Large depth exploration using pulsed radar electromagnetic technology

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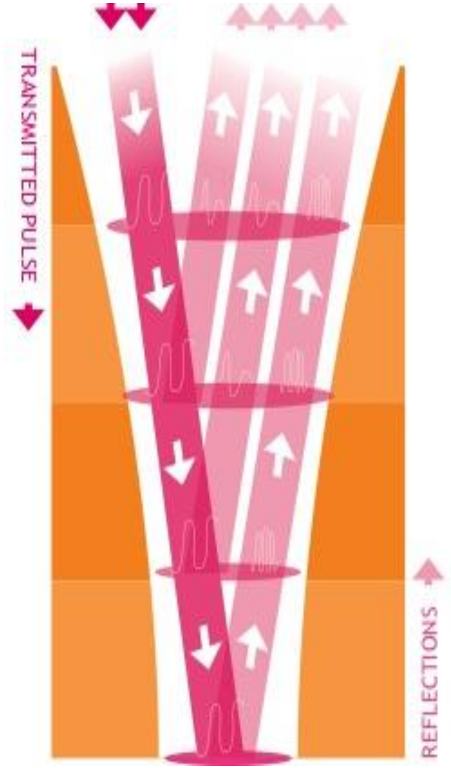
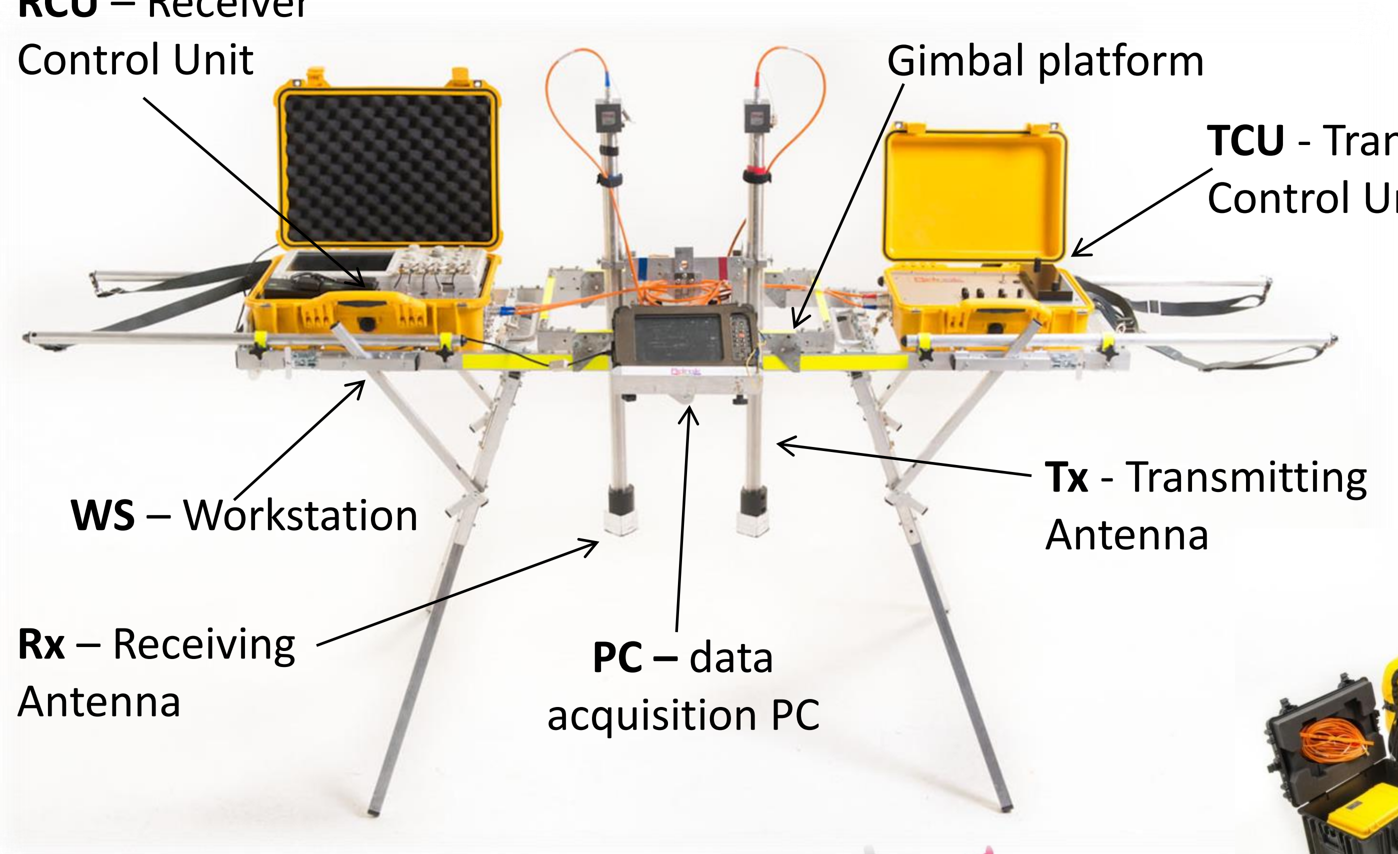
Apparatus and methodology

Atomic Dielectric Resonance (ADR)

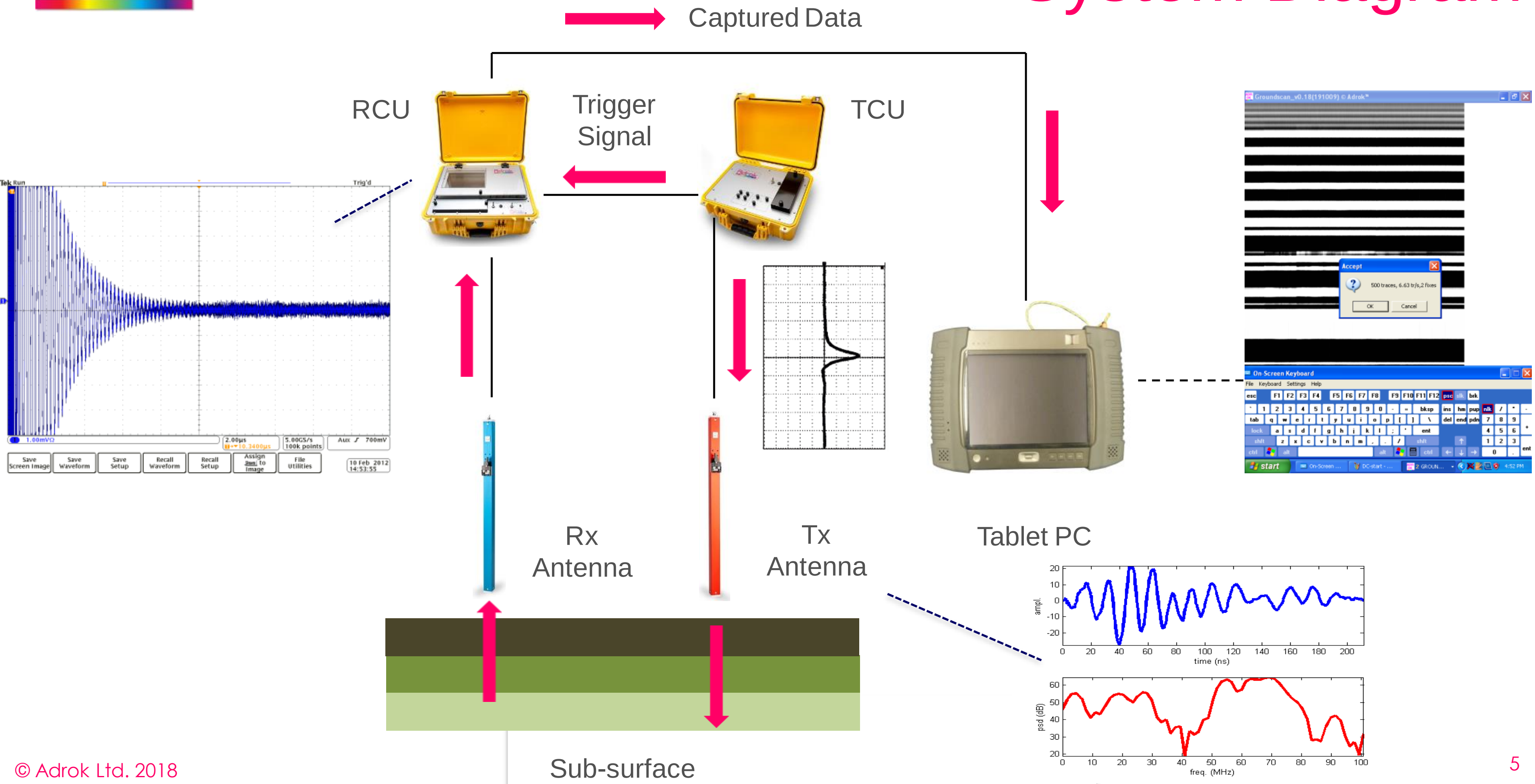
- RAdio Detection And Ranging in visually opaque materials
- ADR sends broadband pulses of radiowaves into the ground and detects the modulated reflections returned from the subsurface structures
- Transmit broad band pulses at a precisely determined Pulse Repetition Frequency (PRF) with low power (of the order of a few milliwatts, Mean Power)
- For large depth geo exploration typically transmit between 1MHz to 100MHz
- ADR measures dielectric permittivity of material
- ADR also uses spectral content of the returns to help classify materials (energy, frequency, phase)



Field ADR Scanner



System Diagram



Field system specifications

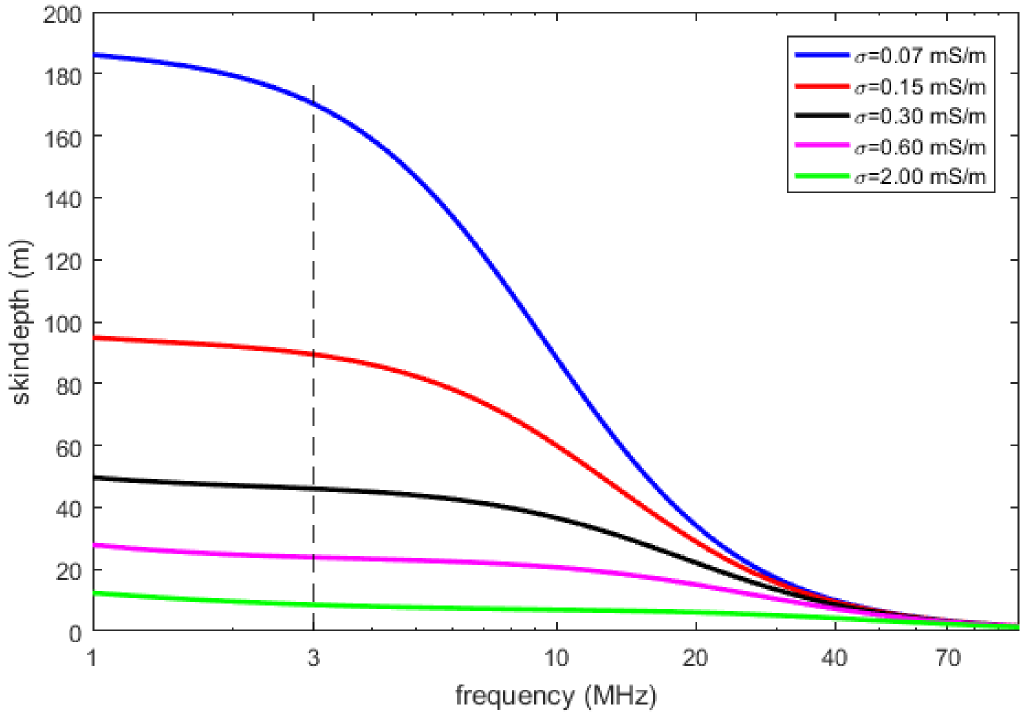
Sub-system	ADR Setting	Typical Range
TCU	Pulse width	~10ns
	Pulse repetition frequency	< 10 kHz
	Mean power	~ 5mW
	Power supply	1 off 15 Vdc Li-Ion battery
	Weight	7kg
Antenna	Tx pulse frequency	1 to 100 MHz
	Weight	5 kg
RCU:	Time Range (typical)	20,000ns, 40,000 & 100,000ns
	Number of samples/trace	100,000
	Power supply	4 off 30Vdc Li-Ion battery
	Power consumption	150W

- Pulsed based RF transmitter
- Proprietary antenna design
- High speed time domain sampling ~5GS/s
- Improvement in signal to noise through multiple waveform capture ~10,000 traces per recording station
- Effectively increase the ENOB of receiver from 8-bit to 16-bit.

Depth of subsurface penetration

- Losses are proportional to distance (in uniform material)
  - No matter what the mechanism is (for fixed frequency)
- Must be exponential exp(-d/sd)
  - d distance through medium
  - sd skindepth in meters
- Skindepth = distance where signal falls off by 1/e
- Skindepth generally decreases with frequency
  - Penetration depth proportional to skindepth
- Depends on conductivity
  - In-situ conductivity value is generally unknown (we measured ADR for limestone)
  - Value found lower than generally assumed but well within possible “book-range”

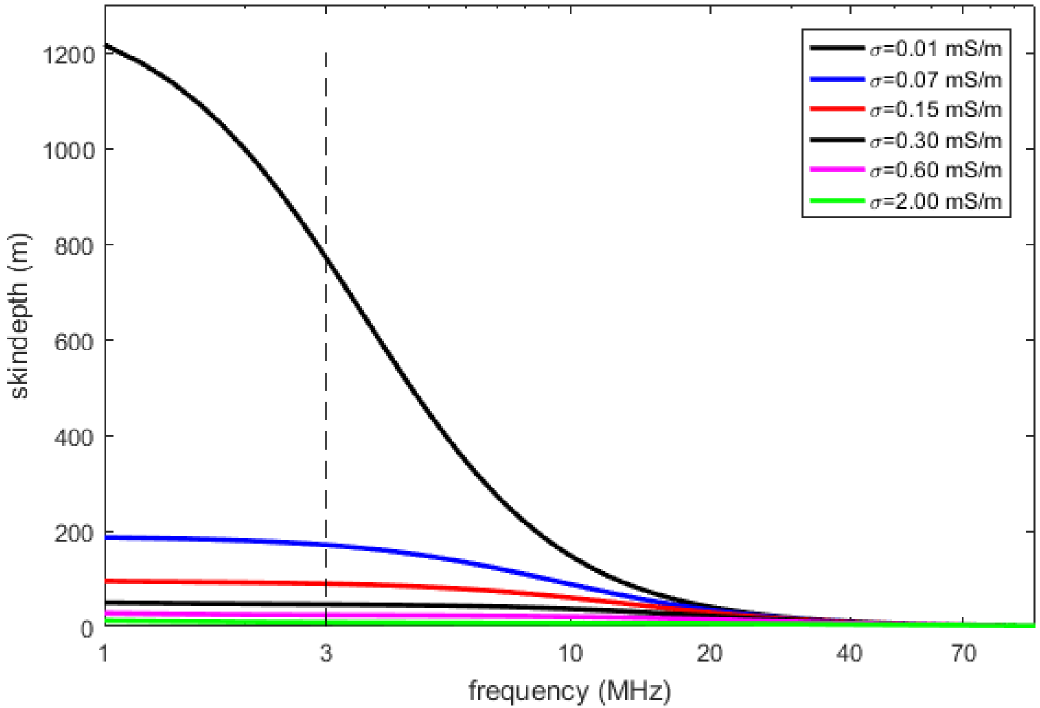
Skin depth versus frequency



- The blue curve is based on in-situ ADR measurement through limestone.
- The other curves represent various other book-values* for the conductivity, with the bottom one perhaps a reasonable guess from a geophysicist used to classical EM methods.
- ADR centre frequency for deep penetration indicated by dotted line (3MHz)

* Reynolds J.M. (2011); Jackson J.D. (1998)

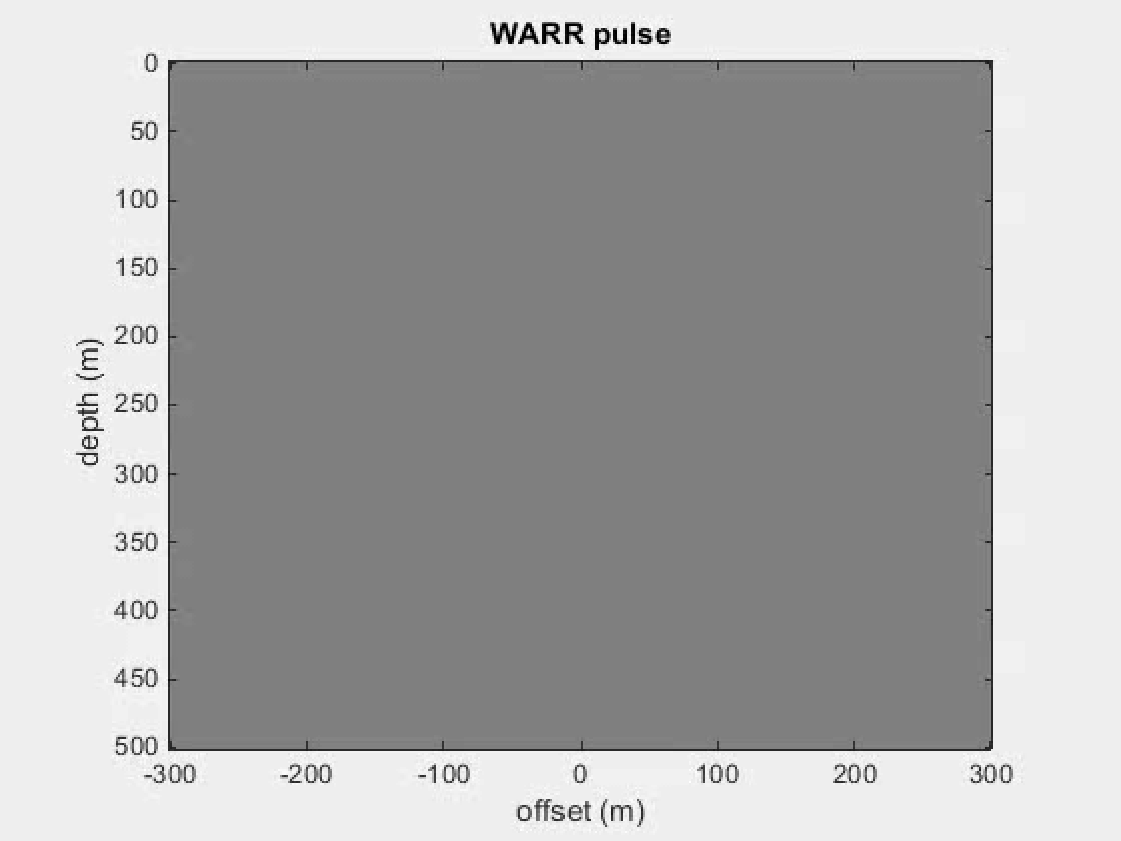
Skin depth versus frequency



- The blue curve is based on in-situ ADR measurement through limestone.
- The black curve based on book value in permafrost*.
- ADR centre frequency for deep penetration indicated by dotted line (3MHz)

* Vanhala et al, Geophysica (2009), 45(1-2), 103-118

Pulse transmission



- Line of transmitters in WARR creates beam (Synthetic Aperture Radar, SAR)
- Note in animation pulse wavelet stays coherent

Forward model

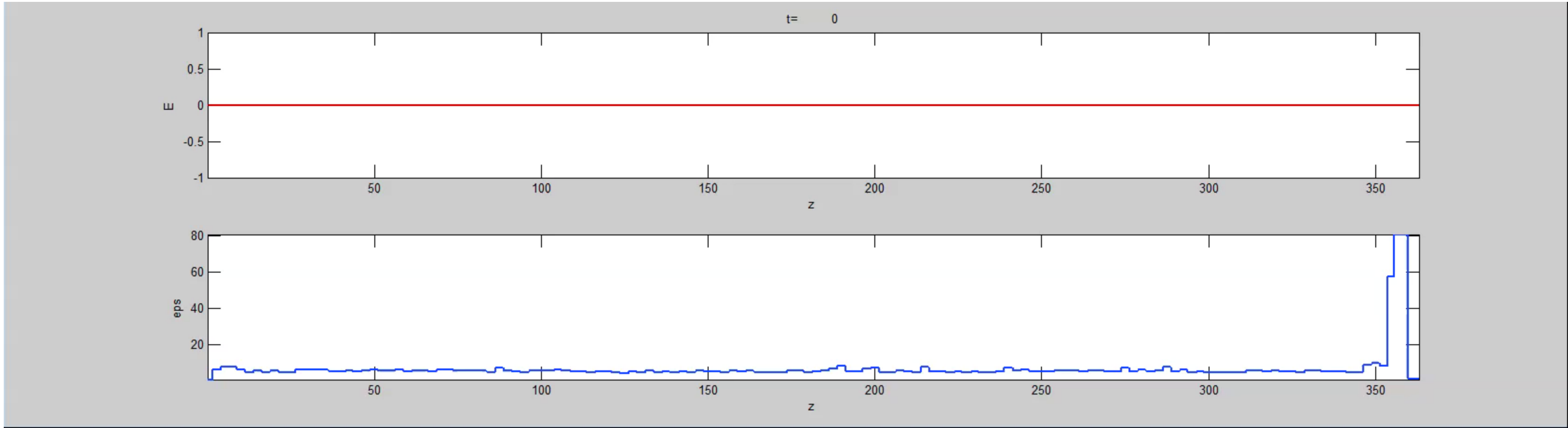
- Maxwell equations coupled to ground model
- Ground model: permittivity, conductivity and polarization (*P*)
  - E electric field, σ conductivity, τ Debye relaxation time, ε_r dielectric
- Resulting system of partial differential equations:

$$\epsilon_0 \frac{\partial^2 E(t,x)}{\partial t^2} + \sigma(x) \frac{\partial E(t,x)}{\partial t} + \frac{\partial^2 P(t,x)}{\partial t^2} - \frac{1}{\mu_0} \frac{\partial^2 E(t,x)}{\partial x^2} = 0, \qquad (1)$$

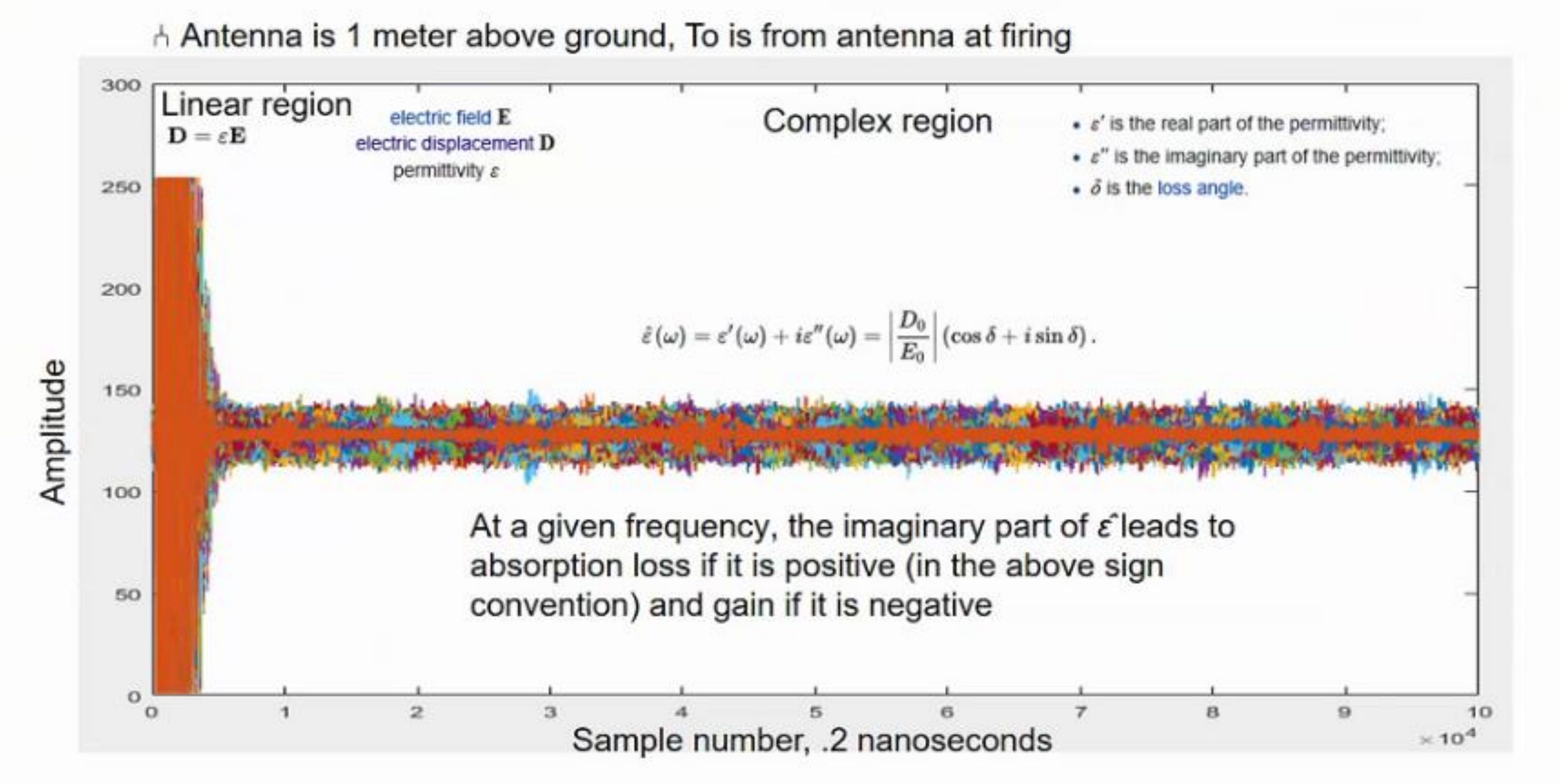
$$\tau(x) \frac{\partial P(t,x)}{\partial t} + P(t,x) = \epsilon_0(\epsilon_r(x) - 1))E(t,x). \qquad (2)$$

Simulation

- Dielectric Constant (DC) profile (bottom graph) take from WARR data
- Other parameters from transillumination experiments
- Peak in dielectric at 350m down represents a water body
- Electric field animated in top graph
  - We observe pulse traveling down (left to right)
  - Small irregularities in DC cause backscatter
  - Big reflection at jump in DC propagates back to surface



Received signals



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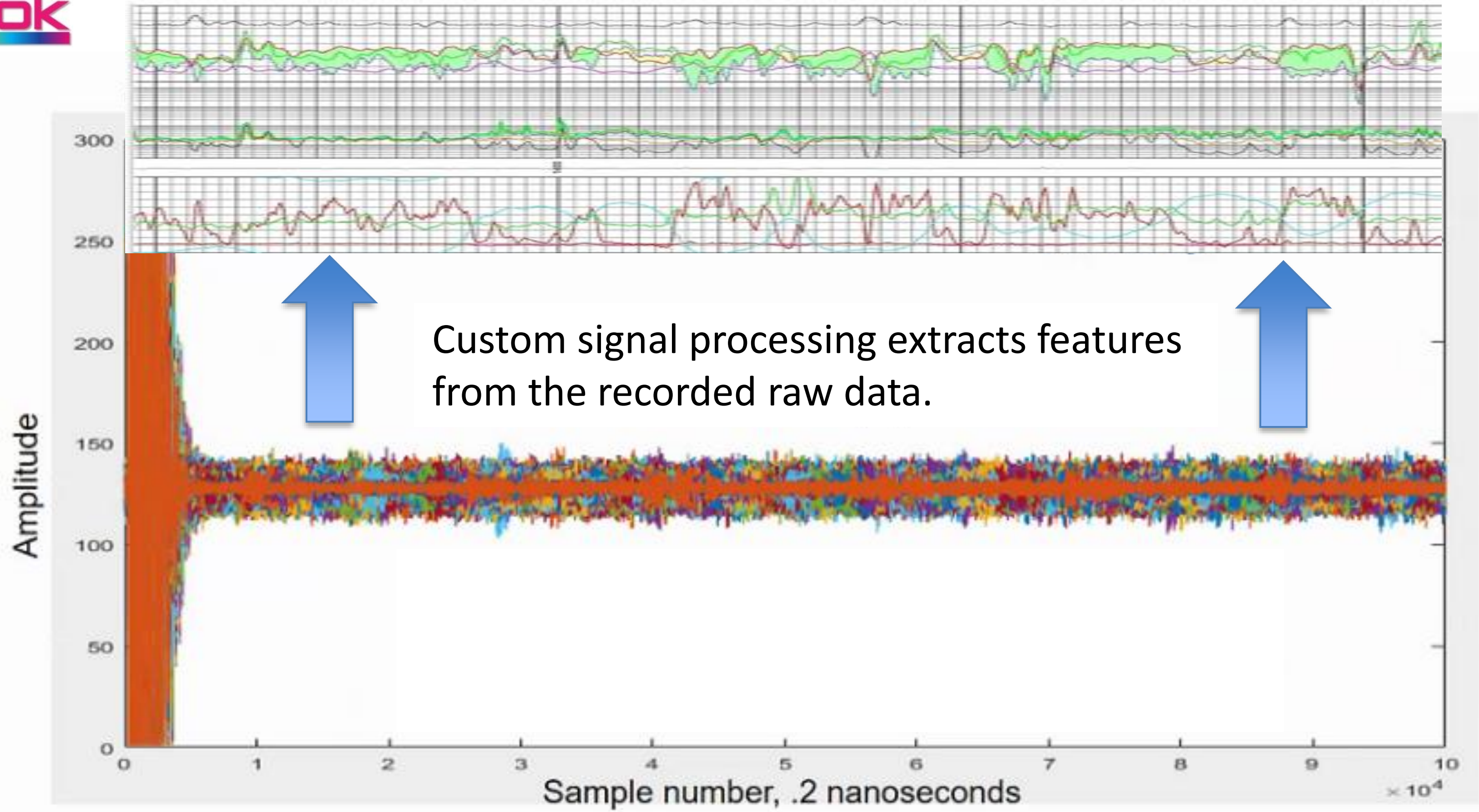
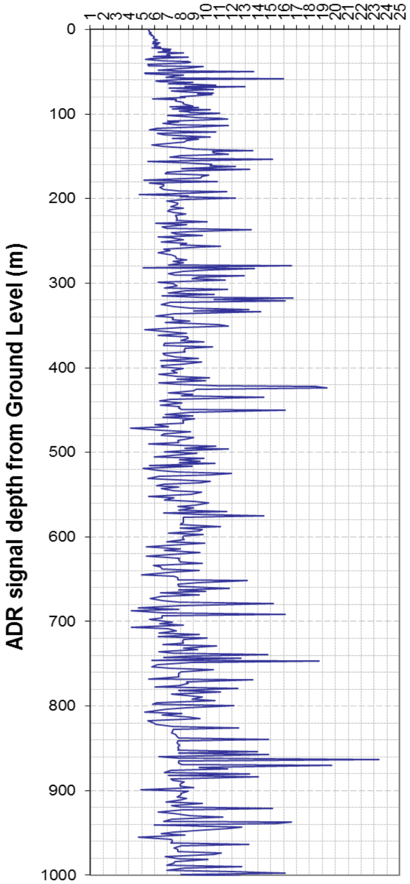


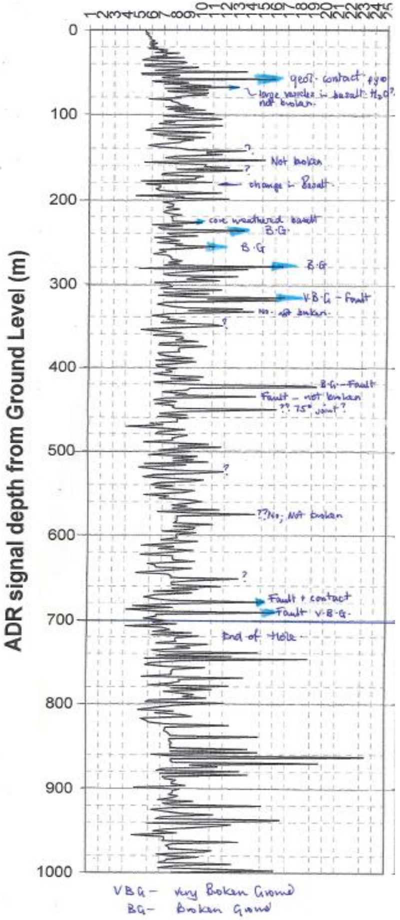
Custom signal processing extracts features from the recorded raw data.

Measurements

Toolbox of ADR measurements

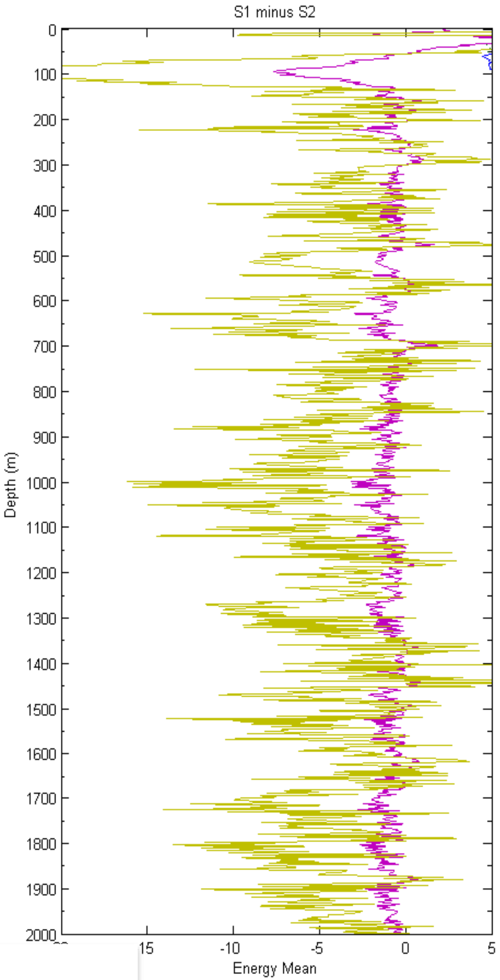
Dielectrics



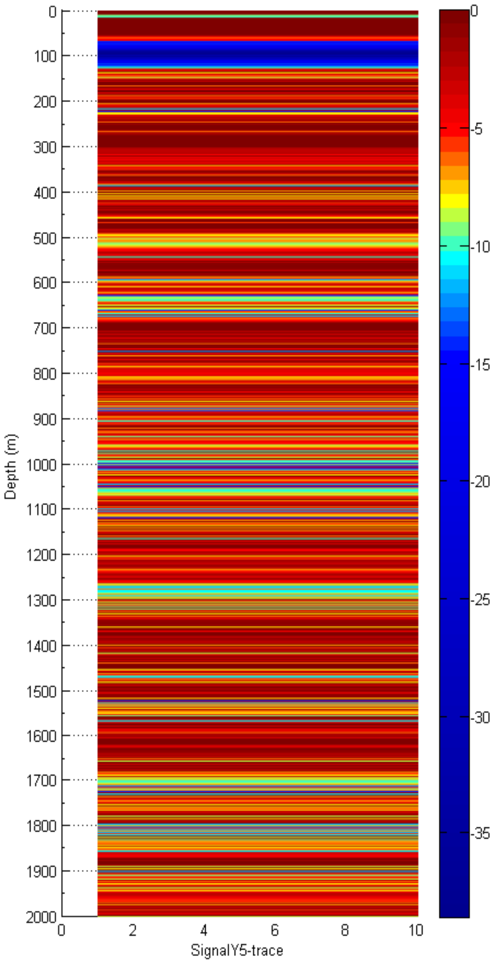


- Dielectric survey log
- In this example, high dielectrics verified by client from core inspection to be broken ground, very broken ground or faulting (caused by moisture)

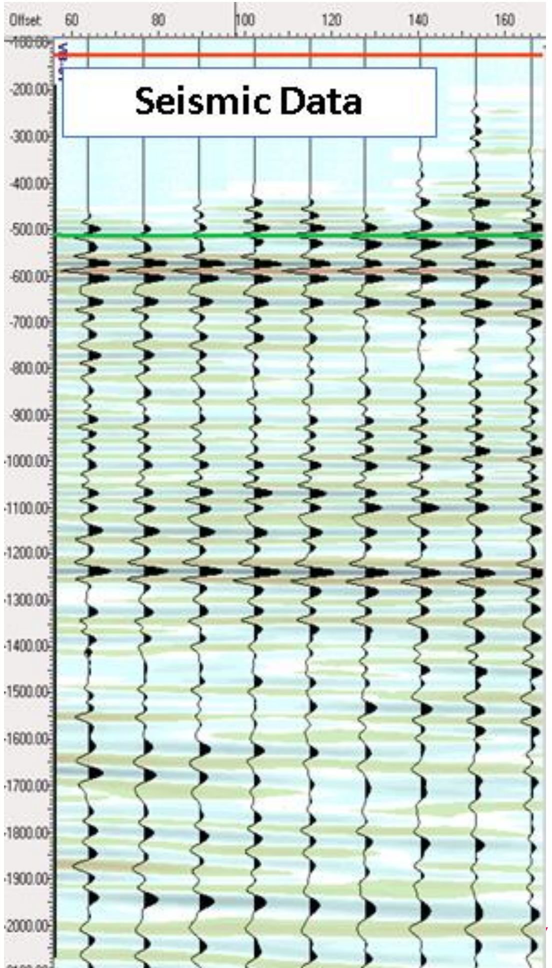
Energy log



S1 minus S2
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
15
-10
-5
0
5
Energy Mean



Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
0
2
4
6
8
10
SignalY5-trace
0
-5
-10
-15
-20
-25
-30
-35



Offset
60
80
100
120
140
160
Seismic Data
-200.00
-300.00
-400.00
-500.00
-600.00
-700.00
-800.00
-900.00
-1000.00
-1100.00
-1200.00
-1300.00
-1400.00
-1500.00
-1600.00
-1700.00
-1800.00
-1900.00
-2000.00

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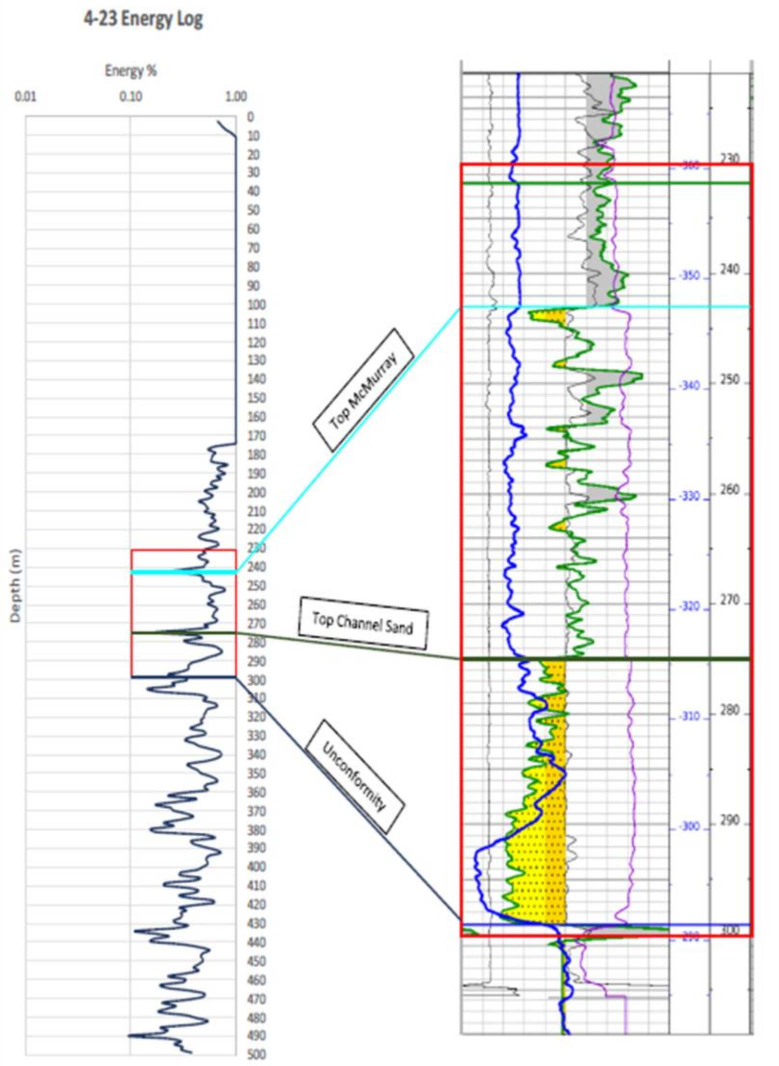
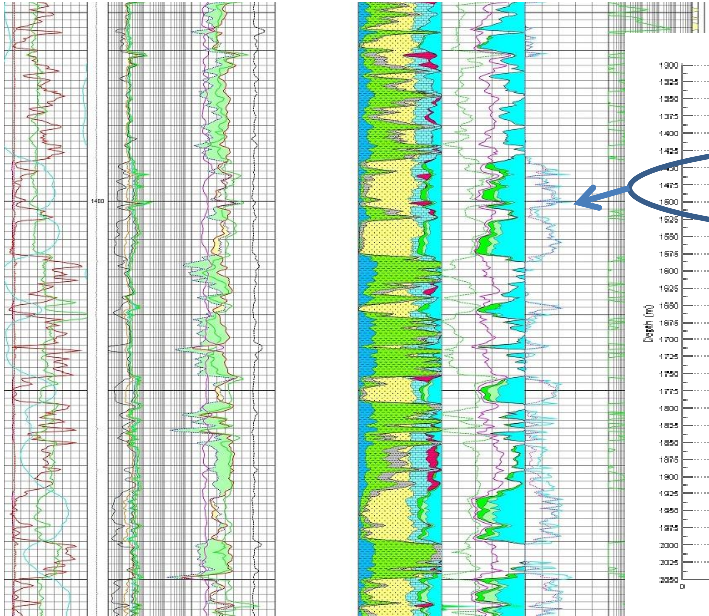
Energy log versus Downhole logs

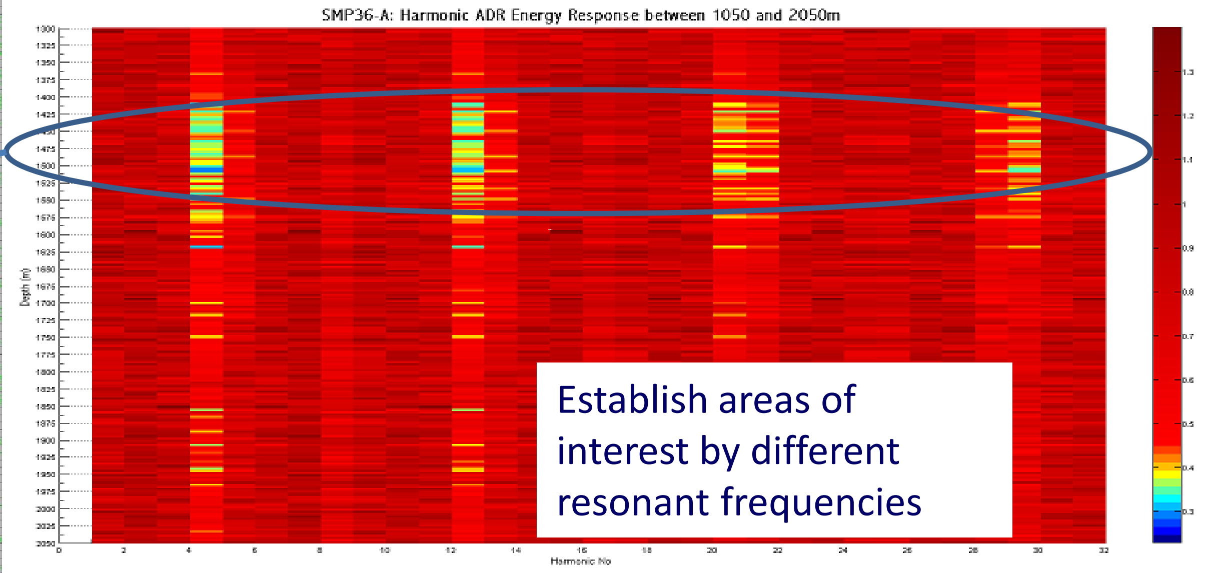


Frequency harmonics

	Frequency																															
Time (ns)	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24	H25	H26	H27	H28	H29	H30	H31	H32
51	100	59.2	22.9	77.4	89.5	71.5	31.9	8.1	20.1	28.1	30.3	27.7	13.9	11.2	4.9	10.3	15	6.8	1.6	2.5	1.4	1.7	1.4	4.1	3	3	3.1	1.2	0.7	0.4	0.8	0.8
102	100	52.1	22	25.5	21.8	14.3	8.4	10.6	14	14.5	12	8.3	6.6	6	5.3	3.7	1.4	1.2	2.2	2.2	1.8	1.3	1.5	1.8	1.3	0.6	0.3	0.6	0.7	0.5	0.3	0.6
153	100	46.2	34.9	29.2	26.5	22.3	15	7.5	3.4	3.8	6.4	8.9	9.6	8.4	6.3	4.7	3.8	3.5	3.3	2.8	2	1.3	1.3	1.5	1.6	1.6	1.4	1.2	0.9	0.8	0.8	0.9
204	100	13.4	20.4	16.2	21.3	13.9	7.8	18.9	11.8	4	7.4	2.1	7.1	5.7	6.3	6.5	4.6	5.2	3	3.2	2.9	3.2	4.3	3.5	3.5	2.5	1.6	1.6	1.3	2	1.5	1.7
255	11.4	34.2	52	91.4	100	22	51.1	22.9	21.8	15.1	6	21.7	17	11.1	24	24	15.2	2	2.8	8.1	5.8	3.5	8.9	21.3	8.9	6.4	9.4	9.5	4.6	1.9	2.1	3.1
306	100	53.6	30	36.3	59.3	40.7	34.4	29.7	27.3	15.5	8.4	14.1	25.9	29.7	24.4	16	23.8	18.2	5	12.2	16.6	13.9	11.6	13.5	16.2	9.6	3.9	6.9	5.9	3.8	7.7	8.7
357	100	71.5	36.1	22	21.1	20.4	9.6	14.5	13.5	9.1	8	11.9	7	6.4	7.7	6.9	4.6	5.1	5.3	3.8	4	3.9	4.5	2.9	3.9	4.1	3.6	3.1	4	3.5	2.6	3.3
408	100	92.5	63.2	37.4	6.4	30.3	29.8	19.1	6.3	12.7	15.9	12.6	10.1	4.7	8.9	12.3	10.2	3.8	5.3	9.7	7.4	4.9	3.6	4.9	6.7	5.7	3.8	2.7	5.6	5.6	3.9	2.3
459	64.2	100	93.3	81.2	72.4	53.1	29.6	18.3	8.9	8.7	13.3	23.4	27.7	21.8	17.4	14.2	10.4	7.4	5.4	10.4	11.7	11.2	11.6	10.8	9.4	7.2	5.3	5.3	5.2	6.4	7.4	7.3

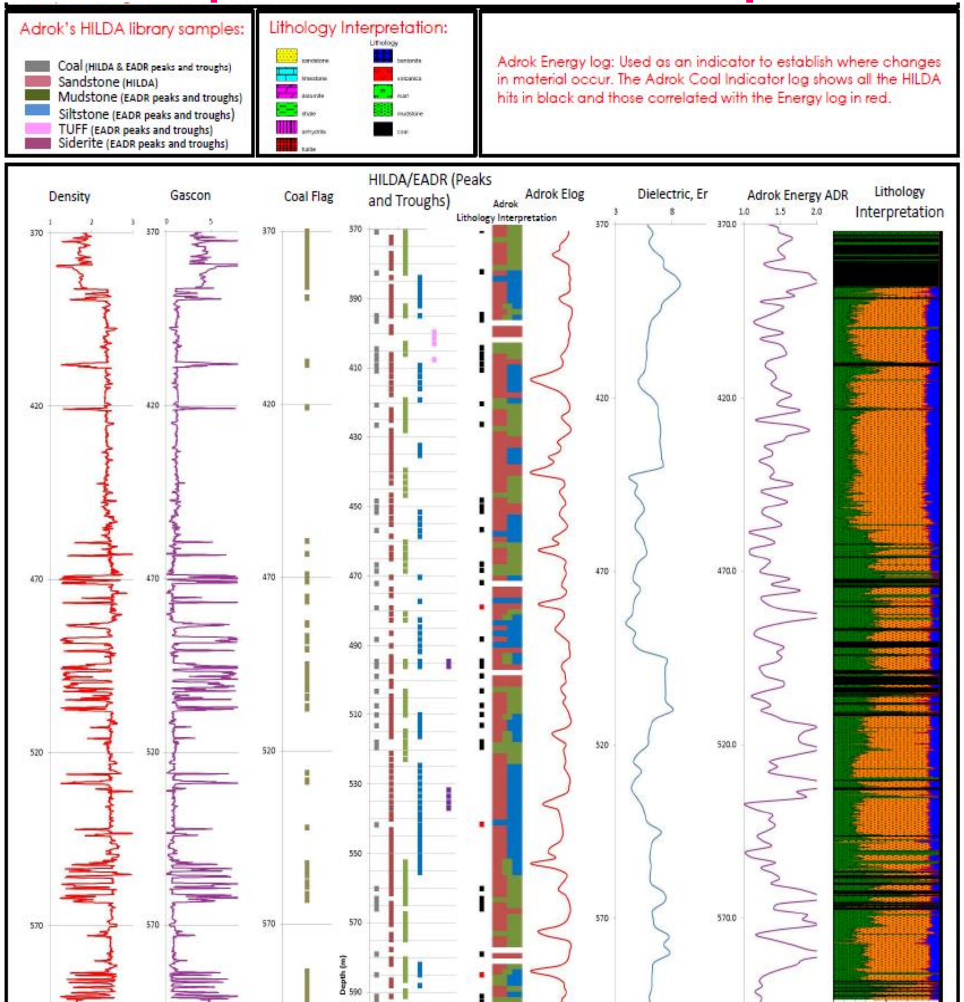
Create image of harmonic energies

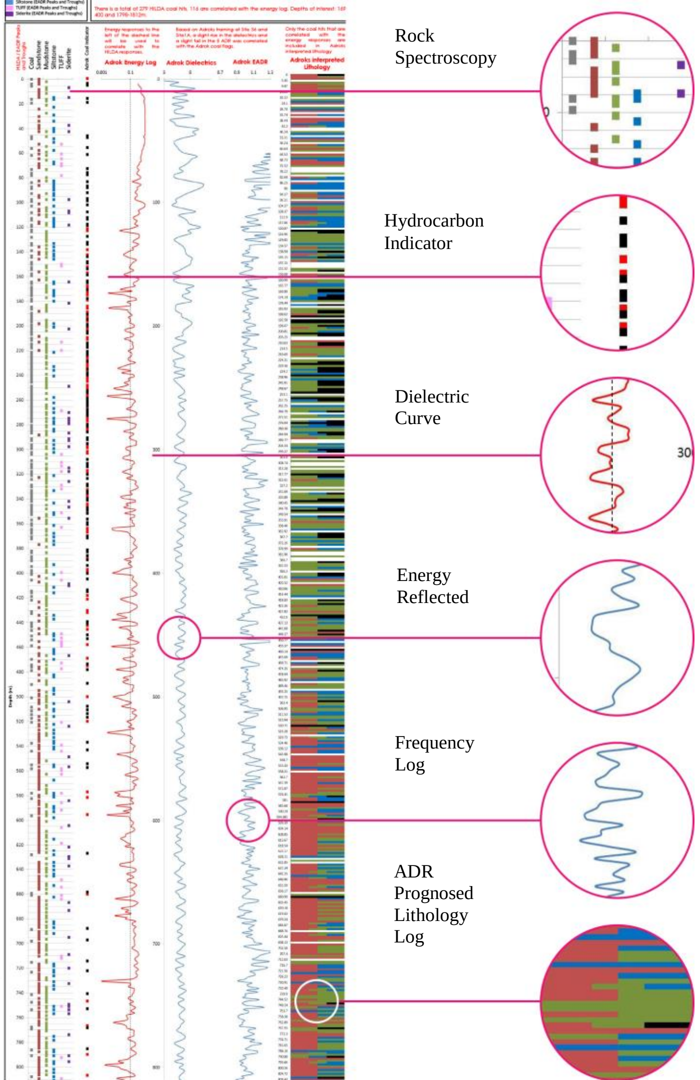




Establish areas of interest by different resonant frequencies

Examples of ADR Output



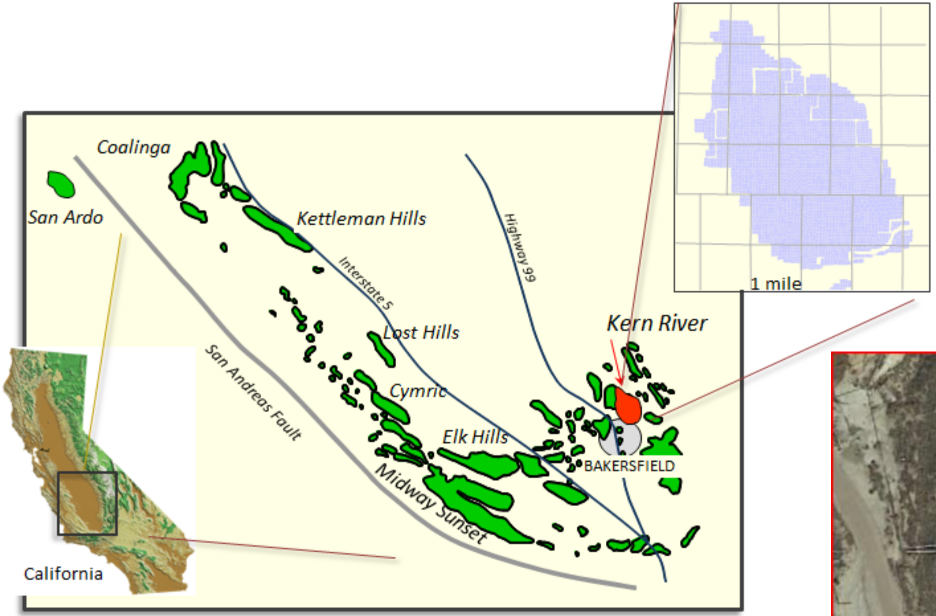


Case Studies

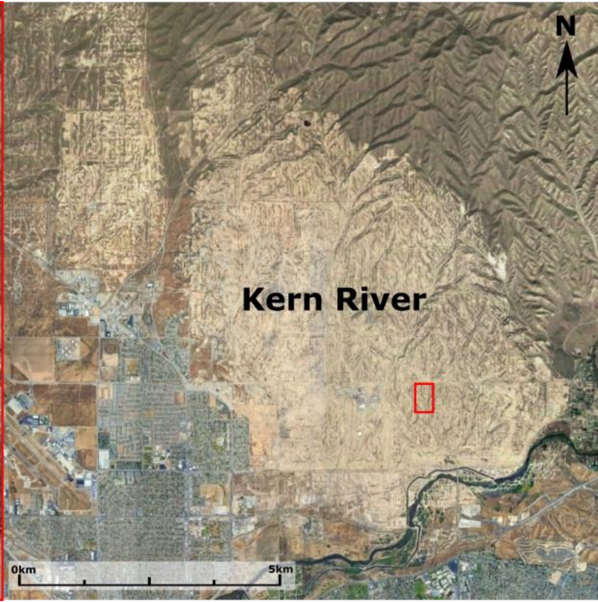
http://adrokgroup.com/case-studies/together-we-rock-vol-1.html

Case Study in California, USA

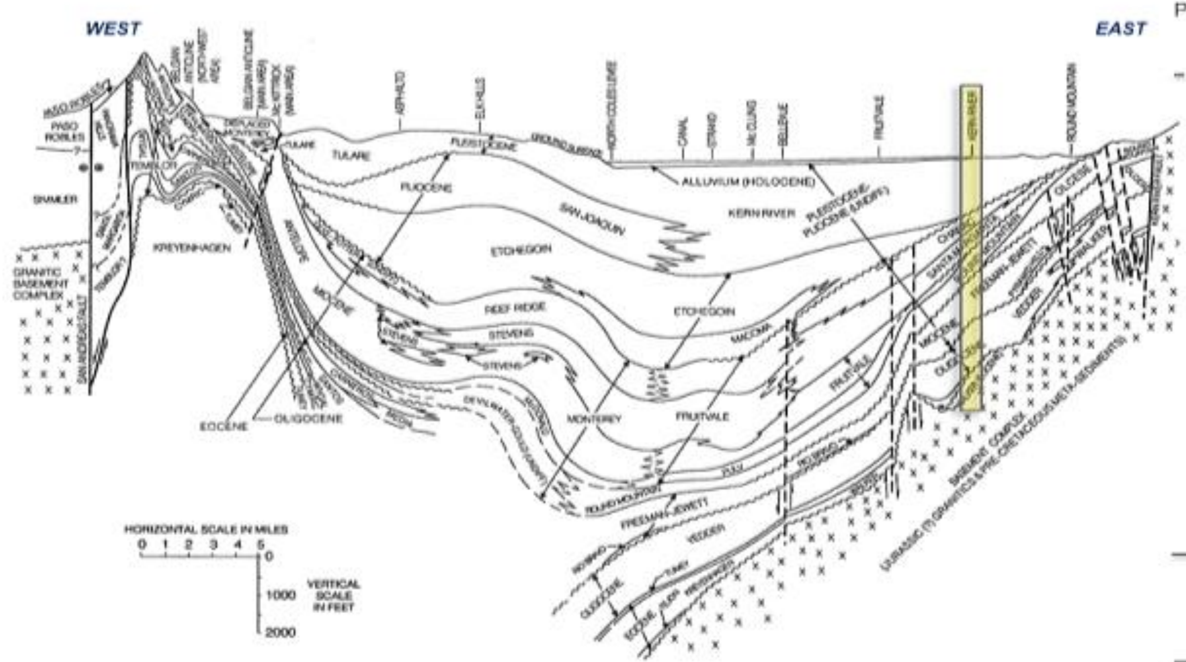
Location

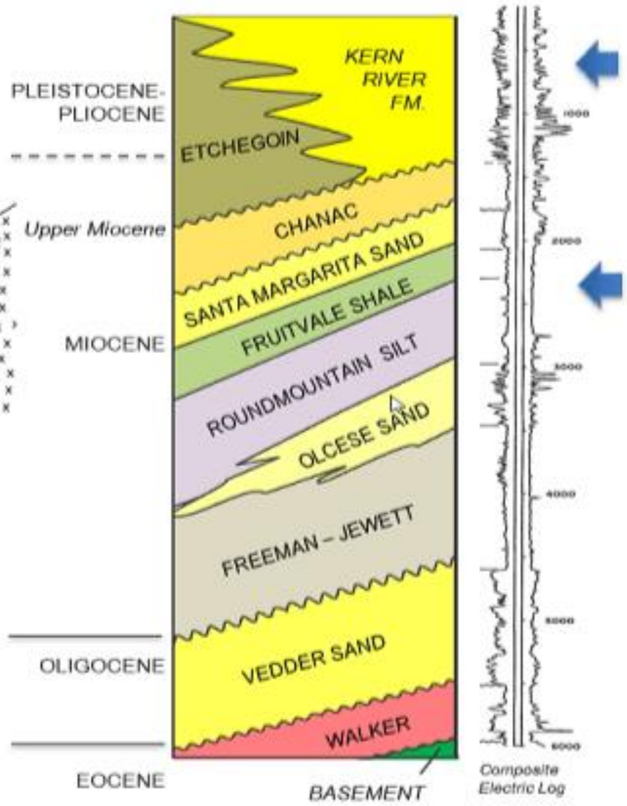

1 mile
Coalinga
San Ardo
Kettleman Hills
Interstate 5
Highway 99
Lost Hills
Cymric
Elk Hills
Kern River
BAKERSFIELD
San Andreas Fault
Midway Sunset
California


100m
0m
0m
100m

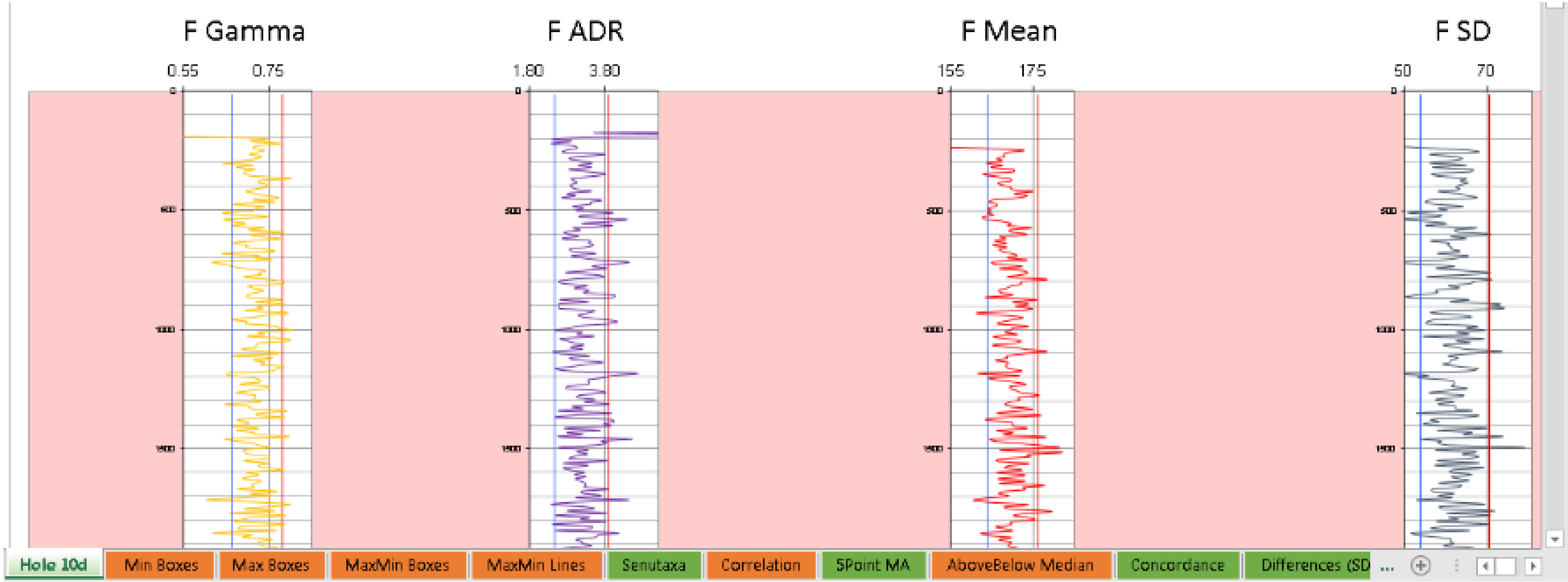

N
Kern River
0km
5km

Kern River Formation
Stratigraphic Framework





Measurements and data processing



Interpretation

- Adrok has successfully completed processing, interpretation and analysis on H10d, located in Kern River, California.
- Adrok has provided raw ADR signals that potentially could identify changes in lithology, structure or fluid content. These changes have been characterised by the zonation and integration of Maximum/Minimum analysis and Differences interpretation.
- Strongest changes across all results seem to be at ~1000ft, 1750ft, 4000ft, 4500ft and 6000ft.
- Zonation identified 15 major changes in data trends.
- MaxMin plots for H10d show greater variability at ~500ft, 1500ft, 4400ft, 4750ft and 6000ft.
- The Differences analysis shows greatest change in data trends at ~250-1000ft, 200ft, 300ft, 4000ft, 4500ft, 5000ft and 6000ft.

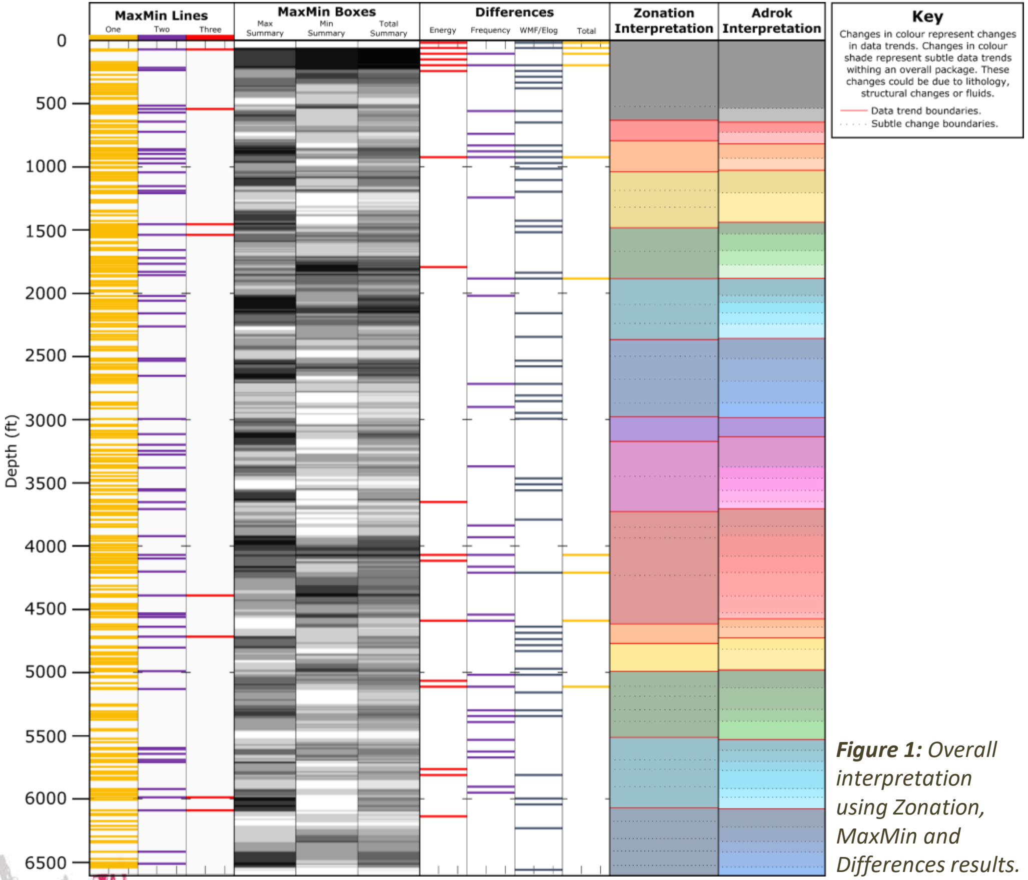
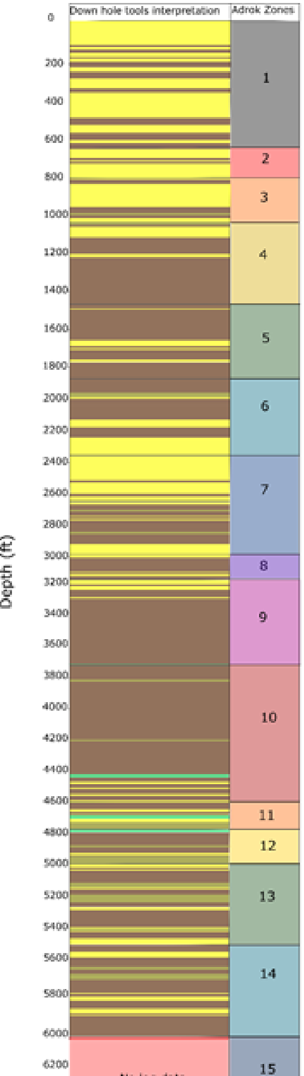
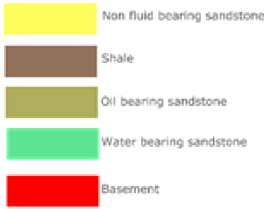


Figure 1: *Overall interpretation using Zonation, MaxMin and Differences results.*





Zones 1-3 Predominantly Sandstone

Zones 4-5 Shale with occasional oil bearing sandstone

Zone 6 Fining upwards from sandstone to shale

Zone 7 Sandstone, some oil bearing layers

Zone 8-10 Predominantly Shale

Zone 11 Water bearing Sandstone

Zones 12-14 Shale and oil bearing sandstone

Zone 15 Basement

Drill hole stops at 6055ft. There's a slight change in lithology just above this which may indicate the Basement. This would explain why the drill was stopped at this point Zone 15 starts at this depth.

Results

Adrok	ft		Chevron	ft			Difference (ft)
Zone 0	0		Vedos	0	CP_001TO		
Zone 1	620		Steam chest KR	75			
Zone 2	790		Saturated KR	854			234
Zone 3	1025		Chanac	937			-88
Zone 4	1490		Santa Margarita	1617	KH_WVD1		127
Zone 5	1870		Round Mountain	1980			110
Zone 6	2350		Middle Round Mountain	2239			-111
Zone 7	2980		Lower Round Mountain	2505			-57
Zone 8	3155		McVan	2619			54
Zone 9	3715		Lower McVan	2654			-82
Zone 10	4600		Olcese	2923			-105
Zone 11	4755		Freeman-Jewett	3450			-25
Zone 12	4990		Vedder 1	4417			
Zone 13	5505		Vedder 2	4654			
Zone 14	6055		Vedder 3	4908			
			Vedder 4	5400			
			Vedder 5	5776			
			Famosa	5941			
			Walker	5983			
			Basement	6030			

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Case Study onshore UK

Energy Catalyst – Early Stage Feasibility – Round 3

Feasibility study for innovative remote sensing to increase onshore UK gas production (completed October 2017)

Innovate UK

IGas Energy

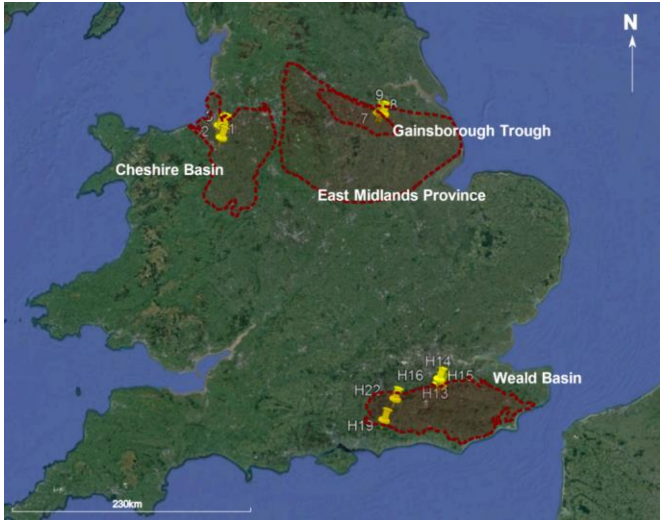
www.paetoro.com

Project's Purpose

- For Adrok to deploy their Atomic Dielectric Resonance (ADR) technologies to detect and map subsurface Oil and Gas deposits in various locations across the UK by collecting and processing 11 Virtual Boreholes to 3000m depth.

The main questions to be answered by this project are as follows:

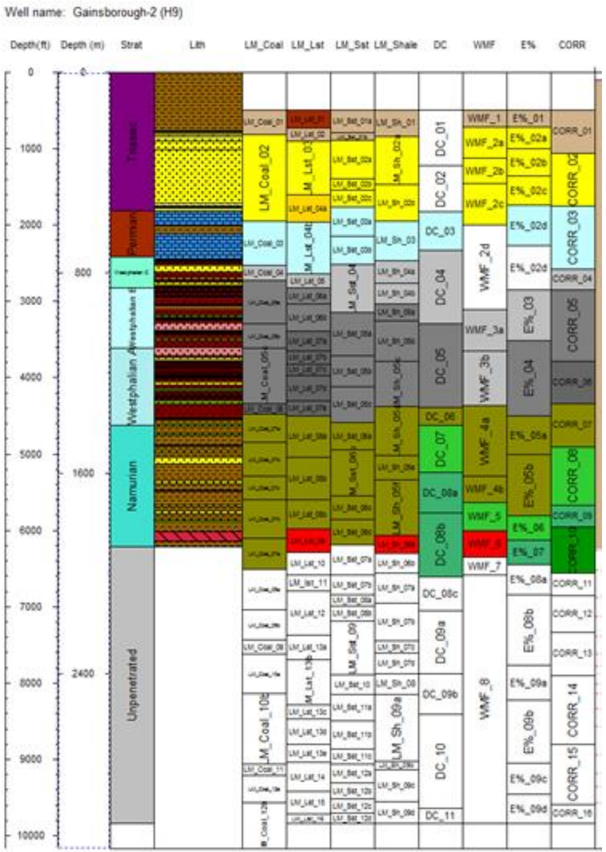
- Can the tool identify changes in lithology?
- Can the tool identify Oil and Gas deposits?
- Are the results within reasonable error?
- Are the results reasonably repeatable?
- Is the tool operationally sound?



Technology development

- Development of hardware
- Development of rock database
- Development of data processing techniques

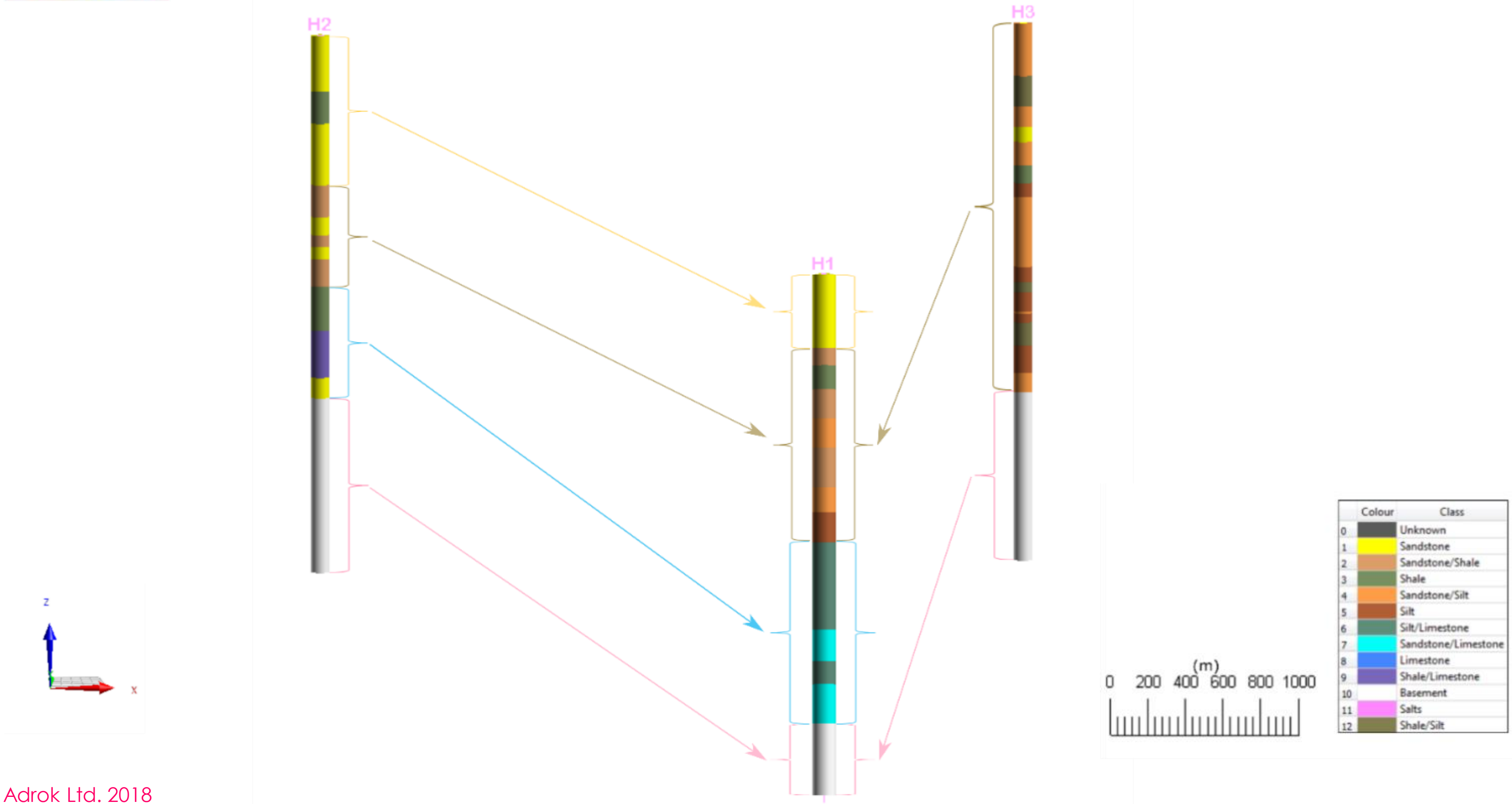
- Shale, Clay, Mudstones
- Sandstone
- Silt
- Limestone
- Gypsum and Anhydrite
- Coal
- Ironstone
- Fireclay/ fireclay with silt
- Igneous Intrusion
- Gas
- Oil
- Water



Quality controlled

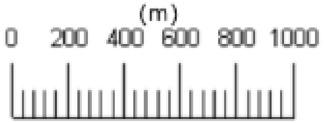
- Second fieldwork excursion to prove reliability and repeatability of Adrok’s field data collection methods
- Independent competent persons report verified and validated robustness of Adrok’s processing methods and results

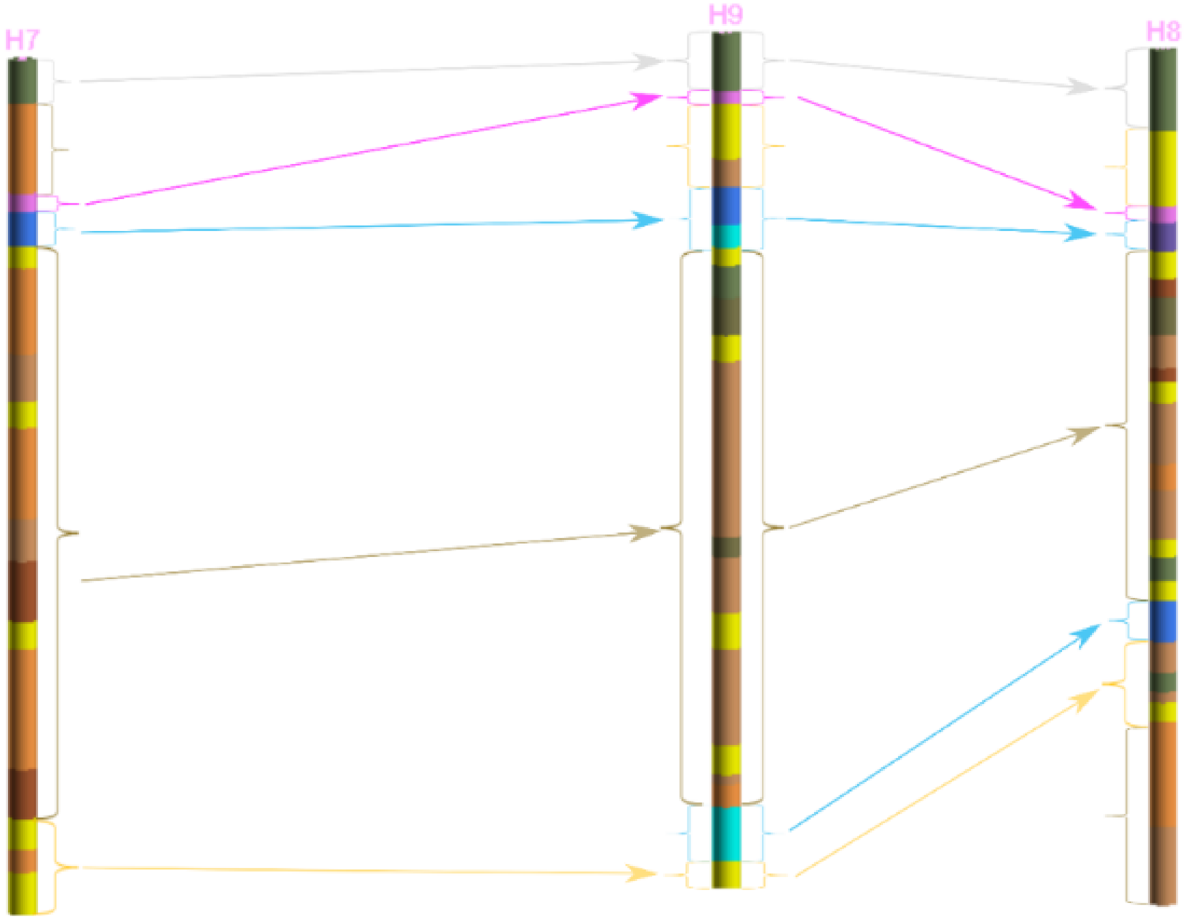
Final Results – Cheshire Basin



Final Results – Gainsborough Basin

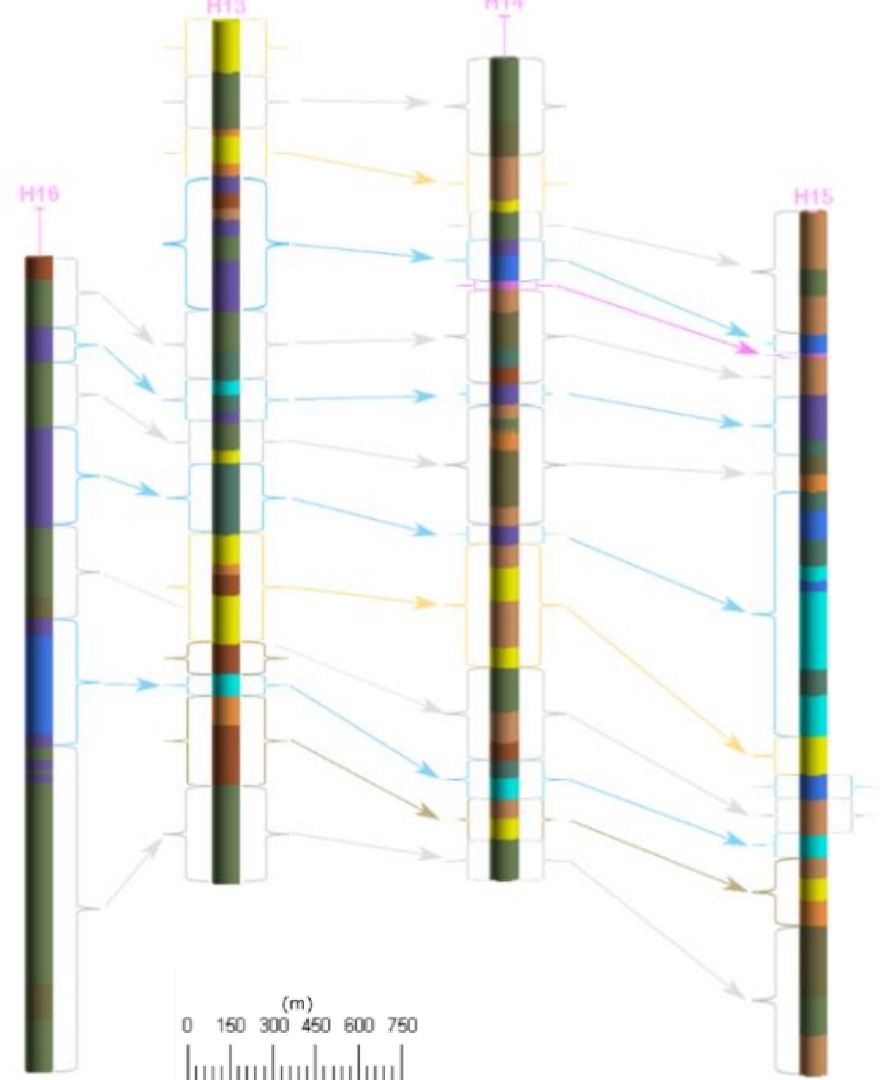
	Colour	Class
0		Unknown
1		Sandstone
2		Sandstone/Shale
3		Shale
4		Sandstone/Silt
5		Silt
6		Silt/Limestone
7		Sandstone/Limestone
8		Limestone
9		Shale/Limestone
10		Basement
11		Salts
12		Shale/Silt





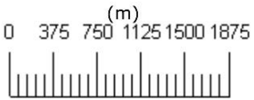
Final Results – Weald Basin

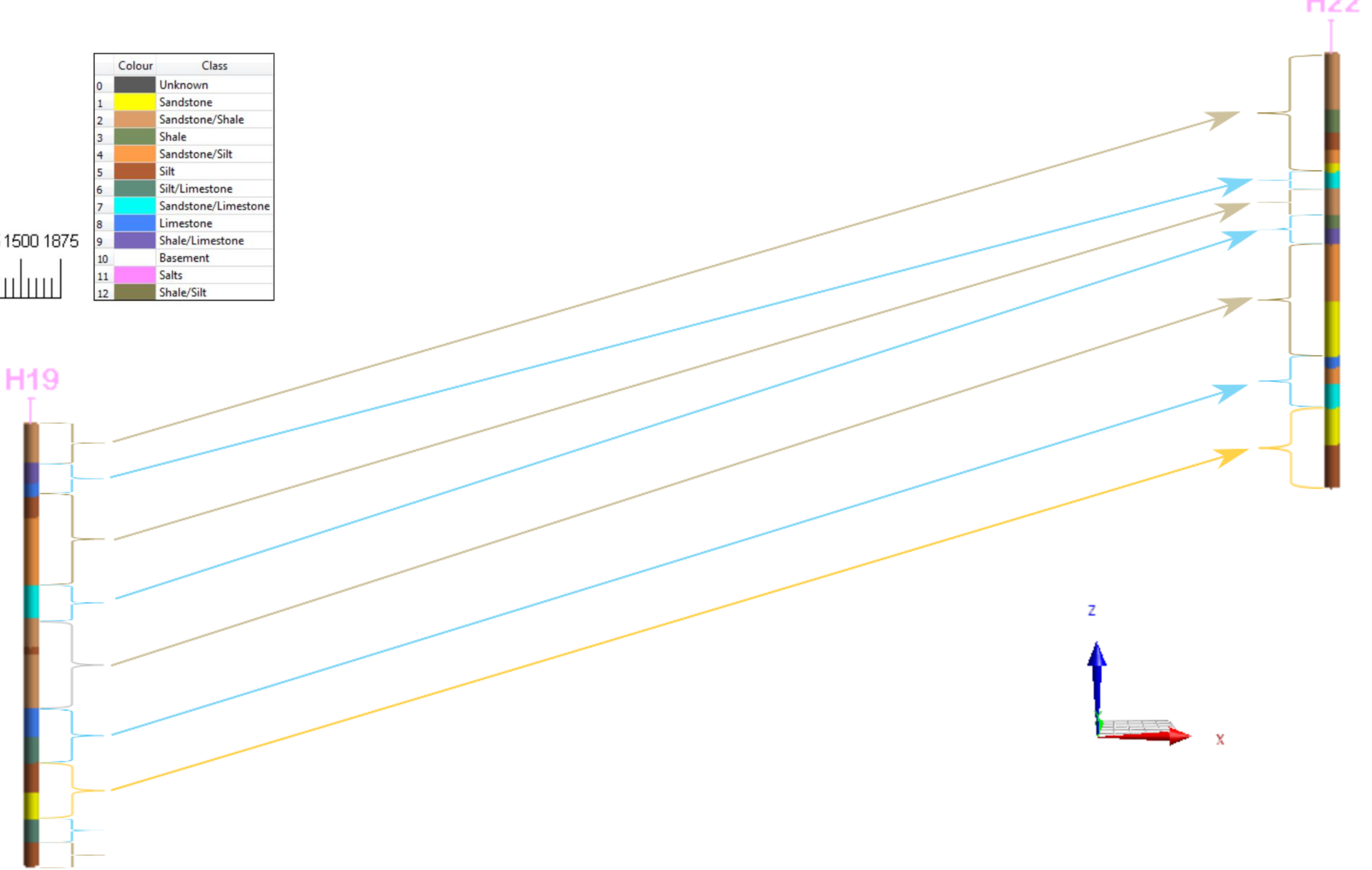
	Colour	Class
0		Unknown
1		Sandstone
2		Sandstone/Shale
3		Shale
4		Sandstone/Silt
5		Silt
6		Silt/Limestone
7		Sandstone/Limestone
8		Limestone
9		Shale/Limestone
10		Basement
11		Salts
12		Shale/Silt



Final Results – Blind Tests

	Colour	Class
0		Unknown
1		Sandstone
2		Sandstone/Shale
3		Shale
4		Sandstone/Silt
5		Silt
6		Silt/Limestone
7		Sandstone/Limestone
8		Limestone
9		Shale/Limestone
10		Basement
11		Salts
12		Shale/Silt





Independent Competent Person's Assessment – Dr Dave Waters, Paetoro Consulting UK Ltd.

"After detailed analysis, I have little doubt that the Adrok scanners are seeing real and important subsurface geological boundaries. This is evident in the consistency of response through time, in different locations, and across different curves and associated metrics that combine and visualise the data in different ways. Real geology is being seen by these tools. That makes them important – because they are managing to do so at a tiny fraction of the cost of drilling a well, and on a much quicker time frame."

Case Study in Saskatchewan, Canada with

Gensource
POTASH CORP

Adrok®

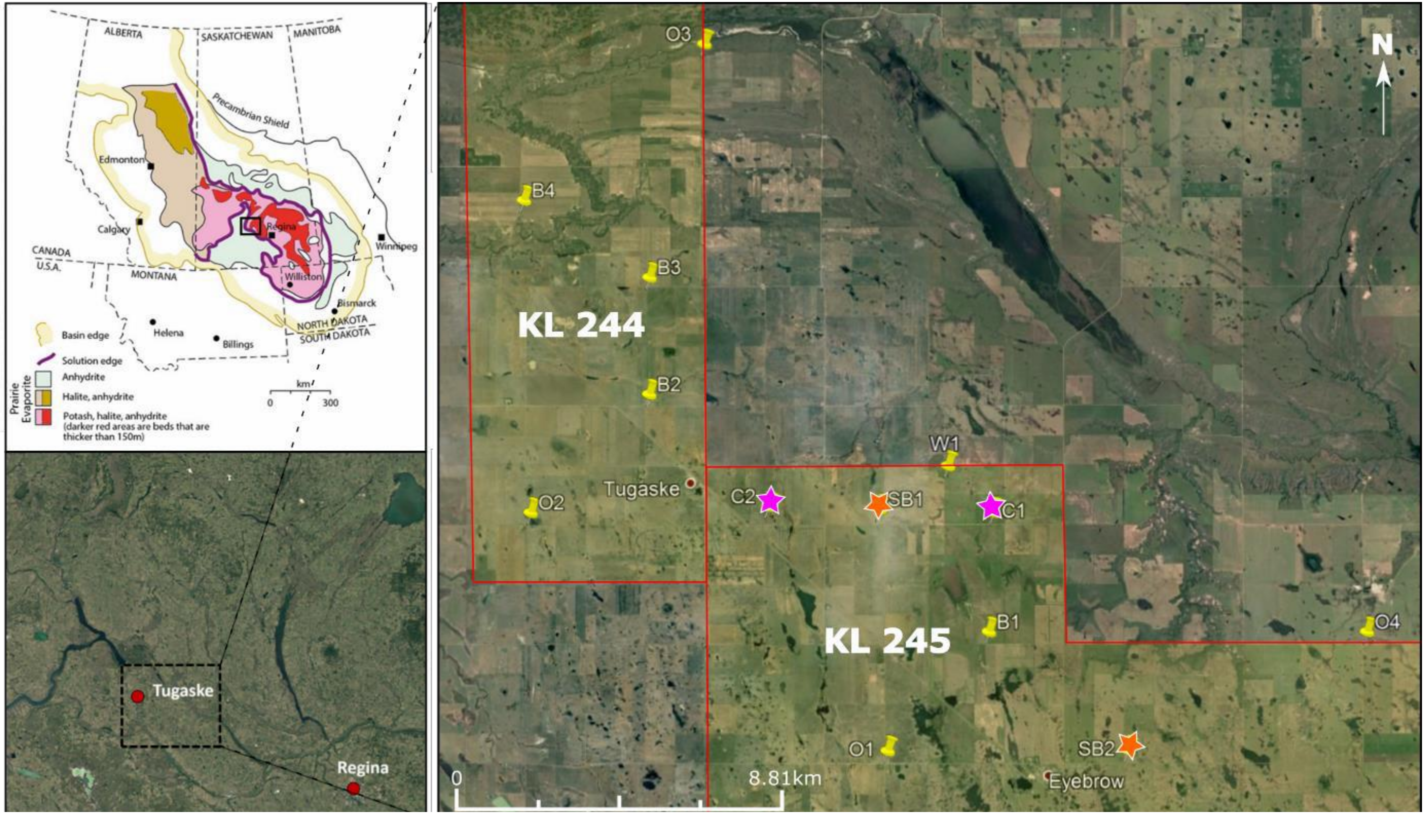


Figure 2: (right) location map displaying the location of Adrok's V-bores in relation to Gensource's two Potash leases in the Tugaske area of Saskatchewan. The pink stars denote training holes H1 (C1) and H2 (C2), and the orange stars represent the semi -blind V-bores H3 (SB1) and H4 (SB 2). (top left) Geological map highlighting the area of study in relation to Potash extent in the area (picture sourced from http://www.saltworkconsultants.com/phanerozoic-potash.html).

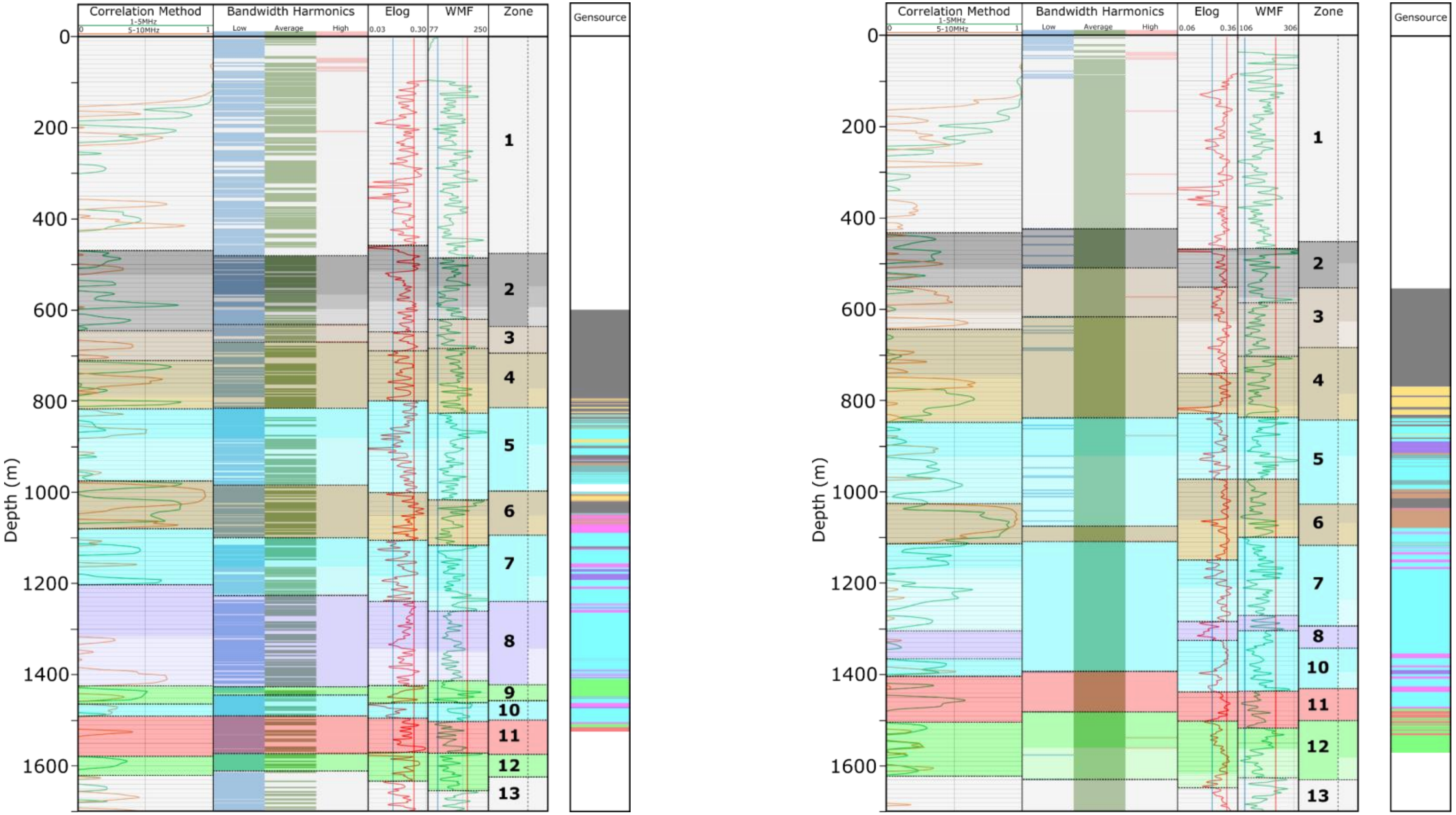


***Figure 7**: Lithological zonations for H3 (SB1) and H4 (SB2). These were interpreted "blindly" without any training lithology. The Gensource lithology displayed above was supplied to Adrok after interpretation was complete so that Adrok could determine the accuracy of the interpretation method.*

Shale | Siltstone | Sandstone | Limestone | Chert | Dolomite | Anhydrite | Halite | Potash Mineralisation

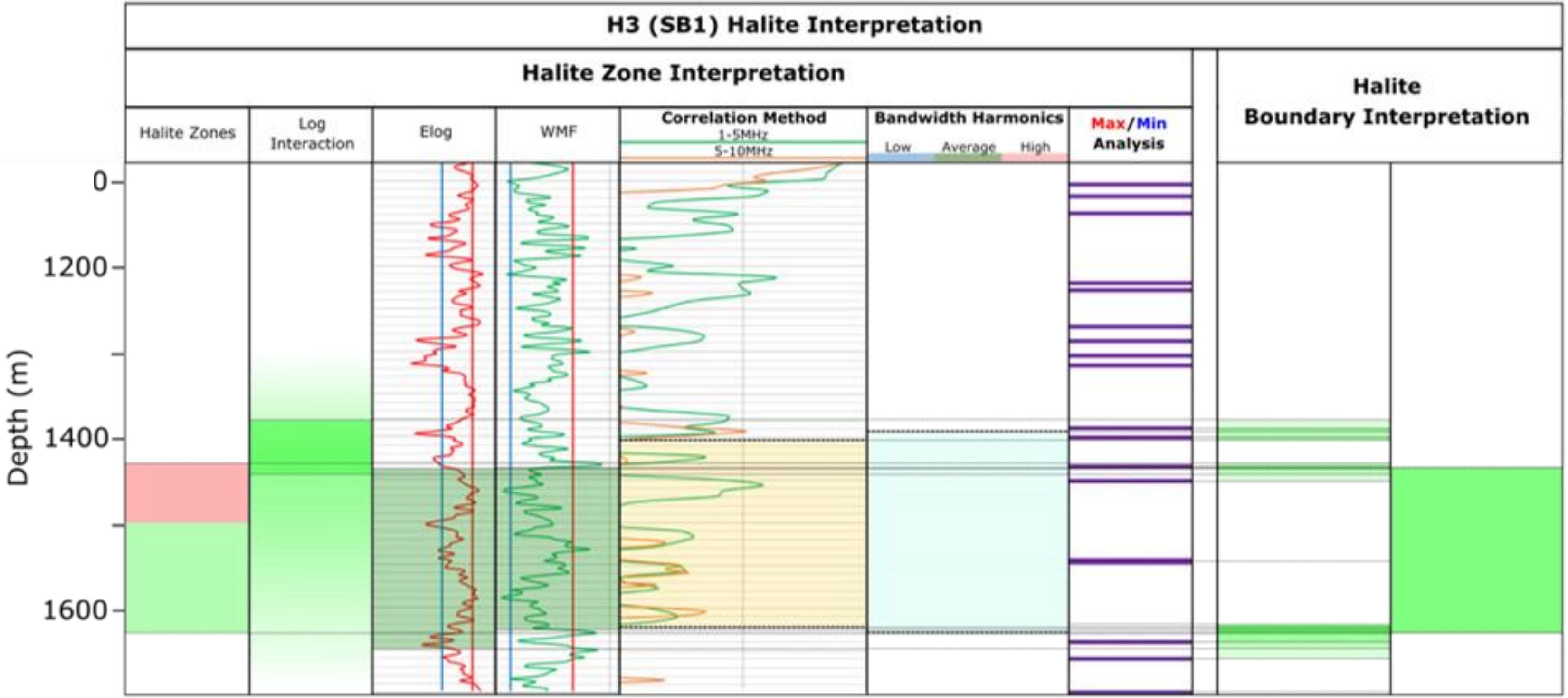


Figure 9: Example from H3 (SB1) of the full integrated interpretation approach for the presence of halite in the section.

Shale | Siltstone | Sandstone | Limestone | Chert | Dolomite | Anhydrite | Halite | Potash Mineralisation

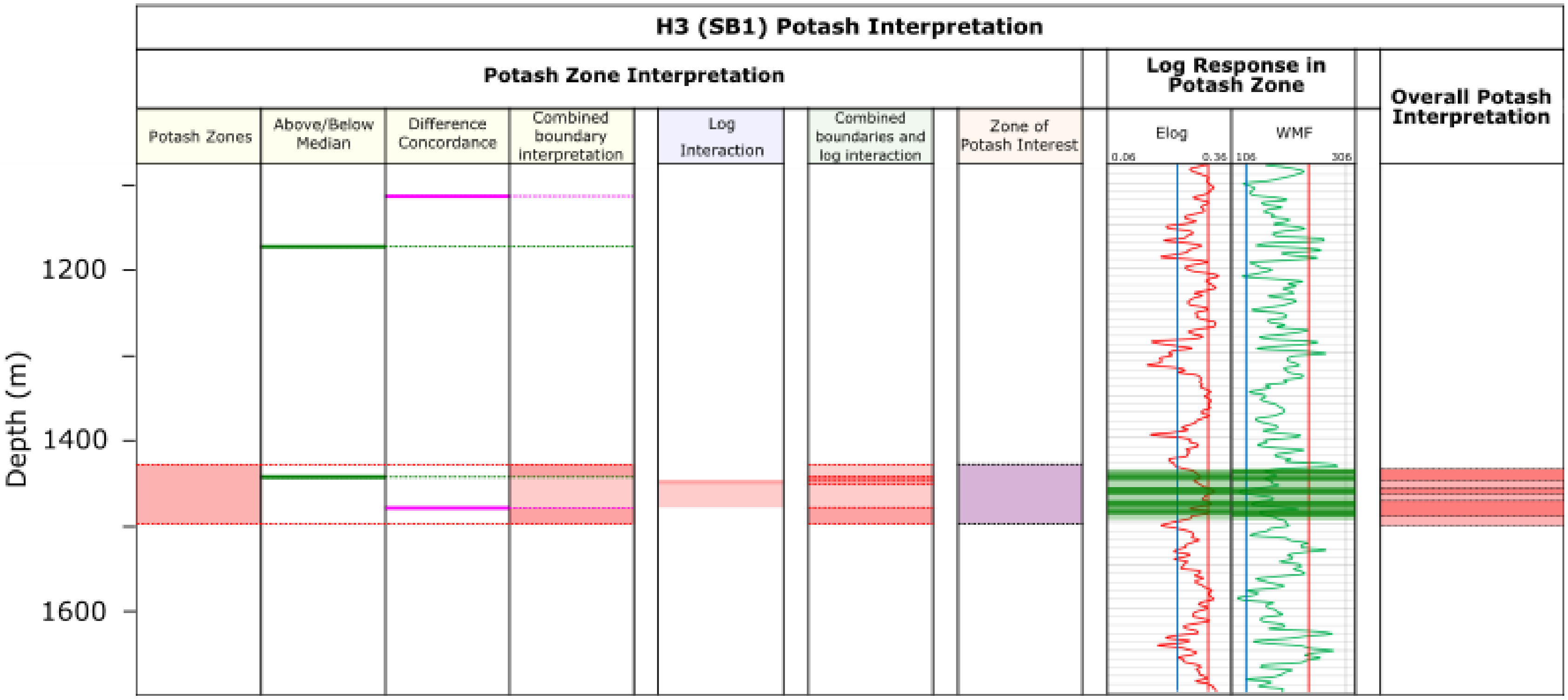


Figure 8: Example from H3 (SB1) of the full integrated interpretation approach for the presence of the potash zone and individual potash members in the section.

Shale · Siltstone · Sandstone · Limestone · Chert · Dolomite · Anhydrite · Halite · Potash Mineralisation

Closing thoughts

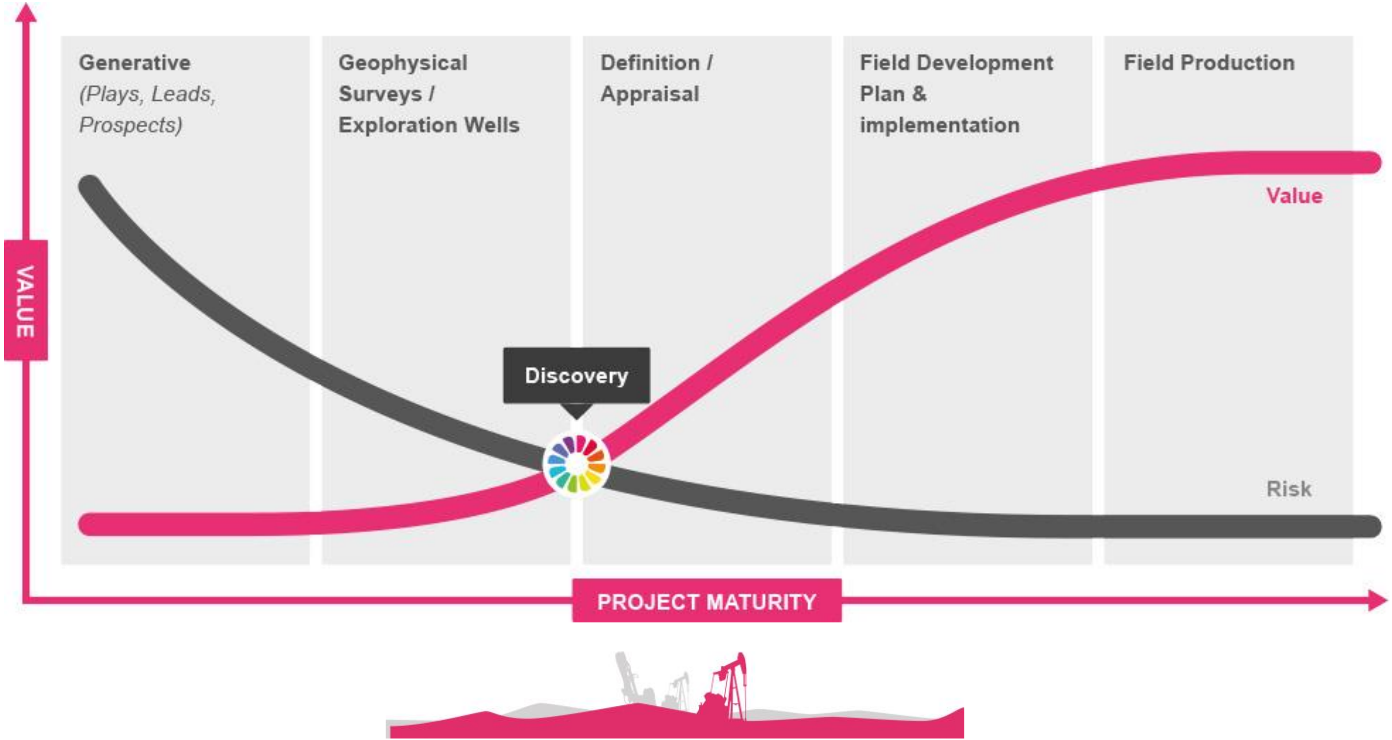
Exploration

Not every exploration challenge can be solved by Seismic or airborne surveys alone, due to:

- Physical constraints of surface terrain onshore
- Permitting issues with landowners
- Near-surface statics
- Depthing uncertainties caused by subsurface geology

Accelerating Discovery

Adrok provides geophysical survey services, usually for a pre-agreed fixed-price during our client's Exploration and/or Appraisal activities as a complementary survey to Seismic or as a cost-effective alternative. We typically aim to save our clients up to 90% of the cost of physically drilling the ground using a borehole.



Conclusions

- ADR is *m* scale resolution at *km* scale depth without wells or seismic
- Three projects using the ADR deep subsurface measurements have been presented as Case Studies
    - Chevron – Kern River oilfield, California, 6600ft depth
    - Igas – UK onshore oil basins, 3000m depth
    - Gensource Potash – Saskatchewan, 1700m depth
- Results are very promising and warrant further research and fieldwork to help improve these techniques
- “Digitally drilling” into the subsurface is the future of exploration

Large depth exploration using pulsed radar electromagnetic technology

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