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www.boardofwatersupply.com

April 10, 2018

Mr. Jeffrey T. Pearson, P.E.
Deputy Director
State of Hawaii
Department of Land and Natural Resources
Commission on Water Resources Management
P.O. Box 621
Honolulu, Hawaii 96809

Dear Mr. Pearson:

Subject: Honolulu Board of Water Supply (BWS) Comments on the Department of the Navy (Navy) Technical Memorandum: Testing and Verification of Packer Integrity at RHMW11, Red Hill Bulk Fuel Storage Facility (RHBFSF) Joint Base Pearl Harbor-Hickam, Oahu, Hawaii, February 9, 2018 completed under Red Hill Administrative Order on Consent (AOC) Statement of Work (SOW) Sections 6 and 7

The BWS offers the following comments on the above referenced Technical Memorandum (Memo) (Navy, 2018) at the request of the Commission on Water Resources Management (CWRM) per your letter dated March 27, 2018 (CWRM, 2018). A copy of the Navy's Memo is enclosed as Attachment A for reference.

General Comments:

Our review of the Navy's Memo did not show sufficient data to support the report's conclusion that the Westbay sampling system successfully isolated specific subsurface sampling zones from each other at RHMW11 as discussed in the report's six areas listed below.

1. Evaluation of the grouted 10-inch and 5-inch blank casing;
2. Manufacturer's certification of packers;
3. Field packer inflation records;
4. Vertical pressure profiles;
5. Vertical temperature profiles; and,
6. Pneumatic testing of multiple zones within monitoring well RHMW11.

Our specific comments are below.

Specific Comments

1. Evaluation of the Grouted 10-inch and 5-inch Blank Casing (Page 3, Lines 22 – 30 and Page 4, Lines 1 - 3)

The Memo's evaluation of the grouted casing in monitoring well RHMW11 consists of very limited analysis as summarized in the statements: "Grout volumes during installation of both casings were consistent with calculated theoretical volumes" (Page 3, Lines 27 and 28) and "All evidence suggests that the cement-bentonite grout outside of the 10-inch casing and outside of the 5-inch inner casing successfully isolated deeper zones from the water from shallower zones within the borehole" (Page 4, Lines 1 through 3). The first statement of calculated theoretical volumes contradicts an earlier statement (Page 2, Lines 6 and 7) that states that "Both grout jobs were successful, with the actual volumes 6 used slightly exceeding the calculated theoretical volumes."

There are no grout calculations provided in the Memo to demonstrate that the injected grout volumes are consistent with or slightly exceeded calculated theoretical volumes. The BWS obtained the injected volumes from the boring log of RHMW11 and we calculated grout volumes using rudimentary assumptions. Our analysis indicates that the 550 gallons of grout injected at a depth of 165 feet is appreciably more than what theoretical calculations indicate is needed to fill the annulus with grout. To substantiate the claims of consistency between the injected grout volumes and the theoretical volumes, the report needs to include grout calculations along with justification of assumptions.

Among the assumptions that are important to calculating the amount of grout to successfully fill the annulus is how intervals of no core recovery affect the grouting process. An interval of no recovery could potentially represent a large void in the weathered or unweathered basalt where grout enters the basalt though a lava tube or a clinker zone. From a depth of 65 feet to 110 feet below ground surface (bgs) at RHMW11 there are six recorded no recovery intervals on the RHMW11 boring log. From a depth of 110 feet bgs to 165 feet bgs, there are ten recorded no recovery intervals. Many of these no recovery intervals are approximately 2 feet in total length, indicating substantial fractures or other void spaces. Among our concerns is that near the "no recovery" intervals in RHMW11, substantial grout was lost into large voids in the subsurface and an effective seal is not achieved between the well casing and the basalt. If this is the case, then the injected volumes may be substantially greater than the calculated theoretical volumes in order to effectively seal the annulus.

A common practice for checking whether an annulus has been properly grouted is to initiate a cement-bond log down a well casing. Cement-bond logs provide information on whether or not there is grout or voids against the outer diameter of the well casing. A cement-bond log is a regulatory requirement for wells in Texas that are required to be cased through useable groundwater. Given the large number of no-recovery zones in the log and the desire to seal and prevent hydraulic communication along the outside of well casing, a cement-bond log should be performed to demonstrate a successful grout of the annulus resulting in an effective seal. Without this information, how effective the steel casing in place at RHMW11 will always be in question.

2. Manufacturer's Packer Certification (Page 4, Lines 4 - 18)

We do not agree that a manufacturer certification is a line of evidence for having achieved a successful seal in the borehole. Such certification attests that the packer will inflate and should provide a seal but is not necessarily proof that a seal actually exists in the RHMW11 borehole. It would be appropriate if the packers were designed and tested to operate in boreholes that penetrate Hawaiian basalts like the Ko'olau Basalt. The Navy should clarify if Westbay has provided written assurances or recommendations for using their packers to isolate sampling zones in geological settings similar to the Ko'olau Basalt.

3. Packer Inflation Records (Page 4, Lines 19 - 37)

The Memo states that the packer inflation records indicate that all Westbay packers inflated normally and are providing effective annular seals between the monitoring zones (Page 4, Lines 36 and 37). The Memo notes that inflation plot for Packer No. 15 (Sheet 16, Attachment F) did not display a normal inflation pattern that includes a characteristic spike at the end (Page 4, Lines 30 through 35). This atypical response was attributed to an enlarged borehole diameter. Based on this information, the report statement "all of the Westbay packers inflated normally and are providing effective annual seals between the monitoring zones" is incorrect and contrary to the available information.

In order to support the statement of providing effective seals, additional information regarding the packing inflation and the caliper log should be discussed. The additional discussion should explain how that the abnormal inflation pattern at Packer No. 15 actually achieved a seal. Such a discussion should also cover the inflation plots for Packer No. 12 (Sheet 13, Attachment F); Packer No. 13 (Sheet 14, Attachment F); and, Packer No. 14 (Sheet 15, Attachment F). These Westbay packers show very similar inflation plots as Packer No. 15, but are not mentioned in this section of the memo and contradict the statement that "all" packers are providing effective seals.

4. Water Level Elevations Profiles Measured in Different Zones

On Page 5, Line 13, Table 2 outlines which water level elevations are reported for the Navy-identified 10 zones of RHMW11 (Zones 1, 2, 3, 4, 5, 6, 7, 8A, 8B, and 8C) during five separate measurement events (conducted in late November and late December 2017). On Memo Page 4, Lines 43 and 44, it is stated that the head differences between the zones (Table 2) supports the fact that the zones "are vertically isolated from one another". Head differences in Table 2 appear to suggest that there may in fact be only **5** separate "Zones" at RHMW11:

1. Zones 8C, 8B, 8A
2. Zone 7
3. Zone 6
4. Zones 5,4,3, & 2
5. Zone 1

The BWS needs more information to be able to evaluate if indeed there are 10 distinct "Zones" at RHMW11. The Memo provides almost no interpretation of why these "Zones" were considered isolated relative to head differences.

The Memo states on Page 4, Line 44 that in the upper three zones, water levels are still stabilizing due to the extremely low hydraulic conductivity of the saprolite that they are completed in. We agree that one explanation for the slow response is a low conductivity of material open to the sampling interval. But, it may not be the only reason. A contributory factor to the long equilibration times could be leakage between packers and perched water draining through a leaky grout seal. To confirm the Memo's conclusion, calculations should be presented to show that the pressure-time response observed in the three upper zones can be explained based on theoretical calculated responses for a low permeability material. A starting point for this analysis is to perform the analysis using the range of hydraulic conductivity of 2.87E-09 centimeters per second (cm/s) to 3.00E-8 cm/s reported for the saprolite.

5. Temperature Profiles Measured in the Different Zones

The Memo states on Line 7, Page 5, "Monitoring of temperature in the zones at 30-minute intervals since December 2017 shows stable temperatures in each zone (Figure 3); each zone temperature are different from those of other zones. This provides additional evidence of isolation between zones."

BWS review of Figure 3 does not support the above statements. The upper Zone 6 and Zone 8 have essentially the same temperature measurements, which are consistently lower than those for Zone 7. Also, the meaning of the word "stable" is unclear. Our review of the temperature for Zone 4 indicates that over the entire period of record, the temperate is primarily decreasing and that stable temperatures have only been approximated during the last few weeks of the measurement record. This trend is also present but less apparent for Zone 5. Based on these observations, data from Zones 8A, 8B, 8C, 6, 5, and 4 is contrary to the above statements. Moreover, some of these observations from these zones are consistent with the impacts associated with leaky Westbay packers.

6. Pneumatic Testing of Multiple Zones within the Well (Page 5, Lines 16 – 33; Page 6, Lines 1 – 46, and Page 7, Lines 1 – 25)

This pneumatic testing discussion is insufficient to support the conclusion that the Westbay zones are isolated and that no leakage is occurring around the packer seals. The section is basically a data dump of pressure plots with little analysis and is presented with too little information to perform an independent analysis of the testing. To effectively demonstrate that the packers are working properly, the Memo needs to include an analysis for the theoretical response at the transducers for the case of a leaky packer AND a properly sealed packer. Because of the combination of the high hydraulic conductivity basalt and the small volumes of water used for testing, the BWS is concerned that there is effectively no substantial difference in the responses for the case of a perfectly sealed packer and a leaky packer. For the large number of graphs (Figures 6 through 25) to be useful to supporting the conclusion that all

Westbay packers are working properly, the section needs to explain and demonstrate that the testing methodology used has been properly designed to identify if a packer is indeed leaking or not.

In the CWRM's solicitation memo, CWRM indicated concerns with two issues: 1) protection of the aquifer from well construction contamination; and, 2) how the Westbay system allows data to be collected and incorporated into the larger ground water monitoring network. CWRM believes that the grouting of the annular spaces around the conductor casing and internal 5-inch casing are sufficient to satisfy their first concern.

Based on our review, we found insufficient data to assure BWS that the aquifer is protected from well construction contamination because we question whether a sufficient amount of grout has been added to seal the annual spaces between the formation and the conductor casing. Incorporating the ground water data collected from the Westbay well into the database for the larger ground water monitoring network may be suspect because the zones identified by the Navy may not be isolated as the Navy Memo indicates.

Thank you for the opportunity to comment. If you have any questions, please feel free to call Erwin Kawata at 808-748-5080.

Very truly yours,

ERNEST Y. W. LAU, P.E.
Manager and Chief Engineer

cc. Mr. Ryan Imata, P.E.
Hawaii Department of Land and Natural Resources

References

Commission on Water Resources Management (CWRM). 2018. Red Hill Monitor Well 11 (State Well No. 3-2253-011). Solicitation Letter to Mr. Ernest Y.W. Lau, P.E. from Mr. Jeffrey T. Pearson, P.E. March 27.

Department of the Navy (Navy). 2018. Technical Memorandum: Testing and Verification of Packer Integrity at RHMW11, Red Hill Bulk Fuel Storage Facility (RHBFSF) Joint Base Pearl Harbor-Hickam, Oahu, Hawaii. February 9.

Enclosure

Attachment A Navy Technical Memorandum: Testing and Verification of Packer Integrity at RHMW11.

Technical Memorandum

Testing and Verification of Packer Integrity at RHMW11

Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O‘ahu, Hawai‘i

Naval Facilities Engineering Command, Hawaii, JBPHH HI
February 9, 2018

Introduction

This Technical Memorandum presents the results of testing and verification of packer integrity at monitoring well RHMW11 for the Investigation and Remediation of Releases and Groundwater Protection and Evaluation project at the Red Hill Bulk Fuel Storage Facility (“Facility”), Joint Base Pearl Harbor-Hickam (JBPHH), O‘ahu, Hawai‘i. RHMW11 was constructed in November 2017 using the multi-level Westbay System in an open borehole.

Purpose

This memorandum presents multiple lines of evidence that demonstrate that discrete zones (e.g., sample intervals) within the RHMW11 borehole are successfully isolated from one another. The Westbay System was installed so that measurements of formation fluid pressure, temperature, hydraulic conductivity, and groundwater chemistry can be obtained from discrete zones at different depths to establish a vertical profile and evaluate the potential for a hydraulic barrier or for preferential pathways to exist. The Westbay System allows flexibility in the construction of each discrete zone (e.g., length, depth), so that all available information obtained during drilling can be used to identify target intervals. The Westbay System has been used on many sites in numerous geologic settings for environmental investigations including investigations under the oversight of the United States Environmental Protection Agency for characterizing a wide variety of contaminants including volatile organic compounds and fuel-related constituents (Attachment A). Isolation of discrete zones was accomplished using the Westbay System following a multi-step process. First, specific well completion depth intervals were identified based on detailed borehole geologic and geophysical logs that would provide head measurements and water samples to meet the project objectives. For each target depth interval, specific packer seat depths of competent, non-fractured unweathered and saprolitic rock were selected. After assembling the well casing and packers and lowering the assembly to isolate the selected completion intervals, the packers were inflated to tightly seat on the borehole wall. The effectiveness of the packer seals in isolating the well completion intervals was then verified using several techniques, including:

- Evaluation of the grouted 10-inch and 5-inch blank casing
- Manufacturer’s Certification of packers
- Field packer inflation records
- Vertical pressure profiles within the well
- Pneumatic testing of multiple zones within the well

RHMW11 Construction

Monitoring well RHMW11 was drilled and constructed during September 25 to November 21, 2017. It is located in South Hālawa Valley, north of the Red Hill Bulk Fuel Storage Facility (Figure 1). RHMW11 is a Westbay well that allows monitoring of multiple-depth discrete zones, and is described further in Overview of Westbay System Installed in RHMW11, below. Drilling activities included air knifing to a depth of 22.8 feet (ft) below ground surface (bgs), hollow-stem auger drilling with a California split-spoon sampler to a depth of 50 ft bgs, and continuous coring from 50 ft bgs to 75 ft bgs. A 10-inch schedule 40 (SCH40) steel casing was grouted into the approximately 15.5-inch-diameter borehole using a cement-bentonite mix to a total depth of 75 ft bgs. Following completion of grouting activities, an approximately 9.375-inch borehole was cored to a total depth of 165 ft bgs, and a 5-inch SCH40 steel casing was installed within the 10-inch steel casing and sealed within the borehole and upper casing using a cement-bentonite mix with a grout basket connected to the bottom of the 5-inch-diameter casing. Both grout jobs were successful, with the actual volumes used slightly exceeding the calculated theoretical volumes. Following completion of construction of the 5-inch inner casing, coring resumed to a total depth of approximately 492 ft bgs. Coring was completed using a PQ core barrel with an outside diameter of 4.95 inches. The contact between alluvium and saprolite was observed at 68.5 ft bgs. The contact between saprolite and the regional basalt aquifer (unweathered) was observed in the core at approximately 279 ft bgs. The depth to water in the fully open borehole stabilized at approximately 192 ft bgs prior to installation of the Westbay System. Geophysical logging was completed in the interval from 165 to 492 ft bgs. Geophysical logging included the following suite of tools: Caliper, Optical Televiewer, Acoustic Televiewer, Electric Log (long-normal, short-normal, and guard), fluid temperature and conductivity, natural gamma, and spontaneous potential. Following completion of geophysical logging, the Westbay System was designed and installed within the open borehole, as described below.

Overview of Westbay System Installed in RHMW11

The Westbay System is composed of a casing string with external packers installed at user-selected positions to create annular seals in the borehole, thus creating multiples zones with the borehole. In some cases, multiple redundant packers are placed between zones. Specialized ports are installed in the casing between the packers to provide hydraulic access to conduct routine monitoring activities such as measurement of formation fluid pressure, collection of fluid samples, and performance of hydraulic tests. The Westbay System is described in a brochure provided by the manufacturer (Attachment B). A detailed technical description of the use and versatility for monitoring depth discrete zones within a single open borehole or well with multiple screen intervals is described in a Westbay technical paper (Attachment C). Utilization of a Westbay System with the capability to monitor multiple depth intervals can lead to investigation cost savings. This is described in further detail in a journal article that describes investigation of an environmentally impacted site in Southern California (Melchior and Cutler 1993). Finally, use of the Westbay System in a basalt geologic environment as well as fractured rock environments is described in a Scientific Investigations Report published by the United States Geological Survey (Bartholomay, Hopkins, and Maimer 2015) and in scientific journals (Sterling et al. 2005; Fitzgerald 1988).

Eight discrete zones were selected for the Westbay System in RHMW11. These zones were selected based on observed lithology, geophysical logging, and regional aquifer features including the depth of the expected basal aquifer water table. The RHMW11 boring log and results of geophysical logging are provided in Attachment D. The caliper log was useful for selection of suitable zones for locating intervals suitable for Westbay System Packers. The optical and acoustic televiewer logs provided confirmation of features observed in continuous core, including clinker zones and lava tubes. The temperature and fluid conductivity logs were useful for understanding the depth of the transition from fresh water to brackish water. The system was constructed from the bottom up and includes the following zones:

- Zones 1, 2, 3, and 5 are the deeper zones located within basalt that is part of the regional basal aquifer and target key features (e.g., clinker, fracture, lava tube) that could serve as preferential pathways within the basalt.
- Zone 4 was established to evaluate groundwater chemistry at the freshwater/brackish water interface.

- Zone 6 was established in the lower portion of the saprolite to evaluate whether it acts as a hydraulic barrier.
- Zone 7 was established to monitor a relict clinker zone in the saprolite to see if such relict features potentially have higher permeability relative to the surrounding saprolite.
- Zone 8 was established at the estimated depth of the regional basal aquifer water table at the time of drilling with an open borehole extending from the low-permeability saprolite and into basalt.

Details regarding each discrete zone and the rationale for selecting each zone are summarized in Table 1.

Each zone is equipped with a pumping port as well as a sampling port. Three sampling ports were installed in the uppermost zone to allow sampling close to the water table, as well as above the water table (e.g., soil gas). A summary of the sampling and pumping ports for each zone is presented in Table 1. Packer depth intervals were selected to allow isolation of zones of interest, and were installed in the competent sections of the borehole to ensure isolation of the zones within the borehole. A schematic of the Westbay System constructed within the RHMW11 borehole shows the location of all sample ports, pumping ports, and packer intervals (Figure 2).

Table 1: Summary of Sampling and Pumping Ports for RHMW11

Sampling Zone	Zone ID	Sample Port Depth (ft bgs)	Pumping Port Depth (ft bgs)	Rationale
159.30–204.5	Zone 8C	169.30	N/A	Unsaturated clinker zone above piezometric surface
	Zone 8B	189.30	194.30	Zone near current piezometric surface
	Zone 8A	200.50	204.50	Zone near current piezometric surface
209.80–239.8	Zone 7	234.80	239.80	Clinker zone in saprolite
245.00–255.50	Zone 6	250.00	255.00	Saprolite
277.30–290.30	Zone 5	285.30	290.30	Lava tube
330.50–342.8	Zone 4	330.50	335.50	Fresh to brackish water boundary based on geophysical logging
347.80–367.00	Zone 3	357.80	362.80	Intensely fractured zone in pāhoehoe
394.00–420.30	Zone 2	396.00	401.00	Clinker zones
450.30–469.50	Zone 1	459.30	464.30	Clinker zones

N/A not applicable

Independent Lines of Evidence for Proper Seals Between Zones

Multiple lines of evidence indicate that the eight discrete sampling zones in RHMW11 are isolated from one another. Each of these lines of evidence is discussed below.

GROUTED 10-INCH- AND 5-INCH-DIAMETER CASING STRINGS

As previously described, a 10-inch casing was installed to a total depth of 75 ft bgs to isolate the valley fill alluvium from the underlying saprolite. This casing was grouted into place using a cement-bentonite mix. A second casing was subsequently installed within the 10-inch casing to a total depth of 165 ft bgs. This casing was also grouted into place using a cement-bentonite mixture. Grout volumes during installation of both casings were consistent with calculated theoretical volumes. No grout was seen in the open borehole below the bottom of the 5-inch inner casing on either video or optical televiewer logs. This suggests that the cement basket at the bottom of the 5-inch casing allowed successful completion of the grout job.

CONCLUSION: All evidence suggests that the cement-bentonite grout outside of the 10-inch casing and outside of the 5-inch inner casing successfully isolated deeper zones from water from shallower zones within the borehole.

MANUFACTURER'S PACKER CERTIFICATION

All Westbay packers are tested by Westbay and are certified for use as part of the Westbay System. Each packer is assigned a unique serial number for traceability of manufacturing test results. The serial number of each packer and its position in the Westbay System completion are recorded on the Westbay Installation Log. At the time of installation, each packer is inspected in the field by an onsite Westbay technician. Each packer installed in RHMW11 as part of the Westbay System was approved for use by the Westbay technician. In addition, Westbay provided a letter for the RHMW11 packers, which is a summary of packer certifications (Attachment E). This summary of packer certification lists the unique RHMW11 packer number, which piece of the Westbay System casing it is located on, the serial number for the specific packer, and the results of Westbay testing of that specific packer during assembly of the packer (e.g., connecting the packer "gland" to the Westbay System casing. The traceability number provides a cross-reference to the gland manufacturer's lot number and gland manufacturing date.

CONCLUSION: All packers installed in RHMW11 met both the manufacturer's and Westbay's certification requirements.

PACKER INFLATION RECORDS

As the Westbay System is constructed, packers are permanently inflated with water supplied by a surface-based inflation apparatus. Packers are inflated individually beginning with the lowermost. The applied inflation pressure and the injected volume are measured with each incremental addition of water during inflation and recorded and plotted for each packer on a Packer Inflation Data Sheet. The measurement of inflation pressure is documentation of contact of the packer element with the borehole wall. The plot of pressure vs. volume has a characteristic shape that is related to inflation pressure and borehole diameter. Borehole diameter is variable, so the actual amount of water used to inflate each packer is variable. However, at smaller borehole diameters, a characteristic pressure 'spike' is seen at the end of the inflation, indicating that inflation is complete. Such a spike may not be observed in sections of the borehole with a slightly enlarged diameter.

A total of 18 packers were inflated in RHMW11, and all inflated normally. Of the 18, only one packer (#15) did not show the previously described pressure increase (spike) at the end of inflation, thus confirming caliper log data indicating a section of slightly enlarged borehole diameter. This does not indicate an incomplete seal. Furthermore, packer #15 is one of two packers (#14 and #15) that isolate the uppermost sample zone in RHMW11 (Zone 8) from the next vertical zone (Zone 7). Packer inflation records for RHMW11 are provided in Attachment F.

CONCLUSION: The Packer Inflation Records indicate that all of the Westbay packers inflated normally and are providing effective annular seals between the monitoring zones.

VERTICAL PRESSURE AND TEMPERATURE PROFILES

Vertical pressure profiles (spot measurements of formation fluid pressure) were measured in RHMW11 on several different days. In general, the bottom five zones in the well, which are completed in the generally unweathered regional basalt aquifer, are equilibrated from pre-installation hydraulic disturbance. A downward vertical gradient has been observed in multiple pressure profiles (Table 2). This is consistent with the conceptual site model. Head differences between the zones support the fact that they are vertically isolated from one another. In the upper three zones, water levels are still stabilizing due to the extremely low hydraulic conductivity of the saprolite that they are completed in. Hydraulic conductivity was measured in the laboratory for three samples collected from the RHMW11 borehole using ASTM Method D5084-10. These samples were collected from the following depth intervals: 162.6–163.6, 174.3–175.0, and 189.5–190.0 ft bgs. The laboratory-reported range of hydraulic conductivity for these three samples of 2.87E-09 to 3.00E-08 centimeters per second (cm/sec). Even though these water levels in the upper three zones do not represent steady-state conditions, consistent head differences between each of them demonstrate that they are isolated from one another. Monitoring of temperature in the zones at 30-minute intervals since December 2017 shows stable temperatures in each zone; each zone’s temperatures are different from those of the other zones (Figure 3). This provides additional evidence of isolation between zones.

CONCLUSION: The pressure profile data and calculated formation heads along with long-term temperature differences between zones indicate that effective annular seals are present between each of the monitoring zones.

Table 2: Water Level Elevations During Pressure Profiling

Zone	Port Depth (ft bgs)	Water Level Elevation (ft msl)				
		11/20/2017	11/21/2017	11/27/2017	12/6/2017	12/29/2017
Zone 8C	169.24	42.39	67.84	85.61	NM	NM
Zone 8B	189.23	31.68	67.67	85.60	NM	NM
Zone 8A	200.42	21.26	67.48	85.61	90.93	98.92
Zone 7	234.69	19.99	41.89	57.58	61.00	76.73
Zone 6	249.88	20.03	40.79	55.90	59.81	75.40
Zone 5	285.15	19.89	20.26	20.26	19.96	20.10
Zone 4	330.31	19.78	20.13	20.13	19.89	20.03
Zone 3	357.60	19.61	19.98	19.95	19.72	19.86
Zone 2	395.77	19.46	19.90	19.85	19.85	19.99
Zone 1	459.03	19.10	19.59	19.59	19.43	19.61

Note: Uses an approximate MP elevation of 211.28.
NM not measured

PNEUMATIC TESTING

Pneumatic testing was completed in Zones 2, 4, 6, 7, and 8 to further demonstrate isolation between zones within the well. It was not necessary to test every zone in the well, as pressure monitoring was conducted in all zones during all pneumatic testing. To complete pneumatic testing, the pumping port in the zone of interest is opened, and water from the zone is allowed to enter the Westbay Center Tube. Once pressure in the Westbay Center Tube is equilibrated with the formation in the zone of interest, water is displaced from the tube into the formation by applying nitrogen gas pressure. This effectively pushes the water level in the Westbay Center Tube down, and the water that was in the tube is forced into the formation. When this happens, formation pressure increases and dissipates at a rate that is a function of the hydraulic conductivity of the zone. The pressure created by depressing the water level in the Westbay Center Tube dissipates very quickly in zones with high hydraulic conductivity (Zones 1–5), and slowly in zones with low hydraulic conductivity (Zones 6–8). Once pressure in the Westbay Center Tube is equilibrated with the formation pressure (e.g., the pressure increase in the formation has dissipated), the Westbay Center Tube is quickly vented. The Westbay Center Tube is vented by opening a valve at the surface that allows the nitrogen to be released to the atmosphere. This rapid venting is analogous to removing a slug of water from the zone, and results in a pressure drop within the formation. The magnitude of the drop and the period of time required for water levels in the zone to re-equilibrate are related to the hydraulic conductivity of the formation properties of the zone being monitored. No response in adjacent zones to pressure changes in the zone of interest confirms that they are isolated from one another.

Both Zones 2 and 4 are completed in the regional basalt aquifer, with very high hydraulic conductivity. Zones 6, 7, and 8 are all within the saprolite, which has an extremely low hydraulic conductivity. Testing in Zones 2 and 4 demonstrates effective isolation between Zones 1 through 5. In addition, a "compliance effect" is observed in Zones 6, 7, and 8 during all testing, including testing of the second-deepest zone (Zone 2). This compliance effect is a common occurrence in low-permeability materials and is due to the fact that all of the packers are non-rigid, flexing very slightly in response to pressurization and depressurization of a different zone. This effect is highlighted in Zones 6, 7, 8, as the pressure applied by the flexing of the packers cannot readily dissipate into the surrounding formation. A schematic that shows the process of pneumatic testing in any zone is provided on Figure 4.

CONCLUSION: The results of pneumatic testing document that effective annular seals are present between each of the monitoring zones.

ZONE 2 PNEUMATIC TESTING

Pneumatic Testing in Zone 2 included pressurization and venting of the zone at approximately 10, 20, and 40 pounds per square inch (psi). The second test, which was intended to be at 20 psi, was aborted because of failure of a seal at the wellhead. This failure was addressed in the field, and testing resumed. The response to pressurization and depressurization of the Westbay Center Tube and Zone 2 is shown on Figure 5. Response to pneumatic testing in Zone 2 and in adjacent Zones 1 and 3 is shown on Figure 6. No response was observed in Zones 1 or 3 associated with testing in Zone 2. A compliance effect is noted in Zones 6, 7, and 8 to testing in Zone 2, the second-deepest zone. Compliance effects in Zones 6, 7, and 8 were observed during every pneumatic test of every tested zone. Pneumatic testing in Zone 2 demonstrates that this zone is effectively isolated from Zones 1 and 3.

ZONE 4 PNEUMATIC TESTING

Pneumatic Testing in Zone 4 included pressurization and venting of the zone at approximately 10, 20, and 40 psi. The pumping port in Zone 4 was opened, and four pressure tests were completed (twice at approximately 40 psi). As was the case during testing in Zone 2, compliance effects were observed in the low-hydraulic-conductivity Zones (6, 7, and 8). Response to pressurization and depressurization of the Westbay Center Tube and Zone 4 is shown on Figure 7. Response to pneumatic testing in Zone 4 and in adjacent Zones 3 and 5 is shown on Figure 8. Pneumatic testing in Zone 4 demonstrates that this zone is effectively isolated from Zones 3 and 5.

ZONE 6 PNEUMATIC TESTING

Pneumatic Testing in Zone 6 included pressurization and venting of the zone at approximately 5 psi (two tests) and 10 psi. Only three tests were performed in this zone over the course of two field days because equalization of the pressure in the zone after pressurization of the Westbay Center Tube took several hours. This is related to the low hydraulic conductivity of the materials isolated within the zone. The response to pressurization and depressurization of the Westbay Center Tube and Zone 6 is shown for two separate tests on Figure 9 and Figure 13. Corresponding response to pneumatic testing in Zone 6 and in adjacent Zone 5 is shown on Figure 10 and Figure 14. Corresponding response to pneumatic testing in Zone 6 in adjacent Zone 7 is shown on Figure 11 and Figure 15. Testing in Zone 6 resulted in compliance effects in both Zone 7 (Figure 11 and Figure 15) and Zone 8 (Figure 12 and Figure 16). Because the hydraulic conductivities of Zones 6 and 7 are very low, the compliance effects are most pronounced in those two zones. The hydraulic conductivity of Zone 8 appears to be slightly higher than Zones 6 and 7, and the compliance effect is muted; pressure dissipates from this zone more quickly than the other zones completed in the saprolite. Despite a very large compliance effect seen in Zone 7, the magnitude of the effect is less than the magnitude of the change in Zone 6 associated with testing in Zone 6. This confirms that the zones are isolated from one another. No response to testing of Zone 6 was observed in Zone 5, confirming that Zone 6 is successfully isolated from Zones 5 and 7.

ZONE 7 PNEUMATIC TESTING

Pneumatic Testing in Zone 7 consisted of two tests over two days. Zone 7 was tested at approximately 5 psi and 10 psi. Data from execution of the 5 psi test are incomplete due to an incomplete data set, so figures related to testing of the zone at approximately 10 psi are provided. The response to pressurization and depressurization of the Westbay Center Tube and Zone 7 is shown on Figure 17. The compliance effects described previously were observed in Zones 6 and 8 associated with testing in Zone 7 (Figure 18 and Figure 19). The hydraulic conductivity in Zone 7 appears to be the lowest of all the zones. The magnitude of the response in the adjacent zones due to the compliance effect varies, indicating that Zone 7 is successfully isolated from Zones 6 and 8.

ZONE 8 PNEUMATIC TESTING

Pneumatic Testing in Zone 8 consisted of two tests over two days. Pneumatic Testing of Zones 6 and 7 demonstrated isolation of Zone 8 from those zones. Testing in Zone 8 was completed for confirmation purposes, to demonstrate compliance effects in other zones, and to gather data for evaluation of hydraulic conductivity. Zone 8 was tested at approximately 10 psi and 15 psi. The response to pressurization and depressurization of the Westbay Center Tube and Zone 8 is shown for two separate tests on Figure 20 and Figure 23. Corresponding response and compliance effects to pneumatic testing in Zone 8 and in Zone 6 are shown on Figure 21 and Figure 24. Corresponding response and compliance effects to pneumatic testing in Zone 8 in adjacent Zone 7 are shown on Figure 22 and Figure 25. The magnitude of the response in Zones 6 and 7 varies, indicating that Zone 8 is isolated from all other zones.

Summary

Multiple lines of evidence have been evaluated to assess isolation between zones. A summary of the lines of evidence is presented in Table 3. All lines of evidence, which complement each other, indicate that effective annular seals are present between each of the eight zones in RHMW11.

Table 3: Lines of Evidence Summary

Zone Identifier	Seal Number	Manufacturer's Certification	Packer Inflation Records	Pressure Profile	Pneumatic Testing	Annular Seal Present?
Zone 8	7-8	+	+	+	+	Yes
Zone 7	6-7	+	+	+	+	Yes
Zone 6	5-6	+	+	+	+	Yes
Zone 5	4-5	+	+	+	+	Yes
Zone 4	3-4	+	+	+	+	Yes
Zone 3	2-3	+	+	+	+	Yes
Zone 2	1-2	+	+	+	+	Yes

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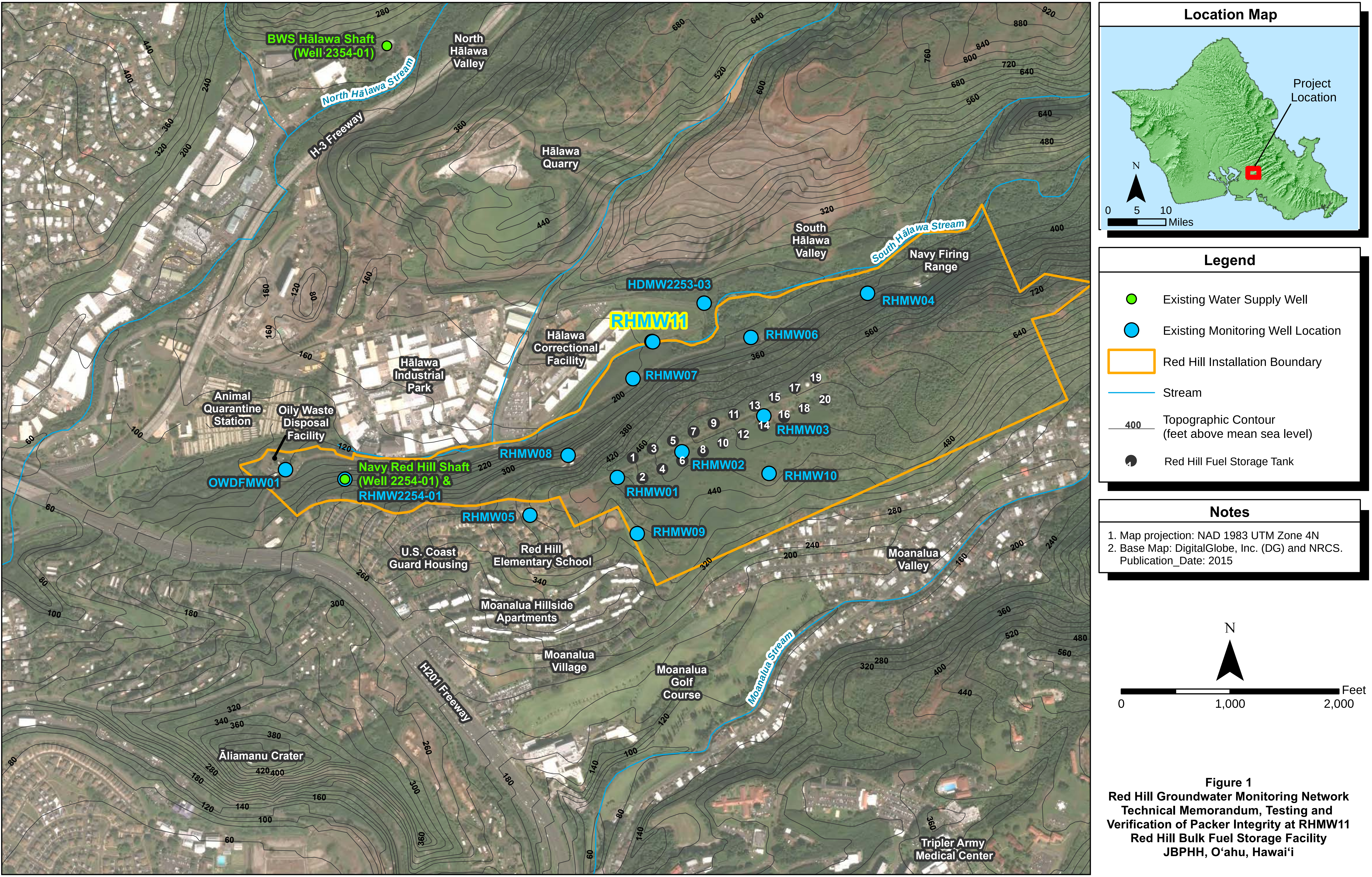
Melchior, D., and M. Cutler. 1993. “Deep Down Cost Reductions.” *Water Environment & Technology* 5(10) (October).

Sterling, S. N., B. L. Parker, J. A. Cherry, J. H. Williams, J. W. Lane Jr., and F. P. Haeni. 2005. “Vertical Cross Contamination of Trichloroethylene in a Borehole in Fractured Sandstone Authors.” *Groundwater* 43(4): 557–573.

Attachment A	Westbay Environmental Projects for U.S. Environmental Protection Agency
Attachment B	Westbay System Brochure
Attachment C	Westbay System Technical Paper
Attachment D	RHMW11 Boring Log and Geophysical Record of Borehole
Attachment E	Westbay System Summary of Model 0235 Packer Certification
Attachment F	Packer Inflation Records



Notes

1. Map projection: NAD 1983 UTM Zone 4N
2. Base Map: DigitalGlobe, Inc. (DG) and NRCS. Publication_Date: 2015

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Figure 1
Red Hill Groundwater Monitoring Network
Technical Memorandum, Testing and Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility
JBPHH, O‘ahu, Hawai‘i

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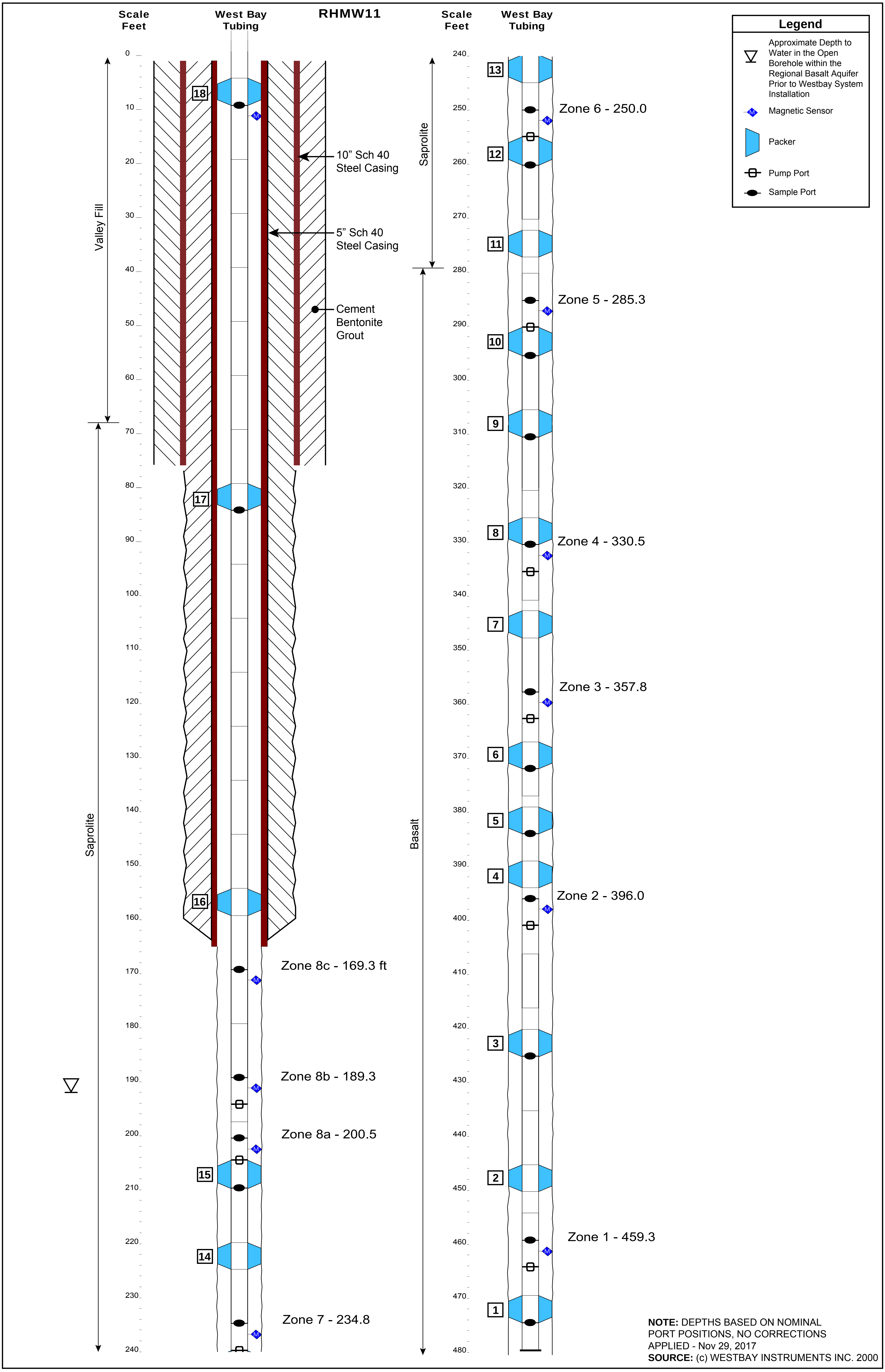

NOTE: DEPTHS BASED ON NOMINAL PORT POSITIONS, NO CORRECTIONS APPLIED - Nov 29, 2017
SOURCE: (c) WESTBAY INSTRUMENTS INC. 2000

Figure 2
RHMW11 - Summary Completion Log
Technical Memorandum, Testing and Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility
JBPHH, O'ahu, Hawai'i

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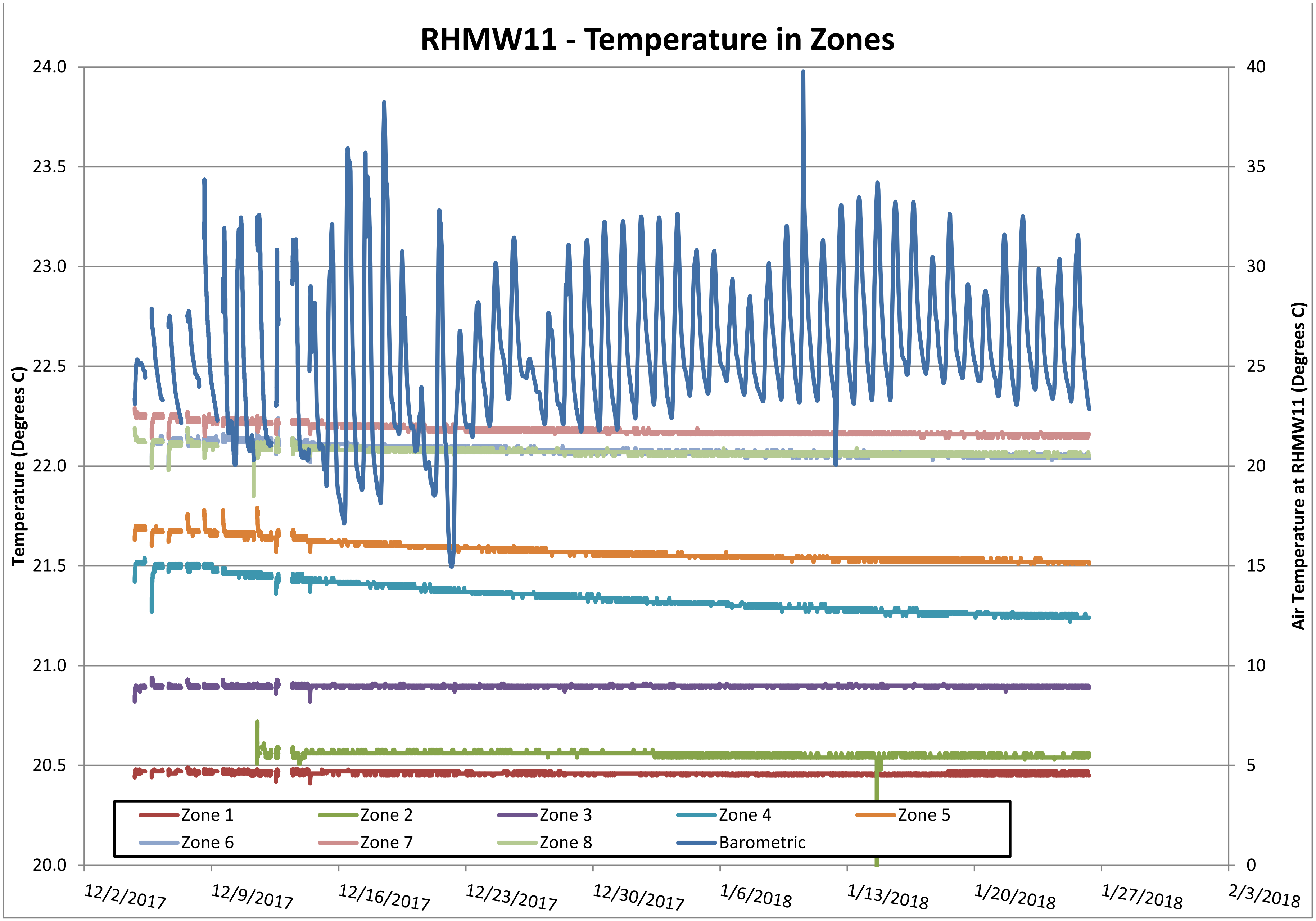

Figure 3
RHMW11 - Temperature in Zones
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

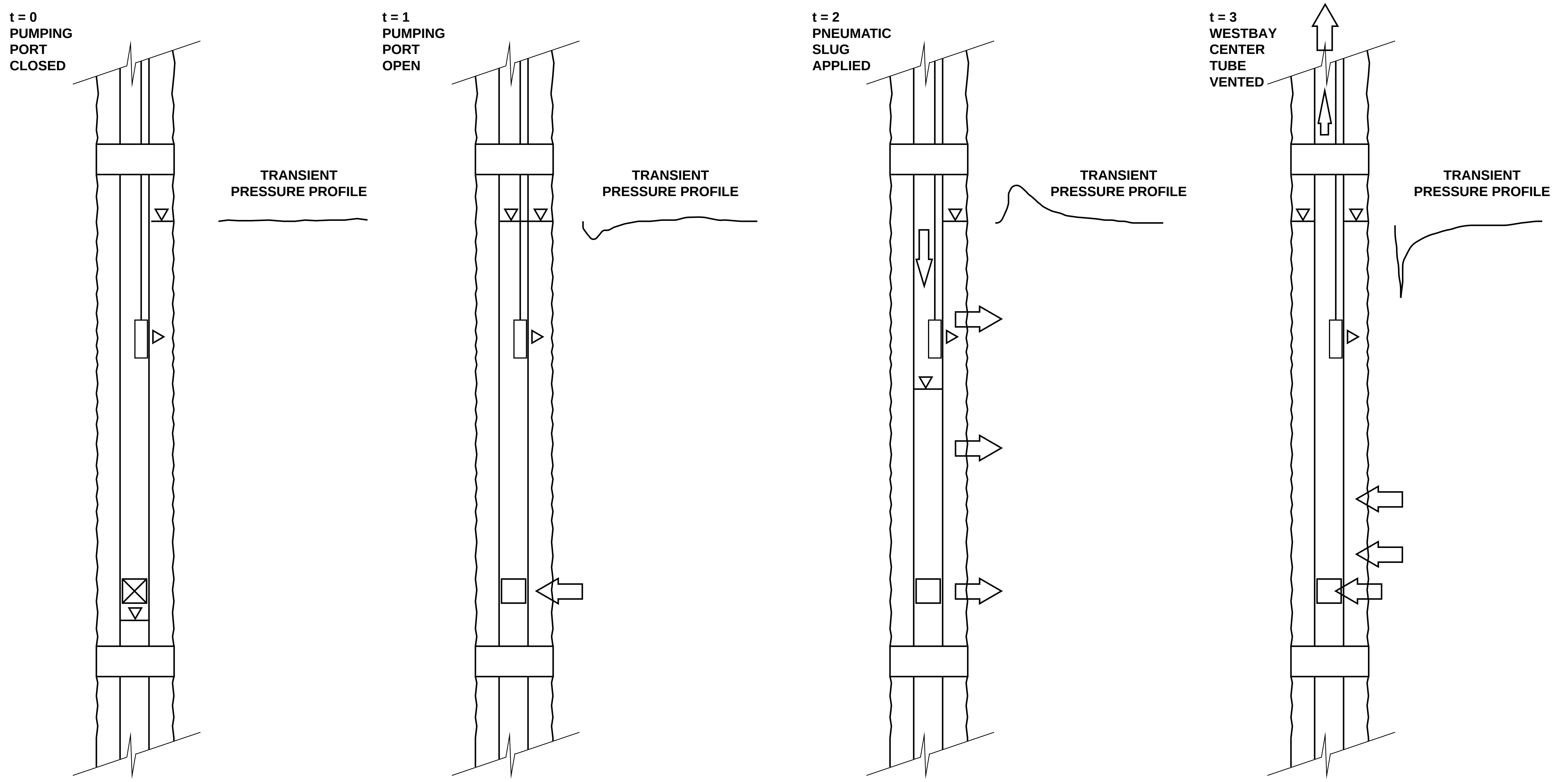

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Figure 4
RHMW11 - Pneumatic Testing Schematic
Red Hill Bulk Fuel Storage Facility
JBPHH, O’ahu, Hawaii

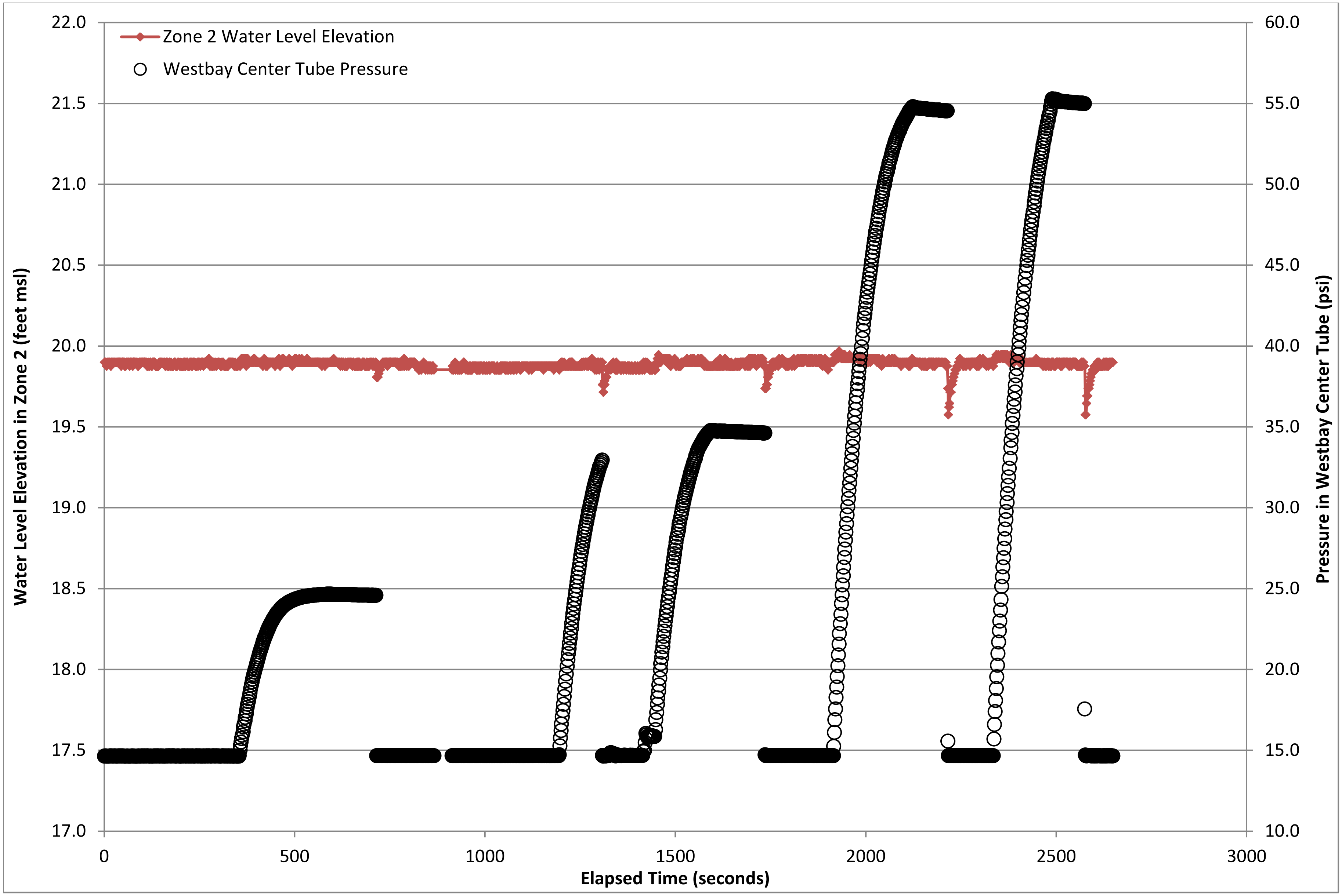

Figure 5
Water Level Response in Zone 2 During Pneumatic Testing
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

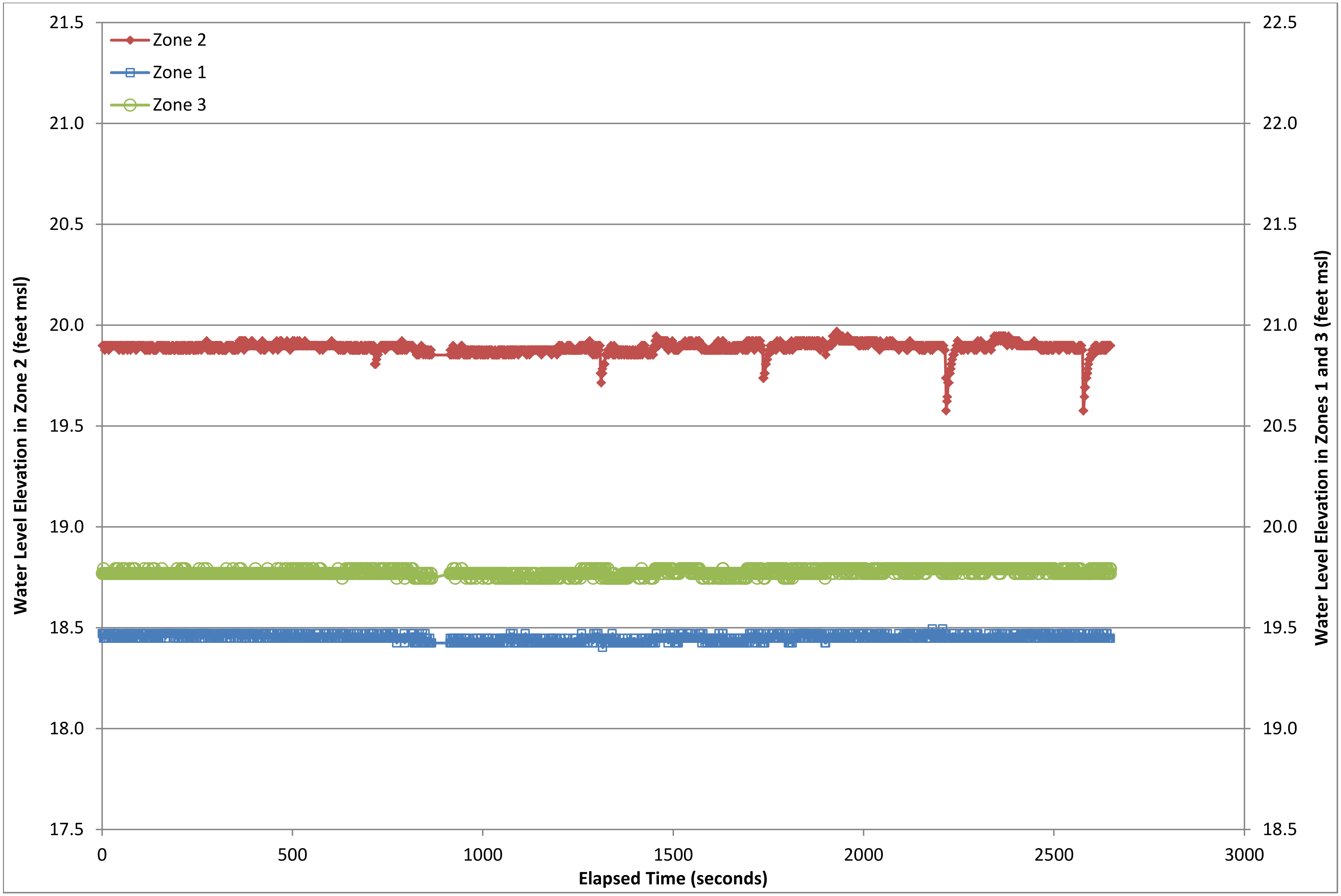

Figure 6
Water Level Response in Zones 1, 2, and 3 to Pneumatic Testing in Zone 2
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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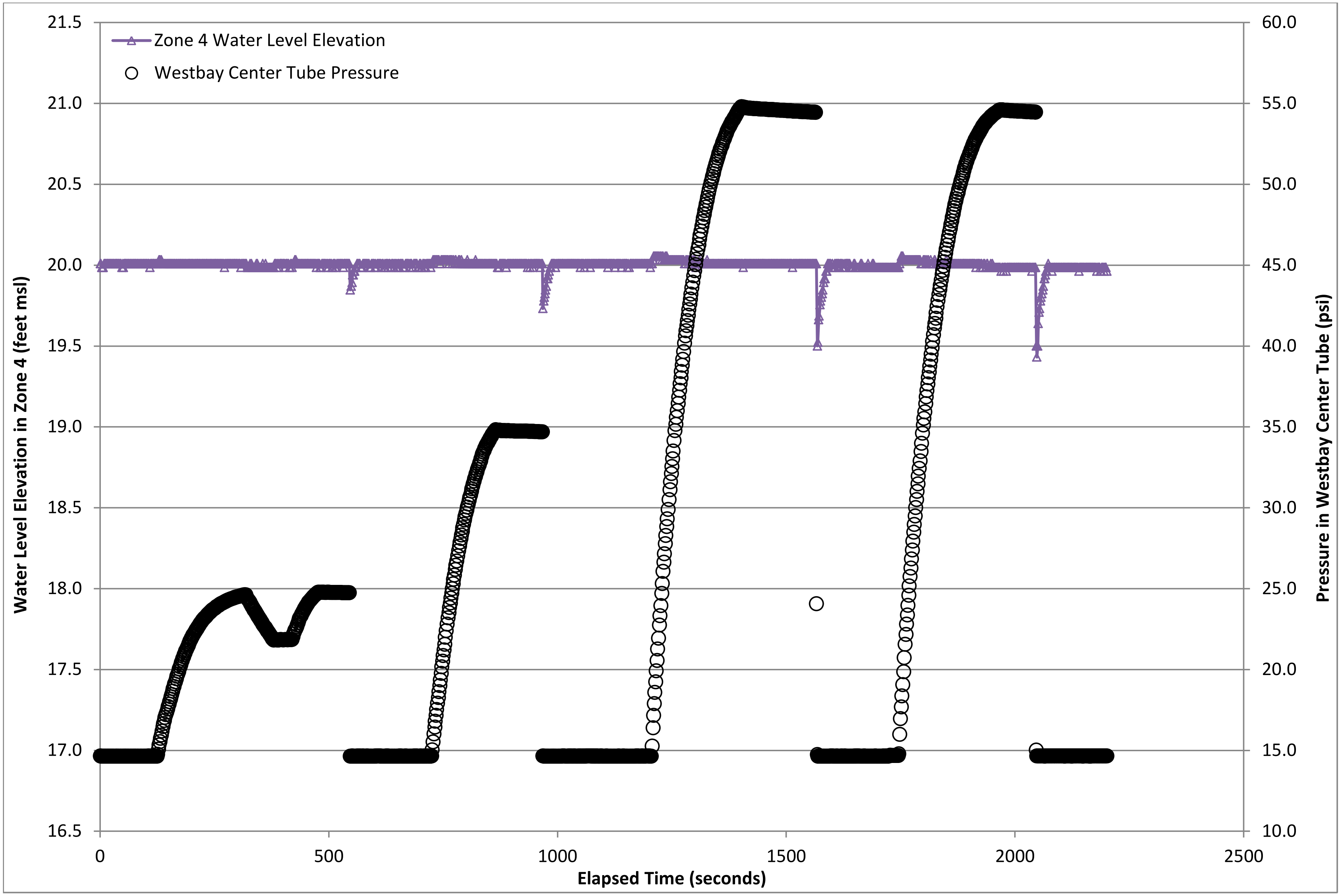

Figure 7
Water Level Response in Zone 4 During Pneumatic Testing
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

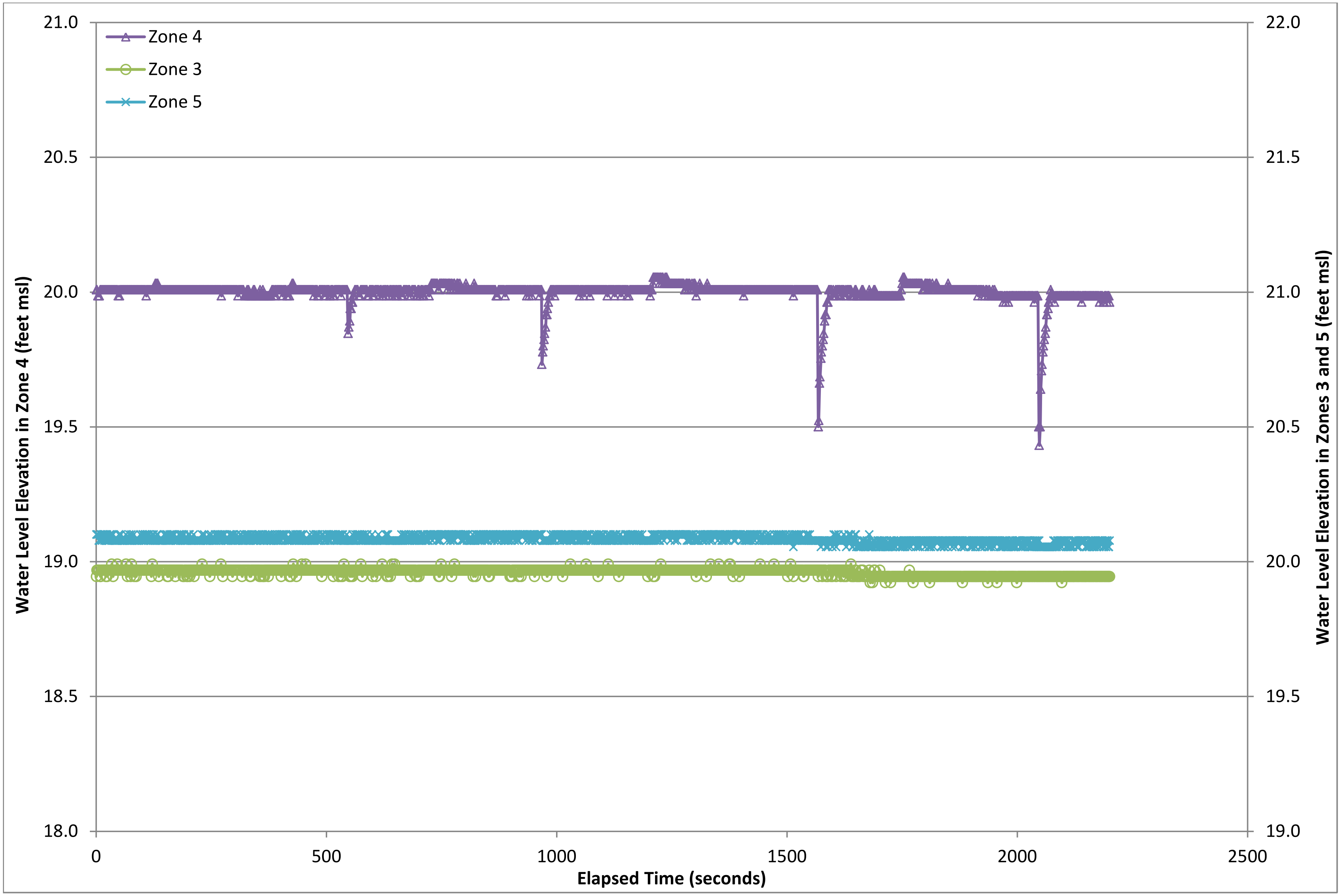

Figure 8
Water Level Response in Zones 3, 4, and 5 to Pneumatic Testing in Zone 4
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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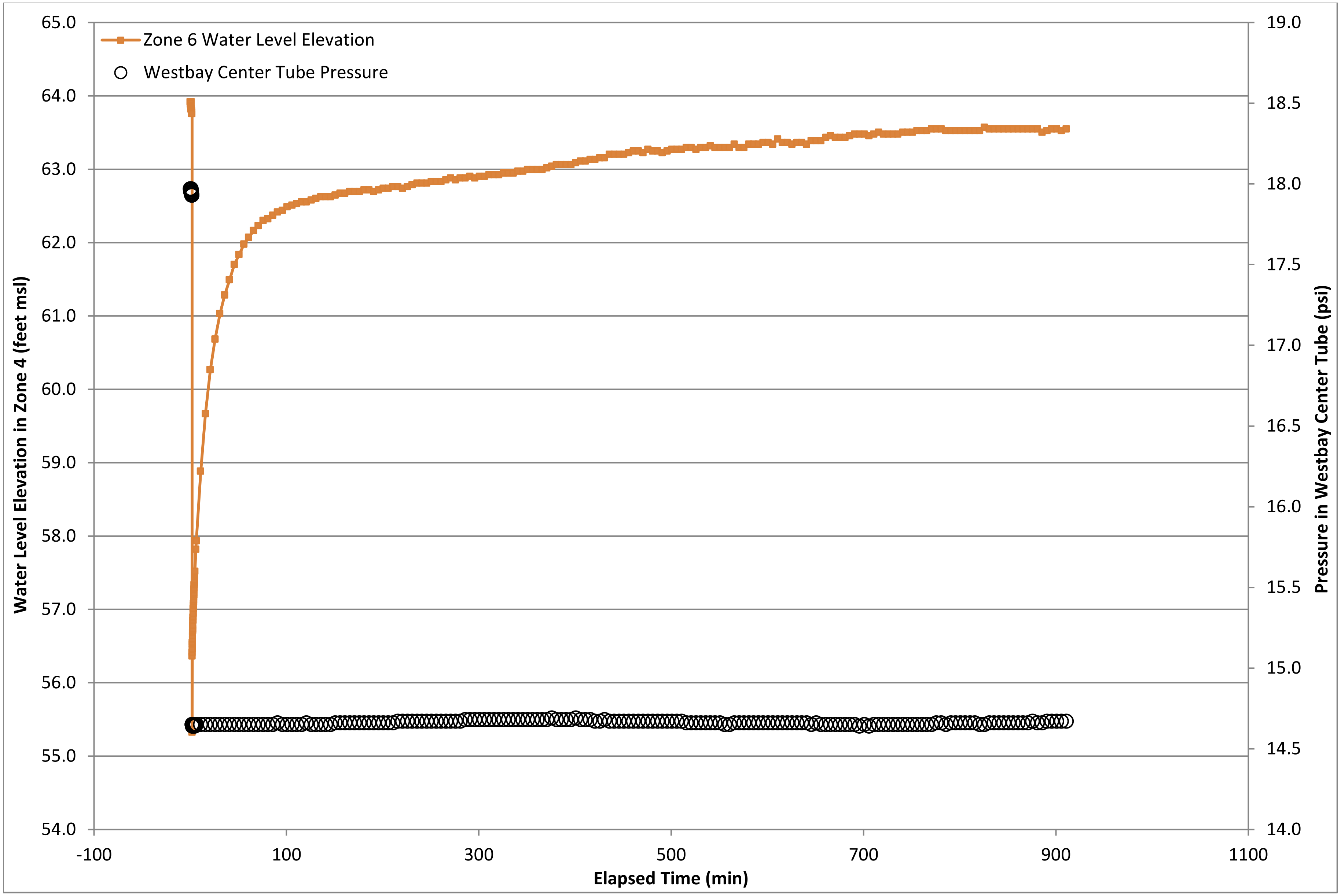

Figure 9
Water Level Response in Zone 6 During Pneumatic Testing at Approximately 5 psi
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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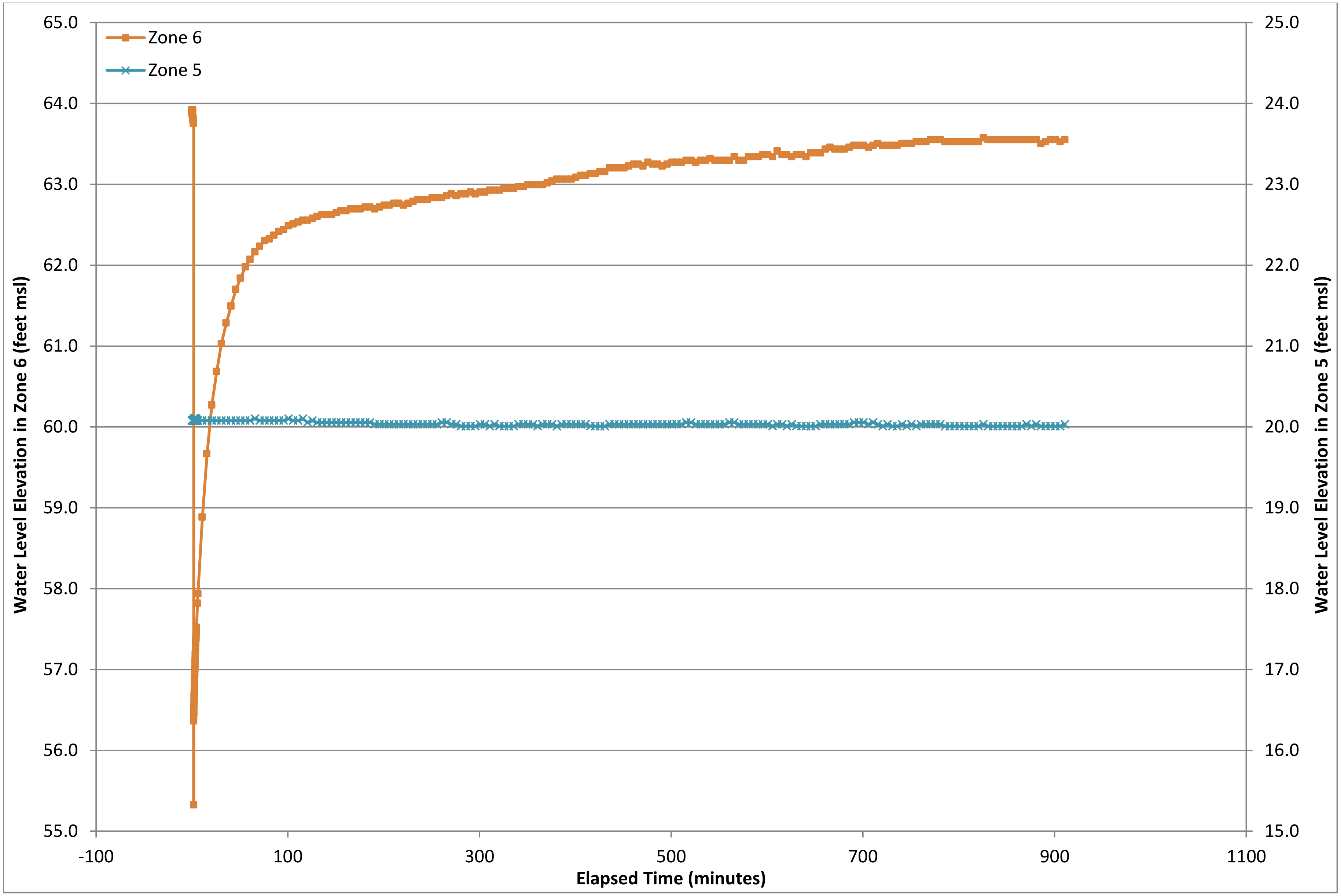

Figure 10
Water Level Response in Zones 5 and 6 to Pneumatic Testing in Zone 6
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

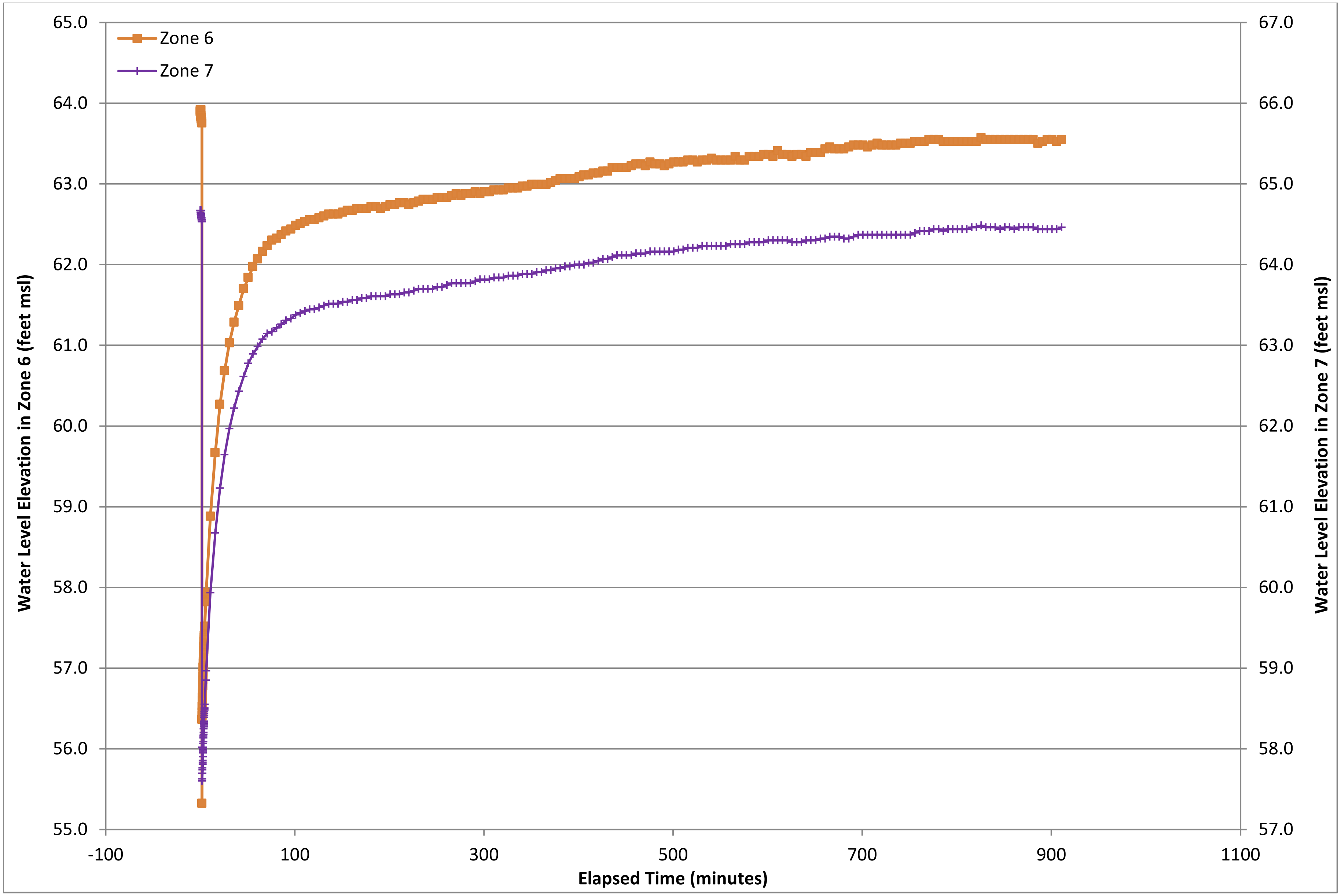

Figure 11
Water Level Response in Zones 6 and 7 to Pneumatic Testing in Zone 6
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

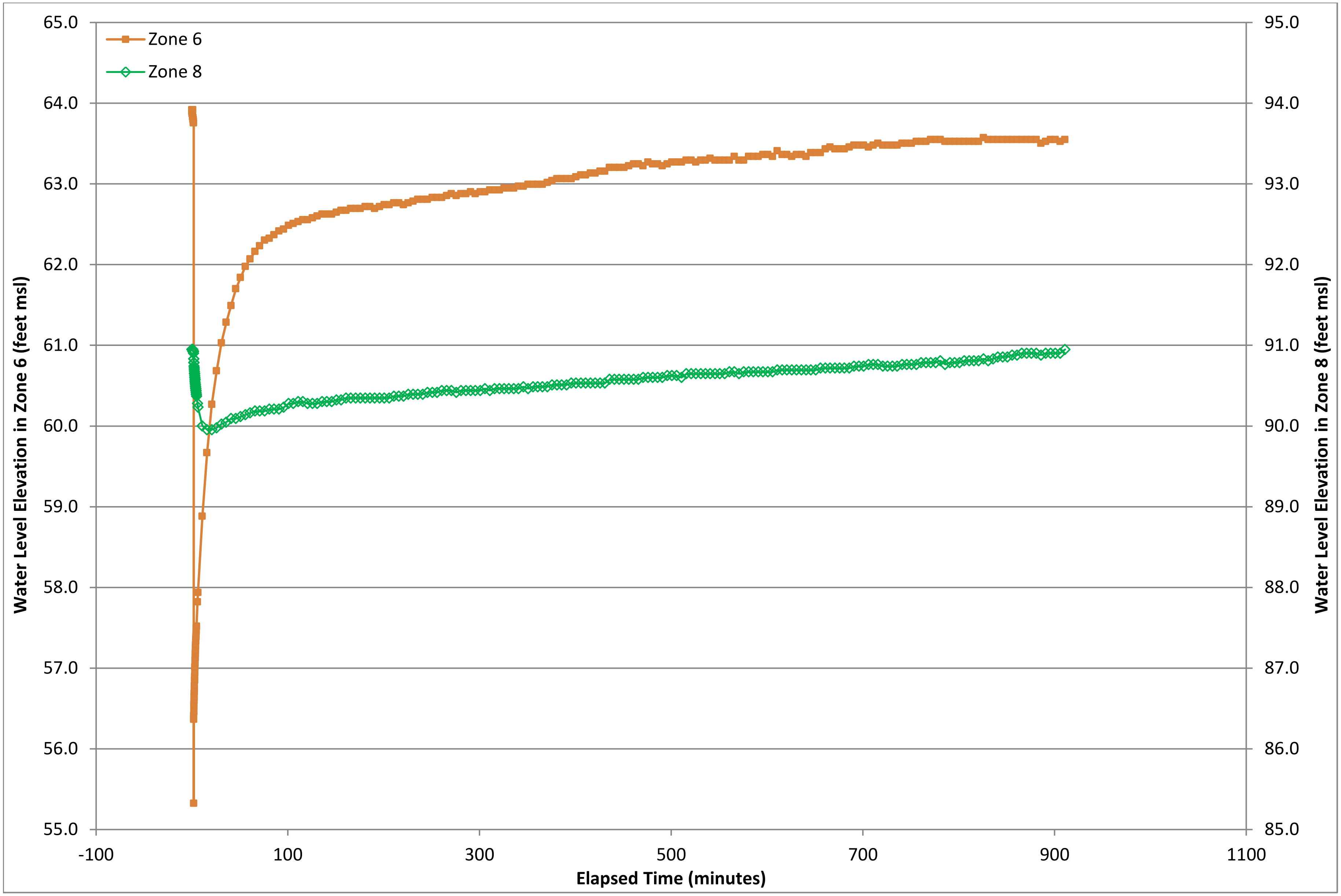

Figure 12
Water Level Response in Zones 6 and 8 to Pneumatic Testing in Zone 6
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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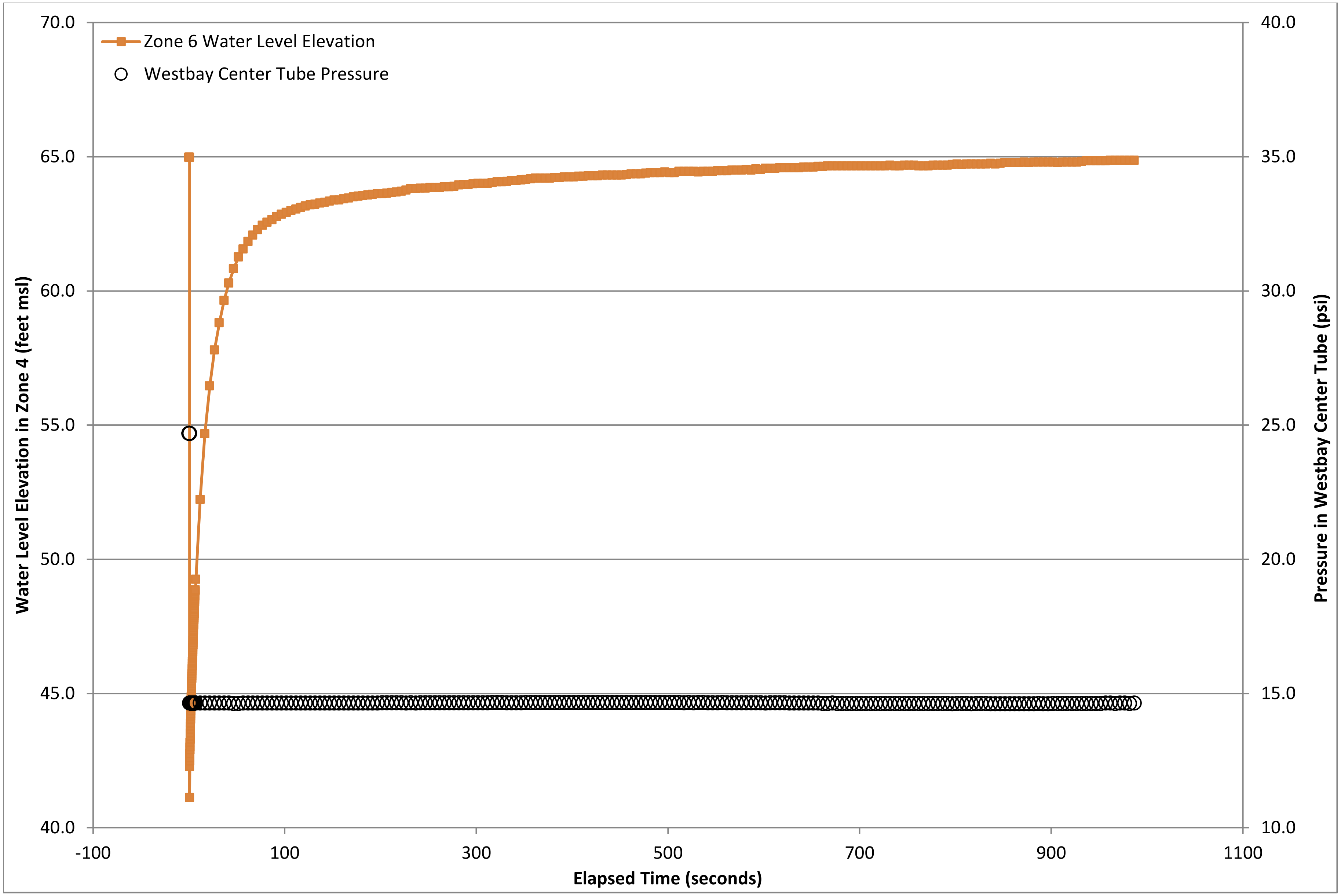

Figure 13
Water Level Response in Zone 6 During Pneumatic Testing at Approximately 10 psi
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

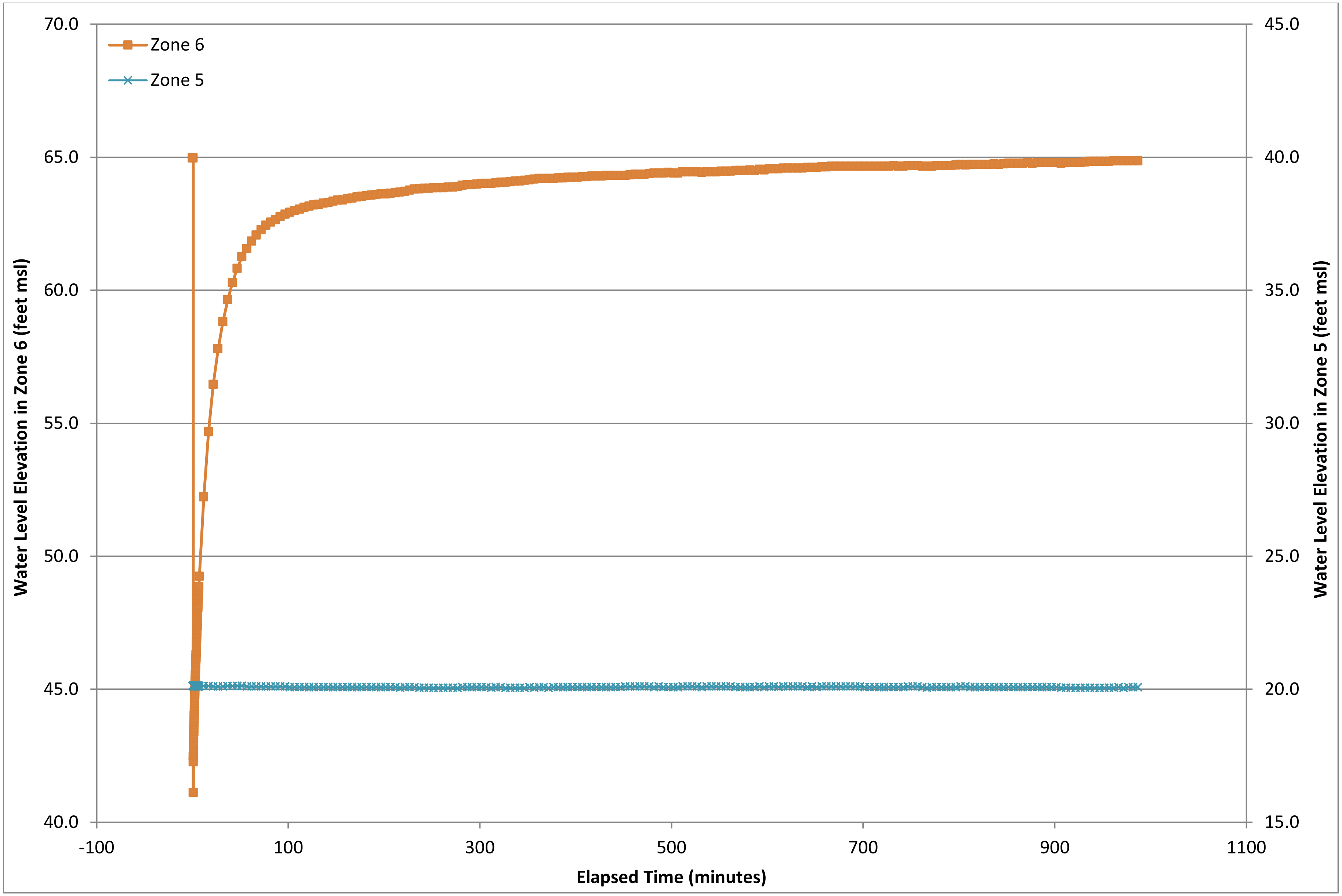

Figure 14
Water Level Response in Zones 5 and 6 to Pneumatic Testing in Zone 6
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

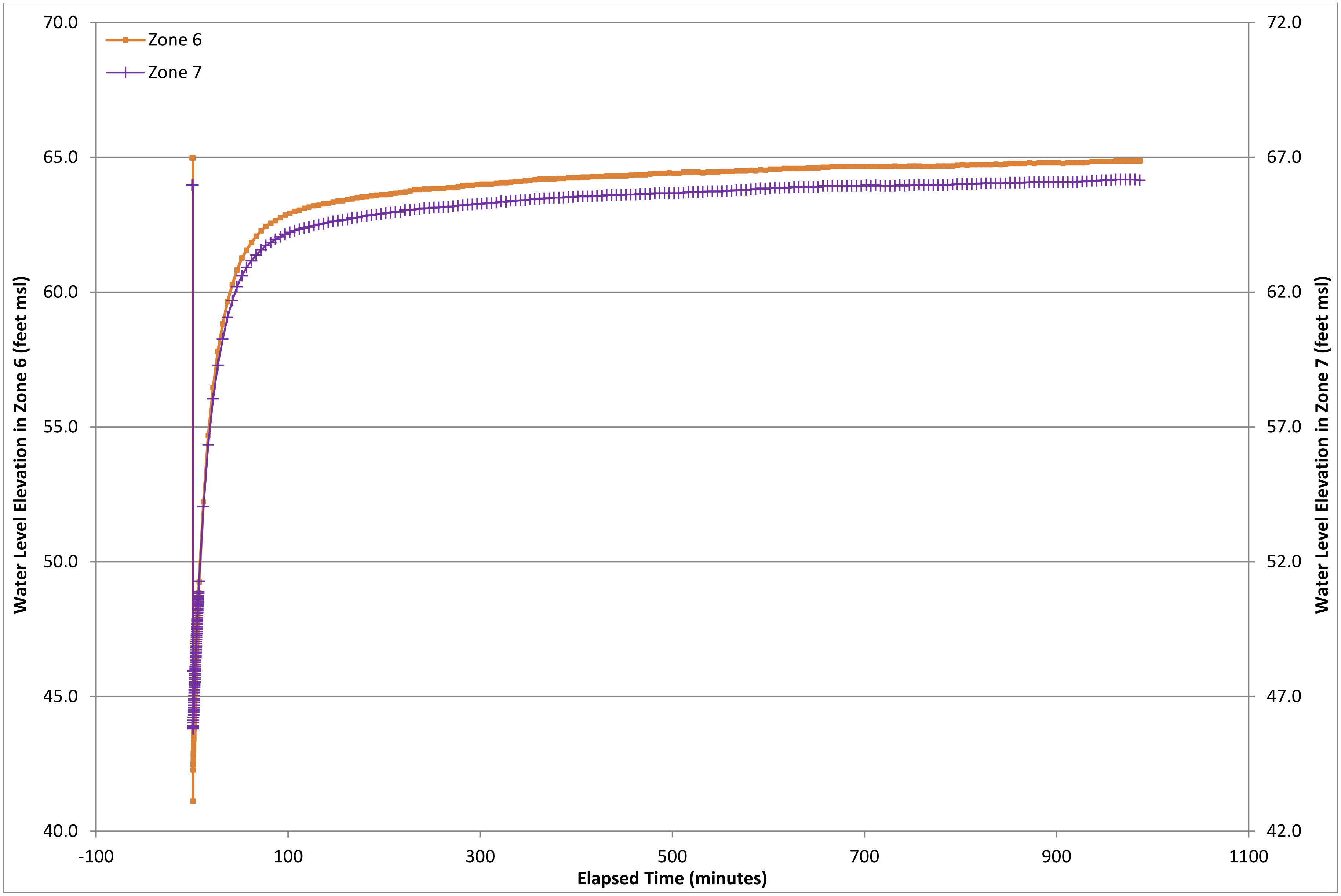

Figure 15
Water Level Response in Zones 6 and 7 to Pneumatic Testing in Zone 6
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

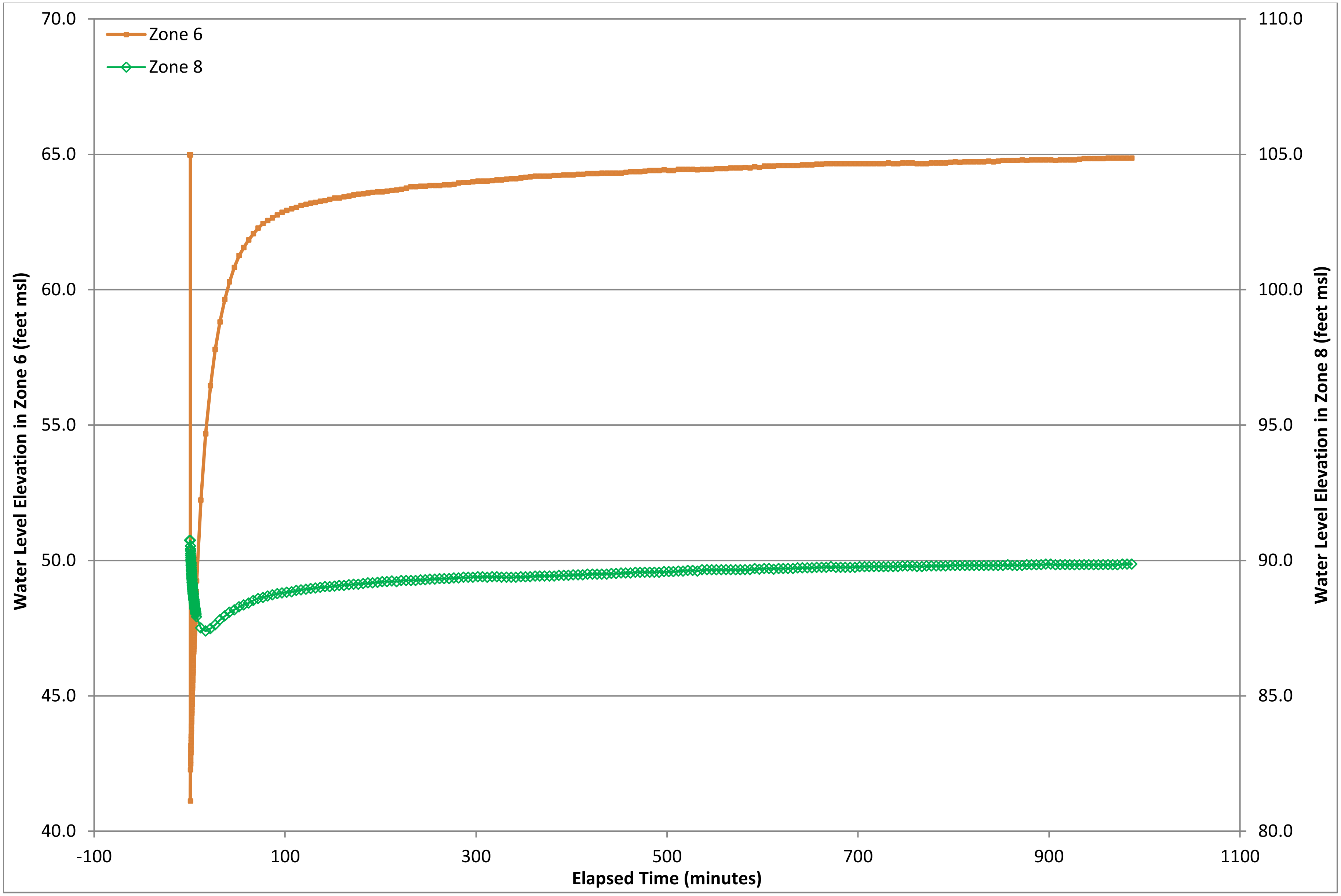

Figure 16
Water Level Response in Zones 6 and 8 to Pneumatic Testing in Zone 6
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

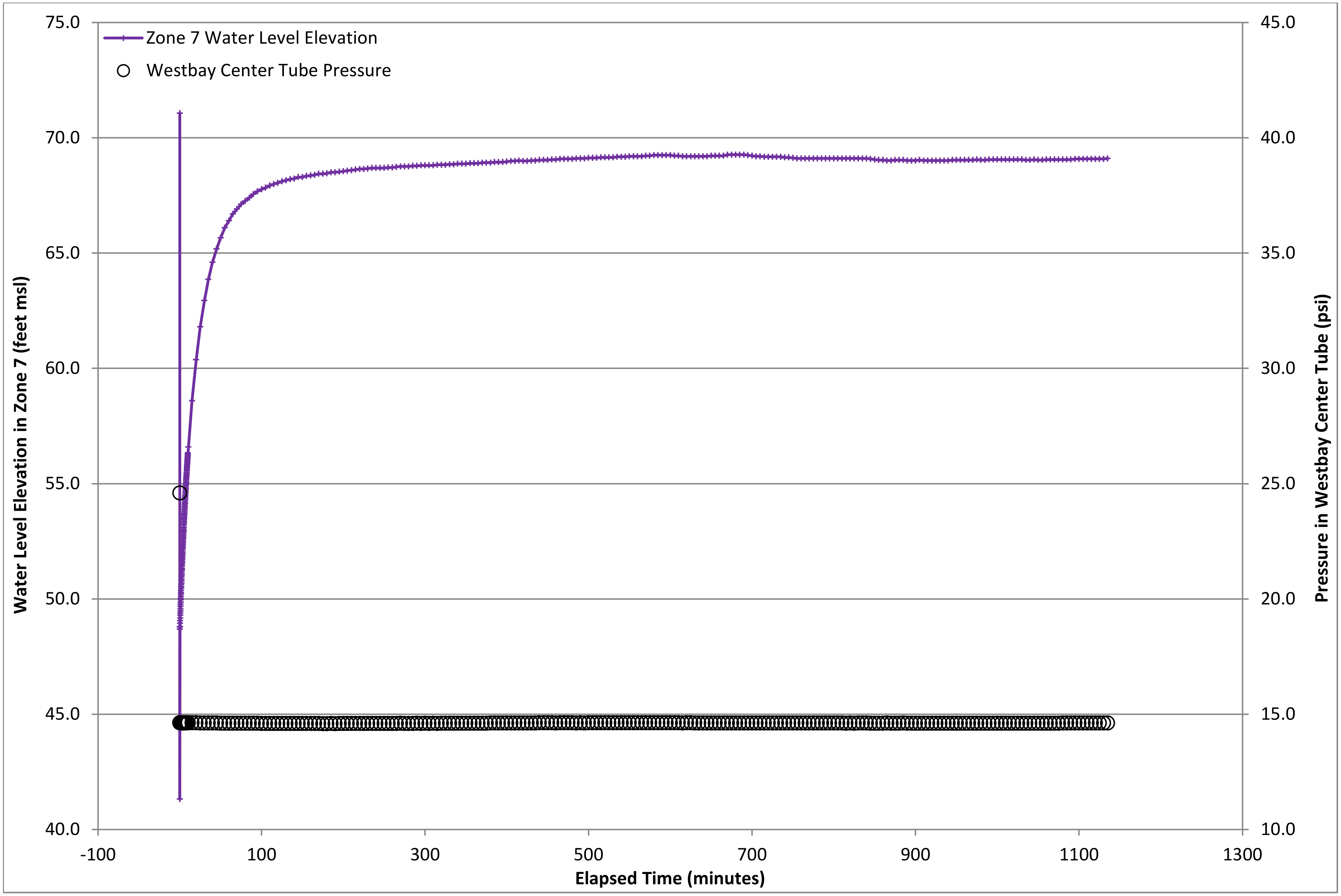

Figure 17
Water Level Response in Zone 7 During Pneumatic Testing at Approximately 10 psi
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Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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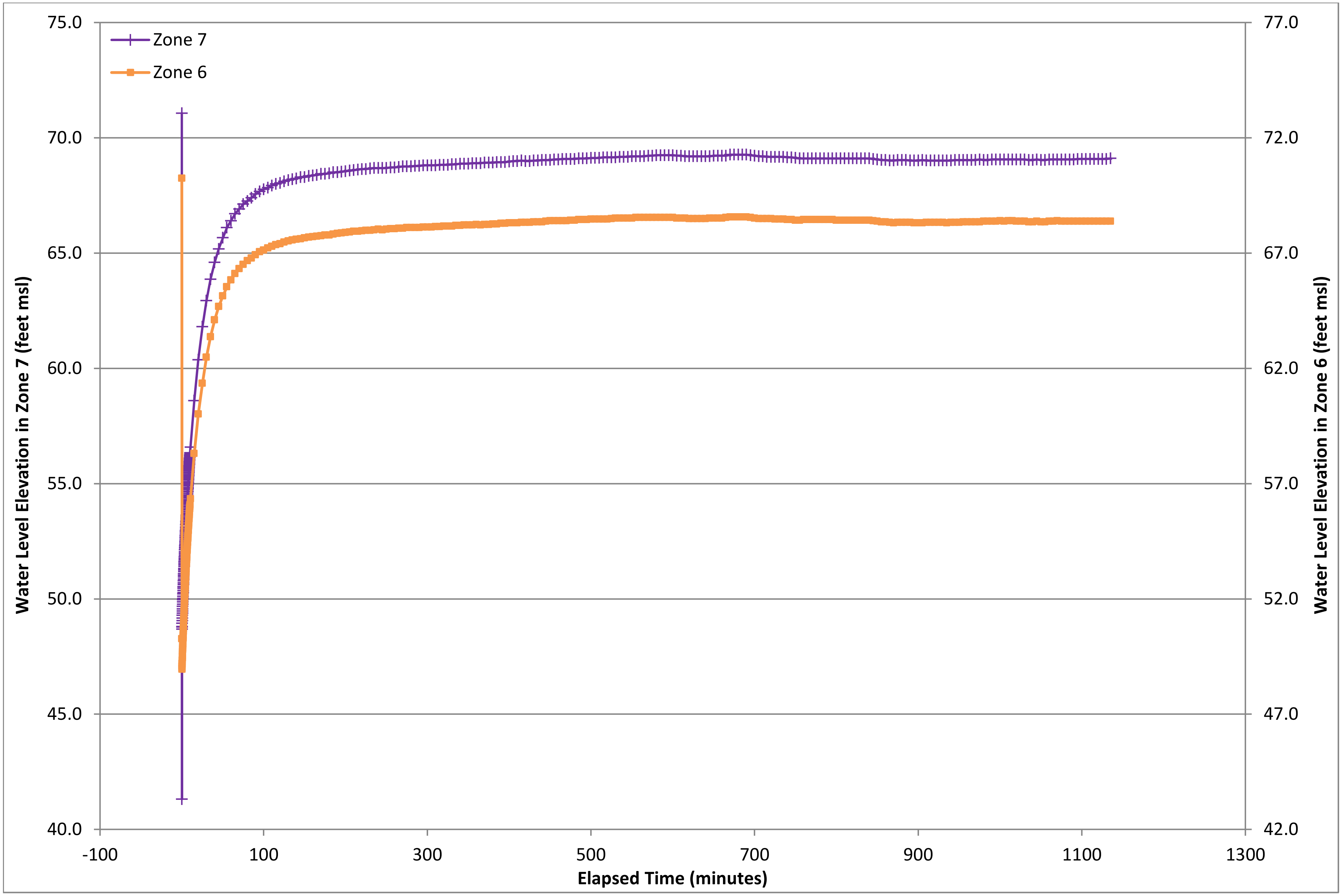

Figure 18
Water Level Response in Zones 6 and 7 to Pneumatic Testing in Zone 7
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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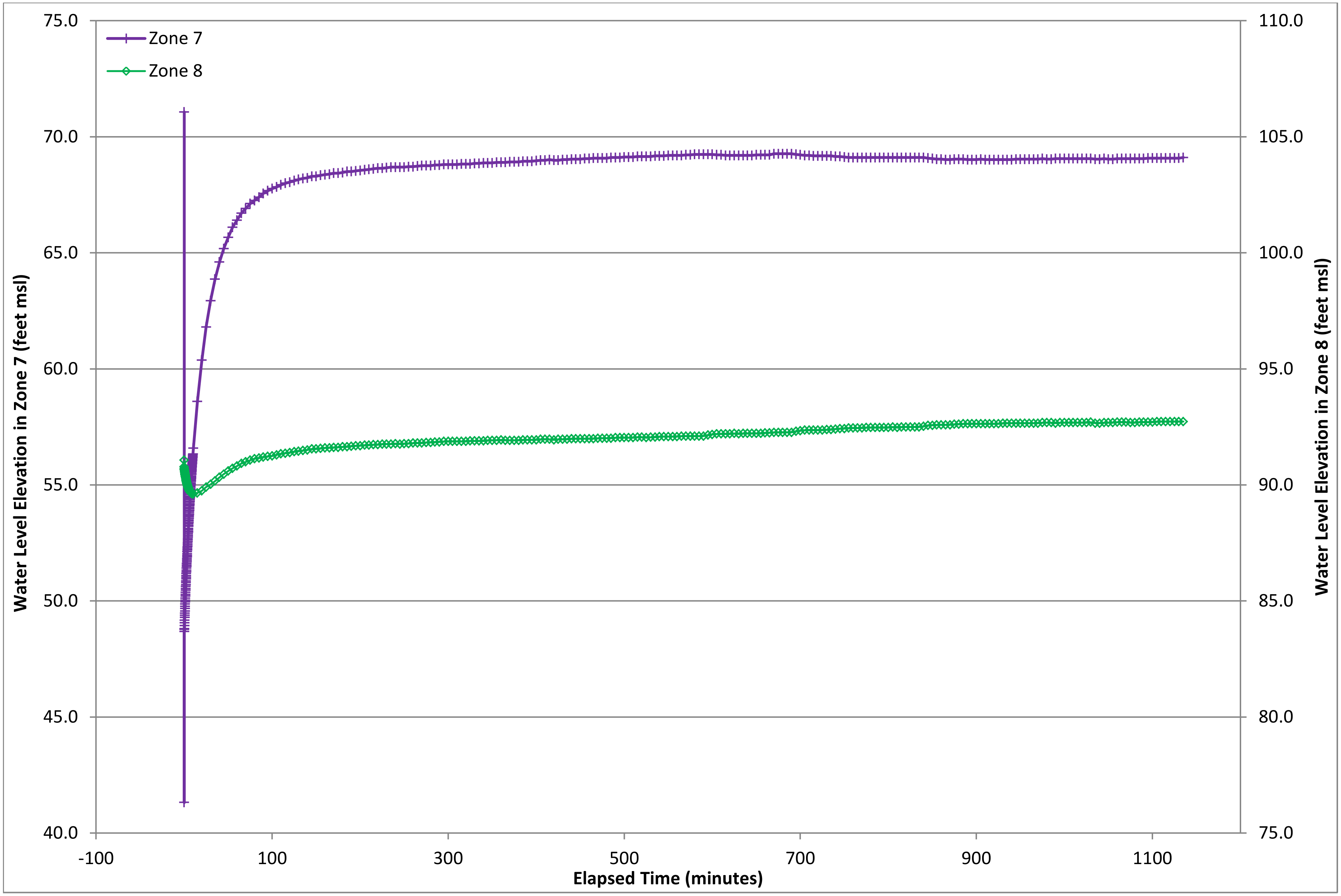

Figure 19
Water Level Response in Zones 7 and 8 to Pneumatic Testing in Zone 7
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Red Hill Bulk Fuel Storage Facility,
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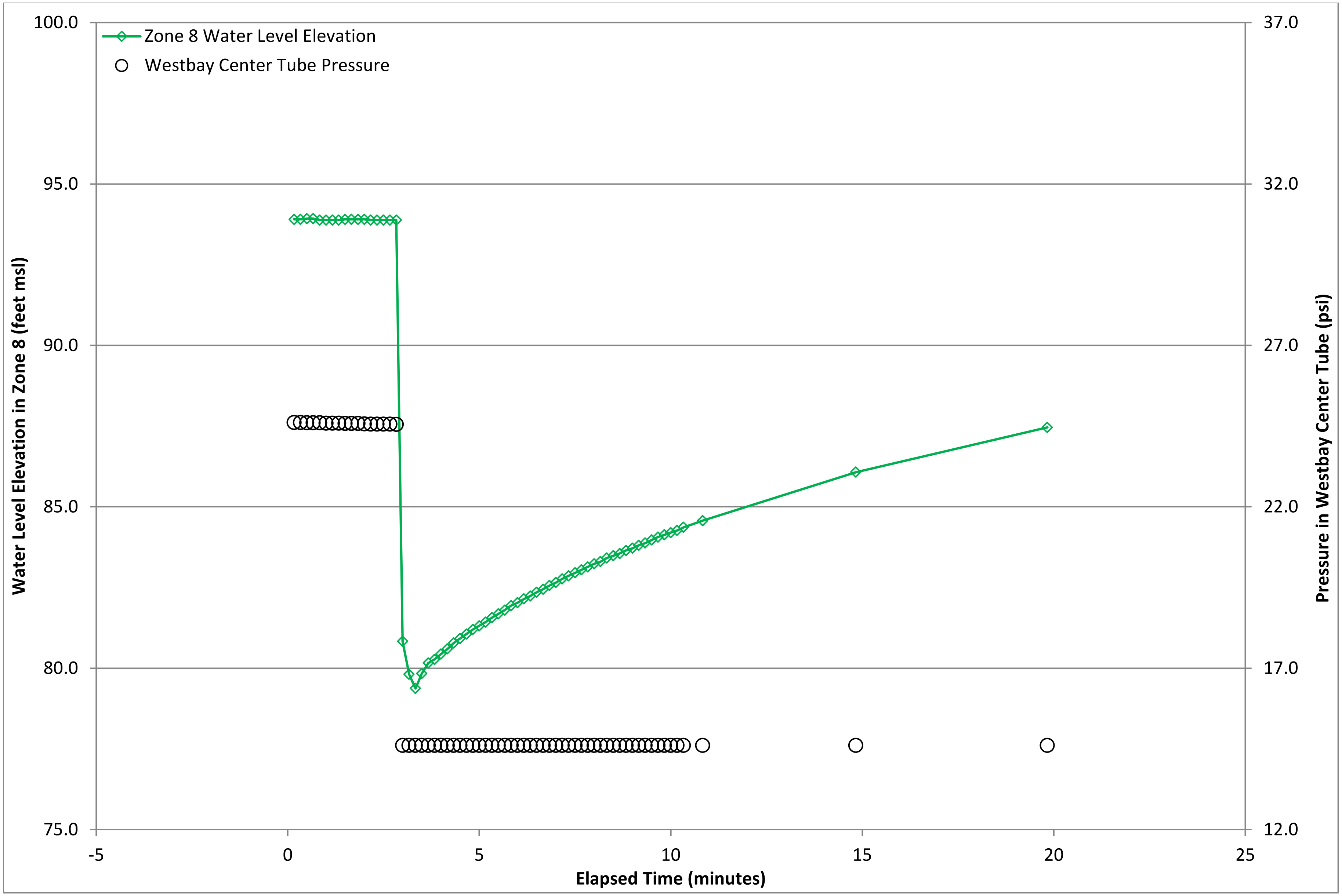

Figure 20
Water Level Response in Zone 8 During Pneumatic Testing at Approximately 10 psi
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Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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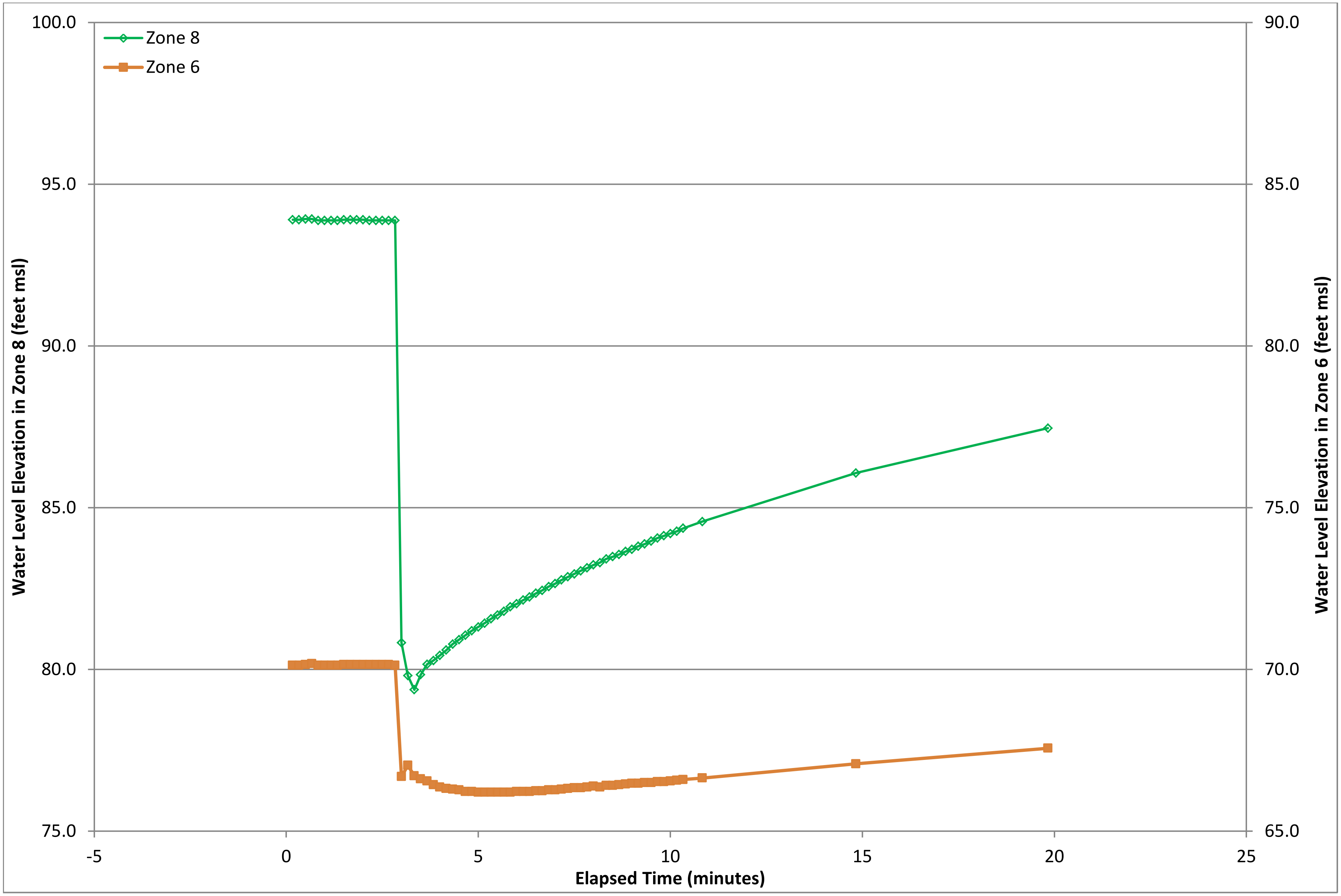

Figure 21
Water Level Response in Zones 6 and 8 to Pneumatic Testing in Zone 8
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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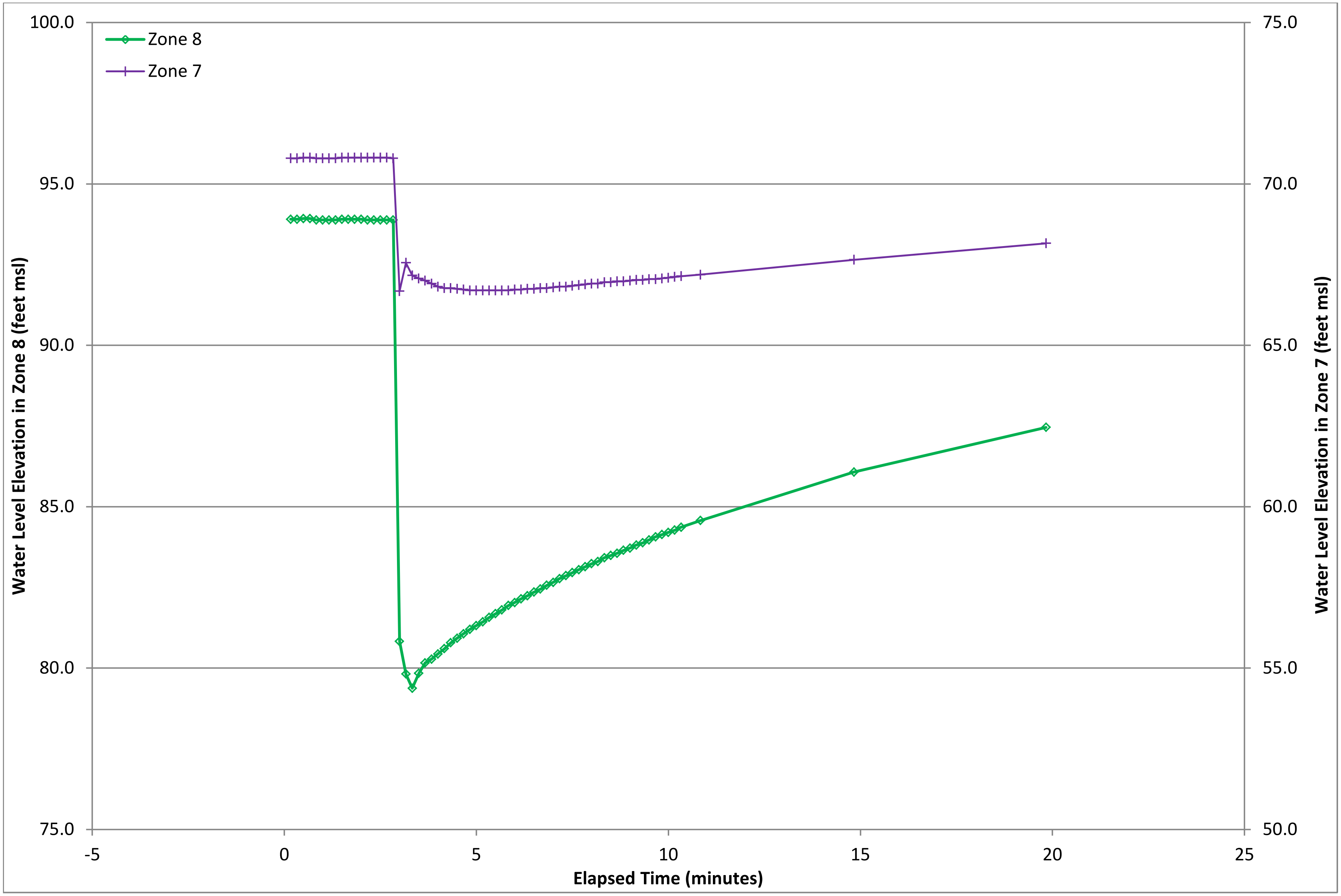

Figure 22
Water Level Response in Zones 7 and 8 to Pneumatic Testing in Zone 8
Technical Memorandum, Verification of Packer Integrity at RHMW11
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Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

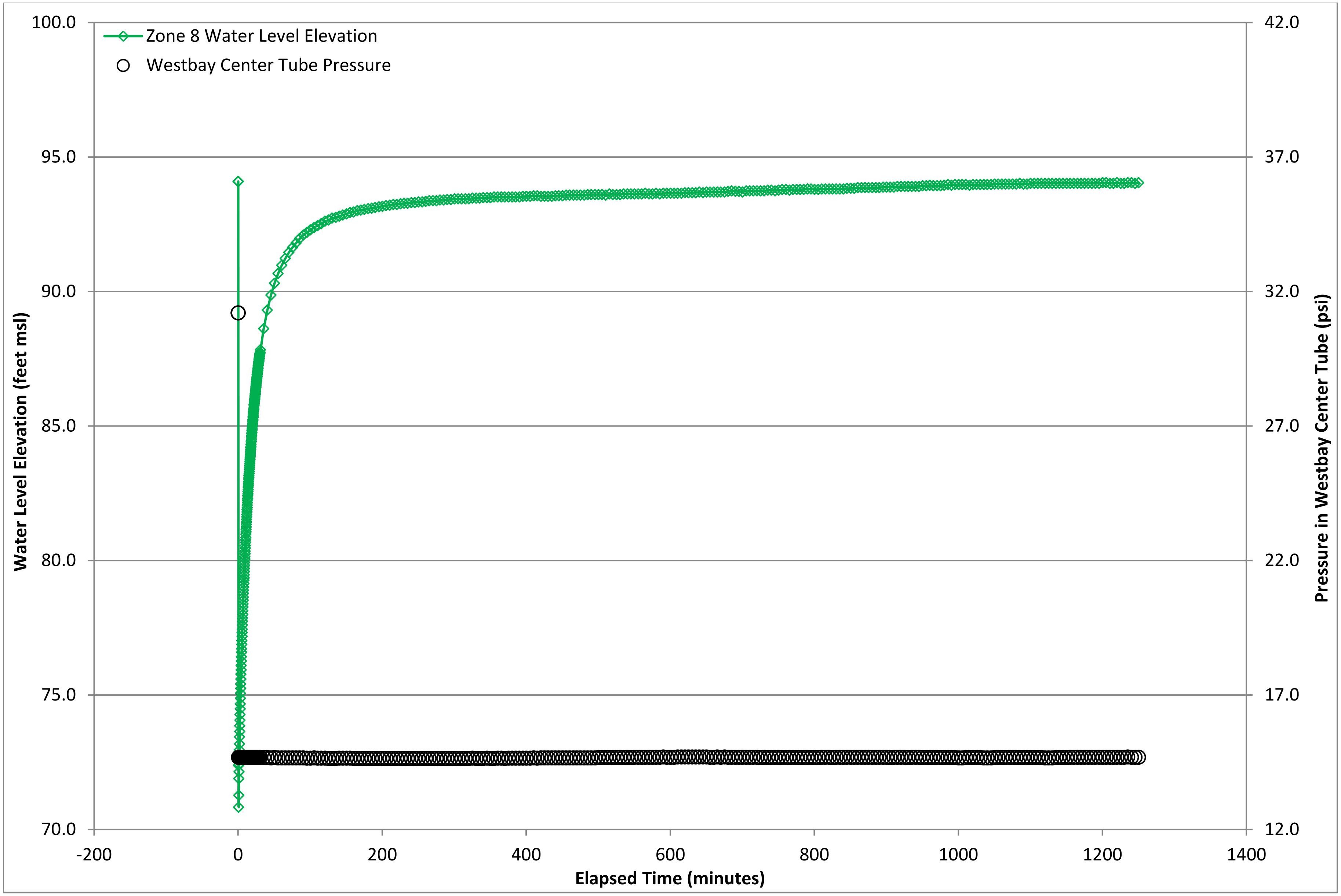

Figure 23
Water Level Response in Zone 8 During Pneumatic Testing at Approximately 15 psi
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

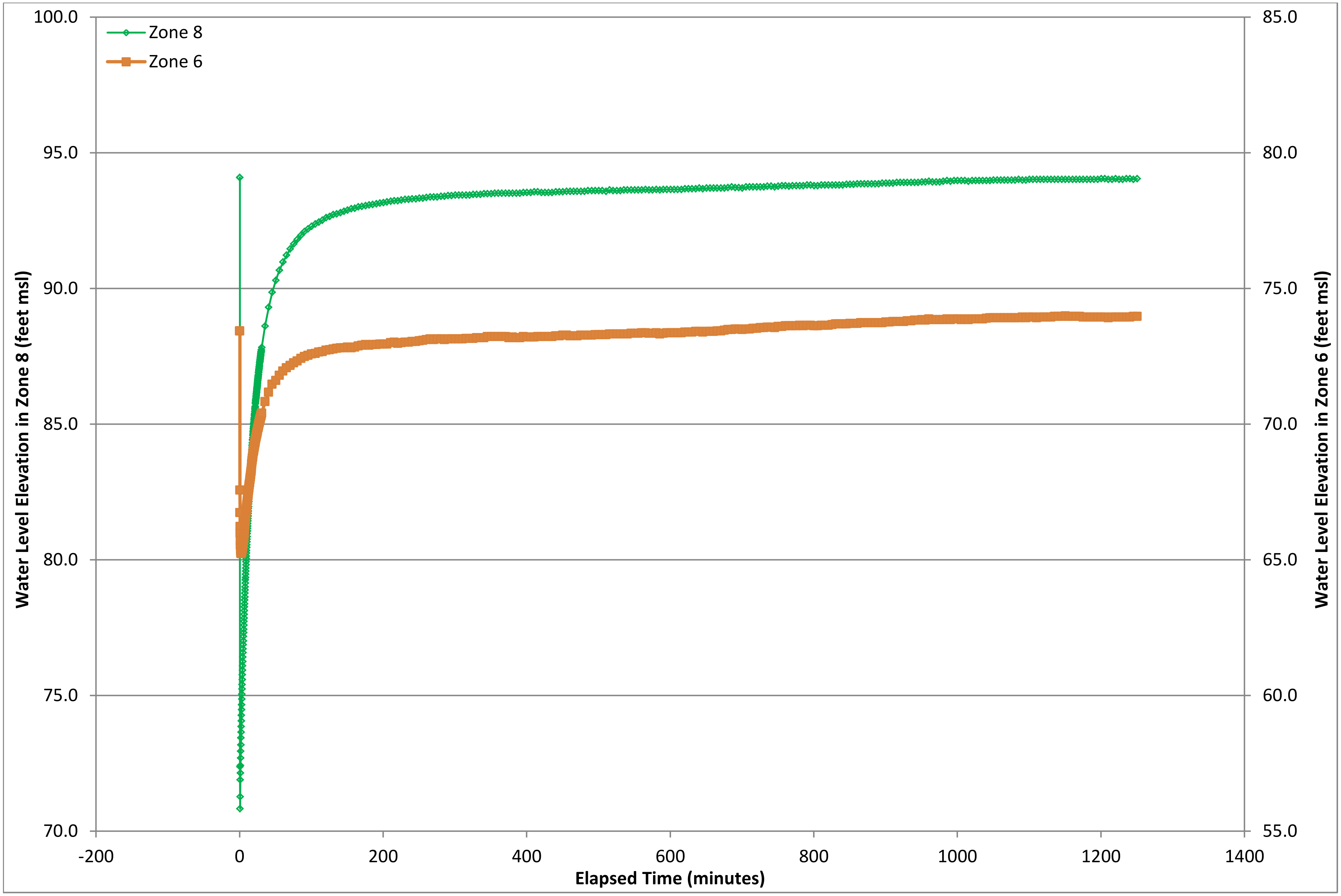

Figure 24
Water Level Response in Zones 6 and 8 to Pneumatic Testing in Zone 8
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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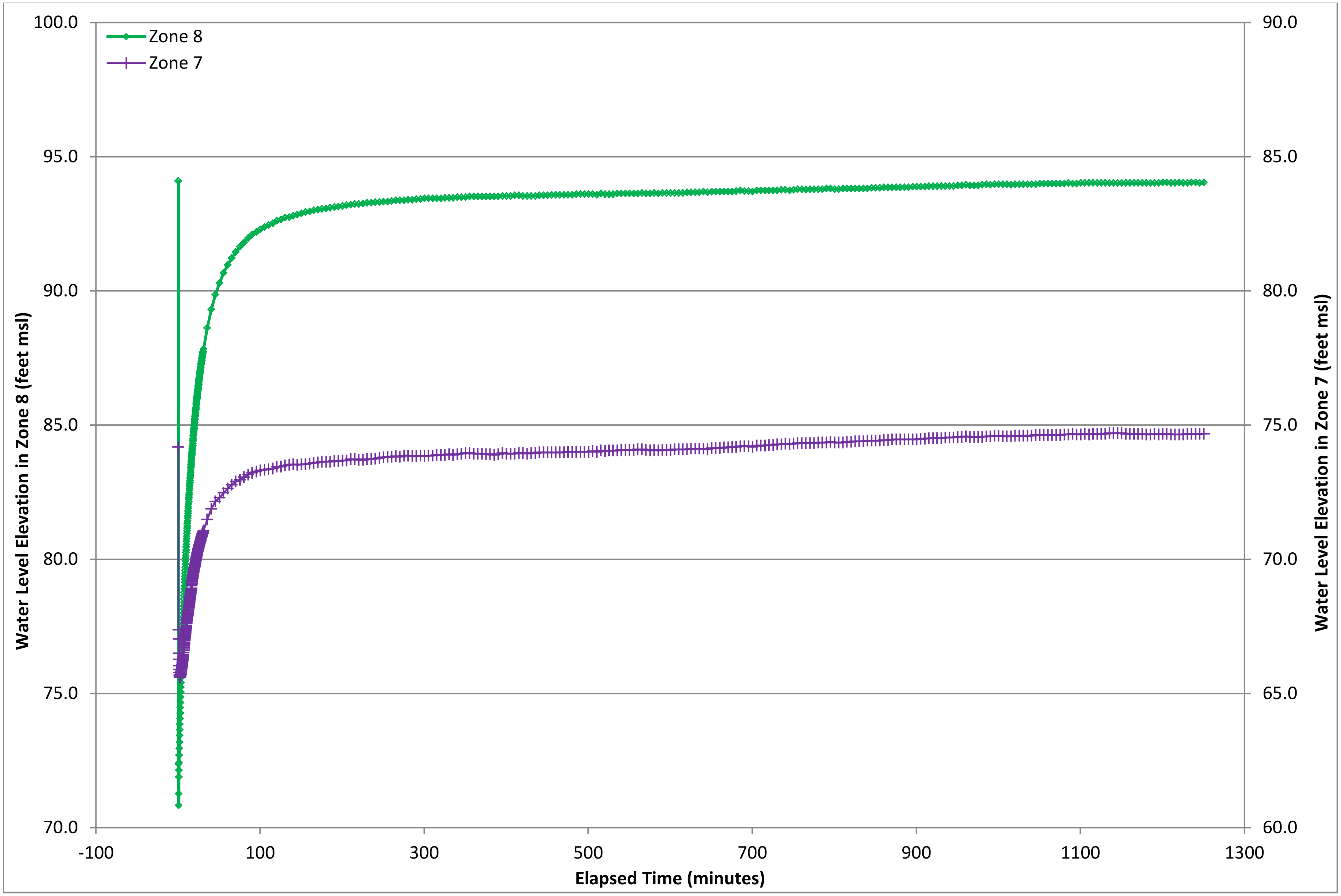

Figure 25
Water Level Response in Zones 7 and 8 to Pneumatic Testing in Zone 8
Technical Memorandum, Verification of Packer Integrity at RHMW11
Red Hill Bulk Fuel Storage Facility,
Joint Base Pearl Harbor-Hickam, O'ahu, Hawai'i

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Attachment A:
Westbay Environmental Projects
for U.S. Environmental Protection Agency

Westbay Environmental Projects

U.S. EPA Region 1

Connecticut Yankee Atomic Power, East Hampton, CT

Clients: CH2M Hill and Connecticut Yankee Atomic Power Company

Start Date: 2004

Investigation and monitoring of groundwater conditions in fractured rock surrounding a superfund hazardous waste site.

Sullivan's Ledge Superfund Site, New Bedford, MA

Clients: Mabbett Environmental, O'Brien & Gere Engineers and Ebasco Services for U.S. EPA

Start Date: 1988

Investigation and monitoring of groundwater conditions in fractured rock surrounding a superfund hazardous waste site.

U.S. EPA Region 2

Niagara Falls Regional Hydrogeology Study, NY

Client: United States Geological Survey, Ithaca, NY for U.S. EPA

Start Date: 1987

Characterization for a regional groundwater model to provide boundary conditions for local flow models at hazardous waste sites in Niagara Falls, NY. Geologic materials consist of a sedimentary sequence including limestones and dolomites (some karst) overlain by glacial drift and alluvium. The project was funded and reviewed by U.S. EPA Superfund.

Industrial Park, Vega Alta, Puerto Rico

Clients: Bechtel Environmental Inc., Geraghty & Miller and Unisys

Start Date: 1989

Characterization of groundwater conditions in a karst limestone underlying an NPL site. Bechtel installed 20 Westbay System monitoring wells in 1989. Geraghty & Miller later took over operation of the monitoring system and installed three additional wells. The wells continue in operation.

Higgins Farm Superfund Site, Princeton, NJ

Client: Sevenson Environmental and U.S. Army Corps of Engineers for U.S. EPA

Start Date: 2000

Characterization and monitoring of groundwater conditions in fractured bedrock underlying an NPL site.

UTC Facility, Hawthorne, NJ

Client: MACTEC, ARCADIS

Start Date: 2005

Characterization and monitoring of groundwater conditions in fractured bedrock. The wells continue in operation.

Industrial Facility, Northvale, NJ

Client: ARCADIS

Start Date: 2005

Characterization and monitoring of groundwater conditions in fractured bedrock.

Industrial Facility, New Brunswick, NJ

Client: ERM Northeast

Start Date: 2004

Characterization and monitoring of groundwater conditions in fractured bedrock. The wells continue in operation.

Jackson Steel Superfund Site, Long Island, NY

Client: Bowser Morner and CH2M Hill for U.S. EPA, NY

Start Date: 2002

Characterization and monitoring of groundwater conditions in unconsolidated sands. The wells continue in operation.

Old Roosevelt Field Superfund Site, Long Island, NY

Client: Various Drilling Companies and CDM for U.S. EPA, NY

Start Date: 2005

Characterization and monitoring of groundwater conditions in unconsolidated sands. Westbay wells installed in various phases through to 2011 and continue in operation.

Cayuga County Superfund Site, NY

Client: Lockheed Martin, Various Drilling Companies and CDM for U.S. EPA, NY

Start Date: 2004

Characterization and monitoring of groundwater conditions in fractured bedrock. The wells continue in operation.

U.S. EPA Region 3

Industrial Facility, Crozet, VA

Client: Groundwater & Environmental Services

Start Date: 2005

Characterization and monitoring of groundwater conditions in fractured bedrock. The wells continue in operation.

Industrial Facility, Belle, WV

Client: DuPont, Wilmington, DE

Start Date: 1994

Installation of multilevel wells to characterize and monitor conditions around an industrial plant in Belle, WV. Geologic materials consist of a sedimentary sequence of sandstones and shales. Westbay wells were installed in various phases and operation continues.

Kendall Amalie Refinery, Bradford, PA

Client: R.E. Wright Engineers

Start Date: 1994

Groundwater characterization and monitoring for remediation activities at an oil refinery.

Butz Landfill Superfund Site, Tannersville, PA

Clients: U.S. Bureau of Reclamation, Roy F. Weston and Tetra Tech NUS for U.S. EPA

Start Date: 1996

Groundwater characterization and monitoring for remedial investigation/feasibility study in fractured rock. The wells continue in operation.

Berkely Products Site, Ephrata, PA

Clients: Gannet Fleming and Tetra Tech NUS, Inc. for U.S. EPA

Start Date: 1997

Installation of multilevel monitoring wells for monitoring related to closure of a landfill at a superfund site. The wells continue in operation.

Crossley Farms Site, Huffs Church, PA

Clients: Tetra Tech NUS, Inc. for U.S. EPA

Start Date: 1999

Installation of multilevel monitoring wells for characterization and monitoring at a superfund site.

Hunterstown Road Site, Gettysburg, PA

Client: Viacom

Start Date: 2001

Characterization and monitoring of groundwater conditions in a fractured rock environment.

Safety Light Site, Bloomsburg, PA

Client: Earth Data Northeast and Tetra Tech NUS

Start Date: 2007

Characterization and monitoring of groundwater conditions in a fractured rock environment.

Galaxy Spectron Superfund Site, Elkton, MD

Client: Earth Data Northeast, O’Brien & Gere and ERM

Start Date: 2000

Characterization and monitoring of groundwater conditions in a fractured rock environment. Wells installed in multiple phases and continue in operation.

U.S. EPA Region 4

U.S. Department of Energy Facilities, Oak Ridge, TN

Clients: Bechtel Jacobs and Lockheed Martin Energy Systems Group for U.S. DOE

Start Date: 1989

Characterization of groundwater conditions in a sedimentary rock environment including limestones at the X-10 and Y-12 plants and neighboring areas. Multiple installations in various phases of work. The wells continue in operation.

Savannah River Site, Aiken, SC

Client: Savannah River Nuclear Solutions, Washington Savannah River Company and Westinghouse Savannah River Company for U.S. DOE

Start Date: 1999

Characterization and monitoring of groundwater conditions in alluvial sediments. Westbay wells installed in multiple phases of work and continue in operation.

Cabot Carbon/Koppers Superfund Site, Gainesville, FL

Client: GeoTrans and Field & Technical Services

Start Date: 2005

Characterization and monitoring of groundwater conditions in limestone aquifer underlying a superfund site. Wells installed in various phases and continue in operation.

Waste Site, Ft. Hartford, KY

Client: Ensafe, Inc.

Start Date: 1993

Characterization of groundwater conditions in a sedimentary rock environment at a superfund site.

U.S. EPA Region 5

Industrial Facility, Cottage Grove, WI

Client: GeoTrans Inc. and Hydrite Chemical Co.

Start Date: 1990

Characterization of groundwater conditions in a weathered sedimentary rock environment (including limestones) as part of a RCRA corrective action plan. Westbay System wells installed and MOSDAX probes used for automated monitoring of multiple zones during a pumping test. Wells installed in multiple phases and continue in operation.

Industrial Facility, Madison, WI

Client: URS Corporation

Start Date: 2007

Characterization of groundwater conditions in a fractured rock environment.

Continental Steel Plant, Kokomo, IN

Client: ABB Environmental Services, Inc.

Start Date: 1993

Characterization of groundwater conditions in a sedimentary rock environment.

BP-Amoco Terminal, Spring Valley, MN

Client: Delta Environmental

Start Date: 1994

Groundwater characterization and monitoring at a petroleum terminal. Additional wells installed in later phases of work.

U.S. EPA Region 6

Waste Facility, Criner, OK

Client: Hardage Steering Committee

Start Date: 1987

Investigation and monitoring of groundwater conditions in low permeability shales underlying an NPL site.

Tinker Air Force Base, Oklahoma City, OK

Client: Science Applications International Corporation

Start Date: 2009

Investigation and monitoring of groundwater conditions in sandstone & shale at an air force base.

NASA White Sands Test Facility, Las Cruces, NM

Clients: Honeywell Technology Solutions Company, BDM International (fka GCL) and NASA

Start Date: 1990

Characterization and monitoring of groundwater conditions in the vicinity of NASA's White Sands Test Facility near Las Cruces, New Mexico. The geology consists of coarse grained alluvium underlain by fractured volcanic and sedimentary bedrock. Multiple installations in various phases of work. The wells continue in operation.

South Valley Superfund Site, Albuquerque, NM

Clients: The Axis Group, BDM International (fka GCL) and General Electric Aircraft Engines

Start Date: 1991

Characterization and monitoring of groundwater conditions in alluvial deposits in the vicinity of a GEAE plant in Albuquerque, New Mexico. The wells continue in operation.

Los Alamos National Laboratory, Los Alamos, NM

Clients: Los Alamos National Security, Kleinfelder, Washington Group International and Los Alamos National Laboratory

Start Date: 1998

Characterization and monitoring of groundwater conditions in complex volcanic geology in the vicinity of Los Alamos National Laboratory. Multiple installations in various phases of work. Wells continue in operation.

City of Perryton, TX

Clients: CH2M Hill and WDC Exploration & Wells for U.S. EPA

Start Date: 1999

Characterization and monitoring of groundwater conditions in alluvial sediments. The wells continue in operation.

Camp Stanley Storage Activity, San Antonio, TX

Clients: Parsons Engineering Science and Camp Stanley Storage Activity

Start Date: 2003

Characterization and monitoring of groundwater conditions in fractured limestones. Wells installed in multiple phases and continue in operation.

Barton Springs/Edwards Aquifer Conservation District, Austin, TX

Clients: Barton Springs/Edwards Aquifer Conservation District

Start Date: 2007

Characterization and monitoring of groundwater conditions in fractured limestones.

U.S. EPA Region 8

Trona Mine, WY

Client: FMC Wyoming Corporation, Green River, WY

Start Date: 1983

Investigation and monitoring of groundwater conditions in the area of trona mill tailings and evaporation ponds. Geology consists of tertiary sediments (sandstones, siltstones, shales, oil shales) overlain by alluvium. 25 Westbay System wells installed in 1983. Additional wells installed in later phases. The wells continue in operation.

Petroleum Refinery, Cody, WY

Clients: GeoWest, Dames & Moore and Flying J, Inc.

Start Date: 1986

Assessment and monitoring of groundwater conditions in the area of a former hazardous waste management facility to obtain a RCRA closure permit. Geology consists of cretaceous sedimentary rocks overlain by gravelly alluvium.

U.S EPA Region 9

Orange County Water District, Orange County, CA

Client: Orange County Water District

Start Date: 1988

Installation and operation of Westbay System monitoring wells throughout the sedimentary groundwater basin managed by the Orange County Water District. Applications include monitoring of effects of artificial recharge of groundwater, distribution of groundwater quality, investigation of specific groundwater quality problems, monitoring of effectiveness of seawater intrusion barriers, etc. Water District staff have installed ~58 Westbay System monitoring wells, several reaching depths of 2,000 ft. The wells continue in operation.

Marine Corps Air Station El Toro, Orange County, CA

Clients: Orange County Water District, CH2M Hill for U.S. Navy and Bechtel for U.S. Navy

Start Date: 1988

Remedial investigation and monitoring of water quality conditions in Irvine, CA in the vicinity of MCAS EL Toro. The work was begun by the Orange County Water District, with additional wells installed for CH2M Hill under a Navy CLEAN contract.

San Gabriel Basin RI/FS, Los Angeles County, CA

Client: CH2M Hill for U.S. EPA

Start Date: 1989

Westbay equipment was first used in the San Gabriel Basin in a full-scale field study to compare the Westbay System to standpipe wells for groundwater monitoring in alluvial basins. The study, which involved installing one 700 ft Westbay System well adjacent to a cluster of five standpipe wells, showed the Westbay System to provide comparable data to standpipes while yielding significant savings in cost and time. Many additional Westbay wells have been installed in the basin for the EPA in the period since 1989 and continue in operation. Multilevel monitoring was found to be key to understanding the heterogeneity of the groundwater basin.

Jet Propulsion Laboratory, Pasadena, CA

Clients: Insight Environmental, Battelle, Tetra Tech FW and JPL

Start Date: 1990

Investigation and monitoring of groundwater conditions in alluvial deposits in the vicinity of NASA's Jet Propulsion Laboratory. Multiple installations in various phases of work. The wells continue in operation.

Central & West Basin Water Replenishment District, Los Angeles County, CA

Client: Bookman Edmonston Engineers

Start Date: 1992

Investigation and monitoring of groundwater conditions in alluvial deposits downstream of the San Gabriel Basin and upstream of a major groundwater supply for suburban Los Angeles. The wells continue to be operated by CH2M Hill as part of the U.S. EPA's monitoring network for the San Gabriel Basin.

San Gabriel Basin RI/FS, Los Angeles County, CA

Clients: San Gabriel Basin Water Quality Authority, CDM, Geosystems Analysis, PES and MACTEC

Start Date: 1995

Westbay System monitoring wells have been installed on behalf of PRPs in a number of operable units in the San Gabriel Basin. The wells range in depth to 1,500 ft. The wells continue in operation.

U.S. Department of Energy LEHR Facility, Davis, CA

Client: Pacific Northwest National Laboratory

Start Date: 1995

Groundwater characterization and monitoring at a DOE facility in Northern California.

Water Reclamation Project, Los Angeles, CA

Client: Los Angeles Department of Water & Power

Start Date: 1997

Characterization and monitoring of groundwater conditions at an artificial recharge facility to study the effects of recharging reclaimed water.

March Air Force Base, Riverside, CA

Client: Tetra Tech, Inc.

Start Date: 1998

Installation of multilevel monitoring wells in alluvial sediments as part of a program of careful characterization, monitoring and modelling of groundwater conditions in the vicinity of March Air Force Base as an alternative to active remediation.

Former Fort Ord, CA

Client: MACTEC E&C

Start Date: 2001

Characterization and monitoring of groundwater conditions in multiple aquifers in alluvial sediments at a former Army facility. Wells have been installed in multiple phases and continue in operation.

Whittaker Bermite Project, Santa Clarita, CA

Clients: CH2M Hill and Lang Exploratory Drilling for U.S. Army Corps of Engineers

Start Date: 2002

Characterization and monitoring of groundwater conditions in alluvial sediments. The wells continue in operation.

Boeing Rocketdyne Facility, Santa Susannah, CA

Clients: MWH Americas, Inc.

Start Date: 2004

Characterization and monitoring of groundwater conditions in fractured sedimentary rock. Wells installed in multiple phases and continue in operation.

Marine Corps Logistics Base, Barstow, CA

Clients: OTIE, Tetra Tech FW and Lang Exploratory Drilling

Start Date: 2002

Characterization and monitoring of groundwater conditions in alluvial sediments. The wells continue in operation.

Mojave Water Agency, Apple Valley, CA

Clients: Mojave Water Agency

Start Date: 2003

Characterization and monitoring of groundwater conditions in alluvial sediments for resource management. Westbay wells installed in multiple phases through to 2009 and continue in operation.

Las Vegas Valley Water District, Las Vegas, NV

Client: Las Vegas Valley Water District

Start Date: 1994

Groundwater characterization and monitoring near an ASR well in an alluvial basin for water resources management. The well continues in operation.

Yucca Mountain, NV

Client: Nye County Nuclear Waste Repository Project Office

Start Date: 1995

Characterization and monitoring of pore pressure responses in the unsaturated zone in a sequence of welded and non-welded tuffs at the site of a proposed nuclear waste repository at Yucca Mountain, Nevada. Later phases of work have included multiple installations for saturated zone monitoring downstream of Yucca Mountain. The wells continue in operation.

Semiconductor Plant, Phoenix, AZ

Clients: Clear Creek Associates and Dames & Moore Consultants for Motorola

Start Date: 1984

Remedial investigation and monitoring of an NPL site. Geology consists of alluvium overlying fractured granite, breccia, arkosic sandstones & conglomerates. Westbay System wells have been installed in various phases since 1984. The wells continue in operation.

General Electric Facility, Chandler, AZ

Client: Dames & Moore Consultants

Start Date: 1991

Characterization of groundwater conditions in alluvial deposits at an industrial facility.

Manufacturing Facility, Phoenix, AZ

Clients: LFR Levine Fricke and F & B Manufacturing Co.

Start Date: 1992

Investigation and characterization of groundwater conditions in alluvial deposits in the vicinity of an industrial facility. The wells continue in operation.

Manufacturing Facility, Phoenix, AZ

Client: Dolphin, Inc.

Start Date: 1993

Investigation and characterization of groundwater conditions in alluvial deposits in the vicinity of an industrial facility. The wells continue in operation.

Naval Air Station Agana, Guam

Client: Ogden Environmental, San Diego, CA

Start Date: 1994

Groundwater characterization and monitoring in a karstic limestone environment at NAS Agana.

U.S. EPA Region 10

U.S. Department of Energy Idaho National Laboratory, Idaho Falls, ID

Client: U.S. Geological Survey, Battelle Energy Alliance and CH2M-WG Idaho

Start Date: 2005

Characterization & monitoring of groundwater in fractured rock environment. Well installed in multiple phases through to present and continue in operation.

U.S. Department of Energy Hanford Site, Richland, WA

Client:	Pacific Northwest National Laboratory
Start Date:	1988

Evaluation of Westbay System monitoring wells as compared to conventional well clusters for characterization and monitoring of groundwater conditions at the Hanford Reservation. Concluded that the Westbay System can yield representative data while eliminating the need for repeated purging of the monitoring zones and providing significant cost savings due to reduced drilling.

The Westbay System wells were also used for automated monitoring of multiple zones during pumping tests to evaluate advanced methods for testing the permeability of highly-transmissive alluvial deposits without withdrawing water.

Industrial Facility, Albany, OR

Client:	CES Consultants, Portland, OR
Start Date:	1996

Groundwater characterization and monitoring in unconsolidated alluvial sediments at an industrial facility.

Boeing Aircraft Plant, Auburn, WA

Client:	Dames & Moore Consultants, Seattle, WA
Start Date:	1984

Investigation of groundwater conditions in silts and sands underlying an operating industrial facility in order to establish compliance with RCRA regulations.

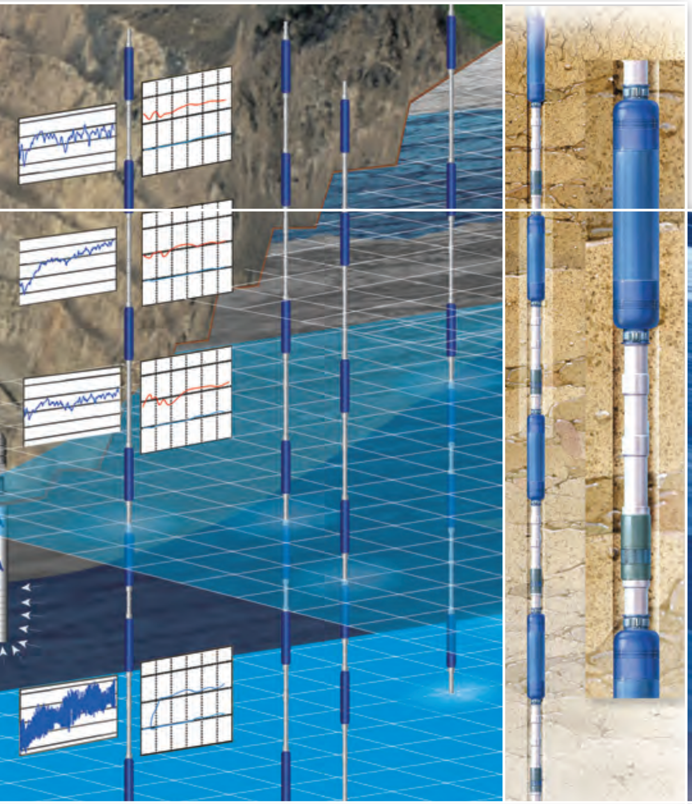
Western Processing Site, Kent, WA

Client:	CH2M Hill for U.S. EPA
Start Date:	1984

EPA-funded small-scale trial of the Westbay System for monitoring at an NPL hazardous waste site. The site has since entered remediation and the monitoring well has been destroyed.

Attachment B:
Westbay System Brochure

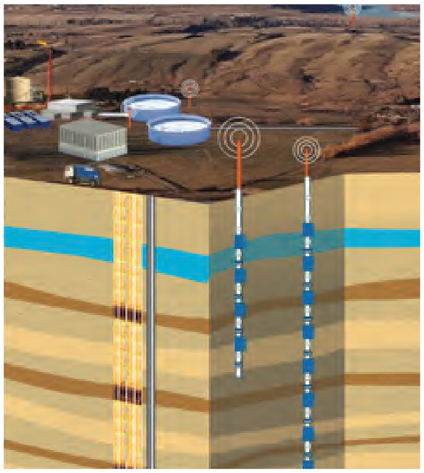
Westbay
Instruments



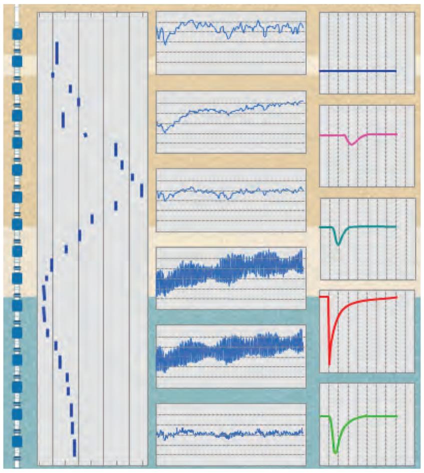
Westbay System

Multilevel Technology for Subsurface Characterization and Monitoring

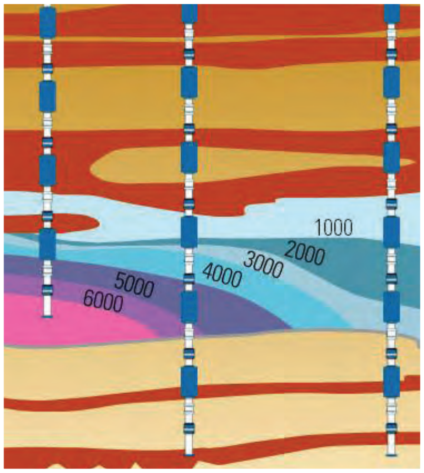
Is Groundwater Monitoring Important?



Environmental monitoring for unconventional oil and gas



4D subsurface characterization using Westbay technology



Characterization of contamination plume using Westbay System

WHY GROUNDWATER MONITORING?

Groundwater is an essential resource of great social, environmental and economic importance. With continuous population growth and industrial expansion impacting the state of groundwater around the world, implementing comprehensive groundwater management strategies is critical.

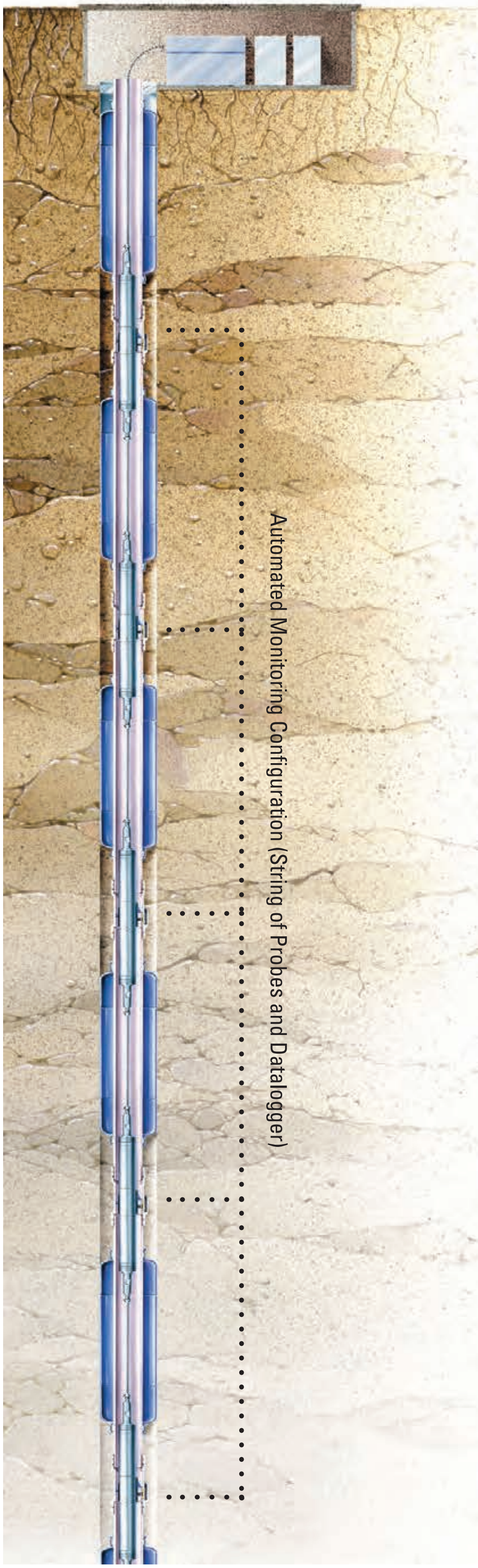
As an essential component of water management, groundwater monitoring networks are designed to optimize the collection of vast amounts of field data during the life of a project. Collection, analysis, and management of water levels and water quality parameters provide fundamental baseline information necessary for identifying potential risks and managing groundwater as a sustainable resource.

Groundwater monitoring networks:

- provide baseline data to map the spatial and temporal distribution of water quality
- identify short-term changes to groundwater flow from pumping, natural recharge and discharge, agricultural and industry use
- isolate impacts to groundwater from contaminant spills and releases
- present early warning of potential risks and the need for mitigation measures
- offer real-time accounting of water use and compliance with regulatory guidelines

OUR SOLUTION

Since 1978, the Westbay* System has provided its clients with a cost-effective, multilevel monitoring technology designed for long-term groundwater monitoring and data acquisition. The Westbay System is designed for collecting subsurface data at any number of discrete positions within a single well. Under even the most complex hydrogeologic conditions, this completely customizable system is a cost-effective, reliable solution that surpasses traditional monitoring methods.



Automated Monitoring Configuration (String of Probes and Datalogger)

Westbay System

Flexible, industry-tested design offers *Superior Performance*

OVERVIEW

The Westbay System is a completely versatile, multilevel monitoring technology that allows testing of hydraulic conductivity, monitoring of fluid pressure and collection of fluid samples from multiple zones within a single borehole. Designed for reliability and defensibility, the Westbay System can accommodate a wide variety of borehole conditions including diameter, depth, temperature and chemistry considerations.

Westbay System advantages:

- obtain measurements and samples at any number of discrete locations along a single borehole
- collect samples without purging
- designed for long-term monitoring
- engineered to operate at great depths
- reduced drilling and installation costs, with minimal site disturbance
- removable probes allow for convenient calibration and servicing
- built-in defensible QA/QC procedures

WELL COMPLETIONS

Westbay Systems are engineered with a unique, customizable casing system. The casing system is available in two sizes (MP38 and MP55) and manufactured from plastic or stainless steel to fit various borehole dimensions and operational requirements. Hydraulically-inflated packers and/or backfill provide engineered seals between monitoring zones, preventing unnatural flow and cross-contamination. Valved ports in the zones provide access for monitoring, sampling and hydraulic testing.

Westbay Systems can be installed in a number of different ways to suit geologic conditions, drilling methods, and project objectives.

Completion methods include:

- packers in open borehole
- packers through temporary casing
- packers in a cased well
- packers in cemented and perforated well
- direct backfill

WESTBAY SYSTEM PROBES

A variety of probes are available for use with the Westbay System. Reliable, accurate, and portable wireline-operated probes can be lowered into the casing system and used to:

- measure groundwater pressure
- test hydraulic parameters
- collect samples in-situ
- perform system specific tests

COLLECTING GROUNDWATER SAMPLES

Westbay Systems offer the unique ability to collect discrete fluid samples at formation pressure. For sample collection the probe and sample container are lowered to the desired depth, where the sample is collected into the container. The probe and container are then retrieved to the surface for further analysis.

Westbay System sampling allows you to:

- collect samples with minimal disturbance and without repeated purging
- maintain samples at formation pressure
- monitor pressure during sampling
- document quality assurance

① PACKERS

- Engineered seal in a range of borehole sizes
- No dedicated inflation lines
- Controlled hydraulic inflation with record of pressure and volume
- Quality control tests to confirm performance at any time after installation

② MEASUREMENT PORT

- For fluid pressure measurements, fluid sampling and low-k testing

③ PUMPING PORT

- For purging, hydraulic conductivity testing, and quality control testing.

Accurate, reliable long-term monitoring delivers *Definitive Results*

MEASURING GROUNDWATER PRESSURE

Westbay pressure probes can be used to take periodic, manual measurements of in-situ fluid pressures or to automatically monitor pressures using telemetry.

With a single probe, pressures are measured one port at a time. The output from the probes is digitized and transmitted through a rugged but lightweight wireline to a control unit at the surface. By attaching a standard laptop to the interface, data can easily be downloaded and stored for interpretation and analysis.

For automated multilevel measurements of fluid pressures, a string of pressure probes can be distributed down the well with each probe located at a selected measurement port. Each probe has a unique identity, allowing them to be polled individually or simultaneously by the datalogger.

Westbay Systems allow you to:

- measure pressure at multiple locations in a single well
- measure manually or automatically
- redeploy probes in alternate locations
- select from a variety of logging modes
- perform in-situ calibration checks
- document quality assurance

TESTING HYDRAULIC PARAMETERS

Westbay technology provides many effective methods for evaluating and testing the hydraulic characteristics of a site.

Discrete monitoring ports offer the unique ability to observe and record details within a single well.

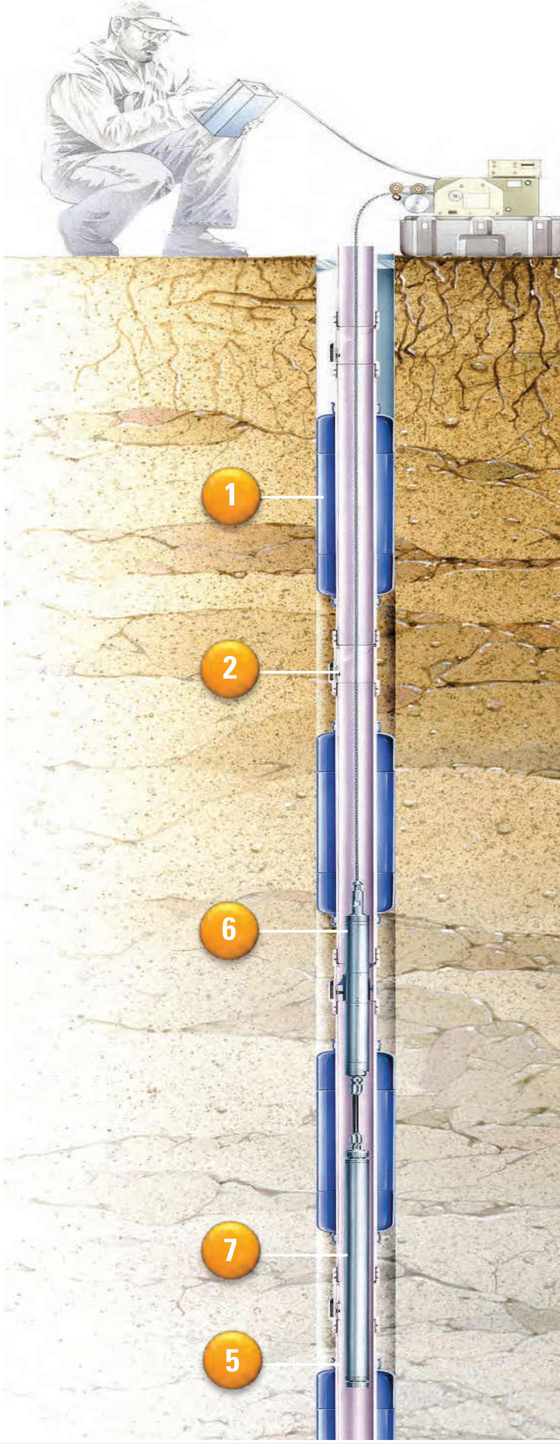
Westbay Systems allow you to:

- observe detailed distributions of groundwater pressures
- observe the effects of pumping tests or changes in barometric pressures
- gain insight into permability variations
- generate a stress in a monitoring zone and observe responses of neighbouring zones and wells

A number of qualitative and quantitative tests can be performed to determine the hydraulic parameters of formation materials or to verify the operation of the system.

- single-zone tests
- slug tests
- pulse-interference tests
- constant-head tests
- vertical interference tests
- cross hole tests
- tracer tests

As part of a complete environmental monitoring project, Westbay Systems are engineered to meet the rigorous demands of a wide range of operations. Westbay Systems provide the highest level data quality necessary to support critical decisions.



4 CENTRAL ACCESS CASING

- Made of plastic (PVC) or stainless steel
- Two sizes: 38 mm [1.5 in], 55 mm [2.2 in]
- Operational capability to depths of 1,200m [4,000 ft]

5 SEALED CONNECTIONS

- All casing connections sealed by o-rings

6 SAMPLER PROBE

- Independently controlled sampling valve
- Silicon strain-guage pressure transducer
- Location/activation mechanism compatible with Westbay System

7 SAMPLE CONTAINER

- Maintains sample pressure during recovery
- Easy to clean

Applications

Groundwater Resource Management

- Groundwater basin management
- Manage aquifer recharge operations
- Seawater intrusion
- Detailed long-term monitoring

Contaminant Site Investigations

- Site characterization
- Plume delineation
- Remediation design and performance monitoring

Geologic Repositories

- Site characterization
- Determine feasibility of underground disposal site

Geotechnical Projects

- Monitoring of pore pressure, slope stability for tunnels, subsidence and drainage
- Groundwater pressure monitoring at large dams

Mining

- Pre-feasibility planning and support
- Subsurface characterization and monitoring
- Acid rock drainage assessment and control
- Monitoring of leach operations
- Environmental impact assessment and site closure
- Sub-permafrost groundwater monitoring

Unconventional Oil and Gas

- Site characterization to reduce risk and minimize regulatory pushback
- Evaluation of water management alternatives
- Optimum placement, design and construction of injection wells
- Compliance monitoring and minimization of cross-contamination
- Closure design and performance monitoring

Features and Benefits

Features

- Unlimited number of monitoring zones in a single well
- Additional data at small incremental cost
- Sealed monitoring zones
- Collect water samples without repeated purging
- Automated pressure monitoring at multiple depths
- Wide suite of hydraulic test methods
- Removable and upgradeable probes
- Improved security
- Excellent field quality control procedures
- Custom components available to meet operational requirements

Benefits

- Improve understanding of hydrogeological conditions and contaminant transport
- Minimize drilling cost and time
- Reduce site disturbances
- Minimize wellbore storage effects
- Minimize cross-contamination
- Increase confidence in data
- Reduce health, safety and environmental risks

Operating worldwide since 1978

Over 2000 wells installed

www.westbay.com

WB-15-09-25 Printed in Canada.

Attachment C:
Westbay System Technical Paper

Multi-Level Groundwater Monitoring with the MP System®

Abstract

Defining the extent of a groundwater contaminant plume in geologic materials requires a three-dimensional array of sampling points. Such an array is commonly installed by placing a single access tube and inlet screen in each of a series of boreholes. With this method, the number of sampling points at a given site is generally limited by the high cost of drilling. An alternative is to install monitoring points at many levels in each borehole. Multi-level monitoring can provide increased data density and therefore an improved understanding of site conditions. This paper describes how the MP System®, one type of multi-level monitoring well, is installed and operated. Field quality control procedures, 1) to verify the integrity of the access tube, inlet valves, and borehole seals, and 2) to confirm the operation of measuring and sampling equipment, are also discussed.

Introduction

When groundwater contaminant plumes are suspected of having significant depth as well as lateral distribution, a three-dimensional array of monitoring points is needed to identify and characterize such plumes. Thus, groundwater data must be obtained from a number of different locations and from a number of different depths at each location. As a result, either a large number of boreholes are required, each with a separate instrument installed, or instruments must be combined and installed at multiple levels in each of a smaller number of boreholes.

Multi-level groundwater monitoring devices have been described by many writers, some discussing the technical benefits and others the advantages to schedules and costs which can result when multi-level monitoring devices are used to reduce the number of boreholes required. Most important, however, are the advantages that accrue from the increased data density and from the field verification procedures that are available. The very fact that one is capable of accessing several different discrete zones in one monitoring well provides a testing and verification capability that is simply not possible in a single-level device such as a standpipe monitor well.

The basic requirements of any groundwater monitoring system are that it provide the user with the ability to measure fluid pressure, purge the monitoring zone, collect fluid samples, and undertake standard hydrogeologic tests, such as permeability tests and tracer tests. In addition, quality assurance plans for groundwater monitoring programs have led to a requirement for periodic testing and calibration of all aspects of groundwater monitoring devices.

Quality assurance plans normally require field verification tests immediately following installation and again at periodic intervals during the operating lifetime of the installation. In fact, few groundwater monitoring devices are designed to allow extensive field verification tests to be carried out. However, some types of multi-level monitoring instruments, such as the MP System® developed by Westbay Instruments Inc., were designed with field verification tests in mind (Patton and Smith, 1986). With such systems, questions of data quality can be readily addressed.

General Description of the MP System

The MP System is a modular multi-level groundwater monitoring device employing a single, closed access tube with valved ports. The valved ports are used to provide access to several different levels of a borehole through a single well casing. The modular design permits as many monitoring zones as desired to be established in a borehole. Furthermore, at the time of installation, zones may be added or modified without affecting other zones or significantly complicating the installation. As a result, the number and location of monitoring zones can be decided based on the information obtained during drilling. Only a broad scope of requirements need be defined in advance of drilling.

The MP System consists of casing components, which are permanently installed in the borehole, portable pressure measurement and sampling probes, and specialized tools. The casing components include casing sections of various lengths, regular couplings, two types of valved port couplings with different capabilities, and packers, which seal the annulus between the monitoring zones. The MP System has been used in many different geologic and climatic environments in boreholes ranging from a few feet to over 4,000 ft (1,200 m) in length. The 1.5-inch (38 mm) I.D. MP38 System has been used in the field since 1978, while the 2.25-inch (55 mm) I.D. MP55 System was developed in 1990-91.

Casing Components

The casing components of the MP System are made in either plastic or stainless steel. While the illustrations are of plastic components, the descriptions of operating principles that follow apply to both types of materials. Most of the components referred to are shown in Figures 1 and 2.

Casing

MP casing is supplied in a number of different lengths to provide flexibility in establishing the position of monitoring zones and associated seals in the borehole. Common nominal casing lengths are 2 ft (0.5 m), 5 ft (1.5 m) and 10 ft (3.0 m). Actual casing lengths are less than the nominal lengths to account for the lengths of the couplings. The casing ends are machined to mate with MP System couplings.

Telescoping casing sections are used to protect the casing string from damage when ground movements are anticipated or where measurements ofvertical displacements are desired.

Regular Couplings and End Caps

MP regular couplings are used to connect casing lengths where valved couplings are not required. The couplings incorporate O-rings for a positive hydraulic seal. A flexible shear rod provides a tensile connection. No adhesives are used when joining casings and couplings. MP38 regular couplings incorporate an internal, helical shoulder for the accurate location of probes and tools in the well. MP55 regular couplings do not incorporate a helical shoulder.

End caps are placed on the bottom of a casing string. They also incorporate an O-ring seal so that the entire casing string is hydraulically sealed during installation. End caps are frequently used to seal the top of the casing between monitoring periods.

Valved Couplings

There are two types of valved couplings, measurement port couplings and pumping port couplings. Measurement port couplings (or measurement ports) are used where pressure measurements and fluid samples are required. In addition to the features of a regular coupling (including the helical shoulder in the case of MP55), measurement ports incorporate a valve in the wall of the coupling, a leaf spring which normally holds the valve closed, and a cover plate or screen which holds the spring in place. When the valve is opened, an access port is provided for the groundwater to enter the coupling.

Pumping port couplings (or pumping ports) are used where the injection or withdrawal of larger volumes of fluid is desired than would be reasonable through the relatively small measurement port valve (such as for purging or hydraulic conductivity testing). Pumping ports incorporate a sleeve valve, sealed by O-rings, which can be moved to expose or cover slots that allow groundwater to pass through the wall of the coupling. A screen is normally fastened around the coupling outside the slots.

Annulus Seals

When there are many monitoring zones in a single borehole, multiple seals are required to prevent fluid migration from one zone to another along the annular opening between the borehole wall and the casing. Placement of these seals can be difficult with any groundwater monitoring device. However, considerable success has been achieved with three types of well completion used with the MP System, provided each is combined with appropriate drilling and placement methods.

With the MP System, seals can be obtained by:
a) backfilling with alternating layers of sand and bentonite or grout, b) using hydraulic (water) inflated packers or
c) using packers inside a cased well with multiple screens. Figure 1 illustrates a borehole containing the MP System with packers. Figure 2 illustrates a single measurement zone where the MP System is completed by each of the three common methods. Each sealing method is possible in most environments, but in many situations one method will stand out as the most advantageous.

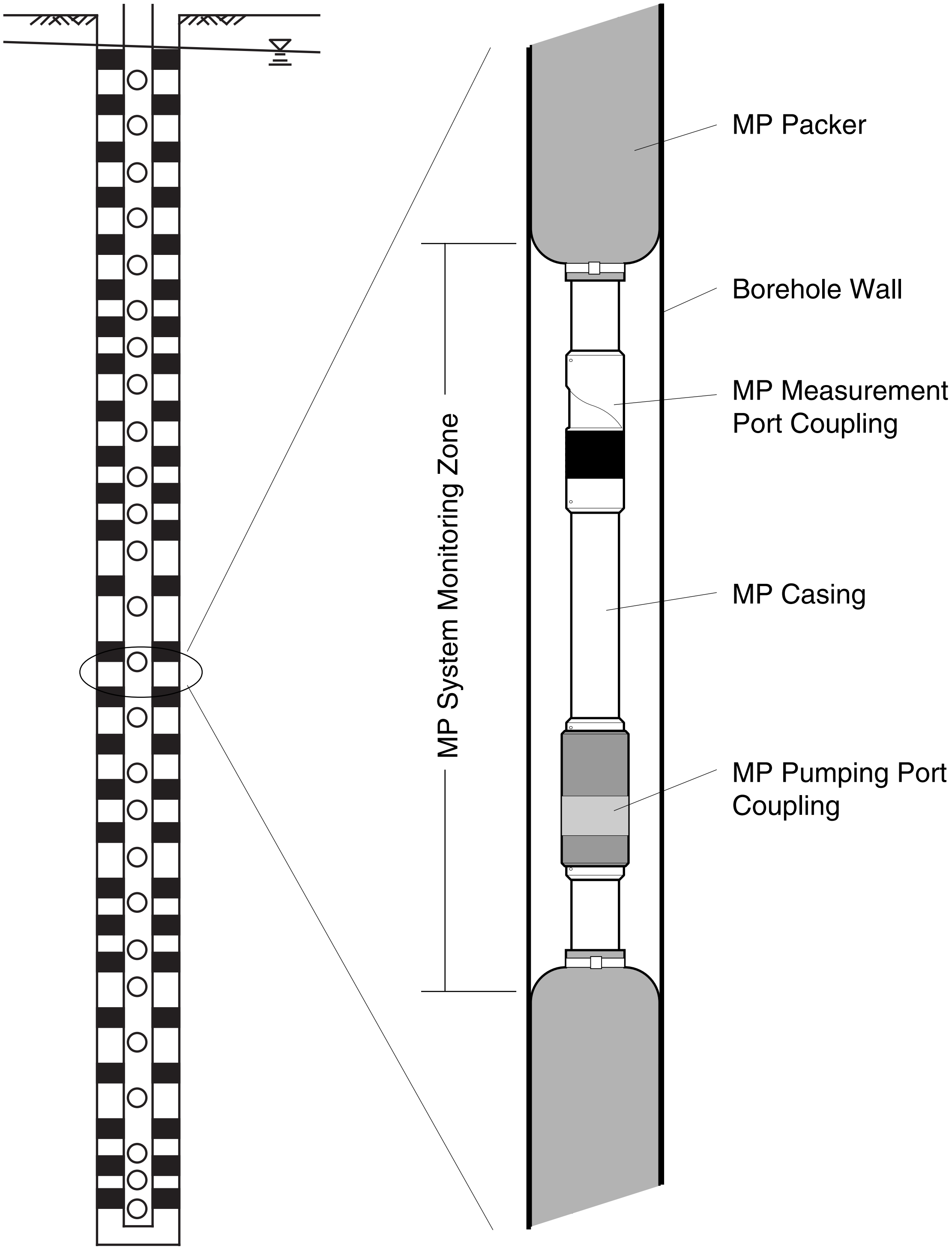
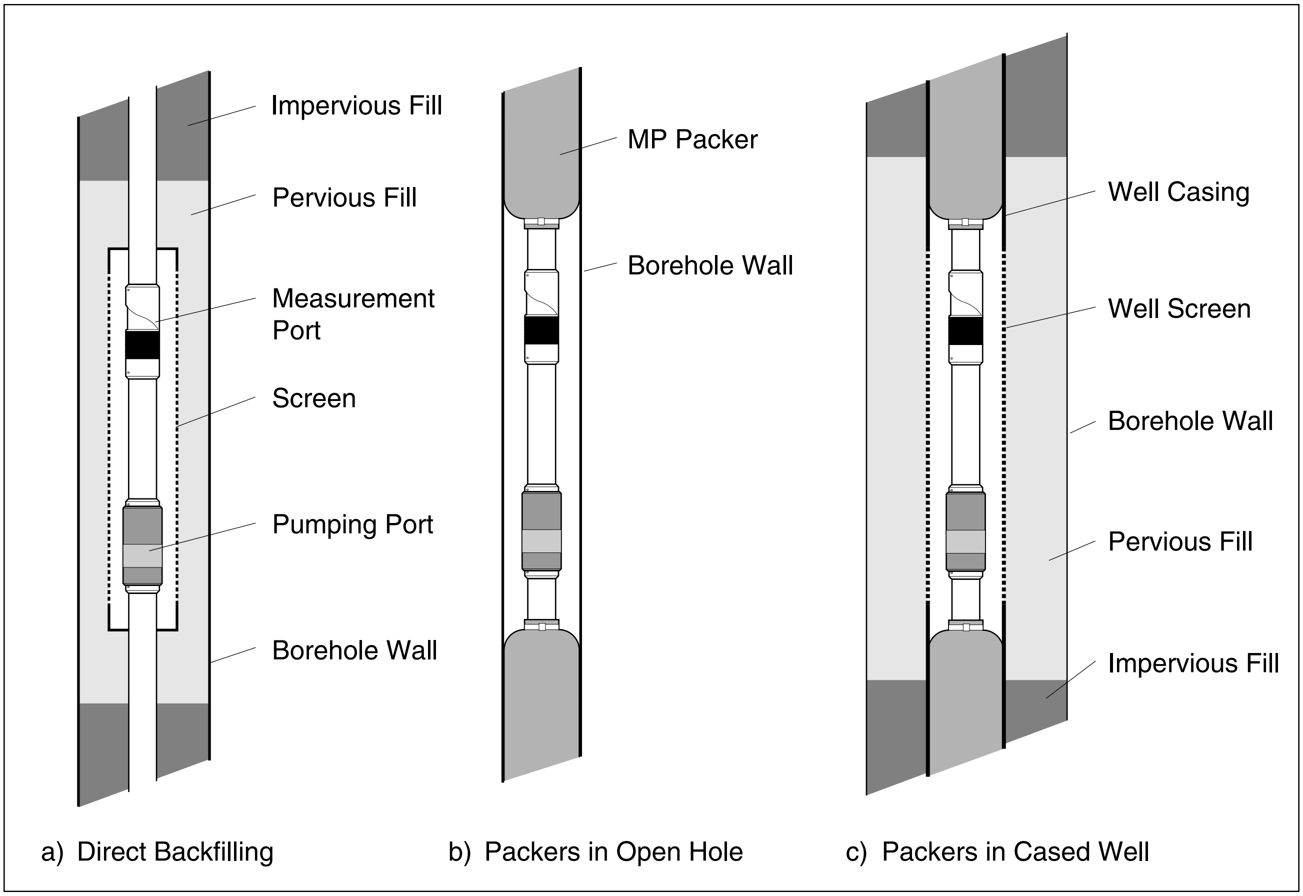


Figure 1. MP System installation with monitoring zones isolated by packers.



a) Direct Backfilling b) Packers in Open Hole c) Packers in Cased Well

Figure 2. Common completion methods for the MP System.

Direct backfilling (Figure 2a) is recommended for: 1) large diameter boreholes, 2) shallow boreholes, 3) boreholes where little or no fluid circulation is anticipated in the hole during installation (i.e., when near-hydrostatic fluid pressures or low hydraulic conductivity is present over the length of the borehole), and d) where packer gland materials are incompatible with the chemistry of the fluids present.

When direct backfilling is considered and fluid sampling is required, a very clean drilling method must be employed. While the MP System does permit purging of monitoring zones, the small size of the casing (particularly MP38) prevents sufficient energy being generated to develop the monitoring zone.

Backfill seals may include bentonite and / or grout slurries, bentonite chips or pellets or other materials with a relatively low hydraulic conductivity in comparison to that of the natural formations present.

MP casing packers incorporate an expandable gland mounted over a standard length of MP casing. The casing incorporates a one-way valve that allows fluid to travel through the wall of the casing into the packer and prevents this fluid from flowing back out of the packer. Gland lengths are typically 3 ft (~1 m).

Packers in an open borehole (Figure 2b) are typically recommended for: 1) small diameter boreholes (those too small for good quality backfilling to be achieved), 2) deep boreholes, and 3) sealing against significant flows (e.g., flowing artesian conditions) in the borehole. When packers are used, field labour is reduced since packer inflation is generally much faster than backfilling. When using packers, additional measurement ports are installed between monitoring zones. Such additional ports provide additional fluid pressure data for quality assurance (QA) purposes.

Packers in a cased well (Figure 2c) is a completion method that has proven very successful, particularly for environments where available hole sizes are too large for packers and / or where drilling additives, such as mud, must be used. This completion method involves drilling a large diameter hole, typically 12-inch (300 mm) and installing a 4-inch (100 mm) (for MP38) nominal diameter well casing with multiple screens. The well screens are located at all of the desired monitoring levels, based on information gathered during and following drilling. Layers of backfill are placed to provide filters around the well screens and annular seals between. Each monitoring zone is then developed through the well casing. Following development, MP casing, ports and packers are installed inside the well casing. The MP packers are inflated against the inside of the well casing, providing interior annular seals between the monitoring zones. This completion method provides the ability to properly develop mud from deep mud-rotary boreholes, as well as to service the MP System during the operating life of the monitoring well.

Whenever casing packers are used, whether in open boreholes or cased wells, additional measurement ports are installed between monitoring zones for QA purposes. Measurements and tests carried out through these additional "QA ports" enable an evaluation of the effectiveness of each annulus seal. In open hole installations, such additional ports also provide added information on piezometric pressures in the portions of the borehole between primary monitoring zones.

Screens and Filters

Where both pumping ports and measurement ports are being used and the ports are likely to be surrounded by sand fill or collapsed geologic material, a single well screen is generally placed over both the measurement port coupling and pumping port coupling in each monitoring zone as shown in Figure 2a. The screen helps ensure that the zone influenced by pumping through a pumping port coupling will extend to and include the region surrounding the adjacent measurement port coupling. Screen slot size and length should be chosen with a knowledge of local site conditions. If only fluid pressure measurements are required, a simpler fabric filter tube can be placed over the measurement port coupling and clamped at either end. This filter will help maintain the length of the monitoring zone and protect the measurement port valve from fine particles. The filter material should be compatible with the chemistry of fluids present.

Installation Procedures

Selection of Casing Components

The valved couplings (measurement port couplings and pumping port couplings) allow many monitoring zones to be established in a single borehole. Horizons of hydrogeological interest are targeted on the basis of the best borehole geologic and geophysical logs available. An installation log is prepared showing the locations of the casing components. If only fluid pressures are needed, only a measurement port coupling is required in each monitoring zone. If sampling, fluid withdrawal or fluid injection is anticipated, both a pumping port coupling and a measurement port coupling are recommended in each monitoring zone. This is the case illustrated in Figures 1 and 2.

The casing lengths are chosen based on the desired locations of the monitoring zones and sealing elements. This requires an interpretation of the hydrogeologic conditions anticipated in each borehole. Caliper logs and borehole video can be useful in selecting packer locations.

If consolidation or heave is expected along the borehole axis, telescoping casing sections may be used to minimize the opportunity for compressional or tensile forces to damage the casing.

MP Casing Installation

The downhole MP System components - casing, couplings and packers- are laid out at the site of the proposed monitoring well in accordance with the casing installation log. At that time, any last minute adjustments required to make the positions of the monitoring zones and seals match hydrogeologic details of the borehole are completed and the appropriate revisions made to the installation log.

Next, the required coupling is attached to the top of each length of casing. The casing layout is checked again for compliance with the installation log. Serial numbers of measurement ports, pumping ports and packers are recorded, indicating their position on the installation log. The length of all casing sections is measured and recorded on the log.

The casing string is then assembled by lowering the casing segments into the borehole and attaching each successive segment to the adjacent coupling one at a time. As each successive MP casing section is attached to the string in the well, the section number is checked and recorded on the installation log. The coupling joint is then subjected to an internal hydraulic pressure to verify its hydraulic integrity and the test result is recorded on the log. At intervals during placement of the MP System casing clean water is added to the inside of the MP casing to reduce its buoyancy.

In collapsing soil and poor quality rock, MP casing with packers and screens may be installed through flush-jointed guide tube such as drill rods or casing. Table 1 provides ranges of borehole, casing and guide tube sizes for the MP38 and MP55 Systems. Figure 3 illustrates the major stages of installing through a guide tube:
A) Following completion of drilling, the guide tube is positioned in the hole. All parts of the guide tube, including any shoe attached to the bottom, must be flush on the interior and of sufficient inside diameter to permit the MP components to pass through; B) The MP components are assembled and lowered into the guide

System	I.D.		Max. Depth		Borehole/Casing Size		Min. Guide Tube Size	
	in.	mm	ft	m	in.	mm	in.	mm
Plastic MP38	1.5	38	1,500	450	3-4 1/2	75-115	3	75
Steel MP38	1.5	38	5,000	1,500	4-4 1/2	100-115	4	100
Plastic MP55	2.25	55	4,000	1,200	4 3/4-6 1/4	121-159	4 3/4	121
Steel MP55	2.25	55	6,600	2,000	4 3/4-6 1/4	121-159	4 3/4	121

Table 1. Important dimensions for the MP System.

tube in such a fashion that the packers and ports will be correctly positioned in the hole when the bottom of the MP is resting on the bottom of the borehole; C) The guide tube is pulled back to expose a packer and that packer is inflated. The pulling / inflating sequence is repeated until all of the packers have been inflated. More than one packer may be exposed during each pull of the guide tube, depending upon the stability of the borehole walls.

Casing without packers can be placed in various sizes of boreholes, with or without protective casing, as long as the borehole diameter (and casing) is compatible with the backfilling method. Good backfilling techniques involve the use of one or more tremie pipes.

Once the MP casing has been placed in the borehole, the packers are inflated (see Figure 3) or backfill is placed. If the MP casing was lowered inside a guide tube, the guide tube may be withdrawn all at once or in steps as the packer inflation or backfilling operation proceeds. An incremental casing withdrawal can reduce the opportunity for the borehole wall to loosen and cave prior to the placement of seals.

Packer Inflation

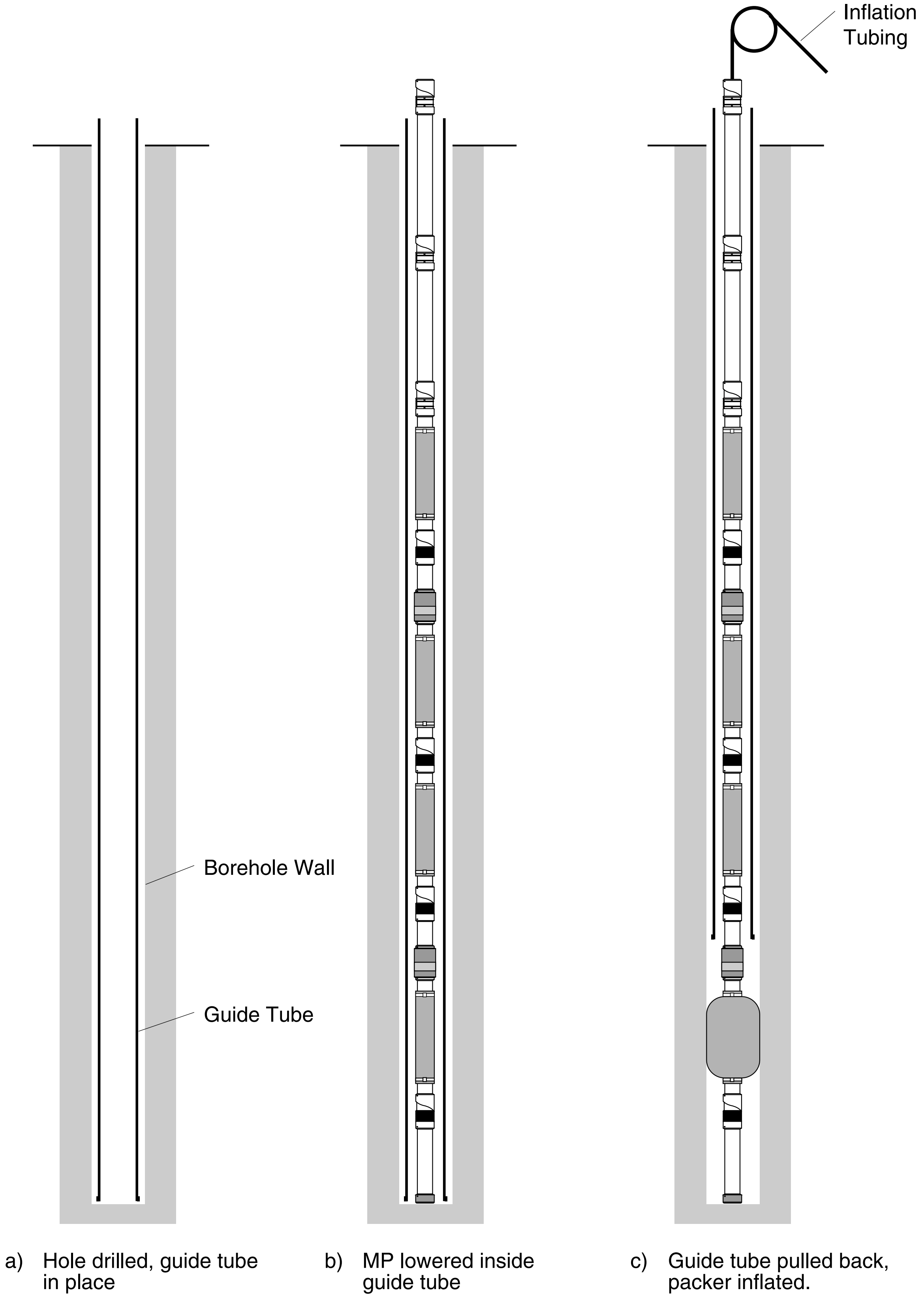
Figure 4a shows the appearance of a casing packer when it has been placed in a borehole before inflation. Figure 4b shows how the MP System casing packers are individually inflated using a packer inflation tool. This tool is lowered down the inside of the MP casing and is located in the correct position by the location arm seating in a coupling adjacent to the packer.

Two small packers (tool packers) are inflated, isolating the short segment of the casing containing the valve for the casing packer. At a pre-set pressure, the tool injection valve opens and water is injected into the casing packer. During inflation the vent-head mechanism on the tool holds open the measurement port beneath the packer. This vents the pressure in the zone below the packer, allowing the packer to square-off without generating unnatural squeeze pressures. Figure 4c shows the inflated MP packer after the inflation tool has been removed. At increments of volume during the inflation process, pumping is stopped and the fluid pressure of the inflation system is measured and recorded. The pressure / volume data is plotted and kept for quality assurance purposes.

Packer inflation proceeds from the bottom of the hole to the top. There are no permanent inflation lines leading to each packer. As a result, there is no limit to the number of packers that can be placed in a borehole apart from the finite limitations of packer length and borehole length.

Purging Monitoring Zones

The strategy for purging the monitoring zones may vary depending on site conditions. Figure 5 shows a typical sequence of events in drilling and completing a monitoring well. Figure 5a shows a typical borehole environment where the invasion of drilling fluids and / or the unnatural circulation of formation fluids has caused groundwater adjacent to the borehole to be nonrepresentative of the formation fluid. Once the casing and annular seals (packer seals are shown in Figure 5b) have been installed, it is usually desirable to remove the nonrepresentative fluid. This removal, or purging, can be done in one of two basic ways: 1) Purging by natural groundwater flow, or 2) Pumping to purge monitoring zones.



a) Hole drilled, guide tube in place

b) MP lowered inside guide tube

c) Guide tube pulled back, packer inflated.

Figure 3. Installation of MP casing through a guide tube.

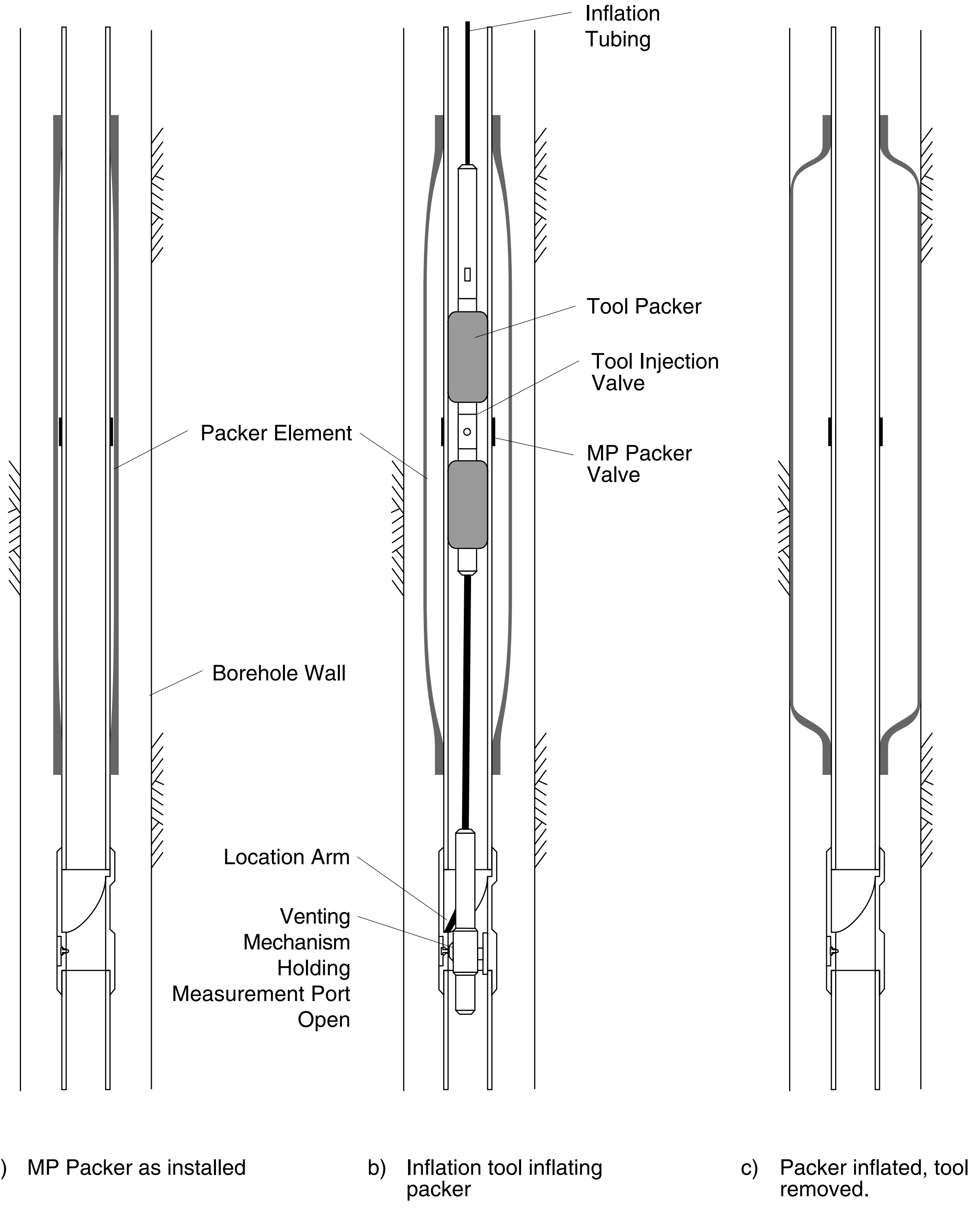
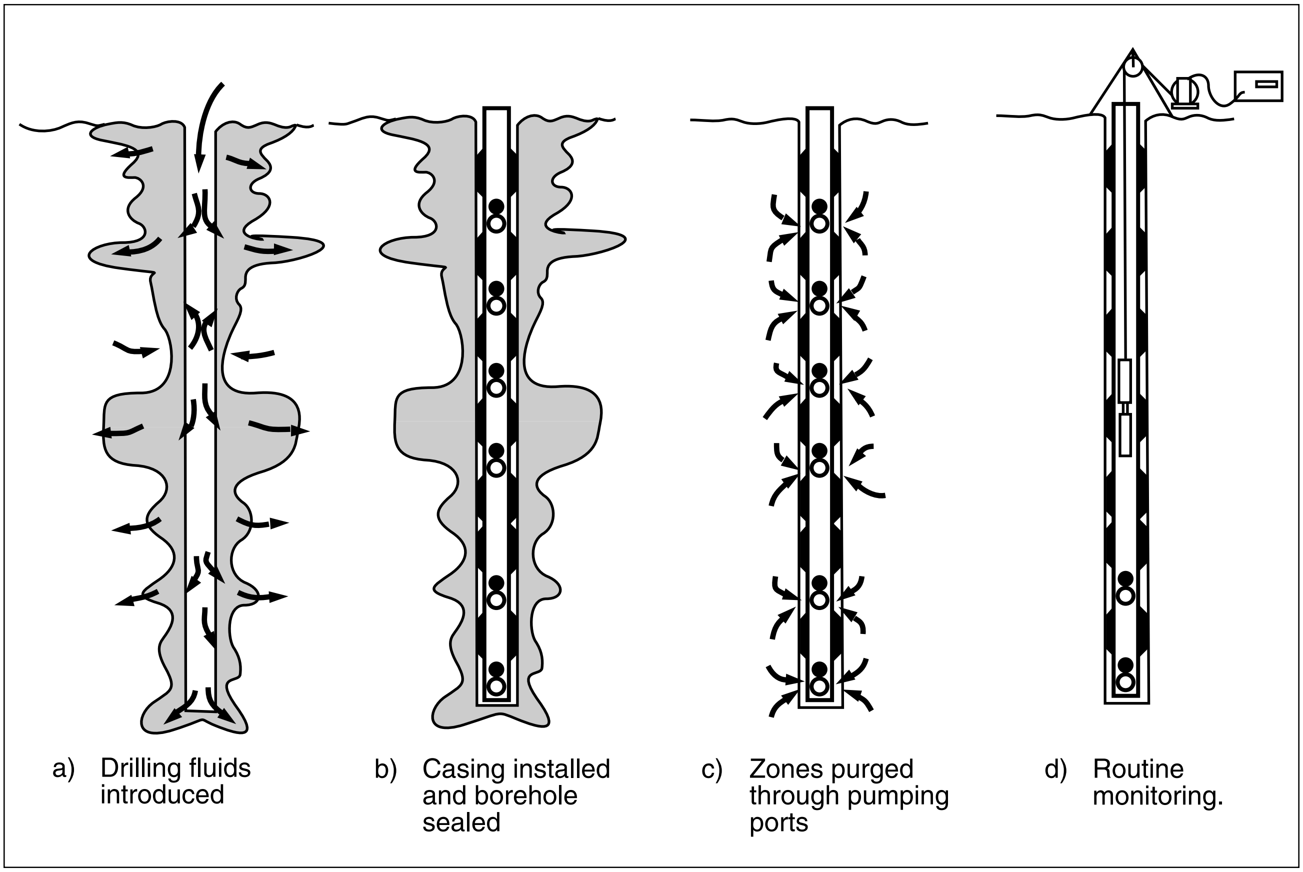


Figure 4. Steps in the inflation of an MP System packer.


a) Drilling fluids introduced

b) Casing installed and borehole sealed

c) Zones purged through pumping ports

d) Routine monitoring.

Figure 5. Typical sequence of events in purging monitoring zones.

Purging by natural groundwater flow is attractive, particularly in environments where groundwater flow is understood to be relatively rapid. In such an environment, unnatural fluids introduced during drilling may no longer be adjacent to the borehole by the time the monitoring system has been installed. In such a case, there may be little to be gained from the investment of time and resources to pumping an arbitrary volume of water from each monitoring zone. Rather, fluid samples might be collected over a period of time and analytical results compared in order to evaluate the stabilization of conditions in the monitoring zone.

When purging by natural flow is not acceptable, monitoring zones can be purged by pumping. Zones may be pumped individually or several at a time (as shown in Figure 5c). Individual hydrogeologists and hydrochemists may prefer different purging techniques depending upon local conditions. However, the purging procedures are essentially the same as would be used for a single standpipe piezometer. One procedure which has been successfully used is described below.

1) An acceptable and convenient tracer is added to the drill fluid during drilling.

2) After the casing has been installed and the packers have been inflated, the pumping ports in all or a portion of the monitoring zones are opened with the use of an open/close tool.

3) Fluid from the inside of the MP casing is pumped out of the well. The volume of fluid removed and the pumping time will depend on many factors including: the drilling method, the length of time the hole was left open prior to completion, the hydrogeological conditions in the borehole, and the accuracy required. The use of a tracer can be helpful in determining when the pumping is completed.

4) Once pumping has been completed, all the pumping ports except one are closed with the use of the open/close tool. With one pumping port open, the MP casing is hydraulically identical to a standpipe piezometer. A quantity of fluid may be pumped from inside the MP casing to complete the development of this monitoring zone. Hydrogeologic testing of this zone and its adjacent casing seals can be done at this time. For example, slug tests can be undertaken to obtain transmissivity and storativity values. This

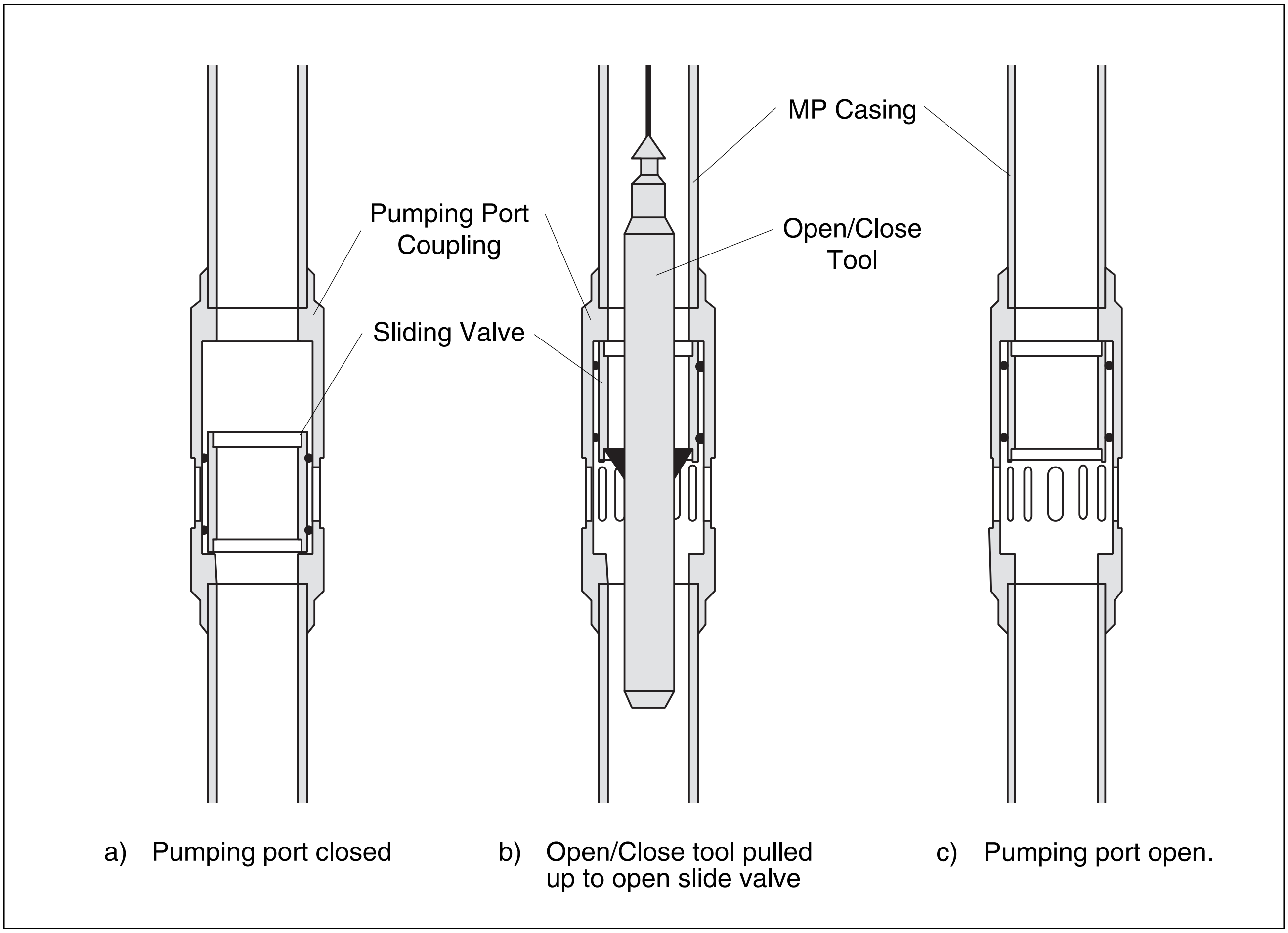


Figure 6. Operation of an MP pumping port.

pumping port can then be closed, the next one opened and the process repeated.

Following purging, the MP System is ready for sampling and for pressure measurements as indicated in Figure 5d.

Operation of the Pumping Ports

To operate the pumping port valve, an open/close tool is used as illustrated in Figure 6. This tool has spring-loaded "jaws" which can be mechanically activated from the surface. The pumping port is shown closed in Figure 6a. To open the valve, the tool is lowered on a wireline with the jaws extended and pointing upward (i.e., so that they will catch on shoulders when the tool is raised). In this condition, the jaws will spring through the couplings as the tool is lowered to just below the desired pumping port coupling. The tool is then pulled up so that the jaws engage the bottom shoulder of the sliding valve. By continuing to pull up on the wireline, the valve can be opened, as in Figure 6b. Once the valve is opened, the jaws can be collapsed into the housing and the tool recovered. With this one valve opened, fluids can be added to or removed from the monitoring interval by injecting or pumping from the MP casing. Other zones may still be monitored in the normal manner using a pressure probe or sampling probe as they will not be hydraulically connected to the interior of the casing.

To close the pumping port coupling, the open/close tool is brought to the surface and the housing is reversed so that the jaws point downward (i.e., the tool will stop on exposed shoulders when the tool is lowered). The tool is lowered to the open pumping port with the jaws collapsed into the housing. Once the tool is located near the pumping port, the jaws are released and the valve is closed by tapping on the top shoulder of the sliding valve with the tool.

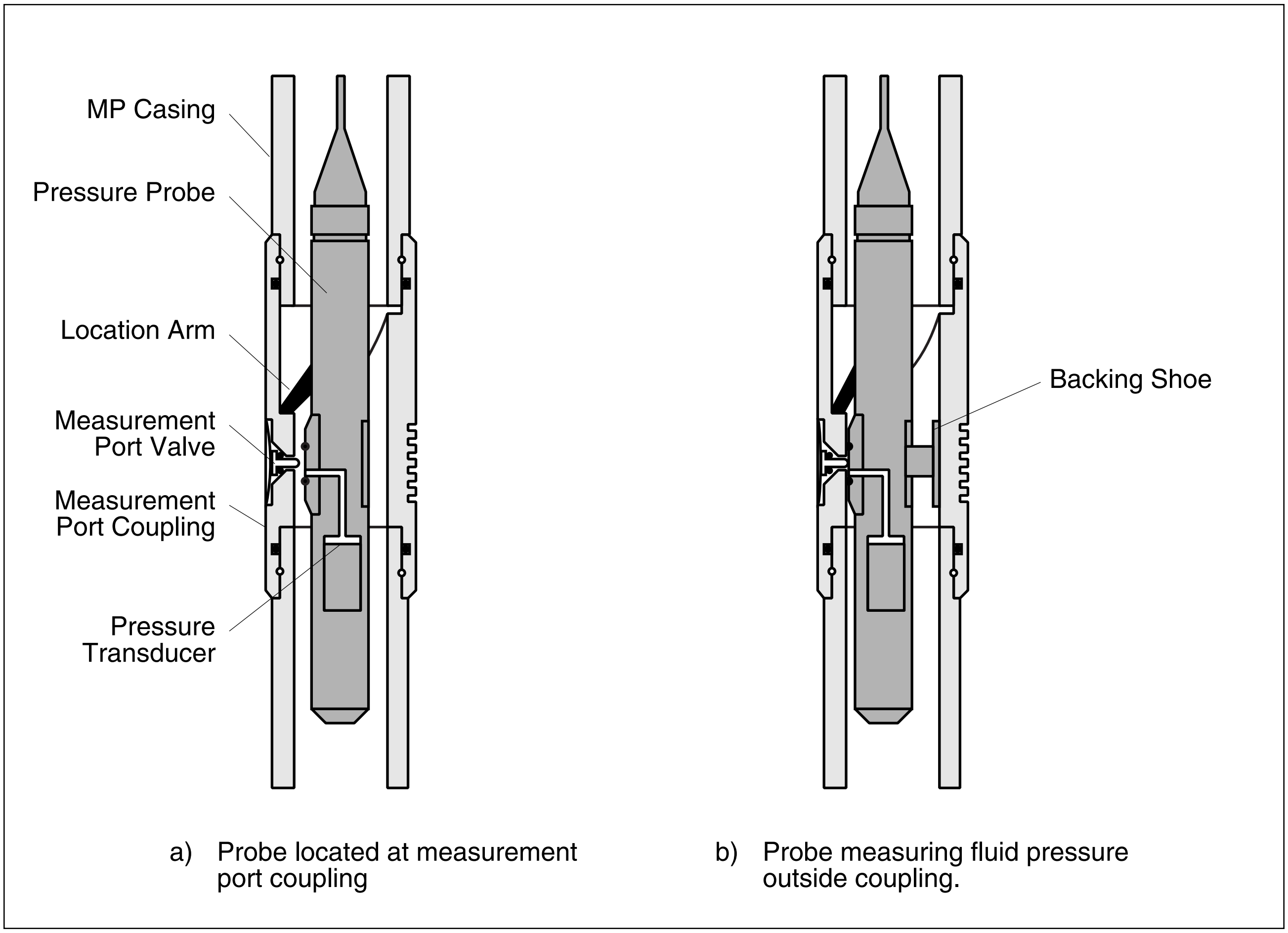


Figure 7. Operation of a pressure probe.

Testing and Monitoring

Fluid Pressure Measurements

Fluid pressure measurements can be made at each location in a borehole where an MP measurement port coupling has been installed. The measurement coupling includes a helical landing ring and a leaf spring valve which is normally closed. The fluid pressure is measured using a MOSDAX® pressure probe which incorporates a location arm, a backing shoe, a face seal, and a fluid pressure transducer. These features are shown on Figure 7. The probe is operated on a cable connected to an interface and portable computer at the top of the monitoring well. Using MProfile™ software, the computer displays the pressure both graphically and digitally, along with transducer temperature, well information and probe status (see Figure 8).

The following procedure is used to make fluid pressure measurements. The probe is lowered to a point below the first measurement port to be accessed (usually the deepest). The location arm is released from within the probe body. The probe is raised to just above the measurement port coupling and then lowered until the location arm rests on the helical landing ring in the coupling. The weight of the probe causes it to rotate into position at the correct depth and orientation to operate the valve (Fig. 7a). At this point the pressure transducer is measuring the fluid pressure inside the MP casing at that depth. This reading will be displayed on the surface computer and is recorded. If convenient, the depth to water inside the MP casing is also measured and recorded at this time as a check on the pressure transducer.

The backing shoe is then activated. It pushes the probe to the wall of the coupling so that the face seal on the probe seals around the measurement port valve at the same time as the face of the probe pushes the valve open. The transducer is now hydraulically connected to the fluid outside the coupling and isolated from the fluid inside the casing (Fig. 7b). The reading displayed on the surface computer will be the fluid pressure in the formation outside the measurement port. The pressure outside the port can be observed as long as desired and recorded as often as desired. After the reading has been recorded, the probe backing shoe is deactivated (retracted) and the valve in the coupling reseals. The probe will again be

Atm Ref: 14.55

PRES: (psi) 36.32

Zone #: 12 : SANDSTONE

TEMP: (C) 27.61

30.00 m. Depth

3.35 m. Elevation

TIME: (elapsed) 00:42

Probe: 001

TRAVELLER

Water OK	NO Collar	Voltage OK	--------	--------

Figure 8. **Data display on surface computer when using MProfile software to operate a MOSDAX pressure probe.**

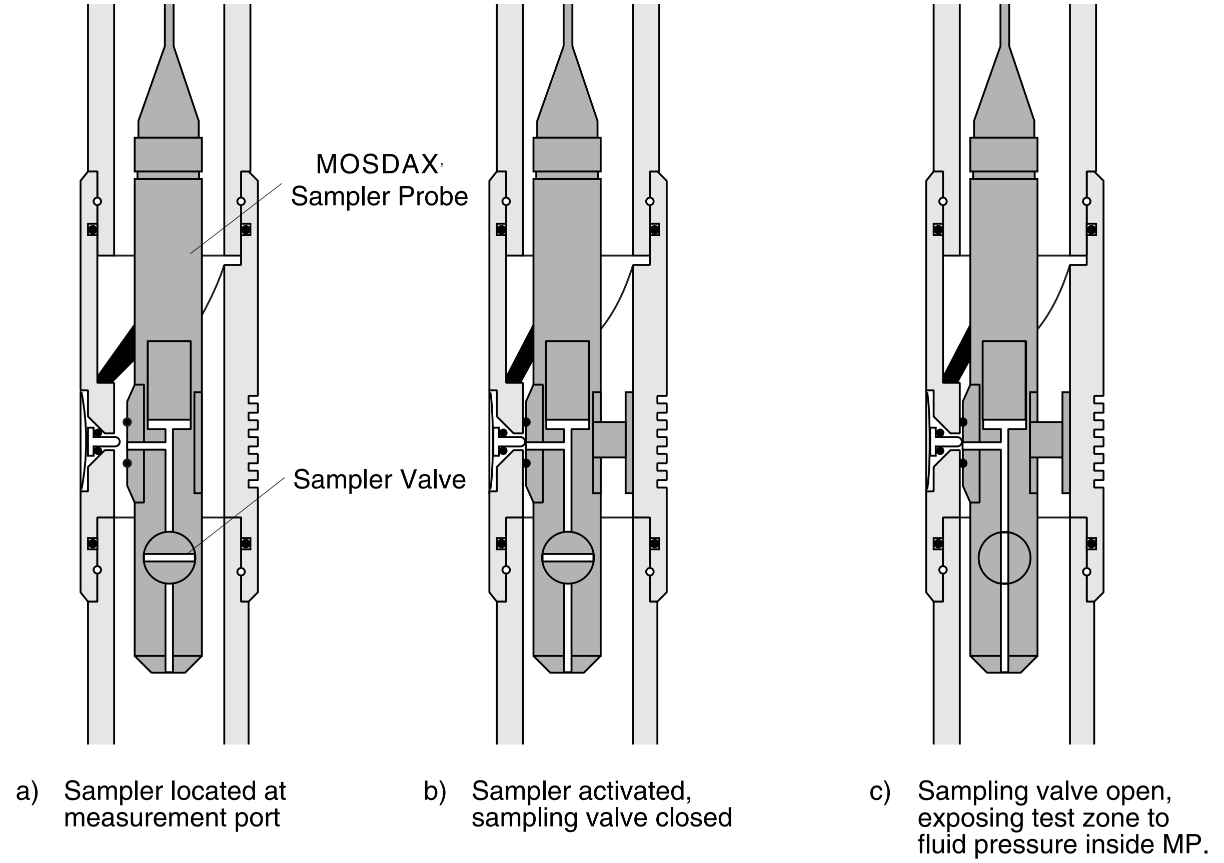
measuring the fluid pressure inside the MP casing (Fig. 7a). The pressure in the casing is again recorded, for quality assurance purposes.

Measuring Pressure in Low Permeability Environments

Very low permeability environments present a special challenge for measuring fluid pressures. When the routine profiling procedures described above are followed, a stable pressure may be observed through the measurement port. However, the act of opening the port may have been sufficient to change the pressure in the monitoring zone, and if the zone is very tight, that pressure change may not dissipate quickly enough to be observed. In such an environment it is always difficult to determine the validity of a static measurement unless some form of dynamic test is carried out as well. In the case of the MP System, this is done throught the use of a MOSDAX sampler probe. As illustrated in Figure 9a), the MOSDAX sampler incorporates all of the features of a pressure probe, plus a valved passage which is controlled via the surface computer. With the sampling valve closed the probe acts identically to a pressure probe and thus may be used for single-probe profiling. The difference is that once the probe is located and activated (Fig. 9b), the fluid level inside the MP casing may be adjusted to a level slightly higher or lower than the piezometric level in the monitoring zone. The sampling valve is then opened (Fig. 9c), exposing the monitoring zone to the fluid pressure in the MP casing. In very low permeability environments, no water will flow during this time. The sampling valve may be kept open for a specified period of time (such as one minute). The sampling valve is then closed (Fig. 9d) and the pressure recovery in the monitoring zone is recorded vs. time (Fig. 10). Standard analytical methods can be applied to the pressure recovery data in order to determine the apparent pressure in the monitoring zone. The same procedure can be used for testing hydraulic conductivity in low-k zones.

Pressure Monitoring Methods

The two principle methods of monitoring fluid pressure with the MP System are illustrated in Figure 11. Single probe profiling (Fig. 11a) involves an operator



a) Sampler located at measurement port

b) Sampler activated, sampling valve closed

c) Sampling valve open, exposing test zone to fluid pressure inside MP.

Figure 9. Using a sampler probe for testing hydraulic conductivity and verifying fluid pressure measurements in low permeability environments.

travelling to each well with a set of portable equipment including a pressure probe, cable and reel, interface and computer. The operator manually locates the probe at each measurement port and carries out fluid pressure measurements one at a time. MProfile stores the data on disk with each record tagged as to the location of the probe in the well, date, time, and probe status. Single probe profiling is generally adequate for monitoring fluid pressure up to a frequency of once per month.

When pressure measurements are desired more frequently than is reasonable for single-probe profiling, or when continual observation and recording of unanticipated events is required, the monitoring well can be configured for automated datalogging (Fig. 11b). Any or all of the measurement ports in a well may be selected for automated monitoring. Lengths of cable are made up to span the distance between each probe and the next. The string of probes and cable is assembled and lowered into the well. The datalogger and a computer are attached at the surface and the lowermost probe is located and activated in the appropriate measurement port. The

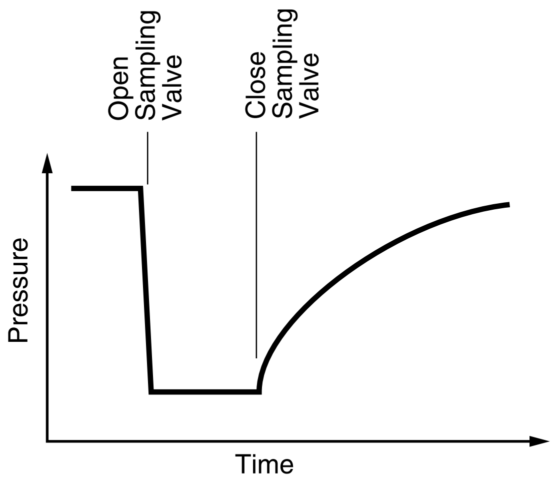


Figure 10. Typical data record from a test in a low permeability zone using sampler.

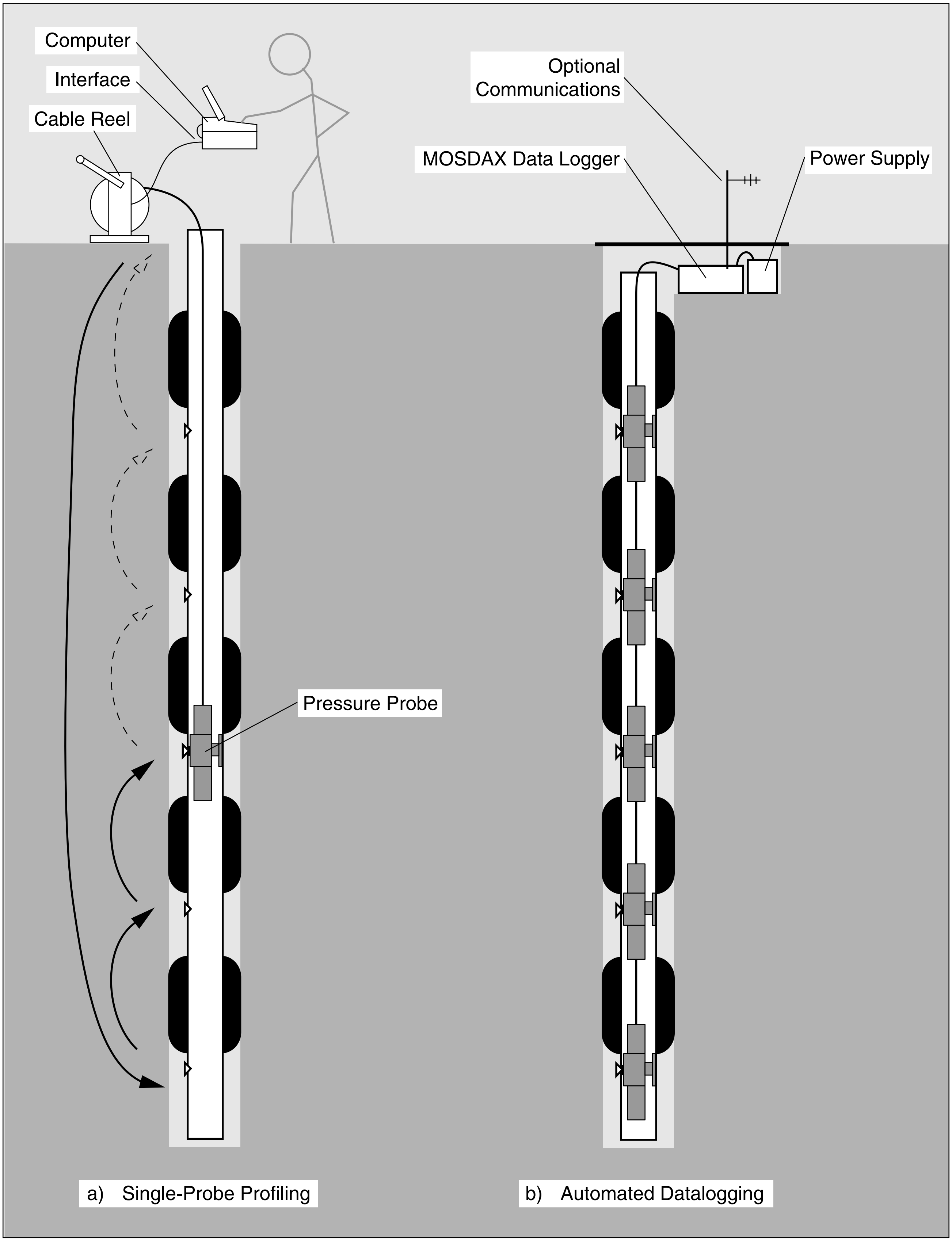


Figure 11. Methods of monitoring fluid pressure with the MP System.

remaining probes are located and activated sequentially from the bottom of the well to the top. Once all of the probes are activated, the computer is used to program the datalogger.

Recording of pressure measurements may be carried out on a simple time basis (e.g., one reading per hour or one per day), or the logger may be programmed to continually scan each probe and record pressures if a specific threshold value is exceeded. Each probe may be assigned an independent threshold (i.e., record data if probe 1's reading changes by 1 ft of water, probe 2 by 3 ft, etc.).

The datalogger may stand unattended, in which case an operator would periodically visit the site to download the stored data, or the datalogger may be connected to a telemetry system such as an RF modem, cell phone system, or landline. When connected to a communication device, a second threshold can be designated for each probe which will cause the logger to transmit an alarm signal to the host computer.

A unique aspect of monitoring in the MP System is that unusual pressure readings can often be verified by means of an in-situ calibration check. When an alarm condition is received, a natural first reaction is to question the validity of the measurement ("is it real, or is it the instrument?"). When datalogging with the MP System, if an alarm were received, the operator can log onto the well via remote communications, deactivate two or more probes including the one causing the alarm and compare their measurements of the fluid pressure within the MP casing. The column of fluid inside the MP casing is independent of all of the monitoring zones and thus serves as a reference pressure source. If the deactivated probes agree on the internal pressure, the alarm condition can be taken to be valid and the probes can be reactivated to resume monitoring. If the probe cauaing the alarm did not agree with the others, instrument error might be suspected. In such a case, an operator could visit the well, remove the string of probes, replace the offending probe and reinstall the string to resume monitoring. The offending probe could then be calibrated and serviced in a laboratory.

Fluid Sampling

Fluid samples are obtained by lowering a sampling probe and sample container to the desired measurement port coupling. As shown on Figure 12, the sampling probe operates in similar fashion to the pressure probe except that a groundwater sample is drawn through the measurement port coupling. Whenever the sampling probe is operated with the sampling valve closed, it is identical to a pressure probe, supplying the same data.

The procedure for taking a groundwater sample is as follows. A clean, empty sample container is attached to the sampling probe. The probe and container are prepared (e.g., evacuated) in a manner suited to the specific project and the sampling valve is closed to prevent the fluid inside the MP casing from entering the sample container. The probe and container are lowered to below the selected measurement port coupling. The location arm is released and the probe is positioned in the measurement port coupling (Fig. 12a). The fluid pressure inside the MP casing is recorded.

The backing shoe is activated and pushes the probe to the wall of the coupling so that the face seal on the probe seals around the measurement port valve at the same time as the face of the probe pushes the valve open. The interior passage of the probe is now hydraulically connected to water outside the coupling (Fig. 12b), but no fluid movement takes place. During this operation the change in fluid pressure is observed at the surface and may be recorded.

The sampling valve in the probe is opened, allowing fluid from outside the measurement port to flow through the probe and enter the sample container (Fig. 12c). The fluid displayed at ground surface drops and then recovers as the fluid in the container builds to formation pressure. Once the container is full, the sampling valve is closed (Fig. 12b), the backing shoe is deactivated (retracted) (Fig. 12a) and the fluid pressure inside the MP casing is once again recorded. The sampling probe and sample container are then pulled to the surface. The sampling probe can then be cleaned, a clean container attached and the procedure repeated.

When using a non-vented sample container, the fluid sample is maintained at formation pressure while the probe and container are returned to the top of the well. Once recovered, there are a variety of methods of handling the sample:

- the sample may be depressurized and decanted into alternate containers for storage and transport,
- the sample container may be sealed and transported to a laboratory with the fluid maintained at formation pressure,
- the sample may be transferred under pressure into alternate pressure containers for storage and transport.

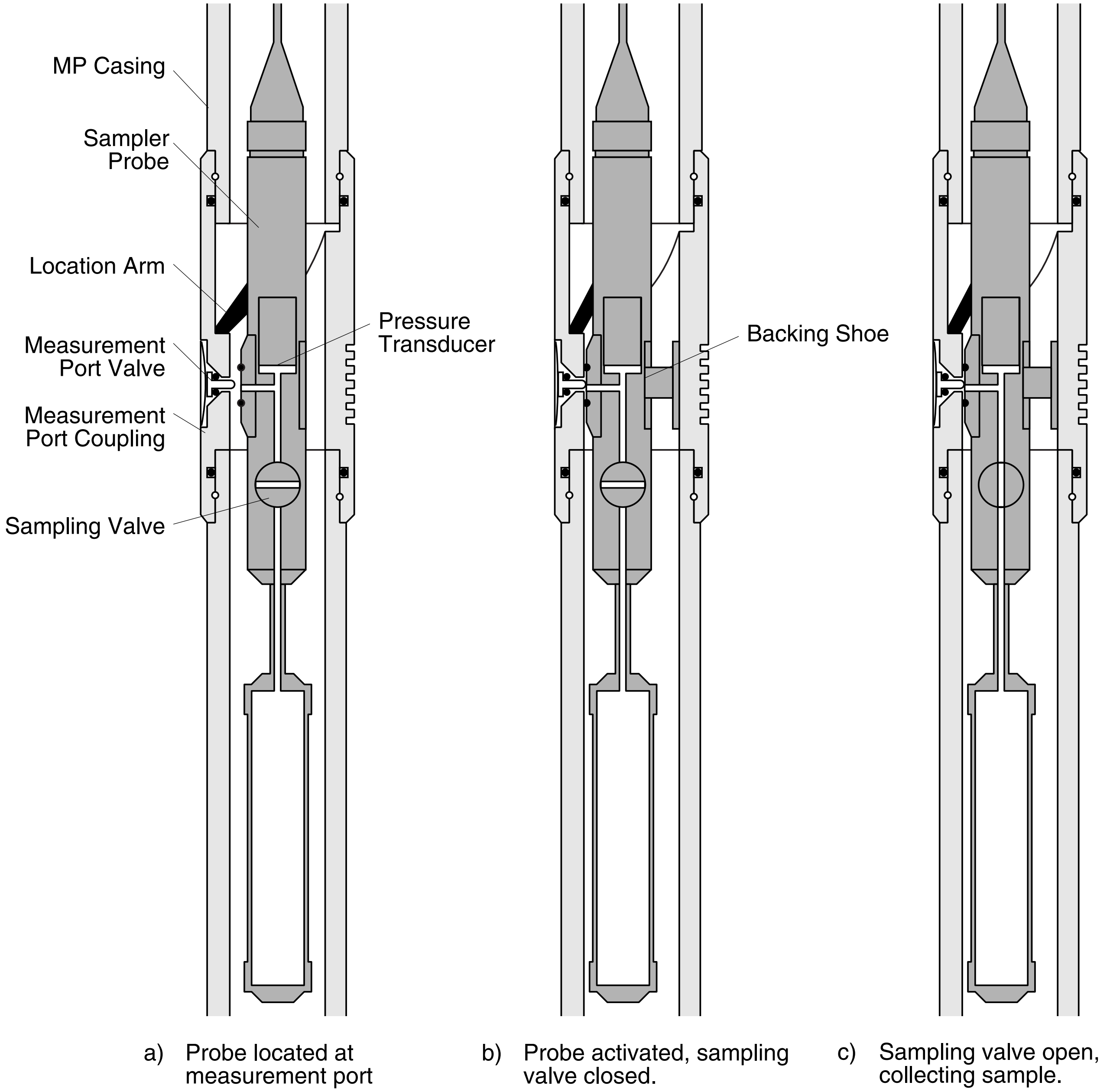


Figure 12. Operation of a sampler probe.

The advantages of this discrete sampling method can be summarized as follows:

1) The sample is drawn directly from formation fluids outside the measurement port. Therefore, there is no need for pumping a number of well volumes prior to each sampling event. Because there is no pumping prior to sampling, the sample is obtained with minimal distortion of the natural groundwater flow regime, the storage and disposal of large volumes of hazardous purge fluids is eliminated, and operator exposure to hazardous fluids is reduced.
2) The lack of pumping means samples can be obtained quickly, even in relatively low permeability environments.
3) The sample travels a short distance into the sample container, typically from 1 to 2 ft (0.3 to 0.6 m), regardless of depth.
4) The risk and cost of storing and disposing of hazardous purge fluids is virtually eliminated.

Hydraulic Conductivity Testing

A variety of different test methods can be employed to measure the hydraulic conductivity of formation materials with the MP System. These include variable head, constant head and pressure-pulse tests.

Variable head tests are the single well test method most commonly used with the MP System. Using these types of tests in the MP System, hydraulic conductivities between 10^{-2} and 10^{-8} cm / sec can be measured.

For variable head tests the valved pumping port couplings are used to provide the hydraulic connection between the interior of the MP riser tube and the test zone. In cases where monitoring zones are to be purged, it is convenient to carry out hydraulic conductivity testing just prior to or following purging. The head (fluid level) inside the MP casing can be adjusted while all port valves are closed, then the selected pumping port can be opened in a controlled manner (pumping port operation is described in the discussion of purging). This allows accurate measurement of both the initial head change and the time at which the head change is applied (t_0). The pumping port valve is opened rapidly (in less than one second), which satisfies the theoretical requirement that an instantaneous head change be applied to the tested zone.

For rising head tests the water level inside the MP casing is bailed or pumped down to a pre-determined level below the static water level in the test zone. For falling head tests the water level is raised to a level above the static water level in the zone to be tested. Measurement equipment is set in place and the pumping port valve is opened. Recovery of the water level in the MP casing is measured and recorded vs. time. A water level tape or pressure transducer is commonly used to record the water level changes. Figure 13 shows a typical record of water levels during a rising head hydraulic conductivity test.

Slug tests are carried out by opening the pumping port coupling at the zone to be tested and allowing the water level in the MP casing to equilibrate to the static water level for that zone with measurement equipment in place. The initial head change is then applied by rapidly lowering a displacement slug (a length of solid rod or sealed pipe) into the water. The recovery of the water level is measured and recorded vs. time. The slug test can be repeated and recorded again when the slug is removed from the water. Figure 14 shows a typical record of water levels during a slug test of hydraulic conductivity.

Data from variable head hydraulic conductivity tests may be analysed using any preferred calculation method. The most commonly used methods are those of Hvorslev (1951), Cooper et al. (1967) and Bouwer and Rice (1976). Selection of these or any other analytical method should be based upon an assessment of how well the test conditions comply with the simplifying assumptions inherent in the analytical method.

In very low permeability environments (hydraulic conductivity less than 10^{-7} or 10^{-8} cm / sec) the formation fluid pressure can be changed with very little fluid movement. As a result, tests can be carried out through the measurement port valve rather than the pumping port valve. Using a sampler probe with a transducer the zone to be tested may be exposed to the fluid pressure inside the MP casing for a period of time (see Fig. 9 and discussion of measuring fluid pressure in low-k environments). The zone may then be shut-in and the recovery of fluid pressure over time measured and recorded. Figure 10 shows a data record from such a test.

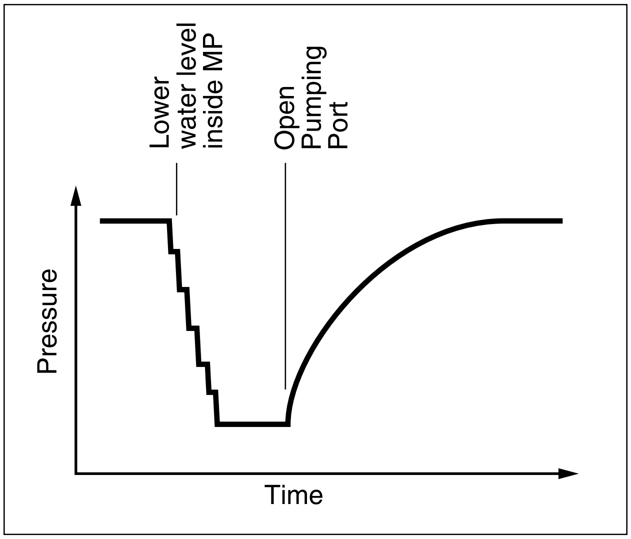


Figure 13. Typical data record from a rising head test.

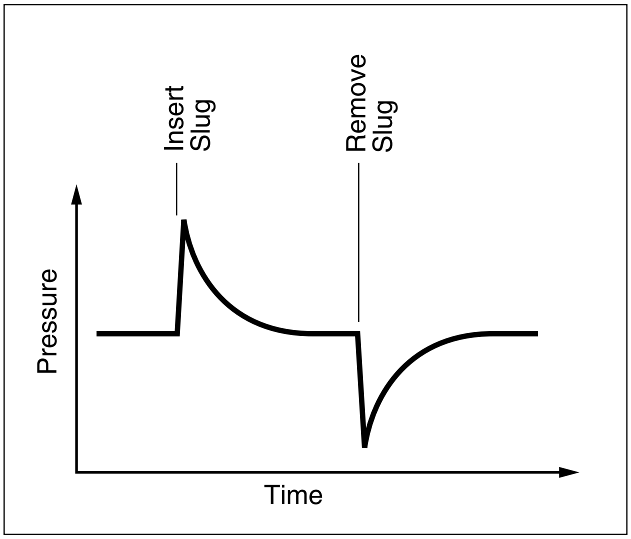


Figure 14. Typical data record from a slug test.

Field Quality Control

There are two distinctive parts to any quality assurance program. The first involves manufacturing and testing procedures which avoid the production or installation of equipment that may result in the collection of erroneous data. The second involves field operational procedures which will ensure that erroneous data are not generated as a result of the failure of any component to function as intended. Although the first part is necessary to allow the installation of useful monitoring wells, the second must also be rigorously applied to identify sources of erroneous and misleading results.

The MP System has many unique features for field quality control which clearly separate it from other types of groundwater monitoring instrumentation. These features are the result of designing components in response to the stringent requirements of users in the fields of nuclear and hazardous waste management.

Quality control tests are carried out at various points during the field use of the MP System and tend to be grouped into three periods: during installation, following installation, and during routine monitoring.

During Installation

During installation of the MP System the following operations form part of the quality control procedures:

Drill core or cuttings and geophysical logs are carefully checked to see that monitoring zones and annular seals are placed at the optimum positions. In cased wells, the well casing is inspected to verify that the interior surfaces are suitable for establishing good quality packer seals and backfill is placed under carefully controlled conditions with frequent measurements of material depths.

Westbay casing components are carefully inspected to see that critical surfaces are undamaged, sealing O-rings are clean and in place, and components are correctly oriented. Serial numbers are recorded along with component position in the installation. These operations link the field quality control to production test results.

As each section of MP casing is attached, the connection is pressurized with water and observed for any signs of leakage. Test results are recorded on the installation log.

During inflation of each MP packer, incremental volumes and pressures are recorded and plotted. These data allow an evaluation of borehole conditions and provide the first indication of the quality of the annular seal obtained.

Following Installation

Immediately following installation further checks are carried out to verify the operation of the system. These include the initial pressure profile which serves to confirm the operation of the inlet valves of the measurement port couplings. Observed head differences across exterior casing seals directly indicate the seal effectiveness. Where such head differences are not observed, the annular seals can be artificially stressed by opening a pumping port in one monitoring zone and withdrawing or adding a slug of water from inside the casing while using the pressure probe to observe the pressure response in the monitoring zone on the other side of the seal. In cased wells and wells in low permeability environments, stresses can be applied through measurement ports in order to evaluate seal integrity.

Additional measurement ports are routinely installed between monitoring zones, further enhancing the ability to carry out thorough quality control tests.

Fluid can be added to packers at any time following installation and the pressure at which further fluid injection occurs can be compared with the injection pressures recorded during the initial inflation.

During Routine Monitoring

A number of quality control checks are built into the routine monitoring procedures.

When measuring fluid pressures, the pressures measured inside the MP casing at each measurement port are recorded immediately before and after the measurement made through the port. These inside casing values serve a number of purposes: 1) comparison of the two values confirms that the transducer was operating the same way after the reading as before, 2) comparison of the inside values from one set of measurements to the next confirms transducer stability over the intervening time period (assuming the water level inside the casing is the same), and 3) if the head of fluid inside the MP casing is known, an in-situ calibration check of head of water versus transducer output is obtained. Any unacceptable changes which show up during monitoring can be checked and corrected through laboratory calibration of the instrument.

Water sampling procedures with the MP System improve quality control because: 1) the short flow path between the formation and the container greatly reduces the surface area contacted by the sample, 2) the contacts between the water sample and the atmosphere are eliminated, 3) observing and recording the water level inside the MP casing during sampling confirms that the sample obtained is from outside the casing, and 4) sampling without purging reduces the disturbance of the natural system, minimizing unnatural changes in chemistry. Sampling methods can be varied to compare the effects of atmospheric contact versus no atmospheric contact and maintaining the sample under pressure versus allowing depressurization of the sample.

During water sampling, sample blanks and spikes may be collected using identical procedures for sampling, preservation, handling and shipping. Travel blanks and spikes may also be collected using identical procedures for handling, preservation and shipping. The chemical analyses of samples obtained using the MP System may be compared with those of samples collected from the same zone by alternate means.

Finally, the pumping port may be reopened should further purging appear to be desirable.

For both fluid pressure and water quality data, the MP System can provide corroborative data. That is, a high density of data can be obtained in a single installation so that significant changes in piezometric pressure and / or water quality can appear as transitions along a depth profile. Thus, neighboring values will corroborate one another rather than indicating abrupt changes which would cause one to question anomalous values.

Serviceability

In the event that quality control testing should reveal a component which is not operating properly, various steps can be taken to remedy the problem including, if certain cases, removing the MP casing string, replacing faulty components and reinstalling the string.

Table 2. Summary of major quality control aspects of the MP System.

Provides the Ability to Verify	
Well Integrity	✓
Individual Seals	✓
Sample Origin	✓
Fluid Pressures	✓
Well is Serviceable	✓

Summary

The modular nature of the MP System permits a large number of monitoring zones to be accessed through valves placed inside a single closed tube or casing installed in a single borehole. Such a monitoring system can provide a detailed view of the variation of piezometric pressure and water quality with depth. The valved couplings permit purging of the well following installation and allow all standard hydrogeologic tests to be carried out in each zone. Routine sampling is carried out without repeated purging, eliminating the need to store and dispose of large volumes of purge fluid and reducing operator exposure to hazardous fluids. The valves also permit an evaluation of the condition of exterior casing seals at any time after installation. Casing packers allow multiple seals to be established easily and quickly, providing the required hydraulic isolation of each monitoring zone. The modular design of the downhole components means the number and location of monitoring zones and seals can be modified on the basis of the best information available in the field at the time of installation. The exact depth of monitoring zones need not be known when equipment is purchased.

Field quality control procedures have been established which permit the quality of a well installation and the proper operation of testing and sampling procedures and equipment to be routinely verified. Thus, groundwater data and the additional data required to define the quality of the field data can be routinely collected. Furthermore, when a high density of groundwater monitoring zones are installed by using multi-level monitoring wells, the redundant monitoring points can provide important corroborative field data to an extent which is not available with single level monitoring wells. The result is a monitoring system which provides data with a degree of defensibility unattainable with any other monitoring method, single or multi-level.

References

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Hvorslev, J.M. Time lag and soil permeability in ground-water observations. Bull. 36, U.S. Corps of Eng., Waterways Exp. Sta., Vicksburg, MI, 1951.

Attachment D:
RHMW11 Boring Log and Geophysical Record of Borehole

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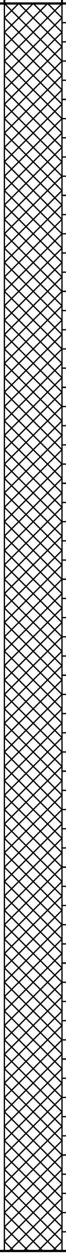
Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

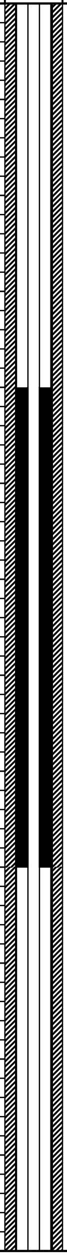
Log of Boring RHMW11

Sheet 1 of 32

Date(s) Drilled	**09/25/17**	Logged By	**Q. Meehan, J. Kronen, J. Vasconcellos**	Checked By (Date)	**J. Kronen**
Drilling Method	**8" OD HSA / HQ core / PQ core / air rotary**	Drill Bit Size/Type	**HQ/PQ diamond bit / 9.5" tricone bit**	Total Depth of Borehole	**492.5 feet**
Drill Rig Type	**Mobile B-59 / T3**	Drilling Contractor	**Valley Well Drilling**	Approximate Surface Elevation	**210.38 feet**
Groundwater Level	**El. 18.27' (10/26/2017)**	Location	**N75290.368, E1675370.691**	Inclination from Horizontal/Bearing	**90°**
Borehole Completion	**Westbay Well**			Hammer Data	**140 lbs/30-inch drop**

Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type	Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	0								**FILL** Very stiff, dry, dark reddish-brown (5YR 5/2), Silty Sandy GRAVEL (GM), fine to coarse sand, angular and subangular gravel to less than 3" and cobbles to 4", predominantly 1" to 2" gravel, matrix composed of silt and fine sand, not plastic						Air knife to 22.8 ft bgs. Visually logged open hole. Installed 16 1/4" steel casing to 20 ft bgs. Pour 4 bags of 3/8" bentonite chips in annulus
	1														
	2														
	3														
	4														
	5														
	6														
	7														
	8								slight moisture						
	9								decreased gravel						
	10														
	11														
	12								increased moisture and decreased gravel						
	13														





Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	13															
	14															
	15															
	16															
	17															
	18								silt							
	19															
	20															
	21															
	22															
	23															End of drilling 9/25/17; begin 10/02/17; Begin using 8" O.D. (4.24" I.D.) hollow stem auger and California Sampler
	24															
	25			100					Soft, moist, variable colored Dark reddish brown (5YR 3/2) to yellowish red (5YR 4/6), CLAY (CH) with sand, high plasticity, 20% fine to coarse sand and subangular gravel to 1", no odor			1	25 56 50	0.2		
	26								Dry, gray (2.5Y 6/1 to 2.5Y 5/1), friable BASALT, oxidized on breaking surfaces, no odor							
	27															
	28															
	29															

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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Elevation, feet	Depth, feet	ROCK CORE						Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES			PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
		Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number				Type	Number	Blows per foot			
	29															
	30			100					Moist, Sandy CLAY (CH), ~15% SAND Moist, Brown (5YR 3/2) to gray (5YR 4/1) with orange mottling (5YR 5/6), Sandy Clayey GRAVEL (GC), ~30% fine to coarse sand, no odor			2	9 17 38	0.1		
	31								Dry, gray (2.5Y 6/1) friable BASALT							
	32															
	33															
	34															
	35			100					Wet, dark brown (7.5YR 3/2), Clayey Sandy GRAVEL (GC), 15% clay, 30% fine to coarse sand, angular to subangular gravel to 1.5", no odor Moist, gray (10YR 5/1) to dark gray (10YR 4/1), highly friable BASALT, no odor			3	15 21 25	0.1		
	36								Moist, dark brown (7.5YR 3/2), Clayey Sandy GRAVEL (GC), 10% clay, 20% fine to coarse sand, rounded gravel to 2", no odor							
	37															
	38															
	39															
	40			100					Wet, gray (7.5YR 5/1) mottled with dark brown (7.5YR 3/2), highly fractured BASALT with CLAY (GC), no odor			4	12 15 23			
	41								Wet, brown (10YR 4/3), Clayey Sandy GRAVEL (GC), medium plasticity, rounded gravel to 2.5", (possible slough)			5	18 20 50	0.0		
	42			100					Moist to dry, gray (7.5YR 5/1) with yellowish brown (7.5YR 5/6) mottling, highly fractured, friable BASALT with trace clay							
	43			100					Wet, yellowish red (5YR 5/6), Silty Sandy GRAVEL (GM), rounded gravel to 2.5"			6	13 25 50	0.0		
	44								Wet, gray (7.5YR 5/1) with yellowish brown (7.5YR 5/6) mottling, highly fractured, friable BASALT with trace clay			7	20 40	0.0		
	45															

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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Elevation, feet	Depth, feet	ROCK CORE: Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES: Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	45			100				▨	Dry, gray (7.5YR 5/1) with strong brown (7.5YR 5/6) mottling, highly fractured, friable BASALT with ~10-20% clay, no odor				50/4"			
	46			60				▨	Dry, gray (10YR 3/2), Sandy GRAVEL (GW), slight silt/clay, fine to coarse sand, rounded to subrounded gravel to 1", mostly 1/4" gravel, 25% silt, 40% sand, 45% gravel			8	23 50/4" 50/1"	0.0		
	47							▨				9	20 50/4" 50/2"	0.0		
	48			47				▨	Dry, gray (10YR 5/1) with yellowish brown (10YR 5/6) and very dark brown (10YR 2/2) mottling, highly fractured, friable BASALT with silt/clay, high plasticity, subrounded gravel to 2.5" with angular fractured rock fragments, no odor							
	49							▨	Stiff, dry, dark brown (10YR 3/3) with brown (10YR 5/3) oxidized mottling, Sandy CLAY (CH) with gravel, high plasticity, subrounded gravel to 2", no odor							End of drilling 10/02/17; begin 10/03/17
	50							▨						0.0	[60]	Begin coring using HQ system
	51							▨	Clay grades to olive gray (5Y 4/2)							
	52	10		66		0		▨	highly friable and fractured BASALT grades with highly friable/weathered basalt cobbles							Water loss ~400 gal
	53		1					▨								
	54							▨								
	55							▨						0.0	[37.5]	
	56							▨	highly weathered, friable and fractured BASALT							
	57	11		66		0		▨								Water loss ~350 gal
	58							▨								
	59		2					▨								
	60							▨						0.3	[30]	
	61															

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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Elevation, feet	Depth, feet	ROCK CORE						Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES			Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
		Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number				Type Number	Blows per foot	PID (ppm)		
	61	12	2	100		0		▩	Basalt Boulder, massive a'a, gray (10YR 5/1), moderately to highly weathered, very weak to weak, <1% vesicles	▨					End of drilling 10/03/17; begin 10/04/17 Water loss ~200 gal
	63.6							▨	**RESIDUAL SOIL** Brown (7.5YR 4/3) Silty CLAY (CH) with 10% gravel, plastic	▨					
	65	13		84		0		▨	no recovery	▨			0.1	[60]	
	65.9							▨	becomes pebble conglomerate with 40% gravel	▨					
	66.4		3					▨		▨					Water loss ~180 gal
	68.5							▨	**VOLCANIC SAPROLITE** Moderately to completely weathered basalt rock, extremely weak to weak, weathers to sandy and gravelly clay and clayey gravel	▨					
	69							▨	69 ft to 70 ft basalt boulder from 69 ft to 70 ft, massive a'a, very dark gray (7.5YR 3/1) with red brown stains, highly weathered, very weak, fractures are very tight with Fe+Mn	▨					
	70	14		80		0		▨	no recovery	▨			0.1	[50]	
	71							▨	saprolite derived from pahoehoe	▨					Water loss ~300 gal
	72.5							▨	saprolite derived from a'a clinker	▨					
	73							▨	saprolite derived from massive a'a	▨					
	75							▨	no recovery	▨			0.0	[75]	End of drilling 10/04/17. Hole reamed to 15 1/2 inches from 42.7-75 ft bgs. Installed 10" steel casing to 75 ft bgs. Tremie grout into annulus:
	77														

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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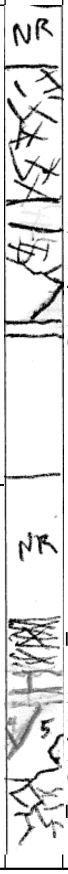
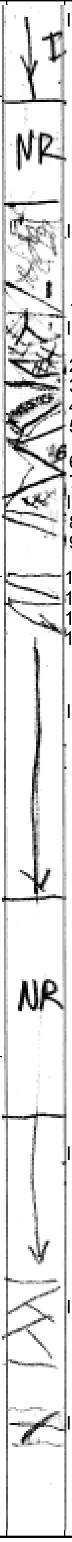
Elevation, feet	Depth, feet	Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	77	15	3	60		0		Basalt Boulder, very dark greenish gray (GLEY 1 3/5GY) weak, highly fractured, with dark yellowish brown (10YR 4/4) clay						450 gal grout total (27.5 - 94 lb bags of cement, 3 - 50 lb bags bentonite). Begin drilling 10/11/17 Water loss ~100 gal
	78							Stiff,dark brown (10YR 3/3) with reddish yellow (7.5YR 6/8) mottling, Sandy CLAY (CH) with gravel, fine to coarse sand, extremely weak to weak, angular gravel to ~1", high plasticity (Volcanic Saprolite)						
	79													
	80	16	4	90		0		no recovery				0.1	[20]	
	81													
	82													Water loss ~100 gal
	83													
	84							contains occasional 2" angular to subangular gravel						Good water circulation near bottom of run 16
	85	17		60		0		no recovery				-	[75]	End of drilling 10/11/17; begin 10/12/17
	86													
	87							0.2 ft zone of weak basalt cobble						Good water circulation, no water loss
	88							0.2 ft zone of weak basalt cobble						
								0.2 ft zone of intensely fractured, weak, basalt cobble						
	89													
	90	18	5	76		0		no recovery				-	[50]	
	91							Basalt Boulder, massive a'a, highly to intensely fractured						
	92							Dark brown (10YR 3/3),Clayey Gravelly SAND (SC), highly weathered to completely weathered basalt with clayey zones (Volcanic Saprolite)						Good water circulation, water loss ~25 gal
	93													

Elevation, feet	Depth, feet	ROCK CORE: Run No.	ROCK CORE: Box No.	ROCK CORE: Recovery, %	ROCK CORE: Fractures per Foot	ROCK CORE: R Q D, %	ROCK CORE: Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES: Type Number	SAMPLES: Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	93														
	94								becomes clayey sandy gravel (GC)						
	95								dark brown (10YR 3/3), sandy clay (CH)				0.0	[30]	
	96														
	97	19	5	100		0			grayish green (GLEY1 5/10Y) massive a'a boulder, moderately weathered, weak						Good water circulation, water loss ~25 gal
	98								yelowish red (5YR 5/6) clayey sandy gravel (GC), highly weathered, extremely weak to weak basalt						
	99														
	100								no recovery				0.0	[60]	
	101								1. 0, J, VN, Fe+Mn, Sp, Wa, R 2. 20, J, VN, Fe+Mn, Sp, Pl, S 3. 10, J, VN, Fe+Mn, Sp, Wa, SR 4. 70, J, VN, Fe+Mn, Sp, Pl, SR 5. 10, J, VN, Fe+Mn, Sp, Pl, SR 6. 10, J, VN, Fe+Mn, Sp, St, SR						
	102	20		86		0	1 2 3 4		basalt boulder, massive a'a, grayish green (GLEY1 4/2) and greenish black (GLEY1 2.5/1) with yellowish red (5YR 5/6) in fractures, moderately to highly weathered, highly fractured						Good water circulation, water loss ~25 gal
	103						5 6								
	104		6						clayey sandy gravel (GC)						
	105								no recovery				0.0	[100]	
	106						IF		Basalt, massive a'a, GLEY1 5/6, weak to moderately strong, ~15% vessicles 1-3mm (Volcanic Saprolite)						
	107	21		70		0	1 2 3 4		vessicles become 0.5-3mm 1. 10, J, VN, Fe+Mn,St, SR 2. 90, J, VN, Fe+Mn, Wa, SR 3. M 4. 45, J, VN, Fe+Mn, Wa, SR 5. 70, J, VN, Fe+Mn, Wa, SR 6. 45, J, T, Fe, St, S						Good water circulation, water loss ~25 gal
	108						5 6 IF								
	109														



Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11



Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	109								clayey intensely fractured clinker zone, highly weathered					
	110	22	6	80		8			no recovery			0.0	[43]	
	111								no clay					
	112								basalt, massive a'a, 5Y 4/1, 1-5% vesicles 1. 45, J, W, Cl, Fi, Wa, SR 2. 45, J, VN, Fe+Mn, Sp, Wa, SR 3. 0, J, N, Fe+Mn+Cl, Pa, St, SR 4. 45, J, W, Cl-Sd, Fi, Wa, SR 5. 45, J, N, Mn+Cl, Pa, Pl, SR 6. 45, J, Vn, Fe+Mn, Sp, St, SR 7. 45, J, VN, Fe+Mn, Sp, St, SR 8. 30, J, VN, Fe+Mn, Sp, Pl, SR 9. 45, J, VN, Fe+Mn, Sp, Wa, SR 10. M 11. 45, J, VN, Fe+Mn, Sp, Wa, SR 12. 0, J, VN, Fe+Mn, Sp, Wa, SR 13. 45, J, VN, Fe+Mn, Sp, Wa, SR					Good water circulation, water loss ~25 gal
	115	23	7	70		0			Basalt, pahoehoe, moderately weathered, moderately strong, highly fractured (Volcanic Saprolite) Basalt, massive a'a, dark gray (5YR 4/1) to dark reddish brown (5YR 3/3), highly weathered, highly to intensely fractured with zones of clay and fine to coarse, angular sand, occasional rounded gravel to 2"(Volcanic Saprolite)			0.0	[50]	Good water circulation, water loss ~25 gal
	118.5								no recovery					
	120	24		86		12						0.0	[30]	
	122								becomes 5Y 4/1, slightly weathered, strong, 5% vesicles <0.5mm becomes <5% vesicles					Good water circulation, water loss ~25 gal
	124		8						clayey sand (SC) with rounded gravel to 0.5" from 124 ft to 124.3 ft becomes moderately weathered, moderately strong, ~25% vesicles 1-2mm					
	125													

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	Type Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	125												0.0	[43]	
	126								no recovery						
	127						1 IF 2 IF		becomes very dark bluish gray (GLEY2 3/10B) with yellowish red (5YR 5/6) oxidation on fracture surfaces, moderately strong to strong, intensely to highly fractured						Good water circulation, water loss ~25 gal
		25		66		0			1. 90, J, MW, Pa, Ir, R 2. 90, J, MW, Pa, Ir, R 3. 80, J, W, Cl+Sd+Gr, Fi, Ir, R						
	128														
	129		8				3								
	130						1		no recovery				0.0	[21]	
	131						2 3 4 5		1. 90, J, VN, Fe+Mn+Cl, Pa, Ir, R 2. 45, J, VN, Fe+Mn+Cl, Pa, Ir, R 3. 45, J, VN, Fe+Mn+Cl, Pa, Ir, R 4. 0, J, N, Fe+Mn, Sp, Wa, R 5. 70, J, N, Fe+Mn+Cl, Pa, Wa, R 6. 30, J, MW, Fe+Mn+Cl, Pa, Ir, R						
	132	26		94		22	IF		reddish brown (2.5YR 4/3) stiff clay (weathered clinker zone)						Good water circulation, water loss ~25 gal
	133						6								
	134														
	135								no recovery				0.0	[43]	
	136						IF								
	137	27	9	90		0	1		contains <5% vesicles						Good water circulation
	138						M 2 3 4		1. 20, J, N, Fe+Mn, Pa, Ir, R 2. 20, J, N, Fe+Mn, Pa, Ir, R 3. 20, J, N, Fe+Mn, Pa, Ir, R 4. 30, J, N, Fe+Mn, Pa, Ir, R						
	139								reddish brown (2.5YR 4/3) very stiff clay (weathered clinker zone)						
	140								no recovery				0.0	[50]	
	141														

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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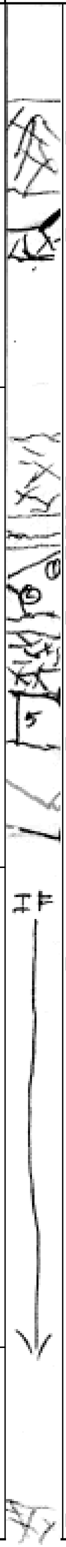

		ROCK CORE									SAMPLES				
Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	Type Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	141								becomes weak to moderately strong, vesicles 0.5-1mm						
	142						IF		becomes highly weathered, very weak to weak, intensely fractured with reddish brown (2.5YR 4/3) clay						Good water circulation, no water loss
		28		90		12			1. 45, J, VN, Fe+Mn, Pa, Ir, R						
	143		9				1 IF								
	144														
	145								becomes extremely weak				0.0	[43]	
									1. 45, J, N, Cl, Fi, Ir, R 2. 60, J, VN, Cl, Fi, Pl, SR 3. 30, J, N, Cl, Fi, Ir, R 4. 20, J, VN, Fe+Mn, Pa, Ir, R 5. 90, J, VN, Fe+Mn, Pa, Ir, R 6. 45, J, VN, Cl, Fi, Pl, SR 7. 30, J, VN, Cl, Fi, Pl, S						
	146						IF M M M								
	147						1 2								Good water circulation, no water loss
		29		100		0	M 3								
	148						4 5 M		becomes moderately weathered, moderately strong						
	149		10				6 7								
									becomes highly weathered, extremely weak						
	150								no recovery				0.0	[38]	
	151						IF		becomes highly to moderately weathered, weak to moderately strong						
	152														Good water circulation, no water loss
		30		90		8									
	153								reddish brown (2.5YR 4/3), Welded Clinker, highly weathered, extremely weak						
	154								becomes grayish green (GLEY1 4/2) highly weathered, weak						
	155								no recovery				0.0	[60]	End of drilling 10/12/17; begin 10/13/17
	156		11						stiff, reddish brown (2.5YR 3/3), sandy gravelly clay (CH), high plasticity, completely weathered						
							IF		clinker zone becomes moderately weathered						
	157														

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

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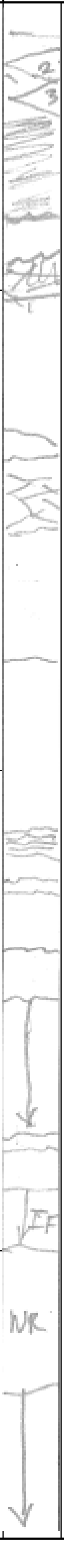

Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	157	31		82		0	1 2 3 4	1. 60-70, J, VN, Fe+Mn, Pa, Ir, R 2. 60-70, J, VN, Fe+Mn, Pa, Ir, R 3. 60-70, J, VN, Fe+Mn, Pa, Ir, R 4. 60-70, J, VN, Fe+Mn, Pa, Ir, R			
	158							Basalt, highly weathered pahoehoe, (2.5YR 4/2), very weak, intensely fractured with zones of clay (Volcanic Saprolite)			Good water circulation, no water loss
	159						M M M	becomes dark greenish gray (GLEY1 4/10Y), extremely weak			
	160							no recovery	0.0	[100]	
	161		11				1 2 IF	1. 30, J, MW, Fe+Mn, Sp, Ir, R 2. 5, J, VN, Fe+Mn, Sp, Ir, R			
	162	32		92		18		Stiff, Reddish brown (2.5YR 3/3), Sandy CLAY (CH) with gravel, fine to coarse sand, subrounded to subangular extremely weak gravel predominantly <0.5" (Volcanic Saprolite)			Good water circulation, no water loss Collect geotechnical sample from 162.6 ft to 163.6 ft
	163										
	164						M				
	165						M IF	becomes very stiff	0.0	[100]	Hole reamed to 9 1/2" from 75-165 ft bgs. Installed 5" steel casing to 165 ft bgs. Tremie grout into annulus: 550 gal grout total (3 - 94 lb bags of cement, 1/4 - 50lb bags bentonite) Good water circulation, no water loss
	166						M M M	becomes ~50% sand			
	167	33		100		20	M IF				
	168						M M	grades with dark greenish gray (GLEY1 4/10Y) angular basalt cobbles			
	169		12				IF	2.5YR 5/6 to 2.5YR 4/6 welded clinker, highly weathered			
	170							no recovery	0.0	[60]	
	171						IF	2.5YR 4/2 pahoehoe, highly weathered, extremely weak, 35% vesicles <1.5 mm			
	172	34		72		0		Stiff, 7.5YR 4/2, gravelly CLAY (CH) with cobbles and boulders, gravel extremely weak, subangular to angular, typically <1", highly to completely weathered massive a'a and pahoehoe (Volcanic Saprolite)			Good water circulation, no water loss
	173										

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
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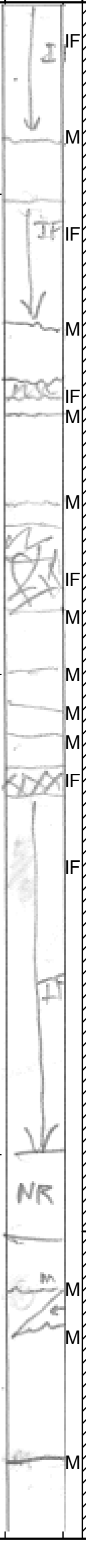

Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	173										
							IF				
	174		12								Collect geotechnical sample from 174.3 ft to 175.0 ft
							M				
	175								0.0	[75]	
							IF				
	176										
							M				
	177						IF M	greenish gray (GLEY1 4/10Y) with strong brown (5YR 5/8) oxidation, basalt a'a, highly weathered, extremely weak to very weak, intensely fractured			Good water circulation, no water loss
		35		100		22		2.5YR 3/2, basalt pahoehoe, highly weathered, extremely weak, 40% vesicles up to 1mm			
	178						M	greenish gray (GLEY1 4/10Y) with strong brown (5YR 5/8) oxidation, basalt a'a, highly to completely weathered, extremely weak, intensely fractured			
	179		13				IF M				
	180						M M M	2.5YR 3/2, basalt pahoehoe, completely to highly weathered, extremely weak, 40% vesicles up to 1mm	-	[75]	
	181						IF	becomes stiff to soft, 7.5YR 4/2 to 7.5YR 5/2 CLAY (CH) with dark greenish gray (GLEY1 4/10Y) gravel and cobble fragments			
	182						IF	remnant pahoehoe structure visible, 30% vesicles 1-2mm			Good water circulation, no water loss
		36		100		0					
	183										
								vesicles increase to 3mm			
	184										
	185							no recovery	-	[60]	
	186						M	Very stiff, brown (7.5YR 4/2) clayey sandy GRAVEL (GC), gravel highly weathered, extremely weak, subrounded to subangular greenish gray (GLEY1 4/10Y) and strong brown (7.5YR 5/6), with basalt a'a cobbles, highly to completely weathered basalt (Volcanic Saprolite)			
	187		14				M				Good water circulation, no water loss
		37		84		0					
	188						M	dark greenish gray (GLEY1 4/10Y), basalt a'a cobble, highly weathered, very weak from 188.1 ft to 188.5 ft bgs			
								gravel predominantly a'a clasts with some pahoehoe			
	189										

Report: CTO53 RED HILL WITH WELL AND PID; File: CTO53 RED HILL CORE LOGS.GPJ; 2/9/2018 RHMW11

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Elevation, feet	Depth, feet	Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	Type Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	189						M IF	Brown (7.5YR 4/2) sandy clay (CH) with gravel, residual pahoehoe structure evident					
	190							no recovery			0.0	[60]	Collect geotechnical sample from 189.5 ft to 190 ft
							M	very stiff, brown (7.5YR 4/2) clayey sandy GRAVEL (GC), gravel highly weathered, extremely weak, subrounded to subangular greenish gray (GLEY1 4/10Y) and strong brown (7.5YR 5/6), highly to completely weathered basalt (Volcanic Saprolite)					
	191						M						
	192						M M						Good water circulation, no water loss
		38		90		20							
	193		14				IF						
	194							basalt boulder, massive a'a, grayish green (GLEY1 4/5GY) with strong brown (7.5YR 5/6) oxidized zones,highly to completely weathered, very weak to extremely weak, intensely fractured					
	195							no recovery			0.0	[75]	Collect analytical sample RHMW11-BS01-S01-D195.1-195.5 from 195.1 ft to 195.5
	196						M M						
							M M 1	basalt boulder, massive a'a, dark greenish gray (GLEY1 4/5GY), highly weathered, very weak to extremely weak					
	197	39		90		26							Good water circulation Total water loss from 155 ft through 200 ft is 10 gal
	198						M						
							M	basalt cobble, pahoehoe, dark reddish brown (5YR 3/3), completely to highly weathered, extremely weak, relict structure intact, ~40% vesicles 0.5-1mm					
	199						M IF	basalt boulder, massive a'a, dark greenish gray (GLEY1 4/5GY), highly weathered, very weak to extremely weak					
	200		15				M				0.0	[43]	End of drilling 10/13/17; begin 10/16/17
							M						
	201						M						
							M IF						
	202							basalt boulder, massive a'a, dark greenish gray (GLEY1 4/5GY), highly weathered, very weak					Water loss ~20 gal
		40		100		20	M						
	203						M						
	204						M						
							M						
	205												

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		ROCK CORE									SAMPLES					
Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	205		15						no recovery					0.0	[75]	
	206						IF IF		basalt boulder, massive a'a, dark greenish gray (GLEY1 4/5GY), highly weathered, very weak							
	207	41		90		0										Good water circulation, water loss ~20 gal
							M M IF IF		Welded Tuff, highly to completely weathered, extremely weak, weathers to brown (7.5YR 4/2) clay with dark greenish gray (GLEY1 4/5GY) to black (GLEY1 2.5/N) basalt a'a gravel to cobble clasts, occasional red (10R 4/6) clast, stong brown (7.5YR 5/6) mottling around clasts(Volcanic Saprolite)							
	208															
	209						M M									
	210		16						no recovery					0.0	[50]	End of drilling 10/16/17; begin 10/23/17 using PQ coring system
	211						IF M M M		basalt boulder, massive a'a, dark greenish gray (GLEY1 4/5GY), highly weathered, very weak, very stiff							
	212	42		90		0	M M M M M M IF									Good water circulation, water loss ~20 gal
	213															
	214						M 1 1 M		1. 45, J, T, Mn, Fi, Pl, Slk-S							
	215													0.0		End of drilling 10/23/17; begin 10/24/17
	216	43	17	100		0										
	217								Stiff, reddish brown (5YR 4/3) clay (CH), highly to completely weathered pahoehoe, extremely weak, relic structure still visible, 30% vesicles 0.5-1mm (Volcanic Saprolite)							
									no recovery					0.0	[300]	
	218															Some water circulation, water loss ~50 gal
	219		18				M M M IF		becomes dark greenish gray (GLEY1 4/10Y) becomes yellowish red (5YR 5/6)							
	220	44		90		46			1. 20, J, VN, Cl, Sp, Ir, R							
	221						1									

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Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	MATERIAL DESCRIPTION	Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	221		18				Basalt, pahoehoe, dark greenish gray (GLEY 4/10Y), moderately weathered, extremely weak, vesicles increase to 2mm (Volcanic Saprolite) becomes yellowish red (5YR 5/6)						
	222												
											0.0	[50]	
	223						grades with dark greenish gray (GLEY 4/10Y) banding, 15% vesicles ~1mm						
	224		19				dark greenish gray (GLEY1 4/10Y), very weak, 15-25% vesicles 1-2mm						Some water circulation, water loss ~80 gal
	225	45		100		0							
	226												
	227						basalt boulder, massive a'a, dark greenish gray (GLEY1 4/10Y), moderately weathered, very weak, <5% vesicles						
							Brown (7.5YR 4/4), clayey gravel (GC) completely to highly weathered basalt, extremely weak, subrounded, medium to coarse sand clasts and occasional gravel and cobble in clay matrix (Volcanic Saprolite)				0.0	[27]	
	228												
	229		20				pahoehoe cobble a'a cobble						Some water circulation, water loss ~150 gal
	230	46		100		0							
	231												
	232						dark olive gray (5Y 3/2) pahoehoe boulder, highly weathered, very weak, 25-30% vesicles 2-3mm				0.0	[23]	
	233						no recovery						
	234												Some water circulation, water loss ~100 gal
	235	47	21	74		0	1. 45, J, T, No, No, Pl, SR						
	236												
	237												

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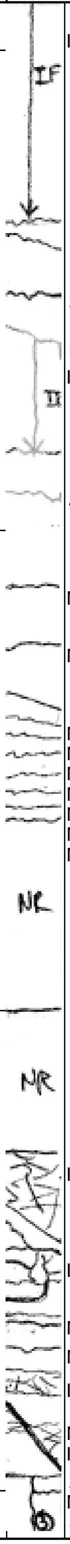

Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	237		21				IF							
	237.5											0.0	[38]	End of drilling 10/24/17; begin 10/25/17
	238–239								basalt boulder, massive a'a, very dark gray (5Y 3/1), moderately weathered, very weak, intensely fractured, <5% vesicles 1. 20, J, VN, Si, Fi, Ir, SR 2. 0, J, N, Cl, Sp, Ir, R 3. 20, J, ?, Cl, Sp, Ir, R 4. 10, J, N, Cl, Sp, Ir, R					
	239.4						1		Yellowish brown (10YR 5/6), basalt a'a clinker, highly weathered, extremely weak to very weak, red (2.5YR 4/8) alteration zone at 239.9 ft					
	240	48	22	100		22	2		Basalt, pahoehoe, dark brown (7.5YR 3/3), highly weathered, weak,15-20% vesicles, some vesicles filled with white clay (Volcanic Saprolite)					Good water circulation, water loss ~20 gal
	241						3 IF		becomes completely weathered, extremely weak, intensely fractured					
	242						4		becomes highly weathered, weak, ~25% vesicles, all vesicles filled with white clay					
	242.5											0.0	[38]	
	243						M							
	244						M 1		1. 30, J, VN, Cl, Fi, Pl, S ~50% vesicles filled with white clay					
	245	49	23	60		34	M M M M M M							Good water circulation, water loss ~10 gal
	245.5–249								no recovery					
	247.5											0.0	[27]	
	249						IF		Basalt, massive a'a, grayish black (GLEY1 2.5/5GY), moderately weathered, weak to moderately strong, intensely fractured, oxidized fracture surfaces (Volcanic Saprolite)					
	250	50	24	70		0	1 IF M		becomes strong 1. 60, J, ?, Fe+Mn, Pa, Pl, SR 2. 70, J, ?, Fe+Mn+Cl, Pa, Ir, R 3. 90, SH, T, Fe+Mn+Cl, Pa, Pl, Slk	⊗				Good water circulation, water loss ~10 gal
	250.9						M IF		Basalt, pahoehoe, reddish brown (5YR 4/3 to 5YR 4/4), highly weathered, weak, 40% vesicles 1-2mm, most vesicles filled with white clay from 250.9 to 251.2 ft (Volcanic Saprolite)					
	251.2–252						M IF 2		at 251.2 ft becomes grayish black (GLEY1 2.5/5GY) with veins of white clay, moderately weathered, weak to moderately strong, ~25% vesicles					
	252.5						M 3					0.0	[60]	
	253													

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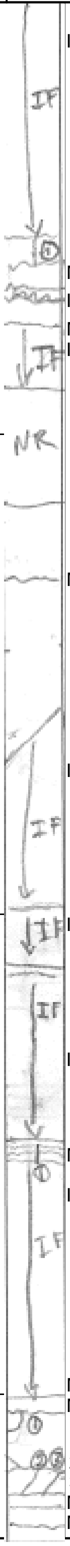

Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	253						IF		highly to moderately weathered, very weak, intensely fractured, many fracture planes are planar/slickensided, white clay infill in vesicles					Good water circulation, water loss ~10 gal
	254													
	255	51	25	90		0								
							1 M IF		yellowish red (5YR 4/6) highly weathered, very weak to extremely weak oxidized zone 1. 80-90, Sh, T, Fe+Mn+Cl, Fi, Ir-Pl, Slk					
	256						M IF		grayish black (GLEY1 2.5/5GY), highly to moderately weathered, very weak, intensely fractured, vesicles filled with white clay					
	257								no recovery			-	[33]	
	258								Welded clinker, very dark gray (5YR 3/1), highly weathered, extremely to very weak, vesicles filled with white clay, frequent extremely weak zones of red (10R 4/6) alteration					
	259		26				M							
	260	52		86		52	1		red zones no longer observved					Good water circulation, no water loss
	261						IF		Basalt boulder, massive a'a, grayish black (GLEY1 2.5/5GY), intensely fractured, fracture planes oxidized with common slickensides and white clay, <5% vesicles 1-2mm 1. 70, Sh, ?, Fe+Mn+Cl, Pa, Ir, Slk-SR					
	262						IF					-	[27]	
	263								contains subrounded clasts coarse sand to gravel size up to 2", some clasts are yellowish red (5YR 5/6)					
	264		27				IF		1. 90, Sh, VN, Cl, Cl, Fi, Pl-Ir, Slk					
	265	53		100		10	M 1 IF		Basalt, pahoehoe, yellowish red (5YR 5/6), completely weathered, extremely to very weak (Volcanic Saprolite) becomes dark gray (5YR 3/1), very weak, ~40% vesicles, some filled with white clay, with yellowish red (5YR 5/6) oxidized zones					Good water circulation, no water loss
	266													
	267						M M 1		moderately weathered, moderately strong, 15% vesicles 1-2mm 1. 90, J, ?, Fe, Su, Ir, R 2. 60, J, N, Fe, Su, Ir, R			-	[43]	
	268		28				2 3 M M		0.2 ft zone of 4mm vesicles filled with clay 3. 70, J, VN, Fe+Mn+Cl, Fi, Pl, S-SR					
	269													

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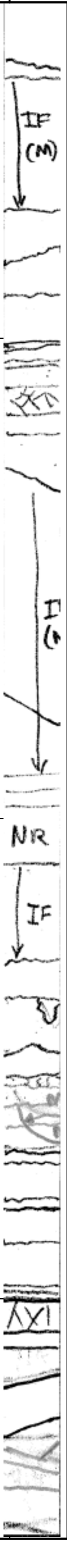

Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	269						M		30-40% vesicles 0.5-2mm, dark reddish brown (5YR 5/6) oxidation around fractures 4 and 5 4. 30, J, VN, Fe, Su, Ir, R 5. 15, J, N, Fe, Su, Ir, R					
							1							
	270	54	28	100		44	IF							Good water circulation, no water loss
	271								grades without white clay in vesicles					
							2							
	272						M							
			29				M		40-50% vesicles up to 3mm			-	[30]	
	273						IF							
							M		30-40% vesicles 1mm					
	274						1							
							IF		yellowish red (5YR 5/6) highly weathered oxidized zone					
	275	55		100		0			1. 60, J, ?, Fe+Mn+Cl, Sp, Ir, R 2. 45, Sh, Fe+Mn+Cl, Fi, Pl, S-Slk					Good water circulation, no water loss
			30											
	276						2							
	277						M M M		yellowish red (5YR 5/6) to dark red (2.5YR 3/6) oxidized zone					
									no recovery			-	[33]	
	278						IF		very dark gray (5YR 3/1), moderately weathered, moderately strong, 25% vesicles 1-2mm, with occasional white and gray clay infilling vesicles					
	279		31				M		**BASALT Pahoehoe** Very dark gray (5YR 3/1), slightly weathered, strong, 15-25% vesicles, alternating zones of smaller (0.5-1mm) and larger (3-5mm) vesicles 1. 20, J, N, Fe+Cl, Sp, St-Ir, VR 2. 5, J, T, No, No, Ir, R 3. 45, J, VN, Fe+Mn+Cl, Fi, Ir, R 4. 5, J, T, Cl, Sp, Ir, SR 5. 30, J, N, Cl, Pa, St, SR-VR 6. 0, J, N, Cl, Sp, Ir, R					
							M 1							
	280	56		90		10	2 IF							Poor water circulation, water loss ~150 gal
							3							
	281						M M 4 5 6							
	282													
			32				M IF					0.0	[100]	
	283						M 1		1. 20, J, VN, Fe+Mn+Cl, Pa, Ir, R 2. 20, J, VN, Cl, Sp, Ir, R 3. 30, J, N, Cl, Pa, St, R 4. 30 J, VN, Cl, Sp, Ir-Pl, SR 5. 20, J, T, Cl, Pa, Pl, Sr 6. 30, J, Cl, Sp, Wa, SR					
	284						2 3 4 5							Poor water circulation, water loss ~200 gal
	285													

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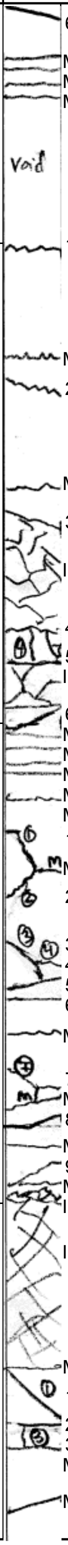
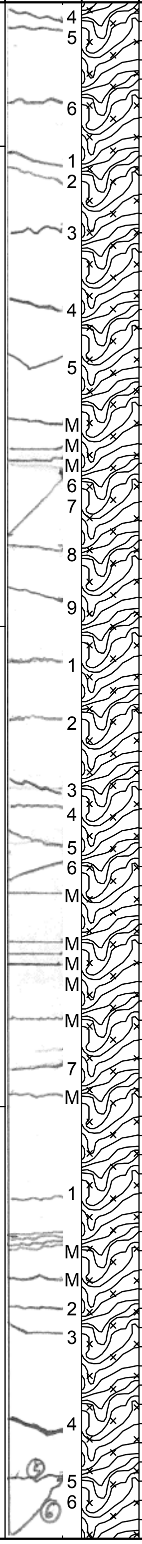


Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	285	57		70		30	6 M M M					
	286–287.5							void/lava tube				Lost water circulation, drill string drops from 286 ft to 287.5 ft
	287.5		33				1	very dark gray (GLEY1 3/N), 15% vesicles 3-10mm, some infilled with white or gray clay		0.2	[75]	End of drilling 10/25/17; begin 10/26/17
	288.4						M 2	30-40% vesicles 1-5mm 1. 0, J, W, Cl, Sp, Ir, R 2. 45, J, MW, Cl, Sp, Ir-Pl, R 3. 60, J, N, Fe, Su, Ir-Pl, R 4. 90, J, VN, Cl, Sp, Pl, SR				Depth to water stabilized at 192.11' bgs on 10/26/17
	290	58	34	100		26	M 3 IF	moderately weathered alteration/oxidation zone, strong, 30 to 40% vesicles 0.5-3mm 5. 80, J, T, Cl, Pa, Pl, SR 6. 45, J, ?, Cl, Sp, Wa, R				No water circulation for the remainder of boring, Water loss ~400 gal
	291.5						4 5 IF	moderately strong, 40% vesicles 0.5-1mm, 70% of vesicles filled with pale brown (2.5Y 7/4) clay				
	292.5						6 M	residual soil, clay (CH), highly weathered		0.0	[60]	
	293						M M M M	moderately weathered alteration/oxidation zone, moderately strong, 40% vesicles 0.5-1mm				
	293.8		35				1 M 2	slightly weathered, strong, 30% vesicles 1-3mm grading to 50% vesicles 3-5mm 1. 70, T, Cl, Pa, Ir, R 2. 70, T, Cl, Pa, Ir, R 3. 45, T, Fe, Su, No, Ir, R				
	295	59		100		32	3 4 5 6	grades to 50% vesicles 0.5-1mm 4. 15, T Cl, Sp, Pl, SR 5. 40, VN, Cl, Sp, Ir, R				Water loss ~450 gal
	295.8						M 7 M	vesicles grade to 1-3mm 6. 20, N, Fe+Mn, Su, Sp, SR 7. 60,T, No, No, Pl, R				
	296.5						8 M 9	vesicles grade to 0.5-1mm 8. 45, VN, No, No, St, R 9. 60, ?, No, No, Ir, R				
	297.2		36				M IF	vesicles grade to 1-3mm		0.0	[60]	
	298						IF	moderately weathered, weak to strong, 50% vesicles 0.5-1mm with pale brown (2.5Y 7/4) and white (8.5/N) clay infill, very dark gray (GLEY1 3/N), pale brown (2.5Y 7/4) and white (8.5/N) clay on fracture surfaces				
	299.2						M 1 2 3 M M	slightly weathered, strong, 10-15% vesicles 2-10mm 1. 70, J, N, Cl, Sp, Ir, R 2. 20, J, N, Cl, Pa, Pl, SR 3. 90, J, VN, Fe+Mn+Cl, Sp, Ir, R 4. 15, J, N, Cl, Fi, Ir, SR 5. 5, J, N, Cl, Fi, Pl, SR 6. 5, J, VN, Cl, Sp, Ir, R				
	300	60	37	100		42						Water loss ~400 gal
	301											

Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	301									
			37							
	302									
								0.0	[60]	
	303									
	304									Water loss ~400 gal
	305	61	38	100		32				
	306									
	307									
								0.0	[75]	
	308									
	309		39							
	310	62		100		36				Water loss ~350 gal
	311									
	312									
			40					0.0	[60]	
	313									
	314									
	315	63		100		62				Water loss ~450 gal
	316		41							
	317									



MATERIAL DESCRIPTION

30-40% vesicles 1-5mm grading to 0.5-1mm with depth

very dark gray (GLEY1 3/N), 30-40% vesicles 2-5mm
becomes brown (7.5YR 4/4), moderately weathered, weak to moderately strong
1. 50, J, Uk, Su, Ir-Pl, R
becomes fresh, strong

15% vesicles 5-10mm
30-40% vesicles 1-3mm
2. 50, J, T, Fe+Mn+Cl, Sp, Ir, R
3. 0, J, VN-N, Fe+Mn, Su, Ir, VR
4. 45, J, N, Cl, Sp, Pl, R
5. 0, J, N, No, No, Ir, VR
6. 5, J, T, Fe+Mn+Cl, Sp, Ir, R
slightly weathered, strong

15% vesicles 5mm

30-40% vesicles 1-3mm
7. 70, J, VN-N, Cl, Pa, Pl, SR-R
8. 20, J, T, Fe+Mn, Su, Pl, SR
9. 20, J, VN, Fe+Mn, Su, Ir, R
oxidized yellowish red (5YR 4/6 to 5YR 5/8), moderately weathered, moderately strong, with pale brown and white clay infill in vesicles
1. 0, J, MW, Cl, Pa, Ir
2. 0, J, N, Fe+Mn+Cl, Su-Sp, Ir, VR
3. 10, J, VN-MW, Fe+Mn+Cl, Pa, Ir, VR
4. 0, J, MW, Fe+Mn+Cl, Fi, Ir, VR
5. 10, J, MW, Cl+Mn, Sp, Ir, R
6. 30, J, VN, Uk, Su, Pl, Slk
very dark gray (GLEY1 3/N) slightly weathered, strong

oxidized yellowish red (5YR 4/5 to 5YR 5/8), completely weathered, extremely weak
highly weathered, very weak to weak

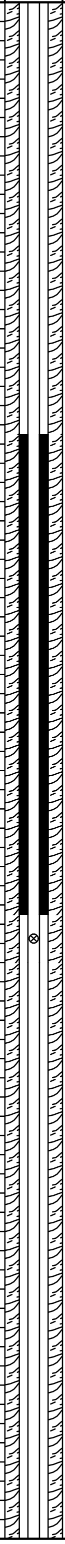
very dark gray (GLEY1 3/N), slightly weathered, strong, 25-40% vesicles 2-5mm
7. 15, J, T, No, No, Pl, R

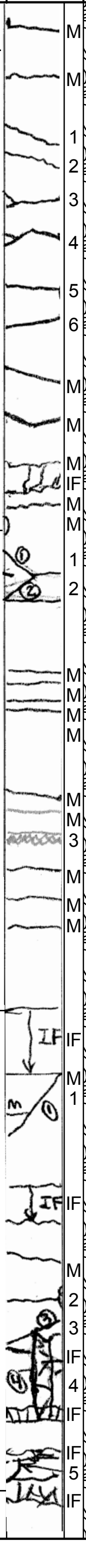
1. 5, J, VN, Cl, Sp, Ir, R
2. 0, J, N, Fe+Mn, Su, Pl, SR
3. 5-10, J, MW, Mn+Cl, Sp, Pl, R
4. 0-45, J, VN, No, No, Pl, R

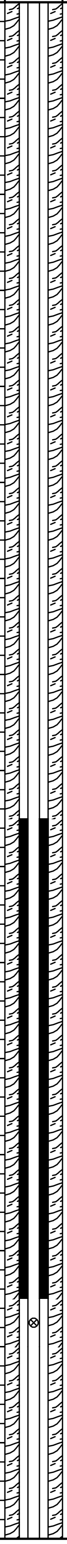
dark reddish brown (2.5YR 2.5/4) to yellowish red (5YR 4/6), highly weathered, weak, 0.1 ft zone of residual soil at 314.2 ft
very dark gray (GLEY1 3/N), slightly weathered, strong, 40% vesicles 0.5-2mm
fresh, strong, 40% vesicles 1-3mm
5. 0, SH, MW, Uk, Su, Ir, Slk
6. 70, SH, MW, Uk, Su, Wa, Slk

oxidized, moderately weathered

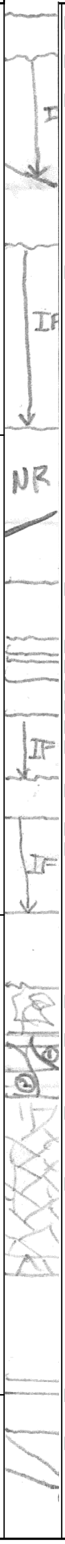
very dark gray (GLEY1 3/N), fresh to slightly weathered, strong, 25-30% vesicles 0.5-10mm

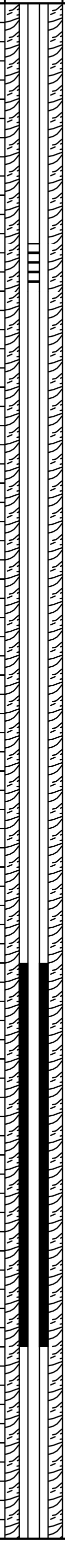






Depth, feet	Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
317						M				
						M	becomes fresh, 25% vesicles 5-10mm 1. 50, Sh, N, Cl+Uk, Sp, St-Ir, SR-Slk 2. 10, J, VN, Cl+Uk, Sp, Ir, SR-Slk 3. 5, J, T, Cl, Sp, Ir, R 4. 5-45, J, VN, Cl, Sp, St, R	0.0	[50]	
318						1 2				
319		42				3 4	5-40% vesicles 1-2mm 5. 2, J, T, Cl, Sp, Pl, R 6. 30, J, MW, Fe+Mn, Su, Ir, SR-R			
320	64		100		48	5 6	becomes slightly weathered			Water loss ~350 gal
321						M M				
322		43				M IF M M	dark reddish brown (5YR 3/3), moderately weathered, moderately strong, oxidized very dark gray (GLEY1 3/N), fresh to slightly weathered, strong, 30-40% vesicles 0.5-5mm	0.0	[75]	
323						1 2	1. 45, J, ?, No, No, Pl-Ir, R 2. 45, J, ?, No, No, Pl-Ir, R 3. 5-10, J, Fe+Cl, Pa, Ir-St, VR			
324						M M M M	moderately weathered, moderately strong, 40% vesicles 0.5-2mm fresh to slightly weathered, strong			Water loss ~450 gal
325	65		100		32	M M 3	moderately weathered, moderately strong			
326		44				M M M	fresh to slightly weathered, strong			
327							becomes fresh, 40% vesicles 1-2mm	0.0	[100]	
328						IF M 1	25% vesicles 2-5mm			
329		45				IF	30-40% vesicles 1-3mm becomes reddish brown (2.5YR 4/3), slightly weathered, strong, 30-40% vesicles 1-3mm			
330	66		100		24	M 2 3	1. 50, J, VN, No, No, Pl, R 2. 0, J, VN, Cl, Sp, Pl-Ir, R 3. 60, J, ?, Cl, Sp, Pl-Ir, R 4. 90, J, VN, Cl, Sp, Ir, R 5. 70-90, J, VN, No, No, Ir, R			Water loss ~350 gal
331						IF 4 IF				
332		46				IF 5 IF		0.0	[100]	
333										





Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	333						M		40-50% vesicles 1-3mm							
							M		30% vesicles 2-5mm							
	334		46				IF									
							1		intensely fractured zone contains no infilling on fracture planes							
	335	67		100		20			1. 45, J, T, No, No, Pl, SR							Water loss ~400 gal
	336						IF		vesicles become 0.5-1mm							
	337															
			47											0.0	[100]	
	338						1		no recovery							
									1. 45, J, ?, No, No, Pl, R							
	339						M		becomes dark gray (5YR 4/1), fresh to slightly weathered, strong, 30-40% variably sized vesicles 1-10mm							
							M M M									
	340	68		80		0	M M IF		intensely fractured zone contains no infill on fracture planes							Water loss ~350 gal
	341		48				M									
							M IF									
	342															
									30% vesicles 1-4mm					0.0	[100]	End of drilling 10/26/17; begin 10/27/17
	343						IF		40% vesicles 1-3mm							
	344						M 1 2 M		1. 90-45, J, VN, No, No, Wa, R 2. 45-90, J, VN, No, No, Wa, R intensely fractured zone contains no infill on fracture planes							
	345	69	49	100		42	IF									Water loss ~250 gal
	346								25% vesicles 1-5mm							
	347						M		25% vesicles 5-10mm					0.1	[75]	
	348		50				M 1 2		1. 70, J, MW, Mn, Su, Wa, SR 2. 45, J, MW, Mn-Cl, Su-Sp, Wa, SR 40% vesicles 1-3mm							
	349															

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
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Depth, feet	Run No.	Box No.	Recovery, %	R Q D, %	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
349–352.5	70	50, 51	100	32			
350							Water loss ~300 gal
352.5–357.5	71	51, 52	100	33	0.1	[100]	
355							Water loss ~350 gal
357.5–362.5	72	53, 54	100	32	0.1	[75]	
360							Water loss ~350 gal
362.5–365		55			0.0	[100]	
364							Water loss ~350 gal

Fracture Drawing Number: 3, IF, 4, 5, 7, M, M, M, IF, M, 8, M, M, 1, 2, 3, 4, 5, M, 6, 7, 8, 9, 11, IF, M, 1, 2, IF, 6, 3, 4, 5, 6, 7, 8, M, M, 1, 2, M, 3, 4

MATERIAL DESCRIPTION

becomes dark gray (5YR 4/1) with wark reddish brown (2.5YR 3/4) mottling, slightly weathered
3. 20, J, ?, Fe, Su, Pl, R
4. 30, J, ?, Cl, Sp, Pl, R
5. 20, J, ?, Fe, Su, Pl, VR
6. 45, J, N, Cl, Sp, Wa, R

dark reddish brown (2.5YR 3/4), slightly to moderately weathered, moderately strong to strong
7. 45, J, N, No, No, Wa, R
8. 90, J, N, Cl, Sp, Pl, R

dark gray (5YR 4/1), fresh to slightly weathered

30% vesicles 2-5mm

50% vesicles 3mm

25-50% vesicles 0.5-1mm
1. 60, J, N, Cl, Sp, Pl, R
2. 2, J, T, Mn-Fe, Su, Ir, R
3. 45, J, VN, No, No, Pl, SR

30-50% vesicles 1-3mm
4. 45, J, VN, No, No, Ir, VR

30-40% vesicles 0.5-1mm
5. 20, J, N, Fe+Mn, Su, Pl, R
6. 20, J, VN, Cl, Sp, Pl, R
7. 35, J, VN, Fe, Su, Pl, SR
8. 2-0, J, ?, Fe+Mn, Su, Ir, VR (contact alteration zone)

becomes dusky red (7.5R 3/4), slightly weathered, 25% vesicles 1-5mm
9. 20, J, ?, Fe+Mn, Su, Pl, R
10. 70, J, ?, Fe+Mn, Su, Pl, R
11. 35, J, ?, Fe+Mn, Su, Ir, VR

becomes dusky red (10R 4/4), 40%vesicles 0.5-1mm
1. 70, J, N, Cl, Sp, Ir, R
2. 0, J, VN, Fe+Mn, Su, Pl, SR
3. 70, J, N, Fe+Mn+Cl, Sp, Wa, R
4. 90, J, VN, Cl, SP, Wa, R
5. 45, J, VN, Fe+Mn, Sp, Pl, R

weak red (10R 4/4), 40-50% vesicles 1-5mm
6. 20, J, N, Cl, Sp, Pl, R
7. 70, J, N, Cl, Sp, Pl, R
8. 60, J, VN, Mn+Cl, Sp, Ir, R

grades to dark reddish gray (2.5YR 3/1)

2-5% olivine phenocrysts

dark reddish brown (5YR 3/2), 30-40% vesicles 1-3mm

very dark gray (5YR 3/1)
1. 70, J, N, Fe+Cl, Su-Sp, St, R
2. 5, J, MW, Cl, Sp, IR, VR
3. 5, J, MW, Fe, Su, IR, VR
4. 20, J, N, No, No, Wa, R

oxidized zone with 50% vesicles 0.5mm

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	SAMPLES PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	365	73	55	100		48	5 6 7 M			
	366		56				M M M 1 8			Water loss ~350 gal
	367						M	0.0	[75]	
	368						2			
	369		57				M M M			
	370	74		100		76				Water loss ~350 gal
	371						3			
	372		58				5 4 6 M M M	0.0	[75]	
	373						1 2 3			
	374						4 5 M			
	375	75	59	100		66	6			Water loss ~400 gal
	376									
	377						M 7	0.0	[60]	
	378		60				1 2 IF 3			
	379						M			
	380	76	60	100		68	4 5 6			Water loss ~400 gal
	381									

MATERIAL DESCRIPTION

becomes dark gray (5YR 4/1), fresh to slightly weathered, 25-30% 2-10mm vesicles
5. 20, J, T, Mn+Cl, Sp, Pl, R
6. 90, J, N, Mn+Cl, Sp, Pl, R
7. 70, J, VN, Mn+Cl, Sp, Wa, R

40% vesicles 1-3mm

8. 80-70, J, N, Mn+Cl, Sp, Wa, R

40% vesicles 1-3mm

moderately weathered, moderately strong zone
1. 20, J, N, Cl, Sp, Pl, R
2. IF/0, J, MW, Fe+Cl, Su-Sp, Ir, R
3. 60, J, VN, Mn+Cl, Sp, St-Pl, SR-R
4. 5, J, T, Fe+Cl, Sp, Pl, R
5. 70, J, T, Fe, Su, Pl, R
6. 70, J, T, Fe, Su, Pl, R

vesicles grade to 3-10mm

40%vesicles 1-3mm

moderately weathered, weak

becomes dark olive gray (5Y 3/3), moderately strong, 40% vesicles 1mm

becomes dark gray (5YR 4/1) to reddish brown (2.5YR 4/4), moderately to slightly weathered, moderately strong to strong

becomes dark gray (5YR 4/1), fresh to slightly weathered, strong
1. 10, J, N, Fe+Cl, Pa, St, VR
2. 10, J, MW, Cl, Pa, Ir, VR

25% vesicles 3-15mm

3. 5-10, J, N-MW, Cl, Pa, Ir, VR
4. 70, J, T, Fe+Mn, Su, St, VR
5. 0, J, VN, Fe+Mn, Su, Pl, R
6. 70, J, VN, Fe+Mn, Su, Pl, R
7. 5, J, N, Fe, Su, Ir, R

40% vesicles 1mm

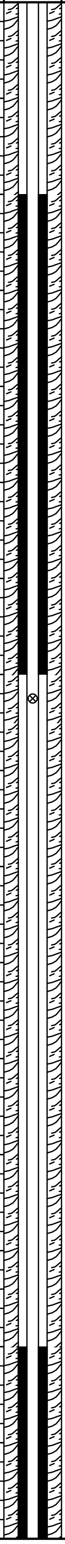
dusky red (10R 3/4), moderately weathered, weak to moderately strong, 40-50% vesicles 1-2mm

black, contact alteration zone

dusky red (2.5YR 3/2), slightly to moderately weathered, moderately strong to strong
1. 0, J, N, Fe, Su, Ir, R
2. 90, J, VN, Cl, Sp, St, R
3. 30, J, VN, Cl, Sp, Pl, R
4. 5, J, VN, Fe+Mn, St, R
5. 5, J, VN, Fe+Mn, Ir, R
6. 60, J, T, Cl, Sp, R

intensely fractured zone has Fe surface stains on most surfaces

dark gray (5YR 4/1), slightly weathered, strong



Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
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Log of Boring RHMW11

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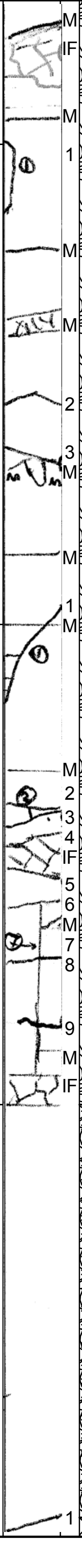

Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	381						M IF		dusky red (10R 3/4), moderately weathered, weak							
	382						M		becomes dark gray (5YR 4/1), slightly weathered, strong, 40-50% vesicles 1-3mm							
			61				1		1. 90, J, T, Cl, Sp, Wa, R					0.0	[100]	
	383															
							M		vesicles increase to 3-5mm							
	384						M									
	385	77		100		92	2		2. M?, 45, J, VN, No, No, St, R 3. 30, J, VN, Fe+Mn, Su, Ir, R							Water loss ~450 gal
							3 M									
	386		62													
							M									
	387						1 M							0.0	[75]	
	388								1. 2. 5, J, MW?, Fe, Su, Ir, R 3. 20, J, MW?, Fe, Su, Ir, R 4. 45, J, T, No, No, Wa, R 5. 45, J, ?, No, No, Wa, R 6. 30, J, N, No, No, Wa, R 7. 85, J, N-MW, No, No, Pl, R 8. 30, J, N, No, No, Wa, R 9. 0, J, T, No, No, Pl, R							
	389		63				M 2 3 4 IF									
	390	78		100		52	5 6 M 7 8									Water loss ~350 gal
	391						9									
	392						M IF		dark gray (5YR 4/1), dark reddish brown (2.5YR 3/3), brownish yellow (10YR 6/6) alteration zone					0.0	[37.5]	
	393								no recovery							
	394		64													
	395	79		50		8			**BASALT a'a Clinker** Variably colored dark reddish brown (2.5YR 3/3), yellowish red (5YR 4/6), weak red (2.5YR 4/2),very dark gray (5YR 3/1), gray (7.5YR 5/1), 0.5-2" angular fragments with 30-50% vesicles 1-3mm in diameter, spherical and lenticular vesicles							Water loss ~500 gal for first 4 feet, ~100 gal for last 1 foot
	396						1		1. 20, J, MW, Mn, Su, Wa, SR							
	397															

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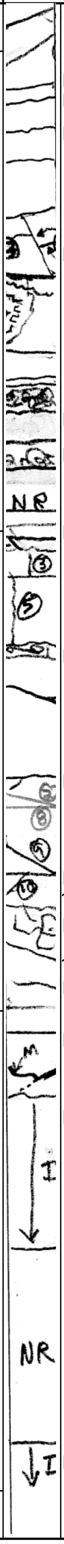
Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	397						2 3 M M	**BASALT Massive a'a** Very dark bluish gray (5PB 3/1), slightly weathered, strong, 15% lenticular vesicles 2-10mm 2. 45, J, MW, Mn, Su, Pl-Wa, SR 3. 45, J, MW, Mn, Su, Wa, R		0.0	[30]	
	398						M 1 2	1. 5, J, VN, Fe+Mn, Su, Wa, SR 2. 5, J, W?, Fe+Mn, Su, Wa, SR-S 3. 0, J, VN, Fe+Mn, Su, Ir, R				
	399		65				4 M 3 5	4. 70, J, T, Fe+Mn, Su, Pl, SR 5. 90, J, VN, Fe+Mn, Su, Wa-Drusy, SR-VR 6. 5, J, VN, Fe+Mn, Su, Wa, SR 7. 0, J, N, Uk+Fe+Mn, Fi-Su, Ir, R-S				
	400	80		90		18	6 7 8	voids with drusy texture 8. 0, J, N, Uk+Fe+Mn, Fi-Su, Ir, R-S				Water loss ~400 gal
	401						IF IF	**BASALT a'a Clinker** Red (10R 4/8) with very dark bluish gray (5PB 3/1) clasts and very dusky red (5R 2.5/2) on fracture planes, moderately to highly weathered, extremely weak to moderately strong				
	402		66				NR M 1 2	no recovery **BASALT Massive a'a** Very dark bluish gray (5PB 3/1), slightly weathered, strong, 15% lenticular vesicles 2-10mm		0.0	[37.5]	
	403						3 4 5 IF	1. 0, J, MW-N, Fe, Su, Ir, VR (a'a texture, possible contact) 2. 70, J, ?, Fe, Su, Pl, SR 3. 90, J, VN, Fe, Su, Pl, R				
	404						6 M	4. 0, J, MW, Fe+Mn, Su, Ir, R (drusy void) 5. 90, J, VN, Fe+Mn, Su, St, R 6. 20, J, MW?, Fe+Mn, Su, Wa, SR 7. 45, J, VN?, Fe+Mn, Su, Pl, SR 8. 20, J, VN?, Fe+Mn, Su, Wa, SR				
	405	81		100		48	7 8 9 M	9. 70, J, N, Fe+Mn, Su, Pl, SR 10. 45, J, ?, Fe+Mn, Su, Pl, SR 11. 20, J, ?, Fe+Mn+Cl, Pa, Wa, R				Water loss ~500 gal
	406		67				10 IF 11					
	407						M 1 M 2	1. 0, J, N, Cl, Sp, Ir, R 2. 20, J, T, Fe+Mn, Su, Pl, R		0.0	[25]	
	408						IF	**BASALT a'a Clinker** Red (10R 4/8) with very dark bluish gray (5PB 3/1), moderately weathered, moderately strong 1. clinker contact				
	409							2. 60, J, VN, Fe+Mn+Cl, Sp, Pl-St, SR-R 3. 60, J, N, Fe+Mn+Cl, Sp, Wa, R 4. 15, J, N-MW, Fe+Mn+Cl, Pa, Wa, R 5. 80, J, T, Fe+Mn, Su, Wa, R				
	410	82	68	60		10						Water loss ~750 gal
	411						NR	no recovery				
	412		69				IF	6. 0, J, VN, Fe+Mn, Su, Ir, R 7. 70, J, VN, Fe+Mn, Su, Pl, SR no recovery		0.0	[37.5]	End of drilling 10/27/17; begin
	413											



Report: CTO53 RED HILL WITH WELL AND PID; File: CTO53 RED HILL CORE LOGS.GPJ; 2/9/2018 RHMW11

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
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Log of Boring RHMW11

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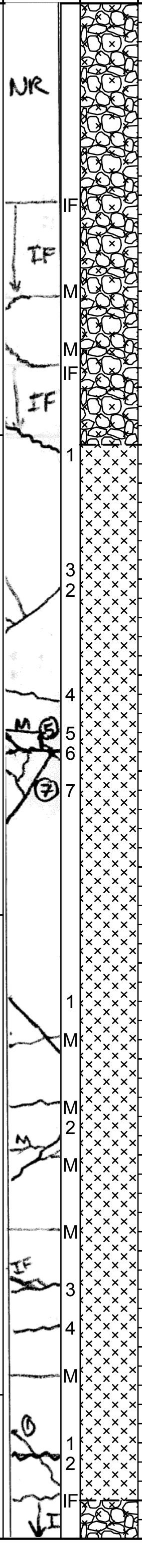
Elevation, feet	Depth, feet	ROCK CORE Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	MATERIAL DESCRIPTION	Well Schematic	SAMPLES Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	413 414 415 416 417	83	69	52		8	no recovery dusky red (10R 3/2) and dark gray (GLEY1 4/N), moderately to highly weathered, strong to moderately strong, sub-angular to sub-rounded fragments 1/4" to 2"					10/30/17 Water loss ~550 gal
	418 419 420 421 422	84	70 71	100		80	**BASALT Massive a'a** Dark gray (GLEY1 4/N), fresh to slightly weathered, strong, 15% lenticular vesicles 1-10 mm no recovery			0.0	[50]	Water loss ~500 gal
	423 424 425 426 427	85	72 73	96		70	1. 70, J, VN, Fe+Mn, Su, Wa, R 2. 60, J, VN, Fe+Mn, Su, Wa, SR 3. 5, J, VN, Fe+Mn, Su, IR, R 4. 5, J, VN, Fe+Mn, Su, Ir, R			0.0	[27.3]	Water loss ~750 gal
	428 429						1. 70, J, VN, Fe+Mn, Su, Wa, SR-R 2. 0, J, N, No, No, Ir, R grades with weak red (10R 4/4) mottling, moderately weathered **BASALT a'a Clinker**			0.0	[25]	

Fracture Drawing / Number / Lithology



Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
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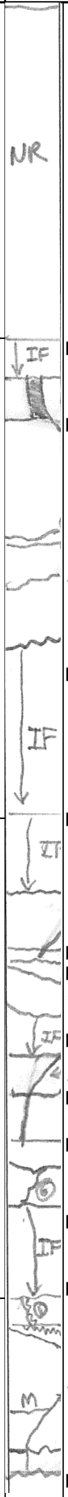
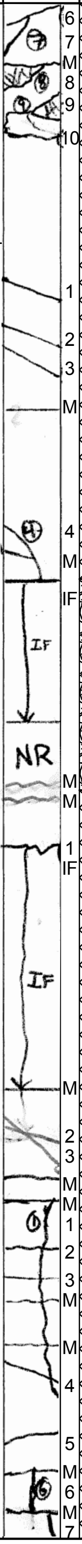


Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	Type Number Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
		ROCK CORE									SAMPLES			
	429								Weak red (10R 4/4) with dark gray (GLEY1 4/N) mottling, moderately to highly weathered, strong, sub-angular fragments 1/4" to 3"					
	430	86	73	32		12								Water loss ~1000 gal
	431								no recovery					
	432													
							IF					0.0	[50]	
	433						1 M		**BASALT Pahoehoe** Very dark greenish gray (GLEY1 3/3), slightly weathered, strong, 25-30% vesicles 1-20mm					
	434		74						1. 90, J, W, Fe+Mn+Cl, Su-Sp, Pl, R 2. 5, J, MW, Fe+Mn, Su, IR, R 30% vesicles 1-3mm with occasional 20mm 3. 5, J, MW, Fe+Mn, Su, IR, R 4. 5, J, MW, Fe+Mn, Su, Ir-Pl, R 5. IF, J, ?, Fe+Mn, SU, Ir, R					
							2 3 4							
	435	87		100		46								Water loss ~500 gal
							5 IF		becomes dark reddish brown (2.5YR 3/3), highly weathered, weak to moderately strong, 40% vesicles 1mm					
	436													
	437								becomes very dark greenish gray (GLEY1 3/3), slightly weathered, strong, 30% vesicles 1-3mm					
			75				IF					0.0	[50]	
	438													
							1 M		grades with dark brown (7.5YR 3/4) weathered patches, moderately weathered, moderately strong to strong, 40% vesicles 1-3mm					
	439						M 2 3 IF		1. 70, J, T, No, No, Pl, R 2. 45, J, VN, No, No, Wa, R 3. IF, ?, Fe+Mn, Su, Ir, R 4. 70, VN, Fe+Mn, Su, Wa, Pl, R 5. 20-45, J, VN, Fe+Mn, Su, Wa, R 6. 45, J, VN, Fe+Mn, Su, Wa, R					
	440	88	76	100		22	4 M 6 M							Water loss ~600 gal
	441						5							
							IF		**BASALT Massive a'a** Very dark greenish gray (GLEY1 3/3) with dark reddish brown (2.5YR 3/3) oxidation, moderately weathered, moderately strong to strong, 25% vesicles 3-10mm, most lenticular					
	442						M							
							1 2 3		becomes dark gray (GLEY1 4/4), slightly weathered, strong, 25% lenticular vesicles 3-10 mm 1. 90, J, N?, Fe+Mn, Su, IR, R (IF along joint) 2. 45. J, MW?, Fe+Mn, Su, IR, R (IF along joint) 3. 4. 70, J, MW, Fe+Mn, Su, Wa, R 5. 10, J, VN, Cl, Pa, Ir, R			0.0	[37.5]	
	443						4							
	444		77				5 M		10-15% vesicles, most spherical 6. 30, J, N, Fe+Mn, Su, Ir, R					Water loss ~700 gal
	445													

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

Sheet 29 of 32



Elevation, feet	Depth, feet	Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number	Lithology	MATERIAL DESCRIPTION	Well Schematic	Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	445	89		100		56	6 7 M		7. 70, J, N, Fe+Mn+Cl, Pa, Pl, SR 25% lenticular vesicles 2-5mm							
	446		77				8 9 10		8. 60, J, MW?, No, No, Wa, R (IF along fracture) 30% vesicles 1-3mm, most spherical 9. 60, J, MW?, No, No, Wa, R (IF along fracture) 10. 45, J, VN, No, No, Pl, R							
	447													0.0	[37.5]	
	448		78				1 2 3 M		becomes 15-20% vesicles 0.5-1mm 1. 45, J, N, No, No, Wa, R 2. 50, J, VN, Fe+Mn, Su, St, R 3. 60, J, VN, Fe+Mn, Su, Wa, R 4. 70, J, VN-N, Fe+Mn, Su, Wa, R							
	449															
	450	90		100		50	4 M		becomes 25% vesicles 2-20mm							Water loss ~700 gal
	451		79				IF		**BASALT a'a Clinker** Very dark gray (GLEY1 3/N), moderately to highly weathered, weak to moderately strong, sub-angular to angular, coarse sand (2.5") size fragments							
	452													0.0	[21.4]	
	453						M M		no recovery **BASALT Massive a'a** Very dark gray (GLEY1 3/N), slightly to moderately weathered, strong, 30% lenticular vesicles 1-5mm							
	454						1 IF		becomes red (10R 4/6), moderately weathered, moderately strong to strong, 25% vesicles 1-10mm 1. flow contact 2. 20, J, VN, Fe+Mn, Su, Pl, SR 3. 70, J, VN, Fe+Mn, Su, Wa, R							
	455	91		86		20			becomes dark gray (GLEY1 4/4), slightly weathered, strong, 25% lenticualr vesicles 1-10mm							Water loss ~1100 gal
	456		80				M 2 3 M									
	457						M 1 2 3 M		1. 90, J, VN, Fe+Mn, Su, Wa, R 2. 0, J, VN, Fe+Mn, Su, Ir, R 3. 0, J, MW, Fe+Mn, Su, Ir, R 4. 20, J, T, Fe+Mn, Su, Ir, R 5. 20, J, VN-MW, Fe+Mn, Su, Ir, R					0.0	[37.5]	
	458															
	459		81				M 4		occasional vesicle voids up to 40mm	⊗						
	460	92		100		48	5 M 6 M 7		6. 90, J, N, No, No, Ir, R 7. 90, J, VN, Fe+Mn, Su, Pl-Ir, R							Water loss ~700 gal
	461															

Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

Sheet 30 of 32

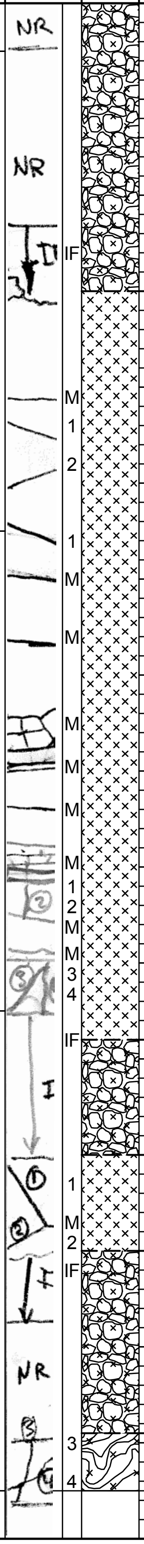
Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Drawing Number	MATERIAL DESCRIPTION	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	461						8 M 9 M M	8. 70, J, VN, Fe+Mn, Su, Pl, SR-S 9. 20, J, VN, Fe+Mn, Su, Pl, SR-S			
	462								0.0	[42.9]	End of drilling 10/30/17; begin 10/31/17
	463							becomes moderately weathered with dusky red (10R 3/3) mottling			
	464							**BASALT a'a Clinker** Dusky red (10R 3/3) with very dark gray (GLEY1 3/N) mottling, highly to moderately weathered, strong, 1/4" to 1" subangular to angular fragments			
							NR	no recovery			
	465	93	82	62		28	1 2 M	**BASALT Massive a'a** Very dark gray (GLEY1 3/N) with dusky red (10R 3/3) mottling, moderately weathered, strong, 25% lenticular vesicles 1-5mm			Water loss ~700 gal
	466						M NR	no recovery			
	467						IF 1 2	**BASALT a'a Clinker** Very dark gray (GLEY1 3/N) with dusky red (10R 3/3) mottling, moderately to highly weathered, strong, 1" subrounded fragments 1. 30, J, N, Fe+Mn, Su, Pl, SR-R 2. 50, J, VN, Fe+Mn, Su, Ir, R	0.0	[27.3]	
	469		83				IF 3 M	**BASALT Massive a'a** Very dark gray (GLEY1 3/N) with dark reddish gray (5R 3/1) mottling, moderately weathered, strong, 25% lenticular vesicles 1-5mm			
	470	94		100		30	4 5 6 7 M 8 M	becomes dark gray (GLEY1 4/N), slightly weathered, 15% lenticular vesicles 1-5mm 1. 30, J, N-MW, Fe+Mn, Su, Ir, VR 2. 80-90, MW, Fe+Mn, Su, Ir-Wa, VR 3. 70, J, VN, Fe+Mn, Su, Pl-Wa, SR 4. 50, J, VN, Fe+Mn, Su, Pl, Wa, SR 5. 45, J, VN, Fe+Mn, Su, Ir, R 6. 20, J, VN, Fe+Mn, Su, Pl, SR 7. 70-90, J, MW-VN, Fe+Mn, Su, Wa, SR 8. 10, J, T, Fe, Su, Pl, SR			Water loss ~650 gal
	472						M 1	1. mechanical break 2. mechanical break 3. 5-20, J, N, Fe+Mn, Su, IR, VR (drusy void) 4. 60, J, T, Fe+Mn, Su, Pl, SR-S 5. mechanical break	-	[30]	
	473		84								
	474						2 3				
	475	95		82		52	M 4 5 6 7	becomes dark gray (GLEY1 4/N) with dark reddish gray (5R 3/1) mottling 6. 90, J, N, Fe+Mn, Su, Ir, SR-S 7. 10, J, T, Fe+Mn, Su, Pl, St, SR-S			Water loss ~650 gal
	476		85				NR	**BASALT a'a Clinker**			
	477										

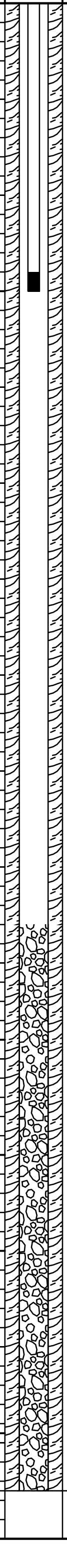
Project: CTO53 - Red Hill Bulk Fuel Storage Facilty
Project Location: CTO53
Project Number: 60481245

Log of Boring RHMW11

Sheet 31 of 32

Elevation, feet	Depth, feet	Run No.	Box No.	Recovery, %	Fractures per Foot	R Q D, %	Fracture Number	MATERIAL DESCRIPTION	Type	Number	Blows per foot	PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
	477							no recovery						
	478	96	85	64		64		no recovery				-	[25]	
	479–480		86				IF	Dusky red (7.5R 3/3), dark brown (7.5YR 3/8), very dark gray (GLEY1 3/N) and dark gray (GLEY1 4/N), moderately to highly weathered, strong, 1/4" to 2" size, subrounded to subangular fragments						Water loss ~1000 gal
	480–482						M 1 2	**BASALT Massive a'a** Dark gray (GLEY1 4/N) with occasional dusky red (7.5R3/3) mottling, moderately to slightly weathered, strong, 25% lenticular vesicles 1-5mm 1. 45, J, VN, Fe+Mn, Su, Pl, SR 2. 30, J, VN, Fe+Mn, Su, Wa, SR-R						
	483–487	97	87	100		100	1 M M M M M M 1 2 M M 3 4	becomes dark gray (GLEY1 4/N), lenticular vesicles 1-20mm 1. 0, J, VN, Fe+Mn, Su, Ir, R 2. 90, J, VN, Fe+Mn, Su, Ir, R 3. 70, J, VN, Fe+Mn, Su, Wa, SR 4. 80, J, VN, Fe+Mn, Su, Wa, SR-R				-	[25]	Water loss ~1200 gal
	487.5–489	98	88	76		0	IF	**BASALT a'a Clinker** Dark gray (GLEY1 4/N) with abundant dark reddish gray (5R 3/1) weak weathered areas, highly weathered, very weak to moderately strong 1. 70, J, N, Fe, Su-Pa, Ir, R 2. 60, J, N, Fe, Su-Pa, Ir, R				-	[23.1]	
	489–490						1 M 2	**BASALT Massive a'a** Dark gray (GLEY1 4/N), moderately weathered strong, 30% vesicles 1-2mm, fractures are dark reddish gray (5R 3/1), highly weathered, very weak to weak						
	490–492						IF	**BASALT a'a Clinker** Dark reddish gray (5R 3/1) with dark gray (GLEY1 4/N) mottling, highly weathered, very weak to weak no recovery						Water loss ~2000 gal
	492–493						3 4	**BASALT Pahoehoe** Dusky red (10R 3/2), moderately weathered, weak to moderately strong, 40% spherical vesicles 0.5-2mm 3. 80, J, T, No, No, Wa, R 4. 60, J, T, No, No, Wa, R						





Elevation, feet	Depth, feet	ROCK CORE						Lithology	MATERIAL DESCRIPTION	Well Schematic	SAMPLES			PID (ppm)	Drill Time [Rate, ft/hr]	FIELD NOTES AND TEST RESULTS
		Run No.	Box No.	Recovery,%	Fractures per Foot	R Q D, %	Fracture Drawing Number				Type	Number	Blows per foot			
	493								Bottom of Boring; TD = 492.5 ft bgs							
	494								Used a total of approximately 27,140 gallons of circulation water. Airknife from 0-20 ft bgs. Installed 16 1/4" steel casing to 20 ft bgs. Drill with 8" O.D. HSA from 22.5 ft bgs to 50 ft bgs. HQ core from 50 ft bgs to 210 ft bgs. Hole reamed to 15 1/2 inches from 42.7-75 ft bgs. Installed 10" steel casing to 75 ft bgs. Hole reamed to 9 1/2" from 75-165 ft bgs. Installed 5" steel casing to 165 ft bgs. PQ core from 210 ft bgs to 492.5 ft bgs. Installed Westbay MP38 multi-level well with 8 isolated sampling zones.							
	495															
	496															
	497															
	498															
	499															
	500															
	501															
	502															
	503															
	504															
	505															
	506															
	507															
	508															
	509															

GEOPHYSICAL RECORD OF BOREHOLE: RHMWW11

Geophysical Investigation at RHSF

Client: NA

Project Number: 60481245

Date: January 31,2018

Datum: NA
Easting:E 1675363.58
Northing:N 75292.81
Ground Elev msl: 230 ft

Depth Reference "0" at TOC
Drilling Method Air Rotary
Borehole Size: HQ/PQ diamond bit / 9.5" tricone bit
Drilled Depth: 492.5 ft

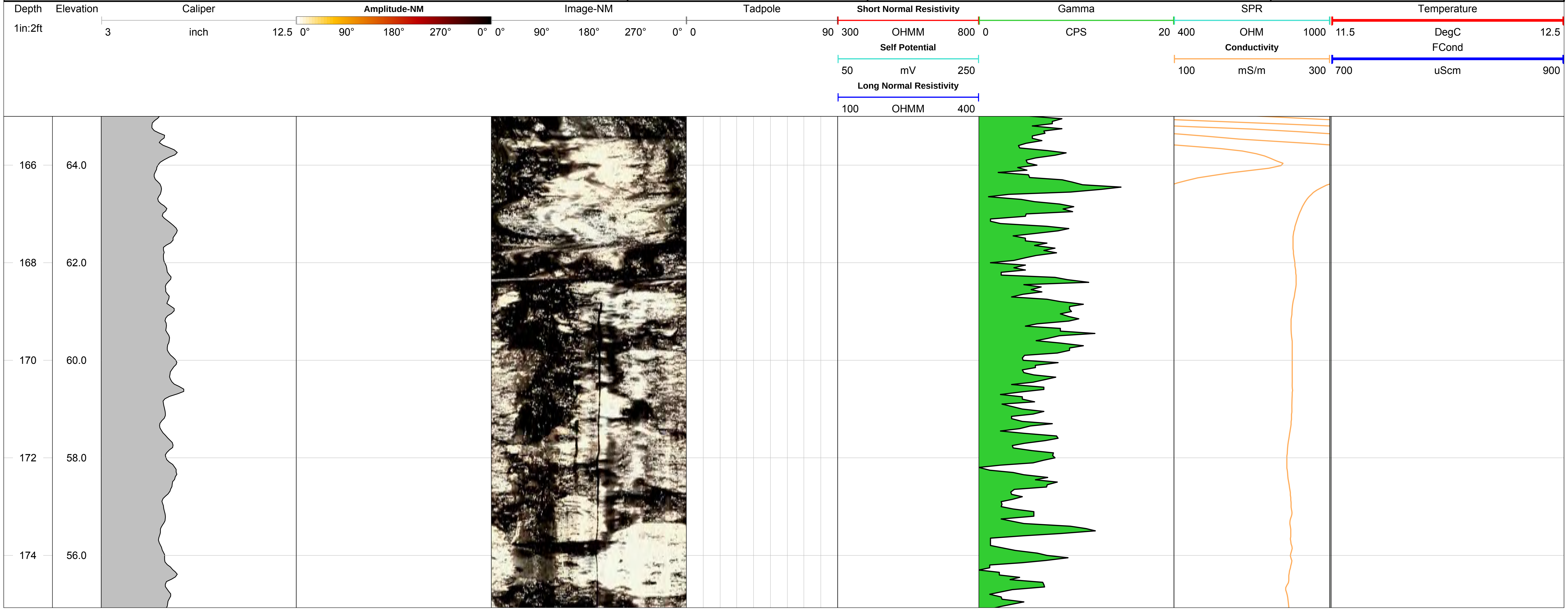
Drill Comp Date: 11/2017
Casing Stick-up: NA
Casing Diameter: NA
Casing Depth: NA

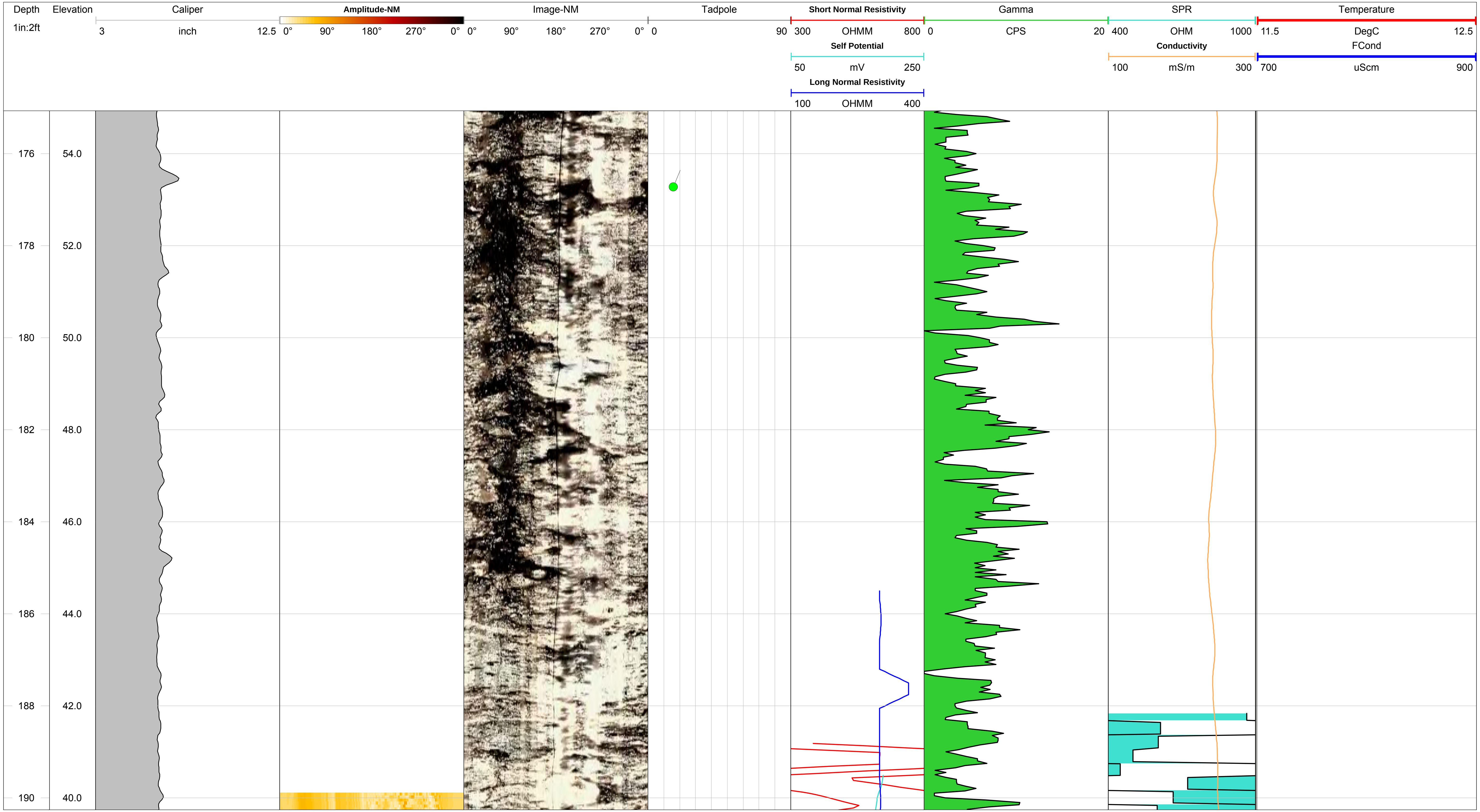
Location: Halawa Heights, HI
Log Date: 11/2017
Logged By: S. Husted

- 🔴 1 - Major Open Joint / Fracture
- 🟣 2 - Minor Open Joint / Fracture
- 🟠 3 - Partially Open Joint / Fracture
- 🟢 5 - Bedding / Banding / Foliation

Notes:

Water Level: NA

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Short Normal Resistivity
300 OHMM 800
Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
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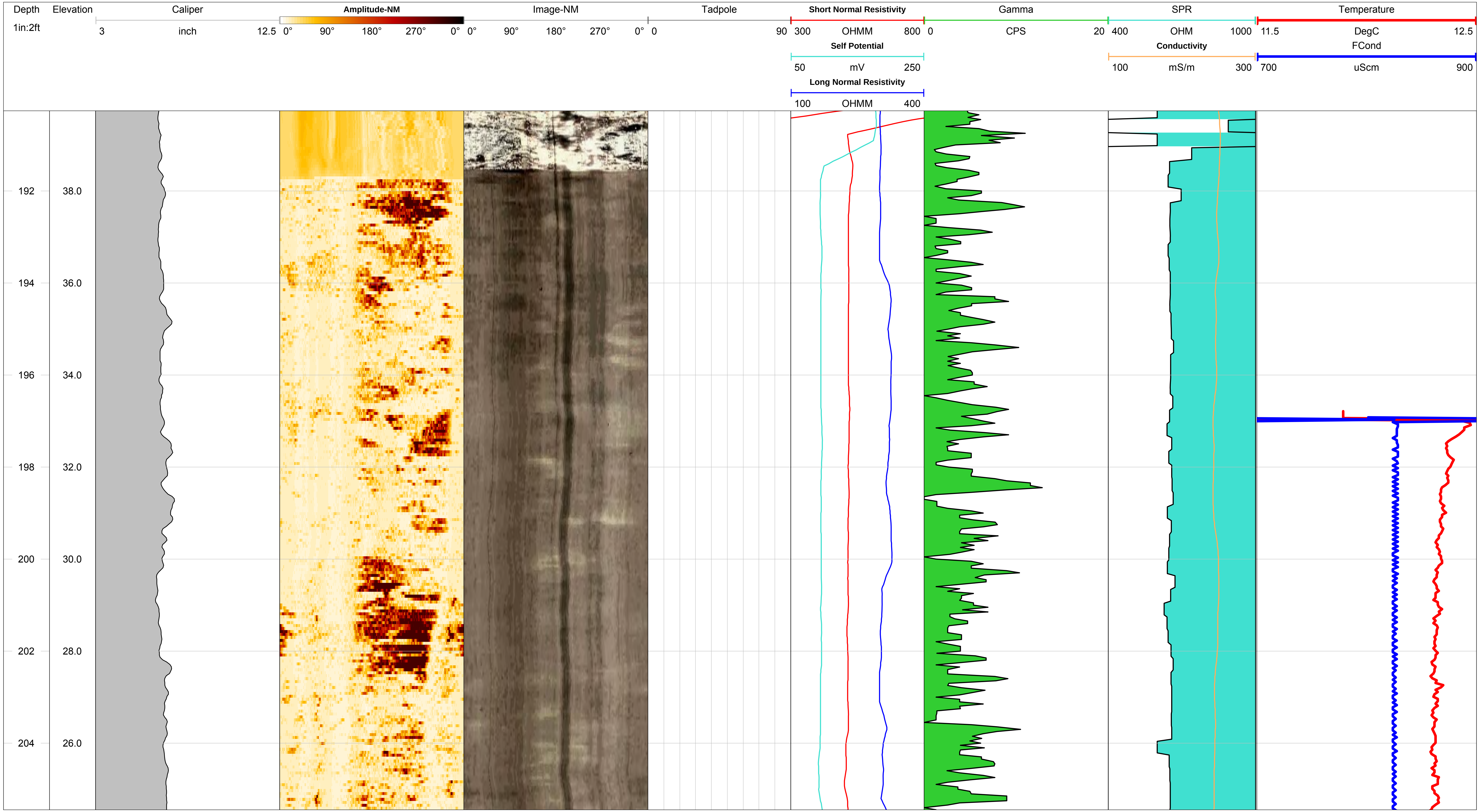
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Tadpole
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Short Normal Resistivity
300
OHMM
800
Self Potential
50
mV
250
Long Normal Resistivity
100
OHMM
400
Gamma
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CPS
20
SPR
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OHM
1000
Conductivity
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mS/m
300
Temperature
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DegC
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FCond
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uScm
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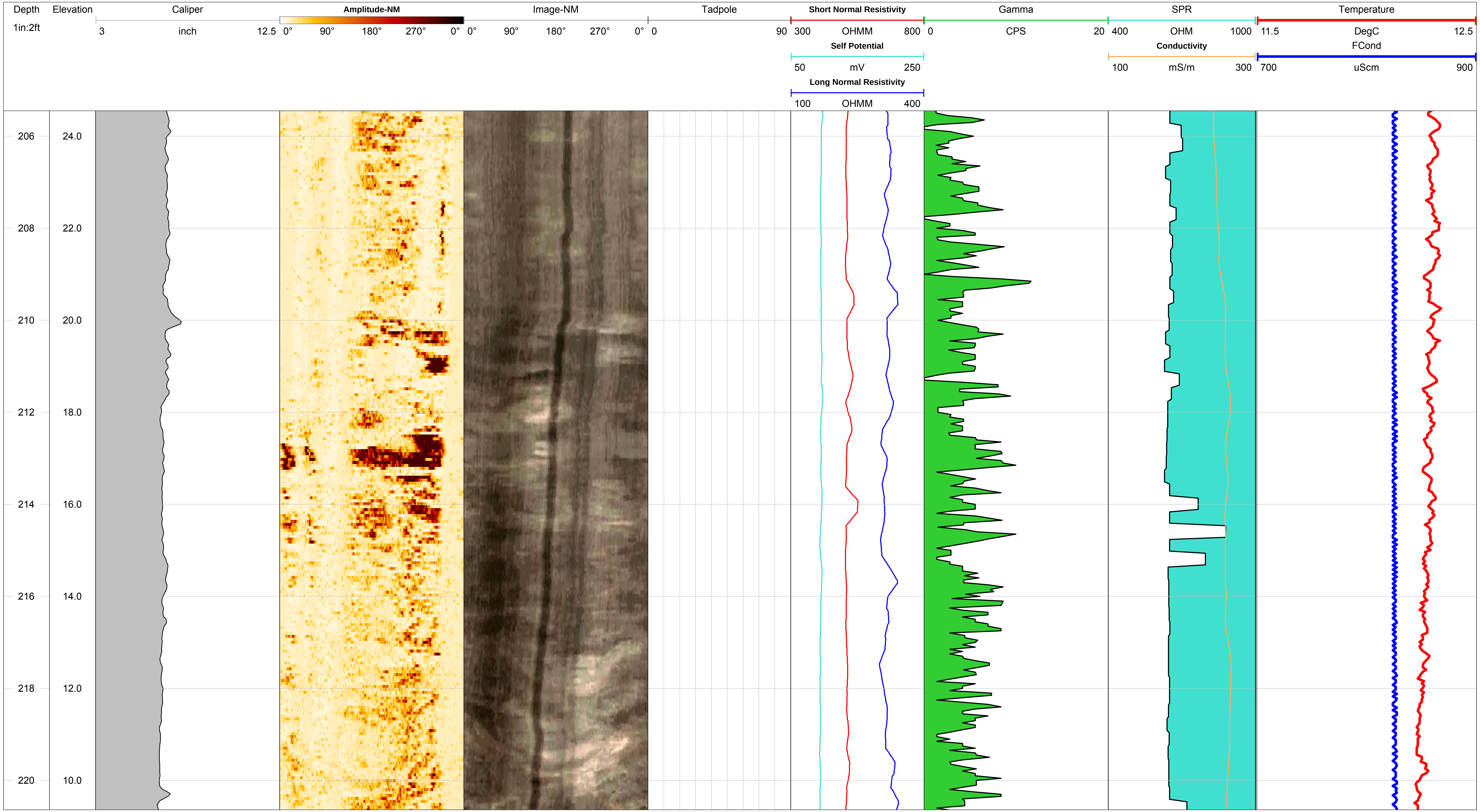
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Tadpole
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Short Normal Resistivity
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OHMM
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Self Potential
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mV
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Gamma
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mS/m
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FCond
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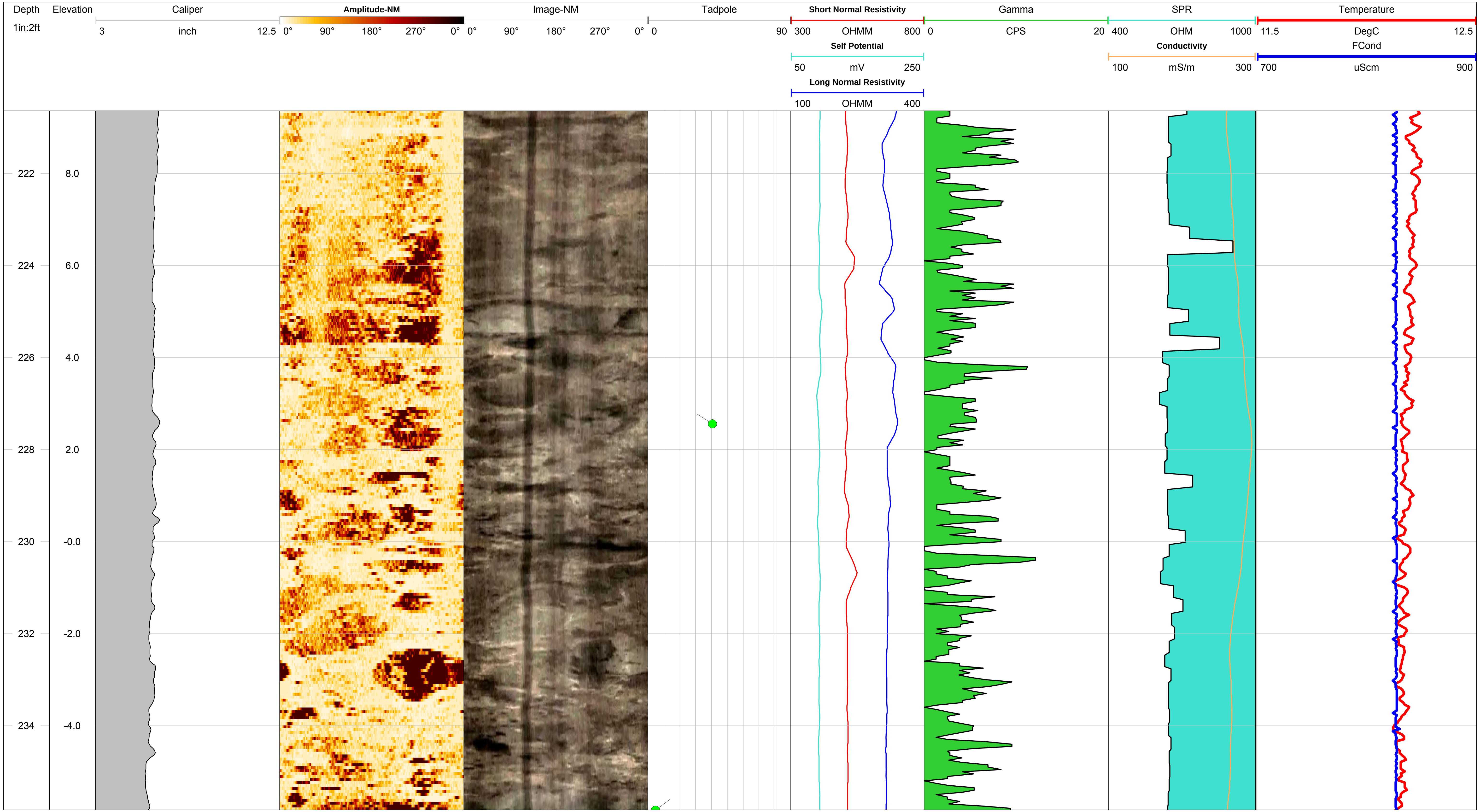
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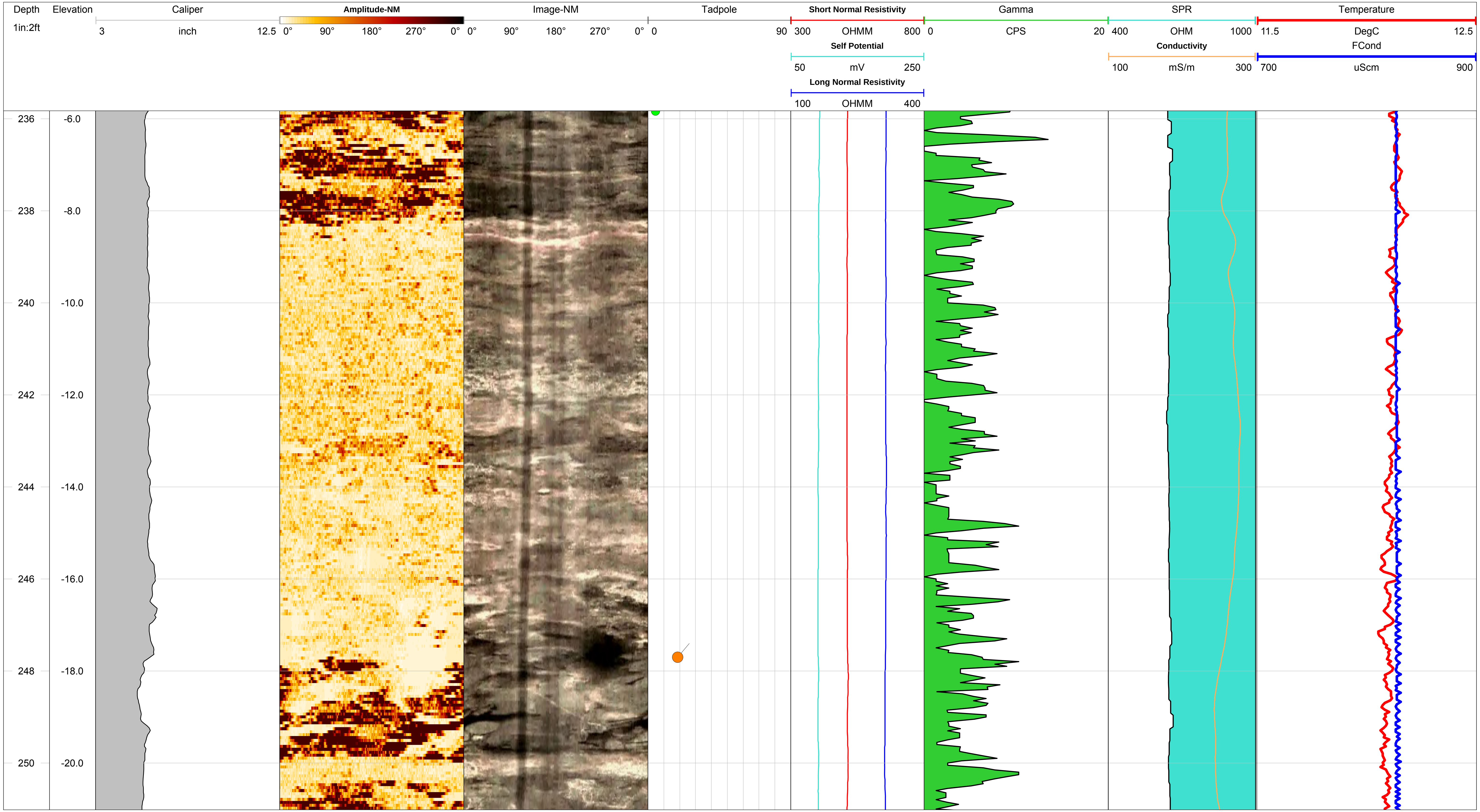
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Tadpole
0 90
Short Normal Resistivity
300 OHMM 800
Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
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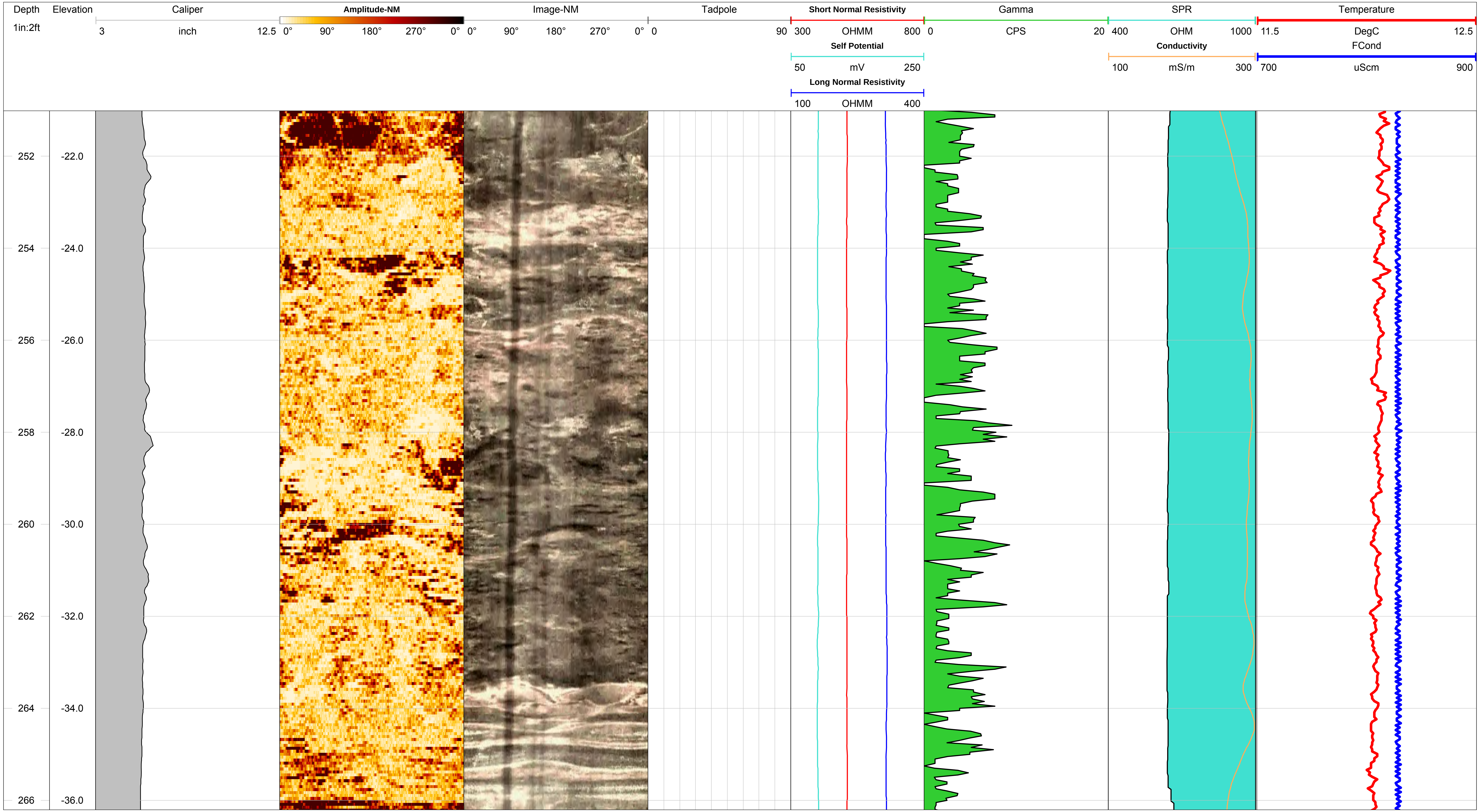
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Tadpole
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300
OHMM
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mV
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OHMM
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Gamma
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mS/m
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DegC
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uScm
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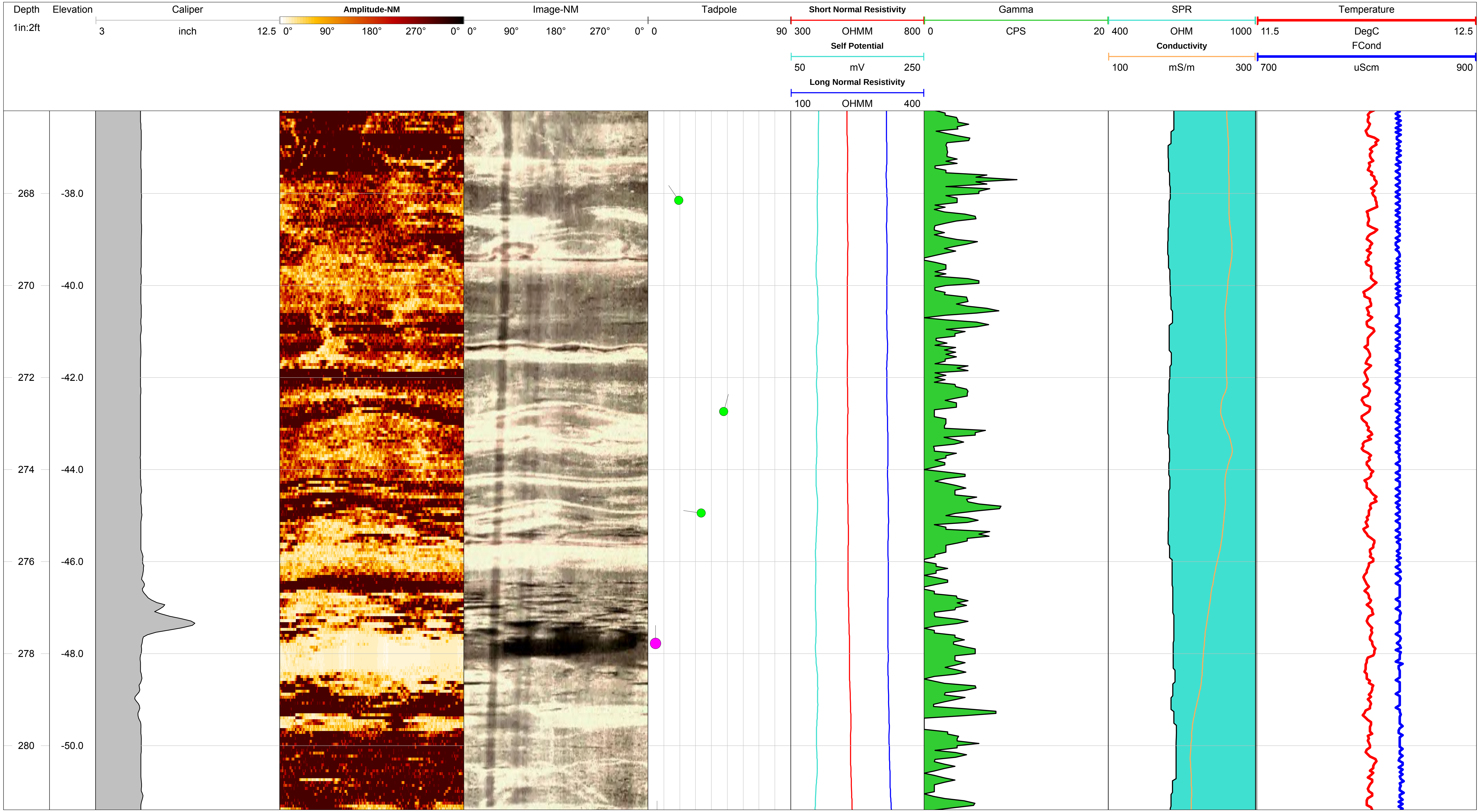
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Short Normal Resistivity
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800
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mV
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OHMM
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Gamma
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CPS
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SPR
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OHM
1000
Conductivity
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mS/m
300
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FCond
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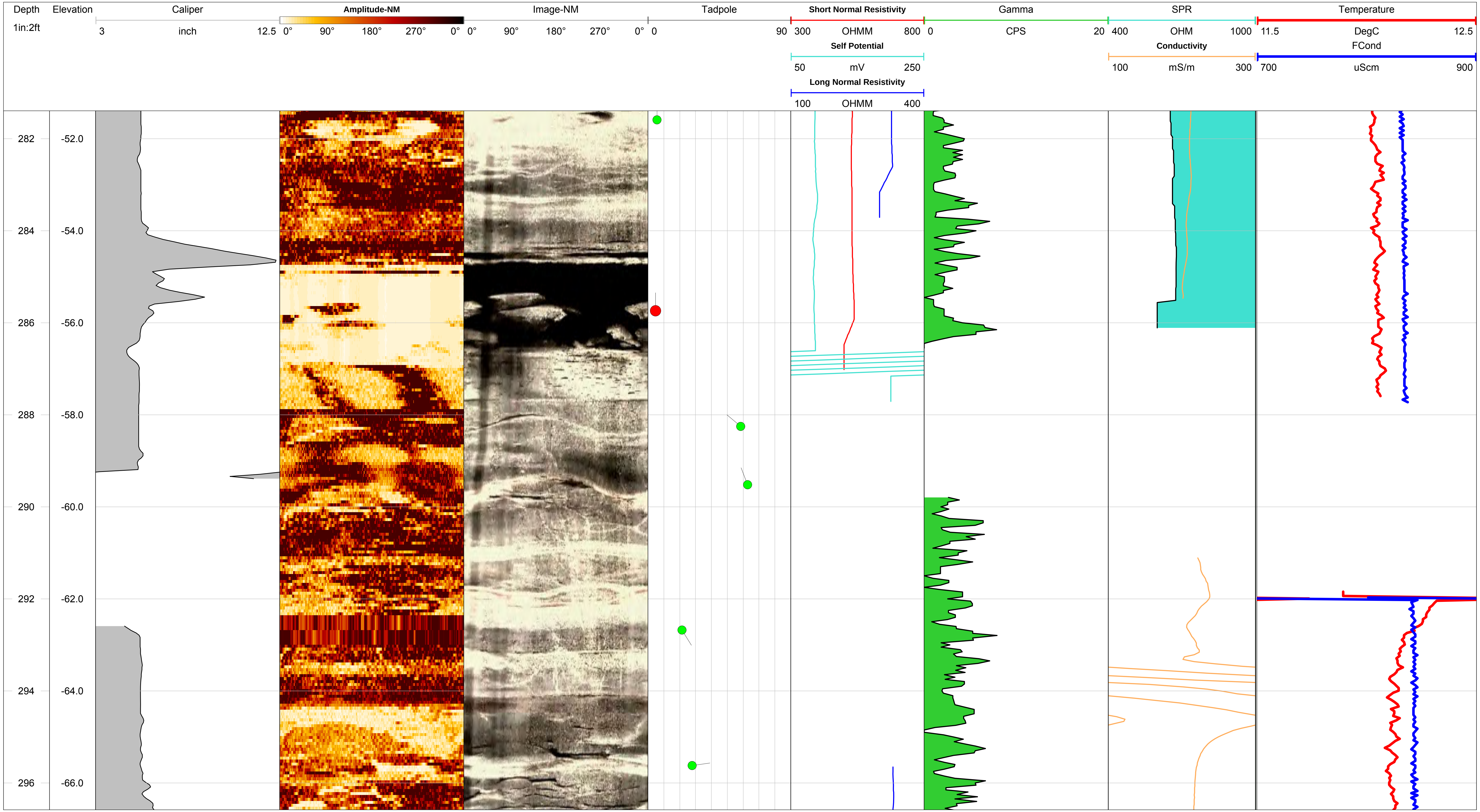
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Tadpole
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Short Normal Resistivity
300
OHMM
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Self Potential
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mV
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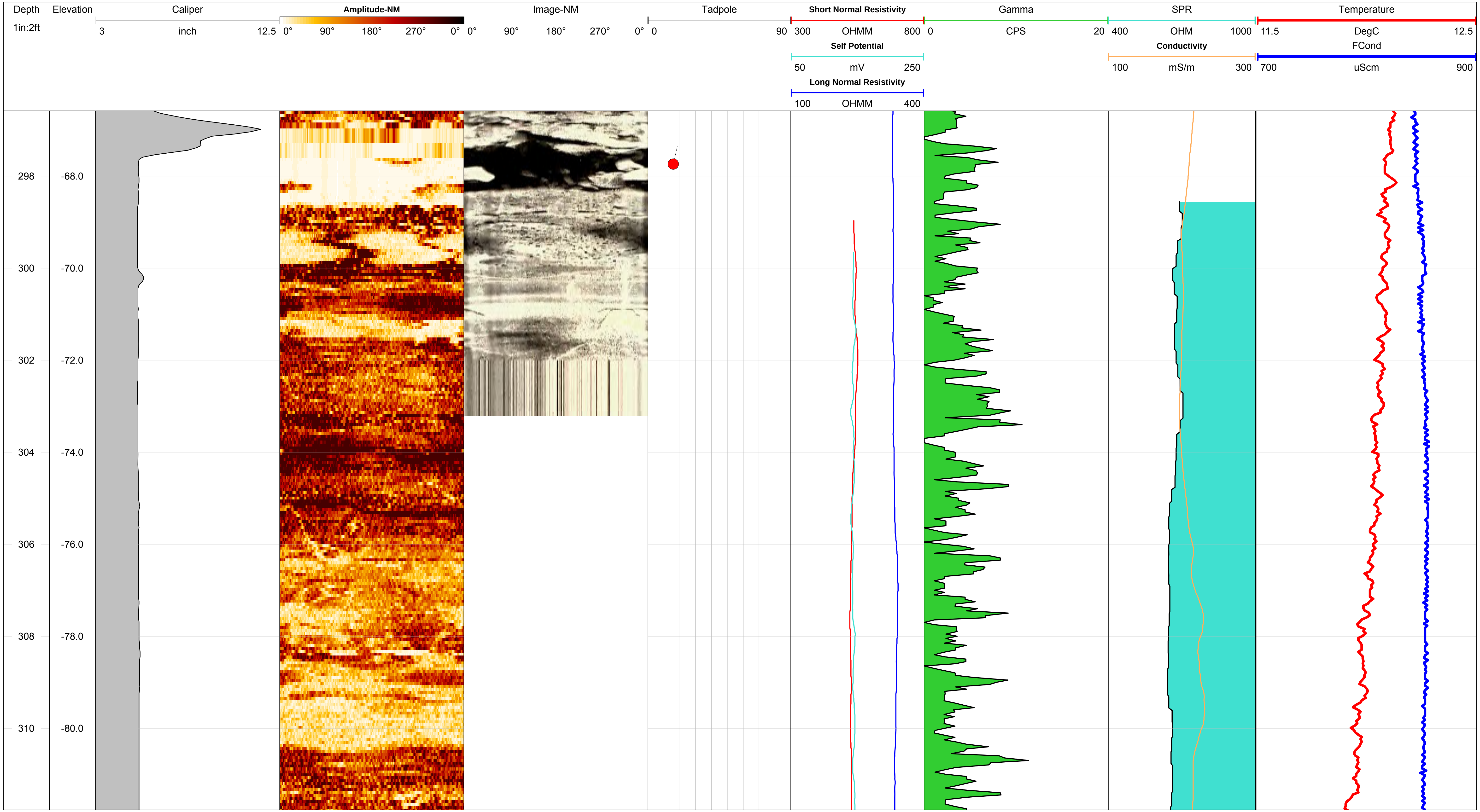
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SPR
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Conductivity
100 mS/m 300
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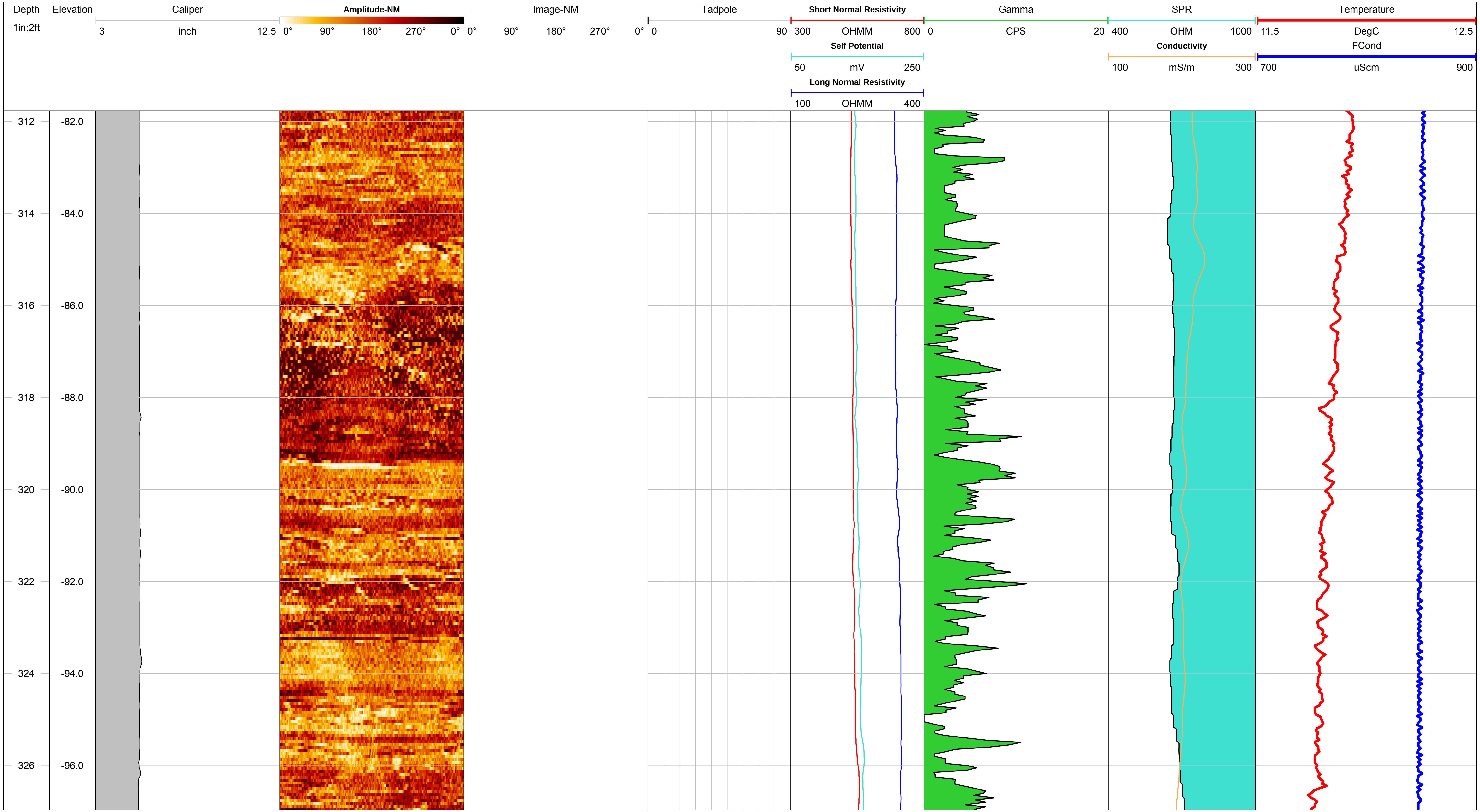
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Tadpole
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Short Normal Resistivity
300
OHMM
800
Self Potential
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mV
250
Long Normal Resistivity
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OHMM
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Gamma
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CPS
20
SPR
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OHM
1000
Conductivity
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mS/m
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Temperature
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DegC
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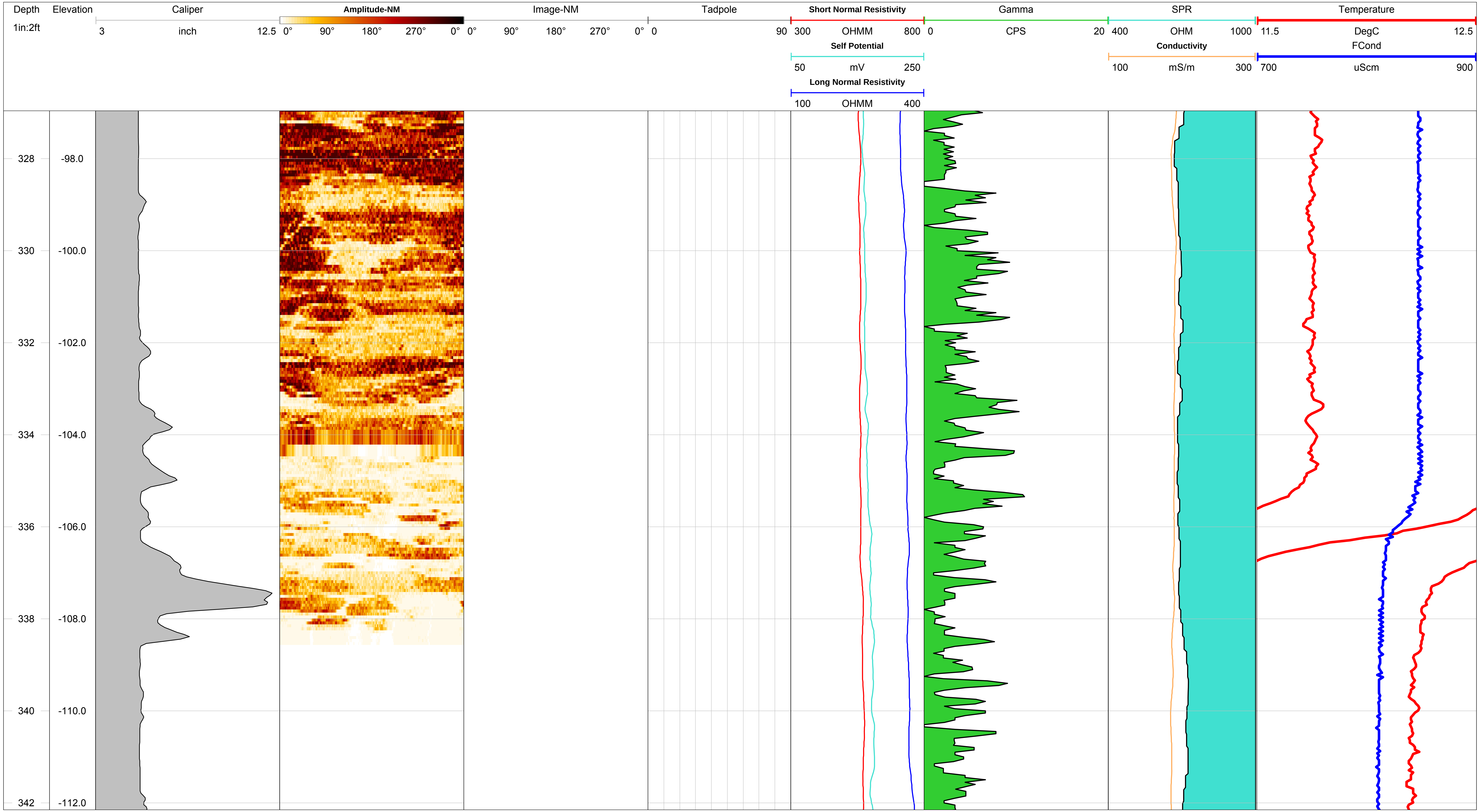
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Image-NM
0°
90°
180°
270°
0°
Tadpole
0
90
Short Normal Resistivity
300
OHMM
800
Self Potential
50
mV
250
Long Normal Resistivity
100
OHMM
400
Gamma
0
CPS
20
SPR
400
OHM
1000
Conductivity
100
mS/m
300
Temperature
11.5
DegC
12.5
FCond
700
uScm
900
328
-98.0
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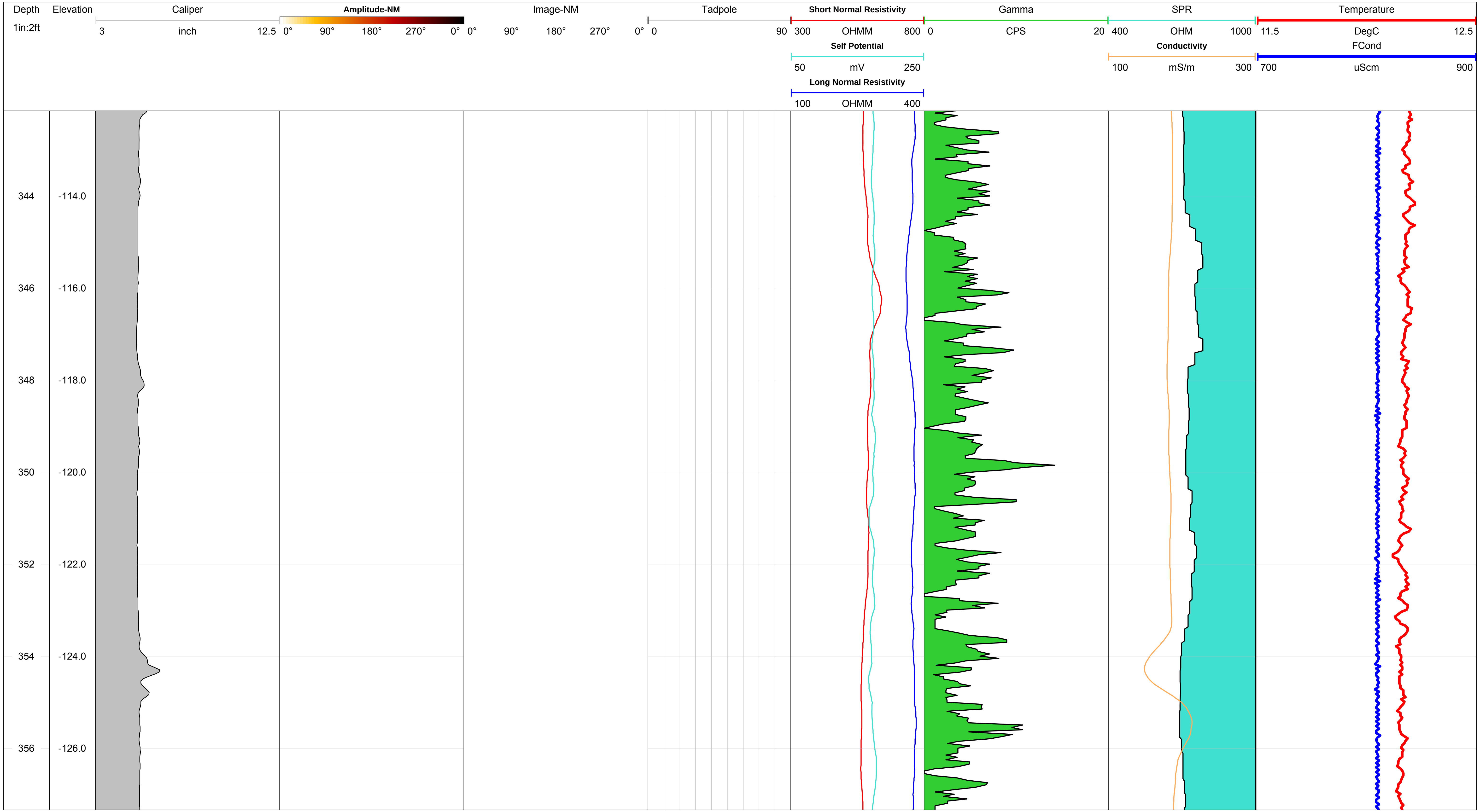
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Short Normal Resistivity
300 OHMM 800
Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
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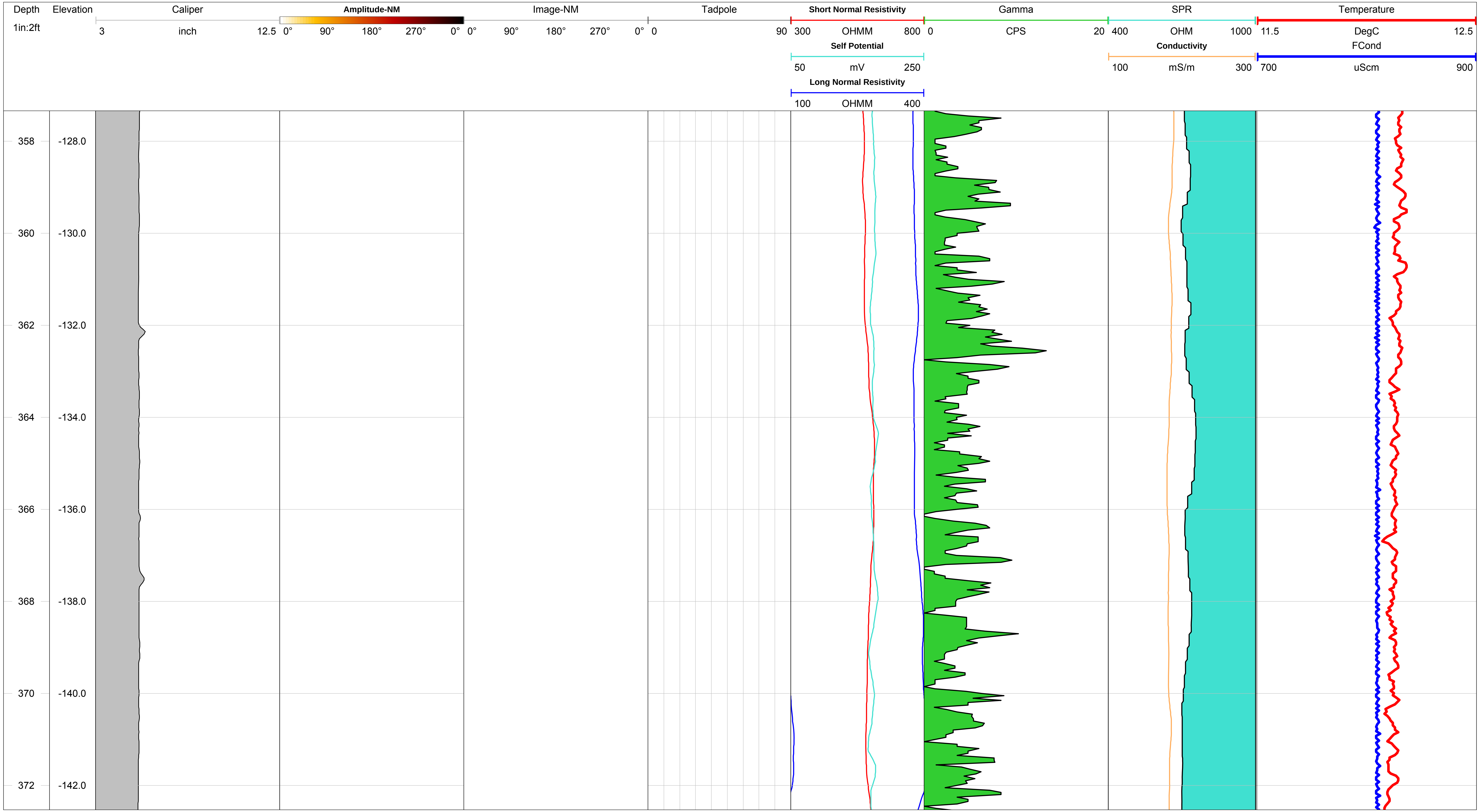
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Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
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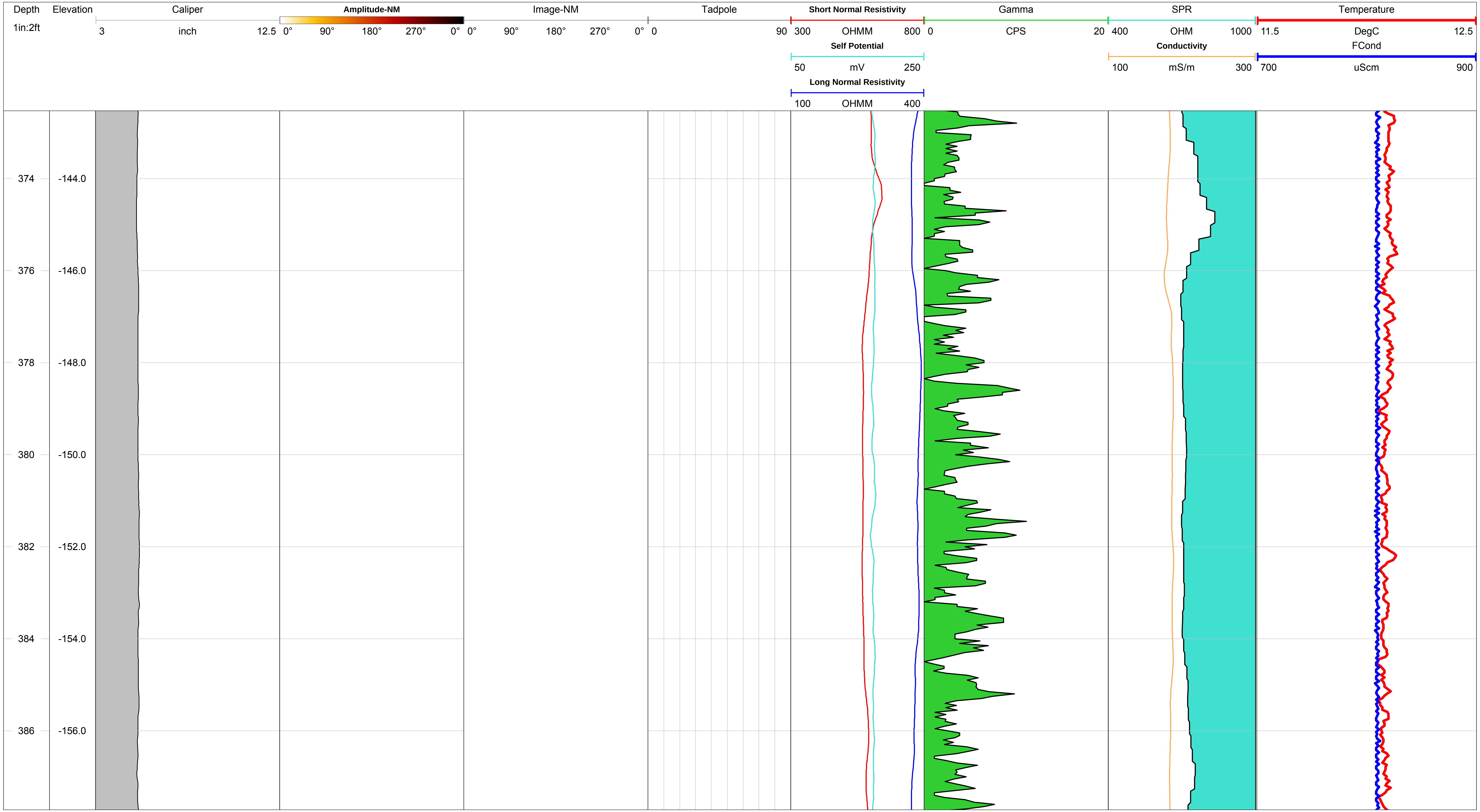
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Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
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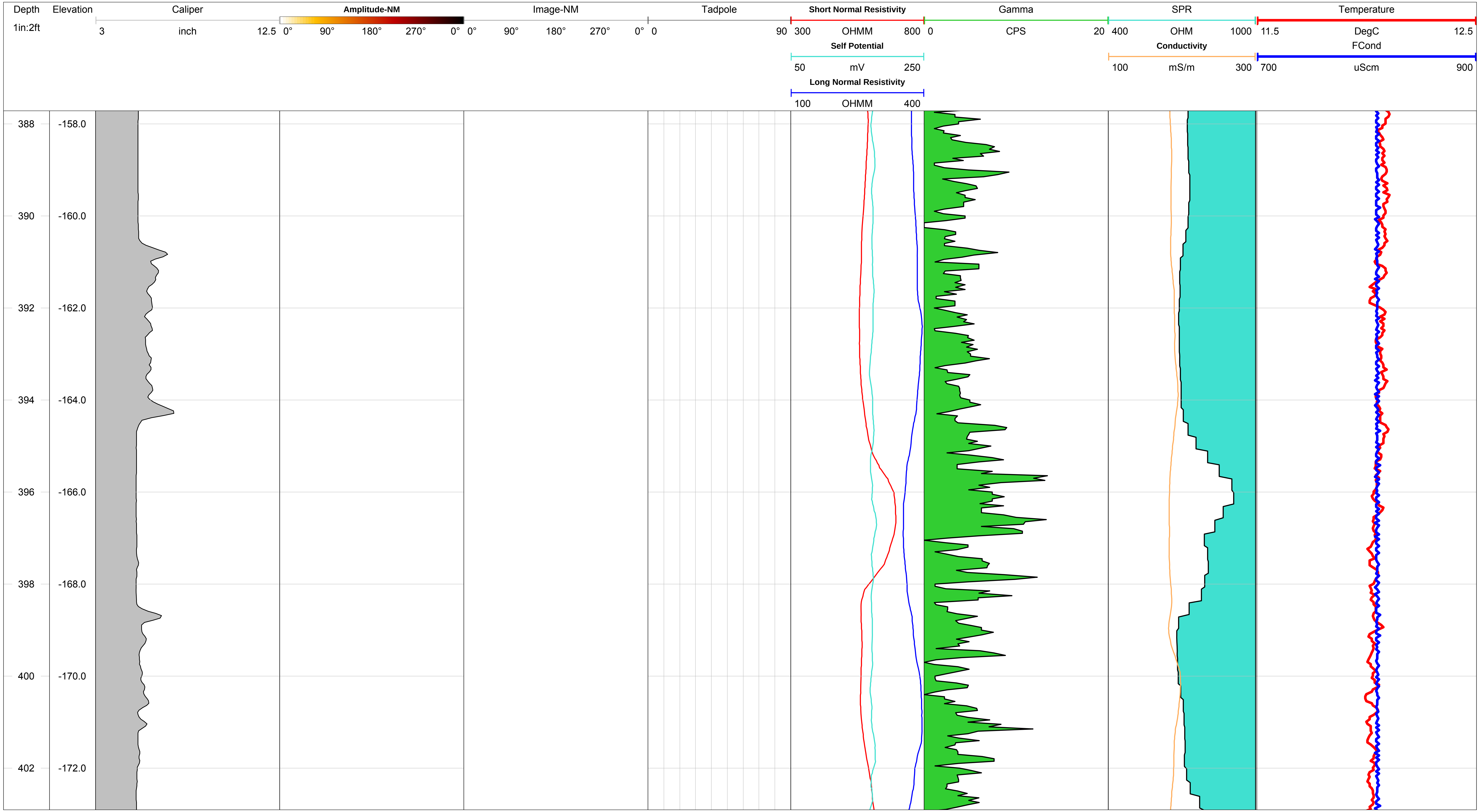
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90°
180°
270°
0°
Tadpole
0
90
Short Normal Resistivity
300
OHMM
800
Self Potential
50
mV
250
Long Normal Resistivity
100
OHMM
400
Gamma
0
CPS
20
SPR
400
OHM
1000
Conductivity
100
mS/m
300
Temperature
11.5
DegC
12.5
FCond
700
uScm
900
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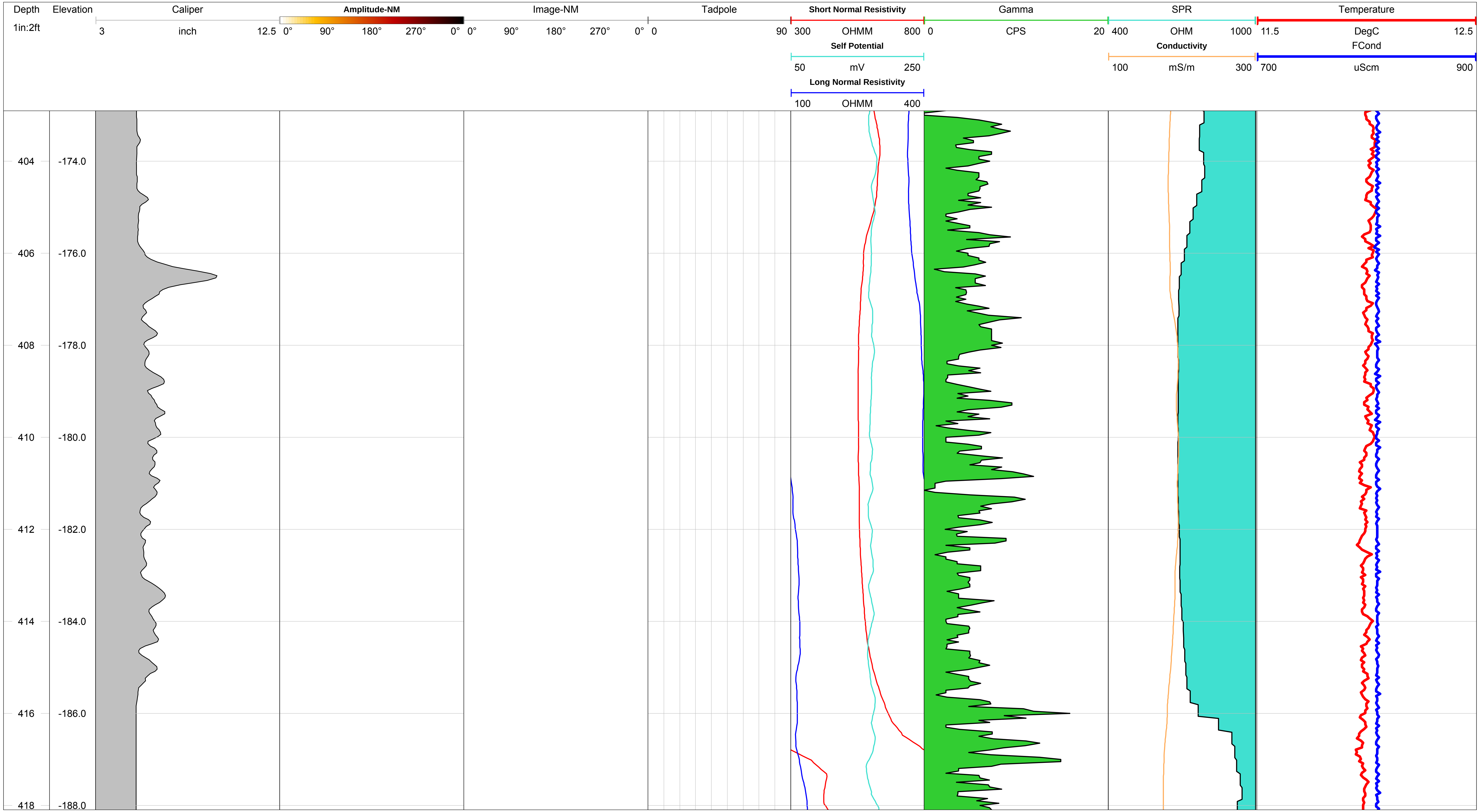
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Tadpole
0 90
Short Normal Resistivity
300 OHMM 800
Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
700 uScm 900
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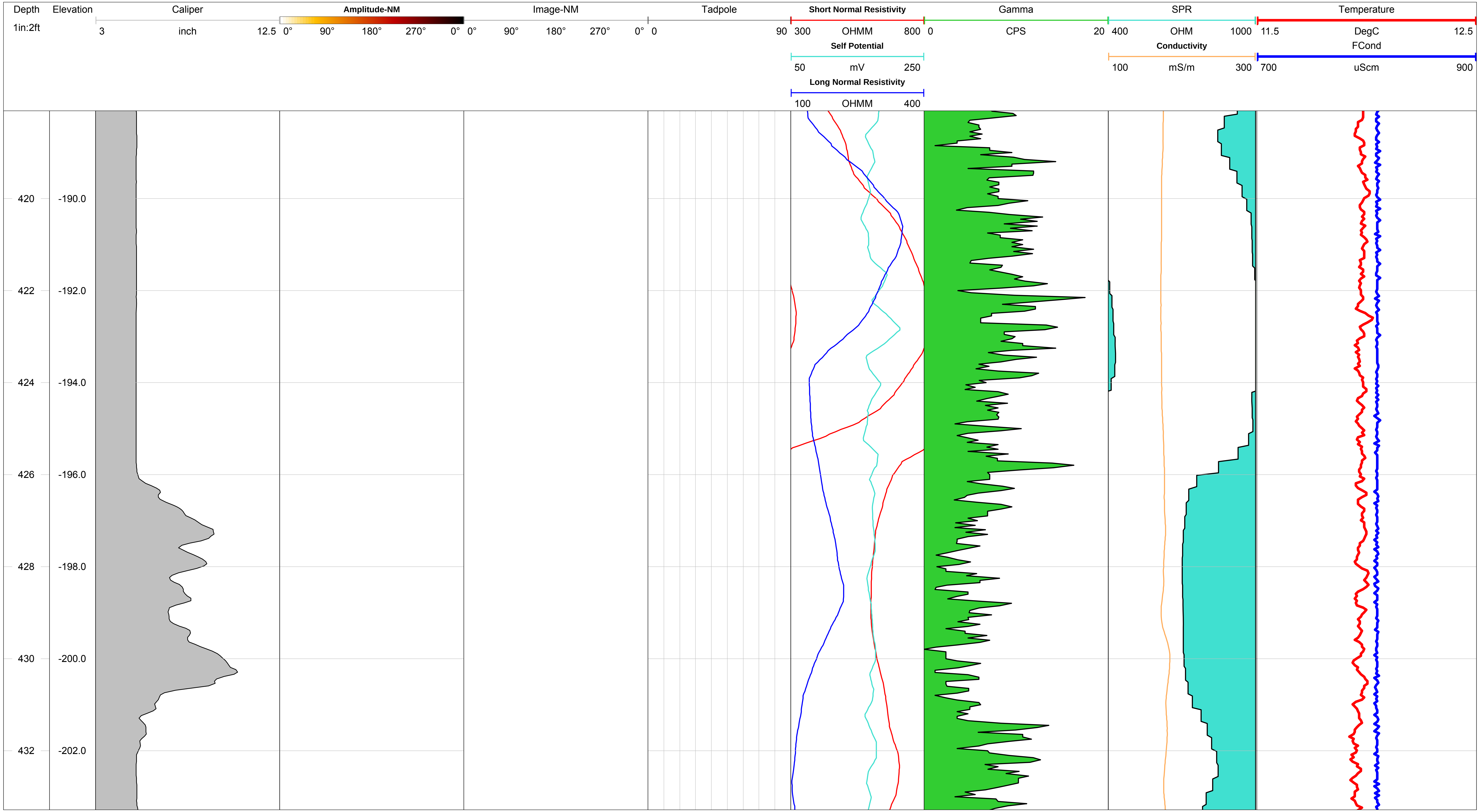
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Image-NM
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Tadpole
0 90
Short Normal Resistivity
300 OHMM 800
Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
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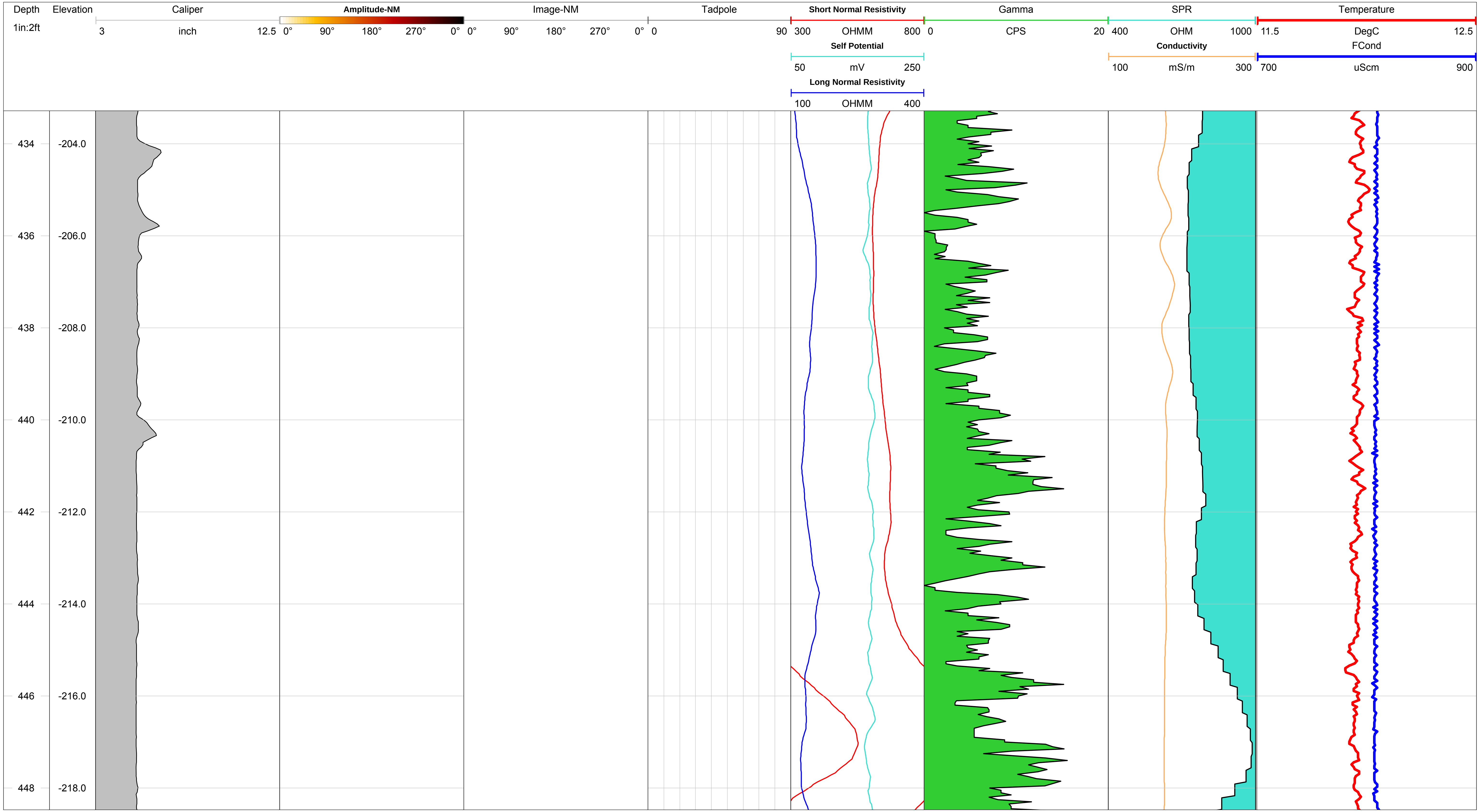
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Tadpole
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Short Normal Resistivity
300 OHMM 800
Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
700 uScm 900
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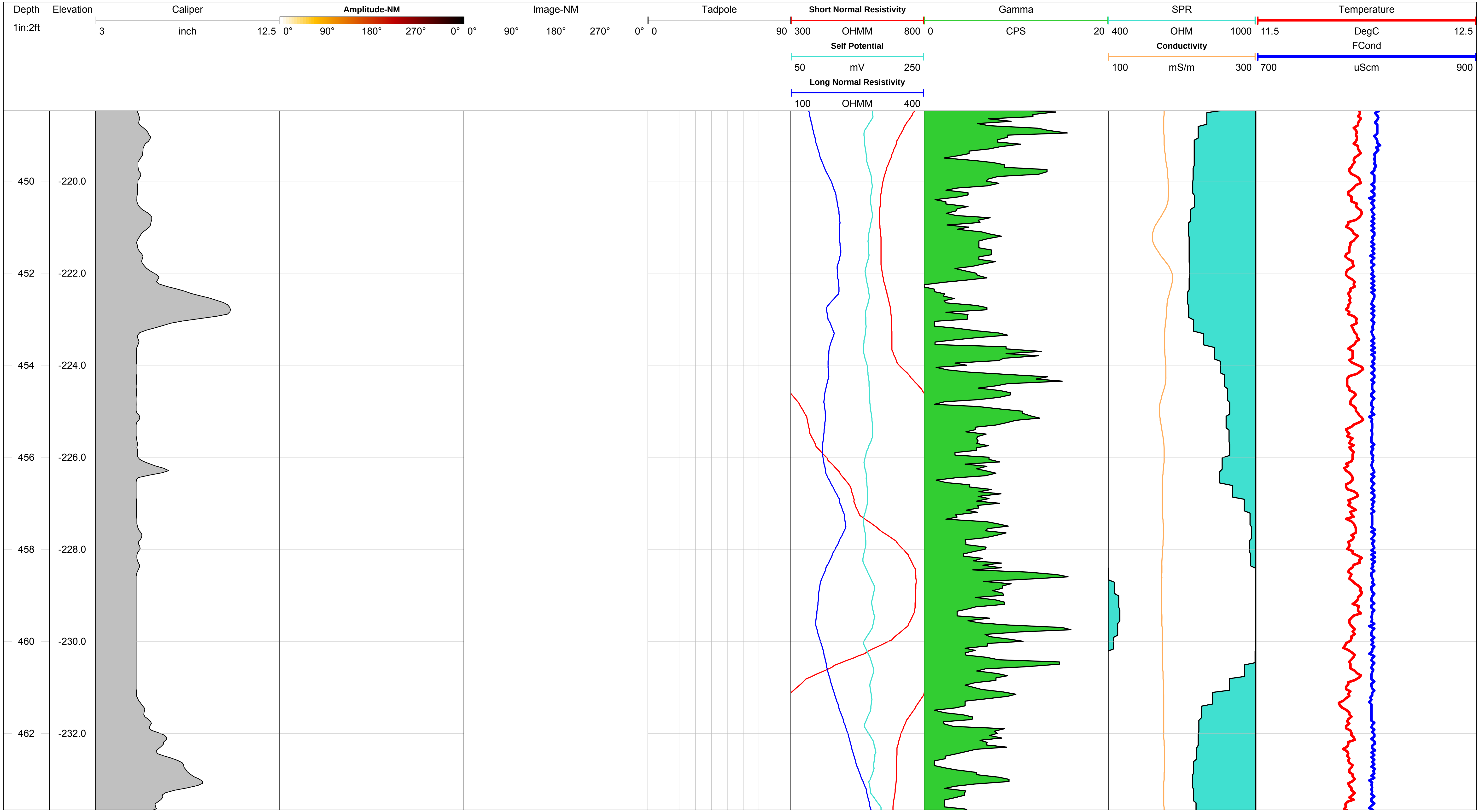
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90°
180°
270°
0°
Tadpole
0
90
Short Normal Resistivity
300
OHMM
800
Self Potential
50
mV
250
Long Normal Resistivity
100
OHMM
400
Gamma
0
CPS
20
SPR
400
OHM
1000
Conductivity
100
mS/m
300
Temperature
11.5
DegC
12.5
FCond
700
uScm
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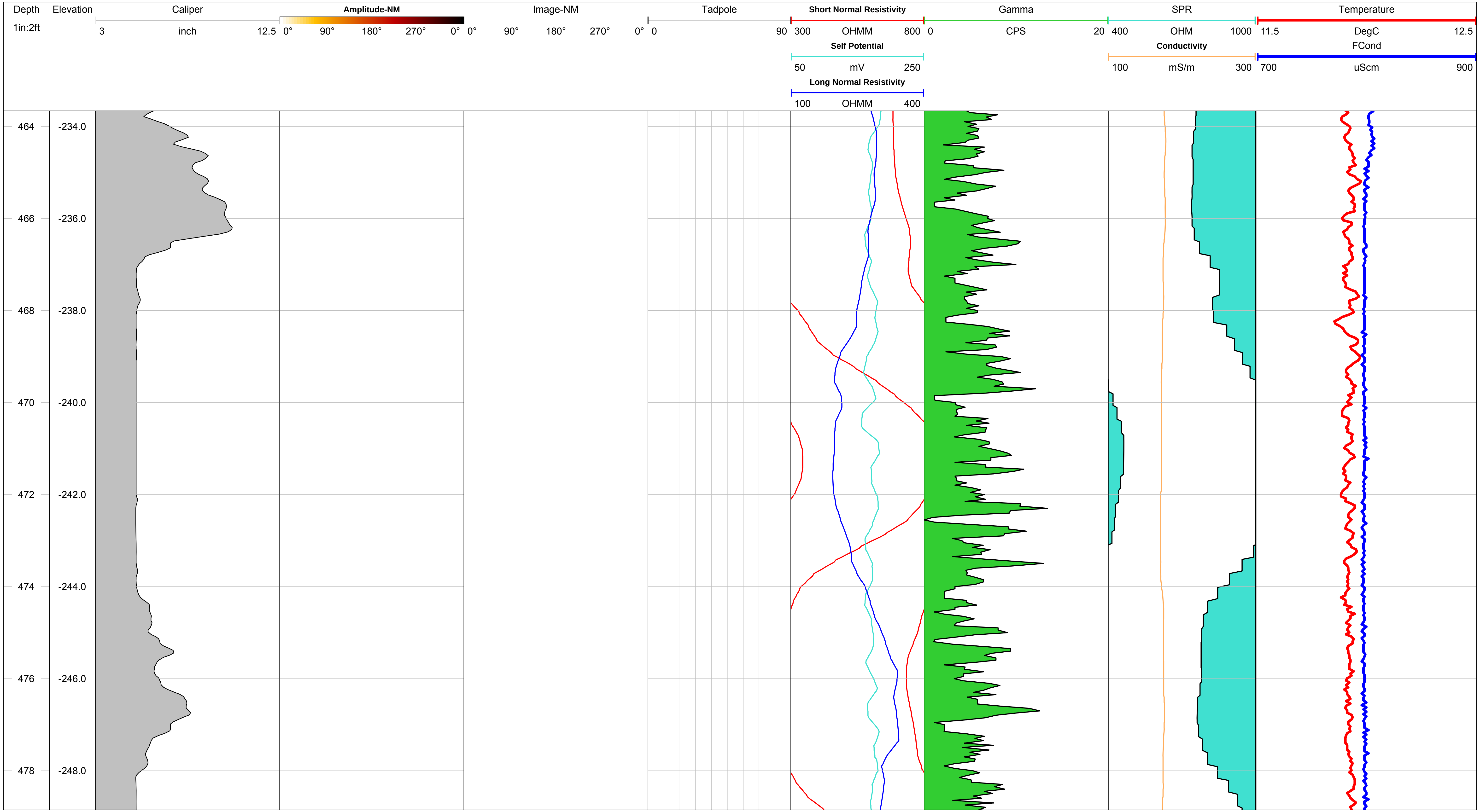
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Tadpole
0 90
Short Normal Resistivity
300 OHMM 800
Self Potential
50 mV 250
Long Normal Resistivity
100 OHMM 400
Gamma
0 CPS 20
SPR
400 OHM 1000
Conductivity
100 mS/m 300
Temperature
11.5 DegC 12.5
FCond
700 uScm 900
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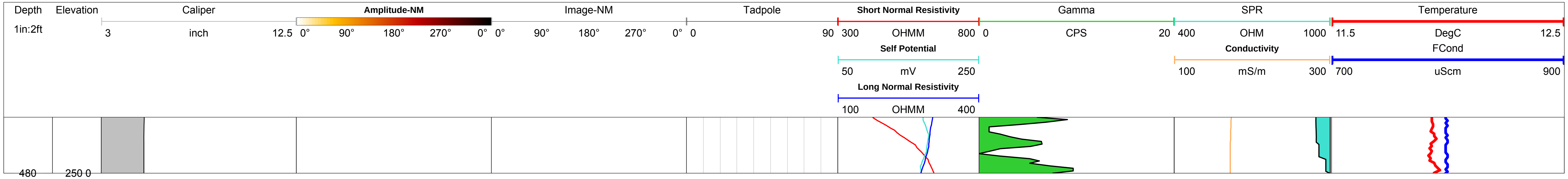
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Elevation
Caliper
3
inch
12.5
Amplitude-NM
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90°
180°
270°
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Image-NM
0°
90°
180°
270°
0°
Tadpole
0
90
Short Normal Resistivity
300
OHMM
800
Self Potential
50
mV
250
Long Normal Resistivity
100
OHMM
400
Gamma
0
CPS
20
SPR
400
OHM
1000
Conductivity
100
mS/m
300
Temperature
11.5
DegC
12.5
FCond
700
uScm
900
480
250.0

Attachment E:

Westbay System Summary of Model 0235 Packer Certification

Westbay Instruments
A Division of Nova Metrix Ground Monitoring (Canada) Limited
8610 Glenlyon Parkway
Unit 134
Burnaby, BC
V5J 0B6

Summary of Model 0235 Packer Certification

Well No.: RHMW11

Westbay Project: WB970

Westbay Specification: WB-S-0201

Packer No. **	Westbay Casing No. **	Serial No: (0235 - xxx)	Valve Reseal (psi)	Valve Open (psi)	Manufacturing Date	Traceability Number
1	2	355	150	170	July 5, 2013	6057
2	7	356	150	175	Dec 16, 2014	6057
3	10	357	155	175	Dec 16, 2014	6288
4	16	351	155	175	July 5, 2013	6057
5	18	347	145	165	July 5, 2013	6057
6	21	348	145	165	July 5, 2013	6057
7	25	349	140	165	July 5, 2013	6057
8	29	352	145	165	July 5, 2013	6057
9	32	350	155	170	July 5, 2013	6057
10	34	354	140	165	July 5, 2013	6057
11	38	369	150	170	Dec 16, 2014	6288
12	41	374	150	165	Dec 16, 2014	6288
13	44	360	140	165	Dec 16, 2014	6288
14	47	371	140	170	Dec 16, 2014	6288
15	49	358	150	170	Dec 16, 2014	6288
16	57	375	150	165	Dec 16, 2014	6288
17	65	382	150	170	Dec 17, 2014	6288
18	73	359	155	175	Dec 16, 2014	6288

** Reference: Westbay Summary Log

Signed:

Dave Larssen

Dave Larssen
Technical Services Manager
Westbay Instruments

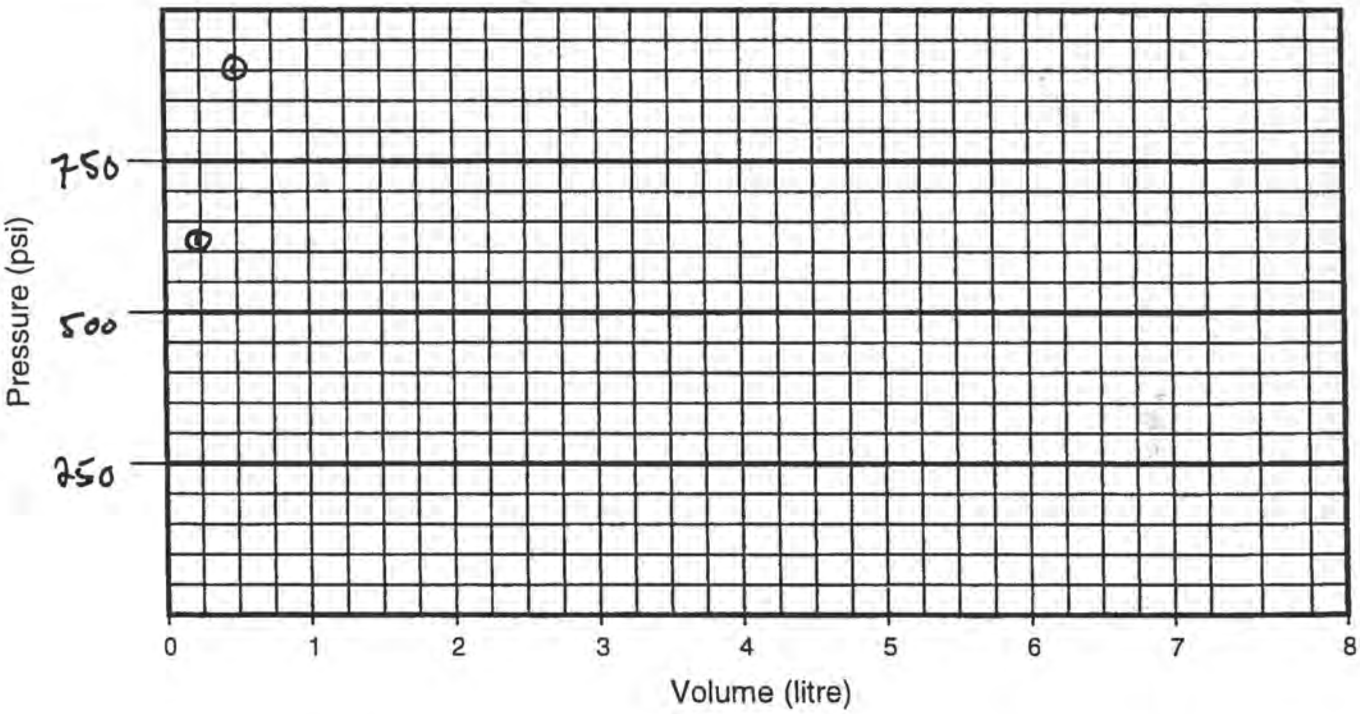
Attachment F:
Packer Inflation Records

Sheet 1 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 20/17
Packer No. Blank Wall Test
Depth (ft): 480
Inflation Tool No.: TFw 3197
Packer Valve Pressure, P_V: n/a psi
Final Line Pressure, P_L: 900 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ n/a psi

Volume, litres	0.25	0.5								
Pressure, psi	620	900								
Volume, litres										
Pressure, psi										



Comments: Blank wall test
Time - 10:05am

Tool pressure is stable at 900 psi.

Sheet 2 of 19

Westbay Instruments

Westbay Packer Inflation Record

Project: AECOM Project No.: WB970 Well No.: RHMW11

Location: Red Hill Completed by: Mark Lessard Date Inflated: Nov 20/17

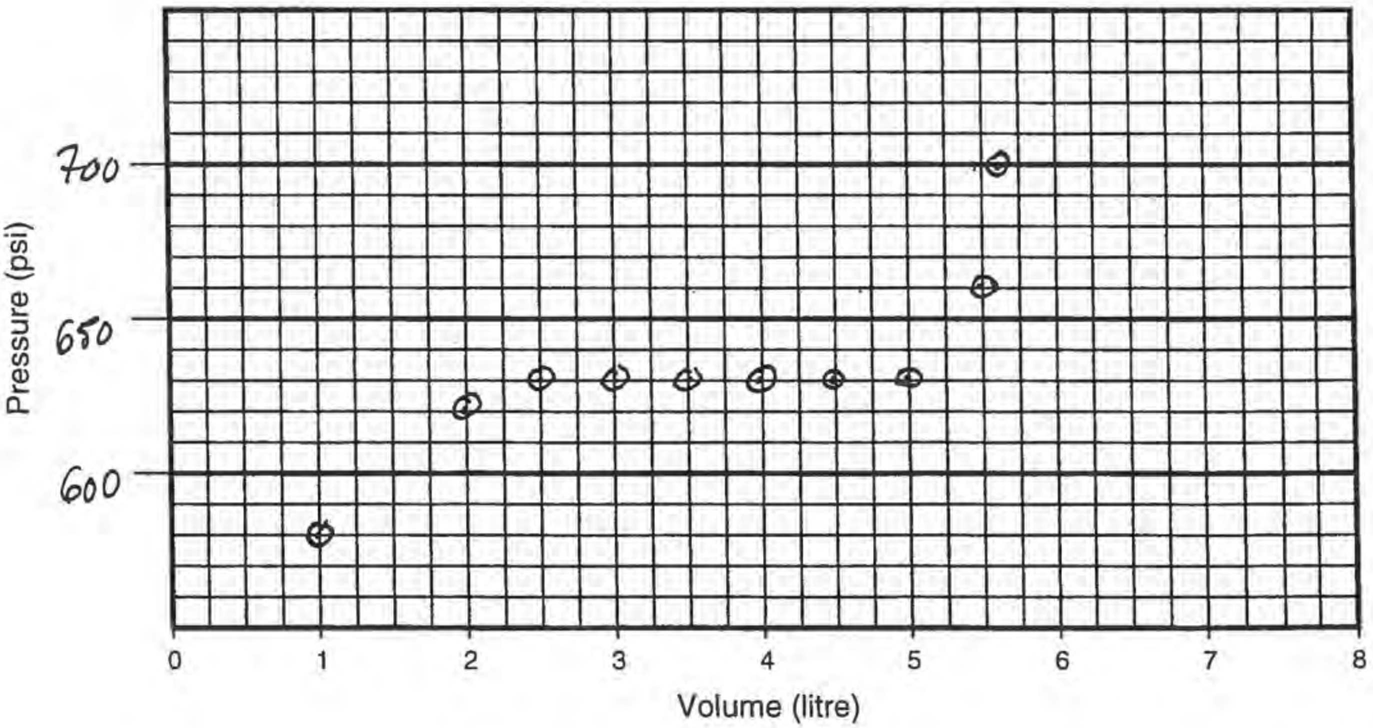
Packer No. 1, comp# 2 SN 355 Depth (ft): 469.5 Inflation Tool No.: TIW3197

Packer Valve Pressure, P_V: 150 psi Final Line Pressure, P_L: 700 psi Tool Pressure, P_T: 500 psi

Borehole Water Level: 193 (ft) = 85 psi (P_W)

Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 135 psi

Volume, litres	1.0	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	5.6
Pressure, psi	580	620	630	630	630	630	630	630	660	700
Volume, litres		5.25								
Pressure, psi		0								



Comments: Packer #1 700 target pressure Time - 10:26 am

0235 packer

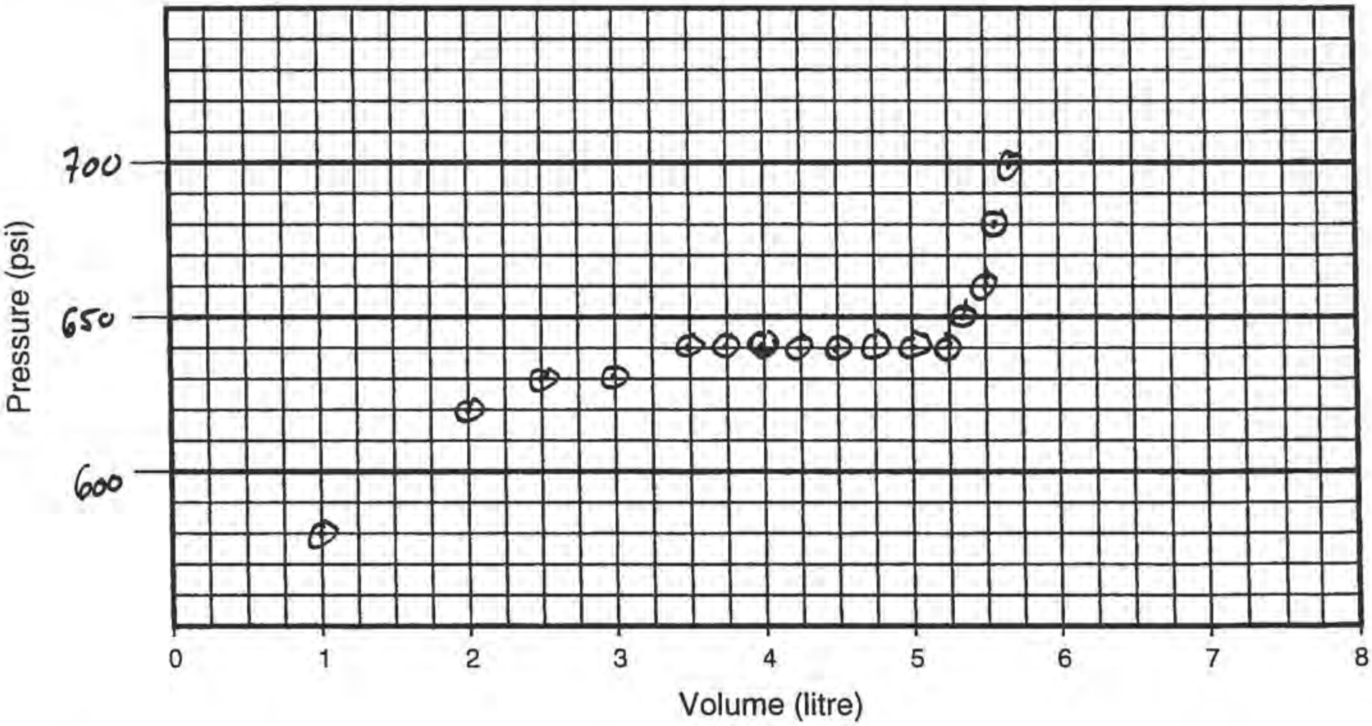
Sheet 3 of 19

Westbay Instruments

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 20/17
Packer No. 2, comp 7 SN# 356
Depth (ft): 445.3
Inflation Tool No.: TFW 3197
Packer Valve Pressure, P_V: 150 psi
Final Line Pressure, P_L: 700 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 135 psi

Volume, litres	1.0	2.0	2.5	3.0	3.5	3.75	4.0	4.25	4.5	4.75
Pressure, psi	580	620	630	630	640	640	640	640	640	640
Volume, litres	5.0	5.25	5.35	5.5	5.6	5.65	/	5.25		
Pressure, psi	640	640	650	660	680	700	/	0		



Comments: Packer #2
Time - 10:54 am

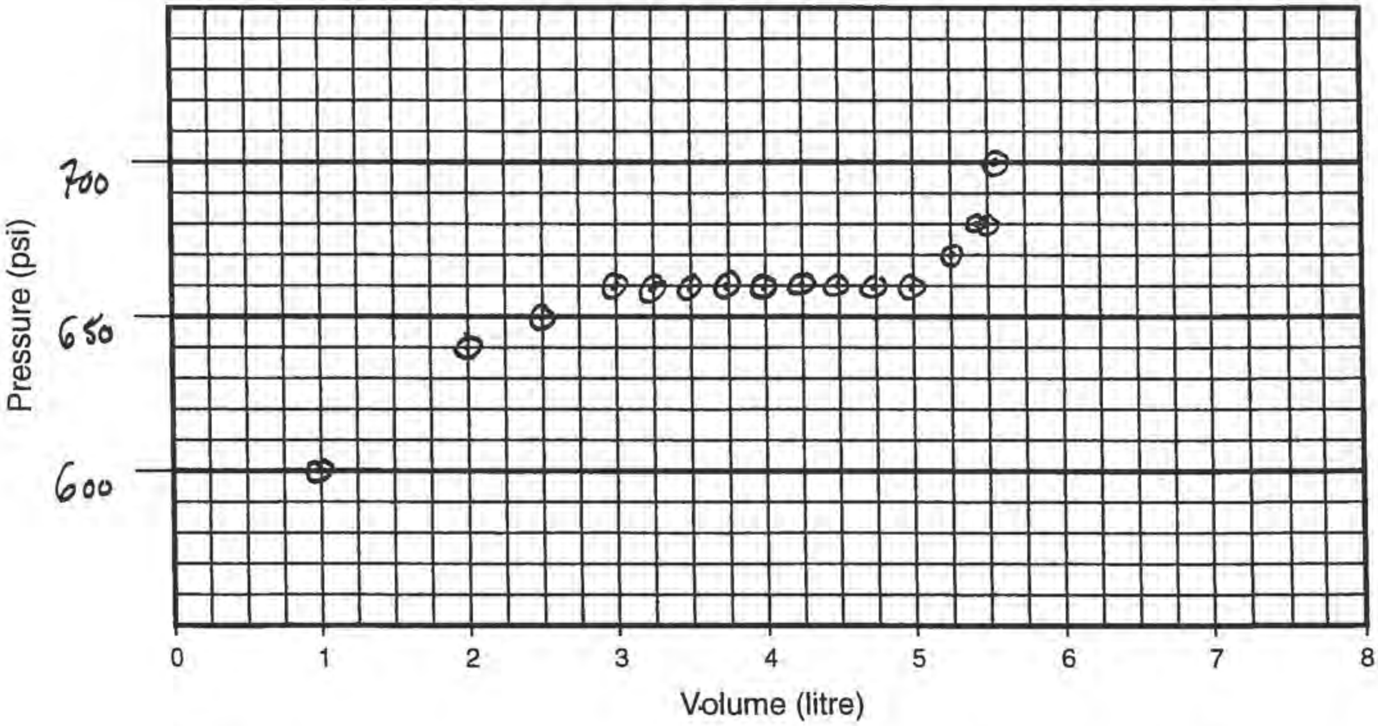
Sheet 4 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 20/17
Packer No. 3, comp 10 SN# 357
Depth (ft): 420.3
Inflation Tool No.: TIW 3197
Packer Valve Pressure, P_V: 155 psi
Final Line Pressure, P_L: 700 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 130 psi

Volume, litres	1.0	2.0	2.5	3.0	3.25	3.5	3.75	4.0	4.25	4.5
Pressure, psi	600	640	650	660	660	660	660	660	660	660

Volume, litres	4.75	5.0	5.25	5.4	5.5	5.6	/	5.25		
Pressure, psi	660	660	670	680	680	700	/	0		



Comments: Packer # 3

Time - 11:47am

Sheet 5 of 19

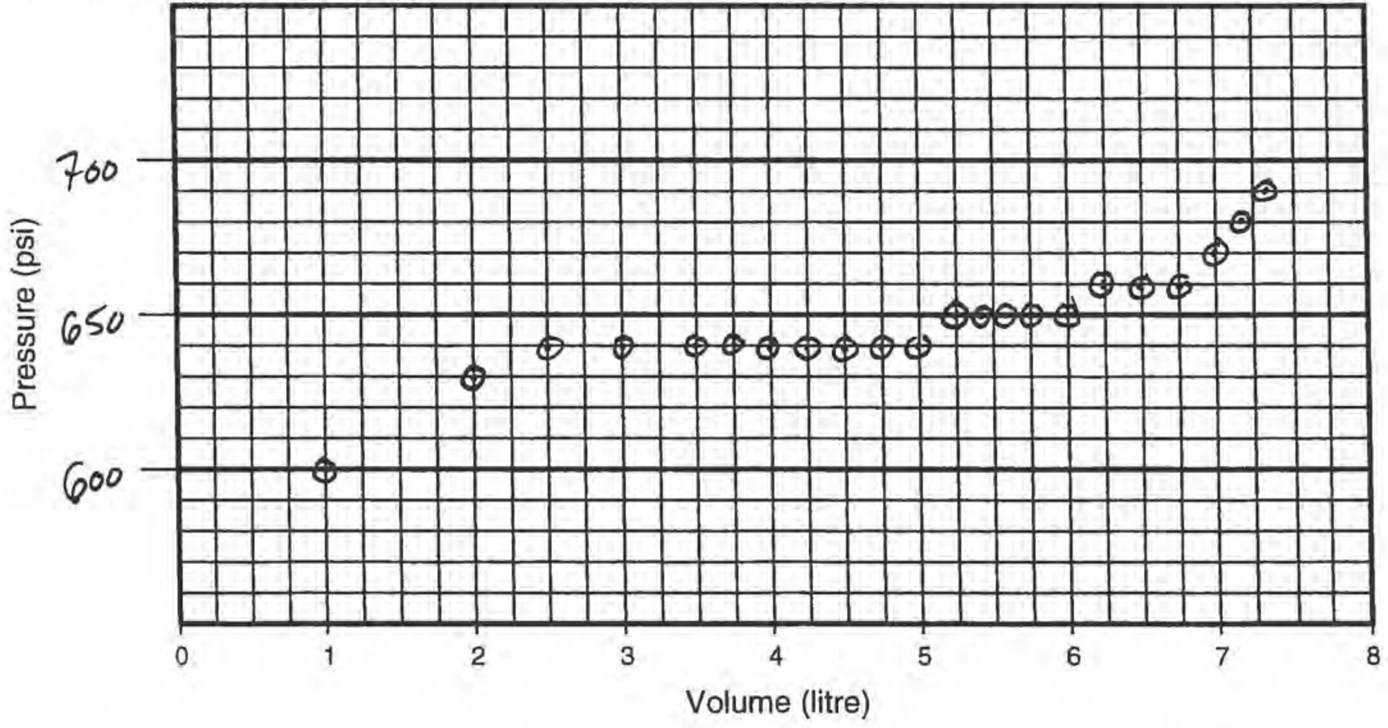
Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov20/17
Packer No. 4, comp 16 SN #351
Depth (ft): 389.0
Inflation Tool No.: TFW 3197
Packer Valve Pressure, P_V: 155 psi
Final Line Pressure, P_L: 690 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 120 psi

Volume, litres	1.0	2.0	2.5	3.0	3.5	3.75	4.0	4.25	4.5	4.75
Pressure, psi	600	630	640	640	640	640	640	640	640	640

Volume, litres	5.0	5.25	5.4	5.6	5.75	6.0	6.25	6.5	6.75	7.0
Pressure, psi	640	650	650	650	650	650	660	660	660	670

Volume, litres	7.2	7.35	/	7.0
Pressure, psi	680	690	/	0



Comments: Packer #4 Larger diameter in borehole
Time - 12:53 pm

Sheet 6 of 19

Westbay Packer Inflation Record

Project: AECOM

Project No.: WB970

Well No.: RHMW11

Location: Red Hill

Completed by: Mark Lessard

Date Inflated: Nov 08/17

Packer No. 5, comp 18 SN# 347

Depth (ft): 379.0

Inflation Tool No.: TIW 3197

Packer Valve Pressure, P_V: 145 psi

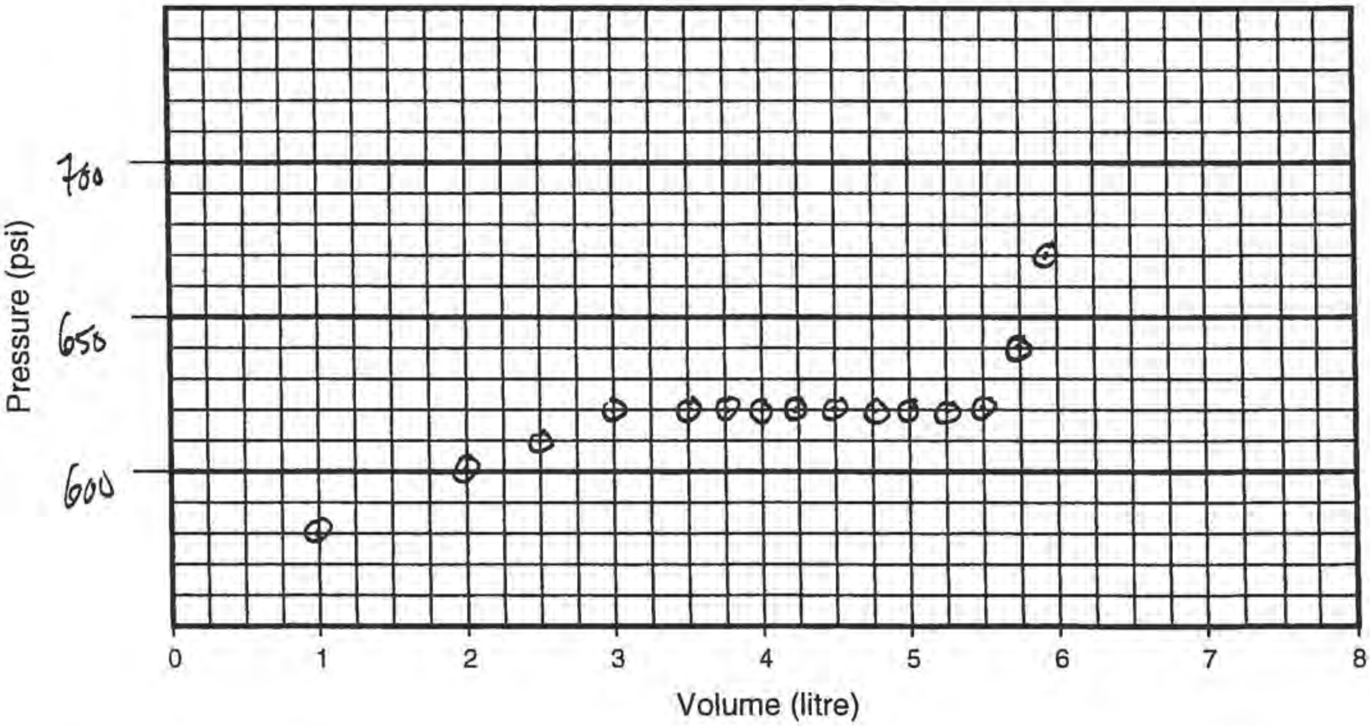
Final Line Pressure, P_L: 670 psi

Tool Pressure, P_T: 500 psi

Borehole Water Level: 193 (ft) = 85 psi (P_W)

Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 110 psi

Volume, litres	1.0	2.0	2.5	3.0	3.5	3.75	4.0	4.25	4.5	4.75
Pressure, psi	580	600	610	620	620	620	620	620	620	620
Volume, litres	5.0	5.25	5.5	5.75	5.9	/	5.7			
Pressure, psi	620	620	620	640	670	/	0			



Comments: Packer #5

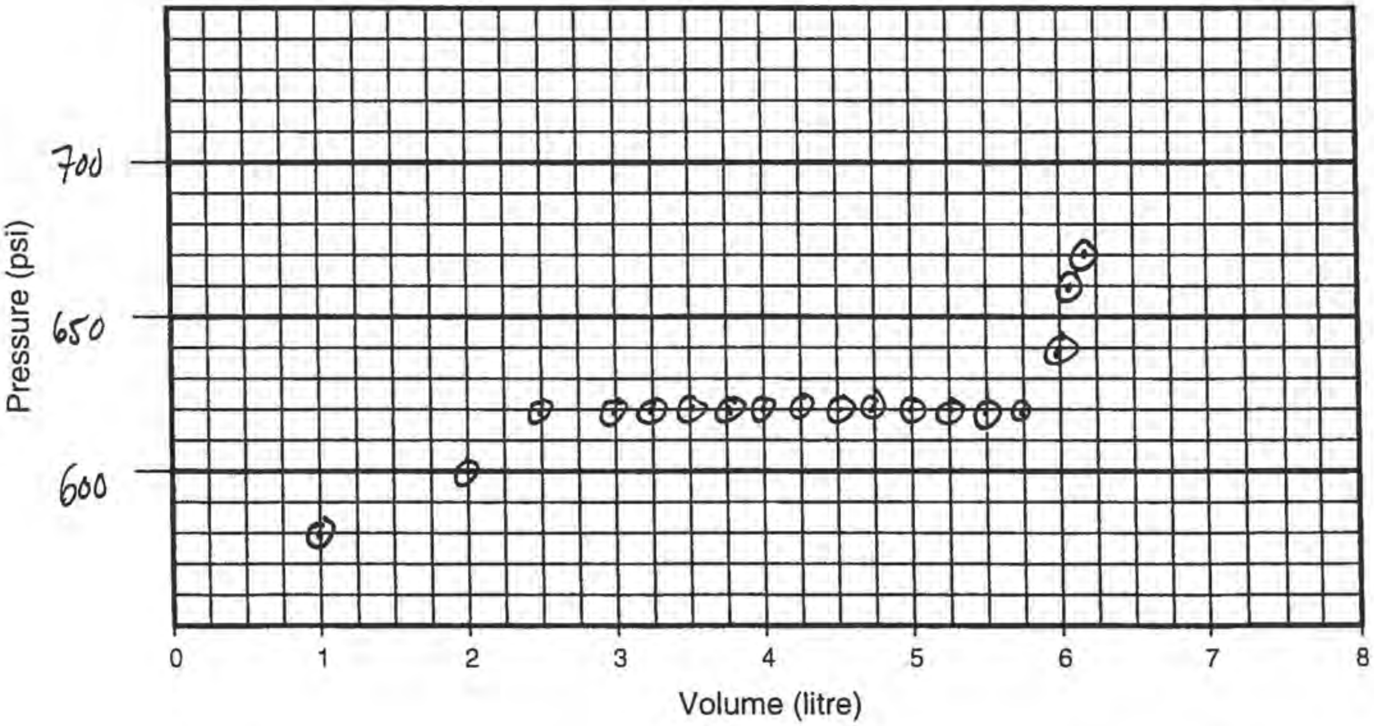
Time - 1:19pm

Sheet 7 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 20/17
Packer No. 6, comp 21 SN# 348
Depth (ft): 367.0
Inflation Tool No.: TIW 3197
Packer Valve Pressure, P_V: 145 psi
Final Line Pressure, P_L: 670 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 110 psi

Volume, litres	1.0	2.0	2.5	3.0	3.25	3.5	3.75	4.0	4.25	4.5
Pressure, psi	580	600	620	620	620	620	620	620	620	620
Volume, litres	4.75	5.0	5.25	5.5	5.75	6.0	6.1	6.2	/	5.85
Pressure, psi	620	620	620	620	620	640	660	670	/	0



Comments: Packer #6
Time - 1:47 pm

Sheet 8 of 19

Westbay Packer Inflation Record

Project: AECOM | Project No.: WB970 | Well No.: RHMW11

Location: Red Hill | Completed by: Mark Lessard | Date Inflated: Nov20/17

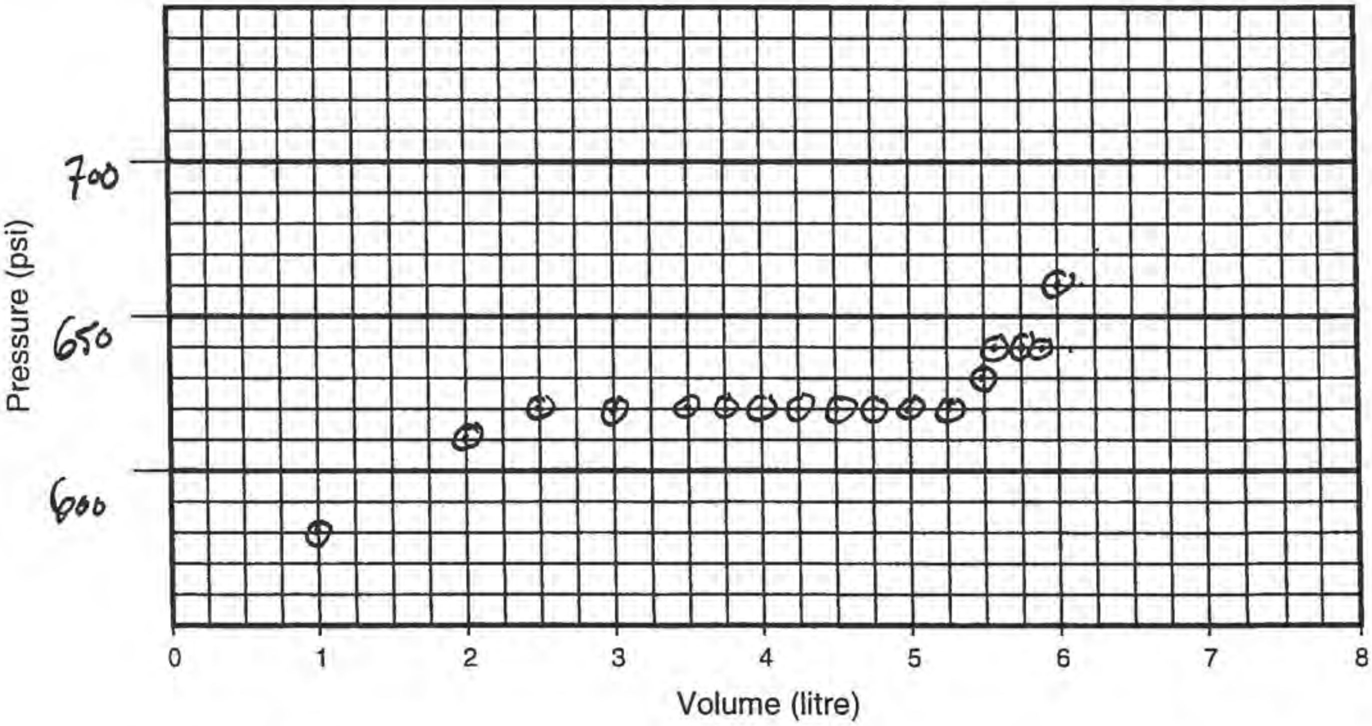
Packer No. 7, comp 25 SN# 349 | Depth (ft): 342.8 | Inflation Tool No.: TFW3197

Packer Valve Pressure, P_V: 140 psi | Final Line Pressure, P_L: 660 psi | Tool Pressure, P_T: 500 psi

Borehole Water Level: 193 (ft) = 85 psi (P_W)

Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 105 psi

Volume, litres	1.0	2.0	2.5	3.0	3.5	3.75	4.0	4.25	4.5	4.75
Pressure, psi	580	610	620	620	620	620	620	620	620	620
Volume, litres	5.0	5.25	5.5	5.6	5.75	5.85	6.0	/	5.75	
Pressure, psi	620	620	630	640	640	640	660	/	0	



Comments: Packer #7

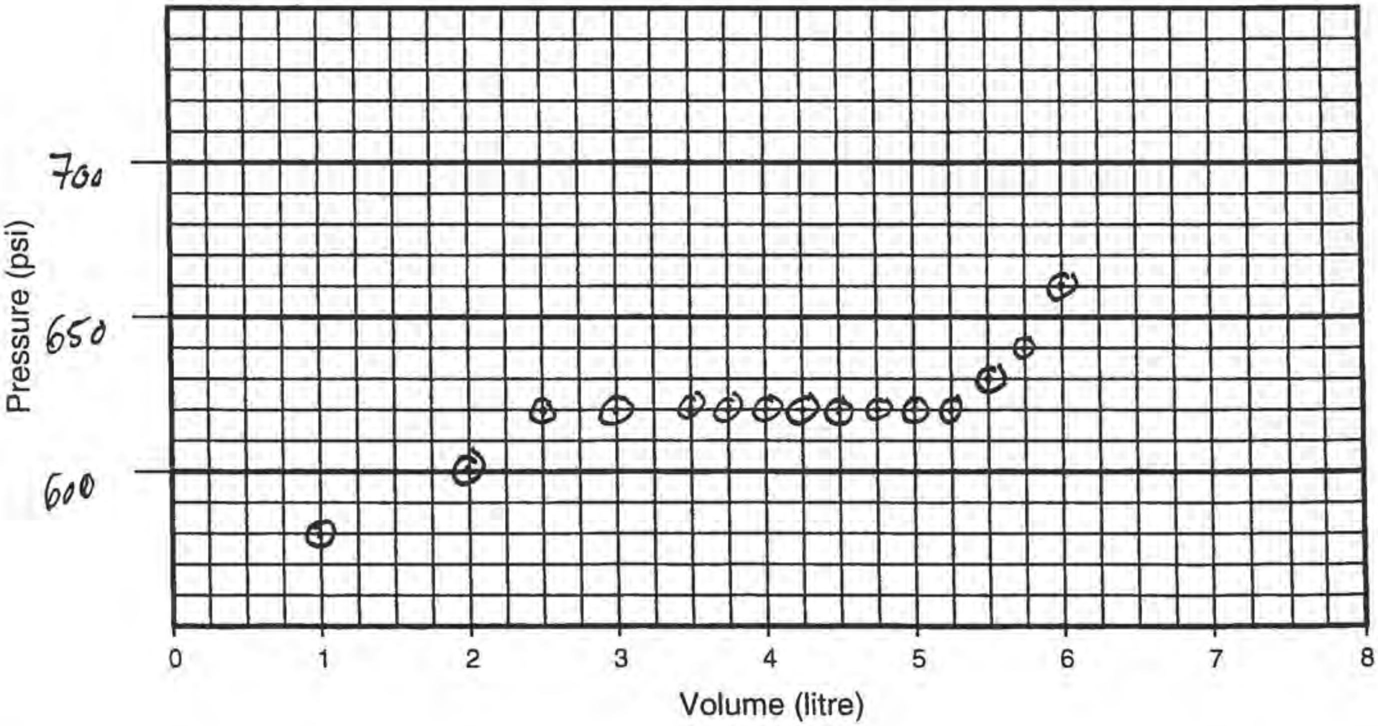
Time - 2:35 pm

Sheet 9 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 20/17
Packer No. 8, comp 29 SN# 352
Depth (ft): 325.5
Inflation Tool No.: TFW 3197
Packer Valve Pressure, P_V: 145 psi
Final Line Pressure, P_L: 660 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 100 psi

Volume, litres	1.0	2.0	2.5	3.0	3.5	3.75	4.0	4.25	4.5	4.75
Pressure, psi	580	600	620	620	620	620	620	620	620	620
Volume, litres	5.0	5.25	5.5	5.75	6.0	/	5.75			
Pressure, psi	620	620	630	640	660	/	0			



Comments: Packer #8

Time - 3:30 pm

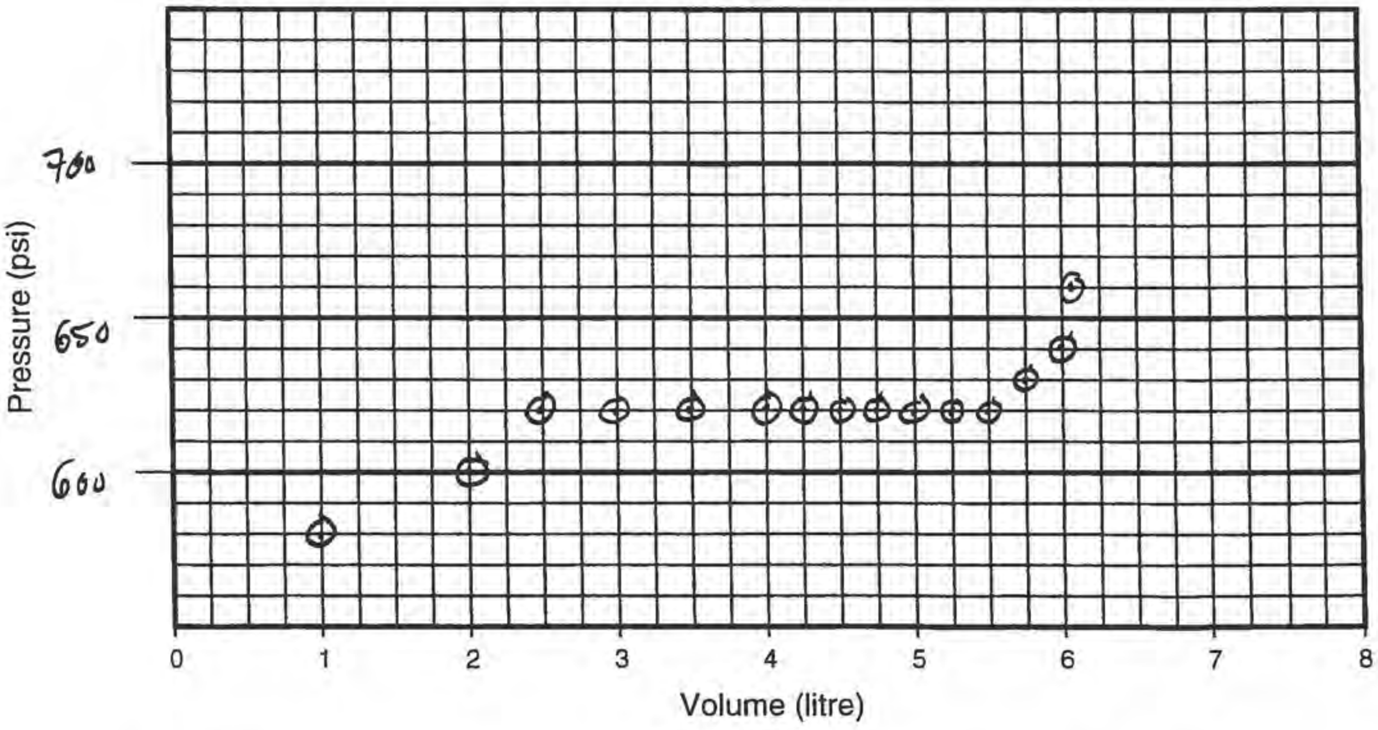
Sheet 6 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 20/17
Packer No. 9, comp 32 SN# 350
Depth (ft): 305.5
Inflation Tool No.: TIW 3197
Packer Valve Pressure, P_V: 155 psi
Final Line Pressure, P_L: 660 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 90 psi

Volume, litres	1.0	2.0	2.5	3.0	3.5	4.0	4.25	4.5	4.75	5.0
Pressure, psi	580	600	620	620	620	620	620	620	620	620

Volume, litres	5.25	5.5	5.75	6.0	6.1	/	5.8			
Pressure, psi	620	620	630	640	660	/	0			



Comments: Packer #9

Time - 3:55 pm

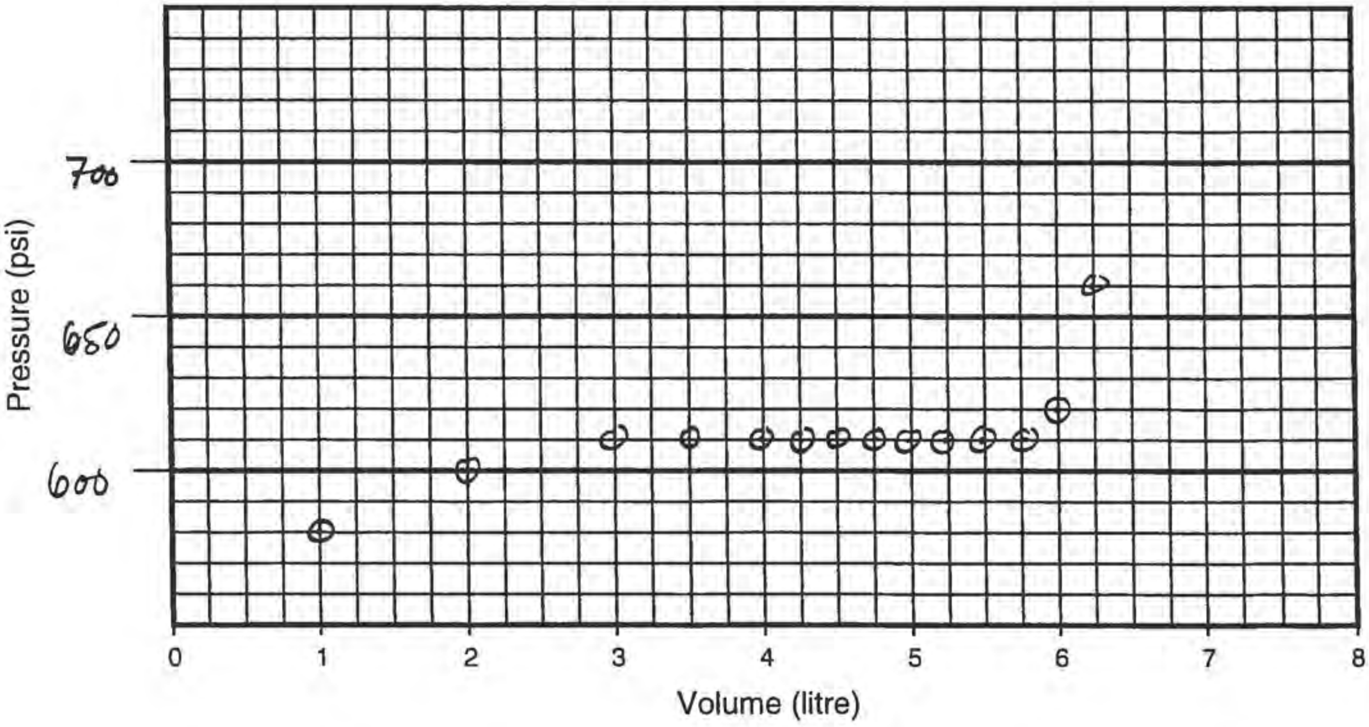
Sheet 11 of 19

Westbay Instruments

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17
Packer No. 10, comp 34   SN# 354
Depth (ft): 290.3
Inflation Tool No.: TIW 3197
Packer Valve Pressure, P_V: 140 psi
Final Line Pressure, P_L: 660 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 105 psi

Volume, litres	1.0	2.0	3.0	3.5	4.0	4.25	4.5	4.75	5.0	5.25
Pressure, psi	580	600	610	610	610	610	610	610	610	610
Volume, litres	5.5	5.75	6.0	6.25	/	6.0				
Pressure, psi	610	610	620	660	/	0				



Comments: Packer # 10
Time - 7:45 am

Sheet 12 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11

Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17

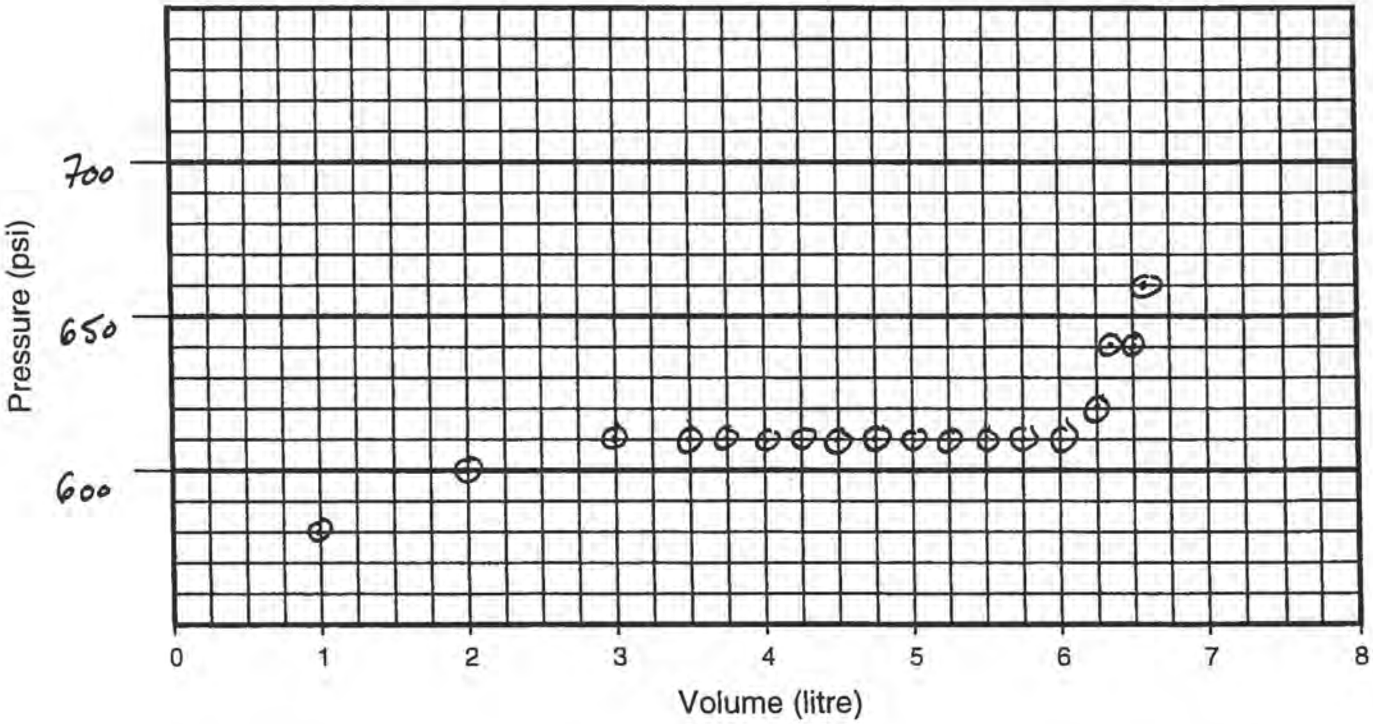
Packer No. 11, comp 38 SN# 369
Depth (ft): 272.3
Inflation Tool No.: TEW 3197

Packer Valve Pressure, P_V: 150 psi
Final Line Pressure, P_L: 660 psi
Tool Pressure, P_T: 500 psi

Borehole Water Level: 193 (ft) = 85 psi (P_W)

Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 95 psi

Volume, litres	1.0	2.0	3.0	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Pressure, psi	580	600	610	610	610	610	610	610	610	610
Volume, litres	5.25	5.5	5.75	6.0	6.25	6.35	6.5	6.6	/	6.25
Pressure, psi	610	610	610	610	620	640	640	660	/	0



Comments: Packer #11
Time - 9:13 am

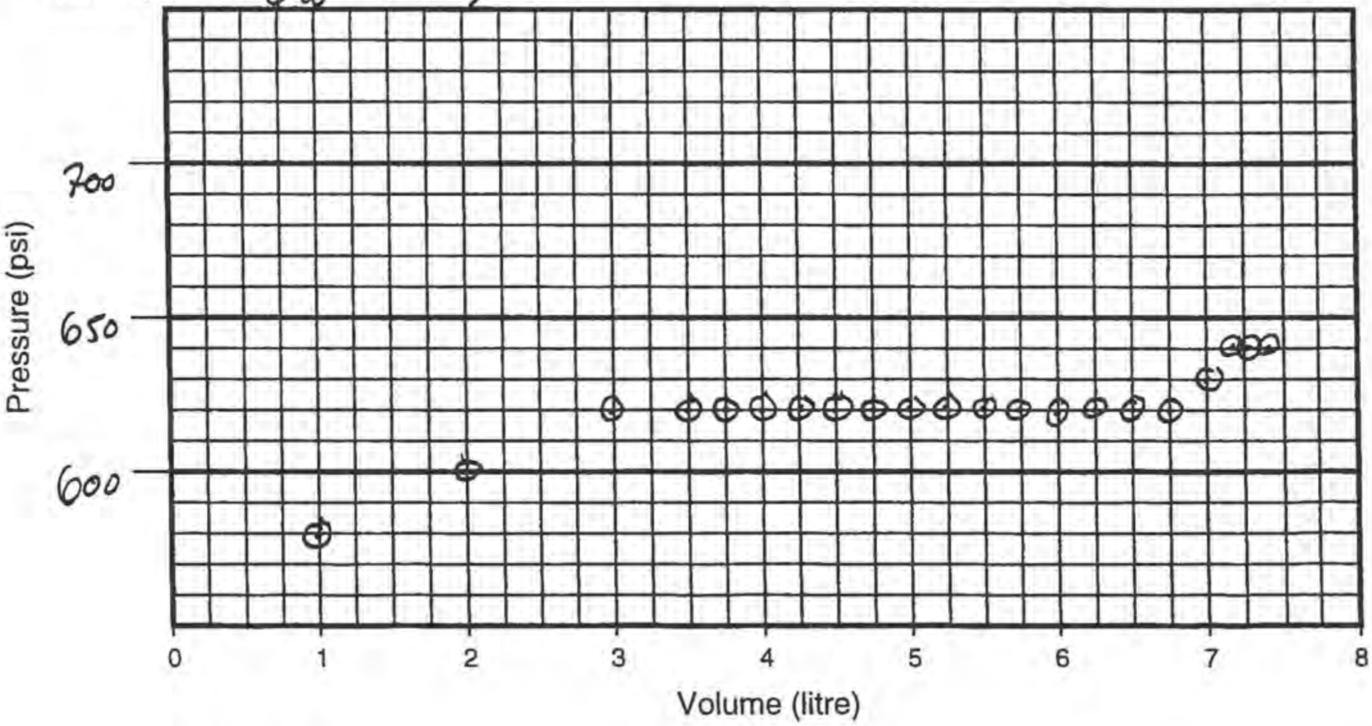
Sheet 13 of 19

Westbay Packer Inflation Record

Westbay Instruments

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17
Packer No. 12, comp 41 SN# 374
Depth (ft): 255.0
Inflation Tool No.: TEW3197
Packer Valve Pressure, P_V: 150 psi
Final Line Pressure, P_L: 640 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 75 psi

Volume, litres	1.0	2.0	3.0	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Pressure, psi	580	600	620	620	620	620	620	620	620	620
Volume, litres	5.25	5.5	5.75	6.0	6.25	6.5	6.75	7.0	7.2	7.25
Pressure, psi	620	620	620	620	620	620	620	630	640	640
Volume, litres	7.35	/	7.1							
Pressure, psi	640	/	0							



Comments: Packer #12

Time - 8:46am

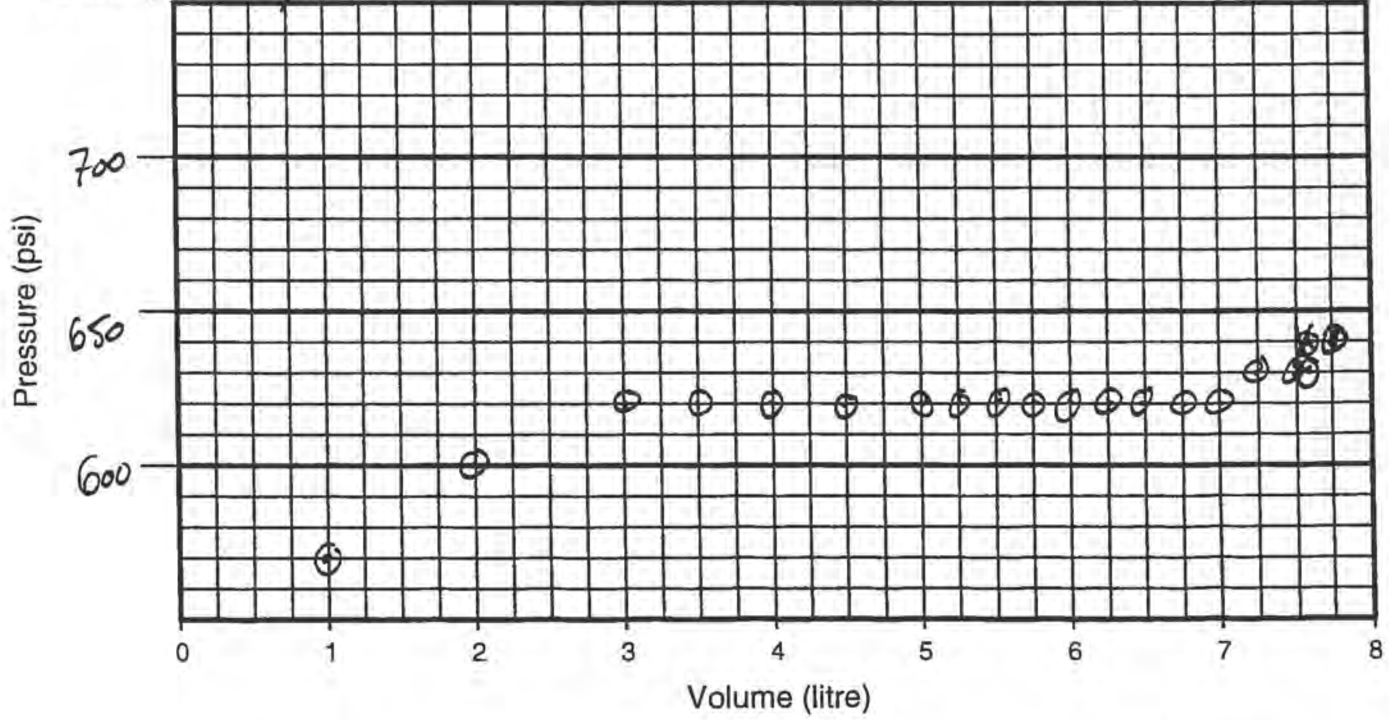
Sheet 14 of 19

Westbay Instruments

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17
Packer No. 13, comp 44   SN# 360
Depth (ft): 239.8
Inflation Tool No.: TFw 3147
Packer Valve Pressure, P_V: 140 psi
Final Line Pressure, P_L: 640 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 85 psi

Volume, litres	1.0	2.0	3.0	3.5	4.0	4.5	5.0	5.25	5.5	5.75
Pressure, psi	570	600	620	620	620	620	620	620	620	620
Volume, litres	6.0	6.25	6.5	6.75	7.0	7.25	7.5	7.6	7.75	/
Pressure, psi	620	620	620	620	620	630	630	630	640	/
Volume, litres	7.4									
Pressure psi:	0									



Comments: Packer #13
Time - 9:43 am

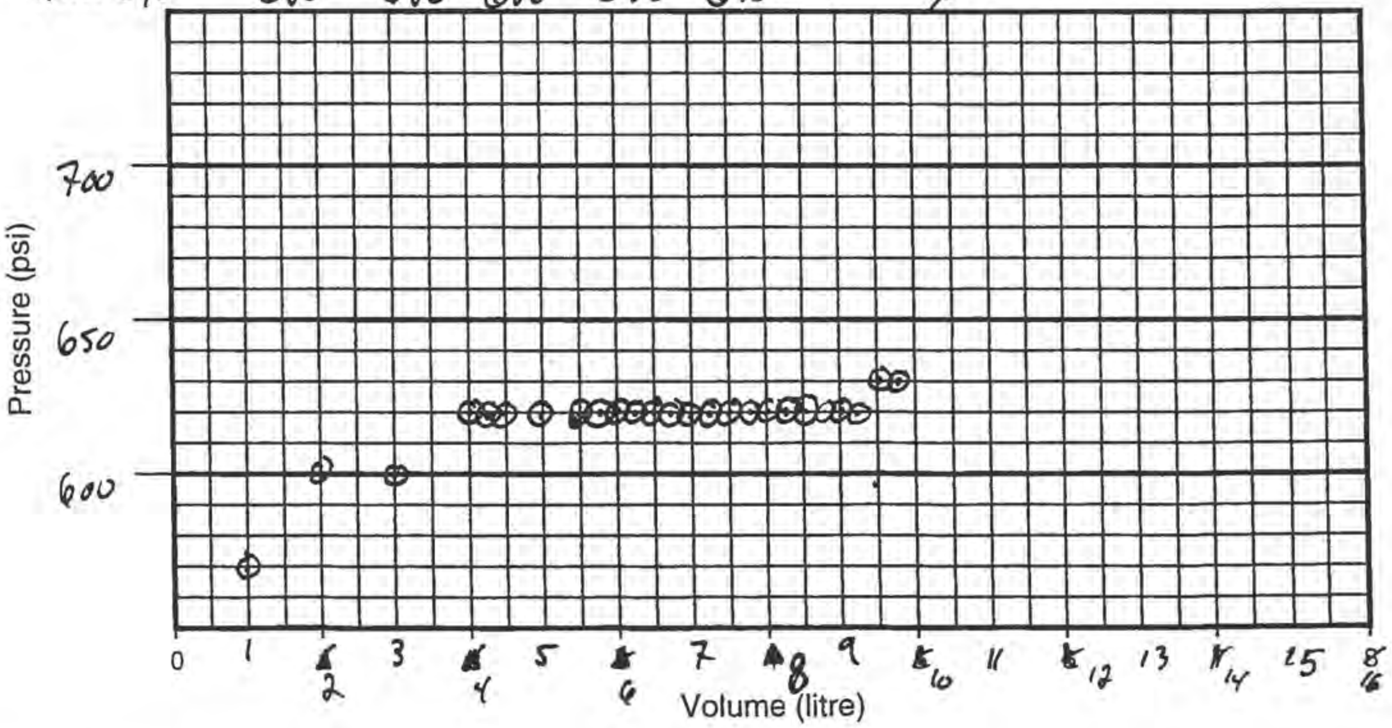
Sheet 15 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov21/17
Packer No. 14, comp 47 SN# 371
Depth (ft): 219.8
Inflation Tool No.: TFM3197
Packer Valve Pressure, P_V: 140 psi
Final Line Pressure, P_L: 630 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)

Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 75 psi

Volume, litres	1.0	2.0	3.0	4.0	4.25	4.5	5.0	5.5	5.75	6.0
Pressure, psi	570	600	600	620	620	620	620	620	620	620
Volume, litres	6.25	6.5	6.75	7.0	7.25	7.5	7.75	8.0	8.25	8.5
Pressure, psi	620	620	620	620	620	620	620	620	620	620
Volume, litres	8.75	9.0	9.25	9.5	9.75	/	9.3			
Pressure, psi	620	620	620	630	630	/	0			



Comments: Packer # 14

Time - 10:22 am

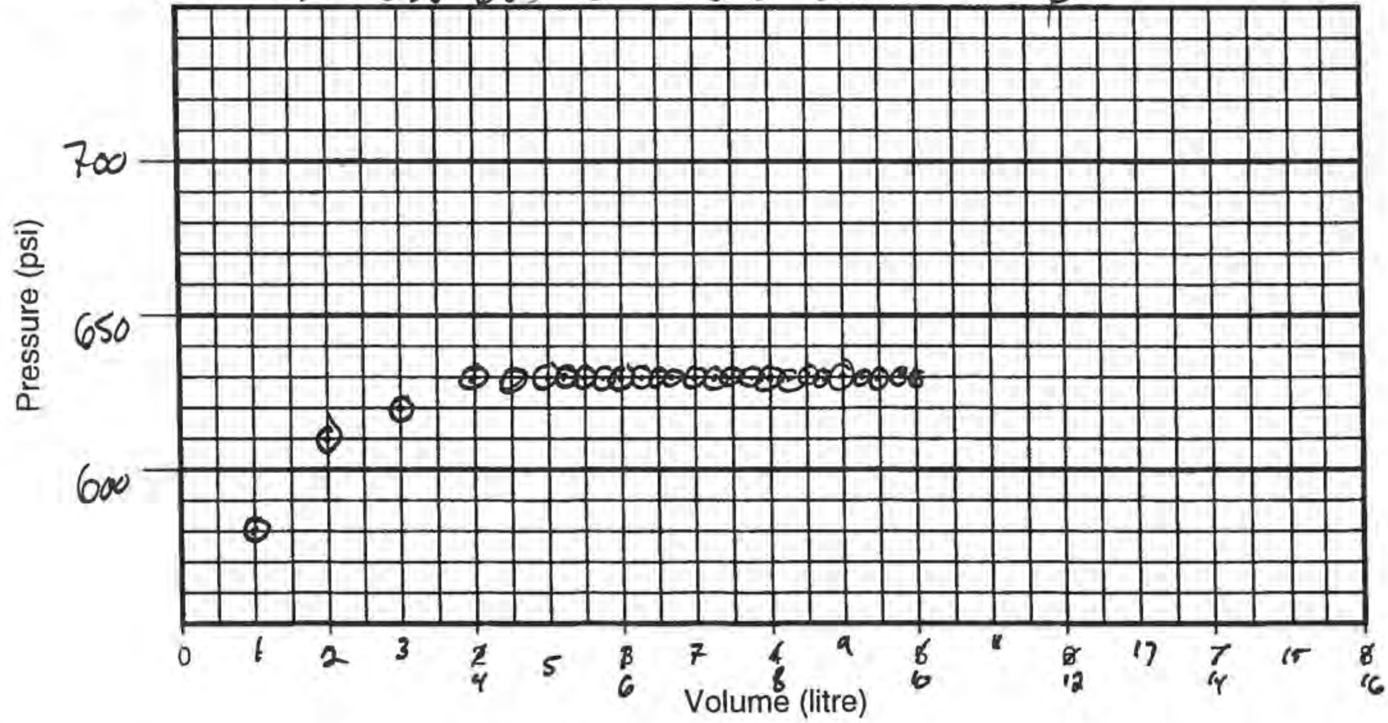
Sheet 16 of 19

Westbay Packer Inflation Record

Westbay Instruments

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17
Packer No. 15, comp 49 SNH 358
Depth (ft): 204.5
Inflation Tool No.: TEW 3197
Packer Valve Pressure, P_V: 150 psi
Final Line Pressure, P_L: 630 psi
Tool Pressure, P_T: 500 psi
Borehole Water Level: 193 (ft) = 85 psi (P_W)
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 65 psi

Volume, litres	1.0	2.0	3.0	4.0	4.5	5.0	5.25	5.5	5.75	6.0
Pressure, psi	580	610	620	630	630	630	630	630	630	630
Volume, litres	6.25	6.5	6.75	7.0	7.25	7.5	7.75	8.0	8.25	8.5
Pressure, psi	630	630	630	630	630	630	630	630	630	630
Volume, litres	8.75	9.0	9.25	9.5	9.75	10.0	/	9.7		
Pressure, psi	630	630	630	630	630	630	/	0		



Comments: Packer #15

Time - 10:58 am

Sheet 17 of 19

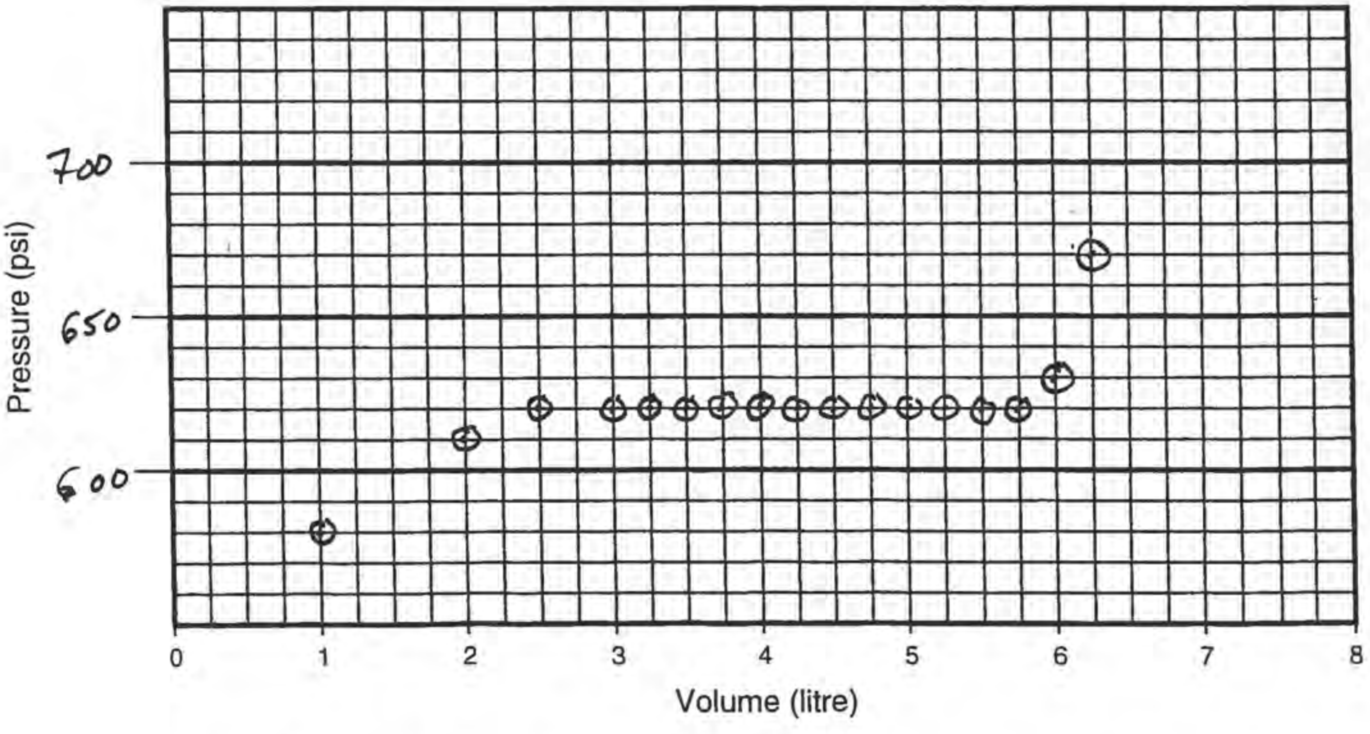
Westbay Packer Inflation Record

Westbay Instruments

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17
Packer No. 16, comp 57 SW#375
Depth (ft): 154.7
Inflation Tool No.: TIW3197
Packer Valve Pressure, P_V: 150 psi
Final Line Pressure, P_L: 670 psi
Tool Pressure, P_T: 500 psi
~~Borehole Water Level~~: 154 (ft) = 65 psi (P_W)
Packer depth
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 85 psi

Volume, litres	1.0	2.0	2.5	3.0	3.25	3.5	3.75	4.0	4.25	4.5
Pressure, psi	580	610	620	620	620	620	620	620	620	620

Volume, litres	4.75	5.0	5.25	5.5	5.75	6.0	6.25	/	6.0	
Pressure, psi	620	620	620	620	620	630	670	/	0	



Comments: Packer #16 In 5" casing
Time - 12:56 pm

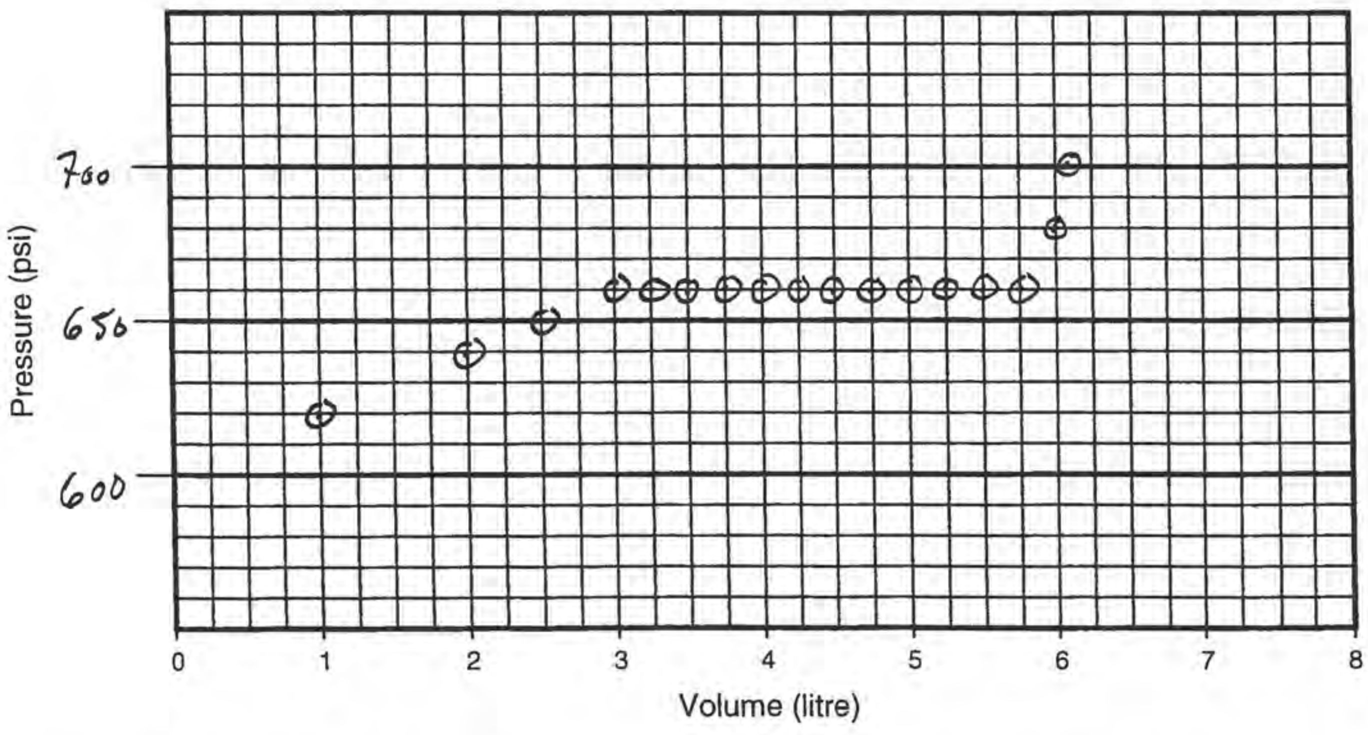
Westbay Instruments

Sheet 18 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17
Packer No. 17, comp 65   SN# 382
Depth (ft): 79.3
Inflation Tool No.: TIW 3195
Packer Valve Pressure, P_V: 150 psi
Final Line Pressure, P_L: 700 psi
Tool Pressure, P_T: 500 psi
~~Borehole Water Level~~: 79 (ft) = 35 psi (P_W)
Packer Depth
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ .85 psi

Volume, litres	1.0	2.0	2.5	3.0	3.25	3.5	3.75	4.0	4.25	4.5
Pressure, psi	620	640	650	660	660	660	660	660	660	660
Volume, litres	4.75	5.0	5.25	5.5	5.75	6.0	6.1	/	5.75	
Pressure, psi	660	660	660	660	660	680	700	/	0	



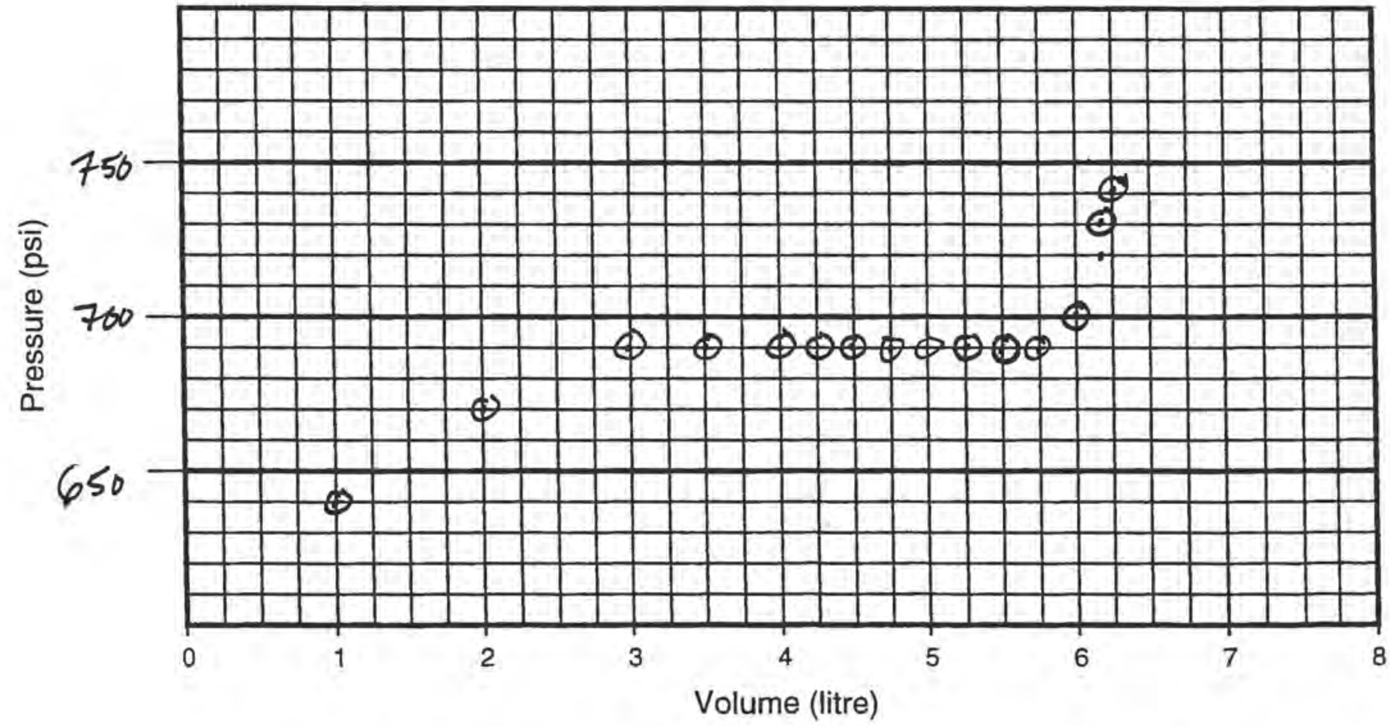
Comments: Packer #17   In 5" casing
Time - 1:25pm

Sheet 19 of 19

Westbay Packer Inflation Record

Project: AECOM
Project No.: WB970
Well No.: RHMW11
Location: Red Hill
Completed by: Mark Lessard
Date Inflated: Nov 21/17
Packer No. 18, comp 73 SN# 359
Depth (ft): 4.3
Inflation Tool No.: TIW 3195
Packer Valve Pressure, P_V: 155 psi
Final Line Pressure, P_L: 740 psi
Tool Pressure, P_T: 500 psi
~~Borehole Water Level~~: 4 (ft) = .0 psi (P_W)
Packer Depth
Calculated Packer Element Pressure, $P_E = P_L + P_W - P_V - P_T =$ 85 psi

Volume, litres	1.0	2.0	3.0	3.5	4.0	4.25	4.5	4.75	5.0	5.25
Pressure, psi	640	670	690	690	690	690	690	690	690	690
Volume, litres	5.5	5.75	6.0	6.2	6.25	/	5.8			
Pressure, psi	690	690	700	730	740	/	0			



Comments: Packer #18 In 5" casing

Time - 1:55pm