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Date: JUL 13 2010
Refer To: EP2010-0271

James Bearzi, Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

Subject: Submittal of the Completion Report for Regional Aquifer Well R-50

Dear Mr. Bearzi:

Enclosed please find two hard copies with electronic files of the Completion Report for Regional Aquifer Well R-50.

If you have any questions, please contact Ted Ball at (505) 665-3996 (tedball@lanl.gov) or Tom Whitacre at (505) 665-5042 (twhitacre@doeal.gov).

Sincerely,

Bruce Schappell, Executive Director
Environmental Programs – Recovery Act Projects
Los Alamos National Laboratory

Sincerely,

Everett Trollinger, Federal Project Director
Environmental Projects – ARRA
Los Alamos Site Office

33796

BS/ET/TB/ME:sm

Enclosures: Two hard copies with electronic files – Completion Report for Regional Aquifer Well R-501 (LA-UR-10-3955)

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LA-UR-10-3955
July 2010
EP2010-0271

Completion Report for Regional Aquifer Well R-50

Los Alamos
NATIONAL LABORATORY
EST. 1943

Prepared by the Environmental Programs Directorate

LA-UR-10-3955
EP2010-0271

Completion Report for Regional Aquifer Well R-50

July 2010

Responsible project manager:

Printed Name	Signature	Title	Organization	Date
Ted Ball		Project Manager	Environmental Programs	7/13/10

Responsible LANS representative:

Printed Name	Signature	Title	Organization	Date
Bruce Schappell		Executive Director	Environmental Programs	7-13-10

Responsible DOE representative:

Printed Name	Signature	Title	Organization	Date
Everett Trollinger		Federal Project Director	DOE-LASO	7-13-10

EXECUTIVE SUMMARY

This well completion report describes borehole drilling, well installation, well development, aquifer testing, and dedicated sampling-system installation for regional aquifer well R-50, located south of Mortandad Canyon, Technical Area 05, at Los Alamos National Laboratory in Los Alamos County, New Mexico. This report was written in accordance with the requirements in Section IV.A.3.e.iv of the Compliance Order on Consent. The well was installed at the direction of the New Mexico Environment Department (NMED) to monitor groundwater quality and contaminant movement and to define the southern extent of chromium contamination in the vicinity of monitoring wells R-28 and R-42.

The R-50 monitoring well borehole was drilled using dual-rotary air-drilling methods. Drilling fluid additives included potable water and foam. Foam-assisted drilling was used only in the vadose zone and ceased approximately 100 ft above the regional aquifer; only small amounts of potable water were added to the air within the regional aquifer. Additive-free drilling provides minimal impacts to the aquifer and formation. Borehole drilling during the R-50 project was troublesome; the original borehole had to be abandoned because of a broken drill bit at 946 ft below ground surface (bgs). The second R-50 borehole was successfully completed to total depth using casing-advance and open-hole drilling methods.

A retractable 18-in. casing was advanced using dual-rotary methods partially into the Bandelier Tuff to a depth of 190 ft bgs. A 16-in. retractable casing was advanced using dual-rotary methods through the remaining Bandelier Tuff, the Cerro Toledo interval, Otowi Member of the Bandelier Tuff, and Guaje Pumice Bed to 555.1 ft bgs. A 15-in. open borehole was advanced with fluid-assisted air-rotary methods and a downhole hammer bit through the Cerros del Rio volcanic rocks and into the Puye Formation sediments to a depth of 895 ft bgs. Twelve-inch casing was then advanced with a tricone bit to a total depth of 1224.5 ft bgs in Miocene pumiceous sediments.

Well R-50 was completed as a dual-screen well to evaluate water quality and to measure water levels at two discrete depth intervals within the regional aquifer. The upper 10-ft-long screened interval is set with the top of the screen at 1077 ft bgs within the Puye Formation, and the lower 20-ft-long screened interval is set with the top of the screen at 1185 ft bgs within Miocene pumiceous sediments. The composite depth to water after well installation and well development was 1066.8 ft bgs. The well screens are separated by a packer as part of the permanent sampling system to ensure isolation of each groundwater-bearing zone.

The well was completed in accordance with an NMED-approved well design and was thoroughly developed; groundwater at both screened intervals met target water-quality parameters. Hydrogeologic testing indicated that both screened intervals in monitoring well R-50 are productive and will perform effectively to meet the planned objectives. Water-level transducers will be placed in both well screens in the R-50 monitoring well, and groundwater sampling will be performed as part of the facility-wide groundwater-monitoring program.

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Acronyms and Abbreviations

APS	Accelerator Porosity Sonde (Schlumberger geophysical logging tool)
amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
Consent Order	Compliance Order on Consent
DO	dissolved oxygen
ECS	Elemental Capture Spectroscopy Sonde (Schlumberger geophysical logging tool)
EES-14	Earth and Environmental Sciences Group 14
Eh	oxidation-reduction potential
EP	Environmental Programs Directorate
EPA	Environmental Protection Agency (U.S.)
F	filtered
FD	field duplicate
FTB	field trip blank
gpm	gallons per minute
HNGS	Hostile Environment Natural Gamma Sonde (Schlumberger geophysical logging tool)
hp	horsepower
I.D.	inside diameter
LANL	Los Alamos National Laboratory
mV	millivolt
NAD	North American Datum
NMED	New Mexico Environment Department
NMSW	New Mexico Special Waste
NTU	nephelometric turbidity unit
O.D.	outside diameter
ORP	oxidation-reduction potential
PVC	polyvinyl chloride
Qbo	Otowi Member of the Bandelier Tuff
Qbog	Guaje Pumice Bed of Otowi Member of the Bandelier Tuff
Qbt	Tshirege Member of the Bandelier Tuff
Qct	Cerro Toledo interval
RPF	Records Processing Facility
SOP	standard operating procedure

TA	technical area
Tb4	Cerros del Rio volcanic rocks
TD	total depth
TLD	Triple Detector Lithodensity (Schlumberger geophysical logging tool)
TOC	total organic carbon
Tpf	Puye Formation
Tsfu	Miocene pumiceous sediments
UF	unfiltered
VOC	volatile organic compound
WCSF	waste characterization strategy form
WES-EDA	Waste and Environmental Services Division–Environmental Data and Analysis

1.0 INTRODUCTION

This completion report summarizes borehole drilling, geophysical logging, well construction, well development, aquifer testing, and dedicated sampling system installation for regional aquifer groundwater monitoring well R-50. The report is written in accordance with the requirements in Section IV.A.3.e.iv of the Compliance Order on Consent (the Consent Order). The first R-50 borehole was abandoned because of a broken drill bit at 946 ft below ground surface (bgs). The second successful R-50 monitoring well borehole was drilled from December 5, 2009, to January 25, 2010, and the well was completed from February 1 to 13, 2010, at Los Alamos National Laboratory (LANL or the Laboratory) for the Environmental Programs (EP) Directorate.

The R-50 project site is located on the mesa top to the south of Mortandad Canyon within Laboratory Technical Area 05 (TA-05) (Figure 1.0-1). The purpose of the R-50 well is to investigate the southern extent of chromium contamination detected in regional aquifer wells R-42 and R-28 (Figure 1.0-1). Additionally, the well will be used to test for hydrologic communication between R-50, R-42, R-28, R-44, R-45, and R-13.

The primary objective of the drilling activities at R-50 was to drill and install a dual-screen regional aquifer monitoring well. Water-level transducers in the upper and lower screened intervals will be used to evaluate hydraulic connections between this monitoring well, other monitoring wells, and nearby water-supply well PM-5. Secondary objectives were to collect drill-cutting samples, conduct borehole geophysical logging, and investigate potential perched groundwater zones.

The R-50 borehole was drilled to a total depth (TD) of 1224.5 ft bgs. During drilling, cuttings samples were collected at 5-ft intervals in the borehole from ground surface to TD. A monitoring well with two screens was installed. The upper 10-ft screen interval is set between 1077 and 1087 ft bgs, and the lower 20-ft-long screen interval is set between 1185 and 1205.6 ft bgs. The composite depth to water after well installation was 1066.8 ft bgs on February 17, 2010.

Postinstallation activities included well development, aquifer testing, surface completion, geodetic surveying, and dedicated sampling-system installation. Future activities will include site restoration and waste management.

The information presented in this report was compiled from field reports, logbooks, and daily activity summaries. Records, including field reports, field logs, and survey information, are on file at the Laboratory's Records Processing Facility (RPF). This report contains brief descriptions of activities and supporting figures, tables, and appendices completed to date associated with the R-50 project. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to NMED in accordance with U.S. Department of Energy policy.

2.0 PRELIMINARY ACTIVITIES

Preliminary activities included preparing administrative planning documents and preparing the drill site and drill pad. All preparatory activities were completed in accordance with Laboratory policies and procedures and regulatory requirements.

2.1 Administrative Preparation

The following documents helped guide the implementation of the scope of work for the R-50 project:

- "Drilling Work Plan for Regional Aquifer Well R-50" (LANL 2009, 107461)
- "Drilling Plan for Regional Aquifer Well R-50" (TerranearPMC 2009, 108564)
- "Integrated Work Document for Regional and Intermediate Aquifer Well Drilling (Mobilization, Site Preparation and Setup Stages)" (LANL 2007, 100972)
- Storm Water Pollution Prevention Plan Addendum (LANL 2006, 092600)
- "Waste Characterization Strategy Form for Regional Well for Chromium Investigation, R-50 (Mortandad Canyon), Regional Groundwater Well Installation and Corehole Drilling" (LANL 2009, 107445)

2.2 Site Preparation

The drill pad was prepared by Laboratory personnel several weeks before mobilizing the drill rig, air compressors, trailers, and support vehicles to the drill site on October 28 through 30, 2009. Additionally, alternative drilling tools and construction materials were staged at the Pajarito Road lay-down yard.

Potable water was obtained from a fire hydrant on Puye Road. Safety barriers and signs were installed around the borehole cuttings containment pit and along the perimeter of the work area.

3.0 DRILLING ACTIVITIES

This section describes the drilling strategy and approach and provides a chronological summary of field activities conducted at monitoring well R-50.

3.1 Drilling Approach

The drilling method and selection of equipment and drill-casing sizes for the R-50 monitoring well were designed to retain the ability to investigate and case-off potential perched groundwater zones above the regional aquifer, although perched water was not anticipated at this mesa-top site between relatively dry canyons. The approach also ensured that a sufficiently sized drill casing was used to meet the required 2-in. minimum annular thickness of the filter pack around a 5.56-in.-outside diameter (O.D.) well.

Dual-rotary air-drilling methods using a Foremost DR-24HD drill rig were employed to drill the R-50 borehole. Dual-rotary drilling has the advantage of simultaneously advancing and casing the borehole. The Foremost DR-24HD drill rig was equipped with conventional drilling rods, tricone bits, downhole hammer bits, a deck-mounted air compressor, and general drilling equipment. Auxiliary equipment included two Sullair trailer-mounted air compressors. Three sizes of A53 grade B flush-welded mild carbon-steel casing (18-in., 16-in., and 12-in.-inside diameter [I.D.]) were used for the R-50 project.

The dual-rotary technique at R-50 used filtered compressed air and fluid-assisted air to evacuate cuttings from the borehole during drilling. Drilling fluids, other than air, used in the borehole (all within the vadose zone) included potable water and a mixture of potable water with Baroid AQF-2 foaming agent. The fluids were used to cool the bit and help lift cuttings from the borehole. Use of foaming agents was terminated at 960 ft bgs, roughly 100 ft above the predicted top of the regional aquifer. No additives other than

potable water were used for drilling below this depth (960 ft bgs). Total amounts of drilling fluids introduced into the borehole are presented in Table 3.1-1.

3.2 Chronological Drilling Activities for the R-50 Well

Mobilization of drilling equipment and supplies to the R-50 drill site occurred from October 28 to October 30, 2009. Decontamination of the equipment and tooling was performed before mobilization to the site. On October 31, following on-site equipment inspections, the first R-50 monitoring well borehole was initiated at 1320 h using dual-rotary methods with 18-in. drill casing and a 17-in. (17.25-in.) tricone roller bit.

Drilling Activities at Original Borehole

Drilling and advancing 18-in. casing proceeded rapidly through alluvium and the upper portion of the Tshirege Member of the Bandelier Tuff. Drilling continued to 187.5 ft bgs where the 18-in. drill casing was landed on November 2, 2009. No indications of groundwater were observed while advancing the 18-in. casing.

On November 3, a string of 16-in. drill casing was started into the borehole. Drilling using dual-rotary methods with the 16-in. casing string and a 15-in. hammer bit started on November 4 at 187.5 ft bgs. Drilling progressed through the remaining portion of the Tshirege Member of the Bandelier Tuff, the Otowi Member ash flows, Guaje Pumice Bed, and the top of the Cerros del Rio volcanic rocks. The 16-in. casing was advanced a few feet into the Cerros del Rio volcanic rocks and was landed at a depth of 559.8 ft bgs on November 6. No indications of groundwater were observed while advancing the 16-in. casing.

Open-hole drilling with a 15-in. hammer bit commenced late in the day of November 6 (1110 h). Drilling progressed smoothly to a depth of 659.5 ft bgs on November 7, at which time the hammer bit ceased firing and erratic performance was noted. The tool string was removed from the borehole, and the bottom bit assembly of the hammer was observed to be absent. The bit was broken at the bit shank. Two video logs and several trips with various overshot alignment and fishing tools were required to fish the broken bit out of the borehole. The broken bit was recovered on the night shift of November 8.

Open-hole drilling resumed with a new hammer bit on November 9 to a depth of 687 ft bgs, just below where a scoria/rubble deposit was encountered. Loose rubble falling into the borehole from above continually trapped the tool string and necessitated cementing the rubble zone in an effort to regain stability. On November 10, 665 gal. of sand grout (Portland cement with a minor amount of silica sand) was installed in the bottom of the borehole at 687 ft bgs. Three more batches of sand grout were installed in the borehole on November 11 (485 gal.), early on November 12 (531 gal.), and late on November 12 (606 gal.) because of cement losses to the formation. Drilling out the cement with a 15-in. (14.75-in.) tricone roller bit and redirecting the cement discharge into rolloff bins took place on November 13. The tricone bit was removed from the tool string and replaced with a 15-in. hammer bit to address slow penetration at a depth of 680 ft bgs.

Drilling progressed smoothly to a depth of 946 ft bgs on November 14, at which time the hammer bit again ceased firing. The tool string was removed from the borehole and the bit assembly of the hammer was observed to be absent with the bit shank again at fault. Between November 14 and December 3, multiple video runs and fishing efforts were conducted 24-h a day without success. Fishing efforts were seriously hampered by the fact that no clear video images of the missing tool were observed. The tool remained obscured by sediments despite repeated efforts to circulate air and clean it off. Without knowing

the tool's true orientation in the bottom of the hole and having reached a calculated point of diminishing returns, the decision was made on December 3 to abandon the first hole and re-drill a new hole.

Drilling Activities at R-50 Borehole

The second R-50 borehole was located approximately 50 ft northwest of the first borehole and was initiated on December 5. The drilling approach for the second borehole was identical to the first borehole. Between December 5 and December 14, a string of 18-in. casing was advanced to 190.7 ft bgs. Between December 14 and December 18, a string of 16-in. casing was advanced to 475 ft bgs when operations were suspended for the Laboratory holiday closure. After the holiday break, on January 4, 2010, the 16-in. (16.75-in.) casing string was advanced using a 15-in. tricone bit and landed at 555.1 ft bgs, 10 ft into the top of the Cerros del Rio volcanic rocks.

The tricone bit was removed from the borehole on January 6, 2010, to prepare for open-hole drilling in the volcanic rocks with a 15-in. hammer bit. Upon removal from the hole, the tricone bit was observed to have an unusual wear pattern and was missing several carbide buttons. A video log was run in the borehole on January 6, and the 16-in. casing was observed to be missing the drive shoe. Two fishing runs were conducted on January 7 using a high-strength fishing magnet below a junk basket, and only a small quantity of steel shavings was recovered from the bottom of the borehole. Open-hole drilling resumed on January 8 with the 15-in. hammer bit, but progress was abnormally slow. The hammer bit was removed from the hole, and a physical measurement of the drilled depth was made and recorded as 570 ft bgs. While the measurement was being made, a 2-ft stainless-steel weight detached from the tagline and was left in the bottom of the hole. Fishing for the stainless-steel weight occurred on January 9 and 10 without success.

Late in the shift on January 10, the decision was made to place cement in the bottom of the hole and drill through the cement, the stainless-steel weight, and whatever was left of the 16-in. casing shoe with a milling tool. Approximately 40 gal. of neat Portland cement was emplaced at the bottom of the hole at 570 ft bgs on January 10. A brief test of the cement in the borehole with the milling tool on January 11 indicated the cement had not cured sufficiently. The milling tool was advanced through the cement and 3 ft into massive basalt to 573.1 ft bgs on January 12. Stainless-steel shavings were observed in the discharge, and the milling tool was removed from the hole, but the field crew was not optimistic that the entire piece of stainless-steel tagline weight had been cleared from the borehole.

Since the milling tool was smaller (13.62 in.) than the borehole (15.88 in.), a 15-in. reaming bit and a 15-in. tricone bit were used in the borehole on January 13 and 14 to ream the hole closer to the gauge of the hammer bit (15.88 in.) and to potentially mill any pieces of the stainless-steel tagline weight that may have remained. The milling and reaming operations, in conjunction with encountering hard, massive volcanic rocks, were successful at removing most of the stainless steel from the borehole. While a substantial amount of metal was observed in the discharge, the fishing magnet was also run in the borehole twice and recovered various pieces of carbon steel from the missing 16-in. casing shoe on both trips. Ultimately, it is believed that the metal in the borehole and the lost 16-in. casing shoe resulted from advancing the 16-in. casing too far into the top of the (weathered) Cerros del Rio volcanic rocks.

Open-hole drilling with the 15-in. hammer bit resumed on January 15 at 573 ft bgs, and unstable borehole conditions were encountered almost immediately. The borehole was advanced to 601 ft bgs into a scoria/rubble interval. Approximately 400 gal. of neat Portland cement was placed in the borehole on January 16. Drilling out the cement with a 15-in. tricone roller bit and redirecting the cement discharge into rolloff bins took place on January 17. The tricone bit was removed from the tool string and replaced with a 15-in. hammer bit to remedy the slow penetration encountered at a depth of 615 ft bgs. Drilling conditions between 601 and 615 ft bgs were also observed to be unstable, with poor circulation and few

returns at the surface. Another cementing operation was undertaken and approximately 400 gal. of neat Portland cement was placed in the borehole at 615 ft bgs on January 17. The 15-in. hammer bit was used to redrill the cemented interval and advance the borehole to 675 ft bgs on January 18. On January 19 and 20 the borehole was advanced through the Cerros del Rio volcanic rocks to 895 ft bgs without any further stability issues. The bottom of the Cerros del Rio volcanic rocks was encountered at 892 ft bgs, and the decision was made to discontinue open-hole drilling methods. The 15-in. hammer bit was removed from the hole. The 16-in. casing was cut at 538.1 ft bgs, approximately 17 ft above the bottom of the casing string on January 20.

A welded string of 12-in. (12.75-in.-O.D.) casing was started in the borehole on January 20 and reached the bottom of the hole at 895 ft bgs on January 23. Dual-rotary drilling with 12-in. casing and a 12-in. tricone roller bit commenced on January 23. Use of the foaming agent was discontinued at 960 ft bgs. The R-50 borehole was drilled to a TD of 1224.5 ft bgs early in the morning (0100 h) of January 25. No problems were encountered during the final portion of dual-rotary casing advance drilling.

During drilling, field crews worked two 12-h shifts each day, 7 d/wk. The R-50 drilling operations encountered numerous difficulties and delays. Difficulties associated with broken tools in the first borehole were the principal issue, but winter weather, unconsolidated rubble and scoria zones, lost circulation, and the holiday break also played roles in hampering progress.

Abandonment of Original Borehole

The abandonment of the first borehole took place in stages. The entire string of 18-in. casing was removed from the borehole on December 4 and 5, 2009, before the drill rig was repositioned on the second hole. One 20-ft stick of 16-in. casing was also removed from the first borehole on December 5 to expose the top of the Cerros del Rio volcanic rocks for geophysical and video logging. Geophysical and video logging with Laboratory equipment took place on December 17. After logging operations were completed, a Pulstar work-over rig was set up over the first borehole. The bottom portion of the borehole was abandoned on December 18 with 18 yd^3 of sand grout consisting of Portland cement with a minor amount of silica sand. The remaining 16-in. casing was removed between January 6 and 8, 2010, after the holiday break. An additional 15 yd^3 of sand grout was emplaced on January 7, and 18 yd^3 was added on January 8 to complete the abandonment of the original borehole from 0 to 946 ft bgs.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities for monitoring well R-50. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Bulk cuttings samples were collected from the original R-50 borehole at 5-ft intervals from ground surface to 946 ft bgs; bulk samples were collected from the second borehole from ground surface to the TD of 1224.5 ft bgs. At each interval, approximately 500 mL of bulk cuttings was collected by the site geologist from the drilling discharge cyclone, placed in resealable plastic bags, labeled, and archived in core boxes. Sieved fractions (>#10 and >#35 mesh) were also collected from ground surface to total depth and placed in chip trays along with unsieved (whole rock) cuttings. Sieved chip tray samples were collected from the first borehole from 0–945 ft bgs; sieved chip tray samples were collected from the second borehole from 945–1224.5 ft bgs. Cuttings recovery was 100% for both R-50 boreholes. Radiation control technicians screened cuttings before removal from the site. All screening measurements were within the range of

background values. The core boxes and chip trays were delivered to the Laboratory's archive at the conclusion of drilling activities.

The stratigraphy encountered at R-50 is summarized in section 5.1, and a detailed lithologic log is presented in Appendix A.

4.2 Water Sampling

A groundwater-screening sample was collected from the drilling discharge on January 24 at 1090.0 ft bgs near the top of the regional aquifer. A second groundwater screening sample was collected on January 25 from the drilling discharge at 1224.0 ft bgs. These two samples were collected after water introduction was halted and air-only circulation was conducted. As the discharge cleared, the water samples were collected directly from the discharge cyclone. The screening samples were analyzed at the Laboratory's Earth and Environmental Sciences Group 14 (EES-14) laboratory for cations, anions, perchlorate, and metals. Table 4.2-1 presents a summary of screening samples collected during the R-50 monitoring-well installation project. Groundwater chemistry and field water-quality parameters are discussed in Appendix B.

Additionally, 14 groundwater screening samples were collected during well development and aquifer testing from the pump's discharge line and analyzed by EES-14 for only total organic carbon (TOC).

Groundwater characterization samples will be collected from the completed well in accordance with the Consent Order. For the first year, the samples will be analyzed for the full suite of constituents, including radioactive elements; anions/cations; general inorganic chemicals; volatile and semivolatile organic compounds; and stable isotopes of hydrogen, nitrogen, and oxygen. The analytical results will be included in the appropriate periodic monitoring report issued by the Laboratory. After the first year, the analytical suite and sample frequency at R-50 will be evaluated and presented in the annual Interim Facility-Wide Groundwater Monitoring Plan.

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at R-50 is presented below. The Laboratory's geology task leader and project site geologists examined cuttings and geophysical logs to determine geologic contacts and hydrogeologic conditions. Drilling observations, video logging, water-level measurements, and geophysical logs were used to characterize groundwater occurrences encountered at R-50.

5.1 Stratigraphy

Stratigraphic units for the R-50 borehole, drilled to a depth of 1224.5 ft bgs, are presented below in order of occurrence from younger to older units. Lithologic descriptions are based on binocular microscope analysis of drill cuttings samples collected from the discharge hose. Cuttings and borehole geophysical logs were used to identify unit contacts. Figure 5.1-1 illustrates the stratigraphy at R-50. A detailed lithologic log is presented in Appendix A.

Fill (0–4 ft bgs)

Fill consisting of mixed constituents including abundant quartzite and rounded volcanic pebbles (typical of construction base-course gravel) and tuffaceous debris was encountered from 0 ft to approximately 4 ft bgs.

Unit 2, Tshirege Member of the Bandelier Tuff, Qbt 2 (4–45 ft bgs)

Unit 2 of the Tshirege Member of the Bandelier Tuff was intersected from 4 to 45 ft bgs and is at least 41 ft thick in the R-50 borehole area. Unit 2 represents a moderately welded rhyolitic ash-flow tuff (i.e., ignimbrite) that is composed of abundant (up to 30% by volume) quartz and sanidine crystals, moderately compressed devitrified pumice lapilli, and minor volcanic lithic fragments set in a matrix (up to 60% by volume) of weathered ash. Cuttings typically contain abundant fragments of indurated tuff and numerous free quartz and sanidine crystals.

Unit 1v, Tshirege Member of the Bandelier Tuff, Qbt 1v (45–150 ft bgs)

Unit 1v of the Tshirege Member of the Bandelier Tuff occurs from 45 ft to 150 ft bgs and is locally 105 ft thick. Unit 1v is a poorly to moderately welded rhyolitic ash-flow tuff that is pumiceous, generally lithic-poor, and crystal-bearing to locally crystal-rich. Abundant ash matrix is locally preserved in cuttings. Cuttings commonly contain numerous fragments of indurated crystal-rich tuff with compressed, strongly devitrified pumice lapilli. Abundant free quartz and sanidine crystals and minor small (generally less than 10 mm in diameter) volcanic lithic inclusions also occur in cuttings.

Unit 1g, Tshirege Member of the Bandelier Tuff, Qbt 1g (150–230 ft bgs)

Unit 1g of the Tshirege Member of the Bandelier Tuff was intersected in the R-50 borehole from 150 ft to 230 ft bgs and has an estimated thickness of 80 ft. Unit 1g is a poorly welded rhyolitic ash-flow tuff that is strongly pumiceous, crystal-bearing, and lithic-poor. Unit 1g cuttings locally exhibit abundant ash matrix and less frequent fragments of indurated tuff than in Unit 2, suggesting generally poor welding. The pumice-rich interval from 210 ft to 230 ft bgs suggests a possible air-fall tephra deposit, the Tsankawi Pumice Bed, forms the base of the Tshirege Member.

Cerro Toledo Interval, Qct (230–247 ft bgs)

The Cerro Toledo interval, a layer of poorly consolidated volcaniclastic sediments that occurs stratigraphically between the Tshirege and Otowi Members of the Bandelier Tuff, is present from 230 ft to 247 ft bgs. Cerro Toledo deposits are estimated to be 17 ft thick. Locally, these sediments consist of poorly sorted pebble gravels with silty fine to coarse sands composed of volcanic and tuffaceous debris. Commonly subrounded detrital clasts are composed of various (predominantly hornblende-phyric) dacites, flow-banded rhyolite, andesite, abundant vitric pumices, and quartz and sanidine crystals.

Otowi Member of the Bandelier Tuff, Qbo (247–505 ft bgs)

The Otowi Member of the Bandelier Tuff is present in the R-50 section from 247 ft to 505 ft bgs and is estimated to be 258 ft thick. The Otowi Member is a poorly welded rhyolitic ash-flow tuff (i.e., ignimbrite) that is pumiceous, crystal-bearing, and locally lithic-rich. Abundant pale orange to white pumice lapilli noted in cuttings are typically glassy, with quartz and sanidine phenocrysts. Orange pumices denoting weak oxidation and iron-oxide staining are most common in the upper part of the Otowi section. Locally abundant volcanic lithics or xenoliths (up to 19 mm in diameter) occur in cuttings as subangular to subrounded fragments of intermediate composition, including porphyritic dacites and andesite. Cuttings locally exhibit abundant fine volcanic ash and numerous quartz and sanidine crystals.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (505–525 ft bgs)

The Guaje Pumice Bed occurs from 505 ft to 525 ft bgs and has an estimated local thickness of 20 ft. This pumice- and ash-fall tephra deposit forms the base of the Otowi Member. The unit contains

abundant (up to 100% by volume) rounded, lustrous, vitric, phenocryst-poor pumice lapilli with trace occurrences of small volcanic lithic fragments and quartz and sanidine crystals.

Puye Formation, Tpf (525–545 ft bgs)

A thin upper section of the Puye Formation was encountered in R-50 from 525 ft to 545 ft bgs and is estimated to be 20 ft thick. Upper Puye volcaniclastic sediments consist of moderately to poorly sorted, moderately cemented, fine to coarse gravels with silty fine to coarse sand. Subrounded to well-rounded detrital constituents are predominantly composed of gray porphyritic dacites, less abundant black vitrophyre, vesicular basalt, minor pumice, and quartz and sanidine crystals.

Cerros del Rio Volcanic Rocks, Tb4 (545–890 ft bgs)

The Cerros del Rio volcanic rocks (formerly Cerros del Rio basalt), encountered in R-50 from 545 ft to 890 ft bgs, locally forms a varied sequence of lavas, tephras, and volcanic sedimentary deposits, primarily of basaltic composition. The cumulative thickness of the Tb 4 series is approximately 345 ft. The upper part of the sequence, from 545 ft to 580 ft bgs, is composed of a 35-ft-thick olivine-clinopyroxene basalt flow with a thin vesicular, rubbly, clay-rich top. The mid-portion of the Cerros del Rio section, from 580 ft to 750 ft bgs, consists of complexly interlayered thin basaltic lavas, cinder deposits, and basaltic sediments that locally exhibit trace granular occurrences of pumice and quartzite. One or more phenocryst-poor basalt lava(s), with possible interflow sediments or tephras, is inferred from 750 ft to 880 ft bgs. The base of the Tb 4 section, from 880 to 890 ft bgs, consists of volcanic sediments with detritus of basaltic to intermediate-composition detritus.

Puye Formation, Tpf (890–1155 ft bgs)

A lower section of the Puye Formation was intersected from 890 ft to 1155 ft bgs. These volcaniclastic sediments consist of poorly sorted to unsorted, moderately indurated, medium to coarse gravels with silty fine to coarse sand. Subrounded to well-rounded detrital constituents throughout the typical Puye section are predominantly composed of gray biotite- and/or hornblende-phyric dacites and locally minor abundances of white pumice.

Miocene Pumiceous Sediments, Tsfu (1155–1224.5 ft bgs)

A pumice-rich volcaniclastic section, preliminarily referred to as Miocene pumiceous sediments, was intersected from 1155 ft to the bottom of the R-50 borehole, at 1224.5 ft bgs. This unassigned unit, locally interfingered with Puye sediments, has a minimum thickness of 69.5 ft. These sediments consist of fine to medium gravels with fine to coarse sand that are moderately to poorly sorted, weakly cemented, and contain detrital pumices making up 50% or more (locally as much as 90%) by volume.

5.2 Groundwater

Drilling proceeded without any groundwater indications until 1090.0 ft bgs in the Puye Formation. Water production was minimal (less than 5 gallons per minute [gpm]) at 1090.0 ft bgs. The borehole was then advanced to a TD of 1224.5 ft bgs, where the groundwater production rate was estimated at 50 gpm. Measured water levels indicated a stabilized depth to water of 1069.4 ft bgs on January 28, 2010, before well installation.

6.0 BOREHOLE LOGGING

Several video logs and a several suites of geophysical logs were collected during the R-50 drilling project. A summary of video and geophysical logging runs is presented in Table 6.0-1.

6.1 Video Logging

Video logs were run to a depth of 658 ft bgs on November 7, 2009, to a depth 936 ft bgs on November 15, and again to 939 ft bgs on November 18 in the first R-50 borehole as part of bit-fishing operations. None of these video runs aided in bit recovery because of murky drilling water in the borehole.

A final video log was run in the first R-50 borehole to a depth of 939 ft bgs before abandonment, with the 16-in. drill casing retracted to 537.8 ft bgs on December 17, 2009. The video verified no perched intermediate water entering the borehole. The video log is presented on DVD as Appendix D included with this document.

In the replacement R-50 borehole, a video survey was run to verify a successful cut in the 12-in. drill casing at 1220.0 ft bgs on January 28, 2010.

Table 6.0-1 details the video logging runs.

6.2 Geophysical Logging

A natural gamma ray log was run in the first R-50 borehole using the Laboratory's geophysical equipment on December 17, 2009, before abandonment. A final natural gamma ray log was run in the second R-50 borehole on January 28, 2010, before well construction started. Details of the logging operations are presented in Table 6.0-1.

A suite of Schlumberger geophysical logs was run inside the drill casing in the second borehole on January 25, 2010. At the time of logging, the terminations of the three casing strings in the R-50 borehole were located at the following depths: 18-in. casing at 190.7 ft bgs, 16-in. casing at 555.1 ft bgs, and 12-in. casing at 1224.5 ft bgs. The geophysical suite included the following tools: Triple Detector Lithodensity (TLD); Accelerator Porosity Sonde (APS); natural and spectral gamma logs (Hostile Environment Natural Gamma Sonde [HNGS]), and Elemental Capture Spectroscopy Sonde (ECS). Interpretation and details of the logging are presented on CD in the geophysical logging report as Appendix E.

7.0 WELL INSTALLATION R-50 MONITORING WELL

The R-50 well was installed between February 1 and February 13, 2010.

7.1 Well Design

The R-50 well was designed in accordance with the approved drilling work plan. NMED approved the well design before the well was installed. The well was designed with dual screens to monitor groundwater quality near the top of the regional aquifer within Puye Formation sediments from 1077 to 1087 ft bgs and deeper in the aquifer within Miocene pumiceous sediments from 1185 to 1205 ft bgs.

7.2 Well Construction

The R-50 monitoring well was constructed of 5.0-in. I.D./5.56-in. O.D., type A304 passivated stainless-steel threaded casing fabricated to American Society for Testing and Materials (ASTM) A312 standards.

Screened sections utilized three 10-ft lengths of 5.0-in.-I.D. rod-based 0.020-in. wire-wrapped screens to make up the 10-ft-long upper and 20-ft-long lower well-screen intervals. Compatible external stainless-steel couplings (also type A304 stainless steel fabricated to ASTM A312 standards) were used to join all individual casing and screen sections. The coupled unions between the threaded sections were approximately 0.7 ft long. All casing, couplings, and screens were steam- and pressure-washed on-site before installation. A 2-in. I.D. threaded/coupled steel tremie pipe (decontaminated before use) was utilized to deliver backfill and annular fill materials downhole during well construction. Short lengths of 12-in. drill casing (4.5-ft casing and shoe, at a depth of 1220.0 to 1224.5 ft bgs) and 16-in. drill casing (17-ft casing and shoe, at a depth of 538.1 to 555.1 ft bgs) remain in the borehole. The 12-in. casing stub was encased in the lowermost bentonite seal, while the 16-in. casing stub was encased in the upper bentonite seal.

An 11.8-ft stainless-steel sump was placed below the bottom of the lower well screen. Stainless-steel centralizers (four sets of four) were welded to the well casing approximately 2.0 ft above and below each screen. A Pulstar work-over rig was used for well-construction activities. Figure 7.2-1 presents an as-built schematic showing construction details for the completed well.

Decontamination of the stainless-steel well casing and screen took place from January 31 to February 1, along with mobilization of initial well-construction materials to the site.

On February 1, at 1325 h the 5-in. stainless-steel well casing began to be lowered into the wellbore. After the well casing was landed at 1217.5 ft bgs, annular materials began to be added on February 4. A lower seal composed of 3/8-in. bentonite chips (3.7 ft^3) was placed from 1210.9 to 1221.4 ft bgs. A 10/20 silica sand filter pack was installed from 1179.8 to 1210.9 ft bgs and surged to promote compaction (total 10/20 sand: 41.4 ft^3). A short 20/40 silica sand transition collar on top the filter pack was placed from 1176.9 to 1179.8 ft bgs (total 20/40 sand: 3.3 ft^3). Installation of annular fill materials was temporarily suspended on February 6 to deploy an inflatable packer inside the well casing between the two screens. The inflatable packer was deployed before the middle bentonite seal was installed to isolate the more productive lower screen zone from the relatively low-producing upper screen zone.

A seal separating the two screened intervals was added from 1092.2 to 1176.9 ft bgs consisting of 3/8-in. bentonite chips (66.7 ft^3). The inflatable packer was removed from the well casing on February 7 before the upper filter pack was emplaced. The upper screen filter pack of 10/20 silica sand was then installed from 1072.3 to 1092.2 ft bgs and surged to promote compaction (total 10/20 sand: 21.3 ft^3). The upper filter pack was then capped with a short 20/40 silica sand transition collar from 1069.2 to 1072.3 ft bgs (total 20/40 sand: 1.8 ft^3).

The well's upper bentonite seal (3/8-in. chips) was installed on February 8 to 12 from 302 to 1069.2 ft bgs using a total of 714.6 ft^3 of bentonite chips. The final surface seal of neat Portland cement was placed above the upper bentonite seal from 3.0 to 302 ft bgs. Well construction was completed on February 13. Table 7.2-1 summarizes volumes of all materials used during well construction.

Operationally, well construction proceeded smoothly, 24 h/d, 7 d/wk, from February 1 to 13.

8.0 POSTINSTALLATION ACTIVITIES

Following well installation, the well was developed and aquifer pumping tests were conducted. The wellhead and surface pad were constructed, a geodetic survey was performed, and a dedicated sampling system has been installed. Site restoration activities will be completed following the final disposition of contained drill cuttings and groundwater, per the NMED-approved waste-disposal decision trees.

8.1 Well Development

Well development was conducted between February 14 and 27, 2010. Initially, both screened intervals were bailed and swabbed to remove formation fines in the filter pack and well sump. Bailing continued until water clarity visibly improved. Final development of each screen was then performed with a submersible pump.

The swabbing tool employed was a 4.5-in.-O.D., 1-in.-thick nylon disc attached to a weighted steel rod. The wireline-conveyed tool was repeatedly drawn across the screened intervals causing a surging action across the screen and filter pack. The bailing tool used was a 4.0-in.-O.D. by 21.0-ft-long carbon-steel bailer with a total capacity of 12 gal. The tool was lowered by wireline and repeatedly filled, withdrawn from the hole, and dumped into the cuttings pit. Approximately 1374 gal. of groundwater was removed during bailing activities. After bailing, a 5-horsepower (hp), 4-in. submersible pump was used for well development of each screen.

During the pumping stage of well development, turbidity, temperature, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), and specific conductance parameters were measured. In addition, water samples for TOC analysis were collected. The required values for TOC and turbidity to determine adequate well development are less than 2.0 parts per million (ppm) and less than 5 nephelometric turbidity units (NTU), respectively. Table B-1.2-1 shows the purge volumes and field parameters measured during well development.

Upper Screen

The pumping assembly was removed from the well on February 18, and a 5-hp Berkley submersible pump was installed in the pump shroud after difficulties with the Grundfos pump were encountered. The upper screen was purged from bottom to top in 2-ft increments from 1087 to 1077 ft bgs. Additional pumping was conducted on February 19 and 20. Because the pump was not properly submerged at the upper screened interval and to prevent it from breaking suction and cavitating, it was lowered to 12 ft below the upper screen at 1099.2 ft bgs. The packer was inflated and an additional 1470 gal. was purged at pumping rates between 1.3 and 2.2 gpm. Approximately 3468 gal. of groundwater was purged during the initial phase of development at the upper well screen.

Lower Screen

On February 21 and 22, the same pump used for the upper screen development was reconfigured without a pump shroud and with a packer above the pump to purge the lower screen. After minor difficulties with the packer and check valves within the pump column, the pump was set at the top of the lower well screen at 1186 ft bgs and 1423 gal. of water was purged from the well on February 25. The lower screen was purged from top to bottom in 2-ft increments from 1186 ft bgs to near the bottom of the well sump at 1214.3 ft bgs. After pumping throughout the lower screened interval, the pump was set 2 ft above the screen at 1183 ft bgs, and the packer was inflated to ensure discrete water-quality parameter samples. Purged water from the lower screened interval displayed turbidity values less than 5 NTUs within the first day of pump development. Approximately 5328 gal. of groundwater was purged during lower well screen development.

Total Purge Volumes

Approximately 8796 gal. of groundwater was purged at R-50 during well development activities: 3468 gal. from the upper screen and 5328 gal. from the lower screen. Another 33,373 gal. was purged during aquifer testing: 1785 gal. from the upper screen, and 28,843 gal. from the lower screen. Total groundwater purged during postinstallation activities from both screened intervals combined was 42,169 gal.

8.1.1 Well Development Field Parameters

Field parameters were measured at well R-50 by collecting aliquots of groundwater from the discharge pipe with the use of a flow-through cell. Water-quality parameters are summarized in Table B-1.2-1, and well development field parameters are discussed in Appendix B.

During development of the upper screen, pH and temperature varied from 6.97 to 8.87 and from 18.20 to 21.90°C, respectively. Concentrations of DO ranged from 5.82 to 7.13 mg/L. Corrected Eh (oxidation-reduction potential) values ranged from 412.2 to 435.2 millivolts (mV). Specific conductance varied from 206 to 348 microsiemens per centimeter (µS/cm).

The final water quality parameters at the end of development of the upper screen were as follows: pH of 7.84, temperature of 21.81°C, specific conductivity of 278 µS/cm, and turbidity of 20.1 NTU. Although turbidity for the upper screened interval was above 5 NTU at the end of development, the final turbidity measurement after aquifer testing was 2.0 NTU.

During development of the lower screen, pH and temperature varied from 8.10 to 8.32 and from 18.98 to 19.89°C, respectively. Concentrations of DO varied from 10.03 to 12.27 mg/L. Corrected Eh values varied from 441.5 to 461.0 mV. Specific conductance varied from 203 to 234 µS/cm, and turbidity values varied from 47.3 to 4.7 NTU. Final parameters measured at the lower screen were as follows: pH of 8.19, temperature of 19.89°C, specific conductivity of 203 µS/cm, and turbidity of 4.9 NTU.

8.2 Aquifer Testing

Aquifer pumping tests were conducted at R-50 between February 28 and March 10, 2010. A 24-h constant-rate pump test was performed on March 5 after several days of no water recovery because of faulty packers in the pump.

A 5-hp pump was used for the aquifer test on the upper screened interval. Initially, the pump's flow rate was set to approximately 1.35 gpm. Approximately 1785 gal. of groundwater was purged from the upper screen interval. A 24-h recovery period followed the pumping of the upper screened interval.

A 10-hp pump was used for the aquifer test on the lower screened interval. A 24-h test, followed by a 24-h recovery period, completed the testing of the lower screen interval. Approximately 28,843 gal. of groundwater was purged from the lower screen interval at a flow rate of approximately 20 gpm.

Turbidity, temperature, pH, DO, ORP, and specific conductance parameters were measured during the 24-h tests. In addition, water samples for TOC analysis were collected and submitted to EES-14.

Approximately 33,373 gal. of groundwater was purged during aquifer testing activities. Field water-quality parameters and TOC analytical results are summarized in Appendix B and detailed in Table B-1.2-1. The results of the R-50 aquifer testing are presented in Appendix C.

8.3 Dedicated Sampling System Installation

The dedicated sampling system for R-50 was installed between May 19 and 21, 2010. The system is manufactured by Baski, Inc., and utilizes a single 3-hp, 4-in.-O.D. environmentally retrofitted Grundfos submersible pump capable of purging each screen interval discretely via pneumatically actuated access port valves. The system includes a viton-wrapped isolation packer between the screen intervals. The pump riser pipe consists of threaded and coupled nonannealed 1-in.-I.D. stainless steel. Two 1-in.-I.D. schedule 80 polyvinyl chloride (PVC) tubes are installed along with and banded to the pump riser for dedicated transducers. The PVC transducer tube for the upper screen is equipped with a 6-in. section of 0.010-in.

slotted screen with a threaded end cap at the bottom of the tube. The PVC transducer tube for the lower screen is equipped with a flexible nylon tube that extends from a threaded end cap at the bottom of the PVC tube through the isolation packer. Two In-Situ, Inc. Level TROLL 500 transducers were installed in the PVC tubes to monitor water levels in each screened interval.

Sampling system details for R-50 are presented in Figure 8.3-1a. Figure 8.3-1b presents technical notes for the well.

8.4 Wellhead Completion

A reinforced concrete surface pad, 10 ft × 10 ft × 6 in. thick, was installed at the R-50 wellhead. The concrete pad was slightly elevated above the ground surface and crowned to promote runoff. The pad will provide long-term structural integrity for the well. A brass survey pin was embedded in the northwest corner of the pad. A 10-in.-I.D. steel protective casing with a locking lid was installed around the stainless-steel well riser. A total of four bollards, painted yellow for visibility, are set at the outside edges of the pad to protect the well from traffic. The bollards are designed for easy removal to allow access to the well. Details of the wellhead completion are presented in Figure 8.3-1a.

8.5 Geodetic Survey

A New Mexico licensed professional land surveyor conducted a geodetic survey on January 25, 2010 (Table 8.5-1). The survey data collected conforms to Laboratory Information Architecture project standards IA-CB02, “GIS Horizontal Spatial Reference System,” and IA-D802, “Geospatial Positioning Accuracy Standard for A/E/C and Facility Management.” All coordinates are expressed relative to the New Mexico State Plane Coordinate System Central Zone (NAD 83); elevations are expressed in ft above mean sea level (amsl) using the National Geodetic Vertical Datum of 1929. Survey points include ground-surface elevation near the concrete pad, the top of the brass marker in the concrete pad, the top of the stainless-steel well casing, and the top of the protective casing for the R-50 monitoring well.

8.6 Waste Management and Site Restoration

Waste generated from the R-50 project included drilling fluids, drilled-out concrete chips and concrete slurry, drill cuttings, development water, decontamination water, municipal solid waste, petroleum-contaminated soils, and contact waste. A summary of the waste characterization samples collected during drilling, construction, and development of the R-50 well is presented in Table 8.6-1.

All waste streams produced during drilling and development activities were sampled in accordance with the “Waste Characterization Strategy Form for Regional Well for Chromium Investigation, R-50 (Mortandad Canyon), Regional Groundwater Well Installation and Corehole Drilling” (LANL 2009, 107445).

Fluids produced during drilling and well development are expected to be land-applied after a review of associated analytical results per the waste characterization strategy form (WCSF) and the ENV-RCRA-Standard Operating Procedure (SOP) 010.1, Land Application of Groundwater. If it is determined that drilling fluids are nonhazardous but cannot meet the criteria for land application, the drilling fluids will be managed and disposed of based upon the regulatory classification of the waste. If analytical data indicate that the drilling fluids are hazardous/nonradioactive or mixed low-level waste, they will be left in a pit or container pending a “contained-in” approval from NMED. If the hazardous wastes are containerized, they are subject to the 90-d accumulation limit, and the “contained-in” approval must be obtained before the accumulation period is exceeded.

Cuttings produced during drilling are anticipated to be land-applied after a review of associated analytical results per the WCSF and ENV-RCRA SOP-011.0, Land Application of Drill Cuttings. If the drill cuttings do not meet the criteria for land application, they will be excavated, containerized, and placed in an accumulation area appropriate for the regulatory classification of the waste. Decontamination fluid used for cleaning the drill rig and equipment is containerized at point of generation. The fluid waste was sampled and will be disposed of at an authorized facility. Characterization of contact waste will be based upon acceptable knowledge, pending analyses of the waste samples collected from the drill cuttings, drilling fluids, and decontamination fluid.

Site restoration activities will include removing drilling fluids and cuttings from the pit and managing the fluids and cuttings in accordance with applicable SOPs, removing the polyethylene liner, removing the containment area berms, and backfilling and regrading the containment area, as appropriate.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling, sampling, and well construction at R-50 were performed as specified in “Drilling Plan for Regional Aquifer Well R-50” (TerranearPMC 2009, 108564).

10.0 ACKNOWLEDGMENTS

Boart Longyear drilled and installed the R-50 monitoring well.

Pat Longmire wrote Appendix B, Groundwater Analytical Results.

David C. Schafer designed, implemented, and analyzed the aquifer tests.

LANL personnel ran downhole video equipment.

Terranear PMC provided oversight on all preparatory and field-related activities.

11.0 REFERENCES AND MAP DATA SOURCES

11.1 References

The following list includes all documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the EP Directorate’s RPF and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), March 2006. “Storm Water Pollution Prevention Plan for SWMUs and AOCs (Sites) and Storm Water Monitoring Plan,” Los Alamos National Laboratory document LA-UR-06-1840, Los Alamos, New Mexico. (LANL 2006, 092600)

LANL (Los Alamos National Laboratory), October 4, 2007. “Integrated Work Document for Regional and Intermediate Aquifer Well Drilling (Mobilization, Site Preparation and Setup Stages),” Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2007, 100972)

LANL (Los Alamos National Laboratory), October 2009. "Drilling Work Plan for Regional Aquifer Well R-50," Los Alamos National Laboratory document LA-UR-09-6272, Los Alamos, New Mexico. (LANL 2009, 107461)

LANL (Los Alamos National Laboratory), November 2, 2009. "Waste Characterization Strategy Form for Regional Well for Chromium Investigation, R-50 (Mortandad Canyon), Regional Groundwater Well Installation and Corehole Drilling," Los Alamos, New Mexico. (LANL 2009, 107445)

TerranearPMC, October 2009. "Drilling Plan for Regional Aquifer Well R-50," plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (TerranearPMC 2009, 108564)

11.2 Map Data Sources

Point Feature Locations of the Environmental Restoration Project Database; Los Alamos National Laboratory, Waste and Environmental Services Division, EP2008-0109; 28 February 2009.

Hypsography, 100 and 20 Foot Contour Interval; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program; 1991.

Surface Drainages, 1991; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program, ER2002-0591; 1:24,000 Scale Data; Unknown publication date.

Paved Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 04 January 2008.

Dirt Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 04 January 2008.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 04 January 2008.

Technical Area Boundaries; Los Alamos National Laboratory, Site Planning & Project Initiation Group, Infrastructure Planning Division; 19 September 2007.

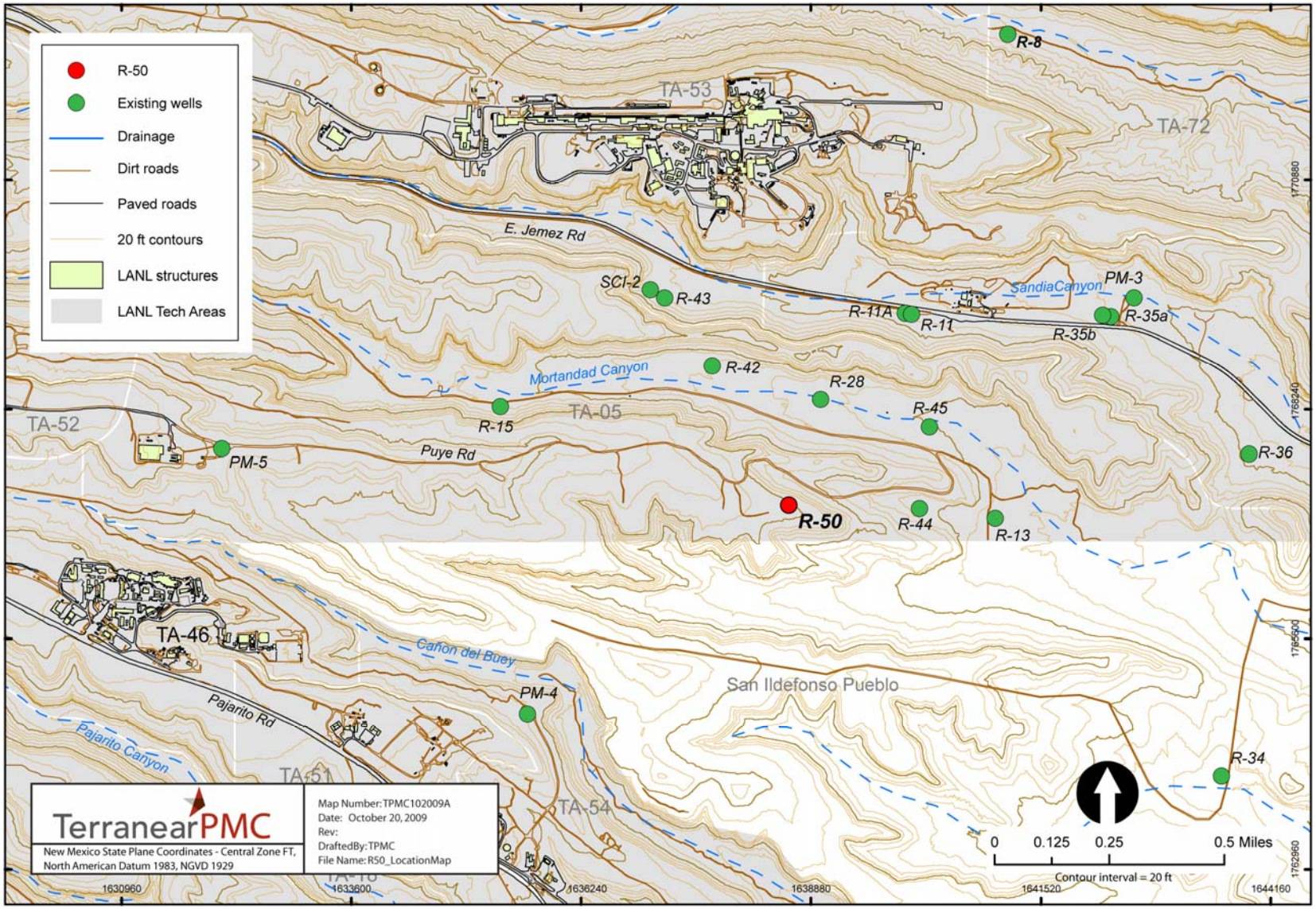

Figure 1.0-1 Location of regional monitoring well R-50

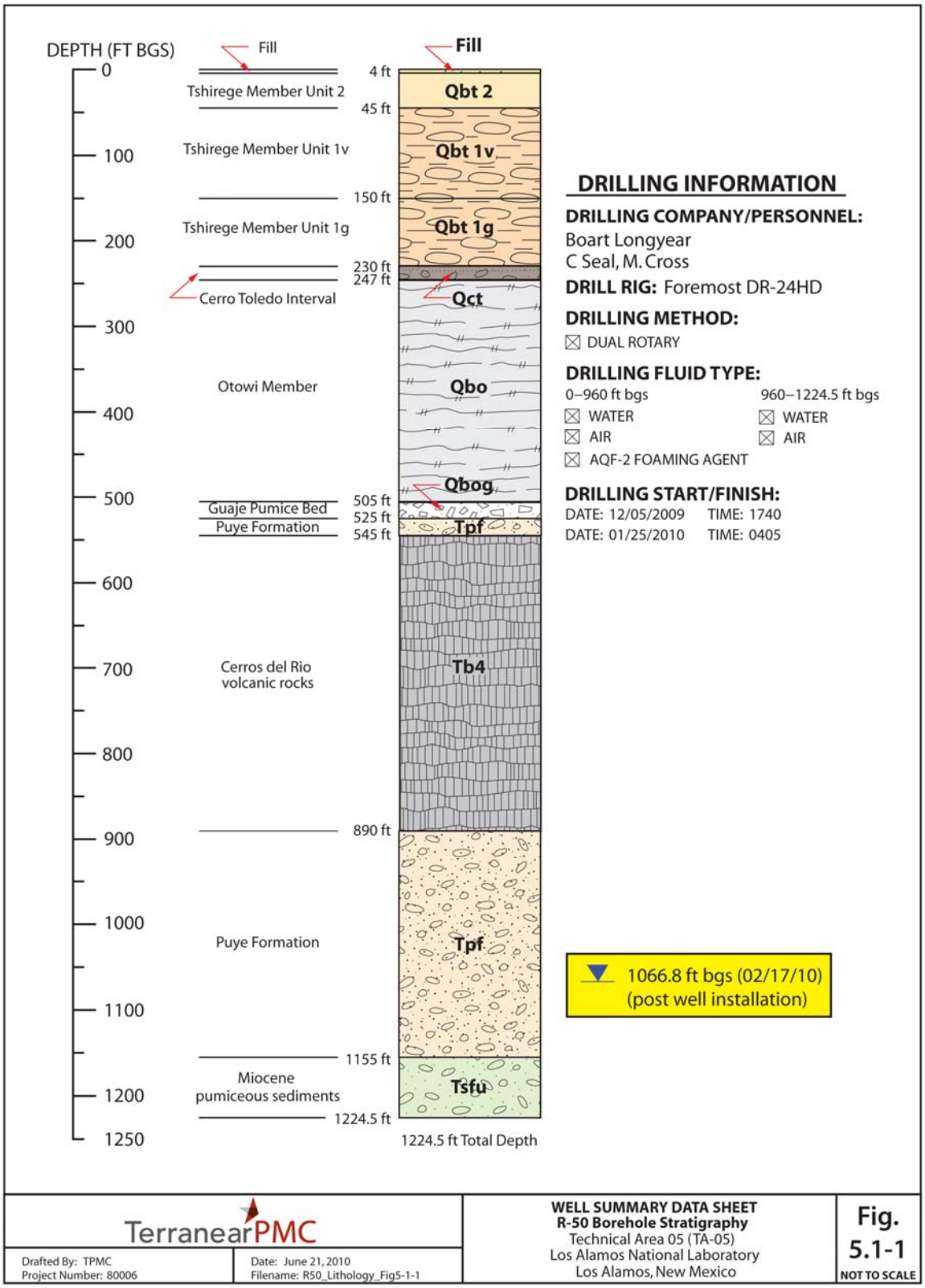

Figure 5.1-1 Regional monitoring well R-50 borehole stratigraphy

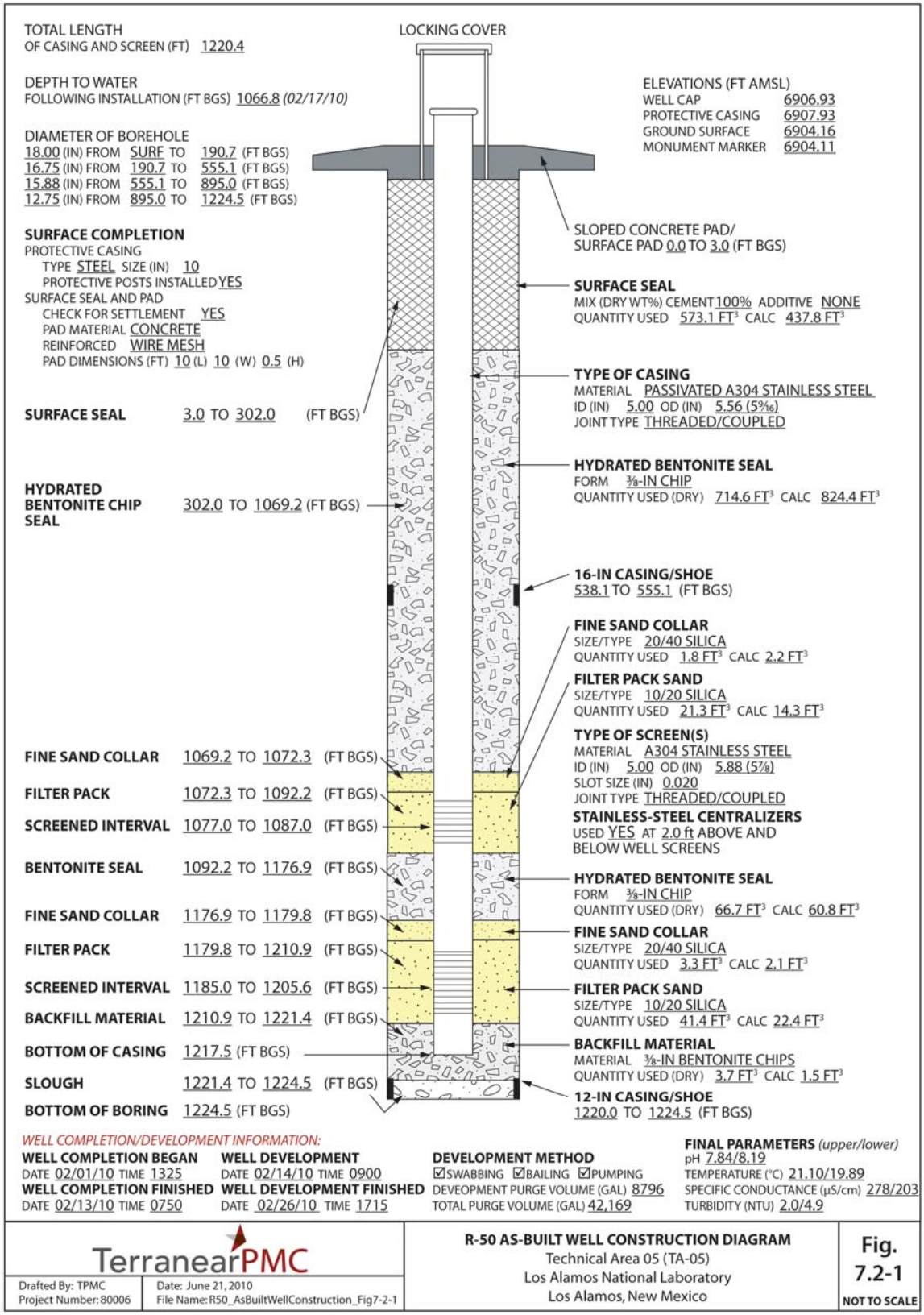

Figure 7.2-1 Regional monitoring well R-50 as-built well construction diagram

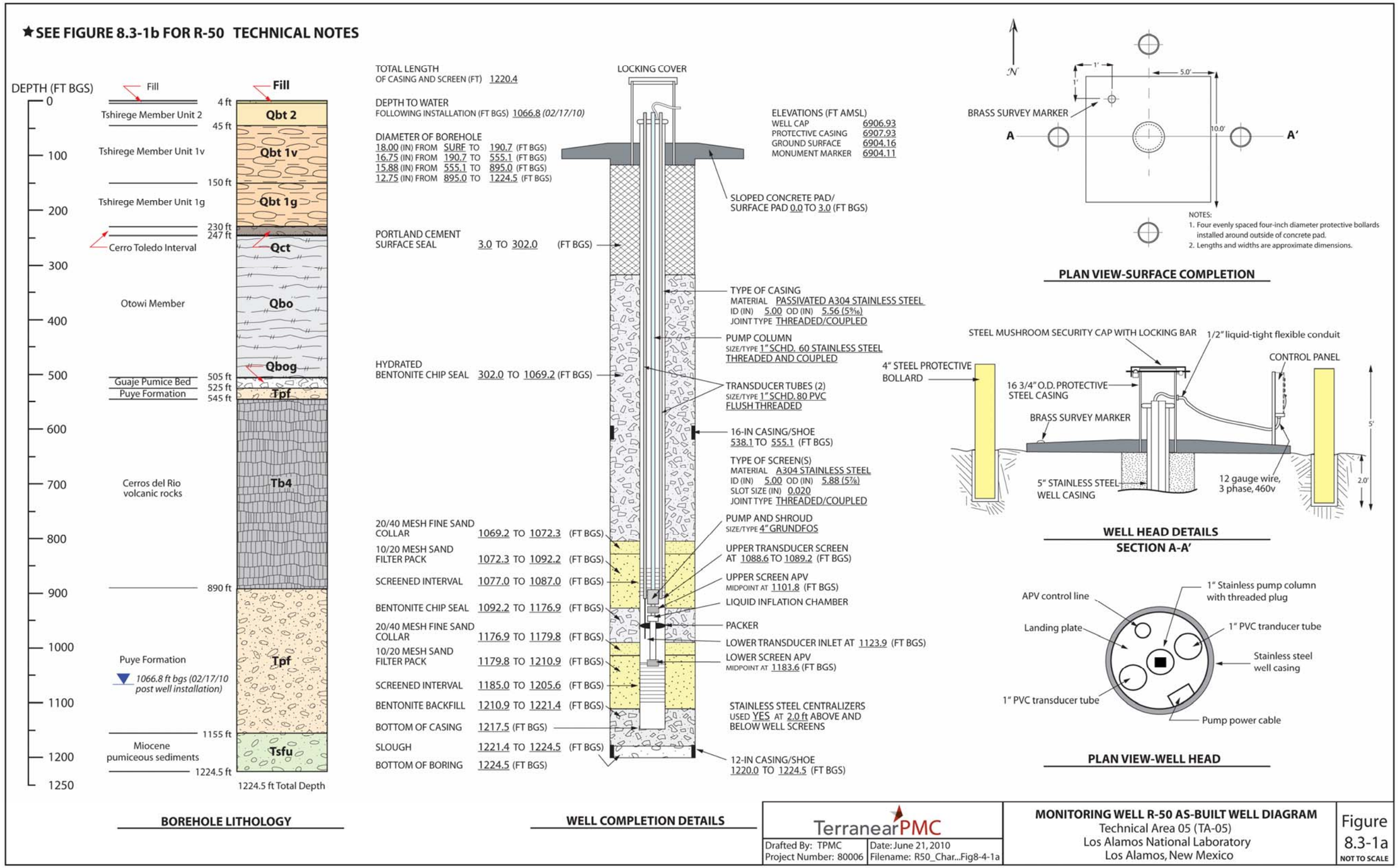

Figure 8.3-1a As-built schematic for regional monitoring well R-50

R-50 TECHNICAL NOTES:

SURVEY INFORMATION*

Brass Marker

Northing:	1767087.32 ft
Easting:	1638666.13 ft
Elevation:	6904.11 ft AMSL

Well Casing (top of stainless steel)

Northing:	1767082.49 ft
Easting:	1638668.23 ft
Elevation:	6906.93 ft AMSL

BOREHOLE GEOPHYSICAL LOGS

LANL: Video (×4), natural gamma ray (×2)
Schlumberger: TLD, ECS, HNGS, APS

DRILLING INFORMATION

Drilling Company
Boart Longyear

Drill Rig
Foremost DR-24HD

Drilling Methods
Dual Rotary
Fluid-assisted air rotary, Foam-assisted air rotary

Drilling Fluids
Air, potable water, AQF-2 Foam (to 960 ft bgs)

MILESTONE DATES

Drilling

Start:	12/05/2009
Finished:	01/25/2010

Well Completion

Start:	02/01/2010
Finished:	02/13/2010

Well Development

Start:	02/14/2010
Finished:	02/26/2010

WELL DEVELOPMENT

Development Methods
Performed swabbing, bailing, and pumping
Total Volume Purged: 8796 gallons (both screens)

Parameter Measurments (Final, upper screen/lower screen)

pH:	7.84/8.19
Temperature:	21.10/19.89°C
Specific Conductance:	278/203 µS/cm
Turbidity:	2.0/4.9 NTU

AQUIFER TESTING

Constant Rate Pumping Test

Upper Screen

Water Produced:	1785 gallons
Average Flow Rate:	1.6 gpm
Performed on:	02/28–03/08/2010

Lower Screen

Water Produced:	28,843 gallons
Average Flow Rate:	20 gpm
Performed on:	03/08–10/2010

DEDICATED SAMPLING SYSTEM

Pump
Make: Grundfos
Model: 5S30-820CBM
2 U.S. gpm, APVs (Access Port Valves) midpoints at 1101.8 (upper) and 1183.6 (lower) ft bgs

Motor
Make: Franklin Electric
Model: 2343262604
3hp, 3-phase

Pump Column
1-in. threaded/coupled sched. 60 stainless steel tubing

Transducer Tubes
1-in. flush-threaded sched. 80 PVC tubing
Upper 0.01-in. slot screen at 1088.6–1089.2 ft bgs,
Lower flexible tube from transducer set at 1123.9 ft bgs

Transducers
Make: In-Situ, Inc.
Type: Level TROLL 500
30 psig range (vented)
S/N: 163673, 163974

NOTES:
* Coordinates based on New Mexico State Plane Grid Coordinates, Central Zone (NAD83); Elevation expressed in feet above mean sea level using the National Geodetic Vertical Datum of 1929.

TerranearPMC		R-50 TECHNICAL NOTES Technical Area 05 (TA-05) Los Alamos National Laboratory Los Alamos, New Mexico	Figure 8.3-1b
Drafted By: TPMC Project Number: 80006	Date: June 21, 2010 Filename: R50_TechnicalNotes_Fig8-3-1b		NOT TO SCALE

Figure 8.3-1b As-built technical notes for regional monitoring well R-50

Table 3.1-1
Fluid Quantities Used during R-50 Drilling and Well Construction

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
Drilling				
12/05/09	800	800	3	3
12/06/09	900	1700	3.5	6.5
12/07/09	250	1950	0.5	7
12/10/09	250	2200	0.5	7.5
12/12/09	450	2650	3	10.5
12/15/09	200	2850	0.5	11
12/16/09	800	3650	3	14
12/17/09	800	4450	3	17
12/18/09	600	5050	6	23
1/04/10	700	5750	2	25
1/05/10	200	5950	1	26
1/06/10	200	6150	3	29
1/08/10	300	6450	2	31
1/11/10	500	6950	2	33
1/12/10	1000	7950	20	53
1/13/10	1500	9450	12	65
1/14/10	300	9750	2	67
1/15/10	1500	11,250	15	82
1/16/10	240	11,490	0	82
1/17/10	2000	13,490	40	122
1/18/10	1800	15,290	80	202
1/19/10	4100	19,390	120	322
1/23/10	2300	21,690	5	327
1/24/10	2400	24,090	0	327
1/28/10	700	24,790	0	327
Well Construction				
2/4/10	1900	1900	n/a*	n/a
2/5/10	1000	2900	n/a	n/a
2/6/10	2600	5500	n/a	n/a
2/7/10	2000	7500	n/a	n/a
2/8/10	3400	10,900	n/a	n/a
2/9/10	2300	13,200	n/a	n/a
2/10/10	2300	15,500	n/a	n/a
2/11/10	3000	18,500	n/a	n/a

Table 3.1-1 (continued)

Date	Water (gal.)	Cumulative Water (gal.)	AQF-2 Foam (gal.)	Cumulative AQF-2 Foam (gal.)
2/12/10	2280	20,780	n/a	n/a
2/13/10	25	20,805	n/a	n/a
Total Water Volume (gal.)				
R-50	45,595			

* n/a = Not applicable. Foam use terminated at approximately 960 ft bgs.

Table 4.2-1
Summary of Groundwater Screening Samples Collected during Drilling, Well Development, and Aquifer Testing of Well R-50

Location ID	Sample ID	Date Collected	Collection Depth (ft bgs)	Sample Type	Analysis
Drilling					
R-50	GW50-10-5028	1/24/10	1090	Groundwater, Airlifted	Cations, anions, perchlorate, metals
R-50	GW50-10-5029	1/25/10	1224	Groundwater, Airlifted	Cations, anions, perchlorate, metals
Development					
R-50	GW50-10-5049	2/20/10	1077–1087	Groundwater, Pumped	TOC
R-50	GW50-10-5050	2/26/10	1185.01–1205.57	Groundwater, Pumped	TOC
Aquifer Pump Testing					
R-50	GW50-10-5051	3/5/10	1077–1087	Groundwater, Pumped	TOC
R-50	GW50-10-5052	3/5/10	1077–1087	Groundwater, Pumped	TOC
R-50	GW50-10-5053	3/5/10	1077–1087	Groundwater, Pumped	TOC
R-50	GW50-10-5054	3/5/10	1077–1087	Groundwater, Pumped	TOC
R-50	GW50-10-5055	3/6/10	1077–1087	Groundwater, Pumped	TOC
R-50	GW50-10-5056	3/6/10	1077–1087	Groundwater, Pumped	TOC
R-50	GW50-10-5057	3/10/10	1185.01–1205.57	Groundwater, Pumped	TOC
R-50	GW50-10-5058	3/10/10	1185.01–1205.57	Groundwater, Pumped	TOC
R-50	GW50-10-5059	3/10/10	1185.01–1205.57	Groundwater, Pumped	TOC
R-50	GW50-10-5060	3/10/10	1185.01–1205.57	Groundwater, Pumped	TOC
R-50	GW50-10-5061	3/11/10	1185.01–1205.57	Groundwater, Pumped	TOC
R-50	GW50-10-5062	3/11/10	1185.01–1205.57	Groundwater, Pumped	TOC

Table 6.0-1
R-50 Video and Geophysical Logging Runs

Date	Type	Depth (ft bgs)	Description
11/7/09	Video	658	LANL personnel ran a video log in the first R-50 borehole to aid in fishing operations for a broken bit; because of foam the video was ineffective.
11/15/09	Video	936	LANL personnel ran a video log in the first R-50 borehole to aid in fishing operations for a broken bit; because of water opacity the video was ineffective.
11/18/09	Video	936	LANL personnel again ran a video log in the first R-50 borehole to aid in fishing operations; the video was also ineffective due to murky water in the borehole.
12/17/09	Video and natural gamma	939	LANL personnel ran a video and a natural gamma ray log in the original R-50 borehole before abandonment.
01/25/10	Schlumberger	1224	Schlumberger ran TLD/APS/HNGS/ECS suite inside 12-in. drill casing after TD was reached.
01/28/10	Video and natural gamma	1220	LANL personnel ran a video log to verify a successful cut in the 12-in. casing at 1220.0 ft bgs. A natural gamma ray log was also run.

Table 7.2-1
R-50 Monitoring Well Annular Fill Materials

Material	Volume
Upper surface seal: cement slurry	573.1 ft^3
Upper bentonite seal: bentonite chips	714.6 ft^3
Upper fine sand collar: 20/40 silica sand	1.8 ft^3
Upper filter pack: 10/20 silica sand	21.3 ft^3
Middle bentonite seal: bentonite chips	66.7 ft^3
Lower fine sand collar: 20/40 silica sand	3.3 ft^3
Lower filter pack: 10/20 silica sand	41.4 ft^3
Backfill: bentonite chips	3.7 ft^3

Table 8.5-1
R-50 Survey Coordinates

Identification	Northing	Easting	Elevation
R-50 brass cap embedded in pad	1767087.32	1638666.13	6904.11
R-50 ground surface near pad	1767083.18	1638662.93	6904.16
R-50 top of 10-in. protective casing	1767082.98	1638668.15	6907.23
R-50 top of stainless-steel well casing	1767082.49	1638668.23	6906.93

Note: All coordinates are expressed relative to the New Mexico State Plane Coordinate System Central Zone (NAD 83); elevation is expressed in ft amsl using the National Geodetic Vertical Datum of 1929.

Table 8.6-1
Summary of Waste Samples Collected during Drilling and Development of R-50

Sample ID	Date Collected	Description	Sample Type
WST05-10-12196	2/4/10	Decon Fluid	Liquid
WST05-10-12192	2/4/10	Decon Fluid	Liquid
WST05-10-12200 (FD[a])	2/4/10	Decon Fluid	Liquid
WST05-10-12204 (FTB[b])	2/4/10	Decon Fluid	Liquid
WST05-10-12493 (UF[c])	2/23/10	Development Water	Liquid
WST05-10-12492 (F[d])	2/23/10	Development Water	Liquid
WST05-10-12494 (FD)	2/23/10	Development Water	Liquid
WST05-10-12495 (FTB)	2/23/10	Development Water	Liquid
WST50-10-13942	3/5/10	NMSW[e]	Solid
WST50-10-13941 (FTB)	3/5/10	NMSW	Solid
WST50-10-13849 (UF)	3/11/10	Drilling Fluids	Liquid
WST50-10-13848 (F)	3/11/10	Drilling Fluids	Liquid
WST50-10-13850 (FD)	3/11/10	Drilling Fluids	Liquid
WST50-10-13851 (FTB)	3/11/10	Drilling Fluids	Liquid

[a] FD = Field duplicate.
[b] FTB = Fielded trip blank.
[c] UF = Unfiltered.
[d] F = Filtered.
[e] NMSW = New Mexico Special Waste.

Appendix A

Borehole R-50 Lithologic Log

Los Alamos National Laboratory
Regional Hydrogeologic Characterization Project
Borehole Lithologic Log

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 1 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
0–4	**FILL:** Construction fill —mixed constituents including abundant quartzite and rounded volcanic pebbles (typical of construction base-course gravel) and tuffaceous debris (i.e., quartz and sanidine crystals plus chips of indurated crystal tuff).	Fill	Note: Drill cuttings for microscopic and descriptive analysis were collected at 5-ft intervals from 0 ft to borehole TD at 1224.5 ft bgs.
4–35	**UNIT 2 OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuff—very light gray (N8) to pinkish gray (5YR 8/1), moderately welded, moderately indurated, crystal-rich, pumice-bearing, lithic-bearing, strongly weathered. 3'– 35' WR: abundant fine volcanic ash. +10F: 50–90% fragments of poorly to moderately welded ash flow tuff [i.e., ignimbrite that is composed of 20–30% quartz and sanidine crystals, 10–15% compressed devitrified (and/or weathered) pumices and less than 5% lithic fragments set in weathered ash matrix that makes up 50–60% by volume]; 10–50% broken quartz and sanidine crystals; 1–2% small (up to 4 mm) dacitic lithic fragments. +35F: 97–99% quartz and sanidine crystals; 1–3% fragments of ash and volcanic lithics.	Qbt 2	Unit 2 of the Tshirege Member of the Bandelier Tuff (Qbt 2), encountered from 4 ft to 45 ft bgs, is 41 ft thick.
35–40	Tuff—light grayish orange (10YR 7/4) poorly welded, crystal-rich, lithic-bearing, strongly weathered. 35'– 40' WR: abundant weathered ash and silt. +10F: 80–90% quartz and sanidine crystals; 10–20% volcanic lithics (up to 5 mm). +35F: 98–99% quartz and sanidine crystals; 1–2% volcanic lithics.	Qbt 2	

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 2 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
40–45	Tuff—very light gray (N8) poorly welded, crystal-rich, lithic -poor, pumice-bearing. 40'– 45' WR: abundant fine ash, strongly weathered. +10F: 40–50% broken quartz and sanidine crystals; 40–50% fragments of moderately welded tuff containing devitrified pumices. 35F: 99% quartz and sanidine crystals; 1% volcanic lithics.	Qbt 2	The Qbt 2–Qbt 1v contact, estimated to be at 45 ft bgs, is based on based on microscopic examination of drill cuttings.
45–70	**UNIT 1v OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuff—light grayish orange (10YR 7/4) poorly welded, crystal-rich, lithic-bearing, strongly weathered. 45'– 70' WR: abundant weathered ash and silt. +10F: 80–90% quartz and sanidine crystals; 10–20% volcanic lithics (up to 5 mm). +35F: 98–99% quartz and sanidine crystals; 1–2% volcanic lithics.	Qbt 1v	Unit 1v of the Tshirege Member of the Bandelier Tuff (Qbt 1v), encountered from 45 ft to 150 ft bgs, is estimated to be 105 ft thick.
45–70	Tuff—pale yellowish orange (5YR 8/1), poorly to moderately welded, poorly indurated, pumiceous, crystal-bearing, lithic-bearing. 45'– 55' WR: abundant (up to 50%) volcanic ash. +10F: 50–90% fragments of strongly weathered, friable, crystal-tuff with distinctive devitrified pumices; 10–40% quartz and sanidine crystals; 3–5% volcanic (dacitic) lithic fragments; minor fragments of silty very fine grained sandstone. +35F: 20–30% devitrified pumice fragments; 70-80% quartz and sanidine crystals. 55'– 60' WR: abundant (30–40%) volcanic ash and silt. +10F: 40–50% fragments of indurated pale tan siltstone containing very fine grained volcanic sand grains; 40–50% fragments of weathered crystal-tuff with devitrified pumices; 2–3% dacitic lithics. 60'– 70' WR: abundant volcanic ash. +10F: 70–90% fragments of weathered crystal-tuff with compressed devitrified pumices (up to 5 mm); 3–5% volcanic (dacitic) lithic fragments (up to 15 mm);10–20% fragments of silty tuffaceous sandstone. +35F: 10–20% volcanic lithics and pumice fragments; 80–90% quartz and sanidine crystals.	Qbt 1v	

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 3 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
70–90	Tuff—very light gray (N8), poorly to moderately welded, weakly indurated, pumiceous, crystal-bearing; locally abundant volcanic lithics. 70'– 90' +10F: 20–70% subangular to subrounded lithic fragments (dacite, andesite, rhyolite, trace Precambrian schist); 10–30% quartz and sanidine crystals. +35F: 5–15% volcanic lithic fragments; 85–95% quartz and sanidine crystals.	Qbt 1v	
90–105	Tuff—pinkish gray (5YR 8/1) to grayish orange pink (5YR 7/2), moderately welded, pumiceous, crystal-rich; lithic-bearing. 90'–105' +10F: 20–30% angular and broken volcanic lithic fragments (up to 25 mm, predominantly dacite); 30–50% quartz and sanidine crystals; 10–20% fragments of weathered crystal-tuff (ignimbrite). +35F: 10–20% volcanic lithic fragments; 80–90% quartz and sanidine crystals.	Qbt 1v	
105–125	Tuff—light brownish gray (5YR 6/1) grading downward to yellowish gray (5Y 7/2), poorly to moderately welded, moderately indurated, pumiceous (pumices devitrified), crystal-bearing, lithic-poor. 105'– 115' WR: abundant fine ash. +10F: 30–40% large (up to 3 mm) broken quartz and sanidine crystals; 20–40% fragments of pumiceous crystal-tuff (devitified pumices); 10–15% volcanic lithic fragments (dacite). 115'– 125' WR: abundant pale yellowish gray fine ash. +10F: 20–50% small (up to 5 mm) dacitic lithic fragments; 10–20% quartz and sanidine crystals.	Qbt 1v	

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 4 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
125–150	Tuff—very light gray (N8) to pale yellowish gray (5Y 8/1), poorly welded, moderately indurated, pumiceous (pumices devitrified), crystal-bearing, lithic-poor. 125'– 135' +10F: 15–25% quartz and sanidine crystals; 10–20% pale tan fragments of pumiceous crystal-tuff; 20–40% volcanic lithic fragments (up to 15 mm) predominantly of gray hornblende-dacite. 135'– 150' +10F: 70–90% pale tan fragments of strongly pumiceous (pumices distinctly devitrified) crystal-rich rhyolite ash flow tuff; 5-15% angular volcanic lithics (gray dacite); 2–3% quartz and sanidine crystals.	Qbt 1v	The Qbt 1v–Qbt 1g contact, estimated to be at 150 ft bgs, is based on based on microscopic examination of drill cuttings and interpretation of natural gamma log data.
150–185	**UNIT 1g OF THE TSHIREGE MEMBER OF THE BANDELIER TUFF:** Tuff—very pale orange (10YR 8/2), poorly welded, moderately indurated, pumiceous (first appearance of glassy pumices noted), crystal-bearing, lithic-poor. 150'– 165' +10F: 85–95% pale orange fragments of indurated ash flow tuff containing abundant quartz and sanidine crystals and vitric pumices that are streaked with black obsidian; 5–15% volcanic lithic fragments (up to 7 mm), predominantly dacite. +35F: 25–50% tuff and pumice fragments 30–50% quartz and sanidine crystals; 5–10% volcanic lithics. 165'– 185' +10F: 80–90% pale orange fragments of glassy, quartz- and sanidine-phyric pumices; 5-20% volcanic (predominantly dacites) lithic fragments; up to 5% fragments of ash flow tuff. +35F: 60–70% glassy pumices and tuff fragments; 30–40% quartz and sanidine crystals; 5–7% volcanic lithic fragments.	Qbt 1g	Note: interval 150'–165' expressed as color change and abrupt appearance of pinkish orange tuff fragments with glassy obsidian-laced pumices. Unit 1g of the Tshirege Member of the Bandelier Tuff (Qbt 1g), encountered from 150 ft to 230 ft bgs, is estimated to be 80 ft thick.

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 5 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
185–210	Tuff—very pale orange (10YR 8/2), poorly welded, weakly to moderately indurated, strongly pumiceous, crystal-bearing, lithic-poor. 185'– 210' +10F: 93–97% fragments of pale orange quartz- and sanidine-phyric glassy pumice; 3–7% volcanic lithic fragments (predominantly dacite); minor fragments of indurated ash-flow tuff. +35F: 40–60% fragments of glassy pumice; 30–50% quartz and sanidine crystals; 5–10% volcanic lithics.	Qbt 1g	
210–230	Tuff—white (N9), pumice-rich, lithic-poor. Samples composed predominantly of pumice fragments and/or lapilli, suggesting possible air-fall tephra deposits. 210'– 230' +10F: 98–100% subrounded fragments of white, lustrous, vitric pumice that is quartz- and sanidine-phyric with pristine (i.e., fresh) appearance; up to 2% small (up to 2 mm) dacitic lithics. +35F: 30–40% white glassy pumice grains; 60–70% quartz and sanidine crystals; 2–3% volcanic lithics.	Qbt 1g	The Qbt 1g–Qct contact, estimated to be at 230 ft bgs, is based on microscopic examination of drill cuttings and interpretation of natural gamma log data.
230–247	**CERRO TOLEDO INTERVAL:** Volcaniclastic and tuffaceous sediments—pale yellowish gray (5y 8/1) coarse to fine gravels with sand and silt, poorly sorted, detritus composed of intermediate volcanic rocks, pumices and crystals in a silty matrix. 225'– 247' +10F: 60–80% broken, subangular and locally rounded volcanic clasts (gray porphyritic dacite, flow-banded rhyolite, andesite) with adhered silt (or clumps of silty sandstone) indicating cemented matrix; 20–40% white, vitric lustrous, quartz- and sanidine-phyric pumice fragments. +35F: 30–40% white glassy pumice grains; 40–50% quartz and sanidine crystals; 20–30% volcanic lithic grains.	Qct	The Cerro Toledo interval (Qct), encountered from 230 to 247 ft bgs, is estimated to be 17 ft thick The Qct–Qbo contact, estimated to be at 247 ft bgs, is based on based on microscopic examination of drill cuttings and interpretation of natural gamma log data.

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 6 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
247–260	**OTOWI MEMBER OF THE BANDELIER TUFF:** Tuff—pale yellowish gray (5y 8/1) poorly welded, weakly indurated, pumice-rich, crystal bearing. 247'– 260' +10F: 60–70% white, glassy, lustrous pumice fragments/clasts; 30–40% angular/broken and subrounded volcanic clasts (predominantly hornblende-dacite). +35F: 70–80% quartz and sanidine crystals; 10–15% pumice grains; 10–15% volcanic lithic grains.	Qbo	The Otowi Member of the Bandelier Tuff (Qbo), intersected from 247 ft to 505 ft bgs, is estimated to be 258 ft thick.
260–275	Tuff— very pale orange (10YR 8/2), poorly welded, weakly indurated, pumice-rich, crystal-bearing, lithic-bearing. 260'– 275' +10F: 95–98% fragments of pale orange-tan, glassy, quartz- and sanidine-phyric pumice; 2–5% angular dacitic lithic fragments. +35F: 30–40% quartz and sanidine crystals; 40–60% orange pumice grains; 20–30% volcanic lithic grains.	Qbo	
275–300	Tuff— very pale orange (10YR 8/2), poorly welded, waekly indurated pumice-rich, crystal-bearing, lithic-bearing. 275'– 285' +10F: 60–80% volcanic lithic fragments; 30–40% orange pumices plus quartz and sanidine crystals. +35F: 10–15% quartz and sanidine crystals; 60–80% pumice grains; 20–40% volcanic lithic grains. 285'–300' +10F: 85–95% pale orange pumices, commonly well rounded; 5–15% volcanic lithics (predominantly dacites). +35F: 10–15% quartz and sanidine crystals; 60–80% pumice grains; 20–40% volcanic lithic grains	Qbo	
300–325	Tuff— very pale orange (10YR 8/2), poorly welded, pumice-rich, crystal-bearing, lithic-bearing to locally lithic-rich. 300'– 325' +10: 50–80% locally well rounded fragments of pale orange vitric, quartz- and sanidine-phyric pumice; 20–50% volcanic lithics (subangular to subrounded, predominantly gray dacite, rare basalt). +35F: made up of fragments of pumice, volcanic lithics and quartz and sanidine crystals in variable proportions.	Qbo	

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 7 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
325–345	Tuff— medium light gray (N6), poorly welded, pumiceous, crystal-poor, lithic-rich. 325'–345' +10F: samples in this interval predominantly made up of volcanic lithic fragments. 97–98% angular/broken volcanic lithic fragments (up to 15 mm) composed of light gray and pinkish dacites, dark brown andesite; 1–3% fragments of lithic- and crystal-bearing ash flow tuff. +35F:samples made up of fragments of pumice, volcanic lithics and quartz and sanidine crystals in variable proportions.	Qbo	
345–360	No sample available for description. No cuttings returned due to lost fluid circulation during drilling in this interval.	Qbo	
360–385	Tuff—very pale orange (10YR 8/2), poorly welded, weakly indurated, pumiceous, crystal-bearing, lithic-rich. 360'– 385' +10F: 50–70% pale orange tan-colored glassy pumices (quartz- and sanidine-phyric, weakly limonite-stained); 30–50% coarse (up to 25 mm) volcanic lithic fragments (gray porphyritic dacites, dark gray andesite). +35F:samples made up of yelllowish pumice grains, volcanic lithics and quartz and sanidine crystals in variable proportions.	Qbo	
385–425	Tuff—varicolored, very pale orange (10YR 8/2) to light gray (N7), poorly welded, weakly indurated, pumiceous, crystal-bearing, lithic-rich. 385'–425' +10F: 40–60% volcanic lithic fragments (dacite, porphyritic vitrophyre, flow-bandedd rhyodacite); 40–60% pale orange tan (i.e., limonite-stained) vitric, quartz- and sanidine-phyric pumices. +35F: fragments of orange to white pumice, volcanic lithics, and quartz and sanidine crystals in variable proportions.	Qbo	

BOREHOLE IDENTIFICATION (ID): R-50	**TECHNICAL AREA (TA):** 05	**PAGE:** 8 of 18
DRILLING COMPANY: Boart Longyear Company	**START DATE/TIME:** 12/05/2009	**END DATE/TIME:** 1/25/2010
DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
425–435	Tuff—white (N9) to very pale gray (5YR 8/1), poorly welded, weakly indurated, pumice-rich, crystal-bearing, lithic-rich. 425'– 435' +10F: 99–100% pumice lapilli (up to 10 mm), white, lustrous, quartz- and sanidine-phyric; trace volcanic lithics. +35F: samples composed predominantly of pumice fragments	Qbo	
435–445	Tuff—medium (N5) to light gray (N7), poorly welded, weakly indurated, pumiceous, crystal-bearing, lithic-rich. 435'–445' +10F: 60–70% volcanic lithic fragments; 30–40% vitric pumices. +35F: vitric pumice grains, volcanic lithics, and quartz and sanidine crystals in variable proportions.	Qbo	
445–490	Tuff—very pale yellowish gray (5YR 8/1), poorly welded, weakly indurated, pumice-rich, crystal-bearing, lithic-bearing. 445'–450' +10F: 60% generally white lustrous, quartz- and sanidine-phyric pumice fragments; 40% volcanic lithics (predominantly dacite). 450'–455' +10F: 100% white, vitric pumice lapilli. 455'–470' +10F: 70% white, vitric pumice lapilli; 30% volcanic lithics. 470'–490' +10F: 60–80% white, vitric pumices; 20–40% volcanic lithic fragments.	Qbo	
490–505	Tuff—pale yellowish gray (5Y 8/1), poorly welded, poorly indurated, pumiceous, crystal-bearing, lithic-bearing. 490'–505' WR: abundant very pale yellowish gray ash matrix. +10F: 80–90% white to light tan glassy, quartz- and sanidine-phyric pumice lapilli (up to 12 mm), locally weathered; 10–20% small (up to 5 mm) angular volcanic lithic fragments (dacite, andesite). +35F: (490'–495') 90% vitric pumice grains; 8% volcanic lithics; 2% quartz and sanidine crystals. (495'–505') 40– 50% pumice grains; 30–40% quartz and sanidine crystals; 30–40% volcanic lithics.	Qbo	The Qbo-–Qbog contact, estimated to be at 505 ft bgs, is based on microscopic examination of drill cuttings and interpretation of natural gamma log data.

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DRILLING METHOD: Dual Rotary	**MACHINE**: Foremost DR24 HD	**SAMPLING METHOD:** Grab
GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
505–525	**GUAJE PUMICE BED OF THE OTOWI MEMBER OF THE BANDELIER TUFF:** Tuff—white (N9), non-welded rhyoliic tephra, pumice-rich. Samples throughout this interval consist predominantly of glassy, pristine-appearing rhyolitic pumice lapilli and fragments. 505'–515' +10F: 98–10%% white vitric, lustrous subrounded pumice lapilli, quartz- and sanidine-phyric; up to 2% angular volcanic (predominantly dacitic) lithics (up to 19 mm). +35F: 98–99% pumice lapilli/fragments; 1–2% volcanic lithics. 515'–525' +10F: 98–99% vitric pumice lapilli (up to 6 mm); 1–2% small (up to 5 mm) volcanic lithics (dacites, andesite).	Qbog	The Guaje Pumice Bed (Qbog), intersected from 505 ft to 525 ft bgs, is estimated to be 20 ft thick. The Qbog–Tpf contact, estimated to be at 525 ft bgs, is based on microscopic examination of drill cuttings and interpretation of natural gamma log data.
525–545	**PUYE FORMATION:** Volcaniclastic sediments—very pale orange (10YR 8/2) silty pebble gravels with fine to coarse sand, moderately sorted, moderately indurated. Samples consist of mixed volcanic and pumiceous detritus and generally rounded (milled during drilling) fragments of siltstone (i.e., indurated matrix) 525'–545' +10F: 30–60% rounded white vitric, rounded pumice granules and pebbles (up to 10 mm); 10–30% partly subrounded volcanic clasts (vesicular basalt, dacite, black vitrophyre); 20–40% subrounded fragments of light pinkish tan indurated siltstone. +35Fsamples of pumices, siltstone and volcanic lithic grains in varying proportions; minor quartz and sanidine crystals.	Tpf	The upper section of Puye volcaniclastic sediments (Tpf), intersected from 525 ft to 545 ft bgs, is estimated to be 20 ft thick. The Tpf–Tb4 contact, estimated to be at 545 ft bgs, is based on microscopic examination of drill cuttings and interpretation of natural gamma log data.

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DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
545–555	**CERROS DEL RIO VOLCANIC ROCKS:** Basalt lava—very pale orange (10YR 8/2) to medium gray (N5), mixed fragments of vesicular basalt and rounded siltstone and/or claystone fragments. 545'–550' +10F: 40–50% angular/broken chips of strongly vesicular basalt; 50–60% rounded fragments of light tan claystone. +35F: grains of similar composition to +10F plus trace quartz and sanidine crystals. 550'–555' WR/+10F: 80–90% angular/broken chips of strongly vesicular olivine-basalt (noted also, clinopyroxene and xenocrystic quartz); vesicles coated with clay and/or Fe-oxides (hematite); 10–20% light tan claystone/siltstone fragments.	Tb4	The Cerros del Rio volcanic rocks (Tb4) section, including basalt lavas, cinder deposits and volcanic sediments, was intersected from 545 ft to 890 ft bgs and is estimated to be 345 ft thick. Note: The interval 545'–555' likely represents the rubbly, vesicular top of a basalt lava flow.
580–610	Basaltic sediments—medium gray (N5), pebble gravels with fine to coarse sand, moderately sorted, poorly indurated. Samples contain abundant granules and pebbles exhibiting subrounded to well rounded morphologies indicating fluvial transport. 580'–610' +10F: 100% subangular to well rounded clasts (up to 18 mm) composed of weakly altered basalt; locally trace abundances of pumice and dacite grains.	Tb4	
610–614.5	Basalt cinder deposits—medium dark gray (N4), fragments/chips of massive basalt that is weakly porphyritic with aphanitic groundmass; olivine- and clinopyroxene-phyric lava. 605'–614.5' +10F: 99–100% angular/broken chips of weakly porphyritic basalt; phenocrysts of clinopyroxene and olivine; fine-grained groundmass is weakly altered.	Tb4	

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
614.5–650	Basaltic cinder deposits—grayish red (5R 4/2) to medium gray (N5), mixed chips of red scoria and gray weakly porphyritic olivine- and clinopyroxene-phyric basalt. 614.5'–625' +10F: 40–60% angular/broken chips of reddish hematitic (oxidized) scoria; 40–60% angular/broken chips of vesicular olivine- clinopyroxene basalt, weakly altered. 625'–630' +10F: angular chips of predominantly gray altered vesicular basalt; trace red scoria. 630'–650' +10F: 20–40% chips of reddish scoria; 60–80% chips of gray vesicular olivine-clinopyroxene basalt.	Tb4	
650–685	Basaltic cinder deposits and reworked sediments—medium (N5) to light gray (N7), angular chips and locally surrounded (i.e.,milled due to drilling) lapilli composed of vesicular to scoriaceous olivine- and clinopyroxene-phyric basalt. 650'–660' +10F: mixed angular chips and subrounded cinders in varying proportions composed of altered basalt with olivine and clinopyroxene phenocrysts. Locally subrounded lapilli suggest reworking of some portion of these cinders. 660'–670' +10F: angular chips and subrounded to well rounded pebbles and granules of dark reddish gray vesicular to scoriaceous basalt; trace well rounded pebbles of altered basalt. 670'–685' +10F: 100% generally small (up to 8 mm) of dark gray to dark reddish gray olivine- and clinopyroxene -phyric basalt; rounding of clasts somewhat less evident in this interval.	Tb4	

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
685–750	Basaltic sediments—very light gray (N8) medium light gray (N6), pebble gravels with fine to coarse sand, moderately to well sorted, poorly indurated. Samples contain locally well rounded detritus composed of altered clinopyroxene-phyric basalt (also noted trace occurrences of plagiolclase and olivine as phenocrysts) ; locally contains detrital grains/granules of pumice and quartzite. 685'–690' No sample available. No cuttings returned due to lost circulation during drilling. 690'–720' +10F/+35F: 85–95% granules and small pebbles of altered basalt; 5–15% rounded granules of pumice, quartzite and fragments of light pinkish clay. 720'–750' +10F/+35F: 85–95% well sorted grains and granules (up to 5 mm) of altered clinopyroxene-phyric basalt. Most particles exhibit some degree of rounding, indicating reworked tephra or cinders.	Tb4	
750–880	Basaltic lavas with likely interflow sediments and/or tephras—medium light gray (N6), pebble gravels with fine to coarse sand, moderately sorted, poorly indurated. Samples contain subangular to partly well rounded detritus composed uniquely of altered (bleached) porphyritic clinopyroxene- and olivine-phyric basalt with fine-grained plagioclase-rich groundmass. 750'–780' +10F: 99–100% broken chips and subrounded to locally well rounded granules of altered vesicular clinopyroxene-phyric basalt; contains reworked tephra of likely apparent composition; trace pumice granules. 780'–800' +10F: pebble gravel with sand, commonly well rounded granules and pebbles (up to 11 mm) made up entirely of porphyritic basalt with phenocrysts (5–7% by volume) of euhedral black clinopyroxene commonly intergrown with, or as overgrowths on, pale green olivine; plagioclase-rich groundmass locally appears weakly altered.	Tb4	

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
750–880 (cont.)	880'–850' WR: contains moderately abundant very light gray (N8) silt-sized particles coating clasts, indicating more strongly altered basalt. +10F: locally well rounded pebbles (up to 15 mm) and subangular chips, suggesting presence of larger clasts; detritus composed of clinopyroxene- and olivine-phyric basalt. 850'–880' +10F: well rounded detrital clasts (up to 7 mm), present in the samples, appear to diminish in frequency with depth in this interval.		
880–890	Basaltic sediments—medium gray (N5), medium to coarse gravels with fine to coarse sand, moderately sorted, poorly indurated. Samples contain predominantly angular chips and rarely rounded detritus composed of fine-grained weakly porphyritic, altered basalt, minor rounded detrital pumice. 880'–890' +10F: a predominance of angular chips composed of fine-grained, massive altered basalt, phenocryst-poor to aphyric. Minor occurrences of rounded granules of altered clinopyroxene-basalt in the interval 885'–890' contains 1–2% rounded detrital pumices.	Tb4	Note: The interval 880'–890' exhibits predominantly angular chips and an apparent compositional change (i.e., phenocryst-poor) in volcanic rock. The Tb4–Tpf contact, estimated to be at 890 ft bgs, is based on microscopic examination of drill cuttings.
890–895	**PUYE FORMATION:** Volcaniclastic sediments—very light gray (N7) fine to medium gravels with silty fine to medium sand, moderately sorted, moderately indurated. Samples consist of mixed angular chips and well rounded pebbles predominantly of dacite. 890'–895' +10F/35F: 70–80% broken chips and well rounded small (up to 8 mm) pebbles/granules of biotite-dacite; 20–30% indurated fragments of pinkish tan fine-grained silty sandstone	Tpf	The lower section of Puye volcaniclastic sediments (Tpf), intersected from 890 ft to 1155 ft bgs, is estimated to be 265 ft thick.

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
895–905	Volcaniclastic sediments—very light gray (N7) to medium gray (N5) fine to medium gravels with silty fine to coarse sand, poorly sorted, moderately indurated. Samples consist of mixed well rounded pebbles/granules; and broken chips; detritus predominantly of biotite- and hornblende-phyric dacites. 890'–895' +10F: 85–90% broken chips and well rounded small (up to 8 mm) pebbles/granules of gray; trace white dacite with fine hornblendes.	Tpf	
905–915	Volcaniclastic sediments—very light gray (N7) to yellowish gray (5Y 8/1), medium to coarse gravels with silty fine to coarse sand, very poorly sorted, moderately indurated; detritus predominantly to entirely of various dacites. 905'–915' WR: Chips and clasts are silt coated. +10F: 90–95% broken chips and subrounded clasts (up to 15 mm) composed almost exclusively of gray and pink, coarsely porphyritic dacites; 5–10% fragments of indurated sandstone.	Tpf	
915–945	Volcaniclastic sediments—pale yellowish gray (5Y 8/1), fine gravels with silty fine to medium sand, moderately sorted, moderately to weakly indurated; detritus composed uniquely of gray porphyritic dacites. 915'–945' WR: chips and clasts are silt coated. +10F: Nearly monolithologic sample; 90–95% subangular to subrounded granules and pebbles (up to 12 mm) composed of mostly of pink and gray hornblende-phyric dacites; minor abundances of white dacite with fine hornblende phenocrysts; 5–10% fragments of indurated fine-grained sandstone. +35F: ; 70–80% subrounded to well rounded grains of porphyritic dacite; 10–15% broken quartz crystals; 10–15% fine-grained sandstone fragments.	Tpf	

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
945–1000	Volcaniclastic sediments—varicolored, medium (N5) to very light gray (N7) coarse gravels with silty fine to coarse sand, very poorly sorted, weakly indurated; detritus composed of nearly monolithologic coarsely porphyritic hornblende-phyric dacites. 945'–955' +10F: 100% dacitic detritus; angular/broken chips and large (up to 20 mm) rounded pebbles predominantly of gray coarsely porphyritic hornblende-dacite and trace occurrences of white fine-grained dacite with fine hornblendes. +35F: 90–95% dacite grains/fragments; 5–10% fragments of indurated fine-grained sandstone. 955'–970' +10F: 100% dacitic detritus; angular/broken chips and subangular to well rounded pebbles (up to 19 mm) of coarsely porphyritic hornblende-dacite, white dacite with fine hornblende phenocrysts, and trace brown plagioclase-phyric intermediate volcanic rock with frothy textures. 970'–1000' +10F: 100% dacitic detritus; angular/broken chips and frequently well rounded pebbles (up to 15 mm) of gray and pink coarsely porphyritic hornblende -dacites and minor white hornblende -dacite.	Tpf	
1000–1055	Volcaniclastic sediments—medium light gray (N6) medium to coarse gravels with silty fine to medium sand, very poorly sorted, weakly indurated; detritus composed of predominantly of porphyritic dacites; some intervals with minor pumiceous detritus. 1000'–1015' +10F: 98–100% angular/broken chips and well rounded pebbles (up to 20 mm) predominantly of gray to pink coarsely porphyritic dacites; trace detrital pumice granules. 1015'–1055' +10F/35F: 90–95% broken and subrounded pebbles (up to 15 mm) composed predominantly of gray and pink coarsely porphyritic hornblende -phyric dacites and trace white hornblende -dacite; 5–10% rounded detrital pumice granules/pebbles (up to 10 mm).	Tpf	

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GROUND ELEVATION: 6904.16 ft amsl		**TOTAL DEPTH:** 1224.5 ft
DRILLERS: C. Seal, M. Cross	**SITE GEOLOGISTS:** J. R. Lawrence, E. Huggins	

Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
1055–1080	Volcaniclastic sediments—very light gray (N8) pebble gravels with fine to coarse sand, moderately well sorted, weakly cemented; detritus composed entirely of hornblende dacites. 1055'–1080' +10F/35F: 100% dacitic detritus; angular/broken chips and well rounded pebbles (up to 10 mm) of gray to pink coarsely porphyritic dacites and minor white dacite with fine hornblende phenocrysts.	Tpf	
1080–1125	Volcaniclastic sediments—pale yellowish gray (5Y 8/1) medium to coarse gravels with fine to coarse sand, very poorly sorted, weakly cemented; nearly monolithologic sample; detritus composed almost entirely of gray hornblende dacites. 1080'–1125' +10F/35F: 100% dacitic detritus; angular/broken chips and subrounded pebbles (up to 15 mm) of light gray coarsely porphyritic hornblende-dacites and minor white dacite with fine hornblende-phenocrysts.	Tpf	
1125–1155	Volcaniclastic sediments—very light gray (N7) to medium light gray (N6) coarse gravels with fine to coarse sand, very poorly sorted, weakly cemented; nearly monolithologic sample; detritus composed almost entirely of gray porphyritic dacites, minor abundances of detrital pumice. 1125'–1155' +10F: 99–100% angular/broken chips and subrounded to subangular clasts (up to 20 mm) composed of pinkish to light gray coarsely porphyritic biotite- and/or hornbende-phyric dacites; up to 1% detrital pumices. +35F: 95–97% sand-sized grains and broken fragments of pink and gray dacites; 3–5% pumice fragments; trace broken quartz crystals.	Tpf	The contact between Tpf and underlying Miocene pumiceous sediments, estimated to be at 1155 ft bgs, is based on microscopic examination of drill cuttings.

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
1155–1160	**MIOCENE PUMICEOUS SEDIMENTS:** Pumiceous volcaniclastic sediments—varicolored, white (N9) to medium light gray (N7) fine to medium gravels with fine to coarse sand, moderately to poorly sorted, weakly indurated; predominantly detrital dacite clasts and lesser pumices. 1155'–1160' +10F: 70% angular/broken chips of light gray biotite-phyric dacite; trace white dacite with very fine hornblende phenocrysts; 30% white phenocryst-poor pumices.	Tsfu	Pumiceous volcaniclastic sediments of Miocene age (no lithologic symbol has yet been assigned for this unit) were intersected from 1155 ft to the bottom of the R-50 borehole at 1224.5 ft bgs. Miocene pumiceous sediments are locally a minimum of 69.5 ft thick
1160–1185	Pumice-rich volcaniclastic sediments—varicolored, white (N9) to medium light gray (N7) fine gravels with fine to medium sand, moderately sorted, weakly cemented. Samples composed of more than 50% detrital pumices and less than 50% dacite grains to granules. 1160'–1185' +10F: 60–70% angular/broken chips and subrounded granules/pebbles (up to 12 mm) of white glassy (lustrous) to weathered detrital pumices (pumices phenocryst-poor to aphyric); 20–40% angular to subrounded pebbles (up to 15 mm) predominantly of gray biotite-phyric dacites; trace flow-banded rhyolite. +35F: 50–70% pumice grains; 30–50% dacite grains; trace quartz crystals.	Tsfu	
1185–1210	Pumice-rich volcaniclastic sediments—varicolored, white (N9) to medium light gray (N7) fine gravels with fine to medium sand, moderately sorted, weakly cemented. Samples composed of more than 50% detrital pumices and less than 50% grains and granules of various volcanic compositions. 1185'–1210' +10F: 50–70% frequently well rounded granules/pebbles (up to 10 mm) of white, tan and reddish pumices, phenocryst-poor, vitric to locally weathered; 30–50% subangular to subrounded pebbles (up to 8 mm) composed of various volcanic lithologies including hornblende-dacite, white biotite-dacites, andesite and banded vitrophyre.	Tsfu	

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Depth (ft bgs)	Lithology	Lithologic Symbol	Notes
1210–1224.5	Pumice-rich volcaniclastic sediments—varicolored, white (N9) to dark brown (10YR 4/2) pebble gravels with fine to coarse sand, moderately sorted, weakly cemented. Samples composed of more than 80% detrital pumices and up to 20% detritus of various intermediate volcanic compositions. 1210'–1224.5' +10F: 80–90% subrounded to well rounded granules and pebbles of white, tan and grayish brown pumices (Note; white pumices exhibit rare biotite and/or hornblende phenocrysts; distinctly well rounded brown pumices are hornblende-phyric); 10–20% generally angular volcanic lithic fragments (predominantly dacites). +35F: 60–80% pumice grains; 20–40% grains of various volcanic lithologies; trace quartz crystals.	Tsfu	

Borehole Lithologic Log (continued)

ABBREVIATIONS

5YR 8/4 = Munsell rock color notation where hue (e.g., 5YR), value (e.g., 8), and chroma (e.g.,4) are expressed. Hue indicates soil color's relation to red, yellow, green, blue, and purple. Value indicates soil color's lightness. Chroma indicates soil color's strength.

% = estimated per cent by volume of a given sample constituent

amsl = above mean sea level

bgs = below ground surface

GM = groundmass

Qbo = Otowi Member of Bandelier Tuff

Qbog = Guaje Pumice Bed

Qbt = Tshirege Member of the BandelierTuff

Qct = Cerro Toledo interval

Tb4 = Cerros del Rio volcanic rocks

Tpf = Puye Formation

Tsfu = Pumiceous sediments

N/S = no assigned symbol for geologic unit

+10F = plus No. 10 sieve sample fraction

+35F = plus No. 35 sieve sample fraction

WR = whole rock (unsieved sample)

1 mm = 0.039 in

1 in = 25.4 mm

Appendix B

Groundwater Analytical Results

B-1.0 SAMPLING AND ANALYSIS OF GROUNDWATER AT R-50

Two groundwater-screening samples were collected at borehole R-50 during drilling at 1090 and 1224 ft below ground surface (bgs) from regional saturation within the Puye Formation and Miocene pumiceous sediments, respectively. The two borehole screening samples were submitted to Los Alamos National Laboratory's (LANL's or the Laboratory's) Earth and Environmental Sciences Group 14 (EES-14) for cations, anions, perchlorate, and metals analyses.

Groundwater-screening samples were collected from the completed well R-50 during development and aquifer testing and were analyzed only for total organic carbon (TOC) by EES-14. These groundwater-screening samples were collected from the upper screen, 1077.0 to 1087.0 ft bgs, within the Puye Formation and from the lower screen, 1185.0 to 1205.6 ft bgs, within the Miocene pumiceous sediments.

B-1.1 Analytical Techniques

Groundwater samples were filtered (0.45-µm membranes) before preservation and chemical analyses. Samples were acidified at the EES-14 wet chemistry laboratory with analytical-grade nitric acid to a pH of 2.0 or less for metal and major cation analyses.

Groundwater samples were analyzed using techniques specified by the U.S. Environmental Protection Agency (EPA) methods for water analyses. Ion chromatography (EPA Method 300, Rev. 2.1) was the analytical method for bromide, chloride, fluoride, nitrate, nitrite, oxalate, perchlorate, phosphate, and sulfate. The instrument detection limit for perchlorate typically varies from 0.002 to 0.005 ppm in borehole water samples (EPA Method 314.0, Rev. 1). Inductively coupled (argon) plasma optical emission spectroscopy (EPA Method 200.7, Rev. 4.4) was used for analyses of dissolved aluminum, barium, boron, calcium, total chromium, iron, lithium, magnesium, manganese, potassium, silica, sodium, strontium, titanium, and zinc. Dissolved antimony, arsenic, beryllium, cadmium, cesium, cobalt, copper, lead, lithium, mercury, molybdenum, nickel, rubidium, selenium, silver, thallium, thorium, tin, vanadium, and uranium were analyzed by inductively coupled (argon) plasma mass spectrometry (EPA Method 200.8, Rev. 5.4). The precision limits (analytical error) for major ions and trace elements were generally less than ±7%. Total carbonate alkalinity (EPA Method 310.1) was measured using standard titration techniques. Charge balance errors for total cations and anions for the two borehole water samples were -6% and -16% collected during drilling of R-50. The negative cation-anion charge balance values indicate excess anions for the filtered samples. TOC analyses were performed on groundwater-screening samples collected during development and aquifer testing following EPA Method 415.1.

B-1.2 Field Parameters

B-1.2.1 Well Development

Water samples were drawn from a flow-through cell into sealed containers, and field parameters were measured using a YSI multimeter. Results of field parameters, consisting of pH, temperature, dissolved oxygen (DO), oxidation-reduction potential (ORP), specific conductance, and turbidity measured during development at well R-50, are provided in Table B-1.2-1. Percent saturation and concentrations of dissolved oxygen (mg/L) were used to measure DO at well R-50.

During development of the upper screen, pH and temperature varied from 6.97 to 8.87 and from 18.20 to 21.90°C, respectively. Concentrations of DO ranged from 5.82 to 7.13 mg/L. Corrected Eh values ranged from 412.2 to 435.2 millivolts (mV). The correction factor of 203.9 mV at 20ºC was used for calculating Eh values from field ORP measurements and was based on an Ag/AgCl, KCl-saturated filling solution

contained in the ORP electrode. Specific conductance varied from 206 to 348 microsiemens per centimeter (µS/cm).

The final parameters at the end of development of the upper screen were pH of 7.84, temperature of 21.81°C, specific conductivity of 278 µS/cm, and turbidity of 20.1 nephelometric turbidity units (NTU). Although turbidity for the upper screened interval was above 5 NTU at the end of development, the final turbidity measurement after aquifer testing was 2.0 NTU.

During development of the lower screen, pH and temperature varied from 8.10 to 8.32 and from 18.98 to 19.89°C, respectively. Concentrations of DO varied from 10.03 to 14.25 mg/L, which are biased high and were probably influenced by instrument calibration or instrument malfunction. Concentrations of DO should be less than 8 mg/L for the recorded temperatures of the groundwater samples and Henry's law constant for DO. Corrected Eh values varied from 441.5 to 461.0 mV. Specific conductance varied from 203 to 234 µS/cm and turbidity values generally decreased from 47.3 to 4.7 NTU. Final parameters measured at the lower screen were pH of 8.19, temperature of 19.89°C, specific conductivity of 203 µS/cm, and turbidity of 4.9 NTU.

B-1.2.2 Aquifer Testing

During aquifer testing of the upper screened interval, pH and temperature varied from 7.51 to 8.04 and from 17.63°C to 23.66°C, respectively. Percent saturation of DO varied from 74.6 to 87.2, implying that groundwater pumped from R-50 is oxic. Concentrations of DO are calculated to range from 5.5 to 6.5 mg/L at 20°C at 5500 ft (approximate elevation of the upper screen) based on measured percent saturation. The maximum solubility of DO at 100% saturation is 7.4 mg/L at 20°C at 5500 ft. Corrected Eh values determined from field ORP measurements varied from 361.8 to 459.4 mV during aquifer testing of the upper screen (Table B-1.2-1). Specific conductance varied from 224 to 416 µS/cm, and turbidity varied from 8.6 to 1.82 NTU during aquifer testing of the upper screen (Table B-1.2-1).

During aquifer testing of the lower screened interval, pH and temperature varied from 7.45 to 8.29 and from 13.12°C to 21.06°C, respectively. Reliable percent saturation of DO varied from 85.5% to 97.1%, and 14 values exceeded 100%, confirming instrument malfunction for these measurements. Concentrations of DO are calculated to range from 6.4 to 7.2 mg/L at 20°C at 5500 ft (approximate elevation of the lower screen) based on measured percent saturation. The maximum solubility of DO at 100% saturation is 7.4 mg/L at 20°C at 5500 ft. Corrected Eh values determined from field ORP measurements decreased from 442.9 to 498.0 mV during aquifer testing.(Table B-1.2-1). Specific conductance generally decreased from 205 to 174 µS/cm, and turbidity varied from 32.7 to 0.1 NTU during aquifer testing of the lower screen (Table B-1.2-1).

B-1.3 Analytical Results for Groundwater-Screening Samples

Analytical results are presented below. Where available, analytical results for samples from well R-50 are screened against regional aquifer background concentrations from developed wells; these background values are for the Laboratory as a whole (LANL 2007, 095817). It should be noted that because of localized variations in geochemistry, background concentrations for the area upgradient of well R-50 may vary.

B-1.3.1 Cations, Anions, Perchlorate, and Metals

Analytical results for two borehole samples collected at well R-50 during drilling are provided in Table B-1.3-1. The filtered-borehole samples (GW50-10-5028 and GW50-10-5029) consist of disaggregated colloidal aquifer material, drilling material, water used during drilling, and native groundwater.

Dissolved concentrations of fluoride were 1.07 and 0.53 mg/L in the two borehole water samples collected during drilling of R-50. For comparison purposes only, background mean, median, and maximum concentrations of dissolved fluoride are 0.37 mg/L, 0.35 mg/L, and 0.57 mg/L, respectively, for developed wells in the regional aquifer (LANL 2007, 095817). Dissolved concentrations of nitrate(N) were 0.40 and 0.50 mg/L in the two borehole water samples collected during drilling of R-50 (Table B-1.3-1). Dissolved concentrations of sulfate were 9.77 and 3.18 mg/L in the same borehole water samples (Table B-1.3-1). For comparison purposes only, median background concentrations for dissolved nitrate(N) and sulfate in developed wells in the regional aquifer are 0.31 mg/L and 2.83 mg/L, respectively (LANL 2007, 095817).

Perchlorate was not detected in the two borehole water samples (Table B-1.3-1) collected during drilling of well R-50.

Metals results for the two borehole water samples do show elevated concentrations of dissolved molybdenum (0.206 ppm and 0.012 ppm), suggesting these samples contain a component of the drilling lubricant used during drilling. Total dissolved concentrations of chromium were 0.007 and 0.005 ppm (7 and 5 ppb) in the two borehole water samples (Table B.1-3-1). For comparison purposes only, background mean, median, and maximum concentrations of total dissolved chromium in developed regional aquifer wells are 3.07 μg/L, 3.05 μg/L, and 7.20 μg/L, respectively, for the regional aquifer (LANL 2007, 095817).

B-1.3.2 Total Organic Carbon

TOC concentrations from development and aquifer testing are presented in Table B-1.3-2. During development, the TOC concentration from the upper screen sample was 0.49 mgC/L, and the TOC concentration from the lower screen sample was 0.28 mgC/L. During aquifer testing, all measured TOC concentrations from the upper screen were less than 0.4 mgC/L; TOC was not detected in samples from the lower screened interval collected during aquifer testing. The median background concentration of TOC is 0.34 mgC/L for regional aquifer groundwater (LANL 2007, 095817).

B-1.4 Summary

In summary, groundwater at well R-50 is relatively oxidizing, based on corrected positive Eh values and DO concentrations measured during well development and aquifer testing. Redox conditions based on corrected field ORP measurements at well R-50 are similar to other previously wells drilled in Mortandad Canyon, including R-1, R-13, R-15, R-28, and R-42. Concentrations of TOC were less than 0.5 mgC/L in groundwater-screening samples collected during development and aquifer testing at well R-50.

B-2.0 REFERENCE

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), May 2007. “Groundwater Background Investigation Report, Revision 3,” Los Alamos National Laboratory document LA-UR-07-2853, Los Alamos, New Mexico. (LANL 2007, 095817)

Table B.1-2-1
Purge Volumes and Associated Water-Quality Parameters during Well Development and Aquifer Testing at R-50

Date	pH	Temp (°C)	DO (mg/L)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development Composite Water from Both Screens								
2/14/10	n/r[b]; swabbing/bailing						442	442
2/15/10	n/r, swabbing/bailing						407	849
2/16/10	n/r, swabbing/bailing						525	1374
Well Development Upper Screen								
2/18/10	n/r, pumping while swabbing screen						48	1422
2/19/10	n/r, pumping while swabbing screen						510	1932
2/19/10	8.87	21.90	6.98	210.3, 414.2	344	93.7	26	1958
	8.87	20.37	6.95	217.8, 421.7	348	89.7	40	1998
	8.76	19.47	7.11	219.9, 423.8	345	85.2	50	2048
	8.76	19.46	7.08	219.1, 423.0	343	80.4	45	2093
	8.63	19.48	7.03	219.3, 423.2	268	44.6	44	2137
	8.58	20.42	6.73	212.3, 416.2	216	27.7	22	2159
	8.56	20.60	6.45	216.0, 419.9	208	23.6	42	2201
	8.53	20.72	6.57	215.4, 419.3	208	20.6	40	2241
	8.52	20.61	6.50	216.4, 420.3	206	20.6	43	2284
	8.49	20.05	6.41	216.6, 420.5	207	16.6	34	2318
2/20/10	6.97	18.20	7.13	213.7, 417.0	344	26.8	502	2820
	8.14	20.73	6.49	231.3, 435.2	286	36.0	42	2862
	7.91	20.74	6.27	223.0, 426.9	281	34.5	42	2904
	7.75	20.65	6.42	229.4, 433.3	272	35.7	42	2946
	7.72	20.34	6.36	227.3, 431.2	272	34.5	43	2989
	7.84	20.37	6.09	222.3, 426.2	272	37.8	43	3032
	7.97	19.94	6.05	222.1, 426.0	281	61.0	43	3075
	8.19	20.76	5.82	223.5, 427.4	280	32.9	41	3116
	7.50	21.09	6.02	226.7, 430.6	275	22.6	97	3213
	7.52	21.45	6.16	216.1, 420.0	275	21.7	81	3294
	7.78	21.27	5.99	210.2, 414.1	276	19.5	81	3375
	7.84	21.81	5.92	208.3, 412.2	278	20.1	80	3455
	n/r, pumped before pump shut off						13	3468

Table B.1-2-1, continued

Date	pH	Temp (°C)	DO (mg/L)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Development Lower Screen								
2/25/10	n/r, pumping while swabbing screen						1423	4891
2/26/10	n/r, pumping while swabbing screen						573	5464
2/26/10	n/r, pumping sump						268	5732
2/26/10	8.12	18.98	10.66	237.6, 441.5	216	47.3	169	5901
	8.32	19.38	10.82	238.9, 442.8	234	20.8	251	6152
	8.26	19.08	14.25	243.9, 447.8	230	12.4	248	6400
	8.31	19.57	10.03	242.8, 446.7	223	10.0	266	6666
	8.24	19.35	11.90	241.9, 445.8	220	8.0	244	6910
	8.10	19.23	12.17	250.0, 453.9	216	7.8	254	7164
	8.20	19.31	12.27	251.2, 455.1	213	6.6	258	7422
	8.26	19.37	11.62	251.6, 455.5	209	7.1	254	7676
	8.22	19.61	11.91	242.7, 446.6	208	5.7	183	7859
	8.25	19.41	11.72	250.0, 453.9	207	5.8	146	8005
	8.29	19.28	11.43	250.3, 454.2	206	5.5	151	8156
	8.31	19.35	10.78	251.5, 455.4	206	5.7	146	8302
	8.24	19.12	11.68	257.1, 461.0	204	4.8	142	8444
	8.25	19.54	11.62	254.0, 457.9	203	4.7	144	8588
	8.19	19.89	11.45	254.5, 458.4	203	4.9	148	8736
	n/r, pumped prior to shutting off pump						60	8796

Table B.1-2-1, continued

Date	pH	Temp (°C)	DO (%)	ORP, Eh[a] (mV)	Specific Conductivity (μS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Aquifer Pumping Test Upper Screen								
2/28/10	n/r, pumping, aquifer test preparation						90	8886
3/1/10	n/r, pumping, aquifer test preparation						49	8935
3/3/10	n/r, pumping, aquifer test preparation						90	9025
3/4/10	n/r, pumping, aquifer test preparation						60	9085
3/5/10	7.66	17.63	77.1	255.5, 459.4	224	n/r	87	9172
	7.95	20.63	74.7	245.4, 449.3	229	n/r	78	9250
	8.04	23.24	78.8	233.0, 431.5	409	8.6	100	9350
	7.68	21.66	74.6	232.1, 436.0	410	6.5	76	9426
	7.51	19.28	74.9	240.1, 444.0	407	4.5	51	9477
	7.94	23.17	83.4	221.8, 420.3	404	5.2	76	9553
	7.90	21.16	77.8	226.8, 430.7	406	4.0	70	9623
	7.89	22.85	85.8	228.8, 427.3	404	n/r	75	9698
	7.81	23.11	83.1	241.2, 439.7	406	n/r	37	9735
	7.70	23.66	81.2	228.6, 427.1	405	n/r	34	9769
	7.78	23.64	78.2	220.7, 419.2	412	n/r	28	9797
	7.74	22.77	82.6	223.8, 422.3	414	n/r	38	9835
	7.57	22.88	83.9	232.6, 431.1	414	n/r	33	9868
	7.67	21.86	79.8	238.7, 442.6	413	n/r	39	9907
	7.78	21.55	85.6	231.1, 435.0	416	n/r	63	9970
	7.86	21.02	79.4	240.4, 444.3	410	3.0	87	10,057
	7.86	22.31	82.2	242.2, 446.1	408	2.7	38	10,095
	7.84	22.55	82.7	242.9, 441.4	410	3.0	38	10,133
	7.82	22.67	83.9	243.3, 441.8	411	2.6	38	10,171
	7.81	22.55	84.2	240.3, 438.8	376	3.1	37	10,208
	7.79	22.37	84.4	241.0, 444.9	248	2.5	38	10,246
	7.85	21.89	84.2	239.8, 443.7	416	2.4	37	10,283
	7.84	22.54	85.3	231.3, 429.8	414	2.7	76	10,359
	7.82	22.10	86.4	231.6, 435.5	416	2.3	74	10,433
	7.76	21.83	85.7	229.9, 433.8	408	2.1	74	10,507
	7.83	22.25	87.2	223.6, 427.5	310	2.3	74	10,581
	7.77	21.78	85.4	207.6, 411.5	415	1.8	74	10,655
	7.80	22.26	84.3	193.7, 397.6	256	1.8	74	10,729
	7.46	22.67	83.7	163.3, 361.8	246	2.0	104	10,833
	n/r, pumped before pump shut off						37	10,870

Table B.1-2-1, continued

Date	pH	Temp (°C)	DO (%)	ORP, Eh[a] (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Aquifer Pumping Test Lower Screen								
3/8/10	n/r, pumping, mini-test preparation						114	10,984
3/9/10	n/r, pumping, mini-test						2357	13,341
3/10/10	8.29	20.09	149.9	239.0, 442.9	205	32.7	645	13,986
	8.16	19.86	105.0	250.2, 454.1	201	11.7	579	14,565
	8.16	20.19	104.1	248.3, 452.2	197	6.0	1202	15,767
	8.10	19.48	115.6	250.7, 454.6	193	2.7	1199	16,966
	8.09	19.89	103.6	253.1, 457.0	191	1.7	1199	18,165
	7.98	20.42	109.7	252.7, 456.6	189	1.1	1197	19,362
	7.78	20.22	112.9	259.0, 462.9	187	0.4	1196	20,558
	7.74	21.06	101.0	252.1, 456.0	185	0.2	1196	21,754
	7.63	21.03	113.1	242.3, 446.2	184	0.1	1197	22,951
	7.99	20.33	101.1	234.9, 438.8	184	0.1	1196	24,147
	7.82	20.12	108.8	248.4, 452.3	182	0.3	1200	25,347
	8.04	18.51	113.2	246.9, 450.8	180	0.5	1216	26,563
	7.60	16.53	100.5	271.8, 480.7	180	0.4	1145	27,708
	7.48	14.87	90.2	278.8, 487.7	179	0.3	1206	28,914
	7.73	17.71	86.3	263.3, 467.2	178	0.6	1205	30,119
	7.98	20.02	86.0	249.3, 453.2	176	0.5	1205	31,324
	7.63	17.58	89.5	271.7, 475.6	177	0.7	1204	32,528
	7.45	13.12	101.4	286.7, 495.6	177	0.8	1206	33,734
	7.89	16.15	85.6	260.2, 469.1	175	0.7	1204	34,938
	7.77	16.07	92.2	268.2, 477.1	175	1.0	1206	36,144
	7.80	15.51	97.1	266.4, 475.3	174	0.8	1208	37,352
	7.74	18.33	85.5	269.0, 472.9	175	0.9	1208	38,560
	7.45	13.78	91.6	289.1, 498.0	175	0.9	1206	39,766
	n/r, pumped before pump shut off						2403	42,169

[a] Eh (mV) is calculated from a Ag/AgCl saturated KCl electrode filling solution at 15ºC, 20ºC, and 25ºC by adding temperature-sensitive correction factors of 208.9 mV, 203.9 mV, and 198.5 mV, respectively.

[b] n/r = Not recorded.

Table B-1.3-1
EES-14 Analytical Results

Sample ID	Date Received	Sample Type	Depth (ft bgs)	Ag rslt (ppm)	stdev (Ag)	Al rslt (ppm)	stdev (Al)	As rslt (ppm)	stdev (As)	B rslt (ppm)	stdev (B)	Ba rslt (ppm)	stdev (Ba)	Be rslt (ppm)	stdev (Be)	Br(-) ppm	Br(-) (U)	Ca rslt (ppm)	stdev (Ca)	Cd rslt (ppm)	stdev (Cd)	Cl(-) ppm	Cl(-) (U)	ClO4(-) ppm	ClO4(-) (U)	Co rslt (ppm)	stdev (Co)	Alk-CO3 rslt (ppm)
GW50-10-5028	1/27/2010	Borehole	1090	0.001	U*	0.434	0.002	0.0011	0.0000	0.183	0.001	0.834	0.010	0.001	U	0.04	0.02	13.41	0.07	0.001	U	13.1	0.02	0.005	U	0.001	U	0.8
GW50-10-5029	1/27/2010	Borehole	1224	0.001	U	0.074	0.003	0.0008	0.0000	0.139	0.001	0.603	0.004	0.001	U	0.03	0.02	13.03	0.10	0.001	U	4.45	0.02	0.002	U	0.001	U	0.8

Table B-1.3-1 (continued)

Sample ID	Date Received	Sample Type	Alk-CO3 (U)	Cr rslt (ppm)	stdev (Cr)	Cs rslt (ppm)	stdev (Cs)	Cu rslt (ppm)	stdev (Cu)	F(-) ppm	F(-) (U)	Fe rslt (ppm)	stdev (Fe)	Alk-CO3+HCO3 rslt (ppm)	Alk-CO3+HCO3 (U)	Hg rslt (ppm)	stdev (Hg)	K rslt (ppm)	stdev (K)	Li rslt (ppm)	stdev (Li)	Mg rslt (ppm)	stdev (Mg)	Mn rslt (ppm)	stdev (Mn)	Mo rslt (ppm)
GW50-10-5028	1/27/2010	Borehole	U	0.007	0.001	0.001	U	0.003	0.000	1.07	0.02	0.04	0.00	110	2	0.00082	0.00009	3.84	0.02	0.032	0.001	2.96	0.01	0.009	0.001	0.206
GW50-10-5029	1/27/2010	Borehole	U	0.005	0.001	0.001	U	0.001	U	0.53	0.02	0.68	0.00	90	2	0.00016	0.00003	1.27	0.01	0.019	0.000	4.20	0.04	0.028	0.001	0.012

Table B-1.3-1 (continued)

Sample ID	Date Received	Sample Type	stdev (Mo)	Na rslt (ppm)	stdev (Na)	N rslt (ppm)	stdev (Ni)	NO2 (ppm)	NO2-N rslt	NO2-N (U)	NO3 ppm	NO3-N rslt	NO3-N (U)	C2O4 rslt (ppm)	C2O4 (U)	Pb rslt (ppm)	stdev (Pb)	Lab pH	PO4(-3) rslt (ppm)	PO4(-3) (U)	Rb rslt (ppm)	stdev (Rb)	Sb rslt (ppm)	stdev (Sb)	Se rslt (ppm)	stdev (Se)	Si rslt (ppm)	stdev (Si)	SiO2 rslt (ppm)
GW50-10-5028	1/27/2010	Borehole	0.025	23.66	0.22	0.001	0.000	0.01	0.003	U	1.76	0.40	0.02	0.35	0.01	0.0002	U	8.34	0.01	U	0.003	0.000	0.001	U	0.001	U	13.3	0.0	28.4
GW50-10-5029	1/27/2010	Borehole	0.001	12.37	0.04	0.001	0.000	0.01	0.003	U	2.28	0.51	0.02	0.01	U	0.0002	U	8.02	0.01	U	0.001	U	0.001	U	0.001	U	35.2	0.3	75.3

Table B-1.3-1 (continued)

Sample ID	Date Received	Sample Type	stdev (SiO2)	Sn rslt (ppm)	stdev (Sn)	SO4(-2) rslt (ppm)	SO4(-2) (U)	Sr rslt (ppm)	stdev (Sr)	Th rslt (ppm)	stdev (Th)	Ti rslt (ppm)	stdev (Ti)	Tl rslt (ppm)	stdev (Tl)	U rslt (ppm)	stdev (U)	V rslt (ppm)	stdev (V)	Zn rslt (ppm)	stdev (Zn)	TDS (ppm)	Cations	Anions	Balance
GW50-10-5028	1/27/2010	Borehole	0.0	0.001	U	9.77	0.02	0.051	0.003	0.001	U	0.005	0.000	0.001	U	0.0028	0.0001	0.003	0.000	0.012	0.001	228	2.06	2.83	-0.16
GW50-10-5029	1/27/2010	Borehole	0.6	0.001	U	3.18	0.02	0.046	0.002	0.001	U	0.003	0.000	0.001	U	0.0003	0.0000	0.004	0.000	0.023	0.001	209	1.58	1.77	-0.06

* U = not detected.

Table B-1.3-2
TOC Analytical Results at R-50

Sample ID	Date Sampled	Sample Type	Depth (ft)	TOC Concentration (ppm)
GW50-10-1049	2/20/10	Well development	1077–1087	0.49
GW50-10-5050	2/26/10	Well development	1185.0–1205.6	0.28
GW50-10-5051	3/5/10	Aquifer testing	1077–1087	0.33
GW50-10-5052	3/5/10	Aquifer testing	1077–1087	0.30
GW50-10-5053	3/5/10	Aquifer testing	1077–1087	0.31
GW50-10-5054	3/5/10	Aquifer testing	1077–1087	0.30
GW50-10-5055	3/6/10	Aquifer testing	1077–1087	0.26
GW50-10-5056	3/6/10	Aquifer testing	1077–1087	0.27
GW50-10-5057	3/10/10	Aquifer testing	1185.0–1205.6	0.20(U*)
GW50-10-5058	3/10/10	Aquifer testing	1185.0–1205.6	0.20(U)
GW50-10-5059	3/10/10	Aquifer testing	1185.0–1205.6	0.20(U)
GW50-10-5060	3/10/10	Aquifer testing	1185.0–1205.6	0.20(U)
GW50-10-5061	3/10/10	Aquifer testing	1185.0–1205.6	0.20(U)
GW50-10-5062	3/10/10	Aquifer testing	1185.0–1205.6	0.20(U)

*U = Undetected at analytical detection limits.

Appendix C

Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydraulic analysis of pumping tests conducted during February and March 2010 at R-50, a dual-screen regional aquifer well located on the mesa above Mortandad Canyon at Los Alamos National Laboratory (the Laboratory). The tests on R-50 were conducted to quantify the hydraulic properties of the two zones in which the well is screened and evaluate the hydraulic interconnection of the zones.

Testing planned for each screen interval consisted of brief trial pumping, background water-level data collection, and a 24-h constant-rate pumping test. Water levels were monitored in both zones during each of the pumping tests in each screen.

As in most of the R-well pumping tests conducted on the Pajarito Plateau (the Plateau), an inflatable packer system was used in R-50 to both hydraulically isolate the screen zones and try to eliminate casing-storage effects on the test data. Storage effects were eliminated successfully from the screen 2 tests. However, the excessive air content in screen 1 made it impossible to pump water on a sustained basis whenever an upper packer was installed. Therefore, it was necessary to remove the upper packer to perform the 24-h pumping test on screen 1.

Conceptual Hydrogeology

In well R-50, screen 1 lies within sands and gravels of the Puye Formation. Screen 1 is 10 ft long, extending from 1077 to 1087 ft below ground surface (bgs). A 5-ft thick layer of silty deposits from 1085 to 1090 ft bgs may provide some hydraulic resistance between the screen 1 and screen 2 zones. Screen 2 is 20.6 ft long and is positioned 98 ft beneath screen 1, extending from 1185 to 1205.6 ft bgs. It is completed within Miocene pumiceous deposits.

The composite static water level measured on February 28, 2010, before testing was 1066.78 ft bgs. The brass cap elevation at the well is 6904.11 ft above mean sea level (amsl), making the composite water level elevation 5837.33 ft amsl.

When the screen zones were isolated using an inflatable packer, the water level in screen 1 rose 0.44 ft, to a depth of 1066.34 ft bgs and an elevation of 5837.77 ft amsl. Meanwhile, there was no measureable change in the head in screen 2, making its depth to water 1066.78 ft bgs at an elevation of 5837.33 ft amsl. Thus, the water levels showed a downward hydraulic gradient typical of most locations on the Plateau.

The observed head difference between the two zones suggested some degree of hydraulic separation, consistent with the observed silty zone at the bottom of screen 1 and implied likely confinement of the lower zone. In analyzing the pumping test data, the screen 1 zone was interpreted as being unconfined while the screen 2 zone was assumed to be confined.

R-50 Screen 1 Testing

Screen 1 was tested from February 28 to March 8, 2010. After filling the drop pipe on February 28, testing began with brief trial pumping on March 1, background data collection, and an attempted 24-h constant-rate pumping test that began on March 3. During the trial test, the discharged groundwater was observed to be excessively aerated. Despite the large air content in the water, however, the pump operated satisfactorily for the 30-min trial pumping period.

Trial testing of screen 1 began at 9:00 a.m. on March 1 at a discharge rate of 1.6 gallons per minute (gpm), continued for 30 min until 9:30 a.m., and was followed by 2718 min of recovery until 6:48 a.m. on March 3. At that time, in preparation for the 24-h screen 1 test, the inflatable packers were deflated temporarily to release any trapped air beneath the upper packer that might have interfered with pump operation.

At 8:00 a.m. on March 3, a 24-h pumping test was attempted. Unfortunately, no water was produced. It was assumed that the large air content of the screen 1 groundwater interfered with efficient operation of the pump sufficiently to make it impossible to lift water to the surface. To facilitate pumping, the packer was deflated temporarily to clear any additional trapped air and allow pumping of both screen 1 and screen 2 water. In this configuration, the pump readily produced nearly 7 gpm. The discharge rate was adjusted to around 2 gpm, a suitable rate for the screen 1 test, and the packers were reinflated. Pumping continued successfully at 2 gpm for about 20 min, after which the discharge pressure and pumping rate began to decline. Within another few minutes, pumping ceased altogether. It was assumed that air in the screen 1 groundwater again had interfered with pump operation.

The decision was made to run the screen 1 pumping test without an overlying inflatable packer to maximize the chances of expelling air from the pumped zone and minimize the effect of air on the pump. The pumping system was pulled from the well, reconfigured without an upper packer, and rerun.

On March 5, the 24-h pumping test was restarted at 7:00 a.m. at a discharge rate of 1.6 gpm. Pumping continued for 1440 min until 7:00 a.m. on March 6. Following shutdown, recovery/background data were recorded for 2880 min until 7:00 a.m. on March 8 when the pump was pulled from the well.

R-50 Screen 2 Testing

Well R-50 screen 2 was tested from March 8 to 12, 2010. After filling the drop pipe on March 8, testing began with brief trial pumping on March 9, background data collection, and a 24-h constant-rate pumping test that was begun on March 10.

Two trial tests were conducted on March 9. Trial 1 was conducted at a discharge rate of 20.3 gpm for 60 min from 10:00 to 11:00 a.m., followed by 60 min of recovery until 12:00 p.m.

Trial 2 was conducted for 60 min from 12:00 to 1:00 p.m. at a rate of 20.0 gpm. Following shutdown, recovery/background data were recorded for 1140 min until 8:00 a.m. on March 10.

At 8:00 a.m. on March 10, the 24-h pumping test began with a rate of 20.1 gpm. Pumping continued for 1440 min until 8:00 a.m. on March 11. Following shutdown, recovery measurements were recorded for 1440 min until 8:00 a.m. on March 12 when the pump was tripped out of the well. As presented below, while the air content of the screen 2 zone did not interfere with pump operation, it may have contributed to spurious pressure transients that rendered the 24-h pumping test data unusable.

Aerated Groundwater

Consistent with observations in many of the recent R-well pumping tests, presence of gas or air in the groundwater in R-50 presented some difficulties in pumping test execution and data analysis. Of note was that significant gas or air content was observed in the water pumped from both screens 1 and 2 during the pumping tests conducted on R-50. It is likely that high-pressure compressed air used in the drilling process invaded the aquifer zones during drilling, collecting in the formation pore spaces and/or dissolving in the groundwater. When water is pumped from the aquifer, trapped gas or air in the formation pores can move with the pumped water as well as expand and contract in response to pressure changes. Also, pressure reduction associated with pumping can allow dissolved gas or air to come out of solution. The significant quantity of gas or air present in the formations in recently tested wells has had several effects including (1) interfering with pump operating efficiency, (2) causing transient changes in aquifer

permeability, (3) inducing pressure transients as the gas or air expands and contracts, and (4) causing storage-like effects associated with changes in gas or air volume in the formation voids, filter pack, and well casing.

As described in this report, presence of gas or air in the aquifers at R-50 had the effect of making it impossible to pump screen 1 on a sustained basis unless the upper packer was removed and may have contributed to odd pressure transients during the 24-h test on screen 2, precluding analytical interpretation of that portion of the data set.

C-2.0 BACKGROUND DATA

The background water-level data collected in conjunction with running the pumping tests allow the analyst to determine what water-level fluctuations occur naturally in the aquifer and help distinguish between water-level changes caused by conducting the pumping test and changes associated with other causes.

Background water-level fluctuations have several causes, among them barometric pressure changes, operation of other wells in the aquifer, Earth tides, and long-term trends related to weather patterns. The background data hydrographs from the monitored wells were compared with barometric pressure data from the area to determine if a correlation existed.

Previous pumping tests on the Plateau have demonstrated a barometric efficiency for most wells of between 90% and 100%. Barometric efficiency is defined as the ratio of water-level change divided by barometric pressure change, expressed as a percentage. In the initial pumping tests conducted on the early R-wells, downhole pressure was monitored using a vented pressure transducer. This equipment measures the difference between the total pressure applied to the transducer and the barometric pressure; the difference is the true height of water above the transducer.

Subsequent pumping tests, including at R-50, have utilized nonvented transducers. These devices simply record the total pressure on the transducer, that is, the sum of the water height plus the barometric pressure. This results in an attenuated “apparent” hydrograph in a barometrically efficient well. Take as an example a 90% barometrically efficient well. When monitored using a vented transducer, an increase in barometric pressure of 1 unit causes a decrease in recorded downhole pressure of 0.9 unit because the water level is forced downward 0.9 unit by the barometric pressure change. However, if a nonvented transducer is used, the total measured pressure increases by 0.1 unit (the combination of the barometric pressure increase and the water-level decrease). Thus, the resulting apparent hydrograph changes by a factor of 100 minus the barometric efficiency and in the same direction as the barometric pressure change rather than in the opposite direction.

Barometric pressure data were obtained from Technical Area 54 (TA-54) tower site from the Waste and Environmental Services Division–Environmental Data and Analysis (WES-EDA) Group. The TA-54 measurement location is at an elevation of 6548 ft amsl, whereas the wellhead elevation is 6904.16 ft amsl. The static water level in R-50 was 1066.78 ft below land surface, making the calculated water-table elevation 5837.38 ft amsl. Therefore, the measured barometric pressure data from TA-54 had to be adjusted to reflect the pressure at the elevation of the water table within R-50.

The following formula was used to adjust the measured barometric pressure data:

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R} \left(\frac{E1 - E_{TA54}}{T_{TA54}} + \frac{E_{WT} - E_{R-50}}{T_{WELL}} \right) \right] \qquad \textbf{Equation C-1}$$

where P_{WT} = barometric pressure at the water table inside R-50

P_{TA54} = barometric pressure measured at TA-54

g = acceleration of gravity, in m/s^2 (9.80665 m/sec^2)

R = gas constant, in J/kg/degree kelvin (287.04 J/kg/degree kelvin)

$E_{R\text{-}50}$ = land surface elevation at R-50 site, in feet (6904.16 ft)

E_{TA54} = elevation of barometric pressure measuring point at TA-54, in feet (6548 ft)

E_{WT} = elevation of the water level in R-50, in feet (5837.38 ft)

T_{TA54} = air temperature near TA-54, in degrees kelvin (assigned a value of 36.1 degrees Fahrenheit, or 275.4 degrees kelvin)

T_{WELL} = air temperature inside R-50, in degrees kelvin (assigned a value of 62.5 degrees Fahrenheit, or 290.1 degrees kelvin)

This formula is an adaptation of an equation WES-EDA provided. It can be derived from the ideal gas law and standard physics principles. An inherent assumption in the derivation of the equation is that the air temperature between TA-54 and the well is temporally and spatially constant and that the temperature of the air column in the well is similarly constant.

The corrected barometric pressure data reflecting pressure conditions at the water table were compared to the water-level hydrograph to discern the correlation between the two.

C-3.0 IMPORTANCE OF EARLY DATA

When pumping or recovery first begins, the vertical extent of the cone of depression is limited to approximately the well screen length, the filter pack length, or the aquifer thickness in relatively thin permeable strata. For many pumping tests on the Plateau, the early pumping period is the only time the effective height of the cone of depression is known with certainty because soon after startup the cone of depression expands vertically through permeable materials above and/or below the screened interval. Thus, the early data often offer the best opportunity to obtain hydraulic conductivity information because conductivity would equal the earliest-time transmissivity divided by the well screen length.

Unfortunately, in many pumping tests, casing-storage effects dominate the early-time data, potentially hindering the effort to determine the transmissivity of the screened interval. The duration of casing-storage effects can be estimated using the following equation (Schafer 1978, 098240):

$$t_c = \frac{0.6\left(D^2 - d^2\right)}{\frac{Q}{s}}$$

Equation C-2

where t_c = duration of casing-storage effect, in minutes

D = inside diameter of well casing, in inches

d = outside diameter of column pipe, in inches

Q = discharge rate, in gallons per minute

s = drawdown observed in pumped well at time t_c, in feet

The calculated casing-storage time is quite conservative. Often, the data show significant effects of casing storage have dissipated after about half the computed time.

For wells screened across the water table, there can be an additional storage contribution from the filter pack around the screen. The following equation provides an estimate of the storage duration accounting for both casing and filter pack storage.

$$t_c = \frac{0.6\left[\left(D^2 - d^2\right) + S_y\left(D_B^2 - D_C^2\right)\right]}{\frac{Q}{s}}$$

Equation C-3

where S_y = short-term specific yield of filter media (typically 0.2)

D_B = diameter of borehole, in inches

D_C = outside diameter of well casing, in inches

This equation was derived from Equation C-2 on a proportional basis by increasing the computed time in direct proportion to the additional volume of water expected to drain from the filter pack. (To prove this, note that the left-hand term within the brackets is directly proportional to the annular area [and volume] between the casing and drop pipe while the right-hand term is proportional to the area [and volume] between the borehole and the casing, corrected for the drainable porosity of the filter pack. Thus, the summed term within the brackets accounts for all of the volume [casing water and drained filter pack water] appropriately.)

In some instances, it is possible to eliminate casing-storage effects by setting an inflatable packer above the tested screen interval before the test is conducted. As described below, this proved effective for the some but not all of the tests, likely because of trapped air in the formation pores. Also, as stated above, the upper inflatable packer had to be removed in order to complete the 24-h pumping test on screen 1.

C-4.0 TIME-DRAWDOWN METHODS

Time-drawdown data can be analyzed using a variety of methods. Among them is the Theis method (1934-1935, 098241). The Theis equation describes drawdown around a well as follows:

$$s = \frac{114.6Q}{T} W(u)$$

Equation C-4

where

$$W(u) = \int_u^\infty \frac{e^{-x}}{x} dx$$

Equation C-5

and

$$u = \frac{1.87 r^2 S}{Tt}$$

Equation C-6

and where, s = drawdown, in feet

Q = discharge rate, in gallons per minute

T = transmissivity, in gallons per day per foot

S = storage coefficient (dimensionless)

t = pumping time, in days

r = distance from center of pumpage, in feet

To use the Theis method of analysis, the time-drawdown data are plotted on log-log graph paper. Then, Theis curve matching is performed using the Theis type curve—a plot of the Theis well function $W(u)$ versus $1/u$. Curve matching is accomplished by overlaying the type curve on the data plot and, while keeping the coordinate axes of the two plots parallel, shifting the data plot to align with the type curve, effecting a match position. An arbitrary point, referred to as the match point, is selected from the overlapping parts of the plots. Match-point coordinates are recorded from the two graphs, yielding four values: $W(u)$: $1/u$, s, and t. Using these match-point values, transmissivity and storage coefficient are computed as follows:

$$T = \frac{114.6Q}{s} W(u)$$

Equation C-7

$$S = \frac{Tut}{2693r^2}$$

Equation C-8

where T = transmissivity, in gallons per day per foot

S = storage coefficient

Q = discharge rate, in gallons per minute

$W(u)$ = match-point value

s = match-point value, in feet

u = match-point value

t = match-point value, in minutes

An alternative solution method applicable to time-drawdown data is the Cooper–Jacob method (1946, 098236), a simplification of the Theis equation that is mathematically equivalent to the Theis equation for most pumped well data. The Cooper–Jacob equation describes drawdown around a pumping well as follows:

$$s = \frac{264Q}{T} \log \frac{0.3Tt}{r^2 S}$$

Equation C-9

The Cooper–Jacob equation is a simplified approximation of the Theis equation and is valid whenever the u value is less than about 0.05. For small radius values (e.g., corresponding to borehole radii), u is less than 0.05 at very early pumping times and therefore is less than 0.05 for most or all measured drawdown

values. Thus, for the pumped well, the Cooper–Jacob equation usually can be considered a valid approximation of the Theis equation. An exception occurs when the transmissivity of the aquifer is very low. In that case, some of the early pumped well drawdown data may not be well approximated by the Cooper-Jacob equation.

According to the Cooper–Jacob method, the time-drawdown data are plotted on a semilog graph, with time plotted on the logarithmic scale. Then a straight line of best fit is constructed through the data points and transmissivity is calculated using

$$T = \frac{264Q}{\Delta s}$$

Equation C-10

where T = transmissivity, in gallons per day per foot

Q = discharge rate, in gallons per minute

Δs = change in head over one log cycle of the graph, in feet

Because many of the test wells completed on the Plateau are severely partially penetrating, an alternate solution considered for assessing aquifer conditions is the Hantush equation for partially penetrating wells (Hantush 1961, 098237; Hantush 1961, 106003). The Hantush equation is as follows:

Equation C-11

$$s = \frac{Q}{4\pi T}\left[W(u) + \frac{2b^2}{\pi^2 (l-d)(l'-d')}\sum_{n=1}^{\infty}\frac{1}{n^2}\left(\sin\frac{n\pi l}{b} - \sin\frac{n\pi d}{b}\right)\left(\sin\frac{n\pi l'}{b} - \sin\frac{n\pi d'}{b}\right)W\left(u, \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}\right)\right]$$

where, in consistent units, s, Q, T, t, r, S, and u are as previously defined and

b = aquifer thickness

d = distance from top of aquifer to top of well screen in pumped well

l = distance from top of aquifer to bottom of well screen in pumped well

d' = distance from top of aquifer to top of well screen in observation well

l' = distance from top of aquifer to bottom of well screen in observation well

K_z = vertical hydraulic conductivity

K_r = horizontal hydraulic conductivity

In this equation, $W(u)$ is the Theis well function and $W(u,\beta)$ is the Hantush well function for leaky aquifers where

$$\beta = \sqrt{\frac{K_z}{K_r}}\frac{n\pi r}{b}$$

Equation C-12

Note that for single-well tests, $d = d'$ and $l = l'$.

C-5.0 RECOVERY METHODS

Recovery data were analyzed using the Theis recovery method. This is a semilog analysis method similar to the Cooper–Jacob procedure.

In this method, residual drawdown is plotted on a semilog graph versus the ratio t/t', where t is the time since pumping began and t' is the time since pumping stopped. A straight line of best fit is constructed through the data points and T is calculated from the slope of the line as follows:

$$T = \frac{264Q}{\Delta s}$$ **Equation C-13**

The recovery data are particularly useful compared with time-drawdown data. Because the pump is not running, spurious data responses associated with dynamic discharge rate fluctuations are eliminated. The result is that the data set is generally “smoother” and easier to analyze.

C-6.0 SPECIFIC CAPACITY METHOD

The specific capacity of the pumped well can be used to obtain a lower-bound value of hydraulic conductivity. The hydraulic conductivity is computed using formulas that are based on the assumption that the pumped well is 100% efficient. The resulting hydraulic conductivity is the value required to sustain the observed specific capacity. If the actual well is less than 100% efficient, it follows that the actual hydraulic conductivity would have to be greater than calculated to compensate for well inefficiency. Thus, because the efficiency is not known, the computed hydraulic conductivity value represents a lower bound. The actual conductivity is known to be greater than or equal to the computed value.

For fully penetrating wells, the Cooper–Jacob equation can be iterated to solve for the lower-bound hydraulic conductivity. However, the Cooper–Jacob equation (assuming full penetration) ignores the contribution to well yield from permeable sediments above and below the screened interval. To account for this contribution, it is necessary to use a computation algorithm that includes the effects of partial penetration. One such approach was introduced by Brons and Marting (1961, 098235) and augmented by Bradbury and Rothchild (1985, 098234).

Brons and Marting introduced a dimensionless drawdown correction factor, s_P, approximated by Bradbury and Rothschild as follows:

$$s_P = \frac{1-\frac{L}{b}}{\frac{L}{b}}\left[\ln\frac{b}{r_w} - 2.948 + 7.363\frac{L}{b} - 11.447\left(\frac{L}{b}\right)^2 + 4.675\left(\frac{L}{b}\right)^3\right]$$ **Equation C-14**

In this equation, L is the well screen length, in feet. Incorporating the dimensionless drawdown parameter, the conductivity is obtained by iterating the following formula:

$$K = \frac{264Q}{sb}\left(\log\frac{0.3Tt}{r_w^2 S} + \frac{2s_P}{\ln 10}\right)$$ **Equation C-15**

The Brons and Marting procedure can be applied to both partially penetrating and fully penetrating wells.

To apply this procedure, a storage coefficient value must be assigned. Storage coefficient values generally range from 10^{-5} to 10^{-3} for confined aquifers and 0.01 to 0.25 for unconfined aquifers (Driscoll 1986, 104226). The screen 1 zone was treated as unconfined in this analysis, while the screen 2 zone was considered confined. Storage coefficient values ranging from 0.01 to 0.10 were used for the screen 1 calculations and a range of 10^{-4} to 10^{-3} was used for screen 2. The calculation result is not particularly sensitive to the choice of storage coefficient value, so a rough estimate is generally adequate to support the calculations.

The analysis also requires assigning a value for the saturated aquifer thickness, b. For screen 1, the aquifer was considered to extend from the static water level of 1066.34 ft to the top of the silty zone at 1085 ft—a thickness of 18.66 ft. This made the usable screen length 8 ft—from 1077 to 1085 ft. For screen 2, the aquifer thickness was arbitrarily assigned a value of 120 ft. For partially penetrating conditions, the calculations are not particularly sensitive to the choice of aquifer thickness because sediments far above or below the screen typically contribute little flow.

C-7.0 BACKGROUND DATA ANALYSIS

Background aquifer pressure data collected during the R-50 tests were plotted along with barometric pressure to determine the barometric effect on water levels.

Figure C-7.0-1 shows aquifer pressure data from R-50 screen 1 during the test period along with barometric pressure data from TA-54 that have been corrected to equivalent barometric pressure in feet of water at the water table. The R-50 data are referred to in the figure as the “apparent hydrograph” because the measurements reflect the sum of water pressure and barometric pressure, having been recorded using a nonvented pressure transducer. The times of the pumping periods for the R-50 pumping tests are included in the figure for reference.

The apparent hydrograph showed a steady decline in observed aquifer pressure through the entire monitoring period. This may have been a response to pumping Los Alamos County well PM-4, which was started on February 28 and operated almost continuously throughout the testing and monitoring period shown in the figure. No significant pressure change in response to barometric pressure fluctuations occurred, suggesting a barometric efficiency of near 100%.

The data in Figure C-7.0-1 showed a clear response in screen 1 to pumping screen 2. The magnitude of the drawdown response to pumping screen 2 at 20.0 gpm for 24 h was approximately 0.03 ft.

Figure C-7.0-2 shows aquifer pressure data collected from R-50 screen 2 during the pumping test effort. The sinusoidal diurnal fluctuations having a magnitude of a few hundredths of a foot were likely induced by Earth tides. In addition to the Earth-tide signal, the overall shape of the apparent hydrograph appeared to be a muted version of the barometric pressure signal.

Figure C-7.0-3 shows an expanded-scale plot of the apparent hydrograph showing its similarity to the barometric pressure plot. The relative scales on the plots implied a possible barometric efficiency of about 75%. Of note, however, was that the fluctuations in the apparent hydrograph appeared to *precede* those in the barometric pressure signal—a phenomenon that is ostensibly impossible but that has been observed previously on the plateau. It may be that the similarity in the shapes of the plots was merely coincidental, as it is difficult to explain how changes in the aquifer pressure could precede barometric pressure changes. Alternatively, it is conceivable that atmospheric pressure changes some distance away are transmitted through the aquifer to R-50 more rapidly than they can travel through the atmosphere to the measuring tower.

According to Figures C-7.0-2 and C-7.0-3, the screen 2 water levels showed no discernable response to pumping screen 1 at 1.6 gpm.

Hydrograph data from additional nearby R-wells were downloaded to check for a possible pumping response during the R-50 pumping tests. Wells examined included R-28 (1320 ft away), R-42 (1940 ft), R-44 (1350 ft) and R-45 (1880 ft). Figures C-7.0-4 through C-7.0-9 show data retrieved from R-28, R-42, R-44 screen 1, R-44 screen 2, R-45 screen 1 and R-45 screen 2, respectively.

Because the barometric pressure fluctuations in the hydrographs were large, it was necessary to correct the water level data by removing the barometric effect. This correction was made using BETCO (barometric and Earth-tide correction) software—a mathematically complex correction algorithm that uses regression deconvolution (Toll and Rasmussen 2007, 104799) to modify the data. The BETCO correction not only removes barometric-pressure effects but Earth tides as well. The BETCO corrected data for each of the screen zones are included in the data plots in Figures C-7.0-4 through C-7.0-9. The packer at R-44 was deflated from March 6 to 10; during this time, the composite water level is shown in Figures C-7.0-6 and C-7.0-7.

Examination of these figures showed no response to pumping R-50 screen 1. Lack of a response was less certain for the 20-gpm test on R-50 screen 2. R-28, R-44 screen 2 and R-45 screen 2 showed a possible response, although the noise in the corrected signal was sufficient to make a confident determination of a response difficult.

C-8.0 WELL R-50 SCREEN 1 DATA ANALYSIS

This section presents the data obtained from the R-50 screen 1 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery from the trial test and the 24-h constant-rate test.

C-8.1 Well R-50 Screen 1 Trial Test

Figure C-8.1-1 shows a semilog plot of the drawdown data collected from the 30-min trial test on screen 1 at a discharge rate of 1.6 gpm. The transmissivity estimated from the plot was 280 gpd/ft. Based on a permeable thickness of 18.66 ft (from the static water level to the top of the silty zone near the bottom of screen 1), the computed hydraulic conductivity was 15.0 gpd/ft^2, or 2.0 ft/d.

Figure C-8.1-2 shows the recovery data collected following shutdown of the trial pumping test. Within several minutes of pump shutoff, nearly full recovery was achieved. The premature water level recovery may have been an indication of hysteretic effects. In unconfined aquifers, rate of recovery can be more rapid than that of drawdown because of a smaller effective storage coefficient during recovery. During pumping the capillary fringe above the water table increases in thickness, while during recover it gets thinner (Bevan et al. 2005, 105186). If the rate of thinning during recovery exceeds the rate of growth during pumping, the effective storage coefficient during recovery will be less than that during pumping, resulting in a more rapid recovery rate than drawdown rate. Additionally, as the water table rebounds during recovery, it can trap air in the previously dewatered pore spaces, further decreasing the effective recovery storage coefficient. Further exacerbating the problem may have been extraneous air already in the formation or air that was dissolved in the groundwater and came out of solution during pumping. It was not possible to estimate aquifer properties from the recovery graph.

The form of the curve in Figure C-8.1-2 was suggestive of storage effects, even though an upper inflatable packer was used for the trial test. The recovery data were plotted as calculated recovery versus recovery time on the log-log graph shown in Figure C-8.1-3. The resulting essentially linear data plot over most of the

range of water-level change was consistent with storage effects and may have resulted from accumulation of additional air in the formation and well casing coming out of solution during the pumping period.

C-8.2 Well R-50 Screen 1 24-Hour Constant-Rate Test

Figure C-8.2-1 shows a semilog plot of the drawdown data collected from the 24-h constant-rate pumping test conducted at 1.6 gpm. Because an inflatable packer was not used for this test, casing-storage effects persisted for a significant duration. The relevant storage times are shown on the graph for reference. The transmissivity estimated from the plot was 220 gpd/ft making the average hydraulic conductivity of the upper 18.66 ft of saturation 11.8 gpd/ft^2, or 1.6 ft/d. The slope fluctuations over the latter part of the test may have reflected aquifer heterogeneity or may have resulted from hydraulic conductivity fluctuations in the aerated portion of the formation near the well bore in response to varying air distribution and content over time.

Figure C-8.2-2 shows the recovery data collected following shutdown of the 24-h constant-rate pumping test. As indicated by the storage times on the graph, the entire span of recovery was casing-storage affected and could not be analyzed.

As seen in the trial test, full recovery was achieved in a relatively short time, suggesting asymmetry between the drawdown and recovery responses. Figure C-8.2-3 shows a comparison plot of drawdown and calculated recovery, highlighting the stunning difference in the two responses.

C-8.3 Well R-50 Screen 1 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound transmissivity value for the permeable zone penetrated by R-50 screen 1 to provide a frame of reference for evaluating the foregoing analyses.

At the end of the 24-h pumping test, the discharge rate was 1.6 gpm with a resulting drawdown of 10.55 ft for a specific capacity of 0.15 gpm/ft. In addition to specific capacity and pumping time, other input values used in the calculations included storage coefficient values ranging from 0.01 to 0.1, a borehole radius of 0.51 ft, a screen length of 8 ft (from the top of screen 1 at 1077 ft to the top of the silty sediments at 1085 ft), and a saturated thickness of 18.66 ft (from the static water level to the top of the silty sediments).

Applying the Brons and Marting method to these inputs yielded lower-bound transmissivity values shown in Figure C-8.3-1. As indicated, the lower-bound transmissivity values fell between 220 and 280 gpd/ft, consistent with the pumping test values cited previously.

C-9.0 WELL R-50 SCREEN 2 DATA ANALYSIS

This section presents the data collected from the R-50 screen 2 pumping tests and the results of the analytical interpretations. Data are presented for drawdown and recovery data from trials 1 and 2.

The data from the 24-h test showed highly unusual response and were not analyzable. Figure C-9.0-1 shows a linear plot of the complete data set obtained from screen 2 during the screen 2 pumping tests. The response to the trial tests appeared normal, but the data from the 24-h test was inexplicable.

As shown on the graph, pressure began rising steadily about an hour before the start of the 24-h test. When the pump was started, an abrupt drop in level occurred, but then the steady rate of rise resumed. It appeared that the pumping drawdown response was superimposed on the rising trend, although the magnitude of the drawdown was substantially less than had been observed during the trial tests.

Several hours into the test, the rate of rise diminished and remained small for the remainder of the pumping period.

When pumping stopped, there was an abrupt rise in pressure/level to an apparent position above the static water level ("super recovery"), followed by a few linear rises in level as well as a brief period of apparent stabilization. Of significance, after 24 h of recovery, when the inflatable packer was deflated, the measured level dropped to the actual static water level.

It was not known if the pressure transducer had malfunctioned or if the recorded pressures had actually occurred, although it is possible that the measurements are reliable. Other pumping tests conducted in wells having air in the formation have shown similar data response. Specifically, tests conducted on R-48 and R-34 showed some of the same linear responses seen in Figure C-9.0-1. Those tests also showed super recovery with magnitudes of up to 15 ft of recovery above the static water level. The common factor among the wells was the presence of gas or air in the formation, as evidenced by its effect on submersible pump operation and/or visible gas or air bubbles in the pumped water.

The anecdotal observation of the transducer producing the correct water level when the packer was deflated at the conclusion of testing lends credibility to the idea that the transducer did not malfunction. It is possible that the apparent super recovery resulted from gas or air pressure around the borehole or in the well at the transducer that could not be relieved until the packer was deflated, allowing air to escape up the well casing. Following similar anomalies observed in the testing of R-48, the pressure transducer used in that test was returned to the vendor for examination and testing and was found to be in perfect working order.

Regardless of the causes of the unusual response recorded in the screen 2 24-h pumping test, the data were unusable and were not analyzed.

C-9.1 Well R-50 Screen 2 Trial 1

Figure C-9.1-1 shows a semilog plot of the screen 2 drawdown data collected from trial 1 at a discharge rate of 20.3 gpm. The early data suggested a transmissivity of 1400 gpd/ft for the 20.6-ft-long screened interval, making the estimated average hydraulic conductivity 68.0 gpd/ft^2, or 9.1 ft/d.

The subsequent progressively flatter slopes may indicate variety of conditions including leakage, vertical growth of the cone of depression into a thicker sequence of sediments, and a lateral increase in hydraulic conductivity and transmissivity. In this instance, it was likely that the flattening trend indicated vertical growth of the cone of depression beyond the screen length. The computed transmissivity for any particular segment of the data plot roughly reflects the transmissivity of the unknown sediment thickness penetrated by the cone of depression at that particular time.

Figure C-9.1-2 shows the recovery data collected following shutdown of the trial 1 pumping test. The transmissivity estimated from the early data was 1380 gpd/ft, making the computed hydraulic conductivity 67.0 gpd/ft^2, or 9.0 ft/d. The subsequent data showed the same steady slope decrease observed in the drawdown data set.

C-9.2 Well R-50 Screen 2 Trial 2

When trial 2 pumping was first initiated, no water was produced for 1 min at which time the pump was shut off. The pump was restarted after a 2-min shutdown and produced water. Subsequent examination of the drawdown data showed that the pump had indeed produced water during the first minute of operation, indicating a significant length of drop pipe must have drained and was being refilled during the initial 1-min pumping period.

Figure C-9.2-1 shows a semilog plot of the drawdown data collected from the trial 2 restart at a discharge rate of 20.0 gpm. The transmissivity value computed from the early data was 1350 gpd/ft, making the average hydraulic conductivity of the screened interval 65.5 gpd/ft^2, or 8.8 ft/d. The subsequent flatter slopes showed the recharge-like effect associated with possible vertical growth of the cone of depression beyond the limited screened interval, leakage and/or lateral heterogeneity.

Figure C-9.2-2 shows Hantush partial penetration curve matching analysis of the data. The analysis was performed for an arbitrary assumed aquifer thickness of 120 ft. The analysis shown in Figure C-9.2-2 was based on an anisotropy ratio of 1.0. The hydraulic conductivity determined from the curve match was 63.3 gpd/ft^2, or 8.5 ft/d.

The Hantush analysis was repeated for anisotropy values of 0.1 and 0.01 as shown in Figures C-9.2-3 and C-9.2-4, respectively. The curve matches became progressively worse for increasing anisotropy severity, suggesting relatively isotropic conditions for the contiguous aquifer zone penetrated by screen 2. Because of the poor curve matches in Figures C-9.2-3 and C-9.2-4, the calculated aquifer parameters were not considered reliable.

Figure C-9.2-5 shows the recovery data collected following shutdown of the trial 2 pumping test. As indicated on the graph, the transmissivty value obtained from the early recovery data was 1330 gpd/ft, implying a hydraulic conductivity of 64.6 gpd/ft^2, or 8.6 ft/d. The later data again showed a continuously flattening slope associated with vertical expansion of the cone of impression (recovery cone) around the well.

C-9.3 Well R-50 Screen 2 Specific Capacity Data

Specific capacity data were used along with well geometry to estimate a lower-bound hydraulic conductivity value for the permeable zone penetrated by R-50 screen 2. This was done to provide a frame of reference for evaluating the foregoing analyses.

During the trial 2 pumping test, the discharge rate was 20.0 gpm for 60 min. The corresponding drawdown was 10.9 ft for a specific capacity estimate of 1.83 gpm/ft. In addition to specific capacity and pumping time, other input values used in the calculations included an arbitrary aquifer thickness of 120 ft, a well screen length of 20.6 ft, storage coefficient values ranging from 10^{-4} to 10^{-3} and a borehole radius of 0.51 ft.

Applying the Brons and Marting method to these inputs yielded the lower-bound hydraulic conductivity values shown in Figure C-9.3-1. As indicated, the lower-bound hydraulic conductivity values ranged from about 80 to 85 gpd/ft^2, depending on the assumed storage coefficient value. The hydraulic conductivity values computed from the pumping test analyses cited previously averaged about 66 gpd/ft^2. Thus, the calculated lower-bound values exceeded the pumping test values, although by a modest amount (20%).

The discrepancy between the lower-bound hydraulic conductivity values and the pumping-test values could have resulted from heterogeneity effects—for example, the non-screened sediments having a greater average hydraulic conductivity than the screened zone. Alternatively, it could imply small errors in the pumping test values. An example of a possible cause of errors in the basic analyses would be a minor storage effect associated with a small amount of air trapped in the formation. The resulting subtle storage effect could lead to a slight underestimate of the hydraulic conductivity. Finally, it is possible that the assumption of fully confined conditions underestimated the storage coefficient for the screen 2 zone. The slight drawdown observed in screen 1 while pumping screen 2 could imply minor dewatering of the upper aquifer during the test, increasing the effective screen 2 storage coefficient. Incorporating a larger storage coefficient in the Brons and Marting calculations would have had the effect of reducing the computed hydraulic conductivity somewhat. It was not possible to determine the nature of the cause(s) of the slight

inconsistency between the pumping test results and specific capacity analysis. Nevertheless, the computed difference was relatively small and inconsequential and of relatively the same magnitude.

C-10 SUMMARY

Constant rate pumping tests were conducted on R-50 screens 1 and 2. The tests were performed to gain an understanding of the hydraulic characteristics of the screen zones and the degree of interconnection between them. Numerous observations and conclusions were drawn for the tests as summarized below.

The static water level observed in screen 1 was 0.44 ft higher than that in screen 2, showing a downward hydraulic gradient—typical for multiple-screen wells at the Laboratory. The silty sediments observed from 1085 to 1090 ft bgs likely created hydraulic resistance between the two screen zones. These sediments were assumed to provide confinement for the screen 2 zone. The screen 1 zone was assumed to be unconfined.

A comparison of barometric pressure and R-50 screen 1 water-level data showed a high barometric efficiency, probably around 100%. The data for screen 2, on the other hand, suggested the possibility of a barometric efficiency for that zone of about 75%, although the hydrograph fluctuations inexplicably preceded the barometric pressure changes.

Pumping screen 1 at 1.6 gpm for 1440 min had no discernable effect on water levels in screen 2, whereas pumping screen 2 at 20.1 gpm for 1440 min caused about 0.03 ft of drawdown in screen 1.

Analysis of the screen 1 pumping tests showed transmissivity values of 220 and 280 gpd/ft, averaging 250 gpd/ft. This made the average hydraulic conductivity of the upper 18.66 ft of saturated formation (from the screen 1 static water level of 1066.34 ft to the top of the silty sediments at 1085 ft) 13.4 gpd/ft^2, or 1.8 ft/d.

Screen 1 produced 1.6 gpm for 1440 min with 10.55 ft of drawdown for a specific capacity of 0.15 gpm/ft. The lower-bound transmissivity computed from this information was between about 220 and 280 gpd/ft, consistent with the pumping tests values.

Analysis of the screen 2 pumping tests suggested a hydraulic conductivity of 66 gpd/ft^2 (8.8 ft/d) for the 20.6-ft-thick screened interval.

Screen 2 produced 20.0 gpm for 60 min with 10.9 ft of drawdown for a short-term specific capacity of 1.8 gpm/ft. The lower-bound hydraulic conductivity computed from this information ranged from 80 to 85 gpd/ft^2, somewhat inconsistent with the pumping test value, but of relatively the same magnitude.

The steadily flattening drawdown curves for screen 2 showed a recharge-like effect associated with vertical growth of the cone of depression (partial penetration), leakage, and/or a lateral increase in hydraulic conductivity.

The data showed significant effects of air in the formation, filter pack and/or well casing. The likely source of the air was the high-pressure compressed air used in drilling the borehole. The presence of air caused storage effects in some of the screen 1 tests and made it impossible to pump water from screen 1 on a sustained basis if an upper packer was used. Much of the data recorded in the screen 2 testing showed extremely unusual response, possibly related to dynamic pressure transients associated with temporal air content and distribution in the formation.

C-11.0 REFERENCES

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

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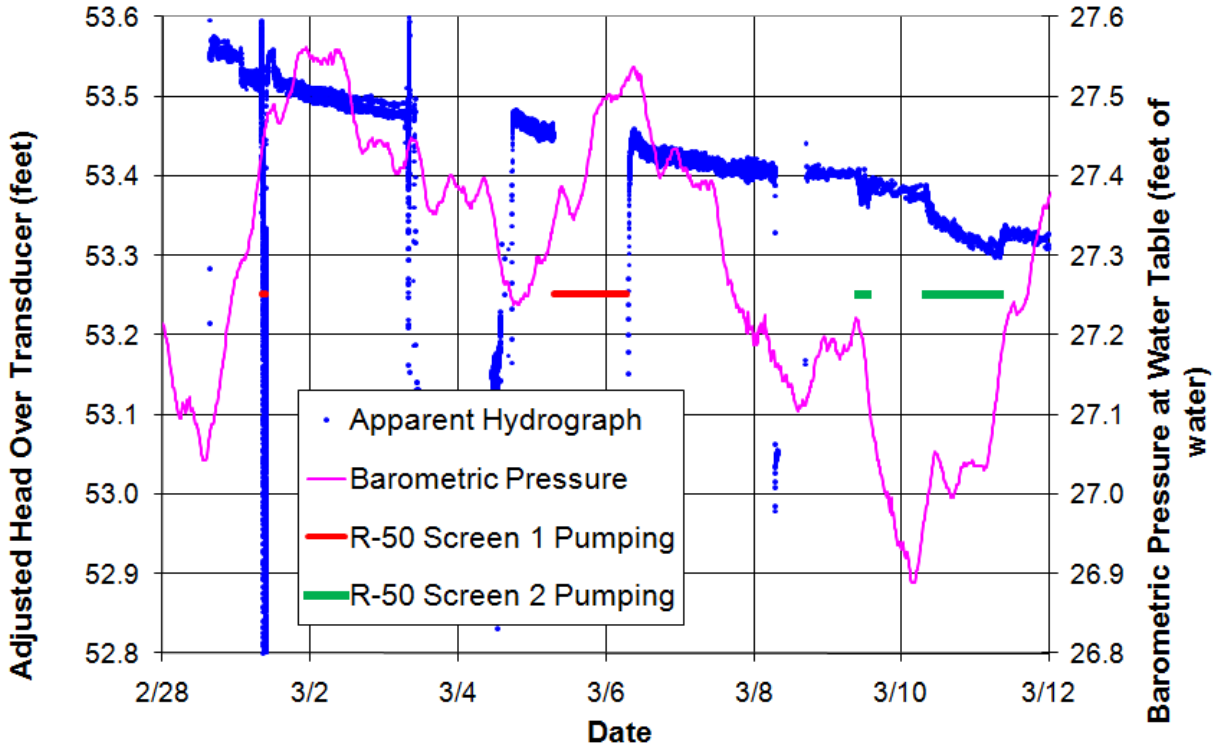


Figure C-7.0-1 Well R-50 screen 1 apparent hydrograph

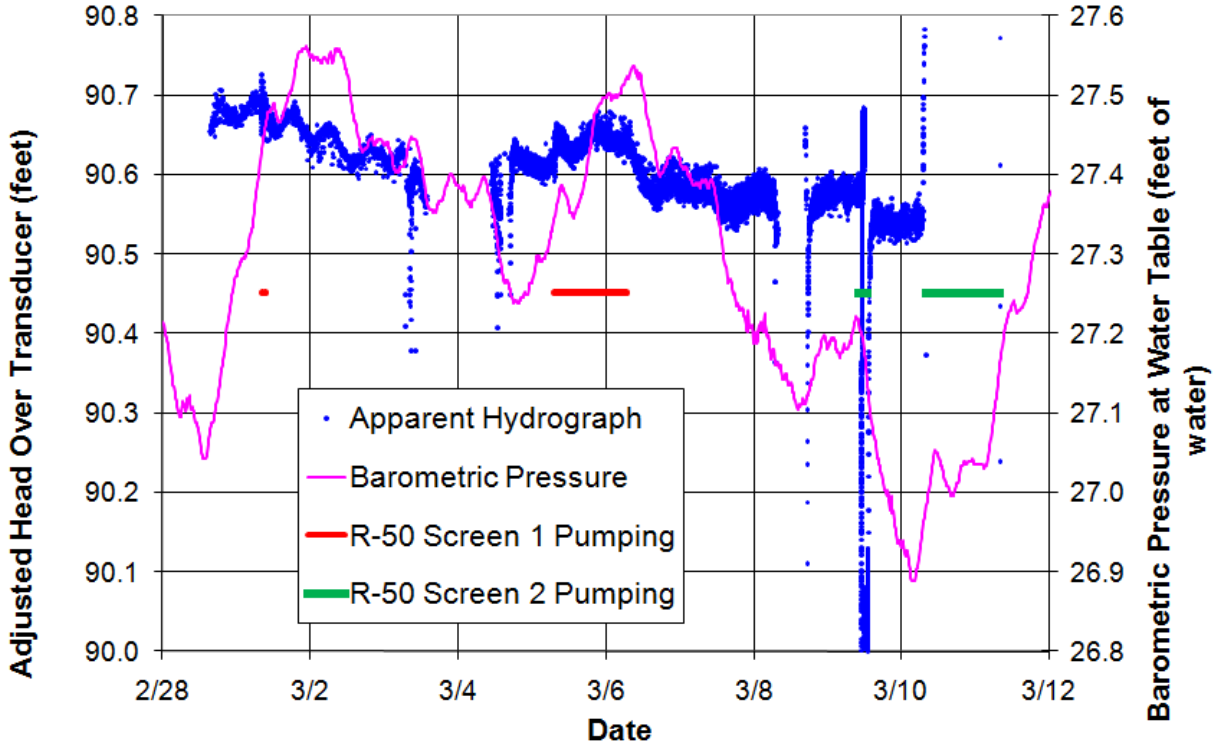


Figure C-7.0-2 Well R-50 screen 2 apparent hydrograph

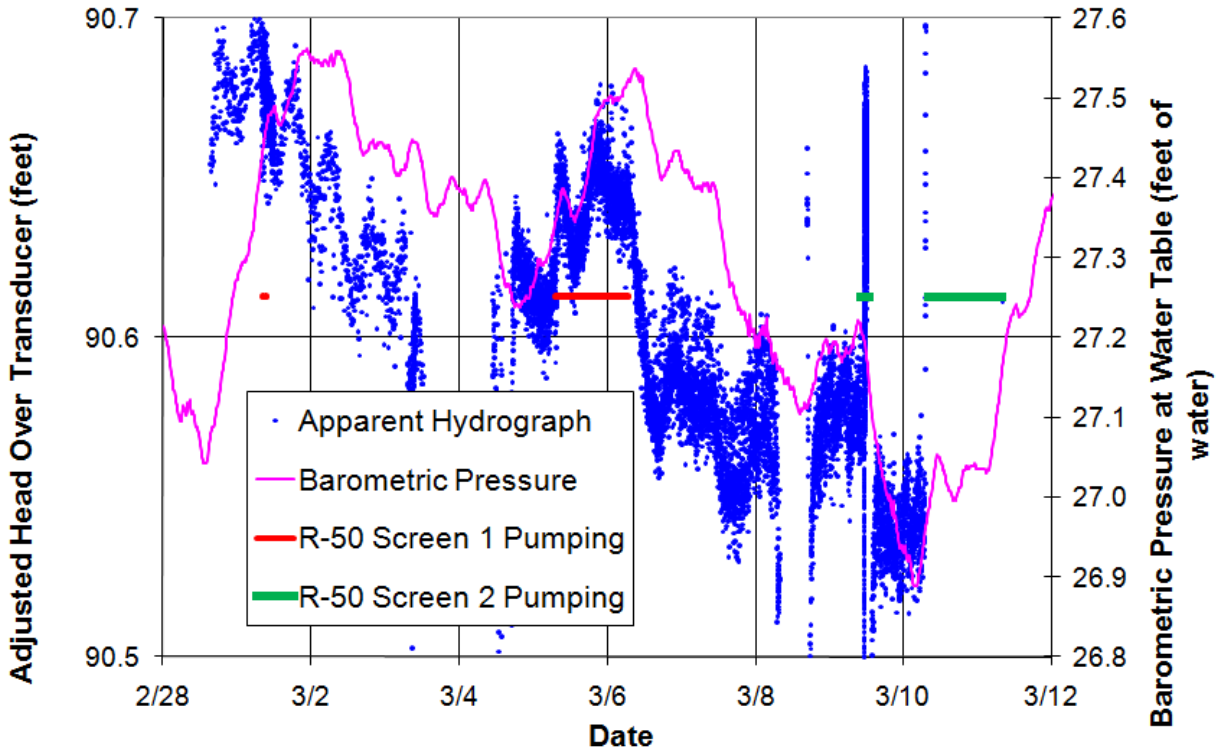


Figure C-7.0-3 Well R-50 screen 2 apparent hydrograph—expanded scale

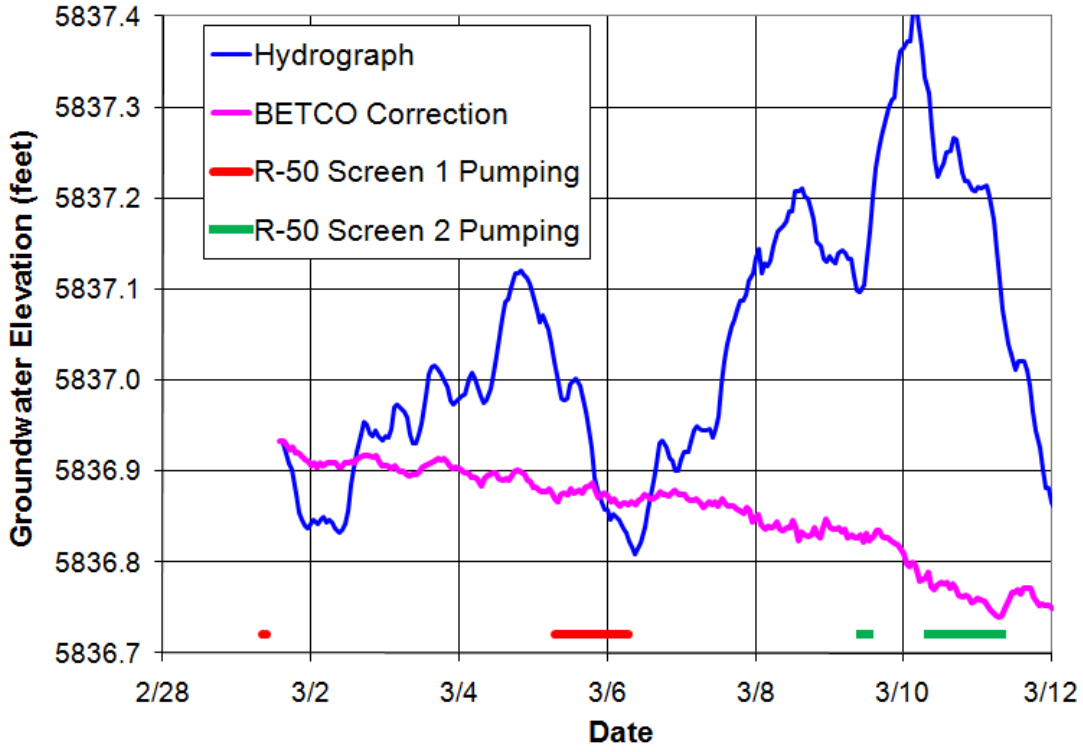


Figure C-7.0-4 Well R-28 hydrograph

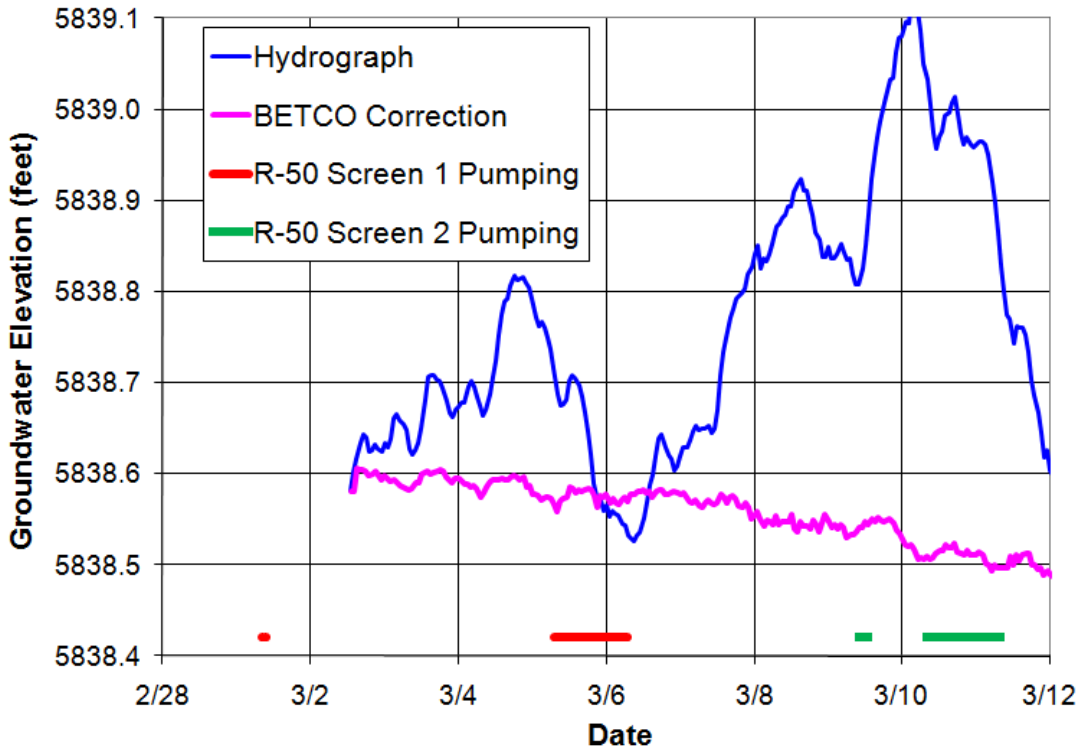


Figure C-7.0-5 Well R-42 hydrograph

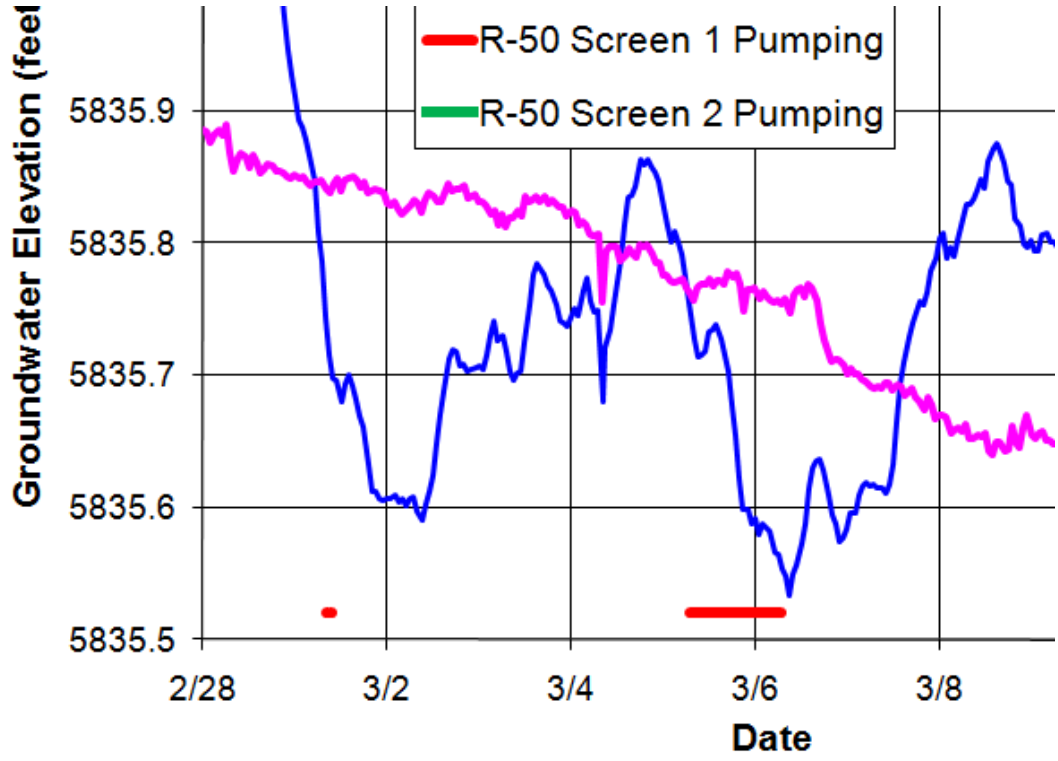


Figure C-7.0-6 Well R-44 screen 1 hydrograph

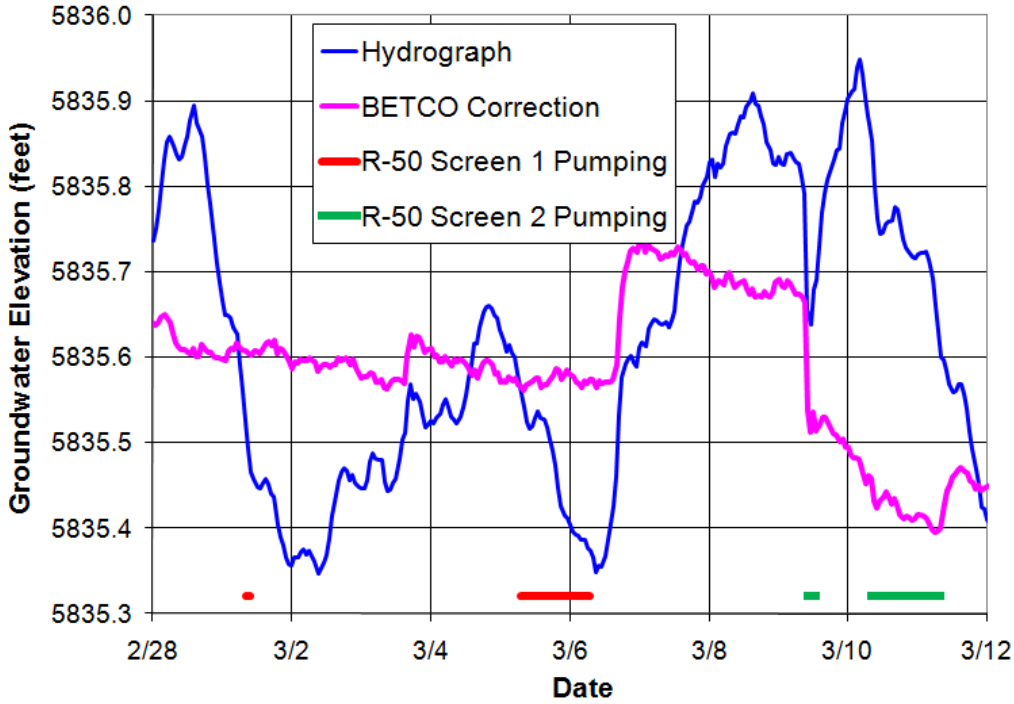


Figure C-7.0-7 Well R-44 screen 2 hydrograph

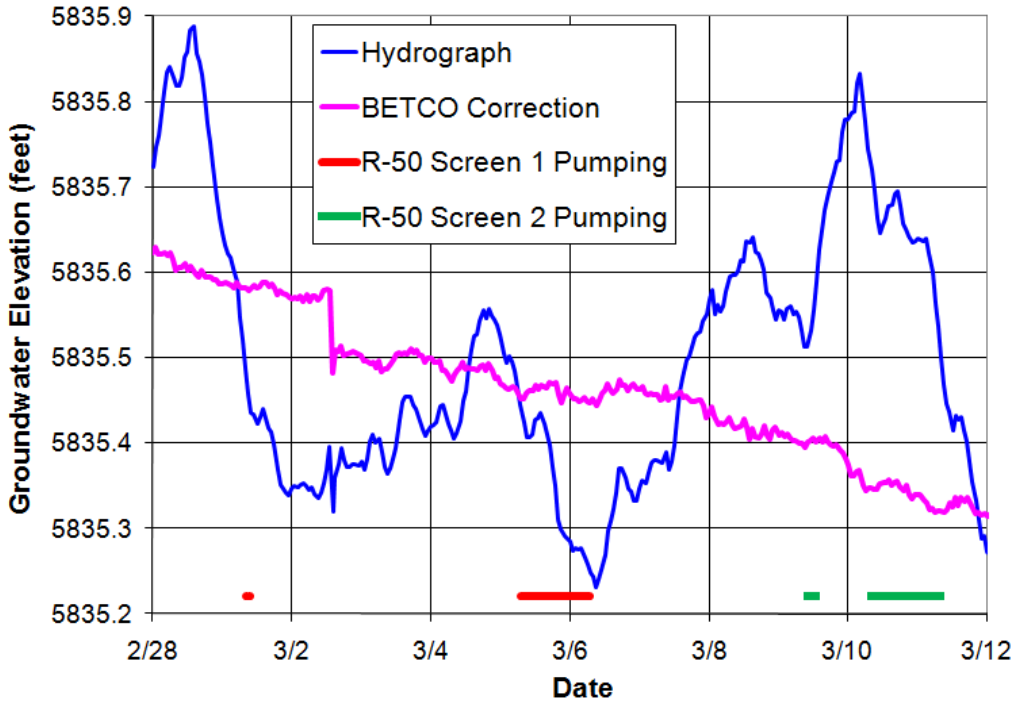


Figure C-7.0-8 Well R-45 screen 1 hydrograph

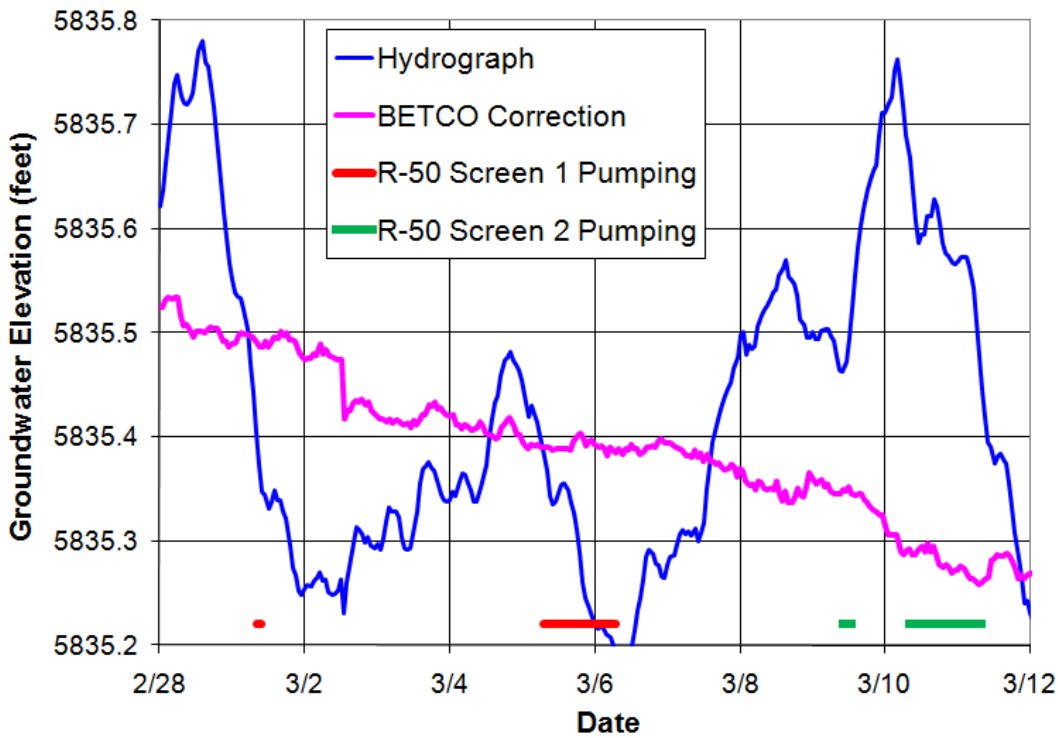


Figure C-7.0-9 Well R-45 screen 2 hydrograph

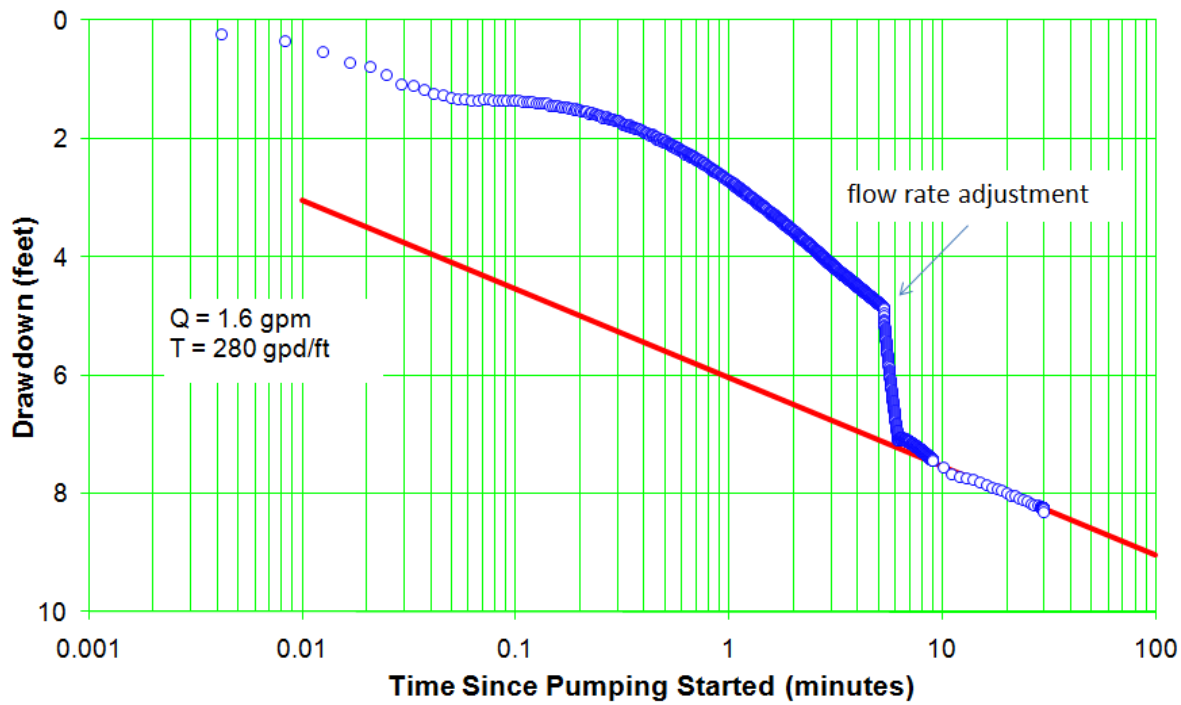


Figure C-8.1-1 Well R-50 screen 1 trial drawdown

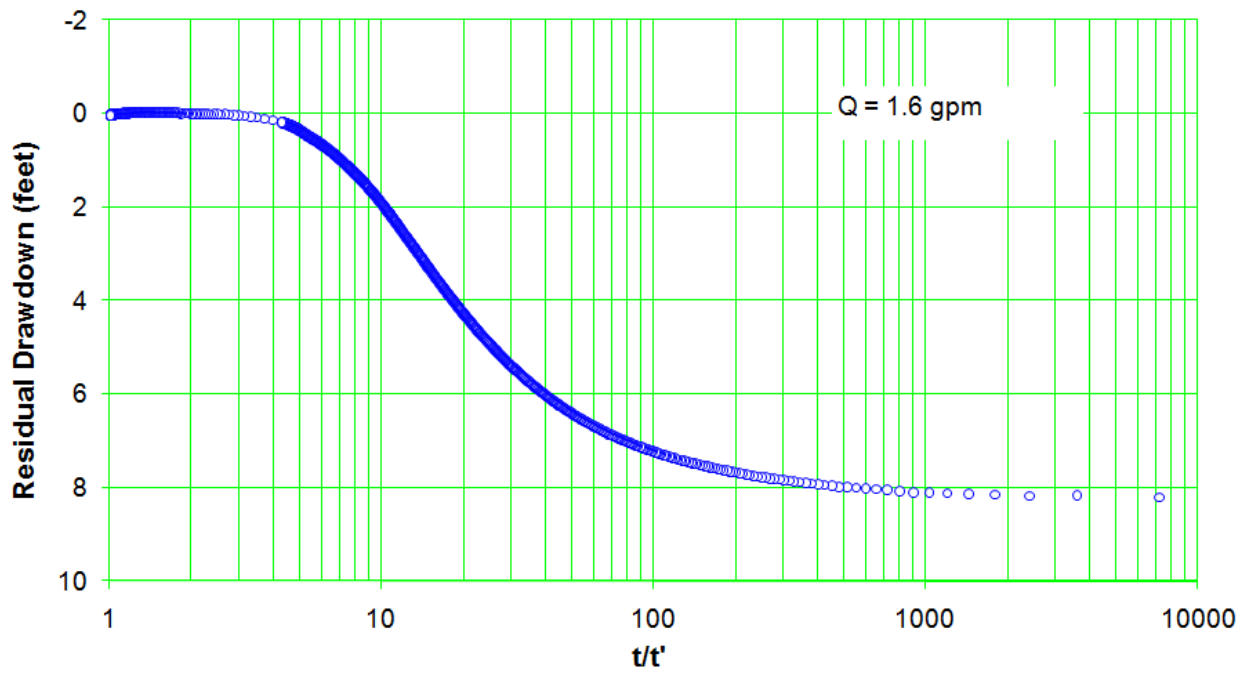


Figure C-8.1-2 Well R-50 screen 1 trial recovery

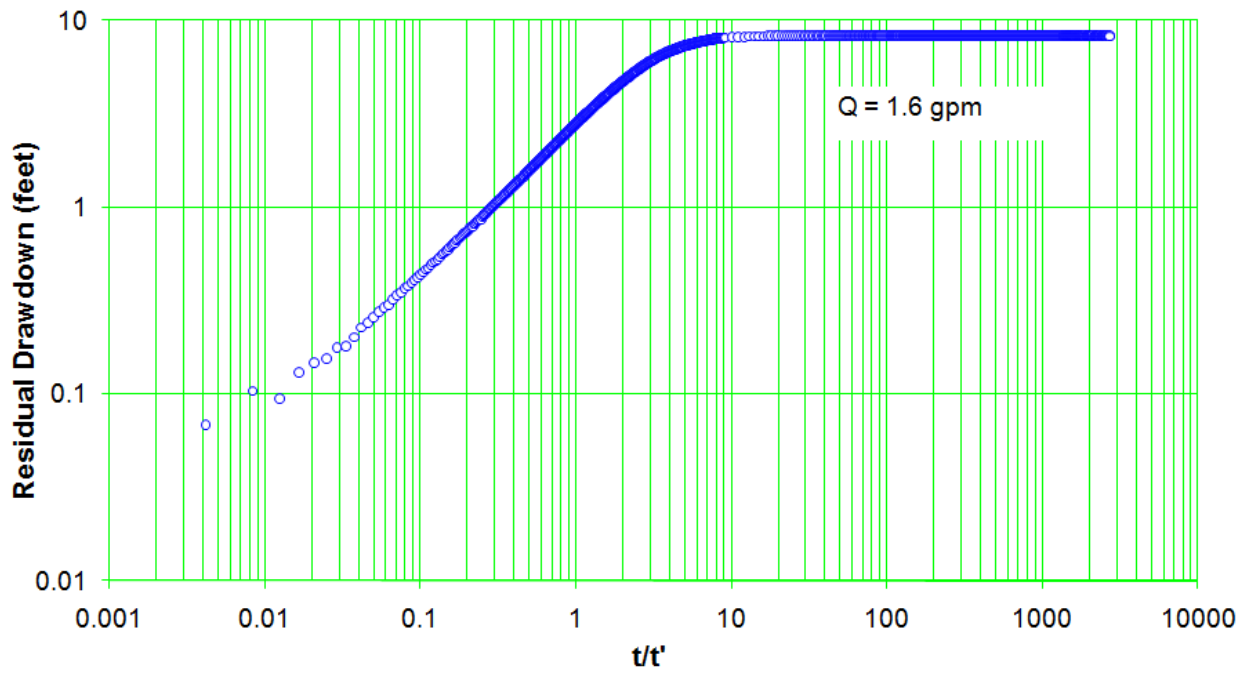


Figure C-8.1-3 Well R-50 screen 1 trial calculated recovery

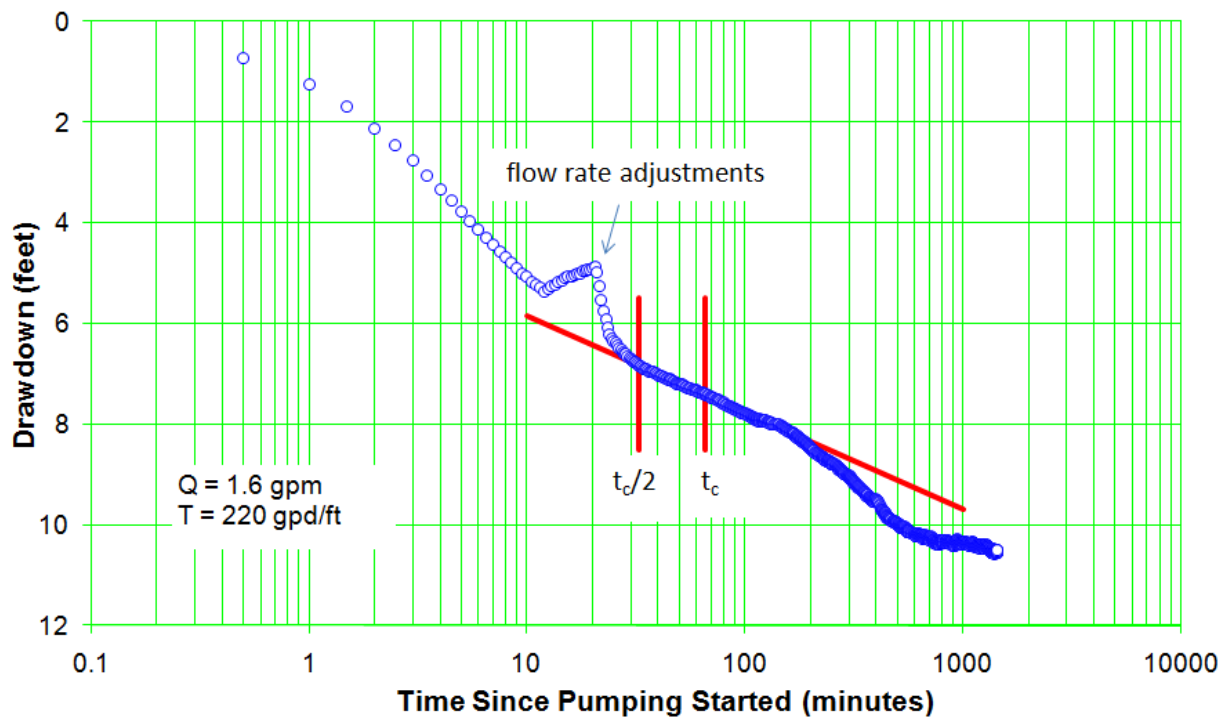


Figure C-8.2-1 Well R-50 screen 1 drawdown

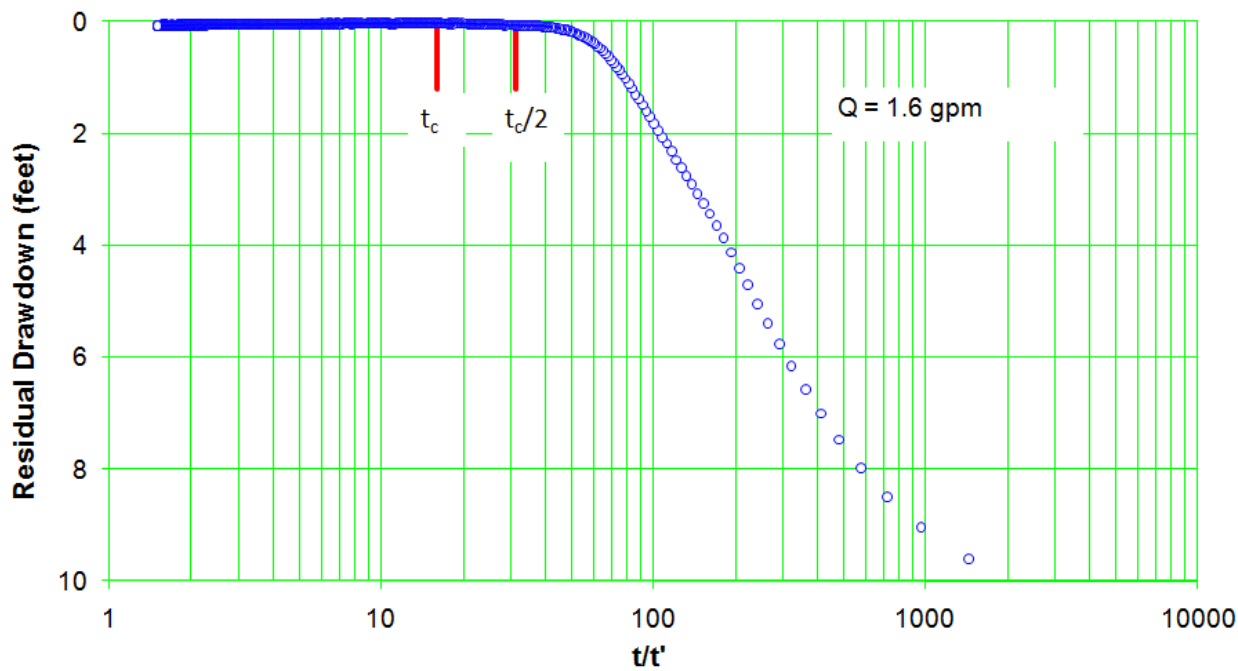


Figure C-8.2-2 Well R-50 screen 1 recovery

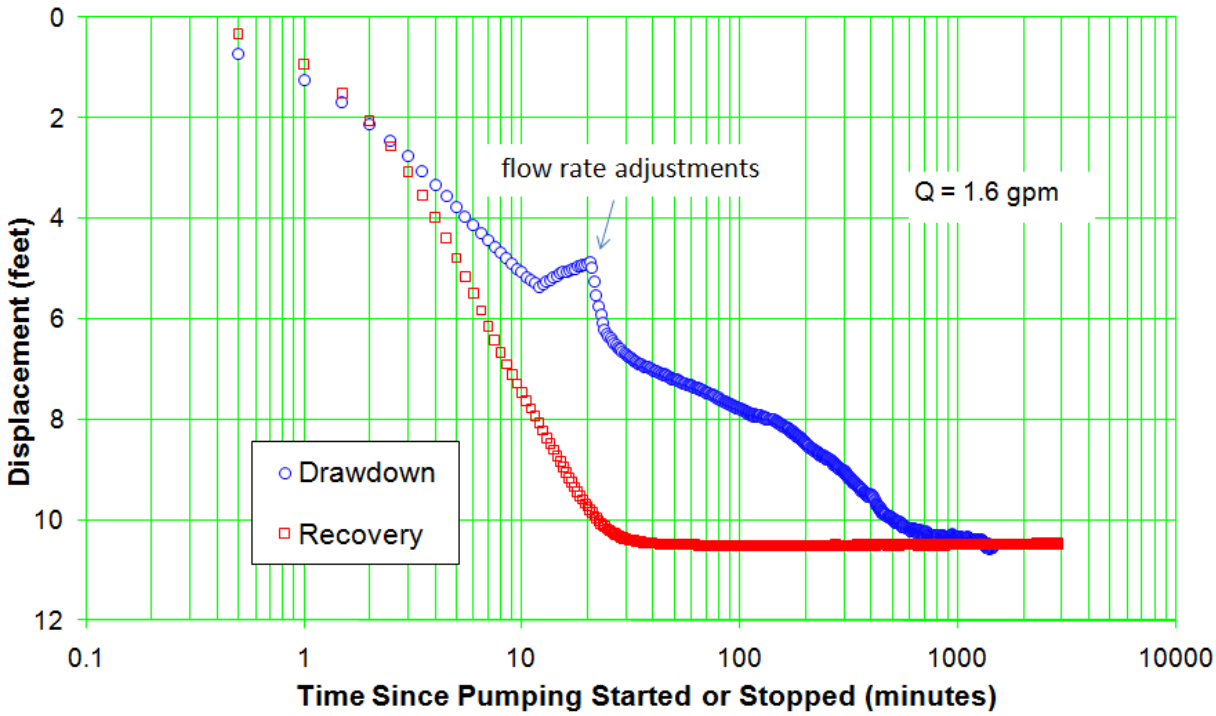


Figure C-8.2-3 Well R-50 screen 1 drawdown and recovery comparison

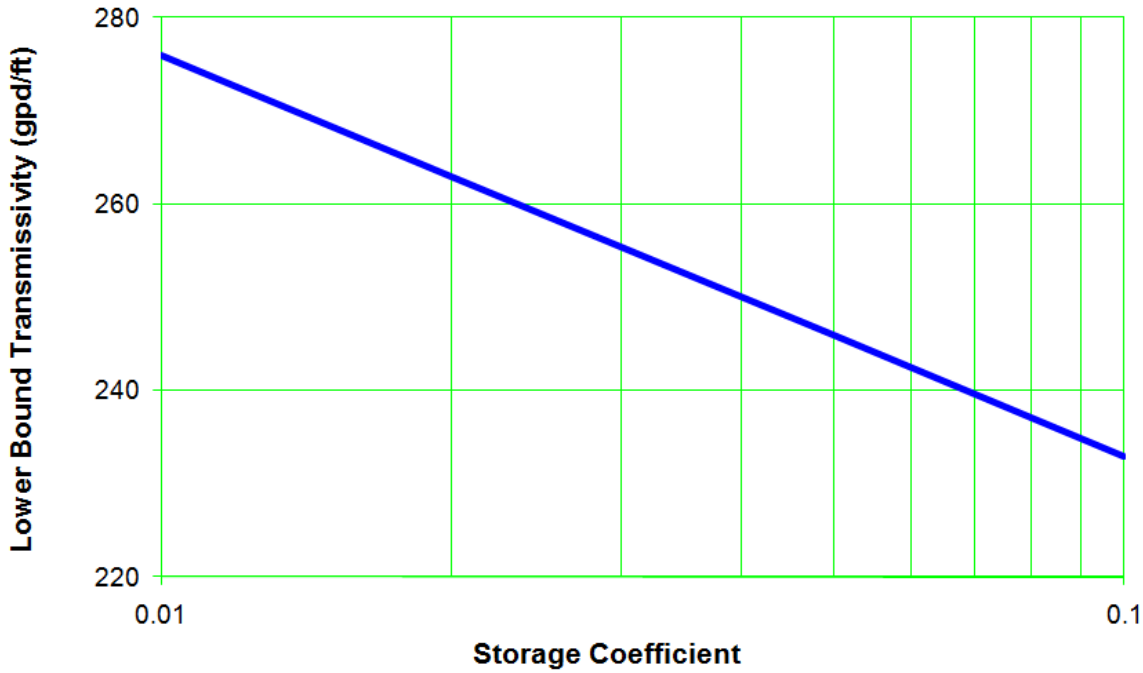


Figure C-8.3-1 Well R-50 screen 1 lower-bound transmissivity

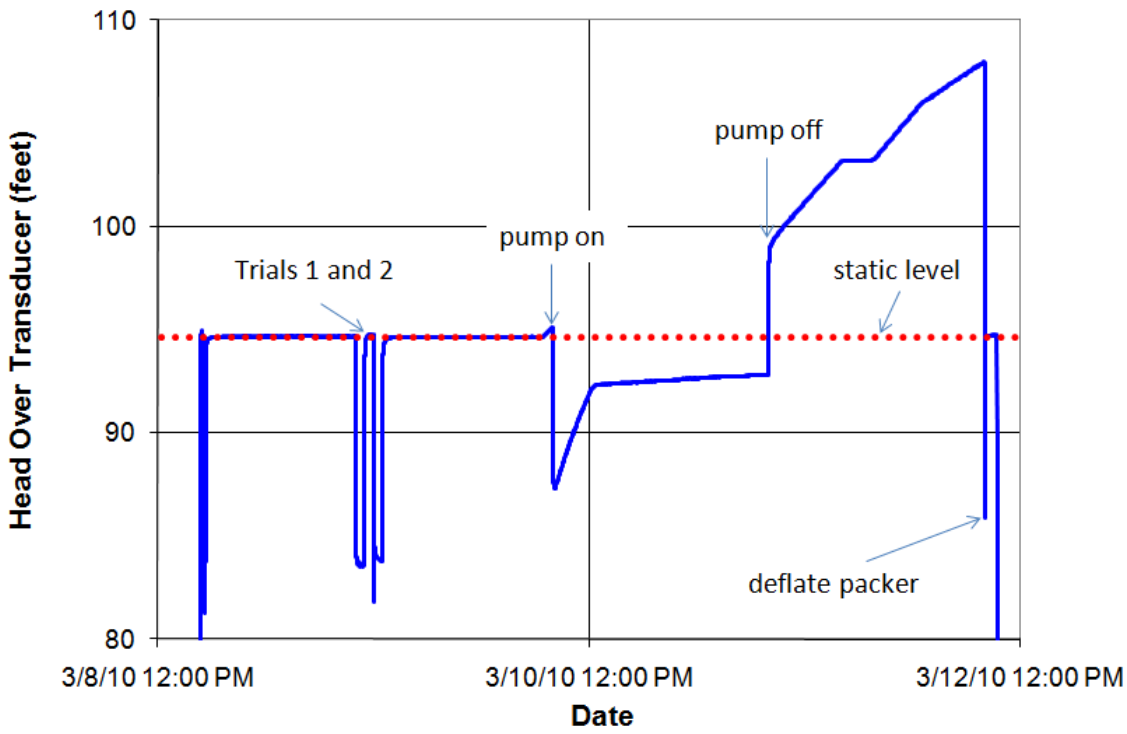


Figure C-9.0-1 Well R-50 screen 2 test data

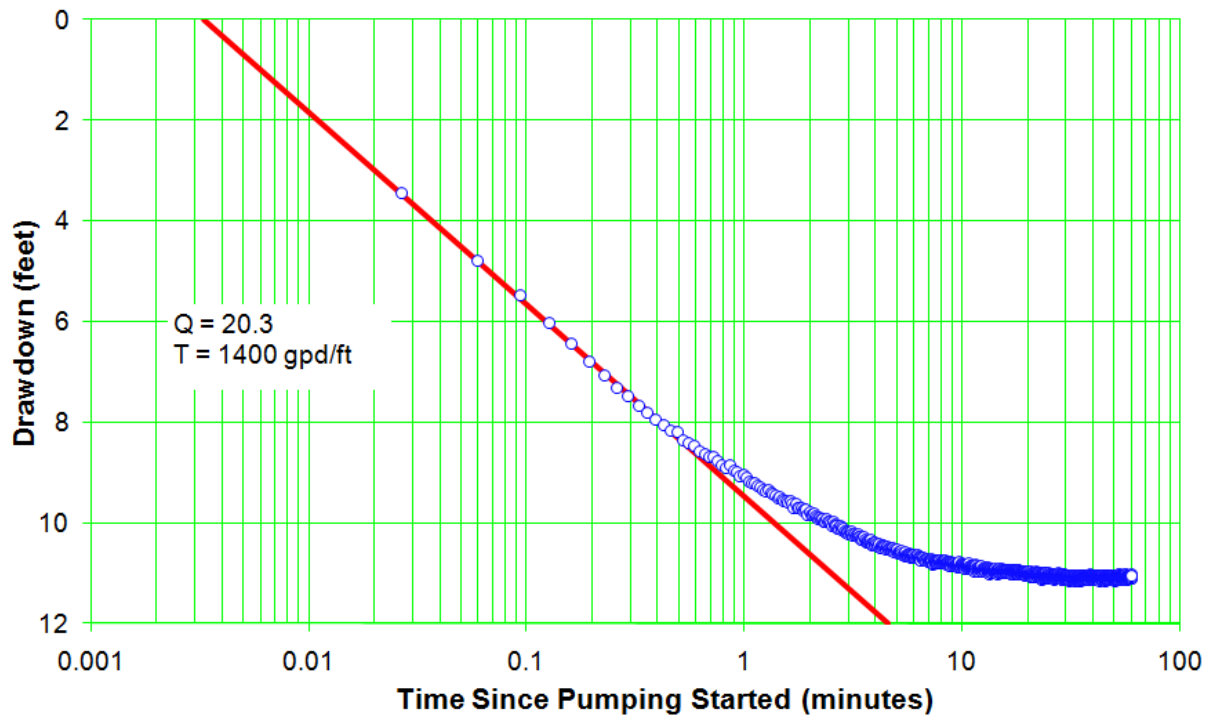


Figure C-9.1-1 Well R-50 screen 2 trial 1 drawdown

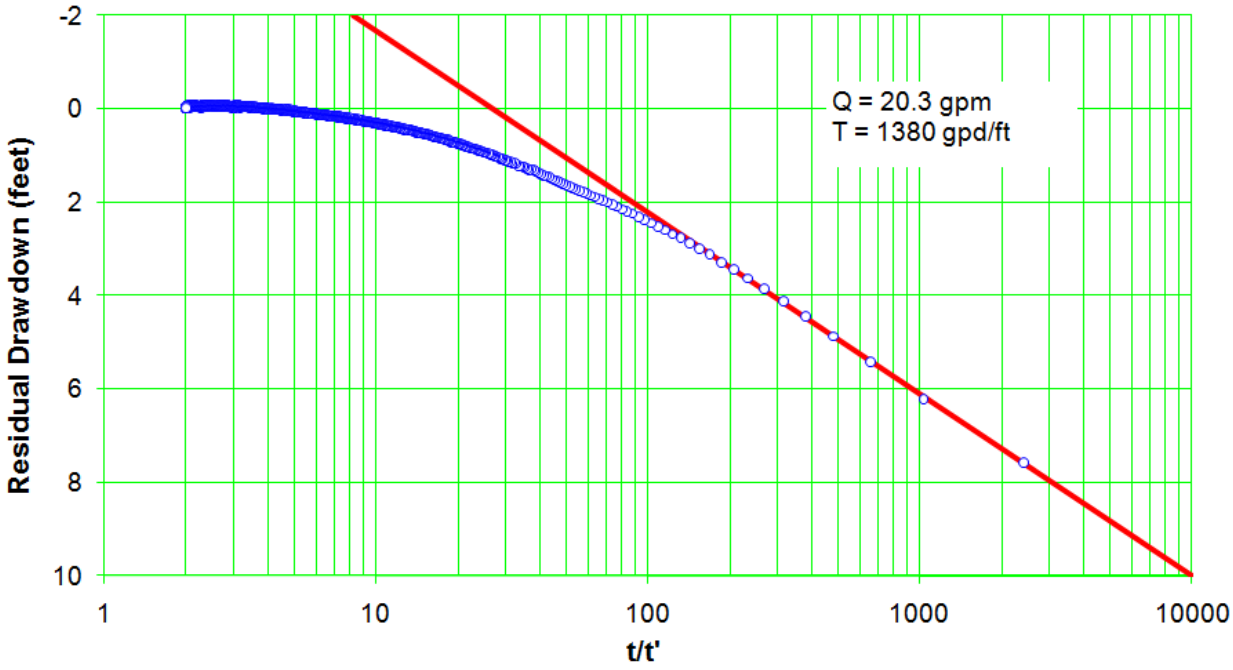


Figure C-9.1-2 Well R-50 screen 2 trial 1 recovery

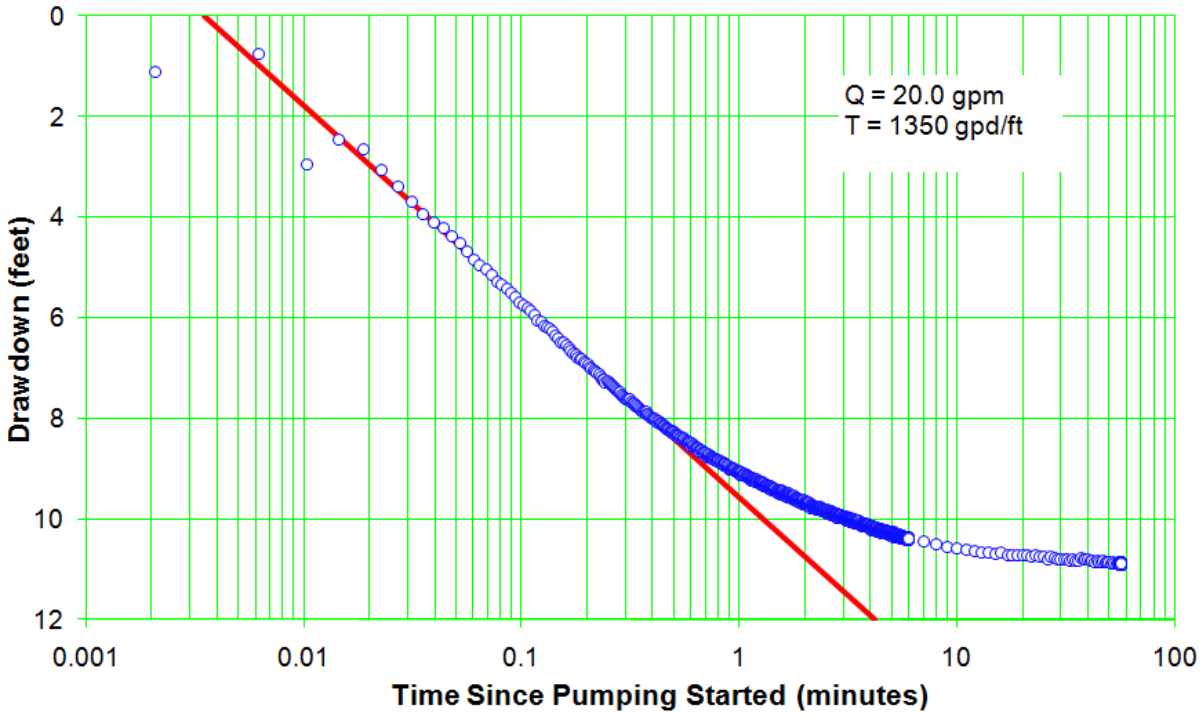


Figure C-9.2-1 Well R-50 screen 2 trial 2 drawdown

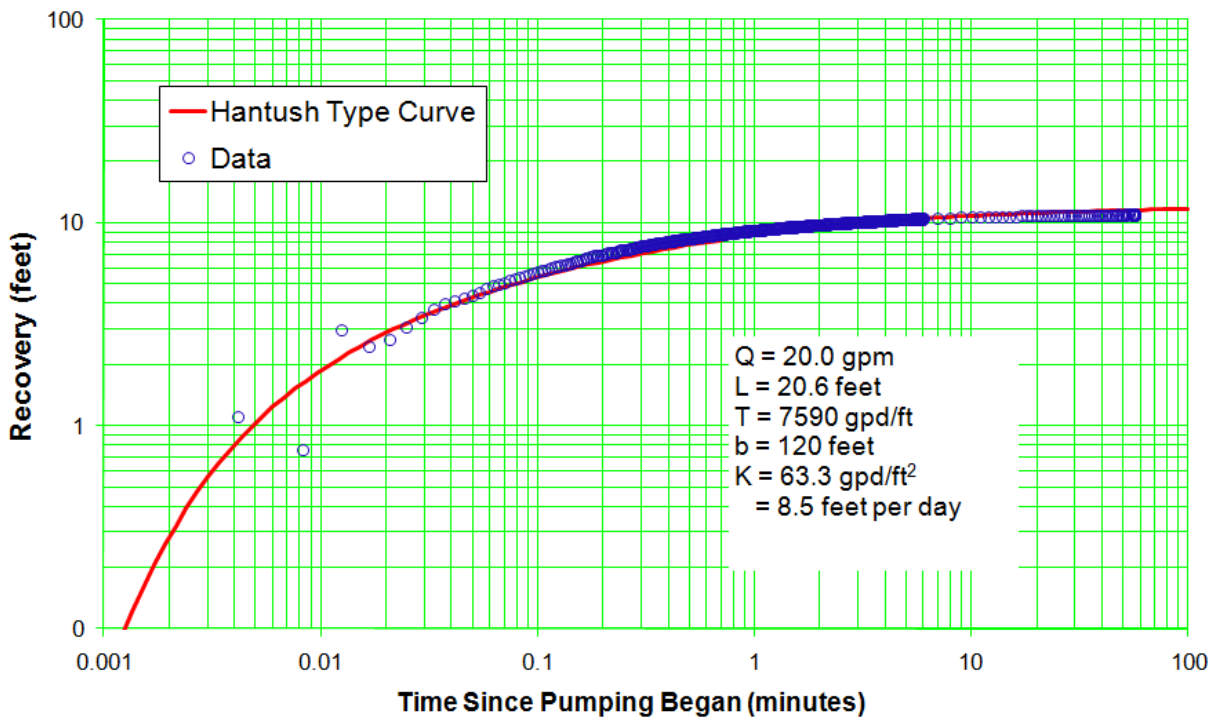


Figure C-9.2-2 Well R-50 screen 2 trial 2 drawdown—Hantush solution for anisotropy of 1.0

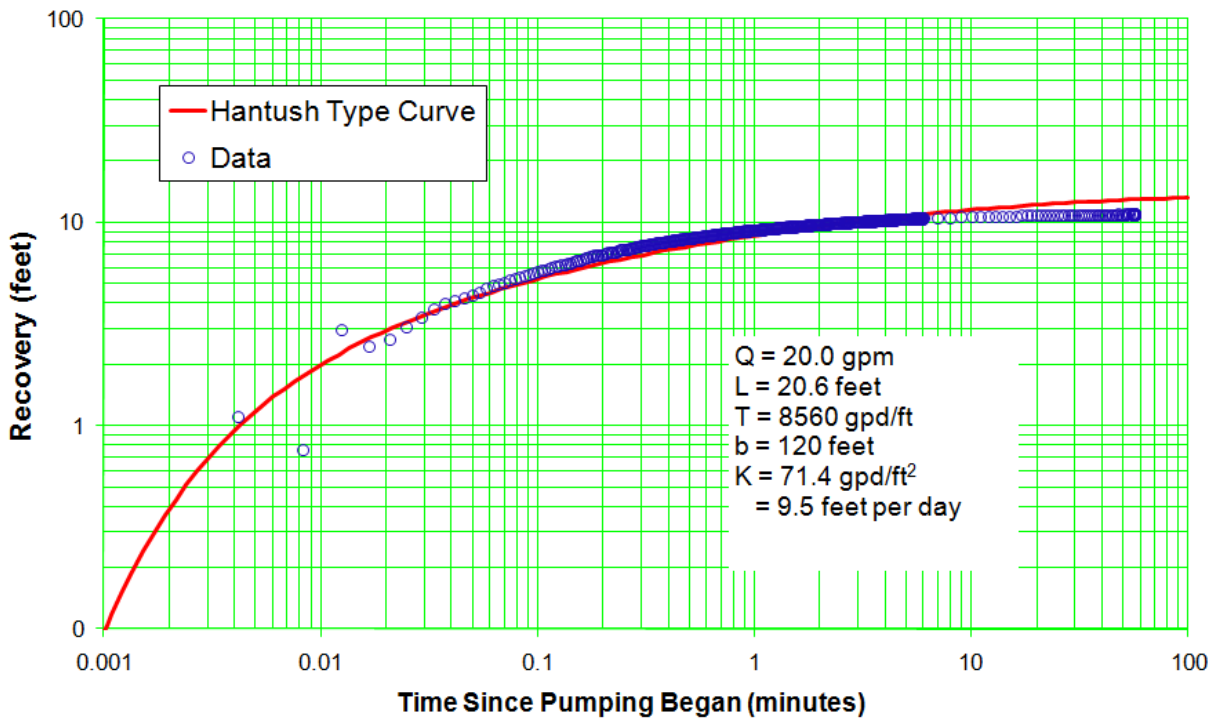


Figure C-9.2-3 Well R-50 screen 2 trial 2 drawdown—Hantush solution for anisotropy of 0.1

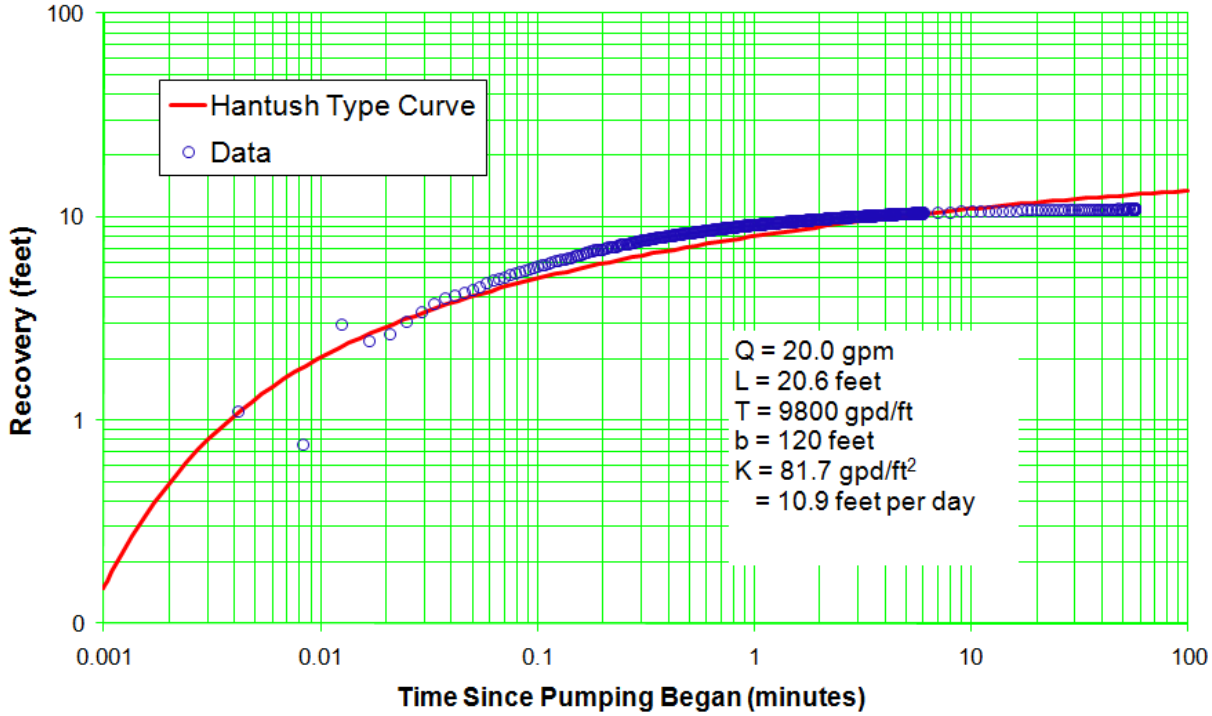


Figure C-9.2-4 Well R-50 screen 2 trial 2 drawdown—Hantush solution for anisotropy of 0.01

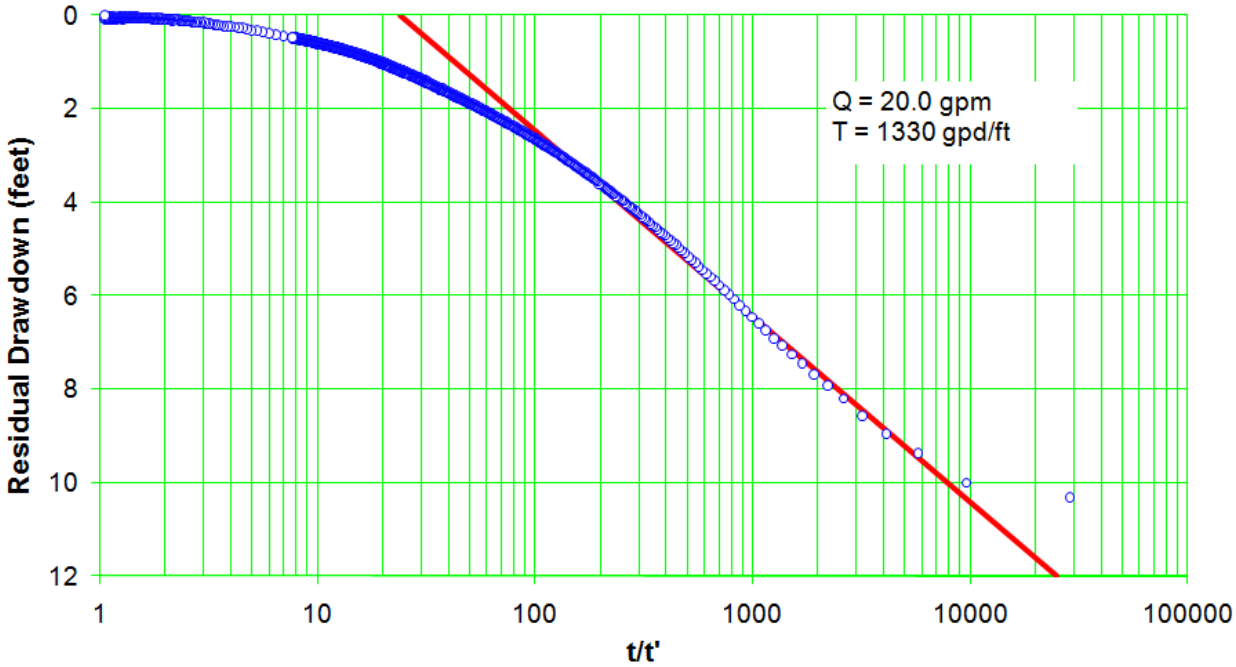


Figure C-9.2-5 Well R-50 screen 2 trial 2 recovery

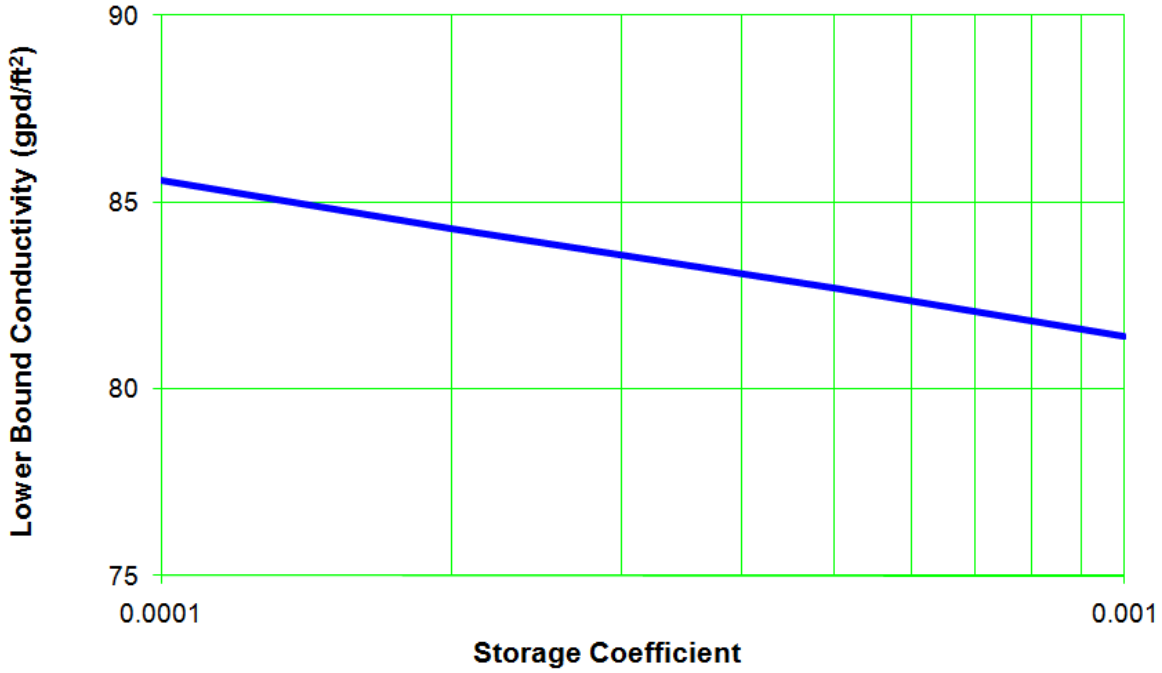


Figure C-9.3-1 Well R-50 screen 2 lower-bound hydraulic conductivity

Appendix D

Borehole Video Logging
(on DVD included with this document)

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

Appendix E

Geophysical Logs and
Schlumberger Geophysical Logging Report
(on CD included with this document)

Integrated Wireline Log Well Montage

Processed Advanced Cased Hole Geophysical Logs

Using the following logs:

APS*, TLD*, HNGS*, SGT*

Trademark of Schlumberger

COMPANY: TRMC (Drilling contractor for LANL)
WELL: R-50 Regional Wells
FIELD: New Mexico
STATE:
County/Parish:
Other Services:
Well Location: 25~Jan~2010 Date Processed: Apr~2010
Elevations:
API Number:
Job Number:
K.B. NA D.F. NA G.L. NA

GEOFRAME PROCESSED INTERPRETATION

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

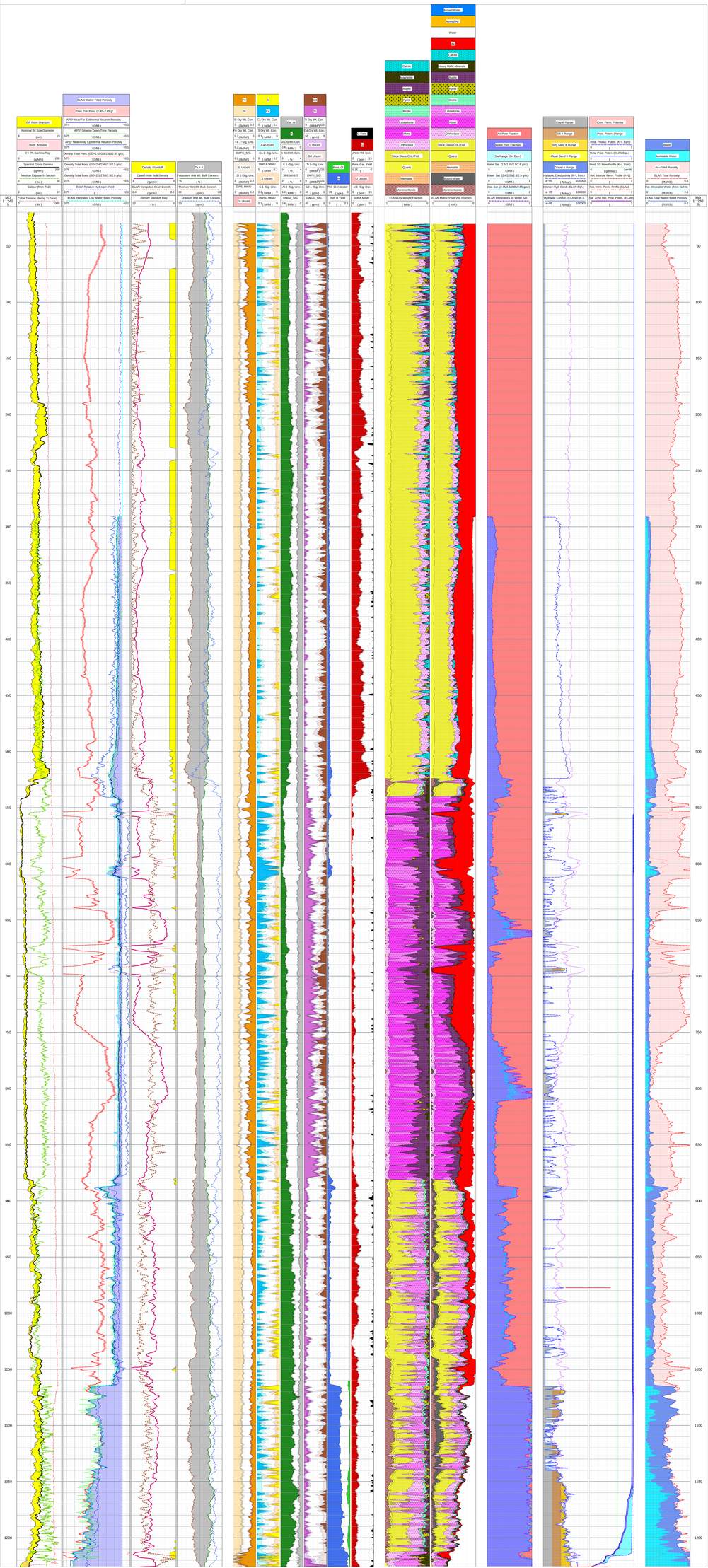
Sen. Order # AZNW~00064 OP Wes.: 17CD~154 Process Date: April~2010 Center: SWS Tucson Baseline: GF4.2 Log Analyst: N. Cl

Mud and Borehole Measurements:

Rm @ Measured Temperature: NA	BHT: 77 degF	Bitsize: 12.25 in	Casing: 12.1 in ID
Rmf @ Measured Temperature: NA	Type Fluid in Hole:	FGW	
Rmc @ Measured Temperature: NA	Mud density: 8.34 lb/ngal	FGW	

Remarks:

Depth reference is ground surface.
Well contained one or more strings of casing (casing advance) during logging.
Well water level at 1064~1066 ft during logging.
ELAN* integrated log anal. performed without porosity or water saturation constraints.
Interpretation should account for well conditions.



Schlumberger

ELAN* Geophysical Log Integrated Analysis

Optimized Mineral + Pore Volume Model

COMPANY: TPMC

WELL: LANL R−50

FIELD: None

State: New Mexico

COUNTRY:

*Elemental Log Analysis, Mark of Schlumberger

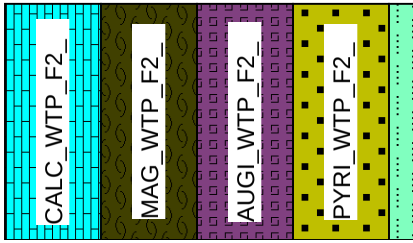
Date Processed:	April−2010	Date Logged:	25−Jan−2010
Job Number:		Processed at:	SWS Tucson
Well Location:			
Latitude:		Longitude:	
Elevations:	KB:	DF:	GL:

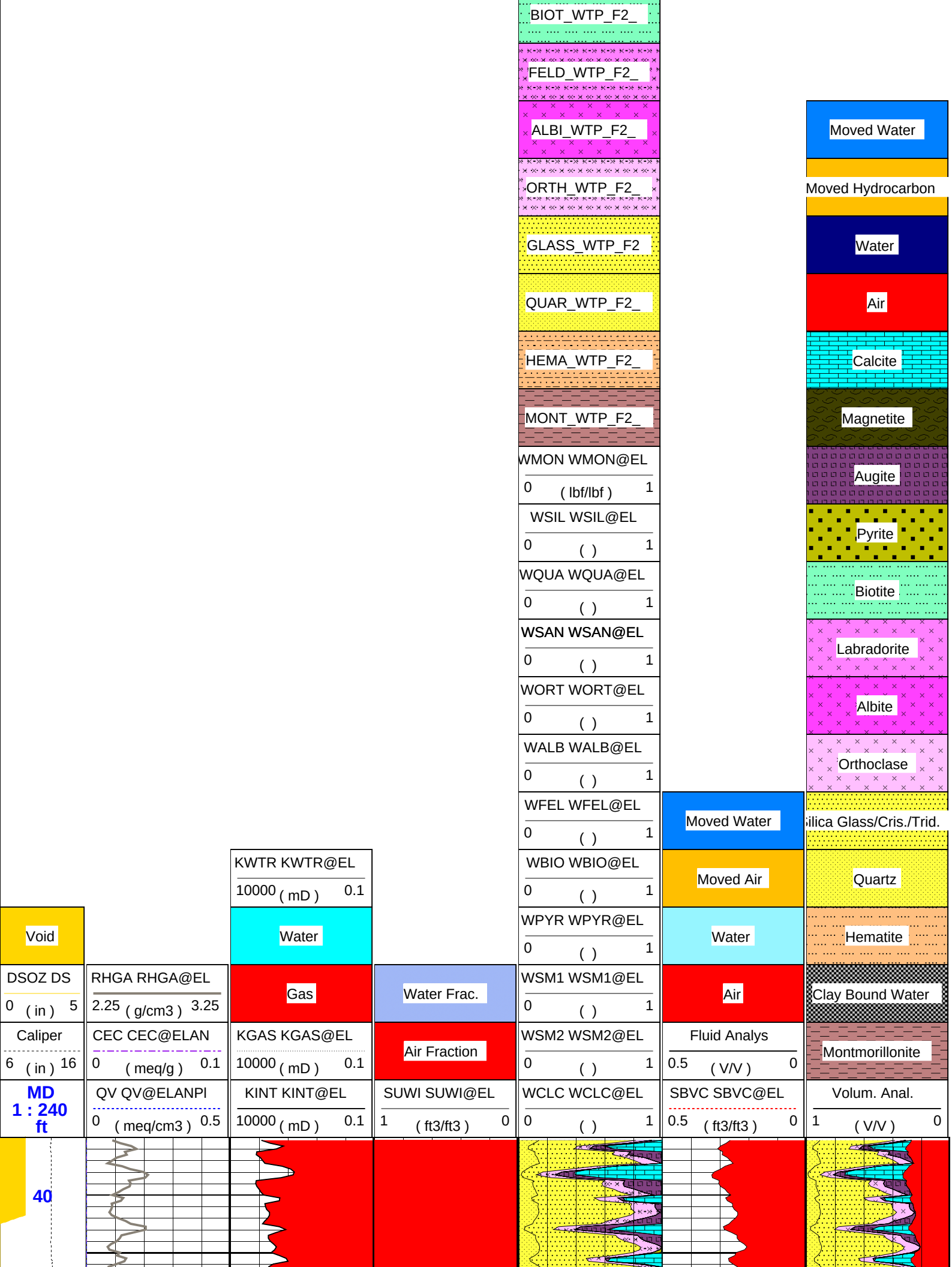
Depth ref. is ground surface. Results are affected by cased hole conditions.

FOLD HERE

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

R−50 [Fun_2]

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Moved Hydrocarbon
Water
Air
Calcite
Magnetite
Augite
Pyrite
Biotite
Labradorite
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Quartz
Hematite
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Caliper
6 (in) 16
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ft
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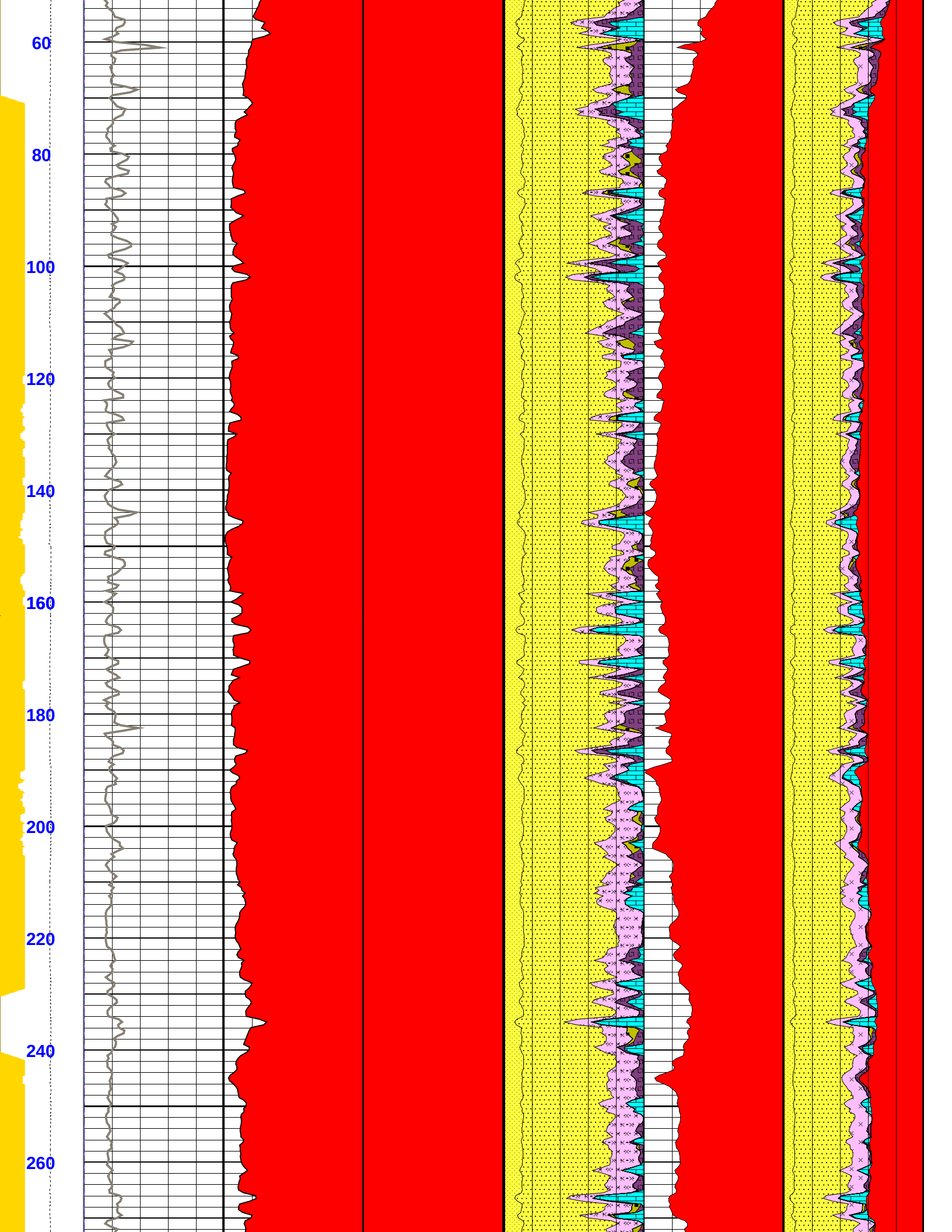
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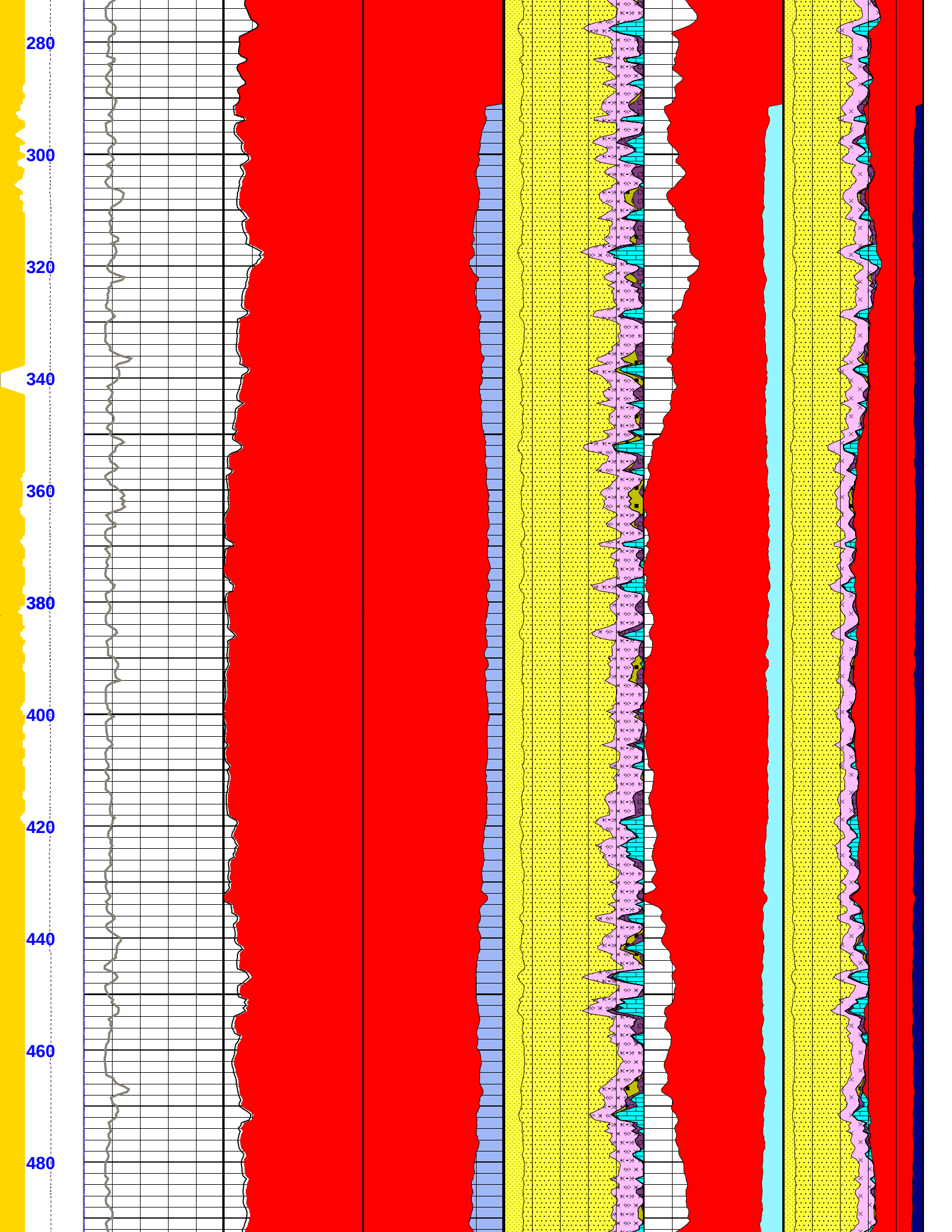
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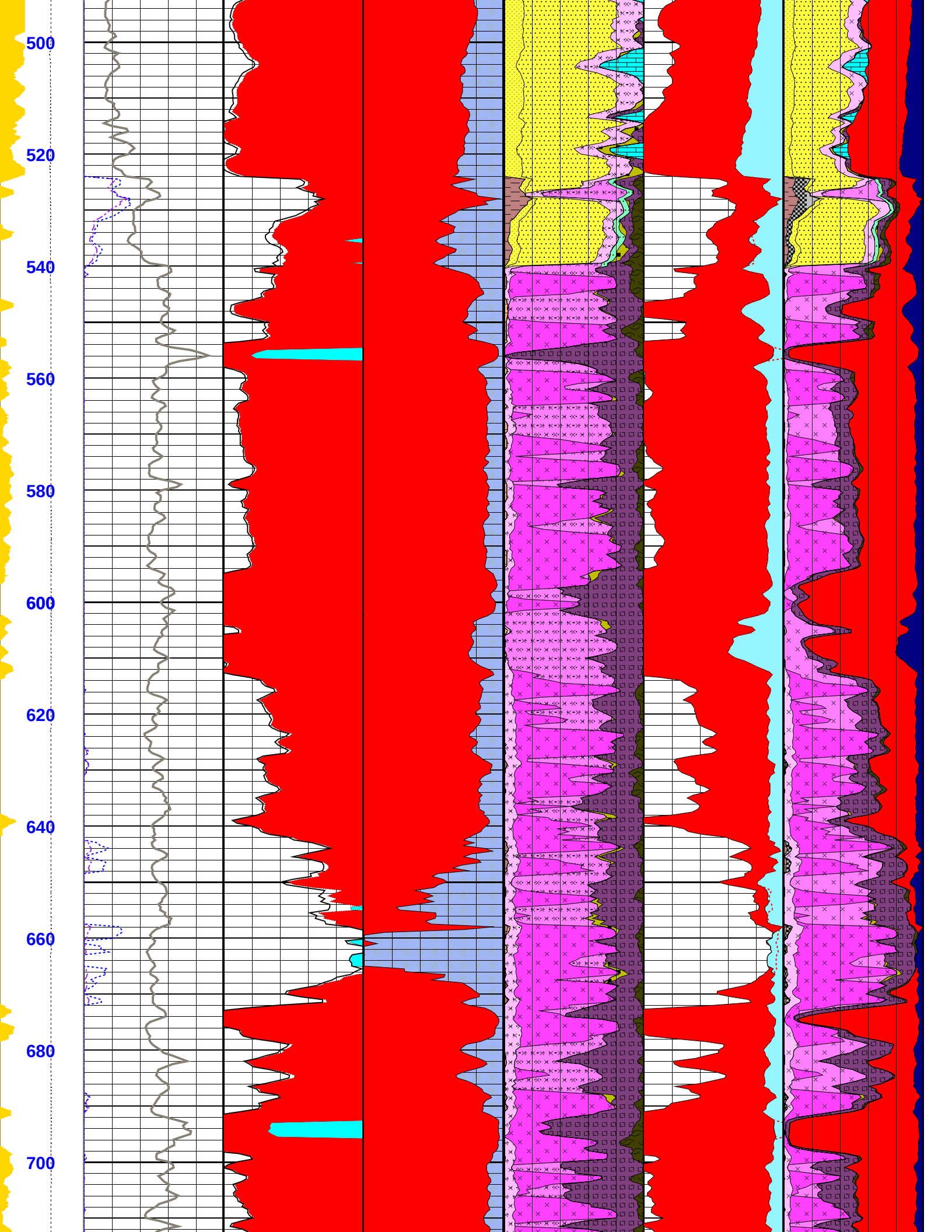
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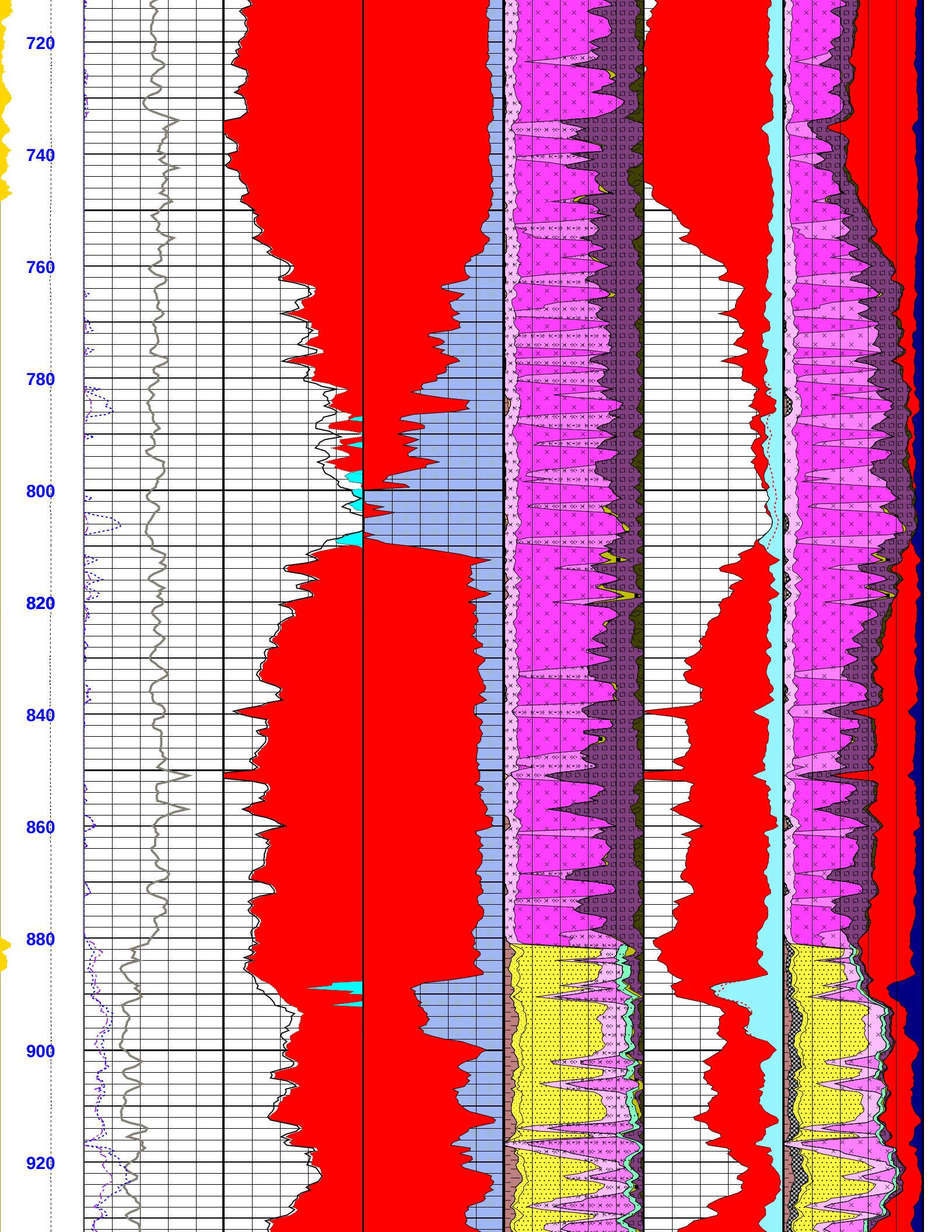
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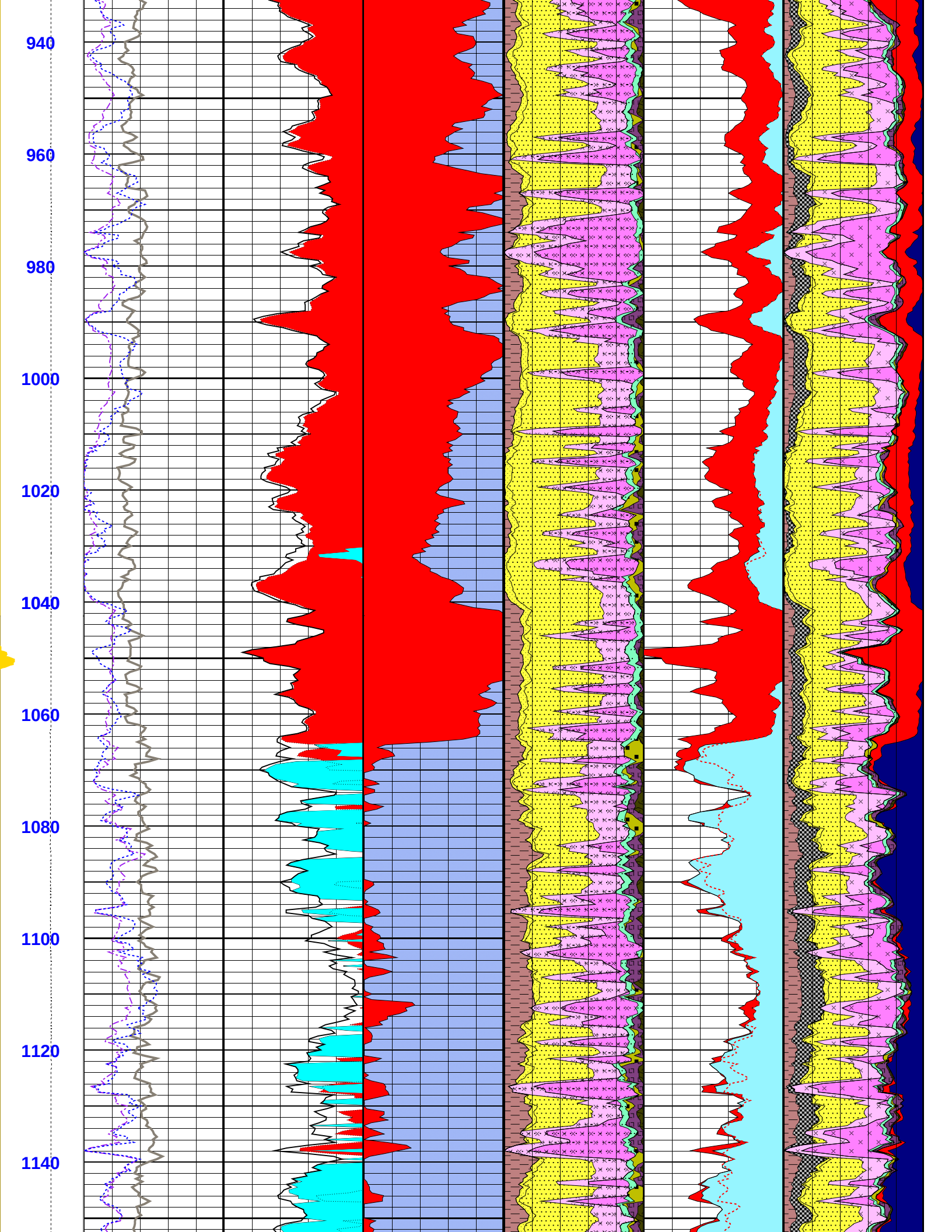
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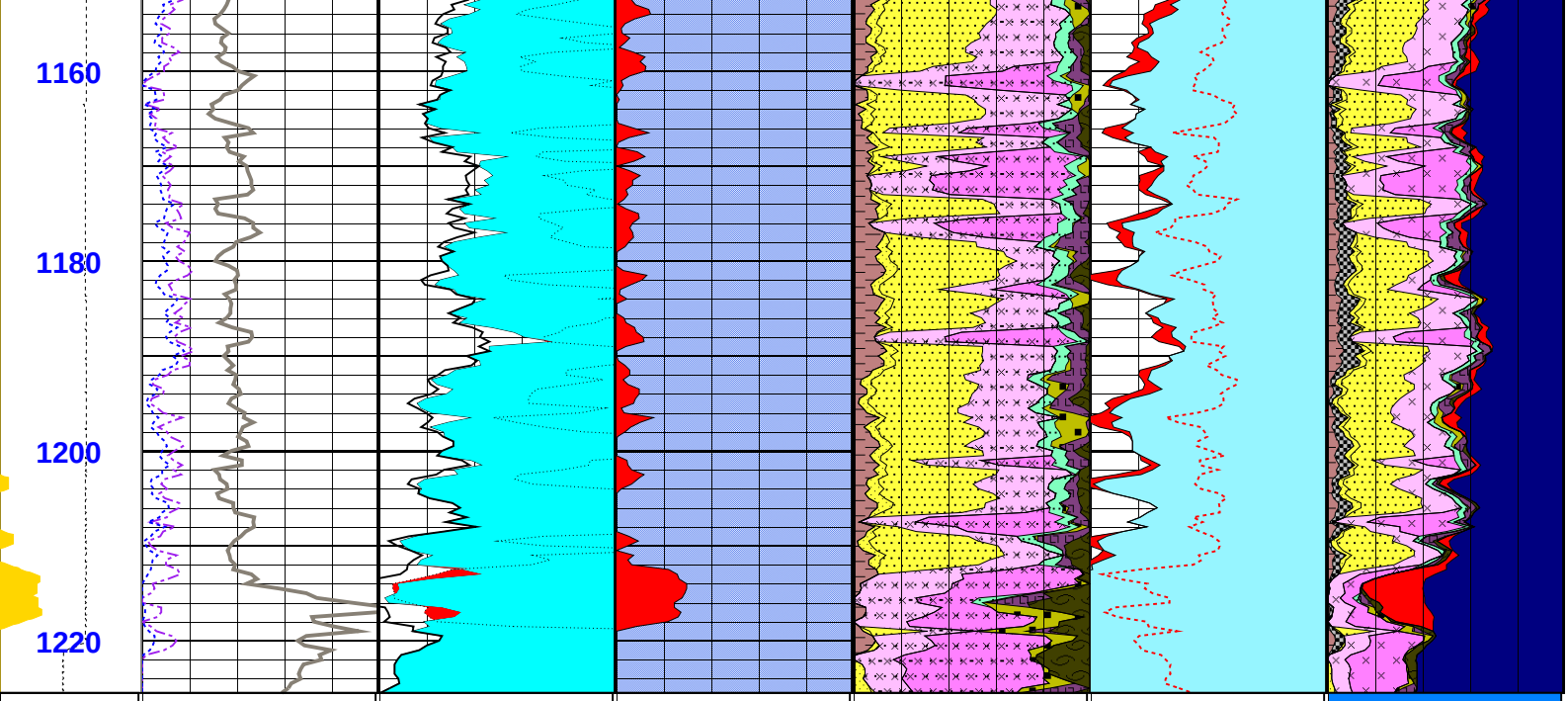

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Caliper 6 (in) 16	CEC CEC@ELAN 0 (meq/g) 0.1	KGAS KGAS@EL 10000 (mD) 0.1	Air Fraction	WSM2 WSM2@EL 0 ( ) 1	Moved Water	Moved Hydrocarbon
DSOZ DS 0 (in) 5	RHGA RHGA@EL 2.25 (g/cm3) 3.25	Gas	Water Frac.	WSM1 WSM1@EL 0 ( ) 1	Moved Air	Water
Void		Water		WPYR WPYR@EL 0 ( ) 1	Water	Air
		KWTR KWTR@EL 10000 (mD) 0.1		WBIO WBIO@EL 0 ( ) 1	Air	Calcite
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				WALB WALB@EL 0 ( ) 1		Augite
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				WMON WMON@EL 0 (lbf/lbf) 1		Orthoclase
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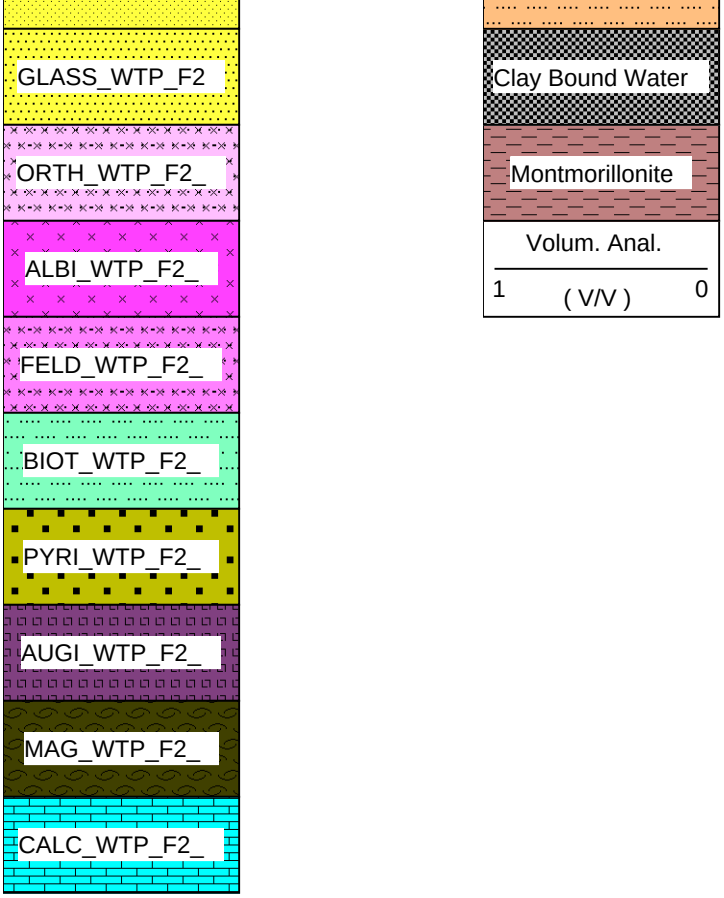
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(V/V)
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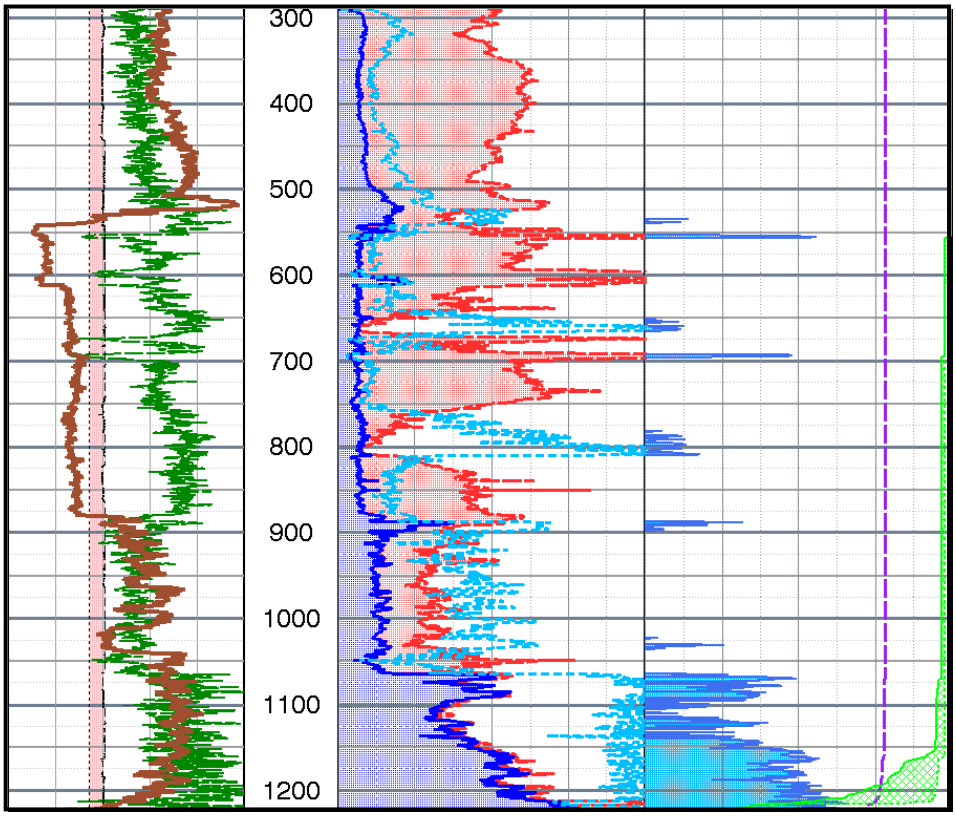
Advanced Borehole Geophysical Logging of LANL Regional Monitoring and Characterization Well R-50

Los Alamos National Laboratory, New Mexico



Prepared for:

TerranearPMC LLC

June 2010

Prepared by:

Schlumberger Water Services
Tucson, Arizona

Schlumberger
WATER SERVICES

Table of Contents

Attachments

Executive Summary

Geophysical logging was performed by Schlumberger in characterization well R-50 in January 2010 before well completion. The logging measurements were acquired from 20 to 1,221 feet (ft) below ground surface (bgs), when the borehole contained 12.1 inch (in.) inner diameter (ID) freestanding steel casing from ground surface to 1,223 ft, drilled with an approximately 12.25 in. diameter bit size in the bottom saturated section.

The primary purpose of the geophysical logging was to characterize the geology and hydrogeology across the depth section where well screens were being considered, with emphasis on determining regional aquifer groundwater level, relative water saturation, depths of porous aquifer zones, and stratigraphy/lithology of geologic units. These objectives were accomplished by measuring, nearly continuously, along the length of the well (1) total water-filled porosity from which, in combination with lithologic composition estimated from the other logs, an indirect estimate of hydraulic conductivity (production capacity) is made; (2) bulk density (sensitive to total water plus air-filled porosity and grain density); (3) neutron induced gamma ray spectroscopy, providing bulk concentrations of a number of important mineral-forming elements, as well as hydrogen; and (4) spectral natural gamma ray, including potassium, thorium, and uranium concentrations.

The following Schlumberger geophysical logging tools were used in the project (Table 1):

- Accelerator Porosity Sonde (APS*);
- Triple Detector Litho-Density (TLD*) tool
- Elemental Capture Spectroscopy (ECS*) tool
- Hostile Natural Gamma Spectroscopy (HNGS*) and gamma ray (GR)

Table 1: Geophysical Logging Tool, Technology, Corresponding Measured Properties

Tool	Technology	Properties Measured
Accelerator Porosity Sonde (APS*)	Epithermal neutron porosity and neutron capture cross-section	Water/moisture content, lithologic variations
Triple Detector Litho-Density (TLD*)	Gamma-gamma bulk density	Bulk density, total porosity, lithology
Elemental Capture Spectroscopy (ECS*)	Neutron induced gamma ray spectroscopy	Formation matrix geochemistry, lithology and mineralogy, formation hydrogen content
Hostile Natural Gamma Spectroscopy (HNGS*) and gamma ray (GR)	Gross and spectral natural gamma ray, including potassium, thorium, and uranium concentrations	Formation matrix geochemistry, lithology and mineralogy

* Mark of Schlumberger

Once the TerranearPMC well drilling project team provided Schlumberger final notification that R-50 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. Table 2 summarizes the geophysical logging runs performed in R-50.

Table 2: Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in well R-50

Date of Logging	Run #	Tool 1 (bottom)	Tool 2 (top)	Depth Interval (ft bgs)
25-Jan-2010	1	TLD	GR	37-1221
	2	HNGS		20-1213
	3	ECS	GR	30-1217
	4	APS	GR	290-1217

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 fully corrected for borehole conditions (particularly casing) 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 provide consistent hydrogeologic and geologic results; 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, relative hydraulic conductivity, lithology).

The geophysical log measurements from Well R-50 provide, overall, good quality results that are consistent with each other across the logged interval. However, the existence, extent, and effect on the geophysical logs of a water or air-filled annulus between the casing and the borehole wall (voids behind the casing) is difficult to determine and, thus, there is uncertainty about how well some of the log measurements represent true geologic formation conditions (unaffected by drilling). The distance between the logging tool sensor and formation is unknown and, thus, difficult to account or correct for. The measurements most affected by voids behind the casing were ones that have a shallow depth of investigation and that require close contact to the uncased borehole wall—the bulk density and the neutron porosity measurements (particularly the former). One indicator that the bulk density is being adversely affected by voids behind the casing is when the computed density porosity is unrealistically high. Where the total porosity estimated from the processed logs reaches above 55% the bulk density measurement is likely being affected by voids. There are number of intervals in R-50 where the density porosity is unreasonably high, indicating the likely impact of annular voids on the density measurement (and, consequently, the derived total porosity): 553–614, 638–642, 672–678, 689–699, 716–745, 879–886, 1048–1052, and 1212–1218 ft bgs. Through the integrated analysis and interpretation of all the logs, the individual shortcomings of the specific measurements are reduced. Thus, the results derived from integrated log analysis (e.g., the optimized water-filled porosity log) are the most robust single representation of the geophysical log measurements—

providing a wealth of valuable high-resolution information on the geologic and hydrogeologic environment of the R-50 locale.

Important results from the processed geophysical logs in R-50 include the following:

1. The well standing water level in R-50 was 1064-1066 ft bgs at the time of logging, and did not vary much between the different logging runs.

2. The processed logs indicate that the intersected geologic section is fully saturated with water from the bottom of the borehole (1,223 ft bgs) to likely 1,064 ft bgs, which lies within alluvium/fanglomerate. Below 1,064 ft the log estimated water content and total porosity closely track each other, ranging mostly 25 to over 40% of total rock/sediment volume with some intervals reaching higher (particularly at the bottom of the borehole). Above 1,064 ft the water content drops precipitously to 10% while the total porosity is mostly over 20%. The estimated water saturation below 1,064 ft is mostly over 90% of the pore volume while above 1,064 ft it is less than 50%. Based on these results, the depth of the Regional Aquifer water level (depth at which there is full water saturation) is most likely 1,064 ft, with very little evidence that it is higher.

3. Above 1,064 ft bgs, which the processed logs definitely show to be within the vadose zone (above the top of the Regional Aquifer), the estimated water content varies from 5% to 30% of total rock volume, mostly remaining below 20% except across the interval 887–902 ft, located at the top of the alluvium/fanglomerate and just below the base of a thick basalt lava sequence. Other intervals with elevated water content are 602–612 ft (reaching 20% and located in basalt lava, possibly at the bottom of a flow unit), 547–548 ft (reaching 15% and located at the top of the basalt lava sequence), and 515–540 ft (reaching 17% and located in the bottom of the tuff sequence, likely with the Guaje Pumice Bed). The water content is notable higher above 540 ft and below 887 ft. The processed logs indicate the highest water saturation within the vadose zone is in the intervals 658–664 and 800–808 ft, where there is 100% water saturation, but these zones have very low porosity and water content (5%), located within tight sections of the basalt lava sequence that is unlikely to flow if it is fully saturated.

4. The location of productive zones within the saturated section is difficult to determine due to the adverse cased well conditions. Higher porosity is not necessarily indicative of higher production capacity since fine grained sediments often have higher porosity and lower productivity than coarser grained sediments. The highest porosities may be associated with washouts behind the casing. Overall, the processed logs indicate the highest permeability within the saturated section is in the highly porous pumice-rich interval at the bottom of the well – below 1154 ft. The predicted relative flow capacity profile generated from the integrated log analysis estimated permeability results suggest that the most productive intervals are 1068–1074, 1078–1080, 1155–1158, 1163–1168, 1178–1186, 1191–1201, 1203–1205, 1209–1213, 1214–1216, and 1221–1223 ft bgs.

5. 5. The geophysical log results clearly delineate that the saturated/water-filled section of the borehole consists of alluvium/fanglomerate that extends into the unsaturated section above 1,064 ft bgs. As noted above, below 1154 ft there is a distinct decrease in bulk density and increase in

porosity, likely corresponding to a pumiceous section of the fanglomerate. The integrated log lithology/mineralogy analysis indicates possible higher clay content in the intervals 1068–1115 and 1128–1142 ft. At 880 ft all the logs delineate the contact between basalt lava flows above and fanglomerate below. The top of the overall lava sequence is 542 ft, although the logs indicate a distinct lava unit from 542 to 612 ft. The geophysical log response in the zone above 525 ft is characteristic of the Guaje Pumice Bed, with a large increase in thorium and uranium concentrations, although it is difficult to delineate the top of the pumice bed from the geophysical logs alone (possibly 510 ft). The zone between the bottom of the Guaje and the top of the basalt (525–542 ft) appears to be a thin section of clastic sediments (fanglomerate/alluvium). The log results corroborate volcanic tuff overlying the Guaje and extending to the top of the log interval (20 ft bgs), with zonal variations in density/porosity and geochemical signature, although it is possible the top section is alluvium composed of reworked tuff-like material.

1. Introduction

Geophysical logging services were performed in characterization well R-50 by Schlumberger in January 2010 before initial well completion. The purpose of these services was to acquire in-situ measurements to help characterize the near-borehole geologic formation environment. The primary objective of the geophysical logging was to provide in-situ evaluation of formation properties (hydrogeology and geology) intersected by the well. This information was used by scientists, engineers, and project managers in the Los Alamos Characterization and Monitoring Well Project to help design the well completion, to better understand subsurface site conditions, and assist in overall decision-making.

The primary geophysical logging tools used by Schlumberger in well R-50 were the

- Array Porosity Sonde (APS*), which measures, through casing and in water or air-filled hole, volumetric water content of the formation at several depths of investigation to evaluate moist/porous zones using a pulsed epithermal neutron measurement, as well as neutron capture cross section, which is sensitive to water and clay content;

- Triple Detector Litho-Density (TLD*) tool, which measures formation bulk density through casing to estimate total porosity;

- Hostile Natural Gamma Spectroscopy (HNGS*) tool, which measures gross natural gamma and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations, to evaluate geology/lithology, particularly the amount of thorium and potassium-bearing minerals; and

- Elemental Capture Spectroscopy (ECS*) tool, which measures neutron-induced spectral gamma ray activity; this determines elemental weight fraction concentrations of a number of key rock-forming elements used to characterize geochemistry, mineralogy, and lithology of the formation, as well as hydrogen content (closely related to water content).

Calibrated gross gamma ray (GR) was recorded with every service for the purpose of correlating depths between the different logging runs. Table 3 summarizes the geophysical logging runs performed in R-50.

Table 3: Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole R-50

Date of Logging	Borehole Status	Run #	Tool 1 (bottom)	Tool 2 (top)	Depth Interval (ft bgs)
25-Jan-2010	Single string of 12.1 in. ID steel free-standing casing from surface to the bottom of the borehole at 1223 ft, with bit size of ~12.25 in. in bottom section.	1	TLD	GR	37-1221
		2	HNGS		20-1213
		3	ECS	GR	30-1217
		4	APS	GR	290-1217

A more detailed description of these geophysical logging tools can be found on the Schlumberger website (http://www.slb.com/content/services/evaluation/index.asp?).

2. Methodology

This section describes the methods Schlumberger employed for geophysical logging of Well R-50, including the following stages/tasks:

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

2.1. Acquisition Procedure

Once the well drilling project team notified Schlumberger that R-50 was ready for geophysical well logging, the Schlumberger district in Farmington, NM, mobilized a wireline logging truck, the appropriate wireline logging tools and associated equipment, and crew to the job site. Upon arriving at the LANL site, the crew completed site-entry paperwork and received a site-specific safety briefing.

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

1. Parking and stabilizing the logging truck in a position relative to the borehole that was best for performing the surveys

2. Setting up a lower and an upper sheave wheel (the latter attached to, and hanging above, the borehole from the drilling rig)
3. Threading the wireline cable through the sheaves
4. Attaching to the end of the cable the appropriate sonde(s) for the first run

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 ECS and TLD, respectively) the sources were taken out of their carrying shields and placed in the appropriate tool source-holding locations using special source-handling tools just before lowering the tool string. 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 were returned to their appropriate storage shields, thus eliminating any radiation hazards. Any post-logging measurement checks were performed as part of log quality control and assurance. The tool string was cleaned as it was pulled out of the hole, separated, and disconnected.

The second tool string was attached to the cable for another logging run, followed by subsequent tool strings and logging runs. After the final logging run was completed, the cable and sheave wheels were rigged down.

Before departure, the logging engineer printed field logs and created a compact disc containing the field log data for on-site distribution and sent the data via satellite to the Schlumberger data storage center. The Schlumberger Water Services data processing center was alerted that the data were ready for post-acquisition processing.

2.2. 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 full calibration of tools when they are first built, regular recalibrations and tool measurement/maintenance checks, and real-time monitoring of log quality

as measurements are made. Indeed one of the primary responsibilities of the logging engineer is to ensure, before and during acquisition, that the log measurements meet prescribed quality criteria.

A tool-specific base calibration that directly relates the tool response to the physical measurement using the designed measurement principle is performed on all Schlumberger logging tools when first assembled in the engineering production centers. This is accomplished through a combination of computer modeling and controlled measurements in calibration models with known chemical and physical properties.

The base calibration for most Schlumberger tools is augmented through regular "master calibrations" typically performed every one to six months in local Schlumberger shops (such as Farmington, NM), depending on tool design. Master calibrations consist of controlled measurements using specially designed calibration tanks/jigs and internal calibration devices that are built into the tools, both with known physical properties. The measurements are used to fine-tune the tool's calibration parameters and to verify that the measurements are valid.

In addition, on every logging job, before and after on-site "calibrations" are executed for most Schlumberger tools directly before/after lowering/removing the tool string from the borehole. For most tools, these represent a measurement verification instead of an actual calibration used to confirm the validity of the measurements directly before acquisition and to ensure that they have not drifted or been corrupted during the logging job.

All Schlumberger logging measurements have a number of associated depth-dependent quality control (QC) logs and flags to assist with identifying and determining the magnitude of log quality problems. These QC logs are monitored in real-time by the logging engineer during acquisition and are used in the post-acquisition processing of the logs to determine the best processing approach for optimizing the overall validity of the property estimates derived from the logs.

Additional information on specific tool calibration procedures can be found on the Schlumberger web page (http http://www.slb.com/content/services/evaluation/index.asp).

The geophysical log measurements from Well R-50 provide, overall, good quality results that are consistent with each other across the logged interval. However, the existence, extent, and effect on the geophysical

logs of a water or air-filled annulus between the casing and the borehole wall (voids behind the casing) is difficult to determine and, thus, there is uncertainty about how well some of the log measurements represent true geologic formation conditions (unaffected by drilling). The distance between the logging tool sensor and formation is unknown and, thus, difficult to account or correct for. The measurements most affected by voids behind the casing were ones that have a shallow depth of investigation and that require close contact to the uncased borehole wall—the bulk density and the neutron porosity measurements (particularly the former). One indicator that the bulk density is being adversely affected by voids behind the casing is when the computed density porosity is unrealistically high. Where the total porosity estimated from the processed logs reaches above 55% the bulk density measurement is likely being affected by voids. There are number of intervals in R-50 where the density porosity is unreasonably high, indicating the likely impact of annular voids: 553–614, 638–642, 672–678, 689–699, 716–745, 879–886, 1048–1052, and 1212–1218 ft bgs.

2.3. Processing Procedure

After the geophysical logging job was completed in the field and the data was archived, the data was downloaded to the Schlumberger processing center. There, the data were processed in the following sequence: (1) the measurements were corrected for near-wellbore environmental conditions and the measurement field processing for certain tools (in this case, the TLD, APS and ECS) was redone using better processing algorithms and parameters, (2) the log curves from different logging runs were depth matched and spliced, if required, and (3) the near-wellbore substrate lithology/mineralogy and pore fluids were modeled through integrated log analysis. Afterwards, an integrated log montage was built to combine and compile all the processed log results.

2.3.1. Environmental Corrections and Raw Measurement Reprocessing

If required, the field log measurements were processed to correct for conditions in the well, including fluid type (water or air), presence of steel casing, and (to a much lesser extent) pressure, temperature, and fluid salinity. Basically, these environmental corrections entail subtracting from the measurement response the known influences of the set of prescribed borehole conditions. In R-50, the log measurements requiring these corrections are the APS porosity, TLD bulk formation density, ECS elemental concentrations, and HNGS spectral gamma ray logs.

Two neutron porosity measurements are available – one that measures thermal ("slow") neutrons and one that measures epithermal ("fast") neutrons (the APS tool). Measurement of epithermal neutrons is required to make neutron porosity measurements in air-filled holes. In water/mud-filled holes, both the epithermal and thermal neutron measurements are valid. Both measurements can be environmentally corrected for a single string of steel-casing. Epithermal neutron porosity measurements were made in R-50. The APS measurements were reprocessed for casing, borehole fluid type (air versus water), and other environmental conditions. The APS also makes a measurement of neutron capture cross section; this measurement was also corrected for well environmental conditions at the time of logging. For further processing and analysis (e.g., integrated log analysis), the reprocessed neutron porosity and neutron capture cross section logs were used.

The raw ECS elemental yield measurements include the contribution of iron from steel casing. The processing consists of subtracting this unwanted contribution from the raw normalized yield, then performing the normal elemental yields-to-weight fraction processing. The contribution to subtract is a constant baseline amount (or zoned constant values if there are bit/casing size changes), usually determined by comparing the normalized raw yields in zones directly below/above the borehole casing/fluid change. Casing corrections were applied to the ECS logs across the entire log interval, attempting to account for one string of steel casing throughout.

The HNGS spectral gamma ray is affected by the material (fluid, air, and 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. The HNGS logs from R-50 were reprocessed to account, as best as possible, for the environmental effects of the casing, borehole fluid (water below 1,064 ft and air above), and hole size.

The measurements cannot be fully corrected for borehole washouts or rugosity since the specific characteristics (e.g., geometry) of these features are unknown (especially in this scenario where they hidden by casing) and their effects on the measurements are often too significant to account for. Thus, the compromising effects of these conditions on the measurements should be accounted for in the interpretation of the log results.

2.3.2. Depth-Matching

Once the logs were environmentally corrected for the conditions in the borehole and the raw measurement reprocessing was completed, the logs from different tool runs were depth-matched to each other, as needed, using the gross gamma ray log, acquired in all the logging runs, for depth correlation, or other logs that are well correlated (e.g., porosity). The depth reference for all field prints and processed logs, including those presented in this report, is ground surface.

2.3.3. Integrated Log Analysis

An integrated log analysis, using as many of the processed logs as possible, was performed to model the near-wellbore substrate lithology/mineralogy and pore fluids. This analysis was performed using the Elemental Log Analysis (ELAN) program (Juneer and Sibbit, 1980; Quieren et al, 1986) – a petrophysical interpretation program designed for depth-by-depth quantitative formation evaluation from borehole geophysical logs. ELAN estimates the volumetric fractions of user-defined rock matrix and pore constituents at each depth based on the known log measurement responses to each individual constituent by itself. ELAN requires an a priori specification of the volume components present within the formation, i.e., fluids, minerals, and rocks. For each component, the relevant response parameters for each measurement are also required. For example, if one assumes that quartz is a volume component within the formation and the bulk density tool is used, then the bulk density parameter for this mineral is well known to be 2.65 grams per cubic centimeter (g/cc).

The logging tool measurements, volume components, and measurement response parameters used in the ELAN analysis for R-50 are provided in Table 4. The final results of the analysis – an optimized mineral-fluid volume model – are shown on the integrated log montage (see Attachment 1), 6th track from the right (inclusive of the depth track). In addition, the ELAN program provides a direct comparison of the modeled versus the actual measured geophysical logs, as well as a composite log of all of the key ELAN-derived results, including geologic/hydrogeologic properties computed from the mineral-fluid volume model (see Attachment 2). To make best use of all the measurement data and to perform the analysis across as much of the well interval as possible (20 to 1,221 ft bgs), as many as possible of the processed logs were included in the analysis, with less weighting applied to less robust logs. Not all of the tool measurements shown in Table 4 and the ELAN modeled versus measured log display 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. In particular, no moisture/water content measurement was available above 290 ft so water was removed from the analysis above this depth.

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 geology and its volcanic origins. For the ELAN analysis, the log interval from 20 to 526 ft bgs was assumed to be volcanic tuff or pumice, and a mineral suite considered representative of this volcanic tuff, based on LANL cuttings mineral analysis, was used (primary "minerals" silica glass/cristobalite/tridymite [indistinguishable from the log measurements], quartz, and potassium feldspar). The results of laboratory analyses of Bandelier Tuff and Puye Formation samples from around the LANL site were also used to constrain the proportion of quartz versus the combination of glass/cristobalite/tridymite in the ELAN analysis. The log intervals 526–542 and 880–1221 ft bgs was assumed to be the Puye Formation, or fanglomerate/alluvium with similar composition, and a mineral suite considered representative of this geology, based on LANL cuttings mineral analysis, was used (primary "minerals" silica glass/cristobalite/tridymite [indistinguishable from the log measurements], plagioclase and potassium feldspar; quartz at a defined small fraction of the silica glass content; montmorillinite clay; with possible accessory/trace minerals biotite, augite, heavy mafic minerals, and pyrite). The log interval 526–880 ft bgs was assumed to be basalt and a mineral suite considered representative of this, based on Laboratory cuttings mineral analysis, was used.

No prior assumption is made about water saturation—where the boundary between saturated and unsaturated zones lies (e.g., the depth to the top of the regional aquifer or perched zones). Thus, the presence and amount of air in the pore space is unconstrained. Total porosity and water-filled porosity are also left unconstrained throughout the analysis interval, despite the obvious influence on the log response of borehole washouts and annular voids behind the casing. However, above 290 ft water content was set to zero for the reasons described above. There is no way to objectively correct for the adverse effect on the log measurements from these borehole conditions; therefore the decision was made to perform the ELAN analysis so as to honor the log measurements. Accordingly, interpretations should be made from the ELAN results with the understanding that the mineral-fluid model represents a mathematically optimized solution

that is not necessarily a physically accurate representation of the native geologic formation. Within this context, the ELAN model is a robust estimate of the bulk mineral-fluid composition that accounts for the combined response from all the geophysical measurements.

Table 4: Tool measurements, volumes, and respective parameters used in the well R-50 ELAN analysis

Volume / Tool Measurement	Air	Water	Albite	Labradorite	Silica Glass, Cristo., Tridy.	Heavy Mafic Minerals	Augite	Montmorillinite	Biotite	Pyrite	Orthoclase	Calcite	Quartz
Bulk density (g/cc)	–0.19	1.00	2.58	2.68	2.33	5.08	3.08	2.02	3.04	4.99	2.54	2.71	2.64
Epithermal neutron poro. (ft^3/ft^3)	0	1.00	-0.01	-0.01	0.0	0.022	-0.01	0.6	0.14	0.165	-0.01	0.0	-0.05
Dry weight silicon (lbf/lbf)	0.0	0.0	0.32	0.247	0.468	0.184	0.225	0.242	0.178	0.0	0.3	0.0	0.468
Dry weight calcium (lbf/lbf)	0.0	0.0	0.0	0.09	0.0	0.0	0.10	0.012	0.007	0.0	0.0	0.405	0.0
Dry weight iron (lbf/lbf)	0.0	0.0	0.02	0.023	0.0	0.22	0.112	0.02	0.199	0.466	0.015	0.0	0.0
Dry weight sulfur (lbf/lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.535	0.0	0.0	0.0
Dry weight titanium (lbf/lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.048	0.001	0.016	0.0	0.0	0.0	0.0
Wet weight potassium (lbf/lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.003	0.004	0.070	0.0	0.12	0.0	0.0
Wet weight thorium (ppm)	0	0	1.5	3	2	10	10	44	50	0	7	0	0
Neutron capture cross section (cu)	0	22.21	11.4	7.87	4	103	25.66	20	54.1	90	15.82	7.4	4.7

ft^3 = cubic feet
ppm = parts per million
cu = neutron capture units
lbf = pounds force
g/cc = grams per cubic centimeter

3. Results

Preliminary results from the wireline geophysical logging measurements acquired by Schlumberger in R-50 were generated in the logging truck at the time the geophysical services were performed and were documented in the field logs provided on site. However, the measurements presented in the field results are not fully corrected for undesirable influence (from a measurement standpoint) of borehole and geologic conditions and are provided as separate, individual logs. The field log results have been processed (1) to correct/improve the measurements, as best as possible, for borehole/formation environmental conditions,

and (2) to ensure that all the logs from different tool runs are on depth. Additional logs were generated from integrated analysis of processed measured logs, providing valuable estimates of key geologic and hydrologic properties.

The processed log results are presented as continuous curves of the processed measurement versus depth and are displayed as (1) a one-page, compressed summary log display for selected directly related sets of measurements (see Figures 1, 2, and 3); and (2) an integrated log montage that contains all the key processed log curves, on depth and side by side (see Attachment 1). The summary log displays address specific characterization needs, such as porosity, production capacity, moisture content, water saturation, and lithologic changes. The purpose of the integrated log montage is to present, side by side, all the most salient processed logs and log-derived models, depth-matched to each other, so that correlations and relationships between the logs can be identified.

Important results from the processed geophysical logs in R-50 are described below.

3.1. Well Fluid Level

The well standing water level in R-50 (within the freestanding 12.1 in. ID casing) was 1064-1066 ft bgs at the time of logging, and did not vary much between the different logging runs.

3.2. Regional Aquifer

The processed logs indicate that the intersected geologic section is fully saturated with water from the bottom of the borehole (1,223 ft bgs) to likely 1,064 ft bgs, which lies within alluvium/fanglomerate. Below 1,064 ft the log estimated water content and total porosity closely track each other, ranging mostly 25 to over 40% of total rock/sediment volume with some intervals reaching higher (particularly at the bottom of the borehole). Above 1,064 ft the water content drops precipitously to 10% while the total porosity is mostly over 20%. The estimated water saturation below 1,064 ft is mostly over 90% of the pore volume while above 1,064 ft it is less than 50%.

Conclusions that can be drawn from these geophysical log results are that the Regional Aquifer water level (depth at which there is full water saturation) is most likely 1,064 ft, with very little evidence that it is higher.

The location of productive zones within the saturated section is difficult to determine due to the adverse cased well conditions. Higher porosity is not necessarily indicative of higher production capacity since fine grained sediments often have higher porosity and lower productivity than coarser grained sediments. The highest porosities may be associated with washouts behind the casing. Overall, the processed logs indicate the highest permeability within the saturated section is in the highly porous pumice-rich interval at the bottom of the well – below 1154 ft. The predicted relative flow capacity profile generated from the integrated log analysis estimated permeability results suggest that the most productive intervals are 1068–1074, 1078–1080, 1155–1158, 1163–1168, 1178–1186, 1191–1201, 1203–1205, 1209–1213, 1214–1216, and 1221–1223 ft bgs (see porosity summary display in Figure 4.1 or integrated log montage in Attachment 1).

3.3. Vadose Zone Perched Water

As mentioned above, the depth to the top of the Regional Aquifer and, thus, the extent of the vadose zone most likely extends above 1,064 ft bgs. Above 1,064 ft bgs the estimated water content varies from 5% to 30% of total rock volume, mostly remaining below 20% except across the interval 887–902 ft, located at the top of the alluvium/fanglomerate and just below the base of a thick basalt lava sequence. Other intervals with elevated water content are 602–612 ft (reaching 20% and located in basalt lava, possibly at the bottom of a flow unit), 547–548 ft (reaching 15% and located at the top of the basalt lava sequence), and 515–540 ft (reaching 17% and located in the bottom of the tuff sequence, likely with the Guaje Pumice Bed). The water content is notable higher above 540 ft and below 887 ft. The processed logs indicate the highest water saturation within the vadose zone is in the intervals 658–664 and 800–808 ft, where there is 100% water saturation, but these zones have very low porosity and water content (5%), located within tight sections of the basalt lava sequence that is unlikely to flow if it is fully saturated.

3.4. Geology

The processed geophysical log results, particularly the matrix geochemistry logs, provide information on lithology and potential formation contacts intersected by R-50 across the log interval (from 20 to 1,221 ft bgs). The generalized geologic stratigraphy observed from the logs across the measured interval is as follows (depth below ground surface):

- **20–75 ft bgs (top of log interval): Relatively high porosity silicon rich volcanic tuff or alluvium** – characterized by high total porosity (30–40% of total rock volume); high silica glass/tridymite/cristobalite or quartz content; varying minor to moderate potassium feldspar content; varying amounts of augite (or similar minerals) and calcite (or other calcium-bearing minerals); and potentially trace amounts of pyrite (or other sulfur-bearing minerals)

- **75–189 ft bgs: Very high porosity thorium and uranium rich volcanic tuff** – characterized by very high total porosity (40–48% of total rock volume); high silica glass/tridymite/cristobalite content; varying minor to moderate potassium feldspar content; minor quartz content; trace to minor amounts of augite and calcite or similar minerals; and potentially trace amounts of pyrite (or other sulfur-bearing minerals)

- **189–232 ft bgs: Very high thorium and uranium rich volcanic tuff** – characterized by very high total porosity (over 45–50% of total rock volume); high silica glass/tridymite/cristobalite content; varying minor to moderate potassium feldspar content; minor quartz content; trace to minor amounts of augite and calcite or similar minerals; and potentially trace amounts of pyrite (or other sulfur-bearing minerals)

- **232–248 ft bgs: High porosity, relatively low uranium volcanic tuff** – characterized by high total porosity (34–45% of total rock volume); high silica glass/tridymite/cristobalite content; varying minor to moderate potassium feldspar content; minor quartz content; trace to minor amounts of augite and calcite or similar minerals; and potentially trace amounts of pyrite (or other sulfur-bearing minerals)

- **248–510 ft bgs: High to very high porosity thorium and uranium rich volcanic tuff** – characterized by high total porosity (30–50%, highest from 350 to 434 ft); high silica glass/tridymite/cristobalite content; moderate potassium feldspar content; minor quartz content; trace to minor amounts of augite and calcite or similar minerals; and potentially trace amounts of pyrite (or other sulfur-bearing minerals)

- **510–525 ft bgs: Very high porosity thorium and uranium rich volcanic tuff (likely Guaje Pumice Bed at bottom)** – characterized by very high total porosity (42–54%); high silica glass/tridymite/cristobalite content; moderate potassium feldspar content; minor quartz content; trace to minor amounts of augite and calcite or similar minerals; and potentially trace amounts of pyrite (or other sulfur-bearing minerals)

- **525–542 ft bgs: Moderate porosity silicon-rich alluvium/fanglomerate** – characterized by moderate total porosity (25–35%); high silica glass/tridymite/cristobalite or quartz content; varying minor to moderate amounts of plagioclase and potassium feldspar; presence of montmorillinite from 525 to 530 ft; trace to minor amounts of augite, magnetite, pyrite and biotite (or similar minerals)

- **542–612 ft bgs: Very low gamma ray, very high porosity plagioclase feldspar and pyroxene rich volcanics (likely basalt)** – characterized by potentially very high to unrealistically high total porosity (40 to greater than 60%, the highest likely elevated due to voids behind the casing); high plagioclase feldspar content; varying moderate to high augite content (or

similar mineral); minor alkali feldspar content; and variably trace to small amounts of magnetite, pyrite, and hematite (or similar minerals)

- **612–642 ft bgs: High porosity, plagioclase feldspar and pyroxene rich volcanics (likely basalt)** – characterized by high total porosity (25 to over 40%); high plagioclase feldspar content; moderate augite content (or similar mineral); variably minor to moderate alkali feldspars; and variably trace to small amounts of magnetite, pyrite and hematite (or similar minerals)

- **642–672 ft bgs: Low porosity plagioclase feldspar and pyroxene rich volcanics (likely basalt)** – characterized by low to moderate total porosity (5–12%); high plagioclase feldspar content; moderate augite content (or similar mineral); variably minor to moderate alkali feldspars; and variably trace to small amounts of magnetite, pyrite and hematite (or similar minerals)

- **672–760 ft bgs: Very high porosity plagioclase feldspar and pyroxene rich volcanics (likely basalt)** – characterized by potentially very high to unrealistically high total porosity (25 to greater than 60%, the highest likely elevated due to voids behind the casing); moderate augite content (or similar mineral); variably minor to moderate alkali feldspars; and variably trace to small amounts of magnetite, pyrite and hematite (or similar minerals)

- **760–810 ft bgs: Low porosity plagioclase feldspar and pyroxene rich volcanics (likely basalt)** – characterized by low to moderate total porosity (5–18%); high plagioclase feldspar content; moderate augite content (or similar mineral); variably minor to moderate alkali feldspars; and variably trace to small amounts of magnetite, pyrite and hematite (or similar minerals)

- **810–880 ft bgs: High porosity plagioclase feldspar and pyroxene rich volcanics (likely basalt)** – characterized by moderate to high total porosity (18–35%); high plagioclase feldspar content; moderate augite content (or similar mineral); variably minor to moderate alkali feldspars; and variably trace to small amounts of magnetite, pyrite and hematite (or similar minerals)

- **880–892 ft bgs: Very high porosity, silicon-rich alluvium/fanglomerate** – characterized by very high to unrealistically high total porosity (40–48%); high silica glass/tridymite/cristobalite or quartz content; varying minor to moderate amounts of plagioclase, potassium feldspar, and montmorillinite; and trace to minor amounts of augite, biotite, magnetite and pyrite (or similar minerals)

- **892–1,035 ft bgs: Moderate porosity silicon-rich alluvium/fanglomerate** – characterized by moderate total porosity (mostly 20–35%); high silica glass/tridymite/cristobalite or quartz content; varying minor to moderate amounts of plagioclase, potassium feldspar, and montmorillinite; and trace to minor amounts of augite, biotite, magnetite and pyrite (or similar minerals)

- **1,035–1,095 ft bgs: Very high, highly variable porosity, silicon-rich alluvium/fanglomerate** – characterized by variably very high total porosity (20 to 45% and higher); high silica glass/tridymite/cristobalite or quartz content; varying minor to moderate amounts of plagioclase, potassium feldspar, and montmorillinite; and trace to minor amounts of augite, biotite, magnetite and pyrite (or similar minerals)

- **1,095–1,154 ft bgs: Moderate porosity, relatively high clay alluvium/fanglomerate** – characterized by moderate total porosity (mostly 25–35%); high silica glass/tridymite/cristobalite or quartz content; moderate montmorillinite content; varying minor to moderate amounts of plagioclase and potassium feldspar; and trace to minor amounts of augite, biotite, magnetite and pyrite (or similar minerals)
- **1,154–1,221 ft bgs (bottom of log interval): Very high porosity, silicon-rich alluvium/fanglomerate (likely pumice rich)** – characterized by very high total porosity (40–50%); moderate to high silica glass/tridymite/cristobalite and alkali feldspar; minor to moderate amounts of plagioclase feldspar; and trace to minor amounts of augite, montmorillinite, augite, biotite, magnetite and pyrite (or similar minerals)

3.5. Summary Logs

Three summary log displays have been generated for R-50 to highlight the key hydrogeologic and geologic information provided by the processed geophysical log results:

- Porosity and hydrogeologic properties summary log showing continuous hydrogeologic property logs, including total porosity (water and air), water-filled porosity, water saturation, estimated hydraulic conductivity, transmissivity, and relative producibility (production capacity); highlights key derived hydrologic information obtained from the integrated log results, including (Figure 1)
- Density and clay content summary showing a continuous logs of formation bulk density and estimated grain density, as well as estimated clay volume, highlights key geologic rock matrix information obtained from the log results (Figure 2)
- Geochemical and lithology summary showing a high vertical resolution, continuous volumetric analysis of formation mineral and pore fluid composition (based on an integrated analysis of the logs), and elemental concentration logs from the ECS geochemical measurement (neutron induced gamma ray spectroscopy); highlights the geologic lithology, stratigraphy, and correlation information obtained from the log results (Figure 3)

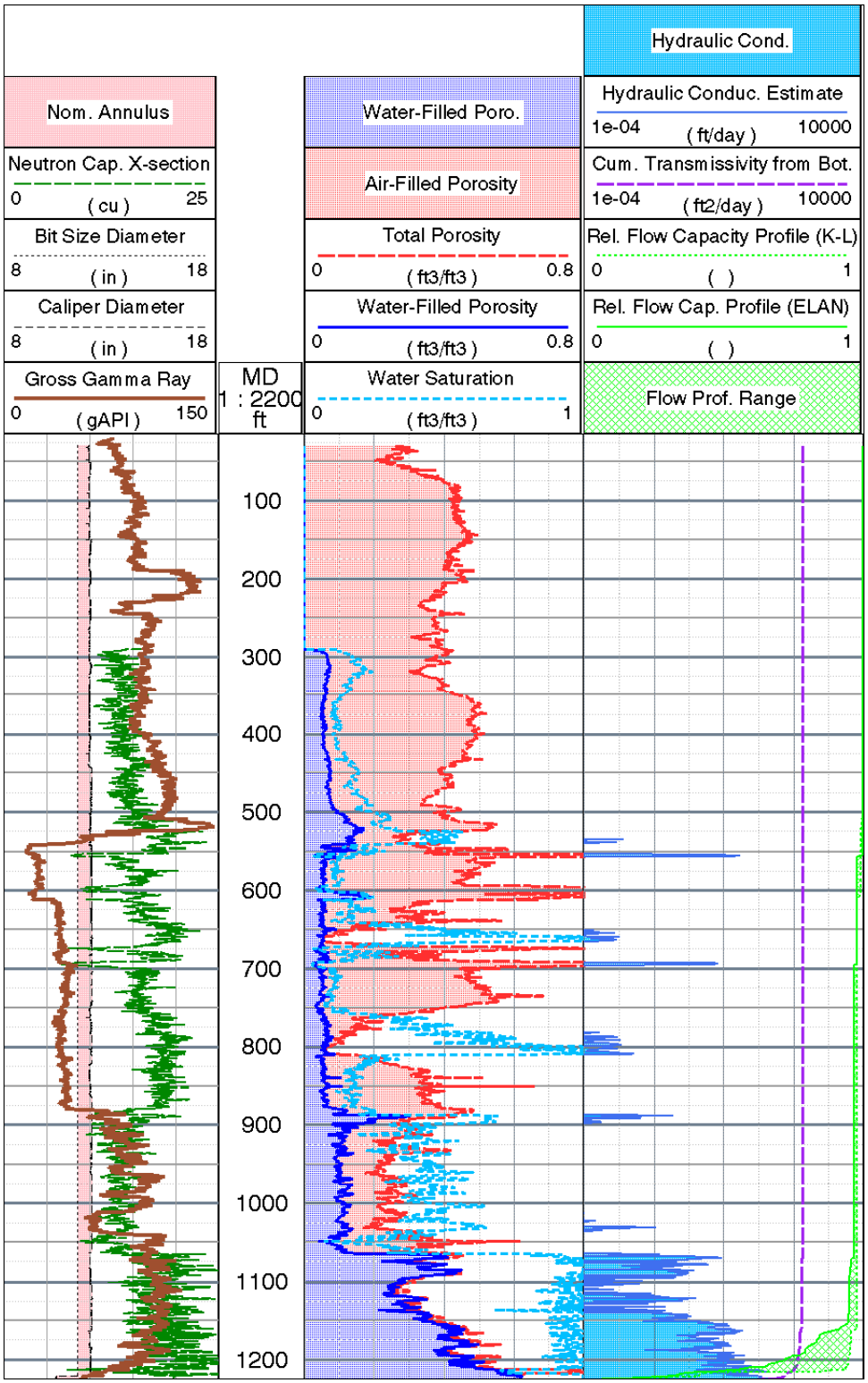


Figure 1: Summary of porosity logs in R-50 borehole from processed geophysical logs, interval of 20 to 1,221 ft bgs, with caliper, gross gamma, neutron capture cross-section, water saturation, estimated relative flow capacity profile, hydraulic conductivity, and transmissivity logs also displayed. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN integrated log analysis.

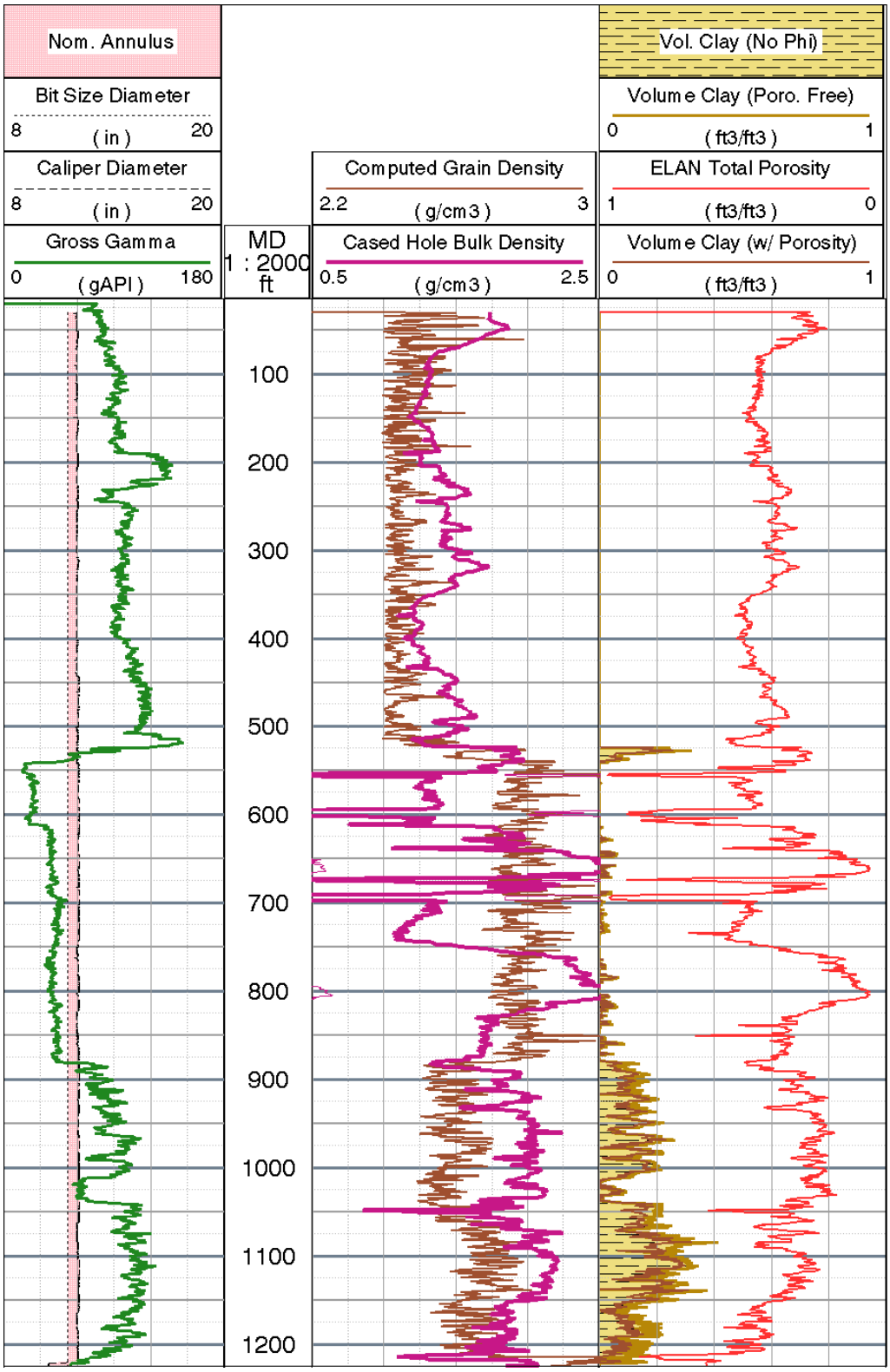


Figure 2: Summary of bulk density and apparent grain density logs in R-50 borehole from processed geophysical logs, interval of 37 to 1,221 ft bgs. Also shown are caliper, gross gamma, volume of clay, and total porosity logs (the latter two derived from the ELAN analysis).

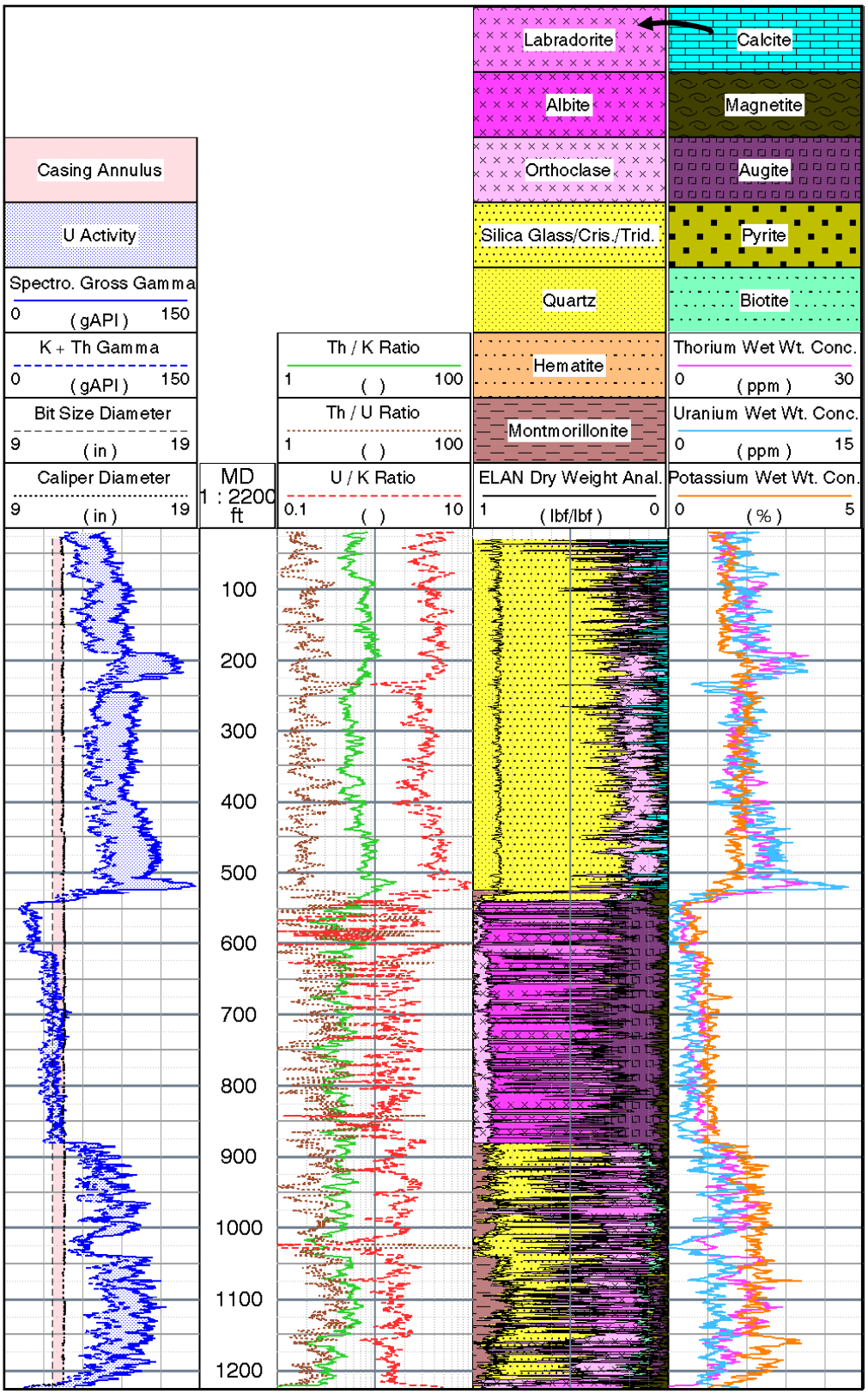


Figure 3: Summary of spectral natural gamma ray logs and ELAN mineralogy/lithology and pore fluid model volumes derived from the ELAN integrated log analysis for R-50 borehole, interval 20 to 1,221 ft bgs. Caliper log is also shown.

3.6. Integrated Log Montage

This section summarizes the integrated geophysical log montage for R-50. The montage is provided in Appendix 1. A description of each log curve in the montage follows, organized under the heading of each track, starting from track 1 on the left-hand side of the montage. Note that the descriptions in this section focus on what the curves are and how they are displayed; the specific characteristics and interpretations of the R-50 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 TLD logging run. All the geophysical logs are depth-matched to the gross gamma log acquired with this logging run.

Track 2–Basic Logs

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

- gamma ray (thick black), recorded in American Petroleum Institute gamma ray standard units (gAPI) and displayed on a scale of 0 to 200 gAPI units;
- single arm caliper from the TLD (thin solid pink) with nominal bit size as a reference (dashed-dotted black) to show nominal annular distance between inside of inner casing to borehole wall (pink shading), recorded as hole diameter in inches and displayed on a scale of 9 to 19 in.;
- cable tension (dashed-dotted dark red) recorded at logging truck and displayed to indicate tool pickup at bottom on a scale of 0 to 1000 lbf;
- neutron capture cross section from the APS (bold long-dashed green), recorded in standard capture units (cu) and displayed on a scale of 0 to 30 cu (left to right).

Two gamma ray curves from the HNGS are displayed:

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

- yellow shading between the two curves to show uranium contribution to the total gamma ray response.

Track 3–Porosity

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

- APS epithermal neutron porosity derived from near-far detector pairing (bold solid dark blue curve) – deepest reading epithermal neutron porosity from APS tool, processed for zoned air-filled and water-filled cased hole;
- APS epithermal neutron porosity derived from near-array detector pairing (solid sky blue curve) – medium depth of investigation epithermal neutron porosity from APS tool, processed for zoned air-filled and water-filled cased hole;
- APS slowing down time porosity derived from pulsed neutron time series in the array detectors (thin dotted green curve) – shallowest reading epithermal neutron porosity from APS tool, processed for zoned air-filled and water-filled cased hole;
- ECS relative hydrogen yield (short-dashed sky blue);
- Total porosity derived from bulk density and ELAN water-filled porosity using a grain density of 2.4/2.8/2.55/2.5 g/cc (dashed red curve), 2.45/2.85/2.6/2.55 g/cc (long-dashed red curve), and 2.5/2.9/2.65/2.6 g/cc (dotted red curve)–with red shading between the 2.4/2.8/2.55/2.5 g/cc and 2.5/2.9/2.65/2.6 g/cc porosity curves to show the range (the lowest grain density range used across the tuff/pumice interval [20–525 ft], the highest grain density range used across the basalt lava flows [542–880 ft], and the middle two grain density ranges used for the alluvium/fanglomerate intervals [20–525 and 880–1,221 ft, the lowest for the pumiceous zone below 1,154 ft]); and
- ELAN water-filled porosity (bold dashed-dotted cyan with dark blue shading to right)–derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents.

Track 4–Density

The fourth track displays the

- bulk density, corrected for single string of steel casing (thick solid maroon curve) on a wrapping scale of 1 to 3 g/cc;
- apparent grain density (dashed brown curve), derived from the ELAN analysis, on a scale of 2.4 to 3.2 g/cc.
- density standoff flag (thin black with yellow area shading) on a scale of 10 to 0 in. (left to right)

Track 5–HNGS Spectral Gamma

The fifth track from the left displays the spectral components of the HNGS measurement results as wet weight concentrations, corrected as best as possible for casing and borehole size and fluid:

- potassium (solid green curve) in units of percent weight fraction and on a scale of -5% to 5%;
- thorium (dashed brown) in units of parts per million (ppm) and on a scale of 30 to -30 ppm; and
- uranium (dotted blue) in units of parts per million (ppm) and on a scale of 20 to 0 ppm.

Tracks 6 to 11 – Geochemical Elemental Measurements

The narrow tracks 6 to 11 present the geochemical measurements, along with their estimated one standard deviation uncertainty range: iron (Fe) and silicon (Si), sulfur (S) and calcium (Ca), estimated aluminum (Al) and potassium (K), titanium (Ti) and gadolinium (Gd), hydrogen yield (H yield), uranium (U) and carbon yield (C Yield) — from left to right respectively, in units of dry matrix weight fraction (except K in wet-weight fraction, U in wet-weight ppm, and H and C Yield in relative yield units).

Track 12 – ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 12 displays the results from the ELAN integrated log analysis (the matrix portion)–presented as dry-weight fraction of mineral types chosen in the model:

- Montmorillinite clay (brown/tan)
- Hematite (orange with small black dots)
- Quartz (yellow with closely spaced small black dots)

- Combined silica glass, tridymite, and cristobalite (yellow with widely spaced large black dots)
- Orthoclase or other potassium feldspar (lavender)
- Albite or similar plagioclase feldspar (violet)
- Labradorite or similar calcium-rich plagioclase feldspar (pink)
- Biotite (light green)
- Pyrite (orange-tan with black squares)
- Augite (maroon)
- Magnetite or similar heavy mafic/ultramafic minerals (dark green)
- Calcite (cyan)

Track 13–ELAN Mineralogy and Pore Space Model Results (Wet Volume Fraction)

Track 13 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- Montmorillinite clay (brown/tan)
- Clay bound water (checkered black and grey)
- Hematite (orange with small black dots)
- Quartz (yellow with closely spaced small black dots)
- Combined silica glass, tridymite, and cristobalite (yellow with widely spaced large black dots)
- Orthoclase or other potassium feldspar (lavender)
- Albite or similar plagioclase feldspar (violet)
- Labradorite or similar calcium-rich plagioclase feldspar (pink)
- Biotite (light green)
- Pyrite (orange-tan with black squares)
- Augite (maroon)

- Magnetite or other heavy mafic/ultramafic mineral (dark green)
- Calcite (cyan)
- Air (red)
- Water (white)
- Moved air (orange)
- Moved water (blue)

Track 14–Water Saturation

Track 14 displays the continuous-in-depth water saturation logs estimated from the processed logs, recorded in units of volumetric fraction of pore space filled with water (ratio of cubic feet per cubic feet [ft3/ft3]) and presented on a scale of 0 to 1 ft3/ft3 (left to right).

- Optimized estimate of water saturation (volumetric fraction of pore space filled with water) from the ELAN analysis (bold dashed-dotted purple curve with blue shading to the right and red shading to the left, corresponding to water-filled and air-filled pore space, respectively);
- Water saturation as calculated directly from the bulk density and ELAN-estimated porosity using a grain density of 2.4/2.8/2.55/2.5 g/cc (dashed cyan curve), 2.45/2.85/2.6/2.55 g/cc (long-dashed cyan curve), and 2.5/2.9/2.65/2.6 g/cc (dotted cyan curve)–with cyan shading between the 2.4/2.8/2.55/2.5 g/cc and 2.5/2.9/2.65/2.6 g/cc porosity curves to show the range (the lowest grain density range used across the tuff/pumice interval [20–525 ft], the highest grain density range used across the basalt lava flows [542–880 ft], and the middle two grain density ranges used for the alluvium/fanglomerate intervals [20–525 and 880–1,221 ft, the lowest for the pumiceous zone below 1,154 ft]).

Track 15–Hydraulic Conductivity

Track 15 displays several estimates of hydraulic conductivity (K) derived from the ELAN integrated log analysis (sensitive to the estimated porosities and mineral composition), presented on a logarithmic scale of 10^{-5} to 10^{5} feet per day (ft/day):

- K-versus-depth estimate derived from using the ELAN permeability equation with water-filled porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (bold solid blue curve with gradational coloring to represent the range of hydraulic conductivity relative to standard unconsolidated clastic sediments);
- K-versus-depth estimate derived from using the k-Lambda permeability equation with water-filled porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (long-dashed sky blue curve); and
- intrinsic K-versus-depth estimate (assuming full saturation) using the ELAN total porosity and mineral-based permeability equation with total porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (dotted purple).

Track 16–Predicted Flow (Production Potential) Profile

Track 16 displays the integrated predicted relative flow (production potential) profile from the permeability (hydraulic conductivity) logs that mimics a flow meter (spinner) acquired under flowing conditions:

- Predicted relative water flow profile derived from the k-Lambda water permeability log (long-dashed blue), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate (ratio of flow rate to flow rate);
- Predicted relative water flow profile derived from the ELAN water permeability log (bold solid blue curve), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate;
- Predicted relative water flow profile across the saturated zone derived from the ELAN water permeability log (bold solid purple curve), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate;
- Relative integrated intrinsic permeability profile derived by integrating the k-Lambda intrinsic permeability log (dashed-dotted red), displayed on a unitless linear scale of 0 to 1;
- Relative integrated intrinsic permeability profile derived by integrating the ELAN intrinsic permeability log (dashed red), displayed on a unitless linear scale of 0 to 1;
- Predicted hypothetical well water flow versus depth profile for the entire log interval (dotted green), assuming a well radius of 4 in., entirely open to flow, and pumping is occurring under

steady state conditions with a drawdown of 25 ft (incremental flow computed using the Thiem steady state flow equation) – derived from the k-Lambda water permeability log (bold solid blue), displayed on a scale of 0 to 1,000,000 gallons per day (gal/day).

Track 17–Summary Logs

Track 17, the second track from the right, displays several summary logs that describe the fluid and air-filled volume measured by the geophysical tools

- Optimized estimate of total volume fraction water from the ELAN analysis (solid blue curve and blue plus cyan area shading);
- Optimized estimate of volume fraction moveable water (non-clay bound moveable water-filled porosity) from the ELAN analysis (dashed cyan curve and cyan area shading);
- Optimized estimate of total volume fraction of air-filled porosity from the ELAN analysis (long-dashed red curve and dotted red area shading);and

The porosity and volumetric water content scales are from 0 to 0.6 total volume fraction, left to right.

Track 18–Depth

The final track on the right, the 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 TLD logging run.

4. References

Juneer, C. and A. Sibbit, 1980. "GLOBAL, A New Approach to Computer-Processed Log Interpretation." Paper SPE 9341 presented at the 1980 SPE Annual Technical Conference and Exhibition.

Quirein, J., S. Kimminau, J. LaVigne, J. Singer, and F. Wendel. 1986. "A Coherent Framework for Developing and Applying Multiple Formation Evaluation Models." Paper DD in 27th Annual Logging Symposium Transactions: Society of Professional Well Log Analysts.

Attachment 1 – Color Print of Integrated Log Well Montage for Well R-50

Integrated Wireline Log Well Montage

Processed Advanced Cased Hole Geophysical Logs

Using the following logs:

APS*, TLD*, HNGS*, SGT*

Trademark of Schlumberger

COMPANY: TRMC (Drilling contractor for LANL)
WELL: R-50 Regional Wells
FIELD: New Mexico
STATE:
County/Parish:
Other Services:
Well Location: 25~Jan~2010 Date Processed: Apr~2010
Elevations:
API Number:
Job Number:
K.B. NA D.F. NA G.L. NA

GEOFRAME PROCESSED INTERPRETATION

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

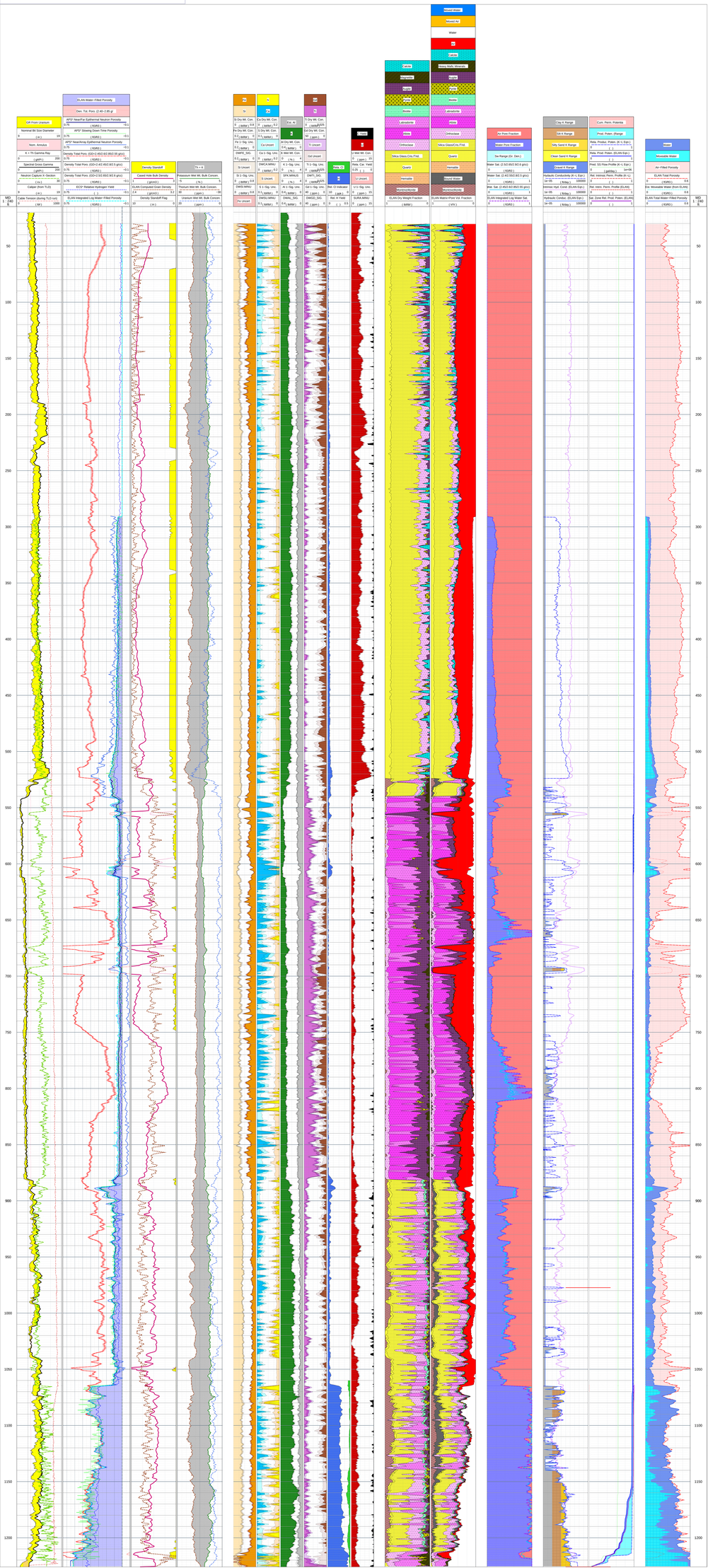
Sen. Order # AZNW~00064 OP Wes.: 17CD~154 Process Date: April~2010 Center: SWS Tucson Baseline: GF4.2 Log Analyst: N. Cl

Mud and Borehole Measurements:

Rm @ Measured Temperature: NA	BHT: 77 degF	Bitsize: 12.25 in	Casing: 12.1 in ID
Rmf @ Measured Temperature: NA	Type Fluid in Hole:	FGW	
Rmc @ Measured Temperature: NA	Mud density: 8.34 lb/ngal	FGW	

Remarks:

Depth reference is ground surface.
Well contained one or more strings of casing (casing advance) during logging.
Well water level at 1064~1066 ft during logging.
ELAN* integrated log anal. performed without porosity or water saturation constraints.
Interpretation should account for well conditions.



Attachment 2 – Color Print of ELAN Optimized Mineral and Pore Volume Model Results for Well R-50

Schlumberger

ELAN* Geophysical Log Integrated Analysis

Optimized Mineral + Pore Volume Model

COMPANY: TPMC

WELL: LANL R−50

FIELD: None

State: New Mexico

COUNTRY:

*Elemental Log Analysis, Mark of Schlumberger

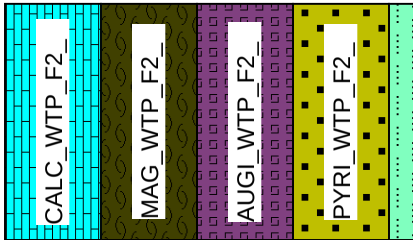
Date Processed:	April−2010	Date Logged:	25−Jan−2010
Job Number:		Processed at:	SWS Tucson
Well Location:			
Latitude:		Longitude:	
Elevations:	KB:	DF:	GL:

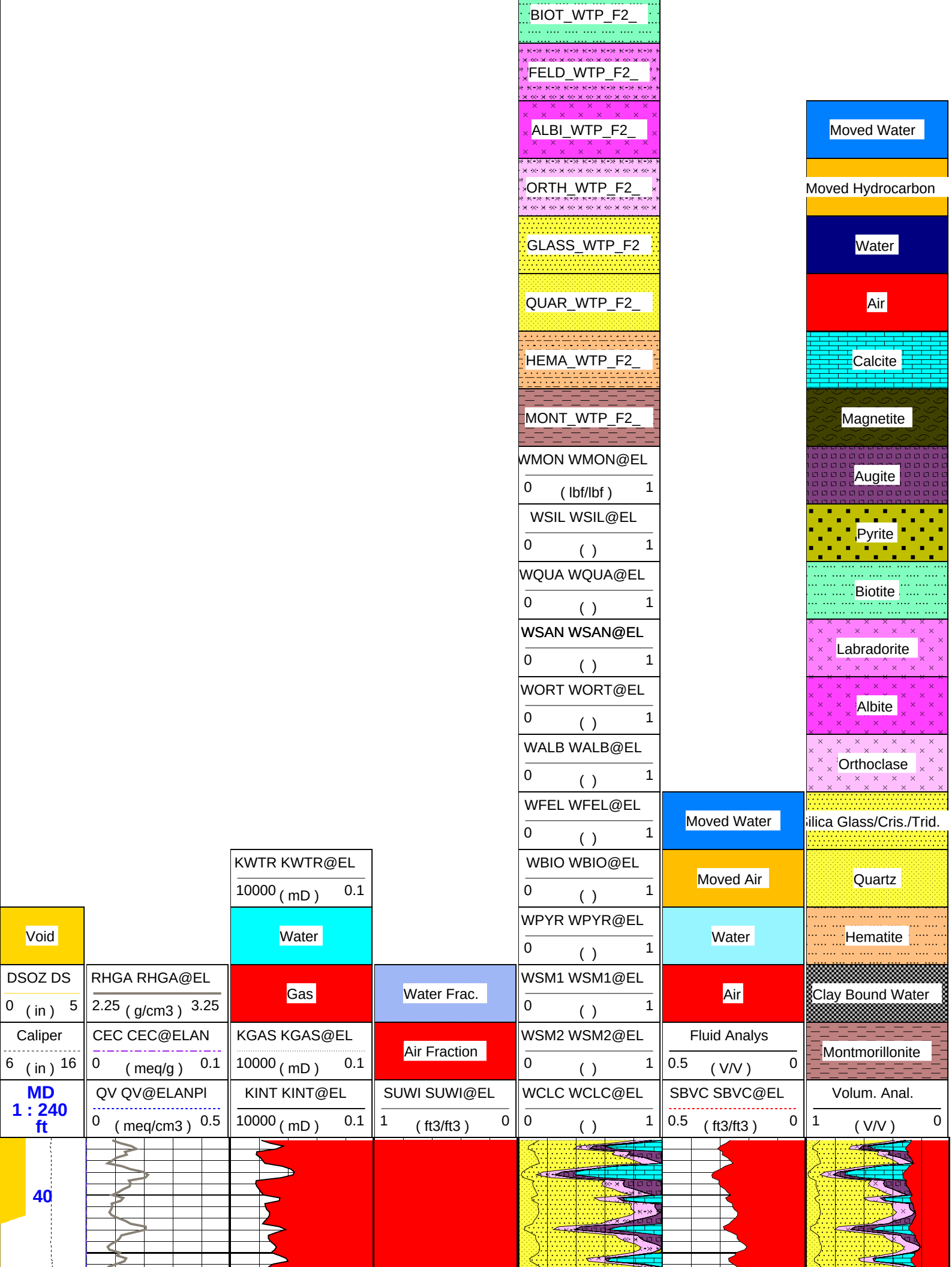
Depth ref. is ground surface. Results are affected by cased hole conditions.

FOLD HERE

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

R−50 [Fun_2]

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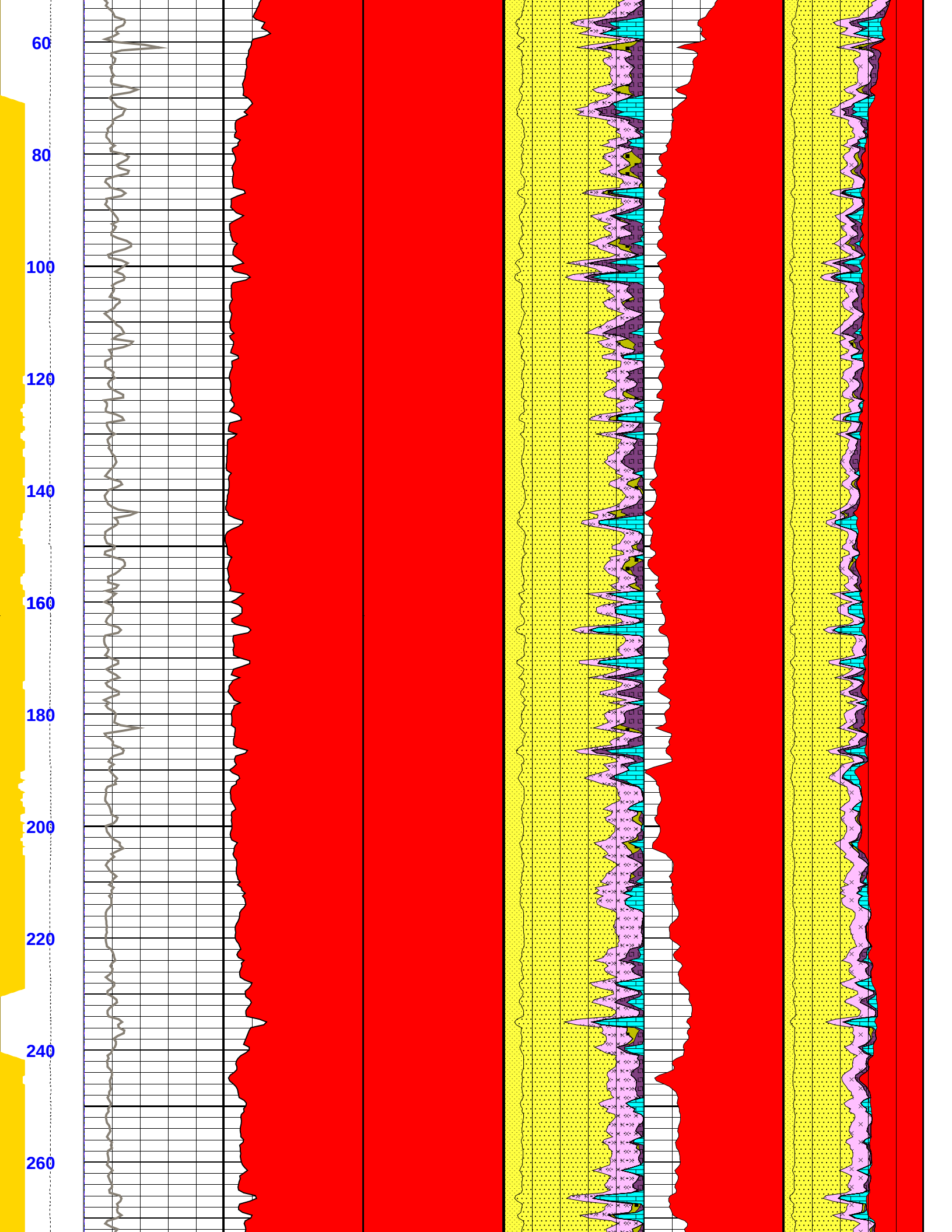
FELD_WTP_F2_
ALBI_WTP_F2_
ORTH_WTP_F2_
GLASS_WTP_F2
QUAR_WTP_F2_
HEMA_WTP_F2_
MONT_WTP_F2_
WMON WMON@EL
0 (lbf/lbf) 1
WSIL WSIL@EL
0 ( ) 1
WQUA WQUA@EL
0 ( ) 1
WSAN WSAN@EL
0 ( ) 1
WORT WORT@EL
0 ( ) 1
WALB WALB@EL
0 ( ) 1
WFEL WFEL@EL
0 ( ) 1
WBIO WBIO@EL
0 ( ) 1
WPYR WPYR@EL
0 ( ) 1
WSM1 WSM1@EL
0 ( ) 1
WSM2 WSM2@EL
0 ( ) 1
WCLC WCLC@EL
0 ( ) 1
Moved Water
Moved Hydrocarbon
Water
Air
Calcite
Magnetite
Augite
Pyrite
Biotite
Labradorite
Albite
Orthoclase
Silica Glass/Cris./Trid.
Quartz
Hematite
Clay Bound Water
Montmorillonite
Volum. Anal.
1 (V/V) 0
KWTR KWTR@EL
10000 (mD) 0.1
Water
Gas
KGAS KGAS@EL
10000 (mD) 0.1
KINT KINT@EL
10000 (mD) 0.1
Void
DSOZ DS
0 (in) 5
Caliper
6 (in) 16
MD
1 : 240
ft
40
RHGA RHGA@EL
2.25 (g/cm3) 3.25
CEC CEC@ELAN
0 (meq/g) 0.1
QV QV@ELANPI
0 (meq/cm3) 0.5
Water Frac.
Air Fraction
SUWI SUWI@EL
1 (ft3/ft3) 0
Moved Water
Moved Air
Water
Air
Fluid Analys
0.5 (V/V) 0
SBVC SBVC@EL
0.5 (ft3/ft3) 0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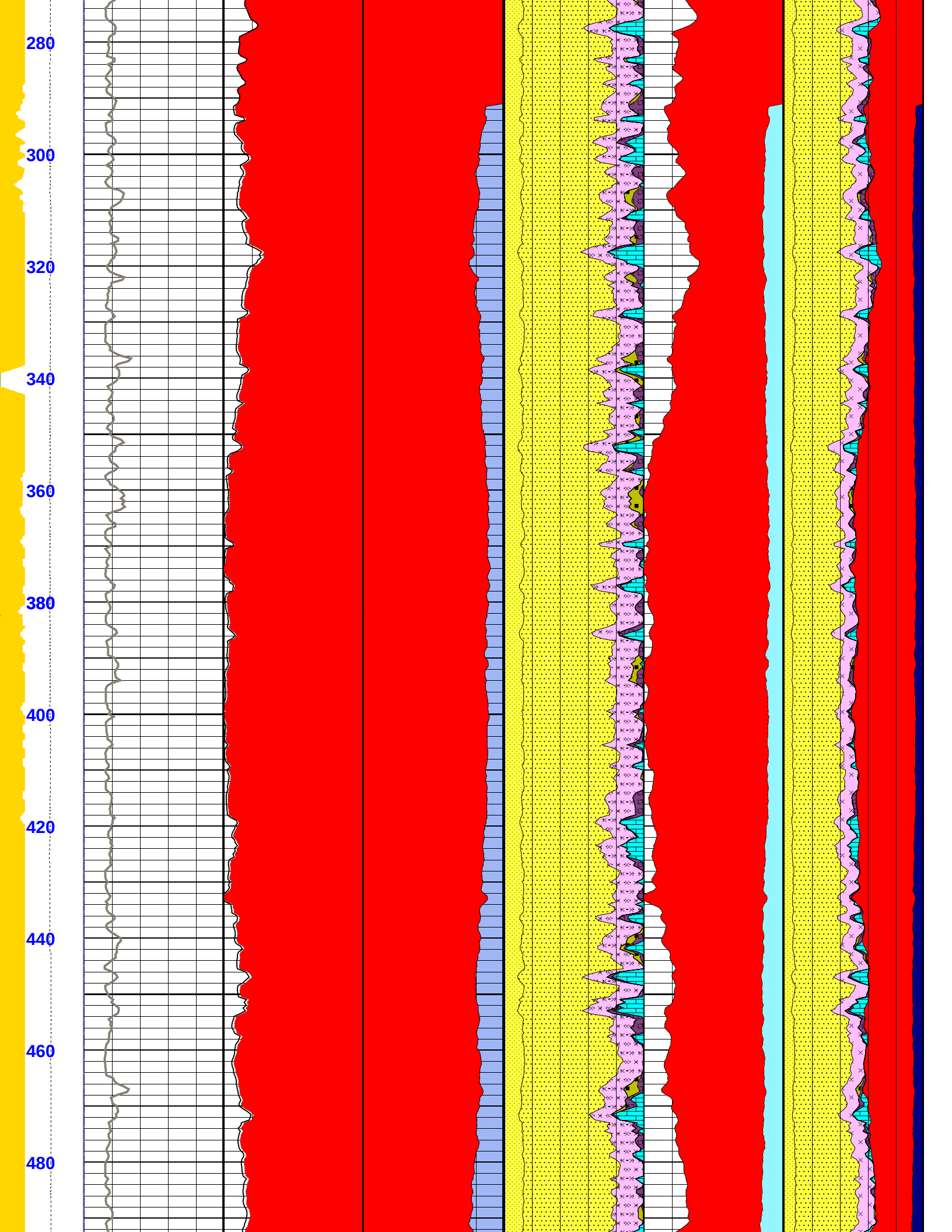
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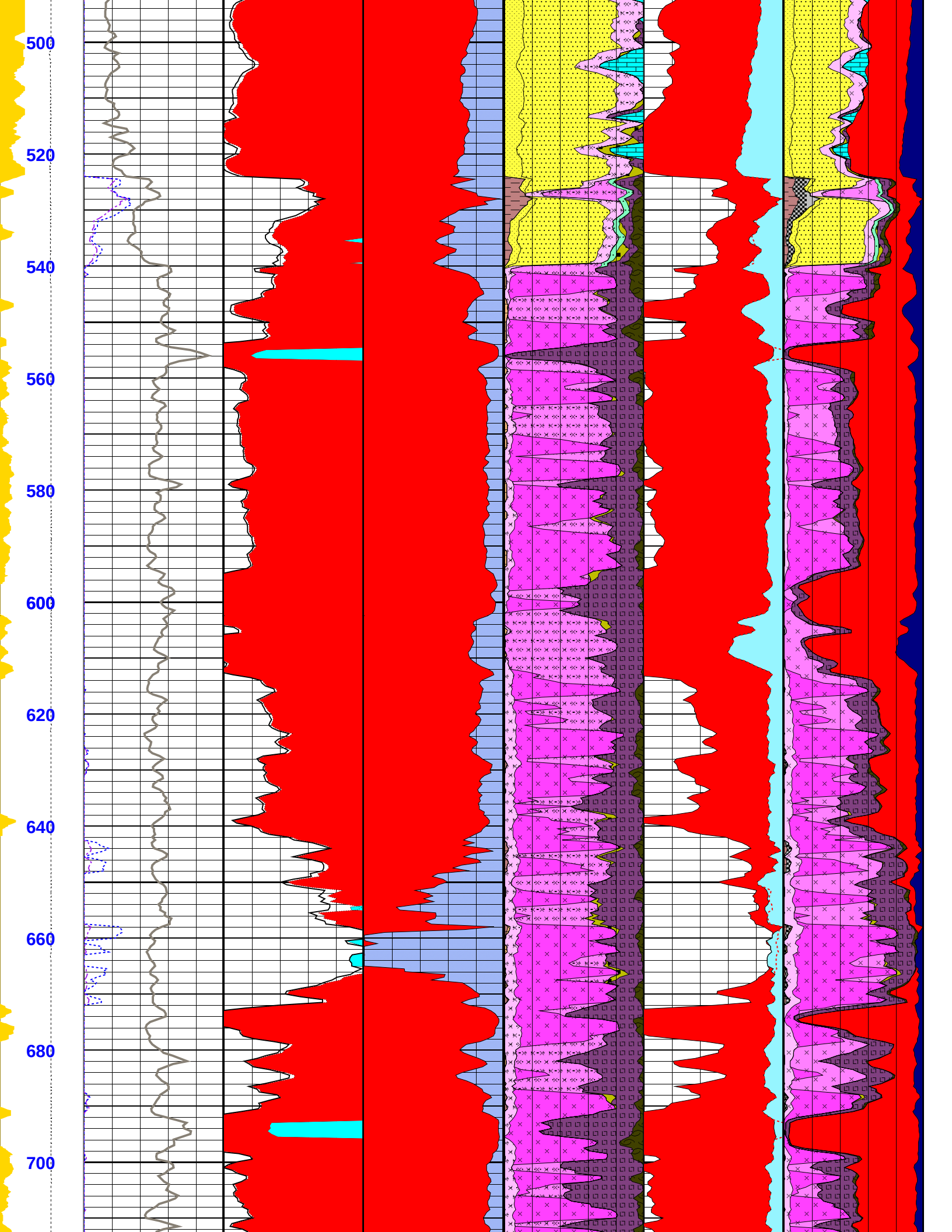
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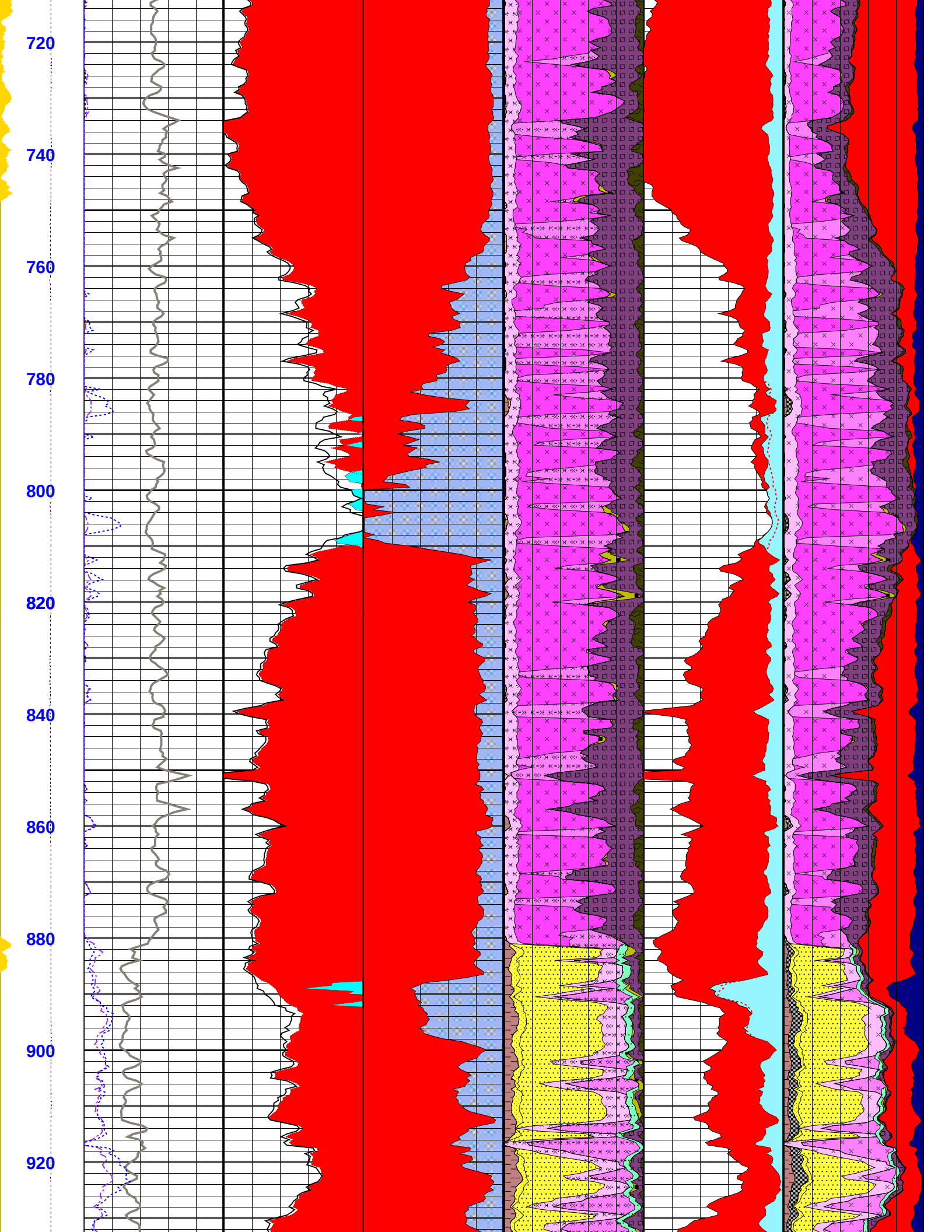
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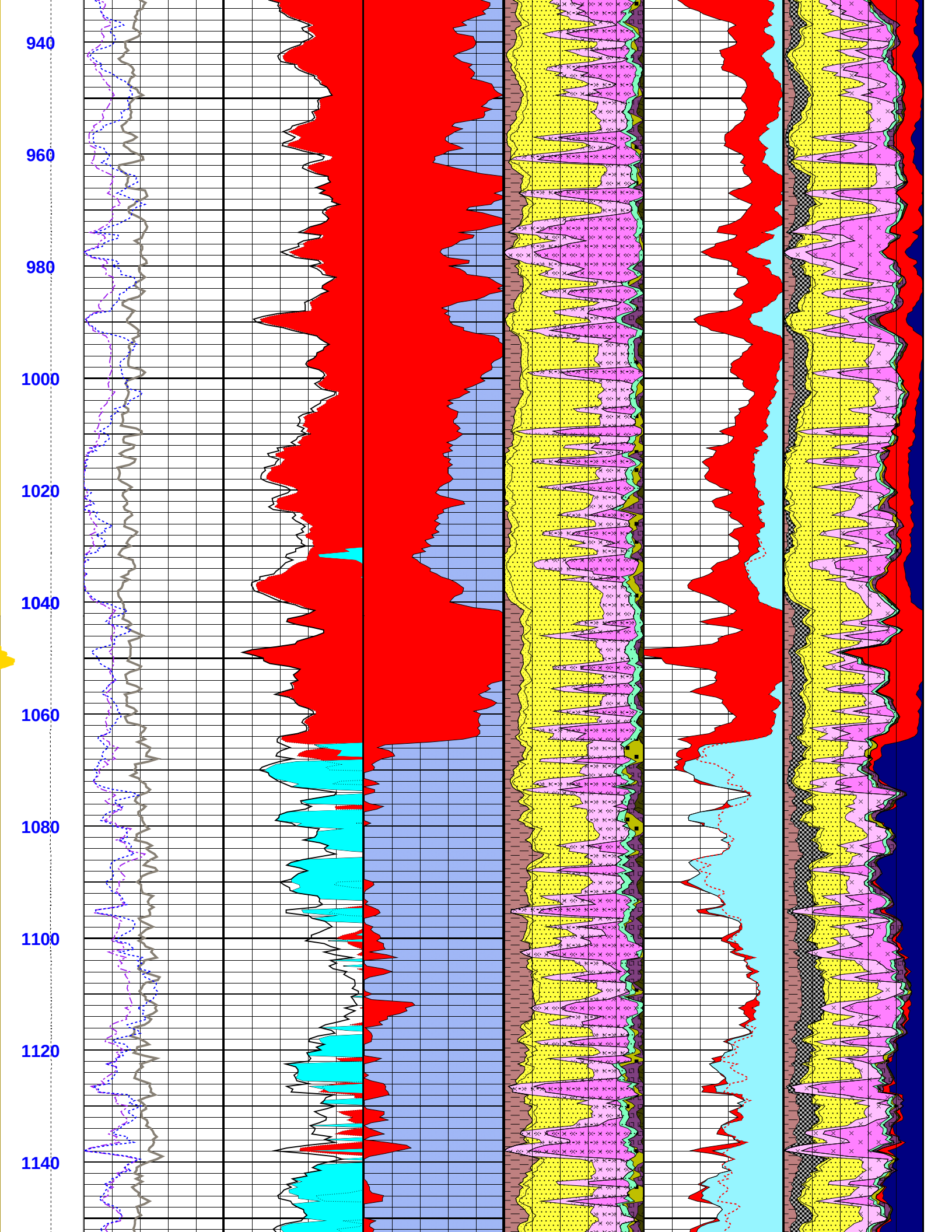
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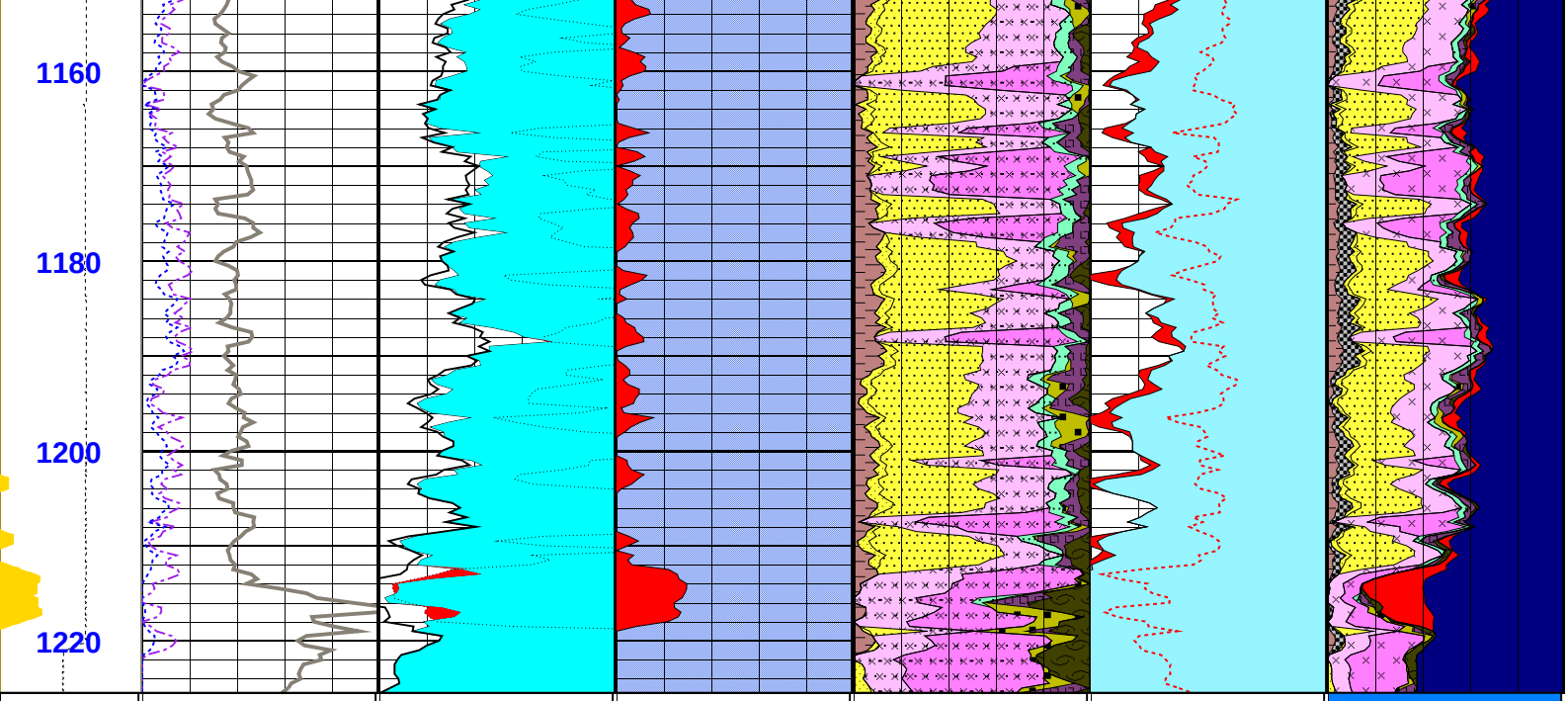
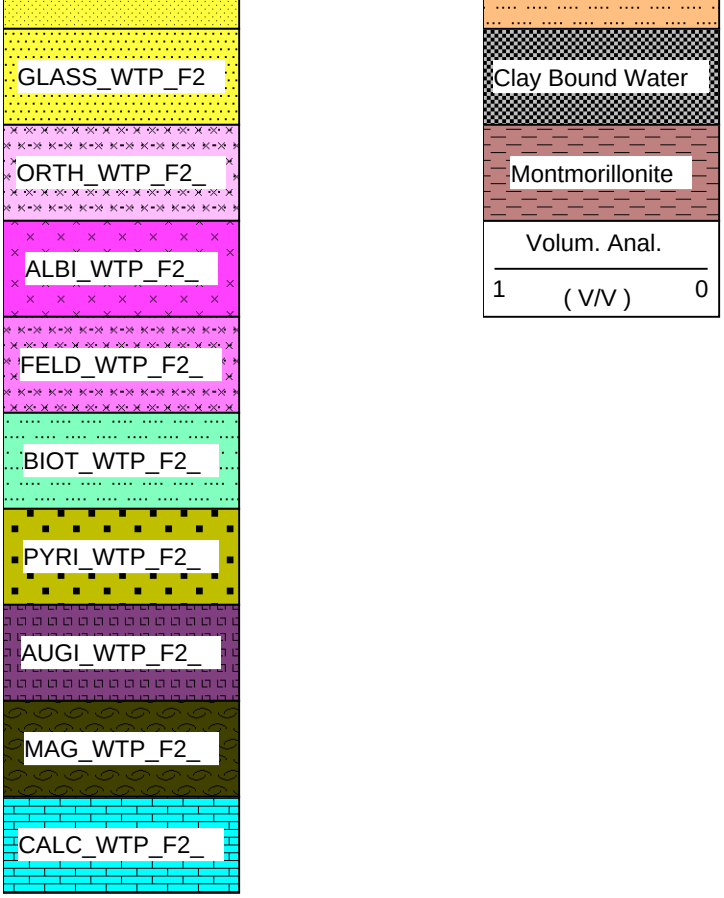
1020
1040
1060
1080
1100
1120
1140



MD 1 : 240 ft	QV QV@ELANPl 0 (meq/cm3) 0.5	KINT KINT@EL 10000 (mD) 0.1	SUWI SUWI@EL 1 (ft3/ft3) 0	WCLC WCLC@EL 0 ( ) 1	SBVC SBVC@EL 0.5 (ft3/ft3) 0	Moved Water
Caliper 6 (in) 16	CEC CEC@ELAN 0 (meq/g) 0.1	KGAS KGAS@EL 10000 (mD) 0.1	Air Fraction	WSM2 WSM2@EL 0 ( ) 1	Moved Water	Moved Hydrocarbon
DSOZ DS 0 (in) 5	RHGA RHGA@EL 2.25 (g/cm3) 3.25	Gas	Water Frac.	WSM1 WSM1@EL 0 ( ) 1	Moved Air	Water
Void		Water		WPYR WPYR@EL 0 ( ) 1	Water	Air
		KWTR KWTR@EL 10000 (mD) 0.1		WBIO WBIO@EL 0 ( ) 1	Air	Calcite
				WFEL WFEL@EL 0 ( ) 1	Fluid Analys 0.5 (V/V) 0	Magnetite
				WALB WALB@EL 0 ( ) 1		Augite
				WORT WORT@EL 0 ( ) 1		Pyrite
				WSAN WSAN@EL 0 ( ) 1		Biotite
				WQUA WQUA@EL 0 ( ) 1		Labradorite
				WSIL WSIL@EL 0 ( ) 1		Albite
				WMON WMON@EL 0 (lbf/lbf) 1		Orthoclase
				MONT_WTP_F2_		ilica Glass/Cris./Trid.
				HEMA_WTP_F2_		Quartz
				QUAR_WTP_F2_		Hematite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BIOT_WTP_F2_
PYRI_WTP_F2_
AUGI_WTP_F2_
MAG_WTP_F2_
CALC_WTP_F2_
Clay Bound Water
Montmorillonite
Volum. Anal.
1
(V/V)
0

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STRT   .FT        1224.87 :START DEPTH
STOP   .FT        2.59183 :STOP DEPTH
STEP   .FT       -0.16404 :STEP
NULL   .          -999.25 :NULL VALUE
COMP   .                  :COMPANY
WELL   .                  :WELL
FLD    .                  :FIELD
LOC    .                  :LOCATION
PROV   .          N/A     :PROVINCE
SRVC   .          N/A     :SERVICE COMPANY
DATE   .                  :DATE
UWI    .          N/A     :UNIQUE WELL ID
~CURVE INFORMATION
DEPT   .FT                :DEPTH
GAMM   .CPS               :Gamma
~PARAMETER INFORMATION
ELEV   .                  :ELEVATION
STE    .                  :STE
DENS   .                  :DENSITY
CASI   .                  :CASING TO1
OPER   .                  :OPERATING RIG TIME
WGT1   .                  :WGT1
CASI   .                  :CASING SIZE1
CASI   .                  :CASING TO2
WGT2   .                  :WGT2
CASI   .                  :CASING SIZE2
WELL   .                  :WELL ID
CASI   .                  :CASING TO3
K.B.   .                  :K.B.
WGT3   .                  :WGT3
TYPE   .                  :TYPE LOG
CASI   .                  :CASING SIZE3
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SALI   .                  :SALINITY
TITL   .                  :TITLE
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CASI   .                  :CASING SIZE5
CTY    .                  :CTY
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D.F.   .                  :D.F.
CASI   .                  :CASING TO6
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RUN1   .                  :RUN1
BIT3   .                  :BIT3
RUN2   .                  :RUN2
PERM   .                  :PERMANENT DATUM
TWP    .                  :TWP
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BIT    .                  :BIT FROM1
RUN3   .                  :RUN3
BIT5   .                  :BIT5
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RUN4   .                  :RUN4
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BIT    .                  :BIT TO2
DEPT   .                  :DEPTH-LOGGER
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   1207.15   47.9883
   1206.99   63.0527
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   1206.66   49.1621
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      1206    73.168
   1205.84   51.1465
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   1205.35    40.959
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