Investigation into the Geothermal Potential of NE Scotland.

29th January 2021

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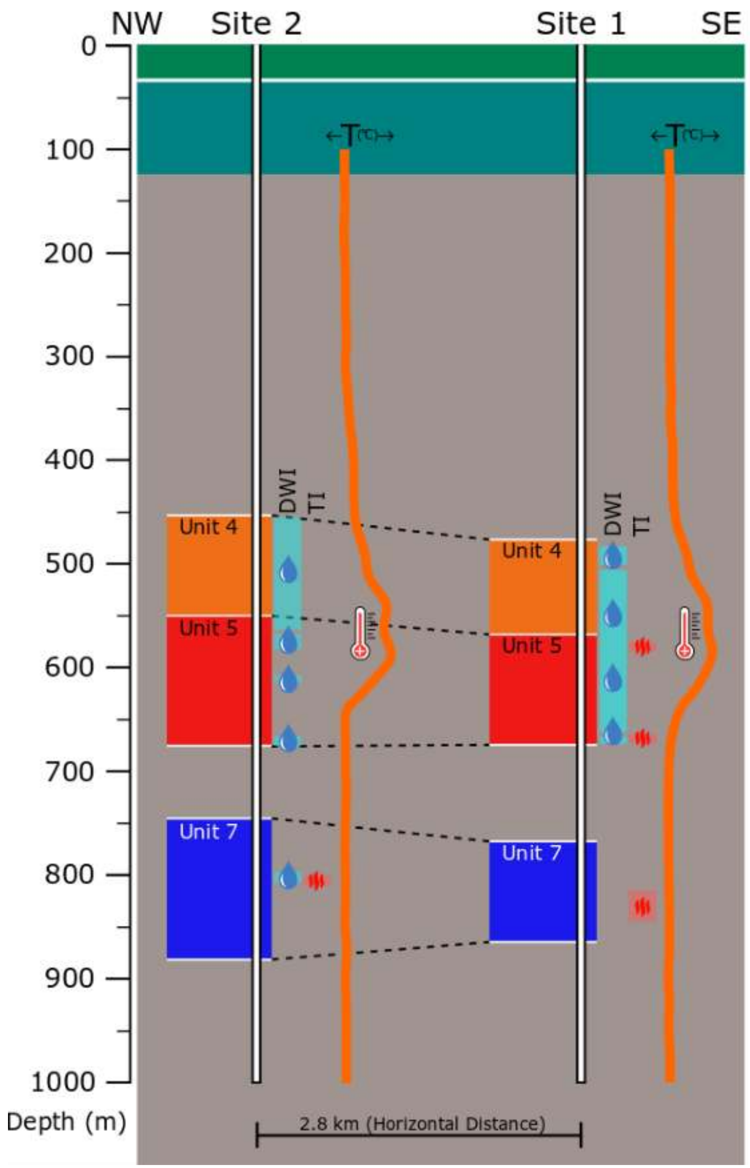

Figure: T = Temperature, DWI = Direct Water Indicator, TI = Thermal Impact

Executive Summary

This project was undertaken as a technology demonstration by Adrok to ClientX with the purpose of investigating the geothermal potential in NE Scotland, Scotland. Adrok sent a crew of three on 13/12/2020 to collect data in two sites and then spent several weeks experimenting on the datasets with proprietary software and techniques.

- **The four main techniques used by Adrok were:**
  - *Direct Water Indicators (DWI):* This uses training data to determine threshold values of Dielectric Permittivity that correspond to water.
  - *Thermal Impact Analysis:* This uses moving average Energy-Gamma plots to determine depths that may have a high thermal impact.
  - *Neural Network (NN) Temperature Analysis:* This uses a trained Neural Network to transform Energy-Gamma to a Temperature output.
  - *Zonation:* This uses a combination of ADR parameters to categorize and define lithological boundaries and units.

- **Adrok's main conclusions are:**
  - There is evidence of a low enthalpy geothermal system in the form of a hot sedimentary aquifer in Units 4 & 5 (450-650m). This is a high-confidence geothermal target due to the combination of a significant DWI target and a high temperature anomaly from the NN Temperature results.
  - There is also evidence of a low-confidence "hot dry rocks" scenario in Unit 7 (650-650m) due to the present of high thermal impact zones in both sites.
  - The economic implications for these findings are that a confirmed geothermal resource in NE Scotland could provide a home-grown, low-carbon and green alternative to Scotland's heat and energy generation.

1) Introduction

- This Adrok project number is 00238 and is funded by Adrok as a demonstration to ClientX during 2021.
- Data was collected in NE Scotland on 13/12/2020 by three Adrokers in collaboration with ClientX.
- The purpose of this report is to provide insights to ClientX on the geothermal potential of NE Scotland, and to help market and develop Adrok's capabilities in the geothermal space. This is the second project we are doing for ClientX, after the success of the sulphide targeting project in Gairloch.

1) Introduction: Project Purpose

PURPOSE

To explore the NE Scotland site and determine its geothermal potential on behalf of ClientX.

Adrok will process 4 V-Bores, 2 WARRs & 5 P-Scans

GOAL

To provide ClientX with quality exploration insights and aid in their decision making.

OBJECTIVES

- **To identify the sandstone unit.**
- **To provide qualitative flow indicators.**
- **To provide water content indicators.**
- **To provide qualitative temperature indicators.**
- **To produce public Case Studies to market in the United Kingdom.**

1) Introduction: Glossary

Term	Definition
ADR	Atomic Dielectric Resonance.
Correlation Method	Stacks a large number of traces from a series of stare scans and applies mathematical filtering to give a baseline over which the signal can be described as being of high quality. The signal returns are analyzed to show distinct changes in lithology for the area under investigation.
Dielectric constant (ϵr) or DC	The index of the rate of transmission of our ADR wave packet through a medium relative to the transmission rate of the beam through vacuum. This is also sometimes called the transmissivity index, or relative permittivity. The vacuum has a dielectric constant of 1. For a medium such as limestone the dielectric constant (ϵr) is typically 9.
Energy-Gamma (E-Gamma)	Energy reflectivity measurement of a subsurface layer of measured thickness.
Harmonic Analysis	"Harmonic Analysis" is a widely accepted mathematical method that studies the functions of signals as the superposition of waves. Using Fourier transforms to analyse the "harmonics" the technique is often used for assessing materials in a laboratory setting in the chemical industry. Unique harmonic energy frequency and phase peaks are produced and can be analysed in a number of ways producing a range of parametric statistical tests. Different rock types with different mineral assemblages will exhibit different spectral harmonic relationships over these levels.
P-Scan	Profile Scan of the subsurface with fixed focus Antenna spacings at ground level. Both Transmitting and Receiving Antennas are moved simultaneously in parallel along the length of the scan line. This produces an image of the subsurface (from ground level) based on the two-way travel time of Adrok ADR Scanner's beams from Transmitter (Tx) to Receiver (Rx) Antenna. The WARR data converts the P-Scan time-stamps into depths in meters.
Stare	A stationary scan where data collected with both antennae pointing the ground.
WARR	Wide Angle Reflection and Refraction scan to triangulate subsurface depths from the surface ground level. The Transmitting Antenna is moved at ground level along the scan line, away from the stationary Receiving Antenna which is fixed to the start of the scan line. Collected by ADR Scanner at ground level (that produces depth calculations).

1) Introduction: Data Collected

- Adrok collected data at two sites:
  - Site 1 at the junction before NE Scotland;
  - Site 2 at NE Scotland's football field.
- The following slides will detail the settings and the geometry of each site.

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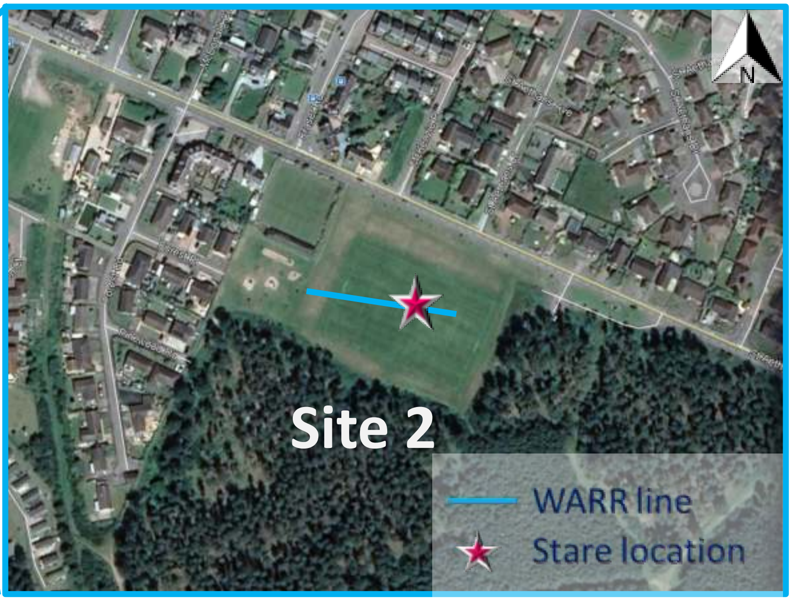
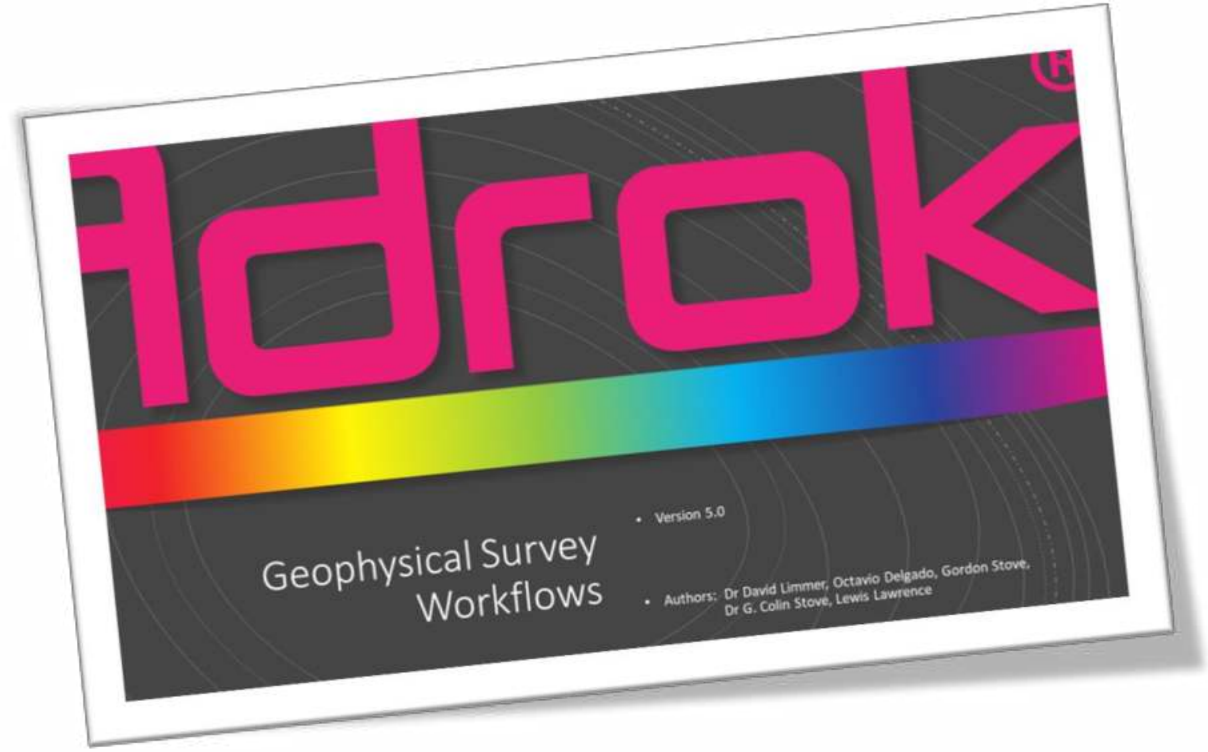
Deliberately blanked out to preserve Client's confidentiality



2) Methods: Adrok Survey Geophysical Workflows

1. Project Management → 2. Pre-survey field modelling → 3. On-site Survey Data Acquisition → 4. Data Processing → 5. Analysis & results Delivery → 6. Interpretation and Report Writing → 7. Integration to other data sets



- The Geophysical Survey Workflows describe which process will be performed in each stage of the project to ensure quality, repeatability and a successful completion.

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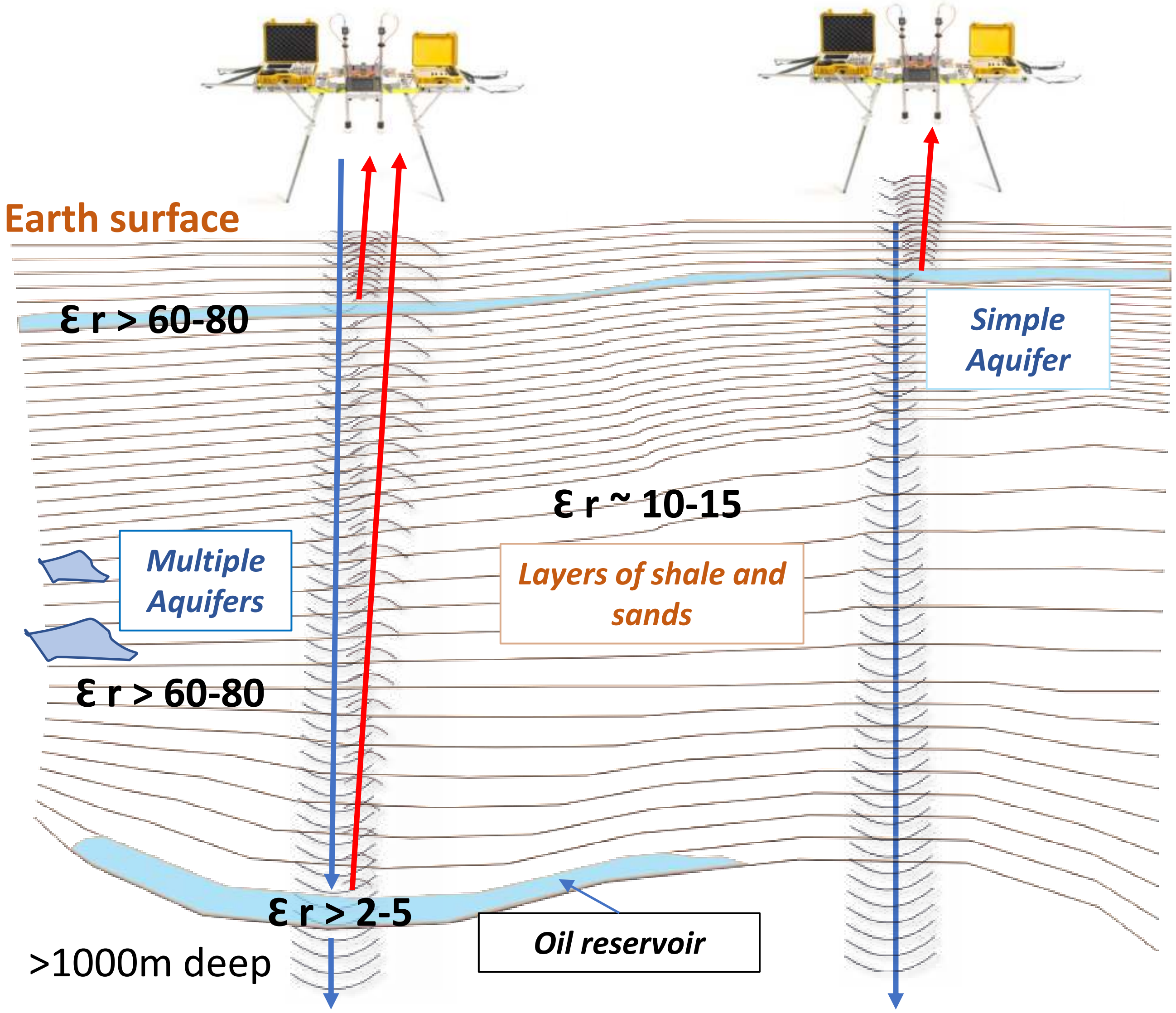
2) Methods: Atomic Dielectric Resonance (ADR)



- Transmits broadband pulses of radio waves between **1 to 70 MHz** into the ground.
- Detects the modulated reflections returned from the subsurface structures.
- Measures dielectric permittivity (Ɛ r) and conductivity of material.
- Analyses spectral content of the returns to help classify materials (energy, frequency, phase).
- Time & frequency domain.
- Time ranges typically 20,000ns, 40,000ns & 100,000ns.
- High speed time domain sampling ~5GS/s
- Stack return signals for improved signal-to-noise 20,000, 100,000…..1million.

2) Methods: Processing & Analysis

The flow diagram below shows a synopsis of Adrok's processing methodology for this project.

Stare Image Processing
- Stare QAQC by analysing the noise to signal ratio and by identification of visual anomalies.
- Merge of those stares with the best signal to noise ratio taken at a single location to boost signal strength.

Harmonics Processing
- Completed at 128 Pixels per step and 128 per window (8192 samples per window for temperature analysis)
- Produced Energy Gamma, across 32 Harmonics as a .prn in Radamatic.

Conversion to .xlsx
- Conversion from .prn Radamatic file to .csv excel file for further analysis.

WARR Tracking
- WARR QAQC by analysing the range of frequencies and by identification of visual anomalies.
- Dielectric WARR tracking down to 1000m at a 5m resolution.

Phase Correction
- Completed based on the .DCO.
- Corrects the signal and produces a more accurate depth model after tracking.

Extraction of .DCO
- Extraction of the time to depth conversion form the .xlsx file.

2) **Methods:** Thermal Impact (E-Gamma)

The flow diagram below shows a synopsis of Adrok's methodology and analysis for this project.

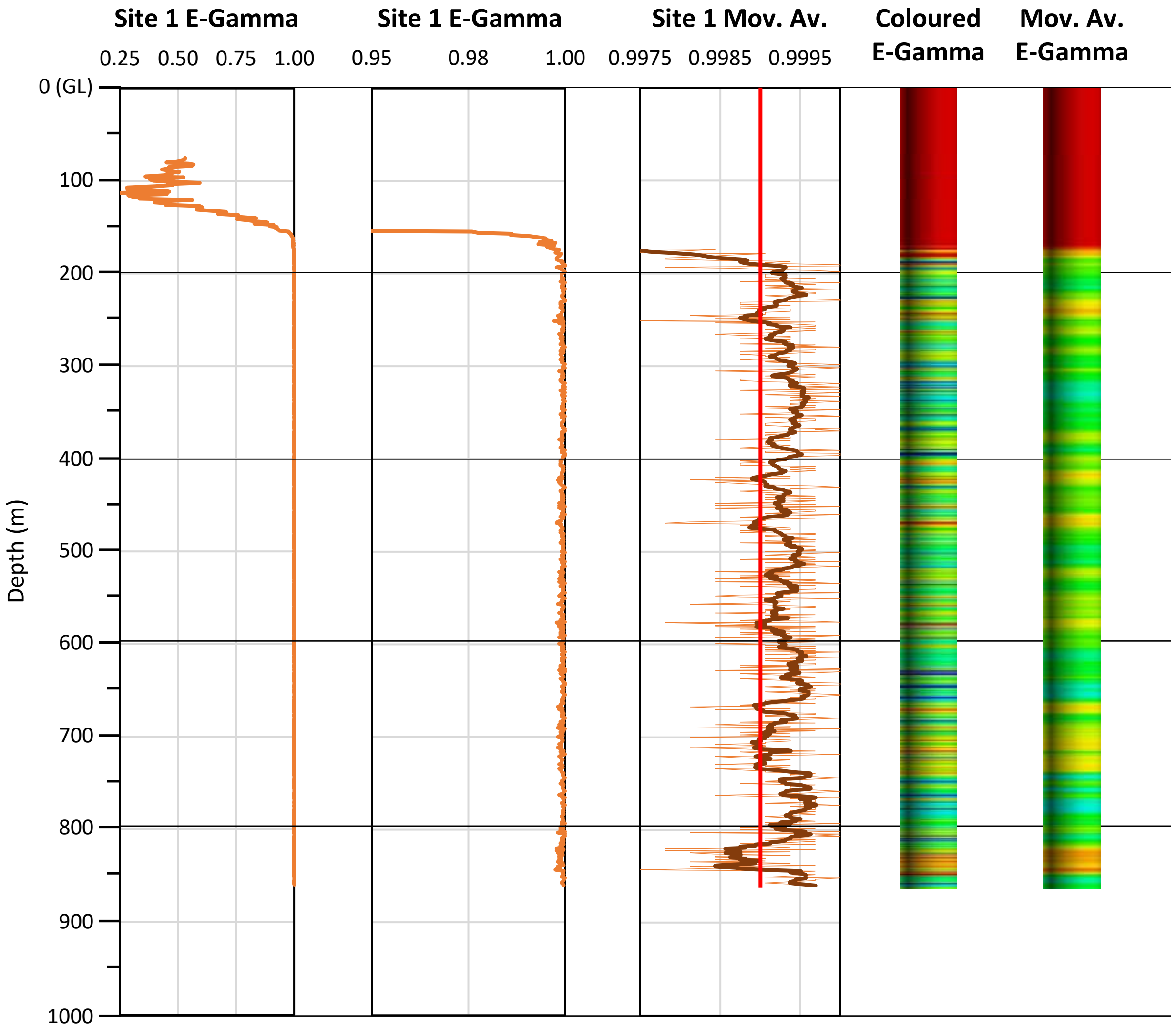
Data Analysis on the .csv

- E-Gamma = Energy-Gamma
- E-Gamma values for the first 32 Harmonics of each horizon were averaged.
- Conversion of Time to Depth data using the .DCO file.

Temperature Impact Analysis

- E-Gamma values plotted against depth, for the full range from 0 to 1 and the clipped range from 0.95 to 1.
- 10 point moving average graphs produced additionally for trend identification.
- Colourisation of the E-Gamma using a logarithmic equal area transformation RGB colour code from Red to Blue.
- Each graph observed and commented in the depth domain.

2) Methods: Thermal Impact (E-Gamma)



For each V-bore five graphs are displayed from left to right.

1) *Site 1 E-Gamma:* Shows data within values of 0.25 to 1.

2) *Site 1 E-Gamma:* Shows data within values of 0.95 to 1.

3) *Site 1 Mov Av:* Shows data within values of 0.9975 to 1, also shows the 10m Moving Average in brown. Baseline at 0.999 in red.

4) *Coloured E-Gamma:* Shows the data colour coded according to the key below.

5) *Moving Average E-Gamma:* Same as 4) but applying a 10m moving average.

E-Gamma values

0.00 – 0.998 **Red indicates high thermal impact.**

0.998 – 0.999 **Yellow indicates medium thermal impact.**

0.999 – 1.000 **Blue indicates low thermal impact.**

2) Methods: Neural Network Temperature

- The flow diagram below shows a synopsis of Adrok's methodology and analysis for this project.

Data Analysis on the .csv

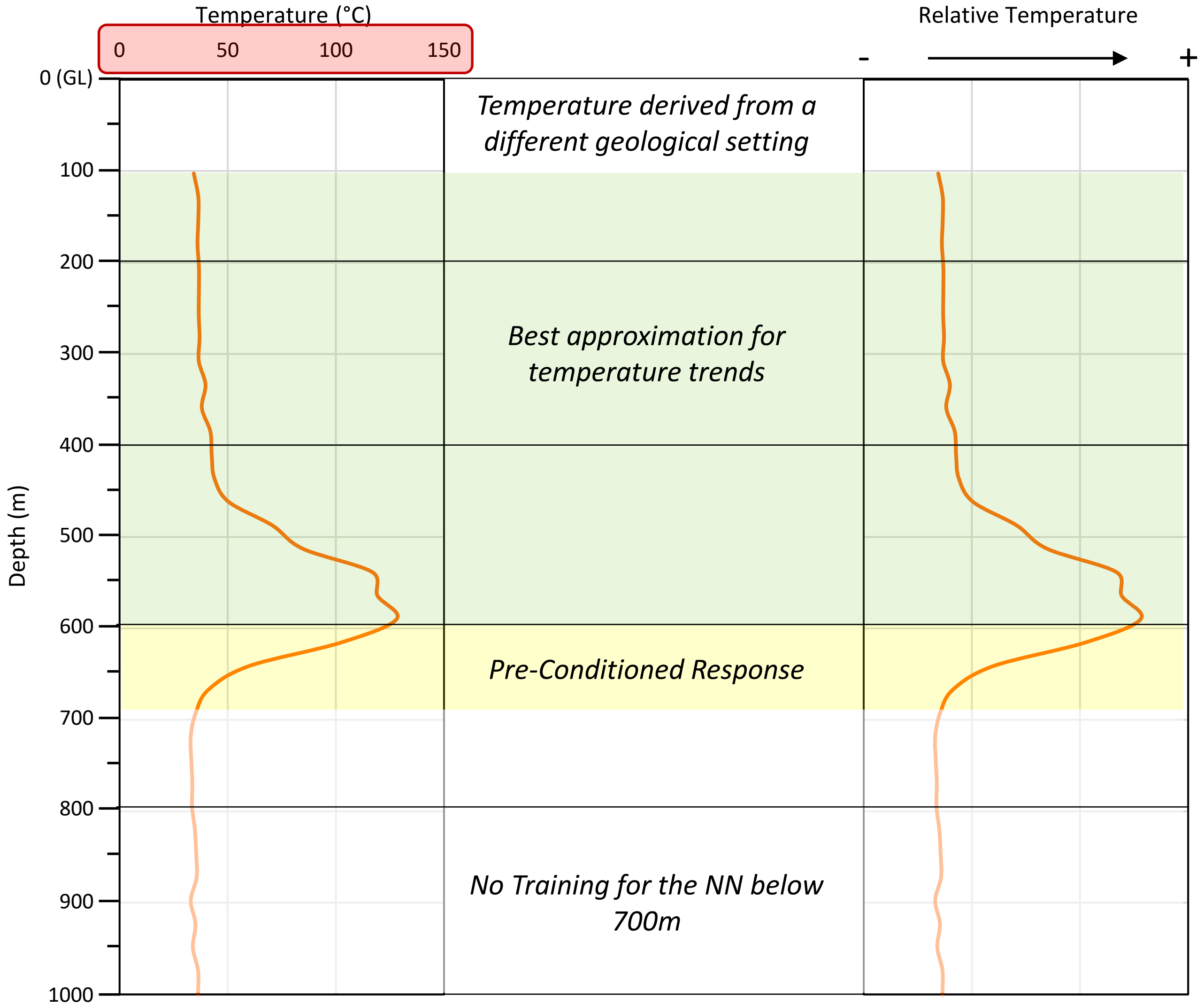
- E-Gamma = Energy-Gamma
- E-Gamma values for the first 32 Harmonics of each horizon were averaged.
- Conversion of Time to Depth data using the .DCO file.

Neural Network (NN) Temperature Analysis

- Train the NN on Temperature logs (T-logs) versus E-Gamma
- Scale the E-Gamma data to map onto the T-logs from training data.
- Train the NN on all training data before inputting the scaled E-Gamma
- Rescale the results to the original units

- To estimate the temperature with E-Gamma using the NN that Adrok has built, we need training data with a set of temperature measurements, usually from a borehole.
- Due to the absence of any training data local to the site, Adrok has used a NN that has trained on 40 training pairs from California.
- A training pair is an Adrok V-Bore coupled with a previously existing borehole with pre-existing temperature records.

2) Methods: Neural Network Temperature



- Adrok have developed a Machine Learning approach that involves building a Neural Network (NN) that can be trained to transform E-Gamma to a Temperature output.
- Due to an absence of temperature training data in the NE Scotland area, we have used 40 training pairs from California.
- The predicted temperatures results will try to conform to the training data, therefore, there are a number of limitations of using this set of training data:
  - E-Gamma encodes both geology and temperature and the NN is training to extract only temperature. Therefore if the geology is different from the training site, the temperature values may be inaccurate.
  - The training data always has a cool zone below the hot zone, so the drop in temperature around 700m is probably incorrect.
- To account for these limitations in the accuracy of the temperature readings, for this project we will focus of the trends of NN temperature results as relative values.

2) Methods: Direct Water Indicator (DWI)

- The flow diagram below shows a synopsis of Adrok's methodology and analysis for this project.

Extract Dielectrics and define a baseline

- Dielectric Permittivity (DC) is calculate during the WARR tracking.
- Extract the dielectrics and compare with training boreholes or previous projects to define a DWI baseline by finding the minimum dielectrics value that could correspond to water.

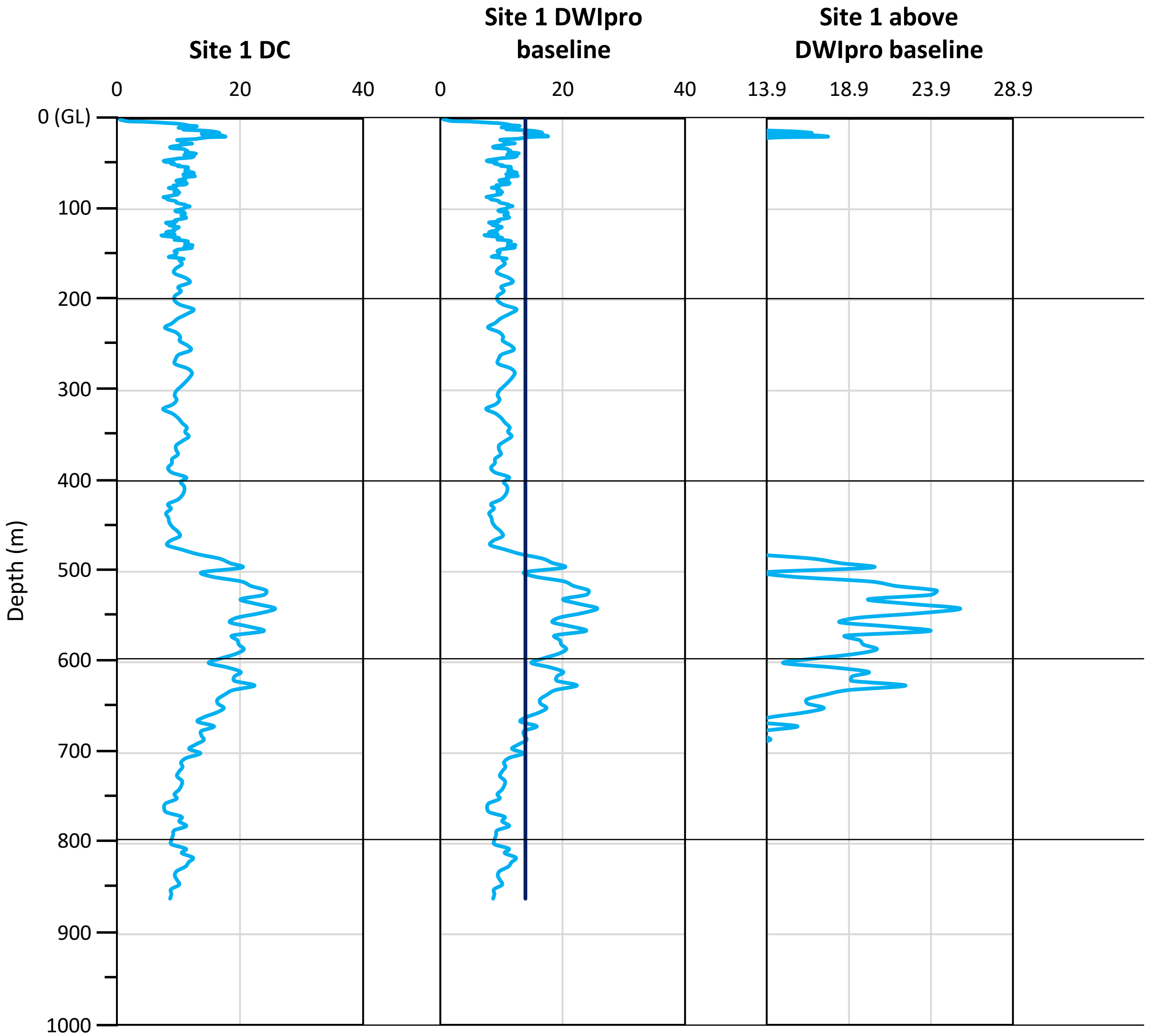
Calculate the DWI pro and apply to blind sites

- For each V-Bore, calculate the Mean and Standard Deviation for the dielectrics.
- Along with the defined baseline, enter these values into the following formula to calculate the DWI pro for each V-Bore:

$$\frac{\text{Baseline} - \text{Mean}}{-\text{Standard Deviation}} = \text{DWIpro}$$

- Dielectric values above the DWIpro for that V-Bore can be interpretated to have the presence of water.
- A high or increase in dielectrics could be caused by:
  - The presence of water (either within a fault, an aquifer, or within pores)
  - Increasing temperature
  - Increased salinity
  - The presence of highly metallic areas e.g. mineral zones

2) Methods: Direct Water Indicator (DWI)



For each V-bore three graphs are displayed from left to right.

1) *Site 1 DC:* Shows the raw dielectrics from 0 to 40 DC.

2) *Site 1 DWIpro baseline:* Shows the raw dielectrics from 0 to 40 DC, with the DWIpro baseline in dark blue (13.9 DC in this example).

3) *Site 1 above DWIpro baseline:* Shows all dielectric values that exceed or are equal to the DWIpro baseline (above or equal to 13.9 DC in this example)

For this project, there is no training data, therefore, the DWIpro has been calculating from training data of a previous geothermal project that has a similar geological setting:

$$\text{DWIpro} = \frac{\text{Baseline} - \text{Mean}}{-\text{Standard Deviation}}$$

$$\text{DWIpro} = \frac{22 - 18.3}{-5.2}$$

$$\boxed{\textbf{DWIpro} = \mathbf{-0.7}}$$

<u>Training Values:</u>

Baseline = 22 DC

Mean = 18.3 DC

Standard Deviation = 5.2 DC

2) Methods: Zonation

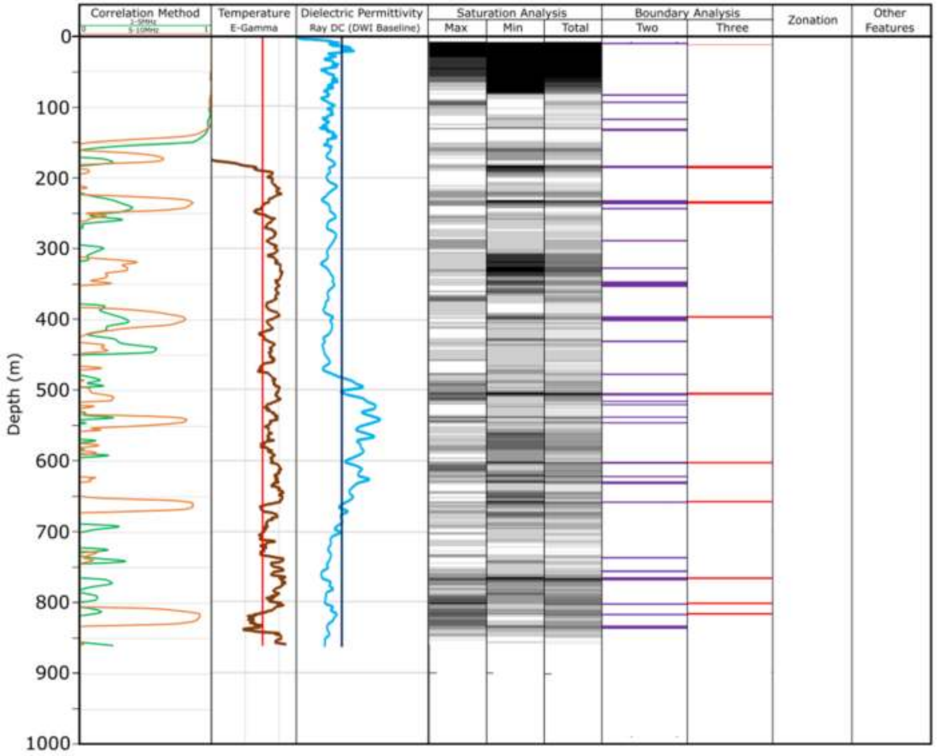
- The Zonation Method pulls together the following ADR results in order to provide interpretations of the lithological changes throughout the V-Bore:
  - Frequency Correlation
  - Thermal Impact (from E-Gamma)
  - Direct Water Indicator (from Dielectric Permittivity)
  - Saturation Analysis (from E- and F- Harmonics)
  - Boundary Analysis (from E- and F- Harmonics)

- The above ADR Data has been used and correlated across both sites to determine major lithological changes and boundaries.
- Seven zones/units have been defined from sites in NE Scotland.
- After the major units are established, Temperature and DWI results can help to identify areas where water may be present and areas with potentially high heat.

2) Methods: Zonation

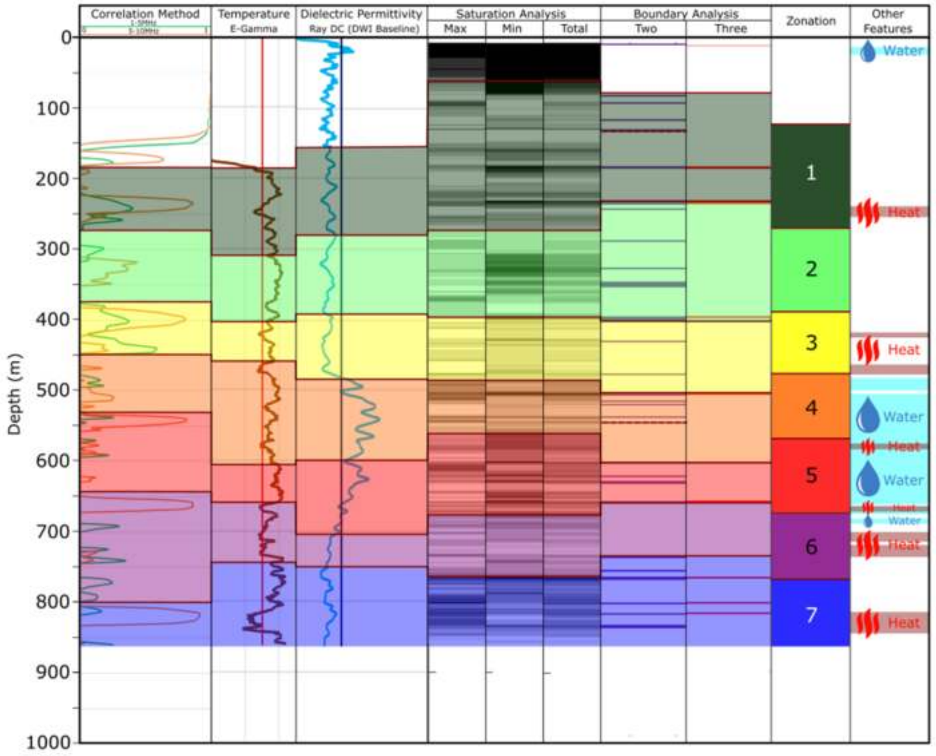
A

The ADR data



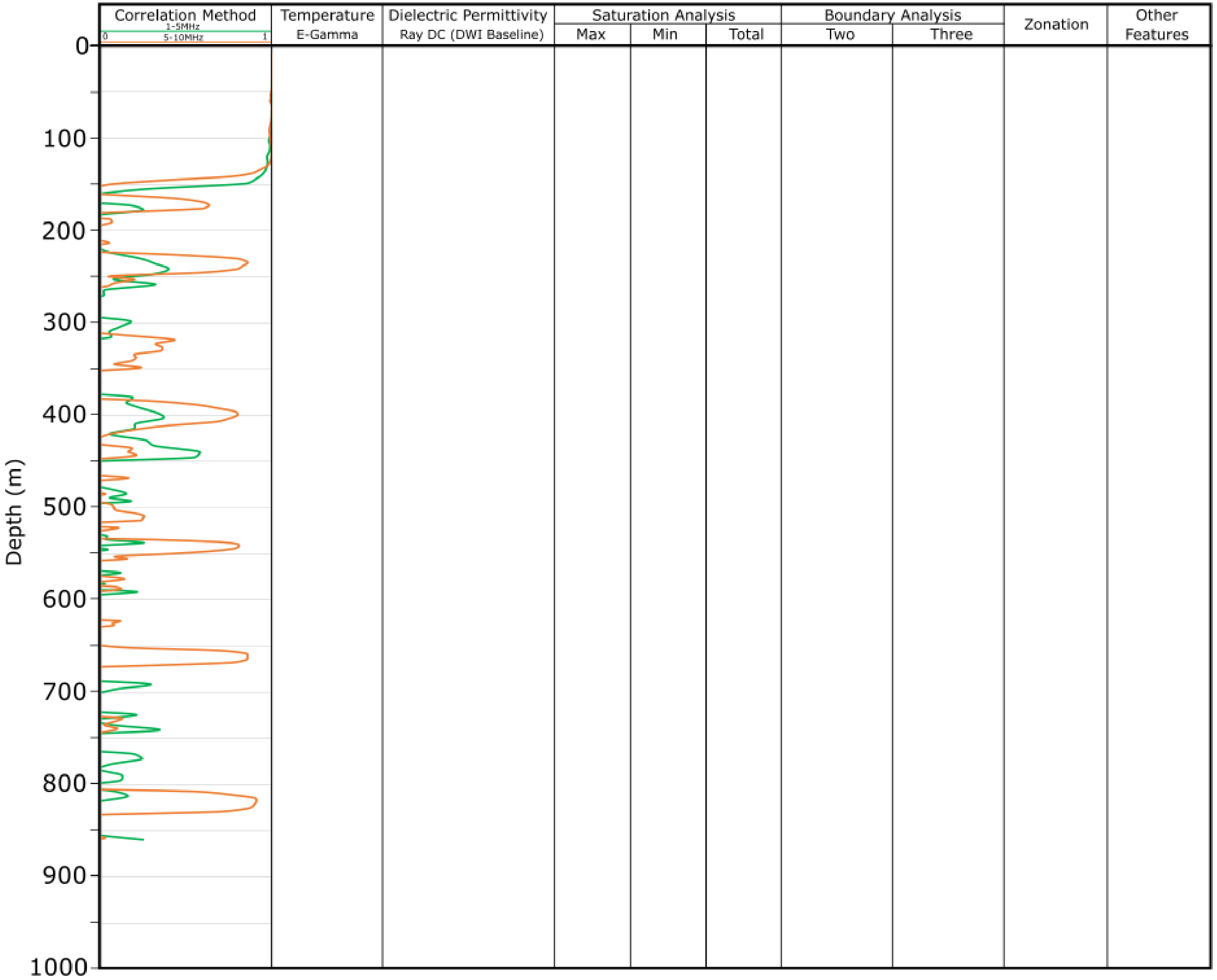
B

The Interpretation for ADR Zones



- The following slides will explain what each of the Zonation parameters are and how they have been interpreted to determine lithological changes.
- Site 1 is used as an example.

2) Methods: Zonation (Frequency Correlation)



These curves are effectively a statistical analysis of the consistency and variation of the many thousands of measurements taken at a particular depth interval.

During a repeated scan at a fixed point, 1000 frequency traces can be repeated up to 100 times, to produce up to 100000 wave packets, increasing the signal to noise ratio and allowing higher resolution.

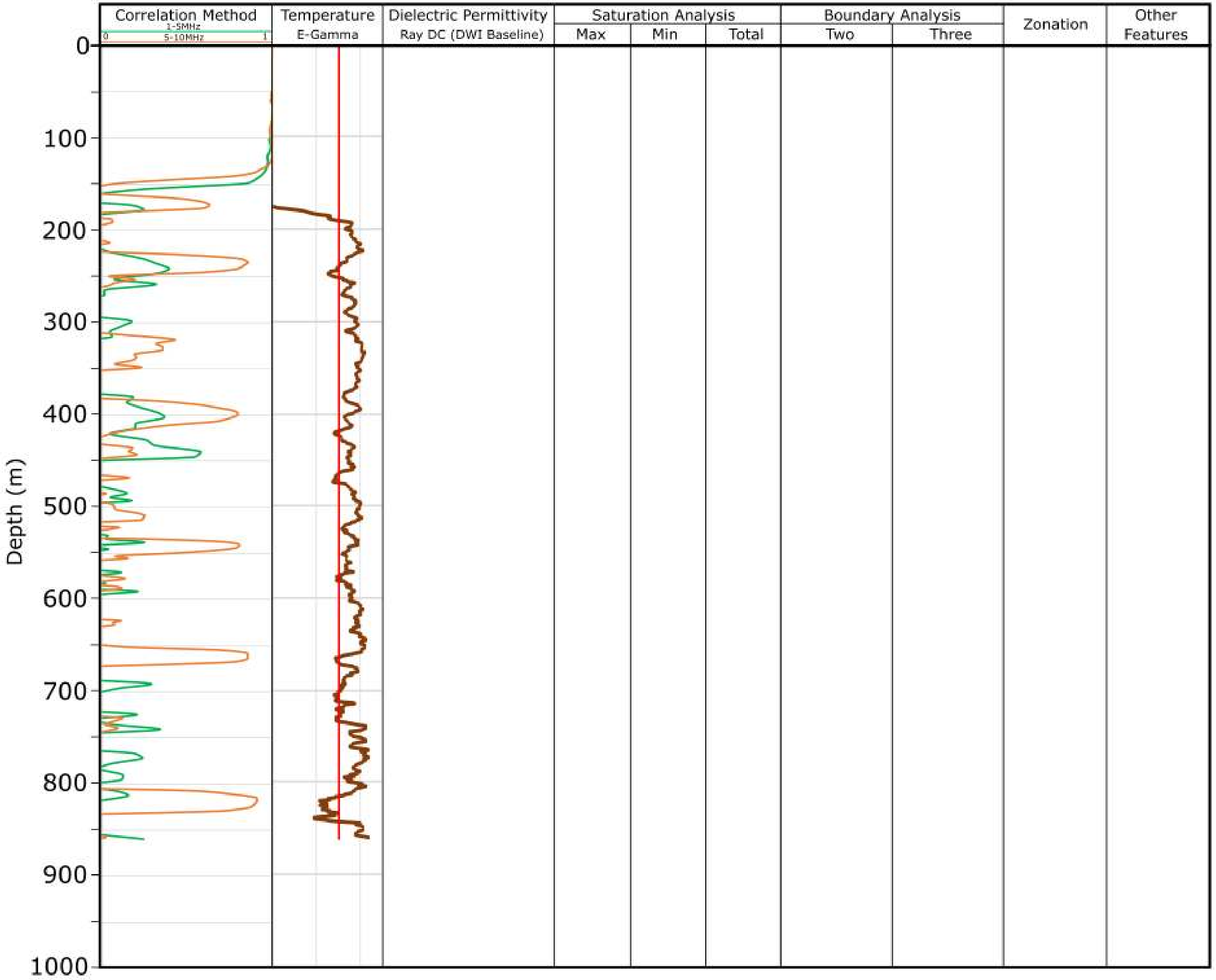
In the time domain before any depth conversion, these responses are stacked. Functionalities within the MATLAB software are then used to relate the responses within different frequency bands with each other. These include raw correlations between individual frequencies, and a stacked correlation for all of that band (γ) as well as the associated standard deviation (σ). The correlations are calculated in windows over a certain time interval, which typically corresponds to a depth interval of between 40-60 meters.

While the approach can be calculated for any frequency band, the bands which Adrok have historically found most useful in a geological context are 1-5 MHz and 5-10 MHz.

Where the correlation value exceeds the standard deviation calculated, it indicates - in a relative sense - that a more consistent correlation is occurring between frequencies and traces within that band, within an interval where the individual frequencies themselves are also behaving more consistently. This is most especially true where the standard deviation (SD) is lowest. Such zones of correlation > SD, where SD is also low, can be thought of as intervals with stronger more consistent reflectance. For this reason, the difference between correlation and SD for a given frequency range is also sometimes shown as a curve alongside the raw data.

For these reasons, it can be helpful to look at various products and dividends of individual curves with the correlation and SD curves, to highlight where a curve's own response can nominally be accorded more reliability
In this case, the data displayed represents correlation minus SD for both 1-5MHz and 5-10MHz). That is, peaks will only appear when the correlation is greater than the SD.

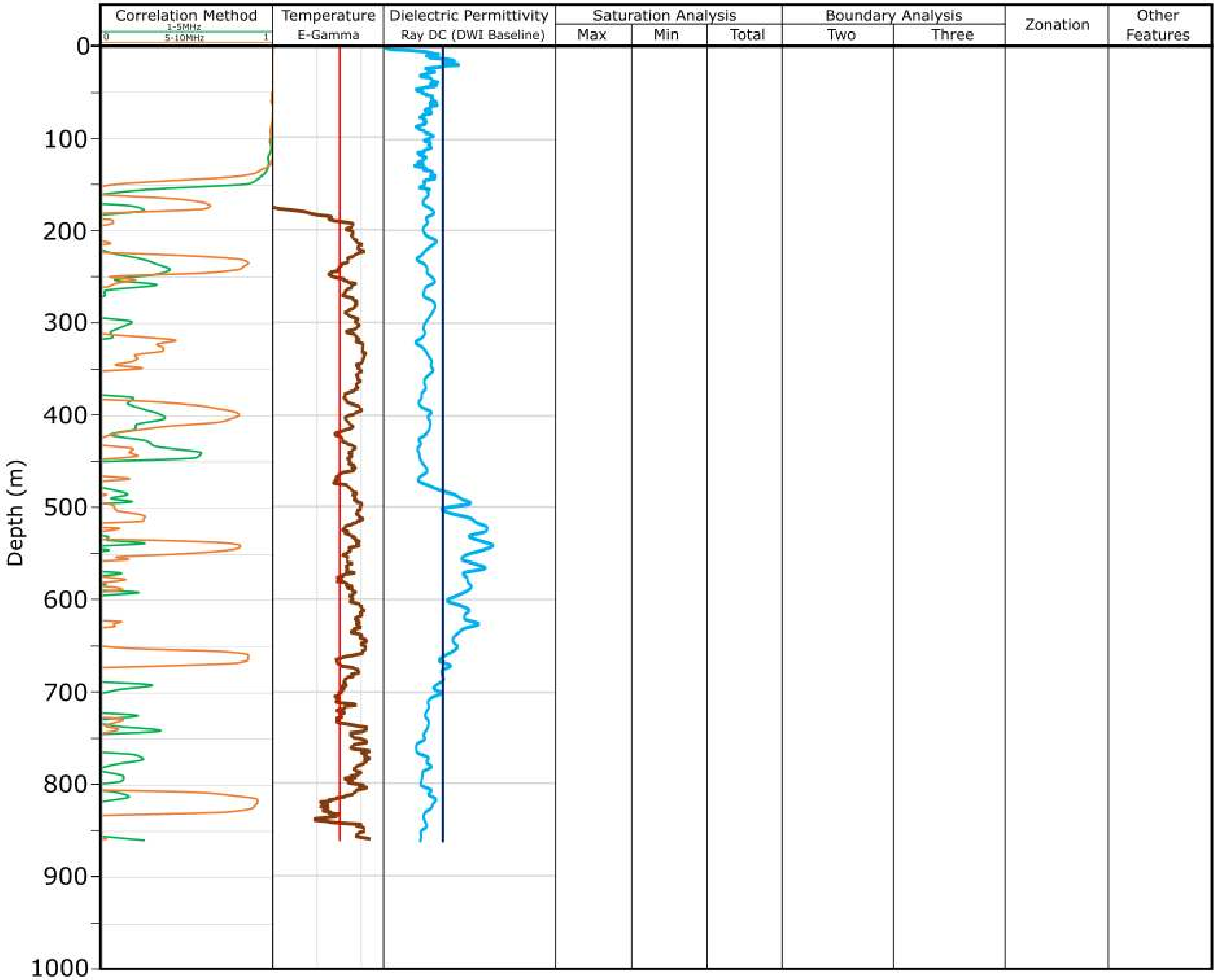
2) Methods: Thermal Impact (E-Gamma)



E-Gamma is an indicator of heat, with low E-Gamma highlighting areas that have a high thermal impact.

The E-Gamma baseline (red) has been derived from Adrok's previous heat studies as a threshold for high thermal impact.

2) Methods: DWI (Dielectrics)



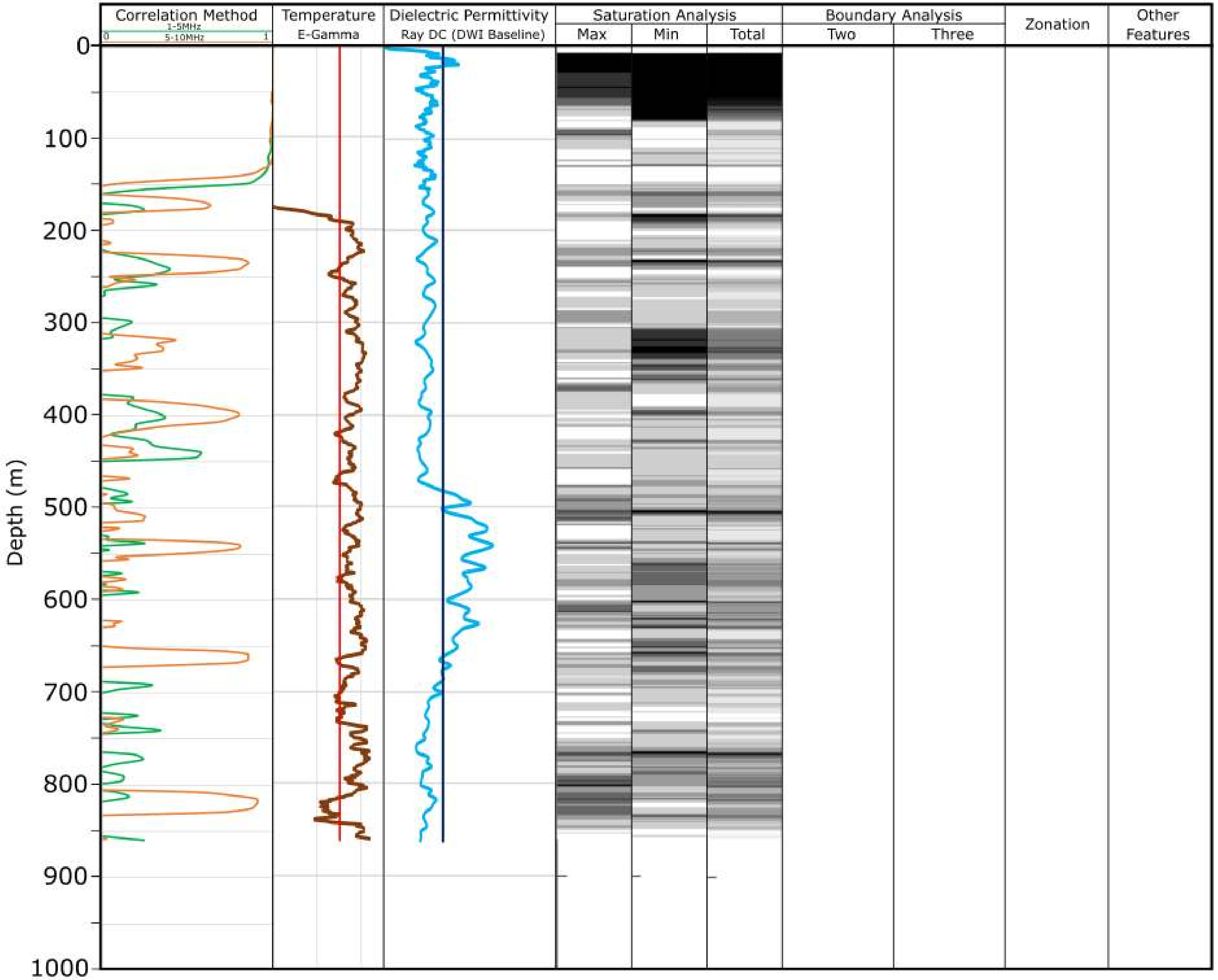
A high or increase in dielectrics could be caused by:

- The presences of water (either within a fault, an aquifer, or within pores)
- Increasing temperature
- Increased salinity
- The presence of highly metallic areas e.g. mineral zones

A low or decrease in dielectrics could be caused by:

- Pockets of air
- Decreasing temperature
- Decreasing salinity
- The presence of organic material (CO^2, coal, oil)

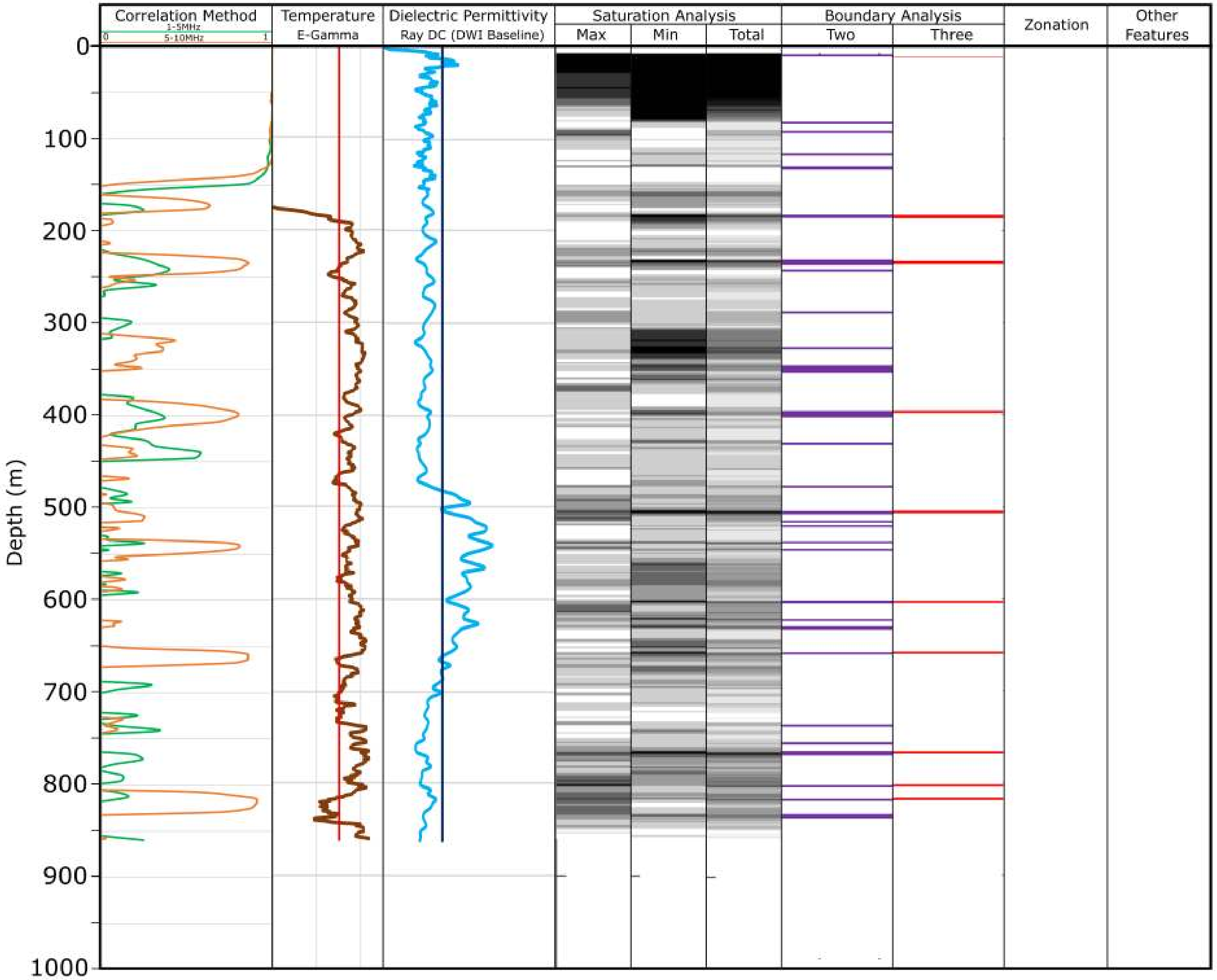
2) **Methods:** Saturation Analysis



Each Energy and Frequency MaxMin box is added together, with a high saturation signifying many boxes stacking at the same depth.

- For Max: All the Max Boxes from each parameter are stacked.
- For Min: All the Min Boxes for each parameter are stacked.
- For Total: The Max Summary and Min Summary saturations are stacked.

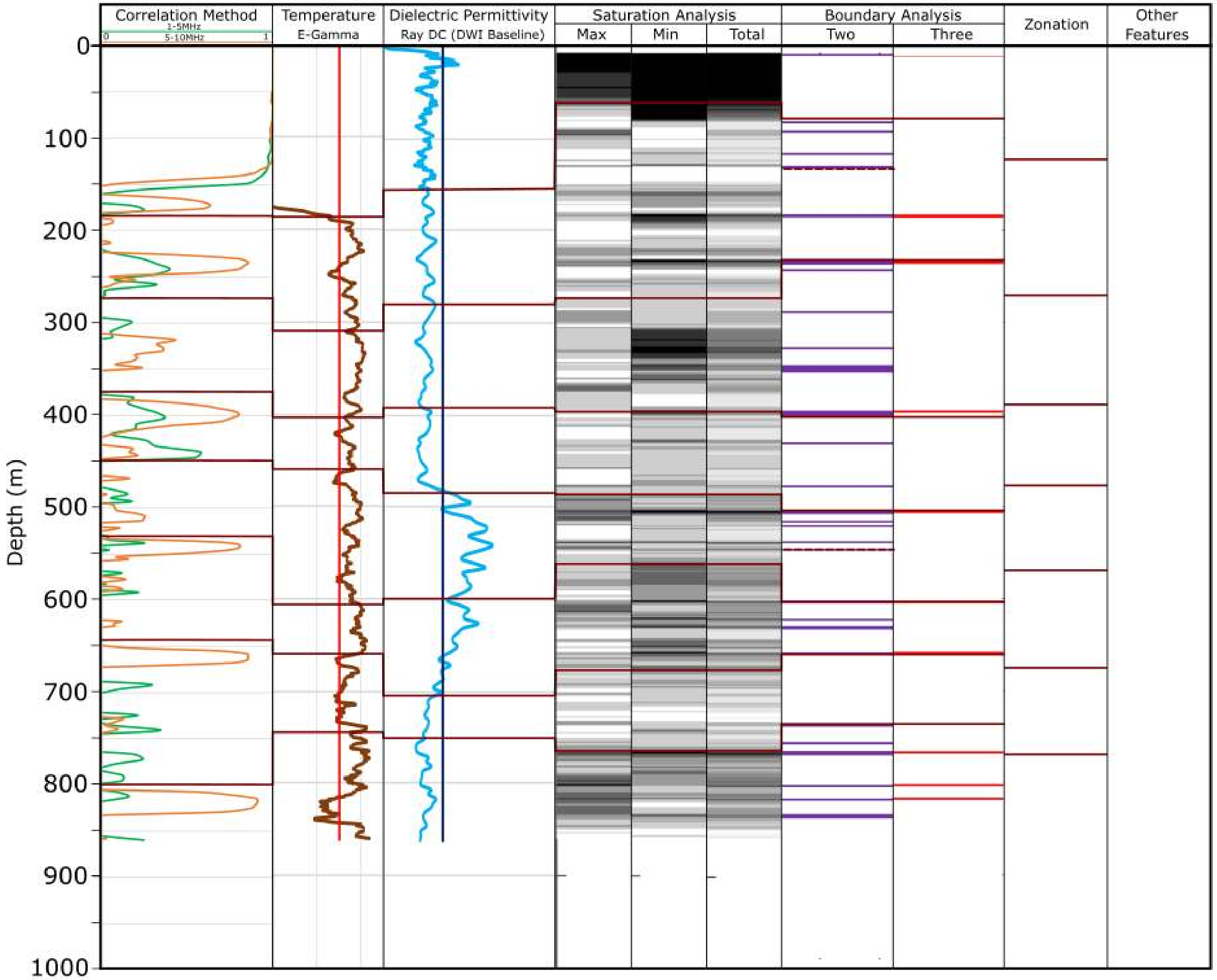
2) Methods: Boundary Analysis



The top and bottom of each Energy and Frequency MaxMin box is plotted as a line.

- For **Two**: Only the points in which two logs have a line in the same depth are shown.
- For **Three**: Only those points in which three or more logs have a line in the same depth are shown.

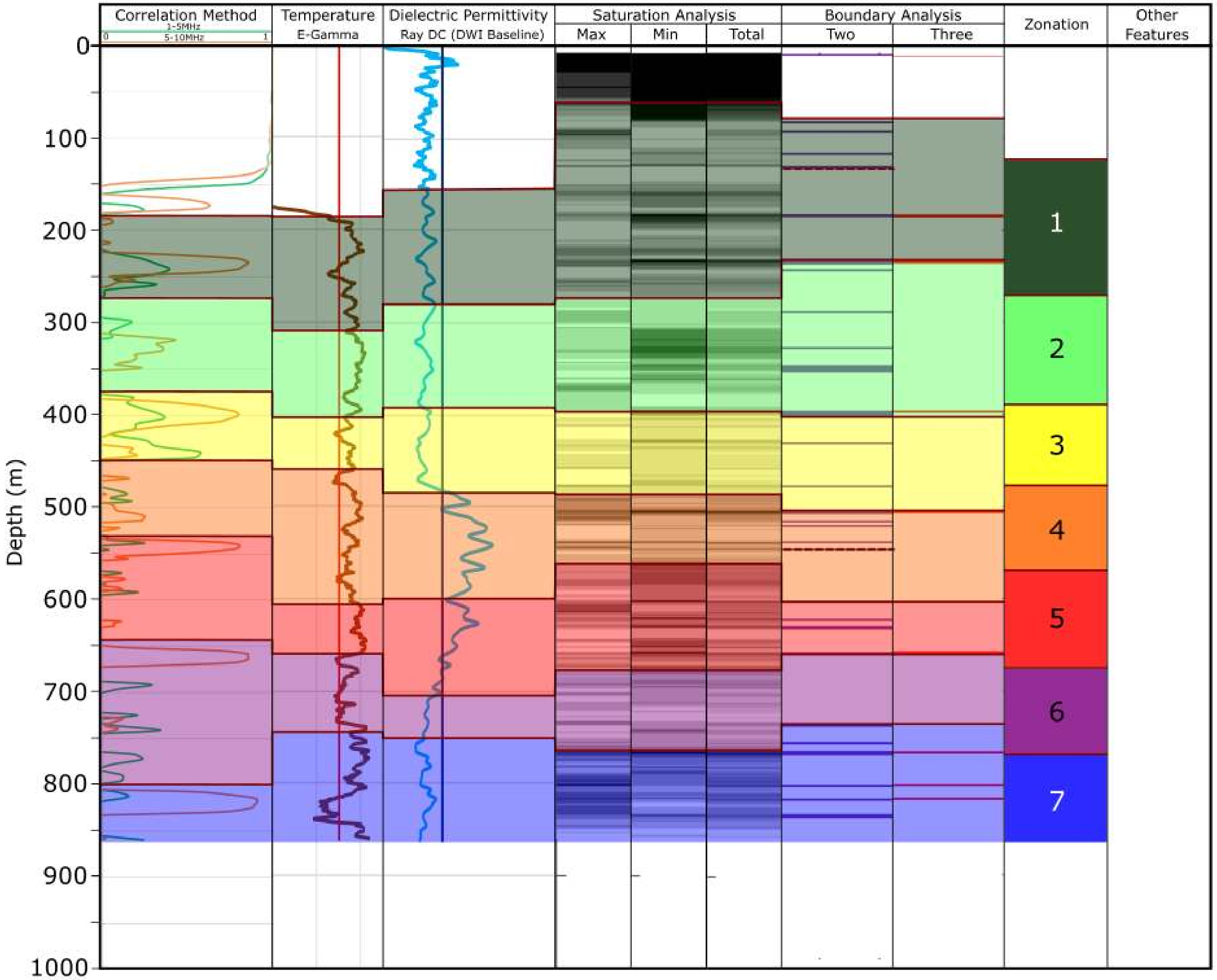
2) Methods: Major Boundaries



Red lines mark the changes in values and trends of the ADR parameters that represent lithological changes.

- Thick red lines represent boundaries that have a high-confidence.
- Dotted red lines represent boundaries with slightly less confidence.

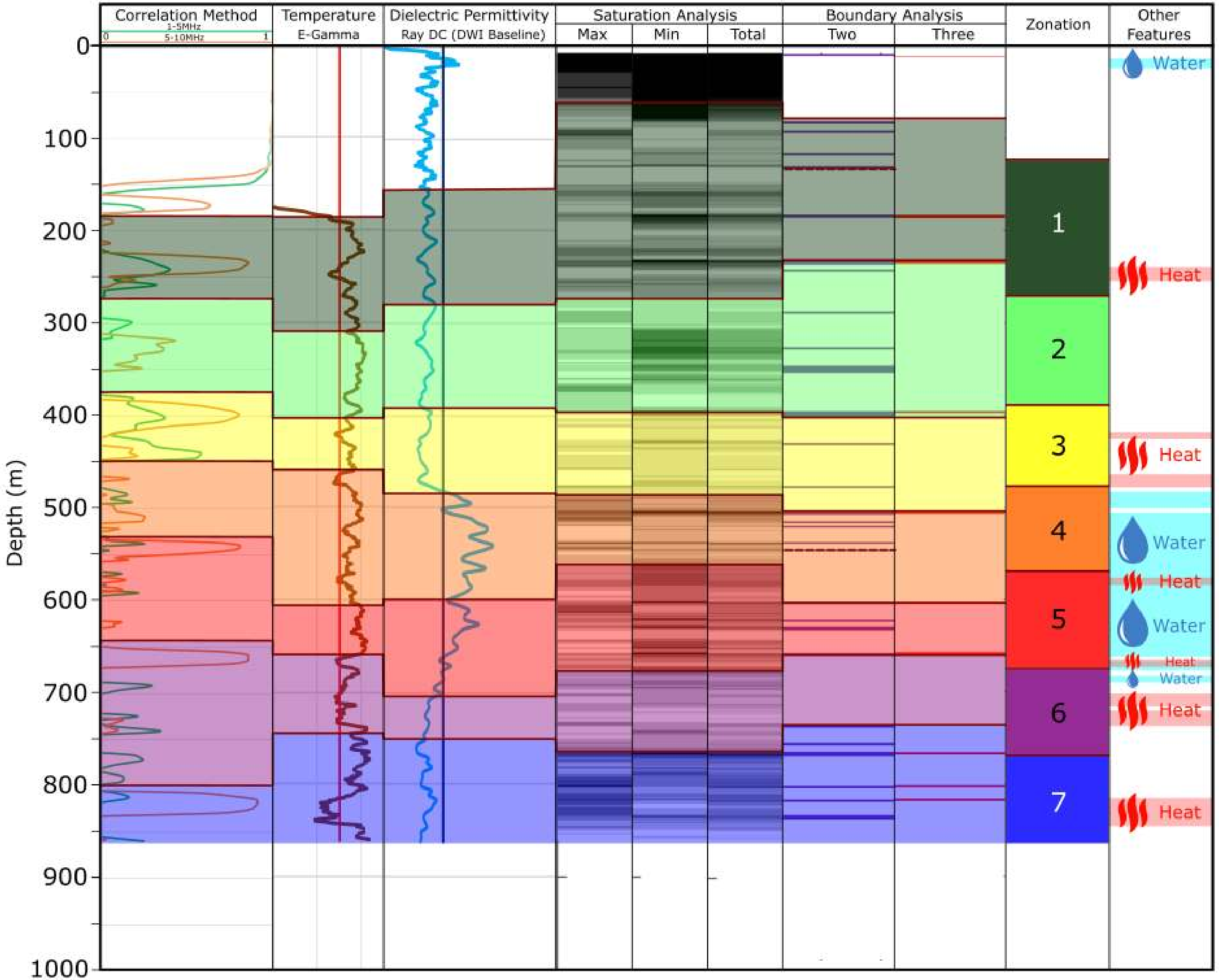
2) Methods: Unit Interpretations



The depths of each interpreted unit boundary is averaged across all parameters to give the final interpreted Zonation unit column.

Formations are largely unknown due to lack of available training data for this project.

2) Methods: Other Features



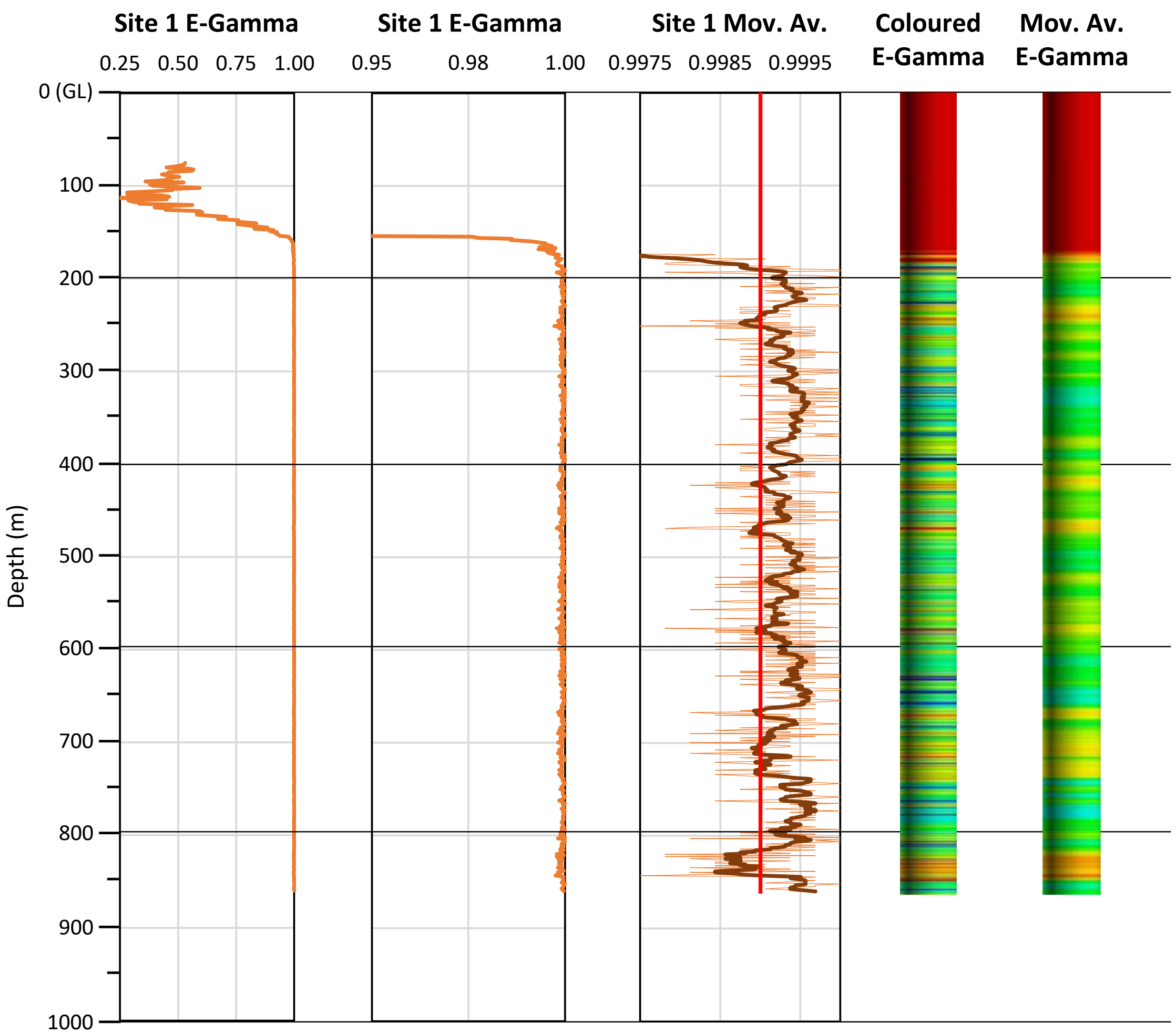
Water can be interpreted where the Ray DC is greater than the Direct Water Indicator (DWI) baseline.

High thermal impact can be interpreted where the E-Gamma is below the Temperature baseline.

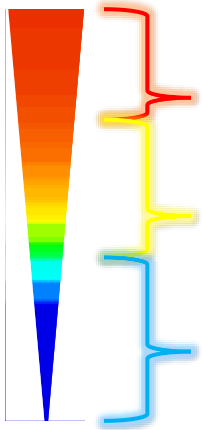
3) Results:

- The following slides will present the Stare results for each site with a slide containing the uninterpreted results followed by a slide with the interpretations added.
- For each site, the Thermal Impact, Relative Temperature, DWI and Zonation analyses will be presented.

3) **Results:** Site 1 Thermal Impact

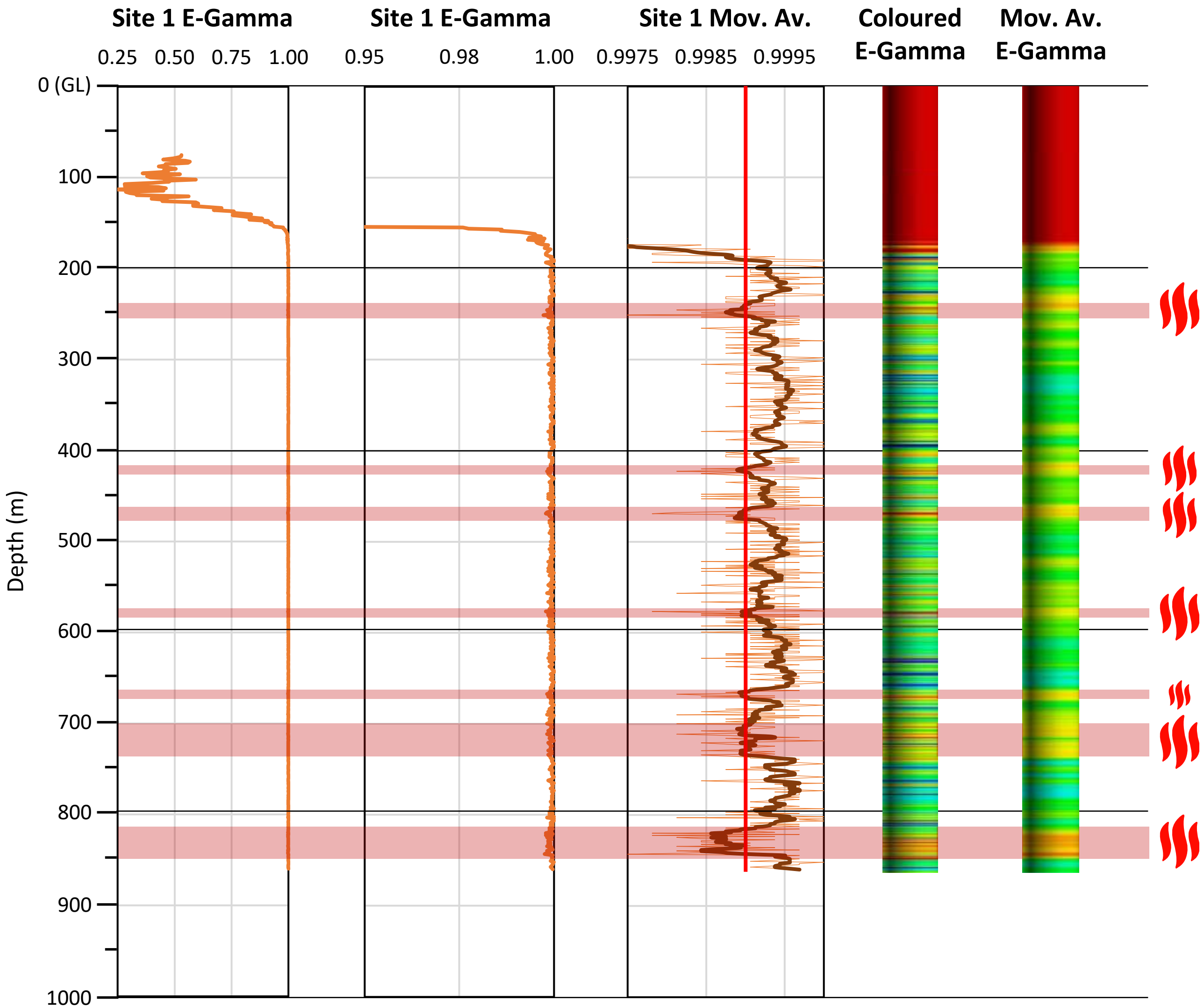


E-Gamma values



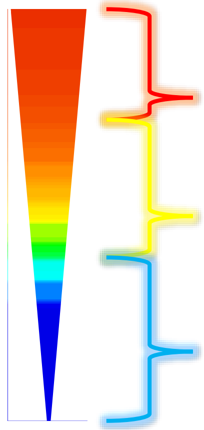
0.00 – 0.998	**Red indicates high thermal impact.**
0.998 – 0.999	**Yellow indicates medium thermal impact.**
0.999 – 1.000	**Blue indicates low thermal impact.**

3) Results: Site 1 Thermal Impact



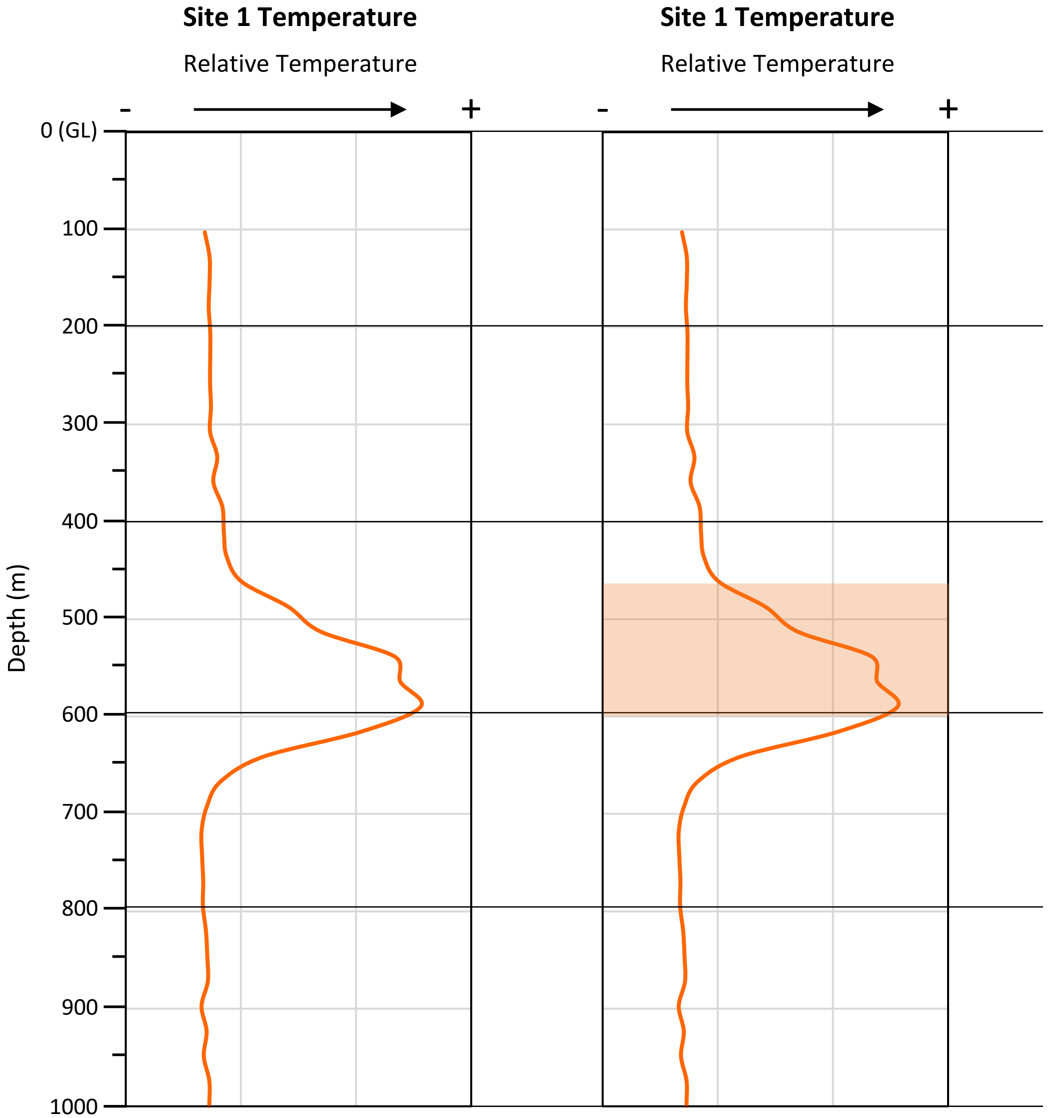
- There are a total of 7 zones in Site 1 that have a medium to high thermal impact.
- The most significant thermal impact zone is at a depth of 815-850m. This zone has the most significant E-Gamma trough beneath the baseline.
- There is also a significant E-Gamma trough below the baseline at 235-255m, which could be a shallow heat source

E-Gamma values



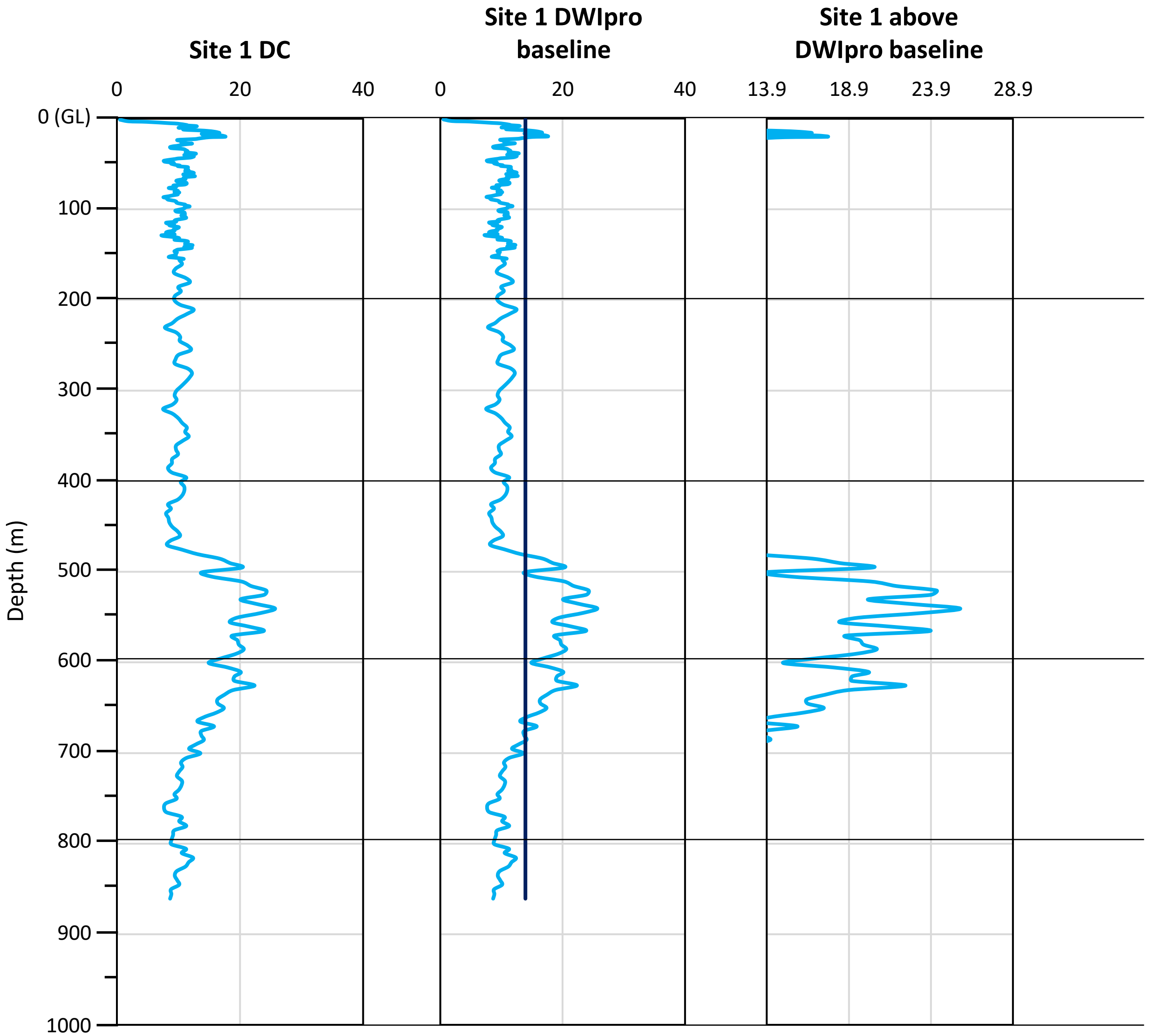
0.00 – 0.998	**Red indicates high thermal impact.**
0.998 – 0.999	**Yellow indicates medium thermal impact.**
0.999 – 1.000	**Blue indicates low thermal impact.**

3) Results: Site 1 NN Temperature



- The NN temperature results at Site 1 indicate a high temperature anomaly at a depth of 460-600m.
- This high temperature zone will become an area of interest.

3) Results: Site 1 DWI



$$\text{DWIpro} = \frac{\text{Baseline} - \text{Mean}}{-\text{Standard Deviation}}$$

Baseline = (DWIpro*-SD) + Mean

Site 1 Baseline = (-0.7*-3.6) + 11.4

Site 1 Baseline = 13.9 DC

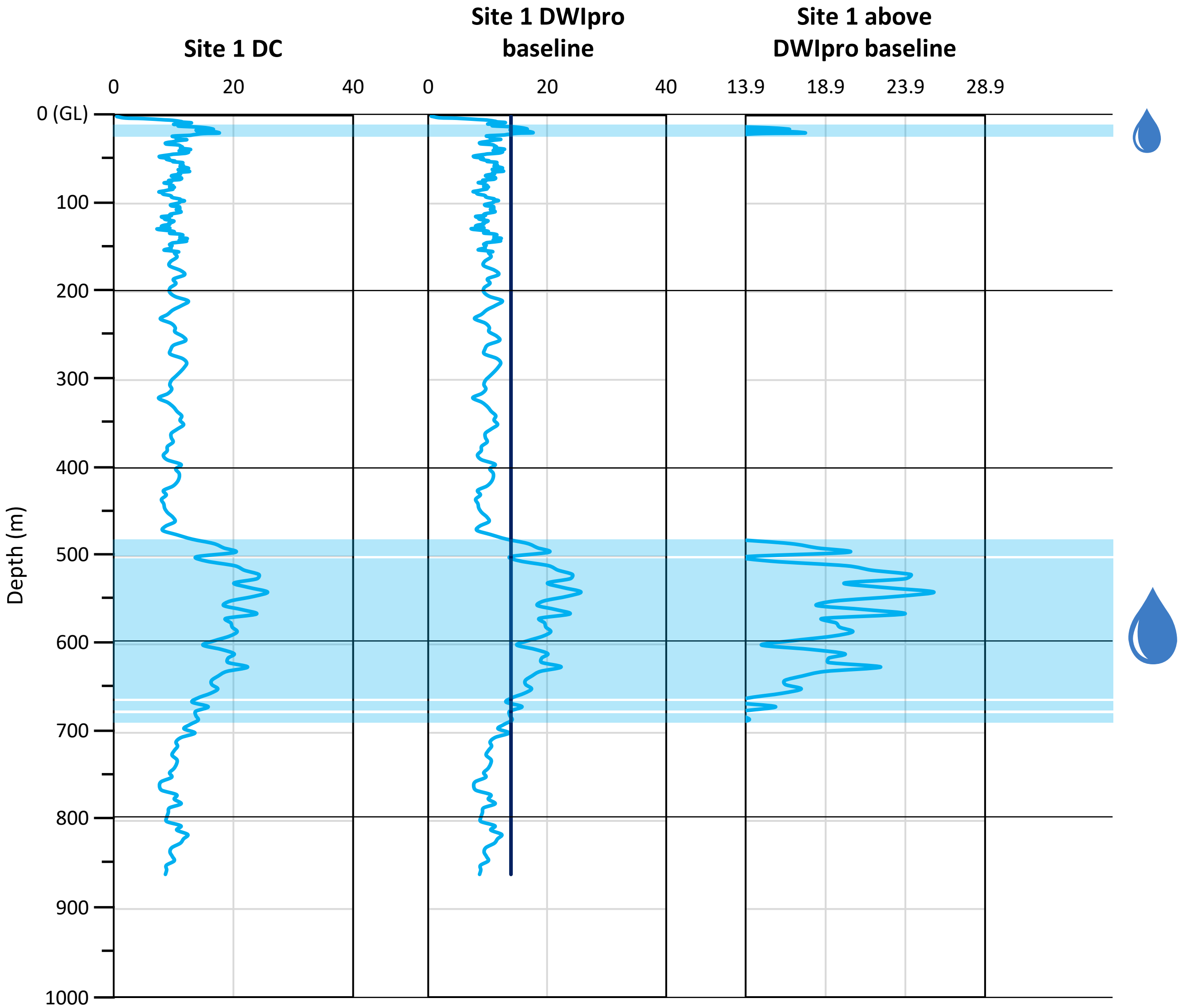
__Site 1 Values:__

DWIpro = -0.7

Mean = 11.4 DC

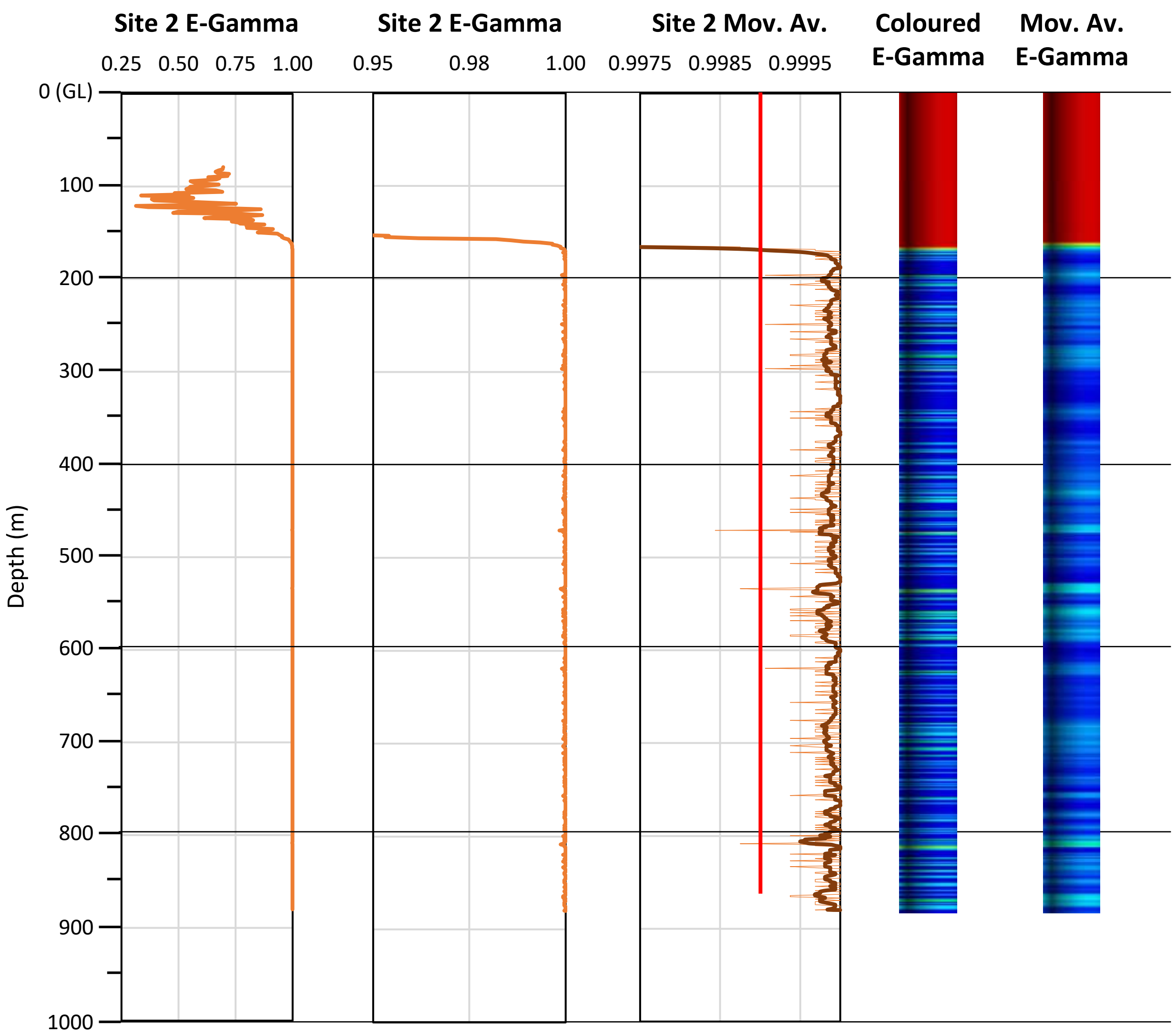
Standard Deviation = 3.6 DC

3) **Results:** Site 1 DWI

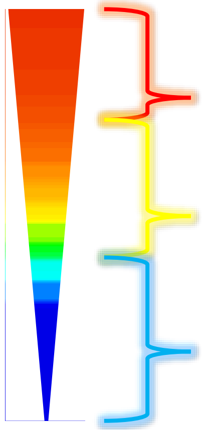


- There are 2 primary DWI zones in Site 1, that may have a presence of water.
- The first is at a shallow depth of 10-25m, with a small 15m peak above the baseline.
- The second is a thicker zone at a depth of 480-685m, with a large 205m zone of high DC above the baseline.

3) **Results:** Site 2 Thermal Impact



E-Gamma values

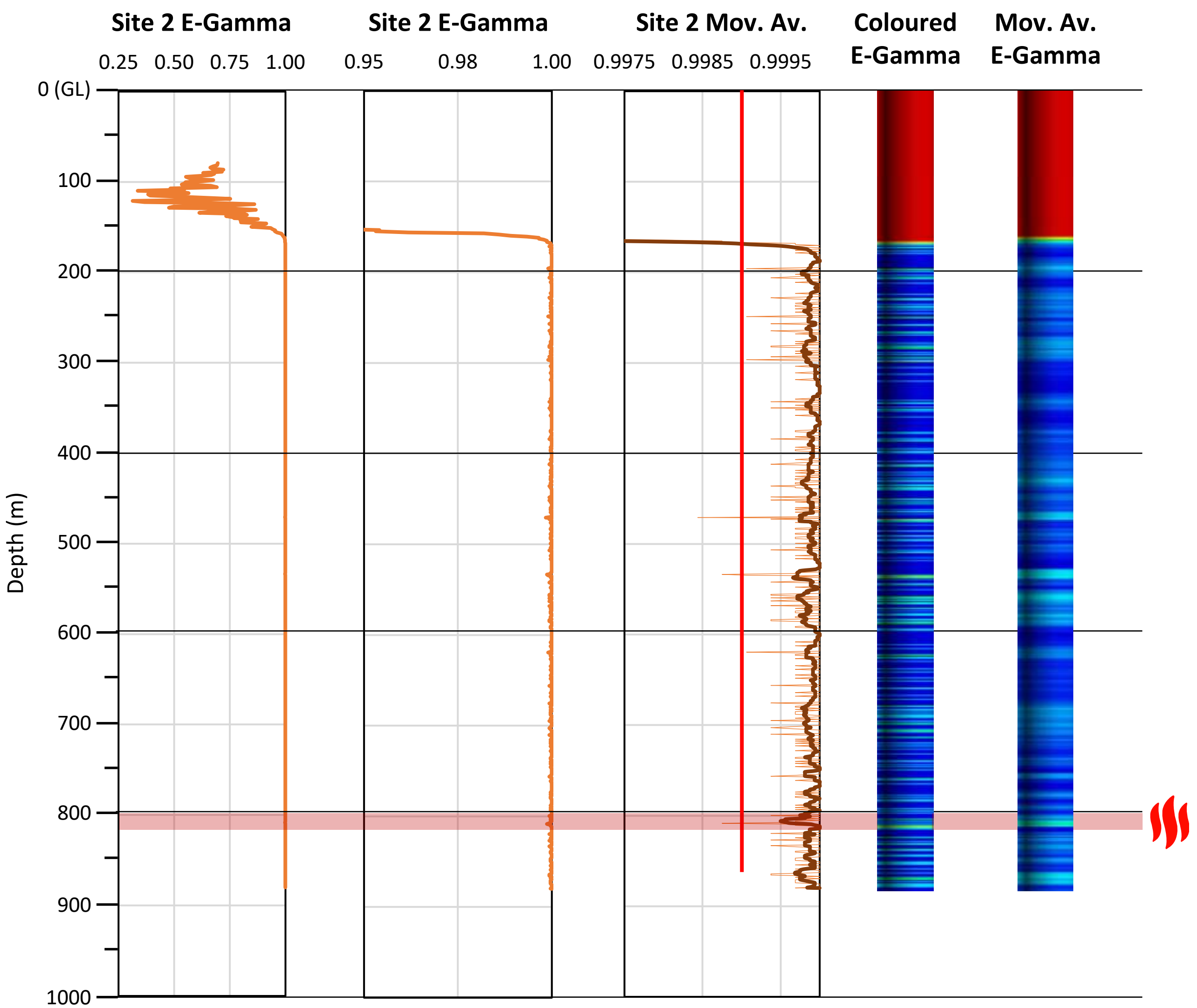


0.00 – 0.998 **Red indicates high thermal impact.**

0.998 – 0.999 **Yellow indicates medium thermal impact.**

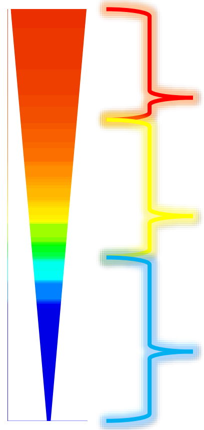
0.999 – 1.000 **Blue indicates low thermal impact.**

3) **Results:** Site 2 Thermal Impact



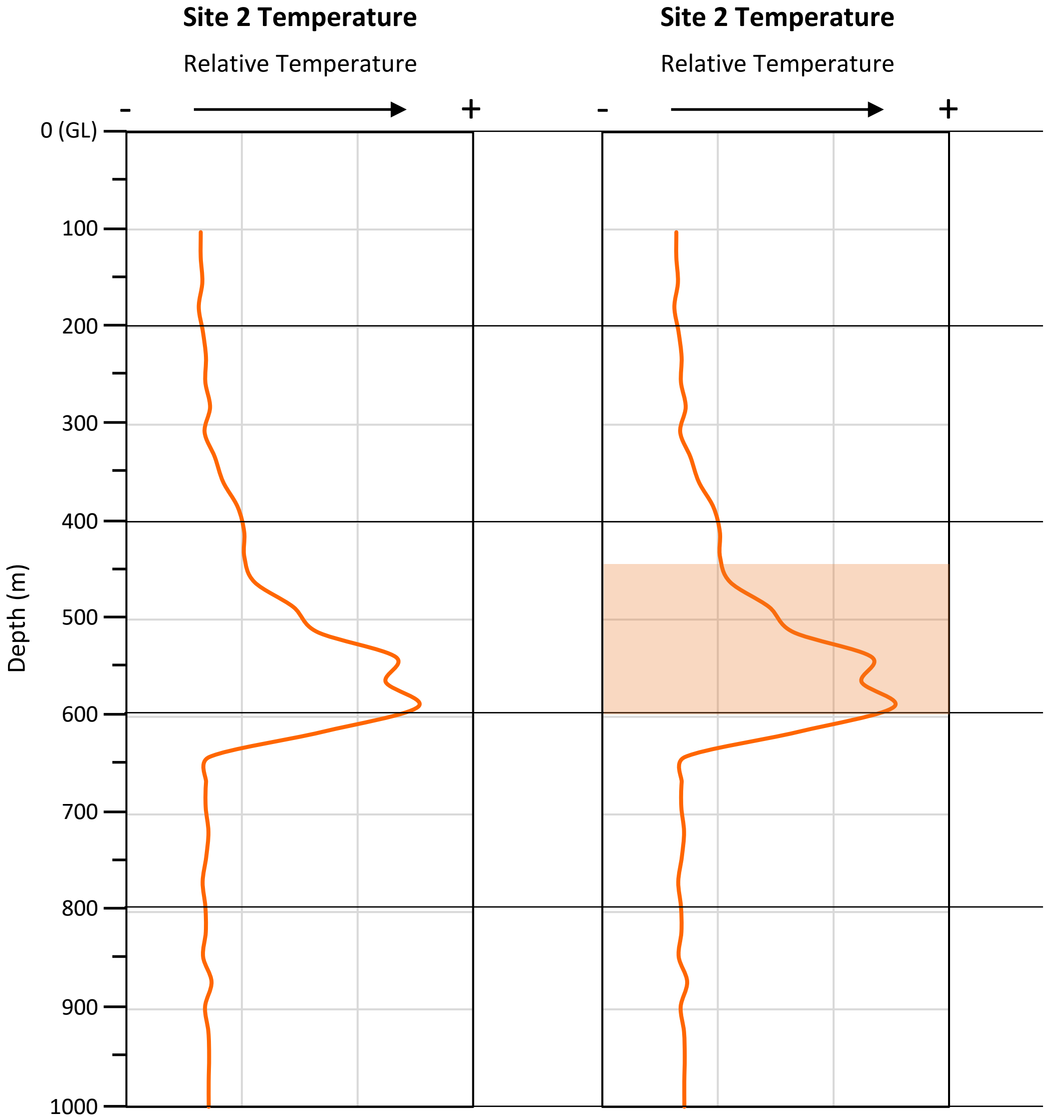
- There aren't any E-Gamma values beneath the baseline in Site 2, as the range of values is higher and more narrow than in Site 1.
- There is an area of interest at 800-820m depth that has a low thermal impact but is the most significant trough in Site 2.
- This area of interest is also correlative in depth to the most significant thermal impact zone in Site 1.

E-Gamma values



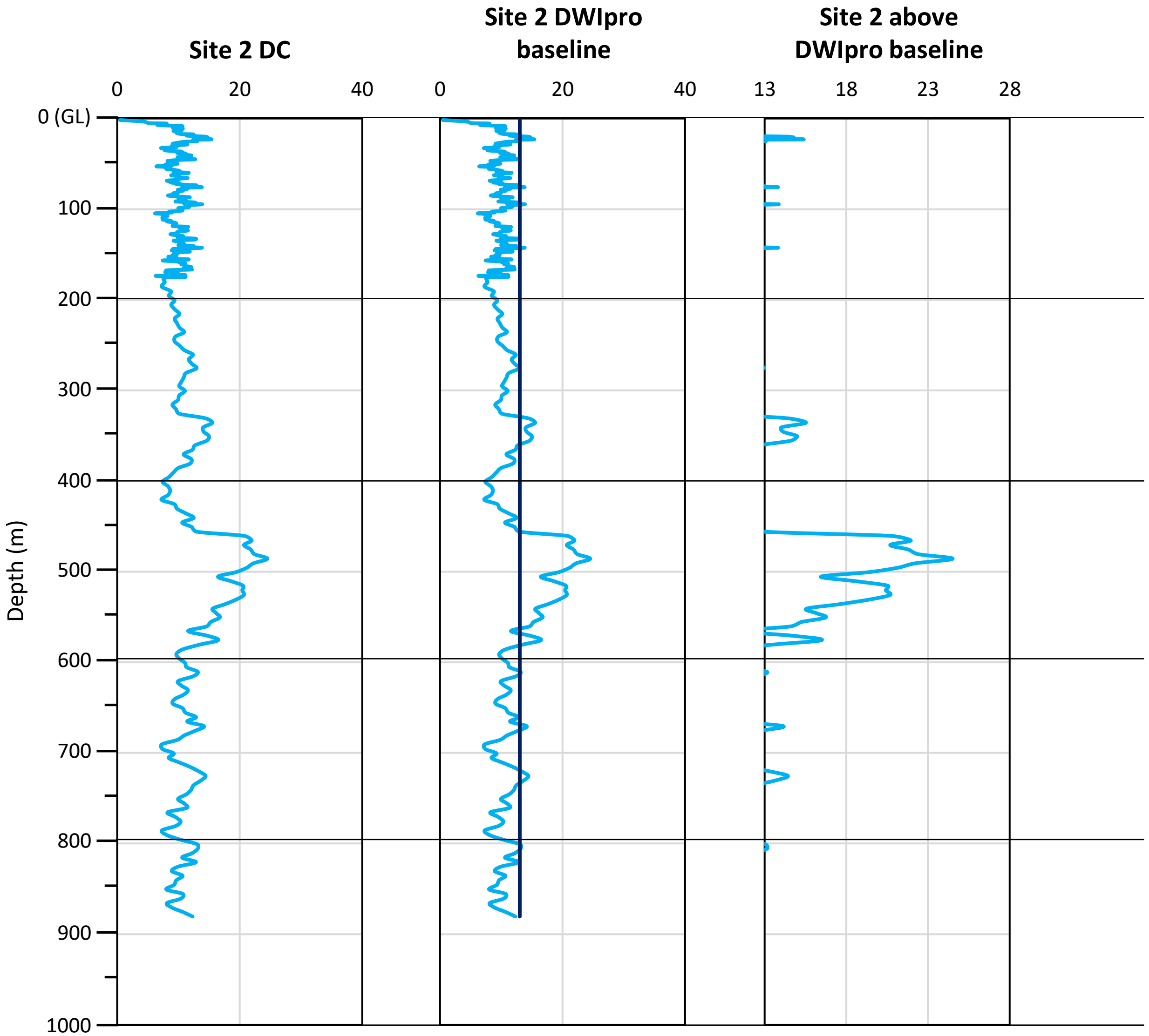
0.00 – 0.998	**Red indicates high thermal impact.**
0.998 – 0.999	**Yellow indicates medium thermal impact.**
0.999 – 1.000	**Blue indicates low thermal impact.**

3) **Results:** Site 2 NN Temperature



- The NN temperature results at Site 2 indicate a high temperature anomaly at a depth of 450-600m.
- This high temperature zone will become an area of interest.

3) Results: Site 2 DWI



$$\text{DWIpro} = \frac{\text{Baseline} - \text{Mean}}{-\text{Standard Deviation}}$$

Baseline = (DWIpro*-SD) + Mean

Site 2 Baseline = (-0.7*-3.1) + 10.8

Site 2 Baseline = 13.0 DC

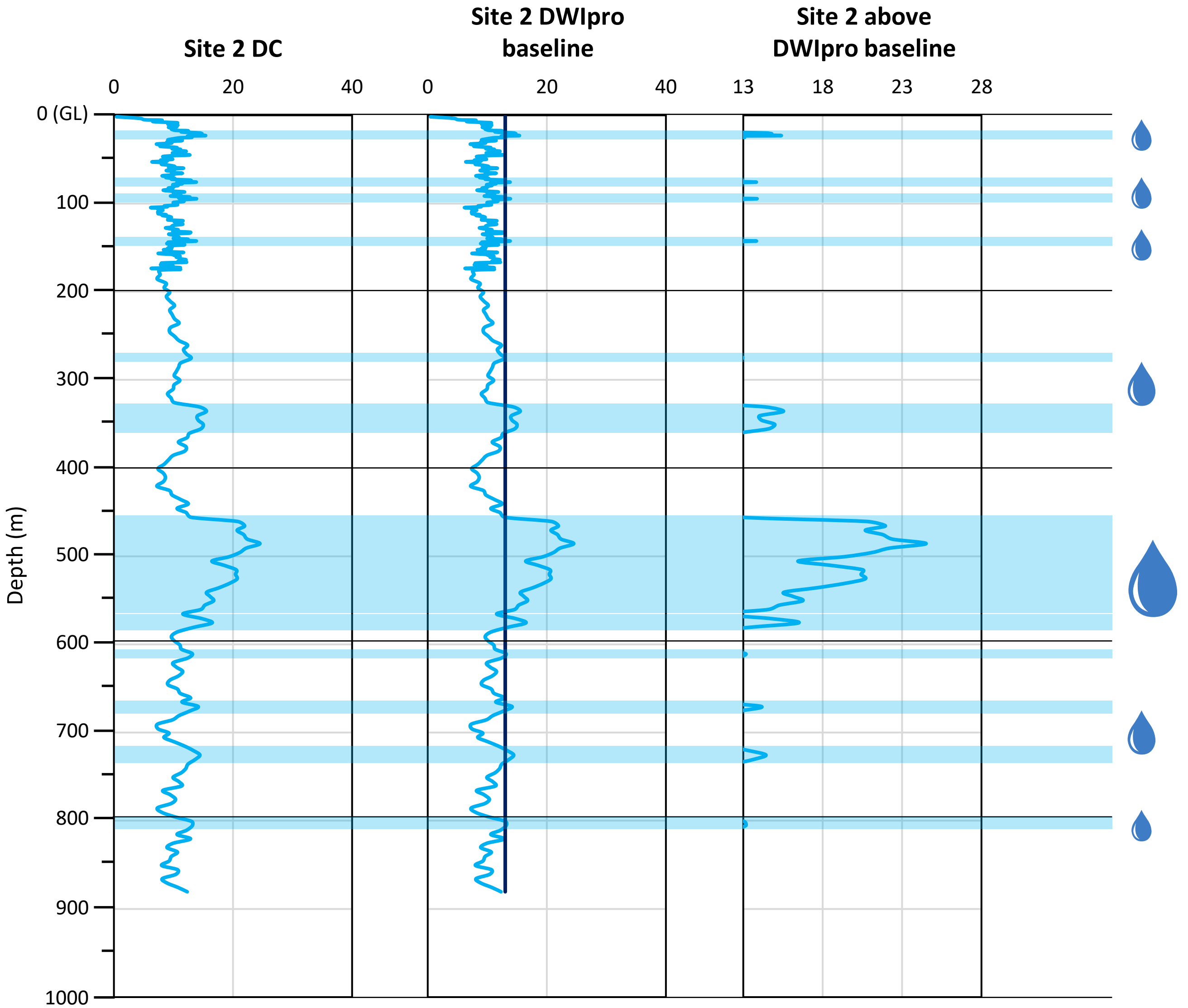
<u>Site 1 Values:</u>

DWIpro = -0.7

Mean = 10.8 DC

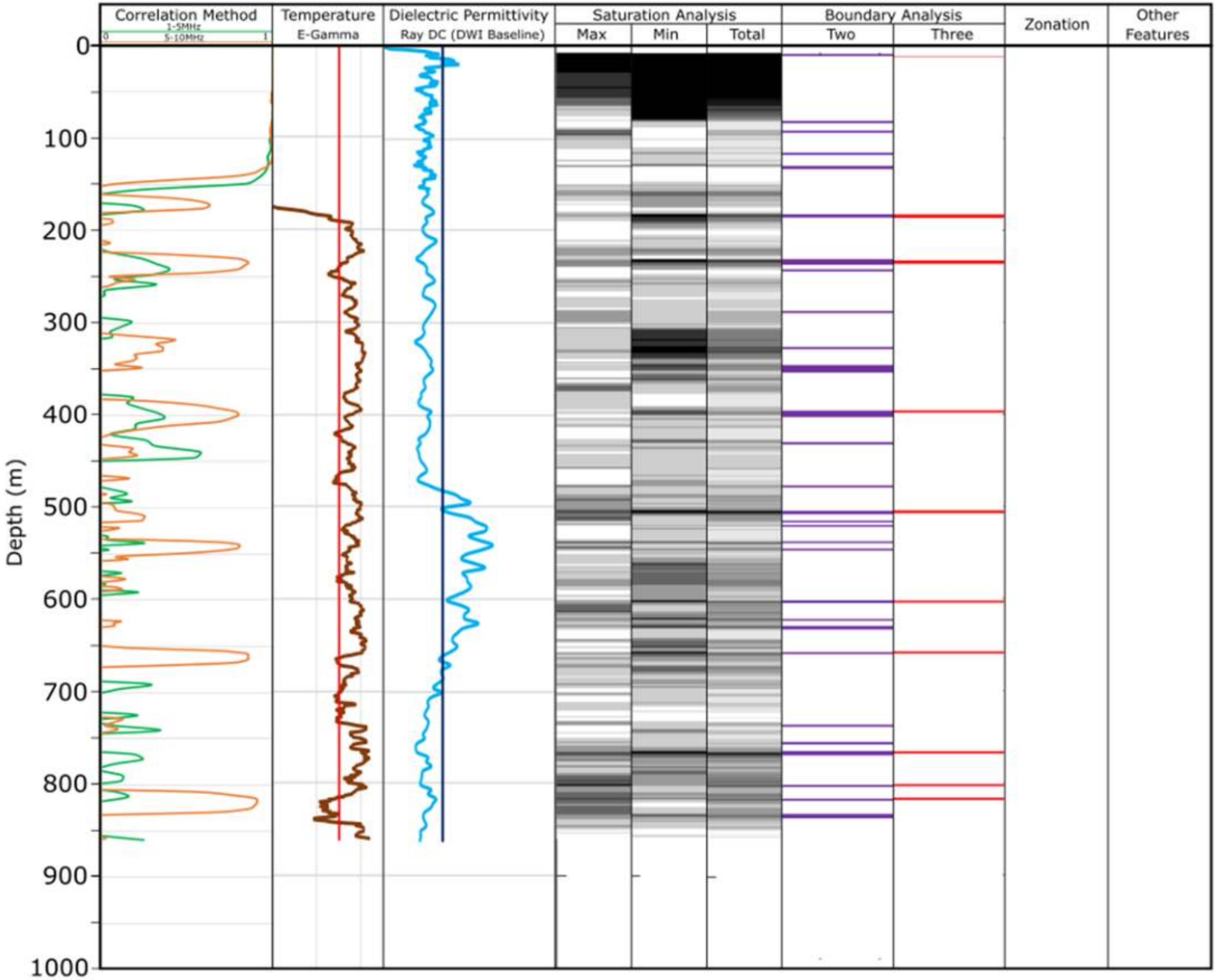
Standard Deviation = 3.1 DC

3) Results: Site 2 DWI



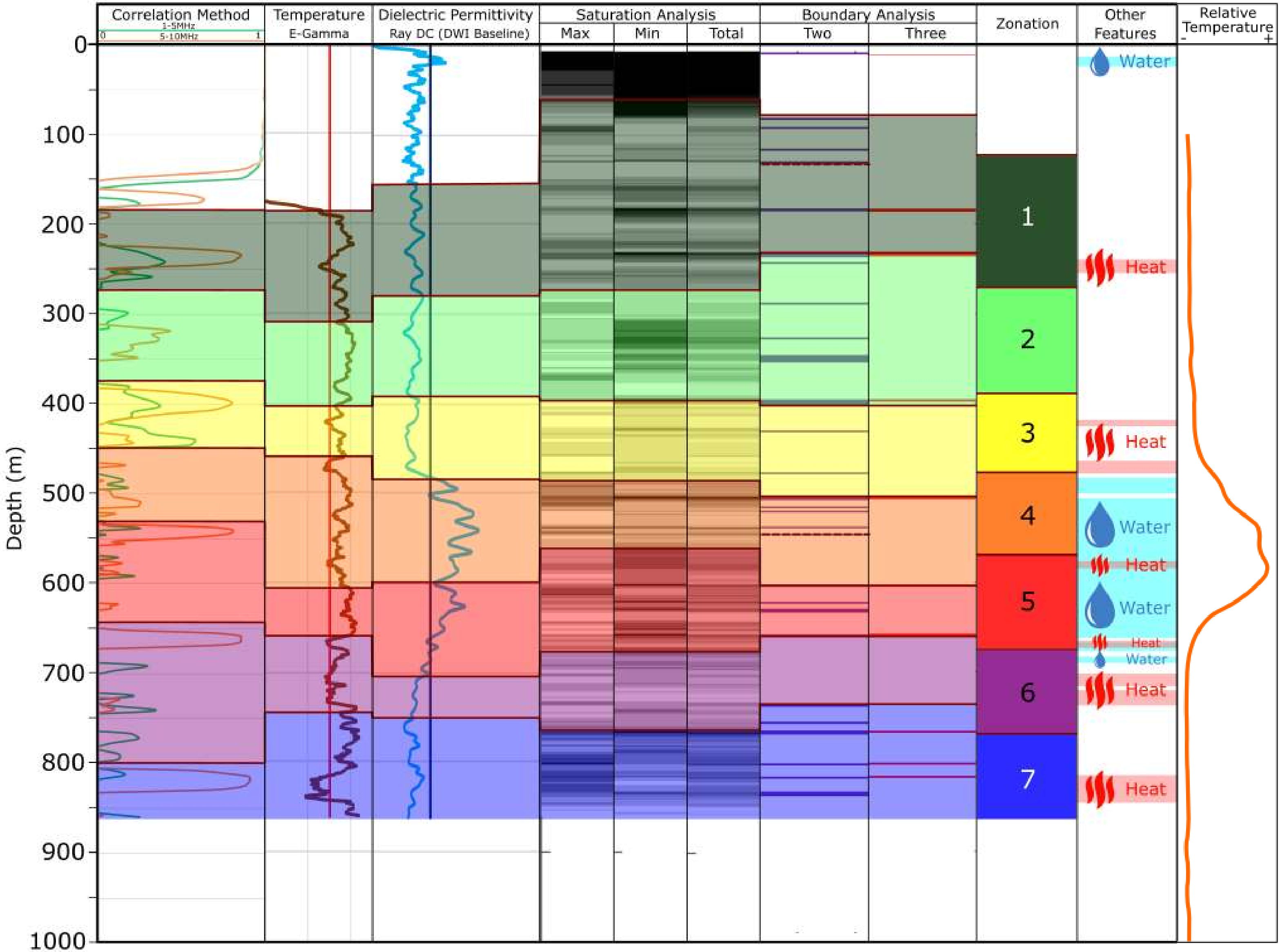
- There are up to 11 DWI zones in Site 2, that may have a presence of water, with two of these zones being primary areas of interest.
- The first significant DWI zone is at a depth of 325-360m, with a 35m DC peak above the baseline.
- The second and most significant DWI zone is at a depth of 455-580m, with a thick 125m zone of high DC above the baseline.
- Site 2 also has a shallow DWI zone at 20-30m, with only a 10m DC peak above the baseline.

3) Results: Site 1 Zonation



- Between ~500-650m where the high DC (DWI) anomaly is situated, there is also a greater concentration of boundaries and saturation, compared to the adjacent units.
- This DWI anomaly also corresponds with a peak in the 5-10MHz frequency correlation towards the top and base of the high DC zone.
- The most significant E-Gamma trough also corresponds to similar features, with a large peak in the 5-10MHz correlation, higher saturations and a concentration of boundaries.

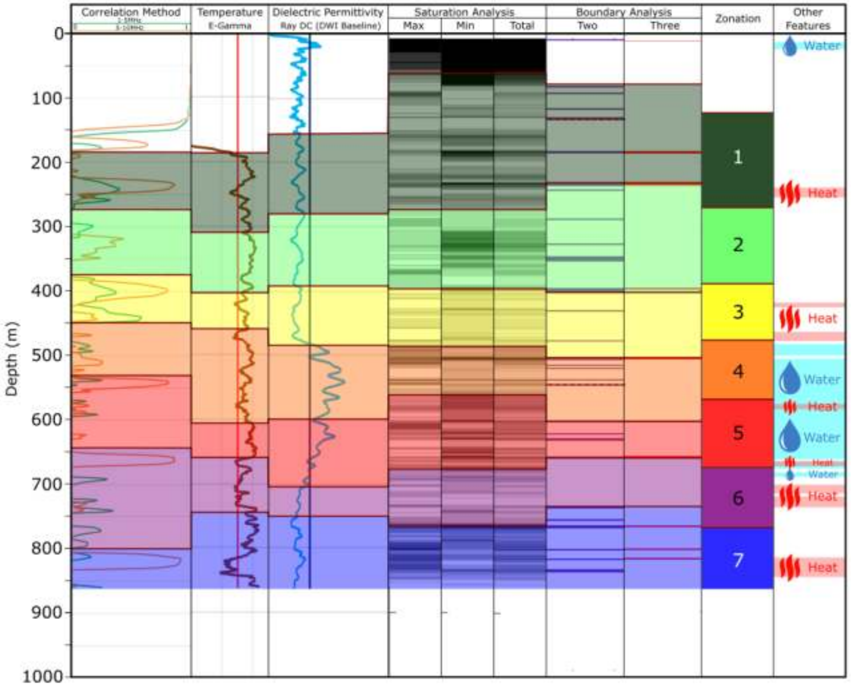
3) Results: Site 1 Zonation



- The zonation method has detected 7 units throughout Site 1 with different geophysical characteristics.
- The primary units of geothermal interest are units 4, 5 and 7.
- Unit 4 and 5 have a strong combination of DWI zones that potentially contain water, and medium-high thermal impact zones. This also coincides with a large temperature anomaly from the NN Temperature results.
- Unit 7 also contains the most significant thermal impact zone.

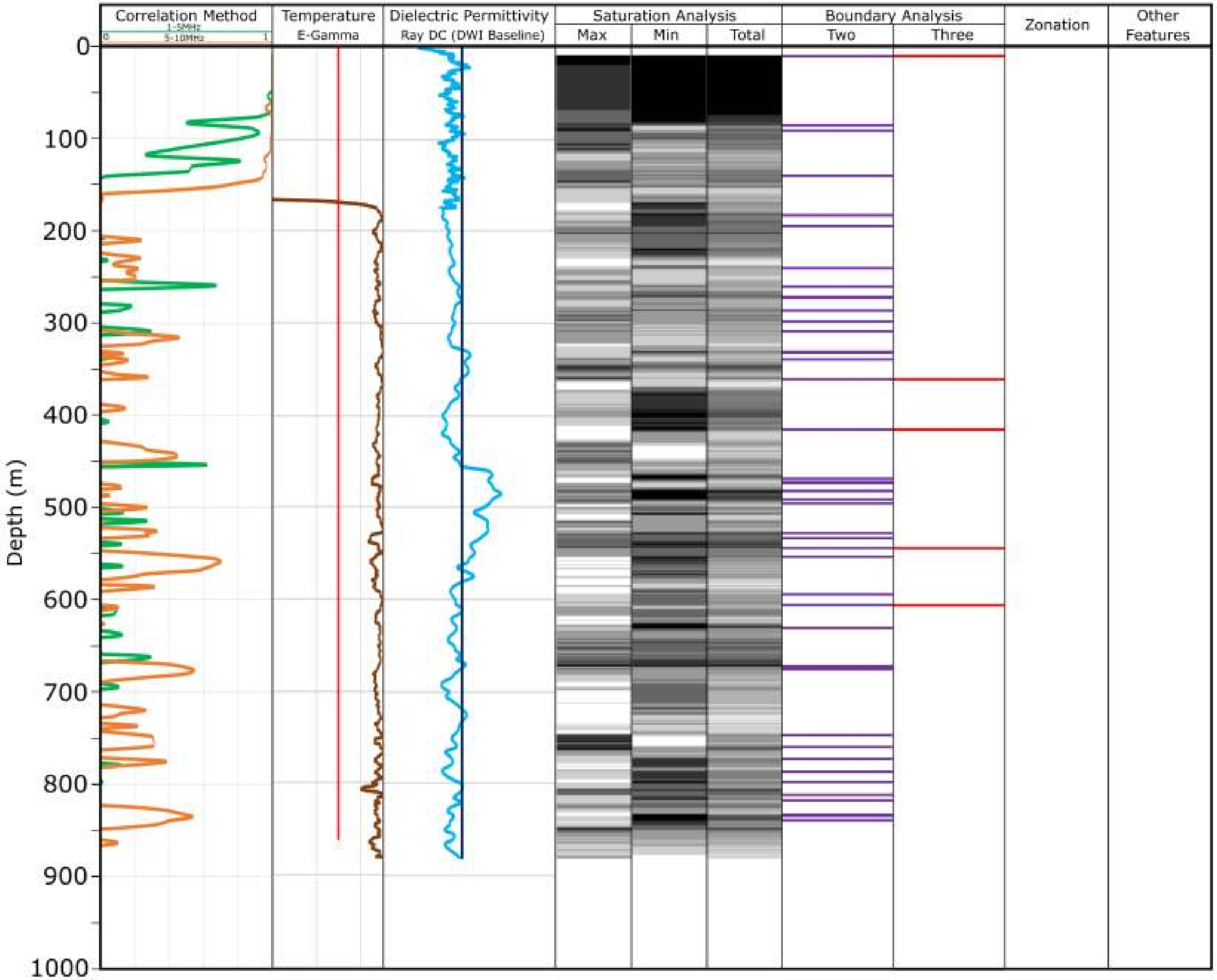
3) **Results:** Site 1 Zonation

- This table identifies and describes the characteristic signals that each ADR parameter displays within each of the 7 defined units.



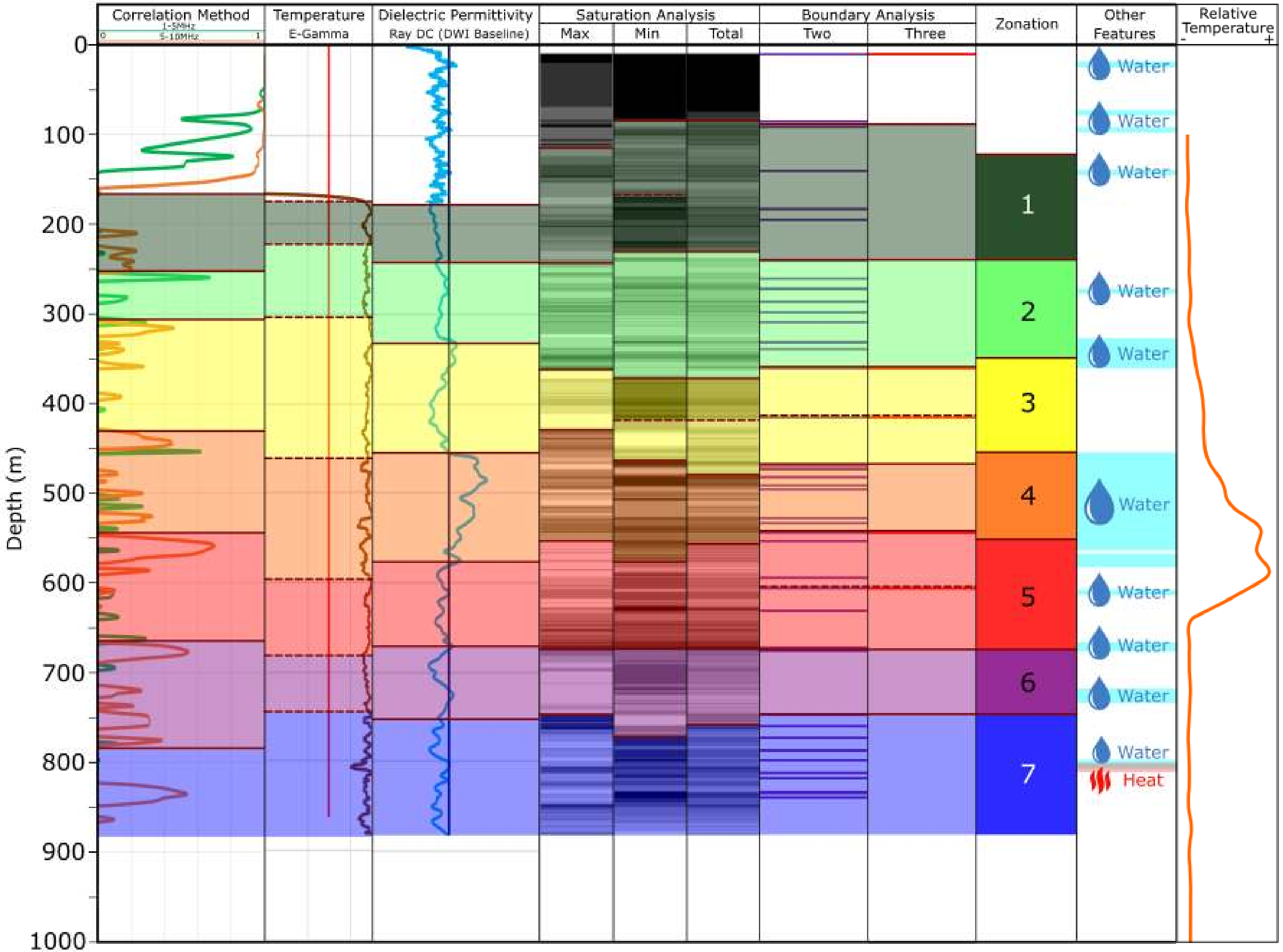
Adrok Unit	Correlation	Temperature (E-Gamma)	Dielectrics (DWI)	Maximum Minimum Boxes	Maximum Minimum Lines	Depth (m)
1	Moderate response in 1-5MHz and strong response in 5-10MHz.	Large variations in E-Gamma with a large trough in the centre of the unit.	Regular small increases and decrease in DC.	High saturation in Min Box. Low to moderate saturation in Max and Total Boxes.	Two and Three Lines present	124-270
2	Weak response in 1-5MHz and moderate response in 5-10MHz	There is a trend towards higher E-Gamma values.	Regular small increases and decrease in DC.	Low to moderate saturation in all three boxes.	Two Lines common. Three Lines rare	270-389
3	Moderate response in 1-5MHz which increases towards the base. Strong response in the 5-10MHz which decreases towards to the base.	Large variations in E-Gamma with a large trough in the centre of the unit.	Regular small increases and decrease in DC.	Low to moderate saturation in all three boxes.	Two Lines common. Three Lines rare	389-476
4	Low to moderate response in both 1-5MHz and 5-10MHz	Small troughs near the top and bottom of the unit. High values in between.	Higher values above the DWI baseline.	Low to moderate saturation in all three boxes.	Two Lines common. Three Lines rare	476-568
5	Low response in 1-5MHz. Strong response in the 5-10MHz decreasing towards the base.	There is a trend towards higher E-Gamma values.	Decreasing values from above the DWI baseline to below the DWI baseline	Low to moderate saturation in all three boxes.	Two Lines common. Three Lines rare	568-674
6	Low to moderate response in 1-5MHz. Strong response in the 5-10MHz decreasing towards the base.	Trend towards lower E-Gamma values with peaks at the top and bottom of the unit.	Regular small increases and decrease in DC with a decreasing trend.	Low to moderate saturation in all three boxes.	No boundary lines present.	674-765
7	Low to moderate response in 1-5MHz. Strong response in the 5-10MHz decreasing towards the base.	Large variations in E-Gamma with large trough towards the bottom of the unit.	Regular small increases and decrease in DC.	Moderate to high saturation in all three boxes.	Two and Three Lines present	765-863

3) Results: Site 2 Zonation



- Between ~450-600m where the high DC (DWI) anomaly is situated, there is also a greater concentration of boundaries and saturation, compared to the adjacent units.
- This DWI anomaly also corresponds with a peak in the 5-10MHz frequency correlation towards the top and base of the high DC zone.
- Similar to Site 1, The most significant E-Gamma trough also corresponds to similar features, with a large peak in the 5-10MHz correlation, higher saturations and a concentration of boundaries.

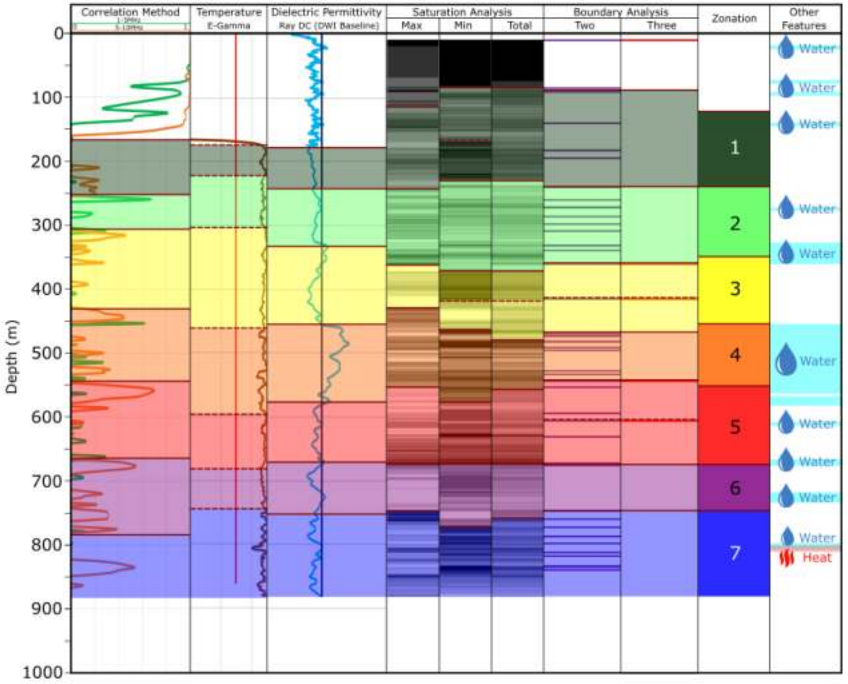
3) Results: Site 2 Zonation



- The zonation method has detected 7 units throughout Site 1 with different geophysical characteristics.
- The primary units of geothermal interest are units 4 and 7.
- Unit 4 hosts the most significant DWI zone that may potentially contain water. This also coincides with a large temperature anomaly from the NN Temperature results.
- Unit 7 also contains the most significant thermal impact zone.

3) **Results:** Site 2 Zonation

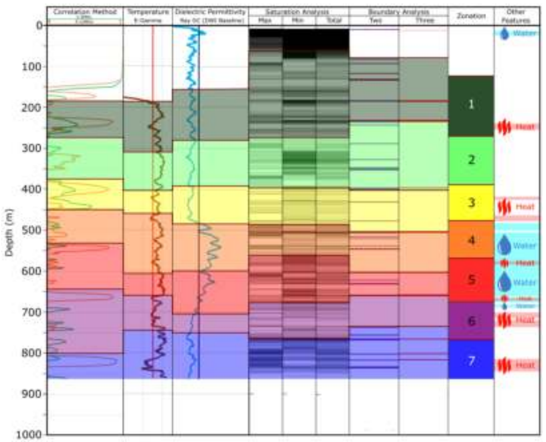
- This table identifies and describes the characteristic signals that each ADR parameter displays within each of the 7 defined units.

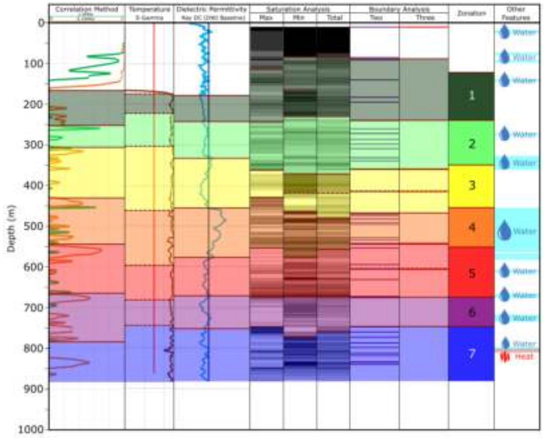


Adrok Unit	Correlation	Temperature (E-Gamma)	Dielectrics (DWI)	Maximum Minimum Boxes	Maximum Minimum Lines	Depth (m)
1	No response from 1-5MHz and consistent low signal in 5-10MHz.	Stepped increase and decrease in E-Gamma.	Slow gradual increase in DC.	High saturation in the Min Boxes and low saturation in the Max Boxes.	Sparse Two Lines boundaries throughout the unit.	122-239
2	No response from 5-10MHz and strong peaks in 1-5MHz.	Consistent E-Gamma signal with flat trend.	Larger jumps in DC with high DC at the base touching the DWI baseline.	No distinct pattern in saturation with ranges of low to medium saturation throughout the unit.	Abundant Two Lines boundaries throughout the unit.	239-349
3	No response from 1-5MHz and consistent peaks in 5-10MHz with signal decreasing towards base.	Smaller variations in E-Gamma signal with slightly higher E-Gamma at the top of the unit.	Large trough in DC bounded by high DC above the DWI baseline.	Max Boxes has low saturation whereas Min Boxes has low saturation at the base and high saturation at the top.	Twi distinct Three Lines boundaries.	349-454
4	Consistent signal response in both frequency ranges, with largest peaks at the top of the unit.	Highly variable E-Gamma throughout the unit with large steps in values.	High DC above the DWI baseline throughout the whole unit, likely to be a water bearing unit.	Generally higher saturation that surrounding units, particularly in the Min Boxes.	Abundant Two Lines boundaries throughout the unit.	454-550
5	Very large peak in 5-10MHz at the top of the unit, followed by minor responses in both frequency ranges.	Flatter trend with less E-Gamma variations, small decrease towards the top of the unit.	Slow decrease in DC with small increases in 10m intervals.	Saturation gradually gets higher towards the base of the unit where it is all in both Max and Min Boxes.	Twi distinct Three Lines boundaries.	550-673
6	Consistent large peaks in 5-10MHz.	Small variations of E-Gamma with shallow increase towards base.	Large step changes in DC.	Generally low saturation bounded by units with higher saturation.	No boundary lines.	673-745
7	No response in 1-5MHz with one large peak in 5-10MHz in the middle of the unit.	Large variations in E-Gamma with large trough in the middle of the unit.	Consistent DC below the DWI baseline with generally flat trend.	High saturation at the top of the unit which decreases towards the base. High saturation more prolonged in the Min Boxes.	Abundant Two Lines boundaries throughout the unit.	745-880

3) Results: Combined Zonation

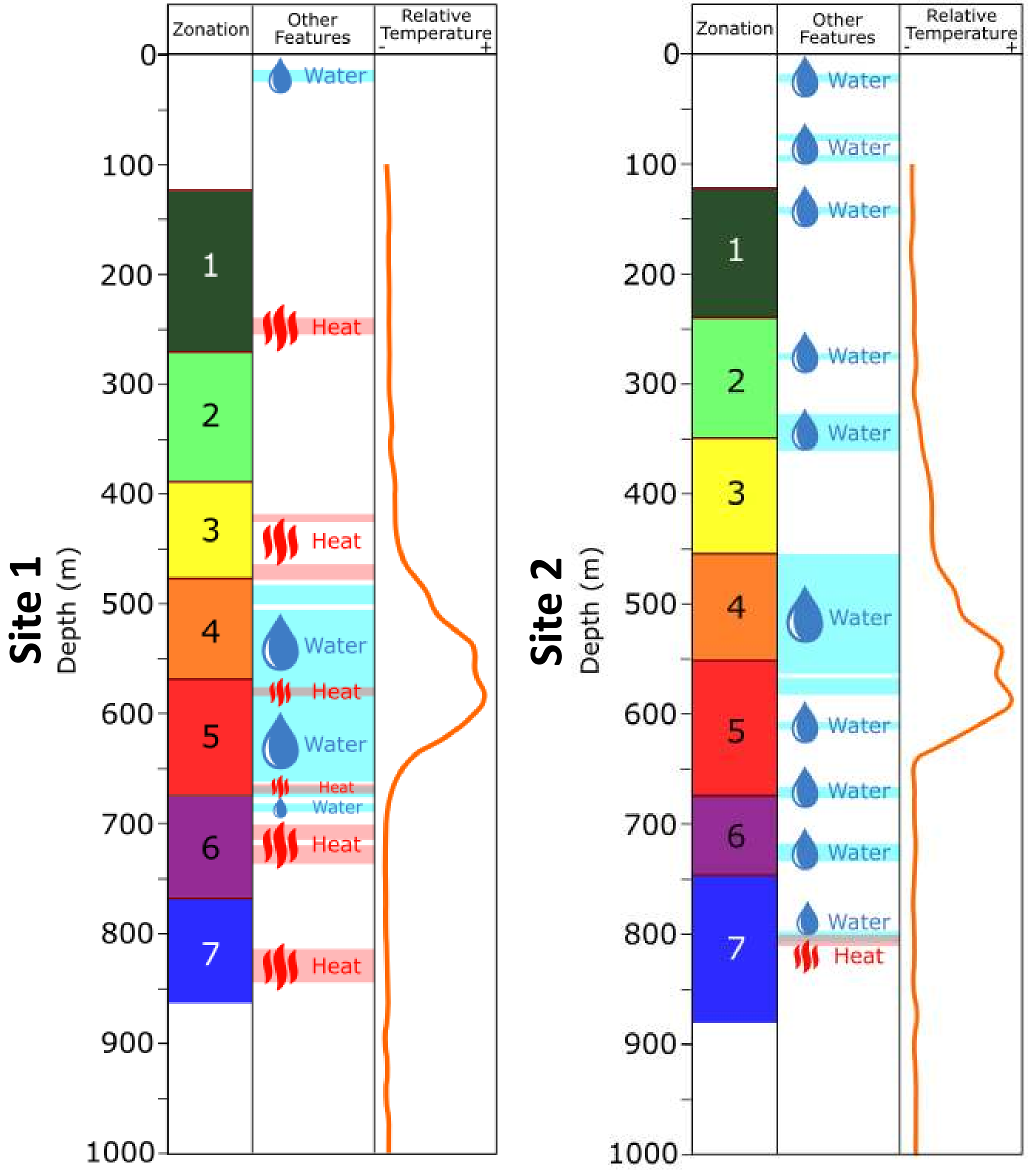
- This table combines and averages the zonation descriptions for each parameter and unit between the two sites.





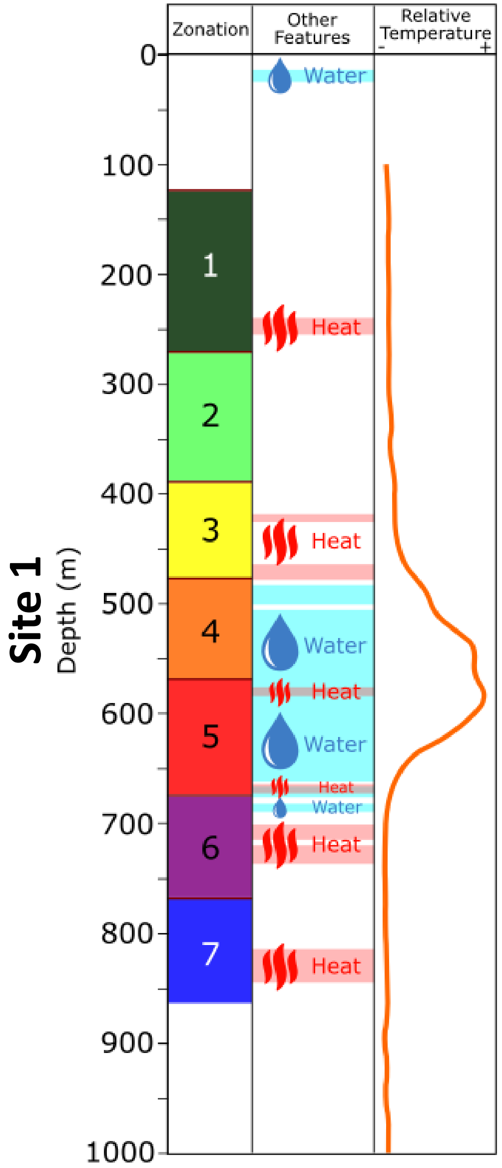
Adrok Unit	Correlation	Temperature (E-Gamma)	Dielectrics (DWI)	Maximum Minimum Boxes	Maximum Minimum Lines
1	Low response from 1-5MHz and dominant response from 5-10MHz.	Large variations in E-Gamma with a large trough in the centre of the unit.	Slow gradual increase in DC.	High saturation in Min Box. Low to moderate saturation in Max and Total Boxes.	Few Two Lines and, contain Three Lines.
2	Mixed response from both frequency ranges.	There is a trend towards higher E-Gamma values.	Regular small increases and decrease in DC.	Low to moderate saturation in all three boxes.	Abundance of Two Lines, no three lines.
3	Moderate response in 1-5MHz. Strong response in the 5-10MHz which decreases towards to the base.	Large variations in E-Gamma with a large trough in the centre of the unit.	Regular small increases and decreases in DC.	Low to moderate saturation in all three boxes with higher saturation in Min Box.	Minimal Two Lines, may contain Three Lines.
4	Consistent signal response in both frequency ranges.	Small troughs near the top and bottom of the unit. High values in between.	High DC above the DWI baseline throughout the whole unit.	Generally higher saturation that surrounding units, particularly in the Min Boxes.	Abundance of Two Lines, no Three Lines.
5	Very large peak in 5-10MHz at the top of the unit, followed by minor responses in both frequency ranges.	There is a trend towards higher E-Gamma values.	Decreasing values from above the DWI baseline to below the DWI baseline	Moderate to high saturation in all three boxes.	Contains both Two Lines and Three Lines.
6	Low to moderate response in 1-5MHz. Strong response in the 5-10MHz decreasing towards the base.	Trend towards lower E-Gamma values with peaks at the top and bottom of the unit.	Regular small increases and decrease in DC with a decreasing trend.	Low to moderate saturation in all three boxes.	No Lines.
7	Low response in 1-5MHz. Strong response in the 5-10MHz.	Large variations in E-Gamma with large trough towards the bottom of the unit.	Consistent DC below the DWI baseline with generally flat trend.	Moderate to high saturation in all three boxes.	Abundance of Two Lines, may contain three lines.

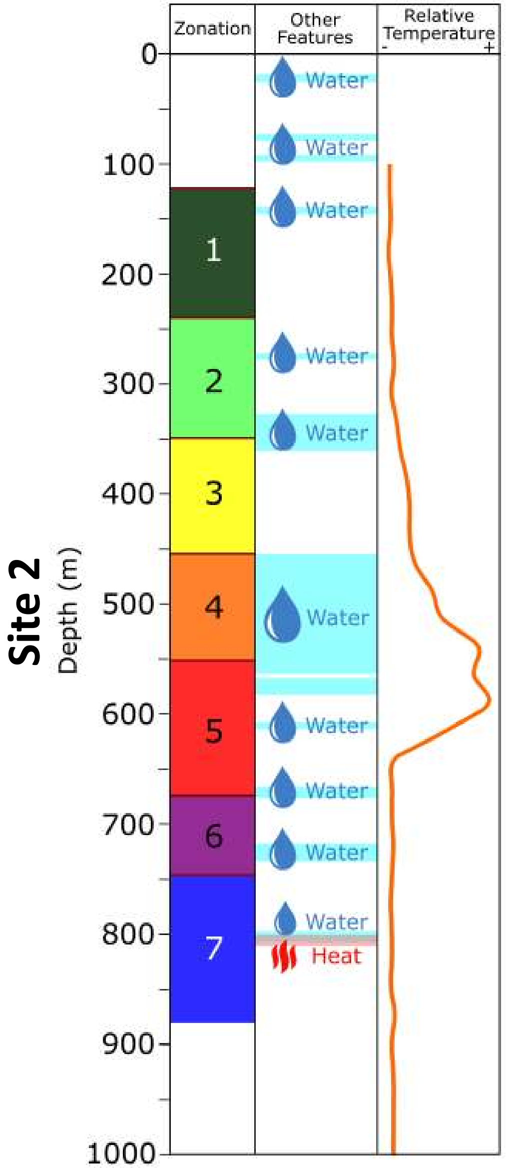
3) Results: Comparisons Between Sites



- There is a strong correlation in the depths of the 7 defined units between Site 1 and Site 2. Many of the units have similar geophysical characteristics between the two sites across the parameters used in the zonation method.
- Site 1 appears to have greater potential for thermal impact with many significant E-Gamma troughs throughout the scan, whereas Site 2 has a much lower thermal impact, with no E-Gamma troughs below the calculated threshold.
- There is, however, a good correlation in the depths of the most significant thermal impact zone in both of the sites, between 800-850m in Unit 7.
- There is a strong correlation between the two sites in regards to the most significant DWI target, with both sites showing high DC anomalies between 450-650m depth.
- Also in both scans at these depths (450-600m), the most significant DWI target coincides with a large high temperature anomaly in the NN temperature results.
- This combined DWI and NN Temperature target is situated within Unit 4 for both sites, and partly within Unit 5, making this a primary geothermal target.

3) **Results:** Most Relevant Units





- The most relevant units in relation to geothermal potential are Units 4, 5 and 7.
- Units 4 and 5 comprise of the most significant DWI target, with high DC for up to 200m across the two units. This DWI target is present throughout most of Unit 5 in Site 1, whereas it is only partially present in Unit 5 in Site 2.
- At the same depths in both sites, the high temperature anomaly in the NN Temperature results hugely increases the geothermal potential in these units.
- There are also some medium-high thermal impact zones within Units 4 and 5 in Site 1, particularly situated towards the base of each unit. This means that the most significant depth for this target is the base of Unit 4, at ~550m.
- Unit 7 hosts the most significant thermal impact zones in both Sites, particularly in Site 1, where the thermal impact is high. There are no DWI targets in Unit 7 in Site 1, although there is a minor DWI in Unit 7 in Site 2.

Unit 4 (& Unit 5)

Relevant due to the DWI and NN Temp. targets

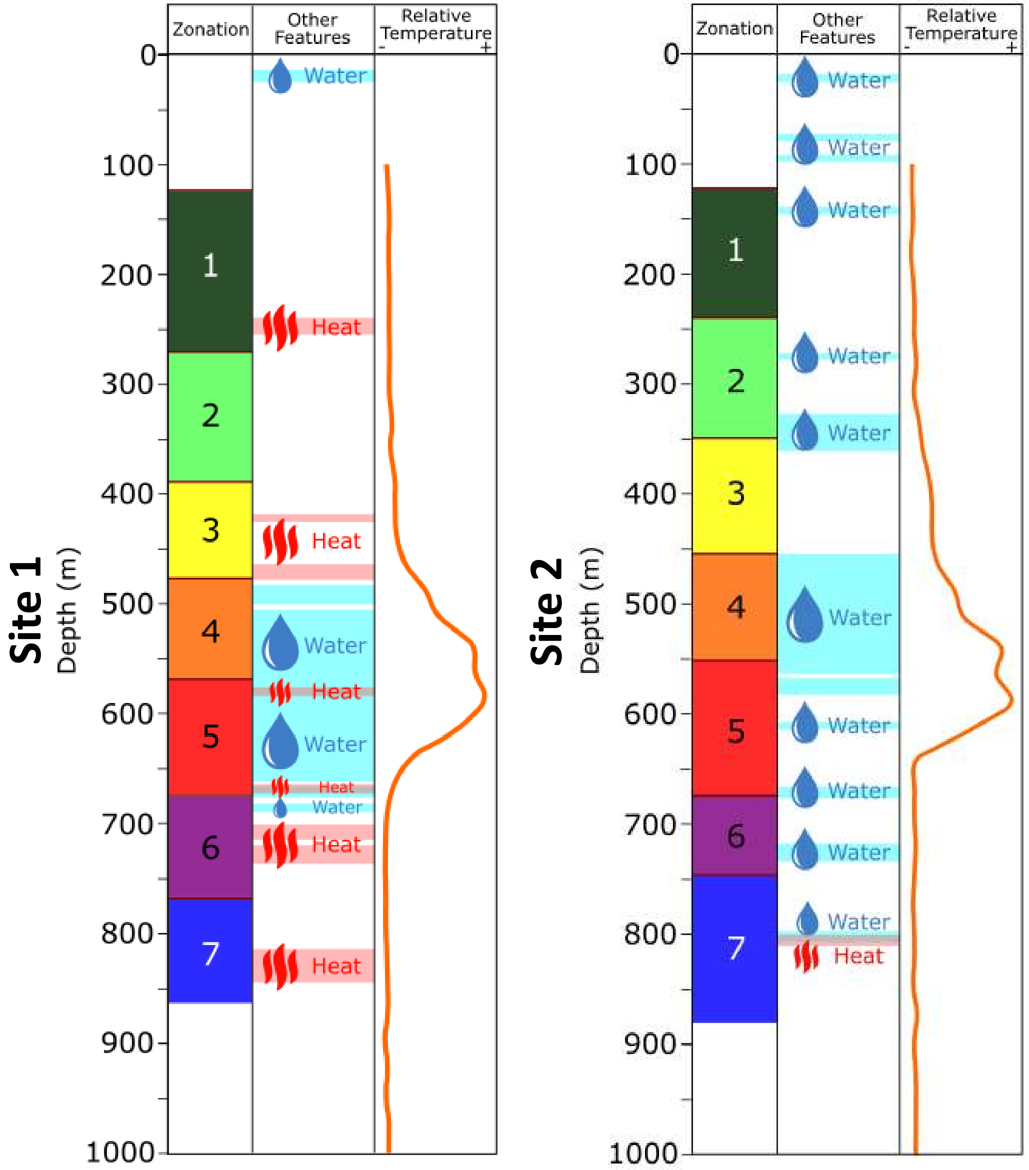
- High DC (DWI)
- High Temperature (NN)
- High Saturation
- Concentration of Boundaries
- Strong peak in 5-10MHz correlation

Unit 7

Relevant due to the high thermal impact zone

- High Thermal Impact
- High Saturation
- Concentration of Boundaries
- Strong peak in 5-10MHz correlation

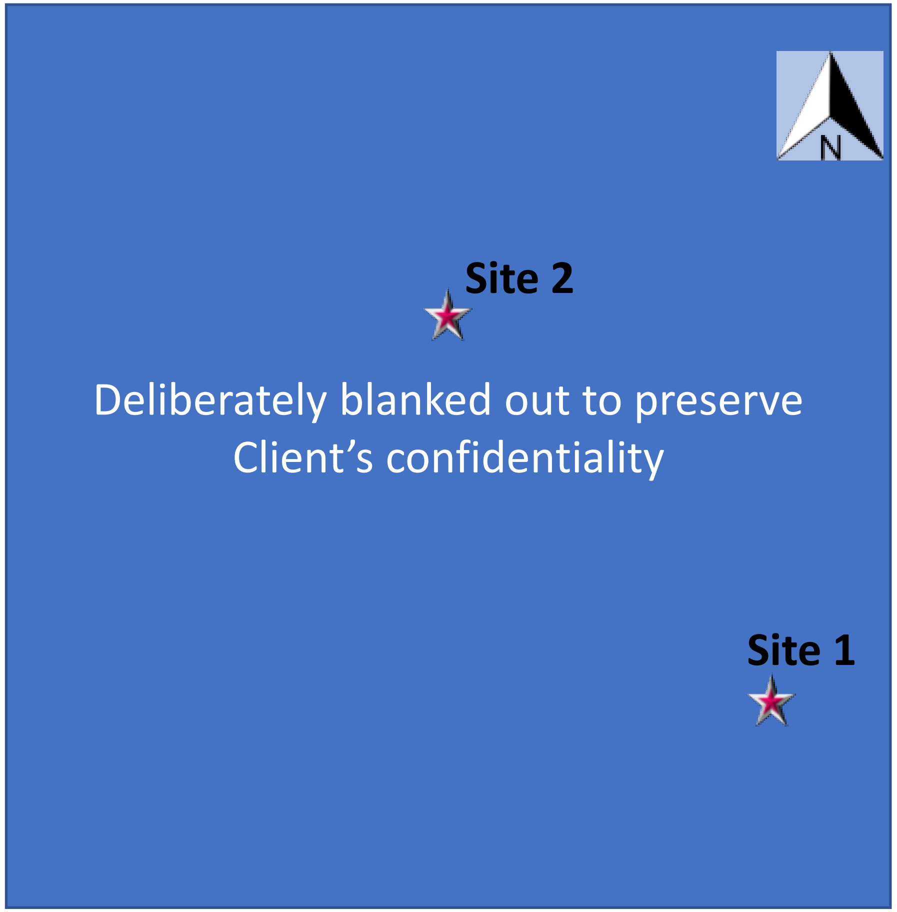
4) Discussion: Tying ADR Units to Lithology



- For this project, it is difficult to directly identify lithologies and formations, due to the lack of training data and deep boreholes in the region. Instead, we must rely on the surface bedrock geology, as well as Adrok's understanding of how ADR responds to different lithologies.
- The main lithological assumption that can be made is Units 4 and 5 are likely to consist of high-porosity lithologies, due to the high DC, which is potentially caused by the presence of water.
- This would correspond well with the known geology of the area, as it is known that highly porous sandstones from the Old Red Sandstone Supergroup are present throughout the NE Scotland area.
- When we take site elevation into account (Site 1 elevation is ~6m greater than Site 2), the boundaries between each of the defined units are roughly level, despite the 2.8km distance between the two sites.
- With the general geological trend dipping shallowly towards the west/north-west, we would potentially expect Site 2 to have a deeper offset. An explanation for this could be that the two sites are situated along the strike of the structure, hence, we don't see this west-dipping structure between Sites 1 and 2.

4) Discussion: Geothermal Potential

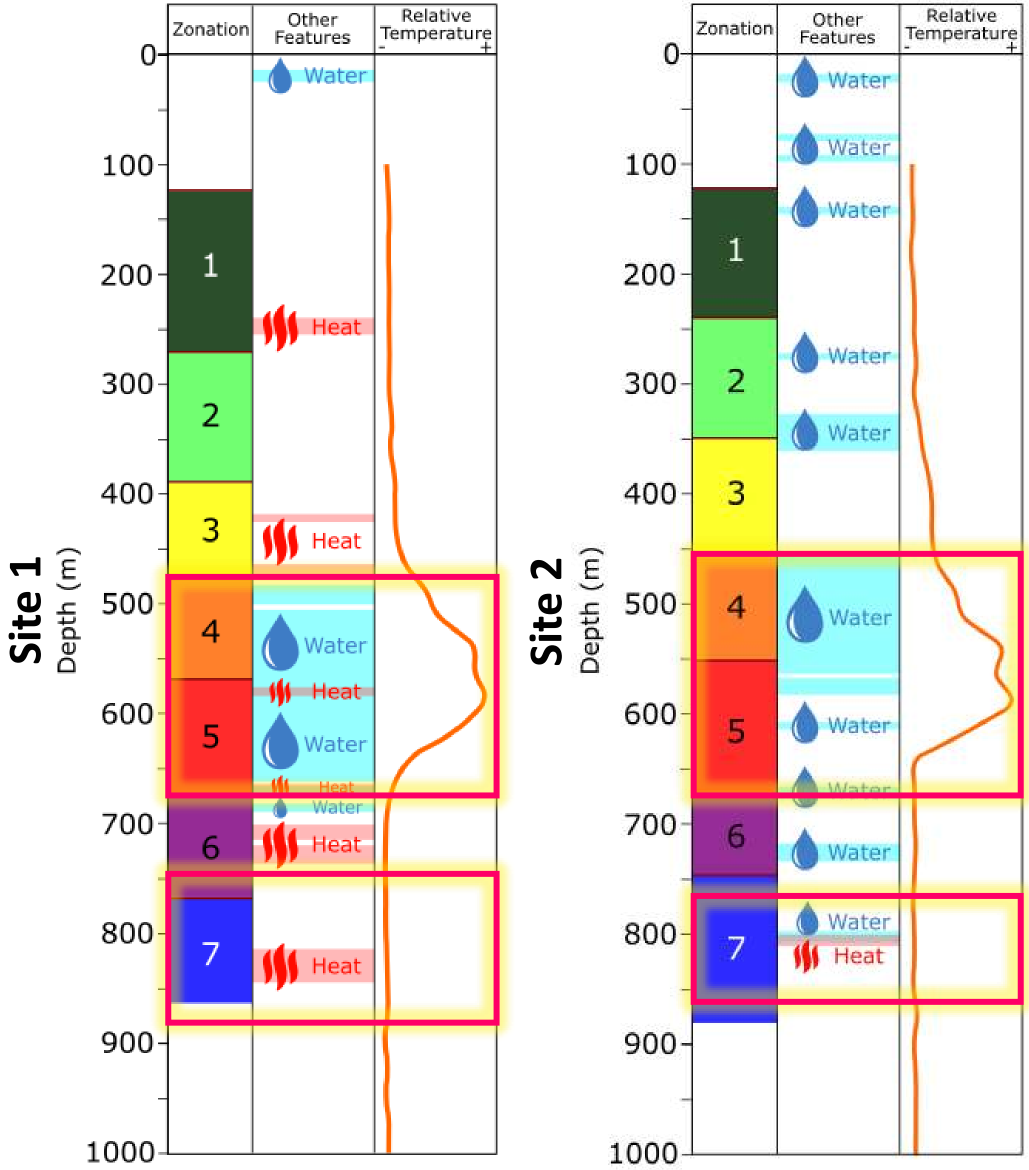
- One of the best lithologies for hosting sedimentary aquifers are sandstones. Both sites in this survey are in localities with sandstone bedrock. Site 1 is situated above the NE Scotland Sandstone Formation and Site 2 is situated above the Kingsteps Sandstone Formation.
- The NE Scotland and Hopeman Sandstones are part of the New Red Sandstone Supergroup, whereas the Kingsteps Sandstone is part of the Old Red Sandstone Supergroup.
- Both of these supergroups are known to have high to very high permeability and high thermal conductivity throughout Scotland (Gillespie *et al*., 2013). This provides an ideal situation for the presence of a sedimentary aquifer.
- This would provide an ideal scenario for a low enthalpy geothermal system within a hot sedimentary aquifer. The combination of a significant DWI target with a high temperature (NN) anomaly in Units 4 and 5 could potentially host a geothermal system of this description. Water could be present within these units that we have interpreted to be high porosity sandstones from the Old Red Sandstone Supergroup.
- A petrothermal system could also be a target if there is a presence of hot dry rocks, however, due to the shallow targets for this project, this may be unlikely. However, Unit 7 could have the potential to host this geothermal system due to the presence of high thermal impact zones in seemingly "dry" rocks.



Map from BGS (https://mapapps.bgs.ac.uk/geologyofbritain/home.html)

Gillespie, M.R., Crane, E.J. and Barron, H.F., 2013. Study into the potential for deep geothermal energy in Scotland. www.scotland.gov.uk/Resource/0043/00437996. pdf: AECOM Energy/The Scottish Government.

5) Conclusions: Geothermal Potential



- The target depths for this geothermal investigation are <1000m, therefore, we would be targeting a low enthalpy (low temperature) resource, which would exploit warm water in the shallow subsurface to provide heat either directly as warm water, or indirectly via heat exchange systems (Gillespie *et al.*, 2013).
- The likely geological setting for this low enthalpy geothermal system would be hot sedimentary aquifers (HSA) and would also be defined as a hydrothermal system.
- Units 4 and 5 are the primary targets as hot sedimentary aquifers, with significant DWI targets in these units in both sites. These DWI targets coincide almost perfectly with the high temperature anomalies from the NN Temperature results.
  - Unit 4 occupies depths of 476-568m in Site 1 and 454-550m in Site 2.
  - Unit 5 occupies depths of 568-674m in Site 1 and 550-673m in Site 2.
- The high DC anomalies in these unit would suggest a presence of water, which would indicate high porosity lithologies. We can use these results to assume the presence of either the New Red Sandstone or Old Red Sandstone at these depths.
- Unit 7 is the secondary geothermal target in the NE Scotland area. The presence of significant thermal impact zones, with relatively low DC, could signify the presence of a hot dry rocks geothermal system.

5) Conclusions: Summary of Findings

- Adrok has found indications of the presence of a low enthalpy geothermal system in the NE Scotland region, in the form of a hot sedimentary aquifer. The high DC anomaly (DWI), combined with the high temperature anomaly from the NN Temperature results in Units 4 and 5 for both sites indicates the presence of heated water within a high-porosity sandstone. We have high-confidence in this target due to the consistency of ADR signals between both Sites 1 and 2.
- Adrok has also identifies a low-confidence geothermal target in Unit 7. The high thermal impact zones in both sites suggest that there is a possibility of a hot dry rocks geothermal system.
- The economic implications for these findings are that a confirmed geothermal resource in NE Scotland could provide a home-grown, low-carbon and green alternative to Scotland’s heat and energy generation.
- Adrok could provide more insights into the geothermal potential of the NE Scotland area if a more extensive ADR survey was completed, to allow the extents, depths, temperature and aquifer potential of our geothermal targets to be further constrained.

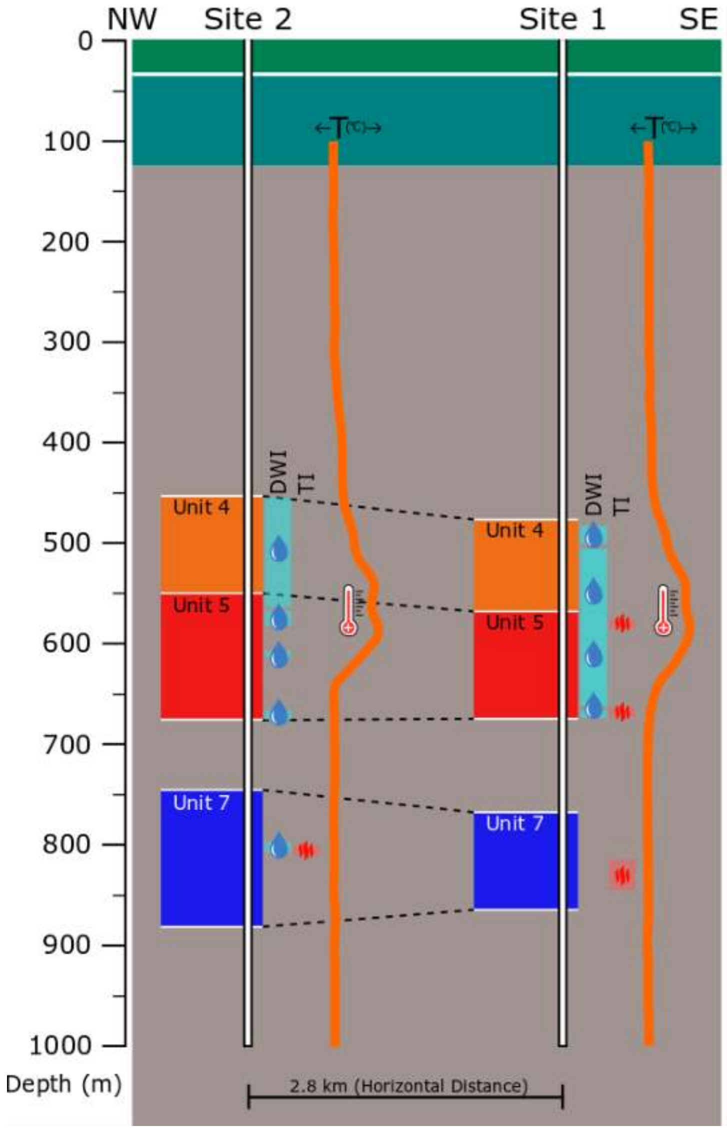


Figure: T = Temperature, DWI = Direct Water Indicator, TI = Thermal Impact