshirege Formation enlarged during drilling, with the upper 20 ft of the open portion enlarging from 12.25 in. to about 14 in. A smaller amount of enlargement is noted in borehole through the Guaje Pumice Bed.

Several large washouts of the borehole are observed in the lower Puye Formation where washouts to 18 and 20 in. occur at 1194 to 1197 ft, 1257 to 1259 ft, 1280 to 1283 ft, and 1774 to 1778 ft. Borehole rugosity to 14-in. diameter is observed throughout the lower Puye Formation, especially from 1200 to 1300 ft, 1530 to 1550 ft, and 1690 to 1804 ft.

Table 3.2-5
Average Borehole Geophysical Data for Each Screen Interval, Geologic Summary

Screen[g] No.	Geologic Parameters									
	Natural Gamma[a] (API)	Neutron Moisture/ Porosity[b,c] (%)	Density Porosity[d] (%)	Total Porosity[e] (%)	Shallow Porosity[b] (%)	Bulk Density[d] (g/cc)	Grain Density[d] (g/cc)	Thorium[f] (ppm)	Uranium[f] (ppm)	Deep Resistivity[a] (ohm-m)
1	306	6.8%	46.6%	26.1%	24.6%	1.55	2.76	50.00	16.60	657
2	165	8.0%	38.6%	19.0%	10.4%	1.95	3.05	33.24	8.81	82
3	101	23.6%	24.2%	17.9%	18.1%	2.01	2.35	8.40	2.32	170
4	140	25.9%	21.6%	21.7%	13.1%	2.06	2.35	13.92	3.87	64
5	121	34.6%	34.1%	31.6%	29.7%	1.87	2.32	9.94	2.51	110
6	124	40.3%	37.1%	34.9%	30.3%	1.83	2.32	10.12	2.72	48
7	116	39.6%	34.5%	34.3%	29.0%	1.86	2.32	9.99	2.27	45

[a] Source data tool is array induction.

[b] Source data tool is APS neutron.

[c] Neutron porosity data measure moisture content in the unsaturated portion of the borehole in screens #1 and #2 and porosity in the saturated portion of the borehole at screens #3 through #7.

[d] Source data tool is lithodensity. Assumed matrix density is 2.65 g/cm^3.

[e] Source data tool is CMR.

[f] Source data tool is HNGS.

[g] Data averaged for screen interval; does not include filter pack.

Table 3.2-6
Average Borehole Geophysical Data for Each Screen Interval, Hydrologic Summary

Screen No.[a]	Bound Fluid Volume (%)	Capillary Bound Fluid (%)	Free Fluid Porosity (%)	Total Porosity (%)	Calculated Permeability (SDR method) (md)[b]	Calculated Permeability (Timor taper method) (md)
1	7.7%	0.4%	18.4%	26.1%	343.16	936.83
2	15.0%	3.9%	3.9%	19.0%	1.10	4.03
3	11.3%	2.0%	11.8%	17.9%	56.10	55.48
4	16.6%	3.6%	5.1%	21.7%	1.01	3.85
5	10.8%	0.4%	20.8%	31.6%	178.77	397.66
6	15.0%	1.5%	19.9%	34.9%	131.79	261.84
7	14.0%	1.4%	20.3%	34.3%	92.68	239.25

Note: Source data tool is CMR.

[a] Data averaged for screen interval; does not include filter pack.

[b] md = millidarcies.

Borehole Deviation Survey

The borehole deviation survey shows that the borehole drifted to the southwest throughout the entire length. The bottom of the borehole is located about 100 ft south and 43 ft west of the surface location. The rate of borehole drift to the west increased at about 900 to 950 ft in the Puye Formation and the Cerros del Rio basalt.

Bed Boundary Dip Data

The FMI tool collected data that were calculated to approximate formation bed dip, strike, and angles. The data were collected below water level at 1178 ft to total depth. Due to the conglomeratic nature of the Puye Formation, the dip data are variable and do not show a definitive bed dip direction. From 1178- to about 1500-ft depth the data show dip angles in all directions, sometimes in a bimodal southwest-northeast or west-east direction. Below 1500 ft to total depth the dip data show a slightly higher preponderance for directions to the southwest. Overall the dip data show that 90% of the dips are less than 10 degrees in magnitude with the highest percentage of strike angles in the northwest and southeast directions.

4.0 HYDROLOGY

4.1 Unsaturated Zone

This section discusses the hydrologic properties of the unsaturated zone at R-19.

4.1.1 Soil-Water Occurrence

4.1.1.1 Methods

For the upper 126 ft, moisture content was determined from core samples recovered by HSA. A total of 25 samples were collected at approximately 5-ft intervals for the cored part of the borehole. Samples were immediately placed in preweighed and prelabeled jars with tightly fitting lids. The moisture content

was determined gravimetrically by drying the samples in an oven in accordance with American Society for Testing and Materials method D2216-90. Samples collected for moisture content are listed with the analytical results in Appendix B. Moisture content is given as the ratio of the weight of water to the weight of the dry sample.

4.1.1.2 Results

Moisture content in the upper 126 ft of the borehole ranges between 2.3% and 7.7% gravimetric (Figure 4.1-1). Overall, there is a general trend of decreasing moisture content with depth. Moisture content in weathered tuff just below the alluvium at a depth of 4 ft has a moisture content maximum of 7.7%. Below this maximum, moisture contents generally decrease with depth until a minimum of 2.6% is reached at about 40 ft. A second maximum is represented by a single sample containing 5.7% moisture at 54-ft depth. Moisture contents range from 2.8% to 3.2% from 60- to 77-ft depth. The lowest moisture measured (2.3%) occurs at a depth of 83 ft. Moisture contents range from 2.6% to 4.3% from 87- to 126-ft depth.

Moisture contents measured in samples from R-19 are consistent with those found in the upper Bandelier Tuff in other parts of the Laboratory. In LADP-4, gravimetric moisture contents for Tshirege Member Qbt-2 range from 10% to 12% in weathered tuff just below the alluvium and 2.5% to 7% in the unweathered tuff in the central part of Qbt-2 (Broxton et al. 1995, 50119).

4.1.2 Soil-Water Movement

4.1.2.1 Methods

When the pores in a rock are not filled with water, the hydrostatic pressure (or matric potential in unsaturated rock) is less than atmospheric pressure. The pressure potential is negative, meaning that work is required to remove water from the rock. The energy making up matric potential arises from capillary forces holding water in the pores, and adsorption that holds water to particle surfaces. Figure 4.1-1 shows the absolute value of the matric potential for core samples collected in the upper 126 ft of R-19.

Matric potential for 25 samples was measured using a chilled-mirror water-activity meter as described by Gee et al. (1992, 58717). Samples were doubly sealed in ziplock bags and wrapped in packing tape immediately following wireline retrieval and opening of the split core barrel. Measurements were made in duplicate within 10 min after loading plastic vials with tight-fitting lids that were directly inserted into the water-activity meter. Core was crushed into millimeter-sized fragments as quickly as possible after the seal was broken in order to load the vials.

Repeat measurements demonstrated that samples produced the same results as long as the measurements were made less than three hours after the vials were loaded and the lids were secured. All analytical runs were bracketed by measurements of standards, which demonstrate a two sigma (2σ) reproducibility of 0.0026 for 114 analyses of the matric potential of distilled water. This is close to the instrumental precision stated in Gee et al. (1992, 58717) of 0.003 water-activity units (-0.4 millipascals [MPa] or -4080 cm H_2O). Data listed in Appendix B for matric-potential analyses represent the average of two measurements made on a sample.

The chilled-mirror psychrometer (or water-activity meter) measures matric potential in very dry soils or rocks. The meter measures water activity, which can be converted to matric potential. The units of matric potential may be given as pressure in pascals (Pa), or as the height of an equivalent column of water, in centimeters (10,200 cm H_2O = 1 MPa). The limit for the meter is reached in soils drier than 0.003 water-activity units (-0.4 MPa or -4080 cm H_2O) (Gee et al. 1992, 58717). This value is shown on the accompanying plots as the limit of the chilled mirror psychrometer.

Despite the limitation of the water-activity meter for measuring matric potential in the driest rocks, the method has advantages. Where the water-activity meter works it is inexpensive, and gives more detailed vertical information than would laboratory measurements on the available core samples. In dry rock such as in R-19 the profile from the water-activity meter provides a picture of vertical matric-potential fluctuations over a 126-ft depth that would not otherwise be apparent.

4.1.2.2 Results

A profile of matric potential versus depth appears next to the moisture-content data in Figure 4.1-1. The axis of the matric-potential plot is reversed so that drier values appear to the left on the plot, corresponding to the direction of drier values of moisture-content data. The values of matric potential range between -5.83E+04 cm and -7.04E+03 cm. All matric-potential measurements were within the working range of the water-activity meter. These samples have gravimetric moisture contents below 7.7%.

4.2 Saturated Zones

R-19 afforded the opportunity to characterize both the occurrence and movement of groundwater, at least as far as possible in a single well. Occurrence includes the depth, stratigraphic interval, and hydrologic condition (perched or regional; unconfined or confined) of all zones of saturation encountered. In the case of a single well, movement includes the vertical gradient from head distribution along the borehole and potential rate of groundwater flow as reflected by hydraulic conductivity.

4.2.1 Groundwater Occurrence

Three zones of saturation were anticipated at R-19. Two were expected to be perched: one in the Guaje Pumice Bed and one in the Puye Formation and/or the upper Cerros del Rio basalt. The third zone of saturation anticipated in R-19 was that beneath the regional water table.

The presence of perched saturation at R-19 is unclear. No water was encountered in the Guaje Pumice Bed. Saturation reported by the driller in the Otowi Member of the Bandelier Tuff at a depth of 738 ft and in the Puye Formation at a depth of 920 ft was possibly associated with drilling water. Drillers often report saturation when there is an increase in return flow of drilling fluid. However, that is not a foolproof indication that the borehole has penetrated a saturated interval. Such an increase can also signify just the opposite. That is, it may be caused by the bit entering a less permeable formation that does not take up as much drilling fluid as did materials up-hole, so more of the injected fluid returns than usual.

Two zones of possible perched saturation were identified based on borehole geophysical logs indicating zones of relatively high moisture content. The upper zone from 834- to 840-ft depth is located at the base of the Guaje Pumice Bed. The second zone is located from 894- to 912-ft depth within the upper part of the Puye Formation. Screens were installed in both zones and will be sampled if they produce water.

The regional water table was predicted to lie at a depth of 1118 ft in Cerros del Rio basalt (Figure 3.0-1). However, it was found to be 60 ft deeper than this in the Puye Formation. Although the driller reported possible saturation at 1156 ft, geophysical logging performed some time later by Schlumberger showed the water table to be at a depth of 1178 ft. This water appeared to be unconfined and saturation continued to total depth (1902.5 ft).

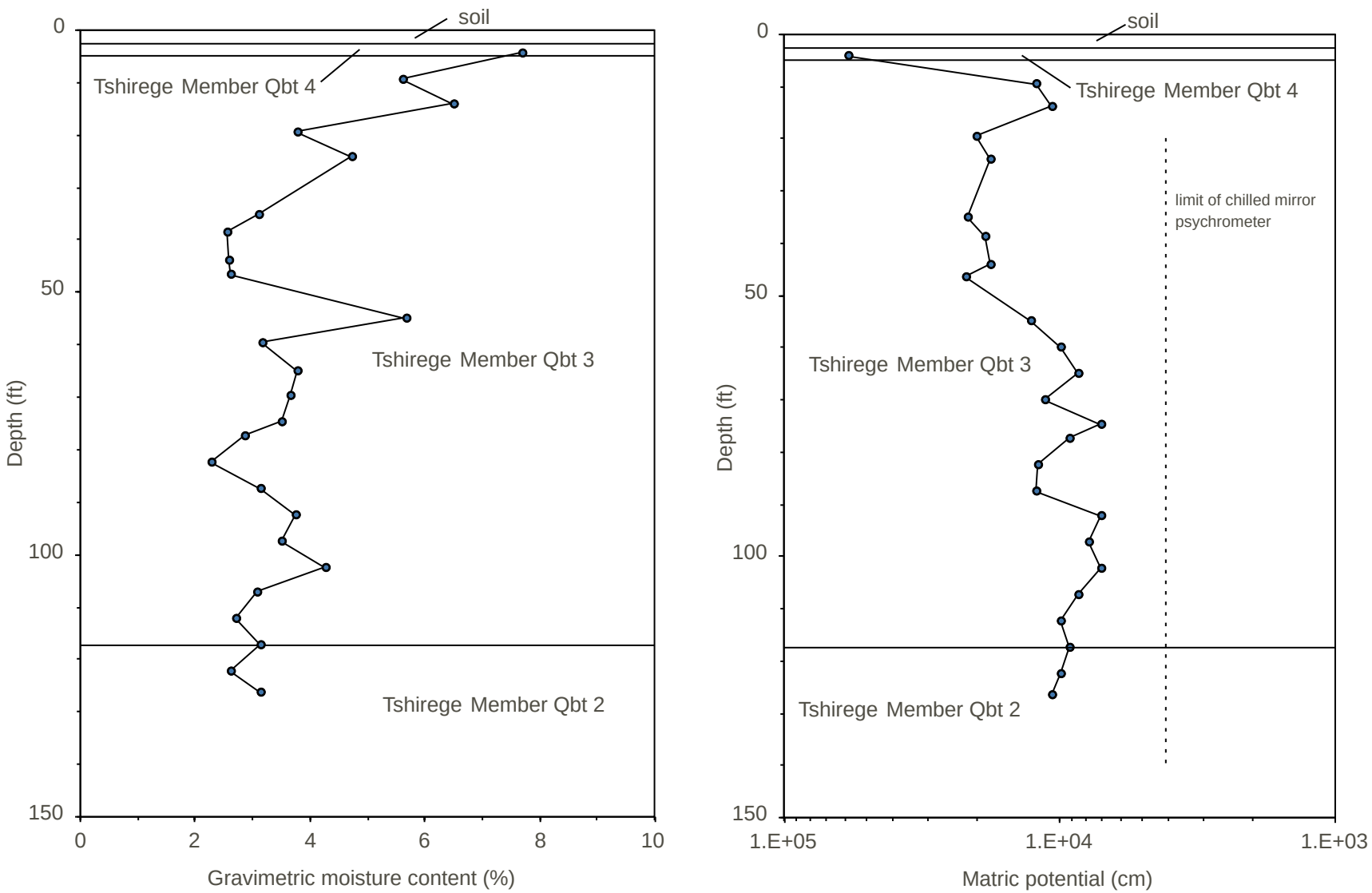


Figure 4.1-1. Gravimetric moisture and matric potential in borehole R-19

4.2.2 Groundwater Movement

Vertical head distribution is essential for determining vertical hydraulic gradient. However, it could not be determined at R-19 as drilling was mainly by open-hole methods and the use of even small volumes of drilling fluids made water-level measurement difficult if not impossible. As a result of the open-hole drilling, the borehole was not a true piezometer at any of the depths where water level was measured. That is, there were no instances when measurements were made while the casing was screwed into the bottom of the borehole and hydraulic head at that depth could be determined. However, a plot of depth-to-water vs. borehole depth using all water-level readings, regardless of whether they are believed to represent static values or not, suggests a general downward vertical gradient. Static water-level elevations during hydrologic testing also indicate a downward vertical gradient: 5932 ft at screen #6 and 5903 ft at screen #7. The observations are consistent with the conceptual hydrogeologic model for the Pajarito Plateau in which R-19 is located in a suspected recharge area. Measurement of head distribution in the Westbay® Instruments, Inc., system confirms the existence of a downward gradient at R-19.

The rate of groundwater movement in saturated materials is dictated by hydraulic conductivity and hydraulic gradient, according to Darcy's law. Although this nonvertical gradient cannot be evaluated using a single well, hydraulic conductivity of the various saturated materials in R-19 was determined by hydrologic testing of selected screened intervals. More specifically, straddle packer/injection slug tests were conducted. The test design called for isolating the target screen with a pair of straddle packers and injecting water at a constant rate. The rate of injection was monitored by reference to a flow meter placed in the line between the water supply and the Bean pump on the UDR drill rig.

Test results are summarized in Table 4.2-1. For the test of the unassigned pre-Puye deposits opposite screen #6 (1726.8- to 1733.4-ft depth), a hydraulic conductivity value of 17.5 ft/day was obtained using the Cooper-Jacob method (1946, 66645). For the test of the lower portion of the pre-Puye deposits opposite screen #7 (1832.4- to 1839.5-ft depth), hydraulic conductivity of 19.6 ft/day was obtained using the Cooper-Jacob method (1946, 66645).

Table 4.2-1
Summary of Data for Straddle-Packer/Injection Testing of Pre-Puye Deposits at R-19

Screen #	Static Water-Level Elevations (ft)	Average Injection Rate (gpm)	Injection Rate Variation (gpm)	Test Duration (min)	Hydraulic Conductivity (ft/d)	Analytical Method
6	5932.2	11.8	0.2 (1.4%)	94	17.5	Cooper & Jacob (1946, 66645)
7	5903.5	14.6	0.2 (1.7%)	86	19.6	Cooper & Jacob (1946, 66645)

5.0 HYDROGEOCHEMISTRY

Screening borehole water samples were collected from R-19 and analyzed for a limited suite of constituents. The samples were collected primarily to determine if potential contaminants within perched zones were being carried down to the regional aquifer during drilling operations. Potential contaminants of concern at R-19 include HE compounds and associated degradation products.

5.1 Geochemistry of Core and Cutting Samples Collected during Drilling

Samples of core and cuttings were not collected from R-19 and analyzed for contaminants because HE compounds were not definitely identified in groundwater at concentrations that would be expected to adsorb onto Bandelier Tuff or Puye Formation lithologies. No other contaminants are known to occur at

R-19, based on previous information presented in the Pajarito Canyon work plan (Chapter 2, LANL 1998, 59577).

5.2 Hydrogeochemistry of Groundwater Samples

Borehole water samples were collected at depths of 738, 833, 1157, and 1860 ft and analyzed for screening constituents and parameters. Borehole water samples were analyzed for HE within a zone of greater water returns (738 ft; based on driller observations) and a possible perched zone (838 ft). Borehole water samples were analyzed for inorganic and organic chemicals and isotopic uranium within the regional aquifer (1157 and 1860 ft) to determine natural solute and contaminant distributions within the different saturated zones.

Due to the presence of EZ-MUD and other drilling fluids, these borehole water samples are not representative of groundwater, especially in the low-yield possible perched zones. Consequently, these data were used only for screening purposes to assist drilling decisions. Groundwater samples shall be collected and analyzed for major ions, trace metals, stable isotopes, organic compounds, selected radionuclides, and other chemicals during quarterly sampling.

Analysis of a groundwater sample collected at 833 ft (possible perched zone) indicated the possible presence of an HE compound and degradation products of 2,4,6-trinitrotoluene (TNT). The compound HMX (cyclotetramethylenetetranitramine) was reported at 0.11 µg/L and this value should be considered an estimated (J) concentration because it is less than the practical quantitation limit but above the method detection limit (EPA method 8330, high-performance liquid chromatography [HPLC]). In addition, the matrix spike recovery was low and the percent difference between the primary HPLC column and secondary HPLC column exceeded 25%. Nitrobenzene was reported at 0.36 µg/L in this zone. This value is considered an estimate (J) based on the percent difference between the primary column and secondary column which exceeded 25%. The TNT degradation product 2-amino-4,6-dinitrotoluene, was reported at 0.62 µg/L in the sample and the value is estimated (J) because the matrix spike recovery was low. The TNT degradation product 2,6-dinitrotoluene, which was reported at 0.34 µg/L, is estimated because the percent difference between the primary column and secondary column exceeded 25%.

Presence of EZ-MUD and other drilling fluids in the groundwater may have caused false positives due to the hydrophobic nature of these fluids. Additional groundwater samples shall be collected during quarterly sampling to evaluate the presence or absence of HE compounds at the well.

Analyses of two groundwater samples collected at 1157 ft and 1860 ft (regional saturation), respectively, did not detect any HE compounds and degradation products of TNT.

6.0 WASTE MANAGEMENT

Management of waste streams generated during R-19 drilling, sampling, and well installation activities was conducted in accordance with the site-specific waste characterization strategy form (WCSF). Wastes consisted of disposable sampling equipment, residual materials from field screening kits, personal protective equipment (PPE), plastic sheeting, sorbent pads, soil contaminated with petroleum products, and decontamination water. No borehole materials exhibited elevated field screening hits; therefore borehole materials were managed onsite as follows:

- Dry drill cuttings were contained in 55-gal. drums, directly from the dust-suppression system discharge, and were transferred and emptied into a bermed waste management storage area

onsite. The material was spread and contoured along the northern edge of the drill pad. The cuttings were covered with topsoil during site restoration.

- Wet drill cuttings generated while injecting TORKease or EZ-MUD slurries mixed with municipal hydrant water, while drilling in unsaturated zones, were transferred and contained within a bermed waste management storage area onsite. The drill cuttings were allowed to dry and were then spread and contoured at the northern edge of the drill pad. The cuttings were covered with topsoil during site restoration.

- Groundwater generated as a result of drilling through saturated zones, purging, and well development operations was contained and transferred directly to potable storage tanks staged within the bermed waste management storage area onsite. Water from different saturated zones was segregated into separate tanks. A total of 63,000 gal. of groundwater was generated from all saturated intervals during drilling activities. Approximately 50,000 gal. of groundwater was generated during well development. The groundwater was applied to the site in accordance with the New Mexico Environment Department (NMED)-approved Notice of Intent to discharge permit.

- Disposable sampling equipment, residual materials from HE field screening kits (solid waste), and PPE were placed in a drum liner, sealed, labeled, and stored onsite in accordance with the WCSF. A total of one bag was generated. A waste profile form was prepared and approved for disposal of the waste at the Los Alamos County landfill.

- Petroleum-contaminated soil as well as plastic sheeting and sorbent pads that had been placed beneath the drill rig and heavy equipment to contain leaking hydraulic fluid, lubricants, and antifreeze, were contained in four 55-gal. drums. The materials were managed and disposed of as New Mexico special waste.

7.0 SURVEY ACTIVITIES

7.1 Geodetic Survey

Regional groundwater characterization well R-19 was geographically surveyed using the Global Positioning System (GPS) on January 9, 2001. Transmitted signals from eight satellites were available through most of the survey. A Trimble 4000 SSE dual-frequency base receiver was set up and initialized over control monument A5402 in TA-54 for conduct of the real-time kinematic survey. Coordinate values for the control were taken from the 1992/1993 GPS Survey establishing the LANL control network; the coordinate values are published in the “LANL Survey Monument Network Manual” (LANL 55599), and the monuments are certified to have been placed in conformance to standards and specifications for Order 2-1 surveys or greater. The datum for the control network is the North American Datum of 1983 (NAD-83).

A Trimble 4000 SSE dual-frequency “roving” receiver collected satellite signals, as well as base-station signals, for calculation of position. The roving receiver was used at the R-19 well, approximately 930 ft east-southeast of the control.

The receiver provided position data relative to the World Geodetic System 1984 ellipsoid; algorithms within the survey controller transformed the WGS-84 position to the New Mexico state plane coordinate system using the North American Datum of 1983 and seven transformation parameters. The elevations provided have been referred to the height of the NAD-83 geodetic datum.

The Facility for Information Management, Analysis, and Display (FIMAD) location identification number for R-19 is TH-10,000.

Table 7.1-1
Geodetic Data for Well R-19

Description	East	North	Elevation
Brass cap in R-19 pad	1629918.4	1760252.1	7066.3
Top of Westbay casing	1629920.1	1760250.0	7066.9

7.2 Surface Radiological Survey

A surface radiological survey was conducted by a Laboratory radiological control technician (RCT) before site construction or drilling activities began at R-19. The site radiation survey was conducted on January 10, 2000, and consisted of sweeping the proposed drill pad for areas of radioactivity above established background levels. Results of the survey indicated levels were below background with the exception of one fragment of shrapnel, which was removed from the site and disposed of using DX protocols for such materials. DX protocols typically require all personnel and equipment that have traveled off the paved roads at TA-36 to be screened by an RCT before exiting TA-36. By establishing the area as a nonradioactive area, DX permitted access of personnel and equipment to and from the R-19 drill site without radiological screening.

8.0 WELL DESIGN, CONSTRUCTION, AND DEVELOPMENT

8.1 Well Design

Geophysical logs, video logs, and borehole cuttings were reviewed to plan screen placements for well construction. The number and placement of screens was designed to meet the following criteria:

- to sample possible perched groundwater (screens #1 and #2) that could be connected upgradient with HE-contaminated perched water at R-25;
- to sample the top of the regional zone of saturation (screen #3);
- to sample high-permeability zones that might act as fast pathways for contaminants in the regional system (screens #5, #6, and #7); and
- to provide spatial coverage for sampling in the thick sequence of less-permeable rocks in the upper part of the regional zone of saturation (screen #4).

The identification of potential perched groundwater and high permeability zones in the regional system was largely based on information developed from geophysical logs. The planned and actual screen locations are given in Table 8.1-1.

8.2 Well Construction

The stainless-steel well components were cleaned using a hot-water cleaner and scrub brushes onsite. The bottom of the borehole was sounded at 1885 ft bgs before installation of well components began. Stainless-steel centralizers were installed above and below each screen to hold the screened intervals away from the borehole wall.

Table 8.1-1
Planned and Actual Screen Placements in Well R-19

Screen #	Planned Depth (ft)	Actual Depth (ft)	Geologic/Hydrologic Setting
1	829–840	827.2–843.6	Possible perched zone at base of Guaje Pumice Bed
2	900–910	893.3–909.6	Possible perched zone in Puye Formation above basalt
3	1173–1213	1171.4–1215.4	Spans regional water table in Puye Formation
4	1410–1420	1410.2–1417.4	Spatial coverage of regional system in Puye Formation
5	1580–1590	1582.6–1589.8	Permeable zone in Puye Formation
6	1730–1740	1726.8–1733.9	Permeable zone in Puye Formation
7	1830–1840	1832.4–1839.5	Permeable zone in Puye Formation

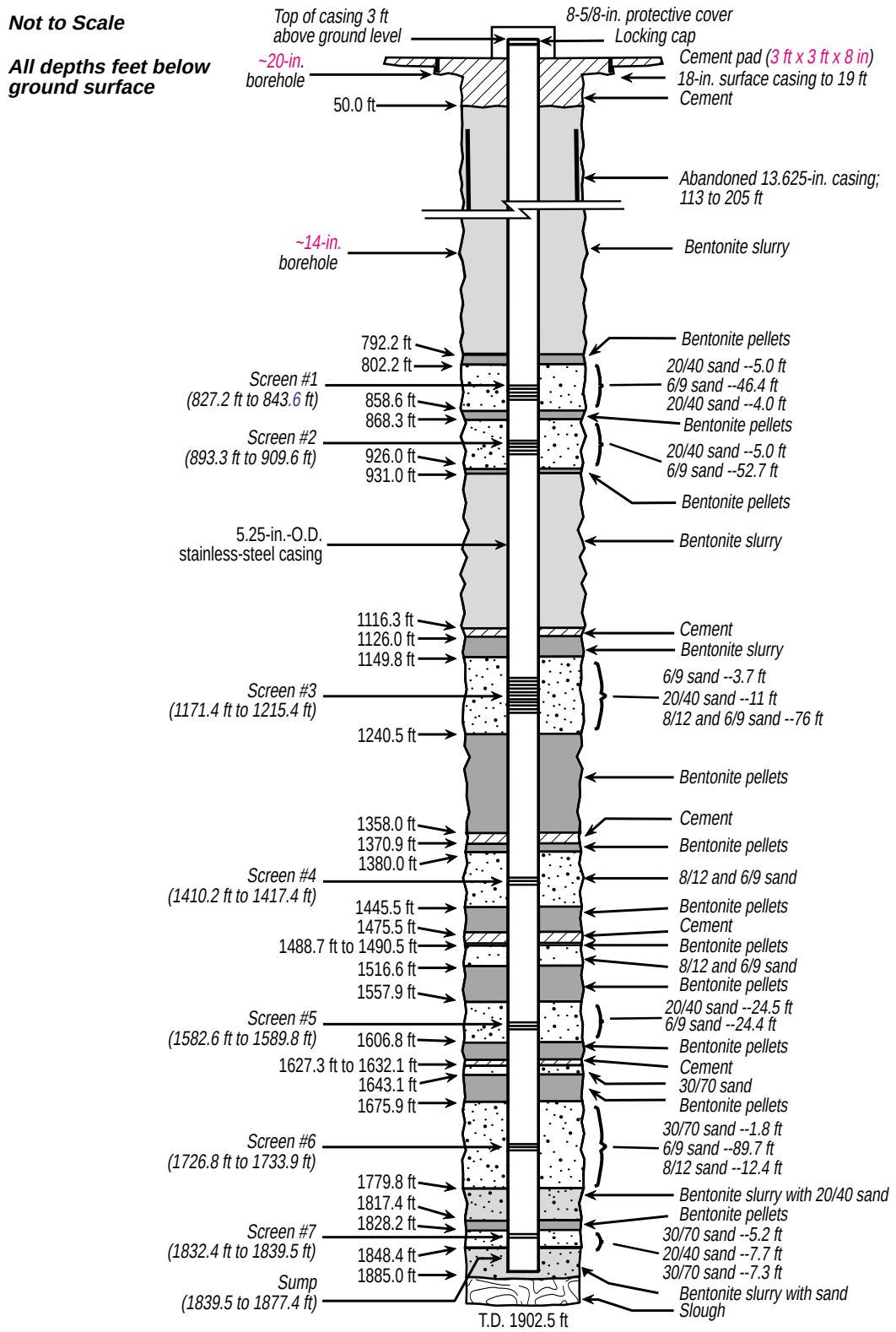
Pipe-base screens were constructed from the same tubulars as the well casing risers (4.5-in.-I.D./5.0-in.-O.D. stainless steel). These screens were constructed by drilling holes into 5 ft and 10 ft sections of well casing, and a wire wrap with a gap of 0.010-in. was attached to the outside of the perforated intervals. Holes are 0.375-in. in diameter. The five-ft screens contain 8 rows of holes with 28 holes per row, giving a flow-through cross-sectional area of 24.7 in^2. The 10-ft screens contain 8 rows of holes, with 42 holes per row giving a flow-through cross-sectional area of 37.1 in^2. A 37.9-ft sump extends below screen #7 to the bottom of the well to accommodate the Westbay sampling probes, which extend below the port during sampling. As constructed, the total depth of the well is 1877.4 ft bgs. The as-built well-completion drawing for R-19 is shown in Figure 8.2-1. All backfill materials were emplaced through a tremie pipe.

8.3 Well Development

Development was especially aggressive at R-19 in response to concerns over the impact of using small volumes of drilling fluid in its construction. Three separate stages of development were applied to each screened interval: jetting, airlifting, and pumping.

First all screens were washed and air-jetted, starting at the top of the well and working down. Each screen was treated for 15 min. As no water was discharged in this process, the various field parameters used to determine if the well had been sufficiently developed were not evaluated.

Next came airlifting. This involved two phases. First the sump was cleaned out and a volume of water equivalent to that introduced in jetting (approximately 8000 gal.) was airlifted out. This took longer than anticipated, as the discharge rate for this method was lower than expected. When this had been accomplished, a sample was taken for polymer titration to determine whether drilling fluid was present. Then airlifting focused on each screen, starting at the bottom of the well and working up, since the tool was already there. Samples were collected approximately every 15 min and field parameters (pH, specific conductance/temperature, turbidity and total organic carbon) were checked. Airlifting at a given screen was halted when field parameters were acceptable (namely, turbidity <5 nephelometric turbidity units [NTUs]) or could not be improved. The tool was raised to the next screen up and the process was repeated.



Note: The screen intervals list the footages of the pipe perforations, not the tops and bottoms of screen joints.

F8.2-1 / R-19 WELL COMPLETION RPT / 083000 / PTM

Figure 8.2-1. As-built well-completion diagram of well R-19

Finally, the saturated screens (#3 through #7) were developed by pumping, starting at the top of the well and working down. As in the case of airlifting, samples were taken for checking field parameters approximately every 15 min. When field parameters were acceptable or could not be improved, the pump was shut off for 15 min. Then it was turned back on and samples were taken again at 15-min intervals to see if the previous values for field parameters could be reproduced. This process was repeated three times. After acceptable or stable values had been reproduced for three episodes, a final sample for polymer titration was collected and the tool was moved to the next screen down where the process was repeated.

Field-parameter values during the development of all screens in R-19 are given in Table 8.3-1. Selected results plotted in Figure 8.3-1 are typical.

Table 8.3-1
Summary of Final (Pumping) Phase of Development at R-19

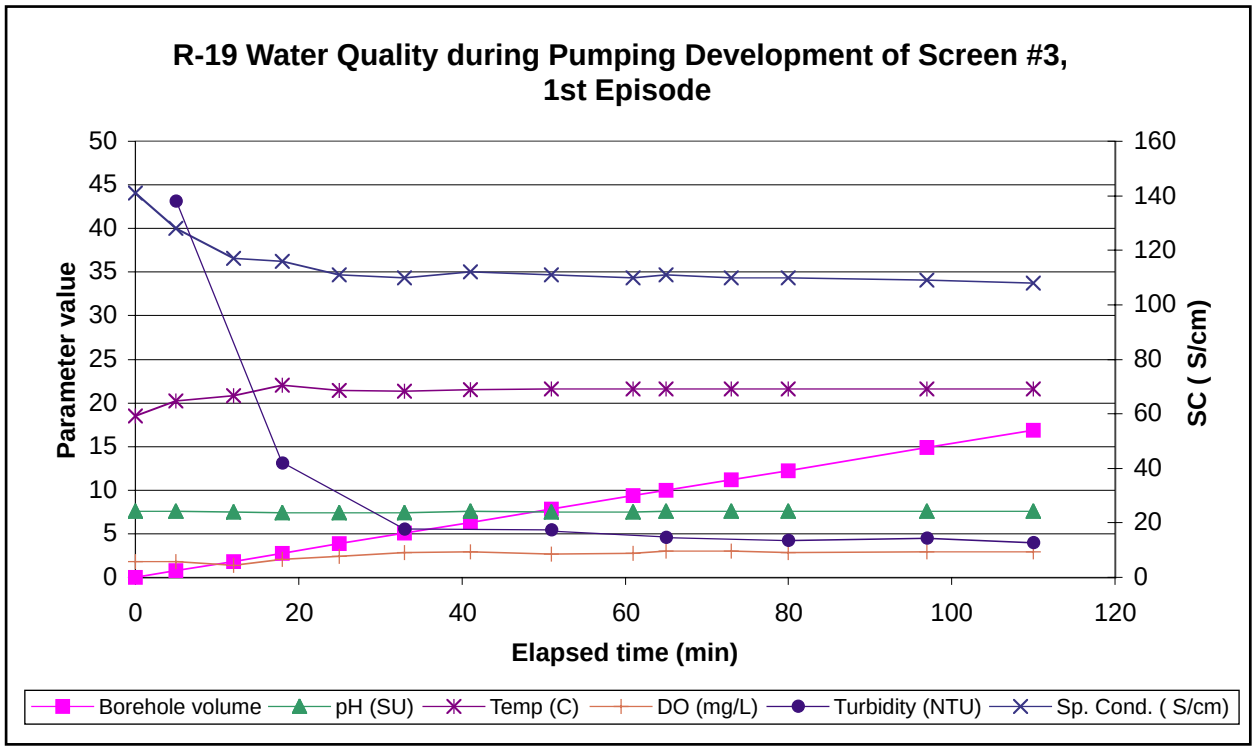
Screen #	Elapsed Time (min)	Range of Field Parameters[a]				
		Water Produced/Rate (gpm)	pH	Specific Conductance (uS/cm)	Temperature (C)	Turbidity (NTU)
3	365	91.25 (0.25)	7.86–7.95	130–116	17.6–21.7	45.40–12.90
4	235	1175 (5)	N.A.[b]	117–109	19.4–221.1	62.25–4.64
5	350	3500 (10)	6.85–7.72	130–122	17.8–20.8	47.40–4.61
6	240	2400 (10)	7.76–7.94	126–127	21.10–20.60	142.10–5.09
7	275	5050 (15–20)	7.46–8.09	125–126	17.9–21.6	27.00–4.90

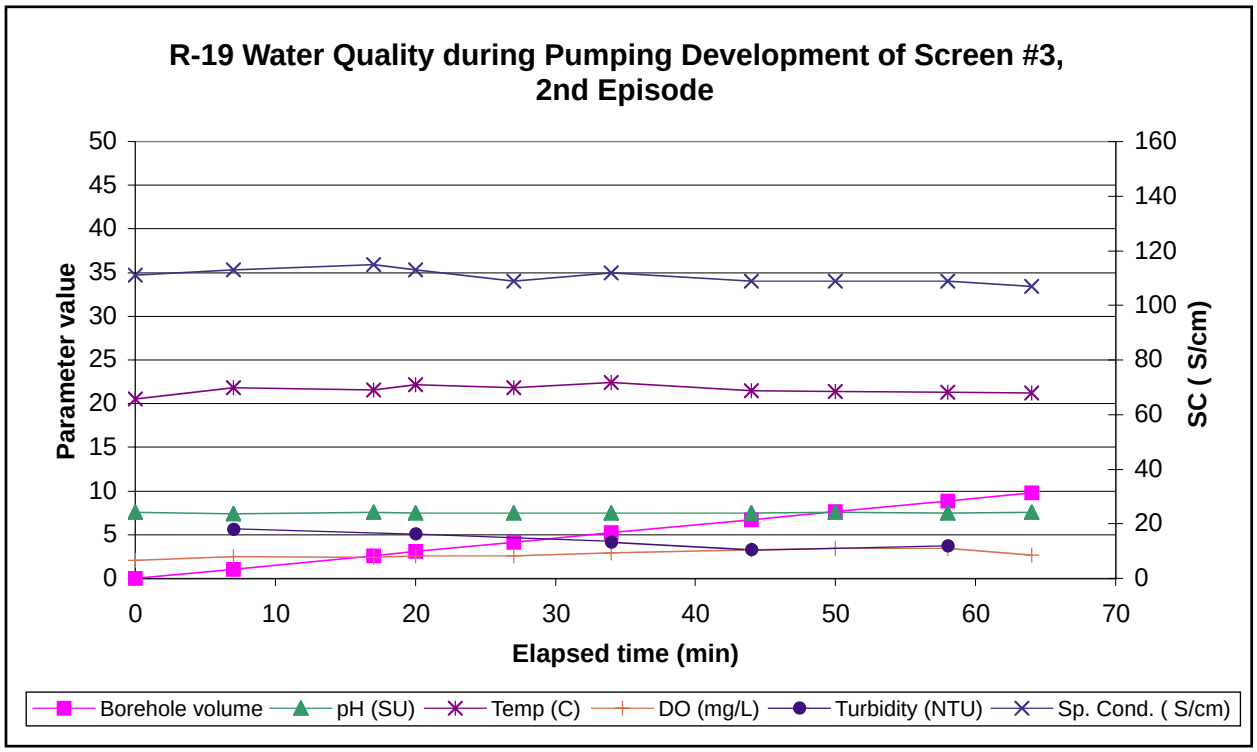
[a] Values at beginning and end of development; intermediate values may be higher than at beginning.
[b] N.A. = not available.

8.4 Geochemical Tests to Evaluate the Cleanup of Drilling Fluids During Well Development

Borehole R-19 was drilled with fluids consisting of regional aquifer water, EZ-MUD, and TORKease to enhance drilling rates. EZ-MUD is a viscosifier and also improves borehole stability. EZ-MUD consists of a polyacrylamide-polyacrylate (PHPA) copolymer that eventually dissociates to smaller organic compounds containing carbon, hydrogen, nitrogen, and oxygen. The substance has a density of 8.7 lb/gal. EZ-MUD has a net negative surface charge of 30% (0.3 mole per mole of polymer). One to two cups of EZ-MUD per thousand gallons of water were used at R-19 during drilling operations. EZ-MUD can be broken down by adding 5% sodium hypochlorite (bleach) to water injected into a well during development. This procedure was not followed at R-19 because of concern about the effect the sodium hypochlorite would have on water-quality parameters. EZ-MUD has a pH of 8.5 at a concentration of 1 quart per 100 gal. of water. TORKease reduces frictional sticking of drill string encountered in low-permeability material. TORKease consists of an emulsion of complex potassium stearates and has a specific gravity of 0.95. TORKease has a pH range of 9.3 to 9.5 when mixed with low-ionic-strength water.

Titration experiments were performed to determine the concentration of EZ-MUD remaining in R-19 during well development. Groundwater samples collected from screens #3 through #7 (those in the regional aquifer; screens #1 and 2 were dry at the time) were tested for EZ-MUD at the beginning of each day and during initial and final pumping. The groundwater samples were collected from June 20, 2000, through June 24, 2000. Baroid developed the titration procedure used during this investigation.





F8.3-1 / R-19 WELL COMPLETION RPT / 091200 / PTM

Figure 8.3-1. Results of final development (pumping) for screen #3

At R-19, approximately 50,000 gal. of regional aquifer water were pumped out of the well during development. Groundwater samples collected from R-19 showed concentrations of EZ-MUD ranging between 0.017 and 0.063 parts per thousand, suggesting most of the residual EZ-MUD has been removed from the well. Concentrations of total organic carbon (TOC) ranged between 1.4 and 36.5 mg C/L, suggesting that some residual EZ-MUD is present at R-19. During well development, concentrations of TOC generally decreased over time, with some increases occurring periodically. The elevated TOC is consistent with the presence of small amounts of residual EZ-MUD. Concentrations of TOC should decrease as EZ-MUD continues to dissociate, eventually approaching natural TOC concentrations. Tests were not performed on quantifying the amounts of TORKease potentially remaining in the borehole. According to the drillers, small amounts of TORKease were used in the Bandelier Tuff to lubricate casing that was rock-locked.

8.5 Installation of Westbay's MP55 System®

Following well development, the Westbay MP55 system for groundwater monitoring was installed in the steel-cased well. Model 2523 MOSDAX® System sampler probe equipment will be used to collect groundwater samples from the completed well.

An MP casing installation log, which specifies the location of each Westbay well component in the borehole, was prepared in the field by Westbay in consultation with the Laboratory based on a draft of the well-completion diagram. Available geophysics logs and an as-built video log taken inside the steel well casing were also reviewed before measurement ports and packers were sited within the well screen intervals. The final version of the MP casing installation log was approved in the field on August 8, 2000, by the Laboratory prior to installation of the Westbay well components. The MP casing installation log as approved was used as the installation guide in the field.

An MP measurement-port coupling and associated magnetic location collar were included in each primary monitoring zone to provide the capability to measure fluid pressures and collect fluid samples. A pumping-port coupling was also included in each of the seven screens to provide purging, sampling, and hydraulic conductivity testing capabilities. Additional measurement-port couplings were included below the pumping ports for monitoring hydraulic tests.

Measurement-port couplings were included in quality assurance (QA) zones to provide QA testing capabilities. All measurement ports were positioned below each of the MP55 packers to permit routine operation of the squeeze relief venting with the MP55 packer inflation equipment during the inflation process.

The MP casing components were set out in sequence according to the MP casing installation log on racks near the borehole. Each casing length was numbered in order beginning with the lowermost as an aid in confirming the proper sequence of components. The appropriate MP Systems® coupling was attached to each piece of MP casing. Magnetic location collars were attached 2.5 ft below the measurement ports in each of the monitoring zones and 2.5 ft below MP coupling No. 226 near the top of the well.

The length of each MP casing section was measured with a steel tape to confirm nominal lengths, and the data were entered on the MP casing installation log. Each casing component was visually inspected, and serial numbers for each packer, measurement-port coupling and pumping-port coupling were recorded on the field copy of the MP casing installation log.

The MP casing components were lowered into the well in sequence. The sections of MP casing were lowered by a Smeal work-over rig provided by the Laboratory. Each casing joint was tested with a minimum internal pressure of 300 psi for one minute to confirm hydraulic seals. Deionized water was

used for the joint tests. A record of each successful joint test and the placement of each casing component is on the field copy of the MP casing installation log. The suspended weight of the MP casing components was monitored during lowering to confirm that operating limits of the MP system casing components were not exceeded. Lowering of the MP casing to the target position was successfully completed on September 9, 2000.

After the casing was lowered into the borehole, the water level inside the MP casing was left at a depth of more than 1531 ft below the top of the MP casing to confirm hydraulic integrity of the casing. The open-hole water level was 1175 ft below ground level. With this differential pressure acting on the MP casing string, the water level inside the MP casing was monitored with a pressure transducer for a period of 40 min, and the measured pressures were stable. The test indicated that the MP casing was watertight.

After the components were lowered into the well and the hydraulic integrity of the MP casing had been confirmed, the MP casing string was positioned as shown in Appendix C. The MP packers were inflated on September 9, 10, and 11, using deionized water. The packers were inflated in sequence beginning with the lowermost. All the packers were inflated successfully and QA tests showed that all the packer valves were closed and sealed.

Westbay's procedure for destressing the MP casing was used after all of the packers had been inflated. The top MP55 casing was cut and trimmed to suit the final configuration of the wellhead assembly and the MP top completion was installed. The final tensile load at the top of the MP casing was 300 lb. The maximum limit for long-term tensile loading of the MP casing is 1000 lb (454 kg). A sketch of the as-built top of the MP casing and final positions of the MP well components are shown in Appendix C. A summary of depth information for key MP well components is shown on Table 8.5-1.

After packer inflation was completed, fluid pressures were measured at each measurement port. The fluid pressure profile measurements were taken on September 11, 2000. At that time, the in situ formation pressures may not have recovered from the preinstallation and installation activities. Longer term monitoring may be required to establish representative fluid pressures.

A plot of the piezometric levels in all zones, including QA zones, based on the September 11, 2000, pressure measurements were examined to confirm proper operation of the measurement ports and as a check on the presence of annulus seals between adjacent monitoring zones. All the measurement ports operated normally. Each of the packers was supporting a differential hydraulic pressure, indicating the presence of packer seals.

8.6 Wellhead Protection

A 6-in.-thick concrete pad, 5 ft by 10 ft, was placed around the wellhead. A 3-in. galvanized-steel pipe was placed towards the end of the pad (opposite the well casing) for future use as a solar panel attachment. The well is protected by a 14-in. steel protective casing with locking lid. Four 4-in. removable steel posts were placed at each corner just outside the pad boundaries. A brass survey marker was placed at the northwest corner of the pad.

9.0 SITE RESTORATION

A portion of the R-19 drill site area will be maintained as a level, graveled pad to serve as a work area for future groundwater sampling events and well maintenance. The cuttings pit and berms will be spread, and the fringes of the pad will be reseeded with native dryland seed; straw mulch will be spread to promote revegetation.

Table 8.5-1
Depths of Key Items Installed During R-19 MP55 Completion

Zone No.	Screen Interval[a] (ft)	Sand Pack Interval[a] (ft)	MP Casing No. (from MP Log)	Packer No.	Packer Serial No. (0612)	Nominal Packer Position[b] (ft)	Magnetic Collar Depth (ft)	Measurement Port Depth[b] (ft)	Pumping Port Depth[b] (ft)	Port Name	Comments
QA2			186				None	402.0		QA2	
			185	1	169	412.3					
QA1			145				None	800.0		QA1	
			144	2	150	810.3					
SQA1			143				None	814.8		SQA1	
			142	3	113	820.1					
Zone 1	827.2 to 843.6	802.2 to 858.6	139				846.7	844.2		MP1A	
			138						849.6	PP1	
			137					855.2		MP1B	
			136	4	161	859.1					
LQA1			135					863.4		LQA1	
			133	5	152	877.0					
SQA2			132					881.5		SQA2	
			131	6	105	886.8					
Zone 2	893.3 to 909.6	868.3 to 926.0	127				911.8	909.3		MP2A	
			126						914.7	PP2	
			125					920.3		MP2B	
			124	7	156	924.0					
LQA2			123				None	928.5		LQA2	
			99	8	164	1153.5					
SQA3			98				None	1158.0		SQA3	
			97	9	160	1163.3					
Zone 3	1171.4 to 1215.4	1149.8 to 1240.5	93				1193.2	1190.7		MP3A	
			92						1196.1	PP3A	
			91				1204.2	1201.7		MP3B	
			90						1207.1	PP3B	
			89					1212.8		MP3C	
			88	10	167	1218.1					
LQA3			87				None	1222.6		LQA3	
			70	11	149	1390.4					
SQA4			69				None	1394.9		SQA4	

Table 8.5-1 (continued)

Zone No.	Screen Interval[a] (ft)	Sand Pack Interval[a] (ft)	MP Casing No. (from MP Log)	Packer No.	Packer Serial No. (0612)	Nominal Packer Position[b] (ft)	Magnetic Collar Depth (ft)	Measurement Port Depth[b] (ft)	Pumping Port Depth[b] (ft)	Port Name	Comments
			68	12		1400.2					
Zone 4	1410.2 to 1417.4	1380 to 1445.5	65				833.4	1412.9		MP4A	
			64						1418.3	PP4	
			63					1423.9		MP4B	
			62	13		1427.6					
LQA4			61				None	1432.1		LQA4	
			47	14		1563.5					
SQA5			46				None	1568.0		SQA5	
			45	15		1573.4					
Zone 5	1582.6 to 1589.8	1557.9 to 1606.8	42				1013.8	1586.1		MP5A	
			41						1591.5	PP5	
			40					1597.1		MP5B	
			39	16		1600.8					
LQA5			38				None	1605.3		LQA5	
			27	17		1707.5					
SQA6			26				None	1712.0		SAQ6	
			25	18		1717.4					
Zone 6	1726.8 to 1733.9	1675.9 to 1779.8	22				1732.6	1730.1		MP6A	
			21						1735.4	PP6	
			20					1741.1		MP6B	
			19	19		1744.8					
LQA6			18				None	1749.3		LQA6	
			11	20		1812.1					
SQA7			10				None	1816.6		SQA7	
			9	21		1822.0					
Zone 7	1832.4 to 1839.5	1828.2 to 1848.4	6				1837.2	1834.7		MP7A	
			5							PP7	
			4					1845.7		MP7B	
			3	22		1849.4			1851.0		
LQA7			2				None	1853.9		LQA7	

[a] All depths are with respect to ground level.

[b] All depths of MP System casing components are the depth to the top of the respective coupling.

10.0 MODIFICATIONS TO WORK PLANS

Table 10.0-1 compares the actual characterization activities performed at R-19 with the planned activities in the “Work Plan for Pajarito Canyon” (LANL 1998, 59577), the Hydrogeologic Workplan (LANL 1998, 59599), and the “Field Implementation Plan for the Drilling and Testing of LANL Regional Aquifer Characterization Well R-19” (LANL 1999, 66644).

The final depth and completion design of R-19 was based on ongoing evaluations of hydrogeologic data collected during drilling activities and discussions with the groundwater integration team and the NMED. In the hydrogeologic work plan, the depth of the well was originally planned at 1278 to 1678 ft (100 to 500 ft into the regional zone of saturation). Because of the identification of HE contamination in groundwater at well R-25, the data quality objectives of R-19 were reevaluated and the well was redesigned as an early warning monitoring well upgradient of the southern part of the Pajarito municipal well field. The depth of the well was increased to 1950 ft during preparation of the field implementation plan in order to provide a more comprehensive monitoring of potential HE contaminants moving in groundwater eastward from TA-16 toward municipal supply well PM-2. The increased depth allowed overlap of R-19 well screens with the most productive zones in the nearby water supply wells based on spinner log data from PM-4. Presumably these productive zones represent fast pathways for groundwater and are most at risk from contaminants originating from TA-16. The borehole was actually completed at a depth of 1902.5 ft when collapsing hole conditions made further drilling activities risky.

The amount of core collected in R-19 (6.6%) was a minor deviation from the amount specified in the hydrogeologic work plan (10%). In the hydrogeologic work plan R-19 is designated as a type 2 well (10% coring). During actual drilling operations, core was collected from the upper 126 ft of R-19 using an HSA method. In R-19, good performance of the HSA system was achieved in the upper Bandelier Tuff and continuous core could be collected without penalizing the drilling rate. Because of open-hole conditions, use of geophysical logs was preferred over additional core collection for geologic and hydrologic characterization. In addition, the groundwater integration team has adopted a characterization strategy emphasizing hydrology tests in completed wells over laboratory testing of core for hydrologic properties.

At R-19, significant problems were encountered while trying to ensure that sand filter packs were correctly placed opposite the screen intervals. Unexpected changes in the vertical positions of annular fill materials were encountered for screens located in the regional zone of saturation. This occurred when annular material volumes were calculated, material was put into the borehole, and the “tagged” depth-to-surface of material differed significantly from what was estimated based on the expected annular volume. At times tagged levels appeared to rise or fall unexpectedly after adding annular fill materials on top of the previous materials.

Solutions used to deal with these problems included

- utilizing high-expansion bentonite pellets to plug fractures or stabilize the hole;
- utilizing coarser-grained sands to settle faster, bridge fractures, and plug larger formation pores and washout zones;
- placing plugs of cement grout to re-establish vertical stabilization immediately below zones that either serve as hydraulic barriers or are hydrostratigraphic zones of interest for well screens;
- introducing high volumes of water to overcome hydraulic pressures of high-producing zones while using a tremie to introduce backfill materials;
- waiting for periods of time (hours or days) for the borehole to stabilize; and
- increasing the vertical distance of annular seal or filter pack lengths to account for vertical movement of backfill materials.

Table 10.0-1
Activities Planned for R-19 Compared with Work Performed

	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-19 Field Implementation Plan	R-19 Actual Work
Planned Depth (ft)	Refers to hydrogeologic work plan	100 to 500 into the regional aquifer (1278 to 1678 ft)	Nominally 1950	1902.5
Drilling Method	Auger or rotary drilling	Methods may include, but are not limited to, HSA, air-rotary/Odex/Stratex, air-rotary/Barber rig, mud-rotary drilling	Phase I – HSA Phase II – Air-rotary under-reamer advance of casing systems	Phase I – HSA Phase II – Air-rotary under-reamer advance of casing systems to 211 ft. Open-borehole drilling from 211 to 1902.5 ft using a 12.25-in. tricone carbide button bit
Amount of Core	Refers to hydrogeologic work plan	10% of the borehole	Core to refusal with HSA	Cored to refusal with HSA; 126.5 ft or 6.6% of the borehole
Lithologic Log	Log to be prepared from core, cuttings, drilling performance	Log to be prepared from core, cuttings, drilling performance	Log to be prepared from core, cuttings, geophysical logs, and drilling performance.	Log was prepared from core, cuttings, geophysical logs, and drilling performance.
Number of Water Samples Collected for Contaminant Analysis	A water sample may be collected from each saturated zone. Well to be sampled at completion and at six months.	A water sample may be collected from each saturated zone. The number of sampling events after well completion are not specified.	A water sample will be collected from each saturated zone. 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 are not specified. Up to six water samples are planned.	To date, water samples were collected for screening purposes from two possible perched zones and two samples were collected from the regional aquifer.
Water Sample Analytes	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Tl, Ti, U, V, Zn **Anions:** Br, ClO_3, Cl, F, NO_3, PO_4, HCO_3, SO_4 **Other Inorganic Chemicals:** Si, cyanide **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, ^{241}Am **Organic Compounds**: pesticides, PCBs, VOCs, SVOCs, HE **Other Analyses:** ^{14}C, ^{13}C, $^{18}O/^{16}O$, D/H, DOC	Radiochemistry I, II, and III analytes; ^{3}H, gamma spectroscopy scan; general inorganic chemicals; metals; stable isotopes	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Tl, U, V, Zn, NH^4 **Anions:** Br, ClO_3, Cl, F, NO_3, NO_2, PO_4, HCO_3, SO_4 **Other Inorganic Chemicals:** Si, cyanide, total organic carbon **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{241}Am, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, gamma spectroscopy, gross-alpha, gross-beta, gross gamma **Organic Compounds:** VOCs, SVOCs **Other Analyses:** ^{14}C, ^{13}C, $^{18}O/^{16}O$, D/H, DOC	Same as field implementation plan except for the deletion of gamma spectroscopy, ^{241}Am, ^{238}Pu, ^{239}Pu, total Cn, and ^{90}Sr. These detected analytes are not present as contaminants in the new mesa-top location for R-19.

Table 10.0-1 (continued)

	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-19 Field Implementation Plan	R-19 Actual Work
Water Sample Field Measurements	Alkalinity, dissolved oxygen, pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, turbidity	Alkalinity, dissolved oxygen (completed well only), pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, turbidity
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Collect and preserve seven cores to represent major hydrogeologic units and zones above and below major hydrogeologic contacts	Twenty samples of core or cuttings to be analyzed for contaminants in each borehole	Up to 31 core/cuttings samples planned; number of samples dependant on number of saturated zones encountered	No samples of cores/cutting have been collected for contaminant analysis because contaminants were not detected in groundwater screening samples during drilling.
Core Sample Analytes	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, Br, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Tl, Ti, U, V, Zn **Anions:** B, Cl, F, SO_4 **Other Inorganic Chemicals:** Si, cyanide **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{230}Th, ^{232}Th, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, gamma spectroscopy, gross-alpha, gross-beta, gross gamma	Uppermost sample to be analyzed for a full range of compounds; deeper samples to be analyzed for radiochemistry I, II, and II analytes; ^{3}H; and metals; four samples to be analyzed for VOCs	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Ag, Tl, U, V, Zn **Anions:** Br, Cl, F, SO_4, NO_3 **Other Inorganic Chemicals:** cyanide **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{241}Am, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, gamma spectroscopy, gross-alpha, gross-beta, gross gamma VOCs and SVOCs to be determined in four samples and where PID detects occur	See text block above.
Laboratory Hydraulic-Property Tests	Selected borehole core samples will be analyzed for bulk density, porosity, moisture content, moisture potential, saturated hydraulic conductivity	Physical properties to be determined on 5 samples and will typically include: moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	Selected unsaturated materials may be tested in the laboratory for the full suite of hydraulic properties.	Twenty-five samples were analyzed for moisture content and matric potential. No samples were submitted for laboratory analysis of other hydraulic properties.
Geology	Refers to hydrogeologic work plan	Approximately 10 samples of core or cuttings will be collected for mineralogy, petrography, and rock chemistry.	The geology task leader will determine the number of samples for characterization of mineralogy, petrography, and rock chemistry based on geologic and hydrologic conditions encountered during drilling.	A total of 11 samples were characterized for mineralogy, 26 samples for petrography, and 34 samples for rock chemistry.

Table 10.0-1 (continued)

	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-19 Field Implementation Plan	R-19 Actual Work
Geophysics	Refers to hydrogeologic work plan	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape, fluid temperature (saturated), fluid resistivity (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, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape, fluid temperature (saturated), fluid resistivity (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	Open-hole geophysics included caliper, resistivity, natural gamma radiation, spontaneous potential, lithodensity, magnetic resonance, borehole color videotape, epithermal neutron, neutron porosity, spectral natural radiation (K, U, Th), formation microimager, hole deviation
Water-Level Measurements			Water levels will be determined for each saturated zone by water-level meter or by pressure transducer. Additional water-level readings are to be made at as many borehole depths as possible for vertical gradient determination.	Water levels were determined for each saturated zone by water-level meter or by pressure transducer. Water-level measurements were taken at various borehole depths, but open-hole conditions precluded true piezometric measurements.
Field Hydraulic-Property Tests			Slug or pumping tests may be conducted in saturated intervals once the well is completed.	Straddle-Packer/injection tests were conducted for two intervals in the regional zone of saturation.
Surface Casing	Refers to hydrogeologic work plan	Approximately 20-in. O.D., extends from land surface to 10-ft depth in underlying competent layer and grouted in place	16-in.- diameter low-carbon steel casing set to a depth of 37 ft	18-in. surface casing extends to a depth of 19 ft.
Minimum Well Casing Size	Refers to hydrogeologic work plan	6-5/8-in. O.D.	5.56-in. O.D.	Nominally 5.0-in. O.D.
Well Screen	Refers to hydrogeologic work plan	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	Five screens ranging from 10 to 25 ft in length; wire-wrapped 304 stainless-steel screens with 0.010-in. gaps.	Seven screens from 7.1 to 44 ft in length of stainless-steel pipe-base screen with wire wrap; 0.010-in. gaps.
Filter Material	Refers to hydrogeologic work plan	>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	>98% silica sand, properly- sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	>98% silica sand; sizes include 30/70, 20/40, 8/12, and 6/9 in various combinations; from 4.2 to 50.9 ft above screen to 7.1 to 45.9 ft below screen

Table 10.0-1 (continued)

	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-19 Field Implementation Plan	R-19 Actual Work
Conductor Casing	Refers to hydrogeologic work plan	Carbon-steel casing from land surface to top of stainless-steel casing	Carbon-steel casing 5.56-in. in diameter extending from land surface to dielectric coupling at top of stainless-steel casing; 10 ft of 5.56-in.-diameter stainless-steel casing below dielectric coupling	5-in.-O.D. stainless-steel casing used throughout well
Backfill Materials (exclusive of filter materials)	Refers to hydrogeologic work plan	Uncontaminated drill cuttings below sump and bentonite above sump	Bentonite in borehole below well; fine sand in transition zone 10 ft above and 3 ft below filter pack; bentonite above transition zone to bottom of surface casing; cement grout between surface casing and borehole wall and between surface casing and well casing	Bentonite below well screen #7; sand next to well screens; bentonite between sand packs; cement placed at 0 to 50 ft, 1116.3 to 1126 ft, 1358 to 1370.9 ft, 1475.5 to 1488.7 ft, 1627.3 to 1632.1 ft
Sump	Refers to hydrogeologic work plan	Stainless-steel casing with an end cap	5.56-in.-diameter stainless-steel casing 10 ft long	37.9 ft of 5-in.-O.D. stainless-steel casing with an end cap
Bottom Seal	Refers to hydrogeologic work plan	Bentonite	Bentonite	Bentonite

At R-19, it was necessary to extend sand filter packs well above and below some screens because the borehole would not stabilize even after using all available solutions. Movement of annular fill materials suggested that these materials could continue to “fall” while annular filling activities were occurring higher up the borehole or even after the well had been completed. This made it difficult to ensure that no annular seal material (i.e., bentonite) would relocate itself over the screens. Emplacing only 5 ft of sand pack above the top of the screen in these instances would have seriously jeopardized the use of these screens. The only solution was to extend the lengths of sand packs to account for subsequent vertical movement of annular fill materials.

11.0 IMPLICATIONS FOR CONCEPTUAL GEOLOGIC, HYDROGEOLOGIC, AND GEOCHEMICAL MODELS

The most significant implications from R-19 for the conceptual hydrogeologic model is that the thick perched zone of saturation encountered at R-25 was not observed at either R-19 or CdV-R-15-3. In fact, the occurrence of any perched water at these wells is uncertain. If such saturation is present, it is markedly thinner than at R-25. These observations suggest there is little danger of transport of HE through perched water from the R-25 area across the area of R-19.

The regional water table is 60 ft deeper at R-19 than anticipated. This is as much a consequence of contouring sparse water-level data as anything else and shows the need for additional spatial data to constrain the depth and geometry of the water table.

Head data collected within the regional zone of saturation at R-19 indicate a downward vertical gradient. This confirms the existing conceptual model that R-19 is located in a recharge area.

Hydrologic testing of pre–Puye Formation deposits yielded hydraulic-conductivity values that are consistent with those for medium sand or silty sand. Hydraulic-property values for these pre-Puye Formation deposits have not previously been available. These deposits were unanticipated in the 3-D sitewide geologic model available at the time R-19 was drilled. Revisions to the 3-D sitewide geologic model will include the incorporation of this pumiceous pre-Puye unit, the adaptation to much thicker Cerro Toledo deposits in this part of the Laboratory, the modeling of thinner Cerros del Rio basaltic units, and the absence of axial river gravels or Santa Fe Group sediments at the depth drilled.

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B. Hull was the drilling consultant, and he contributed to drilling activities, placement of annular fill materials, and well design.

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M. Cash was the host facility point-of-contact for administrative oversight for DX Division. S. T. Alexander was the facility manager for facility management unit 67.

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D. Larssen installed the Westbay sampling system.

D. Counce was the analyst for water chemistry analyses used for screening of groundwaters collected from saturated zones. E. Kluk and M. Snow were analysts for moisture and matric-potential determinations.

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Appendix A

Lithologic Log

LOS ALAMOS NATIONAL LABORATORY
REGIONAL HYDROGEOLOGIC CHARACTERIZATION PROJECT
ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-19	TA/OU: TA-36	Page 1 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7075 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
0	7075	1(2.5/2.5)					ALLUVIUM: (0-2.7 ft) Very dry, light to dark brown, organic, silt and sand, soft, rounded sanidine and quartz grains.		Qa1
		2(2.5/2.5)							Qbt 4
5	7070	3(2.5/2.5)			Moisture Protected HSA Core (4.5-5.0')	R-19-4.5			
		4(2.5/2.5)					Qbt 4 TSHIREGE MEMBER, BANDELIER TUFF: (2.7-5 ft) Light pinkish gray, moderately welded, moderately indurated.		
10	7065	5(2.5/2.5)			Moisture Protected HSA Core (13.4-13.9')	R-19-9.5			
		6(1.6/2.5)							
15	7060	7(2.5/2.5)			Moisture Protected HSA Core (19.7-20')	R-19-14.1			
		8(2.5/2.5)					Qbt 3 TSHIREGE MEMBER, BANDELIER TUFF: (5-117.5 ft) Light gray to light pinkish gray, moderately to poorly welded, slightly indurated, local oxidation.		
20	7055	9(2.5/2.5)			Moisture Protected HSA Core (19.7-20')	R-19-19.7			
		10(2.5/2.5)							
25	7050	11(2.5/2.5)			Moisture Protected HSA Core (24.6-25')	R-19-24.6			
		12(2.5/2.5)							
30	7045	13(2.5/2.5)							
		14(1.8/2.5)							
35	7040	15(2.5/2.5)				R-19-35.2			
		16(1.4/2.5)							
40	7035	17(2.5/2.5)				R-19-38.9			
		18(1.8/2.5)				R-19-41.1			
45	7030	19(1.7/2.5)							
		20(2.5/2.5)				R-19-46.8			
50	7025	21(2.5/2.5)							
		22(2.5/2.5)							
55	7020	23(2.5/2.5)				R-19-55			
		24(2.5/2.5)							
60	7015	25(2.5/2.5)				R-19-60			
		26(2.5/2.5)							
65	7010	27(2.5/2.5)				R-19-65			
		28(2.5/2.5)							
70	7005	29(2.5/2.5)				R-19-70			Qbt 3
		30(2.5/2.5)							
75	7000	31(2.5/2.5)				R-19-75			
		32(2.5/2.5)				R-19-77.5			
80	6995	33(2.5/2.5)							
		34(2.5/2.5)				R-19-82.5			
85	6990	35(2.5/2.5)							
		36(2.5/2.5)				R-19-87.5			
90	6985								

LOS ALAMOS NATIONAL LABORATORY
REGIONAL HYDROGEOLOGIC CHARACTERIZATION PROJECT
ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-19	TA/OU: TA-36	Page 2 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
90	6985	37(2.5/2.5)					Qbt 3 TSHIREGE MEMBER, BANDELIER TUFF: (5-117.5 ft) Light gray to light pinkish gray, moderately to poorly welded, slightly indurated, local oxidation.		Qbt 3
		38(2.5/2.5)				R-19-92.5			
95	6980	39(2.5/2.5)							
		40(2.5/2.5)				R-19-97.5			
100	6975	41(2.5/2.5)							
		42(2.5/2.5)				R-19-102.5			
105	6970	43(2.5/2.5)							
		44(1.4/2.5)				R-19-107.5			
110	6965	45(2.5/2.5)							
		46(2.5/2.5)				R-19-112.5			
115	6960	47(2.5/2.5)							
		48(2.5/2.5)				R-19-117.5	Qbt 2 TSHIREGE MEMBER, BANDELIER TUFF: (117.5-230 ft) Light pinkish gray, slightly welded, moderately indurated.		Qbt 2
120	6955	49(2.5/2.5)							
		50(2.5/2.5)				R-19-122.5			
125	6950	51(1.5/1.5)			Moisture Protected HSA Core (125.9-126.3')	R-19-126.5			
130	6945								
135	6940								
140	6935								
145	6930								
150	6925								
155	6920								
160	6915								
165	6910								
170	6905								
175	6900								
180	6895								

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ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-19	TA/OU: TA-36	Page 3 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
180	6895						Qbt 2 TSHIREGE MEMBER, BANDELIER TUFF: (117.5-230 ft) Light pinkish gray, slightly welded, moderately indurated.		Qbt 2
185	6890								
190	6885								
195	6880								
200	6875								
205	6870								
210	6865								
215	6860								
220	6855								
225	6850								
230	6845						Qbt 1v TSHIREGE MEMBER, BANDELIER TUFF: (230-285 ft) Light gray to light pinkish gray, nonwelded, non indurated.		Qbt 1v
235	6840								
240	6835								
245	6830								
250	6825								
255	6820								
260	6815								
265	6810								
270	6805								

LOS ALAMOS NATIONAL LABORATORY
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ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-19	TA/OU: TA-36	Page 4 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
270	6805						Qbt 1v TSHIREGE MEMBER, BANDELIER TUFF: (230-285 ft) Light gray to light pinkish gray, nonwelded, non-indurated.		
275	6800								
280	6795								
285	6790						Qbt 1g TSHIREGE MEMBER, BANDELIER TUFF: (285-379 ft) Dry, grayish orange pink (5 YR 7/2), vitric pumice lapilli to 1 cm in non-indurated vitric ash matrix, estimated 20% quartz and sanidine phenocrysts and 5-10% oxidized lithics.		
290	6785								
295	6780								
300	6775								
305	6770								
310	6765								
315	6760								
320	6755								
325	6750								
330	6745								Qbt 1g
335	6740								
340	6735								
345	6730								
350	6725								
355	6720								
360	6715								

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BOREHOLE LOG

BOREHOLE ID: R-19	TA/OU: TA-36	Page 5 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
360	6715						Qbt 1 g TSHIREGE MEMBER, BANDELIER TUFF: (285-379 ft) Dry, grayish orange pink (5 YR 7/2), vitric pumice lapilli to 1 cm in non-indurated ash matrix, estimated 20% quartz and sanidine phenocrysts and 5-10% oxidized lithics.		Qbt 1g
365	6710								
370	6705								
375	6700								
380	6695				Geologic (380-382')		TSANKAWI PUMICE BED: (379-380 ft) Chalky pumice lapilli 70% up to 1 cm in ash matrix.		Qbt t
385	6690						CERRO TOLEDO INTERVAL: (380-646 ft) Red-brown ash with estimated 30% pumice lapilli and lithics.		
390	6685								
395	6680								
400	6675								Qct
405	6670								
410	6665								
415	6660								
420	6655								
425	6650								
430	6645								
435	6640								
440	6635								
445	6630								
450	6625								

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BOREHOLE LOG

BOREHOLE ID: R-19	TA/OU: TA-36	Page 6 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
450	6625						CERRO TOLEDO INTERVAL: (380-646 ft) Red-brown ash with estimated 30% pumice lapilli and lithics.		Qct
455	6620								
460	6615								
465	6610								
470	6605								
475	6600								
480	6595								
485	6590								
490	6585								
495	6580								
500	6575								
505	6570								
510	6565								
515	6560				Geologic (510-515')				
520	6555								
525	6550								
530	6545								
535	6540								
540	6535								

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BOREHOLE ID: R-19	TA/OU: TA-36	Page 7 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
540	6535						CERRO TOLEDO INTERVAL: (380-646 ft) Red-brown ash with estimated 30% pumice lapilli and lithics.		Qct
545	6530								
550	6525								
555	6520								
560	6515								
565	6510								
570	6505								
575	6500								
580	6495								
585	6490								
590	6485								
595	6480								
600	6475								
605	6470								
610	6465								
615	6460								
620	6455								
625	6450								
630	6445								

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DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
630	6445						CERRO TOLEDO INTERVAL: (380-646 ft) Red-brown ash with estimated 30% pumice lapilli and lithics.		Qct
635	6440								
640	6435				Geologic (635-640')				
645	6430						OTOWI MEMBER OF BANDELIER TUFF: (646-830 ft) Ash flow tuff, nonwelded, vitric, moderate reddish brown (10 R 6/6), pumice lapilli up to 8 cm (2%), intermediate composition volcanic rock lithics to 5%.		Qbo
650	6425								
655	6420								
660	6415								
665	6410								
670	6405								
675	6400								
680	6395								
685	6390								
690	6385								
695	6380								
700	6375								
705	6370								
710	6365								
715	6360								
720	6355								

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BOREHOLE LOG

BOREHOLE ID: R-19	TA/OU: TA-36	Page 9 of 22
DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
720	6355						OTOWI MEMBER OF BANDELIER TUFF: (646-830 ft) Ash flow tuff, nonwelded, vitric, moderate reddish brown (10 R 6/6), pumice lapilli up to 8 cm (2%), intermediate composition volcanic rock lithics to 5%.		Qbo
725	6350								
730	6345								
735	6340								
740	6335								
745	6330								
750	6325								
755	6320								
760	6315								
765	6310								
770	6305								
775	6300								
780	6295								
785	6290								
790	6285								
795	6280								
800	6275								
805	6270								
810	6265								

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BOREHOLE LOG

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DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
810	6265						OTOWI MEMBER OF BANDELIER TUFF: (646-830 ft) Ash flow tuff, nonwelded, vitric, moderate reddish brown (10 R 6/6), pumice lapilli up to 8 cm (2%), intermediate composition volcanic rock lithics to 5%.		Qbo
815	6260								
820	6255								
825	6250								
830	6245						GUAJE PUMICE BED: (830-840 ft) Light tannish white to very pale orange (10 YR 8/2) vitric pumice lapilli aggregate.		Qbog
835	6240				Geologic (834-835')				
840	6235						PUYE FORMATION: (840-925 ft) Tschicoma Fm intermediate-composition volcanic gravel and cobbles in silty sand matrix.		Tpf
845	6230								
850	6225								
855	6220								
860	6215								
865	6210								
870	6205								
875	6200								
880	6195								
885	6190								
890	6185								
895	6180								
900	6175								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
900	6175						PUYE FORMATION: (840-925 ft) Tschicoma Fm intermediate-composition volcanic gravel and cobbles in silty sand matrix.		Tpf
905	6170				Geologic (900-905')				
910	6165								
915	6160								
920	6155								
925	6150						BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (925-998 ft) Massive basalt.		Tb
930	6145								
935	6140								
940	6135								
945	6130								
950	6125								
955	6120								
960	6115								
965	6110				Geologic (960-965')				
970	6105								
975	6100								
980	6095								
985	6090								
990	6085								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
990	6085						BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (925-998 ft) Massive basalt.		Tb
995	6080								
1000	6075				Geologic (995-1000')		BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (998-1017 ft) Flow-base rubble from 998 to to 1006 ft and massive, poorly bedded scoria from 1006 to 1017 ft.		
1005	6070								
1010	6065								
1015	6060								
1020	6055						BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (1017-1063 ft) Massive vesicular flow.		
1025	6050								
1030	6045				Geologic (1025-1030')				
1035	6040								
1040	6035								
1045	6030								
1050	6025								
1055	6020								
1060	6015				Geologic (1055-1060')				
1065	6010						BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (1063-1067 ft) Flow-base rubble.		
1070	6005						BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (1067-1074 ft) Scoria and basaltic sedimentary deposits.		
1075	6000						BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (1074-1080 ft) Basaltic sand deposits.		

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1080	5995				Geologic (1075-1080')		BASALT OF THE CERROS DEL RIO VOLCANIC FIELD: (1074-1080 ft) Basaltic sand deposits.		Tb
1085	5990						PUYE FORMATION: (1080-1101 ft) Intermediate-composition volcanic clasts 90% to 98%; light to medium gray dacite with some rhyolites; very coarse sands and gravels.		Tpf
1090	5985								
1095	5980								
1100	5975				Geologic (1095-1100')		PUYE FORMATION: (1101-1105 ft) Coarse sand, reworked dacitic materials.		
1105	5970						PUYE FORMATION: (1105-1130 ft) Very coarse sands and gravels, monolithologic.		
1110	5965								
1115	5960								
1120	5955								
1125	5950								
1130	5945						PUYE FORMATION: (1130-1145 ft) Coarse sands and gravels, monolithlogic with some reddish brown dacite (?)		
1135	5940								
1140	5935								
1145	5930						PUYE FORMATION: (1145-1155 ft) Coarse sand consisting of light to medium gray rhyolite (?) Dacitic fragments plus reddish-brown dacite from 1150 to 1155 ft, free quartz crystals up to 1 - 2 mm.		
1150	5925								
1155	5920						PUYE FORMATION: (1155-1159 ft) Tuffaceous sand and gravel; pumice fragments typically < 2mm = 20%.		
1160	5915						PUYE FORMATION: (1159-1165 ft) No recovery.		
1165	5910						PUYE FORMATION: (1165-1180 ft) Coarse sand and gravel consisting of light to medium gray rhyolite and dacite.		
1170	5905								

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ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

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DRILLING COMPANY: Stewart Bro./Dynatec	PHASE 1: 1/7/00 - 1/13/00	PHASE 2: 1/25/00 - 8/16/00
DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1170	5905						PUYE FORMATION: (1165-1180 ft) Coarse sand and gravel consisting of light to medium gray rhyolite and dacite.		Tpf
1175	5900				Geologic (1170-1175')				
1180	5895						PUYE FORMATION: (1180-1185 ft) Gravel consisting of light to medium gray rhyolite and dacite.		
1185	5890						PUYE FORMATION: (1185-1190 ft) Coarse sand with dark reddish gray (purple) andesitic (?) volcanic clasts.		
1190	5885						PUYE FORMATION: (1190-1205 ft) Very coarse sands and gravels, lithologies same as above.		
1195	5880								
1200	5875								
1205	5870						PUYE FORMATION: (1205-1210 ft) Gravel, heterogeneous lithologies consist of light to medium gray rhyolite/dacite plus reddish brown dacite (?) clasts.		
1210	5865				Geologic (1205-1210')				
1215	5860						PUYE FORMATION: (1210-1220 ft) Medium coarse sand consisting of dacitic fragments with some quartz phenocryts.		
1220	5855								
1225	5850						PUYE FORMATION: (1220-1230 ft) Very coarse sands consisting of dacitic clasts.		
1230	5845						PUYE FORMATION: (1230-1240 ft) Gravel, lithology same as above.		
1235	5840								
1240	5835						PUYE FORMATION: (1240-1275 ft) Coarse to very coarse sands and gravels; light to medium gray rhyolite/dacite plus reddish brown dacite (?)		
1245	5830								
1250	5825								
1255	5820								
1260	5815								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1260	5815						PUYE FORMATION: (1240-1275 ft) Coarse to very coarse sands and gravels; light to medium gray rhyolite/dacite plus reddish brown dacite (?)		
1265	5810								
1270	5805								
1275	5800						PUYE FORMATION: (1275-1290 ft) Gravel dominated by light gray rhyloite (?) or dacite fragments with rare black perlite and white pumice fragments.		
1280	5795								
1285	5790								
1290	5785						PUYE FORMATION: (1290-1295 ft) Medium to coarse sand consisting of 80% light to medium gray rhyolite/dacite clasts, 20% white vitric pumice with small biotite phenocrysts.		
1295	5780								
1300	5775						PUYE FORMATION: (1295-1300 ft) Same as above except pumice up to 50%.		Tpf
1305	5770						PUYE FORMATION: (1300-1330 ft) Gravel dominated by light to medium gray rhyloite (?) or dacite lava clasts with subordinate pinkish red to reddish-brown dacite (?) lava clasts.		
1310	5765								
1315	5760								
1320	5755								
1325	5750								
1330	5745						PUYE FORMATION: (1330-1335 ft) No recovery.		
1335	5740				Geologic (1330-1335')		PUYE FORMATION: (1335-1350 ft) Gravel, same lithologies as above, rare pumice.		
1340	5735								
1345	5730								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1350	5725						PUYE FORMATION: (1335-1350 ft) Gravel, same lithologies as above, rare pumice.		Tpf
1355	5720						PUYE FORMATION: (1350-1360 ft) Gravels mixed with very coarse sands, rare white pumice.		
1360	5715						PUYE FORMATION: (1360-1370 ft) Gravel with rare white pumice.		
1365	5710								
1370	5705						PUYE FORMATION: (1370-1380 ft) Very coarse sands and gravels consisting of heterogeneous intermediate-composition lava clasts.		
1375	5700								
1380	5695						PUYE FORMATION: (1380-1393 ft) Tan ash, fine-grained, reworked, tuffaceous, abundant sanidine crystals and medium to dark gray mafic lithics in light colored tuffaceous matrix.		
1385	5690				Geologic (1380-1385')				
1390	5685								
1395	5680						PUYE FORMATION: (1393-1395 ft) Mixture of volcanic ash and coarse sands and gravels.		
1400	5675						PUYE FORMATION: (1395-1400 ft) Gravel, possible Rendija Canyon rhyolite (?).		
1405	5670						PUYE FORMATION: (1400-1420 ft) Very coarse sands and gravels.		
1410	5665								
1415	5660				Geologic (1410-1415')				
1420	5655						PUYE FORMATION: (1420-1425 ft) Heterogeneous intermediate volcanic clasts, not monolithologic as at top of Puye in this borehole.		
1425	5650								
1430	5645						PUYE FORMATION: (1425-1455 ft) Same as above except altered andesite with medium green epidote noted at 1425 ft.		
1435	5640								
1440	5635								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1440	5635						PUYE FORMATION: (1425-1455 ft) Same as above except altered andesite with medium green epidote noted at 1425 ft.		Tpf
1445	5630								
1450	5625						PUYE FORMATION: (1445-1460 ft) Same as above except oxidized altered euhedral hornblende relict crystal as in Keres Group but not in Tschicoma volcanics.		
1455	5620								
1460	5615						PUYE FORMATION: (1460-1480 ft) Very coarse sand consisting of heterogeneous intermediate-composition volcanic clasts and pumice up to 20%.		
1465	5610								
1470	5605								
1475	5600								
1480	5595						PUYE FORMATION: (1480-1500 ft) Gravels, heterogeneous intermediate-composition volcanic clasts, rare pumice, 1.5 mm biotite books in gray lava. Possible reworked fragments noted at 1492 ft, very coarse sands from 1495 ft to 1500 ft.		
1485	5590								
1490	5585								
1495	5580								
1500	5575						PUYE FORMATION: (1500-1515 ft) Coarse to very coarse sands, heterogeneous volcanic lithologies, pumice-poor, many free quartz crystals.		
1505	5570								
1510	5565								
1515	5560						PUYE FORMATION: (1515-1520 ft) Medium to coarse sands and gravels.		
1520	5555				Geologic (1515-1520')		PUYE FORMATION: (1520-1530 ft) Same as above, pumice up to 5%.		
1525	5550								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1530	5545						PUYE FORMATION: (1520-1530 ft) Same as above, pumice up to 5%.		
1535	5540						UNASSIGNED SEDIMENTARY DEPOSITS: (1530-1535 ft) Coarse to very coarse sands, heterogeneous volcanics, pumice-rich.		
1540	5535						UNASSIGNED SEDIMENTARY DEPOSITS: (1535-1550 ft) Same as above, poor to no recovery.		
1545	5530								
1550	5525						UNASSIGNED SEDIMENTARY DEPOSITS: (1550-1555 ft) Coarse to very coarse sands, heterogeneous intermediate-composition volcanics including andesite, pinkish red to light gray or dull black, pumice-rich.		
1555	5520								
1560	5515				Geologic (1555-1560')		UNASSIGNED SEDIMENTARY DEPOSITS: (1555-1560 ft) Same as above with up to 20% very pale orange 10 YR 8/2 vitric rounded pumice lapilli, many free quartz and sanidine crystals.		
1565	5510								Tp?
1570	5505						UNASSIGNED SEDIMENTARY DEPOSITS: (1560-1581 ft) Gravel of heterogeneous volcanics, pumice rare.		
1575	5500								
1580	5495						UNASSIGNED SEDIMENTARY DEPOSITS: (1581-1595 ft) Pumice fall (?), 95 to 100% very pale orange 10 YR 8/2 vitric pumice lapilli and fragments with 0.5 to 1% minute mafic inclusions and subhedral ferro-magnesian phenocrysts. Pumice are rounded to well rounded, mostly 2 to 5 mm, maximum to 1 cm.		
1585	5490								
1590	5485				Geologic (1585-1590')				
1595	5480				Geologic (1590-1595')		UNASSIGNED SEDIMENTARY DEPOSITS: (1595-1605 ft) Heterogeneous volcanic clasts consist of three predominant lithologies, all with varying amounts of Fe staining: 20 to 50% white vitric pumice lapilli, 10 to 40% light to medium gray dacite, and 10 to 40% pale grayish red flow-banded andesite (?) or rhyolite (?)		
1600	5475								
1605	5470								
1610	5465						UNASSIGNED SEDIMENTARY DEPOSITS: (1605-1610 ft) Coarse to very coarse sand of heterogeneous volcanics.		

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1610	5465						UNASSIGNED SEDIMENTARY DEPOSITS: (1610-1615 ft) Medium to coarse sand with some pumice lapilli.		Tp?
1615	5460						UNASSIGNED SEDIMENTARY DEPOSITS: (1615-1640 ft) Very coarse sands and gravels, "salt and pepper" gray and white coloration, tuffaceous reworked material with abundant clasts of gray and pink dacites and pumice lapilli up to 50%.		
1620	5455								
1625	5450								
1630	5445								
1635	5440								
1640	5435						UNASSIGNED SEDIMENTARY DEPOSITS: (1640-1645 ft) No recovery.		
1645	5430						UNASSIGNED SEDIMENTARY DEPOSITS: (1645-1650 ft) Medium to coarse tuffaceous sand dominated by white vitric pumice fragments, free crystals of biotite, quartz, and sanidine; 5 to 10% dacitic clasts, 90 to 95% pumice lapilli.		
1650	5425								
1655	5420								
1660	5415						UNASSIGNED SEDIMENTARY DEPOSITS: (1650-1660 ft) Two populations; 1) same as above; 2) gravel consisting of heterogeneous volcanics including dacite and some flow banded rhyolite.		
1665	5410								
1670	5405						UNASSIGNED SEDIMENTARY DEPOSITS: (1660-1665 ft) Same as above with glassy lava fragments.		
1675	5400						UNASSIGNED SEDIMENTARY DEPOSITS: (1665-1680 ft) Coarse sand and gravel with abundant volcanic ash, broken crystal-poor pumice clasts, glassy and crystal-poor dacitic and rhyolitic fragments.		
1680	5395								
1685	5390						UNASSIGNED SEDIMENTARY DEPOSITS: (1680-1690 ft) No recovery.		
1690	5385						UNASSIGNED SEDIMENTARY DEPOSITS: (1690-1700 ft) Pumice fall (?), white glassy pumice lapilli, notably crystal-poor, sparse phenocrysts of quartz, sanidine, and biotite, less than 5% fragments of rhyolitic and dacitic volcanic clasts.		
1695	5380								
1700	5375								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1700	5375						UNASSIGNED SEDIMENTARY DEPOSITS: (1700-1705 ft) Gravel, light gray to reddish-brown dacitic fragments.		
1705	5370						UNASSIGNED SEDIMENTARY DEPOSITS: (1705-1710 ft) Tuffaceous sediment with mixture of white volcanic ash, small white vitric pumice fragments (crystal poor), and gray to reddish-brown dacitic clasts.		
1710	5365						UNASSIGNED SEDIMENTARY DEPOSITS: (1710-1715 ft) Medium-grained tuffaceous tan to white sand, abundant pumice fragments and free quartz, sanidine and biotite crystals, some small rhyolite and dacite lava clasts.		
1715	5360						UNASSIGNED SEDIMENTARY DEPOSITS: (1715-1720 ft) Same as above, tuffaceous sand and gravel, 50% volcanic ash and small pumice fragments, 50% gray dacitic and rhyolitic clasts.		
1720	5355						UNASSIGNED SEDIMENTARY DEPOSITS: (1720-1725 ft) Tan fine- to medium-grained tuffaceous sand or ash fall, dominated by volcanic ash and vitric pumice fragments, free quartz and sanidine crystals, < 2% dacitic lava fragments.		
1725	5350				Geologic (1720-1725')				
1730	5345								
1735	5340				Geologic (1730-1735')				Tp?
1740	5335				Geologic (1735-1740')				
1745	5330						UNASSIGNED SEDIMENTARY DEPOSITS: (1725-1780 ft) Tuffaceous gravels with white pumice lapilli (50 to 70%) and gray to reddish-brown lava clasts. Pumice is phenocryst-poor with sparse quartz, sanidine, and minute biotite minerals.		
1750	5325								
1755	5320								
1760	5315								
1765	5310								
1770	5305								
1775	5300								
1780	5295						UNASSIGNED SEDIMENTARY DEPOSITS: (1780-1785 ft) No recovery.		
1785	5290								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1785	5290						UNASSIGNED SEDIMENTARY DEPOSITS: (1785-1800 ft) Coarse-grained tuffaceous sand consisting of light tan volcanic ash and pumice fragments with free crystals of quartz, sanidine, and biotite, rhyolitic and dacitic clasts are < 2%.		Tp?
1790	5285								
1795	5280								
1800	5275						UNASSIGNED SEDIMENTARY DEPOSITS: (1800-1805 ft) No recovery.		
1805	5270						UNASSIGNED SEDIMENTARY DEPOSITS: (1805-1820 ft) Gravels and coarse-grained sands consisting of 50:50 mixture of light to medium gray and reddish-brown dacitic and rhyolitic clasts, white vitric crystal poor pumice fragments same as above.		
1810	5265								
1815	5260								
1820	5255						UNASSIGNED SEDIMENTARY DEPOSITS: (1820-1830 ft) No recovery.		
1825	5250								
1830	5245						UNASSIGNED SEDIMENTARY DEPOSITS: (1830-1835 ft) Gravel, 60 to 70% of clasts are light gray dacites and rhyolites, and light reddish-brown dacites, rest is white vitric pumice fragments.		
1835	5240				Geologic (1830-1835')				
1840	5235				Geologic (1835-1840')		UNASSIGNED SEDIMENTARY DEPOSITS: (1835-1855 ft) Tuffaceous sequence consists of very coarse-grained white vitric pumice fragments and gray reddish-brown rhyolitic and dacitic fragments.		
1845	5230								
1850	5225								
1855	5220						UNASSIGNED SEDIMENTARY DEPOSITS: (1855-1860 ft) Gravel, 80 to 90% light gray glassy and devitrified rhyolite fragments, medium gray and reddish-brown dacitic fragments.		
1860	5215								

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DRILLING EQ/METHOD: Failing F-10/Foremost DR24	SAMPLING EQ/METHOD: Wireline core barrel sampling	
GROUND ELEVATION: 7066.3 ft	GEOLOGY P.I.: Vaniman	TOTAL DEPTH = 1902.5 ft bgs
DRILLER: Johnson/Brown,Thoren, Wilson, Woodward		SITE GEOLOGIST: Marin/Goetz

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Property (Geologic) and Archived (Moisture Protected HSA Core)	Moisture/Matric Pot. R19-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
1860	5215						UNASSIGNED SEDIMENTARY DEPOSITS: (1860-1870 ft) Light tan tuffaceous deposit consists of white pumice lapilli, quartz, sanidine, and biotite crystals, light to medium gray intermediate composition volcanic clasts, and some reddish brown volcanic clasts (dacite?).		
1865	5210								
1870	5205						UNASSIGNED SEDIMENTARY DEPOSITS: (1870-1875 ft) Poor recovery.		Tp?
1875	5200						UNASSIGNED SEDIMENTARY DEPOSITS: (1875-1902.5 ft) Light tan tuffaceous sequence same as above.		
1880	5195								
1885	5190								
1890	5185								
1895	5180				Geologic (1895-1900')		UNASSIGNED SEDIMENTARY DEPOSITS: (1895-1902.5 ft) Coarse light tan pumice, up to 2 cm. Moderate clay coatings, vitric.		
1900	5175								

Appendix B

Moisture and Matric-Potential Results

Sample ID	Upper Depth (ft)	Lower Depth (ft)	Geologic Unit	Gravimetric Moisture (%)	Activity (H_2O)	Temperature (°C)	Matric Potential (cm)
R19-4.5	4.2	4.5	Tshirege Qbt 4	7.70	0.960	26.82	-5.83E+04
R19-9.5	9.3	9.5	Tshirege Qbt 3	5.63	0.992	26.89	-1.20E+04
R19-14.1	13.9	14.1	Tshirege Qbt 3	6.53	0.993	26.94	-1.06E+04
R19-19.7	19.5	19.7	Tshirege Qbt 3	3.78	0.986	27.07	-1.99E+04
R19-24.6	24	24.6	Tshirege Qbt 3	4.73	0.988	27.02	-1.77E+04
R19-35.2	35	35.2	Tshirege Qbt 3	3.12	0.985	26.77	-2.13E+04
R19-38.9	38.6	38.9	Tshirege Qbt 3	2.58	0.987	26.88	-1.85E+04
R19-44.1	43.9	44.1	Tshirege Qbt 3	2.59	0.988	26.91	-1.77E+04
R19-46.6	46.4	46.6	Tshirege Qbt 3	2.63	0.985	27.14	-2.18E+04
R19-55	54.8	55	Tshirege Qbt 3	5.68	0.991	26.24	-1.27E+04
R19-60	59.7	60	Tshirege Qbt 3	3.18	0.993	26.21	-9.88E+03
R19-65	64.8	65	Tshirege Qbt 3	3.79	0.994	26.06	-8.46E+03
R19-70	69.8	70	Tshirege Qbt 3	3.67	0.992	26.00	-1.13E+04
R19-75	74.8	75	Tshirege Qbt 3	3.53	0.995	25.84	-7.04E+03
R19-77.5	77.3	77.5	Tshirege Qbt 3	2.87	0.994	26.08	-9.17E+03
R19-82.5	82.4	82.5	Tshirege Qbt 3	2.30	0.992	26.01	-1.20E+04
R19-87.5	87.3	87.5	Tshirege Qbt 3	3.15	0.992	26.27	-1.20E+04
R19-92.5	92.3	92.5	Tshirege Qbt 3	3.76	0.995	26.02	-7.05E+03
R19-97.5	97.3	97.5	Tshirege Qbt 3	3.50	0.995	26.21	-7.76E+03
R19-102.5	102.3	102.5	Tshirege Qbt 3	4.27	0.995	26.07	-7.05E+03
R19-107.5	107.3	107.5	Tshirege Qbt 3	3.09	0.994	26.13	-8.46E+03
R19-112.5	112.3	112.5	Tshirege Qbt 3	2.73	0.993	26.10	-9.88E+03
R19-117.5	117.3	117.5	Tshirege Qbt 3	3.15	0.994	26.26	-9.18E+03
R19-122.5	122.3	122.5	Tshirege Qbt 2	2.63	0.993	26.43	-9.89E+03
R19-126.5	126.3	126.5	Tshirege Qbt 2	3.16	0.993	26.54	-1.06E+04

Appendix C

Westbay's MP55 Well Components Installed in R-19

Summary Casing Log

Company: LANL
Well: R19
Site:
Project: Hydrogeology Characterization

Job No: WB777
Author: DL

Well Information

Reference Datum: ground level
Elevation of Datum: 0.00 ft.
MP Casing Top: 0.00 ft.
MP Casing Length: 1869.67 ft.

Borehole Depth: 1886.00 ft.
Borehole Inclination: vertical
Borehole Diameter: 10.00 in.

Well Description:
Plastic MP55 System
Other References:
4.5 in ID SS casing+screens: LANL31-07
Backfill after LANL 31-07-00
MagneticCollars 2.5 ft below port top

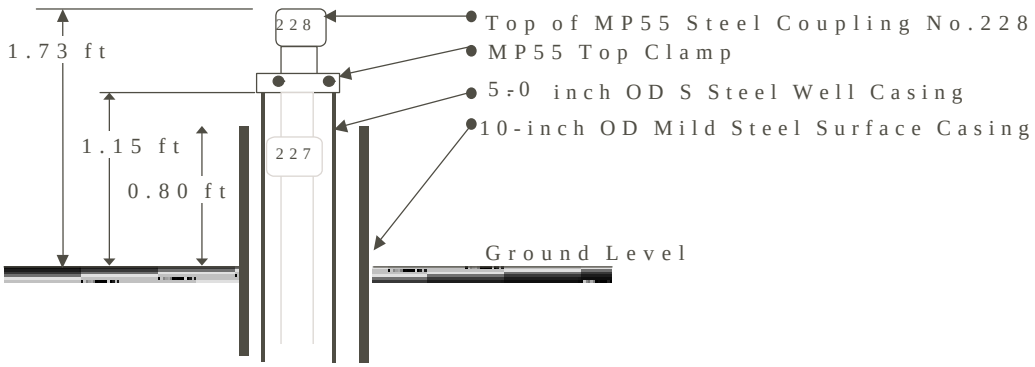
File Information

File Name: 777_R19.WWD
Report Date: Mon Sep 18 22:03:46 2000

File Date: Sep 16 18:33:14 2000

Sketch of Wellhead Completion

R19 Surface Completion



Summary MP Casing Log
LANL

Job No: WB777
Well: R19

Legend

(Qty) MP Components

(2) 0603 - MP55 End Plug

(157) 0601M30 - MP55 Casing, PVC, 3.0m

(22) 0612M15 - MP55 Packer with stiffeners

(31) 0601M15 - MP55 Casing, PVC, 1.5m

(17) 0601M10 - MP55 Casing, PVC, 1.0m

(190) 0602 - MP55 Regular Coupling

(31) 0605 - MP55 Measurement Port

(8) 0607 - MP55 Hydraulic Pumping Port

(12) 0608 - MP55 Magnetic Location Collar

Backfill/Casing

Concrete

Bentonite

Sand Fine

Sand Coarse

Grout

Bentonite, Sand

Stainless Steel

Well Screen

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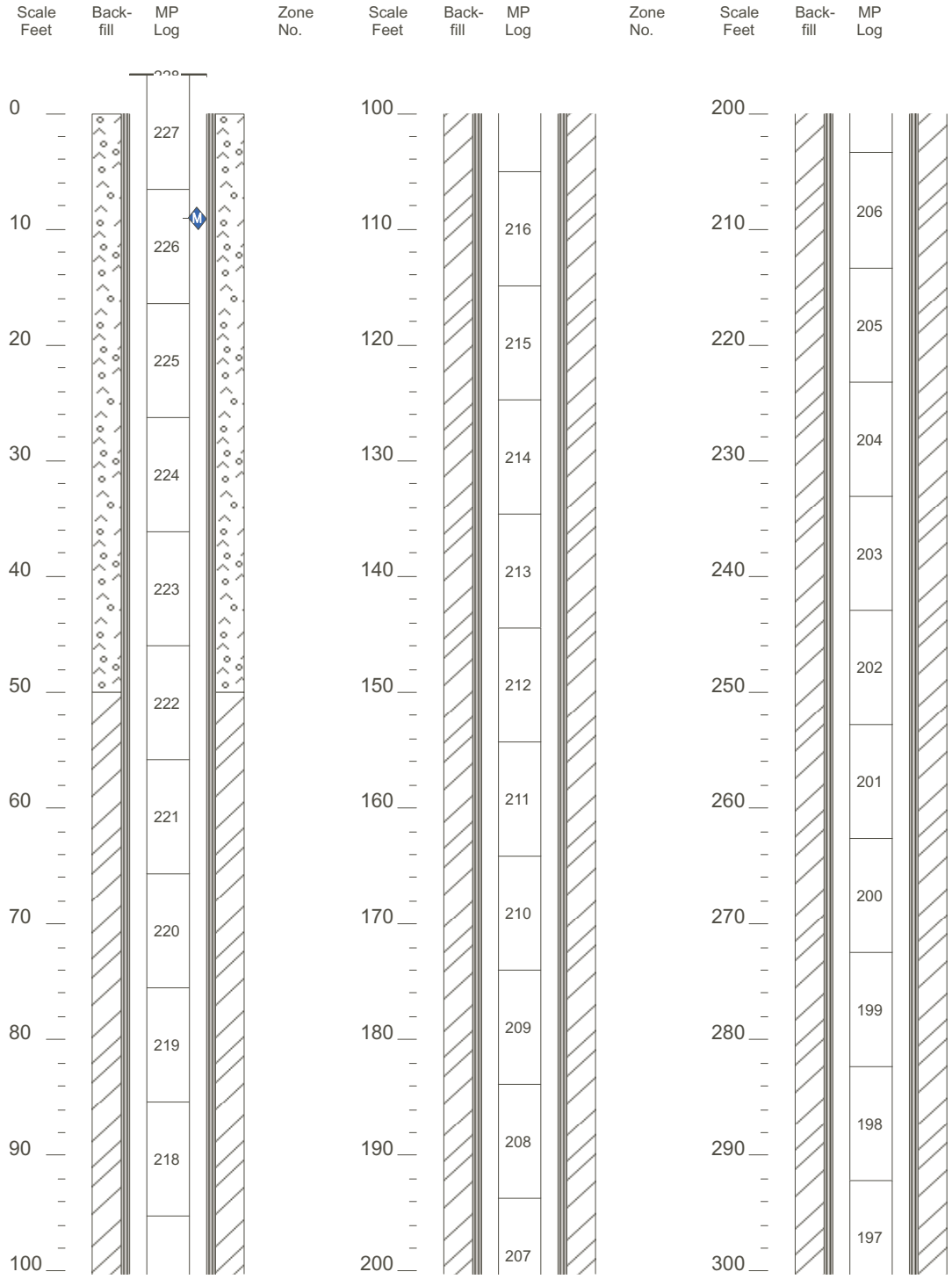
Summary MP Casing Log
LANL

Job No: WB777
Well: R19



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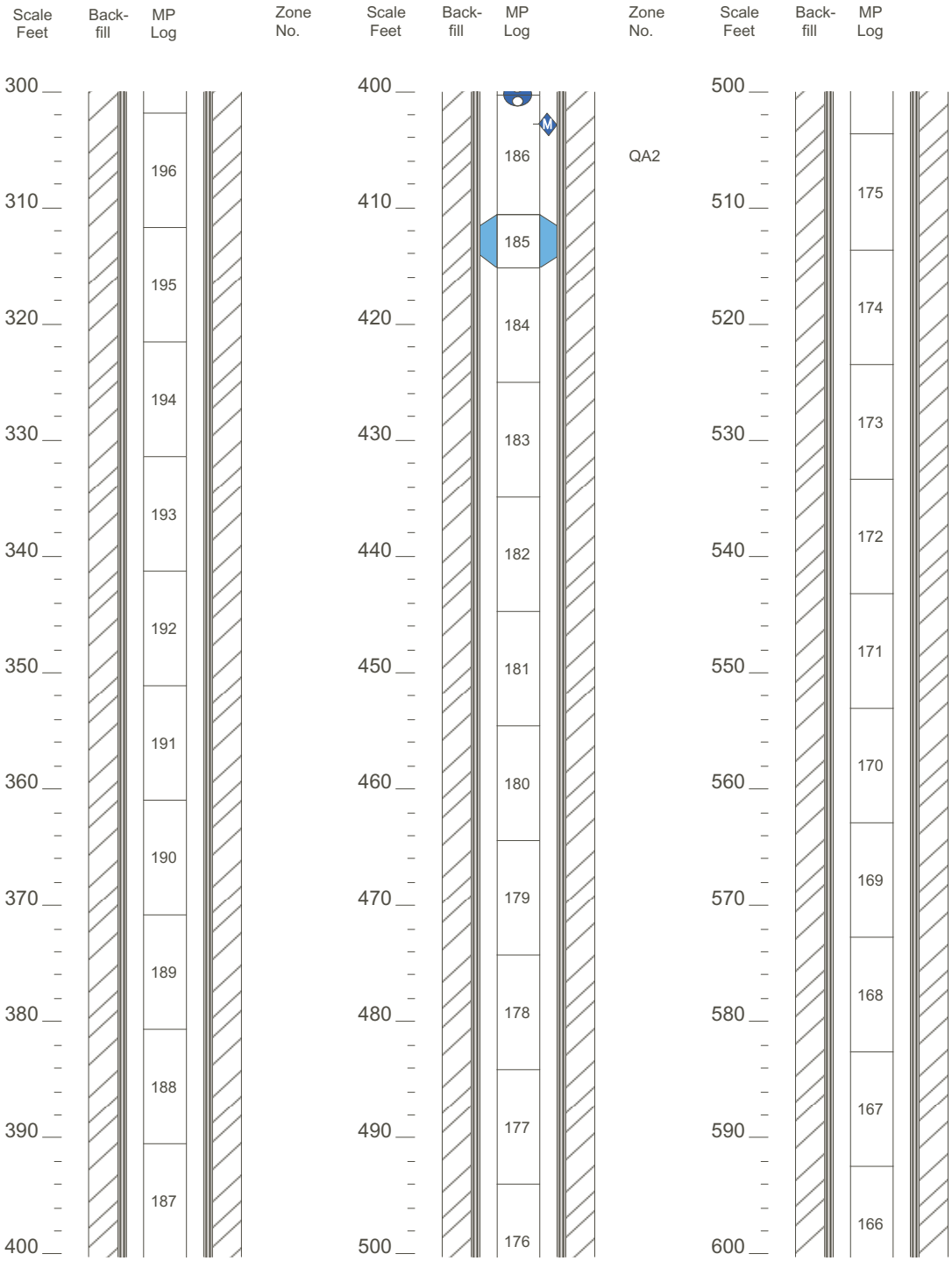
Summary MP Casing Log
LANL

Job No: WB777
Well: R19



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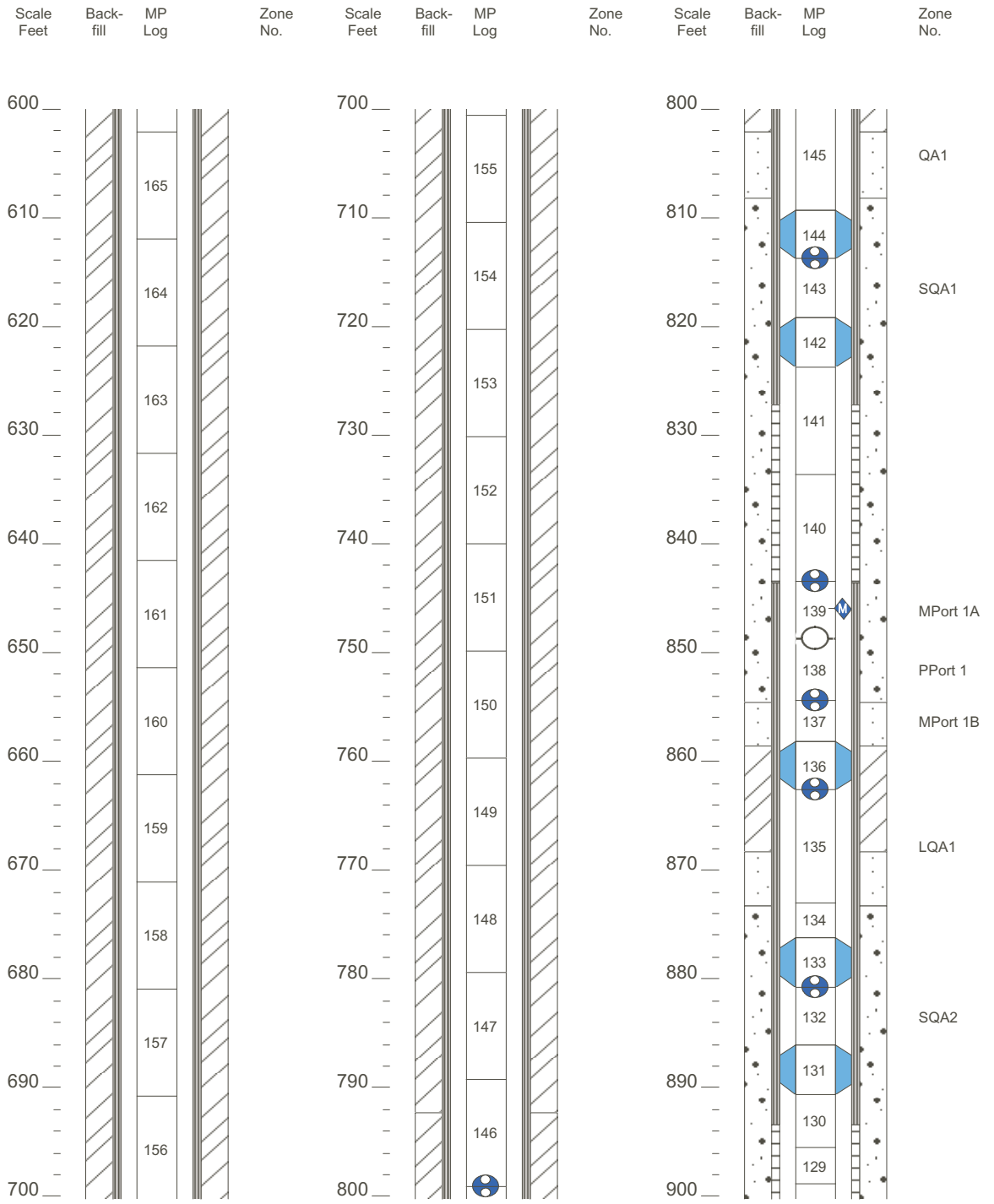
Summary MP Casing Log
LANL

Job No: WB777
Well: R19



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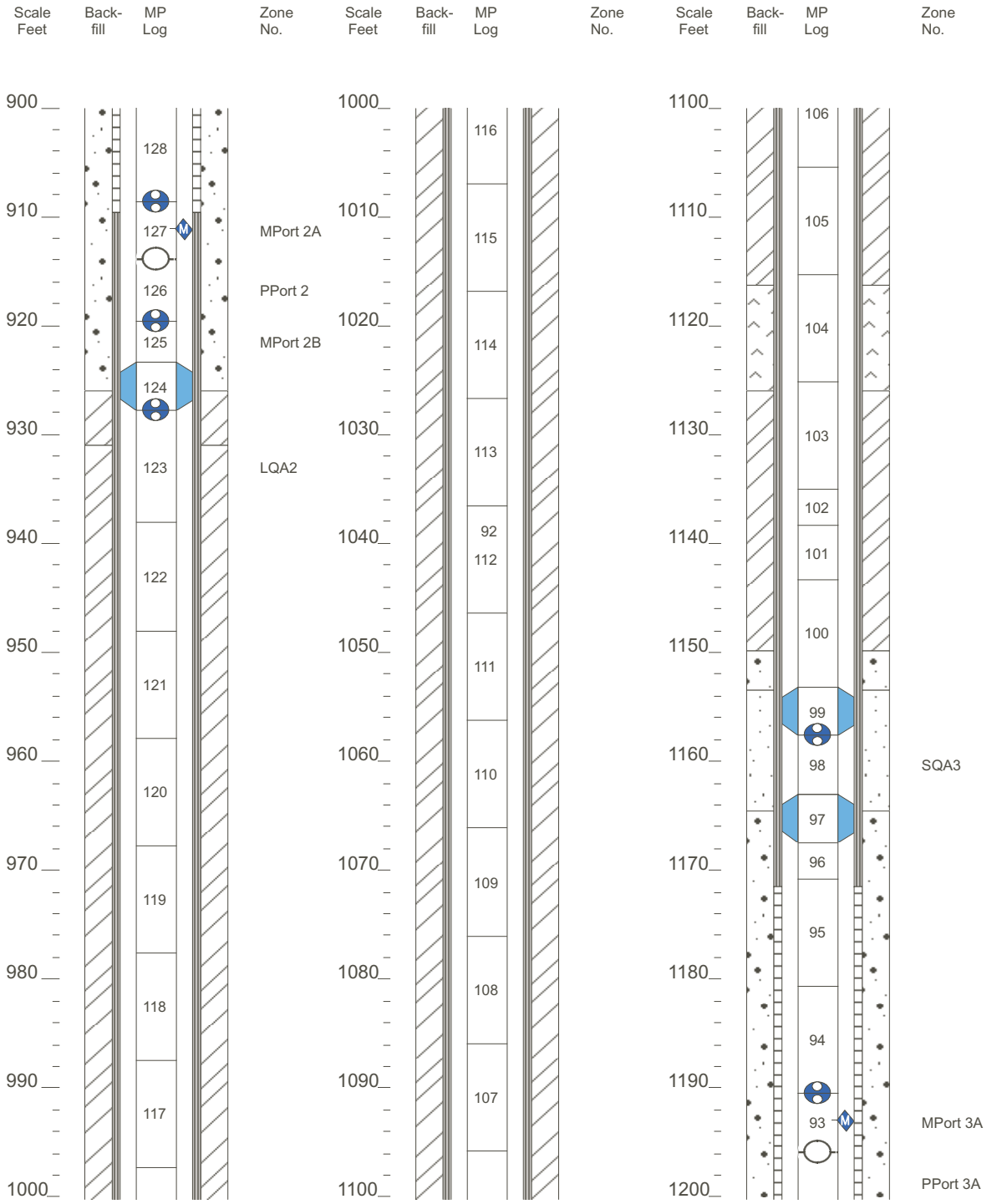
Summary MP Casing Log
LANL

Job No: WB777
Well: R19



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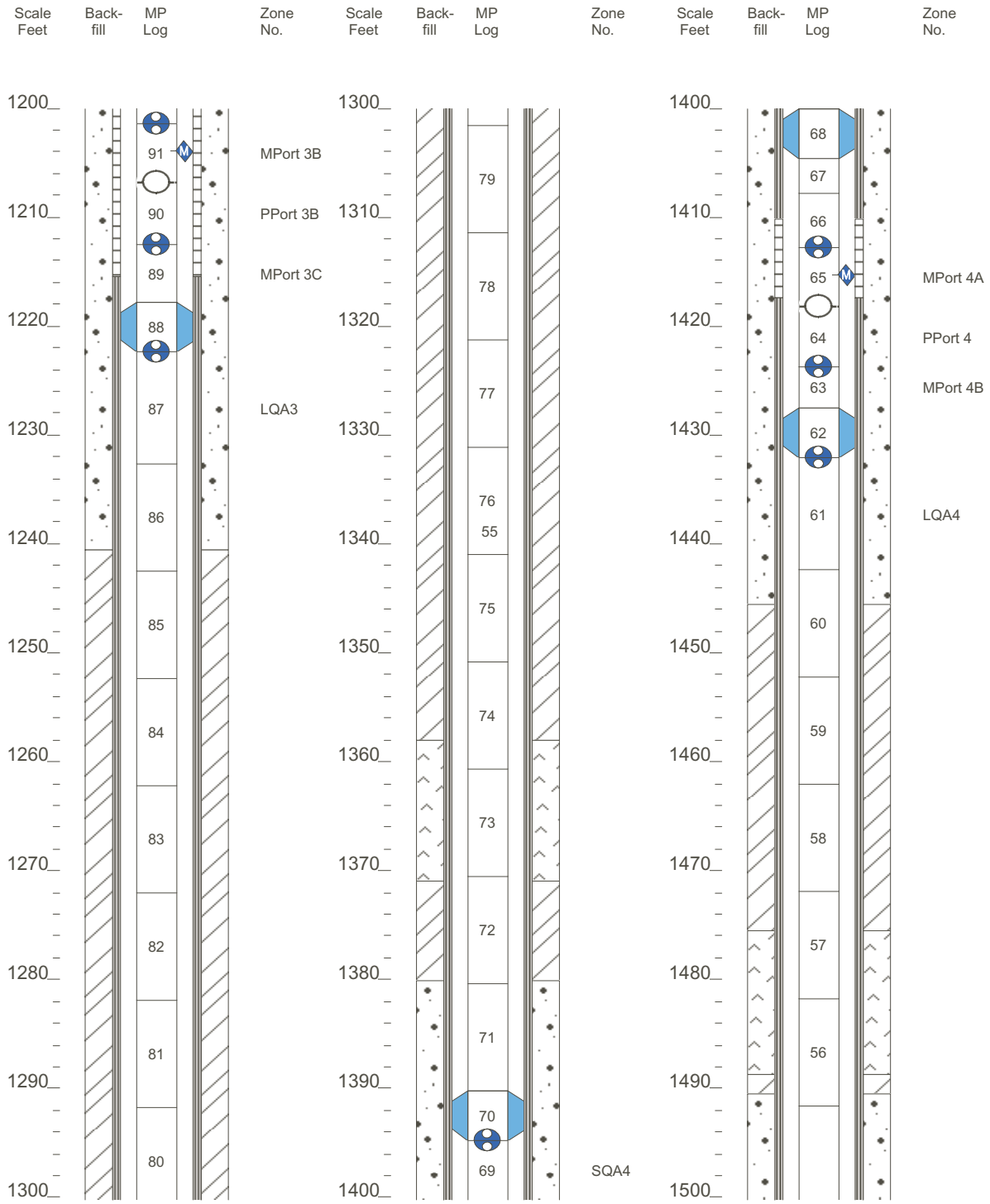
Summary MP Casing Log
LANL

Job No: WB777
Well: R19



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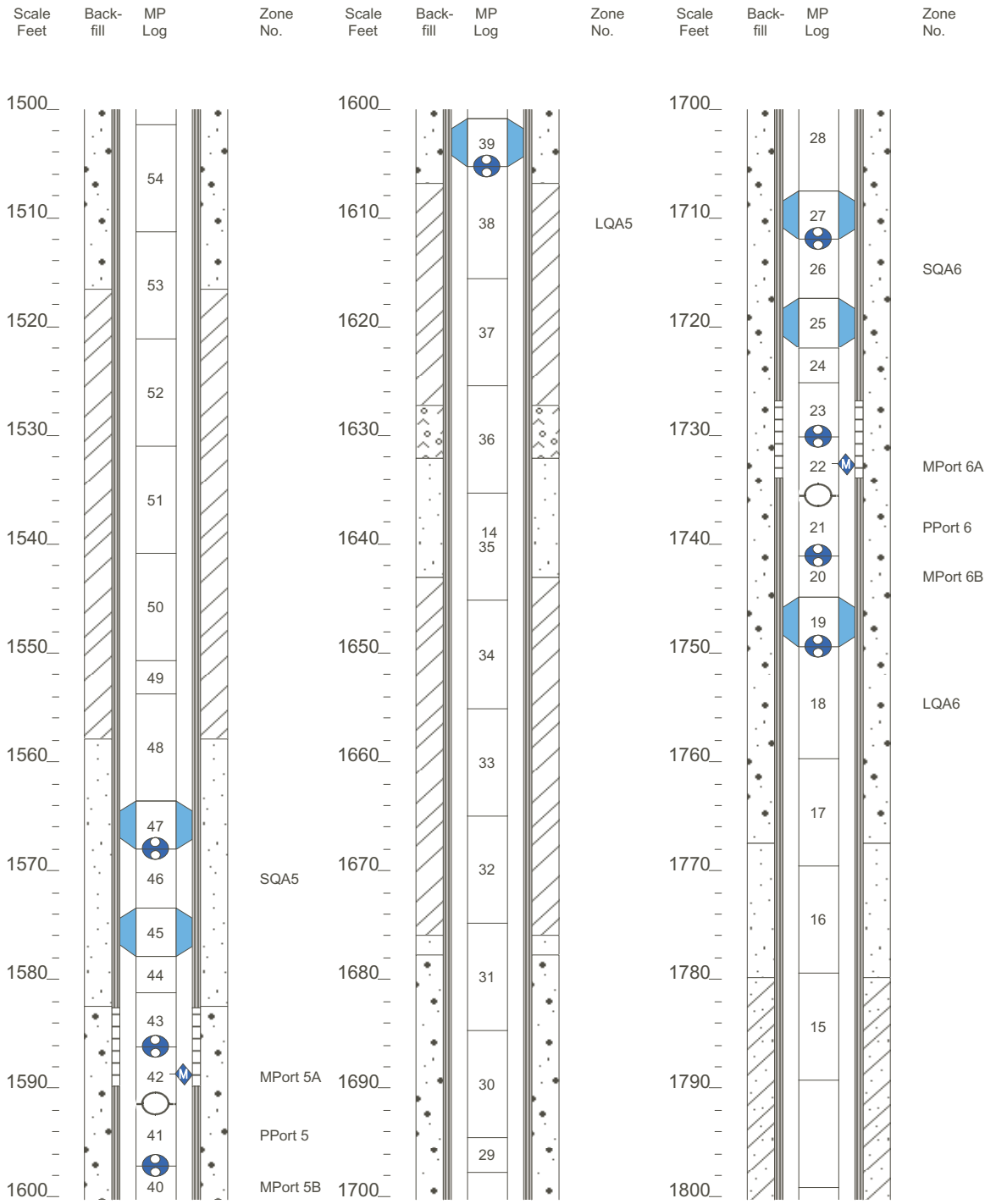
Summary MP Casing Log
LANL

Job No: WB777
Well: R19



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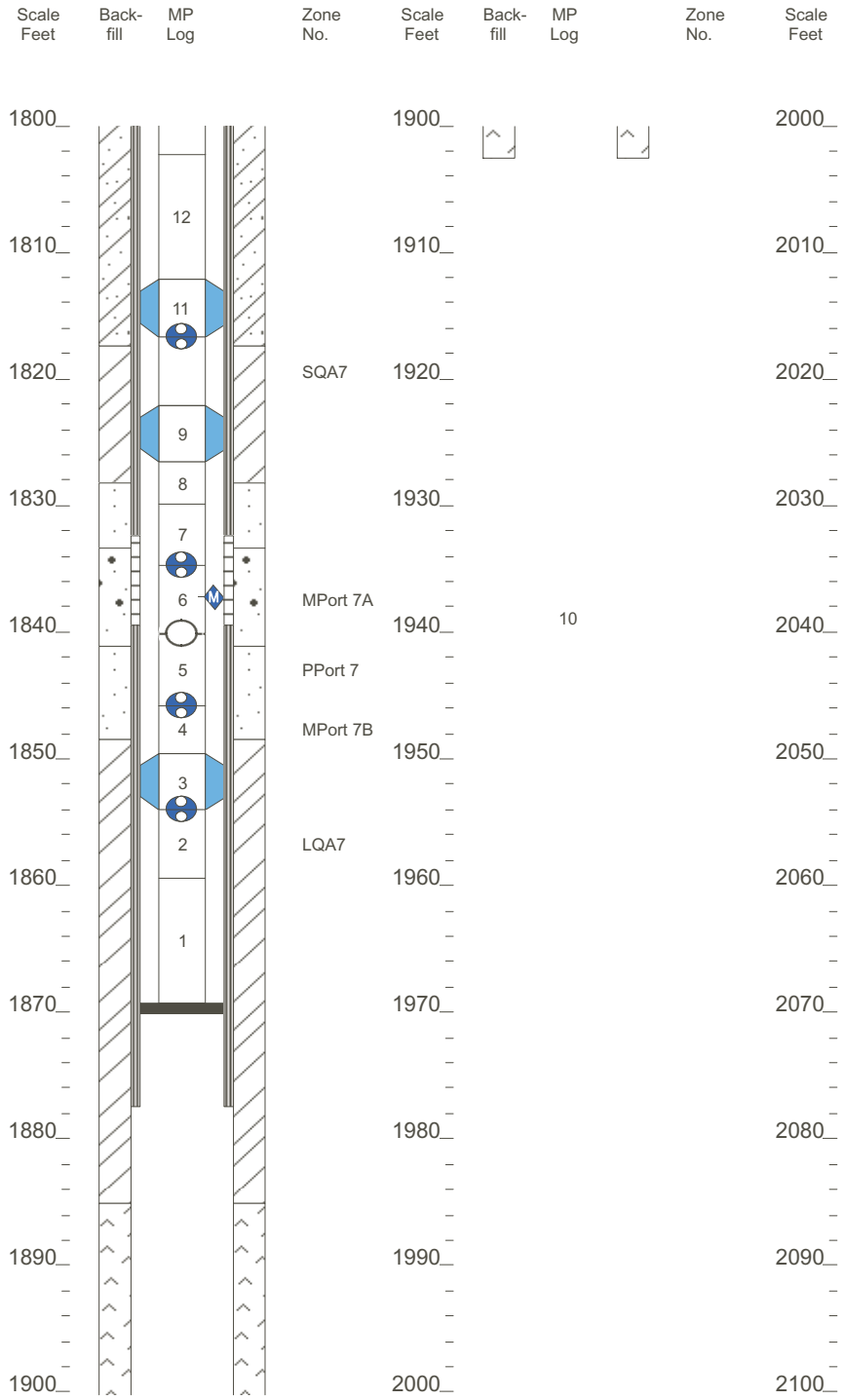
Summary MP Casing Log
LANL

Job No: WB777
Well: R19



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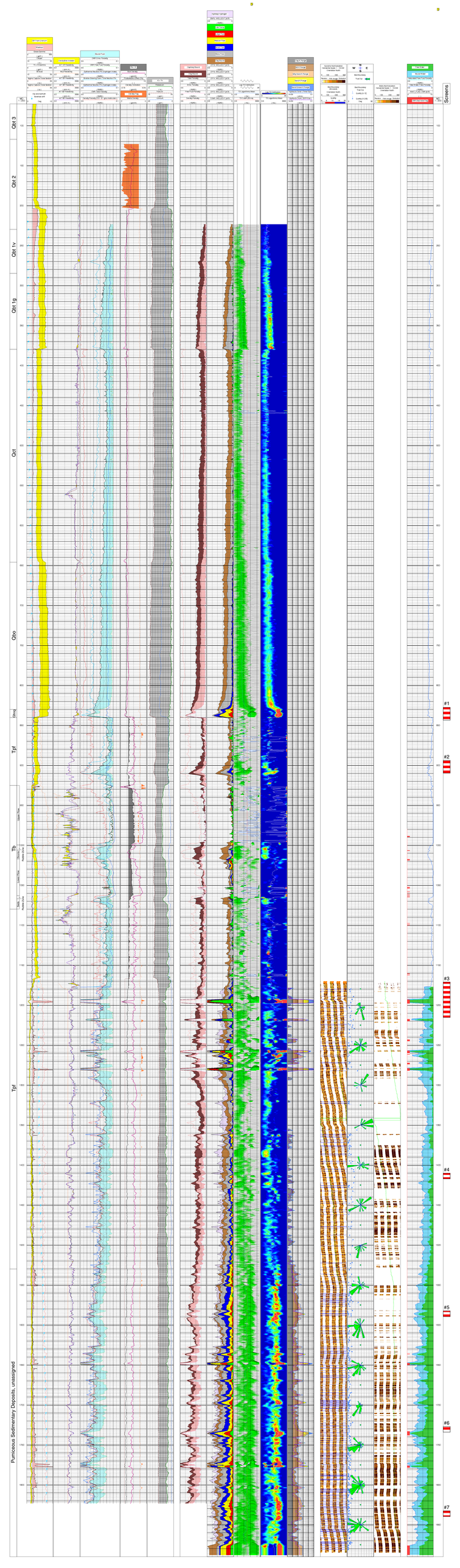
Qbt 3
Qbt 2
Qbt 1v
Qbt 1g
Qct
Qbo
Qbog
Tpf
Tb
Tpf
Pumiceous Sedimentary Deposits, unassigned
Screens
#1
#2
#3
#4
#5
#6
#7