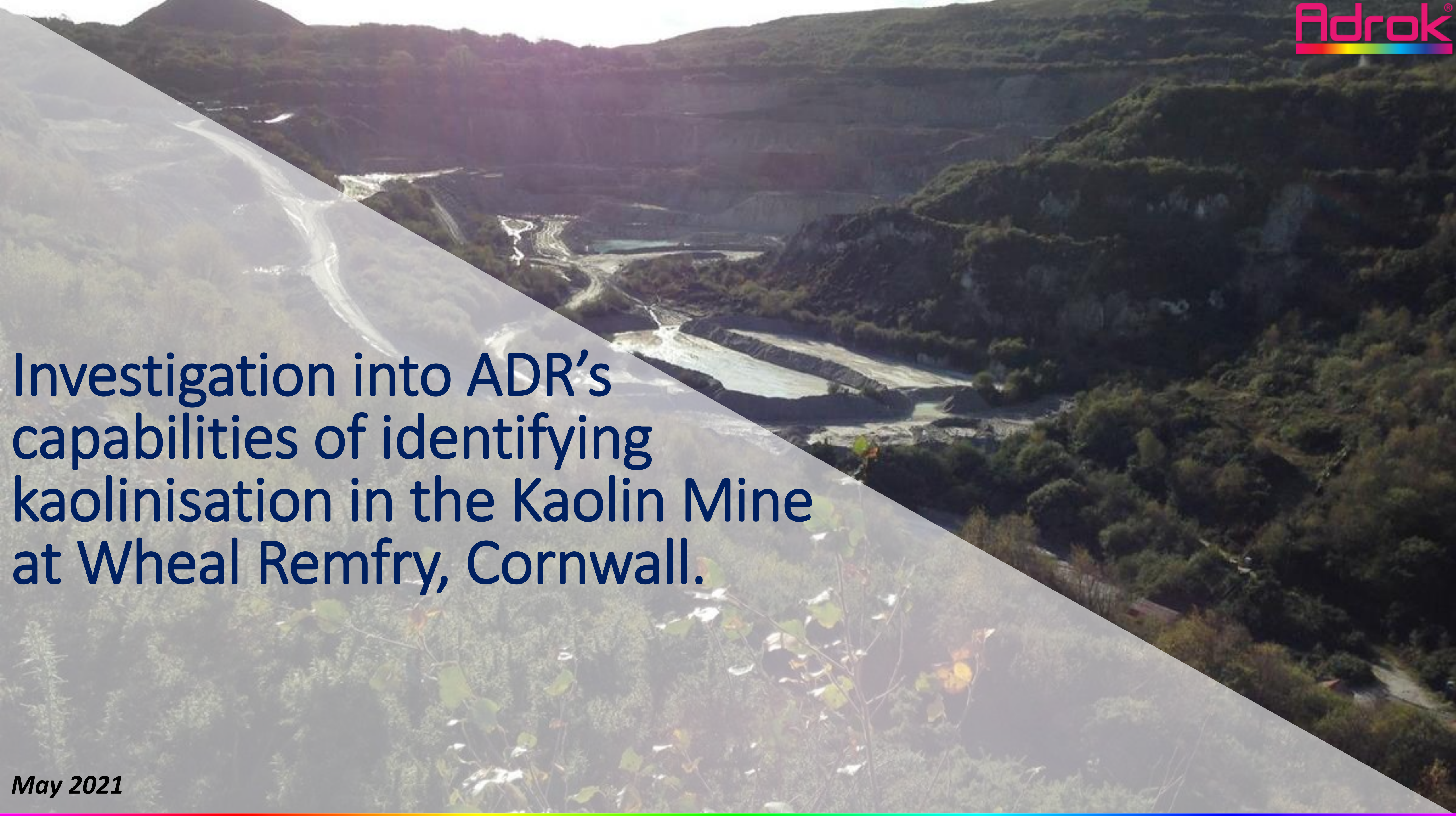
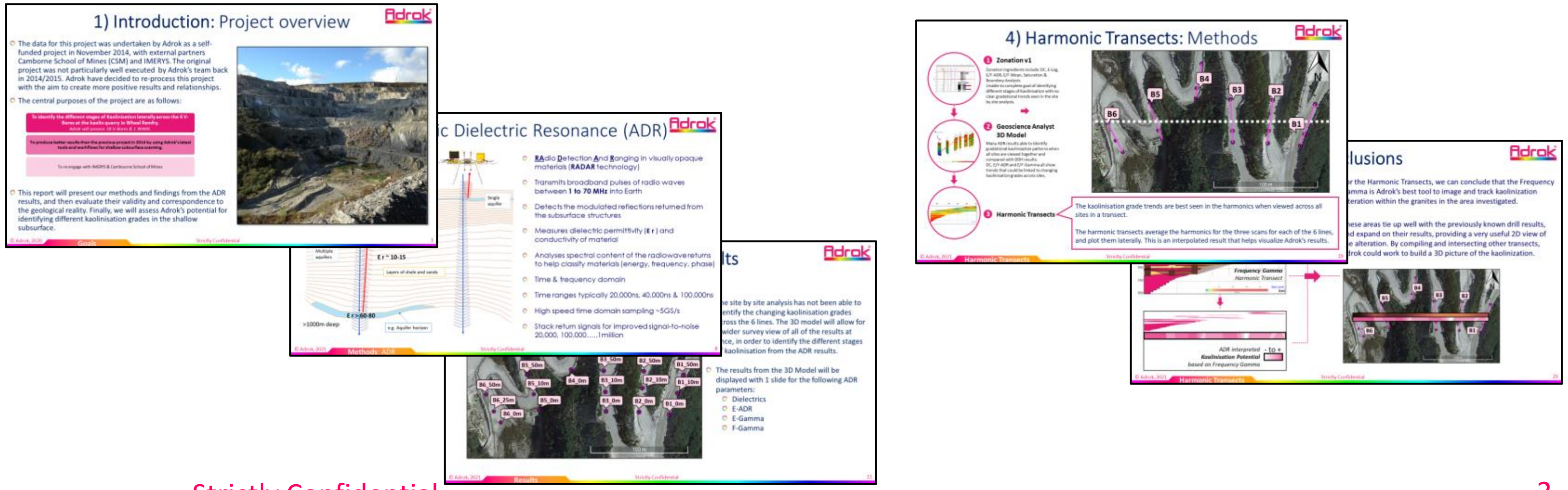


Investigation into ADR's capabilities of identifying kaolinisation in the Kaolin Mine at Wheal Remfry, Cornwall.

May 2021

Index



1) Introduction: Project overview
4) Harmonic Transects: Methods

1) **Introduction:** Project overview

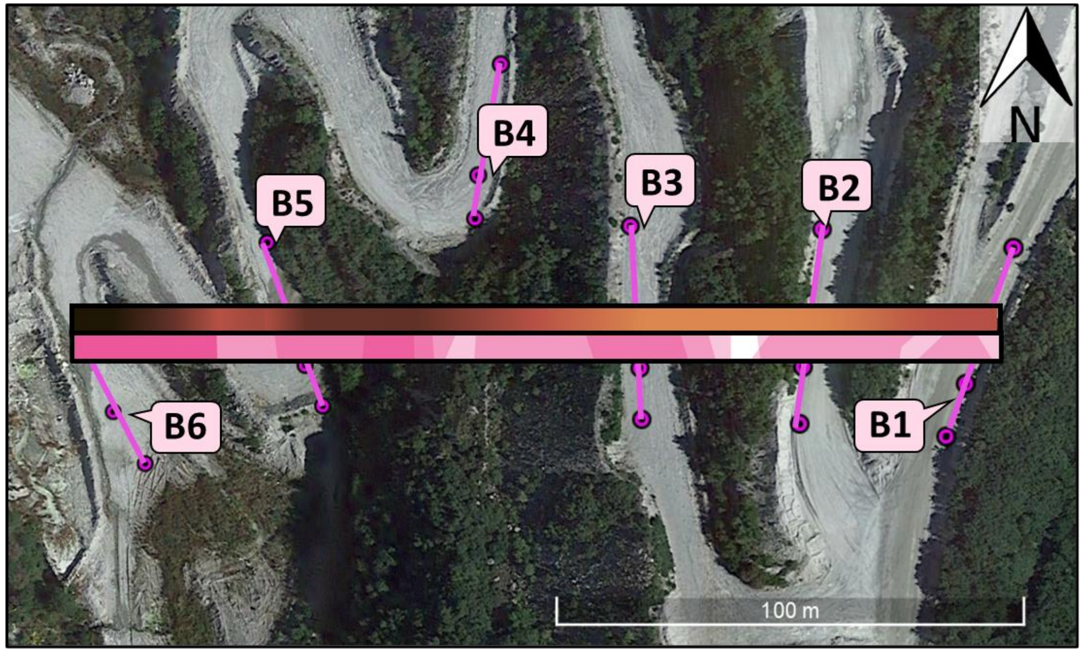
- The data for this project was collected by Adrok as a self-funded project in November 2014, with access help from the Camborne School of Mines (CSM) and IMERYS. Since then, Adrok have greatly developed its tools and techniques and decided to re-process this project with the aim to improve past results.
- The central purposes of the project are as follows:

To identify the different stages of Kaolinisation laterally across the 6 Virtual Boreholes ("V-Bores") at the kaolin quarry in Wheal Remfry.
Adrok will process 18 V-Bores & 1 WARR.

To produce better results than the previous project in 2014 by using Adrok's latest tools and workflows for shallow subsurface scanning.

- This report will present our methods and findings from the ADR results, and then evaluate their validity and correspondence to the geological reality.
- Finally, we will assess Adrok's potential for identifying different kaolinisation grades in the shallow subsurface.

1) Introduction: Executive Summary



Legend:

- to + *ADR interpreted* ***Kaolinisation Potential*** *based on Frequency-Gamma*

1 to 6 *Data on* ***Kaolinisation Grade*** *based on sonic drill logs*

- In March/April 2021, Adrok re-processed data collected back in November 2014 and completed a targeting exercise for identifying different stages of kaolinisation laterally across the kaolin quarry in Wheal Remfry.
- Adrok are confident that the results produced in this report are of greater accuracy and quality than those that were delivered in 2015.
- Interpretations of the kaolinisation grades have been made using Harmonic Analysis of the ADR signal.
- These harmonic signals have been interpolated into an East-West transect across the survey area, with the Frequency-Gamma harmonic chosen as Adrok's best tool to image and track kaolinization alteration within the area investigated.
- The ADR results and interpretations tie up well with the known kaolinisation grades from sonic drill logs.
- The general trend shows an increasing kaolinisation grade from B2 to B6, and a slight increase from B2 to B1. This is highlighted well by the F-Gamma results in the Harmonics Transect.
- Adrok's results are able to provide a very useful 2D view of the alteration. By compiling and intersecting other transects, Adrok could work to build a 3D picture of the kaolinization.

1) Introduction: Adrok Glossary

Term	Definition
ADR	Atomic Dielectric Resonance.
E-ADR	The basic measure of Energy Resonance of the signal returns through each stratigraphic layer.
E-Gamma	The basic measure of Energy Reflectivity.
E-Log	During a stationary scan ("Stare" scan) the ADR transmitter and receiver antennas are positioned at known grid co-ordinates and aimed downward. The energy log ("E-log") indicator is produced by dividing the Stare scan image data in time windows. Windowing is carried out in equal time intervals or the time axis is migrated to depth after our WARR tracking of dielectric and windowing is performed equal spatial intervals. The data windows are subsequently analysed and/or enhanced utilizing a suite of signal and image processing techniques such as Fourier analysis, wavelet decomposition, and image enhancement algorithms using RADAMATIC, Adrok's proprietary data analysis software. Amongst other indicators, this analysis produces the E-Logs which represent estimated energy values as a function of depth and were found to be excellent indicators. They are usually plotted on a logarithmic scale.
F-Gamma	The basic measure of Frequency Reflectivity.
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.
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:** Geological Background

- Kaolinised regions of the granite batholith in Cornwall have been exploited for china clay both in the past and in the present day, predominantly in the centrally positioned St Austell granite (Fig. 1).
- In Wheal Remfry, the granite has undergone kaolinisation due to a combination of hydrothermal and low-temperature weathering processes. The feldspars and micas within the granite are replaced and altered into kaolin, otherwise known as china clay.
- The degree of kaolinisation has a drastic effect on the required design of open pit slopes, with overall slope angles in highly kaolinised zones, which behave as soil-like material, being as low as 25 degrees whereas individual benches can be near vertical in poorly kaolinised granite in which failure is controlled by the discontinuities (joints).
- Graduations between these two extremes of rock type encountered (Fig. 2) are subject to different modes of failure requiring both continuum and discontinuum numerical modelling to determine factors of safety.

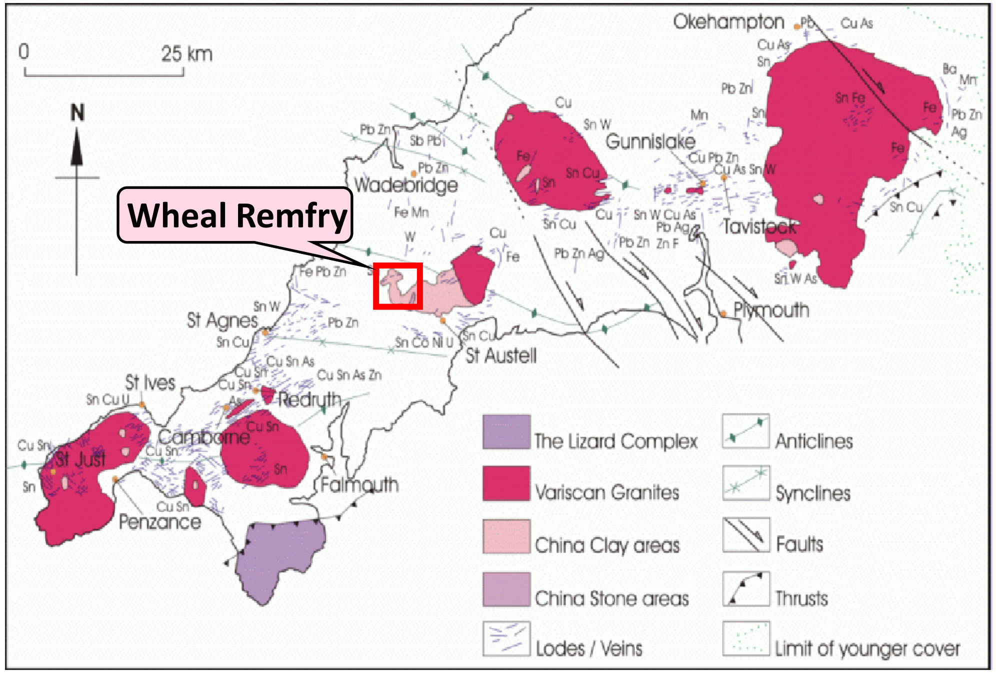


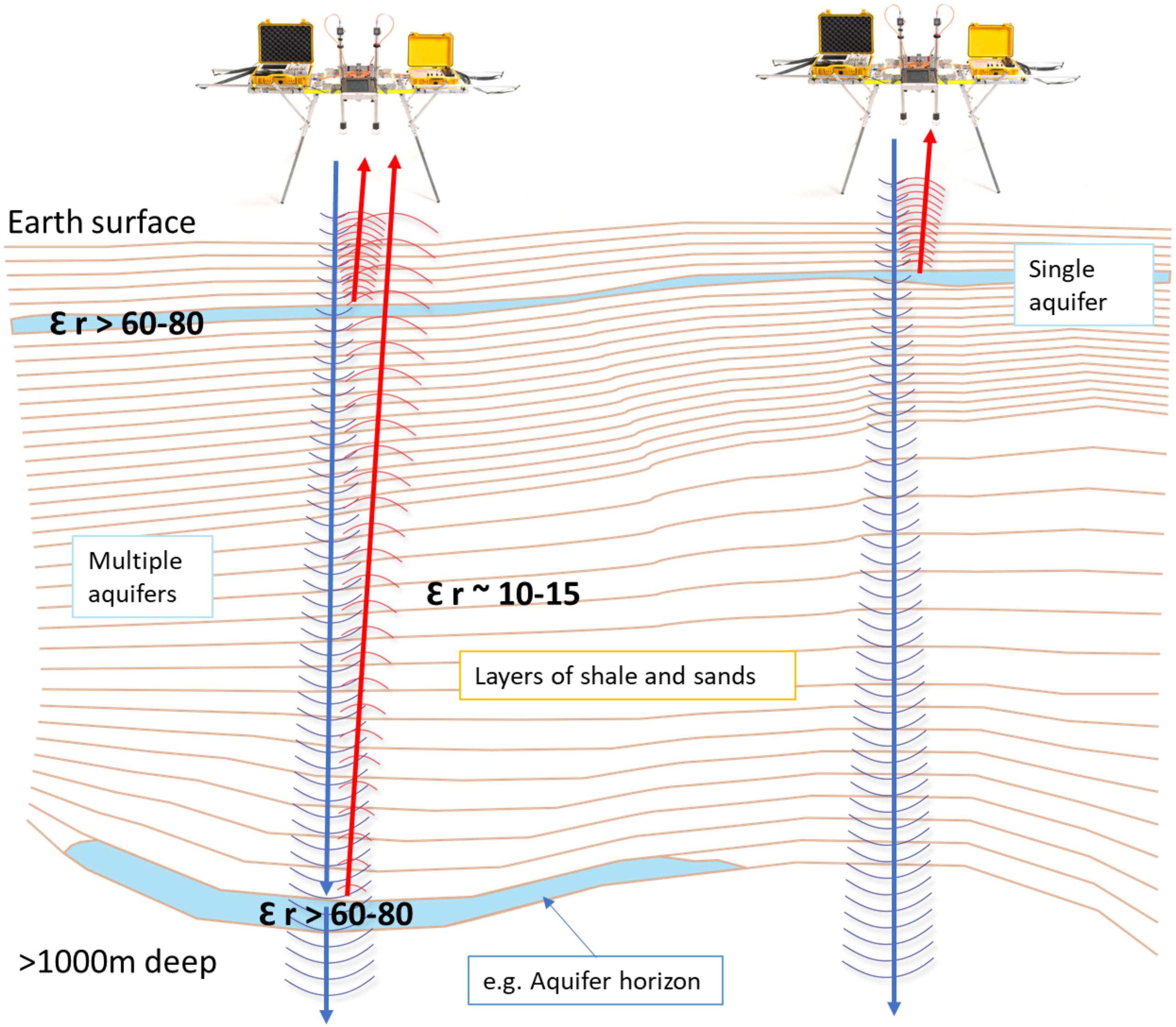
Figure 1: Map of Cornwall indicating the granite batholith exposures (after Dunham et al.).

Figure 2: Examples of poorly kaolinized (left) and highly kaolinised (right) granite slopes.

1) Introduction: Survey Location

- The survey is located in the Wheal Remfry open-pit mine, in Cornwall, UK. The mine is located in between Newquay and St Austell.

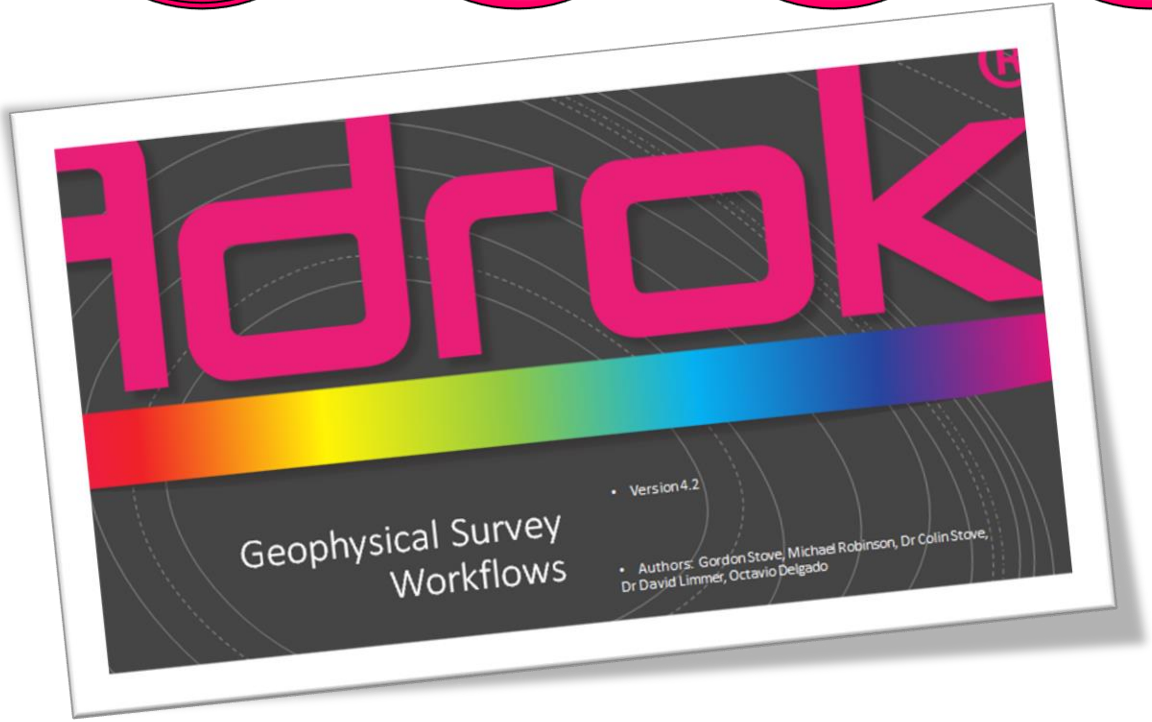
2) **Methods:** Atomic Dielectric Resonance (ADR)



- **RA**dio **D**etection **A**nd **R**anging in visually opaque materials (**RADAR** technology)
- Transmits broadband pulses of radio waves between **1 to 70 MHz** into Earth
- Detects the modulated reflections returned from the subsurface structures
- Measures dielectric permittivity (**Ɛ r**) and conductivity of material
- Analyses spectral content of the radiowave 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: Stage-gated Workflows

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



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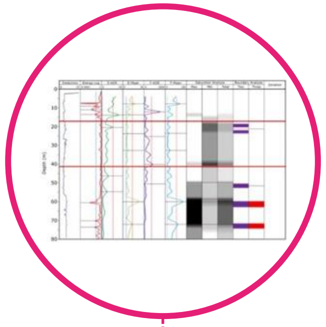
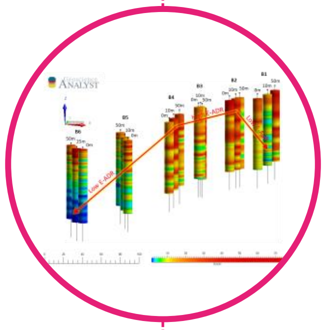
2) Methods: Analysis Flow Chart



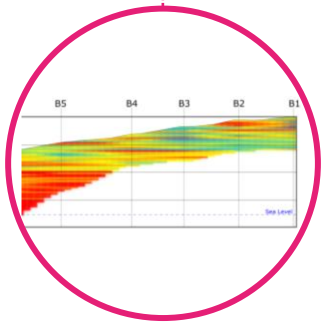
1 **Processing**

Raw data processed to produce full suite of ADR results. Firstly, data is viewed on a site by site basis.
The site by site analysis was unable to complete goal of identifying different stages of Kaolinisation.



2 **Geoscience Analyst 3D Model**

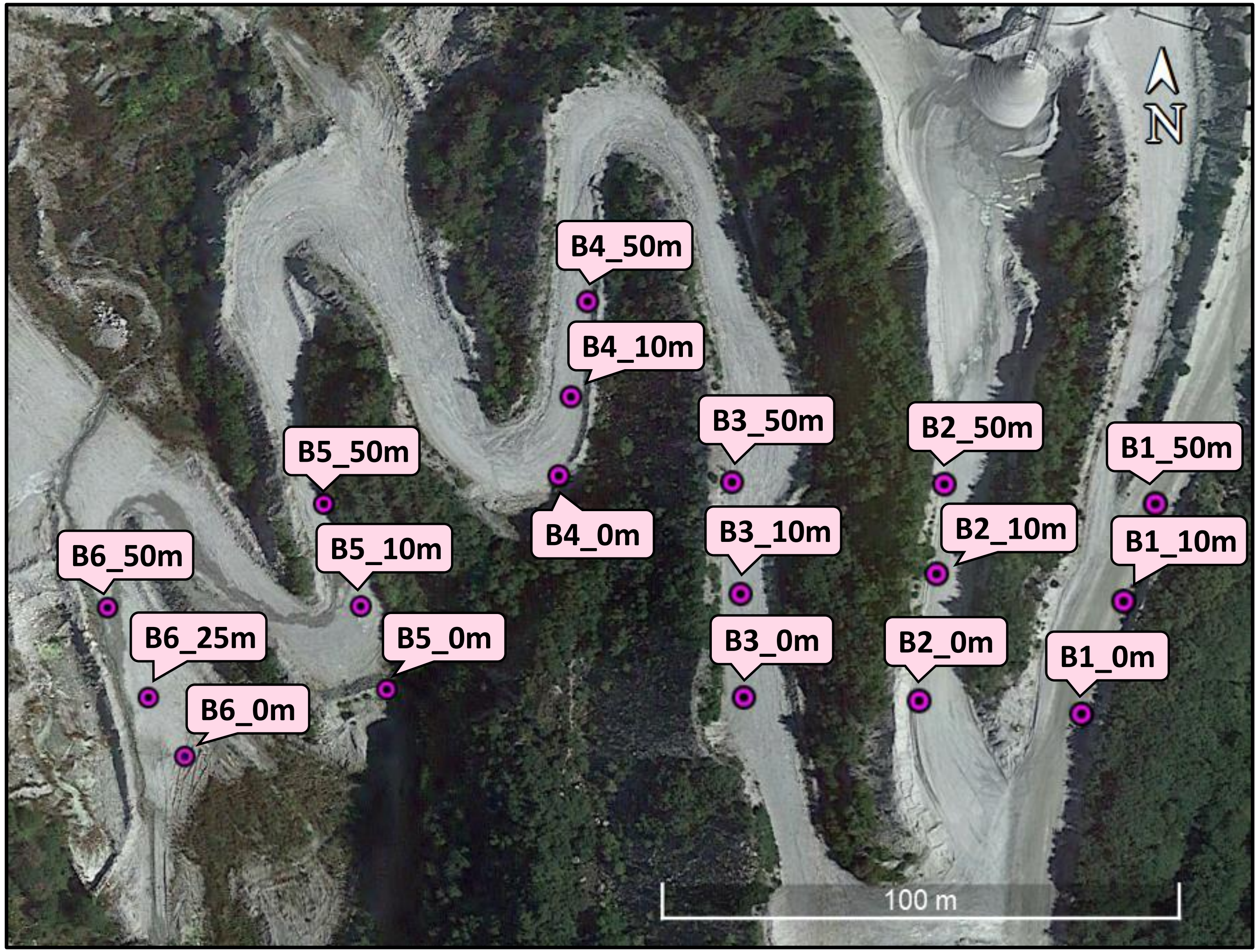
Many ADR results able to identify gradational kaolinisation patterns when all sites are viewed together and compared with DDH results.
DC, E/F-ADR and E/F-Gamma all show trends that could be linked to changing kaolinisation grades across sites.



3 **Harmonic Transects**

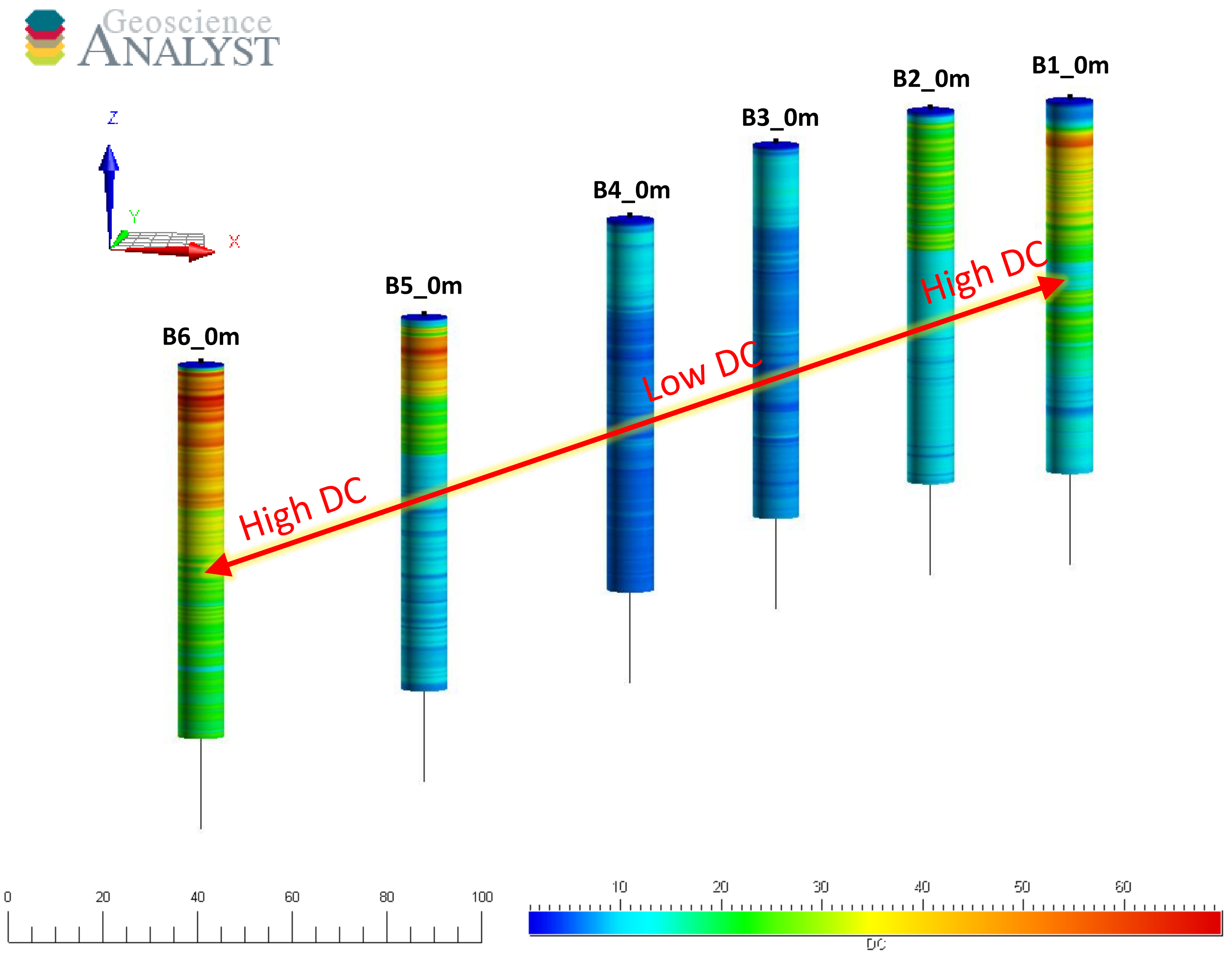
The kaolinisation grade trends are best seen in the harmonics when viewed across all sites.
The harmonic transects average the harmonics for the three scans for each of the 6 lines, and plot them laterally.
E/F-ADR and E/F-Gamma show correlative trends with the kaolinisation trends seen in the DDH results.

3) 3D Model Results



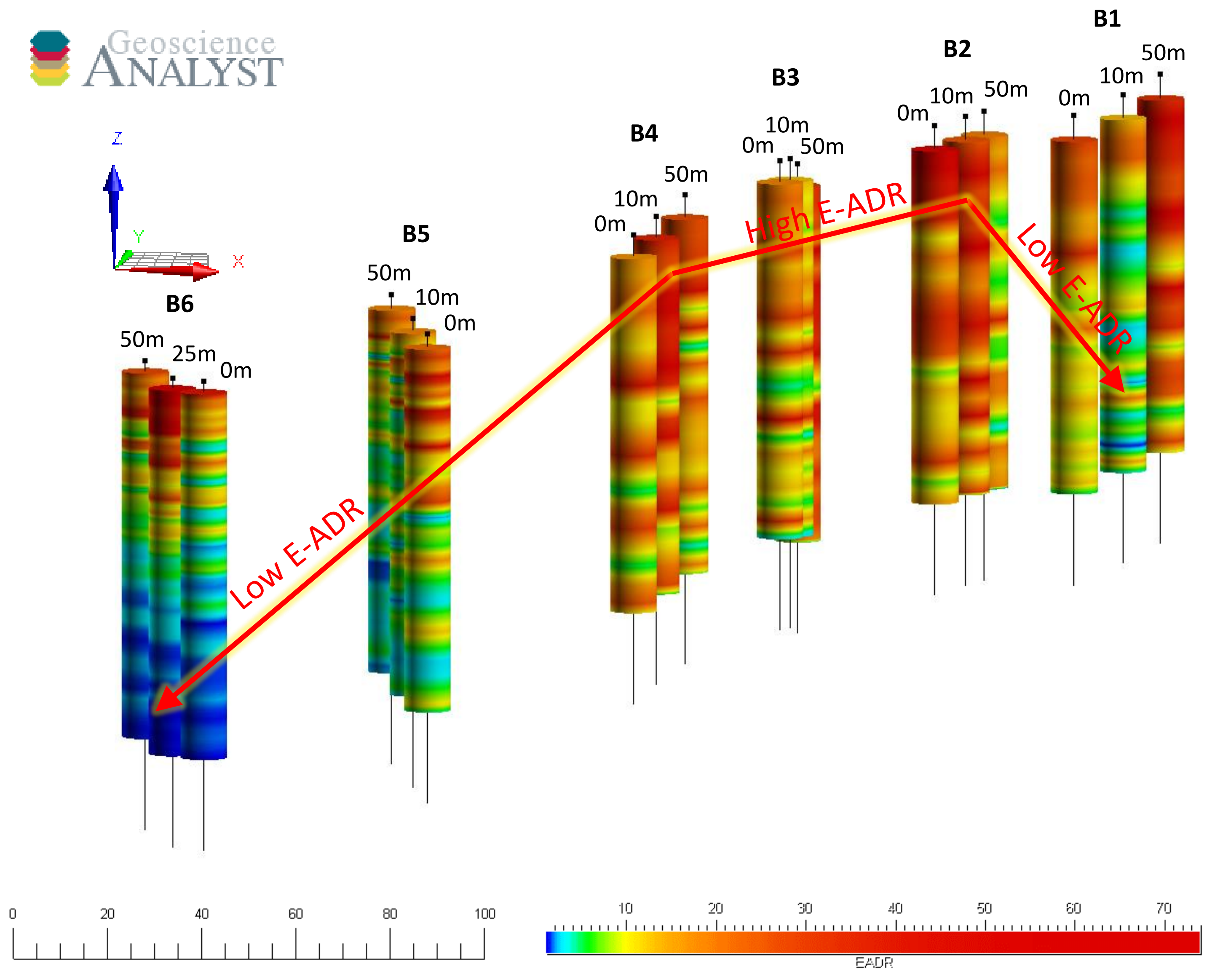
- Many ADR results able to identify gradational kaolinisation patterns when all sites are viewed together and compared with DDH results. DC, E/F-ADR and E/F-Gamma all show trends that could be linked to changing kaolinisation grades across sites.
- The site by site analysis has not been able to identify the changing kaolinisation grades across the 6 lines. The 3D model will allow for a wider survey view of all of the results at once, in order to identify the different stages of kaolinisation from the ADR results.
- The results from the 3D Model will be displayed with 1 slide for the following ADR parameters:
  - Dielectrics
  - E-ADR
  - E-Gamma
  - F-Gamma

3) 3D Model Results: Dielectrics



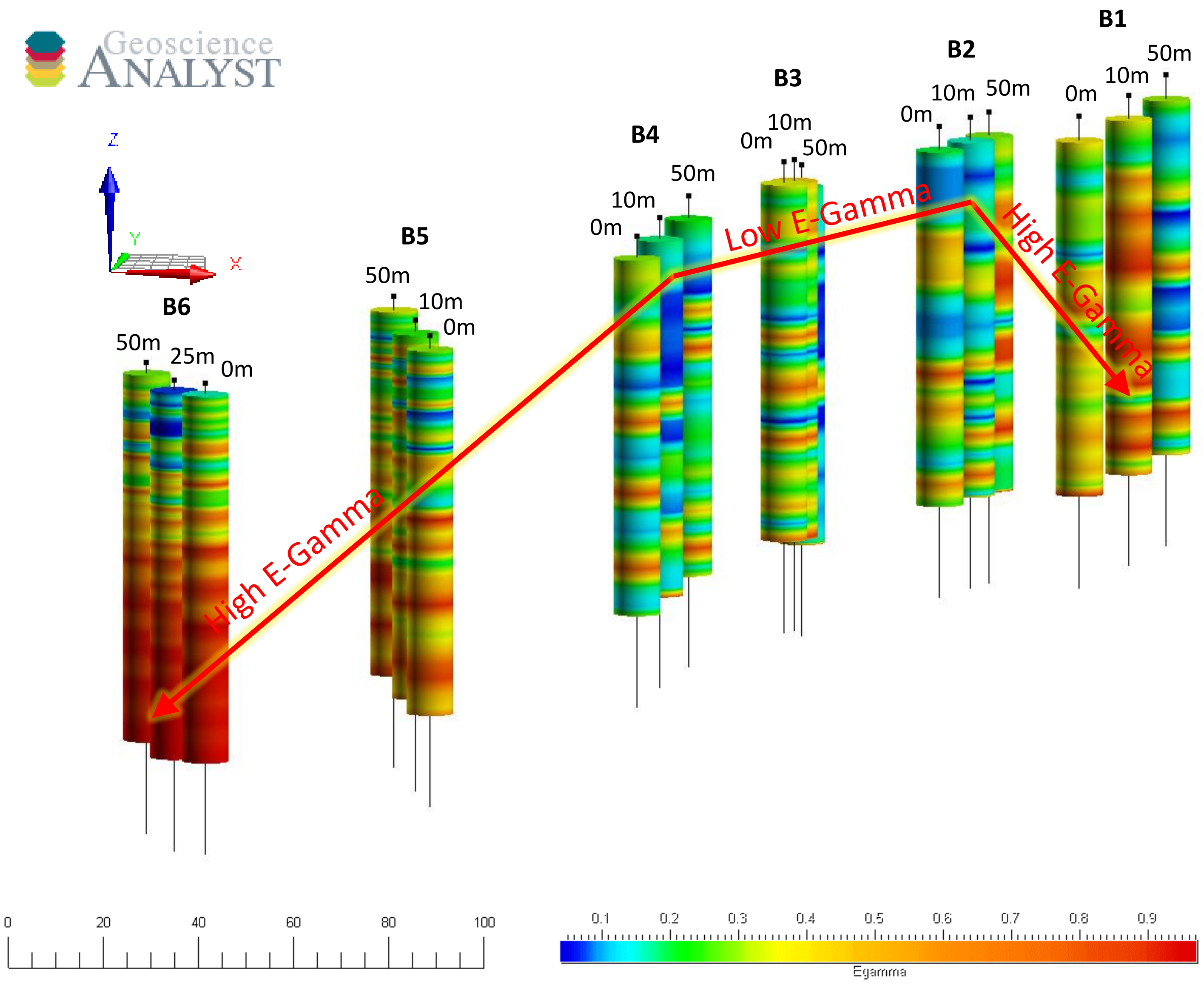
- Dielectric Permittivity increases outwards from B3 and B4 towards B1 and B4, respectively.
- Higher dielectrics seen in B2 and B1 are likely a result of groundwater from the nearby river.
- The highest dielectrics in B5 and B6 are likely a result of local groundwater below the water table, and the low temperature hydrothermal fluids that have caused the high kaolinisation.

3) 3D Model Results: E-ADR



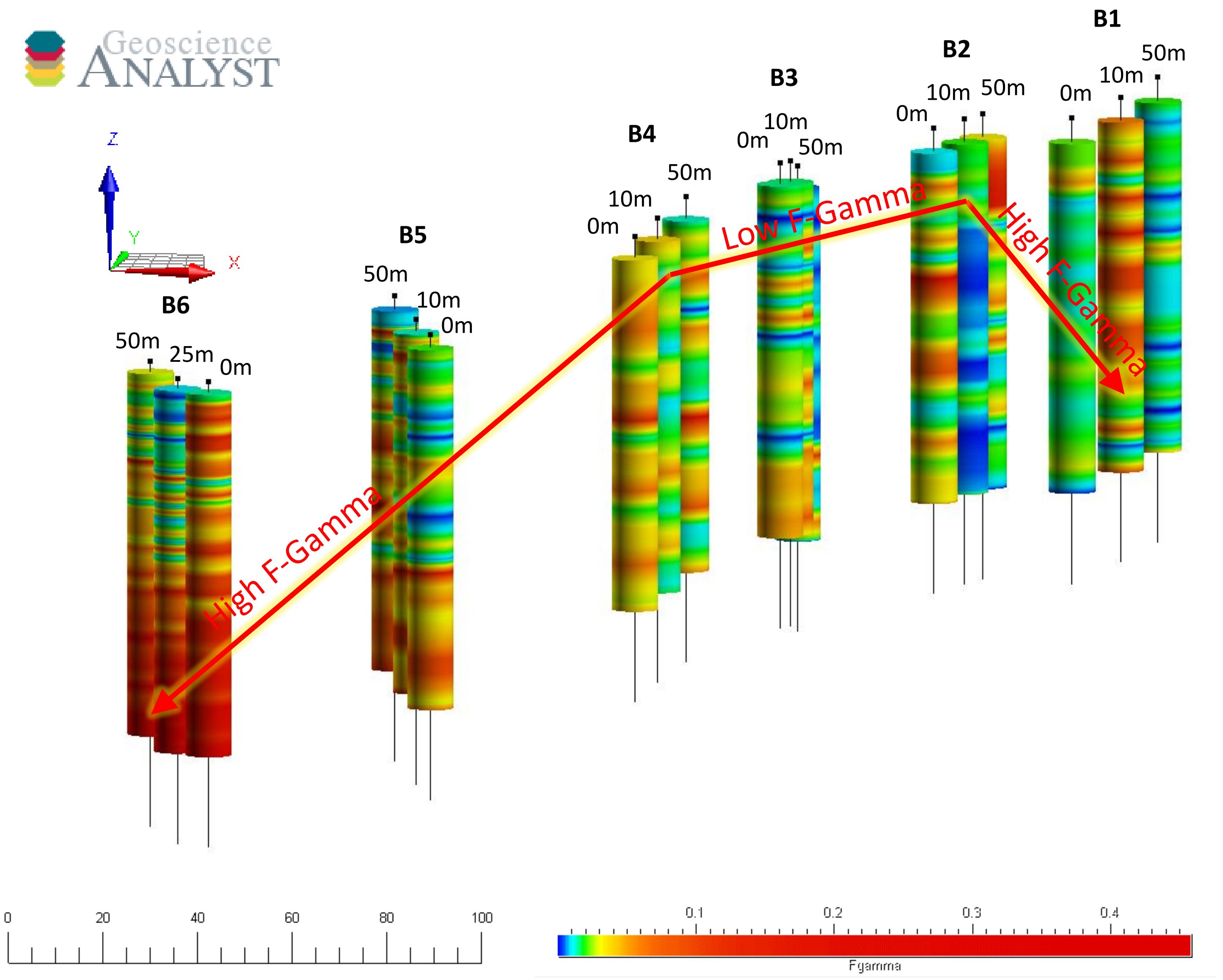
- Most of the E-ADR logs decrease down-hole.
- B2, B3 and B4 displays the highest E-ADR values throughout the full 80m, however, these values drop off progressively faster towards the bottom of the scans towards B5 and B6.
- A similar pattern occurs towards B1, but to a lesser extent.

3) 3D Model Results: E-Gamma



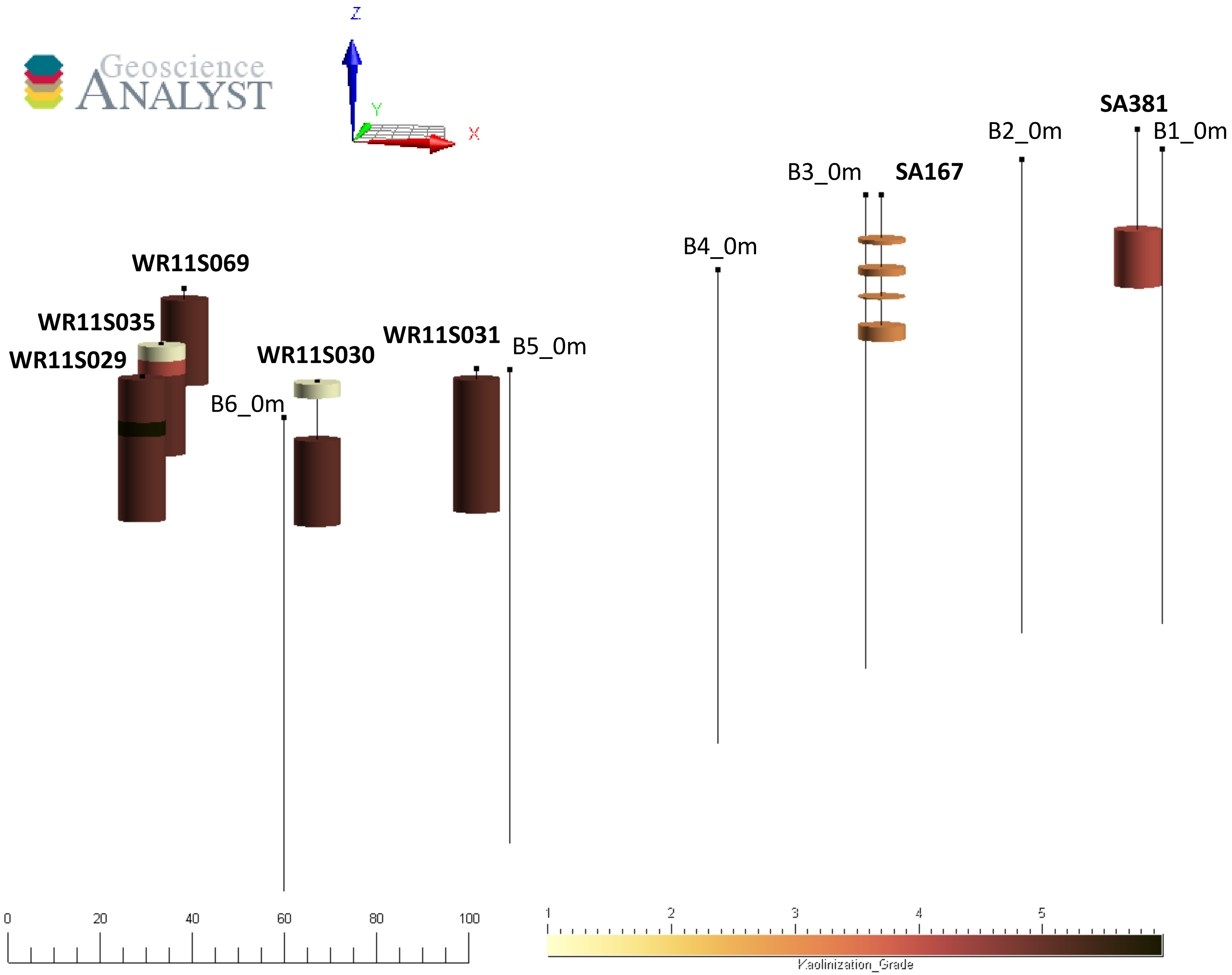
- E-Gamma displays the inverse trend as E-ADR, with E-Gamma increasing towards B5 and B6 progressively down hole.
- The same occurs between B2 and B1 to a lesser extent.

3) 3D Model Results: F-Gamma



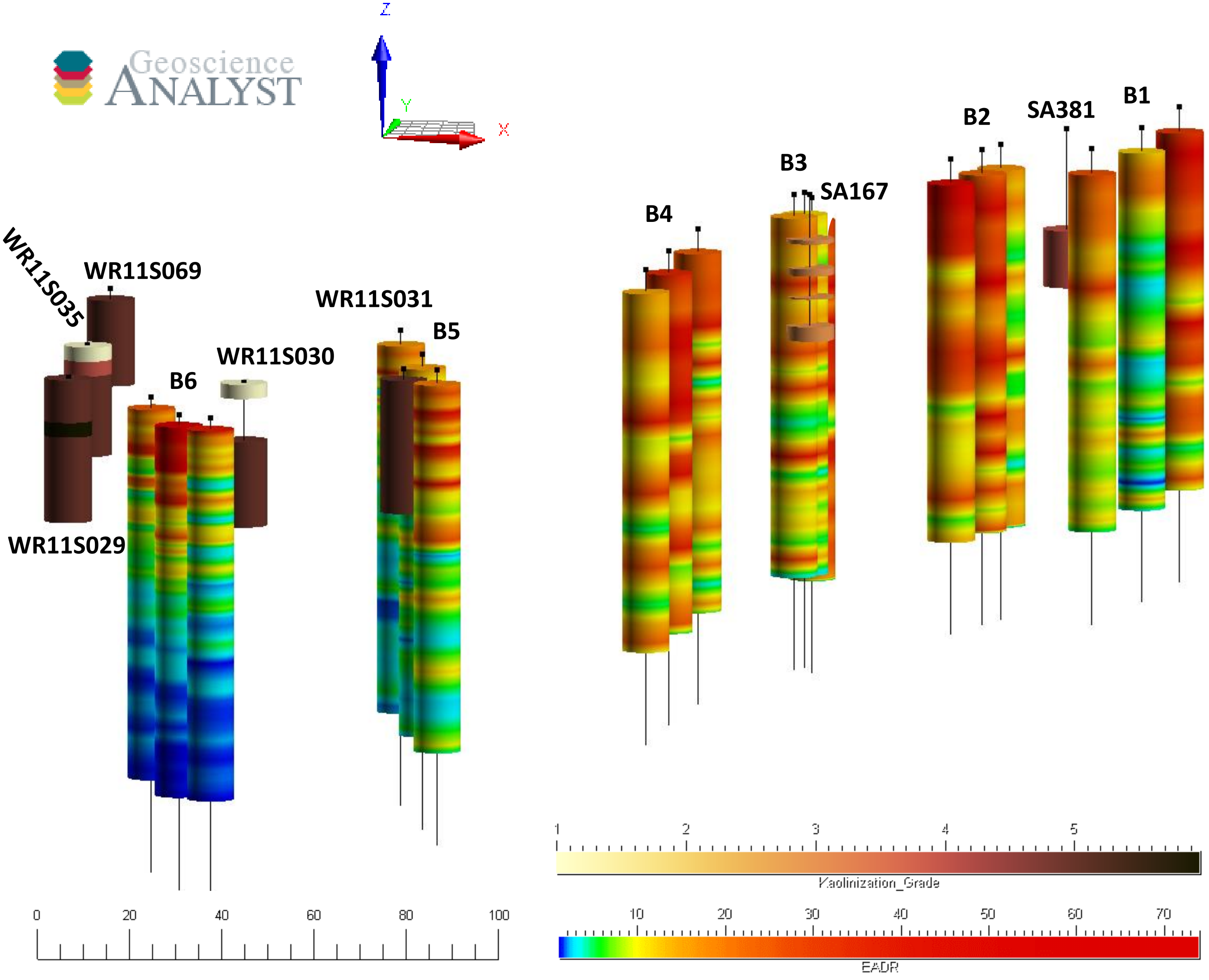
- F-Gamma displays a similar trend as E-Gamma, with F-Gamma values increasing towards B5 and B6 progressively down hole.
- A similar trend occurs between B2 and B1, where F-Gamma is at its lowest in B2, and slightly increases towards B1.

3) 3D Model Results: Training Data



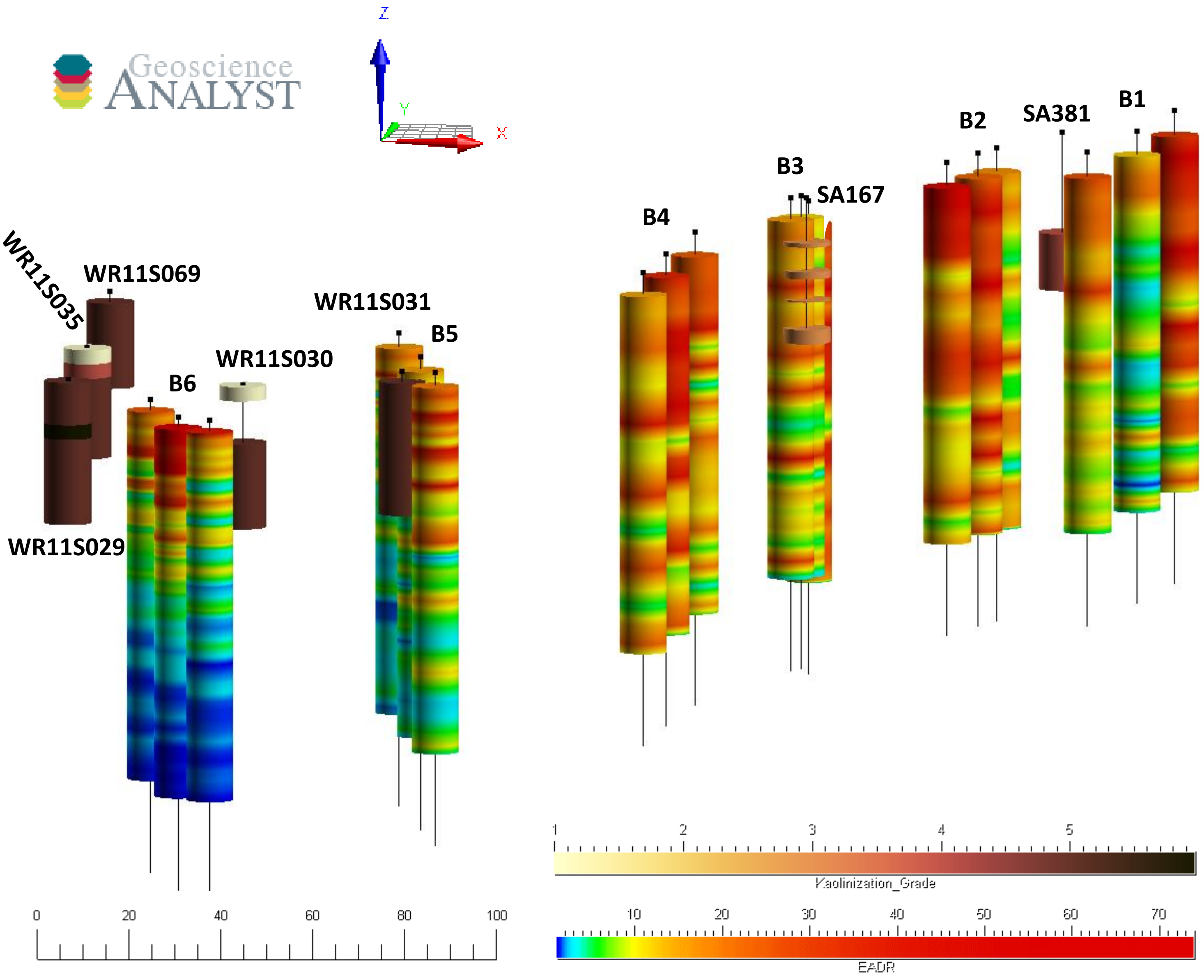
- Training data is available from 7 drillholes that are in close proximity to Adrok's V-Bores. The kaolinisation grade is displayed here from 1-6, and was determined using Sonic drill logs.
- The lowest Kaolinisation grade is grade 3 in SA167, near B3. This increases towards B5 and B6 where the kaolinisation grades are mostly grade 5, with an occurrence of grade 6 kaolinisation in WR11S029.
- Kaolinisation also increase slightly from grade 3 in SA167 (B3) to grade 4 in SA381 (B1).

3) 3D Model Results: Training Data



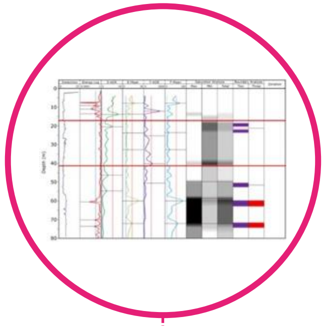
- The changes in kaolinisation grade in the sonic drill logs shows similar trends to what is seen in many of the ADR Harmonics logs, e.g., E-ADR.
- E-ADR is at its highest in B2, B3 and B3 (where kaolinisation grade is low), and decreases significantly towards B5 and B6 (where kaolinisation grade is very high). E-ADR also decreases from B2 to B1 (where kaolinisation grade increases).
- This would suggest that E-ADR has an inverse relationship with kaolinisation grade.

3) 3D Model Results: Training Data



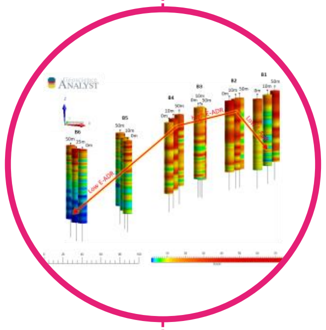
- Kaolinisation grade may have an inverse relationship with E-ADR.
- Kaolinisation may also have a linear relationship with E-Gamma and F-Gamma.
- The decreases or increases in harmonics values do not necessarily directly correlate with the kaolinisation grades in the first 30m of the sonic drill logs. The patterns are seen deeper in the V-Bores, where the harmonics have a faster increase/decrease in the sites that host higher grades of kaolinisation.
- This may be due to how the geophysical characteristics of the higher kaolinisation grades affect the ADR signal with depth.

4) Harmonic Transects: Methods



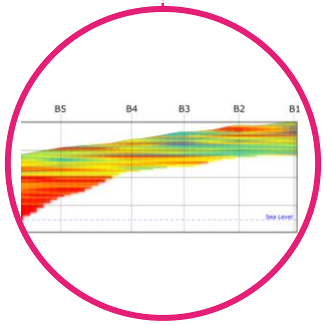
1 Zonation v1

Zonation ingredients include: DC, E-Log, E/F-ADR, E/F-Mean, Saturation & Boundary Analysis.
Unable to complete goal of identifying different stages of Kaolinisation with no clear gradational trends seen in the site by site analysis.

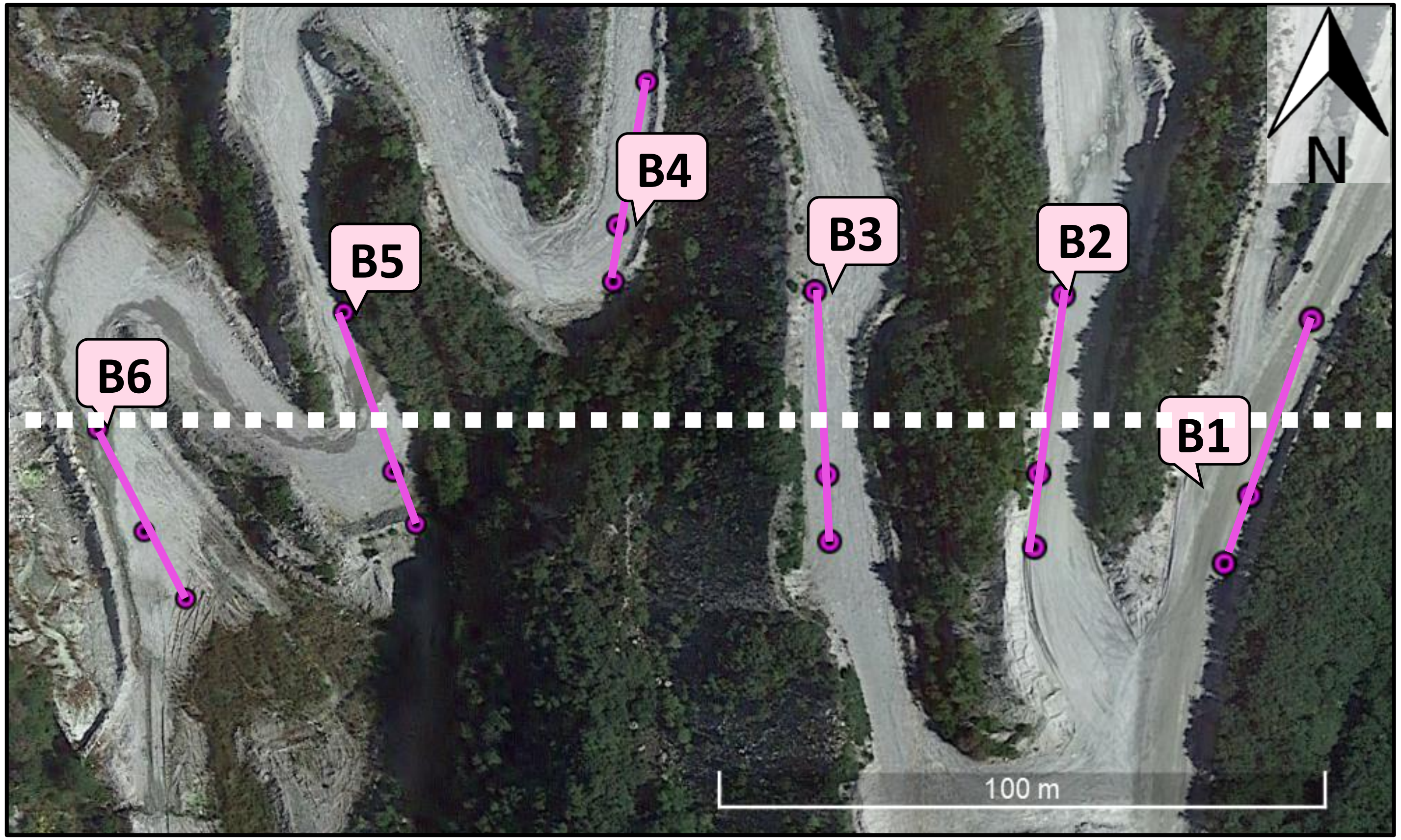


2 Geoscience Analyst 3D Model

Many ADR results able to identify gradational kaolinisation patterns when all sites are viewed together and compared with DDH results.
DC, E/F-ADR and E/F-Gamma all show trends that could be linked to changing kaolinisation grades across sites.



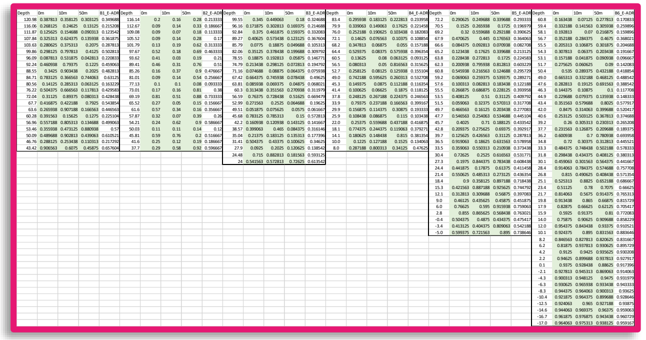
3 Harmonic Transects

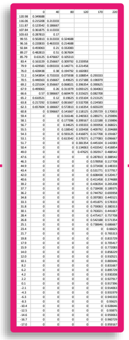


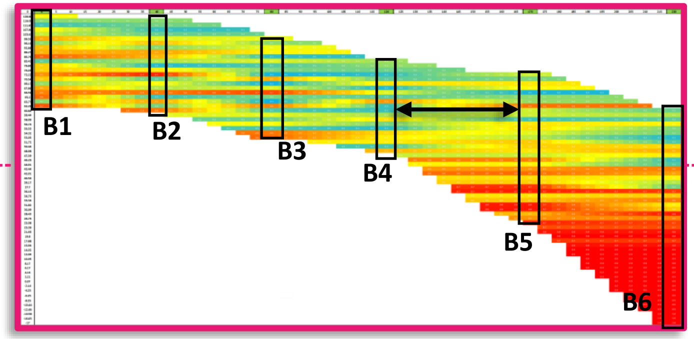
The kaolinisation grade trends are best seen in the harmonics when viewed across all sites in a transect.

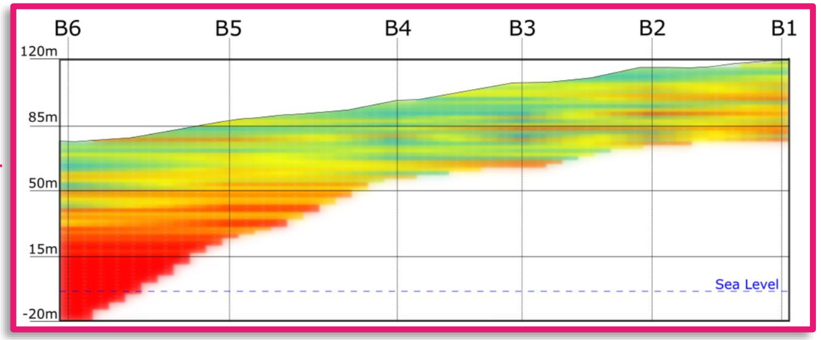
The harmonic transects average the harmonics for the three scans for each of the 6 lines, and plot them laterally. This is an interpolated result that helps visualize Adrok's results.

4) Harmonic Transects: Methods









1 Data Averaging

Firstly, the data for the three sites of each line is averaged for each harmonic parameter, and the depth is translated to elevation above sea level.

2 Vertical Correction

Then, the data for each of the lines in compiled in a single vertical scale.

3 Horizontal Interpolation

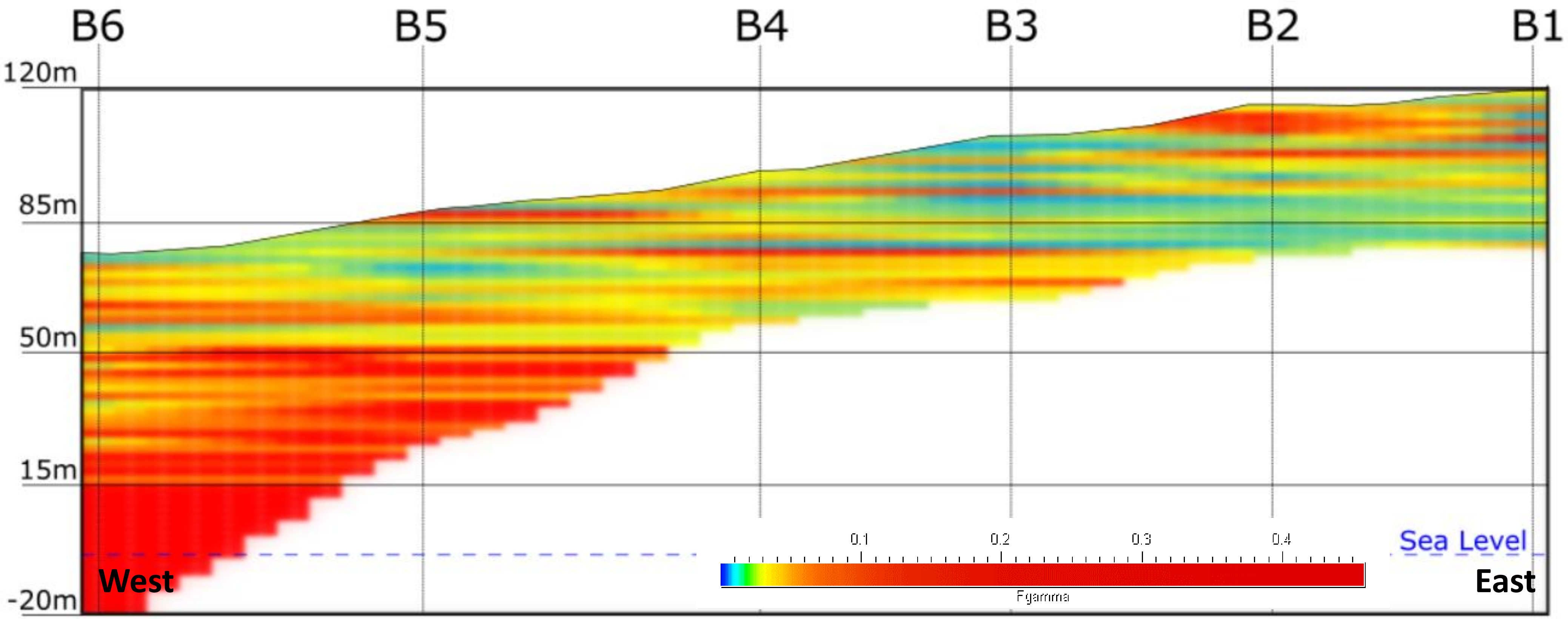
After that, the data is interpolated horizontally between points of the same depth and between sites. At this stage there is a data point every 5 metres horizontally and every 4 metres vertically.

4 Recolouring and Display

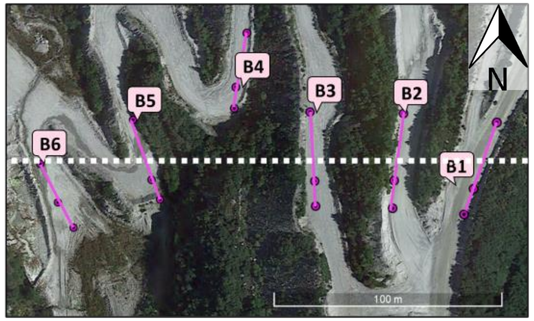
Finally, the data is reoriented West to East, scales and scan labels are added for reference, as well as a key and a slight smoothing is applied for best visualisation.

- This method was chosen due to the faithfulness to the original data, as it respects the initial datapoints, simply interpolating between the sites. The interpolation is done by proximity averaging, closer points hold more weight than faraway ones.
- The harmonic attributes chosen for this were Energy Gamma and ADR as well as Frequency Gamma. These two were selected based on the previous 3D visualisations on Geoscience Analyst and the comparison to the training data from the drilled sites.

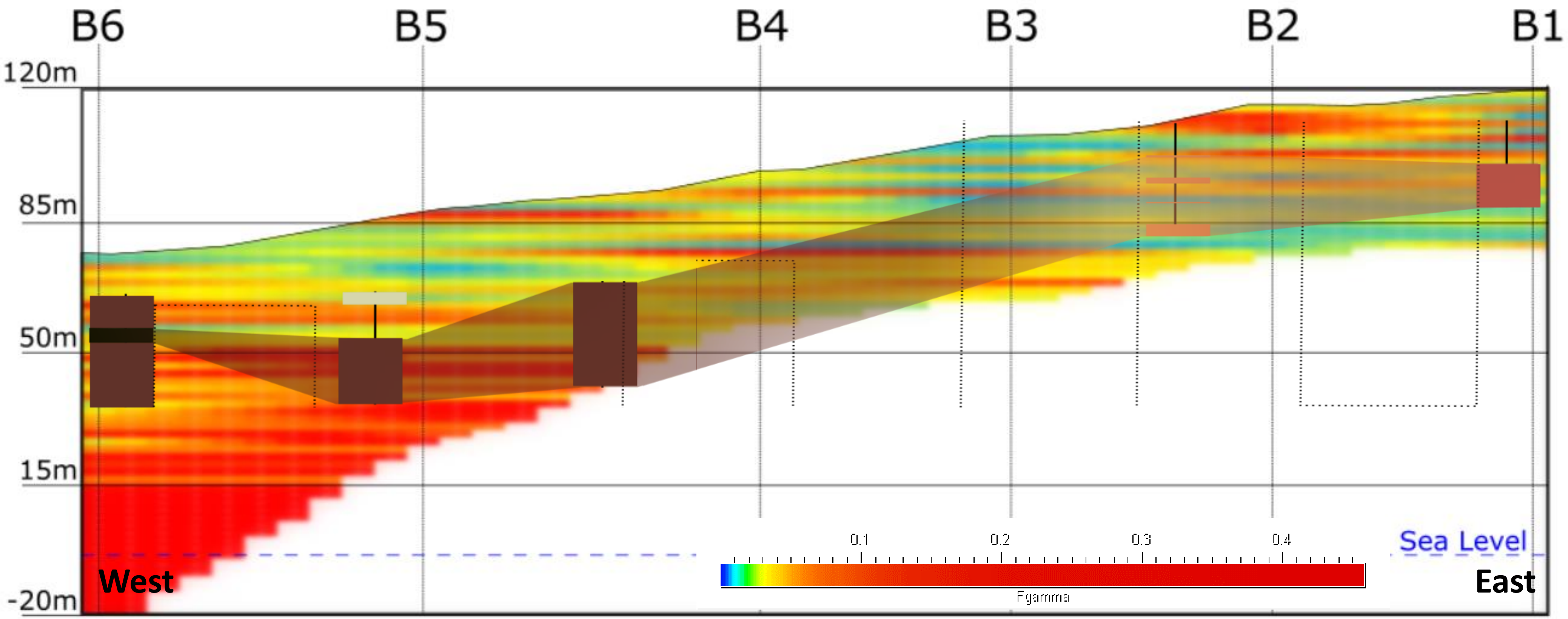
4) Harmonic Transects: F-Gamma



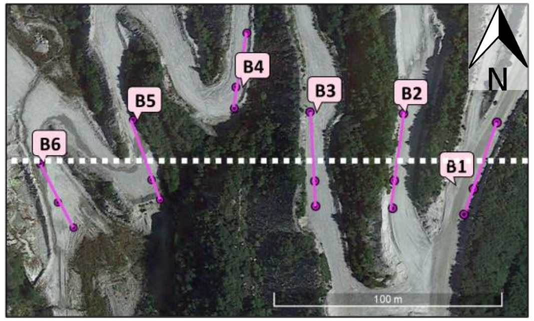
- The Frequency Gamma Harmonic transect shows lower values around B3 and B4, with some higher value locations in B2 and increasingly high from B5 to B6.
- The general trend is for values to be lower towards the West and from below 50m above sea level.



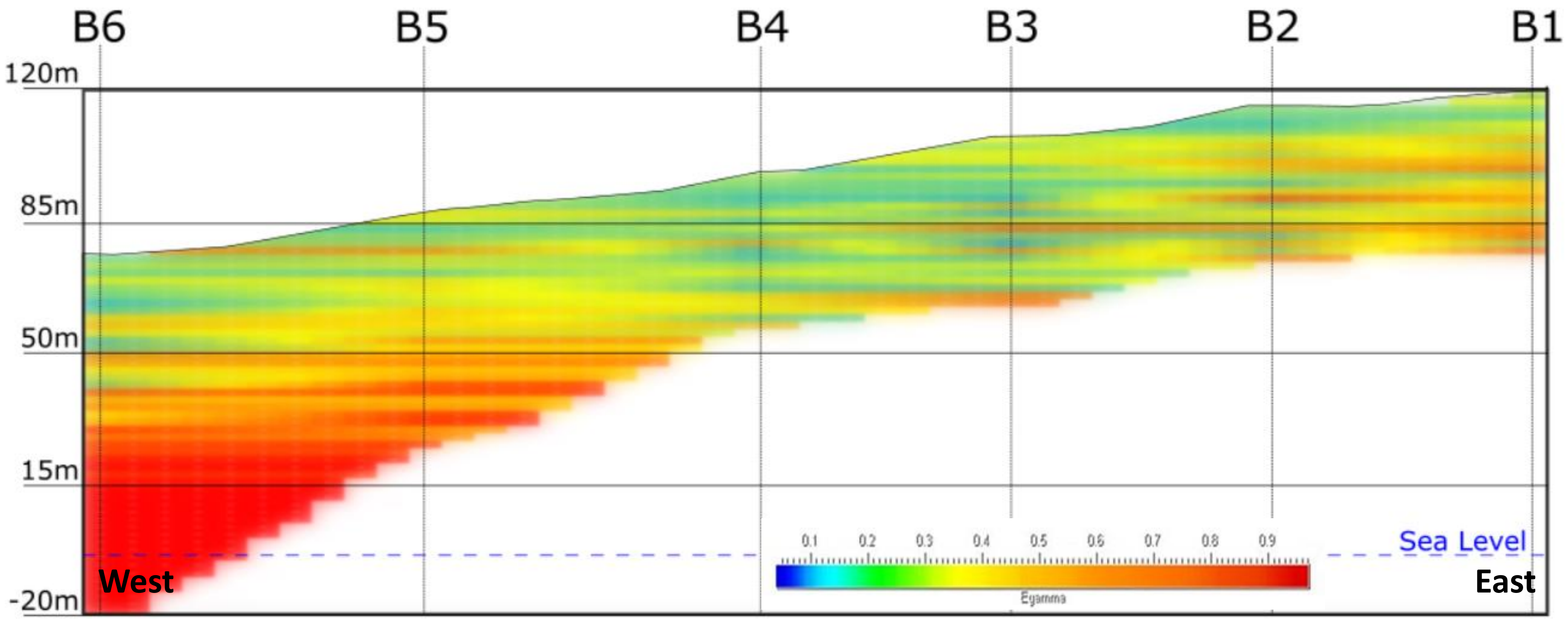
4) Harmonic Transects: F-Gamma



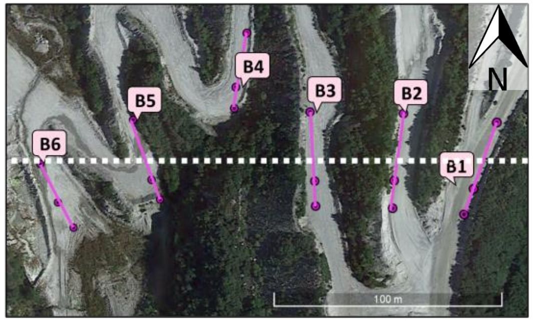
- By overlapping the training data provided by the client on the transect we can make a like-for-like comparison.
- High values of Frequency Gamma tie in well with recorded high levels of Kaolinisation. The low levels at B3 and lower parts of B2 also tie in with lesser grades from the drilled sites.



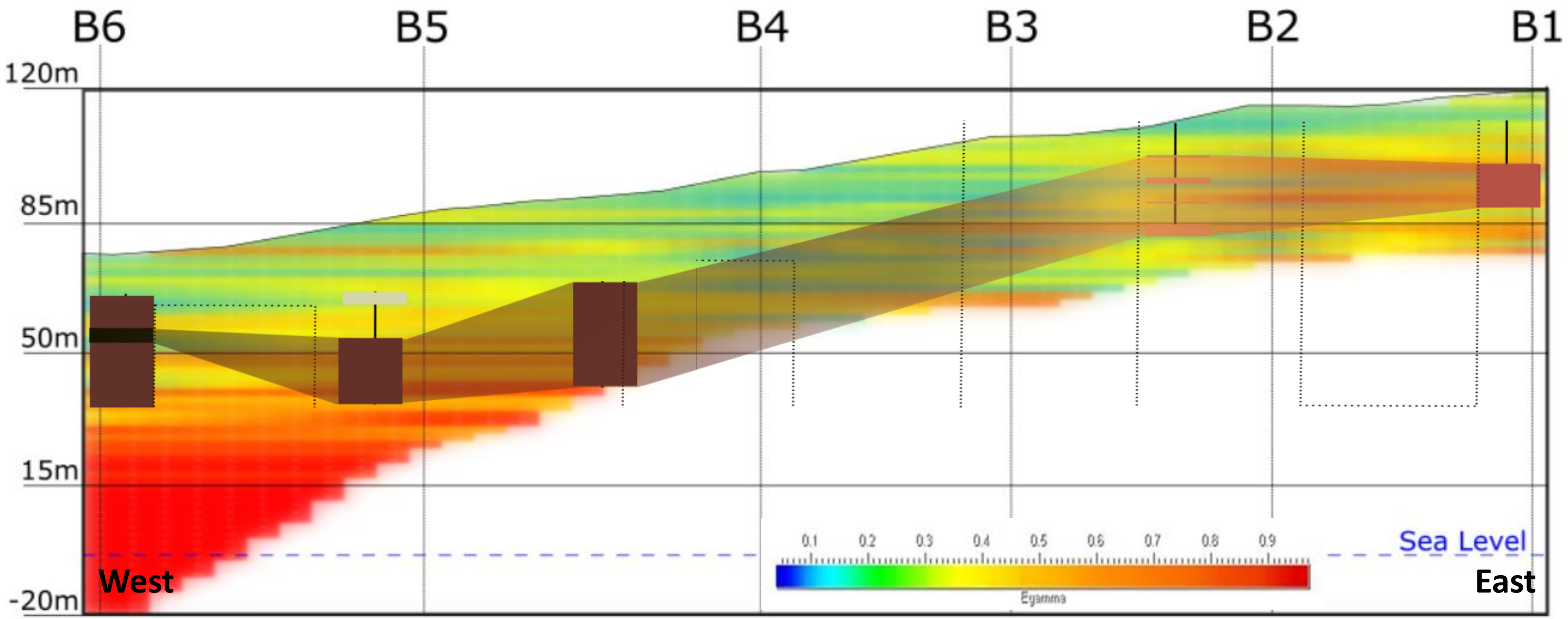
4) Harmonic Transects: E-Gamma



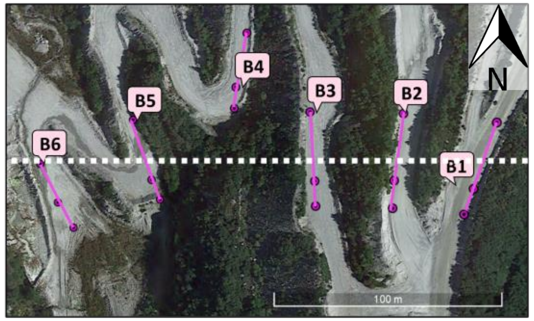
- The Energy Gamma Harmonic transect shows lower values around B3 and B4, this attribute does not show high values in B2, as the Frequency Gamma does.
- The general trend is for values to be higher towards the West and from below 50m above sea level.



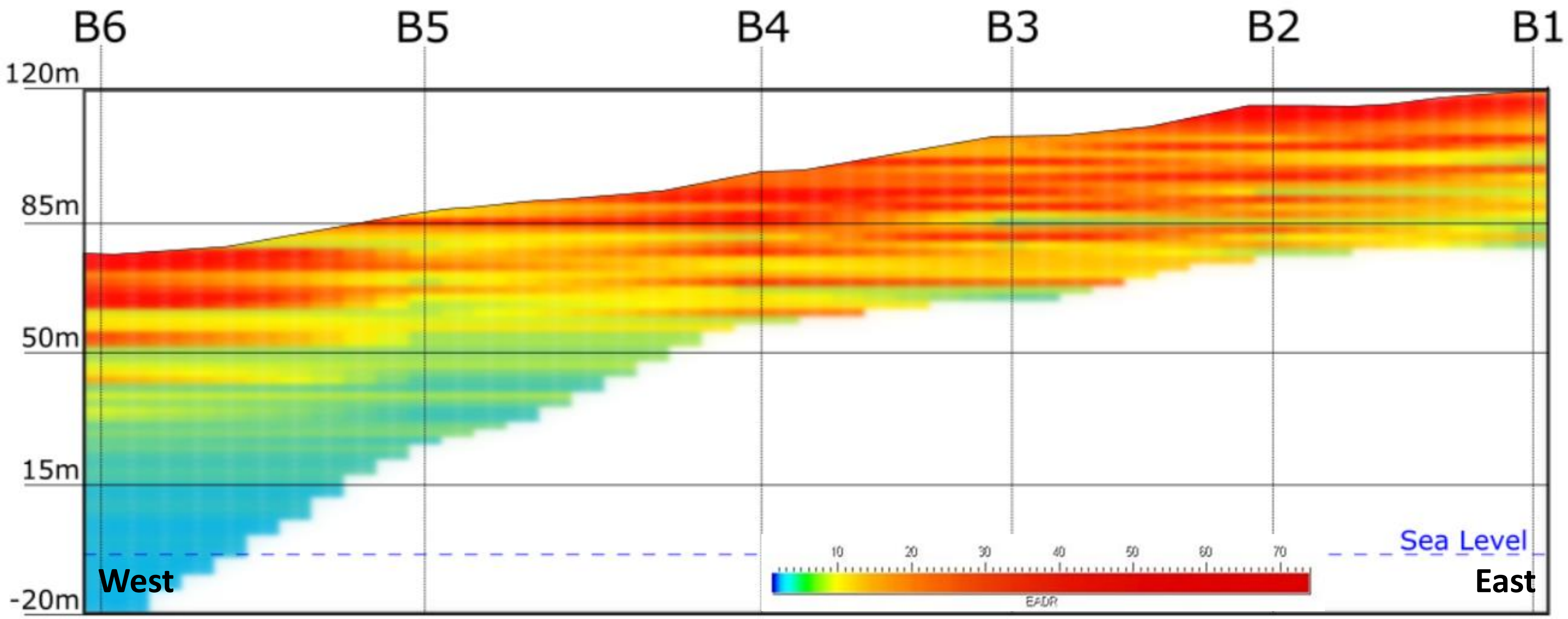
4) Harmonic Transects: E-Gamma



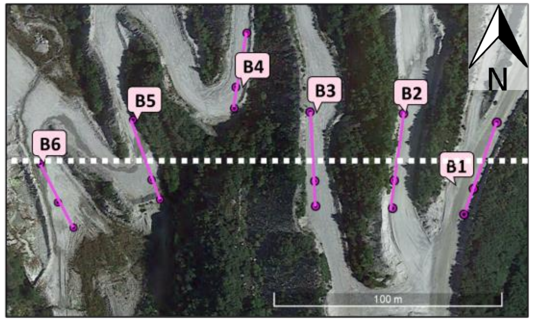
- By overlapping the training data provided by the client on the transect we can make a like-for-like comparison.
- High values of Energy Gamma tie in well with recorded high levels of Kaolinisation. However, the high values seem to be deeper than the start of the alteration, for this, the Frequency Gamma shows better results.



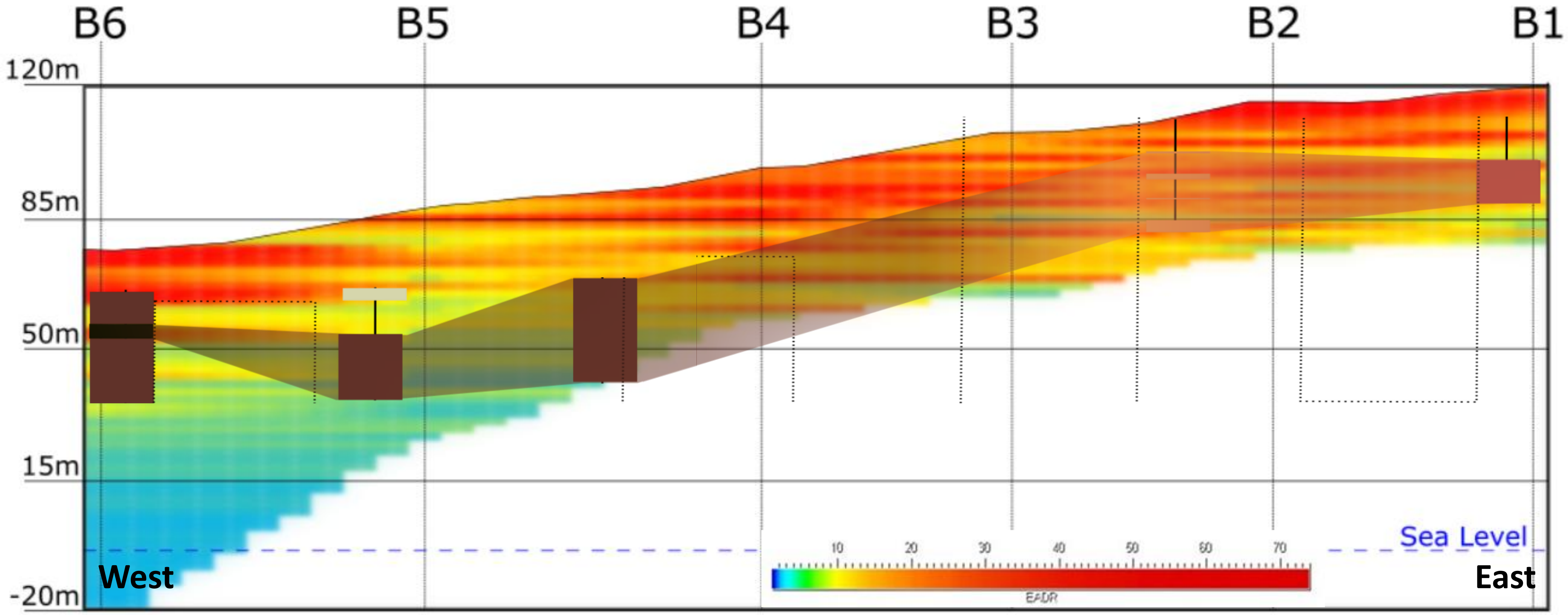
4) Harmonic Transects: E-ADR



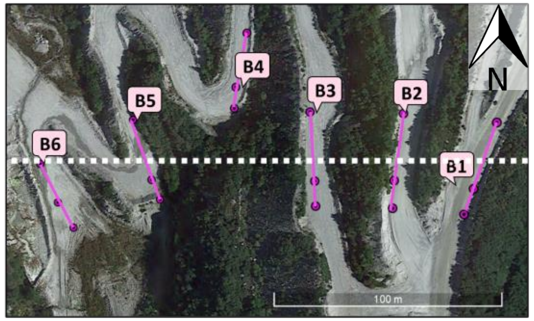
- The Energy ADR Harmonic transect shows higher values around B4 to B1, as well as in the shallow area of B6. It presents some lower value locations in B4 and increasingly low from B5 to B6.
- The general trend is for values to be lower towards the West and from below 50m above sea level.



4) Harmonic Transects: E-ADR

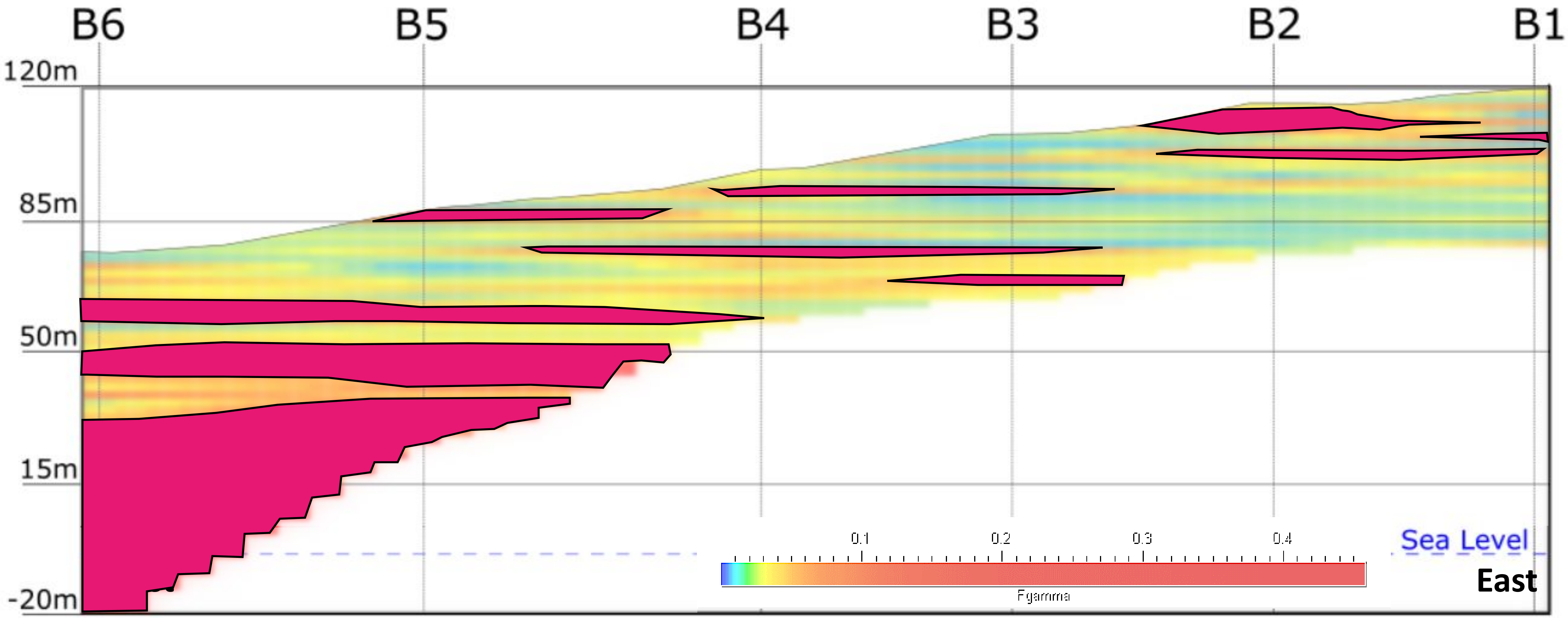


- By overlapping the training data provided by the client on the transect we can make a like-for-like comparison.
- Lower values of Frequency Gamma tie in well with recorded high levels of Kaolinisation. The high levels at B3 tie in with lesser grades from the drilled sites, and the lower levels at B7 and B6 do so too.

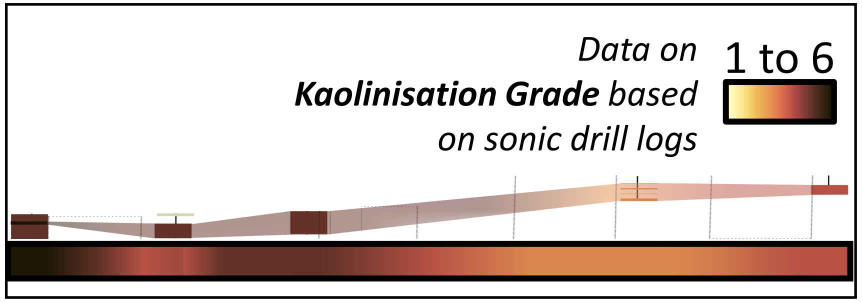


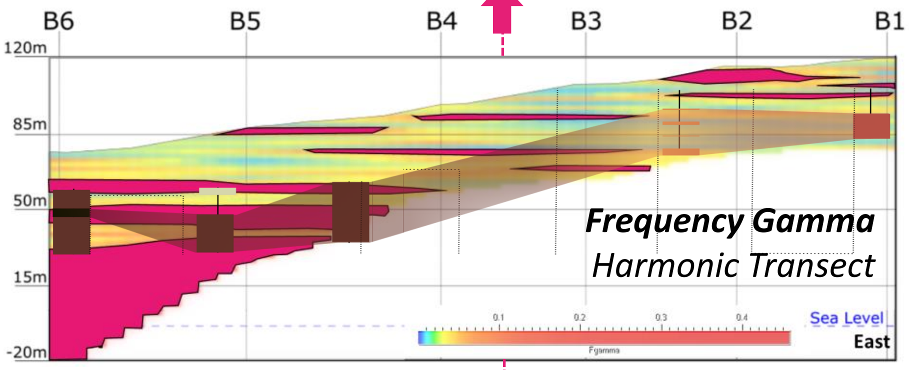
4) Harmonic Transects: Summary

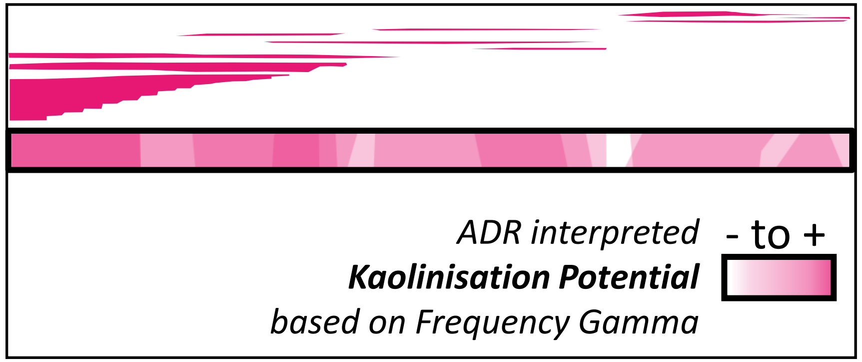
- For the Harmonic Transects, we can conclude that the Frequency Gamma is Adrok's best tool to image and track kaolinization alteration within the granites in the area investigated.
- The transect below shows areas of interest for kaolin extraction **in bright pink outlines**.
- These areas tie up well with the previously known drill results, and expand on their results, providing a very useful 2D view of the alteration. By compiling and intersecting other transects, Adrok could work to build a 3D picture of the kaolinization.



5) Conclusions







- For the Harmonic Transects, we can conclude that the Frequency Gamma is Adrok's best tool to image and track kaolinization alteration within the granites in the area investigated.
- The transect below shows areas of interest for kaolin extraction **in bright pink outlines**.
- These areas tie up well with the previously known drill results, and expand on their results, providing a very useful 2D view of the alteration. By compiling and intersecting other transects, Adrok could work to build a 3D picture of the kaolinization.