Adrok®

Predrilling Virtual Logging®

using a deep-ranging radar system to detect and locate subsurface hydrocarbons, fluids and temperature

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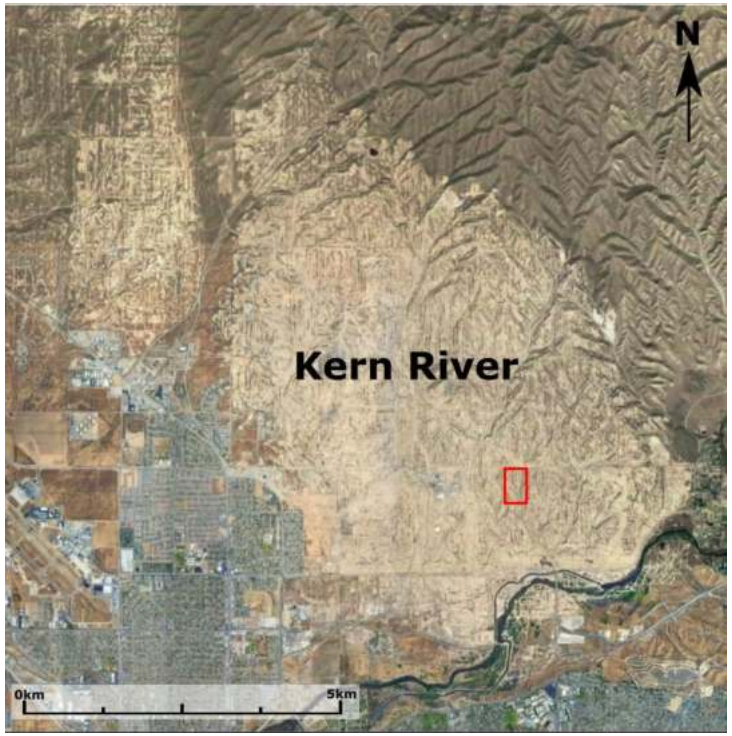
Case Study onshore USA in California, site access provided by

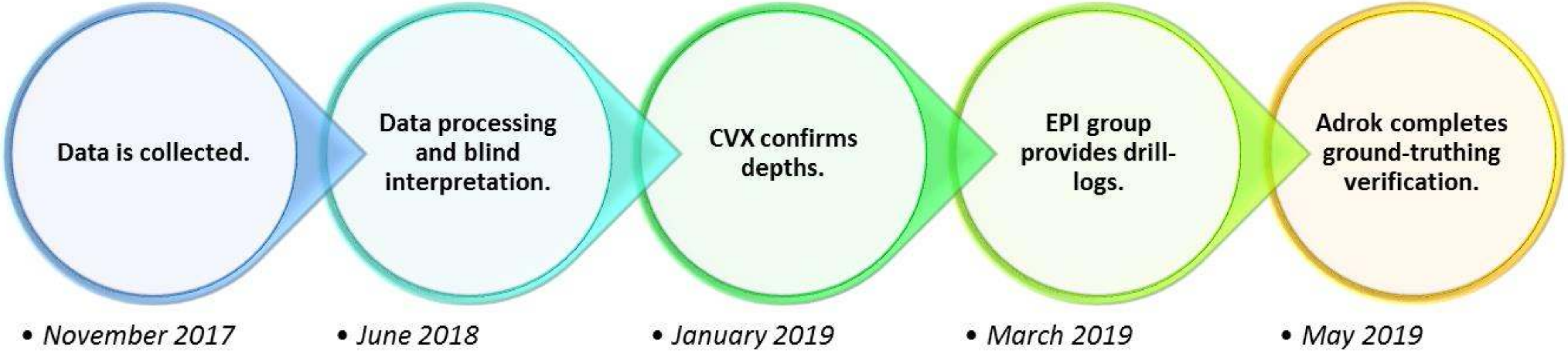
Chevron

Introduction

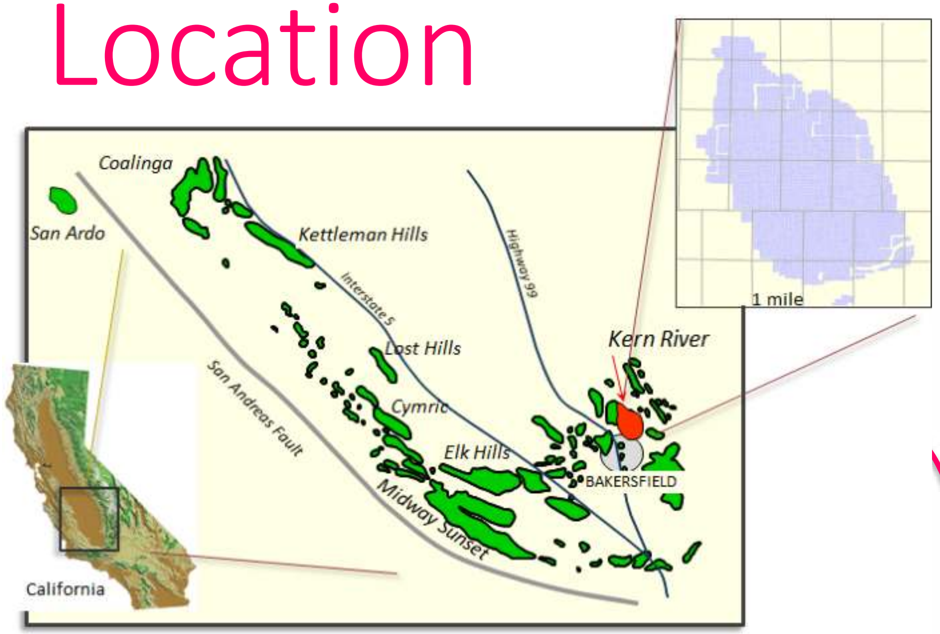
- Adrok funded Case Study showing comparison between Adrok's H10d Deep Scan (down to 6000ft) blind results and the ground-truthing data provided by drilled logs.
- The data was collected in the Kern River Oilfield, near the CP_001TO location. It was collected during November 2017. Site access kindly provided by Chevron.
- The interpretation was made blind (2018Q2), and CVX provided some verification of the depth for the main layers, without releasing the drill hole results.
- Adrok obtained the drill log for Knob Hill and CP_001TO on March 2019 from EPI Group.
- The work presented on this report is a ground truthing interpretation completed in May 2019.



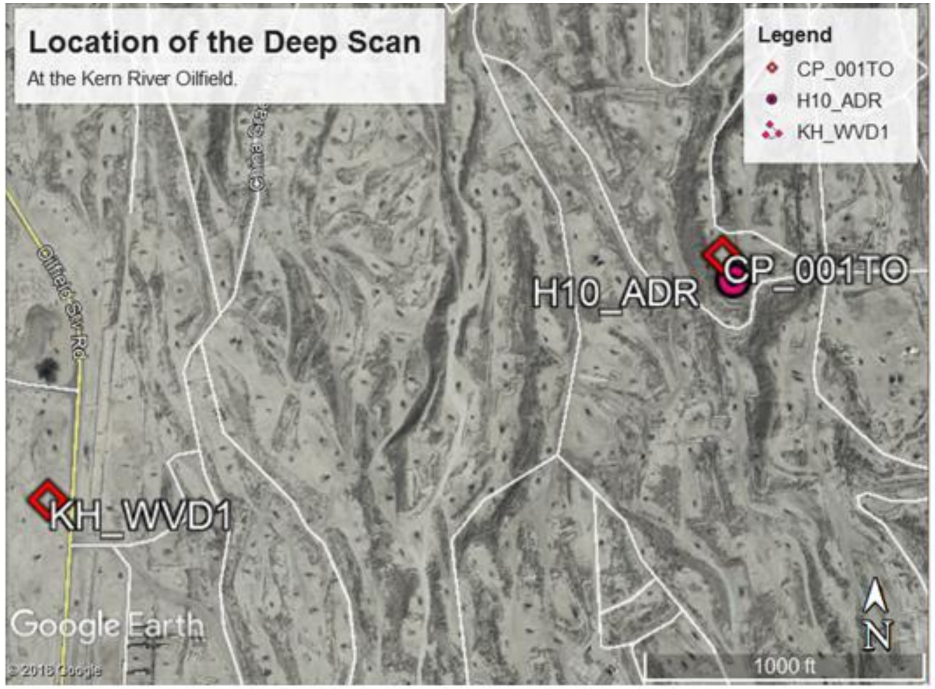
Location map of Kern River Oilfield, H10d is in the red box.

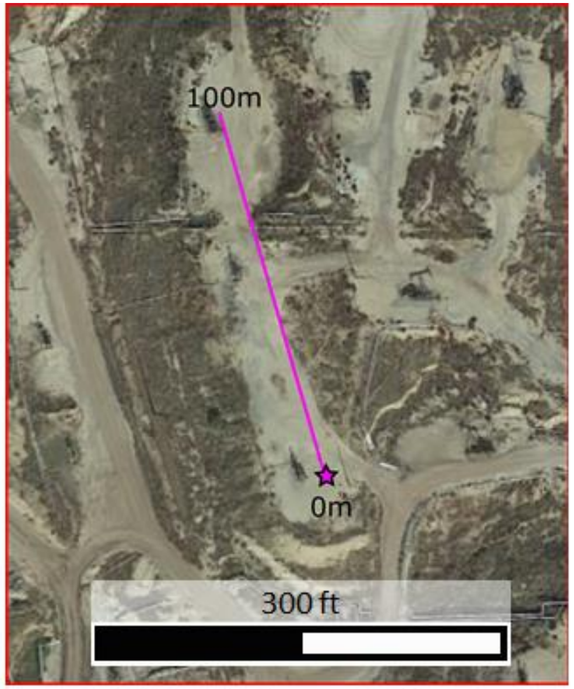


Location



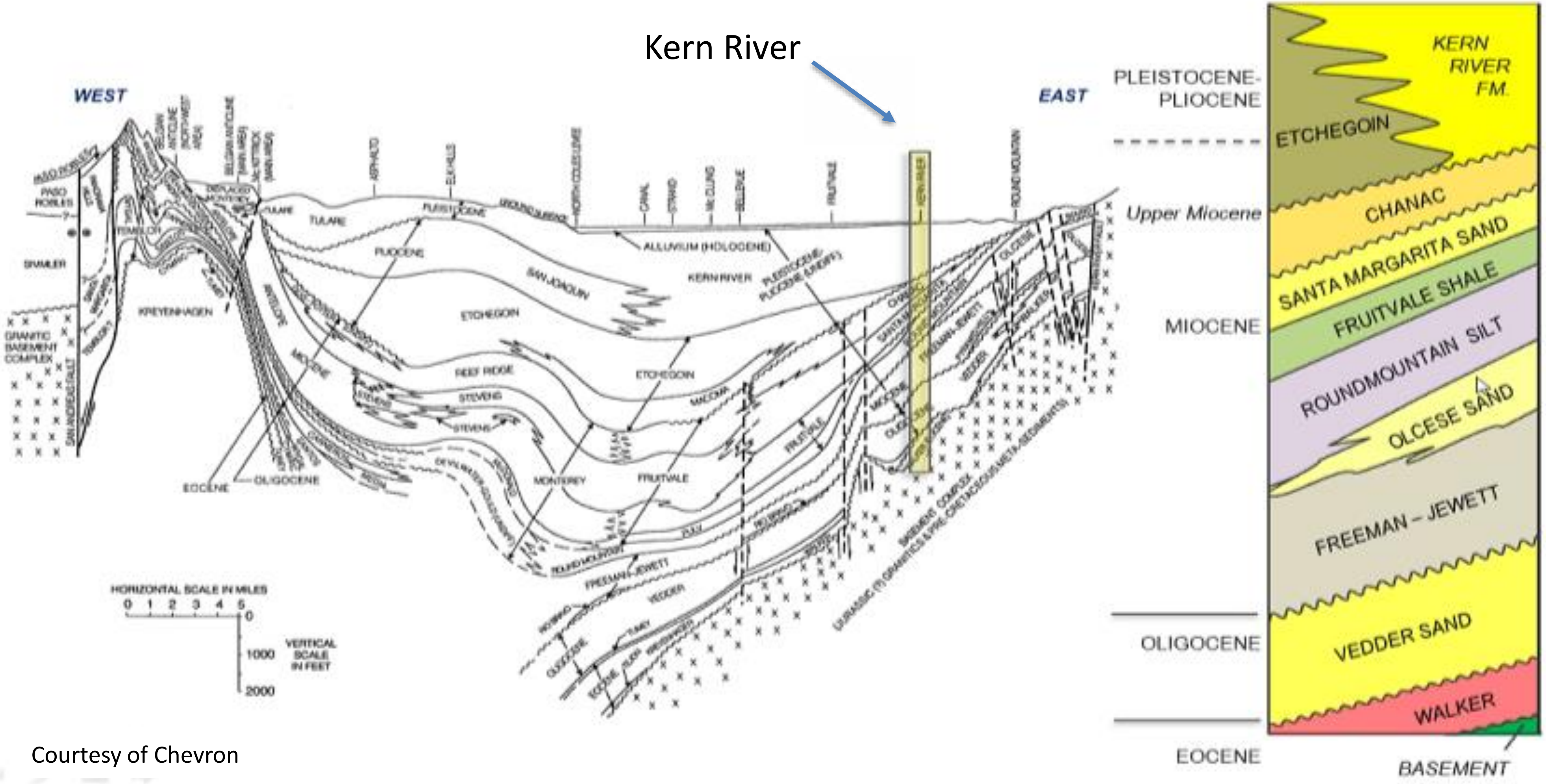
- Kern River Oilfield, California
- Adrok collected ADR at site "**H10_ADR**"
- Site is 2676.4ft away from the location of the Knob hill drill log (**KH_WVD1**) which was used for the deep comparison.
- For shallower comparison, drill log **CP_001TO** was used, only 98ft away from H10_ADR
- Total depth at both drill logs for ground-truthing is -5469.16ft under sea level (-6050ft from the surface).





Location of Knob Hill drill hole at KH_WVD1. Location of H10d V-Bore and WARR, The star on the left marks the position of the V-Bore.

Kern River Formation Stratigraphic Framework

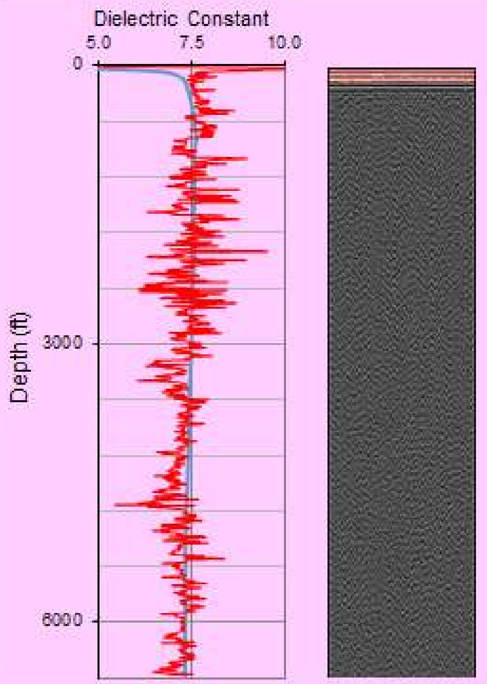


Courtesy of Chevron

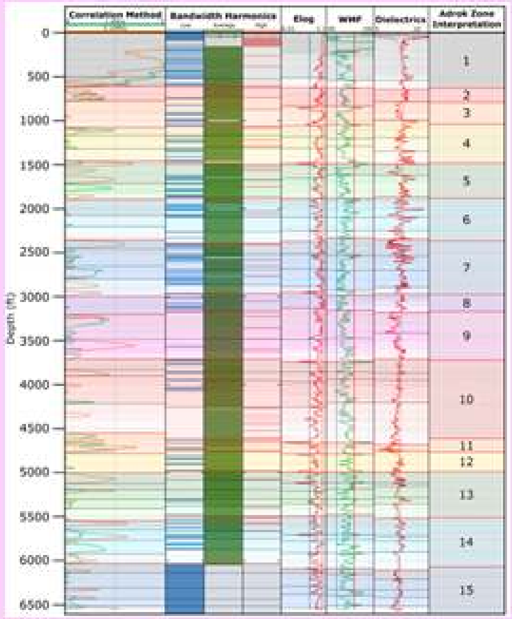
Components for Ground Truthing

- The comparison is made between Adrok's interpretation of the data at H10 and the Knob Hill and Clampitt TO-1 drill reports.
- This slide indicates some key facts about the components used for the comparison.

ADR Deep Scan
- 100m length WARR
- End time of 40000ns
- Collected at 100000 px
- A sample rate of 2.5E+09
- Gain of 1 MV



ADR Zones
- Contrast and Interpretation between 5 ADR attributes (*more in the next slide*).
- Definition of 15 distinct Zones.



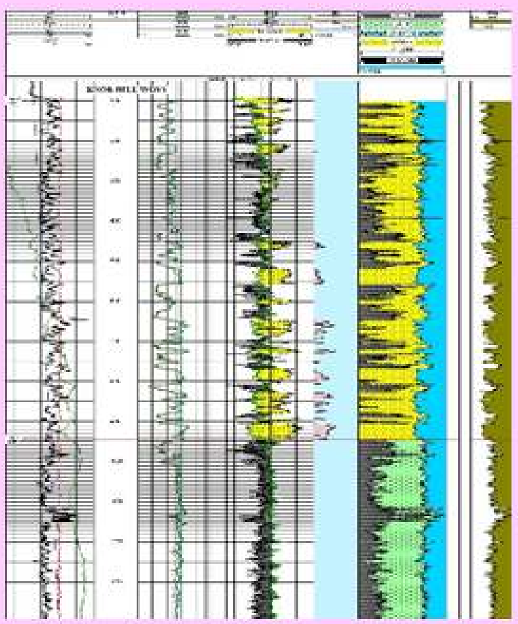
CVX Knob Hill Integrity Report

KH_WVD1 03060652_DATA_2019-02-15
- From well Knob Hill
- Logging data from Apr-2016
- Top Geological markers from surface in ft
- Petrophysical tools:
  - Caliper
  - SP
  - Gamma Ray
  - Temperature

CVX CP_001TO Drill Report

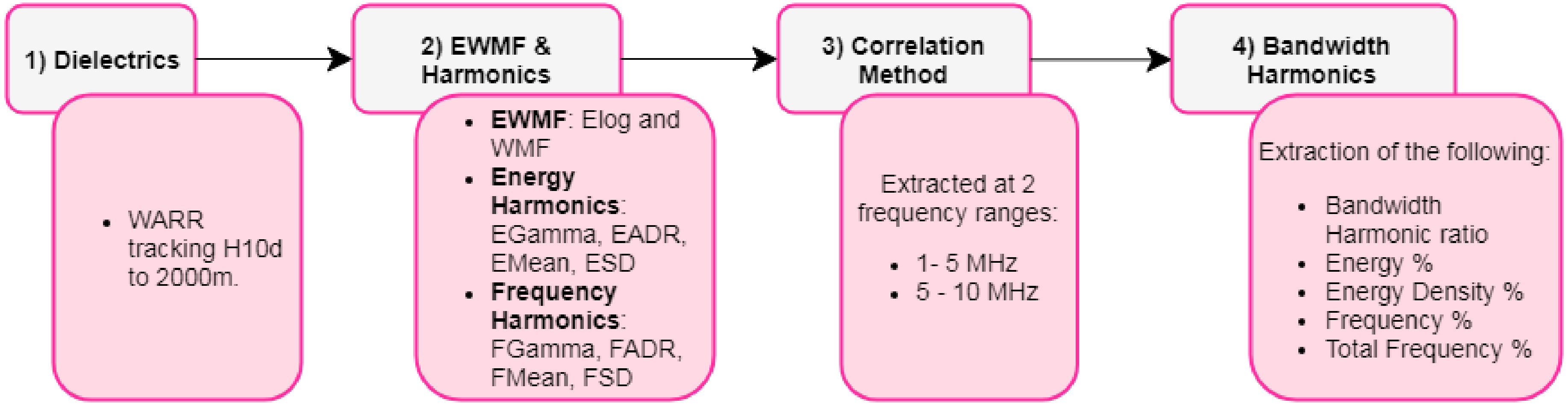
02928992_DATA_11-18-2010
- From Well Campitt TO-1.
- Drilling log from Feb-1916.
- Description of lithologies.
- Depth of formations in ft.
- Depth of fluids found during drilling.

ADR Knob Hill Interpretation
- Lithological interpretation of the petrophysics by Adrok.
- Clay, Silt, Sand and Carbonates fractions.



Methodology

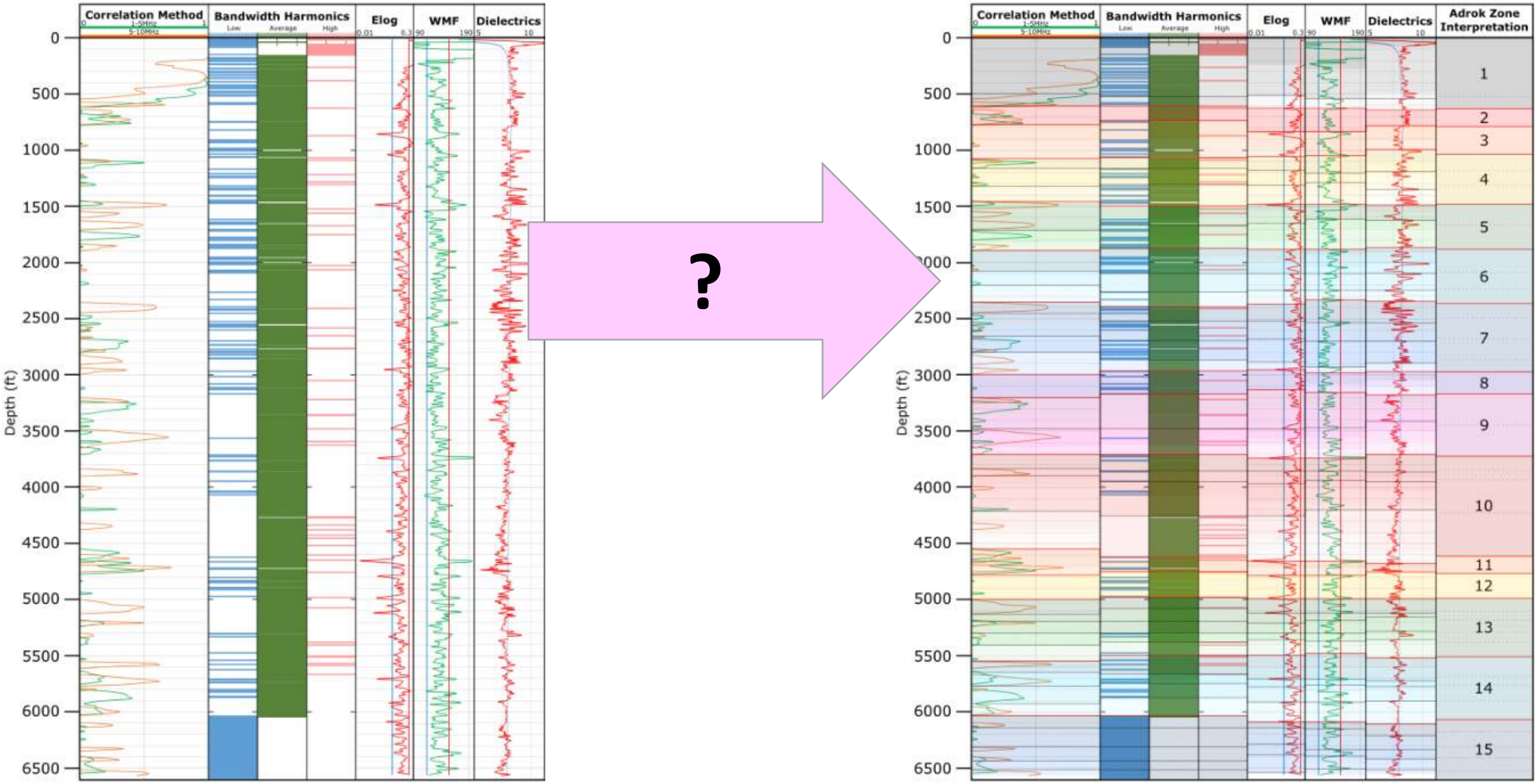
- The following slides will display the results of the ADR zonation for H10d based on:
  - Correlation Method (signal-to-noise)
  - Bandwidth Harmonics (energy, frequency)
  - Elog raw data (energy)
  - Weighted Mean Frequency (WMF) raw data
  - Dielectric Constant log
- Along with the above, a table will accompany the completed zonation that contains the log response for each of the graphs above in every zone
- 15 zones have been identified in H10d based on changes in data trends



ADR Zones: How to get from A to B?

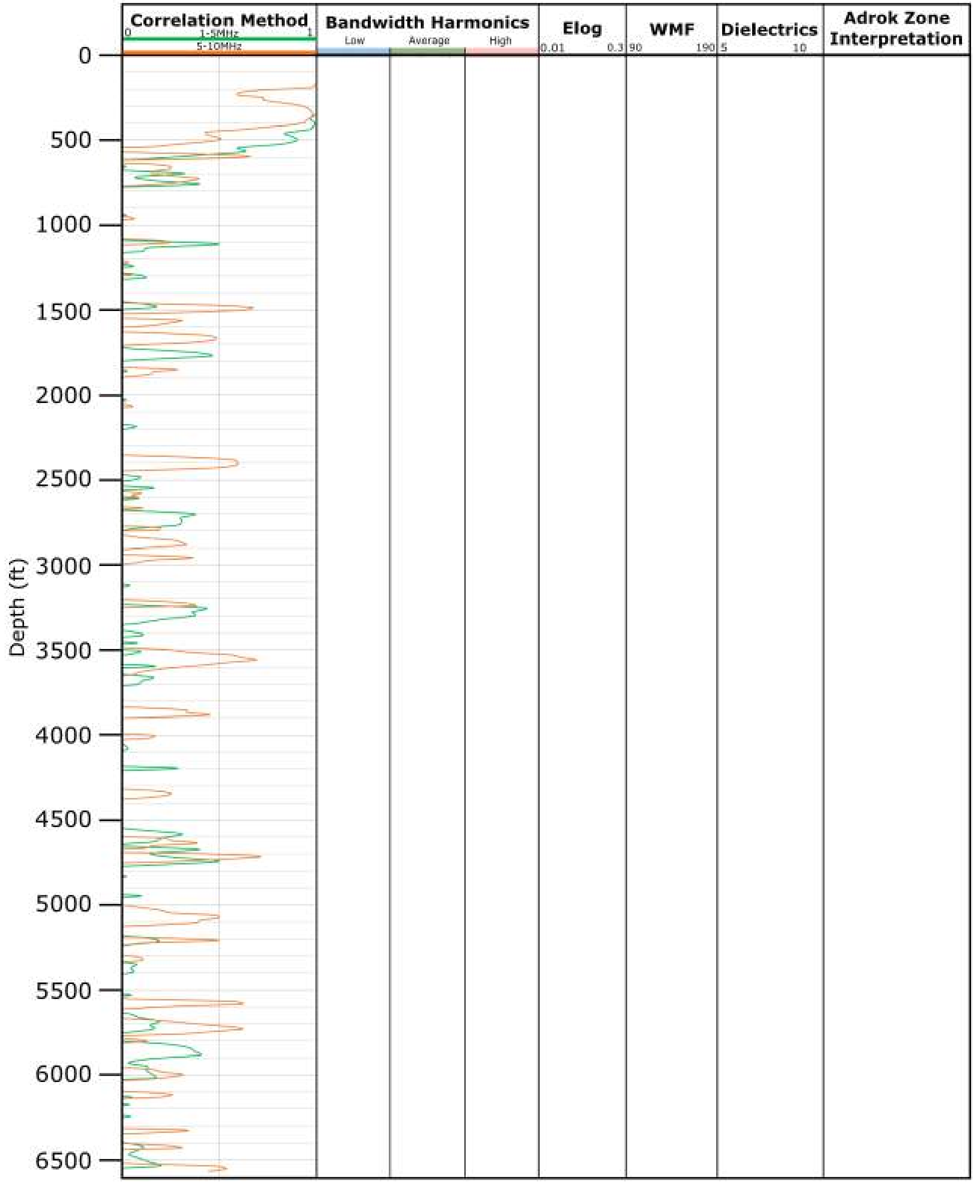
A
The ADR data

B
The Interpretation for ADR Zones



- The following slides will explain what each one of the 5 parameters is and how it was interpreted.

1) Correlation Method (data)



Statistical analysis of the consistency and variation of the many thousands of measurements taken at a particular depth interval.

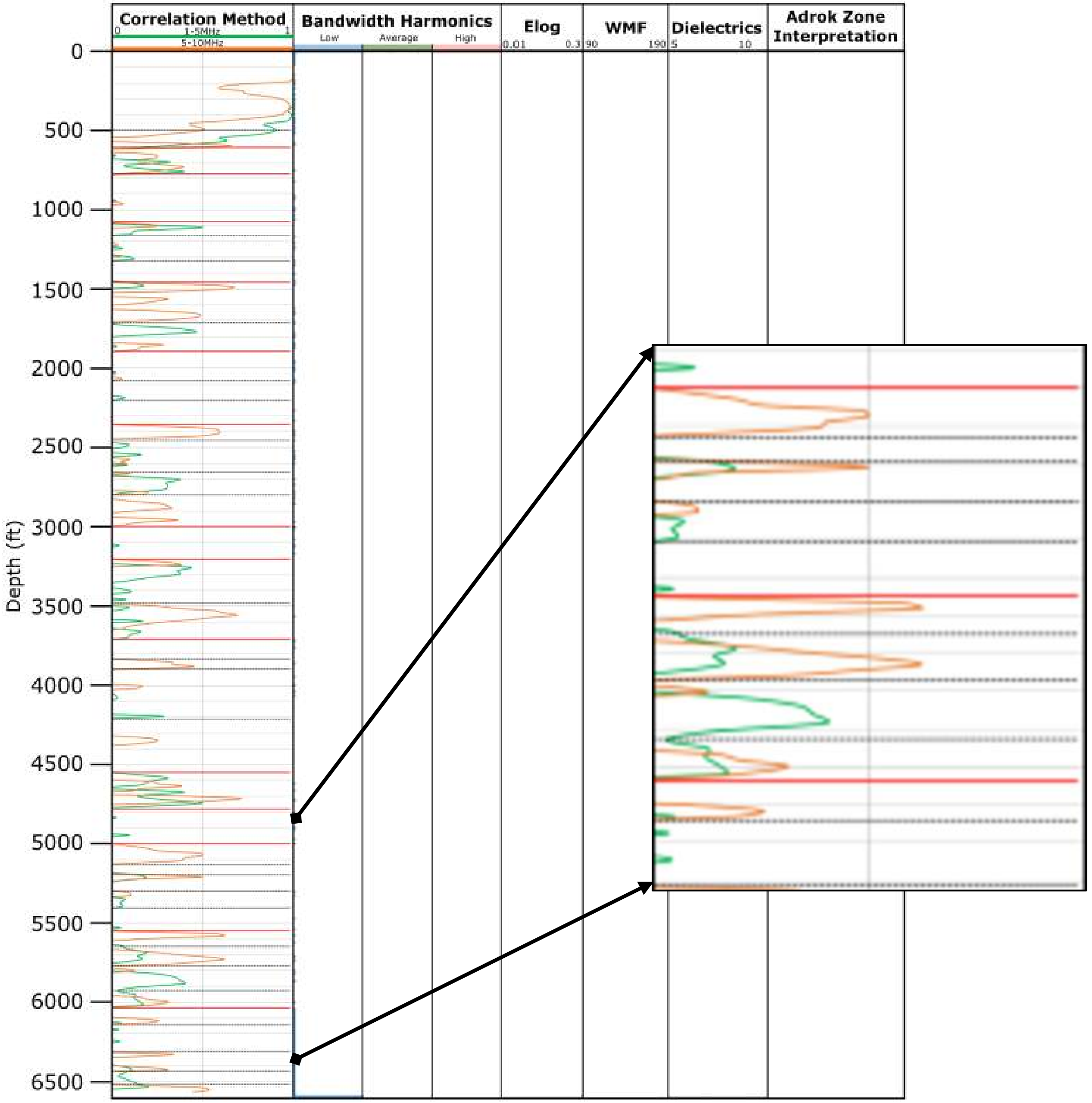
During a repeated scan at a fixed point, 1000 frequency traces can be repeated up to 100 times, to produce up to 100000 wave packets, increasing the signal to noise ratio and allowing higher resolution.

In the time domain before any depth conversion, these responses are stacked. Functionalities within Adrok's 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.

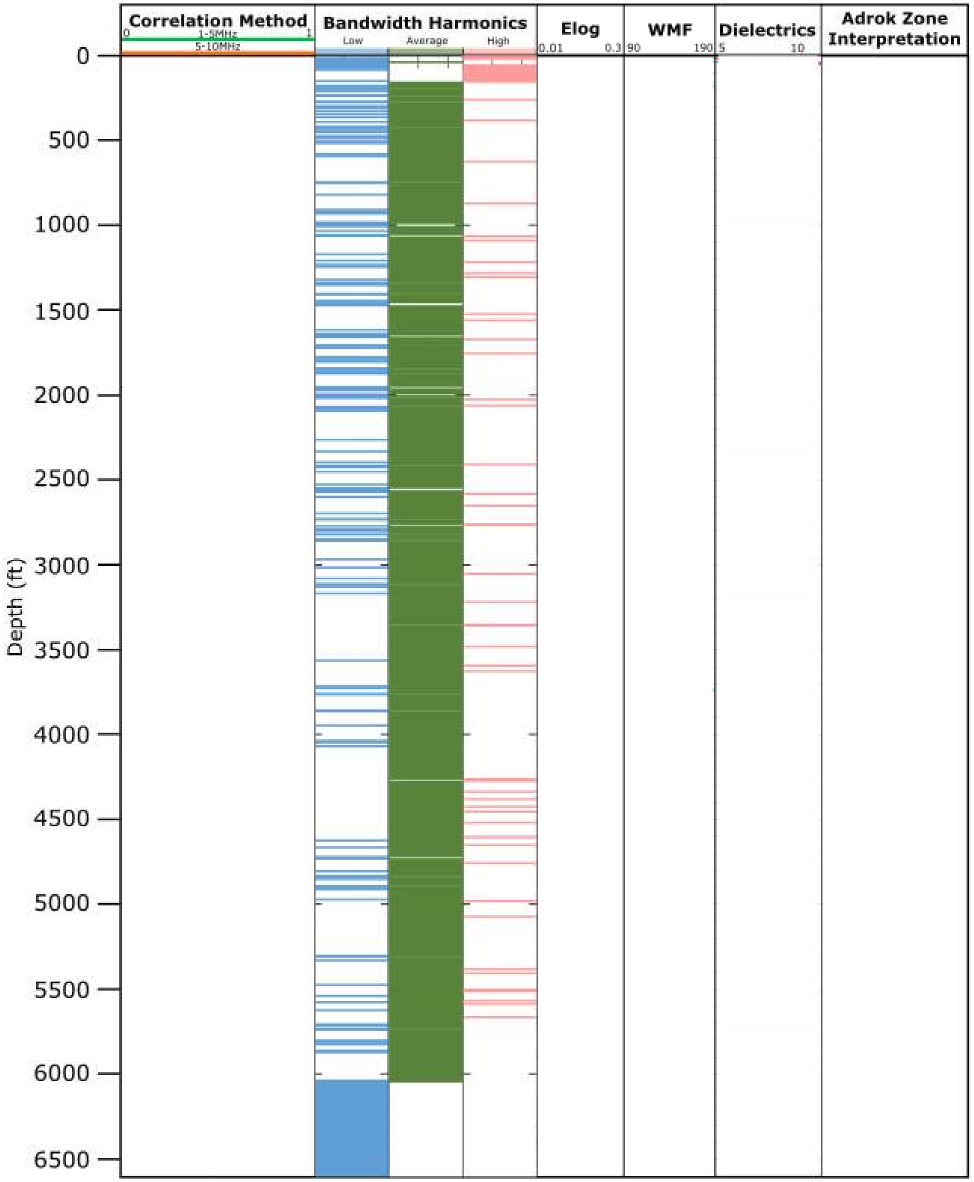
Where the correlation value exceeds the standard deviation calculated, it indicates - in a relative sense - that a more consistent correlation is occurring between frequencies and traces within that band, within an interval where the individual frequencies themselves are also behaving more consistently. 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.

1) Correlation Method (Interp.)



- The **red lines** mark the start of great peaks, or of areas where a Correlation band (either 1-5 or 5 to 10MHz) gets considerably stronger or weaker.
- The ***dotted black lines*** mark the start or end of medium peaks, as well as minor changes in trends.

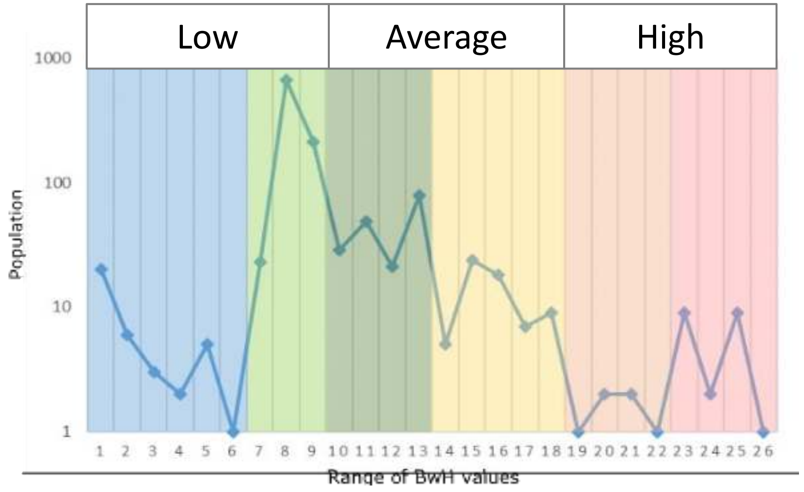
2) Bandwidth Harmonics (data)



Received signal run through Fast Fourier Transform (FFT) analysis. This takes the received resonating signal in the time domain and resolves it into its key harmonic constituents in the frequency domain.

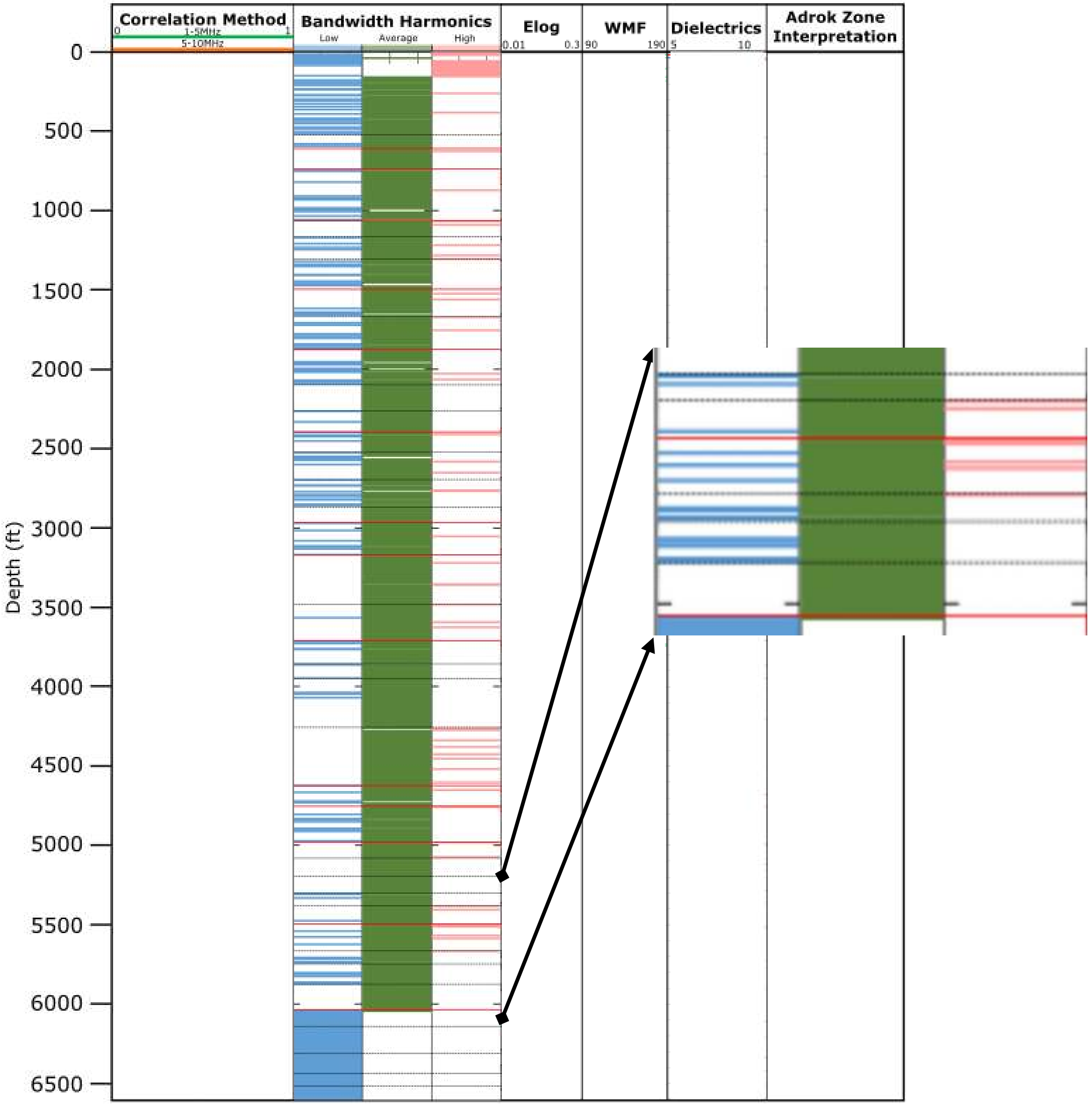
The number of bandwidth harmonics recognised above noise levels is then recorded for each time interval, and later converted to depth.

The values are classified relatively to their populations and values and assigned to Low, Average or High bands.



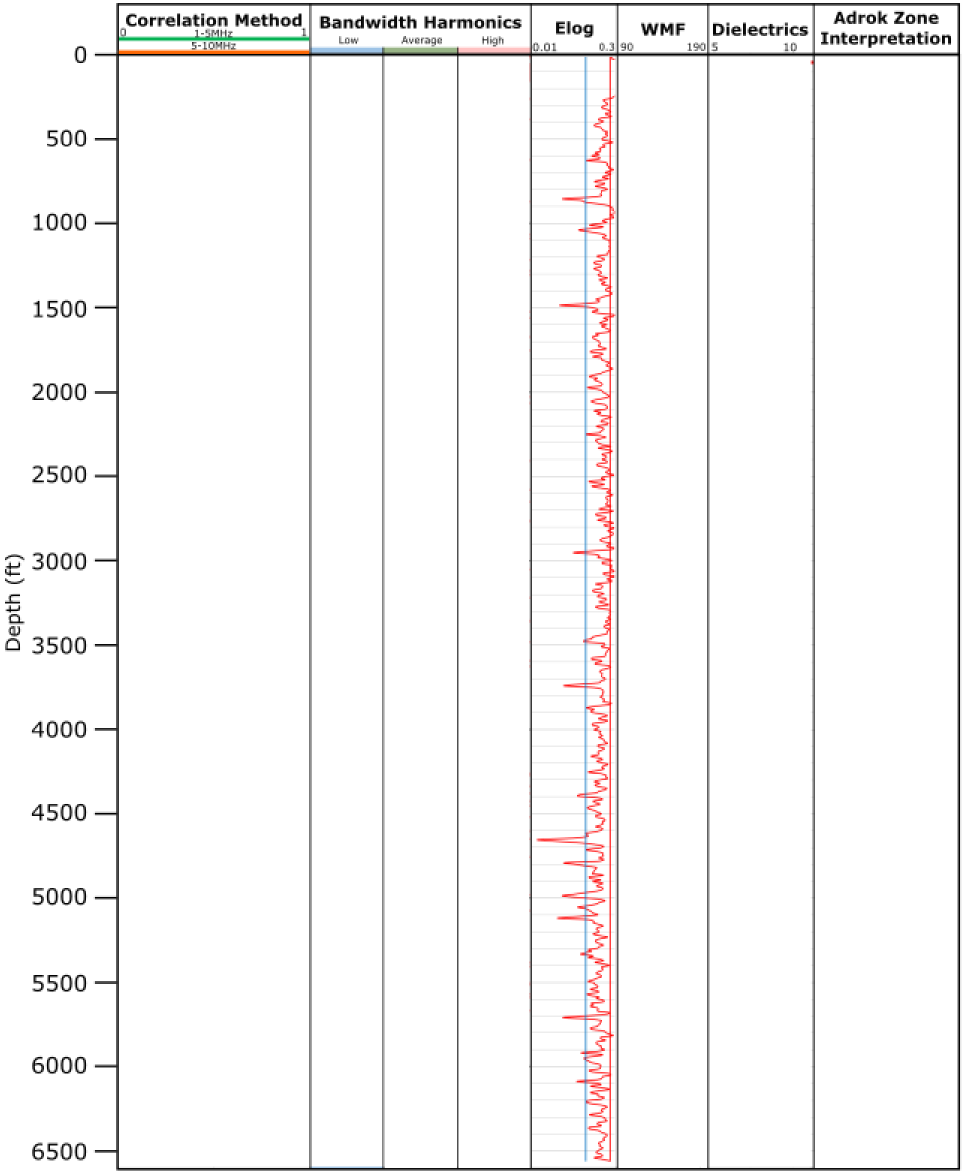
Population graph of Bandwidth Harmonic values showing how classes are determined.

2) Bandwidth Harmonics (interp.)



- The **red lines** mark stark change of bands (i.e. second one in this snip) or the change in trends, such as an of the increase of Low values (i.e. the first red line in the snip).
- The ***dotted black lines*** mark smaller changes, such as the extinguishing of values, or when a line suddenly shows up.

3) Energy Log (data)

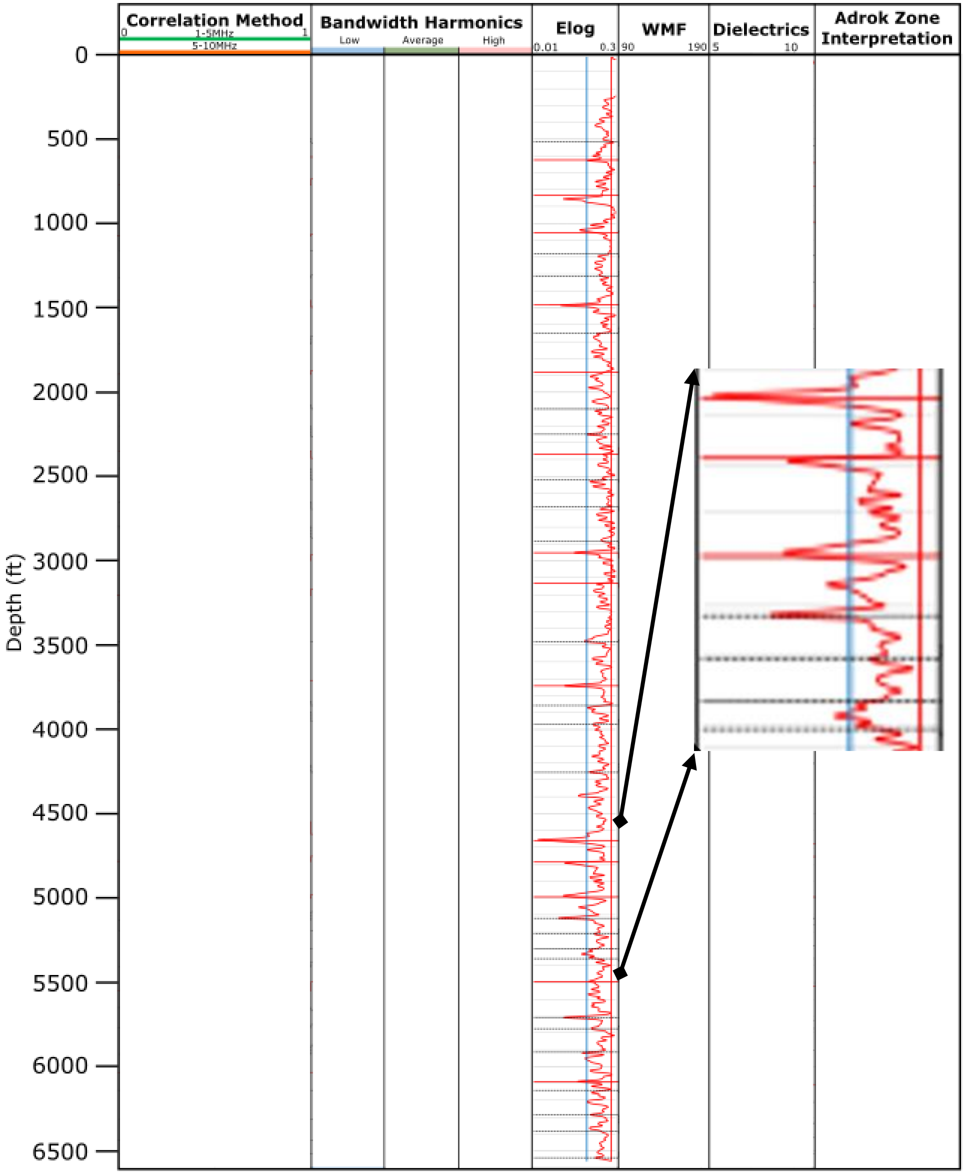


The Energy of a wave is proportional to the square of amplitude, so it is linearly related to the log of the amplitude.

The Energy-log curve (Elog), is a measure of the total energy response from the depth bin in question.

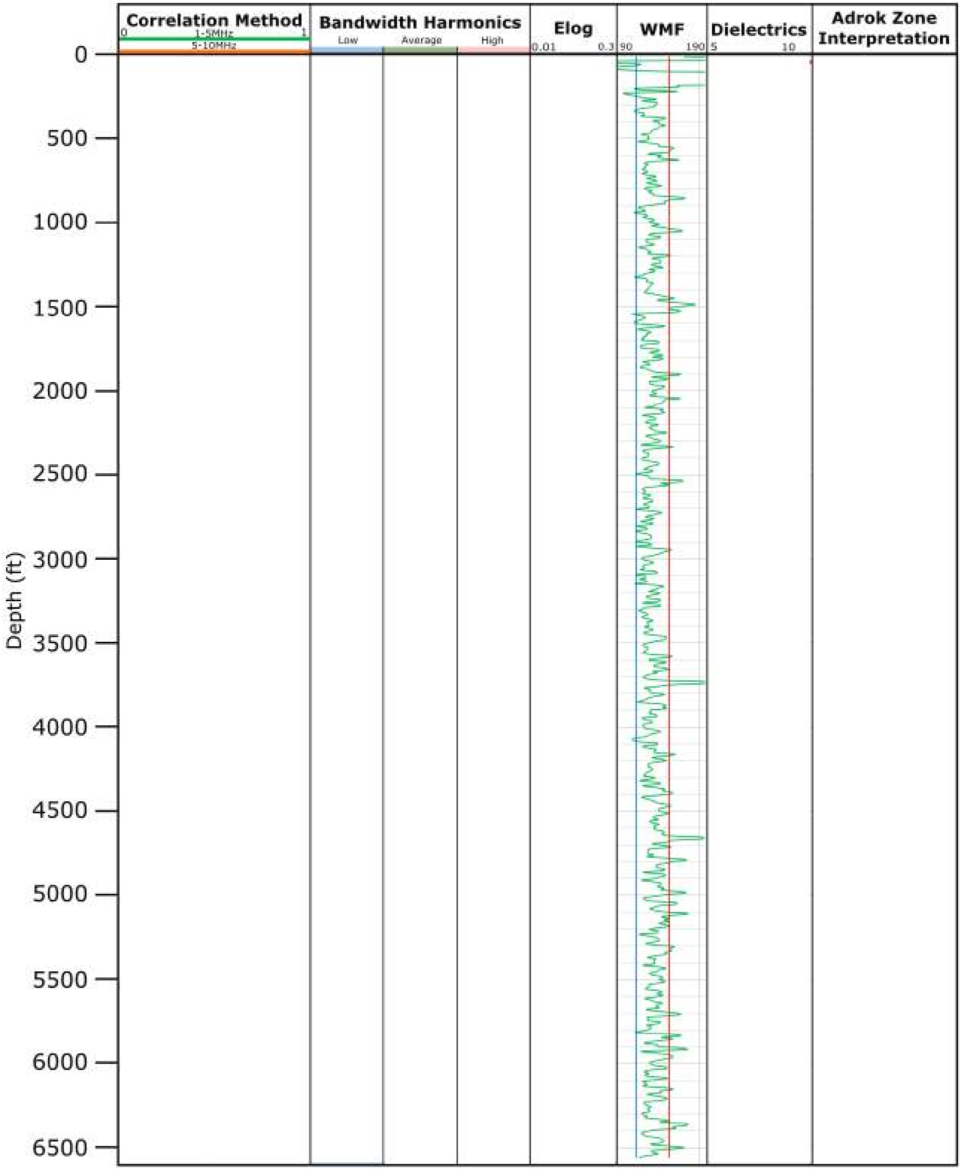
Sometimes low E-log values correspond to sandstones or sandstone boundaries, perhaps reflecting more energy absorption within them and at their interfaces.

3) Energy Log (interp.)



- The **red lines** mark the greatest peaks and troughs, as well as major changes in trends.
- The ***dotted black lines*** mark smaller changes, such as smaller troughs and peaks within a trend.

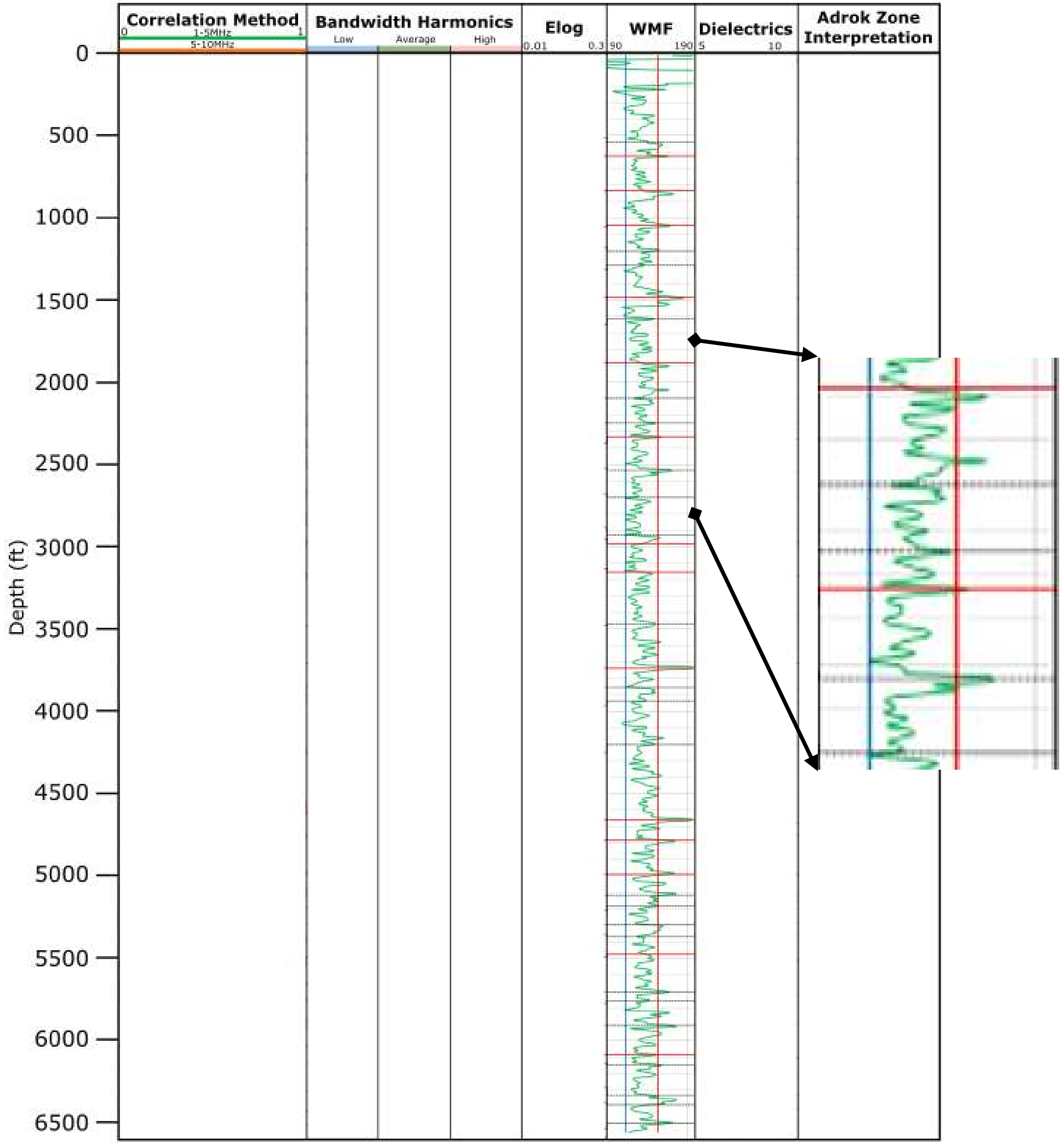
4) WMF Log (data)



For each particular frequency response, the associated energy over a depth bin is multiplied together with it.

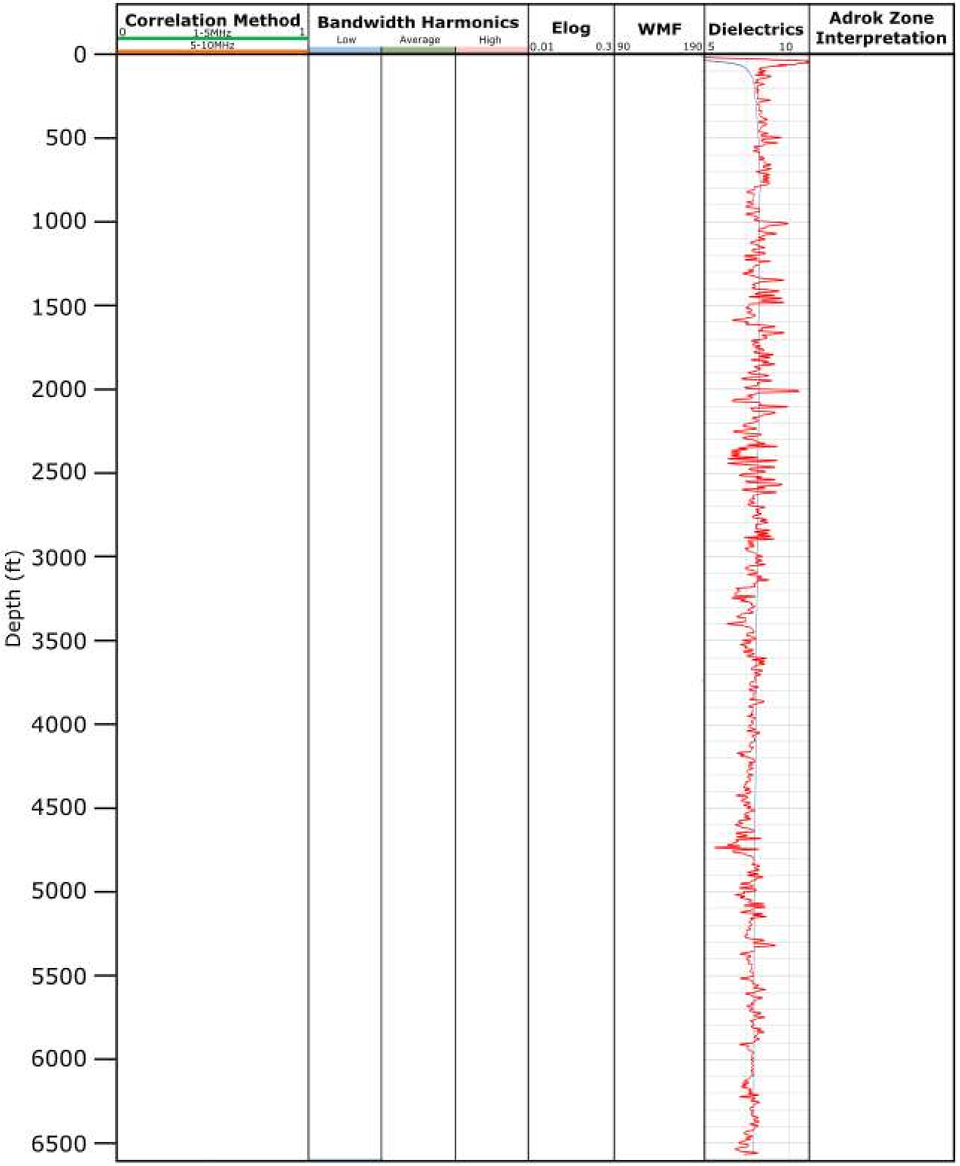
This is summed for all the contributing frequencies, and then the result is divided by the total energy observed for all frequencies, to give the weighted mean frequency.

4) WMF log (interp.)



- The **red lines** mark the greatest peaks and troughs, as well as major changes in trends.
- The ***dotted black lines*** mark smaller changes, such as smaller troughs and peaks within a trend.

5) Dielectric Constant Log (data)

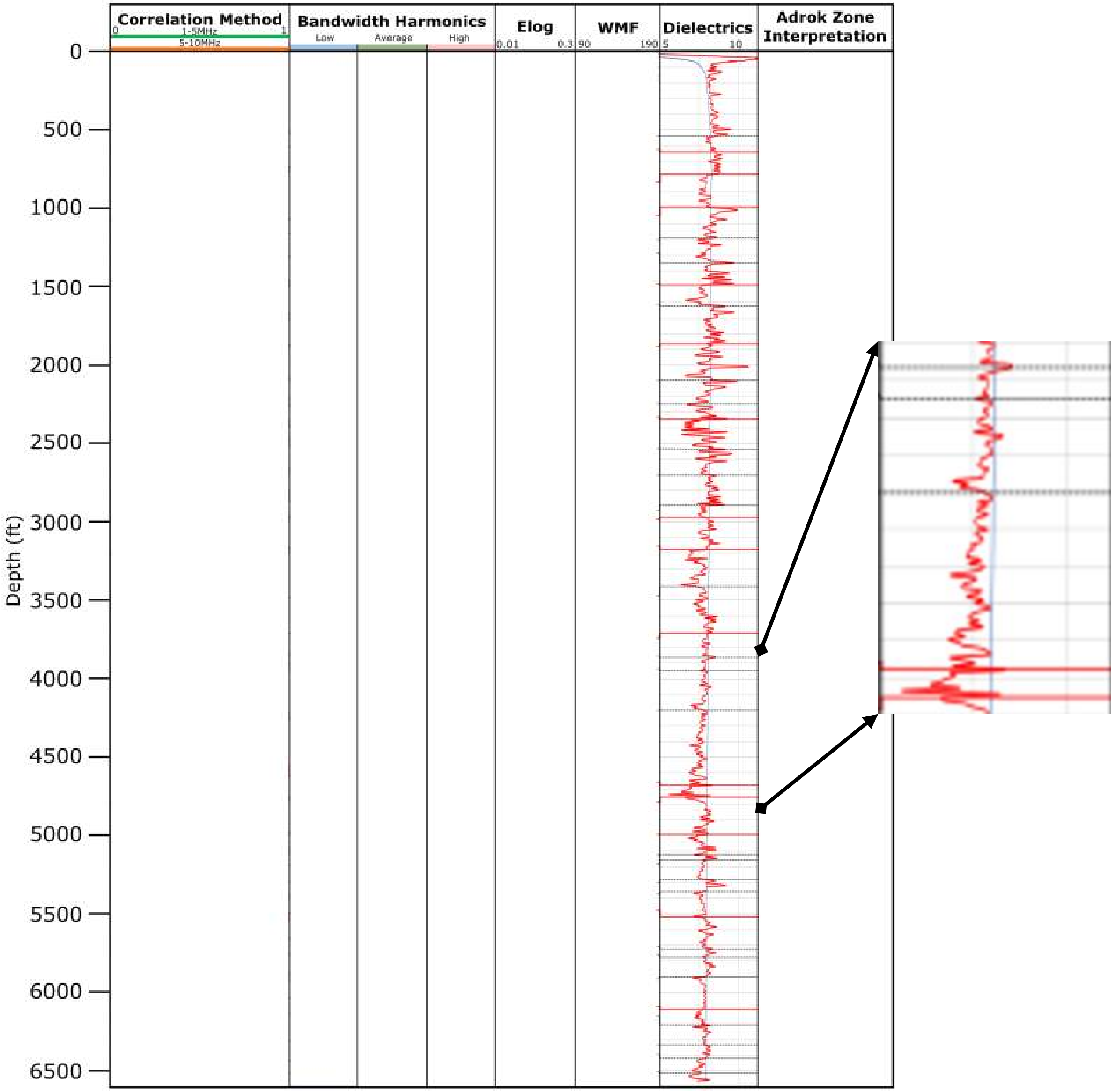


Dielectrics have been calculated from two independent methods: Ray Tracing and Normal MoveOut (NMO) methods.

Dielectrics calculated every 5ft depth.

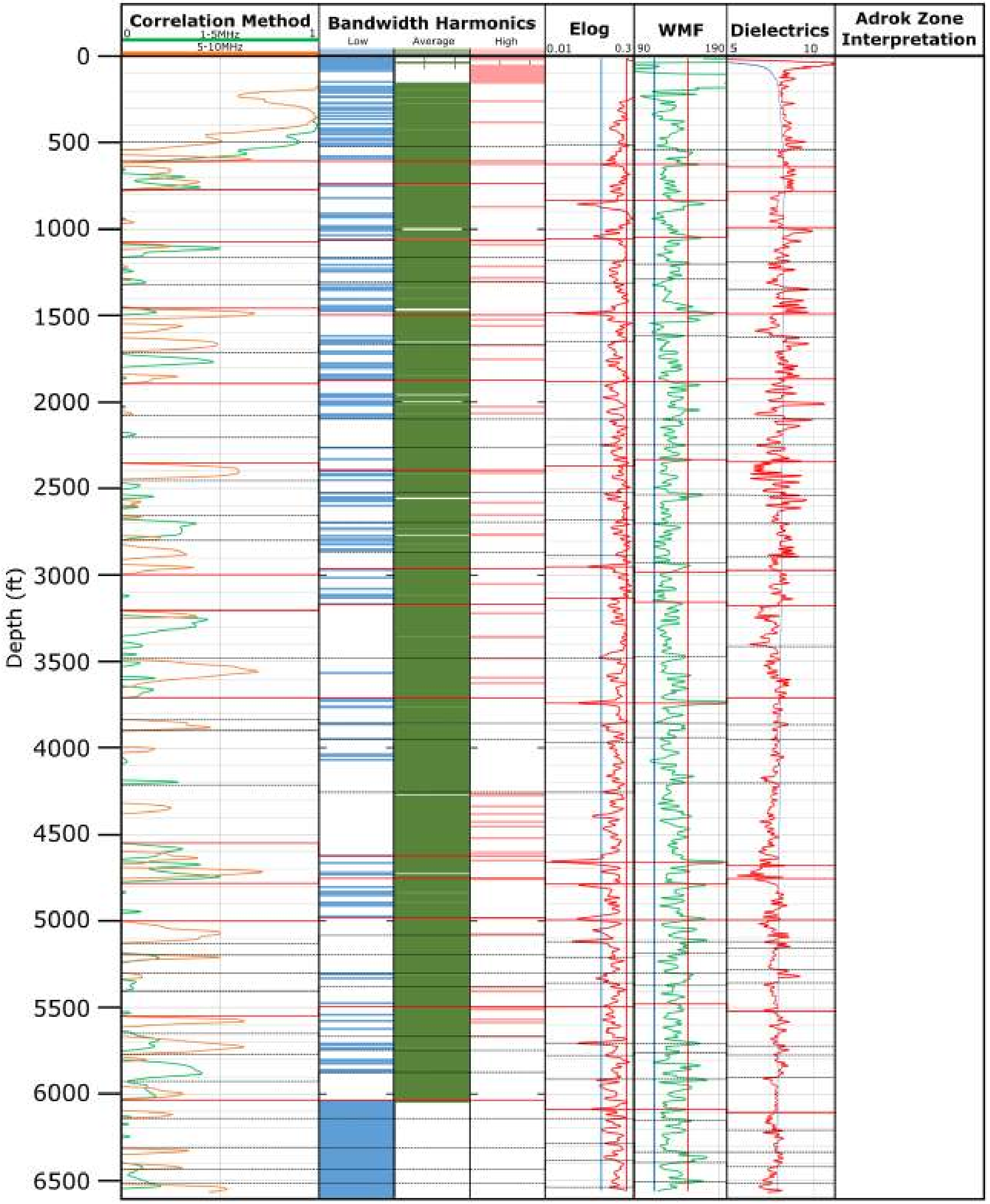
The value to subsurface geology is that hydrocarbons typically have a very low dielectric constant – between 1 and 5, (air and a vacuum ~1), water has a very high one (~80) and most rocks are in the range 4-12, though some pure exotic minerals and clay rich mixtures go higher.

5) Dielectric Constant Log (interp.)



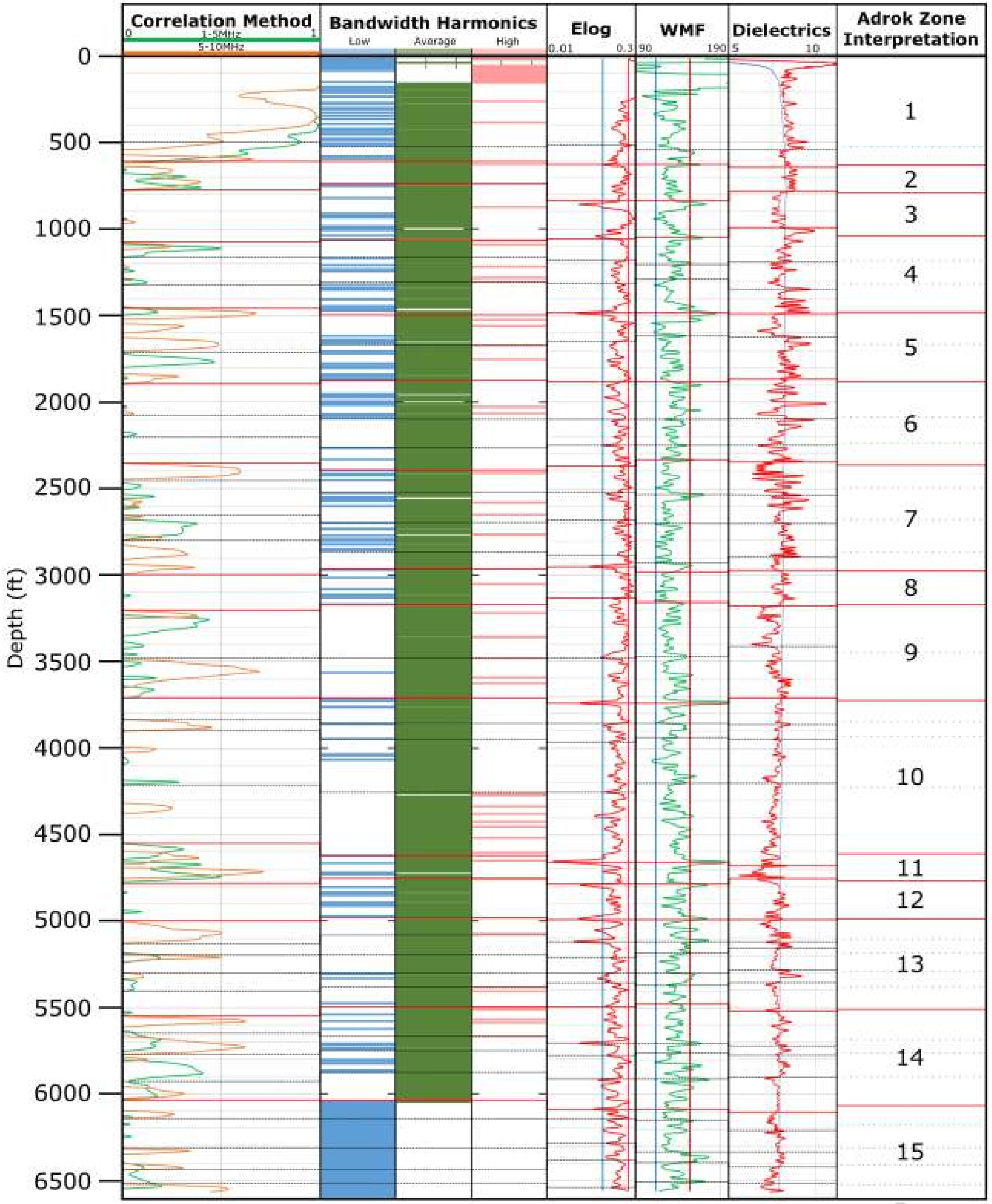
- The **red lines** mark the greatest peaks and troughs, as well as major changes in trends.
- The ***dotted black lines*** mark smaller changes, such as smaller troughs and peaks within a trend.

6) Interpreted Parameters



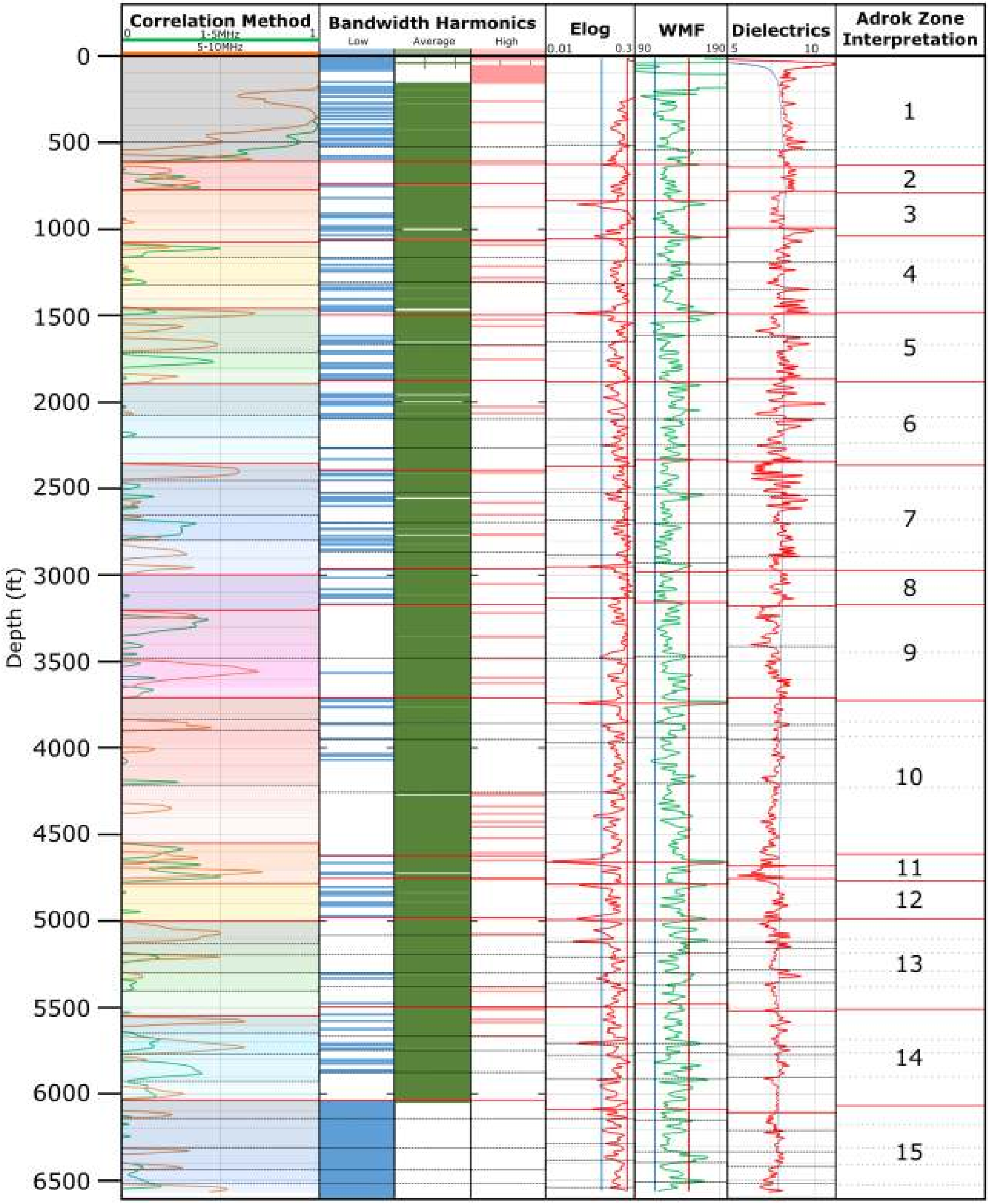
- The **red lines** mark the starkest of value or trend changes over the whole panel of parameters
- The ***dotted black lines*** mark the smaller changes, such as smaller troughs and peaks within a trend, or small changes in the distribution of values.

7) Joint Interpretation



- To generate the final ADR zones, an average depth value for each line (red or dotted) is calculated by seeking the nearest common line.
- The **red lines** will end up determining the start and end of the ADR Zones, as well as the amount of Zones.
- The ***dotted black lines*** will end up determining Sub-Zones within each ADR Zone, potentially identifying gradational contacts or more subtle changes.

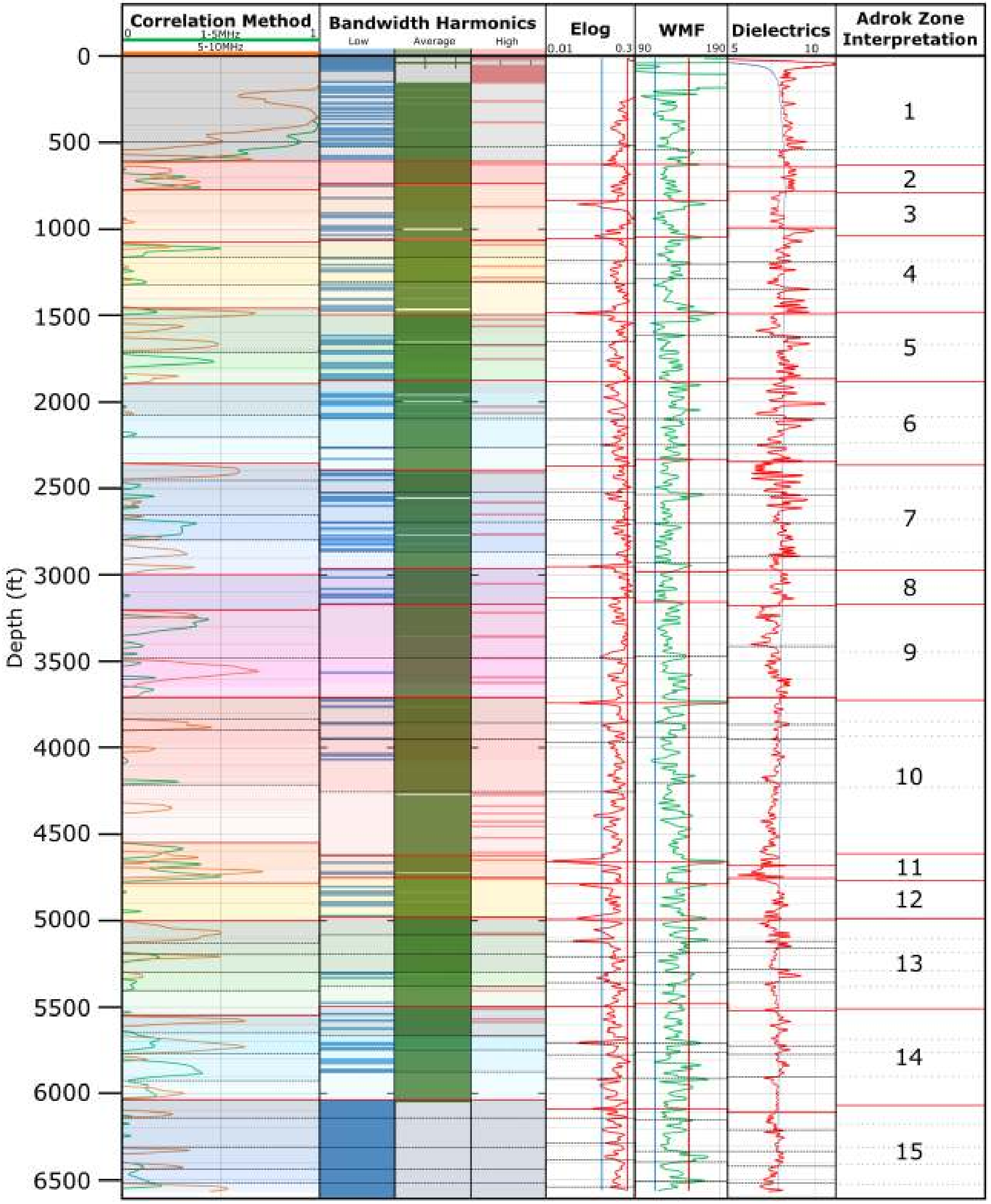
8) Visualisation of Zones (1)



After the ADR zones have been stablished, each Zone is assigned a colour, and each Sub-Zone a subtle variation of that colour.
This process is done for each parameter.

- The Correlation Method
- ...

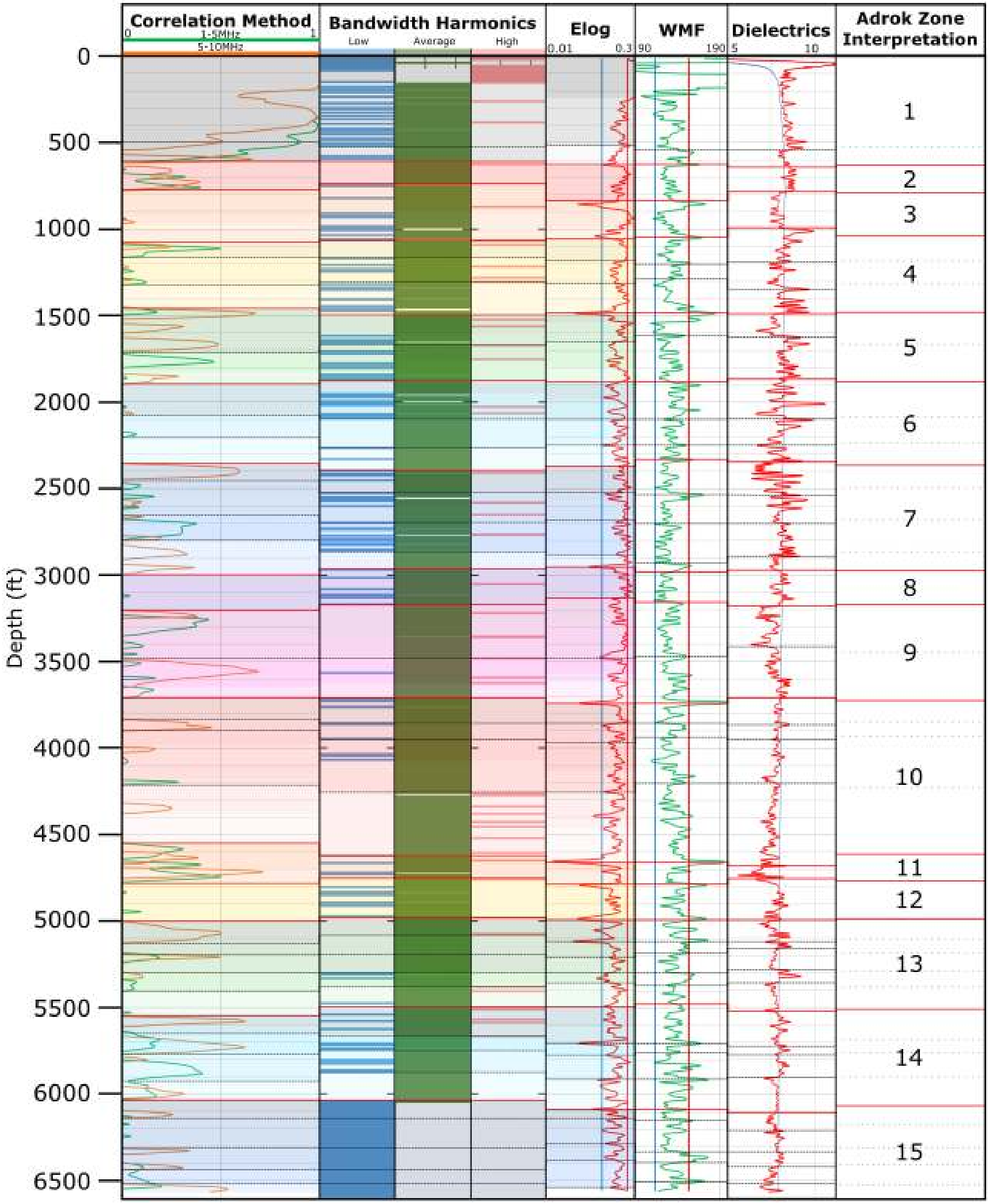
8) Visualisation of Zones (2)



After the ADR zones have been stablished, each Zone is assigned a colour, and each Sub-Zone a subtle variation of that colour.
This process is done for each parameter.

- The Correlation Method
- Bandwidth Harmonics
- ...

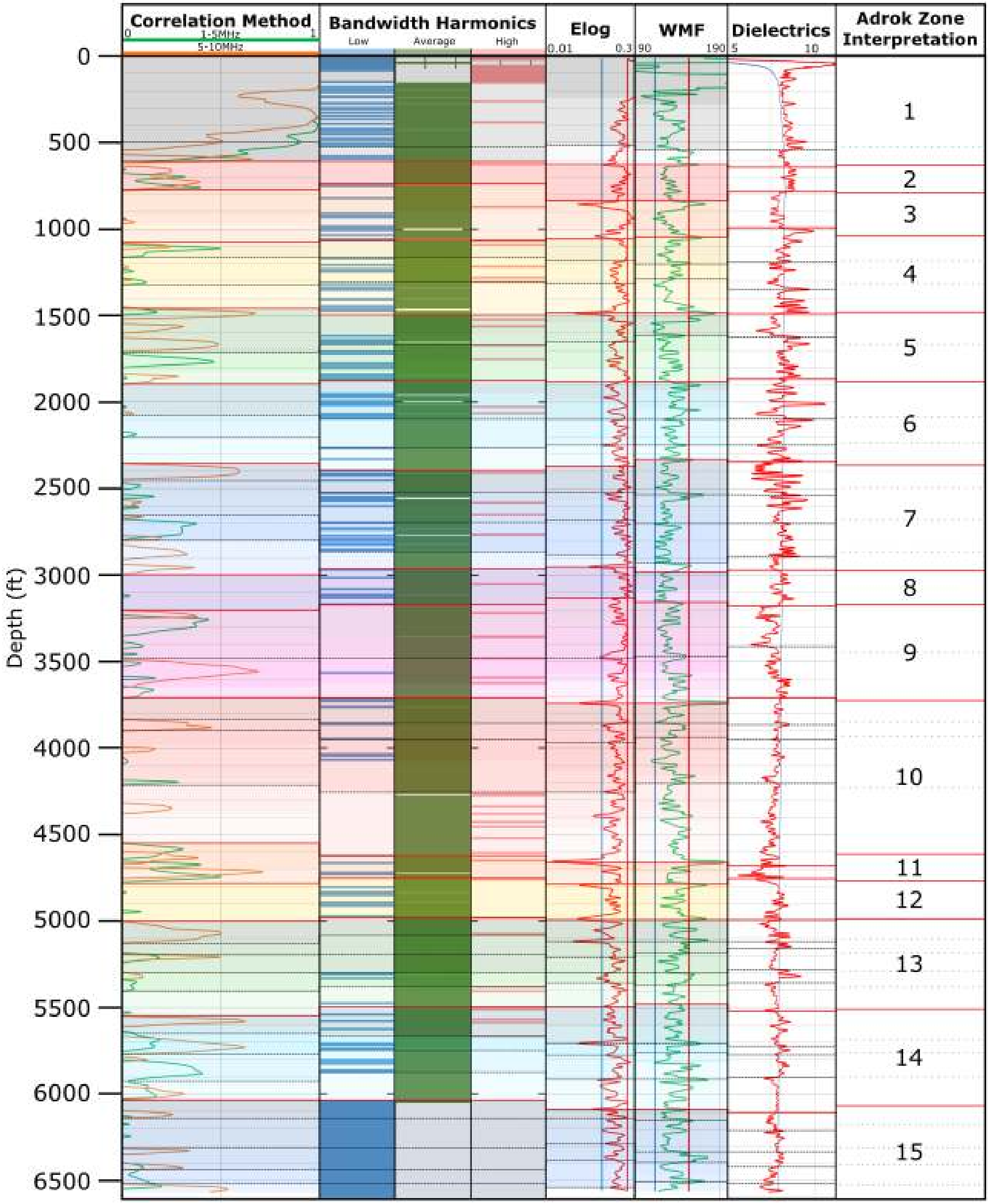
8) Visualisation of Zones (3)



After the ADR zones have been stablished, each Zone is assigned a colour, and each Sub-Zone a subtle variation of that colour.
This process is done for each parameter.

- The Correlation Method
- Bandwidth Harmonics
- Energy Log (Elog)
- ...

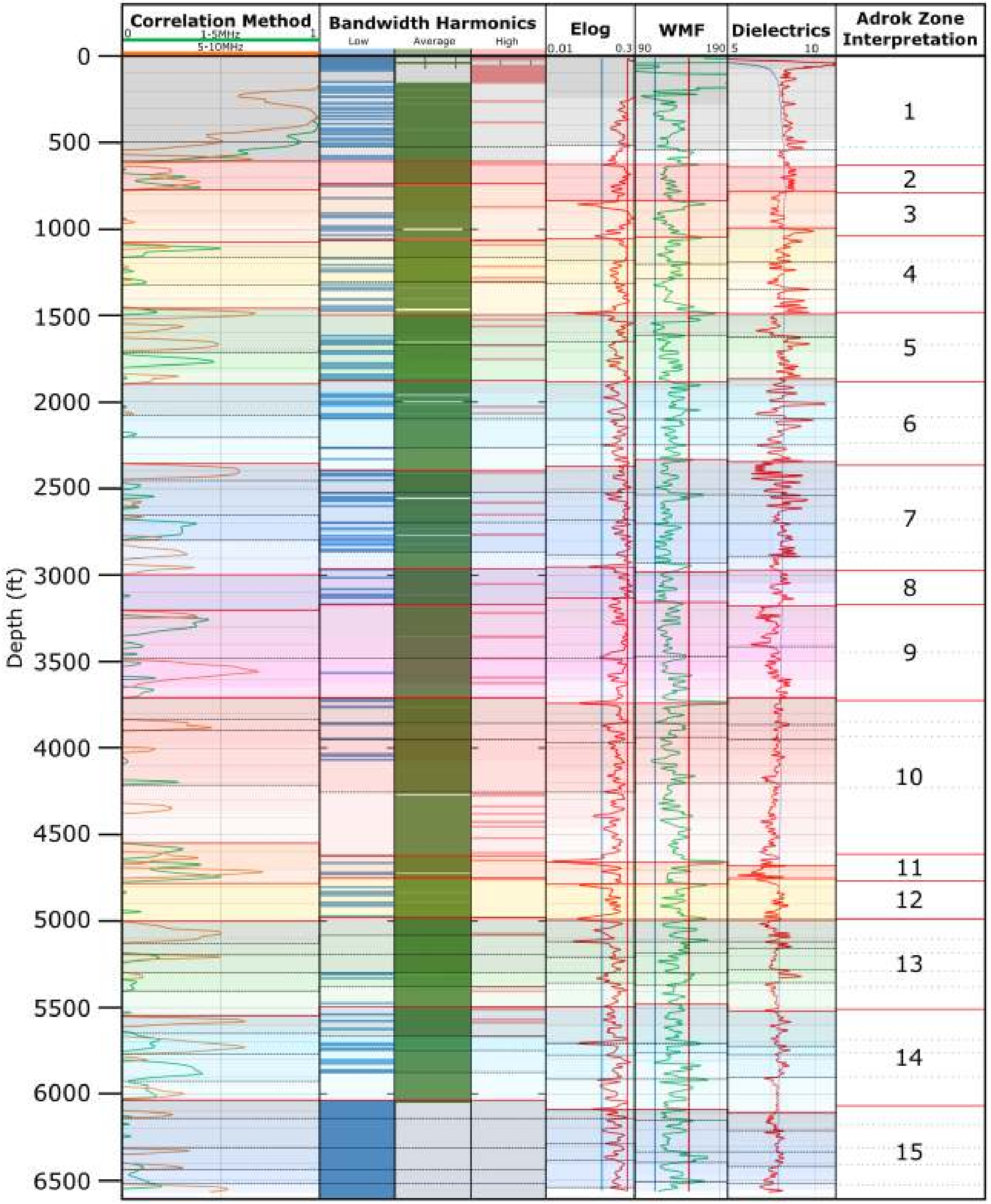
8) Visualisation of Zones (4)



After the ADR zones have been stablished, each Zone is assigned a colour, and each Sub-Zone a subtle variation of that colour.
This process is done for each parameter.

- The Correlation Method
- Bandwidth Harmonics
- Energy Log (Elog)
- Weighted Mean Frequency (WMF)
- ...

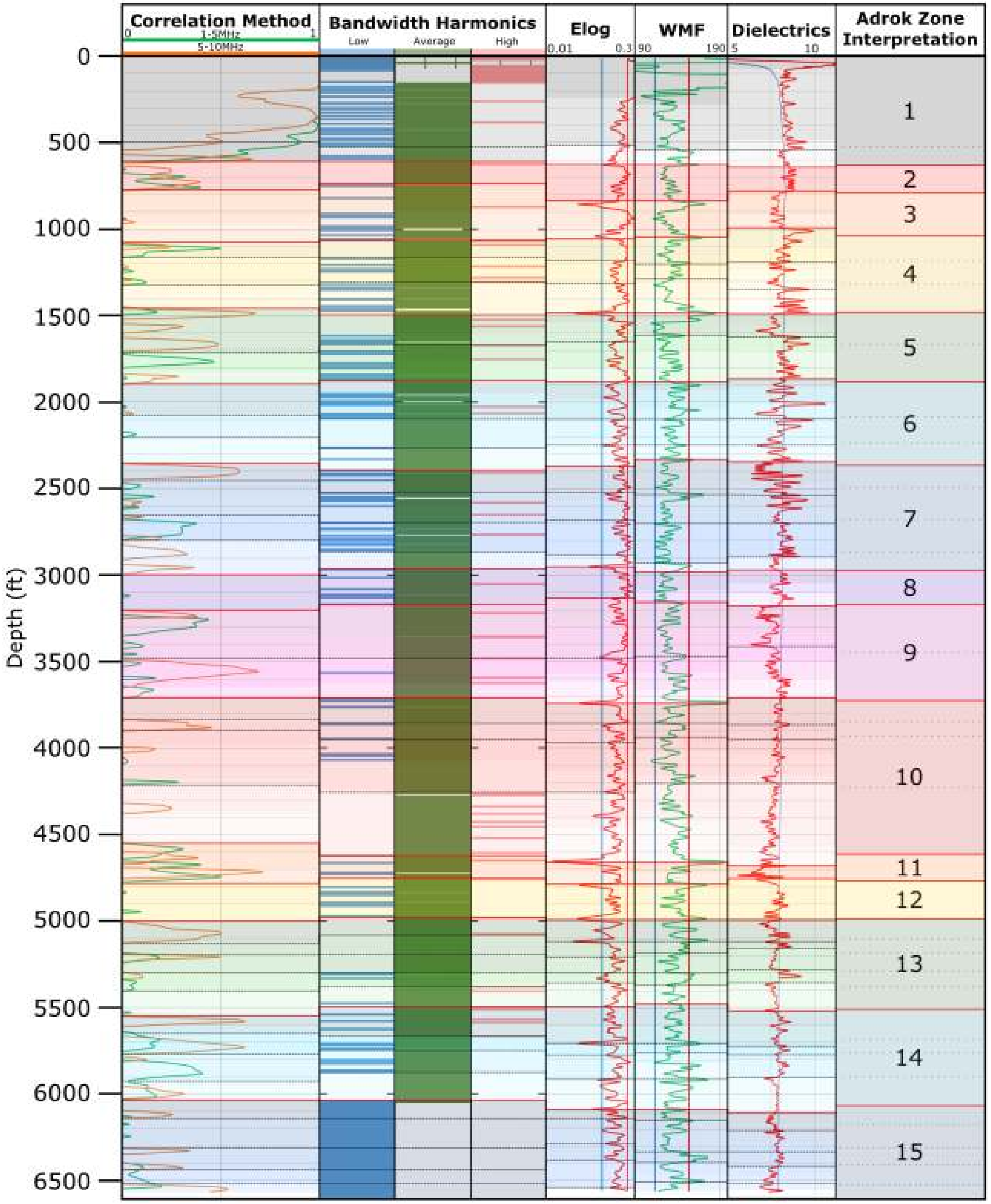
8) Visualisation of Zones (5)



After the ADR zones have been stablished, each Zone is assigned a colour, and each Sub-Zone a subtle variation of that colour.
This process is done for each parameter.

- The Correlation Method
- Bandwidth Harmonics
- Energy Log (Elog)
- Weighted Mean Frequency (WMF)
- Dielectric Constant log (Dielectrics)
- ...

8) Visualisation of Zones (5)



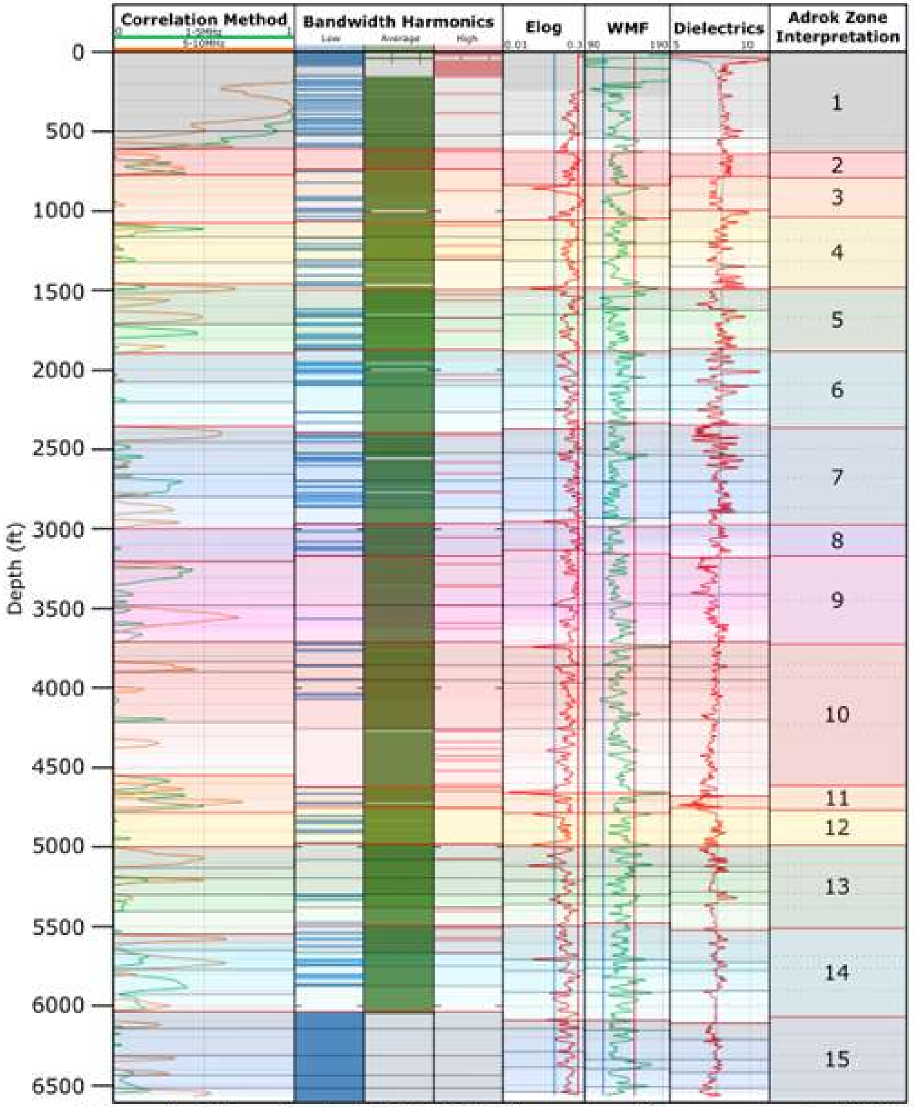
After the ADR zones have been stablished, each Zone is assigned a colour, and each Sub-Zone a subtle variation of that colour.
This process is done for each parameter.

- The Correlation Method
- Bandwidth Harmonics
- Energy log
- Weighted Mean Frequency
- Dielectric Constant log

- **And to complete the process, the ADR Zones**
  - The next slide shows a very detailed breakdown of the behaviour of each of the 5 parameters within each of the 15 detected ADR Zones.

ADR Zones Summary for H10d

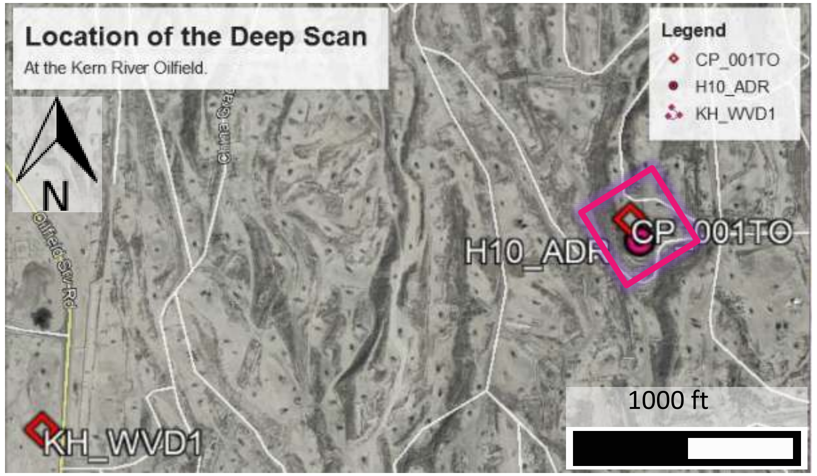
(Delivered in 2018Q2)



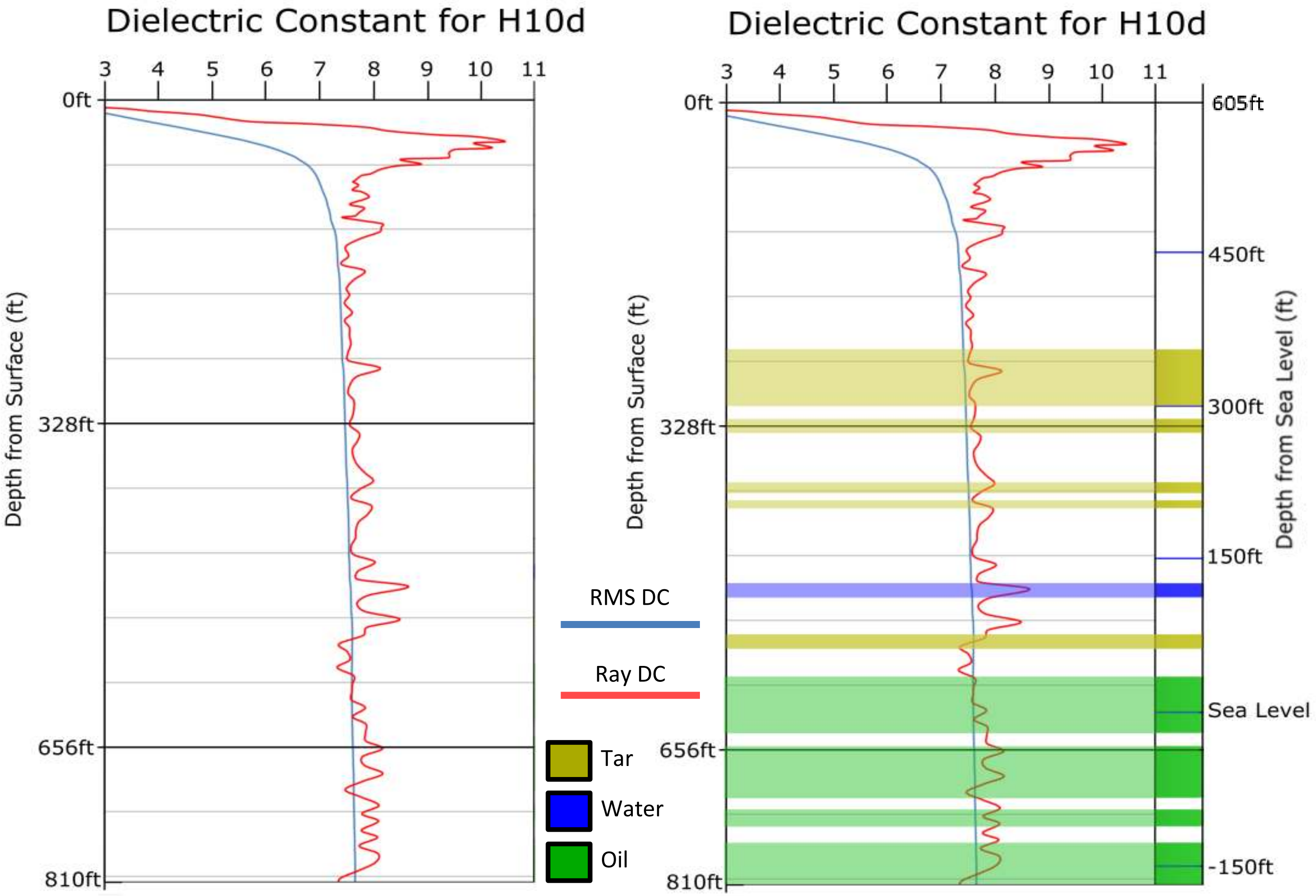
H10d						
Zone	**Zone Top Depth (ft)**	**CORRELATION METHOD**	**BWH**	**ELOG**	**WMF**	**DIELECTRICS**
1	0	Log signatures indicative of gain				
2	620	Broad peaks around 0.4 in both frequencies.	Dominated by average values, with the top marked by a high and base by a low.	High values with little fluctuation between baselines.	Little variation in values between baselines.	Values dominantly above NMO.
3	790	With the exception of two minor peaks, both frequencies do not rise about the SD.	Dominated by average values with low values also present throughout. One high present.	Top marked by a sharp, large trough with values gradually decreasing with depth.	Top marked by a sharp, large peak with values gradually increasing with depth.	Values dominantly below NMO.
4	1025	Two peaks between 0.25 - 0.5 in each frequency, with the size of peaks decreasing throughout the zone.	Dominated by average values but low values present throughout, with highs restricted to top half of zone.	Top marked by a trough. Fluctuation of values between baselines.	Top marked by a peak. Fluctuation of values between baselines.	Large fluctuation of values around NMO.
5	1490	Large peaks up to 0.7 in 5-10MHz, with one small peak in 1-5MHz present at top of zone.	Dominated by average values with low and high values present throughout.	Top marked by a trough. Fluctuation of values between baselines.	Top marked by a large broad peak. Fluctuation of values between baselines.	Top section of zone characterised by values below NMO which change to fluctuating around NMO with depth.
6	1870	With the exception of three minor peaks, both frequencies do not rise about the SD.	Dominated by average values with low and high values mostly present in top half of zone.	Fluctuation of values between baselines, with an overall increasing trend.	Fluctuation of values between baselines, with a slight overall decreasing trend.	Large fluctuation of values around NMO.
7	2350	Top of zone is marked by a large peak in the 5-10MHz correlation, with smaller peaks in the 1-5MHz present throughout rest of zone.	Dominated by average values with low and high values present throughout.	Fluctuation of values between baselines, with an overall increasing trend.	Fluctuation of values between baselines, with a slight overall decreasing trend. Large peak present in middle of zone.	Large fluctuation of values around NMO, with range of values gradually decreasing with depth.
8	2980	With the exception of a minor peak in the 1-5MHz, both frequencies do not rise about the SD.	Dominated by average values with low values also present throughout. One high present.	Top marked by large trough with an overall increasing trend with depth.	Top marked by a large trough with an overall decreasing trend.	Minor fluctuation of values around NMO.
9	3155	Peaks in both frequencies ranging from 0.1 - 0.7.	Dominated by average values with highs sparsely present throughout. One low present.	Variation in value trends between the baselines.	Variation in value trends between the baselines.	Values dominantly below NMO, but gradually start to move closer to the NMO with depth.
10	3715	Sparse peaks in both frequencies ranging up to 0.45 in size.	Dominated by average values with low values restricted to top half of zone and high values restricted to lower half of zone.	Top marked by a large trough with variation in values between the baselines.	Top marked by a very large peak with variation in values between the baselines.	Values close to NMO by mostly below NMO.
11	4600	Large abundant peaks in both frequencies.	Dominated by average values with low values also present throughout. One high present.	Top marked by a very large trough with an overall increasing trend in values.	Top marked by a large peak with an overall decreasing trend in values.	Large range of values that are dominantly below NMO.
12	4755	With the exception of two minor peaks in the 1-5MHz, both frequencies do not rise about the SD.	Average values dominate with low values present throughout zone. Absence of high values.	Top and base marked by a trough, with values fluctuating between baselines.	Top and base marked by a peak, with values fluctuating between baselines.	Fluctuation of values around NMO.
13	4990	Peaks in both frequencies that gradually decrease in size with depth.	Average values dominate with low and high values present sporadically throughout.	Overall increasing trend in values with depth.	Overall decreasing trend in values with depth.	Fluctuation of values around NMO.
14	5505	Abundant peaks in both frequencies that range from 0.2 - 0.6 in size.	Average values dominate with low values present throughout zone. High values present only in top half of zone.	Fluctuation of values between baselines.	Fluctuation of values between baselines.	Fluctuation of values around NMO.
15	6055	Peaks in 5-10MHz gradually increase in size with depth, with minor peaks up to 0.2 in size in 1-5MHz.	Low values dominate with an absence of average and high values.	Fluctuation of values between baselines.	Fluctuation of values between baselines.	Fluctuation of values around NMO.

***Figure:** (Left) Zonation for H10d, (Right) Summary of log responses for H10d. The table shows an overview of the 15 zones identified, providing common log responses for each result within each zone.*

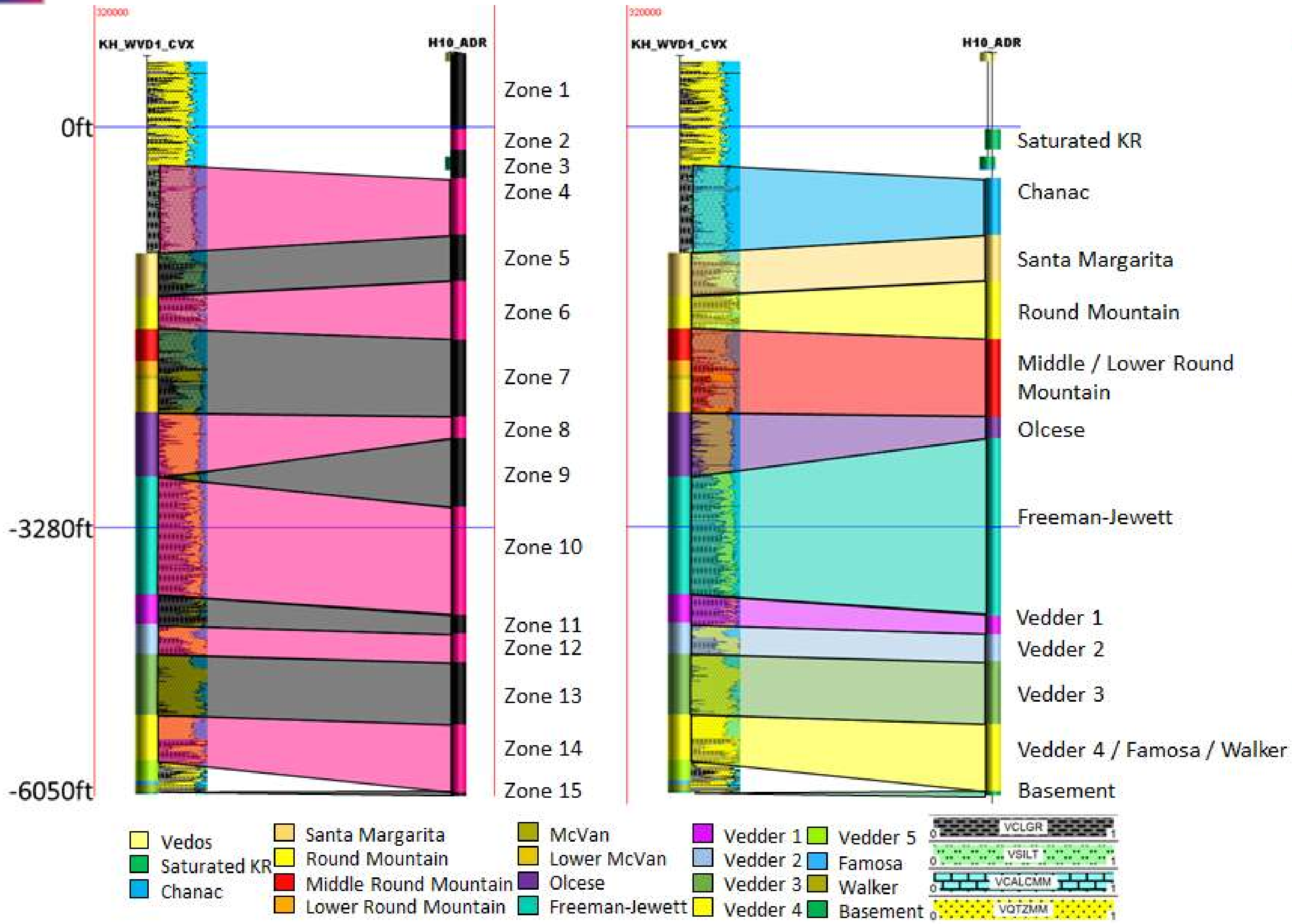
Shallow Fluid Bearing Comparison



- This diagram compares the Dielectric Constant (DC) tracked during 2018 to the Fluid presence data from CP_001TO (5ft corrected for elevation difference).
- The CP_001TO report indicates the depths for Tar Sands, Wet Sands and Oily Sands, those depths are highlighted in the diagram.
- The DC correlates with the water interval just below 140ft above sea level.
- The DC tends to dip below RMS (the blue line) or present a trough at the Oily intervals.
- The comparison indicates that ADR is successful at finding the wet and oily sands.



Deep Scan Comparison (1) - Summary



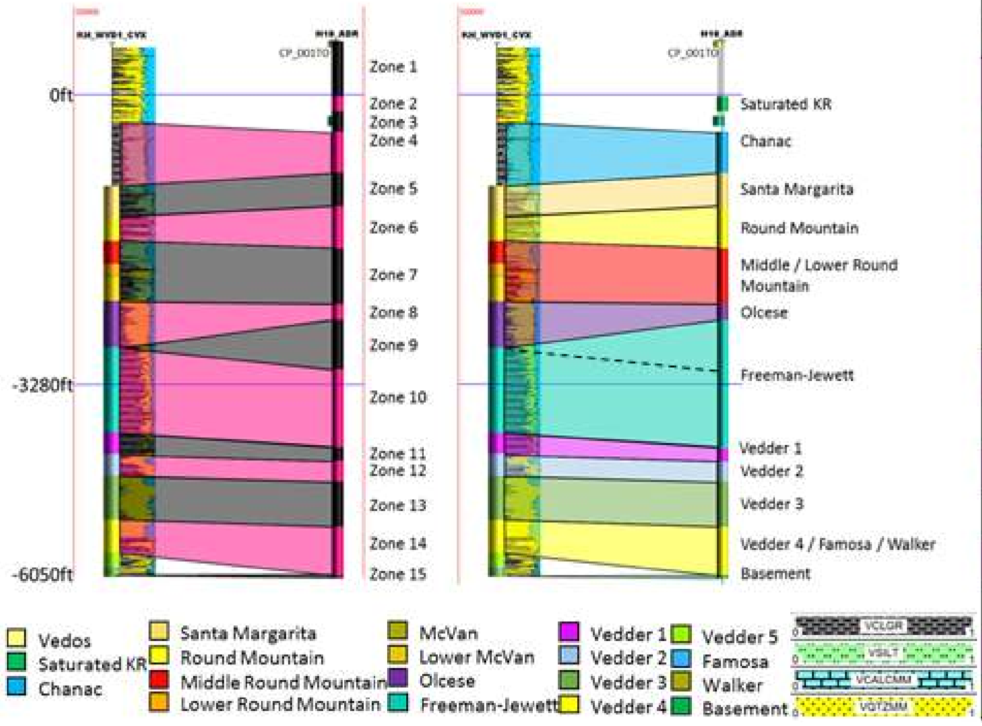
Zones	Formation
Zone 1	-
Zone 2	Saturated KR
Zone 3	Saturated KR
Zone 4	Chanac
Zone 5	Santa Margarita
Zone 6	Round Mountain
Zone 7	Middle/Lower Round Mountain
Zone 8	Olcese
Zone 9	Freeman-Jewett
Zone 10	Freeman-Jewett
Zone 11	Vedder 1
Zone 12	Vedder 2
Zone 13	Vedder 3
Zone 14	Vedder 4 / Famosa / Walker
Zone 15	Basement

- Most of the Zones relate very well in thickness with the formations.
- Zone 15 relates spot on to the Basement depth.
- The amount of distinct ADR Zones corresponds very well to the number of Formations identified/verified by CVX. .

Deep Scan Comparison (2) - Summary

- A numerical comparison has also been carried out to check on the depths of the Formations and Zones, as shown below.
  - The Freeman Jewett Formation is overestimated by 478ft, while the Olcese is underestimated by 352ft.
  - The basement is found 25ft deeper with the ADR Deep Scan.
  - The thickness of the Santa Margarita, and the Vedder formations has been prognosed very close to the drill results
- The average depth difference for the tops is 125 ft. Over 6600ft total depth this represents 2%.
- The average thickness difference is 174 ft.

Zone is Shallower	Zone is Thinner
Zone is Deeper	Zone is Thicker



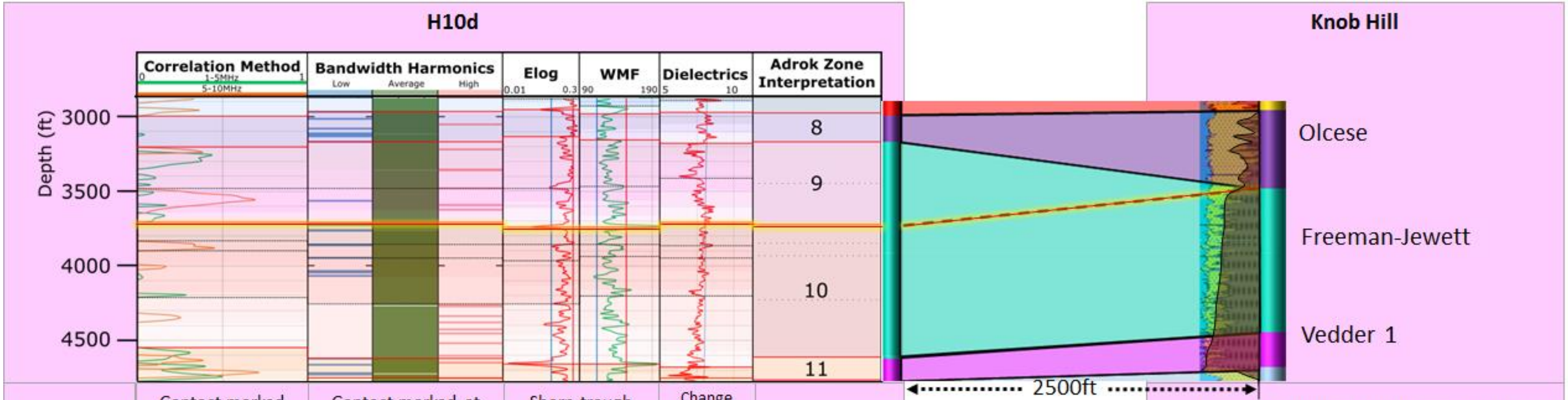
ADR Zone	Top of Zone	Thickness of Zone in ft	Formation	Top of Fm in ft	Thickness of Fm in ft	Difference of top in ft.	Thickness difference
Zone 2	620 ft	170 ft	Saturated KR	854 ft	83 ft	234	-322
Zone 3	790 ft	235 ft					
Zone 4	1025 ft	465 ft	Chanac	937 ft	680 ft	-88	215
Zone 5	1490 ft	380 ft	Santa Margarita	1617 ft	363 ft	127	-17
Zone 6	1870 ft	480 ft	Round Mountain	1980 ft	259 ft	110	-221
Zone 7	2350 ft	630 ft	Mdl/Lwr Round Mt.	2239 ft	684 ft	-111	54
Zone 8	2980 ft	175 ft	Olcese	2923 ft	527 ft	-57	352
Zone 9	3155 ft	560 ft	Freeman-Jewett	3450 ft	967 ft	295	-478
Zone 10	3715 ft	885 ft					
Zone 11	4600 ft	155 ft	Vedder 1	4417 ft	237 ft	-183	82
Zone 12	4755 ft	235 ft	Vedder 2	4654 ft	254 ft	-101	19
Zone 13	4990 ft	515 ft	Vedder 3	4908 ft	492 ft	-82	-23
Zone 14	5505 ft	550 ft	Vedder 4/Famosa/Walker	5400 ft	630 ft	-105	80
Zone 15	6055 ft		Basement	6030 ft		-25	

Discussion (1) – Deep Scan to 6000ft

Olcese and Freeman-Jewett discrepancy

1. The Freeman Jewett Formation is overestimated by 478ft.
2. The Olcese is underestimated by 352ft.

- This is due to the boundary interpreted between Zone 9 and Zone 10, the diagram below outlines the features in the parameters that led to this decision.



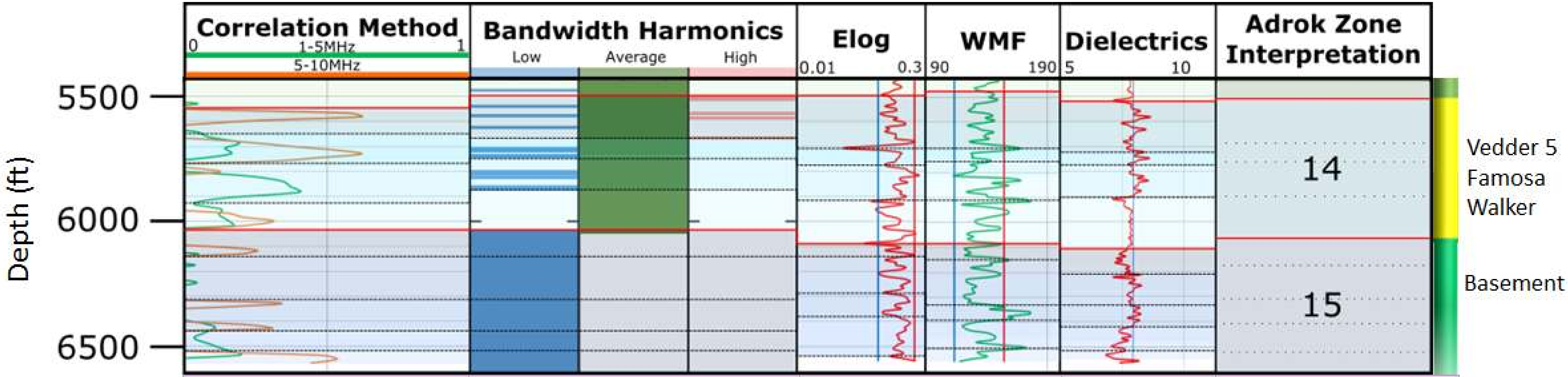
Zone 9 to 10 boundary parameters:	Contact marked by the end of a sequence of small 10-5MHz correlation peaks.	Contact marked at the beginning of several bands of low values, and after several highs.	Sharp trough and peak respectively for Elogs and WMF parameters.	Change from increasing trend to a stable interval.	Zone 10 top at 3715ft.	The contact between the Olcese and the Freeman-Jewet is a gradational contact, which makes the pinpointing of boundaries more complex.

Discussion (2) – Deep Scan to 6000ft

Basement Identification

1. The basement is found merely 25ft deeper than in the drill log, it correlates to Adrok Zone 15.
2. The behaviour of the signal after the top of the basement was recorded and is distinctly different from the shallower zones.

- This interpretation proved very useful and the Bandwidth Harmonics show success



Correlation Method	Bandwidth Harmonics	Elog / WMF	Dielectrics	Adrok Zone Interpretation
Diminishing 1-5MHz band of correlation.	Bandwidth harmonics lose all high and medium values, only low values remain.	Sharp trough and peak respectively for Elogs and WMF parameters.	Variability for DC picks up in the basement.	Zone 15 top at 6055ft. This depth is calculated by averaging the top of the zone at the rest of the parameters.

Closing thoughts

Conclusions

- ADR is *m* scale resolution at *km* scale depth without wells or seismic
- ADR deep subsurface predrilling measurements have been presented as a Case Study
    - Chevron – Kern River oilfield, California, 6600ft depth
- Results are very promising and warrant further research and fieldwork to help improve these techniques
- ADR can be applied to measuring subsurface temperature gradients
- ADR can be applied to measuring subsurface movements of fluids using Doppler Shift techniques
- “Digitally drilling” into the subsurface is the future of exploration

Relevance to subsurface surveillance

- Predrilling Depthing

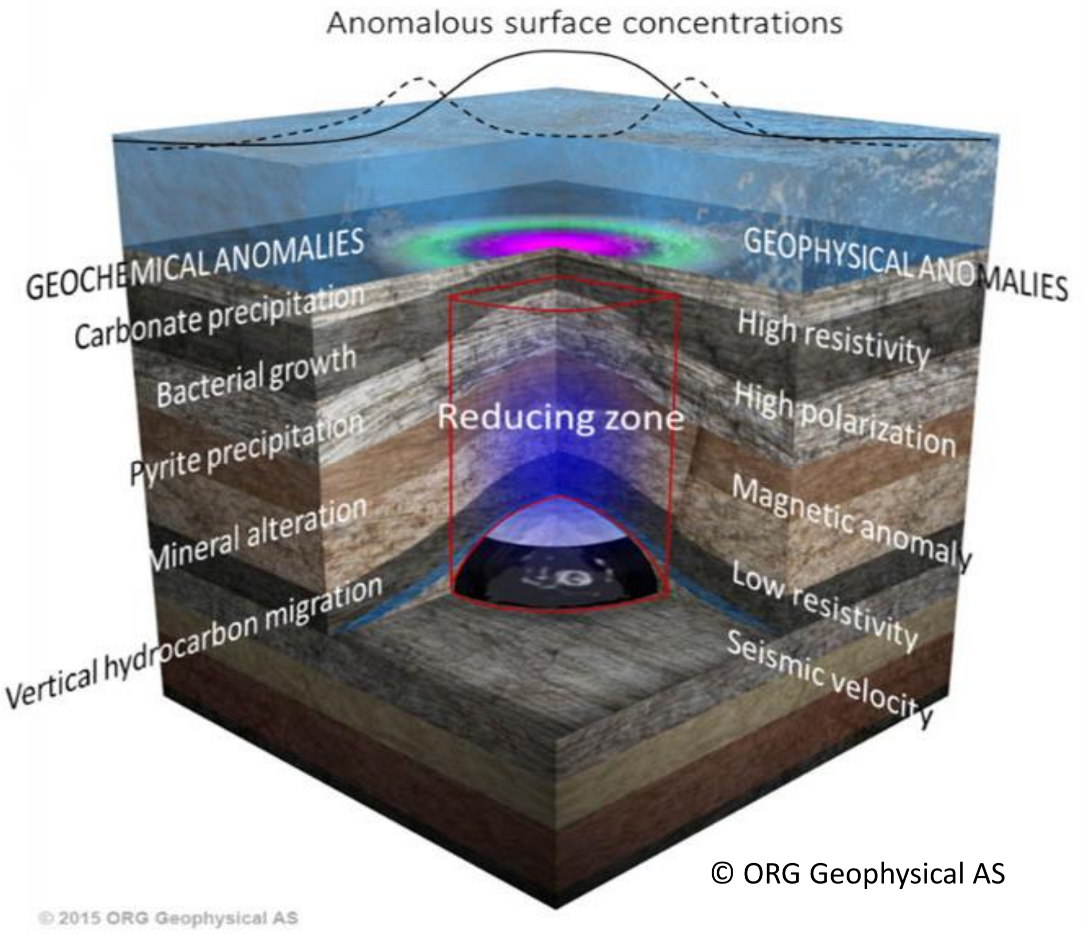
  Use ADR to provide subsurface depth intelligence to subsurface lithology and surface geochemical expressions

- Predrilling Heat Map

  Use ADR to remotely map subsurface temperature gradients from surface

- Predrilling Flow movements

  Use ADR to monitor fluid movements using Doppler Shifts in received signals



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July 2019