TA-05

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Date: May 30, 2003
Refer to: RRES-GPP-03-061

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

SUBJECT: **CHARACTERIZATION WELL R-13 COMPLETION REPORTS**

Dear Mat:

Enclosed are two copies of the Characterization Well R-13 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 Nylander, Program Manager
Groundwater Protection Program

CN/th

Enclosure: Characterization Well R-13 Completion Report (ER2003-0160)

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RPF, MS M707 (ER2003-0377)

MAY 2003

Remediation Program

RRES

LA-UR-03-1373
June 2003
ER2003-0160
GPP-03-023

Characterization Well R-13 Completion Report

Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

Produced by the Water Quality and Hydrology Group, Risk Reduction & Environmental Stewardship Division

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List of Acronyms and Abbreviations

AITH	Array Induction Tool, version H
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMP	best management practice
CH	cased hole
CNTG	Compensated Neutron Tool, model G
CMR	Combinable Magnetic Resonance
CVAA	cold vapor atomic absorption
DH	down hole
DR	dual rotary
DTH	down-the-hole
ECS	Elemental Capture Spectroscopy
EES	Earth and Environmental Sciences (Laboratory division)
EPA	Environmental Protection Agency
ER	Environmental Restoration (Project)
ESH	Environmental, Safety, and Health
FIP	field implementation plan
FMI	Formation Micro-Imager
FMU	facility management unit
FSF	Field Support Facility
gal.	gallon
GPIT	General Purpose Inclinometry Tool

gpm	gallons per minute
GPS	global positioning system
GR	gamma ray
HNGS	Hostile Natural Gamma Spectroscopy
hp	horsepower
IC	ion chromatography
ICPES	inductively coupled plasma emission spectroscopy
ICPMS	inductively coupled plasma mass spectrometry
ID	inner diameter
ISE	ion selective electrode
LANL	Los Alamos National Laboratory
MCFL	Micro Cylindrically Focused Log
NGS	Natural Gamma Spectroscopy
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
OD	outer diameter
OH	open hole
psi	pounds per square inch
PVC	polyvinyl chloride
RC	reverse circulation
RRES	Risk Reduction and Environmental Stewardship Division
RLWTF	radioactive liquid waste treatment facility
SVOC	semivolatile organic compound
TA	technical area
TD	total depth
TDS	total dissolved solids
TLD	Triple detector Litho-Density
TOC	total organic compound
TPH	total petroleum hydrocarbons
UR-DTH	under-reaming down-the-hole (hammer)
VOC	volatile organic compound
WGII	Washington Group International, Inc.
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-13 COMPLETION REPORT

ABSTRACT

Characterization well R-13 was installed under implementation of the "Hydrogeologic Workplan" (LANL 1998, 59599). This well was funded and project directed by the Environmental Restoration (ER) Project as part of the implementation of the Mortandad Canyon Work Plan (LANL 1997, 56835). Execution of the drilling program was carried out by Washington Group International, Inc., under a subcontract to Los Alamos National Laboratory (LANL or the Laboratory). The well is located in Mortandad Canyon, in the east-central portion of the Laboratory. Well R-13 was designed to provide hydrogeologic and water-quality data on the regional aquifer downgradient of contaminant release sites in Mortandad and Ten Site Canyons. Specific sources of concern include the waste water treatment plant at Technical Area 50 (TA-50) and a former waste water treatment facility at TA-35 that have historically released effluent.

Hydrologic, geologic, geochemical, and geophysical information obtained during completion and subsequent sampling of regional wells will provide data for the Laboratory's hydrologic and geologic conceptual models and contribute to implementation of a Laboratory-wide groundwater-monitoring network. Monitoring of this network of wells supports the Laboratory's "Groundwater Protection Management Program Plan" (LANL 1996, 70215).

The R-13 borehole was drilled to a total depth of 1133 ft below ground surface using air-rotary drilling methods. The well was installed on February 25, 2002, to a total depth of 1029.4 ft with a single screen in the regional aquifer and equipped with a dedicated submersible pump.

The stratigraphy encountered during borehole drilling included, in descending order, alluvial sediments, the Tshirege Member of the Bandelier Tuff, the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff, the Guaje Pumice Bed, upper Puye Formation sediments, Cerros del Rio Basalt, and a sedimentary sequence making up a lower section of Puye Formation. Samples of drill cuttings were collected at regular intervals for stratigraphic, petrographic, and geochemical analysis.

No perched water was encountered at R-13. The regional zone of groundwater saturation was encountered at a depth of 834 ft below ground surface in the Puye Formation. Borehole groundwater samples were collected from the regional aquifer for analysis of selected organic and inorganic constituents and radiochemical compounds. Based on the analytical results for the R-13 borehole water samples collected within the Puye Formation, it appears that contamination from Laboratory discharges is not present in the regional aquifer at this well site.

1.0 INTRODUCTION

This completion report summarizes the site preparation, drilling, well construction, well development, and related activities from August 14, 2001, to February 25, 2002, for the installation of characterization well R-13. The well is located on the floor of Mortandad Canyon approximately 5890 ft east-southeast of well R-15 and 250 ft north of the Los Alamos National Laboratory (the Laboratory) boundary that crosses Mortandad Canyon, as shown in Figure 1.0-1.

The information presented in this report was compiled from field reports and activity summaries generated by the Laboratory and subcontractor personnel. Geophysical data provided by Schlumberger, Inc. (Schlumberger) and geodetic survey results are included. Results of these activities are discussed briefly and shown in tables and figures contained in this report. Detailed analysis and interpretation of geologic, geochemical, geophysical, and hydrologic data will be included in separate technical documents to be prepared by the Laboratory.

Well R-13 was funded by the Environmental Restoration (ER) Project, now called the Risk Reduction and Environmental Stewardship (RRES) Division. Washington Group International, Inc. (WGII), under contract to the Laboratory, was responsible for executing the drilling activities.

This characterization well will function primarily to investigate the nature and extent of potential impacts to regional groundwater resulting from Laboratory activities in the Mortandad Canyon watershed. Water quality, geochemical, hydrologic, and geologic information gathered during completion will augment knowledge of regional subsurface characteristics and distribution of any contaminants downgradient of former wastewater plant at TA-35 and wastewater plant at TA-50, a potential source for groundwater contamination. Well R-13 will provide water-quality and water-level monitoring data from the regional aquifer, and data gathered from this well will be used to update the sitewide hydrologic and geologic conceptual models for the Laboratory.

Well R-13 is downstream from active and inactive outfalls at Technical Area (TA)-5, TA-35, TA-48, TA-50, TA-52, TA-55, and TA-60. From a groundwater perspective, the sources of most concern are the former wastewater treatment plant at TA-35 and the present-day wastewater treatment plant at TA-50.

The Laboratory's wastewater treatment plant at TA-35 was operated from 1951 to 1963. Routine and accidental discharges from the wastewater treatment plant resulted in release of contaminants to Ten Site Canyon (Figure 1.0-1). Contaminants of potential concern associated with the TA-35 wastewater plant include lanthanum-140; barium-140; strontium-89, -90; yttrium-90; cesium-137; ruthenium-106; plutonium-238, -239, -240; caustics; acids; sodium carbonate; strontium nitrate; iron sulfate; and dielectric oil (LANL 1997, 56835). By the early 1960s, the wastewater treatment plant at TA-35 reached its capacity to handle the increasing volume of liquid radioactive wastes associated with expanding Laboratory operations. In 1963, TA-35 wastewater operations were transferred to a new radioactive liquid waste treatment facility (RLWTF) at TA-50.

The Laboratory's RLWTF at TA-50 discharges treated wastewater to Mortandad Canyon via Effluent Canyon through an outfall that is currently permitted as NPDES outfall 051. From 1963 through 1995, a total of 342 million gal. (1,294,500 m^3) of treated wastewater were discharged (LANL 1997, 56835). Laboratory surveillance data collected in Mortandad Canyon show elevated concentrations or activities of fluoride; total dissolved solids (TDS); perchlorate; nitrate; tritium; strontium-90; cesium-137; plutonium-239, -240; americium-241; and uranium-234, -235, and -238 in surface water and in alluvial groundwater.

This well completion report focuses on operational activities associated with the drilling, sampling, and completion of well R-13. Detailed analysis and interpretation of geologic, geochemical, geophysical, and

hydrologic data, included as part of previous well completion reports, will be discussed in future technical documents to be prepared by the Laboratory.

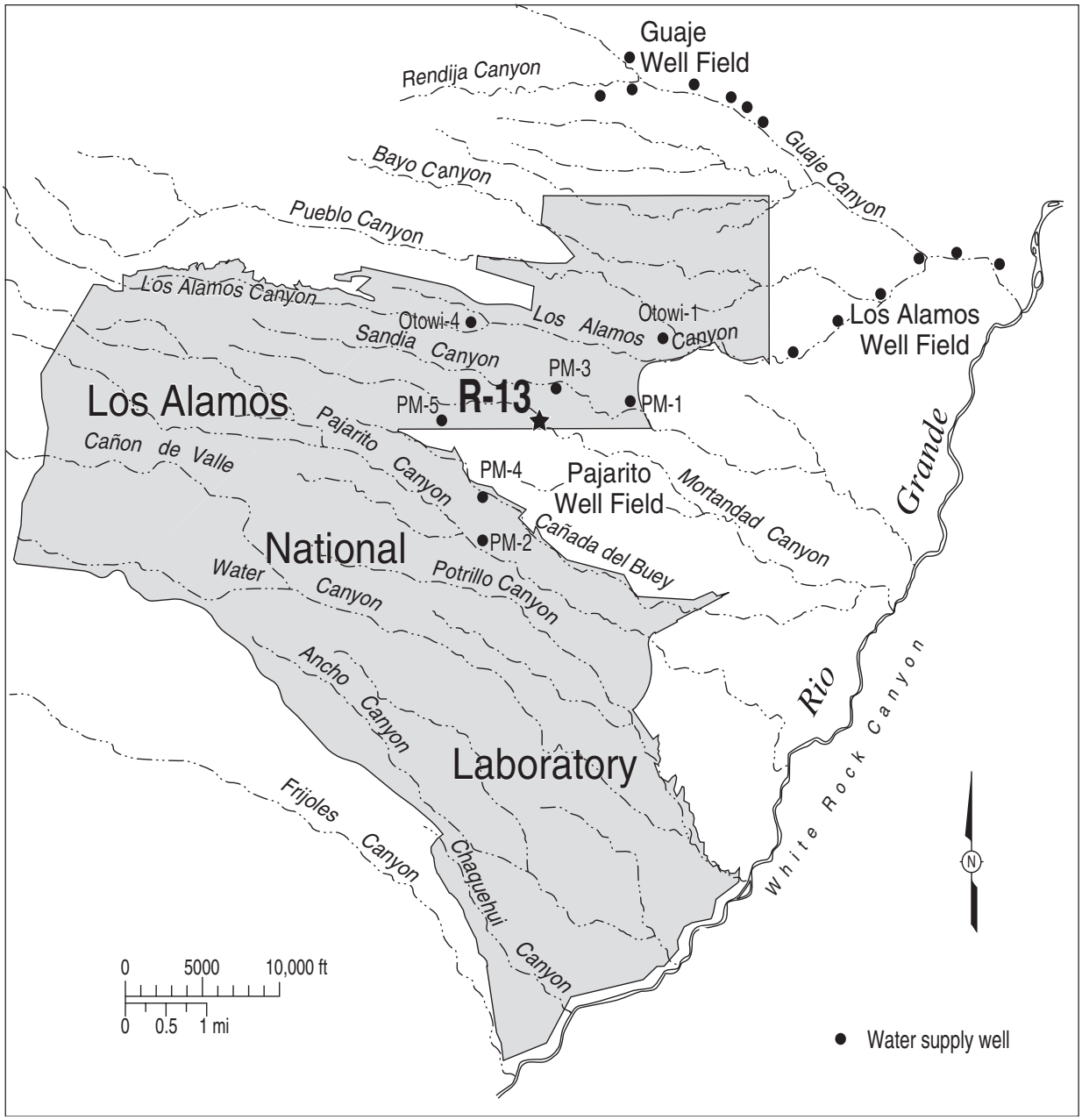


Figure 1.0-1. Map showing location of R-13

2.0 PRELIMINARY ACTIVITIES

To prepare for drilling activities, Washington Group International, Inc., (WGII) developed a modification to the existing site-specific health and safety plan, No. 273, to include well R-13. WGII also prepared the R-13 waste characterization strategy form (WCSF). The Laboratory prepared the field implementation plan (FIP) for R-13 (LANL 2001, 70291.2) which specified drilling and sampling plans to guide personnel

in executing R-13 field activities. The host facility, Facility Management Unit (FMU) 80, signed a Facility-Tenant Agreement to provide for access and security control, safety and health, and regulatory requirements for drilling and completion activities.

A Readiness Review meeting was held on August 9, 2001, to discuss administrative agreements, documents, permits, and plans pertaining to the R-13 project. A Groundwater Investigations Focus Area project representative gave authorization on August 9, 2001, to begin site preparation. The Readiness Review Checklist for drilling activities was signed on August 17, 2001.

S.G. Western Construction Company was subcontracted by WGII to conduct site preparation. Activities included site clearing, access road improvement, construction of drill pad, and construction of a lined cuttings-containment area. Site preparation was conducted from August 14 through 17, 2001 (see Figure 3.0-2).

The R-13 site was initially cleared of small trees and stumps. The drill pad was developed by leveling the area, 100 ft by 150 ft, with a grader and placing Geogrid® geotextile fabric over the main operations area. A primary layer of base-course gravel was then distributed and compacted over the fabric. To store R-13 drilling fluids and cuttings, a 20-ft-wide by 60-ft-long by 4-ft-deep cuttings-containment area was excavated along the north pad boundary. A berm, roughly 3 ft high, was constructed around the containment area, and the entire excavation area was lined with a 6-mil polyethylene liner. An 80-ft by 25-ft secondary containment area was graded and lined with 6-mil polyethylene to accommodate two 20,000-gallon (gal.) tank trailers used for storing drilling fluids pumped from the cuttings-containment area and development water. Drill pad construction was completed with an additional layer of base-course gravel that was also graded and compacted. Safety barriers and signs were installed around the cuttings-containment area and at the site entrance. Office and supply trailers, generators, and safety lighting equipment were moved to the site during subsequent mobilization of drilling equipment.

3.0 SUMMARY OF DRILLING ACTIVITIES

Drilling activities at R-13 were performed by Dynatec Drilling Company, Inc. (Dynatec) under contract to WGII. Dynatec provided a Foremost™ Dual Rotary DR-24 drill rig, along with reverse circulation (RC) drilling rods and support equipment. Equipment and fabrication support for drilling activities was provided by the ER Project's Field Support Facility (FSF).

Fluid-assisted RC air-rotary methods were used to drill open hole or casing advance, as determined by changing geologic and hydrologic conditions. Municipal water mixed with polymer additives was used to improve drilling lubrication and facilitate cuttings removal from the borehole.

The objectives of drilling were to produce samples for geologic characterization, provide a borehole for well installation in the regional aquifer, and collect groundwater samples for contaminant analysis. The R-13 borehole was completed to a total depth (TD) of 1133 ft below ground surface (bgs).

Figure 3.0-1 summarizes well data and graphically depicts groundwater and geologic conditions encountered in R-13. Figure 3.0-2 summarizes graphically the chronology of drilling and other related on-site activities.

Location: TA-5, Mortandad Canyon

Survey coordinates (brass marker in NW corner of R-13 cement pad):
x = 1640992 E y = 1766994 N (NAD 83)
z = 6673.1 ft asl (NGVD 29)
1/29/02

Drilling: fluid-assist air rotary reverse circulation with casing advance
Start date: 8/21/01
End date: 9/20/01

Borehole drilled to 1133 ft total depth (TD)

Data collection:
Hydrologic properties: Field Hydraulic Test: Draw-down Pumping Test
Cores/cuttings submitted for geochemical and contaminant characterization: (0)
Groundwater samples submitted for geochemical and contaminant characterization: (1)
Geologic properties: Mineralogy, petrography, and chemistry: (12)
Borehole logs:
Lithologic: 0–1133 ft
Video (LANL tool): 760–832 ft
Natural gamma (LANL tool): 0–760 ft (cased), 760–830 ft (open hole) ; 0–847 ft (cased), 847–1053 ft (open hole); 0–1126 ft (cased)
Schlumberger Logs: 0–847 ft (cased), 847–1058 ft (open hole): Compensated neutron, array induction, litho-density, electron capture, natural gamma, formation micro-imager.

Contaminants Detected in Borehole Samples:
Regional groundwater: none

Well construction:
Drilling Completed: 9/20/01
Contract Geophysics: 9/24/01
Well Constructed: 9/26/01–10/6/01
Well Developed: 10/11/01–10/30/01
Dedicated Pump Installed: 02/20/02

Casing: 4.5-in. ID, 5.0-in. OD stainless-steel with external couplings

Number of Screens: 1
4.5-in. ID, 5.563-in. OD pipe-based, s.s. wire-wrapped; 0.010-in. slot

Screen (perforated pipe interval):
Screen #1 - 958.3–1018.7 ft

Well development consisted of brushing, bailing, and pumping.

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

Preliminary geologic contacts determined by examination of cuttings and interpretation of geophysical logs.

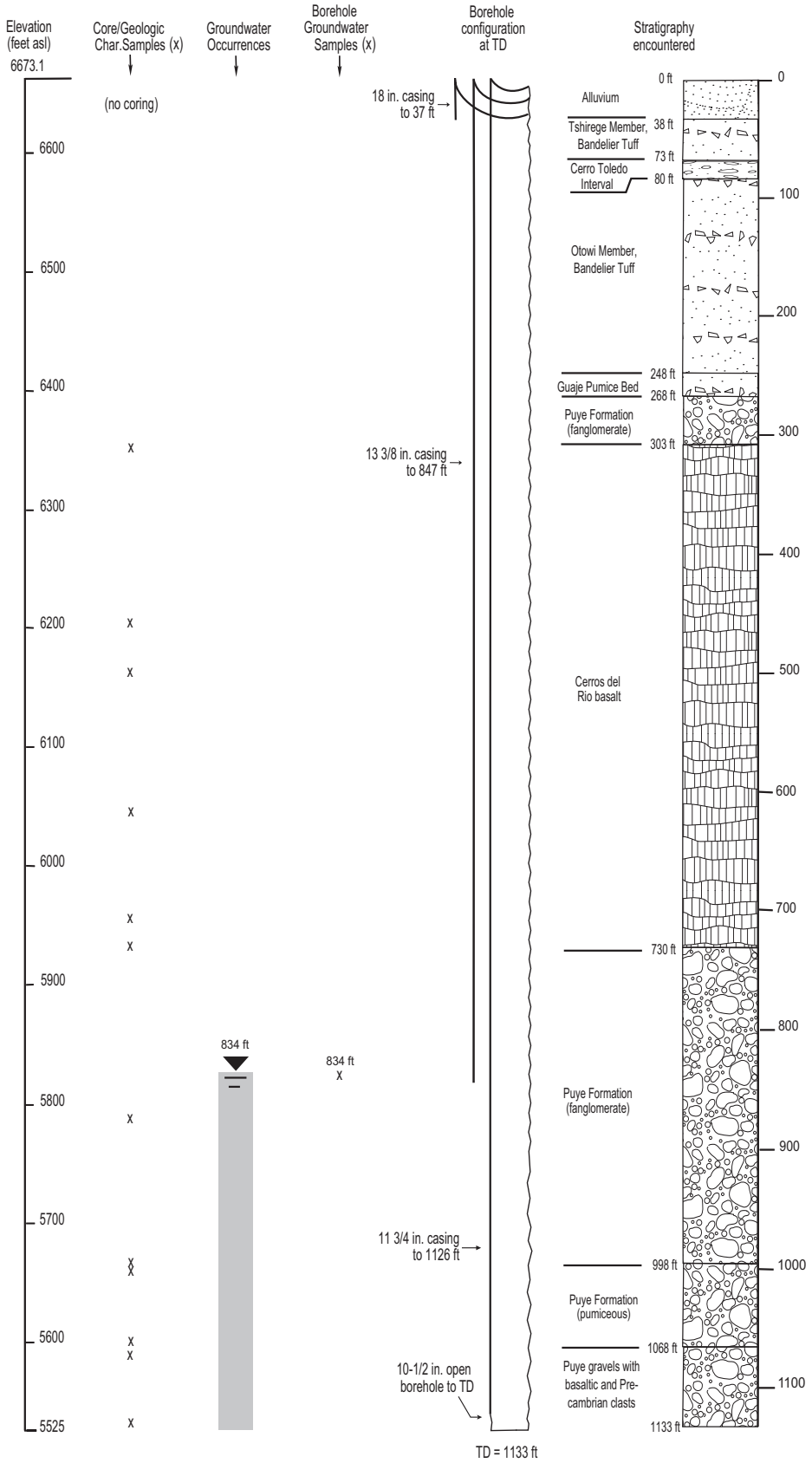


Figure 3.0-1. Well summary data sheet for R-13

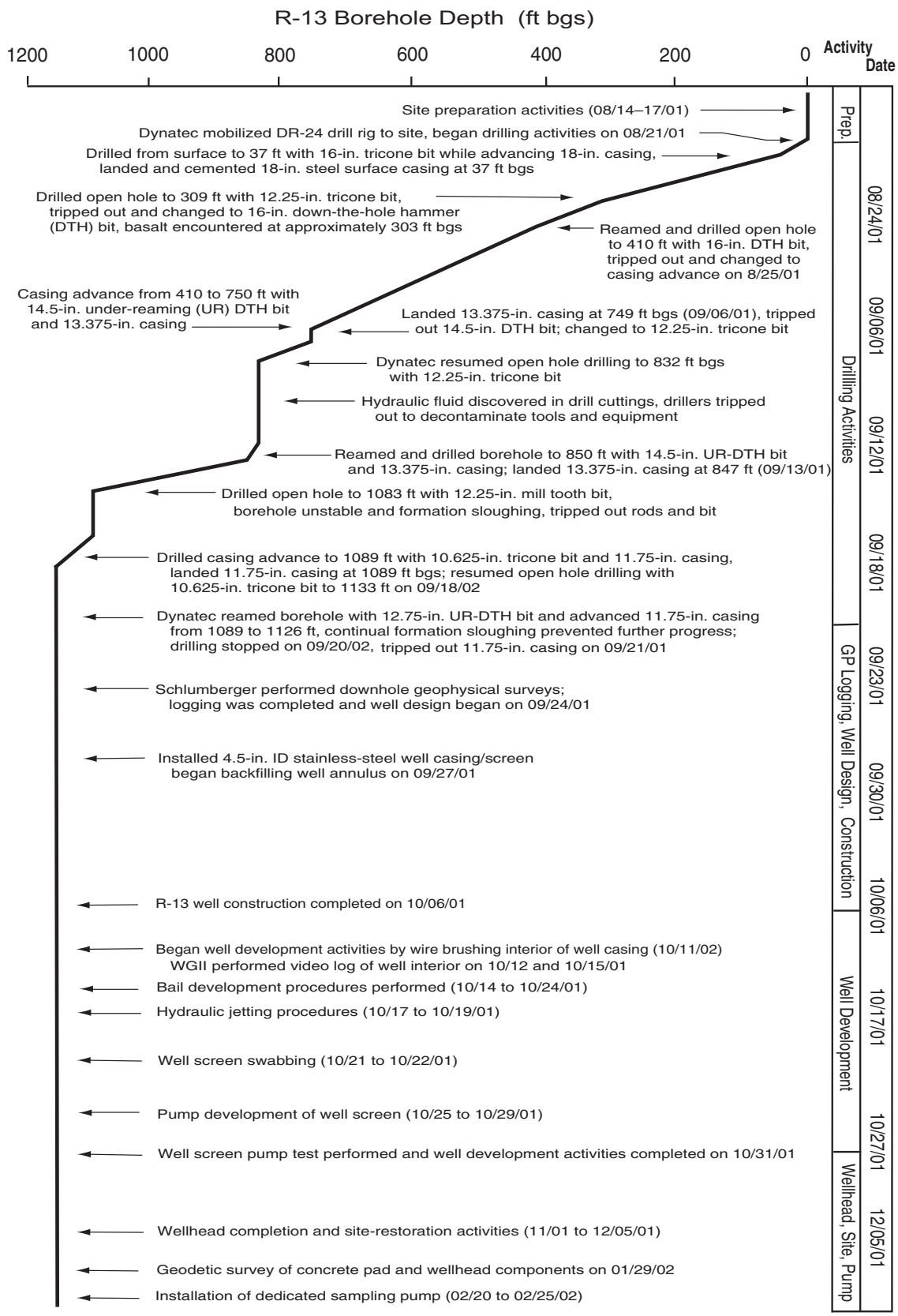


Figure 3.0-2. Operations chronology graph

Drilling activities at R-13 were conducted from August 21 through September 21, 2001 (Figure 3.0-2).

On August 21, 2001, Dynatec mobilized the DR-24 drill rig and support equipment to the site and commenced R-13 drilling operations. Dynatec initially advanced 18-in. steel conductor casing by reaming with the assistance of a 16-in. tricone long-tooth carbide button bit from ground surface to the contact between alluvium and the underlying Tshirege Member of the Bandelier Tuff. The conductor casing was landed at 37 ft bgs and cemented in place on August 22, 2001. Open hole drilling continued with a 12.25-in. tricone bit from 37 ft bgs through the Tshirege Member of the Bandelier Tuff, Cerro Toledo interval, Otowi Member of the Bandelier Tuff, including the Guaje Pumice Bed, and Puye Formation sediments. The top of the Cerros del Rio basalt was encountered at approximately 303 ft bgs.

To offset slow drilling conditions in the basalt, Dynatec switched to a 16-in. down-the-hole (DTH) bit and stabilizer. Drilling progressed to 325 ft bgs before losing circulation in the open borehole. The stabilizer was then removed from the drill string and open hole drilling continued from 325 to 410 ft.

On August 25, 2001, the annular seal outside of the 18-in. conductor casing began leaking air, and cuttings were circulating out along the outside of the casing rather than through the discharge line. To solve this problem, Dynatec advanced 13.375-in. casing using a 14.5-in. under-reaming down-the-hole-hammer (UR-DTH) bit and began casing advance drilling until a suitable depth was reached to land the casing. Drilling progressed through basalt from 410 ft to 705 ft bgs. Operations were then shut down and the site secured for the Labor Day holiday on September 3, 2001.

Drilling operations resumed on September 5, 2001. Casing advance drilling continued from 705 ft to 760 ft bgs where the 13.375-in. casing was landed in the Puye Formation, approximately 30 ft below the base of the Cerros del Rio basalt. Dynatec then changed to a 12.25-in. tricone bit and drilled open hole from 760 ft to 832 ft bgs.

Problems developed at R-13 on September 7, 2001, when hydraulic fluid was discovered in a cuttings sample collected from the 827-ft to 832-ft interval. Drilling operations were shut down until the cause and degree of contaminant impact could be ascertained. It was determined that a leak had developed in a mixing tank pump, and hydraulic fluid had been accidentally introduced into the borehole with the drill fluid. The rig's hydraulic system lost approximately 165 gal. during this incident.

At the time of the incident, the borehole had been advanced to a depth of 832 ft, and the boring was cased to a depth of 760 ft. Because of the nature of the drilling method and the configuration of the drill string, the only portion of the borehole subject to active borehole circulation was the section from the drill bit to the air exchange port. Given the configuration of the drill string at the time of the incident, an estimated 25 ft of the lowermost borehole may have been potentially impacted by hydraulic fluid.

Dynatec immediately began cleanup efforts to mitigate the effects and potential impact to the subsurface. The hose was repaired and the hydraulic oil reservoir on the rig was refilled. The hole was flushed with 500 gal. of clean water mixed with 1 cup of QUIK-FOAM®. The drill string (bit, stabilizer, and rods) was tripped out of the borehole and decontaminated with a high-pressure steam cleaner. The cyclone and cuttings trough were also decontaminated. The cleaned drill string was then tripped back into the hole, and the open hole portion of the boring was flushed with a mixture of hot water and surfactant to remediate the borehole. All fluids involved in the decontamination process were pumped into 3000-gal. polyethylene tanks for storage until they could be properly characterized for disposal. The borehole was rinsed several times to ensure that any possible aftereffects were mitigated. A water sample of the return fluids from the last rinse showed no adverse impact from the hydraulic fluid. On September 10, 2001, the borehole was purged of 300 gal. of water by circulating air through the drill stem. A sample was collected

for analysis to determine if contamination was still present in the borehole; the results showed that the borehole was free of hydraulic fluid.

Site activities were temporarily suspended on September 11, 2001, when all nonessential government operations were halted for security reasons. On September 12, 2001, the DH video camera and natural gamma-logging tool were used to assess the condition of the borehole. Logging was conducted to a depth of 830 ft. These tools showed no obvious effects from the hydraulic fluid.

As a final step to ensure that no contaminant could be carried with continued advancement of the borehole, the uncased portion of the hole was reamed to a larger diameter and the 13.375-in. casing was advanced from 760 to 850 ft. To eliminate the possibility of another occurrence of leaks, the pump mixing setup was reconfigured to avoid accidental contact of hydraulic fluid with drill water. In addition, all hydraulic lines and fittings were thoroughly inspected.

Efforts were made at the surface to contain and minimize all drill fluids and drill cuttings contaminated by the hydraulic fluid. All impacted fluids (drill and decontaminated fluids) in the cuttings pit were pumped to dedicated 3000-gal. polyethylene tanks until the waste streams could be properly characterized and arrangements made to ship and dispose of the waste. All solids (cuttings) were removed from the pit and contained in bulk rolloffs until they could be characterized for shipment and disposal. In addition, all absorbent padding and 6-mil liner was also collected, contained, and readied for shipment and disposal. Table 3.0-1 shows the volumes of the different wastes generated and describes their final disposition. After the liner was removed, a soil sample was collected from the pit bottom and analyzed for total petroleum hydrocarbons (TPH) to ensure that no contamination had breached the 6-mil liner.

Table 3.0-1
R-13 Hydraulic Fluid–Contaminated Waste Streams

Waste Type/ Medium	Quantity	Final Disposition
New Mexico special/ absorbent padding and 6-mil plastic sheeting	2 yd^3	Rio Rancho Landfill, Rio Rancho, NM
Non-New Mexico special/ drill cuttings	61 yd^3	Rio Rancho Landfill, Rio Rancho, NM
Oily waste water, nonregulated/ water	5500 gal.	Rhino Landfill, Otero Co., NM

A new liner was then installed in the same location to contain the clean cuttings from the remaining borehole. The contaminated cuttings were sampled and analyzed for semivolatile organic compounds (SVOCs); benzene, toluene, ethylbenzene, and xylene; diesel range organics; TPH; and gross alpha, beta, and gamma.

The borehole was advanced open hole in Puye sediments from 850 to 963 ft bgs. During this drilling interval, groundwater was detected at a depth of 834.0 ft bgs when the drill hole depth was 964 ft. A borehole groundwater sample was collected and submitted for analysis.

On September 15, 2001, the borehole was advanced to 1083 ft bgs. Sloughing conditions rendered open-hole drilling ineffective. The 11.75-in. drill casing was advanced in an attempt to seal off flowing sands encountered in the Puye Formation. Dynatec completed tripping in of the drill casing on September 17, 2001, and continued casing advance drilling using a 10.625-in. tricone drill bit from 1030 to 1094 ft bgs. Subsequent open hole drilling advanced to a depth of 1133 ft bgs. Continued sloughing prevented further advancement of the borehole; as a result, the 10.625-in. tricone drill bit was tripped out. Casing advance

with a 12.75-in. UR-DTH bit and 11.75-in. casing resumed, in an attempt to deepen the borehole. Flowing sand and gravel conditions prohibited advancement of the borehole beyond 1133 ft bgs. The drill string and 11.75-in. casing were then tripped out in order to proceed with borehole geophysical logging operations. R-13 drilling activities were completed on September 21, 2001.

4.0 SAMPLING AND ANALYSIS OF DRILL CUTTINGS AND GROUNDWATER

During drilling operations at R-13, drill cuttings were collected according to the R-13 FIP. As drilling conditions permitted, a sufficient quantity of borehole material was collected via RC at 5-ft intervals. A portion of the cuttings was sieved (at >#10 and >#35 mesh) and placed in chip-tray bins along with an unsieved portion. These chip trays were studied to determine lithological characteristics and used to prepare the lithologic logs. The remaining cuttings were sealed in Ziploc® bags and set in core boxes for curation. No cuttings samples were submitted for contaminant analysis. Prior to curation of the chip trays and cuttings, 12 samples were removed for mineralogic, petrographic, and geochemical analyses.

During drilling operations, alluvial groundwater was thought to be encountered at 33.6 ft bgs. A sample was collected and, after analysis, it was determined to consist primarily of drilling fluid (see section 4.1). Regional groundwater was encountered at 834 ft bgs. A groundwater sample was collected from the borehole at the depth at which hydraulic fluid had been removed. The total organic carbon (TOC) was 0.70 mgC/L, suggesting that little or no residual hydraulic fluid remained in the borehole. SVOCs, including hydraulic fluid, were not detected in groundwater during the first characterization sampling round conducted at well R-13 on July 3, 2002.

4.1 Geochemistry of Sampled Waters

Waters sampled at R-13 include possible alluvial groundwater and borehole water collected from regional aquifer.

Possible alluvial groundwater was identified based on water returns at 33.6 ft, but the sample had a high solids content (>95%) and a very high viscosity. The sample was collected on August 22, 2001, and was analyzed for anions at the Laboratory's Earth and Environmental Sciences (EES) Division by the Hydrology, Geochemistry, and Geology Group (EES-6). Concentrations of anions, in parts per million, are as follows: bromide (0.07), chloride (20.1), perchlorate (<0.02), fluoride (5.09), nitrite ([as nitrogen] <0.01), nitrate ([as nitrogen] <0.01), oxalate (0.68), phosphate ([as phosphorus] 0.05), and sulfate (17.1). The source of water may include drilling water and possibly alluvial groundwater, although concentrations of perchlorate, nitrate, and nitrite were less than detection.

Two water samples were collected from the undeveloped borehole during drilling and were analyzed for a limited suite of constituents. The samples were collected at depths of 933 and 1120 ft primarily to determine if potential contaminants had been introduced from upper horizons into the regional aquifer during drilling operations. Major potential contaminants of concern at R-13 include mobile solutes such as perchlorate, nitrate, fluoride, and tritium. The two samples contain some drilling fluids (EZ-MUD® and other additives) used for lubricity and were primarily used to assist drilling decisions. The samples are not representative of purely native groundwater but provide baseline groundwater compositions that were present during drilling.

Groundwater samples analyzed for inorganic and organic chemicals and tritium were collected by circulating the water through the drill stem at depths of 933 and 1120 ft in R-13 on September 14 and 20, 2001, respectively. Temperature, turbidity, pH, and specific conductance were not determined on-site. Both filtered (metals, trace elements, and major cations and anions) and nonfiltered (tritium and TOC)

samples were collected for chemical and radiochemical analyses. Aliquots of the samples were filtered through a 0.45-µm Gelman filter. Samples were acidified with analytical-grade nitric acid to a pH of 2.0 or less for metal and major ion analyses. All groundwater samples collected in the field were stored at 4°C until they were analyzed. Alkalinity was determined in the laboratory using standard titration techniques, which may approximate field conditions because of sample degassing, including carbon dioxide gas.

Groundwater samples were analyzed by EES-6 using techniques specified in the US Environmental Protection Agency (EPA) SW-846 manual. Ion chromatography (IC) was the analytical method used for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. Ammonium was analyzed by ion selective electrode (ISE), whereas mercury was analyzed by cold vapor atomic absorption (CVAA). Inductively coupled (argon) plasma emission spectroscopy (ICPES) was used for calcium, magnesium, potassium, silica, and sodium. Aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, thallium, vanadium, uranium, and zinc 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. Analyses of americium-241; cesium-137; plutonium-238, -239, -240; strontium-90; uranium-234, -235; and uranium-238 were not performed because the activity of tritium was 0.64 ± 0.29 (1σ) pCi/L and the presence of other dissolved radionuclides is very unlikely at R-13.

The precision limits (analytical error) for major ions and trace elements were generally less than ±10% using ICPES and ICPMS. Samples of core were not collected from R-13 and therefore not analyzed for contaminants.

Table 4.1-1 presents the results of the screening analyses performed on the two groundwater samples collected from the Puye Formation in R-13. Based on the analytical results for the two samples, it appears that contamination from Laboratory discharges is not present in the regional aquifer at this well site.

Table 4.1-1
Hydrochemistry of Regional Aquifer Samples at R-13

Analysis	Sample from Puye Formation, 933-ft Depth, September 14, 2001	Sample from Puye Formation, 1120-ft Depth, September 20, 2001
pH (laboratory)	7.39	7.45
Alkalinity (mg $CaCO_3$/L)	61.3	66.3
Al (mg/L)	0.09	0.21
NH_4 (as N) (mg/L)	0.03	0.55
Sb (mg/L)	0.0003	0.0005
As (mg/L)	0.0002	0.0002
B (mg/L)	0.011	0.016
Ba (mg/L)	0.023	0.032
Be (mg/L)	[0.001]U[a]	[0.001]U
Br (mg/L)	0.01	0.01
Cd (mg/L)	[0.001]U	[0.001]U
Ca (mg/L)	11.8	12.4
Cl (mg/L)	2.95	2.35

Table 4.1-1 (continued)

Analysis	Sample from Puye Formation, 933-ft Depth, September 14, 2001	Sample from Puye Formation, 1120-ft Depth, September 20, 2001
ClO_4 (mg/L)	[0.002]U	[0.002]U
Cr (mg/L)	[0.001]U	[0.001]U
Co (mg/L)	[0.001]U	[0.001]U
Cu (mg/L)	0.0023	0.0029
F (mg/L)	0.31	0.28
Fe (mg/L)	0.06	0.15
Pb (mg/L)	[0.001]U	[0.001]U
Mg (mg/L)	3.62	4.30
Mn (mg/L)	0.11	0.14
Hg (mg/L)	0.00015	0.00013
Ni (mg/L)	0.0011	0.0026
NO_3 (mg/L) (as N)	0.52	0.51
NO_2 (mg/L) (as N)	0.02	0.02
C_2O_4 (mg/L) (oxalate)	[0.02]U	[0.02]U
PO_4 (mg/L) (as P)	[0.02]U	[0.02]U
K (mg/L)	2.26	2.24
Se (mg/L)	[0.001]U	[0.001]U
Ag (mg/L)	[0.001]U	[0.001]U
Na (mg/L)	12.1	11.4
SiO_2 (mg/L)	51.4	53.1
SO_4 (mg/L)	3.85	3.50
Tl (mg/L)	[0.001]U	[0.001]U
TOC (mgC/L) (nonfiltered)	83.4	35.5
U (mg/L)	[0.001]U	[0.001]U
V (mg/L)	[0.001]U	[0.001]U
Zn (mg/L)	0.001	0.013
δD (permil)	—[b]	–77
$\delta^{18}O$ (permil)	—	–10.9
Tritium (pCi/L) (nonfiltered)	0.64 ± 0.29	—
TDS (mg/L) (calculated)	242	209

[a] U = not detected.

[b] Dash = not analyzed.

5.0 BOREHOLE GEOPHYSICS

Using Laboratory-owned and subcontractor-owned tools, WGII and Schlumberger performed borehole geophysical logging operations at well R-13. Table 5.0-1 lists the surveys performed.

Table 5.0-1
Borehole and Well Logging Surveys Conducted in R-13

Operator	Date	Method	Cased Footage	Open-hole Interval (ft bgs)	Remarks
WGII/ The Laboratory	September 12, 2001	Video, natural gamma	0–758	758–830	To evaluate borehole conditions after down-hole discharge of hydraulic fluid, subsequent purging of hydraulic fluid, and borehole lithologies
WGII/ The Laboratory	September 15, 2001	Natural gamma	0–847	847–1053	To evaluate borehole lithologies
WGII/ The Laboratory	September 20, 2001	Natural gamma	0–1126	0	Conducted before retracting 11.75-in. drill casing and to evaluate borehole lithologies
Schlumberger	September 24, 2001	Logging suite*	0–847	847–1058	Schlumberger borehole logging conducted at TD prior to well installation
WGII/ The Laboratory	October 12, 2001	Video	0–1029	0	Filmed to 832 ft (water level) to evaluate bentonite in the well casing
WGII/ The Laboratory	January 16, 2002	Video	0–1029	0	Final as-built

* Schlumberger suite of borehole logging surveys included triple detector lithodensity, array induction tool, epithermal compensated neutron log, elemental capture sonde, full-bore formation microimager, and natural gamma ray spectrometry.

5.1 LANL-Supported Geophysical Logging

Between September 12 and January 16, 2002, natural gamma and video camera logs were performed in borehole R-13 using down-hole tools provided by the Laboratory. A series of down-hole surveys were conducted in the R-13 borehole and the installed well. The gamma logs were collected to provide lithologic and stratigraphic information that complemented data gathered from cuttings. The video logs were used to troubleshoot drilling-related problems and to observe interior conditions after well completion. Table 5.0-1 summarizes the borehole and well logs conducted in R-13.

Natural gamma logs have proven to successfully discriminate between geologic units containing varying concentrations of uranium, thorium, and potassium. The following three natural gamma logs were run.

1. The first gamma log was carried out from 0 to 830 ft bgs. At that time, the borehole contained an 18-in. surface casing from ground surface to 37 ft bgs and a 13.375-in. drill casing from ground surface to 760 ft bgs. Open borehole conditions extended from 760 to 830 ft bgs. This logging run was conducted shortly after the borehole was flushed to remove hydraulic fluid that had circulated into the bottom of the borehole.

2. The second gamma log run was inside the 13.375-in. drill casing from the surface to 760 ft bgs, with the 18-in. surface casing still in place to 37 ft bgs. The borehole was open from 760 to 1053 ft bgs.

3. The third gamma log run was inside the 11.75-in. drill casing from the surface to 1126 ft bgs, the 13.375-in. casing from the surface to 847 ft bgs, and the 18-in.casing from the surface to 37 ft bgs. In each case, measurements of natural gamma activity were obtained every 0.1 ft as the logging tool was raised upward from the bottom of the borehole at a rate of about 15 ft/min.

Video camera logs were run to assess the stability of the borehole prior to deploying the natural gamma tool and to characterize rock lithologies (bedding features, fractures, and geological contacts). One run was made to evaluate the condition of the borehole after hydraulic fluid decontamination operations. Another video log was made to view the condition of the well interior after it was discovered that a small quantity of bentonite had fallen into the well during backfilling operations. The final camera run was conducted as a quality control procedure to inspect the condition of the stainless-steel well casing and screens installed at R-13. The video log of the open borehole is presented as Appendix C, which can be found on the CD attached to the inside back cover of this report.

5.2 Schlumberger Geophysical Logging

Schlumberger personnel conducted geophysical logging in the R-13 borehole on September 24, 2001. A suite of logging surveys was performed after retracting the 11.75-in. drill casing from 1126 ft to 826 ft bgs. At that time, an 18-in. surface casing extended from ground surface to 37 ft bgs, a 13.375-in. drill casing extended from ground surface to 847 ft bgs, and an 11.75-in. drill casing extended from ground surface to 826 ft bgs. The remaining interval of the borehole between 847 and 1058 ft bgs was uncased.

The primary purpose of the Schlumberger logging was to characterize the conditions in the hydrogeologic units penetrated by the R-13 borehole, with primary emphases on gathering moisture distribution data, identifying possible perched water zones, measuring capacity for flow (porosity and moisture), and obtaining lithologic/stratigraphic data. Secondary objectives included evaluating borehole geometry and determining the degree of drilling fluid invasion along the borehole wall.

Schlumberger personnel ran a suite of geophysical logging tools in the cased borehole; the suite include the following tools:

- Array Induction Tool, version H (AITH™), measures formation electrical resistivity and borehole fluid resistivity, thus evaluating the drilling fluid invasion into the formation, the presence of moist zones away from the borehole wall, and the presence of clay-rich zones.

- Triple detector Litho-Density (TLD™) measures formation bulk density related to porosity, photoelectric effect related to lithology, and borehole diameter using a single-arm caliper.

- Natural Gamma Spectroscopy (NGS™) measures spectral and overall natural gamma ray activity, including potassium, thorium, and uranium concentrations, thus evaluating geology and lithology.

- Elemental Capture Spectroscopy (ECS™) measures concentrations of hydrogen, silicon, calcium, sulfur, iron, potassium, titanium, and gadolinium to characterize mineralogy, lithology, and water content of the formation.

- Compensated Neutron Tool, model G (CNTG™), measures volumetric water content beyond the casing to evaluate formation moisture content and porosity.
- Formation Micro-Imager (FMI™) measures electrical conductivity images of the borehole wall and the borehole diameter with a two-axis caliper to evaluate geologic bedding and fracturing, including strike and dip of these features, fracture apertures, and rock textures.

Additionally, a calibrated natural gamma tool was used to record gross natural gamma-ray activity with every logging method (except the NGS™ run) to correlate depth runs between each of the surveys conducted.

The Schlumberger interpretive logging report and the geophysical logs, compiled as a montage, can be found as Appendix D (see the CD on the inside back cover of this report).

6.0 LITHOLOGY AND HYDROGEOLOGY

A preliminary assessment of the hydrogeologic features encountered during drilling operations at R-13 is presented below. Included is a brief description of the geologic units identified during characterization of drill cuttings. Groundwater occurrences are discussed based on drilling evidence, open-hole video logging, and geophysical logging data.

6.1 Stratigraphy and Lithologic Logging

Rock units and stratigraphic relations, interpreted primarily from visual examination of drill cuttings samples and interpretation of geophysical data, are briefly discussed in order of younger to older occurrence. Such interpretations may be revised upon further analysis of petrographic, geochemical, mineralogical, and geophysical logging. A lithologic log for the R-13 borehole is provided in Appendix B.

Alluvium (0 to 38 ft bgs)

Cuttings samples indicated unconsolidated alluvium in R-13 from ground surface to approximately 38 ft bgs that represent abandoned stream channels of Mortandad Canyon. These Quaternary deposits contain tuffaceous silty sands and gravels derived from the Bandelier Tuff.

Bandelier Tuff (38 to 268 ft bgs)

The Quaternary Bandelier Tuff is comprised of the Tshirege Member, (Qbt 1g), and the Otowi Member, including the Guaje Pumice Bed. Tuffaceous sedimentary deposit of the Cerro Toledo interval separate the two members of the Bandelier Tuff.

Tshirege Member of the Bandelier Tuff, Unit 1g (38 to 73 ft bgs)

Unit Qbt 1g of the Tshirege Member of the Bandelier Tuff was encountered from 38 to 73 ft bgs. This interval represents the basal part of the Tshirege Member that is made up of nonwelded to poorly welded rhyolite ash-flow tuff. Drill cuttings indicate abundant (up to 80% by volume) vitric pumice; hence, the unit is identified as 1g (*g* representing glassy). Cuttings contain 20% or more intermediate to felsic volcanic lithic fragments and lesser amounts of quartz and sanidine crystals. The high abundance of pumice and lithic fragments indicates that much of the fine ash that is normally found in these tuffs was not collected in the cuttings sample.

The Cerro Toledo Interval (73 to 80 ft bgs)

The interval from 73 to 80 ft bgs is interpreted to represent tephra and volcaniclastic sediments of the Cerro Toledo interval. Texturally, this unit is made up of silt to very coarse sands and gravels. Pebble-size clasts are subrounded and typically composed of dacite and rhyodacite volcanics in a matrix of white vitric pumice, quartz, and sanidine crystals.

Ash-flows of the Otowi Member of the Bandelier Tuff (80 to 248 ft bgs)

R-13 penetrated 168 ft of nonwelded to poorly welded rhyolite ash-flow tuff representing the Otowi Member of the Bandelier Tuff. The upper part of this sequence contains abundant fibrous, vitric pumice fragments that are orange-tan in color. Cuttings for the Otowi Member are lithic-rich and typically contain dacitic and andesitic xenolithic fragments and 10% or less quartz and sanidine phenocrysts. The volcanic ash that comprises significant portion of this unit is poorly sampled in cuttings returns. Whole-rock chip samples frequently contain ground vitric ash that indicates the nonwelded character of the tuff matrix.

Guaje Pumice Bed (248 to 268 ft bgs)

The interval from 248 to 268 ft bgs is interpreted to represent the Guaje Pumice Bed that forms the basal unit of the Bandelier Tuff. Drill cuttings indicate that this pumiceous unit is predominantly light pinkish-gray tephra. Pumice fragments, volumetrically as much as 90%, are vitric to locally clay-altered. The remainder is made up of dacitic lithic fragments and quartz and sanidine crystals.

Upper Puye Formation (268 to 303 ft bgs)

The 37-ft-thick interval from 268 to 303 ft bgs in R-13 is made up of generally fine clastic sediments interpreted to represent an upper facies of the Pliocene Puye Formation. Cuttings in this interval are predominantly made up of indurated clay-cemented tuffaceous sandstone and siltstone with less than 10% clasts by volume of mixed volcanic lithologies, including dacite, andesite, basalt, pumice, and minor amounts of quartz and sanidine crystals.

Cerros del Rio Basalt (303 to 730 ft bgs)

R-13 intersected a series of basalt flows and scoriaceous breccias from 303 to 703 ft bgs that make up the Pliocene Cerros del Rio basalt. Basalt flows in this section are generally porhyritic with phenocrysts of olivine, pyroxene, and minor plagioclase in an aphanitic groundmass. Flows exhibit a wide range of vesicularity and are locally scoriaceous. The interval from 460 to 483 ft bgs contains abundant scoria that is reddish with iron-oxide staining, suggesting that this interval is an interflow breccia separating distinct flow events in the sequence. Evidence of local alteration in these rocks also includes alteration of groundmass minerals, iddingsite replacement of olivine phenocrysts, amygdaloidal clays, and clay or calcite coatings on fracture surfaces. Clay-coated, rounded basalt clasts in chip samples from 595 to 605 ft bgs suggest this interval may represent a sedimentary interflow deposit between basalt flows.

Lower Puye Formation (730 to 1133 ft bgs)

Stratigraphically, below the Cerros del Rio basalt R-13 encountered a sequence of clastic sediments from 730 ft bgs to the bottom of the borehole at 1133 ft bgs. This clastic sediment interval is the lower part of the Puye Formation. A wide range of deposits, from silty sands to coarse gravels, is present in this interval, and volcaniclastic materials predominate throughout the chip samples. From 730 to 998 ft bgs, the Puye Formation is dominantly composed of dacitic and basaltic clasts (up to 98% by volume) and typically contains up to 15% fine-grained tuffaceous sandstone and siltstone fragments. Trace amounts of glassy scoria, pumice, and quartz are locally present. The interval from 998 to 1068 ft bgs is notably rich

in pumice (generally 50% or more pumice) with moderate amounts of dacite, silicified dacite, rhyodacite, fine-grained volcanic sandstone, and minor basalt scoria.

The lowermost interval of the Puye Formation, from 1068 to 1133 ft bgs, exhibits a 5 to 20% by volume component of Precambrian quartzite and metamorphosed granitic rocks. Quartzite-bearing gravel horizons interlayered within Puye sediments appear to be common in the study area. Dethier (1997) referred to the Totavi Lentil as a distinct gravel subunit containing 80% or more clasts of quartzite and other Precambrian crystalline rocks. The presence of quartzite in the above-mentioned interval suggests a depositional environment that resulted in the local mixing of volcaniclastic Puye alluvial-fan sediments with axial gravels of the ancestral Rio Grande.

6.2 Groundwater Occurrence and Characteristics

Perched groundwater saturation above the regional aquifer was not predicted in the planned drilling of R-13. As anticipated, no intermediate perched water-bearing zones were encountered during operations.

Water in borehole R-13 was first observed in alluvium at 33 ft bgs. Chemical analysis of a collected sample suggested the presence of naturally occurring groundwater (see section 4.1). Water was measured and sampled again in the borehole at 672.5 ft bgs, after drilling operations were shut down for several days. Visual inspection showed that this water contained a high concentration of drilling fluids and was not naturally occurring groundwater.

Water in the regional aquifer was encountered while drilling in the lower Puye Formation at approximately 834 ft. Drilling was halted at 903 ft and again at 943 ft bgs to circulate fluids within the borehole in an attempt to observe increased water production, which did not occur. At a depth of 963 ft, drilling was again halted, and water level was measured at 832.7 ft bgs. The water level eventually stabilized at 834 At the time these water-level measurements were collected, the bottom of the drill casing was at 847 ft bgs and the borehole was open to 963 ft bgs. After R-13 well installation and development activities were completed, but prior to installation of a dedicated pump, the water level had stabilized on October 28, 2001, with a measurement of 833.7 ft bgs.

7.0 WELL DESIGN AND CONSTRUCTION

Well R-13 was installed as part of the implementation of the work plan for Mortandad Canyon (LANL 1997, 56835) and the “Hydrogeologic Workplan” (LANL 1998, 59599). Sections 7.1 and 7.2 of this report describe the R-13 well design and construction, respectively.

7.1 Well Design

The Laboratory and WGII produced the well design for R-13. Information gathered from geophysical logs, borehole video logs, borehole geologic samples, water-level data, field water-quality data, and driller observations was analyzed by the Groundwater Investigations Team to plan the screen placement interval for the well. The well was designed with a single screen to monitor contaminants in the uppermost productive zone of the regional aquifer. The location of the screen below the top of regional saturation in the productive zone permits adequate development of the well. No intermediate perched zones were identified; therefore, no screens were placed above the regional aquifer. The planned and actual screen location is given in Table 7.1-1.

Table 7.1-1
Summary of Well Screen Information for R-13

Screen #	Planned Depth* (ft)	Actual Depth* (ft)	Geologic/Hydrologic Setting
1	959.1–1020.0	958.3–1018.7	Regional zone of saturation in the Puye Formation

* These intervals represent the perforated area of the screen.

7.2 Well Construction

Well R-13 casing and pipe-based screens were manufactured using 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) A554 standards. External couplings were also type 304 stainless-steel fabricated to ASTM standard A312 and A511, both of which exceed the tensile strength of the threaded casing ends. The pipe-based screens were modified from 10-ft sections of blank well casing. The modifications made consisted of drilling 0.5-in.-diameter holes with 84 holes per ft and then welding a stainless-steel wire-wrap (with 0.010-in. spacing) over the perforated interval. The final OD of the screened sections was 5.56 in.

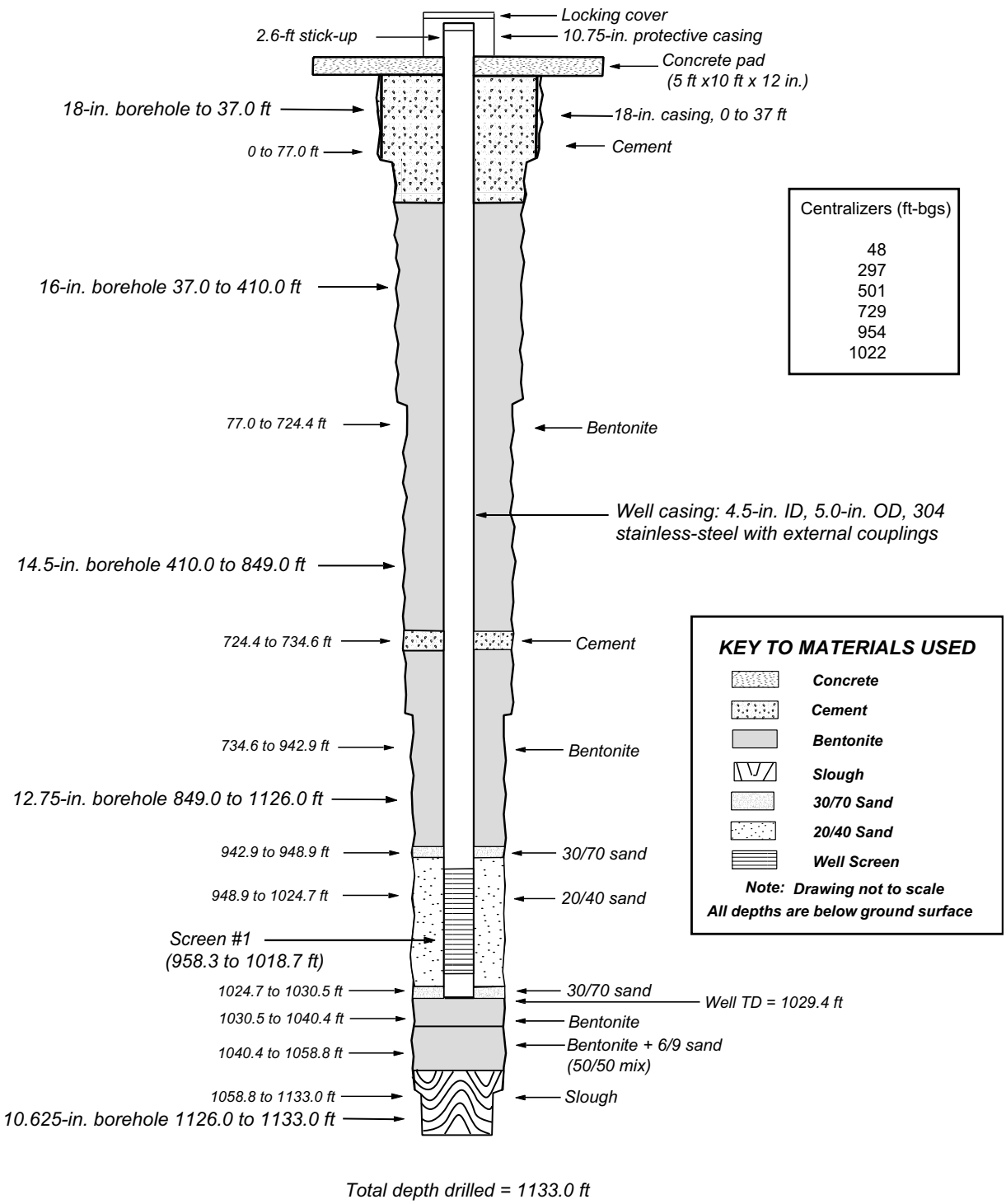
All stainless-steel well components were cleaned at the well site using a high-pressure steam cleaner and scrub brushes. All annular fill was placed in the casing/borehole annulus through a tremie pipe. Well construction activities were completed during the period from September 26 to October 6, 2001.

7.2.1 Steel Installation

Well steel installation consisted of connecting joints of stainless-steel well casing and screen sections by means of threaded couplings. The bottom of the well was set at 1029.4 ft bgs. Stainless-steel centralizers were installed above and below the screen and in several locations above the zone of regional saturation to center the well in the borehole during backfill placement operations. Dynatec installed the R-13 well casing and screen from September 26 to September 27, 2001. Figure 7.2-1 shows the as-built well casing configuration and indicates the depths of the various well components from ground surface.

7.2.2 Annular Fill Placement

Placement of annular fill consisted of using a steel tremie pipe to deliver annular fill to the specified depths (Figure 7.2-1). The bottom of the borehole was measured prior to placing the annular fill. Filter pack across the screened interval consisted of silica sand materials mixed with municipal water and placed in the annulus as a fluid slurry. Bentonite materials and sand were placed below and above the screened interval to seal the annular space and isolate the water-bearing zone. Bentonite was delivered using EZ-MUD® polymer mixed with municipal water as a fluid slurry. Portland cement (mixed at a ratio of 5 gal. of water to 1 bag of cement) was placed at 724.4 to 734.6 ft bgs to provide a foundation for annular fill above the regional aquifer and at 0 to 77 ft bgs to protect the annular space around the well head in the upper part of the borehole. Approximately 20,630 gal. of municipal water were used during placement of annular fill.



Notes: 1. The screen interval lists the footage of the pipe perforations, not the top and bottom of screen joints.
2. Pipe-based screen: 4.5-in. ID, 5.563-in. OD, 304 stainless-steel with s.s. wire wrap; 0.010-in. slot.
3. The interval of slough at the base of the borehole consists of Puye sediments.
4. Dedicated pump location not shown.

Figure 7.2-1. As-built configuration diagram for well R-13

Problems were encountered during placement of bentonite materials at approximately 680 ft when a bridge developed between the 13.375-in. drill casing and well casing. The contractor attempted to use the annular space between the drill and well casing to tremie the bentonite into the well. As a result, a bridge formed and a significant thickness of bentonite accumulated in the drill casing. The tremie pipe remained open below the bridge and, therefore, placement of backfill materials continued as the drill casing was removed joint by joint. With 380 ft of drill casing in the hole, the contractor pulled the entire string when the borehole was deemed stable over that interval. During removal of the last 150 ft, the well cap was dislodged and an undetermined amount of bentonite entered the well. See section 8.0, Well Development and Testing, for a description of the bentonite removal process.

Dynatec performed annular-fill activities from September 27 to October 6, 2001. Table 7.2-1 summarizes the annular fill materials installed. The final configuration of annular materials is illustrated in Figure 7.2-1.

Table 7.2-1
Annular Fill Materials Used in Characterization Well R-13

Material	Use/Function	Amount	Unit*
20/40 sand (medium-grained)	To pack screen intervals	151	bags
30/70 sand (fine-grained)	To separate filter packs from bentonite seals	23	bags
6/9 sand (coarse)	To bridge formation fractures and matrix pores	334	bags
Benseal® (bentonite)	As a high-solids, multipurpose grout	5.5	bags
Holeplug® (.375-in. angular and unrefined bentonite chips)	To provide a borehole annular seal	545	bags
Pelplug® bentonite (.25 in. by .375 in., refined elliptical pellets)	To provide a borehole annular seal below the water table	899	buckets
Portland® cement (mixed with municipal water at a ratio of 5 gal. water to 1 bag)	To provide annular support and surface seal on the upper 100 ft of the borehole	159	bags

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

8.0 WELL DEVELOPMENT AND HYDROLOGIC TESTING

Well development and hydrologic testing activities at R-13 were conducted from October 10 to 31, 2001. Well development procedures, described below, included wire brushing, well screen swabbing, and surging, bailing, and pumping. Development activities were followed by two single-well pumping tests.

8.1 Well Development

Well development at R-13 was performed in two stages. The initial stage consisted of wire brushing the well interior, swabbing and surging the screened interval to draw fine sediment from the constructed filter pack, and bailing to remove solid materials from the well. In the second stage, a submersible pump was lowered to the screened interval where on/off cyclic pumping was performed to remove any remaining fines from the filter pack and adjacent formation.

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

Table 8.1-1
Development of R-13

Method	Water Removed (gal.)	Range of Parameters[a]			
		pH	Temperature (°C)	Specific Conductance (µS/cm)[b]	Turbidity (NTU)
Bailing screen	458	NA[c]	NA–19.5	298–312	317–249
Bailing/jetting	741	NA	20.0–20.5	391–182	>1000
Bailing/swabbing screen	1448	NA–8	19.9–19.1	180–170	1000–214
Pumping screen	22,063	7.48–7.8	21.3–20.3	192–139	494–2.74
Total	**24,710**				

[a] Range is made up of value at beginning, followed by value at end, of a development method.

[b] Specific conductance is reported in microsiemens per centimeter (µS/cm).

[c] NA = Not measured.

Preliminary bailing from the R-13 screened interval and sump was initially performed to remove bentonite materials that had been introduced into the well during construction. An attempt to clean the interior of the well casing and screen using a wire brush was impeded when the brush became clogged with bentonite. A subsequent video camera survey showed that the casing and couplings were splattered with bentonite from the top of the well casing to 832 ft. The bentonite did not affect the screen as a minor bridge formed at the water table surface.

Bailing procedures were initiated by the drillers using a 12-gal.-capacity steel bailer to remove debris and sediment from the sump. Wire brushing was resumed, and high-pressure jetting procedures were used to dislodge the remaining bentonite from the well interior. Bailing procedures continued until all foreign matter was removed. Water turbidity was not reduced significantly and remained greater than 1000 NTU after approximately 700 gal. had been withdrawn from the well. Video logging was performed to evaluate the effectiveness of the activities in dislodging and removing the bentonite. The video logs and final water quality indicate that the jetting and bailing very effectively removed the bentonite from the well interior.

Bailing was followed by surging and swabbing techniques to enhance filter-pack development. In surging the well, a wireline-controlled surge block, with a weighted pipe attached, was used to make rapid upward strokes across the screen and to facilitate changing to a wireline bailer. Next, a swabbing tool was lowered into the well and drawn repeatedly across the screen interval while municipal water was injected at a rate of 20 gal. per min (gpm). Water turbidity exceeded 1000 NTU at the beginning and declined to 214 NTU at the end of the surging, swabbing, and bailing operation (Table 8.1-1).

Pump development procedures were applied to the screened interval (958.3 to 1018.7 ft bgs) using a 10 horsepower (hp) submersible pump. The pump intake was lowered to the bottom of the screen and the pump was cycled on at a nominal rate of 20 gpm while water samples were collected every hour for parameter measurements. The pump was then cycled off for a minimum period of 15 min to allow recovery of the water level. Next, the pump was raised approximately 2 ft and the process was repeated until the entire screen interval was traversed. Approximately 22,000 gal. of water were withdrawn from the

well at the end of 14 pumping cycles. Turbidity levels declined from 494 to 2.74 NTU during the total pump development stage (Table 8.1-1).

Figure 8.1-1 illustrates the effects of pump development on measured field parameters. The graph shows that specific conductance, pH, and temperature were stable during the latter period of pumping and that turbidity values had declined consistently to less than 5 NTU when R-13 was declared fully developed.

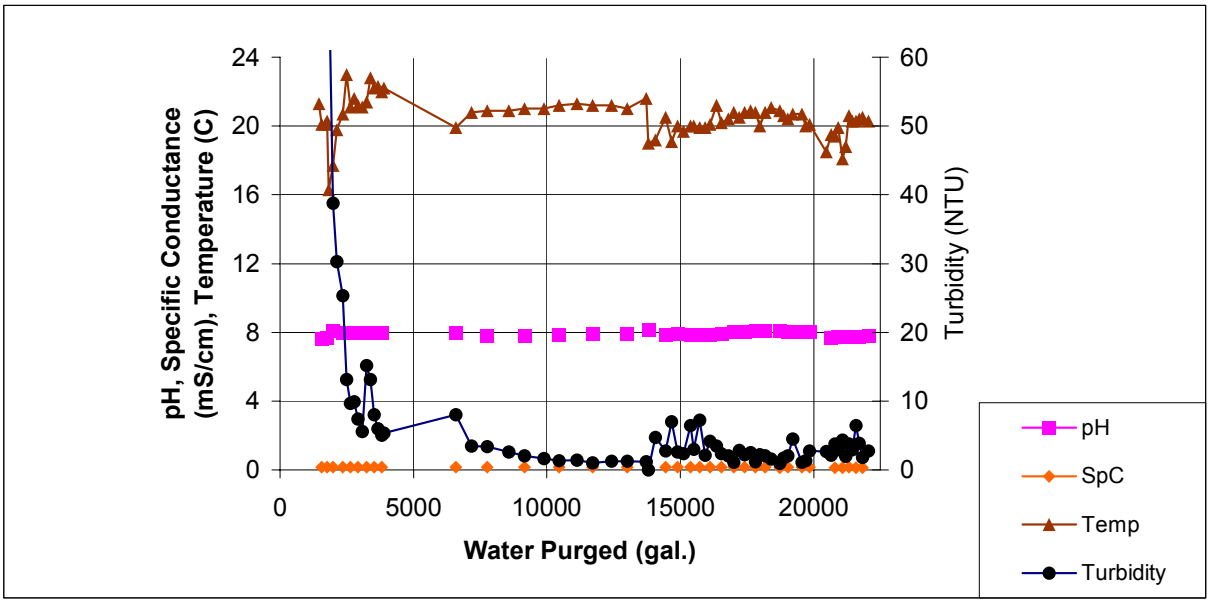


Figure 8.1-1. Effects of pump development on water-quality parameters at R-13

8.2 Hydrologic Testing

Hydrologic testing conducted in well R-13 consisted of a single-well pumping test performed on October 13, 2001, after well development was completed. The pumping test procedure involved lowering a 10 hp submersible pump intake to 931 ft, approximately 27 ft above the top of the well screen. An In-Situ, Inc., transducer (model PXD-261) was placed 10 ft above the pump intake at 921 ft bgs. The pump was turned on and run at an average continuous rate of 19 gpm for 22 min. The water level dropped 3 ft in the first minute before stabilizing for the remainder of the test. The test was repeated to verify the initial results. These tests indicate that the formation is capable of yielding up to 19 gpm. A complete discussion of hydrologic testing for well R-13 can be found in Stone and McLin (2003, 75912).

8.3 Dedicated Pump Installation

On February 20, 2002, a dedicated pump for groundwater sampling was installed in the R-13 well. The pump is a 4-in.-diameter submersible, Grundfos™ Model 10S50-48DS, with a 5 hp, 460-volt motor, rated for 11 gpm at 933 ft. The pump will be used to collect groundwater samples for water quality monitoring. The dedicated pump assembly, riser pipe, and other components were installed with a Smeal work-over rig, provided by, and operated by, Rio Grande Well Supply.

The riser pipe consisted of 1.25-in., Schedule 40S, type 304/TP 304L stainless-steel connected with 3000-lb test F304/F304L stainless-steel couplers. The thread compound used was Loctite® 567. A 1-in. Schedule 40 polyvinyl chloride (PVC) flush-thread transducer access pipe was set at the top of the pump

to permit unobstructed access for water-level measurements. The pump control leads and PVC transducer pipe were secured with stainless-steel bands to the riser pipe 5 ft above the pump and every 60 ft thereafter. In addition, the leads and PVC pipe were secured to the riser pipe every 10 ft with cold-weather vinyl cable and pipe tape that is both water and corrosion resistant. The length of the pump assembly, riser joints, and couplers were measured and assembled to ensure installation of the pump intake at 935.4 ft bgs.

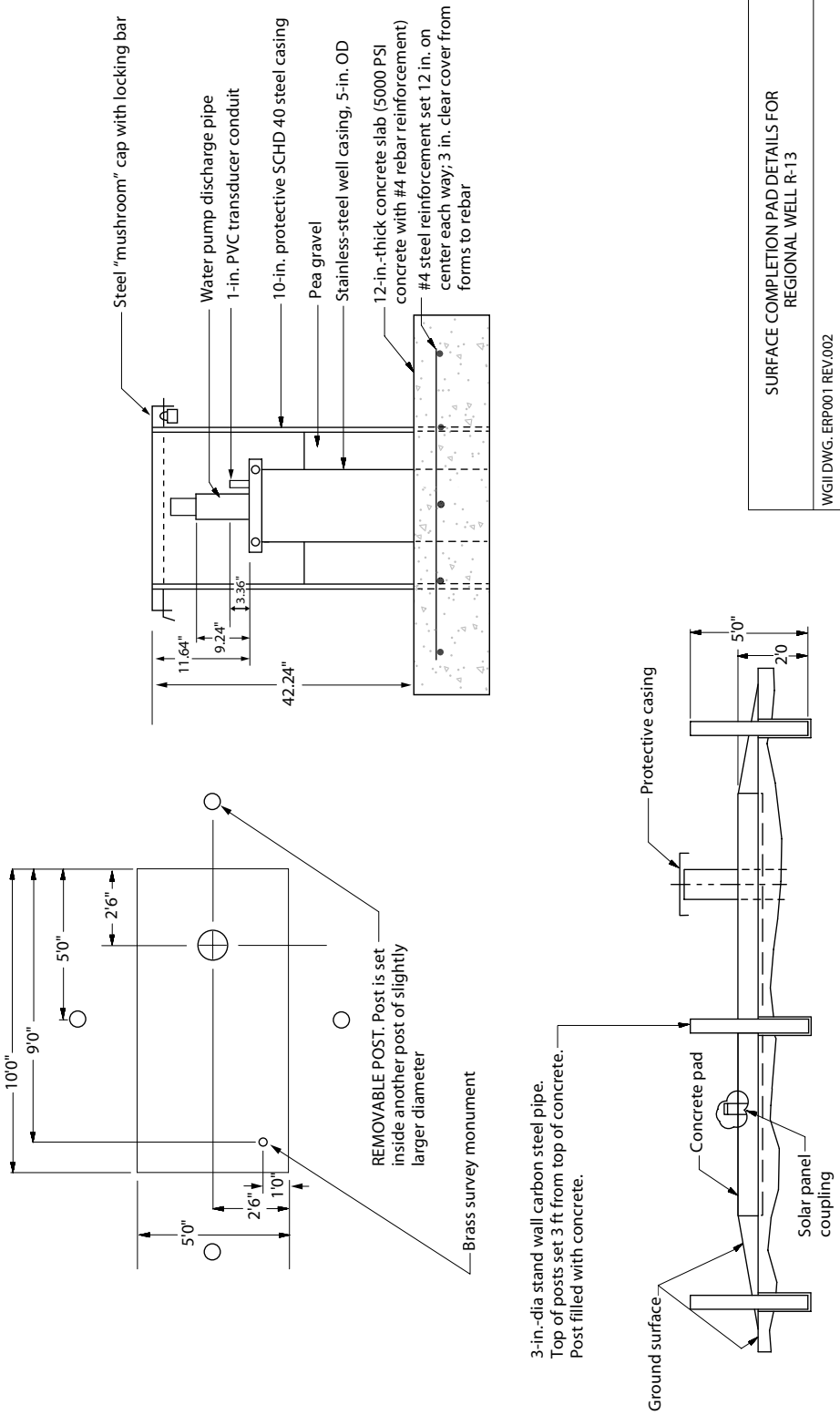
The pump installation was completed and tested on February 25, 2002. The pump yielded a discharge rate of approximately 10 gpm over a 10-min period.

9.0 WELLHEAD COMPLETION AND SITE RESTORATION

After completion of the pump installation, finish work commenced on the wellhead area. Well components were surveyed, and the site underwent final clean up and restoration.

9.1 Wellhead Completion

The surface completion for well R-13 involved pouring a reinforced (5000 psi) concrete pad, 5-ft wide by 10-ft long by 12-in. thick, around the well casing to ensure long-term structural integrity of the well (Figure 9.1-1). The concrete pad was poured on December 5, 2001. A 3-in. galvanized-steel conduit was embedded vertically through the pad and connected to the protective casing to allow for future wiring of a solar power energy supply. A brass survey pin was installed in the northwest corner of the pad. A 10.75-in. steel casing with locking lid protects the well riser. Four 4-in.-diameter steel bollards were placed next to each side of the pad. The bollard next to the west side of the pad is removable to facilitate access to the well for sampling and maintenance. The pad was designed to be slightly elevated, with base course graded up around the pad to allow for drainage.



NOTES:

1. Los Alamos National Laboratory brass monument coordinates: E 1640992, N 1766994, el. 6673.
2. Grundfos™ Model 10S50-48DS, 5 hp, 460-volt pump and motor installed.
3. Pump intake set at 935.4 ft bgs.
4. 1.25-in. Schedule 40S, type 304, stainless-steel riser pipe installed.
5. Not to scale.

Figure 9.1-1. Surface completion configuration diagram

9.2 Geodetic Survey

The location of well R-13 was determined by geodetic survey on January 29, 2002, using a Topcon GTS 302 total station with 3-in. positional accuracy. Control points used for this survey were well MCO-13 (brass cap) and location MO-10009. Prior measurements were provided by Merrick and Co., Los Alamos National Laboratory permanent monument records. Field measurements were reduced using Plus 3 Terra Model software V-6.7. Southwest Mountain Surveys performed the survey.

This survey located the brass cap monument at well R-13 in the concrete pad as well as the four pad corners, the transducer access pipe riser, the top of the stainless-steel well casing, and the top of the 10.75-in. protective steel casing. Table 9.2-1 summarizes the results of readings conducted for various components of the completed wellhead. The coordinates shown are in New Mexico State Plane Grid Coordinates, Central Zone (North American Datum, 1983 [NAD 83]), expressed in US ft. Elevation is expressed in ft above mean sea level relative to the National Geodetic Vertical Datum of 1929.

Table 9.2-1
Geodetic Data for Well R-13

Description	East Coordinate	North Coordinate	Elevation*
Brass cap in R-13 pad	1640991.66	1766994.17	6673.05
Top of stainless-steel casing	1640988.36	1766988.39	6675.37
Transducer access pipe	1640992.71	1766993.14	6673.91
Concrete well pad corner	1640991.61	1766995.46	6672.97
Concrete well pad corner	1640995.16	1766992.07	6673.01
Concrete well pad corner	1640988.40	1766984.84	6673.01
Concrete well pad corner	1640984.85	1766988.31	6673.00
10.75-in. steel casing top	1640988.36	1766988.39	6676.23

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

The location identification number assigned by the Laboratory's Facility for Information Management, Analysis and Display for the R-13 well is MO-10097.

9.3 Site Restoration

From November 16, to December 5, 2001, drilling site restoration activities were conducted by S.G. Western Construction Company at R-13. Prior to and concurrent with restoration, waste management activities were also performed. Waste materials were removed from the site according to the WCSF.

Drilling activity waste streams included drilling fluids, cuttings, and development water, which were sampled for contaminant analysis. The test data were then reviewed by the New Mexico Environment Department (NMED) and the Laboratory, and the waste was approved for on-site disposal. The drill cuttings were used to help backfill the containment area, and the drilling fluids and development water were applied adjacent to the site with a 3-in. pipe irrigation system.

The waste streams included petroleum-contaminated soils and absorbent materials which had been used to clean up minor incidental spills. After the Laboratory approved the waste profile forms submitted by waste management personnel, both waste streams were disposed of as New Mexico Special Waste.

The waste associated with the hydraulic leak, including the types, volume, and final disposition, was discussed above in section 3.0.

The cuttings-containment area was excavated and the plastic lining was removed. The containment basin and water tank storage areas were then backfilled with dirt that had been bermed up during pad construction and regraded. Base-course gravel was also regraded and compacted across the site to form a smaller pad. The site was reseeded with a blend of native grasses mixed with fertilizer and mulch to facilitate regrowth of ground cover.

10.0 DEVIATIONS FROM THE R-13 FIP

Appendix A compares the actual characterization activities that were performed at R-13 with the planned activities described in the “Hydrogeologic Workplan” (LANL 1998, 59599), the “Work Plan for Mortandad Canyon” (LANL 1997, 56835), and the R-13 FIP (LANL 2001, 70291.2). Significant deviations are discussed below.

- Planned depth—the FIP stated that the approximate depth of the well would be 1700 ft bgs. The actual depth of the borehole was 1133 ft, or approximately 300 ft into the regional aquifer. Attempts were made to drill deeper than 1133 ft but, due to formation stability problems, drilling was halted.
- Number of water samples collected for contaminant analysis—intermediate perched groundwater was not encountered during drilling; two groundwater samples were obtained from the regional aquifer.
- Number of core/cuttings samples collected for contaminant analysis—the use of casing advancement techniques precluded the collection of depth-specific sidewall core samples. Additionally, the lack of intermediate perched water zones, the lack of any contaminants of concern in the screening water samples collected from the regional aquifer, and the inconclusive nature of an alluvial water zone precluded the usefulness of submission of cuttings samples.

11.0 ACKNOWLEDGEMENTS

Dynatec Drilling Company provided the rotary drilling services.

Tetra-Tech EM, Inc.; D.B. Stephens and Associates, Inc.; and S.M. Stoller provided support for well-site geology, sample collection, and hydrologic testing.

Southwest Mountain Surveys provided the final geodetic survey of finished well components.

D. Thompson and C. Schultz of PMC Technologies, Exton, PA; and P. Schuh, E. Tow, and R. Lawrence of Tetra-Tech EM, Inc., Albuquerque, NM; 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, P. Longmire, 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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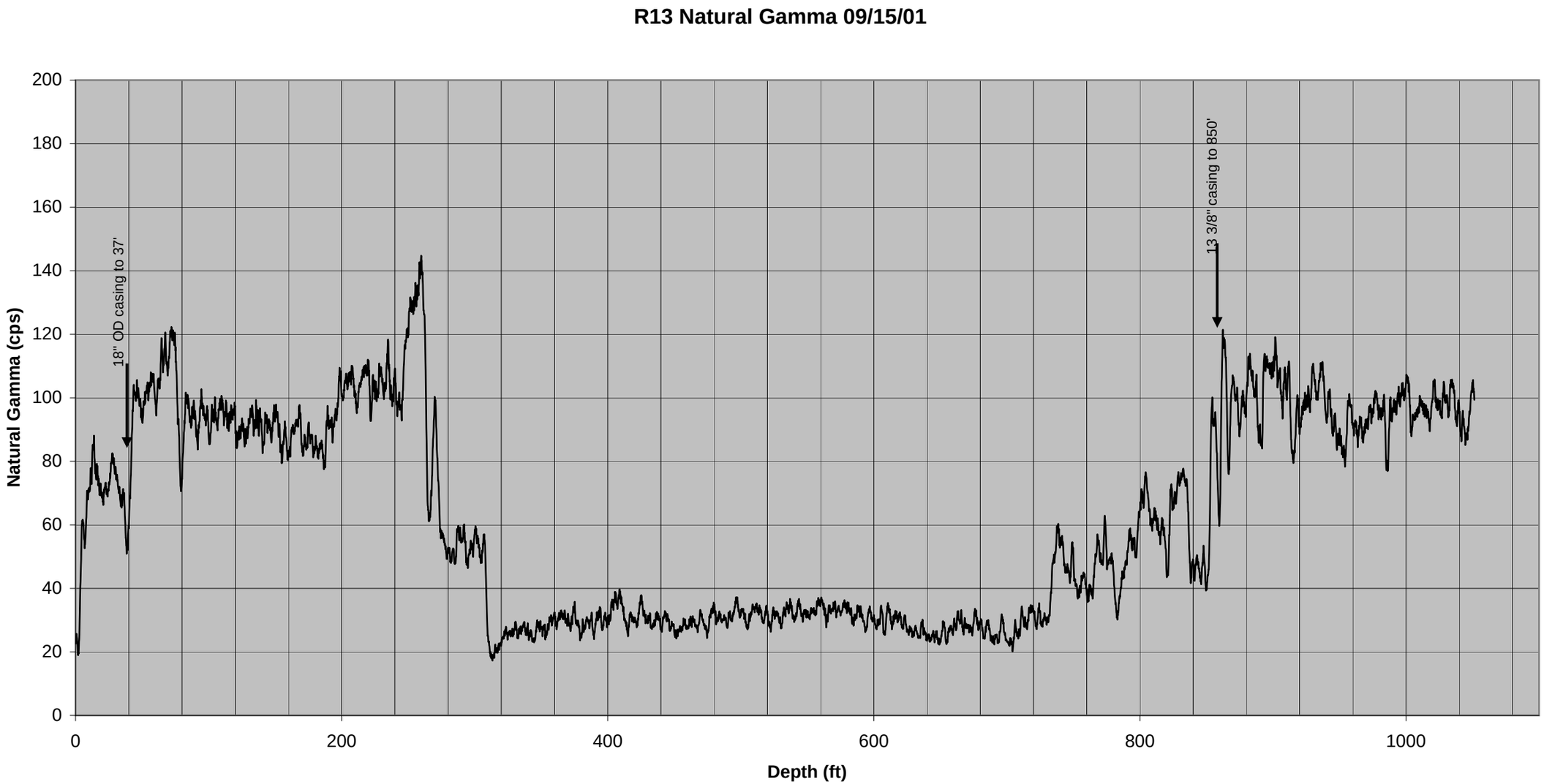
Stone, W.J. and S.G. McLin, March 2003. “Hydrologic Tests at Characterization Wells R-9i, R-13, R-19, R-22, and R-31,” Los Alamos National Laboratory report LA-13987-MS, Los Alamos, New Mexico. (Stone and McLin 2003, 75912)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Natural Gamma (cps)
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13 3/8" casing to 850'
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60
80
100
120
140
160
180
200
0
200
400
600
800
1000

CHEMICAL PROCESSING PLTS.			
1/08/03	2.0		FORCE LEVELS NEAR OPTIMUM ENERGIES.
1/08/03	2.0		ENERGY CONSERVATION IN PROCESS
CHEMICAL PROCESSING PLTS.			
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1/14/97

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873.827	105.941
873.663	118.508
873.5	94.0742
873.336	115.453
873.173	98.3711
873.009	108.125
872.846	92.5156
872.682	83.5195
872.519	91.3398
872.355	110.004
872.192	93.5859
872.028	92.9453
871.865	108.992
871.701	108.813
871.538	102.398
871.374	111.809
871.211	115.18
871.047	107.723
870.884	101.137
870.72	102.344
870.557	105.496
870.393	107.281
870.23	100.324
870.066	94.0898

869.903	117.664
869.739	114.887
869.576	85.25
869.412	105.672
869.249	108.078
869.085	93.2109
868.922	97.3711
868.758	94.375
868.595	100.555
868.431	76.4688
868.268	90.3555
868.104	78.6094
867.941	77.3047
867.777	73.5664
867.614	49.5742
867.45	75.6484
867.287	70.3281
867.123	64.1367
866.96	101.762
866.796	78.1484
866.633	76.9219
866.469	95.0508
866.306	95.5547
866.142	104.684
865.979	89.0781
865.815	97.8789
865.652	110.871
865.488	117.578
865.325	118.465
865.161	119.785
864.998	115.66
864.834	109.293
864.671	141.039
864.507	115.906
864.344	102.242
864.181	99.6563
864.017	131.438
863.854	124.5
863.69	123.992
863.527	115.555
863.363	120.395
863.2	106.637
863.036	126.602
862.873	105.027
862.709	117.984
862.546	119.48
862.382	143.93
862.219	104.215
862.055	94.2695
861.892	88.918
861.728	91.8477

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861.401	92.7578
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860.911	63.0879
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860.42	42.5957
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860.093	75.8398
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859.439	77.1094
859.276	74.2617
859.112	71.75
858.949	90.5898
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858.622	63.5527
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858.131	94
857.968	99.1797
857.804	86.9102
857.641	83.3789
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857.314	98.3242
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856.987	102.258
856.823	80.1875
856.66	105.578
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856.333	76.0938
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852.082	49.1211
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851.592	46.4277
851.428	41.6582
851.265	42.2793
851.101	44.6113
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849.629	39.5996
849.466	53.5527
849.303	53.5664
849.139	50.3242
848.976	66.3359
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848.649	51.9902
848.485	43.7754
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847.831	58.6504
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847.504	49.4414
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845.706	36.6445
845.542	45.8125
845.379	48.8828
845.215	52.0098
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837.204	58.7402
837.041	54.0195
836.877	72.2031
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812.68	63.1582
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812.353	70.5938
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809.083	72.7266
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808.429	66.9492
808.266	50.541
808.102	63.0859
807.939	53.3125
807.775	69.3125
807.612	64.9922
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804.996	77.3281
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798.783	35.9258
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743.849	47.5645
743.686	49.2891
743.522	53.1328
743.359	44.8574
743.195	60.5352
743.032	42.8008
742.868	64.7344
742.705	56.8574
742.541	59.5879
742.378	54.5
742.214	61.9277
742.051	52.6719
741.887	37.4355
741.724	62.7578
741.56	68.2539
741.397	49.4004
741.233	51.4199
741.07	40.7422
740.906	56.2422
740.743	71.8281
740.579	63.6465
740.416	34.3301
740.252	51.7422
740.089	57.998
739.925	59.3496
739.762	44.0137
739.598	59.1035
739.435	50.0566
739.271	77.125
739.108	76.5469
738.944	57.3203
738.781	63.75
738.617	66.4414
738.454	49.9785
738.29	47.9102
738.127	44.7949
737.963	56.0547
737.8	54.5996
737.636	60.3789
737.473	55.832
737.309	54.8906
737.146	40.4355
736.982	56.0547
736.819	51.3066
736.655	41.9063

736.492	43.7246
736.328	50.4082
736.165	45.6953
736.002	43.7285
735.838	57.584
735.675	42.498
735.511	62.2363
735.348	62.502
735.184	44.6816
735.021	47.7051
734.857	35.002
734.694	43.0996
734.53	39.5195
734.367	46.9805
734.203	44.9844
734.04	48.4805
733.876	26.5684
733.713	34.1426
733.549	37.1934
733.386	34.0391
733.222	32.8438
733.059	39.2051
732.895	34.2852
732.732	23.2148
732.568	34.0938
732.405	23.6973
732.241	28.3018
732.078	23.3994
731.914	39.0781
731.751	36.0039
731.587	33.1016
731.424	20.6953
731.26	33.4219
731.097	27.2344
730.933	35.4453
730.77	24.0908
730.606	36.6934
730.443	31.4004
730.279	23.2861
730.116	23.3857
729.952	24.9248
729.789	41.9629
729.625	30.8936
729.462	33.9375
729.298	29.749
729.135	28.2139
728.971	35.8281
728.808	32.582
728.644	29.4434
728.481	35.791
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728.154	32.793
727.99	24.9697
727.827	31.3232
727.663	29.8672
727.5	22.085
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727.009	25.5498
726.846	19.291
726.682	41.8066
726.519	28.6553
726.355	36.3887
726.192	20.4258
726.028	23.6289
725.865	42.1504
725.701	26.332
725.538	30.9033
725.374	21.6816
725.211	53.0176
725.047	37.3457
724.884	40.1934
724.72	24.7109
724.557	37.2637
724.393	21.917
724.23	53.1602
724.066	23.4033
723.903	29.6514
723.739	18.7891
723.576	29.8408
723.413	36.0449
723.249	25.084
723.086	33.2402
722.922	20.8857
722.759	22.4824
722.595	25.6729
722.432	33.6641
722.268	27.1348
722.105	27.0342
721.941	34.834
721.778	34.25
721.614	24.7715
721.451	35.6445
721.287	42.0664
721.124	26.5977
720.96	29.5449
720.797	43.3164
720.633	32.5977
720.47	31.2227
720.306	18.5508
720.143	38.7402
719.979	35.7422

719.816	36.0352
719.652	34.5117
719.489	42.3164
719.325	37.5352
719.162	20.3428
718.998	36.5898
718.835	27.3125
718.671	30.457
718.508	20.791
718.344	36.668
718.181	49.6719
718.017	46.502
717.854	33.2246
717.69	21.8682
717.527	31.1309
717.363	36.1211
717.2	31.2998
717.036	32.5898
716.873	32.541
716.709	21.8477
716.546	34.5273
716.382	31.3057
716.219	23.3301
716.055	29.5908
715.892	28.0869
715.728	28.3271
715.565	23.5459
715.401	17.1387
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714.584	20.7256
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713.603	25.0342
713.439	20.3271
713.276	29.7002
713.112	20.2412
712.949	27.9551
712.785	21.7197
712.622	49.8926
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712.295	40.959
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711.314	31.3027
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710.824	31.5459
710.66	23.6816
710.497	31.7773
710.333	30.3359
710.17	12.8975
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709.352	34.6855
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708.862	24.8691
708.698	26.4502
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708.371	23.2373
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708.044	23.2363
707.881	32.8027
707.717	26.583
707.554	32.625
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707.063	18.791
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706.573	28.1045
706.409	33.3047
706.246	33.6719
706.082	22.6504
705.919	16.0664
705.755	15.9517
705.592	23.8867
705.428	23.7461
705.265	25.0889
705.101	12.4429
704.938	18.5459
704.774	20.1719
704.611	23.4131
704.447	24.9727
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704.12	24.8213
703.957	34.3047
703.793	31.2979
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702.322	22.4365
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699.379	23.251
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698.888	25.0898
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698.561	20.2061
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698.071	27.1504
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697.744	35.2109
697.581	38.5176
697.417	38.793
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696.927	31.3291
696.763	25.0313
696.6	24.9346
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696.273	23.1914
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695.782	26.5928
695.619	24.7969
695.455	20.0801
695.292	23.1797
695.128	26.5088
694.965	20.3438

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694.638	21.7139
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693.003	22.1455
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690.55	12.4868
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689.406	19.3428
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689.079	14.3511
688.915	22.2949
688.752	26.9609
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687.607	35.541
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685.482	28.6338
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685.155	27.1475
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684.828	17.626
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684.501	25.0381
684.338	24.8984
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683.847	17.1855
683.684	20.1279
683.52	21.5693
683.357	20.1387
683.193	37.332
683.03	21.8184
682.866	26.4551
682.703	24.7783
682.539	23.502
682.376	20.5361
682.212	32.8457
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680.904	37.0488
680.741	22.4219
680.577	23.7402
680.414	34.3516
680.25	21.7471
680.087	34.1758
679.923	24.9336
679.76	13.917
679.596	36.9785
679.433	18.5918
679.269	46.9199
679.106	21.8486
678.942	24.8271
678.779	27.7666
678.615	23.3691
678.452	32.8301
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678.125	23.2988
677.961	31.0918
677.798	26.6084
677.634	39.3457
677.471	25.1543
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676.98	36.9121
676.817	37.0313
676.653	27.1533
676.49	25.4023
676.326	36.2891
676.163	31.5137
675.999	39.332
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675.672	23.2012
675.509	32.4434
675.345	21.6914
675.182	21.7793
675.018	32.5098
674.855	23.1748
674.691	23.1924
674.528	24.9043
674.364	17.2139
674.201	32.625
674.037	23.3701
673.874	31.3096
673.71	40.7637
673.547	26.5527
673.383	29.5654
673.22	15.7104
673.057	23.874
672.893	32.2793
672.73	28.8857
672.566	27.002
672.403	27.1104
672.239	27.0889
672.076	25.3555
671.912	32.8828
671.749	20.2119
671.585	26.3984
671.422	32.7773
671.258	34.291
671.095	27.998
670.931	32.5
670.768	27.8799
670.604	25.0029
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670.277	24.7188
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667.988	18.8818
667.825	31.5947
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665.536	28.9277
665.372	20.7373
665.209	20.8164
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664.882	25.9453
664.718	29.3789
664.555	32.6211
664.391	34.4609
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664.064	38.0449
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663.737	28.9668
663.574	41.8555
663.41	30.5605
663.247	25.665
663.083	35.1465
662.92	27.1475
662.756	23.9023
662.593	27.1406
662.429	25.6211
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662.102	22.417
661.939	33.5391
661.775	32.1289
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661.285	33.584
661.121	30.4053
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659.65	29.2637
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657.361	19.1523
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656.871	22.5566
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656.38	22.5537
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655.399	17.9561
655.236	29.4307
655.072	19.4688
654.909	35.3184
654.745	19.0732
654.582	20.6758
654.418	25.7295
654.255	22.4004
654.091	25.4463
653.928	28.6631
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653.601	41.832
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652.947	27.1729
652.783	30.5742
652.62	19.3682
652.456	22.5156
652.293	24.0127
652.129	30.6309
651.966	36.332
651.802	26.3418
651.639	19.6777
651.475	19.7139
651.312	34.5781
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650.985	16.4463
650.821	14.5698
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648.859	17.667
648.696	12.937
648.532	16.1543
648.369	27.2207
648.205	38.4512
648.042	31.9893
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647.388	31.1445
647.225	14.8213
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646.734	18.127
646.571	27.501
646.407	19.333
646.244	28.916
646.08	27.3408
645.917	25.5996
645.753	27.1074
645.59	14.4199
645.426	29.041
645.263	28.9512
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635.289	28.9404
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611.91	33.7285
611.746	35.2012
611.583	41.5234

611.419	28.708
611.256	33.75
611.092	43.3027
610.929	33.6602
610.765	38.707
610.602	33.5254
610.438	27.373
610.275	25.8066
610.111	36.9668
609.948	20.8564
609.785	30.6455
609.621	29.1328
609.458	24.4063
609.294	35.7539
609.131	17.9404
608.967	29.4141
608.804	18.1992
608.64	24.7939
608.477	19.6895
608.313	27.7314
608.15	32.4961
607.986	24.25
607.823	27.5078
607.659	27.2676
607.496	32
607.332	24.0684
607.169	27.3799
607.005	38.5449
606.842	44.6777
606.678	39.666
606.515	33.5566
606.351	35.4785
606.188	27.4736
606.024	32.0469
605.861	33.6621
605.697	32.3809
605.534	35.8242
605.37	25.8594
605.207	33.8379
605.043	30.7314
604.88	16.3232
604.716	28.2432
604.553	19.8633
604.389	41.2793
604.226	29.5098
604.062	36.0723
603.899	36.0469
603.735	17.8301
603.572	31.9531
603.408	23.8691
603.245	31.9873

603.081	27.3506
602.918	30.5313
602.754	25.4756
602.591	22.2773
602.427	25.5703
602.264	33.6836
602.1	27.3164
601.937	25.5645
601.773	27.0947
601.61	31.998
601.446	25.79
601.283	37.0566
601.119	30.5518
600.956	30.502
600.792	22.5898
600.629	42.7441
600.465	24.9502
600.302	36.1504
600.138	22.9619
599.975	42.6992
599.811	21.4756
599.648	22.9883
599.484	33.9375
599.321	24.1201
599.157	30.4268
598.994	33.748
598.83	32.1641
598.667	35.1582
598.503	35.0527
598.34	28.7041
598.176	35.2422
598.013	28.8994
597.849	39.8496
597.686	31.7539
597.522	25.5938
597.359	37.1914
597.196	33.9551
597.032	37.0352
596.869	44.8125
596.705	24.0283
596.542	30.8066
596.378	26.1631
596.215	35.9668
596.051	26.209
595.888	31.2461
595.724	29.5967
595.561	22.9844
595.397	32.7793
595.234	29.2041
595.07	17.6777
594.907	28.9609

594.743	24.0996
594.58	28.7021
594.416	25.5938
594.253	25.5928
594.089	27.5303
593.926	33.8516
593.762	20.6885
593.599	27.0342
593.435	31.96
593.272	33.6777
593.108	28.9482
592.945	30.499
592.781	35.2441
592.618	27.3311
592.454	30.6777
592.291	24.2979
592.127	35.8789
591.964	19.667
591.8	26.4209
591.637	44.7129
591.473	37.8574
591.31	37.4414
591.146	26.0039
590.983	38.9277
590.819	16.3008
590.656	46.8516
590.492	27.0117
590.329	47.8242
590.165	29.0869
590.002	25.749
589.838	38.6328
589.675	28.7607
589.511	15.9546
589.348	46.5371
589.184	35.3887
589.021	33.8008
588.857	49.6523
588.694	24.0508
588.53	35.5313
588.367	32.2832
588.203	19.2402
588.04	43.1855
587.876	22.5869
587.713	39.4355
587.549	44.6777
587.386	24.7324
587.222	14.7041
587.059	36.0215
586.895	39.2969
586.732	32.791
586.568	24.3008

586.405	20.835
586.241	34.9375
586.078	30.2725
585.914	27.3604
585.751	44.8926
585.587	30.4463
585.424	28.6504
585.26	32.0723
585.097	27.5752
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584.607	31.9629
584.443	38.6348
584.28	30.7715
584.116	40.377
583.953	24.0166
583.789	28.8955
583.626	30.8779
583.462	37.8867
583.299	41.2461
583.135	37.791
582.972	29.2295
582.808	14.7061
582.645	37.6816
582.481	26.0273
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582.154	35.168
581.991	22.4521
581.827	33.7578
581.664	52.8848
581.5	41.4824
581.337	28.6289
581.173	27.2119
581.01	45.041
580.846	25.6016
580.683	36.5176
580.519	28.6875
580.356	38.4688
580.192	33.9082
580.029	30.7285
579.865	22.5967
579.702	36.7129
579.538	43.5215
579.375	34.168
579.211	37.6855
579.048	37.7637
578.884	26.2227
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578.557	21.4043
578.394	40.9121
578.23	32.4258

578.067	38.4844
577.903	38.6563
577.74	33.7305
577.576	36.7656
577.413	27.0166
577.249	31.7881
577.086	39.9785
576.922	41.8047
576.759	25.6436
576.595	27.1494
576.432	23.9678
576.268	36.8828
576.105	37.0254
575.941	33.627
575.778	31.9463
575.614	30.4727
575.451	32.2988
575.287	35.5195
575.124	32.3047
574.96	24.4268
574.797	36.3477
574.633	28.2041
574.47	36.3027
574.306	39.3164
574.143	37.5098
573.979	35.6641
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573.652	43.7578
573.489	33.7637
573.325	25.5596
573.162	27.0527
572.998	33.6895
572.835	25.6357
572.671	25.5117
572.508	38.2363
572.344	36.6523
572.181	40.1387
572.017	30.5596
571.854	27.2324
571.691	28.8545
571.527	48.1113
571.364	24.3037
571.2	45.3848
571.037	43.3652
570.873	32.1504
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570.383	33.2305
570.219	31.3486
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569.892	34.2656

569.729	31.2168
569.565	42.4902
569.402	22.5527
569.238	35.1934
569.075	36.7148
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568.421	35.1465
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568.094	33.752
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567.767	36.6758
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567.276	35.418
567.113	33.8984
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566.622	33.8535
566.459	32.8164
566.295	36.3848
566.132	46.1484
565.968	27.8262
565.805	22.873
565.641	27.8711
565.478	17.9961
565.314	22.6426
565.151	45.0117
564.987	35.2168
564.824	30.5176
564.66	24.2178
564.497	21.0244
564.333	35.0156
564.17	22.3701
564.006	46.7031
563.843	40.2832
563.679	22.3965
563.516	48.0098
563.352	38.4863
563.189	24.2451
563.025	24.2695
562.862	30.5449
562.698	41.5488
562.535	41.623
562.371	29.0771
562.208	26.124
562.044	44.1582
561.881	39.3867
561.717	47.6758
561.554	34.4531

561.39	36.3262
561.227	24.5381
561.063	35.7168
560.9	38.668
560.736	35.5938
560.573	44.9785
560.409	27.1104
560.246	38.3926
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559.919	37.0742
559.755	27.3018
559.592	38.3809
559.428	41.9316
559.265	33.7988
559.102	37.127
558.938	22.6748
558.775	49.7305
558.611	44.8809
558.447	35.4512
558.284	38.7988
558.121	22.7852
557.957	26.1309
557.794	44.25
557.63	26.3818
557.467	31.417
557.303	34.5371
557.14	40.8105
556.976	29.4043
556.813	26.0498
556.649	29.1465
556.486	38.7305
556.322	30.4512
556.159	31.9658
555.995	27.248
555.832	37.1113
555.668	32.1797
555.505	36.625
555.341	35.0703
555.178	25.5645
555.014	30.5967
554.851	46.8379
554.687	22.4941
554.524	36.8281
554.36	30.5986
554.197	35.8652
554.033	25.7715
553.87	40.2148
553.706	37.3125
553.543	27.8906
553.379	23.2334
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553.052	42.6367
552.889	42.5137
552.725	26.248
552.562	34.4277
552.398	25.9688
552.235	19.2627
552.071	34.9727
551.908	25.5479
551.744	38.6855
551.581	25.7451
551.417	31.9893
551.254	33.4668
551.09	48.1426
550.927	27.4297
550.763	27.4131
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550.273	27.332
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549.946	29.0029
549.782	41.668
549.619	22.5127
549.455	25.9297
549.292	41.3281
549.128	33.5098
548.965	39.5859
548.801	35.9492
548.638	32.7734
548.474	24.7285
548.311	37.8125
548.147	24.3955
547.984	32.0879
547.82	28.9873
547.657	33.793
547.493	37.0195
547.33	31.9424
547.166	34.9805
547.003	22.4121
546.839	19.2988
546.676	20.8408
546.513	38.3574
546.349	43.0508
546.186	41.7734
546.022	27.5439
545.858	33.8965
545.695	30.498
545.532	30.4277
545.368	35.3848
545.205	34.1387
545.041	29.5
544.878	26.3516

544.714	52.7109
544.551	26.377
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544.224	32.7539
544.06	42.5625
543.897	40.8926
543.733	41.9785
543.57	30.667
543.406	27.3447
543.243	30.375
543.079	30.3691
542.916	33.7402
542.752	35.5117
542.589	35.5176
542.425	28.7529
542.262	20.7588
542.098	35.1973
541.935	33.7852
541.771	32.0723
541.608	38.5117
541.444	25.5869
541.281	25.6738
541.117	22.5059
540.954	43.7539
540.79	24.5215
540.627	26.333
540.463	33.1367
540.3	23.207
540.136	27.8867
539.973	40.6855
539.809	43.8691
539.646	35.8262
539.482	24.3945
539.319	21.0225
539.155	33.3652
538.992	26.9873
538.828	25.8359
538.665	49.9648
538.501	38.5156
538.338	39.8438
538.174	33.4219
538.011	33.5195
537.847	43.2051
537.684	35.1152
537.52	33.5977
537.357	22.4043
537.193	38.6855
537.03	35.5293
536.866	28.8828
536.703	38.498
536.539	27.5645

536.376	33.0039
536.212	24.9238
536.049	34.6133
535.885	37.3945
535.722	39.1523
535.558	31.2158
535.395	50.9258
535.231	32.3965
535.068	30.5986
534.904	27.2568
534.741	35.3359
534.577	36.4121
534.414	36.7793
534.25	22.2715
534.087	26.9385
533.924	36.6914
533.76	32.041
533.596	25.4639
533.433	41.0625
533.269	25.3242
533.106	38.5586
532.943	40.3496
532.779	30.6035
532.616	41.8125
532.452	35.5469
532.289	24.7061
532.125	13.3306
531.962	39.8828
531.798	26.2979
531.635	26.1729
531.471	27.8906
531.308	13.2134
531.144	39.5938
530.981	28.9775
530.817	41.3633
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529.509	36.4297
529.346	26.709
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528.855	28.7637
528.692	23.9668
528.528	35.4434
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528.038	41.1016
527.874	31.291
527.711	26.3594
527.547	34.5391
527.384	24.7354
527.22	46.2656
527.057	19.6543
526.893	19.4736
526.73	48
526.566	27.2451
526.403	39.873
526.239	25.4834
526.076	38.1133
525.912	28.7559
525.749	25.5234
525.585	34.9141
525.422	26.9131
525.258	42.6758
525.095	25.4277
524.931	31.7393
524.768	39.7227
524.604	36.4023
524.441	44.3086
524.277	33.5684
524.114	19.4043
523.95	27.5723
523.787	19.5254
523.623	27.8809
523.46	19.9365
523.296	28.1553
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522.969	37.7012
522.806	31.0352
522.642	27.6445
522.479	29.168
522.315	32.25
522.152	30.3047
521.988	23.8604
521.825	22.3555
521.661	38.5059
521.498	25.5205
521.335	26.8232
521.171	32.9629
521.007	20.5762
520.844	41.291
520.68	33.2266
520.517	53.6211
520.354	31.667
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520.027	30.7266
519.863	35.3242

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519.536	33.9766
519.373	34.4297
519.209	26.5586
519.046	29.7178
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518.719	26.1563
518.555	37.6816
518.392	32.8926
518.228	24.457
518.065	31.8281
517.901	23.8057
517.738	27.1865
517.574	29.0166
517.411	27.2988
517.247	18.9863
517.084	44.2852
516.92	27.0215
516.757	33.4043
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515.776	25.5742
515.612	35.1191
515.449	39.9766
515.285	44.1582
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514.631	32.6484
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513.65	30.2549
513.487	32.1172
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512.833	31.7637
512.669	36.6348
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512.179	36.2988
512.015	27.0137
511.852	39.9277
511.688	23.9121
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511.361	41.4238
511.198	32.2109
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510.871	29.5186
510.707	31.1113
510.544	31.0693
510.38	35.9688
510.217	46.1289
510.053	32.9336
509.89	27.7793
509.726	32.2188
509.563	38.4414
509.399	38.3477
509.236	23.8994
509.072	41.4043
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507.764	34.916
507.601	34.8398
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506.293	32.9102
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504.822	40.125
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504.004	31.5078
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503.514	31.6709
503.35	36.2793
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502.86	32.1875
502.696	27.2695
502.533	27.5625
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502.042	31.3848
501.879	50.502
501.715	34.1758
501.552	30.8916
501.388	27.7354
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500.407	31.0273
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499.59	34.2324
499.426	22.6855
499.263	32.3984
499.099	34.2754
498.936	41.043
498.772	32.8809
498.609	40.9297
498.445	27.9766
498.282	28.3574
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497.628	43.5547
497.464	36.7461
497.301	43.8086
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496.156	30.0771
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495.829	33.4961
495.666	26.8125
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495.339	38.5098
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495.012	28.3213
494.849	35.3164

494.685	23.7236
494.522	35.2168
494.358	27.7285
494.195	42.7676
494.031	21.5859
493.868	30.1592
493.704	28.6621
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493.377	26.916
493.214	27.0166
493.05	33.666
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492.723	37.8613
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492.233	32.8125
492.069	39.4512
491.906	39.541
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491.415	31.21
491.252	25.9229
491.088	23.9355
490.925	34.9922
490.761	39.8848
490.598	20.8379
490.434	22.3867
490.271	28.8252
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489.78	29.1777
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489.453	37.832
489.29	18.252
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488.309	27.9521
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487.982	26.0537
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487.655	30.542
487.491	35.5703
487.328	27.8311
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487.001	31.9141
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485.693	27.5322
485.529	39
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485.202	29.1357
485.039	27.8809
484.875	35.0957
484.712	40.1094
484.548	23.0889
484.385	29.5068
484.221	34.6094
484.058	31.5264
483.894	29.7813
483.731	31.1572
483.567	28.9092
483.404	22.4111
483.24	42.166
483.077	30.8174
482.913	22.585
482.75	23.9648
482.586	36.7227
482.423	38.4277
482.26	25.6406
482.096	25.7227
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479.807	21.585
479.644	38.1191
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479.317	27.498
479.153	52.6797
478.99	24.208
478.826	29.376
478.663	22.6523
478.499	37.0449
478.336	43.2012
478.172	27.3379

478.009	35.2109
477.845	28.624
477.682	34.9297
477.518	22.3145
477.355	33.8535
477.191	27.4385
477.028	35.3926
476.864	24.2666
476.701	34.0703
476.537	35.8613
476.374	31.4102
476.21	11.6655
476.047	18.2539
475.883	26.5703
475.72	19.915
475.556	26.583
475.393	29.8506
475.229	27.9521
475.066	24.5049
474.902	32.4395
474.739	30.5859
474.575	19.3037
474.412	30.5889
474.248	28.9961
474.085	33.9141
473.921	25.707
473.758	22.3945
473.594	20.7178
473.431	30.3037
473.267	28.8887
473.104	28.9063
472.94	30.4893
472.777	35.2383
472.613	30.4443
472.45	29.2275
472.286	30.9561
472.123	24.5713
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469.834	34.1699

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469.507	41.4238
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409.832	44.7637
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408.851	40.7324
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397.406	32.9941
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393.319	35.5762
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345.579	19.4688
345.415	29.3154
345.252	22.7412
345.088	29.4824
344.925	27.7012
344.761	23.0527

344.598	21.6973
344.434	25.0615
344.271	23.1855
344.107	23.1455
343.944	16.4805
343.78	21.5068
343.617	21.3916
343.453	27.5068
343.29	27.3184
343.127	25.8936
342.963	34.0938
342.8	34.0352
342.636	37.0781
342.473	24.0117
342.309	16.0488
342.146	27.4365
341.982	17.8154
341.819	14.5635
341.655	14.5454
341.492	33.9961
341.328	29.3525
341.165	37.3848
341.001	22.6768
340.838	30.6523
340.674	16.1855
340.511	36.2246
340.347	24.9805
340.184	34.7832
340.02	13.2148
339.857	39.9453
339.693	23.3379
339.53	28.1143
339.366	21.4531
339.203	19.5742
339.039	19.3555
338.876	32.3613
338.712	24.4531
338.549	26.0771
338.385	30.6377
338.222	36.9746
338.058	25.8223
337.895	33.8516
337.731	30.5732
337.568	27.25
337.404	35.3867
337.241	21.0303
337.077	27.6729
336.914	21.0361
336.75	28.9775
336.587	25.8613
336.423	27.6504

336.26	27.9248
336.096	37.916
335.933	24.6914
335.769	26.3906
335.606	23.2139
335.442	26.5928
335.279	28.1143
335.115	19.7959
334.952	13.1099
334.788	40.5605
334.625	35.875
334.461	32.668
334.298	22.6602
334.134	19.332
333.971	28.9443
333.807	34.002
333.644	17.8428
333.48	17.6689
333.317	28.9326
333.153	22.5107
332.99	25.9688
332.826	24.3848
332.663	24.1875
332.499	22.498
332.336	30.5371
332.172	24.2783
332.009	29.3281
331.845	32.6465
331.682	32.5723
331.518	24.6387
331.355	31.71
331.191	36.7949
331.028	29.8232
330.864	22.9492
330.701	29.6055
330.537	19.7441
330.374	32.5293
330.211	17.7607
330.047	19.3311
329.884	35.6348
329.72	21.0283
329.557	25.8838
329.393	34.0371
329.23	21.0371
329.066	25.6279
328.903	32.2617
328.739	22.7344
328.576	17.8164
328.412	30.71
328.249	33.8223
328.085	21.0703

327.922	14.7012
327.758	37.4902
327.595	21.0664
327.431	19.5146
327.268	29.4951
327.104	24.8145
326.941	25.0508
326.777	36.3223
326.614	29.6201
326.45	29.5322
326.287	19.7188
326.123	19.751
325.96	25.8545
325.796	20.9063
325.633	27.3965
325.469	24.5537
325.306	19.9785
325.142	21.4443
324.979	36.1367
324.815	18.1064
324.652	28.3213
324.488	34.877
324.325	29.8369
324.161	23.249
323.998	18.3779
323.834	31.6484
323.671	41.793
323.507	23.3545
323.344	14.9536
323.18	28.2959
323.017	23.5449
322.853	22.0898
322.69	18.7705
322.526	30.7725
322.363	22.0742
322.199	33.9668
322.036	22.0498
321.872	27.0195
321.709	21.8604
321.545	21.583
321.382	29.6426
321.218	19.999
321.055	18.3613
320.891	23.6943
320.728	27.2539
320.564	16.9561
320.401	25.6768
320.237	29.084
320.074	13.3853
319.91	14.8179
319.747	34.7129

319.583	26.6416
319.42	16.7109
319.256	21.7031
319.093	23.2656
318.929	24.8779
318.766	16.6299
318.602	15.3374
318.439	18.5977
318.275	28.7412
318.112	22.0508
317.948	32.4238
317.785	17.0518
317.622	18.8525
317.458	10.1143
317.295	15.2051
317.131	21.8311
316.968	23.3379
316.804	23.3691
316.641	20.0303
316.477	26.5166
316.314	16.6006
316.15	24.8262
315.987	26.5039
315.823	21.5918
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315.169	20.0996
315.006	5.01563
314.842	13.2803
314.679	13.2715
314.515	31.5508
314.352	20
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314.025	20.1553
313.861	11.8032
313.698	30.4668
313.534	10.2456
313.371	12.0176
313.207	24.0518
313.044	13.5562
312.88	15.0996
312.717	21.9717
312.553	20.165
312.39	18.3975
312.226	33.3125
312.063	16.6201
311.899	18.4141
311.736	21.7012
311.572	18.2656
311.409	18.166

311.245	24.71
311.082	28.0127
310.918	24.9268
310.755	31.6309
310.591	21.5508
310.428	29.7256
310.264	21.4863
310.101	31.7217
309.937	26.8291
309.774	16.7285
309.61	38.5156
309.447	41.9199
309.283	47.416
309.12	52.9492
308.956	63.2285
308.793	45.6641
308.629	55.8242
308.466	54.1563
308.302	56.0898
308.139	57.2012
307.975	43.0547
307.812	66.793
307.648	53.6504
307.485	58.6289
307.321	53.7227
307.158	82.6836
306.994	42.7832
306.831	43.0781
306.667	68.2656
306.504	43.4082
306.34	36.6406
306.177	44.6523
306.013	41.3945
305.85	48.2734
305.686	63.541
305.523	56.668
305.359	39.7617
305.196	56.6777
305.033	35.1973
304.869	62.7285
304.706	42.5938
304.542	35.8262
304.379	66.3555
304.215	44.2988
304.052	52.7676
303.888	54.3711
303.725	64.0156
303.561	66.3398
303.398	52.9043
303.234	48.6133
303.071	60.4609

302.907	35.166
302.744	67.7031
302.58	59.2344
302.417	41.7246
302.253	58.7988
302.09	67.9609
301.926	57.8906
301.763	59.5684
301.599	38.2891
301.436	60.2188
301.272	75.3008
301.109	60.0508
300.945	61.5625
300.782	61.8477
300.618	53.6328
300.455	50.6934
300.291	49.0039
300.128	72.7617
299.964	44.2285
299.801	35.9043
299.637	47.8828
299.474	72.4844
299.31	46.9824
299.147	53.3672
298.983	43.5195
298.82	31.9658
298.656	66.8125
298.493	74.9336
298.329	61.5566
298.166	41.3652
298.002	51.4883
297.839	51.6973
297.675	56.3184
297.512	54.5195
297.348	39.752
297.185	58.3809
297.021	48.6953
296.858	65.25
296.694	44.8242
296.531	48.1953
296.367	57.0898
296.204	50.2559
296.04	48.6172
295.877	40.4238
295.713	54.3145
295.55	43.1133
295.386	53.1895
295.223	40.9746
295.059	38.7441
294.896	35.2949
294.732	60.498

294.569	55.4473
294.405	50.0313
294.242	52.9355
294.078	59.7383
293.915	31.6865
293.751	61.4668
293.588	43.4941
293.424	71.5156
293.261	49.5762
293.097	66.0391
292.934	61.4785
292.77	50.0547
292.607	57.875
292.444	79.7656
292.28	58.1211
292.117	61.8926
291.953	43.5098
291.79	60.0898
291.626	56.998
291.463	47.4492
291.299	40.7285
291.136	55.084
290.972	51.4199
290.809	47.8555
290.645	87.8906
290.482	59.4082
290.318	49.1465
290.155	57.709
289.991	55.0527
289.828	46.207
289.664	58.1465
289.501	53.541
289.337	65.2344
289.174	67.7969
289.01	51.2891
288.847	49.4922
288.683	53.1406
288.52	51.6074
288.356	54.6621
288.193	64.6445
288.029	71.6836
287.866	63.543
287.702	63.5078
287.539	60.2578
287.375	51.4395
287.212	56.2988
287.048	47.1621
286.885	59.459
286.721	53.3379
286.558	49.3379
286.394	39.168

286.231	30.6777
286.067	39.541
285.904	62.9648
285.74	45.6367
285.577	45.0508
285.413	57.9219
285.25	41.7715
285.086	63.8223
284.923	48.5371
284.759	51.8027
284.596	54.6523
284.432	56.5215
284.269	46.7012
284.105	54.7695
283.942	52.6914
283.778	49.4414
283.615	44.9414
283.451	50.1035
283.288	58.6172
283.124	46.5117
282.961	38.166
282.797	43.4648
282.634	48.8887
282.47	61.2637
282.307	40.8359
282.143	45.8008
281.98	56.2031
281.816	46.1094
281.653	44.5527
281.489	71.2148
281.326	66.1875
281.162	43.3828
280.999	55.0547
280.835	50.3672
280.672	55.4688
280.508	45.2363
280.345	41.7012
280.181	46.4922
280.018	41.875
279.855	63.1465
279.691	53.0039
279.527	46.375
279.364	49.8945
279.201	58.4727
279.037	43.6504
278.874	51.5547
278.71	61.3203
278.547	48.0879
278.383	61.8867
278.22	48.6523
278.056	52.125

277.893	57.3125
277.729	60.7402
277.566	46.168
277.402	63.9766
277.239	51.3105
277.075	61.3438
276.912	47.2852
276.748	59.0723
276.585	62.0234
276.421	56.5996
276.258	59.8477
276.094	44.9492
275.931	61.8867
275.767	63.7773
275.604	48.3418
275.44	66.3125
275.277	48.3867
275.113	67.9688
274.95	51.5371
274.786	45.1563
274.623	56.8457
274.459	57.8887
274.296	76.4063
274.132	63.6777
273.969	52.125
273.805	82.3789
273.642	91.8203
273.478	73.8281
273.315	88.0859
273.151	69.8477
272.988	78.9141
272.824	69.7813
272.661	66.1836
272.497	75.9805
272.334	84.6445
272.17	84.3711
272.007	106.914
271.843	94.75
271.68	88.1641
271.516	102.551
271.353	114.805
271.189	102.855
271.026	80.7109
270.862	102.32
270.699	104.734
270.535	100.527
270.372	94.8164
270.208	89.5078
270.045	104.348
269.881	106.082
269.718	82.4648

269.554	73.3945
269.391	90.2188
269.227	71.7852
269.064	66.9609
268.9	81.8867
268.737	95.4531
268.573	70.332
268.41	78.4727
268.246	63.1055
268.083	61.1777
267.919	73.2227
267.756	38.6895
267.592	59.9531
267.429	89.5117
267.266	66.4531
267.102	62.1641
266.938	48.5293
266.775	67.9492
266.612	56.418
266.448	78.2109
266.285	56.6563
266.121	51.873
265.958	44.8438
265.794	64.2656
265.631	74.4648
265.467	75.3828
265.304	70.3555
265.14	71.8594
264.977	66.7188
264.813	69.7617
264.65	80.375
264.486	73.7813
264.323	103.691
264.159	93.4453
263.996	107.32
263.832	130.391
263.669	129.852
263.505	144.656
263.342	126.344
263.178	134.336
263.015	108.82
262.851	122.266
262.688	118.949
262.524	123.172
262.361	136.078
262.197	114.184
262.034	129.758
261.87	129.875
261.707	159.93
261.543	125.23
261.38	154.688

261.216	136.93
261.053	164.305
260.889	133.273
260.726	150.297
260.562	126.277
260.399	125.211
260.235	133.922
260.072	165.875
259.908	141.375
259.745	159.961
259.581	143.453
259.418	123.926
259.254	144.984
259.091	124.828
258.927	123.383
258.764	172.039
258.6	129.727
258.437	139.672
258.273	116.207
258.11	114.703
257.946	156.688
257.783	107.73
257.619	135.398
257.456	146.523
257.292	130.938
257.129	140.227
256.965	124.473
256.802	143.266
256.638	122.902
256.475	127.758
256.311	131.688
256.148	104.914
255.984	155.781
255.821	152.844
255.657	153.281
255.494	141.227
255.33	113.949
255.167	109.754
255.003	128.758
254.84	117.414
254.676	111.246
254.513	113.035
254.349	151.297
254.186	138.852
254.023	159.813
253.859	122.207
253.696	123.059
253.532	136.438
253.369	115.535
253.205	137.586
253.042	122.75

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252.715	103.102
252.551	123.828
252.388	158.133
252.224	144.289
252.061	157.867
251.897	126.684
251.734	123.828
251.57	135.688
251.407	89.5273
251.243	125.645
251.08	121.98
250.916	94.8516
250.753	121.609
250.589	155.109
250.426	114.289
250.262	108.16
250.099	126.172
249.935	126.113
249.772	125.305
249.608	122.215
249.445	104.488
249.281	113.871
249.118	120.801
248.954	120.707
248.791	142.477
248.627	104.605
248.464	94.375
248.3	117.313
248.137	127.488
247.973	130.563
247.81	92.6523
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247.483	112.055
247.319	114.191
247.156	105.332
246.992	112.914
246.829	90.1211
246.665	85.7773
246.502	98.125
246.338	96.9844
246.175	98.2695
246.011	89.8359
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245.684	107.684
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244.867	112.426
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244.213	83.207
244.049	104.875
243.886	105.227
243.722	107.746
243.559	94.3125
243.395	106.215
243.232	93.3477
243.068	107.188
242.905	92.4453
242.741	97.4219
242.578	76.3125
242.414	98.9844
242.251	102.578
242.087	82.6094
241.924	84.6523
241.76	117.098
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241.434	110.98
241.27	98.6563
241.107	89.6172
240.943	110.648
240.78	118.168
240.616	118.398
240.453	101.258
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240.126	108.77
239.962	115.391
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239.635	70.6211
239.472	94.25
239.308	115.133
239.145	90.4883
238.981	91.8672
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238.654	111.77
238.491	117.336
238.327	115.832
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237.673	90.5508
237.51	120.426
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237.019	90.0625
236.856	86.0391
236.692	103.887
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234.894	112.043
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233.749	102.656
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233.422	86.0664
233.259	117.391
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232.932	98.5313
232.768	90.9609
232.605	113.172
232.441	92.6523
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230.643	114.77
230.479	107.551
230.316	96.9961
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229.825	107.203
229.662	131.234
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226.719	110.273
226.556	88.2148
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226.229	134.141
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216.419	118.246
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215.929	109.289
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215.602	111.563
215.438	98.5781
215.275	102.887
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213.476	96.8789
213.313	91.4922
213.149	115.801
212.986	91.3164
212.822	100.426
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212.168	95.7891
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211.841	107.473
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211.514	101.68
211.351	84.2266

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210.697	101.238
210.533	109.578
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209.552	100.973
209.389	122.449
209.225	100.484
209.062	121.723
208.898	122.238
208.735	105.484
208.571	103.41
208.408	118.438
208.244	111.418
208.081	101.461
207.917	101.941
207.754	101.438
207.59	102.695
207.427	120.305
207.263	100.891
207.1	77.8398
206.936	124.082
206.773	116.793
206.609	117.781
206.446	114.563
206.282	111.535
206.119	100.84
205.955	89.6719
205.792	108.148
205.628	105.93
205.465	87.9141
205.301	108.059
205.138	110.637
204.974	103.66
204.811	99.7344
204.647	119.871
204.484	99.0742
204.32	96.207
204.157	101.359
203.993	116
203.83	105.578
203.666	114.172
203.503	102.398
203.34	126.016
203.176	92.8086
203.013	94.8008

202.849	109.824
202.686	92.1523
202.522	98.2852
202.359	107.547
202.195	107.617
202.032	98.5117
201.868	93.9336
201.705	107.078
201.541	100.523
201.378	88.4492
201.214	97.3125
201.051	101.891
200.887	89.5078
200.724	98.9609
200.56	114.105
200.397	118.387
200.233	92.4766
200.07	105.242
199.906	102.23
199.743	115.723
199.579	104.574
199.416	121.863
199.252	94.8008
199.089	110.445
198.925	113.75
198.762	107.48
198.598	106.602
198.435	121.441
198.271	74.4375
198.108	103.445
197.944	99.7969
197.781	91.9258
197.617	78
197.454	89.0977
197.29	94.7227
197.127	101.555
196.963	118.074
196.8	108.871
196.636	83.3164
196.473	85.8906
196.309	83.918
196.146	85.5977
195.982	104.035
195.819	86.5742
195.655	105.191
195.492	90.6016
195.328	109.875
195.165	99.8008
195.001	100.973
194.838	87.9414
194.674	76.0859

194.511	69.4453
194.347	68.9258
194.184	104.949
194.02	94.2852
193.857	106.016
193.693	87.4805
193.53	73.5117
193.366	89.2188
193.203	86.1133
193.039	105.43
192.876	100.16
192.712	103.422
192.549	81.5508
192.385	79.0625
192.222	95.8516
192.058	102.484
191.895	80.7344
191.731	82.6289
191.568	105.379
191.404	85.9102
191.241	93.7695
191.077	97.6094
190.914	101.672
190.751	73.3516
190.587	86.1953
190.424	84.4609
190.26	100.137
190.097	109.793
189.933	101.359
189.77	90.2813
189.606	105.797
189.443	121.398
189.279	71.9648
189.116	57.8047
188.952	77.0313
188.789	99.9219
188.625	79.457
188.462	90.1484
188.298	74.2695
188.135	73.3945
187.971	60.375
187.808	93.6914
187.644	80.8906
187.481	82.9961
187.317	70.0938
187.154	69.9766
186.99	91.8867
186.827	85.8164
186.663	68.7188
186.5	87.9844
186.336	84.832

186.173	85.3828
186.009	81.8203
185.846	98.7734
185.682	86.5664
185.519	80.6992
185.355	86.8008
185.192	83.7422
185.028	83.7227
184.865	92.0781
184.701	68.4922
184.538	76.5
184.374	105.754
184.211	76.9766
184.047	84.8164
183.884	82.0742
183.72	101.164
183.557	81.668
183.393	71.6992
183.23	73.0508
183.066	86.1641
182.903	80.9648
182.739	80.0234
182.576	70.0273
182.412	89.7813
182.249	76.2773
182.085	95.4258
181.922	88.8633
181.758	102.102
181.595	72.832
181.431	88.4805
181.268	89.2695
181.104	76.0781
180.941	76.5078
180.777	94.2461
180.614	92.9492
180.45	91.6641
180.287	71.7344
180.123	74.8125
179.96	91.0195
179.796	75.9219
179.633	81.5156
179.469	80.6719
179.306	83.6445
179.142	92.0352
178.979	66.8633
178.815	93.2578
178.652	81.7734
178.488	89.9141
178.325	83.9336
178.162	107.551
177.998	99.125

177.835	89.125
177.671	85.625
177.508	76.9492
177.344	83.9883
177.181	81.4453
177.017	82.9375
176.854	84.0117
176.69	85.9219
176.527	90.5703
176.363	81.9922
176.2	109.355
176.036	102.836
175.873	87.1953
175.709	84.1328
175.546	87.4688
175.382	117.418
175.219	83.9375
175.055	81.8633
174.892	81.6406
174.728	79.0352
174.565	70.0117
174.401	66.4609
174.238	88.0313
174.074	91.1719
173.911	77.2656
173.747	100.875
173.584	103.898
173.42	79.4609
173.257	85.4922
173.093	93.3906
172.93	87.957
172.766	75.4688
172.603	80.6719
172.439	72.8047
172.276	100.121
172.112	92.543
171.949	77.3008
171.785	85.2344
171.622	84.5742
171.458	84.0313
171.295	66.7031
171.131	80.3008
170.968	79.0898
170.804	75.332
170.641	97.6758
170.477	87.8789
170.314	106.332
170.15	76.0781
169.987	103.035
169.823	80.5156
169.66	87.1367

169.496	100.902
169.333	104.445
169.169	103.977
169.006	97.4141
168.842	80.9648
168.679	108.93
168.515	98.8516
168.352	108.664
168.188	82.8672
168.025	97.4609
167.861	75.5625
167.698	68.5469
167.534	105.238
167.371	87.7461
167.207	84.3789
167.044	105.852
166.88	86.6484
166.717	103.875
166.553	108.922
166.39	84.8672
166.226	92.4922
166.063	82.1563
165.899	82.4766
165.736	97.1445
165.572	92.7148
165.409	72.1523
165.246	95.8594
165.082	99.6172
164.919	94.2578
164.755	90.3945
164.592	88.4766
164.428	79.2578
164.265	94.6133
164.101	90.6133
163.938	79.4922
163.774	89.5313
163.611	89.9609
163.447	93.8047
163.284	116.094
163.12	69.6602
162.957	100.293
162.793	82.4375
162.63	90.6406
162.466	81.6211
162.303	87.9609
162.139	85.9102
161.976	66.6484
161.812	86.6289
161.649	74.8047
161.485	69.3945
161.322	104.645

161.158	95.0352
160.995	81.7617
160.831	82.9648
160.668	83.207
160.504	69.3359
160.341	80.7695
160.177	72.2422
160.014	91.2344
159.85	78.0781
159.687	77.75
159.523	71.3906
159.36	99
159.196	81.5664
159.033	108.41
158.869	85.582
158.706	83.5938
158.542	98.4922
158.379	85.8477
158.215	92.8984
158.052	83.4258
157.888	87.4297
157.725	92.2227
157.561	92.2344
157.398	108.641
157.234	78.7227
157.071	88.0391
156.907	80.1523
156.744	87.0352
156.58	60.2168
156.417	80.7773
156.253	91.5078
156.09	89.4219
155.926	87.1094
155.763	87.1602
155.599	75.7969
155.436	62.6406
155.272	74.0156
155.109	87.8086
154.945	76.6289
154.782	104.852
154.618	93.5742
154.455	98.1563
154.291	85.4297
154.128	71.9844
153.964	79.9336
153.801	78.2383
153.637	100.309
153.474	103.074
153.31	106.41
153.147	87.7305
152.983	75.293

152.82	91.0313
152.657	84.7891
152.493	91.4531
152.33	114.781
152.166	81.1992
152.003	105.902
151.839	109.574
151.676	99.2266
151.512	89.668
151.349	91.418
151.185	80.3945
151.022	91.8594
150.858	98.1563
150.695	114.727
150.531	77.2188
150.368	92.9453
150.204	103.813
150.041	88.5117
149.877	88.8828
149.714	107.137
149.55	75.6211
149.387	107.148
149.223	120.902
149.06	92.1797
148.896	78.3008
148.733	92.4766
148.569	87.2188
148.406	71.5547
148.242	93.957
148.079	77.3242
147.915	87.2266
147.752	88.7852
147.588	74.8164
147.425	106.41
147.261	86.4063
147.098	81.6133
146.934	100.957
146.771	94.9766
146.607	101.113
146.444	93.2227
146.28	70.9492
146.117	108.289
145.953	80.0508
145.79	96.0117
145.626	89.957
145.463	95.8789
145.299	94.8281
145.136	96.8281
144.972	88.207
144.809	80.1523
144.645	101.75

144.482	85.4102
144.318	68.7305
144.155	124.047
143.991	83.293
143.828	108.379
143.664	109.316
143.501	87.8945
143.337	95.6328
143.174	80.4492
143.01	94.9844
142.847	77.8984
142.683	80.0977
142.52	107.535
142.356	89.332
142.193	68.4961
142.029	81.1445
141.866	78.4727
141.702	93.3594
141.539	86.9063
141.375	82.332
141.212	89.1328
141.048	82.5742
140.885	84.4102
140.721	72.9609
140.558	87.8711
140.394	98.9219
140.231	109.922
140.067	87.9141
139.904	106.109
139.741	115.879
139.577	90.4766
139.414	79.2773
139.25	84.957
139.087	87.2148
138.923	79.8555
138.76	101.684
138.596	120.477
138.433	82.8203
138.269	85.4414
138.106	82.2852
137.942	87.4492
137.779	76.3203
137.615	93.5977
137.452	90.0313
137.288	133.727
137.125	104.594
136.961	93.1445
136.798	71.9648
136.634	84.9688
136.471	77.0781
136.307	122.582

136.144	92.168
135.98	108.223
135.817	94.0898
135.653	109.754
135.49	66.168
135.326	80.9219
135.163	88.2031
134.999	68.7773
134.836	102.574
134.672	89.9844
134.509	92.1406
134.345	104.438
134.182	87.7539
134.018	104.965
133.855	82.3477
133.691	92.7188
133.528	103.227
133.364	107.109
133.201	76.75
133.037	108.625
132.874	104.918
132.71	101.125
132.547	80.6094
132.383	85.7266
132.22	89.0703
132.056	93.4414
131.893	88.8477
131.729	119.348
131.566	98.0273
131.402	93.1016
131.239	88.8984
131.075	98.3477
130.912	75.3203
130.748	81.9219
130.585	97.0391
130.421	87.3438
130.258	93.3125
130.094	94.6719
129.931	88.0234
129.767	99.2852
129.604	73.0039
129.44	80.1211
129.277	89.5664
129.113	88.7578
128.95	108.379
128.786	89.7695
128.623	83.9688
128.459	77.7969
128.296	93.9258
128.132	79.3672
127.969	76.3047

127.805	89.9766
127.642	101.137
127.478	103.141
127.315	65.6641
127.152	79.5703
126.988	80.043
126.825	96.5586
126.661	96.6328
126.498	96.125
126.334	110.914
126.171	90.1797
126.007	87.4531
125.844	94.3789
125.68	86.2031
125.517	91.375
125.353	86.0586
125.19	93.0117
125.026	78.0938
124.863	85.8008
124.699	104.309
124.536	105.352
124.372	83.0625
124.209	65.1641
124.045	81.5469
123.882	89.5859
123.718	86.0859
123.555	91.0703
123.391	96.9883
123.228	99.3164
123.064	99.0234
122.901	99.9219
122.737	62.7168
122.574	93.2344
122.41	86.6367
122.247	63.0957
122.083	101.531
121.92	88.1563
121.756	64.625
121.593	75.6172
121.429	94.3906
121.266	95.3359
121.102	101.824
120.939	99.4414
120.775	101.348
120.612	81.8984
120.448	81.9805
120.285	91.3555
120.121	119.75
119.958	128.273
119.794	73.043
119.631	109.535

119.467	84.7148
119.304	87.6523
119.14	99.2656
118.977	82.7578
118.813	102.563
118.65	82.2891
118.486	82.1094
118.323	120.297
118.159	99.0781
117.996	104.27
117.832	84.2969
117.669	86.6758
117.505	84.3203
117.342	116.348
117.178	106.676
117.015	101.086
116.851	89.3359
116.688	65.6055
116.524	80.1797
116.361	93.9102
116.197	117.664
116.034	99.8398
115.87	95.9336
115.707	82.5586
115.543	79.5938
115.38	93.1445
115.216	86.8711
115.053	94.1836
114.889	103.023
114.726	79.8438
114.563	112.465
114.399	89.1836
114.236	87.7539
114.072	85.9609
113.909	112.676
113.745	77.6563
113.582	122.008
113.418	107.977
113.255	106.352
113.091	97.3828
112.928	91.4648
112.764	79.5
112.601	67.3945
112.437	90.9102
112.274	97.2813
112.11	96.1523
111.947	93.5469
111.783	94.7422
111.62	99.0352
111.456	96.6875
111.293	125.629

111.129	105.98
110.966	82.7266
110.802	96.3125
110.639	93.3633
110.475	85.8438
110.312	119.711
110.148	86.3555
109.985	95.1797
109.821	117.398
109.658	98.4258
109.494	85.7305
109.331	96.1914
109.167	109.961
109.004	95.4531
108.84	90.0859
108.677	101.773
108.513	94.375
108.35	92.0898
108.186	100.855
108.023	92.1602
107.859	99.707
107.696	83.0391
107.532	101.344
107.369	87.875
107.205	84.5547
107.042	93.3281
106.878	83.4336
106.715	68.3047
106.551	102.215
106.388	106.211
106.224	94.7656
106.061	101.141
105.897	100.66
105.734	96.5781
105.57	92.0781
105.407	111.602
105.243	90.3281
105.08	87.7813
104.916	114.328
104.753	106.719
104.589	80.5234
104.426	70.6719
104.262	68.6719
104.099	94.9961
103.935	128.547
103.772	106.059
103.608	95.9492
103.445	98.3359
103.281	90.5273
103.118	95.1523
102.954	89.2227

102.791	99.8047
102.627	82.793
102.464	94.9336
102.3	85.9531
102.137	96.1797
101.974	77.6367
101.81	81.3086
101.647	85.0703
101.483	90.7695
101.32	89.9023
101.156	63.6836
100.993	91.75
100.829	89.7734
100.666	89.4805
100.502	83.082
100.339	103.902
100.175	90.8477
100.012	97.1641
99.8481	103.613
99.6846	112.211
99.5211	93.4766
99.3576	102.582
99.1941	92.9883
99.0306	84.9453
98.8671	107
98.7036	78.8828
98.5401	85.3906
98.3766	84.7227
98.2131	80.1602
98.0497	98.3711
97.8862	95.2305
97.7227	120.648
97.5592	94.1719
97.3957	91.8672
97.2322	99.4883
97.0687	97.5469
96.9052	96.1523
96.7417	82.7031
96.5782	84.9141
96.4147	81.7031
96.2512	116.18
96.0877	107.328
95.9242	86.543
95.7607	112.965
95.5973	101.199
95.4338	113.438
95.2703	78.7344
95.1068	111.523
94.9433	106.133
94.7798	92.3359
94.6163	103.641

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94.2893	91.1953
94.1258	96.5781
93.9623	83.8125
93.7988	108.926
93.6353	111.434
93.4718	72.5547
93.3083	69.4531
93.1449	102.691
92.9814	91.5547
92.8179	82.3164
92.6544	86.2695
92.4909	100.727
92.3274	68.1992
92.1639	88.6328
92.0004	76.2461
91.8369	82.2109
91.6734	88.9258
91.5099	79.75
91.3464	108.305
91.1829	110.625
91.0194	88.0977
90.8559	99.3359
90.6924	74.0469
90.529	76.7578
90.3655	109.953
90.202	102.758
90.0385	98.668
89.875	96.2344
89.7115	90.6914
89.548	104.242
89.3845	85.0547
89.221	118.305
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88.894	82.4844
88.7305	73.5586
88.567	94.9766
88.4035	89.3906
88.24	68.7188
88.0765	112.363
87.9131	84.2305
87.7496	105.293
87.5861	113.582
87.4226	97.3242
87.2591	81.75
87.0956	81.6992
86.9321	74.4531
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86.6051	96.1016
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85.9511	102.305
85.7876	103.941
85.6241	117.695
85.4607	88.6484
85.2972	102.172
85.1337	89.2773
84.9702	96.7773
84.8067	103.891
84.6432	70.0234
84.4797	122.059
84.3162	106.133
84.1527	109.836
83.9892	84.332
83.8257	105.969
83.6622	98.1797
83.4987	102.109
83.3352	81.3789
83.1717	98.5313
83.0083	116.555
82.8448	92.9258
82.6813	104.809
82.5178	90.0078
82.3543	71.1719
82.1908	74.5313
82.0273	81.0547
81.8638	108.109
81.7003	75.9336
81.5368	70.2109
81.3733	94.3984
81.2098	86.5273
81.0463	81.6719
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80.7193	85.0352
80.5558	62.0605
80.3924	65.0234
80.2289	65.3867
80.0654	55.1699
79.9019	75.7344
79.7384	53.1992
79.5749	85.9648
79.4114	80.1602
79.2479	71.4961
79.0844	92.418
78.9209	87.5664
78.7574	91.6367
78.5939	83.2109
78.4304	81.7109
78.2669	85.7031
78.1034	95.8008
77.9399	106.301

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77.613	96.9414
77.4495	107.797
77.286	84.4492
77.1225	97.8711
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76.7955	116.531
76.632	108.094
76.4685	102.094
76.305	124.926
76.1415	143.117
75.978	126.27
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75.651	110.156
75.4875	114.848
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75.1606	122.477
74.9971	104.23
74.8336	143.734
74.6701	123.141
74.5066	131.383
74.3431	119.305
74.1796	105.84
74.0161	125.781
73.8526	117.203
73.6891	119.113
73.5256	114.652
73.3621	117.723
73.1986	116.203
73.0351	123.977
72.8716	108.422
72.7082	130.375
72.5447	126.055
72.3812	126.266
72.2177	136.883
72.0542	125.578
71.8907	101.98
71.7272	120.336
71.5637	118.02
71.4002	97.2656
71.2367	119.063
71.0732	128.664
70.9097	98.0234
70.7462	118.824
70.5827	102.051
70.4192	107.551
70.2558	131.336
70.0923	96.5586
69.9288	113.105
69.7653	91.1992
69.6018	103.188

69.4383	104.281
69.2748	110.441
69.1113	115.023
68.9478	116.633
68.7843	127.703
68.6208	114.961
68.4573	122.809
68.2938	104.496
68.1303	115.625
67.9668	122.879
67.8033	119.969
67.6399	126.332
67.4764	140.023
67.3129	99.1523
67.1494	94.3789
66.9859	109.742
66.8224	114.074
66.6589	97.2969
66.4954	93.6523
66.3319	96.9414
66.1684	124.023
66.0049	117.297
65.8414	115.234
65.6779	125.746
65.5144	130.367
65.3509	116.391
65.1875	128.406
65.024	122.113
64.8605	103.477
64.697	121.555
64.5335	101.969
64.37	100.449
64.2065	83.1563
64.043	94.4961
63.8795	113.113
63.716	76.3906
63.5525	124.797
63.389	93.0117
63.2255	119.012
63.062	112.797
62.8985	115.457
62.735	102.941
62.5716	105.957
62.4081	107.457
62.2446	95.9063
62.0811	81.8906
61.9176	102.852
61.7541	104.188
61.5906	86.1914
61.4271	97.0195
61.2636	98.1914

61.1001	101.504
60.9366	97.5977
60.7731	83.0508
60.6096	89.7578
60.4461	103.652
60.2826	118.281
60.1192	98.9336
59.9557	110.691
59.7922	94.6328
59.6287	99.7578
59.4652	112.168
59.3017	112.73
59.1382	106.707
58.9747	97.8828
58.8112	105.656
58.6477	125.094
58.4842	95.7383
58.3207	92.3008
58.1572	130.758
57.9937	104.449
57.8302	98.7148
57.6667	108.547
57.5033	97.5391
57.3398	106.41
57.1763	119.234
57.0128	103.219
56.8493	85.2344
56.6858	125.25
56.5223	109.09
56.3588	88.2344
56.1953	95.8008
56.0318	114.699
55.8683	106.762
55.7048	99.2461
55.5413	99.5938
55.3778	94.6367
55.2143	105.25
55.0508	100.02
54.8874	92.6328
54.7239	93.5313
54.5604	106.859
54.3969	137.086
54.2334	116.293
54.0699	108.383
53.9064	69.2695
53.7429	117.41
53.5794	96.3594
53.4159	100.125
53.2524	77.2344
53.0889	92.4141
52.9254	95.8828

52.7619	111.648
52.5984	111.715
52.435	104.797
52.2715	102.629
52.108	110.09
51.9445	85.9219
51.781	82.7266
51.6175	104.887
51.454	82.2578
51.2905	92.0156
51.127	99.6211
50.9635	94.5078
50.8	80.168
50.6365	96.9336
50.473	95.9336
50.3095	97.6875
50.146	91.3984
49.9825	99.5156
49.8191	92.5547
49.6556	121.902
49.4921	84.6953
49.3286	81.5547
49.1651	89.2383
49.0016	110.578
48.8381	118.168
48.6746	101.578
48.5111	105.758
48.3476	78.5703
48.1841	86.1445
48.0206	95.1172
47.8571	122.207
47.6936	108.223
47.5301	96.2422
47.3667	98.9141
47.2032	122.477
47.0397	93.5703
46.8762	100.316
46.7127	97.6328
46.5492	103.914
46.3857	97.0625
46.2222	121.215
46.0587	79.4414
45.8952	89.7617
45.7317	113.957
45.5682	82.418
45.4047	109.48
45.2412	95.125
45.0777	106.508
44.9142	115.891
44.7508	108.691
44.5873	87.5078

44.4238	123.801
44.2603	81.0938
44.0968	101.148
43.9333	109.648
43.7698	106.094
43.6063	97.2305
43.4428	84.4063
43.2793	80.8594
43.1158	82.6758
42.9523	98.4805
42.7888	91.4844
42.6253	67.5234
42.4618	61.3164
42.2984	89.3047
42.1349	59.9512
41.9714	81.0938
41.8079	66.3906
41.6444	55.1758
41.4809	70.0117
41.3174	65.4258
41.1539	65.3633
40.9904	68.9727
40.8269	71.0352
40.6634	66.5703
40.4999	54.9551
40.3364	41.5352
40.1729	50.9727
40.0094	37.7148
39.8459	64.2539
39.6825	57.7852
39.519	53.9551
39.3555	53.334
39.192	37.209
39.0285	53.9707
38.865	71.8125
38.7015	53.8281
38.538	45.2891
38.3745	30.623
38.211	65.8516
38.0475	64.7734
37.884	77.5781
37.7205	61.7422
37.557	70.7109
37.3935	64.5859
37.2301	72.7891
37.0666	84.7148
36.9031	81.5273
36.7396	58.0664
36.5761	68.1992
36.4126	65.8125
36.2491	61.5371

36.0856	60.1738
35.9221	79.8164
35.7586	87.1055
35.5951	52.6074
35.4316	68.9453
35.2681	61.0371
35.1046	65.6367
34.9411	54.9688
34.7776	69.6211
34.6142	58.2012
34.4507	83.4648
34.2872	82.0625
34.1237	62.127
33.9602	65.9805
33.7967	64.0273
33.6332	75.7969
33.4697	66.3516
33.3062	79.3477
33.1427	70.918
32.9792	66.1758
32.8157	75.9766
32.6522	73.375
32.4887	69.9102
32.3252	73.1172
32.1618	67.5313
31.9983	69.6484
31.8348	83.7578
31.6713	84.2109
31.5078	76.4492
31.3443	85.75
31.1808	73.8867
31.0173	69.2344
30.8538	79.582
30.6903	57.8945
30.5268	68.6328
30.3633	92.2969
30.1998	87.1875
30.0363	86.2969
29.8728	65.2734
29.7093	74.9609
29.5459	80.625
29.3824	78.5977
29.2189	82.2813
29.0554	85.7148
28.8919	80.7578
28.7284	77.4766
28.5649	84.3594
28.4014	72.8359
28.2379	98.7148
28.0744	79.957
27.9109	84.3477

27.7474	69.4141
27.5839	92.375
27.4204	74.8633
27.2569	75.8125
27.0935	69.2188
26.93	72.6992
26.7665	81
26.603	76.0078
26.4395	69.4961
26.276	75.9219
26.1125	65.4141
25.949	84.7813
25.7855	66.4102
25.622	69.8867
25.4585	76.375
25.295	60.0645
25.1315	81.4414
24.968	64.6523
24.8045	63.1191
24.641	74.7031
24.4776	77.5195
24.3141	64.2461
24.1506	59.2852
23.9871	75.5391
23.8236	73.1641
23.6601	74.6406
23.4966	64.7305
23.3331	74.3672
23.1696	64.832
23.0061	88.7617
22.8426	66.8438
22.6791	99.6602
22.5156	57.4395
22.3521	64.4453
22.1886	64.957
22.0252	66.8086
21.8617	76.1055
21.6982	62.6309
21.5347	59.084
21.3712	75.6172
21.2077	63.8984
21.0442	66.7422
20.8807	71.0234
20.7172	70.6602
20.5537	61.6855
20.3902	79.6523
20.2267	69.9336
20.0632	71.0742
19.8997	70.7422
19.7362	72.125
19.5727	64.5859

19.4093	61.6973
19.2458	74.6094
19.0823	87.5313
18.9188	85.3516
18.7553	66.2188
18.5918	63.25
18.4283	79.8828
18.2648	43.7422
18.1013	63.4453
17.9378	83.2344
17.7743	69.5664
17.6108	86.9883
17.4473	90.6289
17.2838	70.7461
17.1203	84.0273
16.9569	60.7441
16.7934	96.1289
16.6299	70.5977
16.4664	71.3594
16.3029	80.543
16.1394	71.0898
15.9759	88.625
15.8124	60.7559
15.6489	61.4902
15.4854	80.1445
15.3219	86.1758
15.1584	88.3828
14.9949	80.8281
14.8314	68.0195
14.6679	85.2617
14.5044	97.957
14.341	88.707
14.1775	94.5469
14.014	106.359
13.8505	92.5703
13.687	53.3867
13.5235	64.9805
13.36	96.6992
13.1965	74.2656
13.033	82.9609
12.8695	82.3984
12.706	85.6445
12.5425	76.1445
12.379	61.1465
12.2155	63.0156
12.052	60.4121
11.8886	86.8281
11.7251	87.3438
11.5616	79.3945
11.3981	81.918
11.2346	91.7188

11.0711	48.5703
10.9076	48.25
10.7441	69.1055
10.5806	58.5
10.4171	66.3047
10.2536	70.9453
10.0901	80.5039
9.92663	90.3242
9.76314	66.2266
9.59964	76.3633
9.43615	72.625
9.27265	71.125
9.10916	56.6387
8.94567	63.5039
8.78217	62.1406
8.61868	67.582
8.45519	37.9746
8.29169	56.5215
8.1282	56.3516
7.96471	56.8691
7.80121	54.7168
7.63772	57.3613
7.47423	47.2793
7.31073	48.6816
7.14724	47.2832
6.98374	62.0234
6.82025	53.6328
6.65676	66.7539
6.49326	56.6367
6.32977	62.0352
6.16628	71.2578
6.00278	84.2383
5.83929	66.1328
5.6758	48.3965
5.5123	57.9473
5.34881	48.8555
5.18532	51.8945
5.02182	60.043
4.85833	50.2051
4.69483	61.4141
4.53134	27.7568
4.36785	25.8389
4.20435	40.2188
4.04086	44.9688
3.87737	21.1396
3.71387	30.2842
3.55038	33.5137
3.38689	12.2915
3.22339	12.2388
3.0599	14.6606
2.89641	17.2139

2.73291	9.81104
2.56942	19.5762
2.40593	14.5635
2.24243	28.8252
2.07894	24.2559
1.91544	21.8652
1.75195	36.2734
1.58846	26.6602
1.42496	31.3105
1.26147	19.1865
1.09798	33.5645
0.934483	14.54
0.77099	22.0264
0.607496	24.125
0.444003	9.34521
0.280509	10.314

:CWLS LOG ASCII STANDARD-VERSION 2.0
:ONE LINE PER DEPTH STEP

:START DEPTH
:STOP DEPTH
:STEP
:NULL VALUE
:COMPANY
:WELL
:FIELD
:LOCATION
:PROVINCE
:SERVICE COMPANY
:DATE
:UNIQUE WELL ID

:DEPTH
:Gamma

:ELEVATION
:STE
:DENSITY
:CASING TO1
:OPERATING RIG TIME
:WGT1
:CASING SIZE1
:CASING TO2
:WGT2
:CASING SIZE2
:WELL ID
:CASING TO3
:K.B.
:WGT3
:TYPE LOG
:CASING SIZE3
:CASING TO4
:SALINITY
:TITLE
:WGT4
:TOP LOGGED INTERVAL
:CASING SIZE4
:WITNESSED BY
:CASING TO5
:DRILLING MEAS. FROM
:WGT5
:CASING SIZE5
:CTY
:WGT6
:CASING SIZE6
:MAX. REC. TEMP.

:D.F.
:CASING TO6
:OTHER SERVICES
:BIT1
:DEPTH-DRILLER
:BIT2
:RUN No
:RUN1
:BIT3
:RUN2
:PERMANENT DATUM
:TWP
:BIT4
:LOG MEAS. FROM
:BIT FROM1
:RUN3
:BIT5
:CASING FROM1
:TYPE FLUID IN HOLE
:RUN4
:FLD
:BIT6
:BIT TO1
:CASING FROM2
:BIT FROM2
:CO
:RGE
:BIT TO2
:DEPTH-LOGGER
:CASING FROM3
:BIT FROM3
:RUN5
:SEC
:BIT TO3
:G.L.
:CASING FROM4
:BIT FROM4
:RUN6
:BIT TO4
:BTM LOGGED INTERVAL
:CASING FROM5
:BIT FROM5
:STATE
:BIT TO5
:LEVEL
:CASING FROM6
:BIT FROM6
:COUNTRY
:RECORDED BY
:FILING No
:BIT TO6

Appendix A

Activities Planned for R-13
Compared with Work Performed

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"Work Plan for Mortandad Canyon" (LANL 1997, 56835)	R-13 Field Implementation Plan (FIP) (LANL 2001, 70291.2)	R-13 Actual Work
Planned Depth	100 to 500 ft into the regional aquifer	R-13 proposed depth of 1330 ft below ground surface (bgs)	Approximately 1700 ft bgs	Total drill depth 1133 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	Methods may include, but are not limited to HSA, air-rotary/Odex/Stratex, air-rotary/Barber rig, and mud-rotary drilling	Fluid-assisted, open-hole, air-rotary drilling	Same as FIP
Amount of Core	10% of the borehole	Approximately 10%	No core planned	No core collected, same as FIP
Lithologic Log	Log to be prepared from core, cutting, and drilling performance.	Log to be prepared from core, cutting, and drilling performance data.	Log to be prepared from cuttings, geophysical logs, and drilling performance.	Same as FIP
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.	For planning and conceptual design purposes, it has been assumed that four water-bearing zones will be encountered. Groundwater samples will be collected from each water-bearing zone.	Up to three borehole groundwater screening samples will be collected during drilling. These samples will target groundwater in the perched zone(s) and in the regional aquifer. The number of sampling events after well completion is not specified.	One groundwater sample was obtained from the zone of the regional saturation at 903 ft bgs.
Water Sample Analysis	Initial sampling: radiochemistry I, II, and III; tritium; general inorganics; stable isotopes; volatile organic compounds (VOCs); and metals Saturated zones: radionuclides (tritium, strontium-90, cesium-137, americium-241, plutonium isotopes, uranium isotopes, gamma spectrometry, and gross alpha, gross beta, and gross gamma); stable isotopes (hydrogen, oxygen, and, in special cases, nitrogen); major ions (cations and anions); trace metals; and trace elements	Analytical suite for intermediate perched zone and regional aquifer groundwater samples: major and minor ions, trace elements, organic compounds, dissolved organic carbon, total suspended solids, total dissolved solids, neutral species (silicon dioxide), hardness, cyanide, stable and radiogenic isotopes, and radionuclides.	Metals (dissolved); anions (dissolved); gamma spectrometry; ^{241}Am; ^{137}Cs; ^{238}Pu; $^{239,240}Pu$; ^{234}U; ^{235}U; ^{238}U; ^{90}Sr (total); stable isotopes $^{18}O/^{16}O$, D/H, $^{15}N/^{14}N$; tritium; tritium (low level or direct counting); mobile radiological screening for gross alpha, gross beta, gross gamma; total uranium by inductively coupled plasma mass spectroscopy (ICP-MS); total Kjeldahl nitrogen; ClO_4^-.	Same as FIP
Water Sample Field Measurements	Alkalinity, pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, dissolved oxygen, turbidity	pH, specific conductance, temperature, turbidity	Same as FIP

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"Work Plan for Mortandad Canyon" (LANL 1997, 56835)	R-13 Field Implementation Plan (FIP) (LANL 2001, 70291.2)	R-13 Actual Work
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.	Sample locations are based on predicted formation depths.	Up to five core/cuttings samples will be collected for geochemical and contaminant characterization within water-bearing zones encountered during drilling.	No core or sidewall core samples were collected. No cuttings samples were submitted for contaminant analysis.
Core/Cuttings Sample Analytes	Uppermost 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 borehole core samples includes anions, trace elements, organic compounds, total organic carbon, cyanide, and radionuclides.	Testing of core/cutting samples may include radionuclides, metals, and anions, at the discretion of the geochemistry lead.	Cuttings samples were submitted for contaminant analysis.
Laboratory Hydraulic Property Tests	Physical properties analyses will be conducted on five core samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics.	Physical properties analyses will be conducted on core samples and will typically include moisture content, moisture potential, and saturated hydraulic conductivity.	Not specified in plan	No samples submitted
Geology	Ten samples of core or cuttings will be collected for petrographic, x-ray fluorescence (XRF) and x-ray diffraction (XRD) analyses.	Selected samples of core or cuttings will be collected for petrographic, XRF, XRD, and K/Ar or $^{39}Ar/^{40}Ar$ isotopic dating analyses.	The geology task leader will determine the number of samples for characterization of mineralogy, petrography, and rock chemistry based on geologic and hydrologic conditions encountered during drilling.	Twelve samples were characterized for mineralogy, petrography, and rock chemistry.

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"Work Plan for Mortandad Canyon" (LANL 1997, 56835)	R-13 Field Implementation Plan (FIP) (LANL 2001, 70291.2)	R-13 Actual Work
Geophysics	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes gamma-gamma density, natural gamma, and thermal neutron.	Geophysical logs will be run in the boreholes, and compact neutron moisture logs may be run in shallower portions of the boreholes. Natural gamma, neutron moisture, and density logs may be run in shallower portions of the boreholes. Natural gamma, neutron moisture, and density logs may be run if the drilling method and borehole stability permit. Other geophysical logs may be considered if, in the opinion of the technical team, they will satisfy a technical need. In general, open-hole geophysics includes caliper, electromagnetic induction, magnetic susceptibility, borehole color videotape (axial and sidescan), fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes gamma-gamma density, natural gamma, and thermal neutron.	Typical wireline logging service as planned: open-hole geophysics includes array induction imager, triple lithodensity, combinable magnetic resonance, natural gamma, natural gamma spectrometry, epithermal compensated neutron log, caliper, full-bore formation microimager, elemental capture spectrometer, and borehole videotape. In general, cased-hole geophysics includes triple lithodensity, natural gamma, natural gamma spectrometry, epithermal compensated neutron log and elemental capture spectrometer.	Video (LANL tool): 760–832 ft and 847–1053 ft bgs Natural gamma (LANL tool): 0–830 ft bgs (cased 0–758 ft bgs), 0–1053 ft bgs (cased 0–847 ft bgs) and 0–1126 ft bgs (cased 0–1126 ft bgs) Schlumberger geophysics 0–1058 ft bgs (cased 0–847 ft bgs): compensated neutron, array induction, litho-density, electron capture, natural gamma, formation micro-imager
Water-Level Measurements	Procedures and methods not specified in "Hydrogeologic Workplan"	Procedures and methods not specified in "Hydrogeologic Workplan"	Water levels will be determined for each saturated zone by water-level meter or by pressure transducer.	Water-level meter used to measure the regional water table
Field Hydraulic Property Tests	Not specified in "Hydrogeologic Workplan"	Not specified in "Hydrogeologic Workplan"	Slug or pumping tests may be conducted in saturated intervals once the well is completed.	Two single-well pumping tests performed.
Surface Casing	Approximately 20-in. outer diameter (OD) extends from land surface to 10-ft depth in underlying competent layer and grouted in place	Approximately 20-in. OD extends from land surface to 10-ft depth in underlying competent layer and grouted in place.	18-in. OD schedule 40, low carbon steel casing will be installed as deep as possible below ground level (nominally 35-40 ft bgs) and will extend approximately 3 ft above the ground surface and cemented in place.	18-in. OD steel casing set at 37 ft bgs and cemented in place

Activity	"Hydrogeologic Workplan" (LANL 1998, 59599)	"Work Plan for Mortandad Canyon" (LANL 1997, 56835)	R-13 Field Implementation Plan (FIP) (LANL 2001, 70291.2)	R-13 Actual Work
Minimum Well Casing Size	6.625-in. OD	6.625-in. OD	5-in. OD × 4.5-in. inner diameter (ID)	5-in. OD (4.5-in. ID) stainless-steel casing w/ external couplings
Well Screen	Machine-slotted (0.01-in.), stainless-steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to the New Mexico Environment Department (NMED).	Machine-slotted (0.01-in.), stainless-steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED.	Well screen shall be constructed with multiple sections of 5.56-in. OD, pipe-based stainless-steel screen with a 0.01 in. slot size.	Same as FIP
Filter Material	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	Primary filter pack shall consist of round, clean, washed and resieved silica sand with a uniformity coefficient of 2.0 or less, placed 10 ft above and 5 ft below the well screen. The size of the filter pack shall be selected based on the characteristics of the formation to be screened. Secondary filter pack is finer silica sand placed 2 ft above and below the primary pack.	Primary filter pack constructed of 20/40 silica sand placed 6 ft below and 10 ft above the screen. Secondary filter pack constructed of 30/70 silica sand placed in a 6-ft-thick layer above and below the primary filter pack.
Annular Fill Material (exclusive of filter materials)	Uncontaminated drill cuttings below sump and bentonite above sump	Uncontaminated drill cuttings below sump and bentonite above sump	Bentonite, gravel, silica sand, and/or cement in borehole below well; fine sand in transition zone; 50% bentonite and 50% gravel or sand above transition zone to bottom of surface casing; cement grout between surface casing and borehole wall and between surface casing and well casing.	Sand and bentonite in borehole below well casing; bentonite seal below filter pack; bentonite above filter pack. One cement grout plug 724.4 to 734.6 ft bgs and cement from surface to 77 ft bgs.
Sump	Stainless-steel casing with an end cap	Stainless-steel casing with an end cap	5-in.-diameter stainless-steel casing, 30 ft long	5-in.-diameter stainless-steel casing, 10 ft long
Bottom Seal	Bentonite	Bentonite	Bentonite	Same as FIP

Appendix B

Lithology Log

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qal, alluvium	No sample collected.	0–23	6673.1–6650.1
	Unconsolidated sediments, silt (SM), grayish-orange (10YR 7/4), composed of nonwelded vitric pumice. +35F (i.e., plus No. 35 sieve sample fraction): 20% quartz and sanidine crystals, 80% ash. +60F (i.e., plus No. 60 sieve sample fraction): predominantly ash.	23–28	6650.1–6645.1
	Unconsolidated sediments, silty gavel with sand (GM), grayish-orange (10YR 7/4), composed of nonwelded vitric tuff, lithic poor. +35F: predominantly quartz and sanidine crystals.	28–33	6645.1–6640.1
	No sample recovery.	33–38	6640.1–6635.1
Qbt 1g, Tshirege Member of the Bandelier Tuff	Rhyolite tuff, pale brown (5YR 5/2), pumice-rich, nonwelded. +10F: (i.e., plus No. 10 sieve sample fraction) 60–70% subrounded vitric pumice fragments; 15–20% intermediate to felsic volcanic lithics; 10% quartz and sanidine phenocrysts; 5% clasts that are weakly cemented with clay and iron-oxide.	38–43	6635.1–6630.1
	Rhyolite tuff, light brown (5YR 5/2), pumice-rich, nonwelded. +10F: 80% vitric pumice clasts, subrounded; 20% intermediate to felsic volcanic clasts, minor quartz and sanidine crystals (locally, clasts and crystals are weakly cemented with clay). +35F: dominantly quartz and sanidine crystals with lesser amounts of pumice and volcanic lithics.	43–53	6630.1–6620.1
	Rhyolite tuff, pale yellowish-brown (5YR 6/2), pumice- and lithic-rich, poorly welded. +10F: 50% vitric pumice clasts; 50% intermediate to felsic volcanic clasts, subrounded. +35F: composed of pumice, quartz and sanidine crystals, and minor lithics.	53–58	6620.1–6615.1
	Rhyolite tuff, grayish-orange (10YR 7/4), pumice-rich, nonwelded. +10F: 50% glassy pumice fragments, subrounded; 50% intermediate to felsic volcanic clasts. +35F: 60% pumice, 30% volcanic lithics, 10% quartz and sanidine crystals.	58–63	6615.1–6610.1
	Rhyolite tuff, very light gray (N8), lithic-rich, nonwelded. +10F: 70–100% dacite fragments (up to 5 mm), subangular; 10–30% quartz and sanidine crystals; minor pumice. Volcanic clasts commonly silicified, with clay rims.	63–73	6610.1–6600.1
Qct, Cerro Toledo Interval	Tephra deposit /tuffaceous sediments, silty sand with gravel (SM), light pinkish-gray (5YR 8/1), silt to very coarse sand and pebbles. +10F: 60–70% gray to light brown hornblende dacite and rhyodacite lithics, clasts (up to 1.0 cm) are broken to subrounded; 30–40% white vitric pumice. +35F: 70–80% pumice, 5–10% quartz and sanidine crystals, 15–25% dacite lithics.	73–78	6600.1–6595.1
	Tephra deposit/tuffaceous sediments, sand with gravel (SW), pale orange-gray (10YR 8/2), silt to very coarse sand, gravel clasts (up to 8 mm) angular to subrounded +10F: 60–70% gray to pinkish dacite, 30–40% brown to orange-tan vitric pumice. +35F: 10% pumice, 30% volcanic lithics, 60% quartz and sanidine crystals. Note: sudden increase in free crystals and appearance of oxidized pumice fragments suggest the stratigraphic top of Qbo, estimated at 80 ft bgs.	73–83	6595.1–6585.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbo, Otowi Member of the Bandelier Tuff	Rhyolite tuff, light pinkish-gray (5YR 8/1), nonwelded. +10F: 30–40% pinkish-gray and reddish dacite; 60–70% fibrous porphyritic vitric pumice, pale orange, vitric luster (up to 1.8 cm). +35F: 20–30% pumice, 30–40% lithic, 30–40% quartz and sanidine crystals.	83–88	6585.1–6580.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), poorly to nonwelded. +10F: 60-70% dacite and andesite lithic fragments, 10–30% white to light orange-tan pumice (up to 1.0 cm).	88–103	6580.1–6565.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), nonwelded. +10F: 80–90% pumice fragments, large (up to 1.5 cm), fibrous texture; 10–20% dacite lithics.	103–113	6565.1–6555.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), poorly to nonwelded. +10F: 50-60% dacite and latite lithic fragments, 40–50% white and tan pumice (up to 1.0 cm) pumice. +35F: 10–20% pumice, 20–30% lithics, 30–40% quartz and sanidine crystals. WR (i.e., unsieved whole rock) sample has ashy matrix.	113–128	6555.1–6540.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), lithic-rich, nonwelded. +10F: 90-95% dacite lithic fragments (0.5 to 1.5 cm), 5–10% quartz and sanidine crystals, 5–10% pumice. +35F: 3–5% pumice; 20–30% volcanic lithics; 65–75% pumice.	128–143	6540.1–6525.1
	Rhyolite tuff, grayish-orange pink (5YR 7/2), lithic-rich, nonwelded. +10F: 60–70% dacite lithic (up to 2.0 cm), 30–40% vitric pumice fragments, 5–10% quartz and sanidine crystals. +35F: 15–25% pumice, 30–40% volcanic lithics, 30–40% quartz and sanidine crystals. WR sample has ashy matrix.	143–148	6525.1–6520.1
	Rhyolite tuff, pale yellowish-brown (10YR 6/2), nonwelded. +10F: 70-80% dacite and latite fragments (up to 2.0 cm); 15–25% fibrous textured pumice, 5–10% quartz and sanidine crystals. +35F: 5–10% pumice, 30–40% lithics, 40–50% quartz and sanidine crystals.	148–153	6520.1–6515.1
	Rhyolite tuff, pale yellowish-brown (10YR 6/2), nonwelded. +10F: 65-75% dacite and latite fragments, 10–20% fibrous pumice (up to 2.0 cm), 5–10% quartz and sanidine crystals, 10–20% fragments of indurated tuff; spotty Mn-oxide coatings on some pumices. +35F: 10–30% pumice, 20–40% lithics, 50–70% quartz and sanidine crystals. WR sample contains abundant ash.	153–168	6515.1–6500.1
	Rhyolite tuff, very pale orange (10YR 8/2), nonwelded. +10F: 80–90% dacite and latite fragments (up to 1.0 cm), 5–10% quartz and sanidine crystals, 5–10 pumice. +35F: 35–45% white and brown pumice, 20-30% lithics, 30–40% quartz and sanidine crystals. WR sample has ashy matrix.	168–183	6500.1–6485.1
	Rhyolite tuff, grayish-orange pink (5YR 7/2), ash-rich, nonwelded. +10F:60–70% dacite fragments, 5–10% quartz and sanidine crystals, 15–25% pale tan vitric pumice (up to 1.0 cm), pumices commonly exhibit spotty Mn-oxide coatings. +35F: 20–30% pumice, 30–40% lithics, 30–40% quartz and sanidine crystals. WR sample has ashy matrix.	183–188	6485.1–6480.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Qbo	Rhyolite tuff, grayish-orange pink (5YR 7/2), nonwelded. +10F: 60-70% dacite and latite fragments, 20–30%% vitric pumice fragments (up to 3 mm) with local Mn-oxide coatings; 10% coarse quartz and sanidine crystals (up to 3 mm). +35F: 30–40% pumice, 20–30% lithics, 40–50% quartz and sanidine crystals. WR sample has ashy matrix.	188–193	6480.1–6475.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), pumice- and lithic-rich, nonwelded. +10F: 65–75% dacite and andesite fragments (up to 2.0 cm), 10–15% pumice, 5–10% quartz and sanidine crystals. +35F: 10-15% pumice, 20–30% lithics, 60–70% quartz and sanidine crystals. WR sample has ashy matrix.	193–203	6475.1–6470.1
	Rhyolite tuff, light pinkish-gray (5YR 8/1), lithic-rich, nonwelded. +10F: 70–80% dacite and andesite fragments (up to 2.0 cm) commonly coated with clay, 10–15% vitric pumice (up to 1.8 cm), 5–10% quartz and sanidine crystals. +35F: 10–30% pumice, 20–30% lithics, 50-70% quartz and sanidine crystals. WR sample has ashy matrix.	203–213	6470.1–6460.1
	Rhyolite tuff, pinkish-gray (5YR 8/1), nonwelded. +10F: 60–70% dacite and latite fragments, 25–30% white vitric pumice fragments (coarse, up to 2.3 cm) with local Mn-oxide coatings, 5–10% quartz and sanidine crystals. +35F: 15–25% pumice, 15–20% lithics, 60-70% quartz and sanidine crystals. WR sample has ashy matrix.	213–223	6460.1–6450.1
	Rhyolite tuff, light gray (N7), nonwelded. +10F: 65–75% reddish-brown to gray dacite and latite fragments, 20–30% white to pale tan pumice fragments (up to 1.0 cm) with local Mn-oxide coatings, 3–5% quartz and sanidine crystals. +35F: 40–50% pumice, 25–30% lithics, 15–20% quartz and sanidine crystals. WR sample has ashy matrix.	223–233	6450.1–6440.1
	Rhyolite tuff, very light gray (N8), pumice-rich, nonwelded. +10F: 15-20% dacite and latite fragments, 60–70% vitric pumice fragments (up to 1.5 cm), 3–5% quartz and sanidine crystals.	233–238	6440.1–6435.1
	Rhyolite tuff, very light (N8), pumice-rich, nonwelded +10F: 20–25% reddish to dark gray dacite lithic fragments (up to 1.2 cm), 70–75% vitric pumice (up to 1.5 cm),5–10% quartz and sanidine crystals. +35F: 20–30% pumice, 20–30% lithics, 40–60% quartz and sanidine crystals.	238–248	6435.1–6425.1
Qbog, Guaje Pumice Bed	Tephra deposit/tuffaceous sediments, light pinkish-gray (5YR 6/1), vitric, pumice-rich, nonwelded. +10F: 80–90% pumice fragments (0.5 to 2.0 cm), 2–10% dacite lithics, 5–10% quartz and sanidine crystals. Note: 50% of pumices altered to brown clay in 263 to 268 ft interval. The presence of clay-cemented tuffaceous sandstone indicates the basal portion of the Qbog and the proximity to the Puye Formation contact at 268 ft.	248–268	6425.1–6405.1
Tpf, Puye Formation	Clastic sediments, silty sand (SM) with gravel, light brown (5YR 6/4), pebbles (up to 1.0 cm) are subangular to subrounded. WR/+10F: composed of indurated clay-cemented tuffaceous sandstone, various volcanic (andesite, rhyodacite, basalt) rocks, lesser quartz and sanidine crystals (frosted crystal faces), minor pumice.	268–283	6405.1–6390.1
Tpf	Clastic sediments, clayey sand (SC) with gravel, light pinkish-tan (5YR 7/2), pebbles (up to 1.0 cm) are subangular to subrounded. WR/+10F: 85–95% indurated tuffaceous sandstone and siltstone, 5-15% various volcanic (andesite, basalt, pumice) rocks that are locally clay coated.	283–303	6390.1–6370.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb, Cerros del Rio Basalt	Light brown (5YR 7/2), weathered basalt fragments. WR/+10F: 90% broken basalt fragments (up to 0.5 cm), 10% clay. Basalt Tpf contact with underlying basalt estimated at 303 ft.	303–308	6370.1–6365.1
	Basalt, medium gray (N5), weakly porphyritic with aphanitic groundmass, highly vesicular to scoriaceous. WR/+10F: 95–98% olivine basalt; 2–5% other volcanic rocks (andesite, pumice), quartz and sanidine crystals, and tuffaceous sandstone. Clasts are angular to subangular.	308–325	6365.1–6348.1
	Basalt, medium gray (N4), porphyritic with aphanitic groundmass, vesicular . WR/+10F: pale green olivine phenocrysts (10% of volume), euhedral crystals (1–2 mm) locally replaced by iddingsite; fracture and vesicle surfaces coated by white clay.	325–340	6348.1–6328.1
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. WR/+10F: pale green olivine phenocrysts, commonly euhedral (up to 5 mm), less abundant euhedral plagioclase; minor clay lining vesicles.	340–360	6328.1–6308.1
	Basalt, medium gray (N5), slightly porphyritic with aphanitic groundmass, vesicular. WR/+10F: pale green to amber-colored minor olivine phenocrysts, locally altered to iddingsite, white laths of plagioclase; vesicles commonly lined with light brown to white clay.	360–385	6308.1–6283.1
	Basalt, medium gray (N5), slightly porphyritic with aphanitic groundmass, vesicular, basalt fragments show some degree of roundness. +35F: contains 10–20% tuffaceous siltstone clasts possibly indicating volcaniclastic sedimentary interlayer occurring within this interval. WR sample is very clay-rich.	385–390	6283.1–6278.1
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. WR/+10F: pale green olivine phenocrysts (10% volume), mostly euhedral (up to 3 mm), commonly altered to reddish iddingsite. Groundmass locally altered; local clay lining vesicles.	390–405	6278.1–6263.1
	Basalt, medium gray (N5), weakly porphyritic with aphanitic groundmass, highly vesicular to massive. WR/+10F: pale green euhedral (up to 3 mm) olivine phenocrysts. Amygdaloidal clay, locally limonitic, very common.	405–430	6263.1–6238.1
	Basalt, light gray (N6), slightly porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts mostly replaced by iddingsite. Groundmass is partially altered.	430–445	6238.1–6223.1
	Basalt, light gray (N7), porphyritic with aphanitic groundmass, massive to partly scoriaceous. WR/+10F: coarse (up to 5 mm) olivine phenocrysts entirely replaced by iddingsite. Interval is distinctive for its strong alteration of groundmass feldspars, resulting in a pitted surface texture and generally bleached coloration. The interval 460–465 ft contains 40–50% reddish-brown iron-oxide-stained scoriaceous basalt fragments.	445–465	6223.1–6203.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb, Cerros del Rio Basalt	Basalt/scoria, dusky red (5YR 3/4), slightly porphyritic with aphanitic groundmass, scoriaceous. WR/+10F: olivine phenocrysts entirely replaced by iddingsite, intense iron-oxide staining throughout, amygdaloidal clay common. The interval 480–485 ft has 40–50% massive, less vesicular basalt mixed with scoria. Basal contact of scoriaceous basalt estimated at 483 ft bgs.	465–485	6203.1–6183.1
	Basalt, light gray (N6), porphyritic with aphanitic groundmass, vesicular to massive. WR/+10F: olivine phenocrysts entirely replaced by dark red iddingsite. Groundmass has local iron-oxide staining, moderately altered.	485–495	6183.1–6173.1
	Basalt, very light gray (N7), porphyritic with aphanitic groundmass, massive. WR/10F: olivine phenocrysts rimmed or totally replaced by iddingsite; groundmass almost completely altered. Selected fragments are distinctly rounded, possibly the result of abrasion from the drilling process.	495–510	6173.1–6158.1
	Basalt, light gray (N6), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts rimmed or entirely replaced by dark red iddingsite; groundmass almost completely altered and bleached. Selected fragments are well rounded, suggesting they were milled during drilling.	510–540	6158.1–6128.1
	Basalt, light gray (N6), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts replaced by iddingsite. Groundmass altered.	540–545	6128.1–6123.1
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts locally replaced (iddingsite), traces of clay and Mn-oxide.	545–555	6123.1–6113.1
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts locally rimmed or replaced by iddingsite, minor clay present.	555–565	6113.1–6101.1
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts rimmed or replaced by iddingsite, local clay present in lower 10 ft of interval.	565–585	6101.1–6081.1
	Basalt, light olive gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts unaltered to rimmed or replaced by iddingsite, minor plagioclase phenocrysts.	585–595	6081.1–6071.1
	Basalt, medium gray (N6), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts mostly altered to iddingsite; locally rounded clasts.	595–600	6071.1–6066.1
	Basalt, light olive-gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts show advanced alteration to iddingsite. Numerous rounded basalt clasts with clay coatings suggest possible sedimentary interflow deposit.	600–605	6066.1–6061.1
	Basalt, light olive-gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts fresh to locally rimmed or replaced by iddingsite, rare plagioclase phenocrysts; clay lining fractures in interval 615–620 ft.	605–625	6061.1–6041.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tb, Cerros del Rio Basalt	Basalt, light olive-gray (5Y 6/1), porphyritic with aphanitic groundmass, massive to partly vesicular. WR/+10F: olivine phenocrysts show varying states of iddingsite alteration; clay amygdules present. Some clasts partly rounded.	625–635	6041.1–6031.1
	Basalt, light olive-gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: olivine phenocrysts fresh to locally rimmed or replaced by iddingsite, rare pyroxene phenocrysts.	635–650	6031.1–6016.1
	Basalt, light olive-gray (5Y 6/1), porphyritic, groundmass aphanitic to microcrystalline, massive. WR/+10F: phenocrysts of olivine, pyroxene, plagioclase, olivines unaltered to slightly altered (iddingsite), pyroxenes prismatic crystals giving rock a speckled appearance; groundmass microcrystalline with laths of plagioclase visible.	650–685	6016.1–5981.1
	Basalt, light olive-gray (5Y 6/1), porphyritic, groundmass microcrystalline, massive. WR/+10F: phenocrysts of olivine (up to 2 mm) and plagioclase, olivines unaltered to locally rimmed or replaced by iddingsite.	685–705	5981.1–5961.1
	Basalt, light olive-gray (5Y 6/1), porphyritic with aphanitic groundmass, massive. WR/+10F: phenocrysts of olivine, pyroxene, and plagioclase; olivines fresh to locally altered (iddingsite), prismatic pyroxenes impart a speckled texture to rock; clasts locally rounded.	705–710	5961.1–5956.1
	Basalt, dark olive-gray to black (5Y 2/1), porphyritic with aphanitic groundmass, vesicular. WR/+10F: olivine phenocrysts of varying stages of iddingsite replacement; rock locally has cinder or glassy appearance; cinders commonly coated with clay, calcite, or zeolite.	710–715	5956.1–5951.1
	Basalt, medium gray (N5), porphyritic with aphanitic groundmass, vesicular. WR/+10F: phenocrysts of olivine, plagioclase, and pyroxene; olivines partly altered or replaced (iddingsite).	715–725	5951.1–5941.1
	Basalt, medium to dark gray (N4), porphyritic with aphanitic groundmass, vesicular. WR/+10F: phenocrysts of olivine and plagioclase, olivines partly replaced or rimmed by iddingsite, fragments have cinder appearance, cinders coated with clay, calcite, or zeolite.	725–730	5941.1–5936.1
Tpf, Puye Formation	Volcaniclastic sediments, clayey gravel (GC), pale yellowish-brown (10YR 6/2), pebbles (up to 3.0 cm) mostly angular. WR/+10F: 100% lithic clasts made up of dacite, basalt, and pink siltstone.	730–735	5936.1–5931.1
	Volcaniclastic sediments, gravel (GW) with silt and sand, grayish-orange pink (5YR 7/2), pebbles (up to 2.7 cm) are angular to subangular. WR/+10F: 98% lithic clasts made up of dacite and vesicular basalt, 2% pale orange quartz.	735–740	5931.1–5926.1
	Volcaniclastic sediments, clayey gravel (GC), medium orange pink (10R 7/4), clasts angular to subrounded. WR/+10F: 90% lithic clasts made up of laminated siltstone and sandstone, 10% basalt with iddingsite alteration and intermediate volcanics (dacite). Interval may represent a clay interlayer.	740–745	5926.1–5921.1
	Volcaniclastic sediments, gravel (GW) with sand and clay, light olive-gray (5Y 6/1), sand and pebbles (up to 5.0 mm), clasts subangular to subrounded. WR/+10F: lithic clasts made up of 70% basalt, 20% dacite, and 10% sandstone/siltstone.	745–750	5921.1–5916.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravelly sand (SW), light gray (N6), clasts (up to 1 cm) angular to subrounded. WR/+10F: lithic clasts composed of 40–50% glassy basaltic scoria, 50–60% porphyritic dacite. Note: glassy basaltic scoria common in the interval 750–787 ft.	750–757	5916.1–5909.1
	Volcaniclastic sediments, gravel (GW) with silt and sand, light olive-gray (5Y 6/1), pebble gravel with silty matrix, clasts (up to 5.0 mm) angular to subrounded. WR/+10F: lithic clasts composed of 70–80% porphyritic dacite, 20–30% glassy basaltic scoria.	757–762	5909.1–5904.1
	Volcaniclastic sediments, gravel (GP), light gray (N6) to varicolored, pebbles (up to 1.5 cm) are subangular to subrounded. WR/+10F: lithic clasts composed of 80% silicified porphyritic dacite, 20% basaltic scoria.	762–767	5940.1–5935.1
	Volcaniclastic sediments, gravel (GW) with sand and silt, grayish-orange (10YR 7/4), pebbles (up to 1.7 cm) in matrix of sandy silt, clasts subangular to subrounded. WR/+10F: lithic clasts composed of 30–50% silicified dacite, 10–30% tuffaceous siltstone, and 10–20% basaltic scoria.	767–777	5935.1–5925.1
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6) to varicolored, clasts (up to 1.0 cm) subangular to subrounded. WR/+10F: lithic clasts composed of 70–80% dacite and andesite, 10-20% basaltic scoria, and 10–15% tuffaceous siltstone.	777–787	5925.1–5915.1
	Volcaniclastic sediments, gravel (GW) with sand and clay, light olive gray (5Y 6/1), clasts (up to 3.0 cm) subrounded to rounded. WR/+10F: lithic clasts composed of 70–80% dacite, 5–10% basalt, and 5% tuffaceous siltstone.	787–792	5915.1–5910.1
	Volcaniclastic sediments, sand (SW) with gravel and clay, light brownish-gray (5YR 6/1), pebbles (up to 1.2 cm) are subangular to subrounded. WR/+10F: lithic clasts composed of 90–95% dacite, 5% tuffaceous siltstone, and minor basaltic scoria.	792–812	5910.1–5890.1
	Volcaniclastic sediments, sand (SW) with gravel, light brownish-gray (5YR 6/1), medium to very coarse sand, pebbles (up to 1.0 cm) are subangular to subrounded. WR/+10F: lithic clasts composed of 85–95% dacite and andesite, 5–7% dacitic pumice fragments, and minor basaltic scoria.	812–827	5890.1–5885.1
	Volcaniclastic sediments, sand (SW) with gravel and silt, grayish-orange pink (5YR 7/2), clasts (up to 1.3 cm) subangular to rounded. WR/+10F: lithic clasts composed of 95–98% dacite and lesser andesite.	827–832	5885.1–5880.1
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6) to varicolored, clasts (up to 2.0 cm) subangular to rounded. WR/+10F: lithic clasts composed of dacite, andesite, basalt scoria, and tuffaceous siltstone.	832–837	5880.1–5875.1
	Volcaniclastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), clasts (up to 3.0 cm) subangular to subrounded. WR/+10F: composed of 99% dacite to rhyodacite clasts. Note: coarse gravel interval.	837–847	5875.1–5865.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), clasts (up to 1.3 cm) subrounded to rounded. WR/+10F: clasts composed of 98% dacite, rhyodacite, and minor basalt.	847–854	5865.1–5858.1
	Volcaniclastic sediments, clayey sand (SC) with gravel, grayish-pink (%YR 7/2), clasts (up to 5 mm) are subangular to rounded. +10F: clasts composed of 90–95% dacite and rhyodacite, 5–10% vesicular basalt. WR samples have clayey matrix.	854–868	5858.1–5844.1
	Volcaniclastic sediments, gravel (GW) with clay and sand, grayish-pink (5YR 7/2), clasts (up to 2.2 cm) are subangular to rounded. WR/+10F: clasts composed of 95–98% dacite and rhyodacite; 3–5% tuffaceous sandstone, trace quartzite	868–888	5844.1–5824.1
	Volcaniclastic sediments, sand (SW) with gravel, light brownish-gray (5YR 6/1), medium to very coarse sand with pebbles (up to 1.7 cm), subangular to subrounded. WR/+10F: clasts composed of 99% dacite and rhyodacite.	888–908	5824.1–5804.1
	Volcaniclastic sediments, clayey gravel (GC) with sand, grayish-pink (5YR 7/2), clasts (up to 1.0 cm) are subangular to subrounded. +10F: clasts composed of 95–98% dacite and rhyodacite; 3–5% tuffaceous sandstone. +35F: contains 50–60% brown tuffaceous siltstone/sandstone. WR sample is clay rich.	908–918	5804.1–5794.1
	Volcaniclastic sediments, sand (SW) with gravel and silt, grayish-pink (5YR 7/2), clasts (up to 1.2 cm) are subangular to subrounded. WR/+10F: clasts composed of 98% dacite and rhyodacite, minor volcanic siltstone to fine-grained sandstone, minor pumice.	918–933	5794.1–5779.1
	Volcaniclastic sediments, silty sand (SM) with gravel, light pinkish-gray (5YR 7/2), clasts (up to 1.8 cm), subangular to subrounded. WR/+10F: clasts composed of 95–98% porphyritic dacite, 3–5% fine-grained tuffaceous sandstone. +35F: limonite-cemented grains, crystals very common.	933–938	5779.1–5774.1
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6) to pinkish-gray, clasts (up to 1.5 cm) are subangular to rounded. WR/+10F: clasts composed of 99% dacite and rhyodacite.	938–943	5774.1–5769.1
	Volcaniclastic sediments, gravelly sand (SW) with silt, light pinkish-gray (5YR 7/2), clasts (up to 1.0 cm) are subangular to rounded; many clasts broken, suggesting coarse gravel. WR/+10F: clasts composed of 99% dacite and rhyodacite, trace pumice.	943–963	5769.1–5749.1
	Volcaniclastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), clasts (up to 1.5 cm) are subrounded to subangular. WR/+10F: clasts composed of 100% dacite, rhyodacite, and andesite, trace pumice. +35F: contains 90% volcanic lithics, 10% free quartz and sanidine crystals. Upper 5 ft of the interval has clayey matrix.	963–973	5749.1–5739.1
	Volcaniclastic sediments, sand (SP), light brownish-gray (5YR 6/1), medium to very coarse sand and granules (up to 0.5 mm), subangular to rounded. WR/+10F: composed of porphyritic dacite, rhyodacite, and andesite. +35F: contains 5% free quartz and sanidine crystals.	973–983	5739.1–5729.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Volcaniclastic sediments, sand (SW), yellowish-brown (10YR 5/4), very fine to very coarse sand and granules (up to 0.3 mm), subrounded to subangular. +10F: composed of porphyrtic dacite and rhyodacite (less than 10% of the entire sample retained by the No. 10 sieve). Note: fine clastic interval.	983–998	5729.1–5714.1
	Volcaniclastic sediments, sand (SW) with gravel, light brown (5YR 6/4), subrounded to rounded grains (up to 1.0 cm). +10F: 98% white aphyric pumice, minor basalt scoria and dacite. +30F: 80–90% volcanic lithics, 10% quartz and sanidine crystals. Note: pumice-rich interval 998–1068 ft.	998–1003	5714.1–5709.1
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6), to varicolored, clasts (up to 1.2 cm), subrounded to rounded. WR/+10F: 90% silicified dacite porphyry, 10% pumice.	1003–1008	5709.1–5704.1
	Volcaniclastic sediments, gravel (GW) with sand, light gray (N6), clasts subangular to subrounded. WR/+10F:40–60% aphyric pumice, 40–60% dacitic volcanic lithics, 5–10% tuffaceous sandstone.	1008–1018	5704.1–5694.1
	Volcaniclastic sediments, sand (SP) with gravel, varicolored, white (N9), to light gray (N6), medium to coarse sand with pebbles (up to 1.0 cm) subrounded to rounded. WR/+10F: 50–75% aphyric pumice, 25–30% dacite, rhyodacite, and andesite; 2–5% siltstone.	1018–1033	5694.1–5679.1
	Volcaniclastic sediments, sand (SW) with gravel, varicolored, white (N9) to dark gray (N6), clasts (up to 1.0 cm) subrounded to rounded. WR/+10F: 60–80% white and gray pumice, 10–20% dacite and basaltic scoria, and intermediate to felsic volcanics, 5–10% volcanic sandstone.	1033–1043	5679.1–5669.1
	Volcaniclastic sediments, gravel (GW) with sand, varicolored, white (N9) to light gray (N6), clasts (up to 2.0 cm) subangular to subrounded. WR/+10F: 60–80% white and gray pumice, 20–30% dacite and silicified dacite, 10–20% tuffaceous sandstone.	1043–1058	5669.1–5654.1
	Volcaniclastic sediments, gravel (GW) with sand, varicolored, white (N9) to light tan, clasts (up to 1.0 cm) subangular to subrounded. WR/+10F: 75–80% white and gray pumice, 15% silicified dacite, 5% fine-grained volcanic sandstone, 1–2% quartz and sanidine crystals.	1058–1063	5654.1–5639.1
	Volcaniclastic sediments, gravel (GW) with sand, varicolored, white (N9) to light gray (N6), clasts (up to 1.5 cm) subangular to subrounded. WR/+10F: 85% white pumice, 10–15% silicified dacite, 10–15% fine-grained volcanic sandstone. +35F: 10–20% pumice, 70-75% lithics, 3–5% quartz and sanidine crystals, 10–15% volcanic sandstone, minor quartzite.	1063–1068	5639.1–5634.1
	Clastic sediments, sand (SW) with gravel, varicolored, white (N9) to light gray (N6), clasts (up to 5 mm) subangular to subrounded. WR/+10F: 75–80% flow-banded rhyodacite and dacite, 3–5% pumice, 10–15% volcanic sandstone, 3–5% quartzite. Note: first interval with significant Precambrian lithic components indicates river gravel deposits within the Puye Formation from 1068 to 1133 ft bgs.	1068–1073	5634.1–5629.1

Geologic Unit	Lithologic Description	Sample Interval (ft bgs)	Elevation Range (ft above msl)
Tpf, Puye Formation	Clastic sediments, gravel (GW) with sand, varicolored, white (N9) to light gray (N6), clasts (up to 1.5 cm) subrounded to rounded. WR/+10F: 75–85% volcanic lithics (andesite, dacite, rhyodacite), 5-10% fine-grained volcanic sandstone, 5–10% white to pinkish quartzite, trace granitic rocks, 1–2% quartz and sanidine crystals.	1073–1083	5629.1–5619.1
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1), clasts (up to 1.5 cm) subrounded to rounded. WR/+10F: 60-80% rhyodacite and dacite, 20–40% quartzite, 5–10% granitic rocks.	1083–1093	5619.1–5609.1
	Clastic sediments, gravel (GW) with sand, varicolored, white (N9) to light gray (N6), clasts (up to 1.5 cm) subrounded to rounded. WR/+10F: 70–80% volcanic lithics (andesite, dacite, rhyodacite), 10-30% quartzite.	1093–1103	5609.1–5599.1
	Clastic sediments, sand (SW) with gravel, pale yellowish-brownish gray (5YR 6/2), fine to medium sand with pebbles (up to 1.5 cm), subrounded to rounded. WR/+10F: 80–90% porphyritic dacite, 5-10% vesicular basalt, 2–5% quartzite.	1103–1108	5599.1–5594.1
	Clastic sediments, gravelly sand (SW), medium brown (5YR 5/4), fine to medium sand with pebbles (up to 1.0 cm), subrounded to rounded. WR/+10F: 60–80% andesite and dacite, 10–30% vesicular basalt, 5-10% quartzite, minor tuffaceous sandstone.	1108–1118	5594.1–5584.1
	Clastic sediments, sand (SW) with gravel and clay, pale brownish-gray (5YR 7/2), fine to coarse sand with pebbles (up to 1.5 cm), subangular to rounded. WR/+10F: 10–60% basalt, 30–50% rhyodacite and dacite, 5–10% quartzite.	1118–1128	5584.1–5574.1
	Clastic sediments, gravel (GW) with sand, light brownish-gray (5YR 6/1) to varicolored, clasts (up to 2.0 cm), subangular to subrounded. WR/+10F: 70–80% rhyodacite and dacite, 10–20% basalt, 5–10% quartzite, minor granitic rocks, trace micaceous quartzite schist.	1128–1133	5574.1–5559.1
	TOTAL DEPTH = 1133 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-13 lithologic log:

   SW = Well-graded sand GM = Silty gravel SC = Sand/clay
   GW = Well graded gravel GC = Clayey gravel SP = Sand
   GP = Poorly graded gravel SM = Silt

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

Appendix C

Borehole Video
(CD on inside back cover)

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

Appendix D

Schlumberger Geophysical Report and Montages
(CD on inside back cover)

CHARACTERIZATION WELL R-13:

GEOPHYSICAL LOGGING REPORT

Schlumberger Integrated Water Solutions

July 2002

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1. ABSTRACT

This report describes the borehole geophysical logging measurements acquired in Los Alamos National Laboratory Characterization Well R-13 by Schlumberger in September 2001 just prior to well completion. The report explains what measurements were obtained, how they were obtained and processed, and what the results are and what do they show. The logs were acquired from 18 ft. to 1065 ft. below ground surface, when the borehole contained 13.38 in. outer diameter steel casing from 850.5 ft. to ground surface (as measured by the logs) and 12.25 in. diameter open hole (uncased borehole) below 850.5 ft. The borehole was filled with fluid (drilling mud formation water) from approximately 835 ft. to the bottom and air above.

The primary purpose of the geophysical logging was to characterize the geologic/hydrogeologic section intersected by the well – moisture content, regional aquifer water table, capacity for flow, and geologic stratigraphy/mineralogy. A secondary purpose of the geophysical logging was to evaluate the borehole conditions – borehole diameter and deviation versus depth and degree of drilling fluid invasion. These objectives were accomplished by measuring, nearly continuously, along the length of the well:

- total and effective water-filled porosity and pore size distribution, from which an estimate of hydraulic conductivity is made
- bulk density and photoelectric effect, the latter particularly sensitive to lithology
- bulk electrical resistivity at multiple depths of investigation
- bulk concentrations of a number of elements
- spectral natural gamma ray, including potassium, thorium, and uranium concentrations
- bedding orientation and geologic texture
- borehole inclination and azimuth
- 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 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).

The geophysical log measurements from Well R-13 provide good quality results that are consistent with each other through much of the borehole, although the quality of some measurements was degraded in certain sections where the borehole contains large washouts. 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, photoelectric effect, and porosity measurements (particularly the magnetic resonance porosity); instead of measuring formation properties they partially measure borehole fluid properties. While much of the open hole section of the well at the time of logging is washed out, there are only a few depths where the shallow measurements are significantly degraded. The greatest log quality issue is in the interval 24–430 ft. of the cased hole section of the well where the bulk density measurement and, consequently, inferred air-filled porosity are severely affected by washouts behind the casing. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements is 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-13 locale.

Important results from the processed geophysical logs in R-13 include:

1. The depth of the regional aquifer water table most likely coincides with the water level in the well at the time of logging, 835 ft., based on the integrated log analysis results – the depth at which water saturation decreases significantly (air becomes prevalent in the pore space) and stays low in the interval above. It is often difficult to clearly identify the depth of the regional aquifer water table from geophysical log measurements due to their limited depth of investigation coupled with the damage to the near borehole environment

from drilling (e.g. drilling fluid invasion) and the presence of casing (if applicable). In R-13 the processed geophysical log results display a distinct shift at 835 ft. between high water content below and low water content / high air content above – as detected by the combined analysis of the logs.

2. The highest water-filled porosities are at the bottom of the well, averaging 40% at 1050 ft. and decreasing at a constant decline to 25% at 860 ft. Effective porosity (moveable water) and estimated hydraulic conductivity are highest across the zone 980–1022 ft., reaching 30% and 0.001 cm/s, respectively, at 1004 ft. – indicating high groundwater flow capacity; the two decrease rapidly to zero effective porosity and $5x10^{-8}$ cm/s hydraulic conductivity at 910 ft., although there are a number of peaks across this interval. The zone 875–910 ft. is characterized by an increase in effective porosity and hydraulic conductivity to 10% and $1x10^{-5}$ cm/s, respectively, at 890 ft. The formation appears to be a heterogeneous, well-bedded clastic formation derived from volcanic source rock. The inferred mineralogy is dominated by either silica glass or quartz and alkali feldspar, with lesser, but consistent, amounts of hornblende and hypersthene and zones containing plagioclase feldspar; it also contains varying amounts of montmorillonite clay and augite.
3. The interval 850–927 ft. appears to contain significant amounts of clay clay-rich, especially in the zones 873–881 ft. and 858–865 ft., which contain as much as 50% and 20% clay volume fraction, respectively.
4. The interval 835–860 ft. has high water-filled porosity, reaching 40% at 842 ft., but this increase may be due to washouts behind the casing.
5. The zone 730–850 ft. appears quite heterogeneous, with total and water-filled porosity ranging 25–50% and 20–25%, respectively, across the good measurement quality intervals. The inferred mineralogy is dominated by silica glass, alkali feldspar, and hypersthene, with varying amounts of heavy mafic minerals – likely a volcanic deposit.
6. The interval 310–730 ft. is characterized by low water content (5% with some zones reaching 10%) and total porosity averaging 20–30% (where the total porosity is not obviously degraded by air voids behind the casing). The inferred mineralogy contains a large fraction of heavy mafic minerals and augite, with varying amounts of silica glass and plagioclase feldspar – likely a basaltic lava flow.

7. A significant geologic contact exists at 310 ft., marked by a significant increase in thorium, potassium, and uranium and an increase in water content from 5% at 310 ft. to 13% at 277 ft. The inferred mineralogy changes from the section below by a significant reduction in heavy mafic minerals, a large increase in hypersthene and hornblende, and a relatively large increase in alkali feldspar. This contact likely marks the bottom of the volcanic tuff/pumice sequence that is prevalent in the upper geologic section throughout the area, and continues to at least 48 ft. (the top of the geochemical log interval). Water content decreases at a nearly constant rate from 13% at 262 ft. to 6% at 24 ft.
8. Bed boundaries between 857 and 1055 ft. have a wide range of dip azimuths (direction beds are dipping to), with a predominance in the sectors 30–60, 130–180, 200–230, and 250–260 degrees (the mean is 208 degrees). More than 80% of these interpreted bed boundaries have dip angles less than 10 degrees; the mean and maximum dip angles are 2.6 and 23 degrees, respectively. Only one fracture was discernable across this interval. Throughout this interval the electrical resistivity image shows a well-bedded, alternating sand-silt-clay-conglomerate stratigraphy.

2. INTRODUCTION

Geophysical logging services were performed in Los Alamos National Laboratory (LANL) Characterization Well R-13 by Schlumberger in September 2001, prior to initial well completion. The purpose of these services was to acquire in-situ measurements that help characterize the borehole, near-borehole, and abutting geologic formation environment. The primary objective of the geophysical logging was to provide in-situ evaluation of formation properties (hydrogeology and geology) intersected by the well; the secondary objective was to evaluate the borehole conditions. 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-13 were the:

- Compensated Neutron Tool, model G (CNTG*) to measure volumetric water content of the formation in open hole (OH) and beyond the casing in cased hole (CH) – used to evaluate moist/porous zones;
- Combinable Magnetic Resonance (CMR*) tool to measure the nuclear magnetic resonance response of the formation in OH – used to evaluate total and effective water-filled porosity of the shallow formation, and to estimate pore size distribution and in-situ hydraulic conductivity;
- Triple detector Litho-Density (TLD*) tool to measure formation bulk density in both OH and CH, photoelectric effect (P_e) in OH, and borehole diameter using a single-arm caliper – used to estimate total porosity and characterize lithology;
- Array Induction Tool, version H, (AITH*) to measure formation electrical resistivity at five depths of investigation and borehole fluid resistivity in OH – used to evaluate drilling invasion into the formation, presence of moist zones far from the borehole wall, and presence of clay-rich zones;

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* Mark of Schlumberger

- Micro Cylindrically Focused Log (MCFL*) to measure invaded zone high resolution electrical resistivity in fluid-filled OH – used to evaluate invasion into the formation and geologic heterogeneity;
- Hostile Natural Gamma Spectroscopy (HNGS*) tool to measure overall and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations in OH and CH – used to evaluate geology/lithology, particularly the amount of clay and potassium-bearing minerals;
- Elemental Capture Spectroscopy (ECS*) tool to measure elemental weight percent concentrations of a number of elements in OH and CH – used to characterize mineralogy, lithology, and water content of the formation;
- 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.

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 Well R-13.

Date of Logging	Borehole Status	Run #	Tool 1	Tool 2	Tool 3	Depth Interval (ft. below surf.)
24-Sept-2001	Open hole below 850.5 ft. Bit size of 12.25 in. Steel casing above 850.5 ft. Casing OD of 13.375 in.	1	TLD	MCFL	GR	30–1070 ft.
Same	Same	2	AITH	GR		854–1055 ft.
Same	Same	3	HNGS	ECS		47.5–1065 ft.
Same	Same	4	FMI	GPIT	GR	857–1058 ft.
Same	Same	5	CMR	GR		873–1070 ft.
Same	Same	6	CNTG	GR		28–1064 ft.

Table 2.1: Geophysical logging services, their combined tool runs and intervals logged – as performed by Schlumberger in Well R-13.

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. A short history and description of geophysical well logging in the petroleum industry can be found in [Schlumberger 1996].

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

3. logging truck that controls sonde location, provides power and houses a computer that controls sonde operation, as well as processes and displays data in real time. The resulting data are shown on a continuous strip chart commonly called a log.

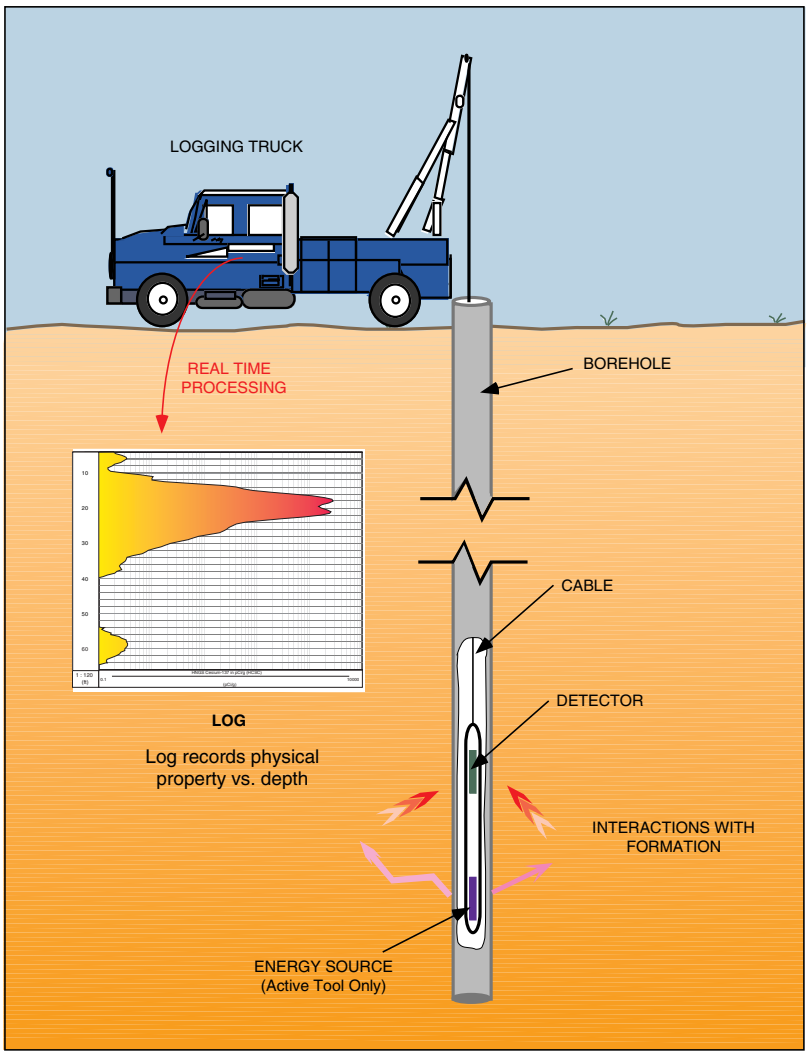

Figure 2.1: Schematic diagram of a wireline logging system in operation.

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

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

2.1.1 Compensated Neutron Tool, Model G (CNTG)

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

The CNTG provides two different porosity measurements, thermal and epithermal. The advantage of the epithermal measurement is that it provides a measurement in air-filled boreholes (not possible with the thermal measurement) and is relatively insensitive to thermal neutron absorbers (such as chlorine in salt water and the rare earth elements in

shale). However, because of less efficient detection and of the relatively brief time spent by the neutrons in the epithermal energy band, epithermal count rates are lower than thermal count rates, under identical conditions in water-filled boreholes, by a factor of ten.

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

Basic measurement specifications for the CNTG are shown below.

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

2.1.2 Combinable Magnetic Resonance (CMR)

The CMR makes pulse-echo Nuclear Magnetic Resonance measurements that are sensitive to the hydrogen nuclei (protons) contained in the pore space of the formation. These measurements contain information relating to both pore water volume and pore size. The pore size information can be used to partition the formation porosity into bound and free fluid volumes. This information can, in turn, be used to estimate formation hydraulic conductivity and water producibility. The pore size information also can be used to extrapolate relative grain size. The pore size information is unique to NMR logging devices.

The CMR log uses a compact magnet and antenna sensor package mounted in a pad-like skid that is pressed against the borehole wall. The tool has a vertical resolution of 6 in [15 cm] and a median depth of investigation of 1.5 in [4 cm]. Since the CMR makes a shallow measurement that requires good borehole wall-to-pad contact, disruption of contact between the skid and the wall due to borehole washout or hole rugosity affects data quality, resulting

in erroneously high/low total and free water content in water/air-filled hole. The measurement also can be significantly affected by a sizeable presence of iron-bearing minerals, such as magnetite.

Basic measurement specifications for the CMR and a schematic diagram of the tool and sensor section are shown below and in Figure 2.2, respectively. The measurement specifications assume good logging conditions – the CMR pad has good contact with the borehole wall and there is not a large presence of magnetic material in the borehole environment.

Repeatability (σ):	Total water-filled porosity – 1%; Effective water-filled porosity – 0.5%
Total margin of error:	2%

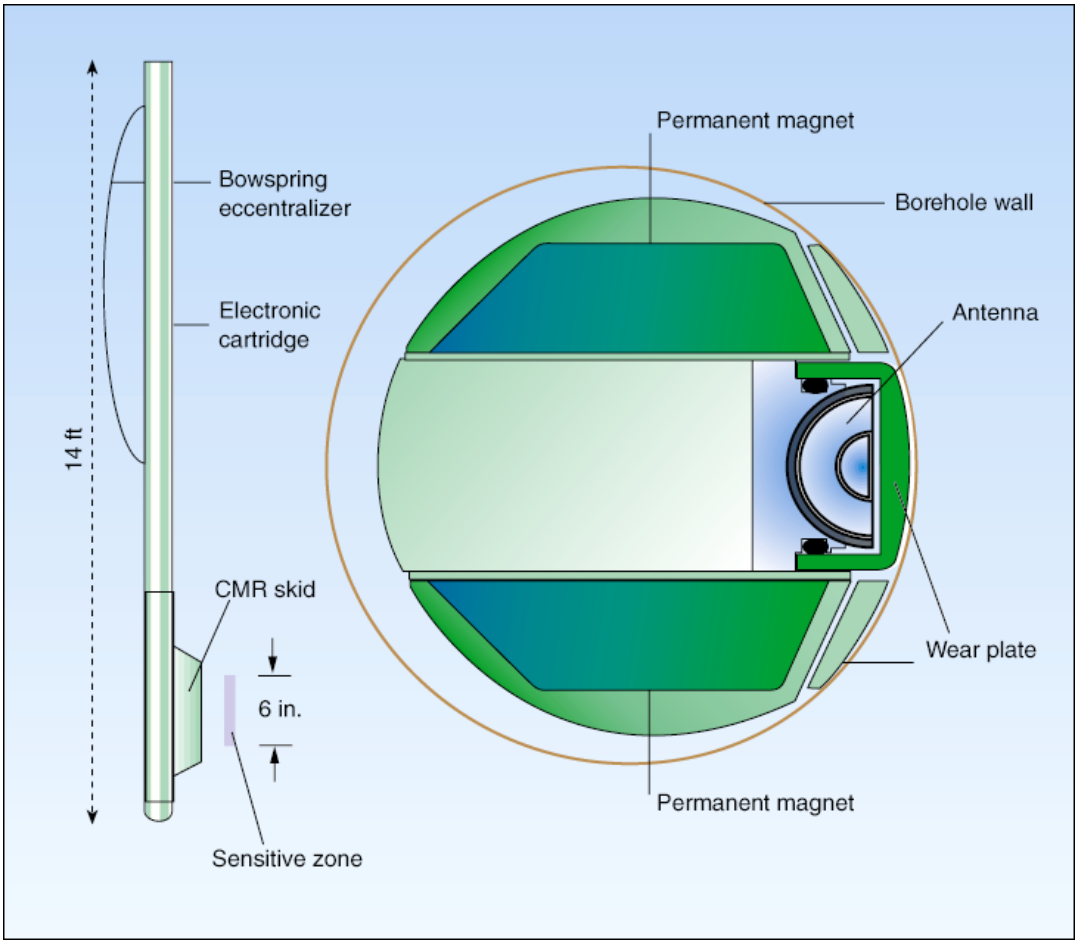

Figure 2.2: Schematic diagram of CMR tool with an enlarged cross-section of the sensor section.

2.1.3 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 due to their small size and heavy shielding—producing 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 2.3.

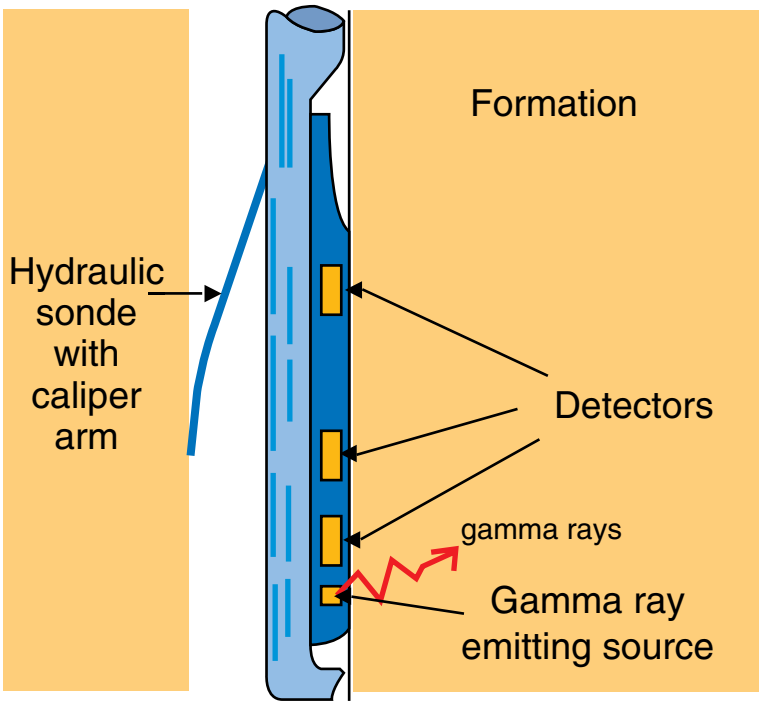

Figure 2.3: Schematic diagram of TLD-type density logging system.

2.1.4 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:

- 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 2.4.

Range of measurement:	0.2 - 1000 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)

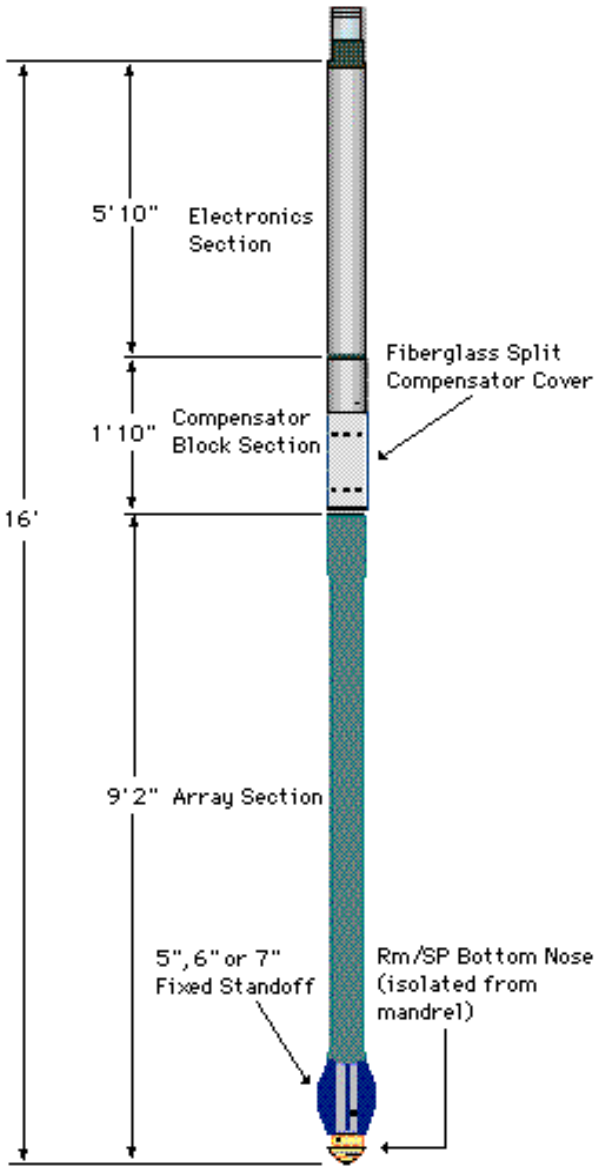

Figure 2.4: Schematic diagram of AIT tool, showing component lengths and standard logging setup.

2.1.5 Micro Cylindrically Focused Log (MCFL)

With the Platform Express*, the MCFL measurements are integrated with the density sensors 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.

Basic measurement specifications for the MCFL are shown below.

Range of measurement:	0.2 - 2000 Ohm.m
Repeatability:	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
Vertical Resolution:	2 in (5 cm); 8 in (20 cm) and 18 in (46 cm)
Depth of Investigation:	2 in. (5 cm.)

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2.1.6 Hostile Natural Gamma Ray Spectroscopy (HNGS) tool

The HNGS tool is a spectral and total passive gamma measuring sonde that can be used in either open or cased boreholes. The tool was designed to quantify naturally occurring radionuclides from within deep oil wells and has been optimized to provide maximum sensitivity so that typical oilfield logging speeds (1800 ft/hr; 600 m/hr) can be used while retaining effective counting statistics. To this end, the system uses two large scintillation detectors composed of bismuth germanate (BGO), with a very low activity ^{22}Na stabilization source sandwiched in between and a photomultiplier tube optically connected to each detector (see Figure 2.5). BGO has a high specific gravity (approximate 7 g/cm^3), which increases efficiency by promoting the capture of more gamma rays that enter the detector (compared to most commonly employed scintillators). Two detectors are employed to increase the sensitivity without degrading the system's vertical resolution.

The tool measures a full gamma energy spectrum that encompasses the spectral energies of potassium [K], uranium [U], and thorium [Th]. A weighted-least squares (WLS) processing algorithm is used to decompose the contributing source component activities. The result is a robust measurement of K, U, Th components and total gamma activity that maximizes the statistical information collected by the scintillators.

Instrument specifications for the HNGS include a 3.75 inch diameter, 8.5 ft length, and 203 pound weight rating. Basic measurement specifications are shown below. Further technical information can be found in [Flanagan et al., 1991].

Basic specifications for the HNGS and a schematic diagram of the measurement sensor are shown below and in Figure 2.5, respectively.

Range of measurement:	GR – 0 to >750 API units; K – 0 to ~50%; Th – 0 to ~10,000 ppm; U – 0 to ~10,000 ppm
Statistical precision (σ):	Th – 0.9 ppm; U – 0.4 ppm; K – 0.14%
Depth of Investigation:	~9.5 in (24 cm), dependent on density of material

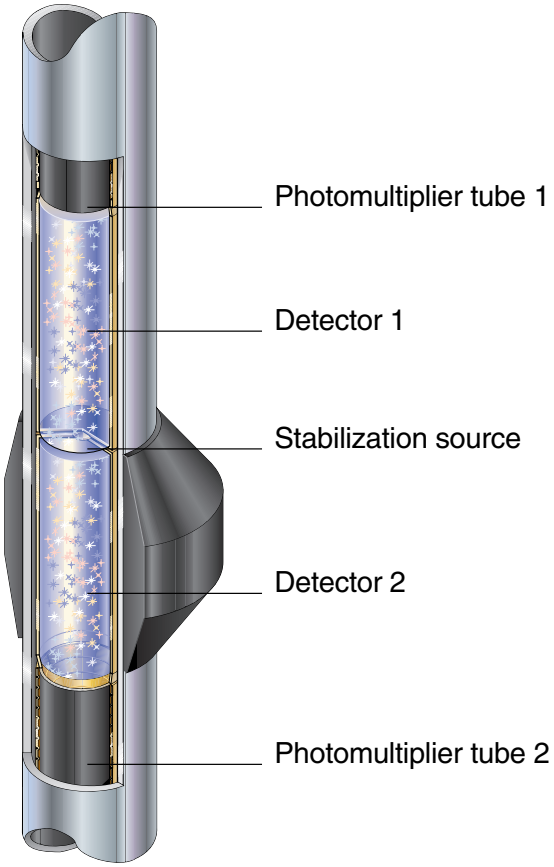

Figure 2.5: Schematic diagram of HNGS-type sensor.

2.1.7 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.

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

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.

2.1.8 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 2.6.

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

2.1.9 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.

3. METHODOLOGY

This section describes the methods employed by Schlumberger for performed geophysical logging services in Well R-13, 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 arrival 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, that includes:

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
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, 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 in Englewood, CO was alerted that the data was ready for initial post-acquisition processing.

3.2 Log quality control and assessment

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

CNTG

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

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

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

HNGS

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

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

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

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

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

<u>ECS</u>

The Schlumberger calibration and verification methodology for the ECS, similar to the HNGS, 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.

TLD

Similar to the CNTG, 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 – in order that the tool electrical induction response can be used to generate accurate electrical resistivity measurements. The initial base calibration only has to be performed 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.

CMR

After an initial base calibration and intensive measurement and electronic system checks performed at the time of tool production, the CMR calibration and verification methodology consists of a routine shop (or master) calibration and well site before and after survey calibration/verification.

The shop calibration consists of a one-point calibration in which the signal amplitude at 100% water-filled porosity is found by placing a calibration jig filled with water in front of the tool sensor section. In addition, an electronic calibration of system gain is performed using an internal test loop located on the tool's antenna. The measured amplitude and electronic gain are saved as a lookup table in the internal memory of the individual CMR tool – to be used when logging in the field for the calculation of CMR porosities.

The well site before survey calibration covers two procedures for tuning the sensor antenna to the magnetic resonance frequency of water (known as the Larmor Frequency) – performed at the surface and downhole in the vicinity of the logging interval. This tuning procedure compensates the sensor response for the well specific effects of pressure, temperature, and metallic debris in the hole. In addition a check of system noise is made.

At the completion of the CMR logging one of the tuning procedures is repeated – the system search for the Larmor Frequency – to verify that the log was run "in tune". This procedure constitutes the well site after survey verification

3.3 Processing procedure

After the geophysical logging job was completed in the field and the data archived, the data was downloaded to the Schlumberger processing center in Greenwood Village, CO. There the data were processed, in the stated order, to (1) correct the measurements for near-

wellbore environmental conditions and redo the raw measurement field processing for certain tools using better processing algorithms, (2) depth match and merge the log curves from different logging runs, and (3) model the near-wellbore substrate lithology/mineralogy and pore fluids through integrated log analysis. Afterwards an integrated log montage was built to combine and compile all the processed log results.

Environmental Corrections and Raw Measurement Re-Processing

If required, the field log measurements were processed to correct for conditions in the well – 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-13 the log measurements requiring these corrections are the CNTG porosity, TLD density, ECS elemental concentrations, and HNGS spectral gamma ray logs.

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

The standard open hole processing algorithm used for the 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) determined by comparing the normalized raw yields in zones directly below/above the borehole fluid/casing change.

The HNGS spectral gamma ray are affected by the material (fluid, air, casing) in the borehole because different types and amounts of these materials have different gamma ray shielding properties; the HNGS 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. After applying the corrections to the spectral gamma measurements there was still a relatively small, but noticeable, increase in the individual logs going from water-filled to air-filled open hole and a decrease going from open to cased hole. It is likely the correction algorithms are not fully compensating for (1) the lack of borehole gamma ray diminishment in the large air-filled open hole section, compared to where it is water-filled, and (2) the shielding effect of the thick steel casing and annular fill in the cased hole section. In R-13 the interval between the start of casing (850.5 ft.) and the well water level (835 ft.) is short and the remaining countering effects of the two on the pre-processed spectral gamma logs appear to essentially cancel each other out.

In addition, the CMR logging runs were reprocessed from raw field measurements in an effort to improve the derived measurement results, which contain a significant amount of variability and noise in sections of the field processed logs. The processing algorithms available in Schlumberger data processing centers are more robust and flexible than those used in the field acquisition logging truck, providing the ability to account for a larger range of environmental conditions, as well as provide additional useful outputs.

The measurements can not 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 well bore 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]. This program is designed for quantitative formation evaluation of cased and open-hole logs level by level. Evaluation is done by optimizing simultaneous equations described by one or more interpretation models.

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

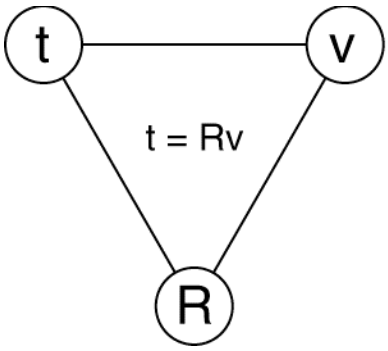

Figure 3.1: Schematic diagram of ELAN mathematical model.

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

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

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"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 CdV-R37-2) 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 can not 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 these unaccounted for properties vary. 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 no others.

The tool measurements, volume components and parameters used in the ELAN analysis for R-13 are provided in Table 3.1 and 3.2. To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (24–1064.5 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. To accommodate fewer tool measurements certain model constituents are removed from the analysis in some intervals. Most notably, capillary bound water can not be solved for where there is no CMR measurement (above 874 ft.) and only a few minerals are retained in the model above 47 ft., where there is no ECS geochemical and HNGS spectral gamma measurements; the latter interval is the only place where gross gamma is used.

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 the saturated and unsaturated zones lies (e.g. the depth to the top of the regional aquifer). Thus, the presence and amount of air in the pore space is unconstrained. Total porosity is also left unconstrained throughout the analysis interval. In the cased hole section there are many places where bulk density is very low – likely due to air voids behind the casing – resulting in very high, physically impossible, air-filled porosity; the bulk density drives the ELAN total porosity since it is the only measurement directly sensitive to total 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 (high porosity) and the presence of small amounts of air below the probable water table – 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, especially where the borehole contains washouts. 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.

Volume / *Tool Measurement*	Air	Moveable Water	Capillary Bound Water	Hornblende	Labradorite	Augite	Heavy Mafic Minerals	Montmorillinite	Hypersthene	Quartz	Pyrite	Orthoclase	Silica Glass
Bulk Density (g/cc)	-0.19	1.00	1.00	3.11	2.65	3.08	4.0	2.20	3.55	2.64	4.99	2.58	2.25
Thermal Neutron Porosity (ft^3/ ft^3)	-0.08	1.00	1.00	0.06	-0.01	0.02	0.07	0.65	0.036	0	0.008	-0.01	0.00
Epithermal Neutron Porosity (ft^3/ ft^3)	-0.02	1.00	1.00	0.05	-0.01	-0.01	0.02	0.60	0.01	0	0.165	-0.01	0.00
Volumetric Photoelectric Effect	0.01	0.40	0.40	12	7	23.8	65.00	4.40	20.2	4.78	82.06	7.3	4.20
Total CMR Water-filled Porosity (ft^3/ ft^3)	0	1.0	1.0	0	0	0	0	0.425	0	0	0	0	0
CMR Bound Fluid Volume (ft^3/ ft^3)	0	0	1.0	0	0	0	0	0.425	0	0	0	0	0
Resistivity (ohm-m)	Very high	37.5	37.5	Very high	Very high	Very high	Very high	1.06	Very high	Very high	Very high	Very high	Very high
Gamma Ray (gAPI)	0	0	0	230	50	30	50	300	50	25	0	500	20

Table 3.1: Tool measurements, volumes, and respective parameters used in the R-13 ELAN analysis – density, porosity, and resistivity tools.

Volume / *Tool Measurement*	Air	Moveable Water	Capillary Bound Water	Hornblende	Labradorite	Augite	Heavy Mafic Minerals	Montmorillinite	Hypersthene	Quartz	Pyrite	Orthoclase	Silica Glass
Dry Weight Silicon (lbf/lbf)	0	0	0	0.213	0.24	0.225	0.184	0.264	0.24	0.468	0	0.3	0.468
Dry Weight Calcium (lbf/lbf)	0	0	0	0.09	0.09	0.10	0	0.014	0	0	0	0	0
Dry Weight Iron (lbf/lbf)	0	0	0	0.065	0	0.11	0.22	0.02	0.20	0	0.466	0.001	0
Dry Weight Sulfur (lbf/lbf)	0	0	0	0	0	0	0	0	0	0	0.535	0	0
Dry Weight Titanium (lbf/lbf *100)	0	0	0	0.5	0.015	4.8	0.01	0.125	1	0.015	0	0.005	0
Wet Weight Hydrogen (lbf/lbf)	0	1	1	0	0	0	0	0.18	0	0	0	0	0
Wet Weight Potassium (lbf/lbf)	0	0	0	0.01	0	0.003	0	0.005	0	0	0	0.102	0
Wet Weight Thorium (ppm)	0	0	0	50	3	20	0	24	25	2	0	5.5	2

Table 3.2: Tool measurements, volumes, and respective parameters used in the R-13 ELAN analysis – geochemical and natural gamma ray spectroscopy tools.

4. RESULTS

This section presents and describes the final log results from the borehole geophysical logging performed by Schlumberger in well R-13. 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, 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 evaluated using the neutron porosity measurements. 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-13 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. Subsequently, 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) – in order to identify wet zones above the water table and porous, water-producing zones below the water table. The CNTG, which measures water content in both open and cased hole, above and below the borehole water level, was the primary service run for this purpose. The CMR was run in the open hole section to measure the water-filled pore size distribution – most importantly the amount of moveable water (effective water-filled porosity) – which, in turn, provides valuable information on formation flow capacity (hydraulic conductivity). The TLD bulk density measurement also provides useful information about water-filled porosity, as well as air-filled porosity.

To provide accurate quantitative measurements of water content the CNTG field measurements had to be corrected for borehole environmental conditions – primarily borehole fluid type. The CMR field measurements did not require any additional environmental corrections beyond those applied at the time of the measurement. However, the CMR raw field measurements were reprocessed to improve the measurement signal-to-noise and to generate additional outputs not computed in the field. The TLD field measurement of bulk density required recomputation in the cased hole section to reduce the influence of the steel casing on the measurement. None of the measurements can be corrected for the effects of borehole washouts and rugosity (causing an increased borehole fluid/air

response), since the specific characteristics of the washouts (e.g. geometry) are unknown or 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 sharp, large washouts (preventing the tool sensors from contacting the borehole wall) that are filled with water. The CMR and TLD are more influenced by these conditions than the CNTG since their measurements are much more shallow.

Since none of these measurements actually directly measures volumetric water content, the best estimate of true water content is obtained from the ELAN integrated log analysis. 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-13 are shown as part of the summary logs in Figure 4.1 (solid dark blue curve in the second track from the right), and in expanded form as part of the integrated log montages provided with the LANL R-13 Well Completion Report (a compressed version of the montage is shown in Figure 4.4). The summary log also displays:

- ELAN moveable water volume fraction, or "effective porosity" (solid cyan curve and cyan shading in second track from right);
- ELAN bound water volume fraction (dotted blue shading in second track from right);
- ELAN total (water- and air-filled) porosity (red hashed curve in second track from right);
- Air-filled porosity (dotted red shading in second track from right);
- ELAN water saturation (dotted light blue curve in second track from right);
- CMR estimated tapered Timur-Coates equation hydraulic conductivity (solid blue curve and blue shading in first track from right);
- Gross gamma ray (solid brown curve in first track from left);
- Caliper with measured washouts (dashed black curve with washouts shown by pink shading, in first track from left); and
- Bulk water chlorinity estimated from the ECS (dashed green curve and green shading in first track from left).

Borehole water level in R-13 at the time of the August 2001 geophysical logging was 835 ft. (using the AIT log run as the depth reference). A definitive unsaturated-saturated zone boundary – below which the formation is fully saturated through the rest of the depth section, as would be expected at the regional groundwater table – is difficult to discern from the processed geophysical logs. However, the ELAN results indicate a sharp, large decrease in water saturation (percentage of pore space occupied by water), in the upward direction, at 835 ft. – coincident with the borehole water level at the time of logging. Above 835 ft. the water saturation remains below 40%, except for a few sharp peaks, and below this depth it is consistently above 65% and predominantly above 80%. While the ELAN water saturation is not consistently at 100% in the inferred saturated zone, the deviations from full saturation are likely within the range of error of the unconstrained ELAN model. There are also step drops in the ELAN water saturation at 890 ft. and 850 ft. (best seen in porosity summary log, Figure 4.1) that possibly correspond to the start of the unsaturated zone; however, the decrease in water saturation at 835 ft. is much larger and pervasive through the above section of the borehole.

The following ordered list describes the R-13 porosity summary log (Figure 4.1) from bottom to top, itemized by depth intervals.

- 1064–1053 ft.: Total and water-filled porosities read unrealistically high (80–85% and 55–65%, respectively), likely the result of a very large washout at the bottom of the hole and the porosity tools not reading correctly until 1053 ft.
- 1053–911 ft.: Total and water-filled porosities more or less track each other and, on average, decrease at a nearly constant rate from about 42% at 1053 ft. to 25% at 911 ft. The effective, or free fluid, porosity is approximately 15% at 1053 ft., has a sharp peak reaching 28% at 1044 ft., then increases steadily to about 30% (minus peaks) at 1004 ft., followed by a steady decrease (minus peaks) to 0% at 911 ft. Estimated hydraulic conductivity from the CMR follows a similar trend as the free fluid porosity: it averages approximately $8x10^{-5}$ cm/s at 1053 ft., has a sharp peak reaching $8x10^{-4}$ cm/s at 1044, then increases steadily to about $1x10^{-3}$ cm/s at 1004 ft., followed by a steady decrease (minus peaks) to $5x10^{-8}$ cm/s at 911 ft. The effective porosity and estimated hydraulic conductivity contain many higher peaks in this interval, but most of the peaks are adjacent to washouts and are, thus, suspect.

- 911–903 ft.: This short interval contains a small peak in free fluid porosity and estimated hydraulic conductivity – 3% and $3x10^{-7}$ cm/s, respectively. Total and water-filled porosity remain between 25% and 30%.
- 903–874 ft.: Water-filled porosity ranges 20–30%, but total porosity starts to increase slightly above water-filled porosity, especially at 890 ft. – suggesting a small amount of air in the pore space, although this could well be due to ELAN model uncertainty (see above). Free fluid porosity and estimated hydraulic conductivity increase in this interval, reaching about 12% and $1x10^{-5}$ cm/s, respectively, at 888 ft. and 894 ft. The top of the CMR log interval is 874 ft., so free fluid porosity and CMR estimated hydraulic conductivity are not available above this depth.
- 874–850.5 ft.: Total and water-filled porosity are similar to the interval below, although they increase to a consistent level of 35% and 29%, respectively, in the interval 850–858 ft.
- 850.5–841 ft.: The bottom of the steel casing used in casing-advance drilling was located at 850.5 ft. at the time of logging. There is an anomalous, sharp trough in the ELAN total and water-filled porosity right at the bottom of the casing; this is likely just a processing artifact associated with the change to cased hole. Above this depth total and water-filled porosity increase to an average of about 50% and 35%, respectively. This increase could be associated with a washout behind the bottom of the casing, although the difference between the two porosity values suggests there is a considerable amount of air either in the annular void or the actual formation pore space. As discussed above, it is possible the regional aquifer groundwater table coincides with the bottom of the casing, but there is still a considerable amount of water detected by the geophysical measurements.
- 841–835 ft.: Water-filled porosity decreases 23–30%, while total porosity briefly to 35% at 840 ft. before increasing to about 47%. At 835 ft. water-filled porosity drops sharply to 10%. As discussed above, it is possible that the regional aquifer groundwater is at 841 ft., but more likely at 835 ft., where the decrease in water is more significant.
- 835–731 ft.: Water-filled porosity increases slightly at 828 ft. and varies between 10% and 15% through the remainder of the interval. Total porosity varies more significantly in the range 30–50% (minus spikes).
- 731–720 ft.: Total and water-filled porosity shift lower to about 30% and 6%, respectively.

- 720–712 ft.: Water-filled porosity rises to about 10% and total porosity ranges 30–40%.
- 712–495 ft.: Water-filled porosity remains nearly constant at 5–6%, except for very slight increases in the intervals 630–644 ft. (maximum 9%) and 574–591 ft. (maximum 7%). Total porosity averages only about 25%.
- 495–460 ft.: Water-filled porosity rises slightly across this interval, reaching 12% at 476 ft. total porosity generally increase upwards, averaging about 42% in the zone 462–474 ft. and reaching a maximum of 52% at 464 ft.
- 460–430 ft.: Total and water-filled porosity decrease to 10–25% and 5–7%, respectively, except total porosity sharply rises at 438 ft., reaching nearly 60% at 430 ft.
- 430–400 ft.: Water-filled porosity increases again to a level of about 10%. Total porosity varies sharply in the range 35–60%. Above 430 ft. the total porosity estimate is likely plagued by washouts and, thus, air voids in between the casing and formation – resulting in very high, unreasonable values.
- 400–311 ft.: Water-filled porosity drops to 3–5%. Total porosity varies dramatically, reaching very high values and, in a few places, very low values – likely corrupted by annular voids.
- 311–276 ft.: Water-filled porosity steadily increases to 13% at 276 ft. Total porosity is again erratic. Based on solely the geophysical logs, this interval may correspond to the bottom of the volcanic tuff sequence that is widespread throughout the area.
- 276–24 ft.: Water-filled porosity slowly and steadily decreases to 6% at 25 ft. Based on solely the geophysical logs, this interval likely is part of the volcanic tuff sequence.

Also shown in the porosity summary log is an estimate of bulk water chlorinity computed from the ECS geochemical measurements – presented in units of parts per thousand (ppk). The estimate is based on the assumption that all chlorine present within the ECS measurement volume (approximately a one foot diameter sphere surrounding the sensor) is dissolved in water. The estimate also can't differentiate between borehole water and formation water; instead it is a combination of both. The computed log indicates relatively low bulk chlorinity (less than 2 ppk) below the presumed regional water table (835 ft.), but bulk chlorinity as high as 13 ppk in the unsaturated zone (see green log in first track from left of Figure 4.1).

An explanation for the high chlorinity is difficult to come by, as the natural groundwater is apparently fresh, as well as the introduced drilling fluid. It is possible that chlorine resides in the matrix, maybe as leached salts. In any case the bulk chlorinity log needs to be verified against core and connate fluid analysis before any robust interpretations can be made, as the measurement is only an experimental estimate at this point in time.

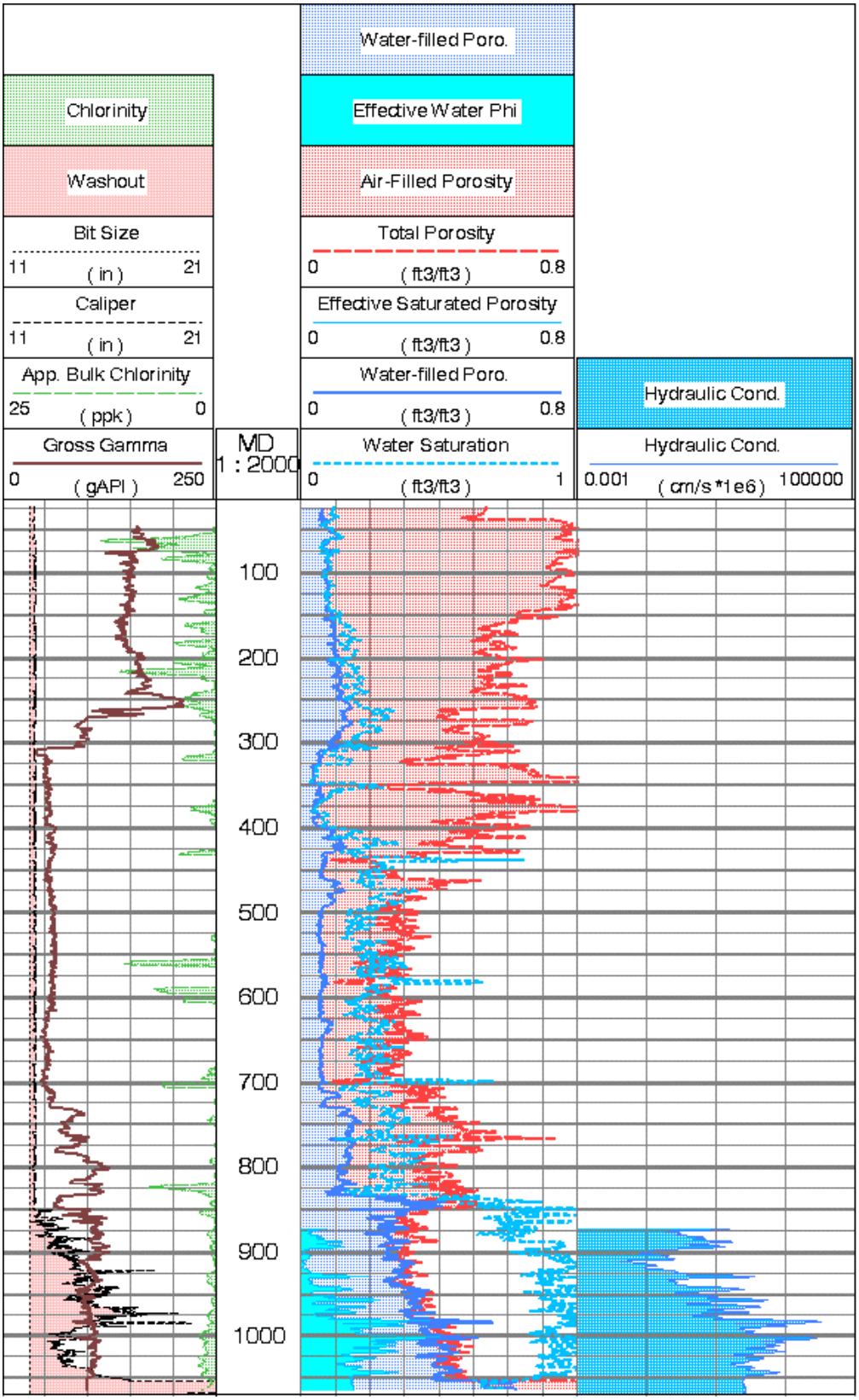

Figure 4.1: Summary porosity logs in R-13 borehole from processed geophysical logs, interval 18–1070 ft, with caliper, gross gamma, bulk chlorinity, water saturation, and hydraulic conductivity logs. Porosity and water saturation logs are derived from the ELAN integrated log analysis.

4.2 Density and Pe

Bulk density and P_e log measurements, obtained from the TLD geophysical tool in R-13 and R-13, provide information about the formation total porosity (water plus air) and lithology, respectively. The bulk density is the only measurement in the suite of logs run in this well (and most geophysical log measurements) that is directly sensitive to all formation components: air-filled porosity, water-filled porosity, and rock matrix. Total air plus water-filled porosity in the vadose zone can be estimated from density porosity when it is computed in conjunction with a water content measurement (e.g. neutron porosity) and an independent measurement/assumption of grain density. The processed bulk density and P_e curves (the latter referred to as "Pef" for photoelectric effect), as well as the apparent grain density derived from the ELAN analysis, are displayed as part of the summary log (third track from left) in Figure 4.2. Other applicable curves in the summary log are gross gamma ray (for stratigraphic correlation) and caliper (for identifying borehole washouts), 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 – measuring water/air density and P_e instead of the 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 – applicable only in open hole (see density track – 5th track from left – on the integrated log montage, Figure 4.4). This flag is used as an indication when the TLD measurement quality may be compromised. Unfortunately, there is no available quality flag for the non-standard cased hole bulk density measurement.

In R-13 the density correction is flagged across various intervals comprising about a third of the open hole section (the flag is nonsensical in the cased hole interval and thus is not presented). Even in most of the flagged zones the density and P_e measurements appear to be reasonable and consistent with the other geophysical log measurements, suggesting the measurements have properly corrected for environmental conditions within these zones,

despite the corrections being quite large. In the open hole section the only places where the quality of the bulk density and P_e are obviously compromised is adjacent to the large washouts at 984 ft. and 1053–1064 ft. The quality of the bulk density estimate in the cased hole section of R-13 (above 850.5 ft.) is much more problematic due to the sensitivity of the measurement to air/water annular gaps between the casing and the formation; P_e is unavailable in cased hole. The only way to know with certainty that the bulk density estimate is compromised is if the derived total porosity is unrealistically high. The ELAN total porosity is consistently above 50% at the top of the logged section (24–160 ft.) and intermittently above 50% across the interval 160–430 ft., as well as at 768 ft.; the cased hole bulk density is likely erroneous (i.e. not reflective of true formation bulk density) in these zones and could be compromised in other zones as well, likely where there it drops sharply (e.g. 464 ft.).

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 (Figures 4.2) and the fourth track from the left in the integrated log montage. 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 log, the ELAN total porosity mimics bulk density since bulk density is the primary measurement providing information on air-filled porosity. Because the bulk density measurement is very good quality below the casing (850.5–1064 ft.), the total porosity estimate should be valid throughout most of the open hole interval – except in the previously mentioned washouts. In contrast, the total porosity estimate is highly suspect in much of the cased hole interval (24–850.5 ft.) due to the likely presence of water/air gaps behind the casing – artificially lowering bulk density and increasing total porosity (see above) – although total porosity appears to be stable and fairly robust below 430 ft.

The P_e measurement is a good indicator of lithologic changes. In this geologic setting, an increase in P_e above 3 is a good indicator of the presence of heavy, probably mafic, minerals; an increase to 5 is an indicator of a very heavy mineral rich bed ("heavy" most likely corresponding to iron), such as a massive basalt lava flow. In the open hole section of R-13 (850.5–1064 ft.) P_e never reaches 3, instead staying consistently between 2 and 2.9; the P_e measurement is invalid in cased hole.

Below 1053 ft. P_e is erroneously very low due to a large washout. Across the interval 1053–989 ft. the P_e log is nearly constant at a value of 2. The mineralogy of this interval inferred by the ELAN integrated log analysis is dominated by either silica glass or quartz and alkali feldspar, with lesser, but consistent, amounts of hornblende and hypersthene and zones containing plagioclase feldspar; it also contains minor amounts of montmorillonite clay, especially below 1014 ft., and augite (see the integrated log montage, fourth track from the right – "ELAN Min. Dry Wt.%", Figure 4.4). Solely based on the integrated geophysical log interpretation, including the FMI electrical image, the formation is likely an interbedded sand-silt-clay-conglomerate clastic deposit, derived from volcanic source rock.

At 989 ft. P_e increases to 2.5 and stays nearly constant up to the bottom of casing (850.5 ft.), except for two small peaks at 858 ft. and 865 ft., where it reaches 2.9. The ELAN inferred mineralogy of the 989–850.5 ft. interval is similar to the interval below; the most notable differences are that there is uniformly more hypersthene and a considerably greater montmorillonite content, especially above 880 ft. Based on the integrated geophysical log interpretation, the formation across this interval is likely a continuation of the interbedded sand-silt-clay clastic deposit, with a notable increase in clay-rich beds.

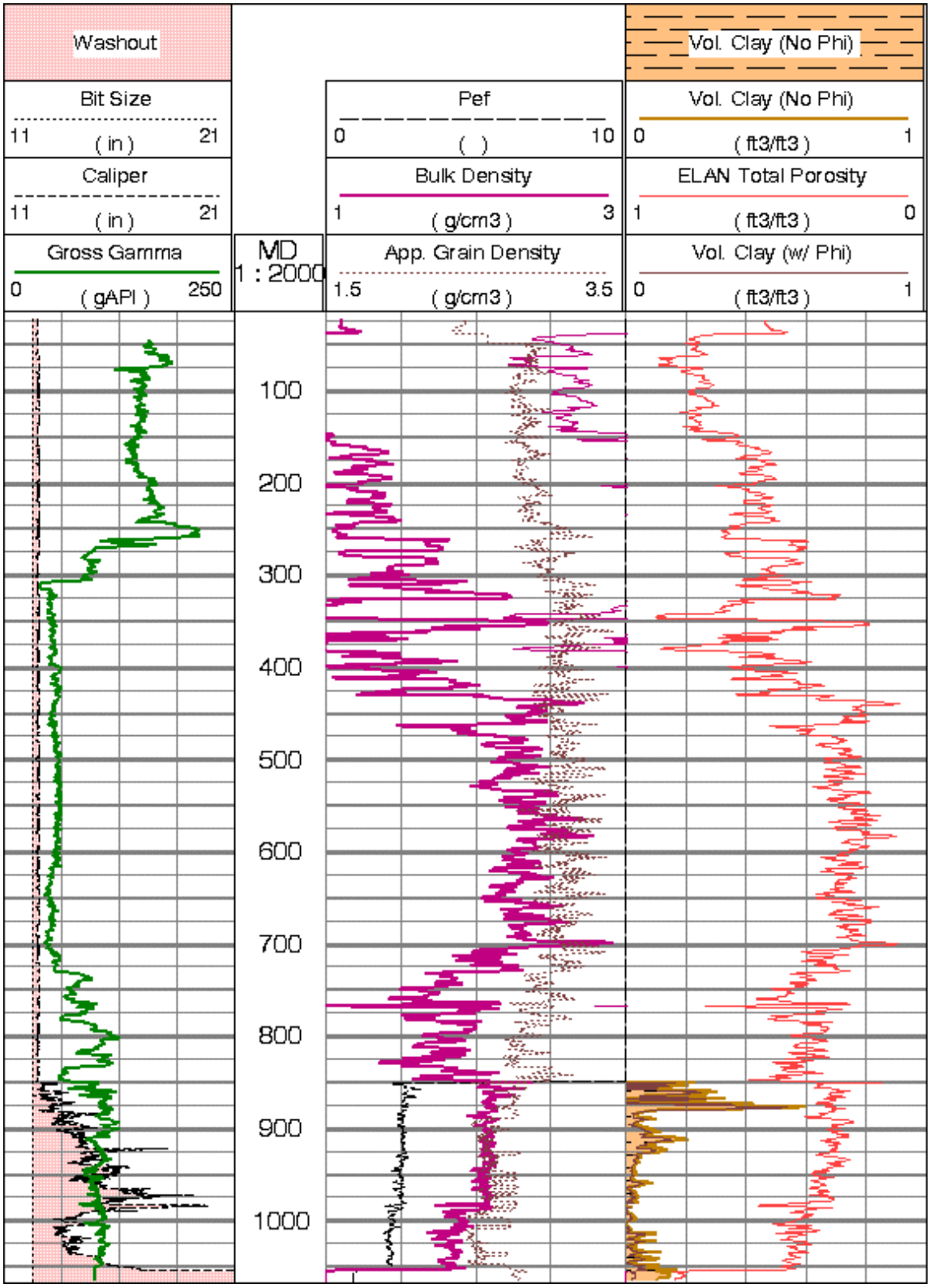

Figure 4.2: Summary bulk density, Pef, and volume clay logs in R-13 borehole from processed geophysical logs, interval 24–1070 ft. Also shown – caliper, gross gamma, apparent grain density, and total porosity logs.

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. Of the logging services run in R-13, the two that provide the most information about clay content is the HNGS spectral gamma ray, since thorium and potassium are often associated with clays, and AIT induction electrical resistivity, since clays typically have low resistivity. However, due to the complex geologic history of the Los Alamos area, including many periods of volcanic activity, the geologic section contains numerous minerals other than clays that produce similar spectral gamma (and gross gamma) responses. This fact greatly complicates the estimate of clay volume directly from gamma ray measurements. The AIT deep resistivity measurement is sensitive to clay since clay has a low bulk resistivity; but the measurement is also sensitive to pore water salinity and porosity. The P_e measurement from the TLD and elemental weight fraction measurements from the ECS provide additional information about bulk mineralogy, since they are sensitive to changes in the atomic number and concentration, respectively, of certain mineral-forming elements, but they don't provide any specific information about clay minerals. In addition, the CMR measures clay-bound water, which can be considered an indirect indicator of clay.

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), hornblende, augite, hypersthene, an analog representative of heavy mafic minerals (such as magnetite and olivine), pyrite, water, and air. Montmorillinite had to be dropped from the analysis in the cased hole section of the hole due to non-uniqueness in the ELAN model solution. This set of volume constituents was

chosen to provide a representative cross-section of possible major minerals in the R-13 geologic environment. The ELAN analysis results are provided as two composite logs provided with the LANL R-13 Well Completion Report – the first one showing the optimized mineral-fluid volume model with modeled versus measured log responses and the second showing the optimized model with additional model-derived fluid and matrix properties. The ELAN volume model result, as well as the dry weight% model result, is also shown as part of the integrated log montage, provided in Figure 4.4 in compressed form.

The volume of clay derived from these ELAN results, 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 log (farthest track to the right) in Figure 4.2. The analysis predicts minor amounts of clay (montmorillonite), and in some zones major amounts, through much of the open hole section. The ELAN inferred clay zones correlate well with zones of lower estimated hydraulic conductivity from the CMR and higher electrical conductivity beds in the FMI electrical conductivity image (see the integrated log montage).

Below 1053 ft. the clay volume fraction with porosity is minor, but the volume fraction without porosity reaches 15% due to erroneously high porosity adjacent to a large washout. In the interval 1053–1014 ft. the inferred clay volume fraction varies from zero to 10% (porosity free), with a number of peaks – probably corresponding to thin interbeds containing minor amounts of clay. Across 1014–928 ft. there is little to no clay inferred, with a small peak (maybe 2% volume fraction clay) at 960 ft. The interval 928–883 ft. contains clay almost throughout, with maximum clay volume fraction of about 5% with porosity (8% without porosity. The ELAN model predicts considerably higher, but variable, clay volumes across the interval 883–850.5 ft., including two thicker clay-rich zones at 873–883 ft. (maximum clay volume fraction 15% with porosity, 20% without porosity) and 858–868 ft. (maximum clay volume fraction 53% with porosity, 60% without porosity). Since clay was removed from the ELAN model in the cased section of R-13, no inferences can be made about the clay volume in the interval 24–850.5 ft. from the integrated geophysical log analysis.

4.4 Spectral Natural Gamma Ray

Natural gamma ray spectroscopy logs were acquired in R-13 for the purpose of:

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

The processed spectral gamma log results are shown as a summary log in Figures 4.3. On the summary log, gross gamma and gross gamma minus the uranium contribution are displayed in the first track (from left), useful radioisotope ratios are displayed in the third track, and the individual radioisotope concentrations – potassium (K), thorium (Th), and uranium (U) – are displayed in the fourth track.

The HNGS spectral gamma measurements are of very good quality throughout the log interval, perfectly acceptable for the purpose of quantitative interpretation. The raw field measurements were pre-processed to correct for borehole environmental conditions – mainly the change from uncased to cased water-filled hole at 850.5 ft. and from water- to air-filled casing at 835 ft. This pre-processing probably did not fully correct for the suppression of the response resulting from casing and surrounding annular material and the increase of the gamma ray response resulting from air instead of water in the borehole – as evidenced by a systematic drop/increase in the spectral gamma logs within the casing/air compared to directly below it. However, the unwanted shifts in the logs are relatively small and the two shifts appear to cancel each other out, leaving just the interval 835–8505.5 ft. where the absolute value of the processed spectral gamma logs are somewhat suspect.

The K and Th spectral components were used as valuable input to the ELAN analysis in R-13. If possible, it is not recommended to use U as an input to the ELAN model, because it can vary significantly for a particular mineral component due to independent processes (e.g. water flow, geochemical conditions). The R-13 ELAN analysis does not use the U measurement.

The most notable features of the R-13 spectral gamma ray logs are described below, from bottom to top of the well:

- 1053–1032 ft.: All spectral gamma logs are relatively constant, with K, Th, and U reading 2.5 wet weight%, 7–9 ppm, and 4–5 ppm, respectively.
- 1032–990 ft.: K jumps to 3.2% at 1032 ft., then decreases slowly to about 2.7% at 990 ft. Th slowly increases from 7.5 ppm to 9 ppm.
- 990–904 ft.: K drops sharply to 2% at 990 ft. and varies 1.7–2.9% through the remainder of the interval. Th increases slightly, ranging 6–13 ppm.
- 904–787 ft.: K increases to a maximum of 2.6%. Th increases to 9–15 ppm.
- 850–835 ft.: All spectral gamma logs systematically decrease across this interval as an artifact of the processing to correct for environmental conditions. This decrease is considered an environmental effect and not a formation change.
- 787–778 ft.: All the spectral gamma logs decrease, with K decreasing to 1%.
- 778–770 ft.: K and Th increase to a peak of 2.2% and 12 ppm, respectively, at 779 ft.
- 770–764 ft.: K and Th decrease to a trough of 1.6% and 9 ppm, respectively, at 764 ft.
- 764–735 ft.: K and Th increase to a peak of 2.3% and 12 ppm, respectively, at 735 ft.
- 735–730 ft.: K and Th decrease steadily to 1% and 6 ppm, respectively, at 730 ft.
- 730–310 ft.: K and Th remain fairly constant in the range 1–1.3% and 6–9 ppm, respectively. Gross gamma is also consistent, except for a slight rise at 625 ft. followed by gentle, steady decrease to 317 ft., then a quick small drop to a low in the interval 310–317 ft.
- 310–272 ft.: All spectral gamma logs increase rapidly from 310–306 ft.
- 272–264 ft.: All spectral gamma logs peak sharply at 268 ft., with Th and U increasing the most, before decreasing.
- 264–250 ft.: All spectral gamma logs increase significantly, with K and Th increase significantly to 2.7% and 30 ppm, respectively.
- 250–210 ft.: K remains relatively constant and Th decreases slightly from bottom to top.
- 210–194 ft.: There is a 3% K peak at 208 ft.
- 194–47 ft.: K rises to 2.5–3.5%. U drops sharply at 194 ft., but varies significantly throughout the interval.

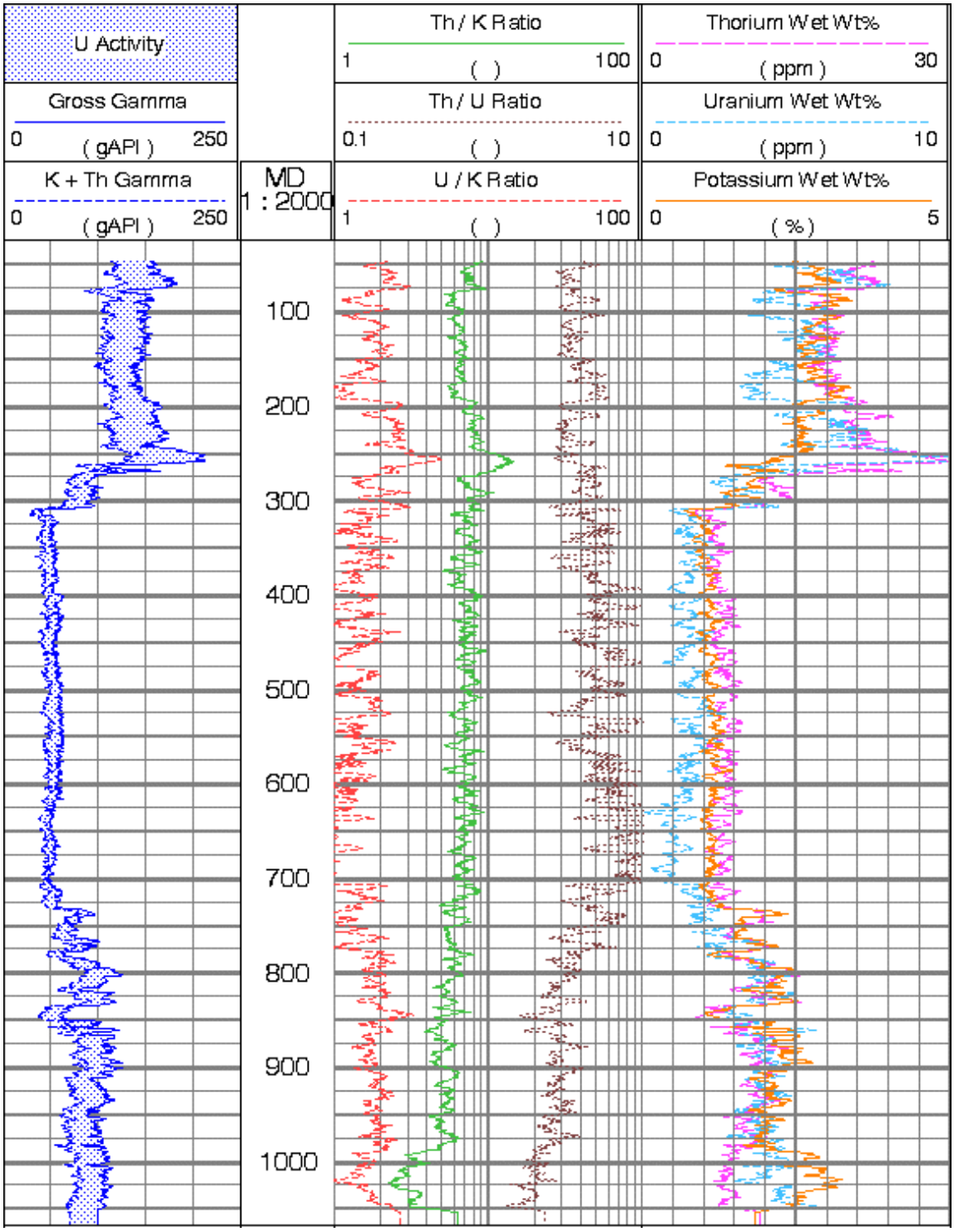

Figure 4.3: Summary spectral natural gamma ray logs from R-13 borehole, interval 47–1664 ft.

4.5 Integrated Log Montage

This section describes the integrated geophysical log montages for R-13: (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 shown compressed in Figure 4.4 and provided in expanded format accompanying the LANL R-13 Well completion Report. 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. The description applies to the montages for both wells, which have the exact same format. 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-13 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 AIT logging run. All the geophysical logs are depth-matched to the AIT gross gamma measurement.

Track 2 – Basic Logs

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

- gamma ray (thick black), recorded in API units and displayed on a scale of 0 to 250 API units;
- two calipers from the FMI (thin dotted and dashed pink) and one from the LDTD (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 10 to 25 in.;
- spontaneous potential or SP (dashed red – valid only below the borehole water level), recorded in millivolts and displayed on a relative scale of 100 to 200 millivolts; and
- bulk chlorinity (dashed green with green shading), recorded in parts per thousand (ppk) and displayed on a scale of 25 to 0 ppk (left to right).

Two gamma ray curves from the HNGS are presented:

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

The difference between the two curves is filled with yellow shading to represent the uranium contribution.

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

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. The calipers show a significant amount of washout (850.5 ft.), with a number of pronounced washouts in the interval 850.5–1006 ft. and a particularly large washout at the bottom of the hole. The washouts and hole rugosity do affect measurement quality, especially the porosity tools.

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.

<u>Track 3 – Resistivity</u>

The third track displays the resistivity measurements from the AITH, spanning the entire open hole section, and the MCFL, valid in the water-filled open hole section. All the resistivity logs are recorded in units of ohmmeters and displayed on a logarithmic scale of 2 to 2,000 ohm-m. The AIT is the primary depth reference for the well; thus the resistivity logs have not been depth matched to any other log.

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 between 10 and 2000 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 – as suggested by the ELAN integrated log analysis results (see Tracks 20 and 21). 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. The shallow resistivity reads higher than the deep resistivity through most of the logged section (blue shading), suggesting the drilling fluid is fresher than the formation water.

<u>Track 4 – Porosity</u>

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 0.5 (left side) to negative 0.1 (right side). Specifically these logs consist of:

- CNTG water-filled epithermal neutron porosity (solid blue curve) – a merged log of thermal neutron porosity processed for water-filled borehole and epithermal neutron porosity processed for air-filled hole (the latter measured well up into the casing);
- CMR total water-filled porosity (dashed black);
- CMR effective water-filled porosity (dashed green);

- CMR bound water porosity (light blue area shading) – representing by the area between the CMR total and effective water-filled porosities;
- Geochemical estimated water-filled porosity derived from the ECS hydrogen weight % measurement (dotted purple);
- 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 plus air-filled porosity (dashed-dotted cyan) – derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

The CNTG logs are environmentally corrected for borehole conditions – particularly casing and borehole fluid (water or air) – as is the bulk density in casing (used for density porosity); the CMR logs do not require additional environmental corrections and the ELAN results are based on fully corrected logs. All the porosity logs are depth matched to the AITH logging run using the gross gamma ray measurement obtained in every logging run.

Track 5 – Density and P_e

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; and
- ECS estimated bulk density (dotted green) on a scale of 1 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). All these logs have been depth matched to the AITH logging run.

Track 6 – HNGS Spectral Gamma

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

- potassium (solid green curve) in units of percent and on a scale of –10 to 10 percent;
- thorium (dashed brown) in units of parts per million (ppm) and on a scale of 50 to –50 ppm; and
- uranium (dotted blue) in units of parts per million (ppm) and on a scale of 40 to 0 ppm.

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

Track 7 – CMR Porosity

Track 7 displays various CMR water-filled porosities along with measurement quality flags. The porosity and measurement quality logs are presented on a scale of 0.5 to zero volume fraction and discrete blocks originating from the left side, respectively. Specifically, the CMR logs shown in this track are:

- Total water-filled porosity (solid black curve) – representing the total water volume fraction measured by the CMR;
- Three millisecond (ms) porosity (short-dashed brown) – representing the water volume fraction corresponding to the portion of the CMR measured T2 distribution that is above 3 ms, a cutoff that is considered to be representative of the break between clay-bound water (less than 3 ms) and all other types of water (greater than 3 ms);
- Effective water-filled, or free fluid, porosity (solid pink) – representing the water volume fraction that is moveable (can flow), based on a 33 ms T2 distribution cutoff that is considered representative of the break between bound water (less than 33 ms) and moveable water (greater than 33 ms) in typical sand-shale clastic rocks;
- Clay-bound water (brown area shading between total and 3 ms porosity logs) – representing the water volume fraction that is bound within clays;
- Capillary-bound water (pink area shading between 3 ms and effective porosity logs) – representing the water volume fraction that is bound within matrix pores by capillary forces;

- CMR wait-time flag (red area shading) – activates when there is significant measurement response at late T2 times, corresponding to large amounts of completely free ("bathtub") water and often associated with washouts or very large pores;
- CMR measurement noise flag (yellow and orange area shading) – activates when there is potentially detrimental amounts of measurement noise detected by the tool, at moderate (yellow) and high (orange) levels.

All these CMR logs have been reprocessed from the field measurements to ensure proper and consistent processing algorithms are applied, to try to improve the signal-to-noise ratio of the measurement, and to generate additional useful outputs unavailable from the field. The reprocessed logs are depth matched to the AITH tool run using gross gamma.

The CMR logs exhibit significant variability throughout the measured interval, indicating significant hydrogeologic heterogeneity (variability in pore-size distribution). Overall, the CMR logs are of good quality, although they are adversely affected by a several severe borehole washouts – resulting in excessively high free fluid and total porosity.

Track 8 –Pore Size Distribution

Track 8 displays the water-filled pore size distribution as determined by the CMR – shown as binned water-filled porosities. The binned porosity logs are presented on a scale of 0.5 to zero volume fraction with colored area shading corresponding to the different bins:

- Clay-bound water – brown area shading;
- Micro pore and small pore water (the sum comprising capillary-bound water) – gray and blue area shading, respectively;
- Medium pore, large pore, and late decay (the sum comprising effective water-filled porosity) – yellow, red, and green area shading, respectively.

In addition, an estimate of clay hydroxyl hydrogen volume fraction is plotted in the water-filled bottom section of the borehole (diagonal hatched purple area shading) – defined by the difference between the CNTG neutron porosity and the CMR total water-filled porosity.

Track 9 – CMR T2 Distribution (Waveforms)

The CMR T2 distribution is displayed in Track 9 as green waveform traces at discrete depths. The horizontal axis, corresponding to relaxation time in milliseconds, is on a logarithmic scale from 0.3 to 3000 ms. Also plotted are the:

- T2 logarithmic mean (solid blue curve) and
- T2 cutoff time used for differentiating between bound and free water (solid red line) – a constant 33 ms in this case.

Track 10 – CMR T2 Distribution (Heated Amplitude)

Track 10 displays the T2 distribution in another way – on a heated color scale where progressively "hotter" color (green to yellow to red) corresponds to increasing T2 amplitude. The remaining aspects of the display are the same as in Track 9, except that the T2 logarithmic mean is shown as a solid white curve and the T2 cutoff is not displayed.

Track 11 – CMR Hydraulic Conductivity

Track 11 displays several estimates of hydraulic conductivity (K) from the CMR measurements, as well as one derived from the ELAN analysis, presented on a logarithmic scale of 10^{-3} to 10^{7} centimeters per second (cm/s) multiplied by 10^{6}:

- A K versus depth estimate derived from using the SDR permeability equation, converted to hydraulic conductivity (dashed purple curve);
- A K versus depth estimate derived from using the Timur-Coates permeability equation applied to a tapered T2 cutoff, converted to hydraulic conductivity (solid blue curve); and
- An intrinsic K versus depth estimate (assuming full saturation) derived from the ELAN analysis, converted to hydraulic conductivity (dotted pink).

The hydraulic conductivity values have been multiplied by 10^{6} to reduce the number of significant figures, since in units of 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 Timur-Coates equation 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 12 – FMI Image (Dynamic Normalization)

Track 12 displays the FMI image, valid in the water-filled section of the well (1195–1660 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) and electrically conductive fractures (thick purple sinusoids).

Track 13 – FMI Bedding and Fractures

Track 13 displays the interpreted bed boundaries and fractures picked from the FMI image, shown in two ways:

- Individually as blue (bed boundary) and red (conductive fracture) 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 14 – FMI Image (Static Normalization)

Track 14 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 is only useable in the water-filled section of the well (1195–1660 ft.).

Tracks 15-19 – Geochemical Elemental Measurements

The narrow tracks 15 to 19 present the geochemical measurements iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), potassium (K) and 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 and K in wet weight fraction, CL in ppk). All these measurements were obtained from the ECS except K, which is from the HNGS. All these measurements have been environmentally corrected for casing and borehole fluid, and are depth matched to the AITH.

Track 20 – ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 20 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 21 – ELAN Mineralogy-Pore Space Model Results (Wet Volume Fraction)

Track 21 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 (dark army green)
- Air (red)
- Moveable water (white)
- Capillary-bound water (light blue).

<u>Track 22 – Summary Logs</u>

Track 22, 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 moveable water from the ELAN analysis (solid green curve and green area shading);
- Optimized estimate of total volume fraction bound water from the ELAN analysis (solid dark blue curve and area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (solid red curve and dotted red area shading);
- Optimized estimate of water saturation (percentage of pore space filled with water) from the ELAN analysis (dashed-dotted purple curve);
- Water saturation as calculated directly from the bulk density and 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;

- Potential for water flow indicator from the CMR log (block green cross-hatched shading coming from the right-hand side of the track).

The water and porosity curves scale from 0 to 0.5 volume fraction, left to right; the water saturation scales from 0 to 1, from left to right. The flow indicator is a discrete-valued flag with a series of different levels, peaking halfway through the first division from the right on the x-axis.

Track 23 – 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 HNGS logging run.

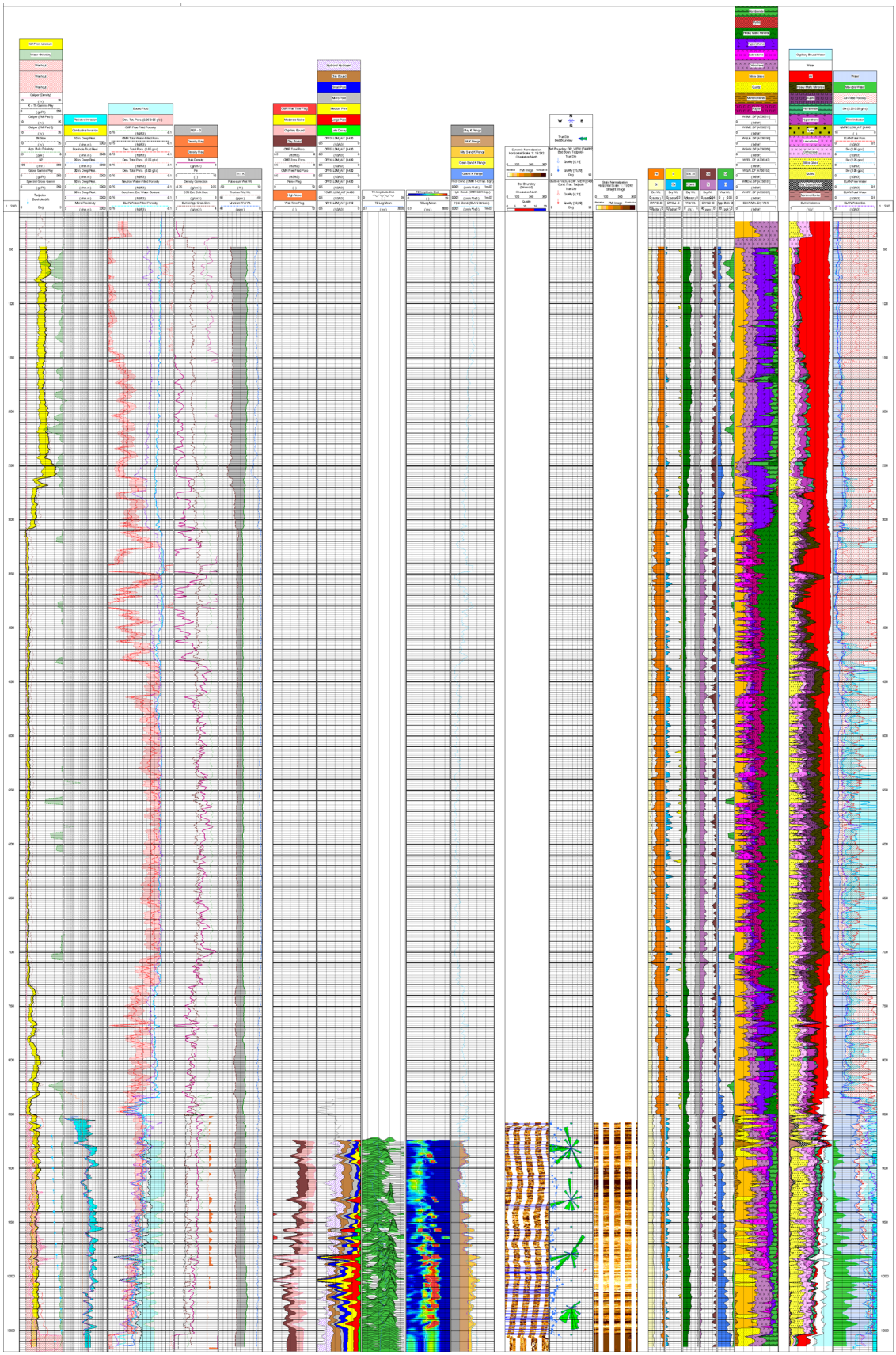

Figure 4.4: Geophysical log montage showing a compressed composite of all processed logs, including ELAN models, from borehole R-13.

5. REFERENCES

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Schlumberger

ELAN*
Integrated Log Analysis
Model Results

COMPANY: Washington Group / LANL

WELL: R-13

FIELD: Los Alamos Characterization and Monitoring Wells

New Mexico

COUNTRY: U.S.

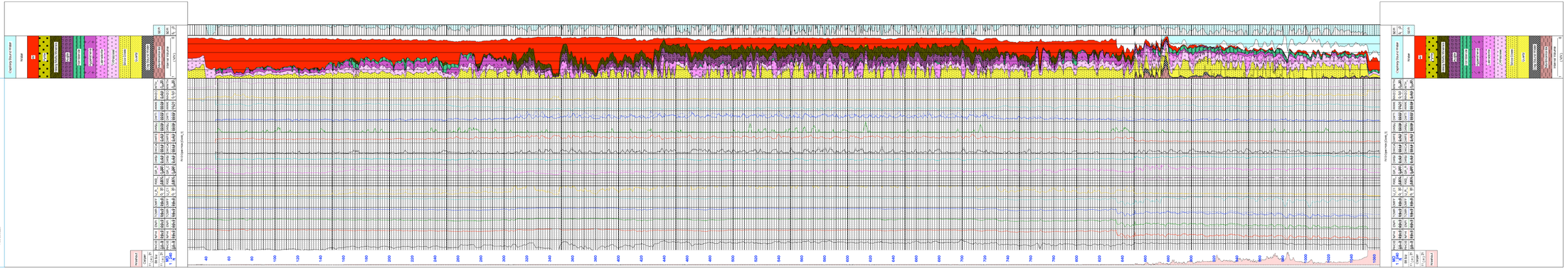
*Mark of Schlumberger

Date Processed:	24-Jun-2002	Date Logged:	24-Sep-2001
Job Number:		Processed at:	SKS Sacramento
Well Location:			
Latitude:		Longitude:	
Elevations:	KB: 6954ft	DF: 6954ft	GL: 6930ft

No water saturation or porosity constraints

FILE HERE

The well data, interpretations and other information derived from interpreting the customer's well data are based on methods and assumptions that are in accordance with generally accepted practices in the oil and gas industry. Schlumberger, however, makes no representation or warranty, express or implied, as to the accuracy, completeness, or fitness for any purpose of such data, interpretations, or other information derived from interpreting the customer's well data, and Schlumberger shall not be liable for any damages or losses incurred by the customer or any other party in connection with the use of such data, interpretations, or other information derived from interpreting the customer's well data.


Cladding Blend Volume
Water
Clay
Tuff
Tuff Lithic
Tuff Vitric
Tuff Zeolite
Tuff Zeolite Vitric
Tuff Zeolite Lithic
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Tuff Clay
Tuff Clay Lithic
Tuff Clay Vitric
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Tuff Zeolite Vitric Clay
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Tuff Vitric Lithic Clay
Tuff Zeolite Vitric Lithic Clay
Tuff Zeolite Vitric Lithic Clay Water
Volume of Mixture
Ft-3/Cubic-Ft
Ft-3/Cubic-Ft
Interpreted Depth
Depth
Ft
Depth
Ft
Depth
Ft

GEOFRAME PROCESSED INTERPRETATION

Integrated Log Well Montage

w/ Modeled Mineralogy / Water Saturation

Using the following logs: AIT*, TLD*, CNTG* ECS*, HNGS* CMR*, FMI*

*= Mark of Schlumberger

COMPANY:	Washington Group	Elevations:	KB:
WELL:	R-13 Open Hole	API Number:	Unavailable
FIELD:	LOS ALAMOS CHARACTERIZATION AND MONITORING WELL		DF:
COUNTY:		Job Number:	GL:
STATE:			
COUNTRY:			
Date Logged:	24-Sep-2001	Date Processed:	10-Oct-2001
Well Location:			

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

All interpretations are opinions based on inferences from electrical or other measurements and we cannot, and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, costs, damages or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to Clause 4. of our General Terms and Conditions as set out in our current Price Schedule.

Field Recording:	Location:	Farmington	Software Version:	9C2-303	Engineer: John Byars
Office Recording:	ICS Center:	MVS Denver	Baseline:		Log Analyst: Ned Clayton

Mud and Borehole Measurements:

Rm @ Measured temperature:	@	BHT: 111.0 degF	Bitsize: 12.2 in
Rmf @ Measured temperature:	@	Type Fluid in Hole	AIR
Rmc @ Measured temperature:	@	Mud Density: 9.25 lbm/gal	

Remarks:

Log tied into TLD run Sept. 24, 2001
Logging intervals as per Client Request
Log run on 2.65 g/cc Sandstone Matrix.