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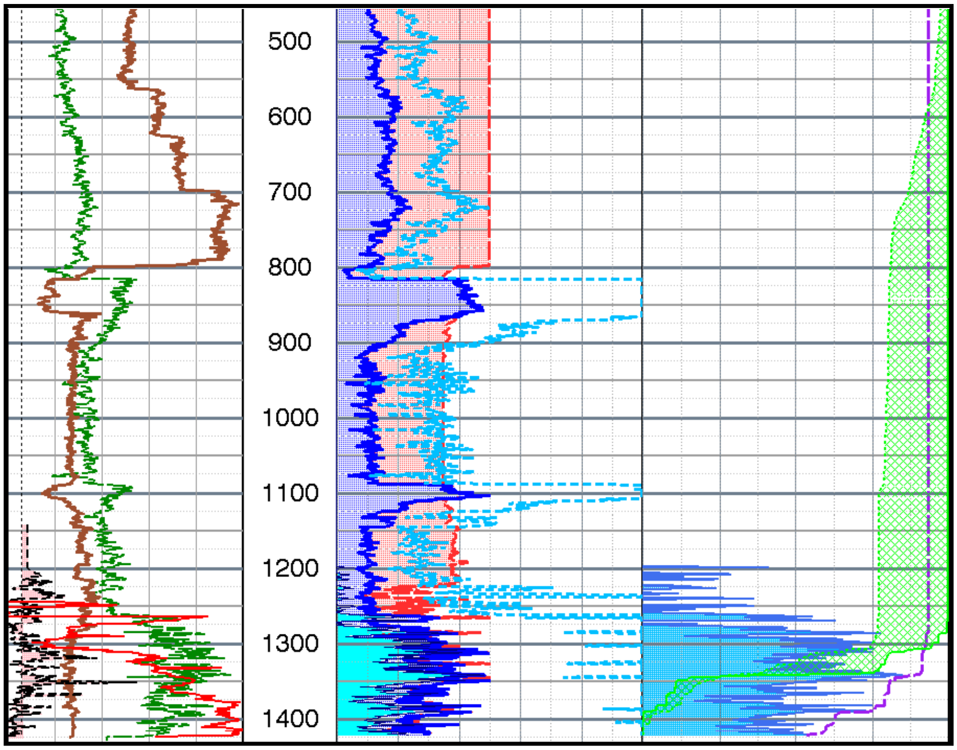
Advanced Borehole Geophysical Logging of LANL Regional Monitoring and Characterization Well R-63

Los Alamos National Laboratory, New Mexico



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Executive Summary

Geophysical logging was performed by Schlumberger in characterization well R-63 in August 2010 before well completion. The logging measurements were acquired from 36 to 1,422 feet (ft) below ground surface (bgs), when the borehole was open (uncased) from 1,145 to 1,425 ft (bottom of hole, as measured by the logs), drilled with an approximately 11.625 inch (in.) diameter bit size, and contained approximately 12 in. inner diameter freestanding steel casing from ground surface to 1,145 ft.

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, moisture content, depths of permeable aquifer zones, and the stratigraphy and lithology of geologic units. A secondary purpose of the geophysical logging was to evaluate the borehole conditions such as borehole diameter versus depth, deviation versus depth, and degree of drilling fluid invasion. These objectives were accomplished by measuring, nearly continuously, along the length of the well (1) total and effective water-filled porosity and pore-size distribution from which an estimate of hydraulic conductivity is made; (2) bulk electrical resistivity at multiple radial depths of investigation, sensitive to drilling fluid invasion and formation water saturation; (3) neutron capture cross-section, sensitive to lithology and water; (4) spectral natural gamma ray, including potassium, thorium, and uranium concentrations; (5) bedding and fracture orientation, fracture aperture, and geologic texture; (6) borehole inclination and azimuth; and (7) borehole diameter.

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

- Combinable Magnetic Resonance (CMR*) tool
- Accelerator Porosity Sonde (APS*);
- Array Induction Tool (AIT*)
- Formation Micro-Imager (FMI*) tool,
- Hostile Natural Gamma Spectroscopy (HNGS*) and gamma ray (GR)

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* Mark of Schlumberger

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

Tool	Technology	Properties Measured
Combinable Magnetic Resonance tool (CMR*)	Magnetic resonance proton precession	Effective (moveable) versus bound water-filled porosity, estimated hydraulic conductivity and relative flow capacity versus depth
Accelerator Porosity Sonde (APS*)	Epithermal neutron porosity and neutron capture cross-section	Water/moisture content, lithologic variations
Array Induction Tool (AIT*)	Bulk electrical resistivity at multiple radial depths of investigation; spontaneous potential and borehole fluid resistivity	Stratigraphic delineation, relative permeability and water saturation from the borehole fluid invasion profile, clay content
Fullbore Formation Micro-Imager (FMI*)	Fully-oriented electrical resistivity imaging	Bedding, geologic texture and structure, discrete fracture characterization; borehole diameter
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

Once the North Wind Inc. well drilling project team provided Schlumberger final notification that R-63 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-63.

Table 2: Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in well R-63

Date of Logging	Run #	Tool 1 (bottom)	Tool 2	Tool 3 (top)	Depth Interval (ft bgs)
23-January-2011	1	AIT	HNGS	GR	34–1417 (AIT top depth 1175)
	2	FMI	GR		1210–1423
	3	APS	GR		206–1418
	4	CMR	GR		1197–1423

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, some require additional for full results (such as the FMI oriented electrical image) 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) generate additional outputs through more refined workstation processing; (3) perform an integrated analysis of the log measurements so that they are all coherent and provide consistent hydrogeologic and geologic results; and (4) 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., effective porosity, water saturation, relative hydraulic conductivity, lithology).

The geophysical log measurements from Well R-63 provide, overall, good quality results that are consistent with each other across the logged interval. The quality of some measurements was degraded across a few intervals where the borehole contained washouts and/or rugose hole. The measurements most affected by the adverse borehole conditions were ones that have a shallow depth of investigation and that require close contact to the borehole wall—primarily the porosity measurements, particularly from the magnetic resonance tool. The greatest impact on the log processing was erroneously high water-filled porosity in the adverse borehole conditions—as estimated from the CMR magnetic resonance and, less so, APS neutron porosity logs (the other logs were not significantly impacted). The depth intervals where the CMR measurements were most affected are 1264–1266, 1279–1281, 1296–1298, 1302–1304, 1306–1310, 1312–1314, 1316–1317, 1334–1336, 1340–1350, 1366–1369, 1373–1374, 1380–1382, 1383–1385, 1388–1393, 1395–1397, 1408–1410, and 1417–1420 ft bgs. Above the standing borehole water level there was also very high water-filled porosity, as measured by the APS, in the cased hole intervals 815–870 and 1088–1110 ft bgs, likely corresponding to saturated annular fill/void behind the casing. 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-63 locale.

Important results from the processed geophysical logs in R-63 include the following:

1. The well standing water level in R-63 was 1262–1265 ft bgs at the time of logging, rising slightly between the first and the last logging runs.

2. The processed logs indicate that the intersected geologic section is fully saturated with water from the bottom of the borehole (1425 ft bgs) to likely 1305 ft bgs (possibly as high as 1285 ft), which lies within alluvium/fanglomerate (Puye Formation). Below 1266 ft the log estimated water content mostly matches total porosity, tracking each other to the bottom of the borehole at 1425 ft, resulting in an estimated water saturation of 100% (relative to pore space volume) – although without the bulk density log, there is limited information on total porosity. Water content ranges between 20% and over 40% of total rock/sediment volume below 1292 ft, very high values (above 40%) likely corresponding to water-filled borehole washouts. At 1290 ft the water content drops to 13% and is highly variable up to 1254 ft, although it decreases to 10% at 1270–74 ft. Above 1254 ft water content is consistently less than 15%. Thus, based on water content measurements from the geophysical logs, continuous saturated conditions may occur as high as 1292 ft. However, the computed flow capacity profile indicates that almost all the flow capacity occurs below 1305 ft. This depth also corresponds to a significant shift in the spontaneous potential log. Based on these results, the depth of the Regional Aquifer water level (depth at which there is full water saturation) is most likely 1305 ft, but possibly as high as 1292 ft.

3. Above 1254 ft bgs, which the processed logs clearly indicate to be within the vadose zone (above the top of the Regional Aquifer), the estimated water content ranges 7–15% of total rock volume up to 1144 ft. Water content is elevated in the interval 1087–1144 ft, reaching as high as 35–50% at the top. This zone is at the bottom of the casing emplaced in the borehole at the time to prevent borehole collapse and seal off water inflow from upper perched water zones; thus, likely the water measured by the geophysical logs is trapped water behind this casing. Water content remains less

than 15% above 1087 ft up to 905 ft, above which it increases to 20%, then 35–50% in the interval 815–870 ft. The highly elevated water content in this zone is likely trapped water behind the casing resulting from the emplacement of casing and grout to seal off perched water inflow to the borehole. Directly above (802–804 ft) measured water content is very low (less than 5% possibly due to a large air-filled void behind casing), but it increases to 15–23% in the interval 574–758 ft. Above 574 ft to the top of the APS epithermal neutron porosity log (200 ft) the measured water content ranges 7–15%, lowest at the top and slightly higher values (up to 19%) in the zone 393–405 ft. Water content could not be quantitatively estimated above 200 ft since there are no APS or other porosity measurements.

4. The relative hydraulic conductivity estimate and flow capacity profile generated from the processed magnetic resonance logs and integrated log analysis, cross checked against the FMI electrical resistivity image, suggest that there are many productive zones in the Puye Formation fanglomerate that extends below 1305 ft to the bottom of the log interval at 1423 ft. Based on these analyses, the most productive zone is 1340–1346 ft, followed by 1306–1313 ft, although much of the section below 1305 ft appears to have high permeability. Additional zones that the processed logs are particularly productive are 1298–1304 ft (note this may be above the Regional Aquifer), 1325–1333 ft, 1352–1358 ft , 1360–1362 ft, 1365–1370 ft, 1373–1376 ft, 1380–1382 ft, 1384–1386 ft, 1389–1397 ft, 1406–1410 ft, and 1418–1422 ft.

5. The geophysical log results clearly delineate that the saturated/water-filled section of the borehole consists of clastic sediments (alluvium/fanglomerate) that extends up to 798 ft. Directly above this, the combined log response is clearly indicative of the Guaje Pumice Bed, with a large increase in thorium and uranium concentrations, likely extending up to 789 ft. The log results corroborate volcanic tuff overlying the pumice bed and extending up to the top of the logged interval.

6. The interpreted planar bedding features across the electrically imaged interval 1263 to 1420 ft bgs have fairly widely varying dip azimuths (direction beds are dipping towards), but the quadrant with highest frequency is to the southwest and secondarily to the east-northeast and north-northwest. Bedding feature dip angles (angle from horizontal) are mostly less than 20 degrees, with a few dips as high as 45 degrees (probably corresponding to cross-bedding). No natural fractures were identified across this interval.

1. Introduction

Geophysical logging services were performed in characterization well R-63 by Schlumberger in August 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-63 were the

- Combinable Magnetic Resonance (CMR*) tool, which measures the nuclear magnetic resonance response of the formation to evaluate total and effective water-filled porosity of the shallow formation and to estimate pore size distribution and in-situ hydraulic conductivity;

- 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;

- Array Induction Tool (AIT*), which measures formation electrical resistivity at five depths of investigation and borehole fluid resistivity to evaluate drilling fluid invasion into the formation (a qualitative indicator of permeability and water saturation), presence of moist zones far from the borehole wall, and presence of clay-rich zones;

- Formation Micro-Imager (FMI*) tool, which measures electrical conductivity images of the borehole wall in fluid-filled open-hole and borehole diameter with a two-axis caliper to evaluate geologic bedding and fracturing, including strike and dip of these features and fracture apertures, and rock/sediment texture; and

- 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.

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-63.

Table 3: Geophysical logging services, their combined tool runs and intervals logged, as performed by Schlumberger in borehole R-63

Date of Logging	Borehole Status	Run #	Tool 1 (bottom)	Tool 2	Tool 3 (top)	Depth Interval (ft bgs)
23-January-2011	Uncased hole below 1145 ft drilling with a bit size of ~11.625 in. Steel casing of ~12 in. ID from surface to 1145 ft.	1	AIT	HNGS	GR	34–1417 (AIT top depth 1175)
		2	FMI	GR		1210–1423
		3	APS	GR		206–1418
		4	CMR	GR		1197–1423

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-63, 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-63 was ready for geophysical well logging, the Schlumberger district in Roswell, 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. The tool string was lowered to the bottom of the borehole and brought up at the appropriate logging speed as measurements were made.

Upon reaching the surface, 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-63 provide, overall, good quality results that are consistent with each other across the logged interval. The quality of some measurements was degraded across a few intervals where the borehole contained washouts and/or rugose hole. The measurements most affected by the adverse borehole conditions were ones that have a shallow depth of investigation and that require close contact to the borehole wall—primarily the porosity measurements, particularly from the magnetic resonance tool. The greatest impact on the log processing was erroneously high water-filled porosity in the adverse borehole conditions—as estimated from the CMR magnetic resonance and, less so, APS neutron porosity logs (the other logs were not significantly impacted). The depth intervals where the CMR measurements were most affected are 1264–1266, 1279–1281, 1296–1298, 1302–1304, 1306–1310, 1312–1314, 1316–1317, 1334–1336, 1340–1350, 1366–1369, 1373–1374, 1380–1382, 1383–1385, 1388–1393, 1395–1397, 1408–1410, and 1417–1420 ft bgs. Above the standing borehole water level there was also very high water-filled porosity, as measured by the APS, in the cased hole intervals 815–870 and 1088–1110 ft bgs, likely corresponding to saturated annular fill/void behind the casing.

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 CMR) was redone or refined using better processing algorithms and parameters, (2) the log curves from different logging runs were depth matched and spliced, and (3) the near-wellbore substrate lithology/mineralogy and pore fluids were modeled through integrated log analysis. Separately, the FMI electrical image was processed to produce scaled and normalized high-resolution images that were interpreted to identify geologic features and compute fracture apertures. Afterwards, an integrated log montage was built to combine and compile all the processed log results.

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-63, the log measurements requiring these corrections are the APS porosity and HNGS spectral gamma ray logs, although the AIT field resistivity logs were also re-processed to improve the environmental corrections.

Two neutron porosity measurements are available – one that measures thermal ("slow") neutrons, and one that measures epithermal ("fast") neutrons. 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. The APS makes epithermal porosity measurements. In R-63 the borehole was partly water-filled (below 1263 ft during the logging) and partly air-filled (above 1263 ft), as well as cased above 1145 ft. 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.

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-63 were reprocessed to fully account for the environmental effects of the borehole fluid (water below 1263 ft and air above), casing (above 1145 ft), 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 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-63 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), 5th 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 (36 to 1,422 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. Most notably, above 1198 ft bgs moveable/free water had to be removed from the analysis because no CMR measurement is available (CMR has the only measurement that is independently sensitive to moveable and bound water independently) and above 1222 ft total porosity had to be set since not enough information is available from the measurements to infer (in particular bulk density is not available). Above 206 ft no moisture/water content measurement was available 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 36 to 798 ft bgs was assumed to be tuff or pumice, and a mineral suite considered representative of this volcanic tuff, based on LANL cuttings mineral analysis, was used, taking into consideration that the geophysical logging measurements most sensitive to lithology could not be acquired since they require radioactive sources (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 798–1422 ft bgs were assumed to be Puye fanglomerate and a mineral suite considered as representative of this geology as possible, based on LANL cuttings mineral analysis of the Puye, was used (primary “minerals” silica glass/cristobalite/tridymite [indistinguishable from the log measurements], potassium feldspar, and plagioclase feldspar; quartz at a defined small fraction of the silica glass content); possible secondary minerals montmorillinite clay and constrained small amounts of biotite and hematite).

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). There were no measurements in the open-hole logging suite specifically sensitive to air-filled or total porosity (e.g., bulk density which could not be acquired in uncased potable aquifer because the tool requires a radioactive source). However, the deep-reading bulk resistivity measurement from the AIT induction tool was found to be sensitive to total porosity and water content, especially when combined and contrasted with shallow-reading resistivity measurements affected by drilling/borehole fluids. Above 1222 ft there was not enough measurement sensitivity to total porosity – thus an arbitrary, albeit realistic, total porosity was chosen. In addition, water was not included in the analysis above 206 ft bgs, as mentioned above, 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 porosity constraints). 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-63 ELAN analysis

Volume Tool Measurement	Uninvaded Zone Air	Invaded Zone Air	Uninvaded Zone Bound Water	Invaded Zone Bound Water	Uninvaded Zone Water	Invaded Zone Water	Silica Glass, Cristo., Tridy.	Hematite	Montmorillinite	Biotite	Plagioclase	Orthoclase	Quartz
Epithermal neutron poro. (ft^3/ft^3)	0	0	1.00	1.00	1.00	1.00	0.0	-0.01	0.55	0	0	-0.01	-0.05
Total CMR porosity (ft^3/ft^3)	NA	0	NA	1.00	NA	1.00	0.0	0	0.55	0	0	0	0
CMR bound fluid volume (ft^3/ft^3)	NA	0	NA	1.00	NA	0	0.0	0	0.55	0	0	0	0
Shallow Resistivity (ohm-m)	NA	Infinite	NA	50.0	NA	40.0	Infinite	Infinite	0.92	Infinite	Infinite	Infinite	Infinite
Deep Resistivity (ohm-m)	Infinite	NA	50.0	NA	50.0	NA	Infinite	Infinite	0.92	Infinite	Infinite	Infinite	Infinite
Wet weight potassium (lbf/lbf)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.003	0.004	0.070	0	0.102	0.0
Wet weight thorium (ppm)	0.0	0.0	0.0	0.0	0.0	0.0	2	25	44	25	3	5	0
Gross gamma ray (gAPI)	0	0	0	0	0	0	20	5	300	127	50	255	25
Neutron capture cross section (cu)	NA	0	NA	22.3	NA	22.3	4	25.66	20	54.1	7.9	15.3	4.7

ohm-m = ohm x meters
ppm = parts per million
cu = neutron capture units
lbf = pounds force
ft^3 = cubic feet
gAPI = gamma ray API units

3. Results

Preliminary results from the wireline geophysical logging measurements acquired by Schlumberger in R-63 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); (2) an integrated log montage that contains all the key processed log curves, on depth and side by side (see Attachment 1); and (3) an expanded scale composite log of the processed and interpreted FMI electrical resistivity image log, also containing other useful log results for high resolution interpretation (see Attachment 3). 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. The electrical image composite log provides a very high resolution visual representation of the geologic section, including characterization of rock/sediment texture and fracturing.

Important results from the processed geophysical logs in R-63 are described below.

3.1. Well Fluid Level

The well standing water level in R-63 was 1262–1265 ft bgs at the time of logging, rising slightly between the first and the last 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 (1425 ft bgs) to likely 1305 ft bgs (possibly as high as 1285 ft), which lies within alluvium/fanglomerate (Puye Formation). Below 1266 ft the log estimated water content mostly matches total porosity, tracking each other to the bottom of the borehole at 1425 ft, resulting in an estimated water saturation of 100% (relative to pore space volume) – although without the bulk density log, there is limited information on total porosity. Water content ranges between 20% and over 40% of total rock/sediment volume below 1292 ft, very high values (above 40%) likely corresponding to water-filled borehole washouts. At 1290 ft the water content drops to 13% and is highly variable up to 1254 ft, although it decreases to 10% at 1270–74 ft. Above 1254 ft water content is consistently less than 15%. Thus, based on water content measurements from the geophysical logs, continuous saturated conditions may occur as high as 1292 ft. However, the computed flow capacity profile indicates that almost all the flow capacity occurs below 1305 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 is most likely 1305 ft, but possibly as high as 1292 ft.

The relative hydraulic conductivity estimate and flow capacity profile generated from the processed magnetic resonance logs and integrated log analysis, cross checked against the FMI electrical resistivity image, suggest that there are many productive zones in the Puye Formation fanglomerate that extends below 1305 ft to the bottom of the log interval at 1423 ft. Based on these analyses, the most productive zone is 1340–1346 ft, followed by 1306–1313 ft, although much of the section below 1305 ft appears to have high permeability. Additional zones that the processed logs are particularly productive are 1298–1304 ft (note this may be above the Regional Aquifer), 1325–1333 ft, 1352–1358 ft , 1360–1362 ft, 1365–1370 ft, 1373–1376 ft, 1380–1382 ft, 1384–1386 ft, 1389–1397 ft, 1406–1410 ft, and 1418–1422 ft.

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 from 1305 ft bgs to ground surface. 3.Above 1254 ft bgs, which the processed logs clearly indicate to be within the vadose zone (above the top of the Regional Aquifer), the estimated water content ranges 7–15% of total rock volume up to 1144 ft. Water content is elevated in the interval 1087–1144 ft, reaching as high as 35–50% at the top. This zone is at the bottom of the casing emplaced in the borehole at the time to prevent borehole collapse and seal off water inflow from upper perched water zones; thus, likely the water measured by the geophysical logs is trapped water behind this casing. Water content remains less than 15% above 1087 ft up to 905 ft, above which it increases to 20%, then 35–50% in the interval 815–870 ft. The highly elevated water content in this zone is likely trapped water behind the casing resulting from the emplacement of casing and grout to seal off perched water inflow to the borehole. Directly above (802–804 ft) measured water content is very low (less than 5% possibly due to a large air-filled void behind casing), but it increases to 15–23% in the interval 574–758 ft. Above 574 ft to the top of the APS epithermal neutron porosity log (200 ft) the measured water content ranges 7–15%, lowest at the top and slightly higher values (up to 19%) in the zone 393–405 ft. Water content could not be quantitatively estimated above 200 ft since there are no APS or other porosity measurements.

3.4. Geology

The geophysical log results clearly delineate that the saturated/water-filled section of the borehole consists of clastic sediments (alluvium/fanglomerate) that extends up to 798 ft bgs. Directly above this, the combined log response is clearly indicative of the Guaje Pumice Bed, with a large increase in thorium and uranium concentrations, likely extending up to 789 ft. The log results corroborate volcanic tuff overlying the pumice bed and extending up to the top of the logged interval.

The generalized geologic stratigraphy observed from the logs across the measured interval is as follows (depth below ground surface):

- **34–789 ft bgs (top of processed log interval): High thorium and uranium rich material (likely volcanic tuff)** – characteristic of the Bandelier Tuff, with high concentrations of silicon, uranium and thorium concentrations (note the decrease in thorium and uranium above 60 ft is likely mostly due to larger hole size and the presence of surface casing)

- **789–798 ft bgs: Very high thorium and uranium rich volcanic tuff/pumice** – characteristic of the Guaje Pumice Bed, with a large increase in thorium and uranium concentrations from the alluvium material below, as well as high water content and large pore size measured by the magnetic resonance tool

- **798–814 ft bgs: Unknown porosity, silicon rich alluvium/fanglomerate** – characterized by unknown total porosity; high silica glass/tridymite/cristobalite or quartz content; moderate potassium feldspar content and possibly augite (or similar mineral); presence of montmorillinite

- **814–860 ft bgs: Unknown porosity, silicon rich alluvium/fanglomerate (possibly clay/silt-rich)** – characterized by unknown, high total porosity (very high-water-filled porosity), high silica glass/tridymite/cristobalite or quartz content; moderate montmorillinite content (likely elevated due to emplaced bentonite chips/grout behind casing); low potassium feldspar content and; trace amounts of and biotite

- **860–1088 ft bgs: Unknown porosity, silicon rich alluvium/fanglomerate** – characterized by unknown total porosity; high silica glass/tridymite/cristobalite or quartz content; low potassium feldspar and biotite content

- **1088–1110 ft bgs: Unknown porosity, silicon rich alluvium/fanglomerate (possibly clay/silt-rich)** – characterized by unknown, high total porosity (very high-water-filled porosity), high silica glass/tridymite/cristobalite or quartz content; low to moderate montmorillinite content (likely elevated due to emplaced bentonite chips/grout behind casing); low potassium feldspar content and; trace amounts of and biotite

- **1110–1222 ft bgs: Unknown porosity, silicon rich alluvium/fanglomerate** – characterized by unknown total porosity; high silica glass/tridymite/cristobalite, quartz or plagioclase content; low potassium feldspar, montmorillinite and biotite content

- **1222–1292 ft bgs: Highly variable porosity, silicon and feldspar rich alluvium/fanglomerate containing clay** – characterized by highly variable porosity (8–50%, highest porosities likely elevated due to washouts); moderate to high plagioclase and silica glass/tridymite/cristobalite or quartz content; small to moderate potassium feldspar and montmorillinite content; and trace amounts of biotite and hematite

- **1292–1358 ft bgs: High to very high porosity, silicon and feldspar rich alluvium/fanglomerate** – characterized by variably high to very high total porosity (20–50%, highest porosities likely elevated due to washouts); high plagioclase and silica glass/tridymite/cristobalite or quartz content; moderate potassium feldspar content; and trace amounts of montmorillinite, biotite and hematite

- **1358–1423 ft bgs (bottom of log interval): High porosity, silicon and feldspar rich alluvium/fanglomerate containing clay** – characterized by high variable porosity (20–40%); high plagioclase and silica glass/tridymite/cristobalite or quartz content; small to moderate potassium feldspar content; and trace amounts of montmorillinite, biotite and hematite

The interpreted planar bedding features across the electrically imaged interval 1263 to 1420 ft bgs have fairly widely varying dip azimuths (direction beds are dipping towards), but the quadrant with highest frequency is to the southwest and secondarily to the east-northeast and north-northwest. Bedding feature dip angles (angle from horizontal) are mostly less than 20 degrees, with a few dips as high as 45 degrees (probably corresponding to cross-bedding). No natural fractures were identified across this interval.

3.5. Summary Logs

Three summary log displays have been generated for R-63 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, moveable water content, water saturation, estimated hydraulic conductivity, transmissivity, and relative producibility (flow capacity); highlights key hydrologic information obtained from the integrated log results (Figure 1)
- Density and clay content summary showing a continuous logs of estimated formation bulk density and grain density, as well as clay volume – all computed from the ELAN integrated log analysis; 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 lithologic/stratigraphic correlation logs from the spectral gamma ray measurement (concentrations of gamma-emitting elements); highlights the geologic lithology, stratigraphy, and correlation information obtained from the log results (Figure 3)

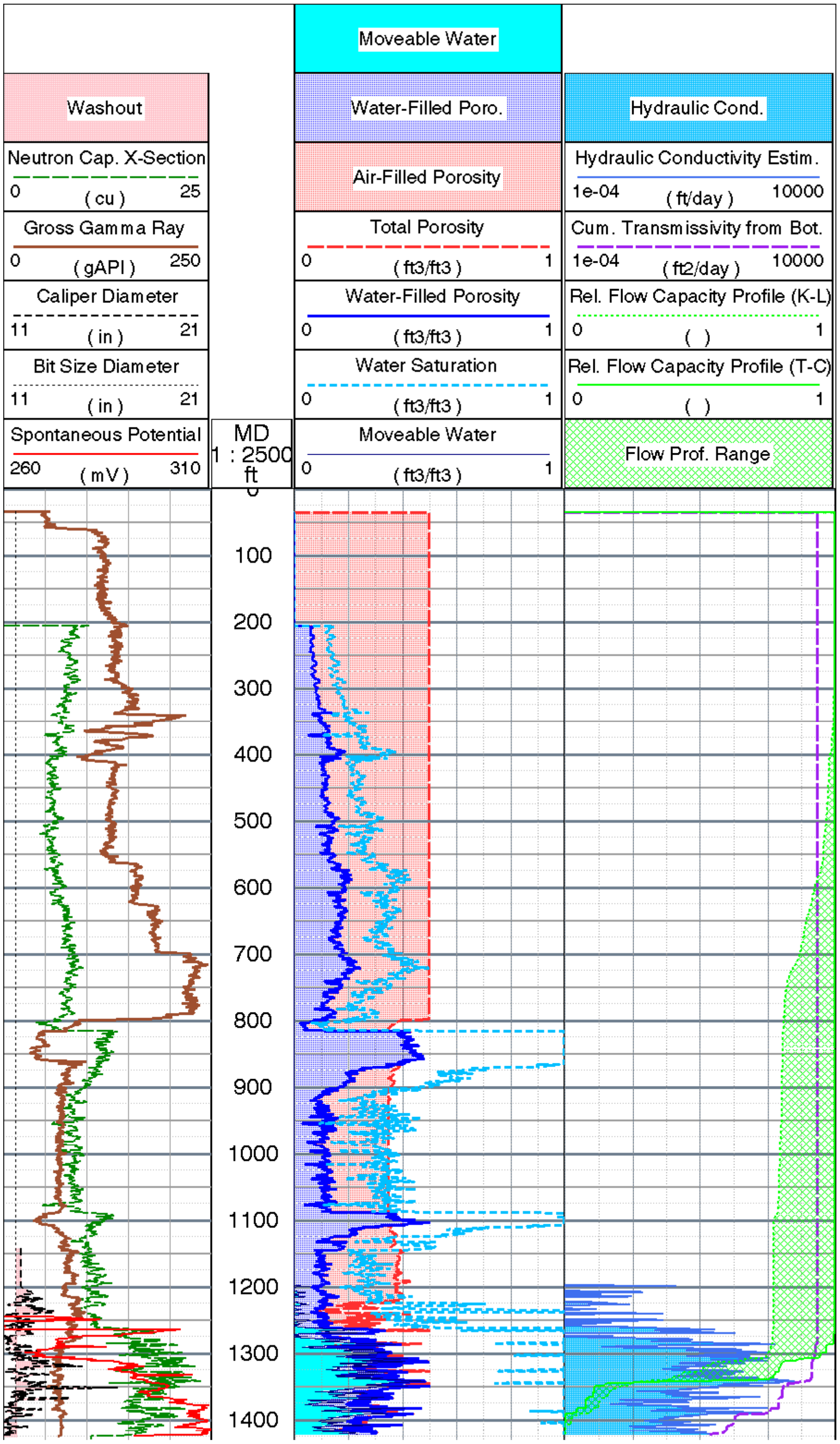


Figure 1: Summary of porosity logs in R-63 borehole from processed geophysical logs, interval of 36 to 1,422 ft bgs, with caliper, gross gamma, spontaneous potential, neutron capture cross-section, water saturation, estimated relative flow capacity profile, hydraulic conductivity, and transmissivity logs also displayed. Porosity, water saturation, and hydraulic conductivity logs are derived from the ELAN integrated log analysis.

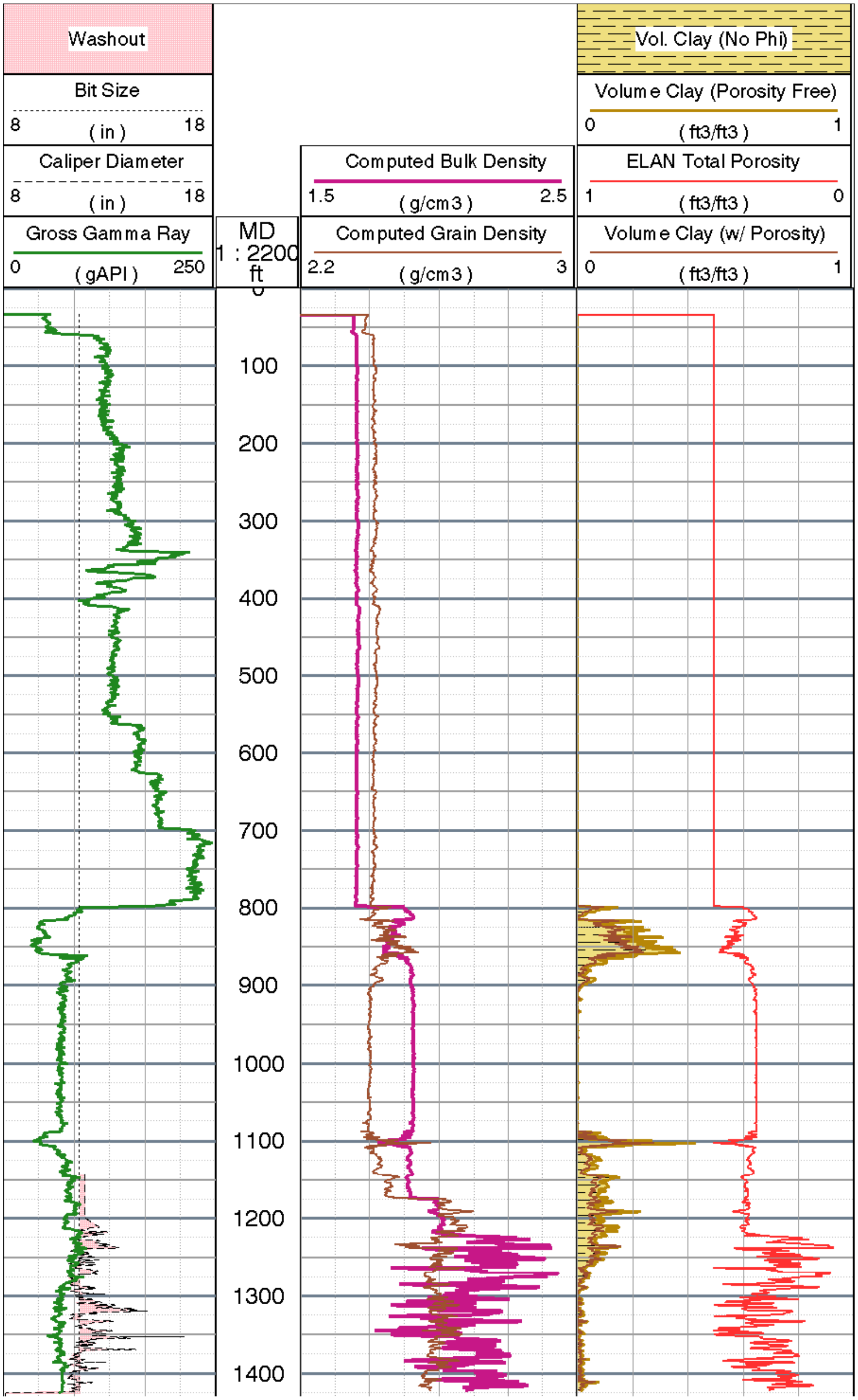


Figure 2: Summary of computed bulk density, apparent grain density and volume clay logs in R-63 borehole from processed geophysical logs, interval of 36 to 1,422 ft bgs. Also shown are caliper, gross gamma, and total porosity logs (the latter and the density logs derived from the ELAN analysis).

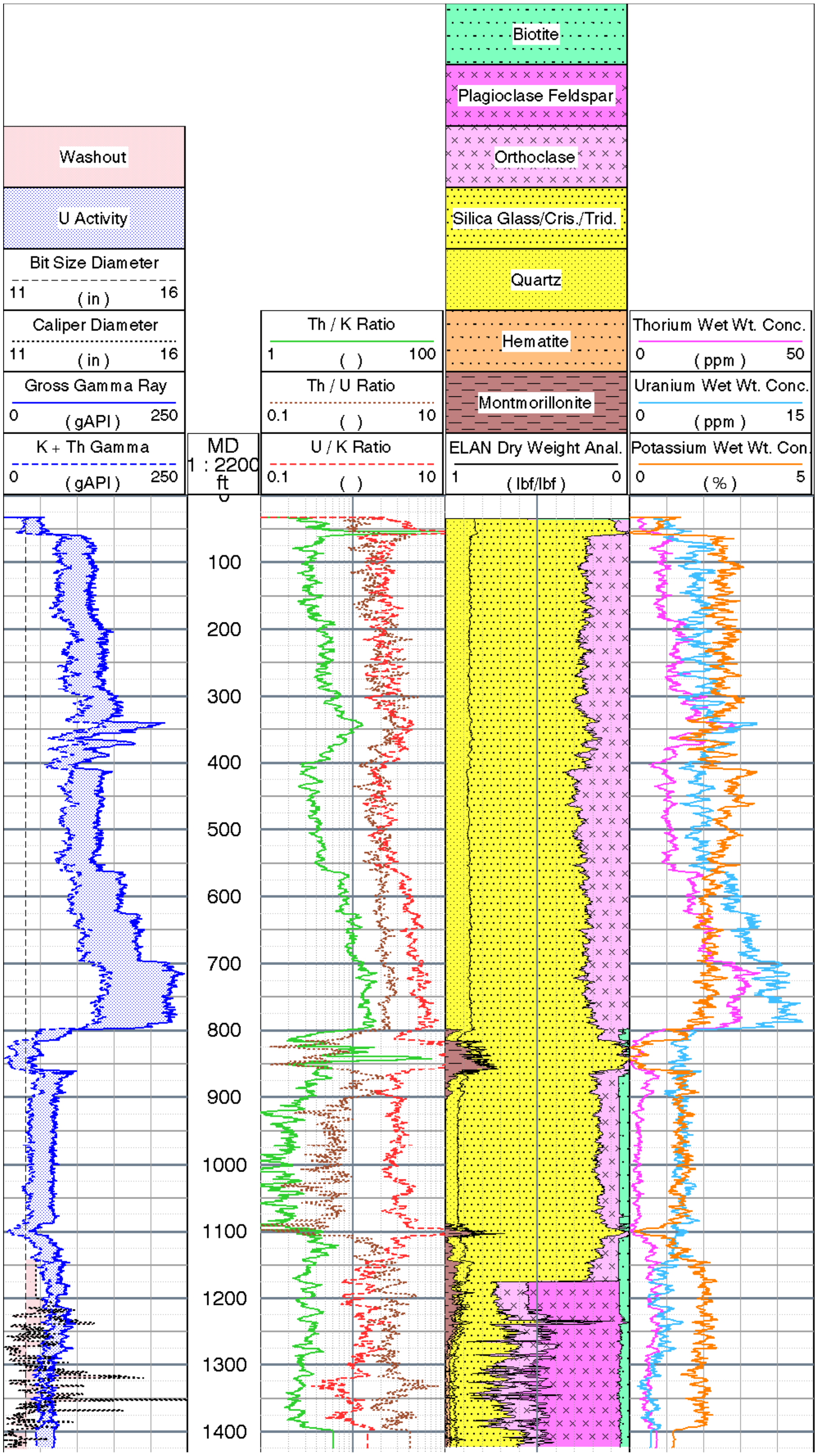


Figure 3: Summary of spectral natural gamma ray logs and ELAN mineralogy/lithology model dry weight fractions derived from the ELAN integrated log analysis for R-63 borehole, interval 36 to 1,422 ft bgs. Caliper log is also shown.

3.6. Integrated Log Montage

This section summarizes the integrated geophysical log montage for R-63. 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-63 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 FMI-HNGS 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 250 gAPI units;
- two orthogonal calipers from the FMI (thin dotted and dashed pink) with bit size as a reference (dashed-dotted black) to show washout (pink shading), recorded as hole diameter in inches and displayed on a scale of 11 to 21 in.;
- borehole deviation displayed as a tadpole every ten feet (light blue dots and connected line segments) – the "head" marks the angular deviation from vertical at that particular depth, on a scale of 0 to 5 degrees, and the "tail" shows the azimuth of the deviation, true north represented by the tail facing straight towards the top of the page.;
- spontaneous potential (bold long-dashed red), recorded in milli-volts (mV) and displayed on a 50 mV relative scale;
- 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 25 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–Resistivity

The third track displays the resistivity measurements from the AIT, spanning most of the open hole section at the time of the logging. All the resistivity logs are recorded in units of ohmmeters (ohm-m) and are displayed on a logarithmic scale of 20 to 2000 ohm-m.

The six resistivity logs from the AIT that are displayed are:

- Borehole fluid resistivity (solid orange curve)–only valid in water-filled hole
- Bulk electrical resistivity at five median depths of investigation–10 in. (black solid), 20 in. (long-dashed blue), 30 in. (short-dashed red), 60 in. (dashed-dotted green), and 90 in. (solid purple)–each having a 2-foot vertical resolution.

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

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

Track 4–Porosity

The fourth 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 in water-filled hole and array-far detector pairing in air-filled hole (bold solid dark blue curve);

- CMR total water-filled porosity (short-dashed black);
- CMR effective water-filled (free fluid) porosity (long-dashed green with green area shading);
- Total porosity derived from ELAN computed bulk density and water-filled porosity using a grain density of 2.4/2.5 g/cc (dashed red curve), 2.45/2.55 g/cc (bold long-dashed red curve), and 2.5/2.65 g/cc (dotted red curve)–with red shading between the 2.4/2.5 g/cc and 2.5/2.65 g/cc porosity curves to show the range (the grain density ranges corresponding to different compositions of tuff and fanglomerate/alluvium); 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;
- ELAN moveable water (bold long-dashed dark green with dark blue shading to right)–derived from the ELAN integrated analysis of all log curves to estimate optimized matrix and pore volume constituents;
- ELAN bound water porosity (cyan area shading) – representing by the area between the ELAN total and moveable water-filled porosities;
- APS slowing down time porosity derived from pulsed neutron time series in the array detectors (short-dashed light blue curve) – shallowest reading and highest vertical resolution epithermal neutron porosity from APS tool, processed for zoned air-filled and water-filled open/cased hole.

Track 5–Density

The fifth track displays the

- computed bulk density (thick solid maroon curve), derived from the ELAN analysis, on a scale of 1 to 3 g/cc;
- apparent grain density (dashed brown curve), derived from the ELAN analysis, on a scale of 2.25 to 3.25 g/cc.

Track 6–HNGS Spectral Gamma

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

- 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 50 to -50 ppm; and
- uranium (dotted blue) in units of parts per million (ppm) and on a scale of 20 to 0 ppm.

Track 7–CMR Porosity

Track 7 displays various CMR water-filled porosities along with measurement quality flags. The porosity and measurement quality logs are presented on a scale of 0.5 to 0 volume fraction and discrete blocks originating from the left side, respectively. Specifically, the CMR logs shown in this track are:

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

- CMR magnetic field variation (dotted yellow) – representing the variation in the measured magnetic field versus the baseline magnetic field used for the logging (used as an indicator of the presence of magnetic minerals which requires a lower T2 cutoff)
- CMR wait-time flag (red area shading) – activates when there is significant measurement response at late T2 times, corresponding to large amounts of completely free ("bathtub") water and often associated with washouts or very large pores;
- CMR measurement noise flag (yellow and orange area shading) – activates when there is potentially detrimental amounts of measurement noise detected by the tool, at moderate (yellow) and high (orange) levels

Track 8–Pore Size Distribution

Track 8 displays the water-filled pore size distribution as determined by the CMR – shown as binned water-filled porosities and valid only in the open-hole section. The binned porosity logs are presented on a scale of 0.5 to 0 volume fraction with colored area shading corresponding to the different bins:

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

In addition, hydroxyl hydrogen is approximated as the difference between the CMR total porosity and ELAN total water-filled porosity (shaded as diagonal purple stripes).

Track 9–CMR T2 Distribution (Waveforms)

The CMR T2 distribution is displayed in Track 9 as green waveform traces at discrete depths. The horizontal axis, corresponding to relaxation time in milliseconds, is on a logarithmic scale from 0.3 to 10000 ms. Also plotted are the:

- T2 logarithmic mean (solid blue curve) and

- T2 cutoff time used for differentiating between bound and free water (solid red line) – chosen as 100 ms

Track 10–CMR T2 Distribution (Heated Amplitude)

Track 10 displays the T2 distribution in another way – on a heated color scale where progressively "hotter" color (green to yellow to red) corresponds to increasing T2 amplitude. The remaining aspects of the display are the same as in Track 9, except that the high vertical resolution T2 logarithmic mean is shown as a solid white curve and the T2 cutoff is displayed as a solid black line.

Track 11–Hydraulic Conductivity

Track 11 displays several estimates of hydraulic conductivity (K) derived from the ELAN integrated log analysis and processed CMR results, presented on a logarithmic scale of 10^{-5} to 10^{5} feet per day (ft/day):

- K-versus-depth estimate derived from using the Timur-Coates permeability equation with total and moveable water content derived from the ELAN analysis, converted to hydraulic conductivity (solid sky blue curve with gradational coloring to represent the range of hydraulic conductivity relative to standard unconsolidated clastic sediments); and
- K-versus-depth estimate derived from using the SDR permeability equation applied to the processed CMR results, converted to hydraulic conductivity (long-dashed purple curve);
- K-versus-depth estimate derived from using the ELAN k-lambda equation with water-filled porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (dashed dark blue curve);
- Intrinsic K-versus-depth estimate (assuming full saturation) using the Timur-Coates permeability equation with total porosity and matrix mineral weight fraction values derived from the ELAN analysis, converted to hydraulic conductivity (dotted light blue).

In addition, an estimate of cumulative transmissivity from the bottom of the log interval is displayed in units of feet squared per day [ft2/day] (bold dashed-dotted green curve) – computed by integrating from bottom to top the ELAN Timur-Coates hydraulic conductivity estimate.

Track 12–FMI Image (Dynamic Normalization)

Track 12 displays the FMI image, processed with dynamic normalization so that small-scale electrical resistivity features are amplified in the image. (With dynamic normalization, the range of electrical resistivity amplitudes – colors in the image – is normalized across a small moving depth window.) The image is fully oriented and corresponds to the inside of the borehole wall unwrapped, such that the left-hand side represents true north, half-way across the image is south, and the right-hand side is north again. The four color tracks in the image correspond to portions of the borehole wall contacted by the four FMI caliper pads; the blank space in between is the portion of the borehole wall not covered by the pads.

Also displayed are interpreted planar bedding features (thin green sinusoids) and bed boundaries (bold dark green sinusoids).

Track 13–FMI Bedding

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

- Individually, as tadpoles at the depths the bedding plane or fracture plane crosses the midpoint of the borehole – where the “heads” (circles/triangles) represent the dip angle, and the “tails” (line segments) represent the true dip azimuth (direction the bed is dipping towards). Bedding features are shown as circular headed light green tadpole and bed boundaries as circular headed dark green tadpoles.
- Summed, as dip azimuth fan plot histograms (green colored fan plots for bed boundaries) – where the number of bedding features having a dip direction within a particular sector are summed and normalized, thus highlighting the predominant dip directions.

Track 14–FMI Image (Static Normalization)

Track 14 displays the FMI image again, but in a different way – processed with static normalization to highlight larger scale features and trends. (With static normalization, the range of electrical resistivity amplitudes – colors in the image – is normalized across the entire length of the log interval.) Also shown is the high-resolution scaled resistivity from one of the FMI pads.

Track 15–ELAN Mineralogy Model Results (Dry Weight Fraction)

Track 15 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)
- Plagioclase Feldspar (pink)
- Biotite (light green with small black dots)

Track 16–ELAN Mineralogy and Pore Space Model Results (Wet Volume Fraction)

Track 16 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)
- Plagioclase Feldspar (pink)
- Biotite (light green with small black dots)
- Air (red)
- Water (white)
- Capillary-bound (irreducible) water (light blue)

- Moved air (orange)
- Moved water (blue)

Track 17–Water Saturation

Track 17 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 ELAN computed bulk density and water-filled porosity using a grain density of 2.4/2.5 g/cc (dashed blue curve), 2.45/2.55 g/cc (bold long-dashed blue curve), and 2.5/2.65 g/cc (dotted blue curve)–with blue shading between the 2.4/2.5 g/cc and 2.5/2.65 g/cc saturation curves to show the range (the grain density ranges corresponding to different compositions of tuff and fanglomerate/alluvium).

Track 18–Predicted Flow (Production Potential) Profile

Track 18 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 ELAN Timur-Coates water permeability log (bold solid blue curve), 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 CMR SDR water permeability log (light blue curve), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate;
- Predicted relative water flow profile derived from the ELAN k-lambda water permeability log (light blue curve), displayed on a unitless linear scale of 0 to 1 relative volumetric flow rate;
- 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 ELAN Timur-Coates water permeability log (bold solid blue), displayed on a linear scale of 0 to 500,000 gallons per day (gal/day).

Track 19–Summary Logs

Track 19, 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 green area shading);
- Optimized estimate of volume fraction moveable water (non-clay bound moveable water-filled porosity) from the ELAN analysis (dashed cyan curve and green area shading); and
- 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 0.5 total volume fraction, left to right.

Track 20–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 FMI 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-63

GEOFRAME
PROCESSED
INTERPRETATION

Integrated Wireline Log Well Montage

Processed Advanced Borehole Geophysical Logs

*A Mark of Schlumberger

Using the following logs: FMI*, AIT*, CMR*
APS*, HNGS*

COMPANY: NORTH WIND (drilling contractor for LANL)
WELL: R−63
FIELD: N/A
STATE: NEW MEXICO
COUNTRY:
Date Logged: 23−Jan−2011 Date Processed: May−2011
Well Location:
Elevations: K.B. NA D.F. NA G.L. 7457 ft
API Number: Job Number:

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

Ser. Oder # BFJS−00040 OP Vers.: 18C0−147 Process Date: May−2011 Center: SWS Tucson Baseline: GF4.2 Log Analyst: N. Clayton

Mud and Borehole Measurements:

Rm @ Meas. Temp.: 39 ohm.m @ 49 degF	BHT: 49 degF	Bitsize: 12 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 was uncased below 1145 ft.
Well water level was 1262−1265 ft at the time of the logging.
ELAN* performed without density (total) porosity measurement (unavailable in open hole).
Total poro. set to constant value in ELAN above 1221 ft to account for lack of density meas.
Interpretation should acount for borehole conditions (particularly washouts and rugosity).

Attachment 2 – Color Print of ELAN Optimized Mineral and Pore Volume Model Results for Well R-63

Schlumberger

ELAN* Geophysical Log Integrated Analysis

Optimized Mineral + Pore Volume Model

COMPANY:	LANL, NORTH WIND
WELL:	R−63
FIELD:	N/A
State:	NEW MEXICO
COUNTRY:	

*Elemental Log Analysis, Mark of Schlumberger

Date Processed:	May−2011	Date Logged:	23−Jan−2011
Job Number:		Processed at:	SWS Tucson
Well Location:			
Latitude:		Longitude:	

Elevations: KB: DF: GL: 2272.89m

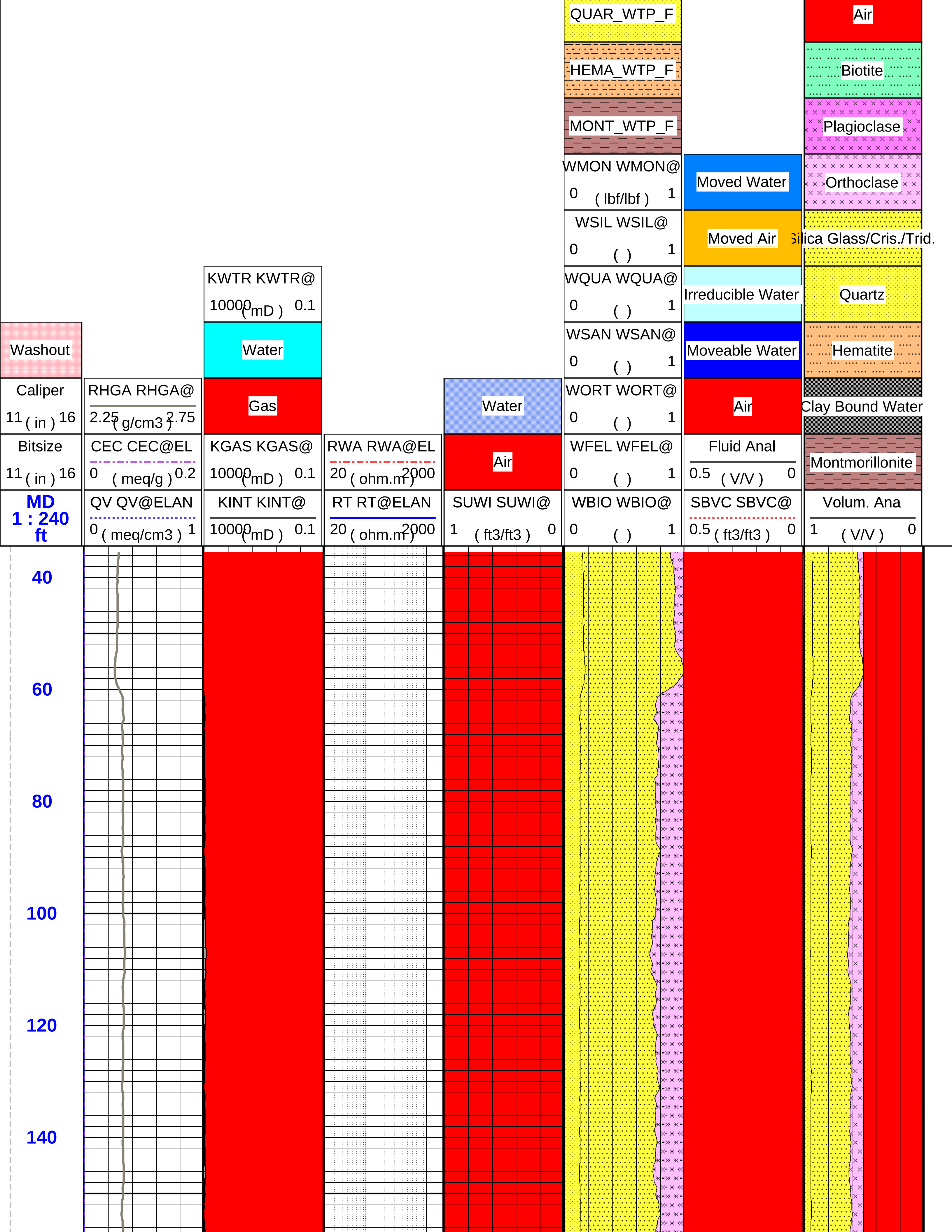
Depth reference is ground surface. Tot. poro. constraints applied above 1221 ft.

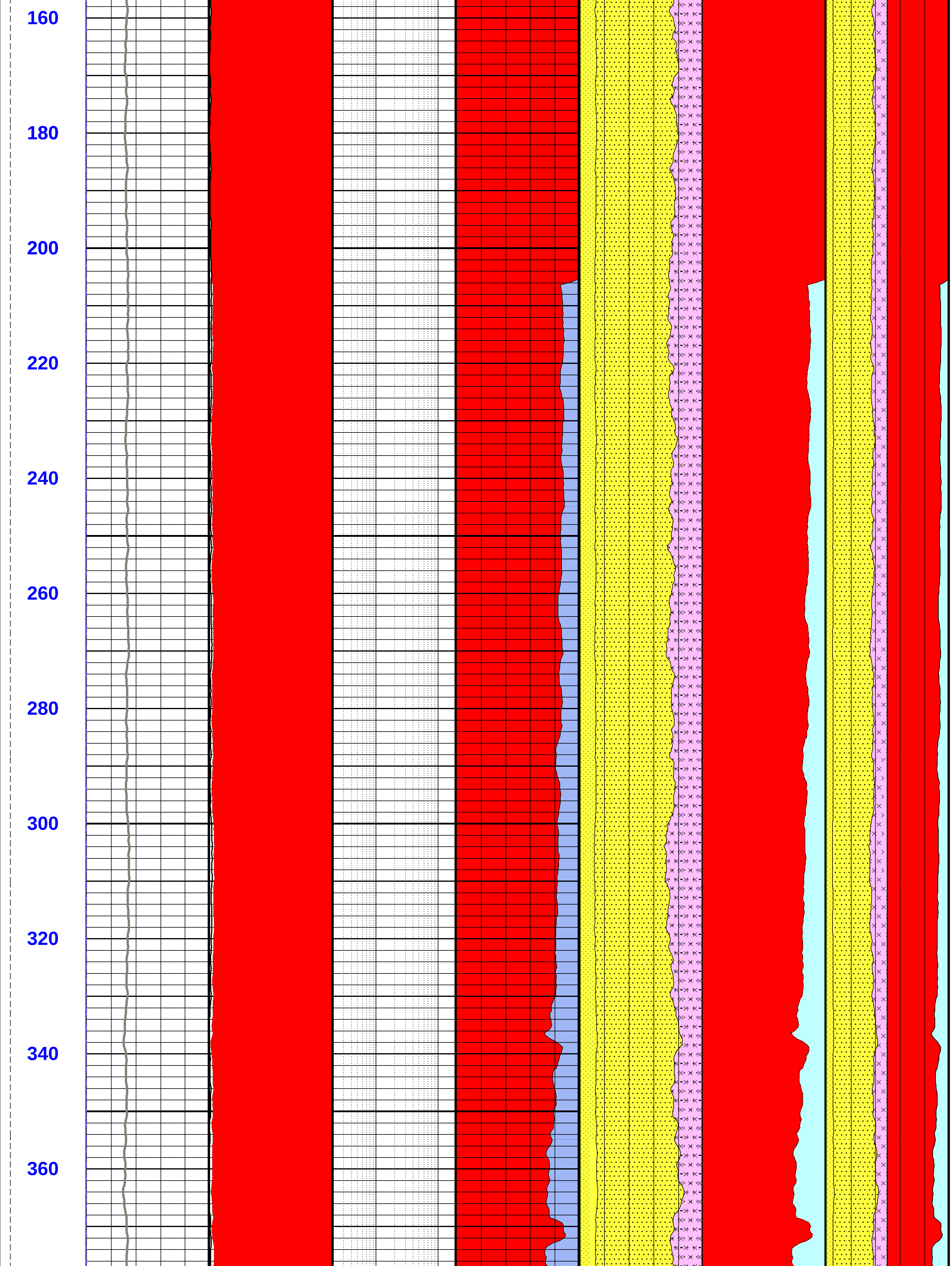
FOLD HERE The well name, location and borehole reference data were furnished by the customer.

R−63 [Fun_2]

BIOT_WTP_F
PLAG_WTP_F
ORTH_WTP_F
GLASS_WTP_

Moved Water
Moved Air
Irreducible Water
Moveable Water


Washout
Caliper
11 (in) 16
Bitsize
11 (in) 16
MD
1 : 240
ft
RHGA RHGA@
2.25 (g/cm3) 2.75
CEC CEC@EL
0 (meq/g) 0.2
QV QV@ELAN
0 (meq/cm3) 1
KWTR KWTR@
10000 (mD) 0.1
Water
Gas
KGAS KGAS@
10000 (mD) 0.1
KINT KINT@
10000 (mD) 0.1
RWA RWA@EL
20 (ohm.m) 2000
RT RT@ELAN
20 (ohm.m) 2000
Water
Air
SUWI SUWI@
1 (ft3/ft3) 0
QUAR_WTP_F
HEMA_WTP_F
MONT_WTP_F
WMON WMON@
0 (lbf/lbf) 1
WSIL WSIL@
0 ( ) 1
WQUA WQUA@
0 ( ) 1
WSAN WSAN@
0 ( ) 1
WORT WORT@
0 ( ) 1
WFEL WFEL@
0 ( ) 1
WBIO WBIO@
0 ( ) 1
Moved Water
Moved Air
Irreducible Water
Moveable Water
Air
Fluid Anal
0.5 (V/V) 0
SBVC SBVC@
0.5 (ft3/ft3) 0
Air
Biotite
Plagioclase
Orthoclase
Silica Glass/Cris./Trid.
Quartz
Hematite
Clay Bound Water
Montmorillonite
Volum. Ana
1 (V/V) 0
40
60
80
100
120
140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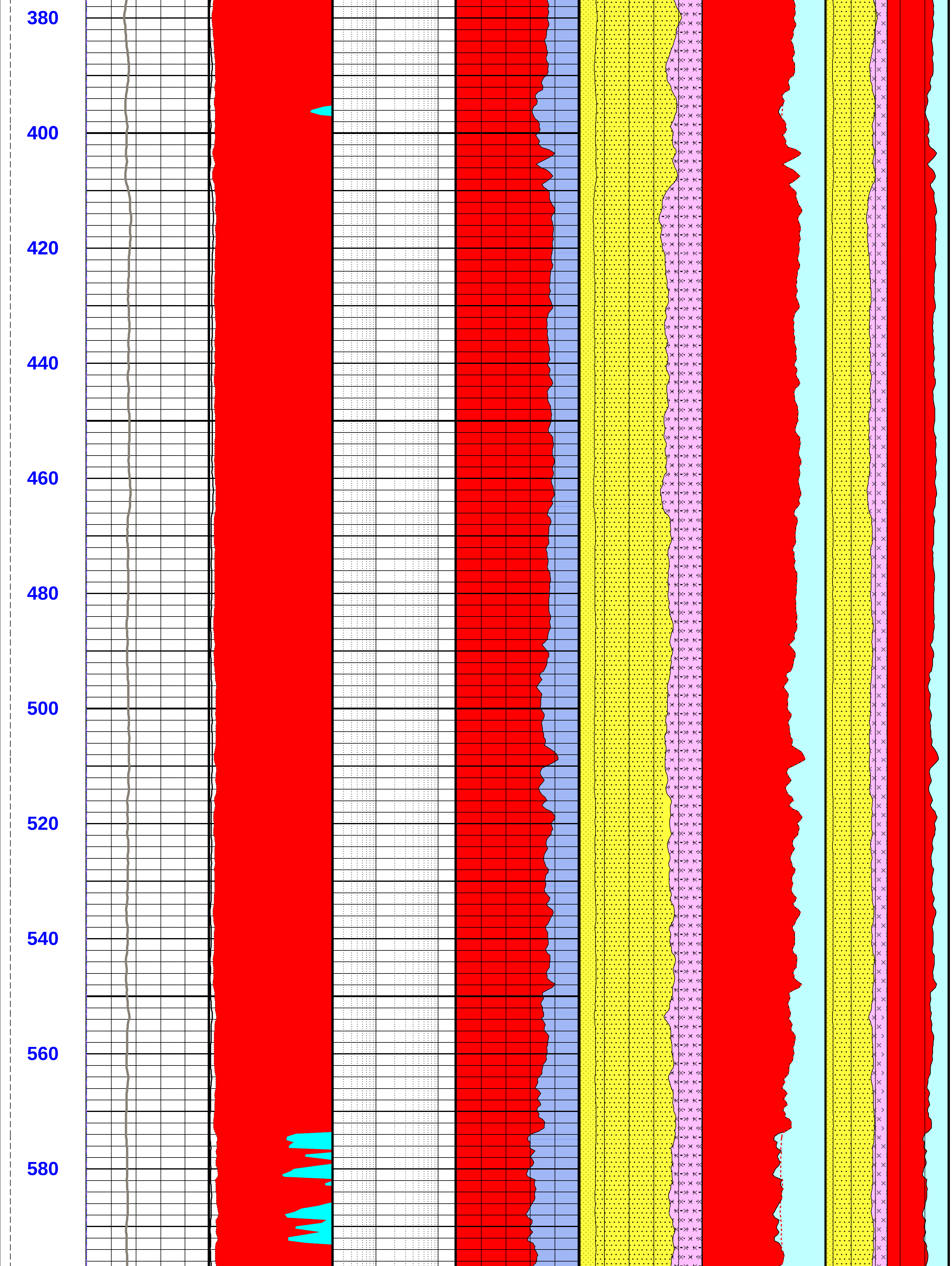
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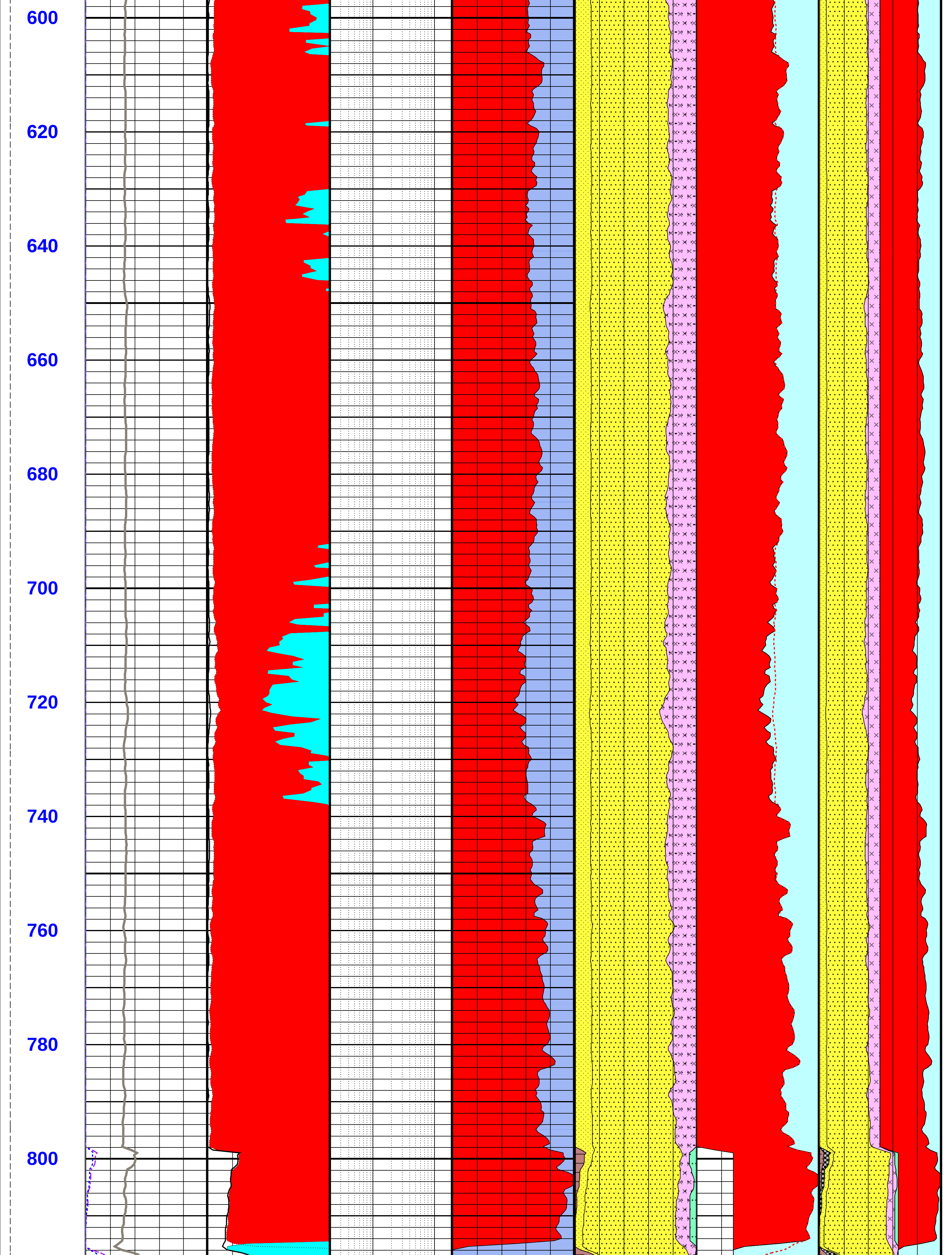
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620
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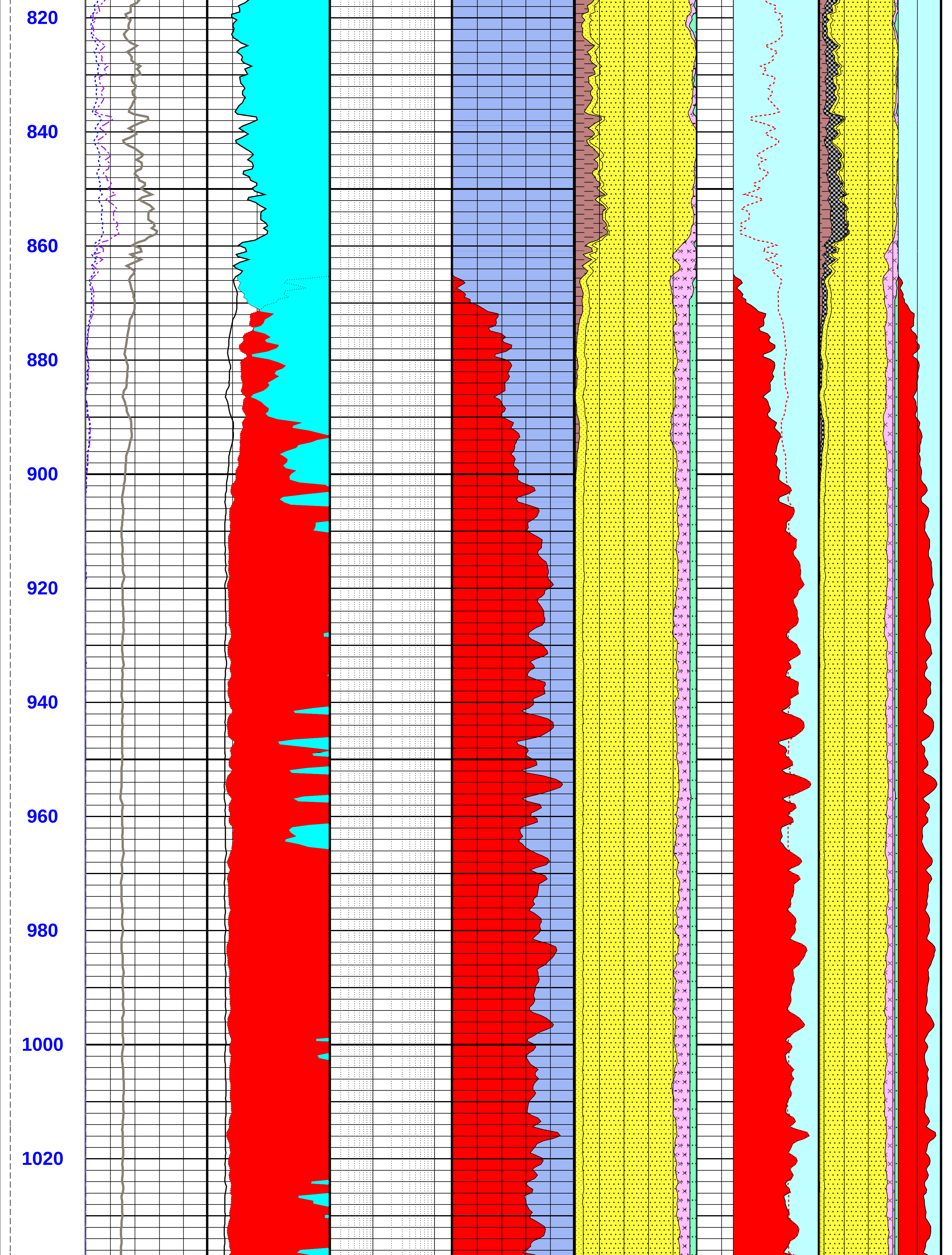
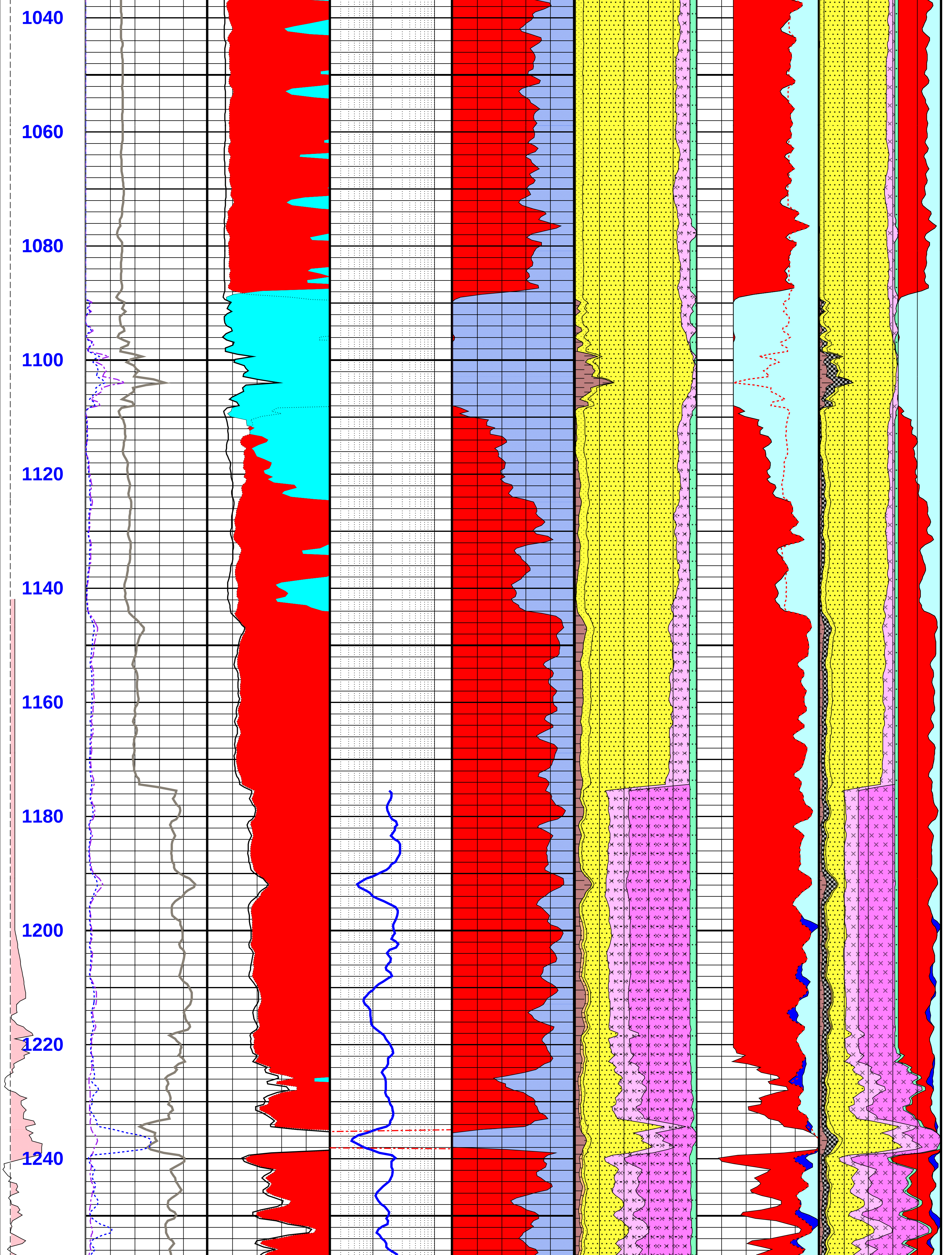
780
800


820
840
860
880
900
920
940
960
980
1000
1020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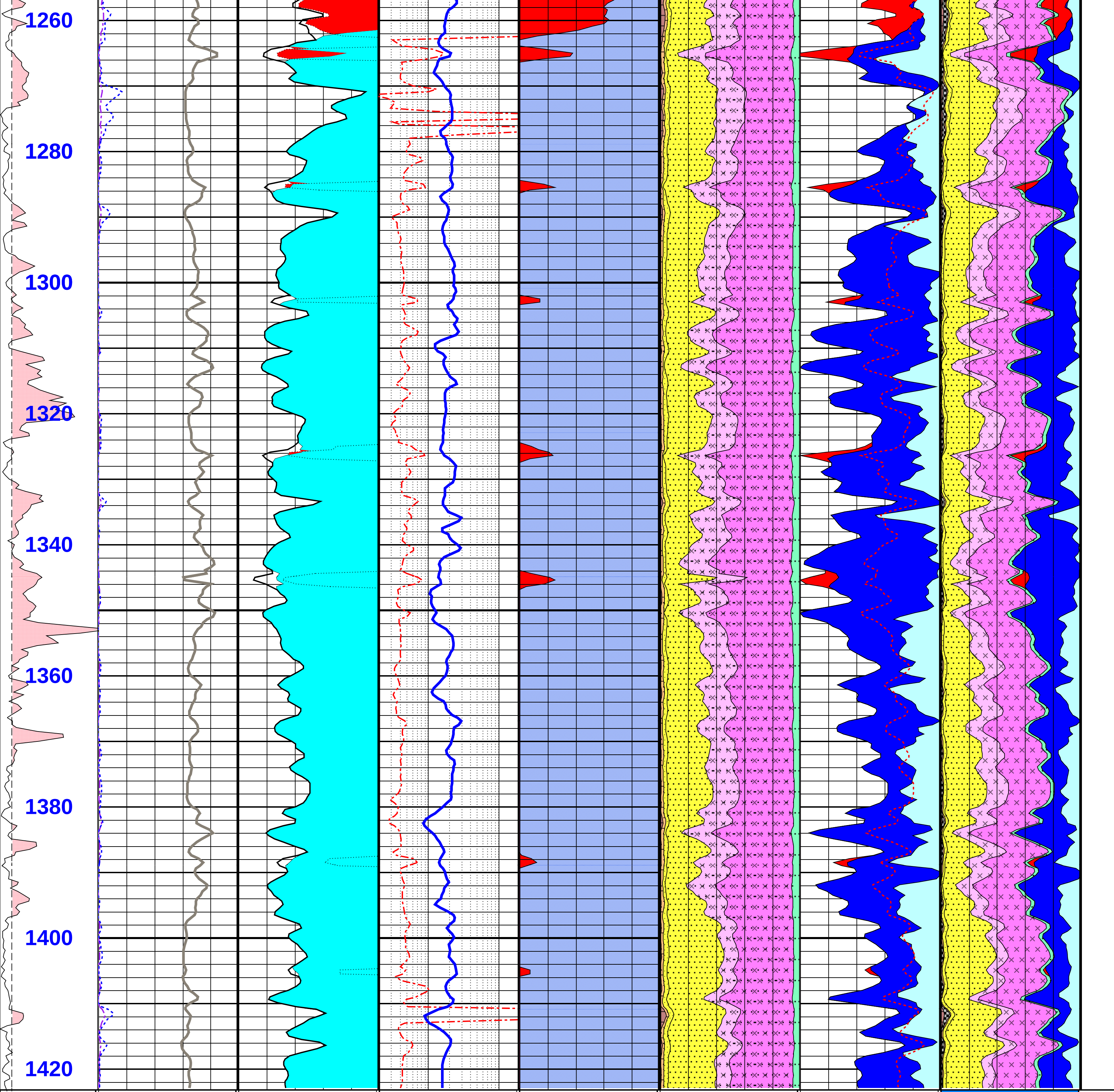
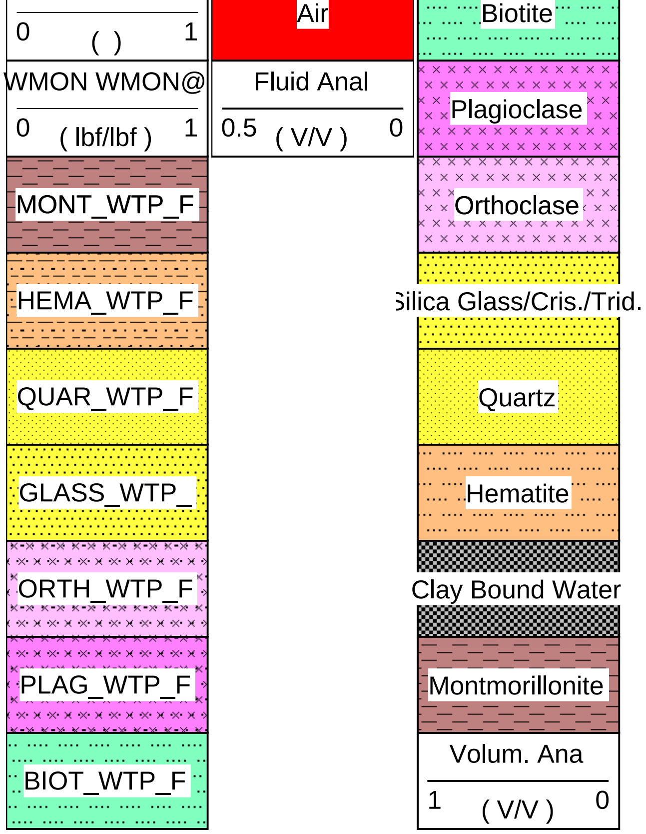
1060
1080
1100
1120
1140
1160
1180
1200
1220
1240



MD 1 : 240 ft	QV QV@ELAN 0 (meq/cm3) 1	KINT KINT@ 10000 (mD) 0.1	RT RT@ELAN 20 (ohm.m) 2000	SUWI SUWI@ 1 (ft3/ft3) 0	WBIO WBIO@ 0 ( ) 1	SBVC SBVC@ 0.5 (ft3/ft3) 0	Moved Water
Bitsize 11 (in) 16	CEC CEC@EL 0 (meq/g) 0.2	KGAS KGAS@ 10000 (mD) 0.1	RWA RWA@EL 20 (ohm.m) 2000	Air	WFEL WFEL@ 0 ( ) 1	Moved Water	Moved Air
Caliper 11 (in) 16	RHGA RHGA@ 2.25 (g/cm3) 2.75	Gas		Water	WORT WORT@ 0 ( ) 1	Moved Air	Irreducible Water
Washout		Water			WSAN WSAN@ 0 ( ) 1	Irreducible Water	Moveable Water
		KWTR KWTR@ 10000 (mD) 0.1			WQUA WQUA@ 0 ( ) 1	Moveable Water	Air
					WSIL WSIL@		


0
( )
1
Air
Biotite
WMON WMON@
0
(lbf/lbf)
1
Fluid Anal
0.5
(V/V)
0
Plagioclase
MONT_WTP_F
Orthoclase
HEMA_WTP_F
Silica Glass/Cris./Trid.
QUAR_WTP_F
Quartz
GLASS_WTP_
Hematite
ORTH_WTP_F
Clay Bound Water
PLAG_WTP_F
Montmorillonite
BIOT_WTP_F
Volum. Ana
1
(V/V)
0

R−63 [Fun_2]

Attachment 3 – Color Print of FMI Composite Log for Well R-63