Offsite

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory/University of California
Risk Reduction & Environmental Stewardship (RRES)
Groundwater Protection Program (GPP), MS M992
Los Alamos, New Mexico 87545
(505) 667-8285/FAX (505) 665-4747

JUN 2003

Date: June 13, 2003
Refer to: RRES-GPP-03-072

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

SUBJECT: **CHARACTERIZATION WELL R-16 COMPLETION REPORTS**

Dear Mat:

Enclosed are two copies of the Characterization Well R-16 Completion Report. This report documents work completed under the Hydrological Work Plan.

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

Sincerely,

Charles L. Nylander

Charles Nylander, Program Manager
Groundwater Protection Program

CN/th

Enclosure: Characterization Well R-16 Completion Report (ER2003-0198/GPP-03-031)

Cy (w/enc.):
D. Broxton, EES-6, MS T003
T. Herrera, RRES-WQH, MS M992
J. McCann, RRES-WQH, MS M992
C. Nylander, RRES-WQH, MS M992
S. Pearson, RRES-WQH, MS M992
N. Quintana, RRES-R, MS M992

4144

S. Rae, RRES-WQH, MS K497
B. Robinson, EES-6, MS T003
B. Enz, LASO, MS A316
T. Whitacre, LASO, MS A316
M. Leavitt, NMED-GWQB
C. Cooper, NMED-HWB
J. Keiling, NMED-HWB
V. Maranville, NMED-HWB
J. Young, NMED-HWB
J. Davis, NMED-SWQB
J. Parker, NMED-DOE OB
S. Yanicak, NMED-DOE OB, MS J993
RRES-GPP File, MS M992
IM-5, MS A150
RPF, MS M707 (ER2003-0416)

Offsite RR3DD

Remediation Program
RRES

LA-UR-03-1841
June 2003
ER2003-0198
GPP-03-031

Characterization Well R-16 Completion Report

Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

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

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List of Acronyms and Abbreviations

AITH	array induction tool, Model H
ASTM	American Society for Testing and Materials
bgs	below ground surface
CNTG	compensated neutron tool, model G
DOE	US Department of Energy
DR	dual rotation
ECS	elemental capture spectroscopy
EES	Earth and Environmental Science Group
ESH	Environmental, Safety and Health
FMI	formation microimager
FSF	Field Support Facility (part of the Risk Reduction and Environmental Stewardship Division)
GPS	global positioning system
GR	gamma radiation
hp	horsepower
HSA	hollow-stem auger
ICPES	inductively coupled plasma emission spectroscopy
ICPMS	inductively coupled plasma mass spectrometry

ID	inner diameter
LANL	Los Alamos National Laboratory
NAD 83	North American Datum, 1983
NGS	natural gamma spectroscopy
NMED	New Mexico Environmental Department
NTU	nephelometric turbidity unit
OD	outer diameter
PFD	phosphate-free dispersant
RC	reverse circulation
RRES	Risk Reduction and Environmental Stewardship Division
SAP	sampling and analysis plan
SSHASP	site-specific health and safety plan
TA	technical area
TD	total depth
TKN	total Kjeldahl nitrogen
TLD	Triple detector Litho-Density
UR-DTH	under-reaming down-the-hole
VOC	volatile organic compound
WCSF	waste characterization strategy form
XRD	x-ray diffraction
XRF	x-ray fluorescence

Metric to US Customary Unit Conversions

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

CHARACTERIZATION WELL R-16 COMPLETION REPORT

ABSTRACT

Characterization well R-16 was installed by Los Alamos National Laboratory (LANL or the Laboratory) under implementation of its hydrogeologic work plan. Well R-16 is located just south of Cañada del Buey near White Rock Overlook Park and immediately upstream from the sanitary sewage treatment plant. The primary purpose of this well is to provide water-quality, geochemical, hydrologic, and geologic information that would contribute to understanding the hydrogeologic setting beneath the Laboratory. In addition, this well was designed to monitor regional groundwater near potential contaminant release sites at Technical Area (TA)-54 and to act as a monitoring point between TA-54 and the Rio Grande.

In addition, hydrologic, geologic, geochemical, and geophysical information obtained during completion and subsequent sampling of R-16 will provide data for the Laboratory's hydrologic and geologic conceptual models and contribute to implementing a Laboratory-wide groundwater monitoring network. Monitoring of this network of wells supports the Laboratory's Groundwater Protection Management Program Plan.

The R-16 borehole was drilled to a total depth of 1287 ft using fluid-assisted air-rotary and conventional mud-rotary drilling methods. No core drilling was conducted at R-16. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analyses. Geologic strata encountered during drilling operations at R-16 included, in descending order, alluvial sediments, the Otowi Member of the Bandelier Tuff, basaltic sediments, Puye Formation lake deposits, Cerros del Rio lavas, more Puye lake deposits, older alluvium, more Cerros del Rio lavas, Totavi axial gravels interspersed with Puye fanglomerates, and sediments of the Santa Fe Group.

The zone of regional groundwater saturation was encountered at a depth of 642 ft below ground surface. Well installation was completed with four screened intervals installed within the regional aquifer. Although no groundwater samples were taken during drilling, water samples were collected during well development activities and following hydrologic testing. A Westbay™ multiport system for groundwater sampling was installed inside the well casing.

1.0 INTRODUCTION

This completion report for characterization well R-16 describes the site preparation, drilling, well construction, well development, hydrologic testing and related activities conducted from July 30 to December 4, 2002. Well R-16 is located on the south rim of Cañada del Buey, near White Rock Overlook Park, and immediately upstream from the sanitary sewage treatment plant (Figure 1.0-1). This well was installed as outlined in the "Hydrogeologic Workplan" (LANL 1998, 59599), in support of Los Alamos National Laboratory's (LANL or the Laboratory) "Groundwater Protection Management Program Plan" (LANL 1996, 70215).

Figure 1.0-1. Location map, characterization well R-16

Well R-16 was funded by the Nuclear Weapons Infrastructure, Facilities, and Construction Program and installed by the Laboratory's former Environmental Restoration Project, now part of the Risk Reduction and Environmental Stewardship (RRES) Division. Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for executing drilling activities.

Information presented in this report was compiled from field reports and activity summaries generated by the Laboratory and the drilling subcontractor. Geophysical data and geodetic survey information are also included. Data from R-16 and similar wells support the Laboratory's "Groundwater Protection Management Program Plan" (LANL 1996, 70215).

The primary purpose of this characterization well is to provide water-quality, geochemical, hydrologic, and geologic information that would contribute to understanding regional subsurface characteristics and distribution of contaminants downgradient of Laboratory releases from Technical Area (TA)–54 and from Laboratory activities in the Mortandad Canyon watershed. Additionally, data from R-16 will be used to update the sitewide hydrologic and geologic conceptual models for the Laboratory.

This report focuses on operational activities associated with drilling, sampling, and completing well R-16. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data, included as part of previous well completion reports, will be discussed in separate technical documents to be prepared by the Laboratory.

2.0 PRELIMINARY ACTIVITIES

WGII received contractual authorization to start administrative preparatory tasks on June 6, 2002. As part of these tasks, WGII prepared a modification to the existing site-specific health and safety plan (No. 271) to include well R-16. WGII also prepared the R-16 waste characterization strategy form (WCSF). The Laboratory prepared "Sampling and Analysis Plan (SAP) for the Drilling of Characterization Wells R-16, R-20, R-21, R-23, and R-32 in the Vicinity of TA-54" (LANL 2002, 73390) to guide field personnel in executing R-16 field activities. Appendix A of this completion report compares activities planned in the sampling and analysis plan (SAP) with the work performed. An agreement to provide access to R-16 on Los Alamos County land was approved on July 25, 2002, to accommodate sampling activities. This access agreement will terminate on December 31, 2017.

A readiness review meeting was held July 9, 2002, to discuss all administrative documents, permits, agreements, and plans pertaining to drilling and installing the R-16 drill pad. The Groundwater Investigations Focus Area project leader signed the readiness review checklist on July 29, 2002, giving authorization to begin work.

K. R. Swerdfeger Construction, Inc., was subcontracted by WGII to conduct site preparation activities, including clearing the site and removing vegetation, placing gravel on the access road, grading and compacting the drill pad, and constructing a lined cuttings-containment area. A temporary chainlink fence was also installed around the site for security. Site preparation was completed between July 30 and August 2, 2002.

The site initially was cleared of vegetation, and portions of the access road were graded and improved. Initial construction involved leveling the designated area with a grader and then compacting the subgrade. Base-course gravel was graded and compacted across the site to complete the drill pad. To store drilling fluids and cuttings, an 18-ft-wide by 85-ft-long by 12-ft-deep cuttings-containment area was excavated along the north end of the site. A 3-ft-high berm was constructed around the containment area, and the entire excavation was lined with a 4-mil polyethylene liner. A secondary fluids-containment area was

graded and lined with a 6-mil polyethylene liner to accommodate two 20,000-gal. tank trailers used for storing drilling fluids pumped from the cuttings-containment area. Safety barriers and signs were installed around the cuttings-containment area and other appropriate locations. Office and supply trailers, generators, and safety lighting equipment were also set up on the site.

3.0 SUMMARY OF DRILLING ACTIVITIES

Dynatec Drilling Company, Inc. (Dynatec), conducted R-16 drilling activities. Drilling operations involved drilling with reverse circulation (RC) air-rotary/fluid-assist to approximately 783 ft and then switching to conventional mud-rotary methods to the total depth (TD) of 1287ft. Coring was not performed at this site. Dynatec provided a Foremost™ dual rotary (DR)-24 drill rig, along with RC drilling rods, conventional mud-drilling equipment, and other support equipment. RRES Division's Field Support Facility (FSF) provided additional equipment and fabrication support for drilling activities.

Open-hole and casing-advance techniques were employed during air-rotary drilling, as determined by changing geologic and drilling conditions. Various additives were mixed with municipal water to improve borehole stability, minimize fluid loss, and facilitate removing cuttings from the borehole. RC air-rotary drilling was assisted with a foam mixture that consisted of municipal water mixed with soda ash, QUICK-GEL®, LIQUI-TROL™, and QUICK-FOAM®. The fluid mixture that was used during mud-rotary drilling typically consisted of municipal water mixed with QUICK-GEL® and LIQUI-TROL™. Magma-Fiber and N-seal were used in the mud mixture to help maintain or regain circulation within the borehole (Appendix B, in a CD attached to the back cover of this document). Table 3.0-1 summarizes quantities of additives and fluids used in the drilling of R-16.

Table 3.0-1
Fluid Additives Used, Characterization Well R-16

Additive	Amount	Unit of Measure
Interval Drilled (0–729 ft)		
Water	35,800	gal.
Quick-Gel®	20,000	lb
Liqui-Trol™	100	gal.
Foam	650	gal.
Soda ash	400	lb
Interval Drilled (729–1287 ft)		
Water	38,350	gal.
Quick-Gel®	31,100	lb
EZ-Mud®	25.5	gal.
Liqui-Trol™	5	gal.
Magma Fiber	800	lb
Pac-L	50	lb
N-Seal	800	lb
Soda ash	100	lb

Dynatec supplied the conventional mud drilling equipment, including a mixing tank and pump assembly, a generator to power the mixing unit, a de-sander unit for removing solids from the discharged drilling fluids, and a large auxiliary pump.

Drilling objectives were to collect groundwater samples for contaminant analysis, produce samples for geologic characterization, and provide a borehole for installation of the well in the regional aquifer. However, no perched water was detected during drilling. Also, because of the type of drilling performed, water samples could not be collected from the regional aquifer. The R-16 borehole was completed to a TD of 1287 ft below ground surface (bgs).

Sections 3.1 and 3.2 below discuss drilling activities. Figure 3.0-1 summarizes well data and depicts groundwater and geologic conditions encountered in well R-16. Figure 3.0-2 is a diagram of the chronology of drilling and other on-site activities.

Drilling Activities

The drill rig was mobilized to the R-16 site on August 16, 2002. Dynatec began drilling with a 16-in. tricone bit to 15 ft below ground surface (bgs), then reamed the borehole with a 22-in. quadcone drill bit. An 18-in. diameter steel conductor casing was then installed and landed at 15 ft bgs on August 17, 2002. Open-hole drilling continued with the 16-in. tricone bit from 15 ft bgs into the Otowi Member of the Bandelier Tuff. While drilling at 84 ft bgs, the driller noticed that the 18-in. conductor casing was subsiding. Dynatec added a 5-ft extension to the conductor casing and then reamed the casing down to 20 ft bgs, where it was landed and cemented in place. On August 18, 2002, open-hole drilling continued with the 16-in. tricone bit from 84 ft bgs. Over the next several days, the borehole was advanced down to the top of the Santa Fe Group sediments at 728 ft bgs on August 21, 2002.

Dynatec then tripped out the drill stem to install surface casing to stabilize the open portion of the borehole before drilling into the regional saturated zone. While tripping out the down-hole tools, the drillers encountered obstructions at various depths in the borehole, indicating collapse and/or swelling of formations with high clay content. After the tools were tripped out, a bridge in the open borehole was measured at 117 ft bgs. From August 21 through August 24, 2002, Dynatec made two unsuccessful attempts to ream out the borehole. After each attempt, bridges were measured at 130 and 107 ft bgs, respectively. An attempt to video log on August 22, 2002, showed bridging at 117 ft bgs. To alleviate the unstable borehole conditions, the decision was made to advance 11.75-in. diameter drill casing the entire bored interval. Dynatec reamed the borehole with a 12.5-in. under-reaming down-the-hole (UR-DTH) hammer bit and landed the 11.75-in. drill casing at 729 ft bgs on August 26, 2002.

Open-hole drilling continued on August 27, 2002, using a 10.625-in. tricone bit from 728 to 867 ft bgs, where drilling was temporarily stopped to monitor the depth to groundwater. A static water level was measured at 621 ft bgs. After switching over to conventional mud-rotary drilling, the borehole was advanced to a total depth (TD) of 1287 ft bgs on August 29, 2002. Drilling operations at R-16 were completed on August 30, 2002. The rig was demobilized on September 8 and 9, 2002.

4.0 SAMPLING AND ANALYSIS OF DRILL CUTTINGS AND GROUNDWATER

Drill cuttings were collected at 5-ft intervals as specified in the R-16, R-20, R-23, R-32 SAP (LANL 2002, 73390). A portion of the cuttings was sieved (at >#10 and >#35 mesh) and placed in chip tray bins along with an unsieved portion. These samples were used to prepare lithologic logs (Appendix C). The remaining cuttings were placed in ziplock bags and set in core boxes for curation. Before curation, 16 sample splits were removed for use in mineralogy, petrography, and geochemical analyses.

Location: West of the waste treatment ponds, north of Overlook Road in White Rock, N.M.

Survey coordinates (brass marker in NW corner of R-16 cement pad):
x: 1659284 E y: 1756711 N (NAD 83)
z: 6256.9 ft asl (NGVD 29)

Drilling: Conventional mud drilling, casing advance.
R-16 Start date: 08/16/02.
R-16 End date: 08/29/02.

Borehole R-16 drilled to 1287 ft. bgs. (T.D.).

Data collection:
- Hydrologic properties: Field hydraulic test: Constant Rate Injection Test on screen #2, screen #3, and screen #4
- Cores/cuttings submitted for geochemical and contaminant characterization: (0)
- Groundwater samples submitted for geochem and contaminant characterization: (3)
- Geologic properties: (16) Mineralogy, petrography, and chemistry
- Borehole logs from R-16:
  - Lithologic: 0-867 ft. and 1047 ft.-1287 ft.
  - Natural gamma (LANL tool): 0-729 ft. (cased), 729-1287 ft. (open hole).
  - Schlumberger Logs: 0-729 ft. (cased), 729-1287 ft. (open hole): Array Induction, Combinable Magnetic Resonance, Micro Imager, Sonic Caliper, Litho density, Spectral Gamma, Elemental Capture, Thermal/Epithermal Neutron, Natural Gamma.

Contaminants Detected in R-16 Water Samples: none.

Well construction:
- Drilling Completed: 08/29/02
- Contract Geophysics: 08/30/02 - 08/31/02
- Well Constructed: 08/31/02 - 09/07/02
- Well Developed: 09/14/02 - 12/04/02
- Westbay Installed: 12/6/02 - 12/10/02

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

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

Screen (perforated pipe interval):
- Screen #1 - 641.0 - 648.6 ft. bgs. (isolated behind stuck casing)
- Screen #2 - 863.4 - 870.9 ft. bgs.
- Screen #3 - 1014.8 - 1022.4 ft. bgs.
- Screen #4 - 1237.0 - 1244.6 ft. bgs.

Well development consisted of wire brushing, bailing, chemical treatments, surging, simultaneous jetting and pumping, and pumping.

Groundwater occurrence was determined for R-16 by recognition of first water produced while drilling, by borehole geophysics, and by borehole video. Static water levels were determined after the R-16 borehole was rested.

Groundwater samples collected from packed off screen intervals after well development.

Geologic contacts for R-16 were determined by examination of cuttings and interpretation of geophysical logs. Contacts may be refined by petrographic, geochemical, or mineralogic analysis of geologic samples.

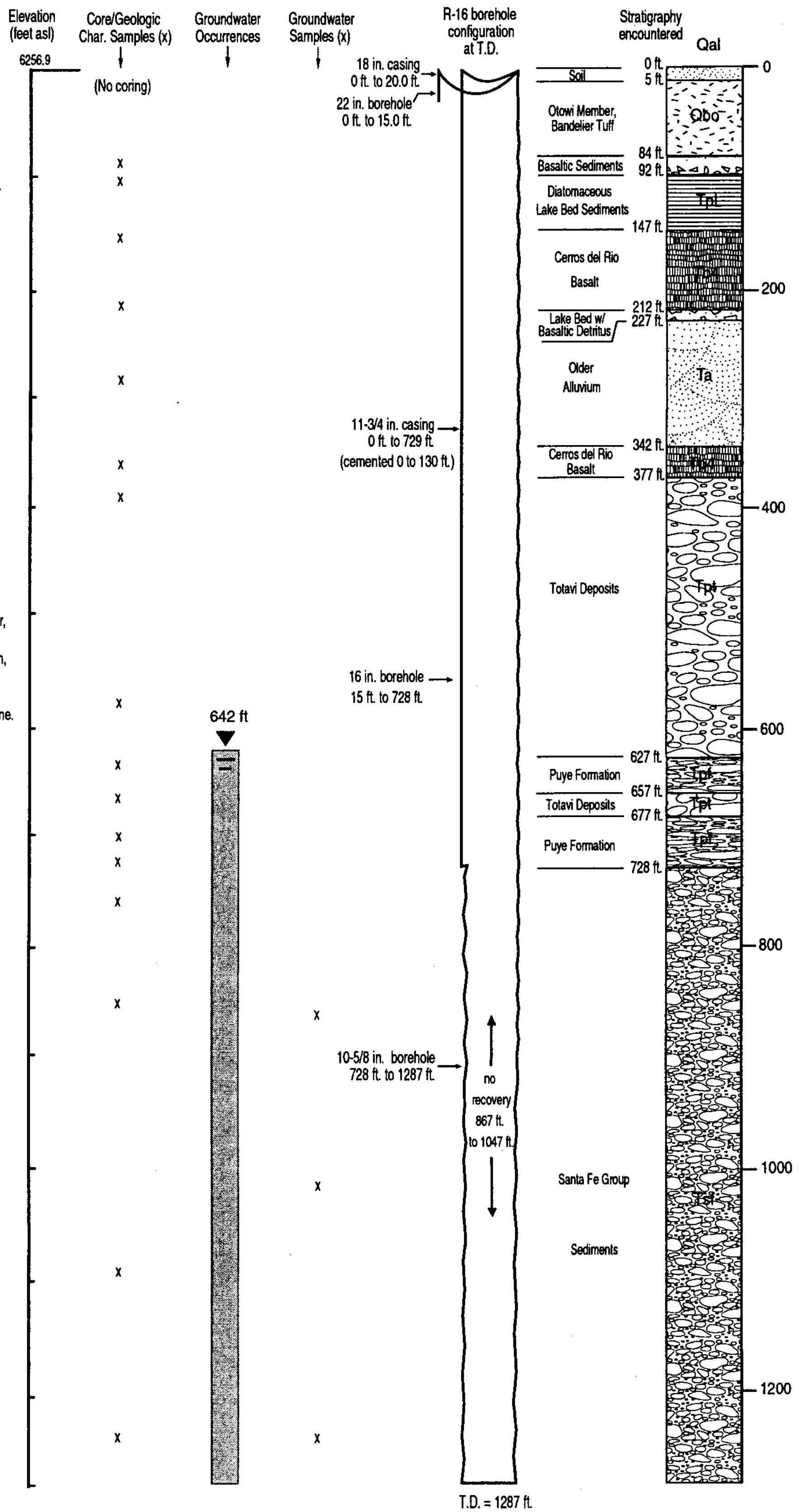


Figure 3.0-1. Well summary data sheet, characterization well R-16

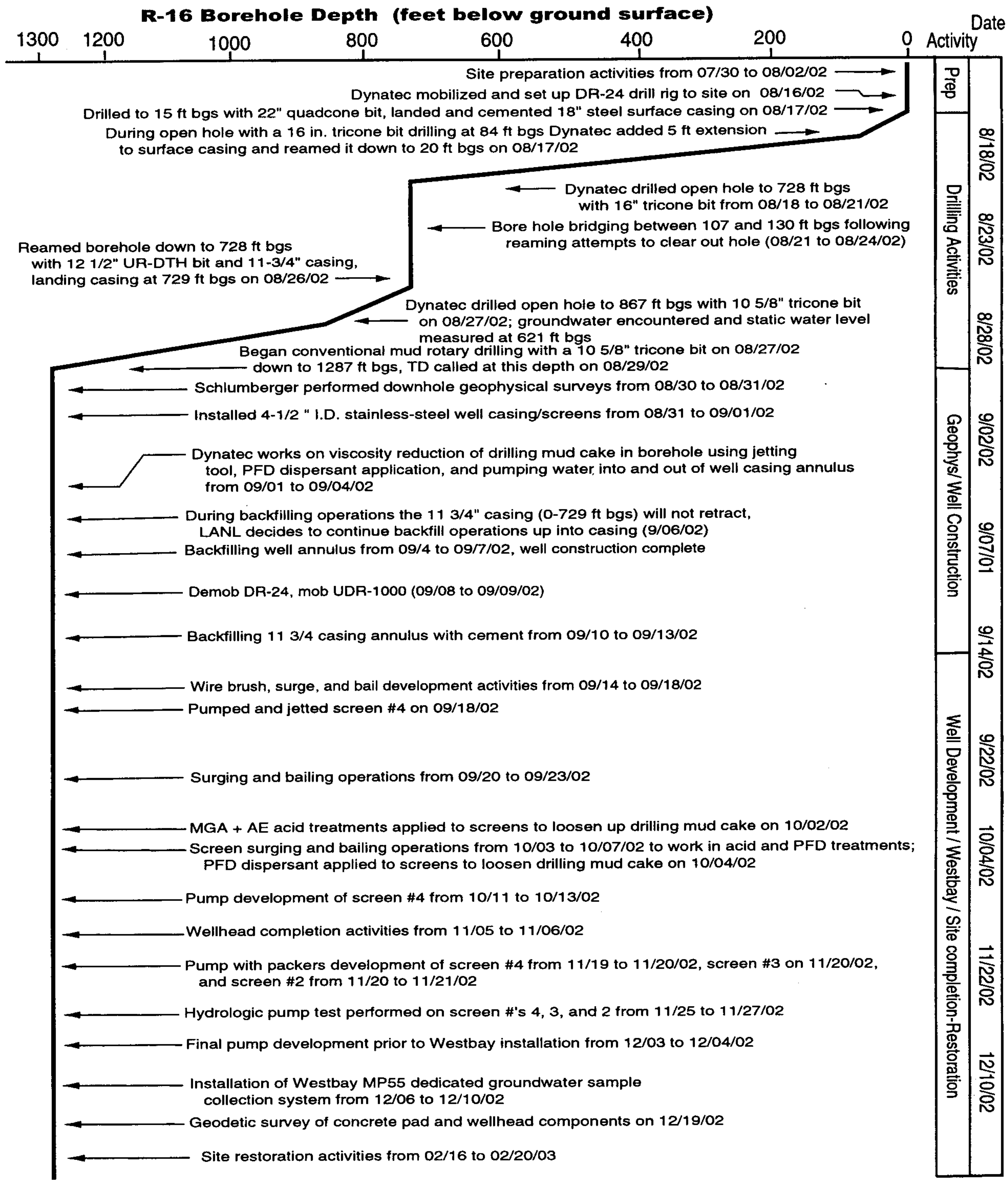


Figure 3.0-2. Operations chronology diagram, characterization well R-16

Groundwater samples were not collected from the open borehole during drilling due to the adverse impact of drilling mud and additives to the groundwater chemistry. However, three samples were collected from screened intervals at 863.4 to 870.9 ft bgs, 1014.8 to 1022.4 ft bgs, and 1237.0 to 1244.6 ft bgs in the regional aquifer after well development. The results are reported below.

Geochemistry of Sampled Waters

Groundwater samples were analyzed to investigate the presence of constituents from laboratory releases. Major potential contaminants of concern at R-16 include perchlorate, nitrate, and tritium.

Groundwater samples were collected using a packer/pump assembly that straddled each screen interval and analyzed for inorganic, organic, and radionuclide constituents. Water was collected and filtered for metal, trace-element, major-cation and major anion analysis. Nonfiltered water was collected for stable isotope, organics, tritium, and radiochemical analysis. Filtered samples were passed through a 0.45-μm Gelman cartridge filter. Samples were acidified as needed with the appropriate analytical-grade acid to a pH of 2.0 or less for metal, major cation, and volatile organic compound (VOC) analyses. All groundwater samples collected in the field were stored at 4°C until they were analyzed.

Groundwater samples were analyzed by laboratories under contract to the Laboratory under the University of California Los Alamos National Laboratory statement of work for analytical laboratories and at the Laboratory's Earth and Environmental Science (EES)-6 laboratory LANL 2000, 71233), using techniques specified in the US Environmental Protection Agency SW-846 manual (available at http://clu-in.org/char1.cfm). Ion chromatography was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used for aluminum, arsenic, barium, chromium, cobalt, copper, iron, manganese, nickel, selenium, silver, calcium, magnesium, potassium, silica, sodium, and zinc. Antimony, beryllium, cadmium, lead, thallium, vanadium, and uranium were analyzed by inductively coupled (argon) plasma mass spectrometry (ICPMS). Tritium activity in a groundwater sample was determined by electrolytic enrichment at the University of Miami. Americium-241 was analyzed according to (HASL)-300; cesium-137 by generic gamma spectroscopy; plutonium-238 and plutonium-239 by isotopic plutonium (HASL-300); strontium-90 by beta counting; and uranium-234, uranium-235, and uranium–238 by isotopic uranium (HASL-300). Delta deuterium and oxygen 18/16 ratios were determined at Geochron Laboratory. VOC analysis was performed by gas chromatography mass spectroscopy. The precision limits (analytical error) for major ions and trace elements generally were less than ±10% using ICPES and ICPMS.

Table 4.1-1 provides results of screening analyses for regional groundwater samples collected from the Santa Fe Group in well R-16. Based on analytical results for three samples, contamination from Laboratory discharges does not appear to be present in the regional aquifer at this well site.

5.0 BOREHOLE GEOPHYSICS

Using Laboratory tools and Schlumberger geophysical logging services (Schlumberger), WGII performed borehole-logging operations at R-16. Table 5.0-1 lists borehole and well logging surveys performed.

Table 4.1-1
Hydrochemistry of Regional Aquifer Samples at R-16

Analysis/Analyte (location/unit of measure)	863.4–870.9 (ft bgs) 11/21/02	1014.8-1022.4 (ft bgs) 11/20/02	1237.0–1244.6 (ft bgs) 11/19/02
Inorganics (EES-6 laboratory)			
Alkalinity (field; mg $CaCO_3$/L)	71	81	72
Conductivity (field; μS/cm)	170	194	179
pH (field)	8.03	7.82	7.98
Temperature (field; °C)	24.3	24.6	23.5
Turbidity (field; NTU)	1.32	0.87	0.9
Al (mg/L)	0.002	0.002	0.002
Sb (mg/L)	[0.0001], U	0.0001	[0.0001], U
As (mg/L)	0.0024	0.0028	0.0026
Ba (mg/L)	0.013	0.018	0.015
Be (mg/L)	[0.001], U	[0.001], U	[0.001], U
B (mg/L)	0.012	0.011	0.011
Br (mg/L)	0.03	0.02	0.04
Cd (mg/L)	[0.001], U	[0.001], U	[0.001], U
Ca (mg/L)	19.1	23.3	20.4
Cl (mg/L)	2.57	2.56	2.57
ClO_4 (mg/L)	[0.002], U	[0.002], U	[0.002], U
ClO_3 (mg/L)	[0.02], U	[0.02], U	[0.02], U
Cr (mg/L)	0.0036	0.0034	0.0040
Co (mg/L)	[0.001], U	[0.001], U	0.0015
Cu (mg/L)	0.0038	[0.001], U	0.0015
F (mg/L)	0.33	0.29	0.28
Fe (mg/L)	0.01	0.01	0.02
Pb (mg/L)	0.0004	0.0001	0.0002
Mg (mg/L)	1.76	2.04	1.92
Mn (mg/L)	0.0019	0.0022	0.0056
Mo (mg/L)	0.0012	0.0012	0.0013
Ni (mg/L)	[0.001], U	[0.001], U	[0.001], U
NO_3 (mg/L; as N)	1.02	0.53	1.02
NO_2 (mg/L; as N)	[0.01], U	[0.01], U	[0.01], U
C_2O_4 (mg/L) (oxalate)	[0.02], U	[0.02], U	[0.02], U
P (mg/L)	[0.006], U	0.075	0.007
K (mg/L)	2.55	3.13	2.48
Se (mg/L)	[0.001], U	[0.001], U	[0.001], U
Ag (mg/L)	0.0004	[0.0001], U	[0.0001], U
Na (mg/L)	13.5	15.4	15.7

Table 4.1-1 (continued)

Analysis/Analyte (location/unit of measure)	863.4–870.9 (ft bgs) 11/21/02	1014.8-1022.4 (ft bgs) 11/20/02	1237.0–1244.6 (ft bgs) 11/19/02
Inorganics (EES-6 laboratory) (continued)			
SiO_2 (mg/L)	56.3	53.3	54.8
SO_4 (mg/L)	4.09	4.13	4.10
Tl (mg/L)	[0.001], U	[0.001], U	[0.001], U
U (mg/L)	0.0010	0.0020	0.0013
V (mg/L)	0.014	0.014	0.014
Zn (mg/L)	0.063	0.25	0.52
δD (permil; Geochron Lab))	-75	-75	-78
D18O (permil; Geochron Lab)	-10.8	-10.8	-10.8
Organics (contract laboratory; additional VOC results were below detection)			
Toluene (mg/L)	BDL	0.002	0.022
Radiochemistry (contract laboratory)			
Am^{241} (pCi/L) (nonfiltered)	[-3.34], U	[5.37], U	[-6.96], U
Cs^{137} (pCi/L) (nonfiltered)	[0.296], U	[-0.524], U	[0.759], U
Gross alpha/beta (pCi/L) (nonfiltered)	[0.519], U	[0.325], U	[0.461], U
Gross beta (pCi/L) (nonfiltered)	[2.42], U	[3.95], U	[2.56], U
Gross gamma (pCi/L) (nonfiltered)	[40.9], U	[70.9], U	[147], U
Pu^{238} (pCi/L) (nonfiltered)	[0.0023], U	[0], U	[0.0062], U
Pu^{239} (pCi/L) (nonfiltered)	[0.0023], U	[0.002], U	[-0.0041}
Sr^{90} (pCi/L) (nonfiltered)	[0.010], U	[0.093], U	[0.048], U
Tritium (pCi/L) (nonfiltered)	[-0.22], U	[0.22], U	[0.48], U
U^{234} (pCi/L) (nonfiltered)	0.719	1.16	0.669
U^{235} (pCi/L) (nonfiltered)	[0.023], U	0.061	[0.026], U
U^{238} (pCi/L) (nonfiltered)	0.391	0.707	0.428

Notes: All samples collected from Santa Fe Group.
BDL = below detection limits.
U = not detected.
J = Analyte is classified as "detected" but reported concentration value is expected to be more uncertain than usual.

Table 5.0-1
Borehole and Well Logging Surveys, Characterization Well R-16

Surveyor	Date	Method	Cased Interval (ft bgs)	Open-Hole Interval (ft bgs)	Remarks
WGII/LANL	August 22, 2002	Video	0–20	20–729 (728)	Conducted to observe borehole conditions; bridging at 117 ft prevented logging to TD
Schlumberger	August 30 to 31, 2002	Logging suite[a]	0–729	729–1287	Schlumberger conducted logging in borehole prior to well design and construction
WGII/LANL	August 31, 2002	Natural gamma	0–729	729–1287	LANL conducted logging in borehole prior to well design and construction
WGII/LANL	November. 13, 2002	Video	0–1276.7	NA[b]	Conducted to document and verify interior well condition prior to Westbay™ installation

[a] Schlumberger's suite of borehole logging surveys included array induction, lithodensity, spectral gamma, elemental capture, compensated neutron, formation microimager, magnetic resonance, caliper, and natural gamma.
[b] NA = Not applicable.

5.1 Geophysical Logging Using LANL Tools

On August 31, 2002, a natural gamma log was run in borehole R-16 using a down-hole tool provided by the Laboratory. The gamma log was run to provide lithologic and stratigraphic information that complement data gathered from cuttings. Natural gamma logs have proven successful in discriminating between geologic units containing varying concentrations of uranium, thorium, and potassium. The gamma log was run prior to well construction inside the 18-in. surface casing from the surface to 20 ft bgs, in the 11.75-in. conductor casing to 729 ft bgs, and in open-hole conditions from 729 to 1287 ft bgs. Measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised upward in the hole at a rate of about 15 ft/min.

One open-hole video was run to inspect borehole conditions and slough/bridging problems. Another video was run to view the interior of the installed well as a quality control procedure to inspect the condition of casing and screens after well development but before installation of the Westbay™ system. The Laboratory open borehole video logs are in Appendix D (on CD attached to the inside back cover of this report).

5.2 Schlumberger Geophysical Logging

Schlumberger conducted borehole geophysical logging activity from August 30 through 31, 2002, in the R-16 borehole. Prior to well construction, a suite of logging surveys was performed inside the 18-in. surface casing from the surface to 20 ft bgs, in the 11.75-in. conductor casing to 729 ft bgs, and in open-hole conditions from 729 to 1287 ft bgs.

The primary purpose of the Schlumberger logging was to characterize hydrogeologic conditions in the units penetrated by the R-16 borehole, with an emphasis on determining moisture distribution in the regional saturated zones, measuring flow capacity, and obtaining lithologic/stratigraphic data. Secondary

objectives included evaluating borehole geometry and assessing the degree of drilling-fluid invasion into the borehole walls.

The Schlumberger suite of geophysical logging tools included the following:

- Array Induction Tool, Version H (AITH™) measures formation electrical resistivity and borehole fluid resistivity, evaluates drilling fluid invasion into the formation, and assesses the presence of moist zones far from the borehole wall and the presence of clay-rich zones.
- Fullbore Formation Micro Imager (FMI™) measures electrical conductivity images of the borehole wall and the borehole diameter with a two-axis caliper, thus evaluating geologic bedding and fracturing, including strike-and-dip of these features, fracture apertures, and rock textures.
- Sonic Delta T Borehole Caliper measures acoustic impedance of sonic wave propagation by the surrounding borehole, thus evaluating variations in borehole dimensions and identifying fractures.
- Triple detector Litho-Density (TLD™) measures total porosity and bulk density of a formation, photoelectric effects, and borehole diameter and characterizes lithology.
- Natural Gamma Spectroscopy (NGS™) measures gross natural and spectral gamma-ray activity (including potassium, thorium, and uranium concentrations) in open- and cased-hole conditions to help characterize geology and lithology, in particular the amount of clay present.
- Elemental Capture Sonde (ECS™) measures elemental weight concentrations of a variety of elements (iron, sulphur, silicon, calcium, thallium, gadolinium, chlorine, and hydrogen) to characterize formation mineralogy and lithology and determine water content.
- Compensated (thermal-epithermal) Neutron Tool, Model G (CNTG™) measures volumetric water content outside the casing to evaluate formation moisture content and porosity.

In addition, a calibrated natural gamma tool was used to record gross natural gamma-ray activity with every logging method (except NGS™) to correlate depth runs between each survey.

The Schlumberger logging summary report for borehole R-16 and the geophysical logs for all Schlumberger methods, compiled as a montage, are in Appendix E (on CD attached to the back inside cover of this report).

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered in borehole R-16 is presented below, including a description of the geologic units identified during cuttings characterization. Groundwater occurrence is discussed and evaluated by drilling evidence and geophysical data.

6.1 Stratigraphy and Lithologic Logging

Lithologic descriptions are based on cuttings samples collected from the R-16 borehole from ground surface to a TD of 1287 ft. The samples were collected at 5-ft intervals and prepared by washing and sieving. Because circulation was lost while drilling, no cuttings were recovered from 867 to 1047 ft (within the Santa Fe Group). Sieved samples were examined microscopically to complete the field lithologic log that is presented as Appendix C. A generalized stratigraphic column is shown in the well data summary sheet for R-16 (Figure 3.0-1).

Rock units and stratigraphic relationships, interpreted primarily from data collected during visual examination of drill cuttings samples, are discussed in order of younger-to-older occurrences. Such interpretations may be refined upon future detailed analysis of petrographic, geochemical, mineralogical, and geophysical data.

Alluvium (0 to 5 ft bgs)

Unconsolidated tuffaceous sands and gravels derived from the Bandelier Tuff were noted in the interval from 0 to 5 ft bgs. These sediments represent soil and alluvium on the canyon rim south of Cañada del Buey.

Otowi Member of the Bandelier Tuff (5 to 84 ft bgs)

The Quaternary-age Otowi Member of the Bandelier Tuff was intersected in the R-16 borehole from 5 to 84 ft bgs. Drill cuttings indicate that this unit is composed of vitric pumice, quartz and sanidine crystals, and abundant volcanic xenoliths. Little of the ash matrix is preserved in chip samples, indicating the poorly welded to nonwelded nature of this rhyolitic ash-flow unit. Pumice fragments are generally glassy with a fibrous structure and commonly are stained with iron oxides. Coarse chip samples are frequently 40% to 60% by volume dacite and basalt lithics. Cuttings and geophysical logs leave some uncertainty as to whether the Guaje Pumice Bed of the Otowi Member is present.

Basaltic Sediments (84 to 92 ft bgs)

Basalt-rich volcaniclastic gravels and sands were encountered from 84 to 92 ft bgs. This sedimentary interval has not been assigned to any unit in the stratigraphic section in the vicinity of R-16. Up to 50% of the cuttings in this interval contain chips of vesicular and massive basalt that probably derive from Cerros del Rio basalt sources. Other sample components include clasts of dacite, silicified dacite, black vitrophyre, and clay nodules.

Puye Formation—Diatomaceous Lakebed Sediments (92 to 147 ft bgs)

A complex, 636-ft-thick sequence of sedimentary deposits and intercalated basaltic lavas was intersected in borehole R-16 below a depth of 92 ft. The sequence is made up of subunits of the Puye Formation and Cerros del Rio basalt, both of Tertiary age. The uppermost subunit in the sequence is discussed here.

An interval of clays and clay-rich sands and gravels occurs from 92 to 147 ft bgs. These sediments are interpreted to represent lakebed deposits associated with a lacustrine depositional environment in the upper part of the Puye Formation. Cuttings are locally (e.g., notably from 92.2 to 107.2 ft bgs) made up of white clay fragments containing microscopic siliceous tubules. Scanning-electron-microscope analysis shows these fragments are the fossil remains of fresh-water diatoms. Basaltic clasts, preserved in the basal part of this unit, exhibit orange-colored, limonite-clay rinds, suggesting palagonite alteration.

Upper Cerros del Rio Basalt (147 to 212 ft bgs)

Two intervals of the Tertiary-age Cerros del Rio basalt are recognized in R-16. These volcanic units are intercalated with sedimentary deposits of the Puye Formation. The upper basalt occurs in the interval from 147 to 212 ft bgs. Evidence from cuttings suggests that this unit represents a discrete flow made up of massive-to-vesicular, porphyritic olivine basalt with an aphanitic groundmass. In general, this basalt is sparsely altered as characterized by iddingsite replacement of olivine phenocrysts, iron-oxide and clay coatings on fractures, and groundmass minerals that are variably altered.

Lakebed Sediments with Basalt Detritus (212 to 227 ft bgs)

Additional lakebed deposits containing basaltic detrital sediments are interpreted to occur in the interval from 212 to 227 ft bgs. Samples in this interval contain abundant altered basalt chips and fragments of clay-cemented sandstone.

Older Alluvium (212 to 342 ft bgs)

A 115-ft-thick sequence of clastic sediments intersected from 212 to 342 ft bgs is interpreted to be "older" (i.e., pre-Quaternary) alluvium (as defined by Griggs [1964, 8795]) intercalated within the Puye Formation. Sands and gravels of this interval contain abundant fragments of quartzo-feldspathic sandstone and subrounded coarser clasts dominantly composed of quartz, feldspars, and granitic rocks derived from Precambrian sources.

Lower Cerros del Rio Basalt (342 to 377 ft bgs)

The interval from 342 to 377 ft bgs represents a stratigraphically lower flow of the Cerros del Rio basalt interlayered with Puye sediments. Cuttings indicate that this clay-rich interval is made up of abundant chips (up to 60% by volume) of olivine basalt and fine-to-coarse quartzo-feldspathic detrital sediments. Samples also contain 30% to 40% by volume quartzo-feldspathic detritus.

Totavi Lentil (377 to 627 ft bgs)

R-16 encountered a 250-ft-thick section of quartzite-rich clastic sediments in the interval from 377 to 627 ft bgs that represents the Totavi Lentil. As described by Dethier (1997, 49843), the Totavi Lentil consists of axial channel deposits of the ancestral Rio Grande that occur as lenses within the Puye Formation. Totavi deposits are predominantly quartzite, granite, and other Precambrian materials. The interval is locally made up of clay-rich sands and gravels containing subangular to subrounded clasts derived from Precambrian and, to a lesser degree, volcanic sources. The proportion of Precambrian source materials in these sediments typically ranges from 60% to 80% by volume. Clasts are composed of quartzite, quartz, feldspars, and granitic and metamorphic lithics, and include abundant fragments of indurated quartzo-feldspathic sandstone. Volcanic detritus (20% to 40% by volume) consists mainly of dacite and minor basalt.

Puye Formation and Intercalated Totavi Deposits (627 to 728 ft bgs)

The interval from 627 to 728 ft bgs is composed of detritus from both volcanic and Precambrian sources. These are fanglomerate deposits in which coarse volcanic detritus occurs as the dominant component, typically in the range of 60% to 80% by volume. The volcanic clasts generally are subrounded to rounded and are composed mainly of pink and grayish dacites with minor basalt. Characteristic percentages of coarse quartzite and granitic detritus range from 10% to 40% by volume. The interval from 657 to 677 ft bgs has been interpreted as representing Totavi-related axial river gravels with little or no Puye fanglomerate.

Santa Fe Group Sediments (728 to 1287 ft bgs)

R-16 penetrated a 559-ft-thick section of clay-rich sandstones and gravels in the lowermost drilled interval, from 728 to 1287 ft (TD), that represent sedimentary deposits of the Tertiary-age Santa Fe Group. These sediments are moderately indurated, as evidenced by locally abundant fragments of quartzo-feldspathic sandstone in chip samples. In general, they are composed of materials from both

volcanic and Precambrian sources in variable, though overall equal, proportions. Volcanic clasts are predominantly dacitic; however, basalt, latite, rhyodacite, black vitrophyre (obsidian), and tuffaceous quartz crystals are also evident. Precambrian lithologies include quartz, pink (microcline) and white (plagioclase) feldspars, quartzite, and granite. Quartzo-feldspathic grains commonly exhibit frosted, well-rounded surfaces.

6.2 Groundwater Occurrence and Characteristics

It was anticipated that the regional water table at R-16 would be encountered at approximately 783 ft bgs in the Santa Fe Group, and no perched groundwater zones were predicted. Drilling was performed throughout the entire depth using either air-rotary methods with foam additives or conventional mud-rotary techniques, substantially reducing the ability to detect and observe perched groundwater zones, when they were present.

The regional water table was encountered on August 27, 2002, while drilling through relatively coarse-grained Santa Fe Group sediments. The increase in water production at the end of the discharge line was first observed when the depth of the borehole was at 867 ft bgs, with 11.75-in. drill casing lining the borehole to 729 ft bgs. The water level in the borehole stabilized at 621 ft bgs. No water samples were collected for chemical analysis during the drilling phase of operations. Drilling continued after the presence of regional groundwater was verified, using conventional mud-rotary and casing advance techniques, thus precluding observation of groundwater characteristics. On November 25, 2002, after well development but before hydrologic testing, the water level in the well was measured at 642 ft bgs.

7.0 WELL DESIGN AND CONSTRUCTION

Well R-16 was designed to provide hydrogeologic, geochemical, and water-quality data for the regional aquifer. Sections 7.1 and 7.2 describe the R-16 well design and construction, respectively.

7.1 Well Design

The design for well R-16 was completed jointly by the Laboratory and WGII, in consultation with the New Mexico Environment Department (NMED) and the US Department of Energy (DOE). Geophysical logs, video logs, borehole geologic samples, water-level data, field water-quality data, and drillers' observations were reviewed by the Groundwater Integration Team to plan screen placement intervals for the well. The well design specified four screens to monitor the distribution and concentration of contaminants in the regional aquifer. The number and placement of the screens were designed to

- monitor the top of the regional zone of saturation (screen 1) and
- monitor deeper, more productive zones within the regional aquifer (screens 2, 3, and 4).

Productive intermediate perched groundwater zones were not encountered during drilling; therefore, no screens were placed above the regional water table. The planned and actual screen locations are given in Table 7.1-1.

Table 7.1-1
Well Screen Information, Characterization Well R-16

Screen	Planned Depth (ft)	Actual Depth (ft)	Geologic/Hydrologic Setting
1	640.6–647.4	641.0–648.6	Spans regional water table in the Puye Formation
2	861.2–868.0	863.4–870.9	Within the regional aquifer in the Santa Fe Group
3	1011.9–1018.7	1014.8–1022.4	Within the regional aquifer in the Santa Fe Group
4	1232.5–1239.3	1237.0–1244.6	Within the regional aquifer in the Santa Fe Group

7.2 Well Construction

The well casing and pipe-based screens in well R-16 used 4.5-in. inner diameter (ID)/5.0-in. outer diameter (OD) type 304 stainless steel fabricated to American Society for Testing and Materials (ASTM) standard A554. External couplings also were type 304 stainless steel fabricated to ASTM standards A312 and A511, thereby exceeding the tensile strength of the threaded casing ends. The pipe-based screens were fabricated by Weatherford Well Screens (Johnson Screens, Inc.) from 10-ft sections of blank well casing by drilling a series of 0.5-in.-diameter holes (168 holes/ft) and then welding a stainless steel wire-wrap (with 0.010-in. spacing) over the perforated interval. The final OD of the screens was 5.53 in.

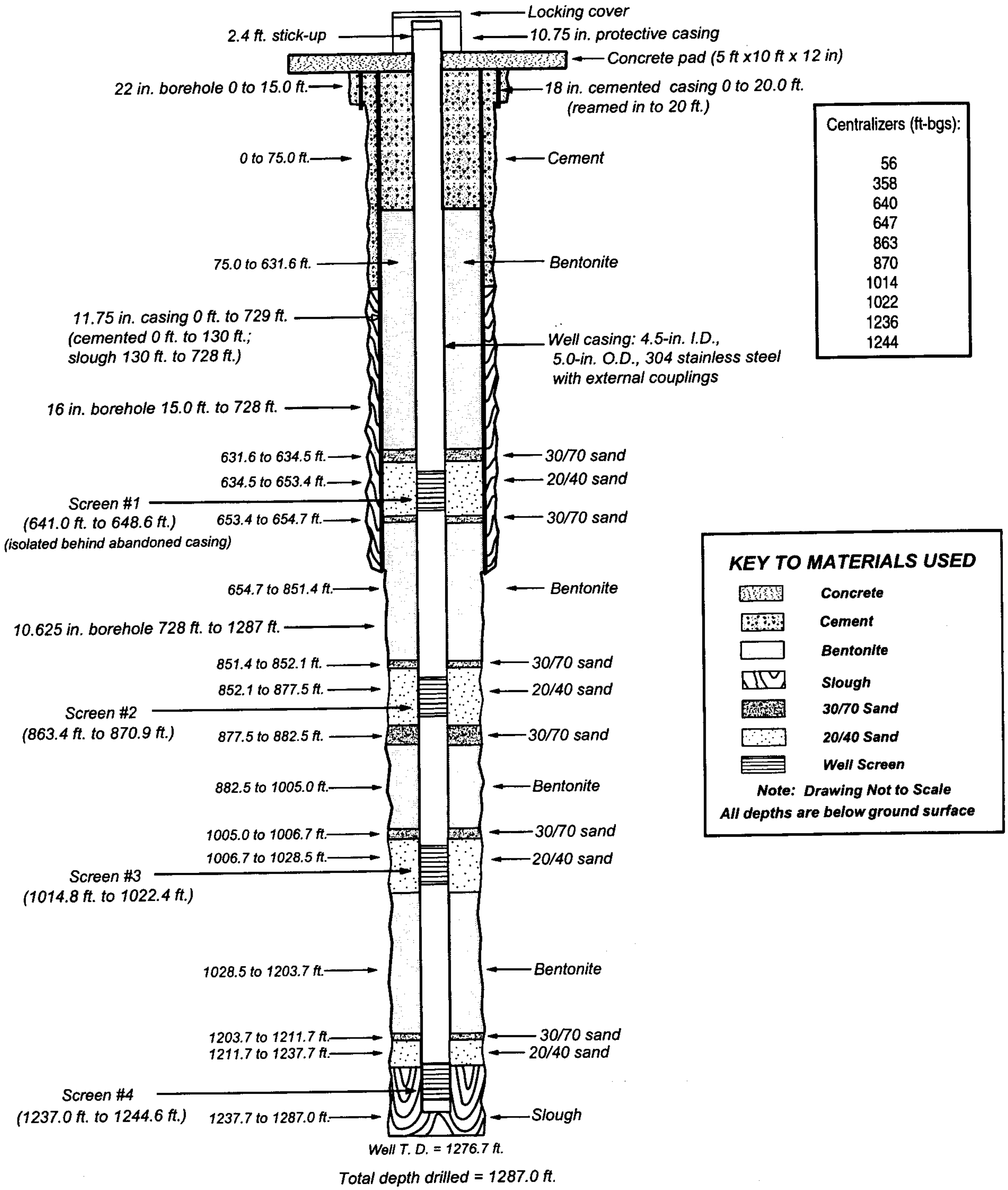
Before installation, all stainless steel well components were cleaned at the well site using a high-pressure steam cleaner and scrub brushes. All annular fill materials were placed in the borehole/well casing annulus through a tremie pipe.

7.2.1 Well Installation

Well installation consisted of connecting joints of stainless steel screens and stainless steel casing joints as specified in the well design (Section 7.1). Dynatec installed the well casing on August 31 and September 1, 2002 (Figure 3.0-2). The base of the well was set at 1276.7 ft bgs. Stainless steel centralizers were installed above and below each screen and in several locations above the zone of regional saturation to centralize the well within the borehole during and after backfill placement. Figure 7.2-1 shows the final well casing configuration and the depths of the various well components from ground surface.

7.2.2 Annular Fill Placement

Before the annular fill material was placed, from September 1 through September 2, 2002, municipal water was pumped into the well annulus at a rate of 20 gal./min to reduce the viscosity of the drilling mud and to enhance placement of backfill material. A jetting tool was used to help remove drill mud cake from the borehole wall. The jetting tool consisted of a tremie rod with a capped end and three evenly spaced 5-mm-diameter holes drilled into the pipe approximately 0.5 ft from the end of the pipe. Municipal water was jetted into the borehole from 730 to 1240 ft bgs. After jetting, approximately 5 gal. of phosphate-free dispersant (PFD) mixed with 2000 gal. of municipal water were injected at 900 ft bgs. An additional 2 gal. of PFD mixed with 1000 gal. of municipal water were injected while the tremie pipe was raised and lowered through the screen 2 interval (863 to 871 ft bgs). Water from the borehole annulus then was airlifted from the borehole, and additional water was pumped in to ensure the viscosity of the borehole fluid was low enough to begin annular fill placement.



Note:
1. Each screen interval lists the footage of the pipe perforations, not the top and bottom of screen joints.
2. All screens are pipe-based 304 stainless steel, 4.5 in. I.D., 5.563 in. O.D., with s.s. 0.010 in. wire wrap slots.
3. The interval of slough consists of sands and gravel of the Santa Fe Group Sediments.
4. Westbay multiport sampling system (MP-55) casing not shown.
5. 11.75 in. casing abandoned in borehole rendered screen #1 non-functional.
6. Well sump interval: 1244.6 to 1276.4 ft.

Figure 7.2-1. As-built configuration diagram, characterization well R-16

Annular fill was placed using a steel tremie pipe to deliver the materials at the depth intervals specified in the well design (Figure 7.2-1). The bottom of the borehole was measured with a tag line at 1237.7 ft bgs before fill material was introduced into the annulus, indicating 49.3 ft of slough remained in the borehole. Dynatec installed the annular fill material from September 4 through 11, 2002. Filter packs across screened intervals consisted of silica sand materials mixed with municipal water and placed in the annulus. Bentonite materials were placed between screened intervals to seal the annular space and prevent interaction between water-bearing zones. Portland® cement also was used for wellhead protection in the annular space in the upper 75 ft of the borehole. Approximately 13,600 gal. of municipal water were used during annular fill material placement.

During annular fill operations between screens 2 and 1, the 11.75 in. drill casing could not be retracted. Removal efforts were unsuccessful, leaving the casing stuck in place from ground surface to 729 ft bgs. The filter pack sequence for screen 1 was placed as planned, although the stuck casing left screen 1 nonfunctional. Since R-16 is a multiscreen completion well, cement or grout could not be placed opposite screen 1 as it would have adversely impacted the entire well. Bentonite seals were placed above and below screen 1 to isolate it from the other screens. The annulus of the 11.75-in. casing was cemented in place from 130 ft bgs to the surface.

Table 7.2-1 lists the annular fill materials installed. The final configuration of the annular materials placed in R-16 is also illustrated in Figure 7.2-1.

Table 7.2-1
Annular Fill Materials, Characterization Well R-16

Material	Use/Function	Amount	Unit*
20/40 sand (medium-grained)	To pack screen intervals	82	bag
30/70 sand (fine-grained)	To separate filter packs from bentonite seals	25	bag
Benseal® (bentonite)	As a high-solids, multipurpose grout	2	bag
Pelplug® bentonite (0.25-in. by 0.375-in. refined elliptical pellets)	To provide a borehole annular seal below the water table	790	bucket
Portland® cement (mixed with municipal water at a ratio of 5 gal. water to 1 bag)	To provide annular support and surface seal on the upper 100 ft of the borehole	70	bag

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

8.0 WELL DEVELOPMENT AND HYDROGEOLOGIC TESTING

Well development and hydrologic testing activities at R-16 were conducted from September 14 to December 4, 2002 (Figure 3.0-2). Well development procedures included preliminary bailing, wire brushing, surging and bailing, chemically treating the well screens, and pumping to develop the well. Development activities were followed by hydrologic slug tests conducted by Hydrogeologic Services, Inc., for screens 2, 3, and 4.

8.1 Well Development

Well development at R-16 consisted of wire-brushing the well interior, swabbing and surging the screen intervals to draw fine sediment from the constructed filter pack, and bailing to remove solid materials from the well. Chemical treatment procedures were applied to individual well screens to break up and disperse borehole-wall filter cake and particulate build-up in the screen and formation, which were consequences

of mud-rotary drilling. To pump each screen level, a submersible pump was lowered to screens 2, 3, and 4, and each isolated water-bearing zone was pumped to remove remaining fines from the filter packs and adjacent formation.

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

Table 8.1-1
Development of Characterization Well R-16

Method	Water Produced (gal.)	Range of Parameters[a]			
		pH	Temperature (°C)	Specific Conductance (µS/cm)[b]	Turbidity (NTU)
Preliminary bailing	610	9.2–8.6	23.4–24.1	NM[c]–329	>1000–>1000
Pumping/jetting	2040	8.4	16.8	NM	>1000
Surging/bailing	1660	8.5–8.0	22.7–24.2	NM–138	249–52.1
Chemical treatment; swabbing 200 gal. In each screen (2, 3, 4)	+600	—[d]	—	—	—
Surging/bailing	1185	2.0–6.2	NM–22.1	NM–188	NM–108
Chemical treatment; added 600 gal. PFD to well	+600	—	—	—	—
Surging/bailing	1300	7.8–7.8	22.8–22.4	141–221	1.4–364
Pumping at screen 4 without packer	54,720	7.2–7.3	18.4–23.2	265–311	141–1.0
Pumping at screen 4 with packer	5675	7.6–8.1	19.5–21.9	215–182	3.76–1.9
Pumping at screen 3 with packer	3270	8.1–7.8	23.4–24.6	178–194	3.16–0.87
Pumping at screen 2 with packer	7590	7.9–8.0	24.7–24.3	173–170	2.7–1.34
TOTAL	76,850				

[a] Parameters presented as value at beginning followed by value at end of development method.
[b] Specific conductance reported in microsiemens per centimeter (µS/cm).
[c] NM = Not measured.
[d] — = No samples collected.

Preliminary bailing using a 9-gal. steel bailer was performed from the R-16 well sump on September 14, 2002, to remove debris and sediment. The casing and screens were cleaned using a wire-brush system

to remove any materials that may have been introduced into the well interior during construction. Surging techniques were then employed across screens 2, 3, and 4 using a wire-line-controlled surge block for rapid upward strokes. The well screens were surged repeatedly; periods of bailing followed from September 17 to 23, 2002. Approximately 610 gal. were removed, and the bailed water consisted primarily of drilling fluid.

Additionally, jetting procedures were performed at screen 4 (September 18, 2002) in an attempt to break up particulate matter in the filter pack and the surrounding formation. Water turbidity exceeded 1000 NTU during this phase; a total of 2040 gal. of water were removed. Following jetting, another 1660 gal. of water were removed by surging and bailing; turbidity decreased from 249 NTU at the beginning of surging to 52.1 NTU at the end of bailing. (Table 8.1-1).

On October 2, 2002, chemical treatment was applied to screens 2, 3, and 4 to assist in breaking down and removing the drilling wall cake. An acidic solution containing 30 lb. of AQUA-CLEAR™-MGA and 3 gal. of AQUA-CLEAR™-AE was mixed per 100 gal. of municipal water. Then 200 gal. of the mixture were injected into the full screen interval for each screen. Surging/bailing procedures resumed briefly at each screen. To enhance wall-cake breakdown and removal, a dispersant mixture containing 1.5 qt of AQUA-CLEAR™-PFD per 100 gal. of municipal water was injected at each screen. The screens were surged, and bailing resumed after the well was allowed to sit for two days. An additional 2485 gal. were bailed from the well (Table 8.1-1) during the chemical-treatment phase.

R-16 pump development began on October 11, 2002. A 10-horsepower (hp) submersible pump was lowered to within the top 2 ft of screen 4. On/off cyclic pumping was conducted with nominal 30-min periods of nonpumping to allow water levels in the well to recover. Water samples were collected at approximately 1-hr intervals to monitor parameters. Initial pumping was done at screen 4 without the assistance of packers. Subsequently, inflatable packers were positioned above and below the screen to isolate the water-bearing zone and pumping resumed. An estimated 60,395 gal. were purged, and turbidity measurements decreased from an initial value of 141 to 1.9 NTU (Table 8.1-1) when pumping stopped.

Pump development using inflatable packers, as described above, were used at screens 2 and 3 on November 20 and 21, 2002. As indicated in Table 8.1-1, field parameters for both screens were consistently within acceptable ranges throughout the process.

8.2 Hydrologic Testing

On November 25, 26, and 27, 2002, the Laboratory conducted straddle-packer/injection tests of saturated materials behind screens 2, 3, and 4 in well R-16. An injection assembly, consisting of two inflatable packers separated by a perforated pipe, was positioned around each screen, in turn. For a given screen, the water-level response to injecting municipal water at different rates for different periods of time was monitored with a pressure transducer. Specifically, three tests were conducted at screens 2 and 3 and two tests were conducted at screen 4. Following the testing, approximately 22,800 gal. of water were purged from the well. This amount represents more than five times the volume of water introduced during the tests. Results of these tests, as well as details of their design, implementation, and analysis, will be presented in a separate Laboratory report.

8.3 Installation of Westbay™ Monitoring System

A Westbay™ sampling system was installed inside the stainless steel well casing after development and testing procedures in well R-16 were completed. The base of the multiport casing was set at 847.5 ft bgs.

The system was set in place using a series of 10 packers inflated with de-ionized water and positioned to target each well screen with a set of valved ports. The R-16 system contains seven measurement ports used to verify packer integrity. Screen 1 is isolated by drill casing, but the zone does contain one measurement port for monitoring zone isolation. Screens 2, 3, and 4 are each accessed by two measurement ports and one pumping port. Quarterly sampling of Westbay™-equipped wells is accomplished using a Laboratory-owned sampling trailer equipped with the MOSDAX® sampling system (controller, sampler probe, and sample bottle train) and a motorized winch and boom system. The Westbay™ summary MP casing log provides details of the installed system (Appendix F).

9.0 WELLHEAD COMPLETION AND SITE RESTORATION

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

9.1 Wellhead Completion

Surface completion for well R-16 involved constructing a reinforced (5000 psi) concrete pad, 5 ft by 10 ft by 12-in.-thick, around the well casing to ensure the long-term structural integrity of the well components (Figure 9.1-1). The concrete pad was poured on November 5, 2002. A 10.75-in. steel casing with locking lid protects the well riser. Steel bollards, 4 in. in diameter, were placed at each side of the pad boundary. The bollard on the west side of the well pad is removable to allow access to the well for sampling and maintenance activities. A brass survey pin was installed in the northwest corner of the concrete pad.

9.2 Geodetic Survey of Completed Well

Southwest Mountain Surveys, Inc. (NMPLS #6998) conducted a geodetic survey of well R-16 on December 19, 2002, using a global positioning satellite (GPS) system. The GPS system utilizes National Geodetic Vertical Datum (NGS) of 99/96 for vertical computations and the datum for the horizontal control network is North American Datum 1983 (NAD 83). The survey located the brass cap monument in the northwest corner of the concrete pad and measured location and elevation at the top of the steel protective casing, the top of the Westbay™ cap, and the top of the Westbay™ plate (Table 9.2-1). The coordinates shown are in New Mexico State Plane coordinates, Central Zone (NAD 83) expressed in feet. To be consistent with current Laboratory standards, elevations are expressed in feet above mean sea level and referenced to the National Geodetic Vertical Datum of 1929 (NVGD29).

9.3 Site Restoration

Site restoration activities at R-16 were conducted by K. R. Swerdfeger Construction, Inc., from February 16 to February 20, 2003 (Figure 3.0-2). Prior to and concurrent with restoration, waste-management activities were also performed. Waste materials were removed from the site as specified in the WCSF. Drilling media included drilling fluids, cuttings, and development water. These media were sampled for contaminant analysis; results are provided in Appendix G. The waste data were reviewed by the Laboratory and the NMED.

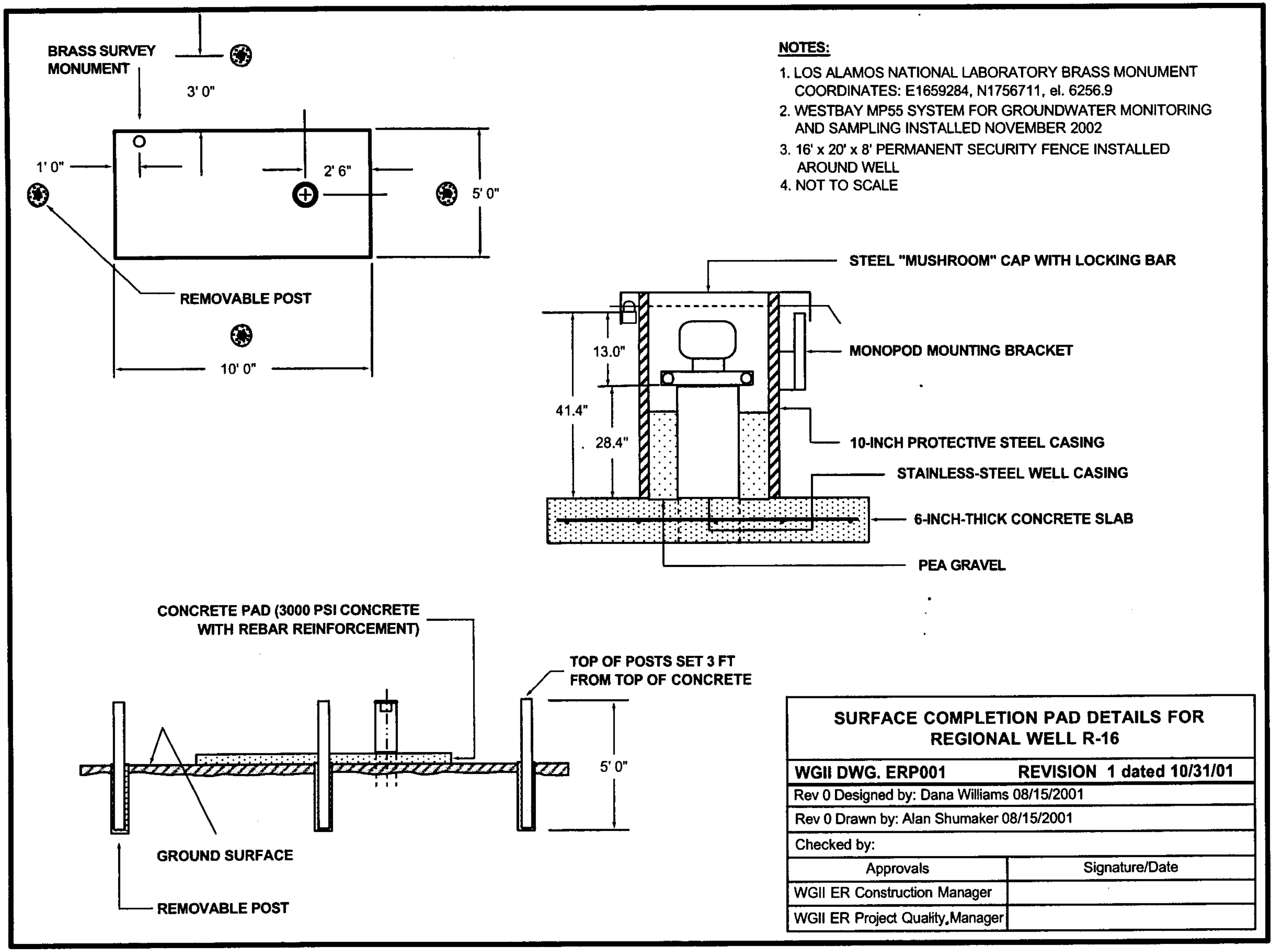


Figure 9.1-1. Surface completion configuration diagram, characterization well R-16

Table 9.2-1
Geodetic Data, Characterization Well R-16

Description	East	North	Elevation
Top of steel protective well casing	1659285.20	1756709.36	6260.40
Top of Westbay™ cap	1659284.75	1756709.34	6260.00
Top of Westbay™ plate	1659284.59	1756709.38	6259.41
Brass cap in R-16 pad	1659283.61	1756710.97	6256.87

The drill cuttings were used to backfill the containment area. The drilling fluids were approved for road application at selected Laboratory locations. Development water was discharged to the White Rock waste-water treatment plant pond. Waste streams from minor spill cleanup included petroleum-contaminated soils and absorbent materials used to clean up all spills. Before the site was regraded, the cuttings-containment area was excavated and the plastic lining was removed. The containment area then was backfilled with drill cuttings and dirt that had been bermed during pad construction. Base-course gravel was regraded and compacted across the site to form a smaller pad. The temporary chainlink fence that had been erected during site pad construction was dismantled and removed. The site was re-seeded with a blend of native grasses mixed with fertilizer and mulch to facilitate regrowth of ground cover. A permanent 16-ft by 20-ft by 8-ft-high fence was installed around the well for long-term security.

10.0 DEVIATIONS FROM THE R-16 SAP

Appendix A compares the actual characterization activities performed at R-16 with the planned activities delineated in the hydrogeologic work plan and the R-16 SAP (LANL 1998, 59599; LANL 2002, 73390). Significant deviations are discussed below.

- *Number of water samples collected for contaminant analysis.* No perched water was detected during drilling. Also, because of the type of drilling performed, water samples could not be collected from the regional aquifer. During final pumping/packer development, a representative sample was collected from screens 2, 3, and 4.
- *Number of core/cuttings samples collected for contaminant analysis.* The SAP called for the collection of up to five cuttings samples for geochemical and contaminant characterization within water-bearing zones encountered during drilling. No perched zones were encountered. The lack of any contaminants of concern in screening-water samples collected from the regional aquifer precluded the usefulness of submitting cuttings samples for analysis.
- *Field hydraulic property testing.* Field hydraulic property testing in the SAP called for performing straddle-packer/injection tests in all screens completed below the regional water table. Screen 1 straddled the water table; therefore, testing was inappropriate.

11.0 ACKNOWLEDGEMENTS

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Southwest Mountain Surveys provided the final geodetic survey of finished well components (NMPLS #6998).

D. Thompson and C. Schultz of PMC Technologies (Exton, Pennsylvania); and P. Schuh, E. Tow, and R. Lawrence of Tetra-Tech EM, Inc. (Albuquerque, New Mexico), contributed to the preparation of this report.

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

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

Schlumberger Integrated Water Solutions provided processing and interpretation of borehole geophysical data.

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Appendix A

Activities Planned for R-16 Compared with Work Performed

Activity	Hydrogeologic Work Plan	R-16 Sampling and Analysis Plan	R-16 Actual Work
Planned depth	100 to 500 ft bgs into the regional aquifer	Estimated depth of 1283 ft below ground surface (bgs)	Total drill depth 1287 ft bgs
Drilling method	Methods may include, but are not limited to hollow stem auger (HSA), air-rotary/Odex/Stratex, air-rotary/Barber rig, and mud-rotary drilling	Foam air rotary, air rotary, mud rotary flooded-reverse circulation, and fluid-assist air rotary with casing advance	Conventional mud rotary and fluid-assist air rotary with casing advance
Amount of core	10% of the borehole	No core collection	No core collected
Lithologic log	Log to be prepared from core, cuttings and drilling performance data.	Log to be prepared from cuttings, geophysical logs and drilling performance	Log prepared from cuttings, geophysical logs, and drilling performance
Number of water samples collected for contaminant analysis	A water sample may be collected from each saturated zone, five zones assumed. The number of sampling events after well completion is not specified	If perched water is encountered, within the unsaturated zone, one groundwater-screening sample will be collected within up to three perched zones. Groundwater-screening samples will be collected within the regional aquifer at the regional water table and at the total depth (TD) of the borehole.	No water samples collected during drilling. Three samples were collected from the three operable screens after well development.
Water sample analysis	Initial sampling: Radiochemistry I, II, and III, tritium, general inorganics, stable isotopes, VOCs, and metals. Saturated zones: radionuclides (tritium, ^{90}Sr, ^{137}Cs, ^{241}Am), plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, beta, and gamma), stable isotopes (hydrogen, oxygen, and in special cases nitrogen), major ions (cations and anions), trace metals, and trace elements.	Metals (dissolved), anions (dissolved), VOCs, ^{99}Tc, gamma spec, ^{241}AM, ^{137}Cs, ^{238}, ^{239} ^{240}Pu, ^{234}, ^{235}, ^{238}U, ^{90}Sr, stable isotopes (^{18}O/^{16}O, D/H, ^{15}N/^{14}N), tritium, tritium (low level or direct counting), RV gross-alpha, beta, gamma	Following well completion and development, groundwater samples (from screens 2, 3, and 4 were analyzed for Metals (dissolved), Anions (dissolved), gamma spectrometry, ^{241}Am, ^{238}, ^{239}, ^{240}Pu, ^{234}, ^{235}, ^{238}U, ^{90}Sr, stable isotopes (^{18}O/^{16}O, D/H, ^{15}N/^{14}N), tritium, tritium (low level or direct counting), U-total, perchlorate, alkalinity, and total Kjeldahl nitrogen (TKN). RV gross-alpha, beta, gamma
Water sample field measurements	Alkalinity, pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, turbidity	pH, specific conductance, temperature, turbidity
Number of core/cuttings samples collected for contaminant analysis	Twenty samples of core or cuttings to be analyzed for potential contaminant identification in each borehole.	Up to five cuttings samples will be collected for geochemical and contaminant characterization within water-bearing zones encountered during drilling.	No cuttings samples submitted for analysis

Activity	Hydrogeologic Work Plan	R-16 Sampling and Analysis Plan	R-16 Actual Work
Core/cuttings sample analytes	Uppermost core or cuttings sample to be analyzed for a full range of compounds: deeper samples will be analyzed for the presence of radiochemistry I, II, and III analytes, tritium (low and high detection levels), and metals. Four samples to be analyzed for VOCs.	Analytical suite for cuttings samples includes anions, stable isotopes, VOCs, tritium profiles, perchlorate, ^{241}Am, $^{238, 239, 240}$Pu, $^{234, 235, 238}$U, ^{90}Sr, gamma spectroscopy, radiological screening (gross alpha, beta, and gamma), radionuclides, and metals.	No analyses were performed
Laboratory hydraulic-property tests	Physical properties analyses will be conducted on 5 core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	No core will be collected for hydraulic property analyses.	No core collected
Geology	Ten samples of core or cuttings will be collected for petrographic, x-ray fluorescence (XRF) and x-ray diffraction (XRD) analyses.	Analytical testing of samples may include mineralogy by XRD, petrography by modal analysis of thin sections, by electron microprobe, and/or by scanning electron microscope, and geochemistry by XRF.	16 samples were characterized for mineralogy, petrography, and rock chemistry.
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and side scan), 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.	The number and types of logs will vary as function of borehole condition, and the presence or absence of drill or well casing. In general, open-hole geophysics includes caliper, array induction, triple litho density, combinable magnetic resonance, natural gamma, natural gamma ray spectrometry, epithermal compensated neutron, mechanical sidewall coring tool, fullbore formation microimager, and borehole color videotape (axial and side scan). In general, cased-hole geophysics includes triplelitho density, natural gamma ray spectrometry, natural gamma, and epithermal compensated neutron.	LANL tools: 0–20 ft bgs (cased), 20–117 ft bgs (open hole) video, 0-729 ft bgs (cased), 729-1287 ft bgs (open hole): natural gamma; 0–1276.7 ft bgs (well): video, natural gamma Schlumberger geophysics: 0–729 ft bgs (cased), 729-1287 ft bgs (open hole): array induction, combinable magnetic resonance, fullbore formation microimager, sonic caliper, triple lithodensity, spectral gamma, natural gamma, elemental capture, and thermal-epithermal neutron
Water-level measurements	Procedures and methods not specified in hydrogeologic work plan.	Water levels will be determined for each saturated zone by water-level meter or by pressure transducer.	Water-level meter determined water levels for the regional water table.

Activity	Hydrogeologic Work Plan	R-16 Sampling and Analysis Plan	R-16 Actual Work
Field hydraulic-property tests	Tests to be conducted not specified in hydrogeologic work plan.	Straddle-packer/injection tests will be performed in all screens completed below the regional water table.	Constant rate injection tests were conducted on screens 2, 3, and 4.
Surface casing	Approximately 20-in. outer diameter (OD) extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	Install 18- or 20-in. OD steel casing to approximately 60 ft.	18.625-in. OD steel casing set at 20 ft bgs, cemented in place
Conductor casing	Unless other technical methods are applied, a temporary steel casing, up to 14-in. OD, will be advanced to total depth of borehole.	Install 11.75-in. OD steel casing from 0 to ~700 to 800 ft bgs, or approximately 100 ft above anticipated regional water level, or set thin-wall casing over problem zone(s) and seal off casing using whatever is required by regulation.	11.75-in. OD drill casing from 0 to 729 ft bgs, cemented in place
Minimum well casing size	6.625-in. OD	5-in. OD	5-in. OD x 4.5-in. inner diameter (ID) stainless steel casing w/ external couplings.
Well screen	Machine-slotted (0.01-in.), stainless steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED.	Well screen shall be constructed with multiple sections of 5.5-in. OD stainless steel pipe with wire wrap (0.010-in. slot opening).	Screened intervals constructed of 5.56-in. OD (4.5-in. ID) pipe based, stainless steel, wire- wrapped, 0.010-in. slotted screen
Filter material	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below each well screen.	Filter pack shall extend at least 5 ft and no more than 10 ft above and below each well screen. No differentiation made between primary and secondary filter packs.	Primary filter pack consisted of 20/40 silica sand placed from 25.3 ft above screen 4 to upper 0.7 ft of screen; slough below. Secondary filter pack consisted of 30-70 silica sand placed in a layer 8-ft-thick above primary filter pack at screen 4. Primary filter pack consisted of 20/40 silica sand placed 6.1 ft below and 8.1 ft above screen 3. Secondary filter pack consisted of 30/70 silica sand placed in a layer 1.7-ft-thick above primary filter pack. Primary filter pack consisted of 20/40 silica sand placed 6.6 ft below and 11.3 ft above screen 2.

Activity	Hydrogeologic Work Plan	R-16 Sampling and Analysis Plan	R-16 Actual Work
Filter material			Secondary filter pack of 30/70 silica sand placed in a layer 5-ft-thick below and 0.7-ft-thick above. Primary filter pack consisted of 20/40 silica sand placed 4.8 ft below and 6.5 ft above screen 1. Secondary filter pack of 30/70 silica sand placed in a layer 1.3-ft-thick below and 2.9-ft-thick above.
Backfill material (exclusive of filter materials)	Uncontaminated drill cuttings below sump and bentonite above sump.	Bentonite and cement in borehole or well annulus.	Slough in borehole and annulus below and around sump and bottom well screen from TD to 0.7 ft below top of screen 4. Bentonite seal above screen 4 filter pack and above and below screens 3, 2, and 1 filter packs. Cement-bentonite grout from surface to 75 ft bgs.
Sump	Stainless steel casing with an end cap	Not specified	5-in.-diameter stainless steel casing, 32.1-ft-long, with an end cap
Bottom seal	Bentonite	Bentonite	None

Appendix B

Drill-Additive Product Specifications
(CD attached to inside back cover)

Appendix C

Lithology Log

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qal, alluvium	Unconsolidated sediments, clay (CH) with sand and gravel, light brown (5YR 6/4). +12F (i.e., plus No. 12 seize sieved sample fraction): clay-coated clasts of volcanic tuff, quartz and sanidine crystals, and dacite lithic fragments. Note: Cuttings were sampled and described in the interval from 0 to 1287 ft bgs)	0–5	6256.9–6251.9
Qbo, Otowi Member of the Bandelier Tuff	Rhyolite tuff, light brownish (5YR 6/4), lithic-rich. +12F: 15%–25% pumice fragments; 1%–3% basalt fragments; 75%–85% dacitic fragments that are strongly oxidized. WR sample (i.e., unsieved cuttings sample) is clay-rich.	5–10	6251.9–6246.9
	Rhyolite tuff, medium light gray (N6), poorly welded to nonwelded, lithic-rich. +12F: 1%–3% pumice fragments; 2%–3% quartz and sanidine crystals; 90%–95% abundant dacitic and lesser basalt fragments that are strongly oxidized.	10–14	6246.9–6242.9
	Rhyolite tuff, yellowish-gray (5YR 6/1), poorly welded to nonwelded. +12F: 60%–70% vitric pumice fragments; 25%–30% dacitic and basalt fragments in equal proportions. +40F (i.e., plus No. 40 size sieved sample fraction): contains 50% pumice, 40% quartz and sanidine crystals, and 10% volcanic lithics.	14–15	6242.9–6241.9
	Rhyolite tuff, medium light gray (N6), poorly welded to nonwelded, lithic-rich. +12F: 15%–20% oxidized pumice fragments; 75%–85% abundant basalt and lesser dacite volcanic lithics.	15–20	6241.9–6236.9
	Rhyolite tuff, grayish-orange pink (5YR 7/2), poorly welded to nonwelded, pumiceous. +12F: 80%–90% glassy fibrous pumice lapilli (up to 1 cm), light limonite-staining; 2%–4% quartz and sanidine crystals; 5%–15% volcanic lithics (basalt and lesser dacite). +40F: contains 60%–70% quartz and sanidine crystals.	20–28.5	6236.9–6228.4
	Rhyolite tuff, grayish-orange pink (5YR 7/2), poorly welded to nonwelded. +12F: 25%–30% white, unaltered, vitric pumice fragments (up to 1.5 cm); 20%–40% quartz and sanidine crystals; 20%–40% volcanic lithic fragments (dacite with lesser basalt).	28.5–43.5	6228.4–6213.4
	Rhyolite tuff, grayish-orange pink (5YR 7/2), poorly welded to nonwelded, lithic-rich. +12F: 20%–25% white vitric pumice fragments; 15%–20% quartz and sanidine crystals; 50%–60% volcanic lithic fragments (up to 0.7 cm) made up of dacite, basalt, rhyodacite, and latite.	43.5–48.2	6213.4–6208.7
	Rhyolite tuff, grayish-orange pink (5YR 7/2), poorly welded to nonwelded, pumice-rich. +12F: 70%–75% white vitric pumice fragments (up to 1.0 cm) that are partly limonite-stained; 5%–10% quartz and sanidine crystals; 10%–15% volcanic lithic fragments made up of pink and gray dacite with minor basalt.	48.2–63.2	6208.7–6193.7
	Rhyolite tuff, grayish-orange pink (5YR 7/2), poorly welded to nonwelded, pumice- and lithic-rich. +12F: 50% white vitric, fibrous pumice fragments (up to 0.6 cm); 5%–10% quartz and sanidine crystals; 35%–40% volcanic lithic fragments made up of intermediate to felsic lithologies. +40F: contains 97%–98% quartz and sanidine crystals.	63.2–68.2	6193.7–6188.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Rhyolite tuff, grayish-orange pink (5YR 7/2), poorly welded to nonwelded, pumice-rich. +12F: 90%–95% white vitric, fibrous pumice fragments; 5%–10% quartz and sanidine crystals; 2%–3% volcanic lithic fragments made up of intermediate to felsic lithologies.	68.2–78.2	6188.7–6178.7
Qbo	Rhyolite tuff, grayish-orange pink (5YR 7/2), poorly welded to nonwelded, pumice-rich. +12F: 95%–97% white vitric, fibrous and limonite-stained pumice fragments (up to 1.0 cm); <1% quartz and sanidine crystals; 2%–3% dacitic lithic fragments. +40F: contains 75%–80% quartz and sanidine crystals.	83–88	6178.7–6173.7
Basaltic sediments	Basalt-rich sediments, gravel (GW) with sand, varicolored light tan (10 YR 6/2) to dark gray (N3), subangular to subrounded clasts (up to 0.5 cm). +12F: contains mixed volcanic lithologies including 30%–50% vesicular to massive basalt, 20%–30% dacite and silicified dacite, 5%–20% white to light tan clay nodules and fragments; and 1%–2% black vitrophyre. Basalt and dacite clasts have clay or iron-oxide/clay coatings. +40F: orange-colored limonite cementing clasts/chips; 40% clay particles/nodules. Note: stratigraphic top of this unit is estimated at 84 ft bgs; its base is estimated at 92 ft bgs.	88–103	6173.7–6164.7
Tpl, Puye lakebed sediments	Lakebed sediments, yellowish-gray (5Y 8/1), clay (CH) with broken gravel chips and subrounded pebble-size clasts. +12F: 10%–15% vesicular basalt chips and pebbles; 3%–5% dacite; 80%–85% whitish tan chips of soft clay containing microscopic tubules that appear siliceous, locally limonite-stained; Mn-oxides common.	92.2–102.2	6164.7–6154.7
	Lakebed sediments, yellowish-gray (5Y 8/1) to medium dark gray (N4), clayey gravel (GC), broken chips and subrounded pebble-size clasts (up to 1.0 cm). +12F: 7%–10% vesicular basalt clasts with strong clay and/or limonite coatings; 90%–93% whitish fragments of clay that are subrounded (milled), clays contains abundant silica tubules (diatomaceous clay); 1%–2% dacite chips.	102.2–107.2	6154.7–6149.7
	Lakebed sediments, yellowish-gray (5Y 8/1), clay (CH). WR: whole rock sample only collected. 100% clay of high plasticity.	107.2–127.2	6149.7–6129.7
	Lakebed sediments, very pale yellowish-orange (10YR 8/2), clay (CH) with gravel. WR: whole rock sample only collected. 10%–15% angular vesicular basalt fragments (up to 0.7 cm); 85%–95% clay of high plasticity.	127.2–142.2	6129.7–6114.7
	Transition Tpl/Tb interval, very pale orange (10YR 821), clay (CH) with gravel, broken chips (up to 0.5 cm) in clay matrix. +12F: 85%–90% vesicular, olivine-basalt chips; 10%–15% clay-cemented sandstone clasts; 1%–2% bright-orange, altered volcanic lithics (possible palagonite). Note: Basal contact of lakebed sediments with underlying Cerros del Rio basalt estimated at 147 ft bgs.	142.2–152.2	6114.7–6104.7

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb4, Cerros del Rio basalt	Basalt with clay (CH), light gray (N6), sparsely porphyritic with aphanitic groundmass, massive to sparsely vesicular. +12F: chips finely ground and clay coated, textures obscured. Groundmass is unaltered or very weakly altered. Local clay nodules suggest amygdaloidal fillings.	152.2–162.2	6104.7–6094.7
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, sparsely vesicular. +12F: brownish-olivine phenocrysts (up to 1.0 mm) are oxidized, groundmass altered and bleached; 3%–5% clay nodules, partly limonite-stained and yellowish. WR sample moderately clay-rich.	162.2–172.2	6094.7–6084.7
	Basalt, light brownish-gray (5YR 6/1), porphyritic with aphanitic groundmass, sparsely vesicular. +12F: 85%–95% basalt chips that are partially alteredd, clay coatings obscure textures; 5%–15% whitish clay fragments and clay-cemented sandstone. WR sample clay-rich.	172.2–177.2	6084.7–6079.7
	Basalt, light brownish-gray (5YR 6/1), porphyritic with aphanitic groundmass, sparsely vesicular. +12F: olivine phenocrysts (up to 2 mm) are replaced by iddingsite, chips clay-coated obscuring textures, slight Fe-oxide/clay coating on some fractures. WR sample contains clay binding chips.	177.2–187.2	6079.7–6069.7
	Basalt, medium light gray (N5), slightly porphyritic with aphanitic groundmass, vesicular. +12F: olivine phenocrysts (1%–3% of volume, up to 3 mm) commonly rounded and wholly replaced by iddingsite; groundmass is bleached and partially altered; some vesicles contain yellowish clay.	187.2–197.2	6069.7–6059.7
	Basalt, medium light gray (N5), slightly porphyritic with aphanitic groundmass, vesicular. +12F: pale green olivine phenocrysts (2%–3% of volume, up to 2 mm) are unaltered; groundmass partially altered, bleached, trace light tan clay fragments.	197.2–212.2	6059.7–6044.7
	Transitional Tb4/lakebed sediments, light gray (N7) to grayish orange (10YR 7/4), slightly porphyritic with aphanitic groundmass, vesicular. +12F: olivine phenocrysts (1%–2% of volume, up to 2 mm) mostly replaced by iddingsite; groundmass strongly altered, strongly bleached; yellowish clay chips, angular, hard, locally limonite-stained. Note: Basal Tb4 contact estimated at 212 ft bgs.	212.2–222	6044.7–6034.9
Tpl, Puye Lakebed Sediments	Lakebed sediments, pale reddish-brown (10YR 5/4), basalt chips in clay matrix. +12F: 80%–85% angular altered basalt chips, mostly clay-coated; 10%–15% reddish-brown, fine-grained sandstone clasts; 2%–3% clay nodules locally containing sand grains. WR sample clay-rich. +40F: contains 40%–50% sandstone, 1% granitic grains.	222–227	6034.9–6029.9
Ta, Older Alluvium	Clastic sediments, gravel (GW) with sand and clay, pale reddish-brown (10R 5/4). +12F: 20%–25% angular basalt chips, clay-coated; 60%–70% clay-cemented, fine-grained sandstone fragments (up to 0.5 cm) composed of quartz, granite, and volcanic grains; 5%–10% angular granitic clasts. WR sample clay-rich.	227–232	6029.9–6024.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Ta, Older Alluvium	Clastic sediments, gravel (GW) with sand and clay, light brown (5YR 6/4). +12F: 15%–30% angular basalt chips, clay-coated; 20%–25% clay-cemented, fine-grained sandstone and clay; 50%–60% subrounded quartz, microcline, and granitic clasts (up to 0.5 cm).	232–242	6024.9–6014.9
	Clastic sediments, clayey gravel (GC) with sand, light brown (5YR 6/4). +12F: 15%–20% basalt and other volcanic lithics; 25%–30% whitish claystone and clay-cemented sandstone; 40%–50% broken to subrounded quartz, microcline, and granitic clasts (up to 0.5 cm). WR sample clay-rich.	242–252	6014.9–6004.9
	Clastic sediments, gravel (GW) with clay, light brown (5YR 6/4). +12F: 5%–7% angular basalt chips; 15%–20% quartzo-feldspathic sandstone fragments; 70%–75% coarse sand /granules composed of quartz, microcline, chert, Precambrian granite and quartzite. WR sample clay-rich.	252–262	6004.9–5994.9
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2), subangular to subrounded pebbles (up to 0.7 cm). +12F: 60%–70% clasts of various granitic rocks, 5%–10% quartzo-feldspathic sandstone fragments; 5%–10% quartzite; 5%–10% white clay nodules; rare basalt fragments. Clasts commonly clay-coated.	262–272	5994.9–5984.9
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2). +12F: 50%–80% clasts made up of quartz, pink microcline, metamorphic and granitic rocks, and quartzite; 20%–50% fine-grained sandstone; 1%–2% basalt.	272–287	5984.9–5969.9
	Clastic sediments, clayey sand (SC) with gravel, pale yellowish-brown (10YR 6/2). +12F: 50%–80% subangular to subrounded clasts (up to 0.7 cm) made up of pinkish pink microcline, quartz, and metamorphic and granitic rocks; 20%–50% micaceous sandstone and siltstone; 1%–2% basalt.	287–302	5969.9–5954.9
	Clastic sediments, clayey sand (SC) with gravel, pale yellowish-brown (10YR 6/2). +12F: 60%–70% clay-cemented tuffaceous sandstone and siltstone; 30%–40% coarse sand and granules (up to 0.5 cm) made up of pinkish pink microcline, quartz, and metamorphic and granitic rocks, minor basalt and dacite; clasts commonly clay-coated.	302–312	5954.9–5944.9
	Clastic sediments, clayey sand (SC) with gravel, pale yellowish-brown (10YR 6/2). +12F: 90%–95% clay-cemented, quartz-bearing tuffaceous sandstone and siltstone; 5%–10% granitic and minor volcanic fragments.	312–317	5944.9–5939.9
	Clastic sediments, clayey gravel (GC) with sand, pale yellowish-brown (10YR 6/2). +12F: 10%–30% clay-cemented, quartz-feldspar-mica-volcanic sandstone; 70%–80% subangular to subrounded clasts (up to 0.5 cm) made up of pinkish pink microcline, quartz, and granitic rocks; 3%–5% dacitic volcanic clasts.	317–322	5939.9–5934.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Ta, Older Alluvium	Clastic sediments, clayey sand (SC) with gravel, pale yellowish-brown (10YR 6/2). +12F: 30%–50% fine-grained, quartz-volcanic-sandstone and siltstone; 50%–60% subangular to subrounded clasts (up to 0.5 cm) made up of clay-coated pink microcline, quartz, and granitic rocks; 2%–3% light gray dacitic volcanic clasts. WR sample clay-rich.	322–332	5934.9–5924.9
	Clastic sediments, clayey sand (SC) with gravel, pale yellowish-brown (10YR 6/2), coarse sand to granules (up to 0.5 cm), subrounded to angular. +12F: 40%–50% indurated fragments of quartz-volcanic and hornblende-volcanic sandstone; 50%–60% subrounded clasts made up of pink microcline, white feldspar, quartz, and granitic rocks; 3%–5% light gray dacitic volcanic clasts. WR sample clay-rich.	332–342	5924.9–5914.9
	Basalt/clastic sediments, clayey gravel (GC) with sand, light olive-gray (5Y 6/1). +12F: 40%–60% angular chips of olivine-basalt; 30%–40% fine-grained, quartz-feldspar sandstone fragments; 10%–30% subrounded clasts made up of pink and white feldspar, quartz, and granitic rocks. WR sample clay-rich	342–352	5914.9–5904.9
	Basalt/clastic sediments, clayey gravel (GC) with sand, light olive-gray (5Y 6/1). +12F: 70%–80% angular chips of vesicular olivine-basalt, commonly clay-coated; 30%–40% subrounded coarse sand and granules (up to 0.9 cm) composed of quartz, feldspar, and granitic and metamorphic rocks; 10%–15% fragments of fine-grained sandstone and siltstone. WR sample clay-rich	352–367	5904.9–5889.9
	Basalt/clastic sediments, clayey gravel (GC) with sand, light olive-gray (5Y 6/1). +12F: 50%–60% angular/broken chips of olivine-basalt, commonly clay-coated; 40%–50% subrounded/broken clasts composed of quartz, feldspar, and granitic lithics; 10%–15% fragments of fine-grained sandstone and siltstone. WR sample clay-rich.	367–377	5889.9–5879.9
Tpt, Totavi Lentil	Clastic sediments, clayey sand (SC) with gravel, light olive-gray (5Y 6/1). +12F: 35%–45% angular/broken chips of clay-coated basalt, minor rounded hornblende dacite; 10%–20% light tan fragments of fine-grained, quartzo-feldspathic sandstone and siltstone; 50%–60% subrounded/broken clasts (up to 0.5 cm) pink and white feldspar, quartz, quartzite, and granitic lithics. WR sample clay-rich.	377–392	5879.9–5864.9
	Clastic sediments, clayey sand (SC) with gravel, light olive-gray (5Y 6/1). +12F: 30%–40% angular/broken chips basalt and subrounded hornblende-bearing dacite; 10%–20% light tan fragments of sandstone and siltstone; 50%–60% subrounded/broken clasts (up to 0.4 cm) pink and white feldspar, quartz, quartzite, and granitic lithics. WR sample clay-rich.	392–407	5864.9–5849.9
	Clastic sediments, clayey sand (SC) with gravel, light olive-gray (5Y 6/1). +12F: 35%–45% angular/broken chips basalt and broken/subrounded clasts of light gray dacite; 10%–15% fragments of quartzo-feldspathic sandstone; 50%–60% subrounded/broken clasts (up to 0.5 cm) pink microcline, plagioclase, quartz, quartzite, and meta-granitic lithics.	407–422	5849.9–5834.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpt, Totavi Lentil	Clastic sediments, clayey sand (SC) with gravel, light olive-gray (5Y 6/1), medium to coarse sand with pebbles (up to 0.5 cm) +12F: 30%–40% angular/broken chips basalt and subangular/subrounded clasts dacite; 10%–15% fragments of fined-grained sandstone; 50%–60% subrounded/broken clasts pink and white feldspar, quartz, quartzite, and granitic lithics. WR sample clay-rich.	422–432	5834.9–5824.9
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange pink (5YR 7/2), broken to rounded clasts, pebbles (up to 0.5 cm). +12F: 50%–60% volcanic lithics (dacite, basalt, and possible pumice); 30%–40% clasts pink microcline, quartz, and quartzite of Precambrian sources; 5%–10% siltstone fragments. WR sample clay-rich.	432–442	5824.9–5814.9
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange pink (5YR 7/2), broken to rounded clasts, pebbles (up to 0.5 cm). +12F: 25%–35% mixed clay-coated dacite and basalt chips; 10%–15% whitish clay fragments; 60%–70% subrounded/broken clasts of pink microcline, quartz, granite, and quartzite of Precambrian sources. WR sample clay-rich.	442–457	5814.9–5799.9
	Clastic sediments, clayey sand (SC) with gravel, light olive-gray (5Y 6/1), medium to coarse sand with pebbles (up to 0.5 cm). +12F: 35%–45% clay-coated dacite and minor basalt chips; 15%–20% fine-grained sandstone and clay fragments; 40%–60% subrounded/broken clasts pink microcline, quartz, granite, and quartzite of Precambrian sources. WR sample clay-rich.	457–472	5799.9–5784.9
	Clastic sediments, clayey sand (SC) with gravel, light olive-gray (5Y 6/1), medium to coarse sand with pebbles (up to 0.5 cm). +12F: 25%–35% clay-coated dacite and minor basalt chips; 10%–15% fine-grained sandstone and claystone fragments; 50%–60% subrounded/broken clasts of pink microcline, quartz, chert, granite, and quartzite. WR sample clay-rich.	472–482	5784.9–5774.9
	Clastic sediments, clayey gravel (GC) with sand, light olive-gray (5Y 6/1), broken and subrounded clasts (up to 1.0 cm). +12F: 10%–20% rounded dacite and minor basalt chips; 15%–20% fine-grained quartzo-feldspathic sandstone fragments; 65%–75% subrounded to rounded clasts of quartzite, pink microcline, and granitic lithics. WR sample clay-rich.	482–492	5774.9–5764.9
	Clastic sediments, clayey gravel (GC) with sand, light olive-gray (5Y 6/1), broken and subrounded clasts (up to 1.0 cm). +12F: 10%–20% dacite clasts and minor basalt chips; 15%–25% fine-grained quartzo-feldspathic sandstone fragments; 60%–70% subrounded to rounded clasts (up to 1.0 cm) of quartzite, pink microcline, chert, granite, and meta-granite lithics. WR sample clay-rich.	492–507	5764.9–5749.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpt, Totavi Lentil	Clastic sediments, clayey gravel (GC) with sand, light olive-gray (5Y 6/1), subrounded and broken clasts. +12F: 15%–25% volcanic lithic clasts, mostly dacite with minor basalt chips; 5%–7% indurated siltstone fragments; 70%–80% subangular to subrounded clasts (up to 1.5 cm) of quartzite, pink microcline, granite, and metamorphic lithics. WR sample clay-rich.	507–522	5749.9–5734.9
	Clastic sediments, clayey gravel (GC) with sand, light olive-gray (5Y 6/1), subrounded and broken clasts. +12F: 15%–25% volcanic lithic clasts, mostly dacite with minor basalt chips; 3%–5% indurated fine-grained sandstone; 75%–80% subangular to subrounded clasts (up to 0.7 cm) of quartzite, pink microcline, chert, granite, and metamorphic lithics.	522–537	5734.9–5719.9
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange pink (5YR 7/2), subrounded and broken clasts. +12F: 15%–25% rounded to broken dacite clasts; 3%–5% indurated fine-grained, quartzo-feldspathic sandstone; 70%–80% subrounded and broken clasts (up to 0.7 cm) of quartzite, pink microcline, granite, and metamorphic lithics. WR sample clay-rich.	537–547	5719.9–5709.9
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange pink (5YR 7/2), subrounded and broken clasts. +12F: 15%–25% dacite clasts; 10%–20% indurated fine-grained quartzo-feldspathic sandstone; 60%–70% clasts of quartzite, pink microcline, granite, and metamorphic lithics. WR sample clay-rich.	547–562	5709.9–5694.9
	Clastic sediments, gravel (GW) with sand, grayish-orange pink (5YR 7/2), subangular to subrounded clasts (up to 1.0 cm), clay-coated. +12F: 15%–20% dacite clasts; 5%–10% indurated fine-grained sandstone; 60%–70% clasts of quartzite, quartz, pink microcline, granite, and metamorphic lithics.	562–577	5694.9–5679.9
	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2). +12F: 15%–25% dacite clasts; 85%–90% clasts of quartzite, pink microcline, granite, and metamorphic lithics. WR sample clay-rich.	577–602	5679.9–5654.9
	Clastic sediments, clay (CH) with sand, grayish-orange pink (5YR 7/2). +12F: clay-rich matrix binding chips and obscuring composition. +40F: 10%–20% dacite clasts; 80%–90% grains of quartzite, quartz, pink microcline, granite, and metamorphic lithics in clayey matrix. WR sample contains 40%–50% clay.	602–612	5654.9–5644.9
	Clastic sediments, clay (CH) with sand, grayish-orange pink (5YR 7/2). +12F: 60%–70% volcanic clasts with clay-rich matrix. +40F: 35%–45% grains of dacite lithics; 45%–55% grains of quartzite, quartz, pink microcline, granite, and metamorphic lithics in clayey matrix; 5%–10% fragments of white clay. WR sample contains more than 50% clay.	612–617	5644.9–5639.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpt, Totavi Lentil	Clastic sediments, clay (CH) with sand, grayish-orange pink (5YR 7/2). +12F: unidentified volcanic clasts in clay-rich matrix. +40F: 30%–35% grains of dacite lithics; 60%–70% grains of quartzite, quartz, pink microcline, and granite lithics. WR sample contains 30%–50% clay matrix.	617–627	5639.9–5629.9
Tpf, Puye Formation	Clastic sediments, clayey sand (SC), yellowish-gray (5Y 8/1). +12F: 80%–95% subrounded to rounded granules/pebbles (4–7 mm) of pink and gray dacite lithics; 5%–7% clasts of quartzite and rare granitic and metamorphic lithics, 5%–15% sandstone clasts. WR sample contains 30%–35% clay matrix binding fine to very coarse sand.	627–642	5629.9–5614.9
	Clastic sediments, clayey sand (SC), yellowish-gray (5Y 8/1), fine to very coarse sand, 30%–35% clay/silt. +12F: 97%–98% subrounded to rounded granules/pebbles (up to 0.5 mm) of pink and gray dacite lithics; 2%–3% clasts of quartzite and rare granitic lithics.	642–647	5614.9–5609.9
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange pink (5RY 7/2), fine to very coarse sand/granules, 20%–25% clay matrix, +12F: 60%–70% broken and subrounded to rounded clasts (up to 1.0 cm) of pink and gray dacite lithics; 15%–20% clasts of quartzite, granite, and chert lithics, 10%–15% fine-grained sandstone and siltstone fragments.	647–657	5609.9–5599.9
Tpt, Totavi Lentil	Clastic sediments, clayey gravel (GC), yellowish-gray (5Y 8/1). +12F: 45%–55% rounded to subrounded dacite granules; 30%–40% angular/broken chips of quartzite and granitic lithics, 5%–10% sandstone clasts. WR sample contains clayey matrix, white clay.	657–667	5599.9–5589.9
	Clastic sediments, clayey gravel (GC), yellowish-gray (5Y 8/1). +12F: 75%–85% well-rounded clasts and broken chips of pink and gray dacite; 10%–20% broken chips of quartzite, chert, and metamorphic lithics. WR sample contains clayey matrix.	667–677	5589.9–5579.9
Tpf, Puye Formation	Clastic sediments, clayey gravel (GC), yellowish-gray (5Y 8/1). +12F: 70%–85% subrounded granules (4–6 mm) gray dacite; 10%–15% broken chips/clasts of quartzite, pink microcline, and granitic lithics; 5%–7% sandstone fragments. WR sample contains 30%–40% clay matrix.	677–687	5579.9–5569.9
	Clastic sediments, clayey gravel (GC) with sand, grayish-orange pink (5YR 7/2). +12F: 50%–60% subrounded granules pink and light gray dacite; 5%–10% clasts of quartzite lithics; 25%–35% sandstone and white claystone fragments. WR sample contains 30%–40% clay matrix.	687–697	5569.9–5559.9
	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2). +12F: 50%–60% rounded to subrounded pebbles (up to 1.0 cm) of dacite volcanics; 5%–20% clasts and broken chips of quartz, quartzite, white and pink feldspar, and metamorphic lithics; 10%–25% light tan siltstone fragments. WR sample contains 30%–40% clay matrix.	697–712	5559.9–5544.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, clay (CH) with sand, grayish-orange pink (5YR 7/2). +12F: 30%–40% subrounded to rounded clasts of pink and gray dacite; 20%–30% clasts of quartzite and granite lithics; 10%–25% pink to white claystone fragments. WR sample contains at least 50% clay matrix.	712–722	5544.9–5534.9
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2), gravel clasts subrounded and broken (up to 1.0 cm). +12F: 15%–20% clasts of dacite and minor basalt; 50%–60% clasts of quartzite and granite lithics; 20%–25% fine-grained sandstone and pink to white claystone fragments. WR sample contains 30% clay matrix.	722–728	5534.9–5528.9
Tsf, Santa Fe Group Sediments	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2). +12F: less than 1% of sample retained on No. 12 sieve; 80%–90% volcanic clasts; 10%–15% lithic clasts of Precambrian sources. +40F: mixed fine sand grains of volcanic rocks and quartz that are rounded and frosted. WR sample contains 20%–30% clay matrix.	728–747	5528.9–5509.9
	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2). +12F: less than 10 per cent of sample retained on No. 12 sieve; 70%–80% light and dark gray dacite; 10%–20% grains of Precambrian quartzite; 5%–15% indurated fine-grained sandstone. WR sample contains fine- to medium-grained with 20%–30% clay matrix.	747–762	5509.9–5494.9
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2). +12F: 70%–80% broken chips of pink and gray dacite, rhyodacite, trace basalt; 15%–20% clasts of quartzite; 3%–5% fine-grained carbonate-cemented sandstone. WR sample contains fine- to medium-grained with 20%–30% clay matrix.	762–772	5494.9–5484.9
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2). +12F: 40%–45% volcanic rocks, predominantly gray dacite; 30%–40% clasts of quartzite, pink and white feldspar, and granitic lithics; 10%–15% fine-grained carbonate-cemented sandstone fragments. WR sample contains 20%–30% clay matrix.	772–782	5484.9–5474.9
	Clastic sediments, clayey sand (SC) with gravel, grayish-orange pink (5YR 7/2). +12F: 50%–65% volcanic rocks, mostly broken chips of dacite, minor rhyodacite, trace altered pumice; 15%–20% clasts of quartzite, pinkish feldspar, and granitic lithics; 20%–25% fine-grained, carbonate-cemented sandstone fragments. WR sample contains 20%–30% clay matrix.	782–787	5474.9–5469.9
	Clastic sediments, clayey sand (SC), grayish-orange pink (5YR 7/2). +12F: less than 5% of sample retained on No. 12 sieve; roughly equal parts grains of volcanic lithologies(with 1%–2% altered pumice), Precambrian quartzite, and sandstone fragments. WR sample contains 20%–30% clay matrix.	787–797	5469.9–5459.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group Sediments	Clastic sediments, sand (SW) with clay, grayish-orange pink (5YR 7/2), subrounded and broken chips (up to 0.5 cm). +12F: 30%–35% volcanic rocks, dominantly gray dacite with minor pumice; 35%–45% clasts of quartzite, pink and white feldspar, and granitic lithics; 10%–25% fine-grained carbonate-cemented sandstone fragments. WR sample contains 20%–30% clay matrix.	797–812	5459.9–5444.9
	Clastic sediments, sand (SW) with clay, light brown (5YR 6/4), subrounded to subangular clasts (up to 0.5 cm). +12F: 30%–35% volcanic lithics, mostly gray dacite with minor basalt; 30%–35% clasts of quartzite, pink and white feldspar, and granitic lithics; 15%–20% indurated fine-grained sandstone fragments. WR sample contains 10%–15% clay matrix.	812–822	5444.9–5434.9
	Clastic sediments, sand (SW), light brown (5YR 6/4), subangular to broken (up to 0.5 cm). +12F: 25%–35% volcanic lithics, mostly gray dacite; 40%–45% clasts of quartzite, pink and white feldspar, and granitic lithics; 25%–35% indurated fine-grained sandstone fragments.	822–837	5434.9–5419.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4), grains subangular. +12F: less than 1% of sample retained on No. 12 sieve in the interval 842 to 847 ft bgs; 20%–30% volcanic lithics, mostly gray dacite, minor basalt and pumice; 40%–50% broken chips of quartzite, pink and white feldspar, and granitic lithics; 15%–25% indurated fine-grained sandstone fragments. WR sample contains 25%–35% clay matrix.	837–852	5419.9–5404.9
	Clastic sediments, clayey sand (SC) with gravel, light brown (5YR 6/4), subrounded clasts (up to 1.5 cm). ; +12F: less than 10% of sample retained on No. 12 sieve, 20%–30% dacite lithics; 40%–50% broken chips of lithics from Precambrian sources; 25% indurated fine-grained sandstone fragments. WR sample contains 30%–35% clay matrix.	852–857	5404.9–5399.9
	No cuttings recovered in this interval.	857–862	5399.9–5394.9
	Clastic sediments, sand (SW) with clay, grayish-orange pink (5YR 7/2), subrounded pebbles (up to 0.5 cm). ; +12F: 10%–20% dacite lithics; 65%–75% broken chips of quartz, feldspar, and granitic lithics from Precambrian sources; 10%–15% indurated fine-grained, quartzo-feldspathic sandstone fragments.	862–867	5394.9–5389.9
	No cuttings recovered because of lost circulation of drilling fluids in this interval.	867–1047	5389.9–5209.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4), fine to medium sand with 35% clay. +12F: dominantly Precambrian-source grains, lesser volcanic lithics, clayey matrix. +40F: 25%–35% grains of dacite, black vitrophyre, and rare rhyodacite; 65%–75% rounded, frosted grains of quartz and feldspar.	1047–1057	5209.9–5199.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group sediments	Clastic sediments, sand (SW) with clay, light brown (5YR 6/4), fine to medium sand. +12F: sample clay-rich. +40F: 20%–30% grains of dacite, well rounded black vitrophyre, and rare rhyodacite; 75%–80% rounded, frosted grains of quartz and feldspar.	1057–1062	5199.9–5194.9
	Clastic sediments, clayey sand (SC) to clay (CH) with sand, light brown (5YR 6/4), fine to medium sand. +12F and +40F: samples very clay rich, 40%–50% grains of volcanic lithics; 40%–50% grains of quartz and feldspar.	1062–1072	5194.9–5184.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4), fine to coarse sand with 30%–35% clay. +12F: sample clay-rich. +40F: 30%–40% grains light gray dacite, black vitrophyre; 65%–75% grains of quartz and feldspar.	1072–1082	5184.9–5174.9
	Clastic sediments, clayey gravel (GC) with sand, light brown (5YR 6/4), 25%–30% clay, 40%–45% pebble gravel. +12F: sample clay-rich, abundant well-rounded and frosted clasts, mixed volcanic and Precambrian lithics. +40F: 35%–45% grains dacite, basalt, and spherical black vitrophyre; 45%–50% well rounded grains of quartz with frosted surfaces, feldspar, granite, quartzite, chert; 10%–15% indurated fine-grained sandstone fragments.	1082–1097	5174.9–5159.9
	Clastic sediments, clayey sand (SC) with gravel, light brown (5YR 6/4), 25%–50% clay, 15%–20% pebble gravel. +12F: sample clay-rich, 50%–60%clay-cemented balls of fine-grained sandstone; 25%–35% volcanic lithics; dacite, minor basalt; 10%–20% clasts of quartz with frosted surfaces, feldspar, granite, and quartzite.	1097–1107	5159.9–5149.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4), fine to medium sand, 30%–40% clay, 10% granules. +12F: 20%–30% clay-cemented fragments of fine-grained sandstone; 55%–65% volcanic lithics (pink and gray dacite, minor basalt); 10%–15% clasts of quartz and quartzo-feldspathic lithologies.	1107–1117	5149.9–5139.9
	Clastic sediments, clayey sand (SC) to clay (CH) with sand, light brown (5YR 6/4), fine to medium sand, 40%–50% clay, 10%–15% granules. +12F: 70%–85% clay-cemented fragments of fine-grained sandstone and clay clots; 15%–25% subrounded clasts (up to 0.5 cm) of volcanic lithics; pink and gray dacite, minor basalt; 5%–7% clasts of quartz, quartzite, feldspar, and granitic lithologies.	1117–1132	5139.9–5124.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4), fine to medium sand, 30%–40% clay. +12F: 75%–90% light tan clay-cemented, fine-grained quartzo-feldspathic sandstone fragments and clay clots; 10%–25% clasts of volcanic lithics (dacite, basalt). +40F: 20%–30% grains of dacite, well rounded of black vitrophyre; 70%–80% grains of frosted quartz and feldspar.	1132–1147	5124.9–5109.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group sediments	Clastic sediments, clayey sand (SC) with gravel, light brown (5YR 6/4), fine to coarse sand, 25%–35% clay, 10%–15% pebble gravel. +12F:15%–30% clay-cemented sandstone fragments; 30%–40% clasts of volcanic lithics; pink and gray dacite, basalt; 25%–30% subangular clasts (up to 0.5 cm) quartzite, quartz, feldspar and granite lithics.	1147–1157	5109.9–5099.9
	Clastic sediments, clayey sand (SC) with gravel, light olive-gray (5Y 6/1), fine to coarse sand, 15%–20% clay, 20%–25% pebble gravel. +12F: 20%–30% clay-cemented fine-grained sandstone fragments; 40%–50% subrounded clasts (up to 0.5 cm) of volcanic lithics; dacite, minor basalt; 20%–30% quartzo-feldspathic component.	1157–1172	5099.9–5084.9
	Clastic sediments, clayey sand (SC) with gravel, light brown (5YR 6/4), fine to coarse sand, 25%–35% clay matrix. +12F: 15%–25% clay-cemented fine-grained sandstone fragments; 55%–65% clasts of pink and gray dacite; 15%–20% quartz, feldspar, quartzite, and granite lithics. +40F: contains abundant well-rounded grains of frosted quartz.	1172–1182	5084.9–5074.9
	Clastic sediments, clayey sand (SC) with gravel, light brown (5YR 6/4), fine to medium sand, 20%–25% clay matrix. +12F: 70%–75% clay-cemented, fine-grained sandstone fragments; 15%–20% subrounded clasts (up to 0.4 cm) of dacite and minor basalt; 10%–15% quartz, feldspar, quartzite, and granite lithics. +40F: contains 75% quartzo-feldspathic and 25% volcanic grains.	1182–1192	5074.9–5064.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4), 20%–25% clay matrix. +12F: 15%–30% clay-cemented, fine-grained sandstone fragments; 40%–50% clasts of pink and gray dacite, minor basalt; 20%–25% quartz, feldspar, quartzite, and granite lithics.	1192–1207	5064.9–5049.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4), 30%–40% clay matrix. +12F: 25%–30% clay-cemented, fine-grained sandstone fragments; 40%–50% clasts of dacite, minor basalt; 15%–20% quartz, feldspar, and granite lithics.	1207–1222	5049.9–5034.9
	Clastic sediments, sand (SW) with clay and gravel, light brown (5YR 6/4). +12F: 15%–20% clots of indurated sandy clay; 60%–70% subrounded clasts of pink and gray dacite, latite, tuffaceous quartz crystals, and minor basalt; 10%–15% Precambrian (quartzite, granite) lithics.	1222–1232	5034.9–5024.9
	Clastic sediments, sand (SW) with clay and gravel, light brown (5YR 6/4). +12F: 20%–30% clots of clay-cemented fine-grained sandstone; 50%–60% rounded clasts of pink and gray dacite and white latite; 5%–10% Precambrian (quartzite, granite) lithics.	1232–1247	5024.9–5009.9
	Clastic sediments, clayey sand (SC), light brown (5YR 6/4). +12F: 3%–5% indurated, fine-grained sandstone fragments; 80%–90% volcanic clasts of pink and gray dacite (tuff, quartz porphyritic?) white biotite-bearing latite, and rare basalt; 5%–7% Precambrian (quartzite, granite) lithics.	1247–1262	5009.9–4994.9

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tsf, Santa Fe Group sediments	Clastic sediments, clayey sand (SC), light brown (5YR 6/4). +12F: 5%–7% indurated, fine-grained sandstone fragments; 70%–80% subrounded volcanic clasts of pink and gray dacite (tuff, quartz porphyritic?) white biotite-bearing latite and rare basalt; 5%–7% Precambrian (quartzite, granite) lithics.	1262–1277	4994.9–4979.9
	Clastic sediments, gravel (GW) with clay and sand, light brown (5YR 6/4). +12F: 5%–10% indurated, fine-grained sandstone fragments; 80%–90% volcanic clasts of pink and gray dacite (tuff, quartz porphyritic?) white biotite-bearing latite and rare basalt; 3%–5% quartzite clasts.	1277–1287	4979.9–4969.9
R-16 borehole total depth (TD) = 1287 ft bgs			

Notes:

1. American Society for Testing Materials (ASTM) standards (D 2488-90: Standard Practice and Identification of Soils [Visual-Manual Procedure]) were used to describe the texture of drill chip samples for sedimentary rocks such as alluvium and the Puye Formation. ASTM method D 2488-90 incorporates the Unified Soil Classification System (USCS) as a standard for field examination and description of soils. The following standard USCS symbols were used in the R-16 lithologic log:

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

2. Cuttings at R-16 were collected at nominal 5-ft intervals and divided into three sample splits: (1) unsieved, or whole rock (WR) sample; (2) +12F sieved fraction (No. 12 sieve equivalent to 1.75 mm); and (3) +40F sieved fraction (No. 40 sieve equivalent to 0.425 mm).
3. The term *percent*, as used in the above descriptions, refers to percent by volume for a given sample component.
4. Color designations such as hue, value, and chroma (e.g., 5YR 5/2) are from the Geological Society of America's Rock Color Chart.

Appendix D

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

Appendix E

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

Appendix F

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

Appendix G

Waste Characterization Data

Los Alamos NATIONAL LABORATORY

Risk Reduction & Environmental Stewardship Division
Water Quality & Hydrology Group (RRES-WQH)
PO Box 1663, MS K497
Los Alamos, New Mexico 87545
(505) 667-7969/Fax: (505) 665-9344

Date: October 31, 2002
Refer to: RRES-WQH: 02-403

Mr. John Young
Hazardous Materials Bureau
New Mexico Environment Department
P.O. Box 26110
Santa Fe, New Mexico 87502

Mr. Curt Frischkorn
Ground Water Quality Bureau
New Mexico Environment Department
P.O. Box 26110
Santa Fe, New Mexico 87502

SUBJECT: NOTICE OF INTENT TO DISCHARGE, HYDROGEOLOGIC WORKPLAN WELL R-16

Dear Mr. Young and Mr. Frischkorn:

On October 28, 2002, your agency concurred with Los Alamos National Laboratory's request to land apply approximately 75,000 gallons of ground water produced during the development of Hydrogeologic Workplan Well R-16 (personal communication, Mr. Bob Beers, Los Alamos National Laboratory, and Mr. Curt Frischkorn, New Mexico Environment Department). The Laboratory's proposal to discharge development water from Workplan Well R-16 was made in accordance with the requirements of the Hydrogeologic Workplan Notice of Intent (NOI) submitted to your agency on August 2, 2001, and subsequently revised on July 16, 2002. Under the Hydrogeologic Workplan NOI, when development water produced from a Hydrogeologic Workplan Well exceeds a New Mexico Water Quality Control Commission (NM WQCC) Regulation 3103 ground water standard or a RCRA regulatory limit the Laboratory will coordinate disposal with the NMED. Since the development water produced from Workplan Well R-16 exceed the NM WQCC Regulation 3103 ground water standards for manganese (Mn) and cobalt (Co), your agency's concurrence was requested.

The Laboratory has containerized approximately 75,000 gallons of ground water produced during the development of Workplan Well R-16. Workplan Well R-16 is located in White Rock in the vicinity of Los Alamos County's White Rock WWTP. Depth to ground water at the land application site is approximately 622 feet. In accordance with our proposal, all development water from Workplan Well R-16 will be land applied to the grounds of Los Alamos County's WWTP. Los Alamos County has granted the Laboratory permission for this activity. As required by the Workplan NOI, no ponding, pooling, or run-off of the discharged water will be permitted. Information regarding the quality of the development water is provided below.

Mr. Young and Mr. Frischkorn - 2 - October 31, 2002
RRES-WQH:02-403

Water Quality Data

Attachment 1.0 contains analytical reports (metals, general chemistry, perchlorate, nitrate, tritium, and high explosives) from the sampling of containerized development water from Workplan Well R-16. All samples were filtered prior to analysis. Sample results were compliant with all NM WQCC Regulation 3103 ground water standards with the exception of the following contaminants:

Contaminant	Screening Result (mg/L)	NM WQCC ground water standard (mg/L)
Mn	0.95	0.2
Co	0.054	0.05

No perchlorate, tritium, nitrate/nitrite, or high explosives were detected in the Workplan Well R-16 development water at concentrations greater than the analytical laboratory's Method Detection Limits (MDLs).

Please call me at (505) 667-6969 or Roy Bohn of the Laboratory's Environmental Restoration Project (RRES-R) at (505) 665-5138 if additional information is required.

Sincerely,

Bob Beers
Water Quality & Hydrology Group

BB/tml

Enclosures: a/s

Cy: M. Leavitt, NMED/GWQB, Santa Fe, NM, w/enc.
J. Davis, NMED/SWQB, Santa Fe, NM, w/enc.
J. Bearzi, NMED/HWB, Santa Fe, NM, w/enc.
J. Vozella, DOE/OLASO, w/enc., MS A316
G. Turner, DOE/OLASO, w/enc., MS A316
M. Johansen, DOE/OLASO, w/enc., MS A316
J. Holt, ADO, w/enc., MS A104
B. Ramsey, RRES-DO, w/o enc., MS J591
K. Hargis, RRES-DO, w/o enc., MS J591
D. Stavert, RRES-EP, w/enc., MS J978
S. Rae, RRES-WQH, w/o enc., MS K497
D. Rogers, RRES-WQH, w/o enc., MS K497
M. Saladen, RRES-WQH, w/o enc., MS K497
R. Bohn, RRES-R, w/o enc., MS M992
D. McInroy, RRES-R, w/o enc., MS M992
RRES-WQH File, w/enc., MS K497
IM-5, w/enc., MS A150

Los Alamos
NATIONAL LABORATORY

Risk Reduction & Environmental Stewardship Division
Water Quality & Hydrology Group (RRES-WQH)
PO Box 1663, MS K497
Los Alamos, New Mexico 87545
(505) 667-7969 / Fax: (505) 665-9344

Date: December 3, 2002
Refer to: RRES-WQH: 02-444

Mr. John Young
Hazardous Materials Bureau
New Mexico Environment Department
P.O. Box 26110
Santa Fe, New Mexico 87502

Mr. Curt Frischkorn
Ground Water Quality Bureau
New Mexico Environment Department
P.O. Box 26110
Santa Fe, New Mexico 87502

SUBJECT: NOTICE OF INTENT TO DISCHARGE, HYDROGEOLOGIC WORKPLAN WELL R-16, DRILLING WATER

Dear Mr. Young and Mr. Frischkorn:

On November 26-27, 2002, your agency concurred with Los Alamos National Laboratory's proposal to land apply water produced during the drilling of Hydrogeologic Workplan Well R-16 (November 26, 2002, personal communication, Mr. Curt Frischkorn, NMED, and Mr. Bob Beers, LANL; and November 27, 2002, voicemail, Mr. John Young, NMED, to Mr. David Broxton, LANL). The Laboratory's proposal to discharge drilling water from Workplan Well R-16 was made in accordance with the requirements of the Hydrogeologic Workplan Notice of Intent (NOI) submitted to your agency on August 2, 2001, and subsequently revised on July 16, 2002. Under the Hydrogeologic Workplan NOI, when drilling water produced from a Hydrogeologic Workplan Well exceeds a New Mexico Water Quality Control Commission (NM WQCC) Regulation 3103 ground water standard or a RCRA regulatory limit the Laboratory will coordinate disposal with the NMED. Since the drilling water produced from Workplan Well R-16 exceeds the NM WQCC Regulation 3103 ground water standard for manganese (Mn), your agency's concurrence was requested.

The Laboratory has containerized approximately 60,000 gallons of water produced during the drilling of Workplan Well R-16. Workplan Well R-16 is located in White Rock near Los Alamos County's White Rock WWTP. Candidate sites for the land application of R-16 drilling water are as follows:

- The road to Mortandad Canyon from TA-52. Depth to ground water: regional = 1260 ft.
- The road to the R-14 drill site: Depth to ground water: regional = 1180 ft.
- The roads at TA-49: Depth to ground water: regional = 1180 ft.

Mr. Young and Mr. Frischkorn - 2 - December 3, 2002
RRES-WQH:02-444

Because current weather conditions are not conducive to evaporation (lower temperatures, higher humidity) and recent precipitation has increased soil moisture, it is necessary for the Laboratory to utilize a variety of land application sites. The conditions at each site will be carefully evaluated before use. In accordance the Workplan NOI, no ponding, pooling, or run-off of the discharged water will be permitted. Information regarding the quality of the Workplan Well R-16 drilling water is provided below.

Water Quality Data

Attachment 1.0 contains analytical reports (metals, general chemistry, perchlorate, nitrate, total Hg, and tritium) from the sampling of containerized drilling water from Workplan Well R-16. All samples were filtered prior to analysis (with the exception of total Hg). Sample results were compliant with all NM WQCC Regulation 3103 ground water standards with the exception of the following contaminant:

Contaminant	Screening Result (mg/L)	NM WQCC ground water standard (mg/L)
Mn	0.61	0.2
Mn	1.29	0.2
Mn	0.18	0.2

No perchlorate or tritium were detected in the Workplan Well R-16 drilling water at concentrations greater than the analytical laboratory's Method Detection Limits (MDLs).

Please call me at (505) 667-6969 or Roy Bohn of the Laboratory's Environmental Restoration Project (RRES-R) at (505) 665-5138 if additional information is required.

Sincerely,

Bob Beers
Water Quality & Hydrology Group

BB/tml

Attachments: a/s

Cy: M. Leavitt, NMED/GWQB, Santa Fe, NM, w/att.
J. Davis, NMED/SWQB, Santa Fe, NM, w/att.
J. Bearzi, NMED/HWB, Santa Fe, NM, w/att.
J. Vozella, DOE/OLASO, w/o att., MS A316
G. Turner, DOE/OLASO, w/att., MS A316
M. Johansen, DOE/OLASO, w/att., MS A316
J. Holt, ADO, w/att., MS A104

Mr. Young and Mr. Frischkorn - 3 - December 3, 2002
RRES-WQH:02-444

Cy (continued):
B. Ramsey, RRES-DO, w/o att., MS J591
K. Hargis, RRES-DO, w/o att., MS J591
D. Stavert, RRES-EP, w/att., MS J591
C. Nylander, RRES-GP, w/o att., MS M992
S. Rae, RRES-WQH, w/att., MS K497
D. Rogers, RRES-WQH, w/o att., MS K497
M. Saladen, RRES-WQH, w/o att., MS K497
J. McCann, RRES-WQH, w/o att., MS M992
R. Bohn, RRES-R, w/att., MS M992
D. Volkman, FWO-UI, w/o att., MS K718
RRES-WQH File, w/att., MS K497
IM-5, w/att., MS A150

ATTACHMENT 1.0

HYDROGEOLOGIC WORKPLAN WELL R-16

CONTAINERIZED DRILLING WATER

ANALYTICAL REPORTS:

- GENERAL CHEMISTRY
- METALS
- PERCHLORATE
- NITRATE/NITRITE
- TOTAL HG
- TRITIUM

SAMPLE DATES:

SEPTEMBER 9, 2002
SEPTEMBER 12, 2002
OCTOBER 1, 2002

Workplan Well R-16 Drilling Water
Screening Data

ER WATER SAMPLES

SAMPLE ID	DESCRIPTION	DATE MM/DD/YY	ER Req#	Ag ppm	Al ppm	Std.D. +/-	As ppm	Std.D. +/-	B ppm	Std.D. +/-	Ba ppm
GW16-02-49356	R-16 mud, analyzed after filtering	09/09/02	1188S	<0.0003	0.57	0.01	0.033	0.001	0.064	0.002	0.30
GW16-02-49357	R-16 mud, analyzed after filtering	09/09/02	1188S	<0.0003	0.84	0.01	0.021	0.001	0.077	0.001	0.70
GW16-02-49358	R-16 mud, analyzed after filtering	09/09/02	1188S	<0.0003	0.22	0.01	0.023	0.001	0.074	0.001	0.094

Page 1

Workplan Well R-16 Drilling Water
Screening Data

SAMPLE ID	Std.D. +/-	Be ppm	Br ppm	Ca ppm	Std.D. +/-	Cd ppm	Cl ppm	ClO3 ppm	ClO4 ppm	Co ppm	Std.D. +/-	Cr ppm	Std.D. +/-	Cs ppm	Cu ppm
GW16-02-49356	0.01	<0.002	<0.1	103	1	<0.001	7.15	<0.1	<0.01	0.0018	0.0001	0.010	0.001	<0.003	0.010
GW16-02-49357	0.01	<0.002	0.08	144	4	<0.001	7.50	<0.1	<0.01	0.0022	0.0001	0.013	0.001	<0.003	0.0078
GW16-02-49358	0.001	<0.002	<0.1	20.3	0.6	<0.001	10.9	<0.1	<0.01	0.0013	0.0001	0.0093	0.0006	<0.003	0.0095

Workplan Well R-16 Drilling Water
Screening Data

SAMPLE ID	Std.D. +/-	F ppm	Fe ppm	Std.D. +/-	Hardness CaCO3 ppm	Hg ppm	Std.D. +/-	K ppm	Std.D. +/-	Li ppm	Std.D. +/-	Mg ppm	Std.D. +/-	Mn ppm	Std.D. +/-
GW16-02-49356	0.001	0.28	0.28	0.01	305	0.0018	0.0002	7.87	0.03	0.14	0.01	11.7	0.1	0.61	0.01
GW16-02-49357	0.0002	0.41	0.73	0.01	439	0.0015	0.0001	10.7	0.1	0.13	0.01	19.3	0.2	1.29	0.08
GW16-02-49358	0.0002	0.40	0.24	0.01	62.5	0.0009	0.0001	4.27	0.05	0.12	0.01	2.86	0.03	0.18	0.01

Page 3

Workplan Well R-16 Drilling Water
Screening Data

SAMPLE ID	Mo ppm	Std.D. +/-	Na ppm	Std.D. +/-	Ni ppm	Std.D. +/-	NO2 ppm	NO3 ppm	N total ppm	Oxalate ppm	Pb ppm	Std.D. +/-	PO4 ppm	Rb ppm	Std.D. +/-
GW16-02-49356	0.057	0.001	296	1	0.010	0.001	0.51	0.75	0.32	<0.1	0.0015	0.0001	1.29	0.011	0.001
GW16-02-49357	0.066	0.002	265	2	0.012	0.001	0.44	0.21	0.18	0.41	0.0015	0.0001	1.20	0.019	0.001
GW16-02-49358	0.068	0.003	237	2	0.0042	0.0001	0.27	3.52	0.88	0.49	0.0021	0.0001	1.56	0.006	0.001

Workplan Well R-16 Drilling Water
Screening Data

SAMPLE ID	Sb ppm	Std.D. +/-	Se ppm	Std.D. +/-	Si ppm	Std.D. +/-	SiO2 ppm calc	SO4 ppm	Sn ppm	Sr ppm	Std.D. +/-	Th ppm	Std.D. +/-	Ti ppm	Std.D. +/-
GW16-02-49356	0.0011	0.0001	0.004	0.001	21.5	0.1	46.0	177	<0.002	1.46	0.01	<0.001		0.004	0.001
GW16-02-49357	<0.001		0.004	0.001	24.3	0.3	52.0	224	<0.002	1.69	0.01	0.0016	0.0001	0.009	0.001
GW16-02-49358	<0.001		0.002	0.001	21.5	0.1	46.0	141	<0.002	0.44	0.01	<0.001		<0.001	

Workplan Well R-16 Drilling Water
Screening Data

SAMPLE ID	Tl ppm	U ppm	Std.D. +/-	V ppm	std.D. +/-	Zn ppm	Std.D. +/-	Acetate ppm	Formate ppm	comments
GW16-02-49356	<0.002	0.0082	0.0001	0.022	0.001	0.008	0.001	+	+	unknown peak before NO3
GW16-02-49357	<0.002	0.0092	0.0001	0.030	0.002	0.006	0.001	+	+	unknown peak before NO3
GW16-02-49358	<0.002	0.0066	0.0001	0.013	0.001	0.002	0.001	+	+	unknown peak before NO3

Certificate of Analysis

Company : Los Alamos National Lab
Address : PO Box 1663
TA-3, Bldg. 271, Drop Pt. 01U
Los Alamos, New Mexico 87545
Contact: Keith Greene
Project: Groundwater Project

Report Date: October 24, 2002

Page 1 of 1

Client Sample ID:	GW16-02-49614 05	Project:	LANL00401
Sample ID:	68194001	Client ID:	LANL004
Matrix:	Ground Water		
Collect Date:	01-OCT-02 00:00		
Receive Date:	03-OCT-02		
Collector:	Client		

Parameter	Qualifier	Result	DL	RL	Units	DF	Analyst	Date	Time	Batch	Method
Mercury Analysis Federal											
7470 Cold Vapor Hg Liquid											
Mercury	U	ND	0.943	4.00	ug/L	20	NOR1	10/23/02	1818	210028	1

The following Prep Methods were performed

Method	Description	Analyst	Date	Time	Prep Batch
SW846 7470A Prep	EPA 7470A Mercury Prep Liquid	KHN	10/22/02	1500	210025

The following Analytical Methods were performed

Method	Description	Analyst Comments
1	SW846 7470A	

Notes:
The Qualifiers in this report are defined as follows :

< Actual result is less than amount reported
> Actual result is greater than amount reported
B Analyte found in the sample as well as the associated blank.
BD Flag for results below the MDC or a flag for low tracer recovery.
E Concentration exceeds instrument calibration range
H Holding time exceeded
J Indicates an estimated value. The result was greater than the detection limit, but less than the reporting limit.
P The response between the confirmation column and the primary column is >40%D
U Indicates the compound was analyzed for but not detected above the detection limit
UI Uncertain identification for gamma spectroscopy.
X Lab-specific qualifier - must be fully described in case narrative and data summary package
Y QC Samples were not spiked with this compound.

The above sample is reported on an "as received" basis.

Where the analytical method has been performed under NELAP certification, the analysis has met all of the requirements of the NELAC standard unless qualified on the Certificate of Analysis.

This data report has been prepared and reviewed in accordance with General Engineering Laboratories, Inc. standard operating procedures. Please direct any questions to your Project Manager, Stacy Griffin.

Reviewed by

Certificate of Analysis

Company : Los Alamos National Lab
Address : PO Box 1663
TA-3, Bldg. 271, Drop Pt. 01U
Los Alamos, New Mexico 87545
Contact: Keith Greene
Project: Groundwater Project

Report Date: October 24, 2002

Page 1 of 1

Client Sample ID:	GW16-02-49615 05	Project:	LANL00401
Sample ID:	68194002	Client ID:	LANL004
Matrix:	Ground Water		
Collect Date:	01-OCT-02 00:00		
Receive Date:	03-OCT-02		
Collector:	Client		

Parameter	Qualifier	Result	DL	RL	Units	DF	Analyst	Date	Time	Batch	Method
Mercury Analysis Federal											
7470 Cold Vapor Hg Liquid											
Mercury	U	ND	0.943	4.00	ug/L	20	NOR1	10/23/02	1824	210028	1

The following Prep Methods were performed

Method	Description	Analyst	Date	Time	Prep Batch
SW846 7470A Prep	EPA 7470A Mercury Prep Liquid	KHN	10/22/02	1500	210025

The following Analytical Methods were performed

Method	Description	Analyst Comments
1	SW846 7470A	

Notes:
The Qualifiers in this report are defined as follows :

< Actual result is less than amount reported
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B Analyte found in the sample as well as the associated blank.
BD Flag for results below the MDC or a flag for low tracer recovery.
E Concentration exceeds instrument calibration range
H Holding time exceeded
J Indicates an estimated value. The result was greater than the detection limit, but less than the reporting limit.
P The response between the confirmation column and the primary column is >40%D
U Indicates the compound was analyzed for but not detected above the detection limit
UI Uncertain identification for gamma spectroscopy.
X Lab-specific qualifier - must be fully described in case narrative and data summary package
Y QC Samples were not spiked with this compound.

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This data report has been prepared and reviewed in accordance with General Engineering Laboratories, Inc. standard operating procedures. Please direct any questions to your Project Manager, Stacy Griffin.

Reviewed by

Certificate of Analysis

Company : Los Alamos National Lab
Address : PO Box 1663
TA-3, Bldg. 271, Drop Pt. 01U
Los Alamos, New Mexico 87545
Contact: Keith Greene
Project: Groundwater Project

Report Date: October 24, 2002

Page 1 of 1

Client Sample ID: GW16-02-49616 05
Sample ID: 68194003
Matrix: Ground Water
Collect Date: 01-OCT-02 00:00
Receive Date: 03-OCT-02
Collector: Client

Project: LANL00401
Client ID: LANL004

Parameter	Qualifier	Result	DL	RL	Units	DF	Analyst	Date	Time	Batch	Method
Mercury Analysis Federal											
7470 Cold Vapor Hg Liquid											
Mercury	U	ND	0.0472	0.200	ug/L	1	NOR1	10/22/02	1212	207403	1

The following Prep Methods were performed

Method	Description	Analyst	Date	Time	Prep Batch
SW846 7470A Prep	EPA 7470A Mercury Prep Liquid	KHN	10/21/02	1630	207402

The following Analytical Methods were performed

Method	Description	Analyst Comments
1	SW846 7470A	

Notes:
The Qualifiers in this report are defined as follows :

< Actual result is less than amount reported
> Actual result is greater than amount reported
B Analyte found in the sample as well as the associated blank.
BD Flag for results below the MDC or a flag for low tracer recovery.
E Concentration exceeds instrument calibration range
H Holding time exceeded
J Indicates an estimated value. The result was greater than the detection limit, but less than the reporting limit.
P The response between the confirmation column and the primary column is >40%D
U Indicates the compound was analyzed for but not detected above the detection limit
UI Uncertain identification for gamma spectroscopy.
X Lab-specific qualifier - must be fully described in case narrative and data summary package
Y QC Samples were not spiked with this compound.

The above sample is reported on an "as received" basis.

Where the analytical method has been performed under NELAP certification, the analysis has met all of the requirements of the NELAC standard unless qualified on the Certificate of Analysis.

This data report has been prepared and reviewed in accordance with General Engineering Laboratories, Inc. standard operating procedures. Please direct any questions to your Project Manager, Stacy Griffin.

Reviewed by

Certificate of Analysis

Company: Los Alamos National Lab
Address: PO Box 1663
TA-3, Bldg. 271, Drop Pt. 01U
Los Alamos, New Mexico 87545
Contact: Keith Greene
Project: Groundwater Project

Report Date: September 23, 2002

Page 1 of 1

Client Sample ID: GW16-02-49356 13/14
Sample ID: 67047001
Matrix: Misc Liquid
Collect Date: 12-SEP-02
Receive Date: 13-SEP-02
Collector: Client

Project: LANL00401
Client ID: LANL004

Parameter	Qualifier	Result	DL	TPU	RL	Units	DF	AnalystDate	Time	Batch	Mtd.
Rad Liquid Scint											
LSC, Tritium Dist, Liquid											
Tritium		-55.3	252	68.0	250	pCi/L		CAF1 09/23/02	1102	202687	1

The following Analytical Methods were performed

Method	Description
1	EPA 906.0

Notes:
TPU is calculated at the 67% confidence level (1-sigma).
The Qualifiers in this report are defined as follows :

< Actual result is less than amount reported
> Actual result is greater than amount reported
B Analyte found in the sample as well as the associated blank.
E Concentration exceeds instrument calibration range
H Holding time exceeded
J Indicates an estimated value. The result was greater than the detection limit, but less than the reporting limit.
P The response between the confirmation column and the primary column is >40%D
U Indicates the compound was analyzed for but not detected above the detection limit
UI Uncertain identification for gamma spectroscopy.
X Lab-specific qualifier - must be fully described in case narrative and data summary package

The above sample is reported on an "as received" basis.

This data report has been prepared and reviewed in accordance with General Engineering Laboratories, Inc. standard operating procedures. Please direct any questions to your Project Manager, Stacy Griffin.

Reviewed by

Certificate of Analysis

Company : Los Alamos National Lab
Address : PO Box 1663
TA-3, Bldg. 271, Drop Pt. 01U
Los Alamos, New Mexico 87545
Contact: Keith Greene
Project: Groundwater Project

Report Date: September 23, 2002

Page 1 of 1

Client Sample ID: GW16-02-49357 13/14
Sample ID: 67047002
Matrix: Misc Liquid
Collect Date: 09-SEP-02
Receive Date: 13-SEP-02
Collector: Client

Project: LANL00401
Client ID: LANL004

Parameter	Qualifier	Result	DL	TPU	RL	Units	DF	AnalystDate	Time	Batch	Mtd.
Rad Liquid Scint											
LSC, Tritium Dist, Liquid											
Tritium		-27.3	170	50.7	250	pCi/L		CAF1 09/20/02	1157	202687	1

The following Analytical Methods were performed

Method	Description
1	EPA 906.0

Notes:
TPU is calculated at the 67% confidence level (1-sigma).
The Qualifiers in this report are defined as follows :

< Actual result is less than amount reported
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Reviewed by ______________

Certificate of Analysis

Company : Los Alamos National Lab
Address : PO Box 1663
TA-3, Bldg. 271, Drop Pt. 01U
Los Alamos, New Mexico 87545
Contact: Keith Greene
Project: Groundwater Project

Report Date: September 23, 2002

Page 1 of 1

Client Sample ID: GW16-02-49358 13/14
Sample ID: 67047003
Matrix: Misc Liquid
Collect Date: 09-SEP-02
Receive Date: 13-SEP-02
Collector: Client

Project: LANL00401
Client ID: LANL004

Parameter	Qualifier	Result	DL	TPU	RL	Units	DF	AnalystDate	Time	Batch	Mtd.
Rad Liquid Scint											
LSC, Tritium Dist, Liquid											
Tritium		-53.1	165	48.5	250	pCi/L		CAF1 09/20/02	1327	202687	1

The following Analytical Methods were performed

Method	Description
1	EPA 906.0

Notes:
TPU is calculated at the 67% confidence level (1-sigma).
The Qualifiers in this report are defined as follows :

< Actual result is less than amount reported
> Actual result is greater than amount reported
B Analyte found in the sample as well as the associated blank.
E Concentration exceeds instrument calibration range
H Holding time exceeded
J Indicates an estimated value. The result was greater than the detection limit, but less than the reporting limit.
P The response between the confirmation column and the primary column is >40%D
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The above sample is reported on an "as received" basis.

This data report has been prepared and reviewed in accordance with General Engineering Laboratories, Inc. standard operating procedures. Please direct any questions to your Project Manager, Stacy Griffin.

Reviewed by

AQUA-CLEAR™ AE

Acid Enhancer/Antifoulant

Description

AQUA-CLEAR AE is a liquid blend of acids and acid enhancers formulated to control bacterial slime contamination due to the presence of iron-related and sulphate-reducing bacteria.

Applications/Functions

- Remove the bio-mass matrix caused by bacterial fouling
- Reduce sulphur taste and odor in water
- Clean up well screens, pumps and distribution system
- Restore well productivity and reduce power and maintenance costs
- AQUA-CLEAR AE can be used in combination with AQUA-CLEAR MGA and other acids such as, hydrochloric (muriatic), phosphoric and sulfamic to enhance their effectiveness and to remove more difficult scale and incrustation

Advantages

- ANSI/NSF Standard 60 certified
- Safe to use on all plastics, rubber and metals
- Cost effective, efficient extended life treatment
- Improves water quality and renews well production rate
- Mitigates corrosion and equipment failure
- Reduces pumping costs

Typical Properties

Appearance	Light amber colored liquid
Specific gravity	1.08
pH of solution	1.1

Recommended Treatment

To treat bacteria fouling

- Record initial well water pH
- The preferred application method is to apply a solution of AQUA-CLEAR AE into the screened interval through a tremie pipe.

Recommended Treatment (continued)

- Mix AQUA-CLEAR™ AE with water at 6 - 12 ounces per gallon of water or 47 - 94 ml per liter of water and apply directly into screened interval with a tremie pipe. When utilizing this method, calculate the volume of water in the screened area and double the calculated volume to account for the water in the gravel pack and formation interface.

Note: The above concentration of* AQUA-CLEAR AE *is recommended for a complete reconditioning of an existing well.

- Calculation for volume in well:
- Gallons per foot = (diameter, inches)^2 x 0.042
- Liter per meter = (diameter, millimeters)^2 x 0.0008
- Displace solution into the well screen and formation, then surge, swab, agitate or jet well through screen and gravel pack for 20-30 minutes.
- Allow to stand in well for up to two hours and then repeat activity approximately every two hours for a period of 24 hours.
- Pump well to waste until at least 23 well volumes have been removed and well water pH is within 0.5 of original well pH.

Note: Wastewater can be neutralized by adding soda ash or lime.

- Chlorinate well and reconnect to water distribution system.

Caution: Never mix chlorine and* AQUA-CLEAR AE *in well.

- If necessary, AQUA-CLEAR AE may be poured directly into well as per treatment table, but results will not be as good as if applied via a tremie pipe.

Notes:

- ***In heavily encrusted wells, it is desirable to brush or scrape the casing and screen, then pump or airlift the debris to waste prior to treating with acid.***
- ***The following charts recommend a concentration of* AQUA-CLEAR AE *that is suitable for a typical maintenance treatment of an existing well.***

AQUA-CLEAR AE Application Amounts per 10 Feet of Standing Water					
Well Diameter (Inches)	**Gallons of Product**	**Well Diameter (Inches)**	**Gallons of Product**	**Well Diameter (Inches)**	**Gallons of Product**
2	0.04	12	1.27	24	5.10
4	0.14	14	1.73	26	6.00
5	0.22	16	2.26	28	6.93
6	0.32	18	2.87	30	7.96
8	0.57	20	3.54	36	11.46
10	0.88	22	4.28	48	20.40

AQUA-CLEAR™ AE Application Amounts per 10 Meters of Standing Water					
Well Diameter (millimeters)	**Liters of Product**	**Well Diameter (millimeters)**	**Liters of Product**	**Well Diameter (millimeters)**	**Liters of Product**
51	0.49	305	17.60	610	70.35
102	1.95	356	23.94	660	82.57
127	3.05	406	31.27	711	95.76
152	4.40	457	39.57	762	109.93
203	7.82	508	48.86	914	158.29
254	12.21	559	59.12	1219	281.41

Recommended Treatment (continued)

Note: The concentrations of **AQUA-CLEAR AE** ***shown in the previous tables do not take into account the 100% excess volume required to compensate for the water present in the formation interface and gravel pack. The previous tables only account for the product concentration required for the volume of water occupying a 10 foot or 10 meter section of a given size of screen.***

For other diameters:

- Gallons per foot = $(\text{diameter, inches})^2 \times 0.042$
- Liter per meter = $(\text{diameter, millimeters})^2 \times 0.0008$
- Gallons of AQUA-CLEAR AE = (gallons per foot x 8.34) x 0.0026
- Liters of AQUA-CLEAR AE = (liters per meter) x 0.0241
- Double the calculated volume in order to take into account the water present in the gravel pack and formation interface.

Treating Severe bio-fouling and scaling

- AQUA-CLEAR AE is used as an enhancer when mixed in the well with AQUA-CLEAR MGA
- One gallon of AQUA-CLEAR AE to every 10 pounds of AQUA-CLEAR MGA
- 3.8 liters of AQUA-CLEAR AE to every 4.5 kilograms of AQUA-CLEAR MGA

Safety

- Use recognized standard practices for handling corrosive and acidic materials (refer to Material Safety Data Sheet)
- Avoid skin and eye contact – flush with water
- Do not ingest and avoid prolonged inhalation
- When disposing of waste fluid make sure to comply with all federal, state and local regulations as applicable.

Packaging

AQUA-CLEAR™ AE is packaged in 1-gallon (3.8-liter) and 5-gallon (19-liter) plastic containers.

Shipping

- The following are required for commercial transport:
- Insurance policy must include an endorsement for transporting hazardous cargo.
- Vehicle driver must have a Hazmat endorsement on his/her Commercial Drivers License.
- Hazardous Materials Certificate of Registration issued by the U.S. Department of Transportation (renewable annually) is required.
- Consult the state in which operating for any additional requirements that may exist.
- No hazardous materials placard is required for shipments less than 1000 pounds.

Availability

AQUA-CLEAR AE can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you, contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products

A Product and Service Line of Halliburton Energy Services, Inc.

3000 N. Sam Houston Pkwy E.

Houston, TX 77032

Customer Service	(800) 735-6075 Toll Free	(281) 871-4612
Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

AQUA-CLEAR™ MGA

Modified Granular Acid

Description	AQUA-CLEAR MGA is a dry blend of granular acid and additives used in the removal of iron, manganese and carbonate scale. It retains strength longer than most liquid acids, which increases its cleaning capability.

Applications/Functions

- Disperse scale and incrustation
- Remove scale and incrustation from the water well screen, casing, gravel pack and pumping equipment
- Restore well production
- AQUA-CLEAR MGA can be used in combination with AQUA-CLEAR AE to remove more difficult scale and incrustation

Advantages

- ANSI/NSF Standard 60 certified
- Safe to use on all plastics, rubber and metals
- No harmful vapors
- Improves water quality (color, taste and appearance)
- Reduces equipment and piping failures due to scale build-up and corrosion
- Reduces pumping costs

Typical Properties

Appearance	Free-flowing, off-white granules
Specific gravity	2.00
pH (10% solution)	0.9
Solubility in water	Complete with slight to hazy turbidity

Recommended Treatment

- Record initial well water pH
- The preferred application method is to apply a solution of AQUA-CLEAR MGA into the screened interval through a tremie pipe.

Recommended Treatment (continued)

- Mix AQUA-CLEAR™ MGA with water at ½ - 1 pound per gallon of water or 0.06 - 0.12 kilograms per liter of water and apply directly into screened interval with a tremie pipe. When utilizing this method, calculate the volume of water in the screened area and double the calculated volume to account for the water in the gravel pack and formation interface.

Note: The previous concentration of* AQUA-CLEAR™ MGA *is recommended for a complete reconditioning of an existing well.

- Calculation for volume in well:
- Gallons per foot = (diameter, inches)^2 x 0.042
- Liter per meter = (diameter, millimeters)^2 x 0.0008
- Displace solution into the well screen and formation, then surge, swab, agitate or jet well through screen and gravel pack for 20-30 minutes.
- Allow to stand in well for up to two hours and then repeat activity approximately every two hours for a period of 24 hours.
- Pump well to waste until well water pH is within 0.5 of original well pH.

  Note: Wastewater can be neutralized by adding soda ash or lime
- Chlorinate well and reconnect to water distribution system.

  Caution: Never mix chlorine and* AQUA-CLEAR MGA *in well.
- If necessary, AQUA-CLEAR MGA may be poured directly into well as per treatment table, but results will not be as good as if applied in a dissolved form via a tremie pipe. The undissolved form will require more mechanical agitation.

Note:

- ***In heavily encrusted wells, it is desirable to brush or scrape the casing and screen, then pump or airlift the debris to waste prior to treating with acid.***

The following charts recommend a concentration of* AQUA-CLEAR MGA *that is suitable for a typical maintenance treatment of an existing well.

AQUA-CLEAR MGA Application Amounts per 10 Feet of Standing Water					
Well Diameter (Inches)	**Pounds of Product**	**Well Diameter (Inches)**	**Pounds of Product**	**Well Diameter (Inches)**	**Pounds of Product**
2	0.35	12	12.73	24	50.94
4	1.41	14	17.33	26	59.78
5	2.21	16	22.64	28	69.33
6	3.18	18	28.65	30	79.60
8	5.66	20	35.37	36	114.61
10	8.84	22	42.80	48	203.75

Recommended Treatment (continued)

AQUA-CLEAR™ MGA Application Amounts per 10 Meters of Standing Water					
Well Diameter (millimeters)	**Kilograms of Product**	**Well Diameter (millimeters)**	**Kilograms of Product**	**Well Diameter (millimeters)**	**Kilograms of Product**
51	0.53	305	18.97	610	75.90
102	2.11	356	25.83	660	89.10
127	3.29	406	33.73	711	103.31
152	4.74	457	42.69	762	118.60
203	8.43	508	52.71	914	170.77
254	13.18	559	63.78	1219	303.60

Note: The concentrations of* AQUA-CLEAR MGA *shown in the previous tables do not take into account the 100% excess volume required to compensate for the water present in the formation interface and gravel pack. The previous tables only account for the product concentration required for the volume of water occupying a 10 foot or 10 meter section of a given size of screen.

For other diameters:

- Gallons per foot = $(\text{diameter, inches})^2 \times 0.042$
- Liter per meter = $(\text{diameter, millimeters})^2 \times 0.0008$
- Pounds of AQUA-CLEAR MGA = (gallons per foot x 8.34) x 0.026
- Kilograms of AQUA-CLEAR MGA = (liters per meter) x 0.026
- Double the calculated volume in order to take into account the water present in the gravel pack and formation interface.
- AQUA-CLEAR AE can be used with AQUA-CLEAR MGA for iron bacteria treatment. When used together, utilize one gallon of AQUA-CLEAR AE for every 10 pounds of AQUA-CLEAR MGA or 0.84 liters of AQUA-CLEAR AE for every kilogram of AQUA-CLEAR MGA.

Safety

- AQUA-CLEAR MGA is safe to handle when in dry form, but when mixed with water it should be handled in accordance with recognized standard practices for handling corrosive and acidic materials (refer to Material Safety Data Sheet).
- Avoid skin and eye contact – flush with water
- Do not ingest and avoid prolonged inhalation
- When disposing of waste fluid make sure to comply with all federal, state and local regulations as applicable.

Packaging

AQUA-CLEAR™ MGA is packaged in 5-gal (19-liter) pails containing 50 pounds (22.7 kg) and in 1-gallon (3.8-liter) plastic jars containing 10 pounds (4.5 kg).

Shipping

The following are required for commercial transport:

- Insurance policy must include an endorsement for transporting hazardous cargo.
- Vehicle driver must have a Hazmat endorsement on his/her Commercial Drivers License.
- Hazardous Materials Certificate of Registration issued by the U.S. Department of Transportation (renewable annually) is required.
- Consult the state in which operating for any additional requirements that may exist.
- No hazardous materials placard is required for shipments less than 1000 pounds.

Availability

AQUA-CLEAR MGA can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products,

A Product and Service Line of Halliburton Energy Services, Inc.

3000 N. Sam Houston Pkwy E.

Houston, TX 77032

Customer Service	(800) 735-6075 Toll Free	(281) 871-4612
Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

AQUA-CLEAR™ PFD

Phosphate-Free Dispersant

Description

AQUA-CLEAR PFD is a concentrated liquid polymer dispersant that provides superior mud and sediment removal from the producing formation and gravel pack. This product is also a highly effective mud thinner. AQUA-CLEAR PFD contains no phosphates.

Applications/Functions

- Disperse mud, sediment and clay from the producing formation and gravel pack in the screened interval.
- Reduce viscosity and gel strength of drilling fluids

Advantages

- ANSI/NSF Standard 60 certified
- Reduces development time
- Increases well yield and capacity
- Safe to use on most plastics, rubber and metals
- Non-fermenting
- Reduces pumping costs

Typical Properties

• Appearance	straw colored liquid
• Specific gravity	1.2 to 1.4
• pH (neat)	6.5 to 7.5

Recommended Treatment

As a Well Development Aid

- Determine volume of water in screen area and double the calculated volume to account for water in gravel pack and formation interface ***or*** determine the static volume of water and add 50% excess.
- Once the water volume is determined, calculate the required treatment volume of AQUA-CLEAR PFD by the following formula:

  AQUA-CLEAR PFD (gal or L) = 0.002 x Water Volume (gal or L)

This equates to one gallon of AQUA-CLEAR PFD for every 500 gallons of water (0.2% by volume) or 2.0 liters of AQUA-CLEAR PFD for every cubic meter of water.

- Mix thoroughly before introducing into well.
- The preferable application method utilizes a tremie line with the product applied into the screened area.
- If necessary, the AQUA-CLEAR PFD/water solution may be poured into the well.
- Mixture should be thoroughly blended in well, then agitated using a surge

Recommended Treatment (continued)

and swab, jetting, or other developmental technique repeatedly every two hours for a period of up to 24 hours.

- Pump to waste until turbidity clears up and then connect well to distribution system.

As a Mud Thinner

- Start by adding one pint of AQUA-CLEAR™ PFD to 500 gallons of mud. Increase concentration until desired viscosity is achieved.

Well Capacity Chart (Gallons per Foot)					
Well Diameter (Inches)	**Well Capacity in Gallons/ft**	**Well Diameter (Inches)**	**Well Capacity in Gallons/ft**	**Well Diameter (Inches)**	**Well Capacity in Gallons/ft**
2	0.2	12	5.9	24	23.5
4	0.7	14	8.0	26	27.6
6	1.5	18	13.2	30	36.7
8	2.6	20	16.3	36	52.9
10	4.1	22	19.7	48	94.0

Well Capacity Chart (Liters per Meter)					
Well Diameter (millimeters)	**Well Capacity Liters/meter**	**Well Diameter (millimeters)**	**Well Capacity Liters/meter**	**Well Diameter (millimeters)**	**Well Capacity Liters/meter**
51	2.0	305	73.0	610	292.0
102	8.1	356	99.3	660	342.6
152	18.3	457	164.2	762	456.1
203	32.4	508	202.7	914	656.8
254	50.7	559	245.3	1219	1167.7

Note: The volumes in these tables show only the volume of water in a 1 foot or 1 meter section of a given size of screen. Excess volume must be included to account for water present in the formation interface and gravel pack.

Packaging

AQUA-CLEAR PFD is packaged in a 5-gal (19-liters) plastic pail or 1-gal (3.8-liter) plastic container.

Availability

AQUA-CLEAR PFD can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you, contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products

A Product and Service Line of Halliburton Energy Services, Inc.

3000 N. Sam Houston Pkwy E.

Houston, TX 77032

Customer Service	(800) 735-6075 Toll Free	(281) 871-4612
Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

BENSEAL®

Sealing and Plugging Agent

Description

BENSEAL is a granular (8-mesh), natural Wyoming sodium bentonite for use in sealing and grouting well casings and earthen structures. BENSEAL is not recommended for use as a drilling mud.

Applications/Functions

- Seal or grout plastic or steel casings in monitor and water well construction
- Seal or plug abandoned boreholes
- Seal leaking ponds, ditches and dams
- Soil stabilization
- Prepare BENSEAL/EZ-MUD® grouting system
- Aid in controlling loss of circulation

Advantages

- High swelling capacity
- Uniform particle size
- No heat of hydration
- Prevents commingling of aquifers and contamination from surface
- Forms a flexible seal to protect casing from corrosive contaminants
- Allows for hole re-entry
- ANSI/NSF Standard 60 certified

Typical Properties

• Appearance	Bluish to gray granules
• Dry screen analysis	85% of 8 mesh
• Volume, ft^3/sack	0.7 (as packaged)
• Specific gravity	2.6
• Permeability	less than 1×10^{-8} cm/sec (in fresh water)

Recommended Treatment

As a casing drill and drive operation:

1. Dig a cone-shaped depression around casing. Depression should be 6 - 8 inches (152-203 mm) larger than the outside diameter of the casing and 2 - 3 feet (60-75 cm) deep.
2. Keep cone-shaped depression filled with dry BENSEAL while driving the casing.

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Recommended Treatment (continued)

Note:

When drilling and driving a 4" (102mm) pipe, expect to use 2.5 pounds of BENSEAL® per foot of hole or 3.7 kilograms of BENSEAL per meter of hole.

Sealing ponds or earthen structures:

Depending on the native soil, disc in or mix 3 to 5 pounds of BENSEAL per square foot (14-24 kg/m^2) uniformly over the area to be sealed so that a 6-inch (~152 mm) blanket of soil and BENSEAL is formed. Do not neglect the edges of the dam or the sides/walls of the pond. This sealing blanket should then be compacted in place and as a further protection to the sealing blanket, 2 to 4 inches (51-102 mm) of local soil or sand should cover the sealing blanket and be compacted.
If the leaking area can be identified and isolated, an attempt can be made to broadcast BENSEAL uniformly at 4 to 6 pounds of BENSEAL per square foot (20-30 kg/m^2) of surface area into the water over the area of concern.
Note*:* Bentonite is more effective as a sealing agent when confined. Therefore, every effort should be made to cover the BENSEAL after it is broadcast with a 2-3 inch (51-76 mm) layer of sand. This will reduce the potential for dispersion into the water and un-yielded bentonite particles interfering with the gill action of fish.

Lost returns (moderate):

1. Begin with the pit full of mud.
2. Raise the pump suction off bottom and place a shovel next to it and slightly under suction.
3. Pour dry BENSEAL slowly into the space between shovel and suction and pump it down the hole.

Packaging

BENSEAL is packaged in 50-lb (22.7 kg) multiwall paper bags, containing 0.7 ft^3 (0.02 m^3).

Availability

BENSEAL can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products,
A Product and Service Line of Halliburton Energy Services, Inc.
3000 N. Sam Houston Pkwy. E.
Houston, TX 77032

Customer Service	(800) 735-6075 Toll Free	(281) 871-4612
Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

EZ-MUD®

Polymer Emulsion

Description

EZ-MUD, a liquid polymer emulsion containing partially hydrolyzed polyacrylamide/polyacrylate (PHPA) copolymer, is used primarily as a borehole stabilizer to prevent reactive shale and clay from swelling and sloughing. EZ-MUD is also added to low-solids drilling fluids to increase lubricity, fluid viscosity, and to improve carrying capacity of air/foam injection fluids.

Applications/Functions

- Stabilize reactive shale and clay formations
- Improve borehole stability
- Enhance slurry rheological properties
- Alleviate mud rings, bit balling and booting-off in clay formations
- Reduce drill pipe torque and pumping pressure
- Minimize rod chatter in diamond core drilling
- Create "stiff-foam" and maintain foam integrity
- Flocculate non-reactive solids in reserve pit at low concentrations

Advantages

- Mixes easily with minimum shear in fresh water
- Provides effective clay and shale stabilization with lower viscosity
- Imparts high degree of lubricity
- Non-fermenting
- Breaks down chemically with bleach (sodium hypochlorite)
- ANSI/NSF Standard 60 Certified

Typical Properties

Appearance	Thick, opaque white liquid
Density	8.5 lb/gal (1.02 g/cm^3)
pH (1 quart per 100 gallons water)	8.5
Flash point, PMCC °F, °C	>200 (>93.3)
Thermal stability, °F, °C	250 (121)

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Recommended Treatment

Approximate Amounts of EZ-MUD® Added to Drilling Fluid System			
Drilling Application/Desired Property	**Quarts/ 100 gal**	**Pints/bbl**	**Liters/m³**
Added to fresh water (To formulate a clay-free drilling fluid)			
• To stabilize reactive clay and shale	0.5 - 2.0	0.5 - 1.75	1.25 - 5.0
• To retard rod vibration, reduce torque and pumping pressure	1.0 - 2.0	1.0 - 1.75	2.5 - 5.0
Added to QUIK-GEL® or BORE-GEL™ Drilling Fluids			
• To retard reactive shale and clay and enhance lubricity	0.5 - 1.0	0.5 - 1.0	1.25 - 2.5
Added to injection liquid in air/foam drilling applications			
• To improve foam performance and hole conditions	0.5 - 1.0	0.5 - 1.0	1.25 - 2.5

Notes:

- Make-up water used to mix EZ-MUD should meet the following quality:
  total chloride less than 1500 ppm (mg/L)
  total hardness less than 150 ppm as calcium
  total chlorine less than 50 ppm
  water pH between 8.5-9.5
- Reduce total hardness of make-up water by adding soda ash (sodium carbonate) at 0.5 to 1 pound per 100 gallons (0.6 - 1.2 kg/m^3) of make-up water.
- EZ-MUD can be chemically broken down with liquid bleach in regular household concentration (5% sodium hypochlorite). Use one gallon of liquid bleach per 100 gallons (10 liters/m^3) of fluid formulated with EZ-MUD. Do not use perfumed liquid bleach or solid calcium hypochlorite.

Packaging

EZ-MUD is packaged in 5-gal (19-liter) and 1-gal (3.8-liter) plastic containers.

Availability

EZ-MUD can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products,
A Product and Service Line of Halliburton Energy Services, Inc.
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Houston, TX 77032

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Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

HOLEPLUG®

Graded Sodium Bentonite

Description

HOLEPLUG is a naturally occurring Wyoming sodium bentonite clay that is a sized and graded chip material used to seal and plug earthen boreholes.

HOLEPLUG is available in two particle size grades:

- HOLEPLUG 3/4" (100% of particles pass through 3/4" screen; all particles retained on 3/8" screen)
- HOLEPLUG 3/8" (100% of particles pass through 3/8" screen; all particles retained on 1/4" screen)

Applications/Functions

- Highly recommended for use in grouting annulus in all types of wells, particularly environmental monitoring well applications
- Seal above gravel packs
- Plug decommissioned boreholes
- Stemming shotholes
- Seal around conductor pipe
- Seal lost circulation zones
- Shut off artesian flow

Advantages

- Prevents entry of surface water into boreholes
- High swelling potential
- In situ swelling to provide a superior seal with excellent casing stabilization
- Easier to apply than pellets
- Cost effective
- Simple to apply, mixing not required
- Prevents vertical movement of fluids in the hole between porous zones
- Forms a permanent, flexible downhole seal
- Allows hole re-entry
- Rehydratable
- ANSI/NSF Standard 60 certified

Typical Properties

Volume of 50-lb (22.7 kg) sack	
HOLEPLUG 3/4"	0.73 ft^3 or 0.027 yd^3 or 0.021 m^3
HOLEPLUG 3/8"	0.70 ft^3 or 0.026 yd^3 or 0.020 m^3
Permeability	1.5 x 10^{-9} cm/sec (in fresh water)
Appearance	Beige to tan chips

Rev. 6/2001 · IDP 006

Recommended Treatment

Plugging and Stemming Drill Holes

Due to shipping and handling, a small amount of fine bentonite particles may be present. For optimum results, HOLEPLUG® should be poured over a mesh or screen with ¼" (6.4 mm) openings to "sift out" the smaller particles. The screen should be large enough (approx.1 yd^2 or $1m^2$) to be folded into a "V" shape to allow sifting while the product is being poured into the hole. Also, HOLEPLUG should be poured slowly. Allow approximately two minutes to pour a 50-lb (22.7 kg) bag.

1. Position the screen with the lower end placed over the borehole
2. Slowly pour HOLEPLUG down the "V" so that fine particles fall through the screen before the larger particles fall into the borehole
3. Fill hole as required (above static water level or to ground level)
4. Observe all regulatory specifications

Stopping loss of circulation and stabilizing unconsolidated formations

1. Pull drill pipe out of hole
2. Pour HOLEPLUG into hole to fill above problem zone
3. Drill ahead slowly with reduced pump pressure

Plugging flowing wells

Pour HOLEPLUG into hole until water flow subsides or hole is filled to surface.

Treatment Considerations

§ Adequate annular space should be present to allow for the placement of HOLEPLUG into the area of concern without bridging. It is recommended that a minimum annular space of two inches on either side of the outside dimension of the casing be present. This will facilitate the placement of tremie lines and reduce the potential of the HOLEPLUG bridging during pouring operations. The use of this product should always correspond with applicable federal, state and local well construction guidelines.

Application Amounts

Amounts of HOLEPLUG® Required for Plugging Applications				
Hole Diameter (inches)	Hole Volume (ft^3/ft)	Pounds HOLEPLUG Needed to Fill One Foot	Feet Filled by One Bag HOLEPLUG	Bags HOLEPLUG Needed to Fill 100 ft
2	0.022	1.6	32.6	3.2
2.5	0.034	2.4	20.5	5.0
3	0.049	3.5	14.3	7.0
3.5	0.067	4.8	10.4	9.6
4	0.087	6.3	7.9	12.6
4.5	0.110	7.9	6.3	15.8
5	0.136	9.8	5.1	19.6
5.5	0.165	11.9	4.2	23.8
6	0.196	14.1	3.5	28.2
6.5	0.230	16.6	3.0	33.2
7	0.267	19.2	2.6	38.4
7.5	0.307	22.1	2.3	44.2
8	0.349	25.1	2.0	50.2
8.5	0.394	28.4	1.8	56.8
9	0.442	31.8	1.6	63.6
9.5	0.492	35.4	1.4	70.8
10	0.545	39.2	1.3	78.4
11	0.660	47.5	1.1	95.0
12	0.785	56.5	0.89	113.0
15	1.227	88.3	0.57	176.6
18	1.767	127.2	0.39	254.4
20	2.182	157.1	0.32	314.2
25	3.409	245.4	0.20	490.8
30	4.909	353.4	0.14	706.8

Application Amounts (metric equivalents)

Amounts of HOLEPLUG® Required for Plugging Applications				
Hole Diameter (mm)	Hole Volume (m^3/m)	Kilograms HOLEPLUG Needed to Fill One Meter	Meters Filled by One Bag HOLEPLUG	Bags HOLEPLUG Needed to Fill 10 meters
51	0.002	2.3	9.87	1.0
64	0.003	3.6	6.31	1.6
76	0.005	5.2	4.38	2.3
89	0.006	7.0	3.22	3.1
102	0.008	9.2	2.47	4.1
114	0.010	11.6	1.95	5.1
127	0.013	14.4	1.58	6.3
140	0.015	17.4	1.30	7.7
152	0.018	20.7	1.10	9.1
165	0.021	24.3	0.93	10.7
178	0.025	28.2	0.81	12.4
191	0.029	32.4	0.70	14.3
203	0.032	36.8	0.62	16.2
216	0.037	41.6	0.55	18.2
229	0.041	46.6	0.49	20.5
241	0.046	51.9	0.44	22.9
254	0.051	57.5	0.39	25.3
279	0.061	69.6	0.33	30.7
305	0.073	82.8	0.27	36.5
381	0.114	129.4	0.18	57.0
457	0.164	186.4	0.12	82.1
508	0.203	230.1	0.10	101.4
635	0.317	359.5	0.06	158.4
762	0.456	517.7	0.04	228.1

Packaging

HOLEPLUG graded bentonite is packaged in 50-lb (22.7 kg) multiwall paper bags.

Availability

HOLEPLUG can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

Baroid Industrial Drilling Products,

A Product and Service Line of Halliburton Energy Services, Inc.

3000 N. Sam Houston Pkwy E.

Houston, TX 77032

Customer Service	(800) 735-6075 Toll Free	(281) 871-4612
Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

LIQUI-TROL™

Modified Cellulosic Polymer Suspension

Description

LIQUI-TROL is a free-flowing, liquid suspension of a modified natural cellulosic polymer, in an ultra-clean oil. LIQUI-TROL, when added to a QUIK-GEL® or BORE-GEL™ slurry, yields a drilling mud system suitable for drilling in water sensitive formations.

Applications/Functions

- Provide filtration control in fresh or brackish water-based drilling fluids
- Promote borehole stability in water sensitive formations
- Pour a slug of concentrate into drill string directly to sweep the hole
- Minimize rotational torque and circulating pressure
- Improve hole cleaning and core recovery
- Stiffen the foam to improve cuttings transport in air/gel-foam drilling
- Reduce air requirements, uphole velocity and borehole annulus pressure

Advantages

- Effective in fresh water, salt water and brackish water-based drilling fluids
- Effective in small quantities for filtration control
- Non-fermenting
- Compatible with other Baroid drilling fluid additives
- Resistant to harsh environments and contaminants

Typical Properties

• Appearance	Off-white, free-flowing, viscous fluid
• Specific gravity	0.98
• pH (0.3% solution)	9.0
• Flash point, PMCC °F (°C)	185, (85)
• Pour point, °F (°C)	35, (1.7)
• Freeze point, °F (°C)	-40, (-40)

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Recommended Treatment

- Using Venturi Mixer, or into vortex of a high-speed stirrer, add slowly and uniformly to entire circulating system.
- Used to slug down the rods to produce a high viscosity hole-cleaning sweep.

Approximate Amounts of LIQUI-TROL™ Added to Water-Based Fluids		
Desired Condition/Result		
Added to fresh or salt water	**qt/100 gal**	**liters/m^3**
• To stabilize water sensitive formation	4-6	10-15
• To reduce torque and lower circulating pressure	2-4	5-10
Added to QUIK-GEL® slurry (25 pounds per 100 gallons) (30 kilograms per m^3)	**qt/100 gal**	**liters/m^3**
• To enhance drilling mud fluid properties	1-2	2.5-5
• To improve drilling mud suspension and stabilization capabilities	2-4	5-10
Added to injection liquid in air/foam drilling	**qt/100 gal**	**liters/m^3**
• To improve foam performance and hole cleaning	1-4	2.5-10

Note:

<u>Salt water may require twice as much LIQUI-TROL as fresh water</u>. Preferably, LIQUI-TROL should be mixed in freshwater before it is added to salty water.

Packaging

LIQUI-TROL is packaged in 5-gal (19-liter) metal pails with an integrated, resealable pour spout.

Availability

LIQUI-TROL can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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N-SEAL™

Lost Circulation Material

Description

N-SEAL, acid soluble lost circulation material, is specially formulated extrusion spun mineral fiber. Due to its solubility in weak acids, N-SEAL is easily removed from production zones.

Applications/Functions

N-SEAL can be used in concentrations of up to 70 lb/100 gallons (86 kg/m^3) in slug treatments or as additive to entire system.

Advantages

- Acid soluble
- Easily-wetted
- Inorganic and non-fermenting

Typical Properties

• Appearance	Gray white fiber
• Specific gravity	2.6

Recommended Treatment

N-SEAL can be added directly through the hopper.

- For normal treatment to the active system, add 5-20 lb/100 gallons drilling fluid (6-24 kg/m^3)
- As a pill, add 20-70 lb/100 gallons of drilling fluid (24-86 kg/m^3)

N-SEAL is 95% acid soluble. To dissolve 1 lb of N-SEAL, treat with either

- 1-2 lb AQUA-CLEAR™ MGA (1-2 kg/kg)

  or
- 0.5-1 gal of 10% HCl/5% Acetic acid blend (1-2 liters/kg)

Packaging

N-SEAL is packaged in 30-lb (13.6 kg) multiwall paper bags.

Availability

N-SEAL can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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Houston, TX 77032

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Technical Service	(877) 379-7412 Toll Free	(281) 871-4613

Rev. 8/2001 · IDP 061

QUIK-FOAM®

High Performance Foaming Agent

Description

QUIK-FOAM, a proprietary blend of alcohol ethoxy sulfates (AES) which are biodegradable, is an effective foaming agent. QUIK-FOAM can be added to fresh, brine, or brackish water for air/foam, air/gel-foam, or mist drilling applications.

Applications/Functions

- Enhance the rate of cuttings removal
- Increase the ability of lifting large volumes of water
- Improve hole-cleaning capability of the airstream
- Reduce the sticking tendencies of wet clays, thereby eliminating mud rings and wall packing
- Reduce erosion of poorly consolidated formations
- Provide a technique for drilling in zones with lost circulation
- Increase borehole stability
- Reduce air-volume requirement
- Suppress dust during air drilling operation

Advantages

- ANSI/NSF Standard 60 Certified
- High quality, high expansion foam with a consistency similar to shaving foam
- High stability with excellent retention time
- Versatile and compatible with various types of make-up water
- Readily undergoes primary and ultimate (>99%) biodegradation
- Proven product for multi-discipline application

Typical Properties

Appearance	Light yellow, transparent liquid
Specific gravity	1.03
pH (0.5% solution)	7.1
Flash point, PMCC °F, °C	82, (28)
Pour point, °F, °C	0, (-18)

Recommended Treatment

Approximate Amounts of QUIK-FOAM® Added to Injection Water			
Application	**Amount/100 gal**	**Amount/bbl**	**Liters/m³**
Dry-air drilling (as a dust suppressant)	0.5 - 1 pints	0.2 - 0.5 pints	0.5 - 1.5
Mud-mist drilling in sticky clays	1 - 2 quarts	1 - 2 pints	2.5 - 5
Foam and gel-foam drilling	0.5 - 2 gallons	1.5 - 7 pints	5 - 20
As a slug to clean the annulus	1 pint*	0.5 pints*	0.5**

* in drill pipe, followed by 3 to 5 gallons of water; ** followed by 20 liters of water

Note:

Close product container immediately after use to avoid gelation of remaining QUIK-FOAM.

Product Make-ups for Air Drilling Injection Slurries				
Main Ingredient of Injection Slurry	**Water (gallons)**	**QUIK-GEL® viscosifier (pounds)**	**QUIK-TROL® polymer (pounds)**	**QUIK-FOAM foaming agent (% by volume)**
Foam Drilling System	100	…	…	0.02 - 3.0
Mixing/Injection Procedure Add QUIK-FOAM to injection water. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate. Increase amount of QUIK-FOAM as required to compensate for downhole water dilution				
Firm-Foam Drilling System	100	…	0.5 - 1	0.1 - 2.0
Mixing/Injection Procedure Mix polymer with water before adding QUIK-FOAM. 1-2 pints of EZ MUD® may be used as a substitute for QUIK-TROL. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate.				
Mud-Mist Drilling System	100	25	…	0.3 - 1.0
Mixing/Injection Procedure Mix viscosifier with water before adding QUIK-FOAM. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate. Resulting viscosity is 32-40 sec/qt as measured by Marsh Funnel.				
Gel-Foam Drilling System	100	12 - 15	1	0.3 - 1.0
Mixing/Injection Procedure Mix viscosifier and polymer with water before adding QUIK-FOAM. Inject into the air stream at a rate necessary to maintain hole stability and penetration rate. Resulting viscosity is 32-40 sec/qt as measured by Marsh Funnel.				

Note:

In some states, it is illegal to discharge any foreign substance into the water shed due to potential contamination of ground water. After use, the foam mixture must be localized in an earthen pit or some type of containment and allowed to biodegrade naturally.

Packaging QUIK-FOAM® is packaged in 5-gal (19-liter) plastic containers or in 55-gal (208 liter) drums.

Availability QUIK-FOAM can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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QUIK-GEL®

Viscosifier

Description

QUIK-GEL is an easy-to-mix, finely ground (200-mesh), premium-grade, high-yielding Wyoming sodium bentonite. QUIK-GEL imparts viscosity, fluid loss control and gelling characteristics to freshwater-based drilling fluids.

Applications/Functions

- Mix with fresh water to form a low-solids drilling flluid for general drilling applications
- Viscosify water-based drilling fluids
- Reduce filtration by forming a thin filter cake with low permeability
- Improve hole-cleaning capability of drilling fluids
- Mix with foaming agents to make "gel/foam" drilling fluids for air/foam drilling applications

Advantages

- ANSI/NSF Standard 60 certified
- Single-sack product and cost effective
- Provides lubricity for drilling fluids
- Mixes easily and quickly reaches maximum viscosity
- Yields more than twice as much mud of the same viscosity as an equal weight of API oilfield grades of bentonite

Typical Properties

• Appearance	Grey to tan powder
• Bulk density, lb/ft^3	68 to 72 (compacted)
• pH (3% solution)	8.9

Recommended Treatment

Mix slowly through a jet mixer or sift slowly into the vortex of a high-speed stirrer.

Approximate Amounts of QUIK-GEL Added to Freshwater

Application/Desired Result	lb/100 gal	lb/bbl	kg/m^3
Normal Drilling Conditions	15-25	6-10	18-30
Unconsolidated Formations	35-50	15-21	42-60
Make-Up For Gel/Foam Systems	12-15	5-7	14-18

- 1 bbl = 42 U.S. gallons

Additional Information

***Note*:**

- For optimum yield, pre-treat make-up water with 1-2 pounds of soda ash per 100 gallons of water (1.2-2.4 kg/m^3).

Rev. 6/2001 · IDP 009

Packaging QUIK-GEL® is packaged in 50-lb (22.7-kg) multiwall paper bags.

Availability QUIK-GEL can be purchased through any Baroid Industrial Drilling Products Distributor. To locate the Baroid IDP distributor nearest you contact the Customer Service Department in Houston or your area IDP Sales Representative.

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Geophysical Logging Report

Schlumberger Water Services
February 2003

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1.0 ABSTRACT

This report describes the borehole geophysical logging measurements acquired in characterization well R-16 by Schlumberger, logged in August 2002 just prior to well completion. It also presents the final processed results from these measurements and discusses the interpretation of these results. The logs were acquired from 145 ft to 1285 ft below ground surface, when the borehole was open (uncased) below 729 ft, drilled with 10.625 in diameter bit size, and contained 11.75 in outer diameter free-standing steel casing, used in casing-advance drilling with 12.25 in diameter bit size, above 729 ft (as measured by the logs). The primary purpose of the geophysical logging was to characterize the geologic/hydrogeologic section intersected by the well with emphasis on determining moisture content, perched groundwater zones, capacity for flow, and the stratigraphy/mineralogy of geologic units. A secondary purpose of the geophysical logging was to correlate seismic velocity versus depth for calibrating surface seismic surveys and to evaluate the borehole conditions such as borehole diameter versus depth, deviation versus depth, and degree of drilling fluid invasion. These objectives were accomplished by measuring, nearly continuously, along the length of the well: (1) water-filled porosity, (2) bulk density (sensitive to total water- plus air-filled porosity), (3) bulk electrical resistivity at multiple depths of investigation, (4) bulk concentrations of a number of important mineral-forming elements, (5) bedding orientation and geologic texture, (6) acoustic compressional wave velocity, (7) borehole inclination and azimuth, and (8) borehole diameter.

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

Most of the geophysical log measurements from Well R-16 provide good quality results that are consistent with each other through much of the borehole, although the quality of some measurements was degraded in sections where the borehole contains large washouts behind the free-standing casing, as well in an open hole zone directly below the bottom of the casing (731 ft). The measurements most affected by the adverse borehole conditions were ones that have a shallow depth of investigation and require close contact to the borehole wall—the bulk density and porosity measurements (particularly neutron and density porosity); instead of measuring formation properties they partially measure borehole fluid properties. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements are reduced. Thus, the integrated log analysis results (e.g. the optimized water-filled porosity log) are the most robust single representation of the geophysical log results—providing a wealth of valuable high resolution information on the geologic and hydrogeologic environment of the R-16 locale.

Important results from the processed geophysical logs in R-16 include the following:

1. The estimated water saturation (fraction of pore space filled with water) remains high through most of the logged section, never dropping below 50% of total pore volume. These processed log results, interpreted by themselves, suggest that the entire interval from 311–1285 ft may lie within the regional aquifer, below the water table, although the results could be an artifact of borehole conditions behind the casing within the cased hole section. No information about the water content or the water table above the well water level can be inferred from the geophysical logs; it is possible the well water level at the time of the logging (311 ft) corresponds to the water table.

2. In the open hole log interval (731–1285 ft) water content and total porosity averages around 32% of total volume, varying between 20% and 70%; the highest water content and total porosity occurring just below the bottom of the casing from 731–788 ft, ranging predominantly 40-70%, but the measured porosity could be elevated due to significant washouts in this interval. In the cased hole log interval (146–731 ft) there are many zones with unrealistically high estimated water content and total porosity (greater than 50%), likely due to washouts behind casing.

3. The integrated log analysis indicates highly heterogeneous mineralogy across the open hole log interval (731–1285 ft), but an overall high silica content (quartz and silica glass)—as high as 70% dry weight fraction. The inferred mineralogy includes significant, highly variable amounts of montmorillonite clay (0–70% by volume) throughout this interval. The processed logs indicate the geologic formation across this interval consists of a thinly-bedded sequence of silica-clastic sediments with highly variably grain size (alternating clay to sand/gravel beds). In the cased hole log interval an accurate estimate of the mineralogy from the processed logs is not possible due to the limited number of valid log measurements.

4. Interpreted bed boundaries across the imaged interval 768–1290 ft have dip azimuths (direction beds are dipping to) predominantly in the sector 230–330 degrees, with the highest concentration falling in the 10 degree range 290–300 degrees. The mean dip azimuth across this interval is 278 degrees. The interpreted bed boundaries have a wide range of dip angles (degrees of dip) from zero to 60 degrees, although more than 80% have dip angles less than 20 degrees and the average dip angle is 6 degrees. No fractures were discernable across this interval. Throughout this interval the electrical resistivity image shows a well-bedded, thinly-bedded alternating sand-silt-clay stratigraphy.

5. The borehole was enlarged and/or washed out in the top half of the open hole log interval (731–975 ft), but it appears only the severe washouts (as large as 19 in borehole diameter) just below the casing (731–804 ft) caused any possible impact on geophysical log quality. However, washouts were likely present in a number of zones within the cased hole log interval (145–731 ft), causing the log measurements to be heavily influenced by the annular space between the casing and formation. Borehole deviation is measured with the GPIT, run as part of the FMI across the interval 790–1290 ft. The maximum deviation of the borehole across the log interval it was measured (790–1290 ft) is only 2.5 degrees; the azimuth of deviation is to the southeast.

2.0 INTRODUCTION

Geophysical logging services were performed in characterization well R-16 by Schlumberger in August 2002, prior to initial well completion. The purpose of these services was to acquire in situ measurements that help characterize the borehole, near-borehole, and abutting geologic formation environment. The primary objective of the geophysical logging was to provide in situ evaluation of formation properties (hydrogeology and geology) intersected by the well. This information was (and is) used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to design the well completion, better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging services performed by Schlumberger in well R-16 were the

- Compensated Neutron Tool, (CNT*) to measure volumetric water content of the formation, which is used to evaluate moist/porous zones;
- Triple detector Litho-Density (TLD*) tool to measure formation bulk density , which is used to estimate total porosity;
- Array Induction Tool, version H, (AITH*) to measure formation electrical resistivity at five depths of investigation, which is used to evaluate drilling fluid invasion into the formation, presence of moist zones far from the borehole wall, and presence of clay-rich zones;
- Formation Micro-Imager (FMI*) tool to measure electrical conductivity images of the borehole wall in fluid-filled OH and borehole diameter with a two-axis caliper – used for evaluating geologic bedding and fracturing, including strike and dip of these features and fracture apertures, and rock texture;
- General Purpose Inclinometry Tool (GPIT*) to measure borehole deviation and azimuth in OH – used to evaluate borehole position versus depth and to orient FMI images;
- Elemental Capture Spectroscopy (ECS*) tool to measure elemental weight percent concentrations of a number of elements – used to characterize mineralogy and lithology of the formation;
- Digital Sonic Logging Tool (DSLT*) to measure acoustic compressional (P-wave) velocity – used to correlate seismic velocity versus depth for calibrating surface seismic surveys.

In addition, calibrated gross gamma ray (GR) was recorded with every service except the HNGS, for the purpose of depth matching the logging runs to each other. Table 2.1 summarizes the geophysical logging runs performed in R-16.

* Mark of Schlumberger

Table 2.1
Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole R-16

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Tool 3	Depth Interval (ft)
30-Aug-2003	Open hole below 729 ft Bit size of 10.625 in. Steel casing without any emplaced annular material above 729 ft. Casing OD of 11.75 in. Bit size of 12.25 in.	1	ECS	GR		698–1294.5 ft
Same	Same	2	CNT	TLD	GR	149–1285 ft
Same	Same	3	FMI	GPIT	GR	768.5–1289 ft
Same	Same	2	AITH	GR		732–1286 ft
Same	Same	5	DSLT	GR		732–1282 ft

2.1 Technology Description

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

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

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

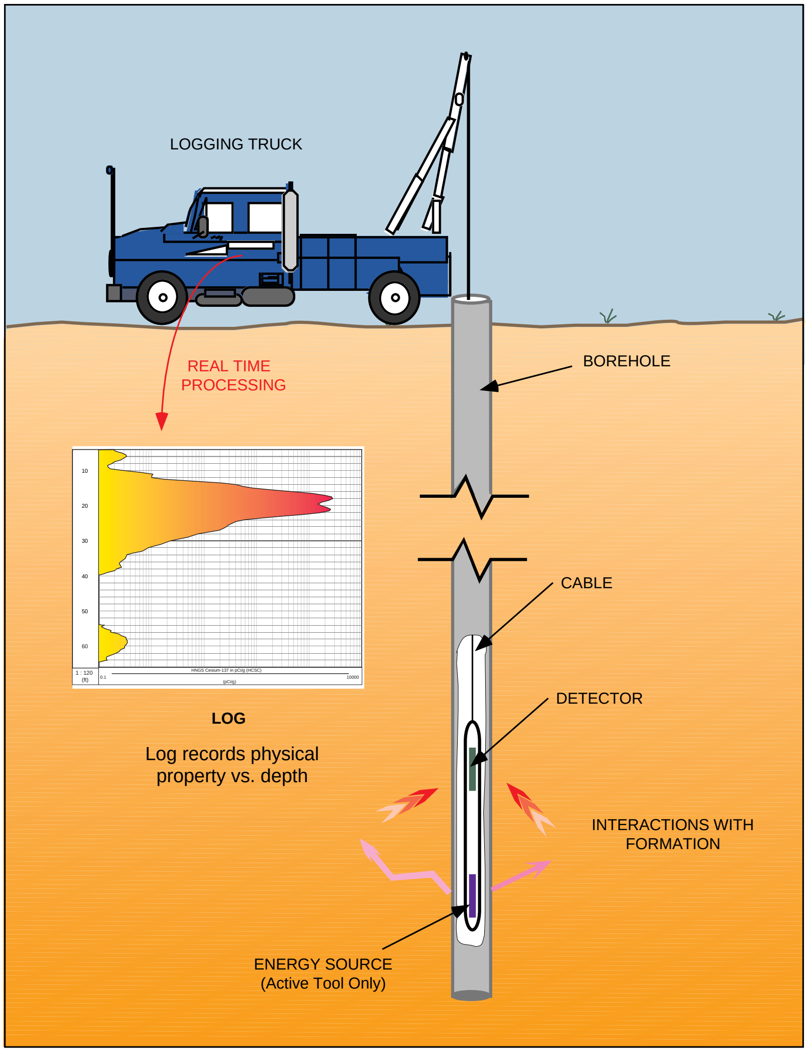

Figure 2.1: Schematic diagram of a wireline logging system in operation.

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

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

2.1.1 Compensated Neutron Tool (CNT)

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

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

Basic measurement specifications for the CNTG are shown below.

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

2.1.2 Triple Detector Litho-Density Tool (TLD)

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

The TLD also employs a third backscatter detector that improves the environmental correction for borehole washouts and rugosity, improves the dynamic range of the P_e, and has higher count rates and, thus, better measurement statistics, in hard rocks.

The TLD tool has a vertical resolution as high as 1.2 in. (3 cm) and a depth of investigation of 4 in. (10 cm). The tool is sensitive to changes in bulk density down to 0.01 g/cm3 and can be run in open hole and certain types of cased hole completions, and in both saturated and unsaturated formations.

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

A schematic diagram of a TLD-type sensor system is shown in Figure 2.2.

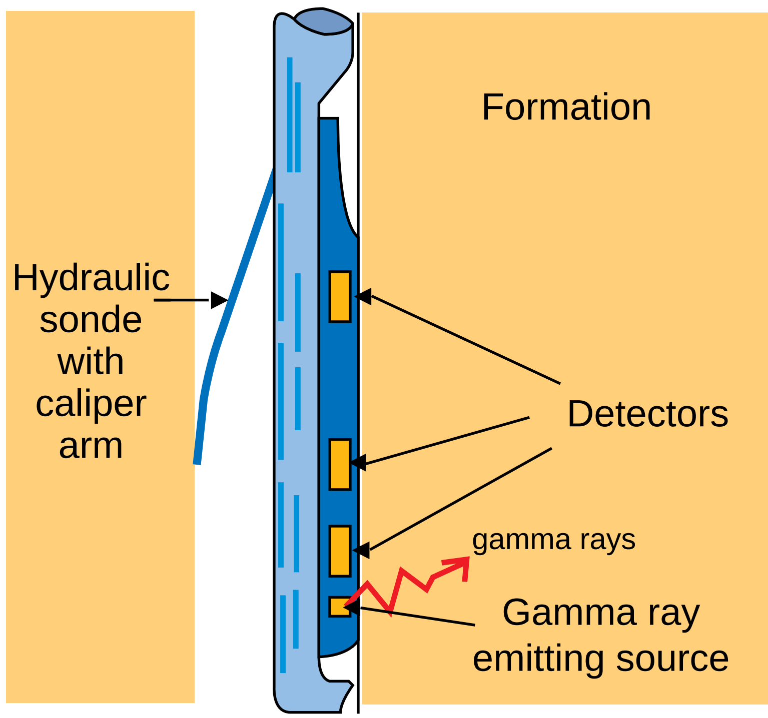

Figure 2.2. Schematic diagram of TLD-type density logging system.

2.1.3 Micro Cylindrically Focused Log (MCFL*)

With the Platform Express*, the MCFL measurements are integrated with the density sensors (TLD) in a single pad that presses against the formation. Consequently, the MCFL micro-resistivity measurement investigates the same volume of formation as the density measurement, with a vertical resolution of 2 in (5 cm). This high vertical resolution allows for enhanced thin bed analysis and fracture identification. The MCFL can be readily correlated and compared with the FMI* Formation Micro Imager high-resolution results. The MCFL measurements are based on three different depths of investigation, providing a highly focused micro-resistivity that is automatically corrected for standoff and mudcake during data acquisition.

The MCFL passes an electrical current into the borehole wall and, thus, requires water in the borehole and cannot be operated in cased hole. The MCFL uses a pad-like skid that is pressed against the borehole wall. Because the tool has a relatively shallow depth of investigation it can be severely affected by borehole washouts and rugosity.

* Mark of Schlumberger

Basic measurement specifications for the MCFL are shown below.

Range of measurement:	0.2–2000 Ohm.m
Repeatability (precision):	5% of measurement
Total measurement error:	20% from 0.2 to 2 Ohm.m 5% from 0.2 to 200 Ohm.m 20% from 200 to 2000 Ohm.m
Min/Max. hole size:	4.75 in./20 in.
Vertical Resolution:	2 in (5 cm); 8 in (20 cm) and 18 in (46 cm)
Depth of Investigation:	2 in. (5 cm.)

2.1.3 Array Induction Tool, Version H (AITH)

The AITH is a focused electrical induction probe that measures electrical conductivity/resistivity at multiple depths of investigation and vertical resolutions. The measurement is made by emitting an electromagnetic field that induces a current in the formation, subsequently creating a secondary electromagnetic field that is measured by the tool. The tool measures R- and X-signals from eight arrays, six of which operate at two frequencies simultaneously. The surface acquisition unit processes these raw measurements into five resistivity logs in real-time, each with matched vertical resolution and with median depths of investigation ranging from 10 to 90 in (25–230 cm). These depths of investigation change minimally over the entire range of formation conductivities. Each set of five logs is available in vertical resolution widths of 4, 2, and 1 ft (120, 60 and 30.5 cm).

From these measurements the AITH provides quantitative estimates of the following.

- True bulk formation resistivity–Formation resistivity is a function of water content, water salinity, and clay content.
- Drilling fluid invasion–In instances where the borehole fluid and formation fluid possess contrasting conductivity values, the depth of invasion of filtrate can be mapped and the zones with higher permeability can be identified.

The results are also useful for stratigraphic correlation. Vertical resolutions down to 1 ft (30.5 cm) show laminations and other formation structures with minimal environmental effects.

Since a current is not directly emitted into the formation, the measurement does not require water in the borehole and is accurate in the sub-saturated zone above the water table.

The AITH is largely insensitive to borehole environmental conditions since it has a deep depth of investigation.

Basic measurement specifications for the AITH are shown below and a schematic diagram of the basic tool setup in Figure 2.5.

Range of measurement:	0.2–2000 Ohm.m
Total measurement error:	2% of measurement
Min/Max. hole size:	4.75 in./20 in.
Vertical Resolution:	1 ft (30.5 cm), 2 ft (61 cm), 4 ft (122 cm)
Depth of Investigation:	10, 20, 30, 60 and 90 in. (median response) (25, 51, 76, 153, and 229 cm)

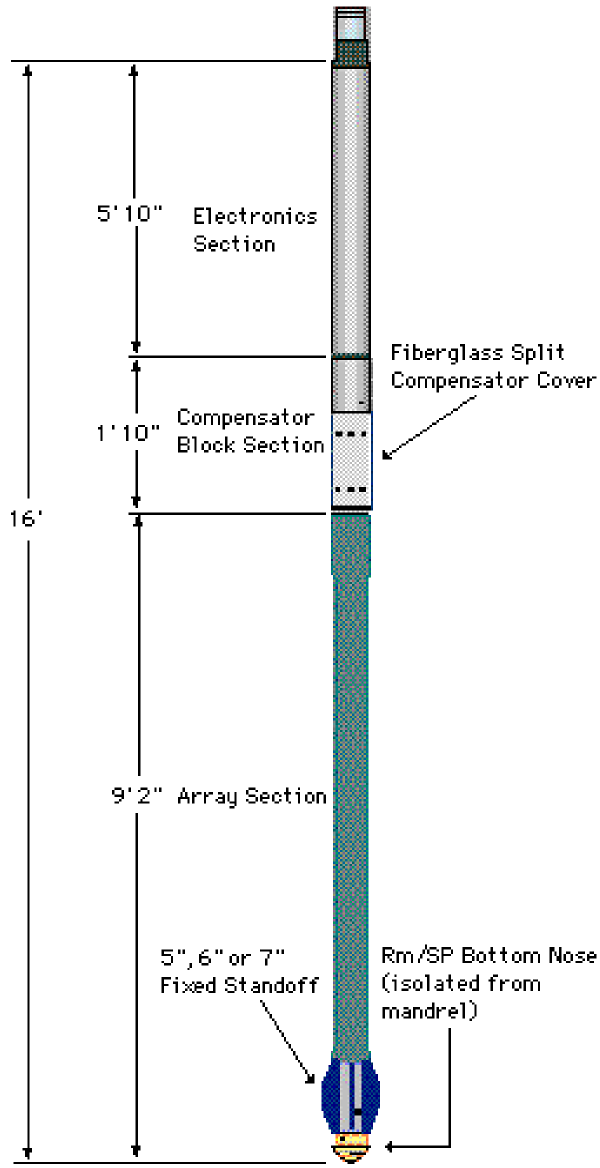

Figure 2.3. Schematic diagram of AIT tool, showing component lengths and standard logging setup.

2.1.4 Formation Micro Imager (FMI)

The FMI provides a high-resolution (≈ 0.2 in.) electrical image of the borehole wall using four pads with over 192 electrode buttons total. In addition the tool provides a two-axis caliper measurement. The position and orientation of the image is maintained through the utilization of down hole 3-axis inclinometer and 3-axis magnetometer; this information also provides a measurement of borehole deviation. These data permit the determination of orientation of any imaged borehole features. Features than can be identified and measured include:

- Bedding planes that permit the determination of structural strike and dip plus the orientation of stratigraphic features such as foresets

- Structural features such as faults, folds, or soft-sediment deformation
- Non-bedding features such as fractures, burrowing, vugs, pebbles, concretions, fissures, stylolites, etc. Fracture orientation and aperture can also be determined.

The FMI passes an electrical current into the formation and, thus, requires water in the borehole and cannot be operated in cased hole. However, unlike borehole video, borehole water opacity has no effect on the measurement. The measurement is best when the four pads are in physical contact with the borehole wall, but is still obtainable when the pad(s) lose contact. The tool general handles washouts quite well.

Basic measurement specifications for the FMI are shown below and a photo of the sensor section of the tool in Figure 2.4.

Statistical precision (σ):	Inclination – ±0.2°; Orientation – ±2°
Vertical Resolution:	<0.4 in (1 cm)
Min/Max. hole size:	6.25 in. / 21 in.

Figure 2.4. Photo of FMI sensor section, showing the four caliper arms, each containing a main pad and extender pad with electrode buttons (copper colored plates).

2.1.5 General Purpose Inclinometry Tool (GPIT)

The GPIT uses a three-axis magnetometer and a three-axis accelerometer to accurately define the tool system of axis with respect to the earth's gravity (G) and magnetic field norm (F). Since both vectors (G and F) are well defined within the earth's system, a relation can be established between the tool system and that of the earth. The logging truck computer system uses the three components of the magnetometer and accelerometer to calculate deviation, azimuth and relative bearing.

The GPIT is run as part of the FMI, but can be run by itself, as well, for open hole deviation surveys.

2.1.6 Elemental Capture Spectrometer (ECS)

The ECS geophysical logging tool provides accurate measurements of the relative weight % concentrations of specific elements in the formation (such as Si, Ca, Fe, S, Ti, and Gd). The measurements have sensitivities as low as 1% dry weight concentration or less (dependent on which element and the logging speed).

The ECS actively emits a large flux of neutrons into the region surrounding the probe using a 16-Ci Americium-Beryllium chemical neutron source. The neutrons collide and interact with atomic nuclei, prompting the release of gamma rays having characteristic energies, depending on the specific element and type of interaction. These induced gamma rays are measured by the tool’s scintillation gamma ray detector, resulting in a total gamma energy spectrum measurement when the sum of gamma rays generated from all neutron-element interactions is considered. A weighted least squares algorithm is used to decompose the gamma ray contributions from specific elements based on a known detector spectral response, or standard, for each important constituent. The relative spectral contribution of the elements, or relative elemental yields, are converted to relative elemental dry weight % based on measurement characteristics of the tool type and an assumed mineralogical assemblage (oxide closure model).

The ECS employs a large shielded BGO spectral gamma ray detector that has very good measurement statistics. Because of the large detector, the ECS has a 5 in (127 mm) diameter.

The ECS works in either open or cased hole, and is relatively insensitive to borehole conditions, since the measurement is a dry matrix measurement (fluid contributions to the measurement are removed in the standard processing) and the radius of investigation is about 1 ft (30 cm). Thus, the ECS provides robust direct concentration measurements of important mineral-forming elements and provides robust mineralogical/lithologic control, very useful for developing a continuous mineralogy model along the borehole section when integrated with other wireline logs and core analysis results.

The statistical precision of the ECS measurement, for the standard suite of elements it measures, is shown in Table 2.2.

Table 2.2
ECS elemental weight % statistical precision at 100 ft/hr (30 m/hr) logging speed and 1.5 ft (0.46 m) depth average

Element	Weight % Precision (1 σ)
Si	0.63
Fe	0.07
S	0.27
Ca	0.57
Ti	0.03
Gd (ppm)	0.65
H	0.12

2.1.7 Digital Sonic Logging Tool (DSLT)

Sonic wireline logging tools are used to measure acoustic wave properties of the geologic formation intersected by a borehole. The main property measured by sonic tools is the acoustic wave velocity or slowness (also referred to as delta travel time or DT) versus depth. Most sonic tools, including the DSLT, measure sonic velocity / DT for the compressional / primary acoustic wave, but more advanced tools also measure the shear wave and sometimes Stoneley wave as well. The compressional wave velocity / DT helps in determining porosity, lithology, formation correlation, and formation mechanical properties. Compressional wave velocity / DT and transmitter to receiver transit times are also used in computing integrated transit time and generating synthetic seismograms, which help convert the time measurement made during surface seismic exploration to depth. Finally, in cased wells that are cemented in place, the amplitude of the first arrival is used in cement bond logging (CBL) to determine the quality of cement bond behind the casing.

The basic operation of the DSLT is as follows: A series of monopole transmitters in the DSLT (two in the typical tool setup) sequentially generate an acoustic wave that travels through the borehole fluid column (mud or water is required in the borehole), reaches the formation and travels through the formation. As the wave travels through the formation it generates waves in the borehole fluid. Therefore, for the borehole fluid, the wave traveling in the formation acts like a moving source. This source is moving at a velocity larger than the wave propagation velocity in the borehole fluid because the wave propagation velocity in the formation (a solid body) is larger than the wave propagation in the borehole fluid. As a result of this fast moving source, a head wave will be generated and will be detected by a series of sonic receivers (four in the typical tool setup) positioned a distance from the source.

The DSLT digitizes the recorded waveforms downhole and uses the Digital First Arrival Detection (DFAD) algorithm to measure the first arrival transit time (TT) and amplitude of the received signal. Older generation analog sonic tools use less reliable analog first arrival detection algorithms. In addition the DSLT can transmit the digitized waveform to surface using telemetry where the full waveform can be recreated and analyzed. Borehole compensated (BHC) compressional slowness (DT) is later computed from the measured transit times of the different DSLT transmitter-receiver couples.

3.0 METHODOLOGY

This section describes the methods employed by Schlumberger for performed geophysical logging services in Well R-16, including the following stages/tasks:

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

3.1 Acquisition procedure

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

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

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

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

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

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

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

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3.2 Log Quality Control and Assessment

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

CNT

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

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

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

TLD

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

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

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

AITH

The Schlumberger calibration and verification methodology for the AITH consists of an initial base calibration and verification, routine shop verification, and a well site before and after electronics verification. The initial base calibration constitutes the determination of electronic gains and offsets and hardware adjustments for each individual tool so that the tool electrical induction response can be used to generate accurate electrical resistivity measurements. The initial base calibration has to be performed

only once for all AITH tools produced to develop a tool specific response catalog for electronic gains and offsets.

The routine shop verification consists of taking measurements with specially designed calibration sleeves to verify correct measurement response as well as internal electronic gain checks.

Well site before and after checks consist of internal electronic checks.

ECS

The Schlumberger calibration and verification methodology for the ECS, similar to the CNT, consists of an initial base calibration and verification, routine shop verification, and a well site before and after verification. The initial base calibration constitutes the development of gamma ray energy elemental spectral standards for each of the elements the tool measures, accounting for environmental and tool design-specific conditions that influence the measurements. The initial base calibration only has to be performed once for all ECS tools produced to develop a tool response catalog for individual elements that the ECS is sensitive to.

The routine shop verification consists of taking measurements in a specially designed water tank to verify correct identification of the spectral hydrogen peak and performing detector electronic gain checks using the small cesium internal check source.

Well site before and after checks consist of background internal electronic checks.

3.3 Processing Procedure

After the geophysical logging job was completed in the field and the data archived, the data were downloaded to the Schlumberger processing center. There the data were processed, in the stated order to (1) correct the measurements for near-wellbore environmental conditions and redo the raw measurement field processing for certain tools using better processing algorithms, (2) depth match and merge the log curves from different logging runs, and (3) model the near-wellbore substrate lithology/mineralogy and pore fluids through integrated log analysis. Separately the FMI electrical image was processed to produce scaled and normalized high resolution images which were interpreted to identify geologic features and compute fracture apertures. Afterwards an integrated log montage was built to combine and compile all the processed log results.

Environmental Corrections and Raw Measurement Reprocessing

If required, the field log measurements were processed to correct for conditions in the well, including fluid type (water or air), presence of steel casing, and (to a much lesser extent) pressure and temperature. Basically these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In R-16 the log measurements requiring these corrections are the CNT porosity, TLD density, ECS elemental concentrations, and gross gamma ray logs.

The version of the CNT used in R-16 only measures thermal neutrons, not epithermal neutrons. To make neutron porosity measurements in air-filled hole measurement of epithermal neutrons is required. Thus, above 311 ft (water level in the well) the neutron porosity measurement is not valid. However, the thermal neutron porosity measurement was corrected for the casing above 731 ft.

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

The raw ECS elemental yield measurements include the contribution of iron from steel casing and hydrogen from fluid in the borehole. The processing consists of subtracting these unwanted contributions from the raw normalized yields, then performing the normal elemental yields-to-weight fraction processing. The contribution to subtract is a constant baseline amount (or zoned constant values if there are bit/casing size changes), usually determined by comparing the normalized raw yields in zones directly below/above the borehole fluid/casing change. The water level in R-16 at the time of logging was high (311 ft), well above the top of the ECS log. Thus, the hydrogen baseline subtraction was determined from best judgment and experience from other Los Alamos wells, as well as by comparing the ECS derived water content with the CNT and TLD porosities to check relative agreement between the different measurements. The ECS was run only in the open hole section of R-16, except for the very top of the log interval.

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

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

Depth-Matching

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

Integrated Log Analysis

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

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

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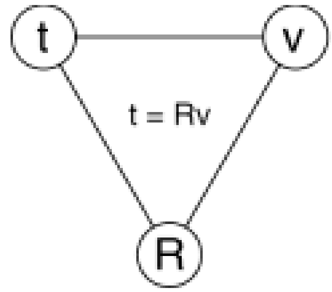

Figure 3.1. Schematic diagram of ELAN mathematical model

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

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

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

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

A key point in properly using ELAN is the input of the most representative parameter values possible. For certain minerals (e.g., quartz) most parameter values are fairly constant and easy to select; other mineral (e.g., clays) present the potential for wide variability in many parameters due to compaction (sonic slowness, bulk density) and minor changes in chemistry (Th, K, Fe, Al, H). Estimation of parameters, or their changes with depth, can be a major limitation to ELAN. Geochemical logs (acquired in R-16) are particularly helpful measurements for ELAN since they provide abundances of a number of important mineral forming elements.

ELAN simultaneously solves for multiple volume components using different tools. Some tools are highly influenced by parameters other than mineralogy and pore fluid (e.g., sonic), including geomechanical properties and borehole environmental conditions that cannot be corrected for in pre-processing. The dependency of the tool measurements on these conditions depends on the specific tool type and measurement. Including log measurements that are being highly influenced by these properties in the ELAN can significantly affect the solution, since variations in the logs are not only due to changes in mineralogy or pore fluid—what ELAN is trying to estimate. For example, if some of the logs are sensitive to washouts ELAN will try to match the log response in washed out zones by increasing the amount of porosity in the model, possibly at the expense of matching other log measurements used in the analysis that are not as sensitive to washouts (although the latter can be rectified by assigning more weight to the better logs). If some of the logs are affected by borehole conditions, or other properties not explicitly

accounted for in the model (e.g. formation water salinity), while the others are not, often there is a poor match between modeled and actual log measurements in intervals where there are variations in these unaccounted for properties. Sometimes the solution can also become unstable—the model results change significantly due to only minor variations in log responses. In such cases it may be better to not include such measurements in the ELAN. In short, ELAN results are only as accurate at depicting true formation mineralogy and fluid content as the input logs are sensitive to the formation components included in the model—and insensitive to components/properties not included.

The tool measurements, volume components and parameters used in the ELAN analysis for R-16 are provided in Table 3.1. To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (146–1285 ft), as many as possible of the processed logs were included in the analysis, with less weighting applied to less robust logs. Not all the tool measurements shown in these tables are used for the entire interval analyzed, as not all the measurements are available, or of good quality, across certain sections of the borehole. For example, in the cased hole section AITH resistivity and TLD volumetric photoelectric effect, as well as ECS elemental concentrations, have to be removed from the analysis since they are invalid in casing and not measured in the cased section, respectively. To accommodate fewer tool measurements certain model constituents are removed from the analysis in some intervals. Most notably, only a few minerals are retained in the model above 698 ft, where there is no ECS geochemical measurements.

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

Table 3.1
Tool measurements, volumes, and respective parameters used in the R-16 ELAN analysis .

Volume / Tool Measurement	Air	Water	Hornblende	Hypersthene	Labradorite	Silica Glass	Heavy Mafic Minerals	Augite	Montmorillinite	Pyrite	Orthoclase	Quartz
Bulk density (g/cc)	–0.19	1.00	3.11	3.55	2.65	2.2	4.0	3.08	2.02	4.99	2.58	2.64
Thermal neutron porosity (ft^3/ ft^3)	-0.05	1.00	0.06	0.04	-0.01	0.0	0.07	0.02	0.65	0.01	-0.01	0.0
Volumetric photoelectric effect	0	0.40	12	20.2	7	4.2	65.00	23.8	4.4	82.1	7.3	4.8
Resistivity (ohm-m)	Very high	4.3	Very high	Very high	Very high	Very high	Very high	Very high	1.3	Very high	Very high	Very high
Dry weight silicon (lbf / lbf)	0.0	0.0	0.21	0.24	0.24	0.47	0.18	0.23	0.26	0	0.3	0.47
Dry weight calcium (lbf / lbf)	0.0	0.0	0.09	0.0	0.09	0.0	0.0	0.10	0.01	0.0	0.0	0.0
Dry weight iron (lbf / lbf)	0.0	0.0	0.07	0.20	0.0	0.0	0.22	0.11	0.02	0.47	0.0	0.0
Dry weight sulfur (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.53	0.0	0.0
Dry weight aluminum (lbf / lbf)	0.0	0.0	0.005	0.01	0.0	0.0	0.0	0.048	0.0	0.0	0.0	0.0
Dry weight titanium (lbf / lbf)	0.0	0.0	0.068	0.0	0.16	0.0	0.0	0.175	0.11	0.0	0.104	0.0
Weight water (lbf / lbf)	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.18	0.0	0.0	0.0
Dry weight clay (lbf / lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Gross gamma ray (gAPI)	0.0	0.0	230	50	50	20	50	30	300	0	500	25

4.0 RESULTS

This section describes the final log results from the borehole geophysical logging performed by Schlumberger in R-16. These results have been processed, if required, to correct for the well environment and depth-match the logs from different tool runs in the well. Also, some of the results are not directly measured logs but are instead logs generated from integrated analysis of measured logs. In the following description of the results, an attempt is made to organize the discussion based on the evaluation needs addressed by the logs instead of describing each log independently.

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

First the R-16 final processed log results are presented as a number of useful summary logs and described according to specific evaluation needs addressed by the geophysical logs. Next, the integrated log montage is described track by track.

4.1 Water-Filled Porosity

One of the primary objectives of the geophysical logging was to evaluate volumetric water content (water-filled porosity) to identify wet and porous water-producing zones. The CNT neutron porosity, which measures water content in both open and cased hole below the borehole water level, was the primary service run for this purpose. The TLD bulk density measurement provides useful information about total porosity—the sum of water-filled and air-filled porosity. The ECS geochemical measurement provides secondary information on water content through non-standard processing to obtain hydrogen weight fraction. In Well R-16 the CNT neutron porosity appears to be adversely impacted by fluid-filled voids behind the free-standing casing that was present above 731ft at the time of logging—yielding unrealistically high water content values across many intervals.

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

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

The ELAN water-filled porosity results for R-16 are shown as part of the summary logs in Figure 4.1 (solid dark blue curve and blue shading in the second track from the right), and in expanded form, as part of the integrated log montage provided in Appendix E of the LANL R-16 Well Completion Report (compressed form shown in Figure 4.7). The summary log also displays

- ELAN total (water- and air-filled) porosity (red hashed curve in track furthest to the right);
- Air-filled porosity (dotted red shading in track furthest to the right);
- ELAN water saturation (dotted light blue curve in track furthest to the right);

- Gross gamma ray (solid brown curve in first track from left);
- Apparent bulk chlorinity estimate from the ECS (dashed green curve and green shading in first track from left) and
- Caliper with measured washouts (dashed black curve with washouts shown by pink shading).

Borehole water level in R-16 at the time of the August 2002 geophysical logging was 311 ft (using the AITH log run as the depth reference), as indicated by the thermal neutron porosity measurement becoming negligible in air-filled hole in which the measurement cannot be made. Below the bottom of the free-standing casing (731 ft) the processed log results clearly indicate fully-saturated conditions throughout most of the open hole interval (see Figure 4.1). In the cased hole section there is significant uncertainty in defining where true 100% saturation of the virgin geologic formation occurs from the geophysical logs (corresponding to conditions within the regional aquifer or in perched zones above, where the entire pore space is filled with water)—due to the unknown condition of the borehole beyond the casing and it's effects on the log measurements. The measurements are detrimentally affected by the existence of an annulus and voids between the free-standing casing and borehole wall (resulting in elevated water content and water saturation if the annulus is filled with water or drilling fluid, and lowered water content/saturation if filled with air), as well as drilling damage to the formation. Even without such borehole conditions, the water saturation estimate from the geophysical logs is very sensitive to the matrix grain density. The processed log results indicate high water content throughout the cased hole section, ranging from 20–90%. The estimated water saturation across this interval is also high, but from 400–575 ft water saturation is consistently below 100%, reaching as low as 50%. Although this could be an indication of the top of the regional aquifer groundwater level, the integrated log analysis results indicate full saturation again above 430 ft (note that above the well water level at 311 ft the ELAN model is forced to have full saturation due to the absence of any moisture log).

These processed log results, interpreted by themselves, suggest that the entire interval from 311–1285 ft may lie within the regional aquifer, below the water table, although the results could be an artifact of borehole conditions behind the casing within the cased hole section. No information about the water content or the water table above the well water level can be inferred from the geophysical logs; it is possible the well water level at the time of the logging (311 ft) corresponds to the water table.

Other significant features of the R-16 porosity summary log are as follows:

- In the open hole log interval (731–1285 ft) water content and total porosity averages around 32%, varying between 20% and 70%.
- In the open hole log interval the highest water content and total porosity occurs just below the bottom of the casing from 731–788 ft, ranging predominantly 40-70%, but the measured porosity could be elevated due to significant washouts in this interval.
- In the cased hole log interval (146–731 ft) zones with unrealistically high estimated water content and total porosity (greater than 50%), likely due to washouts behind casing:
  - 150–152 ft
  - 170–181 ft
  - 220–340 ft
  - 346–359 ft
  - 372–377 ft
  - 380–390 ft

- 404–429 ft
- 447–454 ft
- 559–576 ft
- 606–608 ft
- 621–637 ft
- 657–665 ft
- 674–676 ft
- 682–730 ft

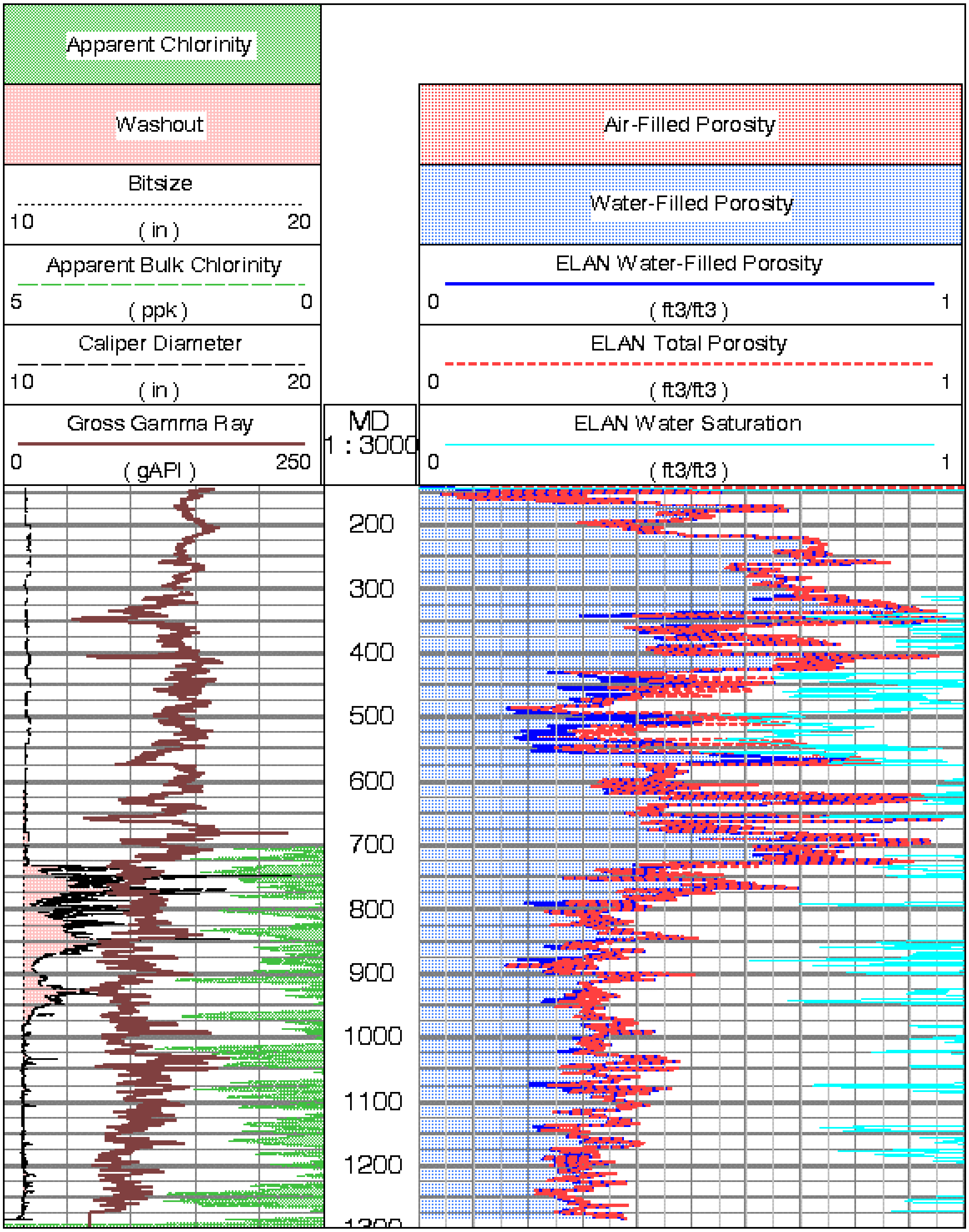

Figure 4.1. **Summary porosity logs in R-16 borehole from processed geophysical logs, interval 146–1285 ft, with caliper, gross gamma, apparent chlorinity, and water saturation logs. Porosity and water saturation logs are derived from the ELAN integrated log analysis.**

4.2 Density

Bulk density and P_e log measurements, obtained from the TLD geophysical tool in R-16, provide information about the formation total porosity (water and air) and lithology, respectively. The TLD measurements are typically only valid in open borehole, but there is a cased hole bulk density algorithm that has been adapted and implemented at Los Alamos. This algorithm was used in R-16 since much of the log interval (146–731 ft) contained free-standing casing at the time of logging. There is no way to rectify the P_e measurement in casing; thus, P_e could not be utilized in the cased hole section of R-16. The bulk density is the only measurement in the suite of logs run in R-16 (and most geophysical log measurements) that is directly sensitive to all formation components: air-filled porosity, water-filled porosity, and rock matrix. Total air plus water-filled porosity in the vadose zone can be estimated from density porosity when it is computed in conjunction with a water content measurement (e.g., neutron porosity or ECS hydrogen weight fraction) and an independent measurement/assumption of grain density. The processed bulk density curve, as well as the apparent grain density derived from the ELAN analysis, are displayed as part of the summary logs (third track from left) for R-16 in Figure 4.2. Another applicable curve in this summary log is gross gamma ray (for stratigraphic correlation), shown in the farthest left track.

The bulk density and P_e measurements have a shallow depth of investigation and, thus, the measurements can be severely affected by borehole washouts and standoff from the formation (i.e. when measuring through casing where there is an annulus between the casing and formation)—measuring the density and P_e of water/air instead of the formation. The TLD has a strong caliper arm to push the sensor pad against the borehole wall, but, with casing in the well, the pad can only be pushed as far as the inner wall of the casing and, thus, cannot compensate for any annulus between the casing and formation. The bulk density measurement is made using three detectors; the tool tries to compensate for differences in the near and far detector response by performing an internal processing correction, which is shown on logs as a density correction curve, flagged when it goes above/below quality cutoff thresholds. This flag is used as an indication when the TLD measurement quality may be compromised. However, the density correction cannot be computed for cased hole. In the R-16 open hole section (731–1285 ft) the density correction is flagged only in the interval directly below the casing bottom, from 731–804 ft, generally correlating with washouts or rugose hole. Even in this interval the processing correction largely seems to be properly compensating for the borehole conditions.

The cased hole bulk density measurement in R-16 is much less robust than if the logs were run in open hole, since the casing in place at the time of logging was emplaced as freestanding pipe to support the borehole while drilling progressed. If the formation did not collapse around the casing a water, drilling fluid, or air filled annulus would remain between the casing and the formation. In such a scenario the bulk density measurement, which is very sensitive to standoff from the borehole wall, would be heavily influenced by the water/air in the annulus—biasing the measurement towards the density of water (1 g/cc) or air (close to 0 g/cc). Unfortunately, there is no automatic internal processing flag to indicate when the casing-to-formation standoff is problematic to the measurement. However, there are zones in the R-16 log interval were the bulk density and total porosity (derived from bulk density) are unreasonably low and high, respectively, for natural geologic formations—indicating the likelihood of problematic standoff. Intervals where density porosity is above 50% and/or bulk density is below 1.75 g/cc include (directly correlative with the unreasonably high water content estimates noted in the previous section): 150–152 ft, 170–181 ft, 220–340 ft, 346–359 ft, 372–377 ft, 380–390 ft, 404–429 ft, 447–454 ft, 559–576 ft, 606–608 ft, 621–637 ft, 657–665 ft, 674–676 ft, 682–730 ft. In these intervals the bulk density measurement may not be representative of true formation bulk density and, consequently, the total porosity estimate may not be valid due to fluid- or air-filled annulus behind casing. Even in these intervals it is not certain that the

bulk density is unrepresentative since certain volcanic tuff lithology types in the Los Alamos area are known to have very high porosity and low bulk density.

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

The P_e measurement is a good indicator of lithologic changes. In this geologic setting, an increase in P_e above 3 is a good indicator of the presence of heavy, probably mafic, minerals; an increase to 5 is an indicator of a very heavy mineral-rich bed ("heavy" most likely corresponding to iron interval), such as a massive basalt lava flow. P_e is consistently below 3 throughout the open hole interval (731–1285 ft); the measurement is not valid in cased hole. The optimized ELAN mineral model results (see the integrated log montage, fourth track from the right) indicate highly heterogeneous mineralogy, but an overall high silica content (quartz and silica glass)—as high as 70% dry weight fraction.

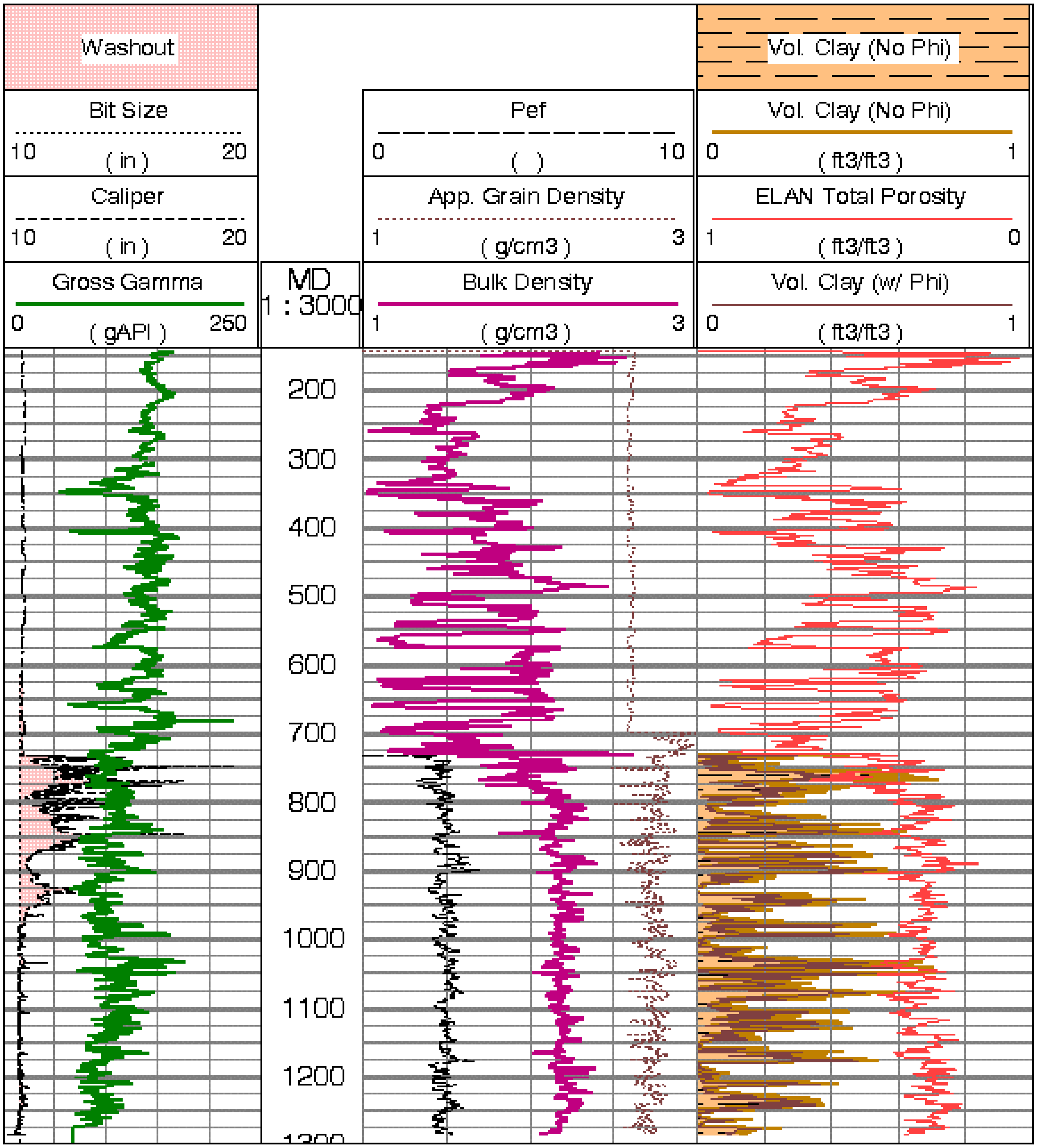

Figure 4.2. Summary bulk density and volume clay logs in R-16 borehole from processed geophysical logs, interval 149–1285 ft. Also shown– caliper, gross gamma, apparent grain density, and total porosity logs.

4.3 Volume of Clay

Volume of clay is of interest particularly because clay can have a large influence on hydraulic conductivity as well as the groundwater geochemistry. Unfortunately, there is no way to directly measure volume of clay from geophysical logging. It can only be derived indirectly from other log measurements, preferably a

combination of measurements. The ECS provides important information about the collection of all minerals present since it measures the concentration of a number of important mineral-forming elements. Unfortunately, it cannot directly measure aluminum—the most important clay-forming element—although an indirect geochemical-derived estimate of aluminum can be made that is valid in siliciclastic rocks. The P_e measurement from the TLD provides additional information about bulk mineralogy, since it is sensitive to changes in the atomic number of mineral-forming elements, but it doesn't provide any specific information about clay minerals. The AIT resistivity measurement is sensitive to clay since clay has a low bulk resistivity; however, the measurement is also sensitive to pore water salinity and porosity.

Considering the above-mentioned circumstances, the most robust way to estimate clay volume from the geophysical logs is to use all the logs together to solve for the full mineral and fluid volumetric composition of the formation. This type of analysis constitutes an inverse problem and can be performed using the ELAN program. Clay volume, along with the remaining matrix and fluid volumes, was estimated using the ELAN integrated log analysis approach with a fairly comprehensive mineral/fluid model containing montmorillonite, silica glass/quartz, orthoclase (representative of alkali feldspars), labradorite (representative of plagioclase feldspars), hypersthene, hornblende, augite, an analog representative of heavy mafic minerals (such as magnetite and olivine), water, and air. This set of volume constituents was chosen to provide a representative cross-section of possible major minerals in the R-16 geologic environment. However, montmorillonite, the one clay mineral, had to be eliminated from the mineral assemblage above 731 ft in the ELAN analysis in order for the model to be constrained. This requirement was precipitated by the need to eliminate the P_e and resistivity measurements from the analysis above this depth due to the presence of steel casing. Thus, the forced assumption of the ELAN model is that there is no clay above 731 ft.

The ELAN volume model result, as well as the dry wt% model result, is shown as part of the integrated log montage, provided in Appendix E of the LANL R-16 Well Completion Report (and in Figure 4.4 in compressed form). The volume of clay derived from these ELAN results for R-16, presented both as (1) fraction of the total (matrix plus pore space) volume and (2) fraction of just the matrix volume (pore space subtracted out), are shown as part of the summary logs (farthest track to the right) in Figure 4.2. The analysis predicts significant, highly variable amounts (0–70% by volume) of clay (montmorillonite) throughout the entire interval where clay is included in the ELAN model (731–1285 ft). The ELAN inferred clay zones correlate well with zones of higher estimated aluminum content from the ECS, lower electrical resistivity from the AIT measurement, and higher electrical conductivity beds in the FMI electrical conductivity image (see the integrated log montage). The processed logs indicate the geologic formation across this interval consists of a thinly-bedded sequence of silica-clastic sediments with highly variably grain size (clay to sand/gravel beds) and bed dip magnitudes.

4.4 Integrated Log Montage

This section describes the integrated geophysical log montage for R-16: It includes a discussion of (1) what each log curve represents and how it was derived and (2) what are some of the most notable features in the displayed logs. The montage is provided in Appendix E of the LANL R-16 Well Completion Report and is shown compressed in Figure 4.4. A description of each log curve in the montage follows—organized under the heading of each track, starting from track 1 on the left-hand side of the montage. Note that the descriptions in this section focus on what the curves are and how they are displayed; the specific characteristics and interpretations of the R-16 geophysical logs are provided in the previous section.

Track 1–Depth

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

Track 2–Basic Logs

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

- gamma ray (thick black), recorded in API units and displayed on a scale of 0 to 250 API units;
- two calipers from the FMI (thin dotted and dashed pink) and one from the TLD (thin solid pink) with bit size as a reference (dashed-dotted black) to show washout (pink shading), recorded as hole diameter in inches and displayed on a scale of 8 to 18 in.;
- spontaneous potential or SP (dashed red – valid only below the borehole water level), recorded in millivolts and displayed on a relative scale of -50 to 25 millivolts;
- bulk chlorinity (dashed green with green shading), recorded in parts per thousand (ppk) and displayed on a scale of 5 to 0 ppk (left to right); and
- borehole deviation displayed as a tadpole every ten feet (light blue dots and connected line segments) – the "head" marks the angular deviation from vertical at that particular depth, on a scale of zero to 5 degrees, and the "tail" shows the azimuth of the deviation, true north represented by the tail facing straight towards the top of the page.

The gross gamma curve from the AITH tool run is used as the depth reference for all other logs. Gross gamma measurements are sensitive to radioactive elements in the near wellbore environment, which are potassium, thorium, and uranium—assuming the gamma activity is from naturally occurring sources. The response of the gross gamma curves is the result of the formation chemical makeup, including lithology/mineralogy. This gross gamma measurement was environmentally corrected for borehole conditions, including borehole fluid (water/air) and presence/absence of the thick free-standing casing.

The two FMI caliper curves are from the tool's two independent, orthogonal sets of arms containing the four electrode pads; the TLD caliper curve is from the single arm that is used to press the tool sensor against the borehole wall. They have been depth-matched to the AITH tool run using gross gamma ray as a reference. The calipers show a significant amount of washout in the interval 731–968 ft. The washouts and hole rugosity do appear to affect measurement quality in some instances, especially the porosity tools—possibly resulting in unrepresentative elevated water-filled porosity in some zones adjacent to large washouts. The caliper is constant above 731 ft in R-16 since the well was cased for casing-advance drilling at the time of logging. However, washouts could have been present behind the casing and likely were, as evidenced by very high porosity measurements.

The bulk chlorinity log is estimated from the ECS and is considered an experimental measurement of average water chlorine content seen by the tool—assuming all the chlorine is dissolved in water.

The SP log is measured with the AIT and is only valid in the open hole section.

Borehole deviation is measured with the GPIT, run as part of the FMI across the interval 790–1290 ft. The maximum deviation of the borehole is about 2.5 degrees; the azimuth of deviation is to the southeast.

Track 3–Resistivity

The third track displays the resistivity measurements from the AITH, spanning most of the open hole section. All the resistivity logs are recorded in units of ohmmeters and displayed on a logarithmic scale of 2 to 2000 ohm-m.

Six electrical resistivity logs from the AITH are displayed:

- Borehole fluid resistivity (solid orange curve)
- Bulk electrical resistivity at five median depths of investigation–10 in. (black solid), 20 in. (long-dashed blue), 30 in. (short-dashed red), 60 in. (dashed-dotted green), and 90 in. (solid purple)–each having a two-foot vertical resolution.

The area between the 10 in. and 90 in. resistivity curves, representing radial variations in bulk resistivity (potentially from invasion of drilling fluids), is shaded:

- blue when the 10 in. resistivity is greater than the 90 in. resistivity (labeled “resistive invasive”) and
- yellow when the 90 in. resistivity is greater than the 10 in. resistivity (labeled “conductive invasive”).

A high vertical resolution (~8 in.), shallow-reading (~2 in.) micro-resistivity log from the MCFL is also displayed in this track (solid brown curve). This log measures the bulk electrical resistivity of the “invaded zone” – the zone directly surrounding the borehole that is typically heavily influenced by the drilling process, most notably the replacement of connate formation water with drilling fluids.

The resistivity logs vary across the full-scale range from 2.5 and 60 ohm-m, exhibiting a lot of character up and down the borehole. Zones where all the resistivity logs shift left significantly, corresponding to relative low resistivity readings, are likely associated with intervals where clay is present in the formation; in general, the lower resistivity values correlate quite well with increases in the gross gamma ray and the ECS aluminum content estimate. Conversely, zones where the resistivity logs shift right significantly, corresponding to relative high resistivity readings, are likely associated with intervals where clay is not present in significant amounts and the average pore size is larger; where there is separation between the resistivity curves with different depths of investigation (yellow shading) there has been drilling fluid invasion of these intervals – indicative of permeable material.

Track 4–Porosity

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

- CNT water-filled thermal neutron porosity (dashed sky blue curve)– valid only in the water-filled borehole (below 311 ft);
- Geochemical estimated water-filled porosity derived from the ECS hydrogen weight % measurement (dotted purple);
- Sonic porosity derived from compressional wave interval transit time (DT) using the Raymer-Hunt-Gardner equation (long dashed maroon);

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

The ECS water-filled porosity is environmentally corrected for borehole conditions–particularly casing and borehole fluid (water)–as is the CNT water-filled porosity and bulk density (used for density porosity), the latter only requiring casing correction. The ELAN results are based on fully corrected logs. All the porosity logs are depth matched to the AITH tool run using the gross gamma ray measurement obtained in every logging run.

Track 5–Density

The fifth track displays the:

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

Grey area shading is shown where the P_e increases above 3 (indicating the presence of heavy, possibly mafic, minerals) and orange shading is shown where the density correction is greater than the absolute value of 0.25 (indicating the density processing algorithm had to perform a major correction to the bulk density calculation). The bulk density log is environmentally corrected for casing, but cannot be corrected for any annulus. All these logs have been depth matched to the AITH tool run using the gross gamma ray log.

Track 6–Sonic Interval Transit Time and Velocity

The sixth track from the left displays the compressional acoustic wave interval transit time (black curves), on a scale of 240 to 40 microseconds per foot, and velocity (brown curves), on a scale of 0 to 10000 feet per second, measured with the DSLT tool. The logs from two passes are displayed for both properties.

The log results have been depth matched to the AITH tool run using the gross gamma ray log.

Track 7–Sonic Waveform

The seventh track from the left displays the measured acoustic waveform from one of the receivers in the DSLT tool, displayed as a “variable density log” (VDL) with red as peaks and blue as troughs on a scale of 90 to 1180 microseconds. The VDL has NOT been depth matched to the other logs because doing depth shifting the large array representing the waveform is computationally difficult.

Track 8–Sonic Integrated Transit Time

The eighth track from the left displays the integrated compressional acoustic wave transit time (solid black curve) starting from the bottom of the sonic log, derived from the DSLT tool measurements and displayed on a scale of 0 to 150000 microseconds.

Track 9–Hydraulic Conductivity

Track 9 displays an estimate of intrinsic hydraulic conductivity (K) derived from the ELAN analysis (dotted light blue curve), presented on a logarithmic scale of 10^{-3} to 10^{7} centimeters per second (cm/s) multiplied by 10^{6}: The intrinsic K assumes full water saturation. The hydraulic conductivity values have been multiplied by 10^{6} to reduce the number of significant figures, since in cm/s the values are very small. Thus, when using these hydraulic conductivity estimates for quantitative analysis, the values should be divided by10^{6} or converted to other units.

Area color shading has been applied from the left side of the track up to the ELAN intrinsic K estimate, with different colors corresponding to ranges of K with representative clastic grain sizes:

- Grey–Clay K range (10^{-9} to 10^{-7} cm/s)
- Brown–silt K range (10^{-7} to 10^{-5} cm/s)
- Orange–silty-sand K range (10^{-5} to 10^{-3} cm/s)
- Yellow–clean sand K range (10^{-3} to 10^{-1} cm/s)
- Blue–gravel K range (10^{-1} to 10 cm/s)

Track 10– FMI Image (Dynamic Normalization)

Track 10 displays the FMI image, measured across the interval 768–1290 ft and processed with dynamic normalization so that small-scale electrical resistivity features are amplified in the image. (With dynamic normalization the range of electrical resistivity amplitudes – colors in the image – is normalized across a small moving depth window.) The image is fully oriented and corresponds to the inside of the borehole wall unwrapped, such that the left-hand side represents true north, half-way across the image is south, and the right-hand side is north again. The four color tracks in the image correspond to portions of the borehole wall contacted by the four FMI caliper pads; the blank space in between is the portion of the borehole wall not covered by the pads.

Also displayed are the interpreted bed boundaries (thin blue sinusoids), cross-bedding (red sinusoids), and unconformable bed boundaries (purple sinusoids).

Track 11– FMI Bedding and Fractures

Track 11 displays the interpreted bed boundaries and fractures picked from the FMI image, shown in two ways:

- Individually as blue (bed boundary), red (cross bedding), and brown (unconformable bed boundary) tadpoles at the depths the bedding plane or fracture crosses the midpoint of the borehole – where the “heads” (circles) represent the dip angle and the “tails” (line segments) represent the true dip azimuth (direction the bed is dipping towards);

- Summed as dip azimuth rose histograms (green/red colored fan plots for bed boundaries/fractures) every 50 ft. – where the number of bed boundaries/conductive fractures having a dip direction within a particular sector are summed, thus highlighting the predominant dip directions.

Track 12– FMI Image (Static Normalization)

Track 12 displays the FMI image again, but in a different way – processed with static normalization to highlight larger scale features and trends. (With static normalization the range of electrical resistivity amplitudes – colors in the image – is normalized across the entire length of the log interval.) Again, the FMI image was measured across the open hole interval 768–1290 ft.

Tracks 13 to 17– Geochemical Elemental Measurements

The narrow tracks 13 to 17 present the geochemical measurements iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), estimated aluminum (Al), titanium (Ti) and gadolinium (Gd), and hydrogen (H) and bulk chlorinity (Cl)—from left to right respectively, in units of dry matrix weight fraction (except H in wet weight fraction, Cl in ppk). All these measurements were obtained from the ECS and are depth matched to the AITH tool run using the gross gamma ray log.

Track 18–ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 18 displays the results from the ELAN integrated log analysis (the matrix portion)–presented as dry weight fraction of mineral types chosen in the model:

- Montmorillonite clay (brown/tan)
- Quartz (yellow with small black dots)
- Silica glass (orange)
- Orthoclase or other potassium feldspar (lavender)
- Labradorite or other plagioclase feldspar (pink)
- Hypersthene (purple)
- Hornblende (forest green)
- Augite (maroon)
- Heavy mafic/ultramafic minerals, such as magnetite or olivine (dark green)
- Pyrite (cross-hatched red).

Track 19–ELAN Mineralogy-Pore Space Model Results (Wet Volume Fraction)

Track 19 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- Montmorillonite clay (brown/tan)
- Clay-bound water (checkered gray-black)
- Quartz (yellow with small black dots)
- Silica glass (yellow with large black dots)

- Orthoclase or other potassium feldspar (lavender)
- Labradorite or other plagioclase feldspar (pink)
- Pyrite (tan with large black squares).
- Hypersthene (purple)
- Hornblende (forest green)
- Augite (maroon)
- Heavy mafic minerals, such as magnetite or olivine (dark army green)
- Air (red)
- Water (white)

Track 20–Summary Logs

Track 20, the second track from the right, displays several summary logs that describe the fluid and air-filled volume measured by the geophysical tools, including water saturation:

- Optimized estimate of total volume fraction water from the ELAN analysis (solid dark blue curve and area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);
- Optimized estimate of water saturation (percentage of pore space filled with water) from the ELAN analysis (thick dashed-dotted purple curve);
- Water saturation as calculated directly from the bulk density and neutron porosity using a grain density of 3.05 g/cc (dotted light blue curve), 2.65 g/cc (long-dashed light blue curve), and 2.25 g/cc (dashed light blue curve)–with light blue shading between the 2.25 and 3.05 g/cc saturation curves to show the range;

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

Track 21–Depth

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

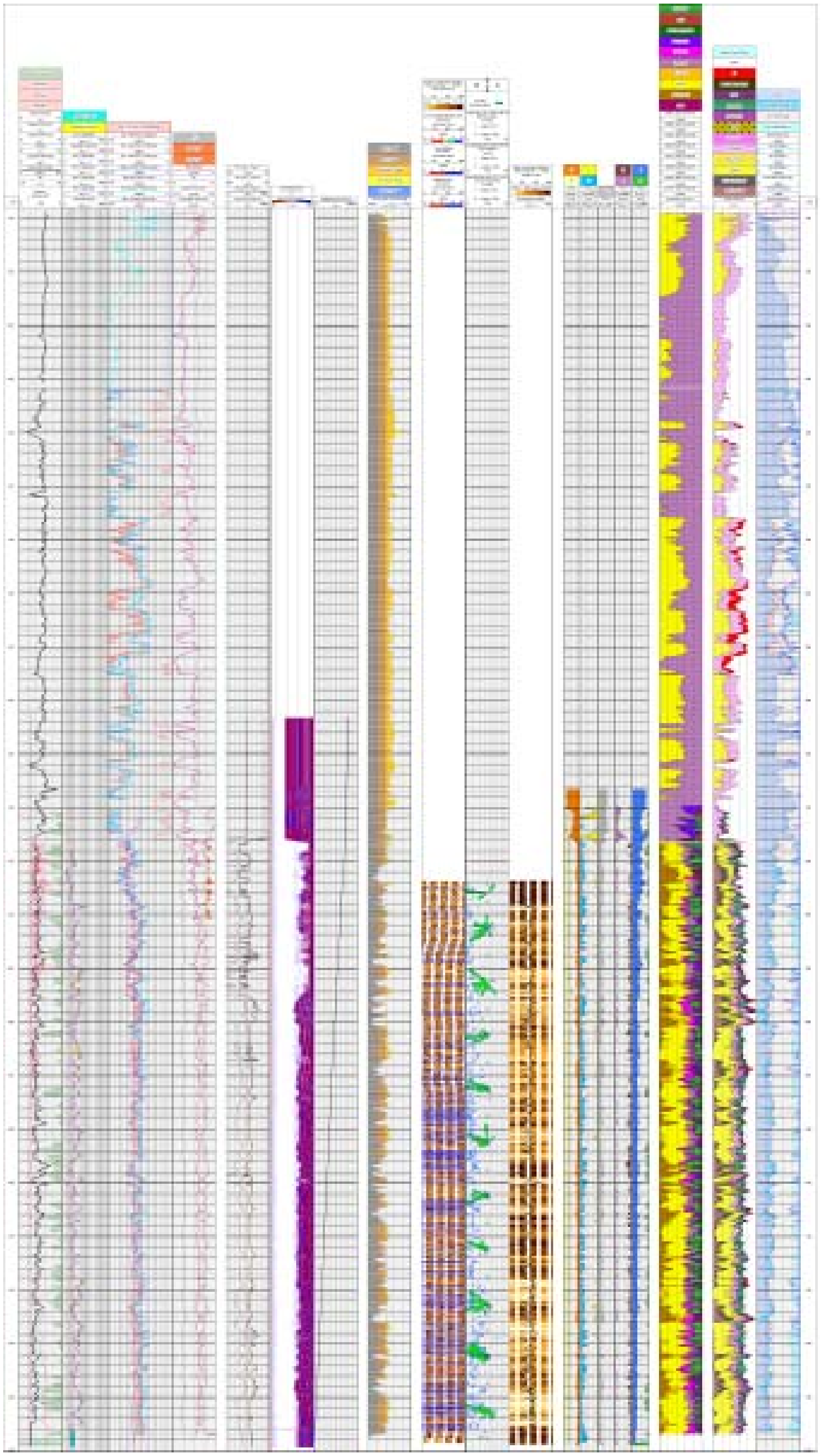

Figure 4.3. Geophysical log montage showing a compressed composite of all processed logs, including ELAN models, from borehole R-16.

5.0 REFERENCES

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~VERSION INFORMATION
VERS. 2.0: CWLS LOG ASCII STANDARD VERSION 2.0
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~WELL INFORMATION
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STOP .FT [illegible]: STOP DEPTH
STEP .FT [illegible]: STEP
NULL. [illegible]: NULL VALUE
COMP. N/A: COMPANY
WELL. N/A: WELL
FLD. N/A: FIELD
LOC. N/A: LOCATION
PROV. N/A: PROVINCE
SRVC. N/A: SERVICE COMPANY
DATE. N/A: LOG DATE
UWI. N/A: UNIQUE WELL ID
~CURVE INFORMATION
DEPT .FT: DEPTH
GAMM .CPS: GAMMA
~PARAMETER INFORMATION
[illegible]
~A

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179.919	43.5449
180.083	46.1582
180.247	59.7148
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180.74	37.9121
180.904	29.7324
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181.56	43.4375
181.724	43.6191
181.888	40.4375
182.052	35.209
182.216	43.6875
182.38	19.1543
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182.872	44.041
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183.856	40.2129
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185.497	37.7559
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185.989	32.2266
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187.301	24.8135
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187.957	30.2139
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188.285	29.5762
188.449	18.7852
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1003.57	63.6172
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1002.75	50.2168
1002.58	43.4297
1002.42	64.8438
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1002.09	50.0762
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1001.43	70.5742
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806.553	79.9453
806.389	92.8711
806.225	64.2813
806.061	61.4277
805.897	71.5938
805.733	103.27
805.569	54.3242
805.405	84.1289
805.241	86.7539
805.077	72.0703
804.913	79.1797
804.749	53.9551
804.585	66.7539
804.421	71.3555
804.257	93.8828
804.093	68.7773
803.929	97.0859
803.765	92.543
803.6	68.5313
803.436	84.3906
803.272	66.4258
803.108	87.7188
802.944	58.1621
802.78	60.1152
802.616	58.5684
802.452	74.9883
802.288	80.9375
802.124	59.7891
801.96	76.1992
801.796	49.4375
801.632	80.9414
801.468	71.6719
801.304	73.8242
801.14	90.4258
800.976	75.2813
800.812	82.5117
800.648	71.8477
800.484	81.1328
800.32	71.0586
800.156	58.1563
799.992	66.5391
799.828	109.238
799.664	93.5469
799.499	88.4727
799.335	64.6719
799.171	75.1836
799.007	84.1797
798.843	93.9258
798.679	69.8008
798.515	66.3672
798.351	80.3516
798.187	77.4922
798.023	73.1289
797.859	60.8613
797.695	78.7031
797.531	71.7969
797.367	61.8398
797.203	58.2734
797.039	85.7578
796.875	84.4102
796.711	78.6602
796.547	54.6836
796.383	85.3516
796.219	83.5781
796.055	70.8242
795.891	65.5469
795.727	68.5313
795.563	64.3984
795.398	81.625
795.234	65.3906
795.07	77.875
794.906	56.5313
794.742	61.7324
794.578	77.5625
794.414	65.8672
794.25	70.7305
794.086	78.7305
793.922	82.6641
793.758	62.5703
793.594	91.8945
793.43	78.8789
793.266	66.6758
793.102	75.1758
792.938	66.8594
792.774	62.7422
792.61	75.4102
792.446	50.9316
792.282	73.9531
792.118	72.8867
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791.79	87.1055
791.626	51.1289
791.462	61.6914
791.297	88.1563
791.133	85.4297
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790.805	64.5977
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790.477	73.668
790.313	75.7344
790.149	63.2754
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789.821	77.9609
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789.493	75.6523
789.329	90.5234
789.165	69.7344
789.001	78.5938
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788.673	84.7734
788.509	72.7813
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788.017	74.9805
787.853	76.5664
787.689	74.5977
787.525	79.1289
787.361	67.207
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787.032	64.5391
786.868	77.0039
786.704	61.3027
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786.048	64.8789
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785.556	76.9414
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785.228	108.391
785.064	85.0664
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784.572	81.0547
784.408	82.9258
784.244	61.2383
784.08	69.2656
783.916	85.5
783.752	65.3281
783.588	77.4063
783.424	79.7461
783.26	74.75
783.095	77.6328
782.931	90.5078
782.767	91.5547
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782.439	58.3496
782.275	90.7109
782.111	80.4531
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781.783	76.9727
781.619	85.8203
781.455	73.3867
781.291	62.9141
781.127	93.6602
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780.799	73.832
780.635	61.625
780.471	63.4375
780.307	62.2168
780.143	61.166
779.979	72.0391
779.815	88.9102
779.651	90.6133
779.487	74.6641
779.323	63.9824
779.158	51.2891
778.994	72.2031
778.83	72.5547
778.666	70.6016
778.502	87.9922
778.338	68.6289
778.174	79.8867
778.01	64.8164
777.846	63.6133
777.682	56.9922
777.518	80.0195
777.354	54.2363
777.19	64.6953
777.026	83.4453
776.862	46.2598
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776.042	59.5137
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775.714	65.2461
775.55	80.0625
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775.222	47.8945
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774.893	77.2773
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774.565	85.332
774.401	63.3418
774.237	71.582
774.073	70
773.909	85.6172
773.745	63.3926
773.581	75.1055
773.417	74.793
773.253	78.293
773.089	70.0508
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772.761	75.4258
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772.105	66.0508
771.941	80.0078
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771.613	55.3496

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752.092	67.375
751.928	69.4922
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748.319	93.7617
748.155	77.5508
747.991	62.2695
747.827	59.9863
747.663	78.6875
747.499	71.082
747.335	66.9375
747.171	65.5781
747.007	68.1992
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746.679	62.4043
746.514	63.9453
746.35	56.7852
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746.022	53.1602
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742.578	85.918
742.413	92.6484
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741.265	67.8633
741.101	94.4531
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740.609	74.5352
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739.953	75.8242
739.789	74.6953
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739.133	79.9023
738.969	88.7656
738.805	72.7539
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738.476	72.1328
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736.672	57.1816
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736.18	73.9063
736.016	62.125
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733.227	74.8203
733.063	60.4336
732.899	60.8867
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726.83	36.3359
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724.697	27.9863
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724.369	27.3848
724.205	31.04
724.041	27.6924
723.877	24.1748
723.713	25.8594
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723.385	37.9121
723.221	31.209
723.057	31.1699
722.893	43.6016
722.729	34.6289
722.565	36.3652
722.401	29.5732
722.237	24.3623
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721.744	33.7871
721.58	41.3652
721.416	30.2725
721.252	23.0068
721.088	15.8271
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720.76	31.5244
720.596	25.9912
720.432	25.8848
720.268	37.6875
720.104	36.207
719.94	25.9453
719.776	32.8457
719.612	37.9492
719.448	22.4844
719.284	41.6113
719.12	15.5542
718.956	51.4766
718.792	41.125
718.628	55.541
718.464	43.707
718.3	50.5293
718.136	41.5371
717.971	29.5283
717.807	36.9219
717.643	53.3477
717.479	37.3984
717.315	23.084
717.151	30.126
716.987	48.1816
716.823	46.1387
716.659	33.4668
716.495	29.5732
716.331	27.6758
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715.675	27.4707
715.511	41.375
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715.183	41.5273
715.019	39.6035
714.855	34.5215
714.691	22.4951
714.527	36.6699
714.363	38.3574
714.199	34.6895
714.034	46.5723
713.87	36.4434
713.706	35.0645
713.542	42.4395
713.378	42.5078
713.214	26.543
713.05	24.9658
712.886	37.7441
712.722	37.3379
712.558	35.0078
712.394	46.8027
712.23	34.5938
712.066	31.2979
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711.41	41.6113
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709.769	29.7256
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708.785	30.0674
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708.457	35.2461
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707.801	39.7949
707.637	39.4902
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707.145	46.707
706.981	46.4551
706.817	30.9277
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705.832	31.2539
705.668	38.2188
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705.34	38.2363
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698.779	22.5615
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695.498	27.7666
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57.8734	113.887
57.7094	136.281
57.5453	108.449
57.3813	123.113
57.2172	111.445
57.0532	112.988
56.8892	109.207
56.7251	102.254
56.5611	98.2422
56.397	116.258
56.233	104.578
56.069	99.4727
55.9049	105.277
55.7409	124.16
55.5768	95.1953
55.4128	126.508
55.2488	109.609
55.0847	111.207
54.9207	126.641
54.7566	114.84
54.5926	115.012
54.4286	86.2031
54.2645	111.375
54.1005	106.781
53.9364	116.715
53.7724	121.602
53.6084	111.828
53.4443	90.3555
53.2803	97.3477
53.1162	125.32
52.9522	115.203
52.7882	125.203
52.6241	99.8906
52.4601	112.492
52.296	109.395
52.132	104.867
51.968	101.969
51.8039	84.4609
51.6399	96.0977
51.4758	115.652
51.3118	135.828
51.1478	84.0859
50.9837	95.6563
50.8197	111.699
50.6556	120.891
50.4916	121.852
50.3276	119.164
50.1635	100.488
49.9995	101.734
49.8354	79.9258
49.6714	94.9609
49.5074	115.398
49.3433	121.359
49.1793	110.219
49.0152	100.66
48.8512	105.25
48.6872	95.4766
48.5231	117.766
48.3591	106.938
48.195	118.984
48.031	105.281
47.867	112.375
47.7029	110.258
47.5389	114.984
47.3748	111.434
47.2108	124.477
47.0468	123.129
46.8827	92.1836
46.7187	126.137
46.5546	97.4414
46.3906	107.188
46.2265	109.703
46.0625	100.332
45.8985	119.992
45.7344	104.684
45.5704	102.371
45.4063	129.055
45.2423	88.1094
45.0783	112.105
44.9142	127.031
44.7502	120.867
44.5861	128.758
44.4221	113.977
44.2581	103.172
44.094	121.254
43.93	128.648
43.7659	121.207
43.6019	118.805
43.4379	103.305
43.2738	110.367
43.1098	118.957
42.9457	115.48
42.7817	124.813
42.6177	107.852
42.4536	119.398
42.2896	116.559
42.1255	101.008
41.9615	94.7773
41.7975	130.328
41.6334	121.633
41.4694	127.645
41.3053	140.508
41.1413	128.313
40.9773	88.5391
40.8132	131.453
40.6492	122.789
40.4851	116.379
40.3211	76.4375
40.1571	102.535
39.993	98.4102
39.829	111.984
39.6649	101.789
39.5009	79.4453
39.3369	133.273
39.1728	102.074
39.0088	120.168
38.8447	80.0313
38.6807	96.7266
38.5167	109.953
38.3526	118.711
38.1886	105.82
38.0245	133.391
37.8605	110.25
37.6965	122.227
37.5324	102.355
37.3684	97.582
37.2043	108.988
37.0403	110.559
36.8763	126.031
36.7122	101.355
36.5482	136.93
36.3841	130.297
36.2201	104.477
36.0561	128.133
35.892	113
35.728	102.574
35.5639	105.703
35.3999	109.59
35.2359	91.543
35.0718	121.844
34.9078	123.359
34.7437	120.992
34.5797	111.547
34.4156	94.6367
34.2516	124.191
34.0876	107.422
33.9235	136.141
33.7595	127.074
33.5954	125.398
33.4314	89.8633
33.2674	106.625
33.1033	113.023
32.9393	122.809
32.7752	113.973
32.6112	121.566
32.4472	117.313
32.2831	116.844
32.1191	123.5
31.955	108.898
31.791	113.016
31.627	118.984
31.4629	101.199
31.2989	112.418
31.1348	100.855
30.9708	112.75
30.8068	123.711
30.6427	88.1172
30.4787	95.8438
30.3146	125.898
30.1506	113.699
29.9866	129.906
29.8225	88.0859
29.6585	129.172
29.4944	137.648
29.3304	103.848
29.1664	125.711
29.0023	133.914
28.8383	89.3359
28.6742	100.738
28.5102	120.746
28.3462	113.121
28.1821	93.1289
28.0181	108.047
27.854	139.633
27.69	120.863
27.526	133.539
27.3619	128.336
27.1979	122.926
27.0338	121.609
26.8698	103.574
26.7058	109.652
26.5417	124.148
26.3777	109.234
26.2136	100.609
26.0496	94.5039
25.8856	123.539
25.7215	125.82
25.5575	112.52
25.3934	113.297
25.2294	103.809
25.0654	106.852
24.9013	154.977
24.7373	115.781
24.5732	124.457
24.4092	112.023
24.2452	120.031
24.0811	139.633

23.9171	140.633
23.753	122.266
23.589	116.754
23.425	117.047
23.2609	122.895
23.0969	82.2109
22.9328	123.719
22.7688	95.2695
22.6048	124.801
22.4407	125.102
22.2767	100.051
22.1126	92.3906
21.9486	110.234
21.7845	98.582
21.6205	119.746
21.4565	98.5117
21.2924	103.813
21.1284	89.4805
20.9643	67.8398
20.8003	64.4609
20.6363	78.0664
20.4722	90.6523
20.3082	71.4688
20.1441	74.7305
19.9801	89.4336
19.8161	94.1719
19.652	63.457
19.488	93.6836
19.3239	80.7148
19.1599	76.4766
18.9959	69.1836
18.8318	99.5117
18.6678	78.6875
18.5037	74.5586
18.3397	96.9297
18.1757	77.0703
18.0116	83.6289
17.8476	96.7344
17.6835	99.4805
17.5195	66.0898
17.3555	85.5977
17.1914	75.9883
17.0274	84.9961
16.8633	63.9492
16.6993	75.1055
16.5353	61.834
16.3712	54.3594
16.2072	58.3867
16.0431	58.6992
15.8791	36.3086
15.7151	28.6523
15.551	62.1016
15.387	38.2949
15.2229	34.8809
15.0589	41.6973
14.8949	41.8652
14.7308	29.9766
14.5668	33.0137
14.4027	29.0732
14.2387	29.3047
14.0747	32.4395
13.9106	35.8945
13.7466	19.6436
13.5825	14.627
13.4185	24.3066
13.2545	17.6953
13.0904	13.1084
12.9264	17.9824
12.7623	16.1836
12.5983	32.4219
12.4343	19.5869
12.2702	13.106
12.1062	14.6372
11.9421	34.2363
11.7781	25.9951
11.6141	24.3896
11.45	29.4092
11.286	31.4668
11.1219	40.1758
10.9579	20.0498
10.7938	40.1504
10.6298	29.9863
10.4658	33.5508
10.3017	45.1055
10.1377	23.2822
9.97365	34.5645
9.80961	32.3418
9.64557	42.541
9.48153	21.3096
9.31749	26.1563
9.15345	42.3965
8.98941	30.7227
8.82537	32.8926
8.66133	35.9785
8.49729	35.8164
8.33325	22.5791
8.16921	37.1719
8.00517	41.9473
7.84112	34.2266
7.67708	27.9766
7.51304	44.1914
7.349	42.2207
7.18496	27.6895
7.02092	27.7061
6.85688	31.0898
6.69284	29.5645
6.5288	28.0098
6.36476	34.9082
6.20072	36.6113
6.03668	19.9961
5.87264	25.0742
5.7086	34.9629
5.54456	21.4346
5.38052	31.3818
5.21648	34.8066
5.05244	37.7891
4.8884	37.498
4.72436	37.0898
4.56032	40.5059
4.39628	26.1777
4.23224	33.0645
4.0682	40.8516
3.90416	29.1807
3.74012	29.1621
3.57608	27.5029
3.41204	34.3125
3.248	36.0469
3.08396	38.4238
2.91992	27.251
2.75588	40.7324
2.59184	26.6934
2.4278	44.0977
2.26376	25.6807
2.09972	20.4814
1.93568	15.5576
1.77164	30.1572
1.60759	10.5752
1.44355	22.9326
1.27951	17.4629
1.11547	17.4141
0.951434	12.1704
0.787393	12.1982
0.623353	18.8105
0.459313	17.2256
0.295272	22.0615
0.131232	28.4453
-0.0328081	25.0088
-0.196848	14.8223