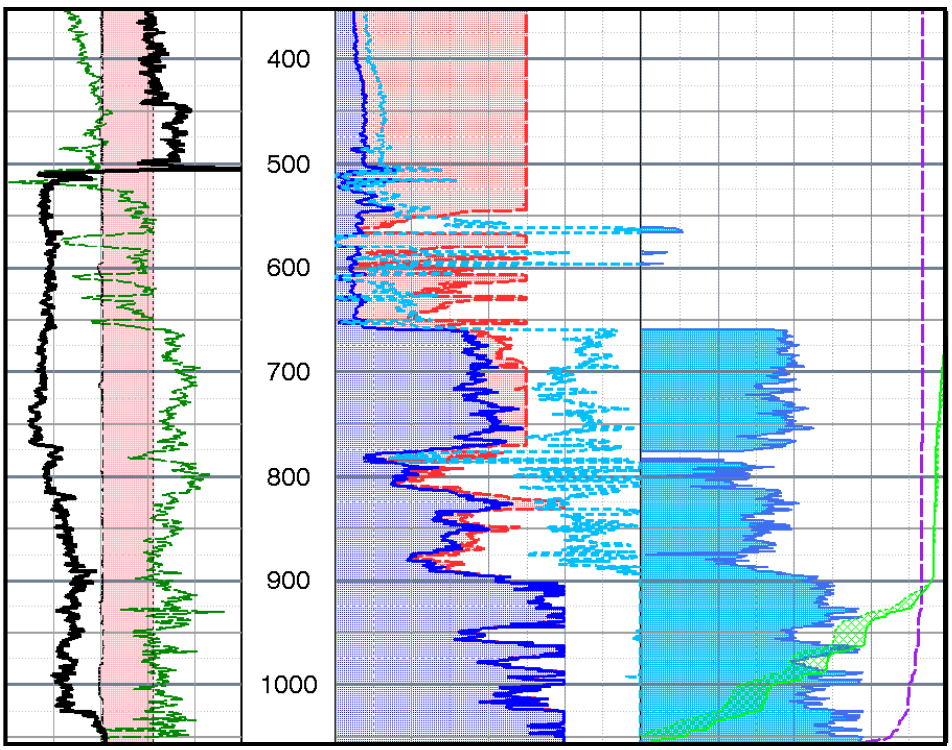
Appendix D

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

DOE LANL Project Subcontract # 72006-000-009

Advanced Borehole Geophysical Logging of LANL Regional Monitoring and Characterization Well R-51

Los Alamos National Laboratory, New Mexico



Prepared for:

North Wind Inc.
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Executive Summary

Geophysical logging was performed by Schlumberger in characterization well R-51 in September 2009 before well completion. The logging measurements were acquired from 00 to 1,051 feet (ft) below ground surface (bgs), when the borehole contained 12.1 inch (in.) inner diameter (ID) freestanding steel casing from ground surface to 1,054 ft, drilled with an approximately 14.25 in. diameter bit size.

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) gross natural gamma ray.

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
- Gamma Ray Tool (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
Gamma Ray (GR)	Gross natural gamma ray	Formation lithology and mineralogy

Once the North Wind Inc. well drilling project team provided Schlumberger final notification that R-51 was ready for geophysical well logging, the Schlumberger district in Farmington, NM, mobilized a wireline

* Mark of Schlumberger

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-51.

Table 2: Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in well R-51

Date of Logging	Run #	Tool 1 (bottom)	Tool 2 (top)	Depth Interval (ft bgs)
15-Jan-2010	1	TLD	GR	0–1051
	2	ECS	GR	0–1048
	3	APS	GR	200–1048

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-51 provide, overall, decent 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), especially prevalent and significant in this well, 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 very likely being affected by voids. There are large sections of R-51 where the density porosity is unreasonably high, indicating the impact of annular voids on the density measurement (and, consequently, the derived total porosity): 100–535, 568–580, 589–592, 607–614, 628–631, 651–653, 718–770, 823–831, 902–945, 962–973, 987–991, 996–1000, and 1025–1051 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 valuable high-resolution information on the geologic and hydrogeologic environment of the R-51 locale.

Important results from the processed geophysical logs in R-51 include the following:

1. The well standing water level in R-51 was 891–892 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 (1,054 ft bgs) to likely 892 ft bgs, which lies within alluvium/fanglomerate. Below 892 ft the log estimated water content and total porosity closely track each other, ranging 25 to over 50% of total rock/sediment volume, higher obviously corresponding to significant annular voids between the casing and surrounding rock. Above 892 ft the water content drops noticeably to less than 30% and the total porosity stays mostly 5% or more above the water content. The estimated water saturation below 892 ft is mostly 100% (relative to pore space volume) while above 892 ft it rapidly decreases to 80% by 886 ft. Based on these results, the depth of the Regional Aquifer water level (depth at which there is full water saturation) is most likely 892 ft. Water content remains high up to 660 ft (possibly as a result of fluctuating borehole fluid level during drilling), but total porosity is higher and, thus, water saturation remains mostly below 90%.

3. Above 892 ft bgs, which the processed logs indicate to be within the vadose zone (above the top of the Regional Aquifer), the estimated water content ranges 10–50% of total rock volume up to 660 ft (average about 35%), dropping substantially above 660 ft to 5–15% (average about 7%). In the interval with high water content (660–892 ft) there are several zones where the processed logs indicate 100% water saturation: 787–792, 794–795, 800–803, 806–810, 833–836, 847–848, and 881–882 ft. However, it is quite likely that the elevated water content and saturation in this interval are the result of borehole water level fluctuations during the drilling process causing artificial saturation of the rock and/or residual water in the annulus between the casing and rock. Above 660 ft the water content is highest in the intervals 504–507 ft (18%), 516–517 ft (20%), and 542–544 ft (15%). The processed logs indicate 100% water saturation in the zones 562–567 ft and 597–598 ft, but the water content and total porosity are very low in these zones (5–7%), likely corresponding to competent low porosity lava that, while possibly saturated, has very low permeability.

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 are likely associated with washouts (water-filled voids) behind the casing. The predicted relative flow capacity profile generated from the integrated log analysis estimated permeability results suggest that the most productive intervals are 926–932, 936–944, 964–970, 988–992, 996–1000, 1026–1035, and 1042–1045 ft bgs.

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 probably up to at least 833 ft bgs. Above 833 ft the geochemical logs suggest a possible change to lavas, although it is not clear whether the rock is composed of basalt, andesite, or dacite. From 660 to 770 ft the geochemical logs indicate high iron and low silicon content, possibly corresponding to basalt lava.

From 510 to 660 ft the geochemical logs indicate lower iron and higher silicon, possibly corresponding to andesite/dacite lava or breccia/alluvium derived from dacite. The geophysical log response in the zone above 510 ft is characteristic of the Guaje Pumice Bed, with a large gamma ray peak, although it is difficult to delineate the top of the pumice bed from the geophysical logs alone (possibly around 500 ft). The log results corroborate volcanic tuff overlying the pumice bed and extending to at least 100 ft. There is a decrease in gross gamma ray and change in the geochemical log elemental concentrations above 68 ft that may correspond to surface alluvium.

1. Introduction

Geophysical logging services were performed in characterization well R-51 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-51 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;
- 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); and
- Gamma Ray (GR) tool, which measures gross natural gamma ray activity to help evaluate geology/lithology.

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-51.

Table 3: Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole R-51

Date of Logging	Borehole Status	Run #	Tool 1 (bottom)	Tool 2 (top)	Depth Interval (ft bgs)
15-Jan-2010	Single string of 12.1 in. ID steel free-standing casing from surface to the bottom of the borehole at 1054 ft, with bit size of ~14.25 in.	1	TLD	GR	0–1051
		2	ECS	GR	0–1048
		3	APS	GR	200–1048

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-51, 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-51 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).

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 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-51, the log measurements requiring these corrections are the APS porosity, TLD bulk formation density, ECS elemental concentrations, and GR 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-51. 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 below 100 ft and two strings above.

The GR 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 GR 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 GR gross gamma ray log from R-51 was reprocessed to account, as best as possible, for the environmental effects of the casing, borehole fluid (water below 891 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 are 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 (Mayer 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-51 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 (0 to 1,051 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 200 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 0 to 506 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 interval 506 to 820 ft bgs was assumed to be andesite/dacite or basalt lava or breccia/sediments derived from it, and a mineral suite considered representative of this volcanic material, based on LANL cuttings mineral analysis, was used (primary "minerals" plagioclase and potassium feldspar, augite; possible secondary minerals magnetite and hematite). The log interval 820 to 1,051 ft bgs was assumed to be the Puye Formation, or fanglomerate/alluvium with somewhat 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; with possible accessory/trace minerals biotite, augite, heavy mafic minerals, and pyrite).

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). However, total porosity (combined all water and air) was constrained to 60% of total rock/sediment volume below 820 ft bgs and 50% above in order to account for the deleterious effect of large voids behind the casing on the integrated analysis. In addition, as mentioned above, water was not included in the analysis above 200 ft bgs because there are no log measurements sensitive to water above that depth. There is no way to objectively correct for the adverse effect on the log measurements from borehole washouts; therefore the decision was made to perform the ELAN analysis so as to primarily honor the log measurements (other than the total porosity constraint). 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-51 ELAN analysis

Volume / Tool Measurement	Air	Water	Hematite	Labradorite	Silica Glass, Cristo., Tridy.	Magnetite	Augite	Biotite	Pyrite	Orthoclase	Calcite	Quartz
Bulk density (g/cc)	–0.19	1.00	5.16	2.68	2.33	5.08	3.08	3.04	4.99	2.54	2.71	2.64
Epithermal neutron poro. (ft^3/ft^3)	0	1.00	0.06	-0.01	0.0	0.022	-0.01	0.14	0.165	-0.01	0.0	-0.05
Dry weight silicon (lbf/lbf)	0.0	0.0	0.0	0.247	0.468	0.184	0.225	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	0.007	0.0	0.0	0.405	0.0
Dry weight iron (lbf/lbf)	0.0	0.0	0.70	0.023	0.0	0.22	0.112	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	0.535	0.0	0.0	0.0
Dry weight titanium (lbf/lbf)	0.0	0.0	0.01	0.0	0.0	0.0	0.048	0.016	0.0	0.0	0.0	0.0
Gross gamma ray (gAPI)	0	0	5	50	20	50	30	127	0	255	11	25
Neutron capture cross section (cu)	0	22.21	101.4	7.87	4	103	25.66	54.1	90	15.82	7.4	4.7

gAPI = gamma ray API (American Petroleum Institute) standard unit
ft^3 = cubic feet
ppm = parts per million
cu = neutron capture units
lbf = pounds force
ohm-m = ohm x meters
g/cc = grams per cubic centimeter

3. Results

Preliminary results from the wireline geophysical logging measurements acquired by Schlumberger in R-51 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-51 are described below.

3.1. Well Fluid Level

The well standing water level in R-51 (within the freestanding 12.1 in. ID casing) was 891–892 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 (1,054 ft bgs) to likely 892 ft bgs, which lies within alluvium/fanglomerate. Below 892 ft the log estimated water content and total porosity closely track each other, ranging 25 to over 50% of total rock/sediment volume, higher obviously corresponding to large annular voids between the casing and surrounding rock. Above 892 ft the water content drops noticeably to less than 30% and the total porosity stays mostly 5% or more above the water content. The estimated water saturation below 892 ft is mostly 100% (relative to pore space volume) while above 892 ft it rapidly decreases to 80% by 886 ft.

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 892 ft. Water content remains high up to 660 ft (possibly as a result of fluctuating borehole fluid level during drilling), but total porosity is higher and, thus, water saturation remains mostly below 90%.

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 are likely associated with washouts (water-filled voids) behind the casing. The predicted relative flow capacity profile generated from the integrated log analysis estimated permeability results suggest that the most productive intervals are 926–932, 936–944, 964–970, 988–992, 996–1000, 1026–1035, and 1042–1045 ft bgs (see porosity summary display in Figure 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 892 ft bgs. Above 892 ft bgs, which the processed logs indicate to be within the vadose zone (above the top of the Regional Aquifer), the estimated water content ranges 10–50% of total rock volume up to 660 ft (average about 35%), dropping substantially above 660 ft to 5–15% (average about 7%). In the interval with high water content (660–892 ft) there are several zones where the processed logs indicate 100% water saturation: 787–792, 794–795, 800–803, 806–810, 833–836, 847–848, and 881–882 ft. However, it is quite likely that the elevated water content and saturation in this interval are the result of borehole water level fluctuations during the drilling process causing artificial saturation of the rock and/or residual water in the annulus between the casing and rock. Above 660 ft the water content is highest in the intervals 504–507 ft (18%), 516–517 ft (20%), and 542–544 ft (15%). The processed logs indicate 100% water saturation in the zones 562–567 ft and 597–598 ft, but the water content and total porosity are very low in these zones (5–7%), likely corresponding to competent low porosity lava that, while possibly saturated, has very low permeability.

3.4. Geology

The processed geophysical log results, particularly the matrix geochemistry logs, provide information on lithology and potential formation contacts intersected by R-51 across the log interval (from 0 to 1,051 ft bgs). The generalized geologic stratigraphy observed from the logs across the measured interval is as follows (depth below ground surface):

- **<u>0–68 ft bgs (top of log interval):</u> High porosity silicon rich, iron poor material (likely surface alluvium)** – characterized by high total porosity (40–50% of total rock volume, possibly elevated due to voids behind the casing); high silica glass/tridymite/cristobalite and/or quartz content; and trace to minor amounts of augite, calcite, pyrite or similar minerals

- **68–100 ft bgs: High porosity silicon rich material (likely surface alluvium or volcanic tuff)** – characterized by high total porosity (40–45% of total rock volume, possibly elevated due to voids behind the casing); high silica glass/tridymite/cristobalite and/or quartz content; and trace to minor amounts of augite, calcite, pyrite or similar minerals

- **100–187 ft bgs: Very high porosity silicon rich volcanic tuff (with high calcium zone 151–163 ft)** – characterized by very high total porosity (over 50%, likely elevated due to voids behind the casing); high silica glass/tridymite/cristobalite content; minor quartz content; and trace to minor amounts of augite and calcite or similar minerals (except moderate calcium/calcite 151–163 ft)

- **187–201 ft bgs: Very high porosity and gamma ray, silicon rich volcanic tuff** – characterized by very high total porosity (over 50%, likely elevated due to voids behind the casing); high silica glass/tridymite/cristobalite content; minor quartz content; and trace to minor amounts of augite and calcite or similar minerals

- **201–443 ft bgs: Very high porosity silicon rich volcanic tuff** – characterized by very high total porosity (over 50%, likely elevated due to voids behind the casing); high silica glass/tridymite/cristobalite content; minor quartz content; and trace to minor amounts of augite and calcite or similar minerals

- **443–498 ft bgs: Very high porosity, high gamma ray, silicon rich volcanic tuff** – characterized by very high total porosity (over 50%, likely elevated due to voids behind the casing); high silica glass/tridymite/cristobalite content; minor quartz content; and trace to minor amounts of augite and calcite or similar minerals

- **498–510 ft bgs: Very high porosity, high gamma ray, silicon rich volcanic tuff (likely Guaje Pumice Bed)** – characterized by very high total porosity (over 50%, likely elevated due to voids behind the casing); high silica glass/tridymite/cristobalite content; minor quartz content; and trace to minor amounts of augite and calcite or similar minerals

- **510–545 ft bgs: Very high porosity, calcium-rich material (possibly alluvium/fanglomerate or lava)** – characterized by very high total porosity (over 50%, likely elevated due to voids behind the casing); high calcium content (possibly due to emplaced cement); high plagioclase content; trace to minor amounts of potassium feldspar, augite (or similar minerals), pyrite and biotite

- **545–660 ft bgs: Variable porosity, silicon rich lava flows (likely andesite or dacite in composition)** – characterized by highly variable total porosity (7% to over 50%, likely elevated due to voids behind the casing); moderate to high potassium and plagioclase feldspar; minor to moderate augite (or similar minerals); and variably trace to minor amounts of magnetite, pyrite and hematite

- **660–770 ft bgs: Moderate to very high porosity, iron and calcium rich lava flows (likely andesite or basalt in composition)** – characterized by moderate to high total porosity (30% to over 50%, likely elevated due to voids behind the casing); high plagioclase feldspar; minor to moderate augite and magnetite (or similar minerals); and variably trace amounts of pyrite and hematite

- **770–810 ft bgs: Low to moderate porosity, silicon and titanium rich lava flows (likely andesite or dacite in composition)** – characterized by low to moderate total porosity (15% to 40%); moderate to high potassium and plagioclase feldspar; minor to moderate augite (or similar minerals); and variably trace to minor amounts of magnetite, pyrite and hematite

- **810–833 ft bgs: Very high porosity, silicon and titanium rich lava flows (likely andesite or dacite in composition)** – characterized by very high total porosity (20% to over 50%, likely elevated due to voids behind the casing); moderate to high potassium and plagioclase feldspar; minor to moderate augite (or similar minerals); and variably trace to minor amounts of magnetite, pyrite and hematite

- **833–901 ft bgs: High porosity, silicon-rich alluvium/fanglomerate** – characterized by variably high total porosity (20–45%); moderate to high potassium and plagioclase feldspar; varying minor to moderate amounts of augite (or similar minerals); trace to minor amounts of magnetite, quartz or silica glass/ tridymite/cristobalite, pyrite and biotite

- **901–1,051 ft bgs (bottom of log interval): Very high, silicon-rich alluvium/fanglomerate** – characterized by very high total porosity (33% to over 60%, likely elevated due to voids behind the casing); moderate to high potassium and plagioclase feldspar; highly variable silica glass/tridymite/cristobalite or quartz content; varying minor to moderate amounts of augite (or similar minerals); trace to minor amounts of magnetite, quartz or silica glass/ tridymite/cristobalite, pyrite and biotite

3.5. Summary Logs

Three summary log displays have been generated for R-51 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)

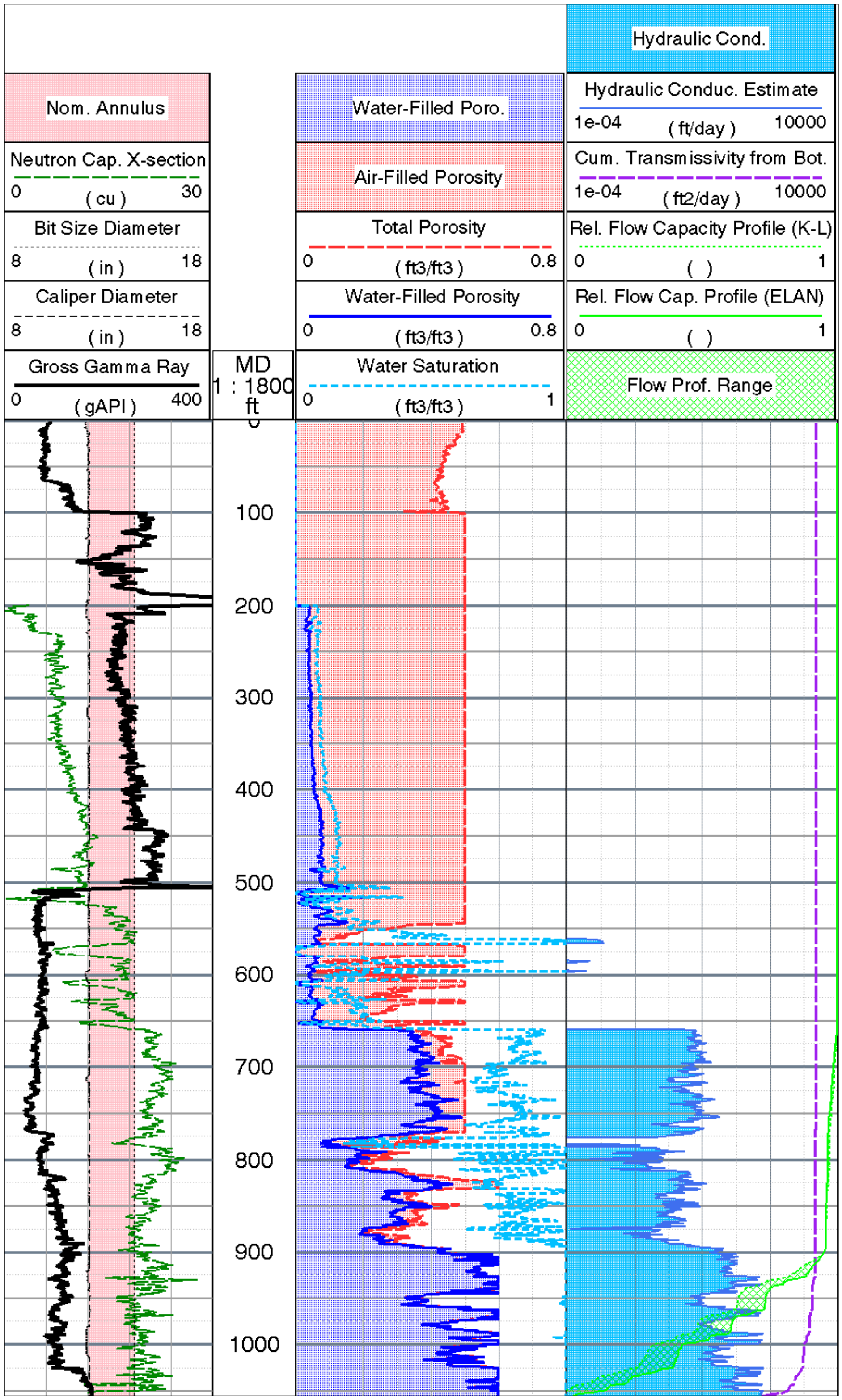


Figure 1: Summary of porosity logs in R-51 borehole from processed geophysical logs, interval of 0 to 1,051 ft bgs, with caliper, gross gamma, neutron capture cross-section, water saturation, estimated relative flow capacity profile, hydraulic conductivity, and transmissivity logs also displayed. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN integrated log analysis.

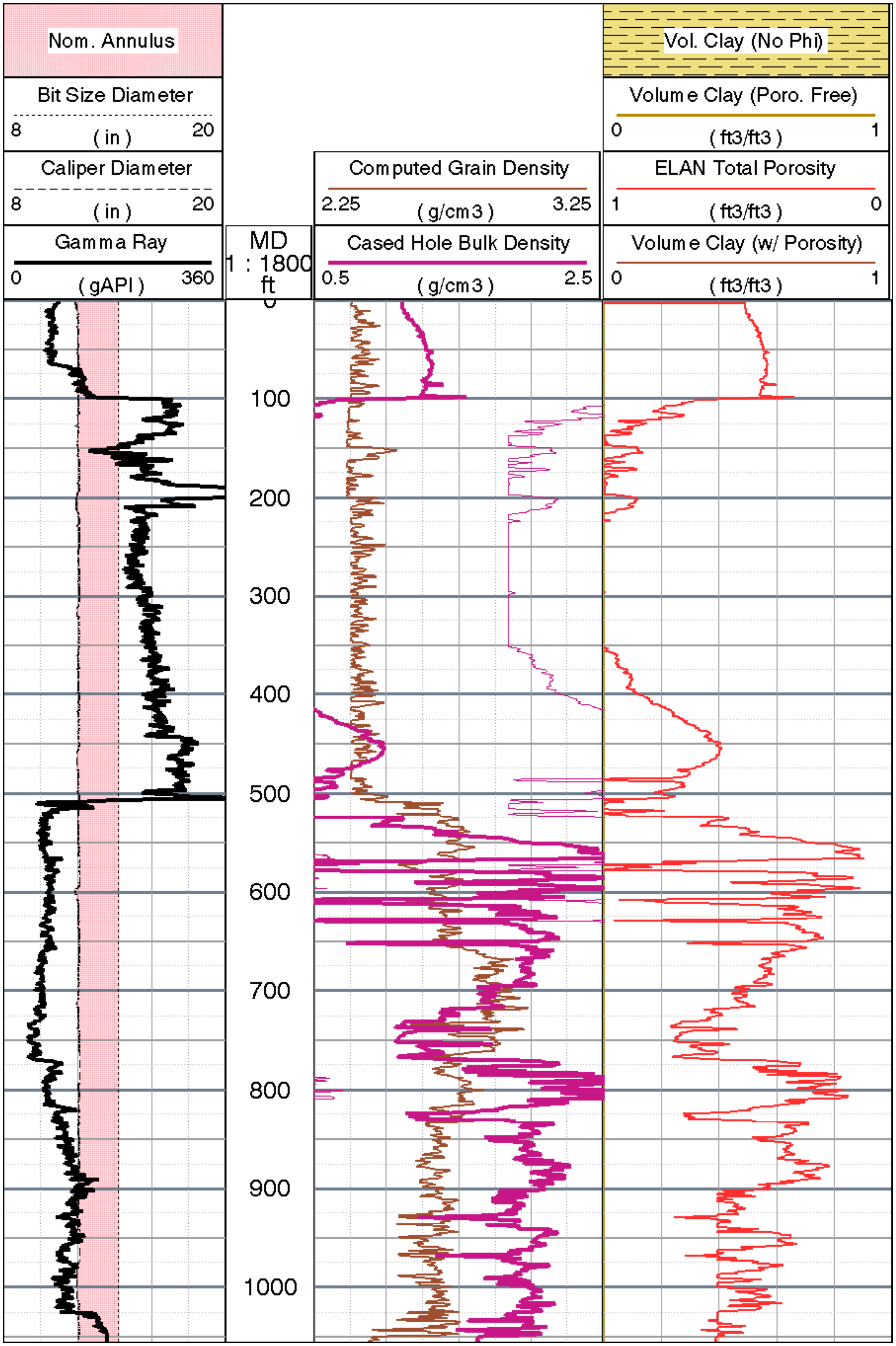


Figure 2: Summary of bulk density and apparent grain density logs in R-51 borehole from processed geophysical logs, interval of 0 to 1,051 ft bgs. Also shown are caliper, gross gamma, volume of clay, and total porosity logs (the latter two derived from the ELAN analysis).

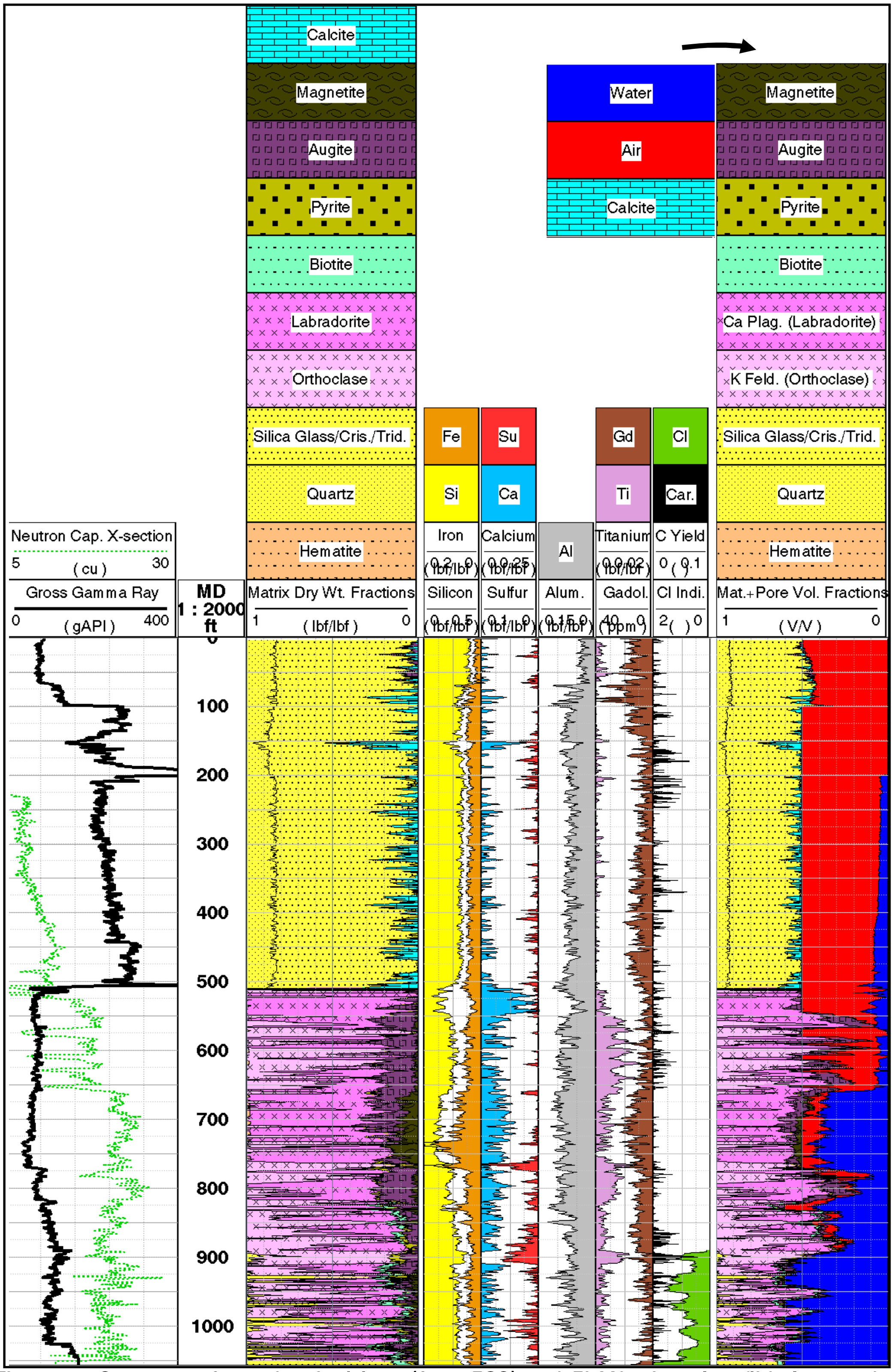


Figure 3: Summary of geochemical logs (from ECS) and ELAN mineralogy/lithology and pore fluid model volumes and matrix dry weight fractions derived from the ELAN integrated log analysis for R-51 borehole, interval 0 to 1,051 ft bgs. Also shown are caliper, gross gamma, and neutron capture cross section.

3.6. Integrated Log Montage

This section summarizes the integrated geophysical log montage for R-51. 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-51 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 400 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 1200 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).

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 2.4/2.65/2.8/2.6 g/cc (dashed red curve), 2.45/2.7/2.85/2.65 g/cc (long-dashed red curve), and 2.5/2.75/2.9/2.7 g/cc (dotted red curve)–with red shading between the 2.4/2.65/2.8/2.6 g/cc and 2.5/2.75/2.9/2.7 g/cc porosity curves to show the range (the lowest grain density range used across the tuff/pumice interval [0–510 ft], the next highest grain density range used across the alluvium/fanglomerate interval [833–1,051 ft], the next highest grain density range used across the top of lava flow/breccia deposits interval [510–559 ft], and the highest grain density used across the bottom of the flow/breccia deposits interval, presumed to contain basalt [559–833 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)

<u>Tracks 5 to 10 – Geochemical Elemental Measurements</u>

The narrow tracks 5 to 10 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), titanium (Ti) and gadolinium (Gd), hydrogen yield (H yield) and apparent relative bulk chlorinity (Rela. Cl), and carbon yield (C Yield) — from left to right respectively, in units of dry matrix weight fraction (except ela. Cl in ppk, H and C Yield in relative yield units).

<u>Track 11 – ELAN Mineralogy Model Results (Dry Weight Fraction)</u>

Track 11 displays the results from the ELAN integrated log analysis (the matrix portion)–presented as dry-weight fraction of mineral types chosen in the model:

- 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)
- 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)

<u>Track 12–ELAN Mineralogy and Pore Space Model Results (Wet Volume Fraction)</u>

Track 12 displays the results from the ELAN integrated log analysis–presented as wet mineral and pore fluid volume fractions:

- 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)
- 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 13–Water Saturation

Track 13 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 2.4/2.65/2.8/2.6 g/cc (dashed red curve), 2.45/2.7/2.85/2.65 g/cc (long-dashed red curve), and 2.5/2.75/2.9/2.7 g/cc (dotted red curve)–with red shading between the 2.4/2.65/2.8/2.6 g/cc and 2.5/2.75/2.9/2.7 g/cc porosity curves to show the range (the lowest grain density range used across the tuff/pumice interval [0–510 ft], the next highest grain density range used across

the alluvium/fanglomerate interval [833–1,051 ft], the next highest grain density range used across the top of lava flow/breccia deposits interval [510–559 ft], and the highest grain density used across the bottom of the flow/breccia deposits interval, presumed to contain basalt [559–833 ft].

Track 14–Hydraulic Conductivity

Track 14 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 15–Predicted Flow (Production Potential) Profile

Track 15 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.

Track 16–Summary Logs

Track 16, 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 17–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

Mayer, 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-51

GEOFRAME
PROCESSED
INTERPRETATION

Integrated Wireline Log Well Montage

Processed Advanced Cased Hole Geophysical Logs

Using the following logs: APS*, TLD*
ECS*
GR

*A Mark of Schlumberger

COMPANY: North Winds (Drilling contractor for LANL)
WELL: R−51
FIELD: TA−18
STATE: New Mexico
COUNTRY: U.S.
Date Logged: 15−Jan−2010 Date Processed: April−2010
Well Location: LANL
Elevations: K.B. NA D.F. NA G.L. NA
API Number: Job Number:

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

OP Vers.: 17C0−154 Process Date: April−2010 Center: SWS Tucson Baseline: GF4.2 Log Analyst: N. Clayton

Mud and Borehole Measurements:

Rm @ Measured Temperature: NA	BHT: NA	Bitsize: 14.25 in
Rmf @ Measured Temperature: NA	Type Fluid in Hole: Air, Wat.	FGM:
Rmc @ Measured Temperature: NA	Mud density: 8.34 lbm/gal	FGM:

Remarks:

Depth reference is ground surface.
Well contained one or more strings of casing (casing advance) during logging.
Well water level at 891−892 ft during logging.
ELAN* integrated log anal. performed without water saturation constraints, but porosity constrained to high value.
Interpretation should account for well conditions.

Attachment 2 – Color Print of ELAN Optimized Mineral and Pore Volume Model Results for Well R-51

ELAN* Geophysical Log Integrated Analysis

Optimized Mineral + Pore Volume Model

COMPANY:	LANL− NORTH WIND
WELL:	R−51
FIELD:	TA−18
State:	New Mexico
COUNTRY:	

*Elemental Log Analysis, Mark of Schlumberger

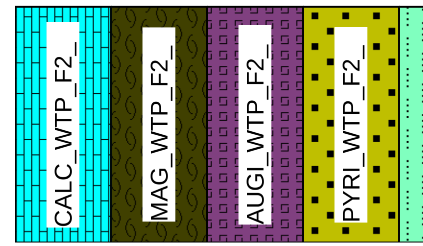
Date Processed:	April−2010	Date Logged:	15−Jan−2010
Job Number:		Processed at:	SWS Tucson
Well Location:	LANL		
Latitude:		Longitude:	
Elevations:	KB:	DF:	GL:

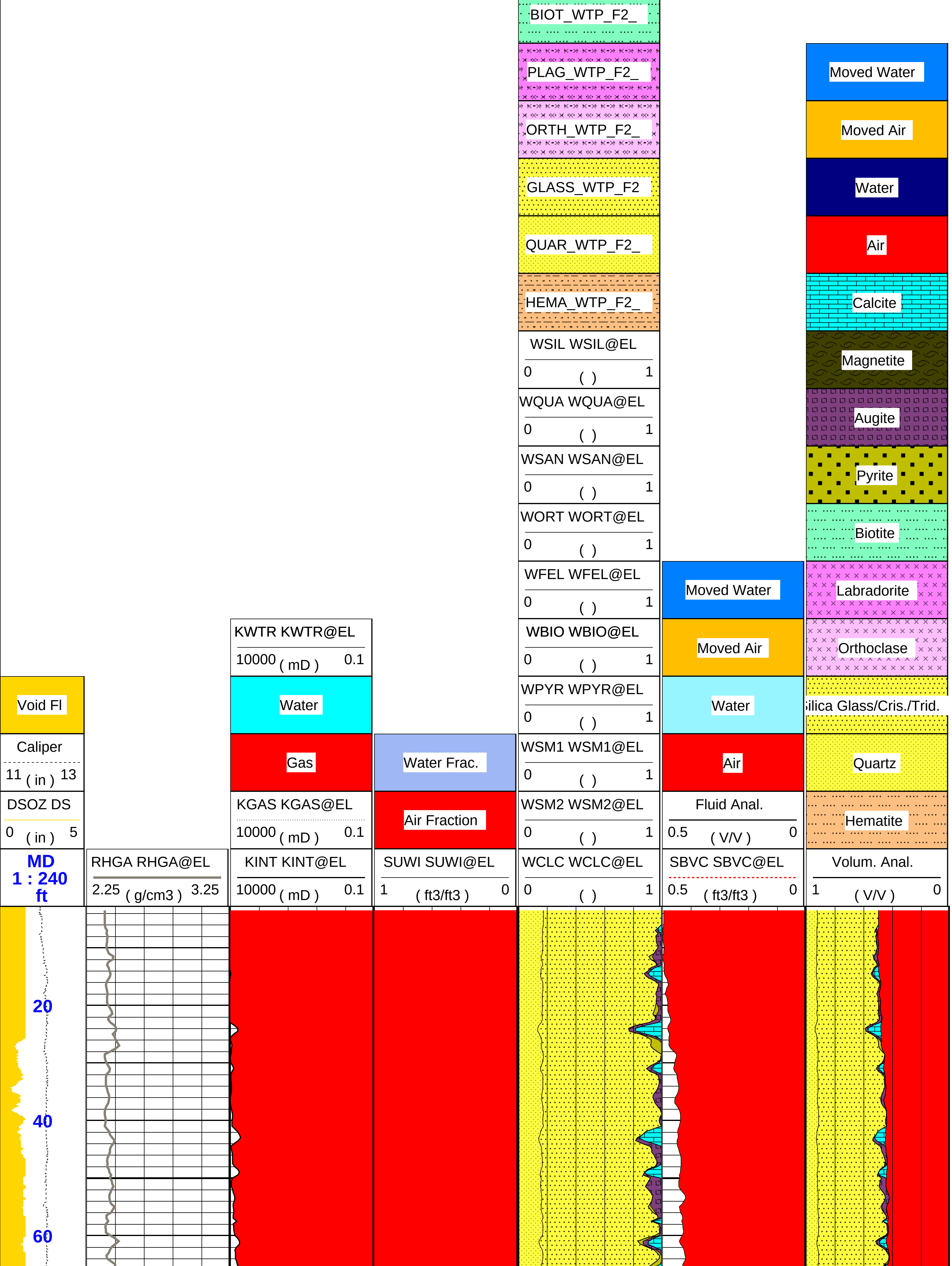
Depth ref. is ground surface. Results are affected by cased hole conditions.

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

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

R−51 [Fun_2]





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WQUA WQUA@EL 0 ( ) 1
WSAN WSAN@EL 0 ( ) 1
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WFEL WFEL@EL 0 ( ) 1
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WPYR WPYR@EL 0 ( ) 1
WSM1 WSM1@EL 0 ( ) 1
WSM2 WSM2@EL 0 ( ) 1
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Augite
Pyrite
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Labradorite
Orthoclase
Silica Glass/Cris./Trid.
Quartz
Hematite
Volum. Anal. 1 (V/V) 0
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Moved Air
Water
Air
Fluid Anal. 0.5 (V/V) 0
SBVC SBVC@EL 0.5 (ft3/ft3) 0
KWTR KWTR@EL 10000 (mD) 0.1
Water
Gas
KGAS KGAS@EL 10000 (mD) 0.1
KINT KINT@EL 10000 (mD) 0.1
Water Frac.
Air Fraction
SUWI SUWI@EL 1 (ft3/ft3) 0
Void Fl
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ft
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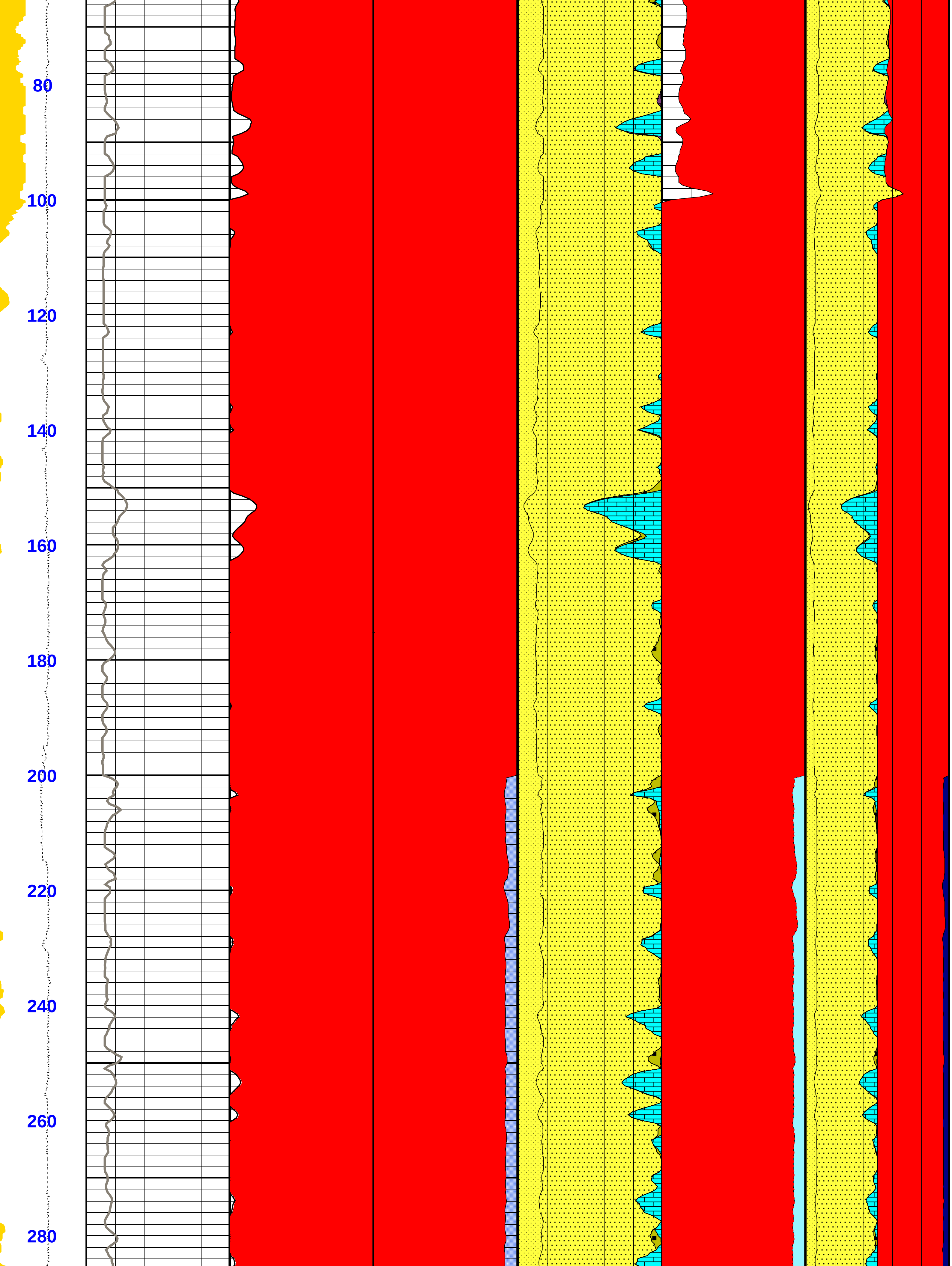
20
40
60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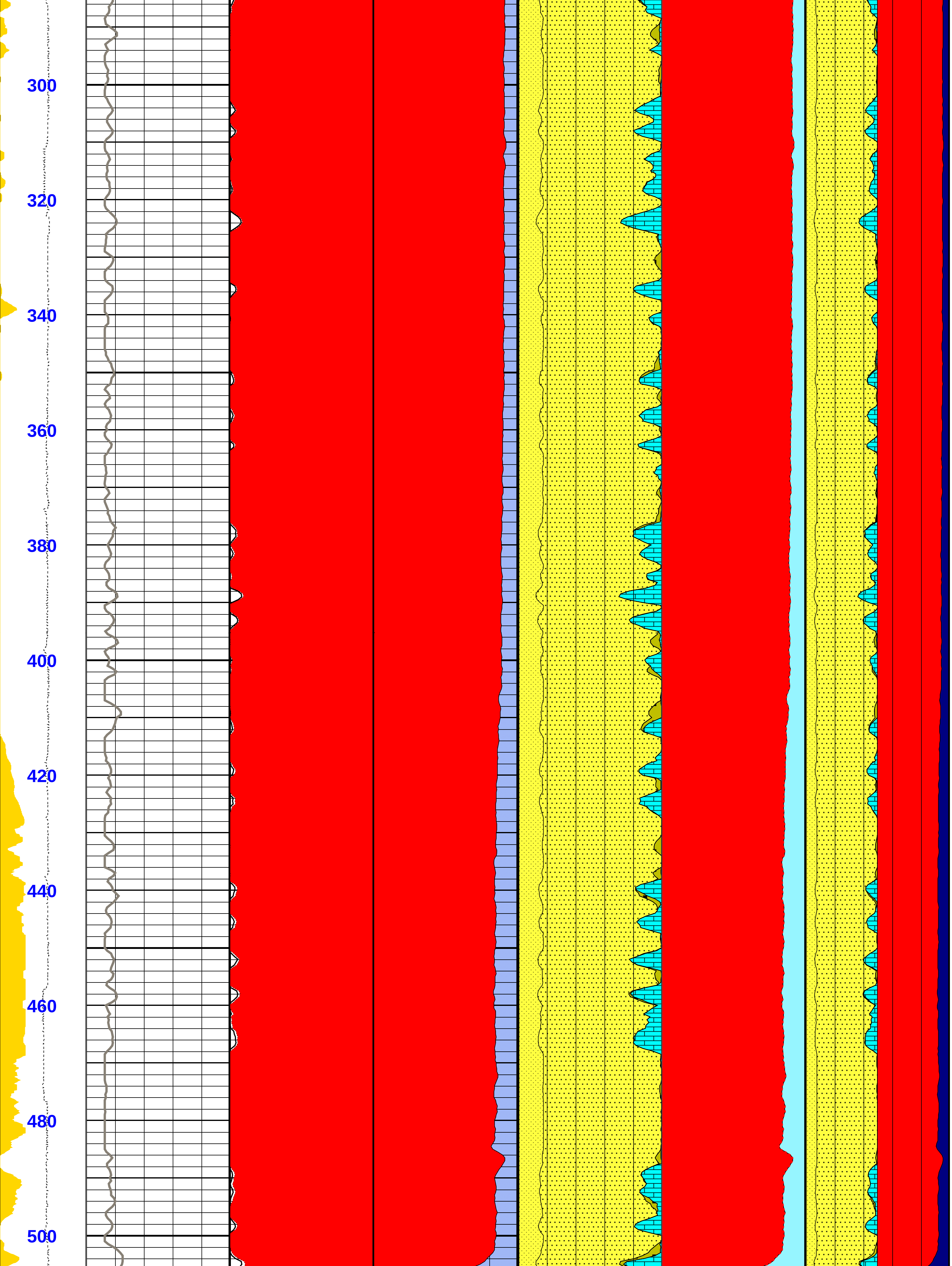
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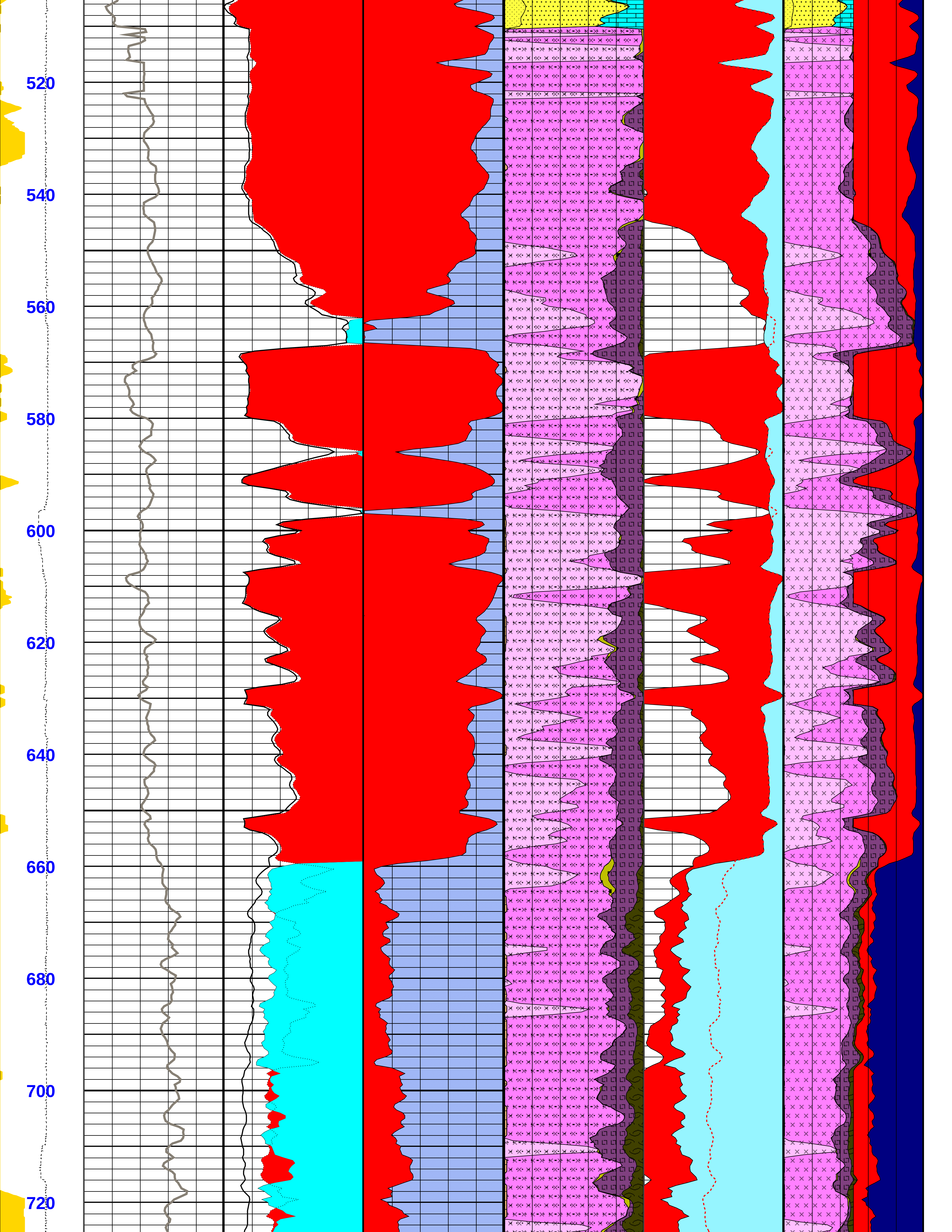
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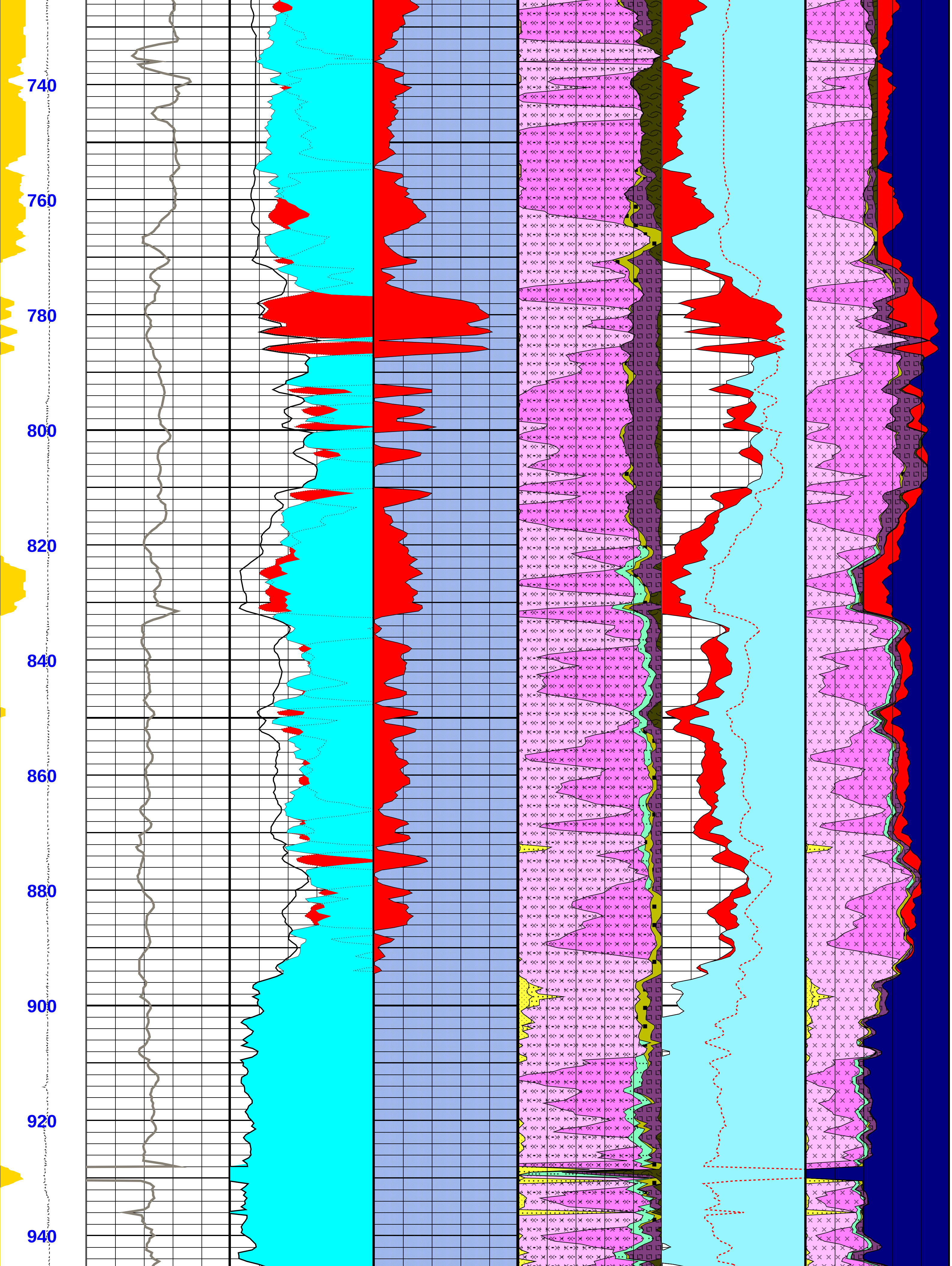
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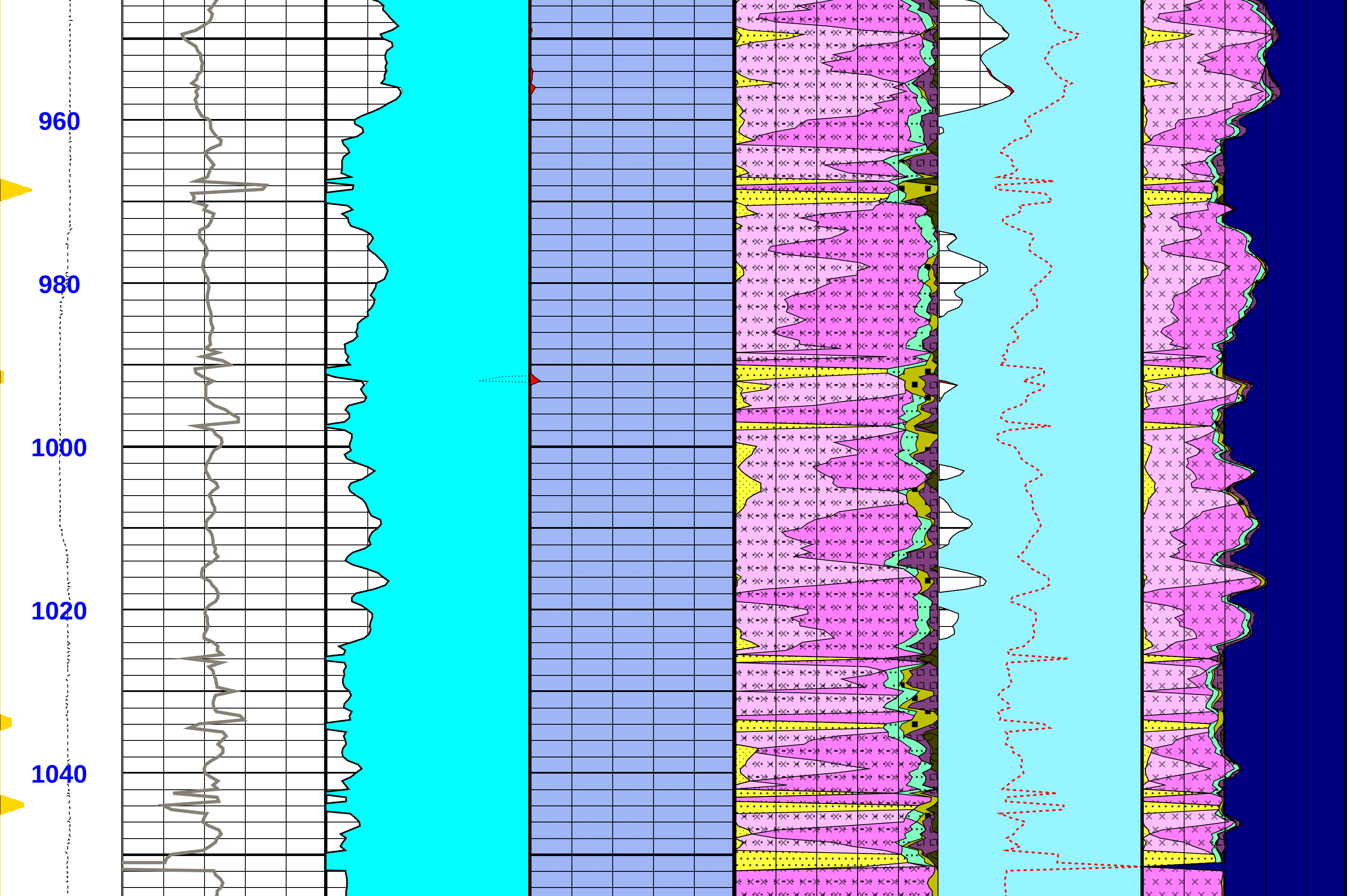


MD
1 : 240
ft

DSOZ DS
0 (in) 5

Caliper
11 (in) 13

Void Fl

RHGA RHGA@EL
2.25 (g/cm3) 3.25

KINT KINT@EL
10000 (mD) 0.1

KGAS KGAS@EL
10000 (mD) 0.1

Gas

Water

KWTR KWTR@EL
10000 (mD) 0.1

SUWI SUWI@EL
1 (ft3/ft3) 0

Air Fraction

Water Frac.

WCLC WCLC@EL
0 ( ) 1

WSM2 WSM2@EL
0 ( ) 1

WSM1 WSM1@EL
0 ( ) 1

WPYR WPYR@EL
0 ( ) 1

WBIO WBIO@EL
0 ( ) 1

WFEL WFEL@EL
0 ( ) 1

WORT WORT@EL
0 ( ) 1

WSAN WSAN@EL
0 ( ) 1

WQUA WQUA@EL
0 ( ) 1

WSIL WSIL@EL
0 ( ) 1

HEMA_WTP_F2_

SBVC SBVC@EL
0.5 (ft3/ft3) 0

Moved Water

Moved Air

Water

Air

Fluid Anal.
0.5 (V/V) 0

Moved Water

Moved Air

Water

Air

Calcite

Magnetite

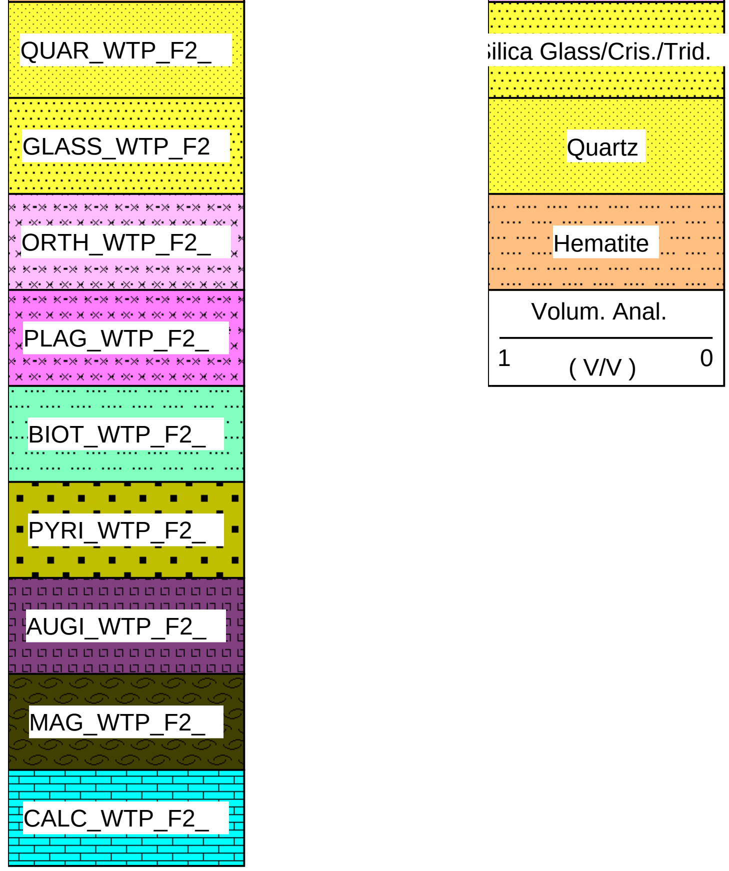
Augite

Pyrite

Biotite

Labradorite

Orthoclase



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Quartz
Hematite
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(V/V)
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R−51 [Fun_2]