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NEAR SURFACE GEOSCIENCE'18

Workshop:
Worldwide Mineral Exploration Challenges and Cost-Effective Geophysical Methods

9 SEPTEMBER 2018 ▲ PORTO, PORTUGAL

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Large depth exploration using pulsed radar electromagnetic technology

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Adrok

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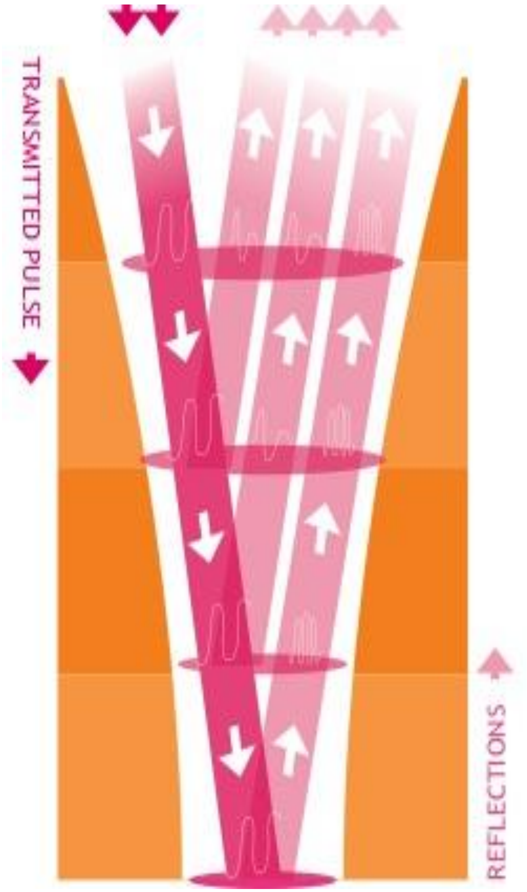
September 2018

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)



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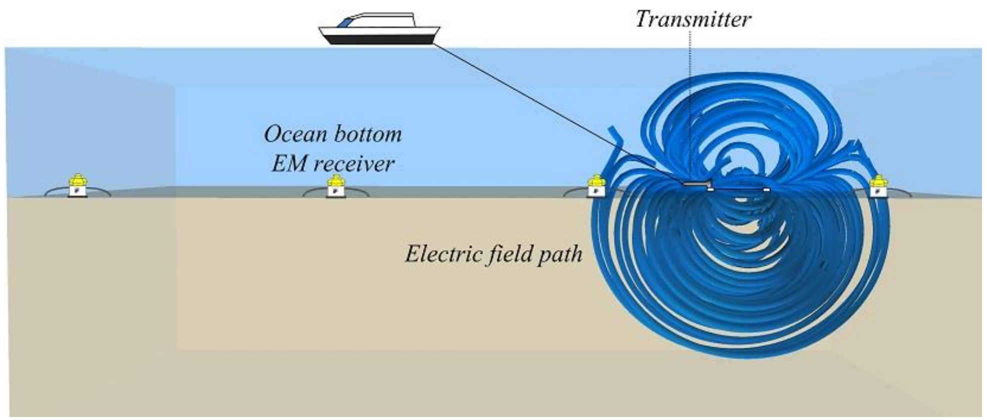
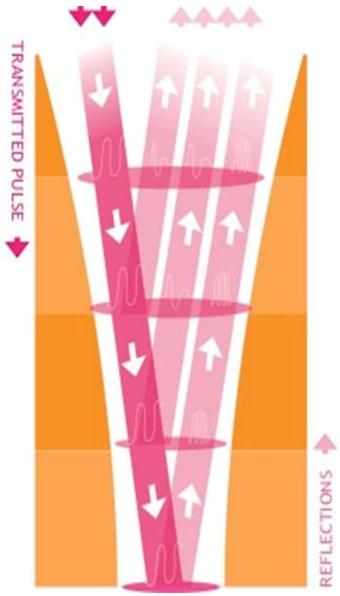
Classical Electromagnetics (EM) versus Atomic Dielectric Resonance (ADR)

ADR differs from classical EM (e.g., IP, Resistivity, CSEM, MTEM) in that:

- ADR utilizes propagating waves in the MHz range.
- Classical EM utilizes slowly varying electrical and/or magnetic fields which do not propagate as waves.
    - As such ADR is governed by the full Maxwell equations whereas classical EM uses the semistatic approximation





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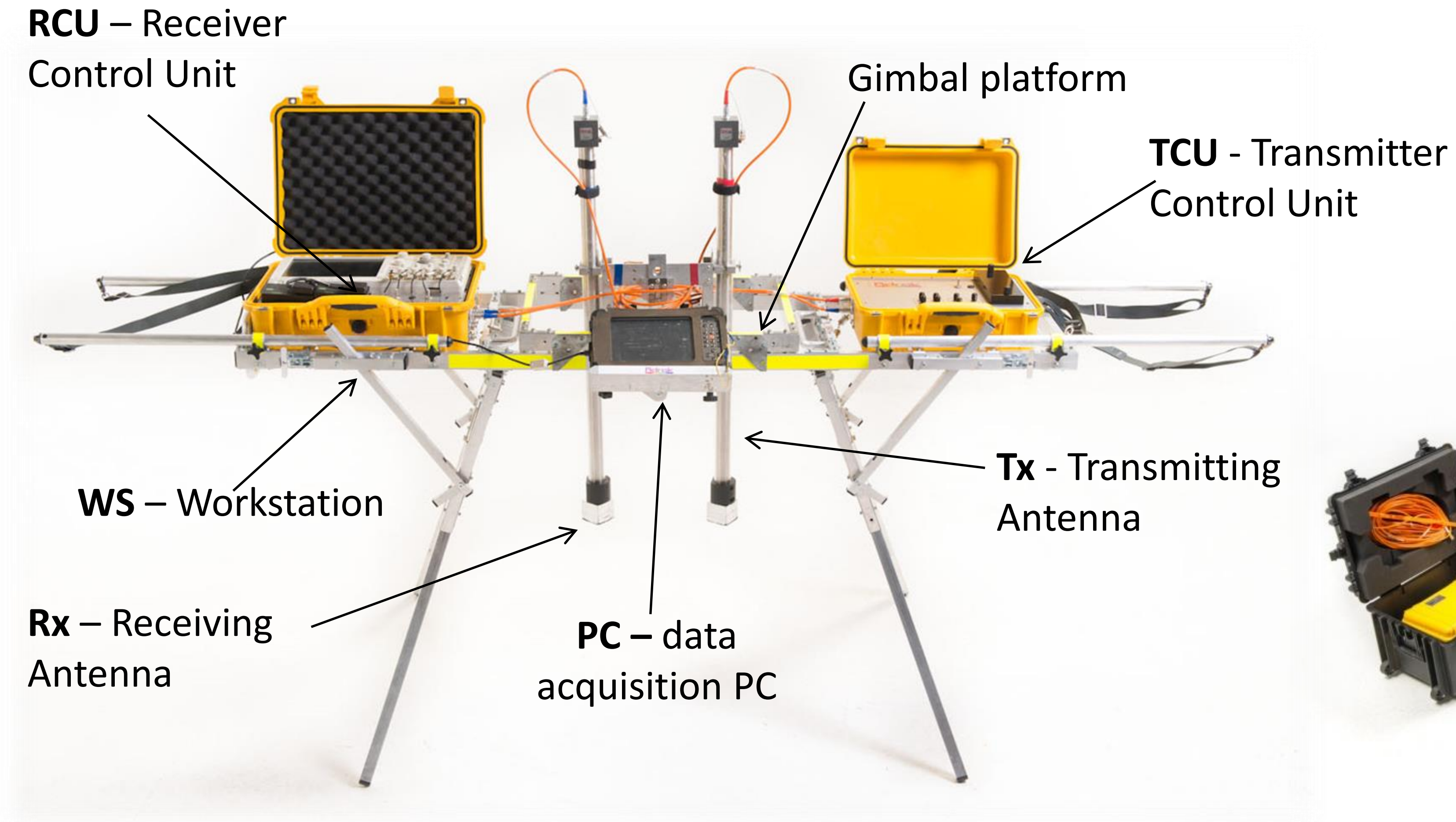
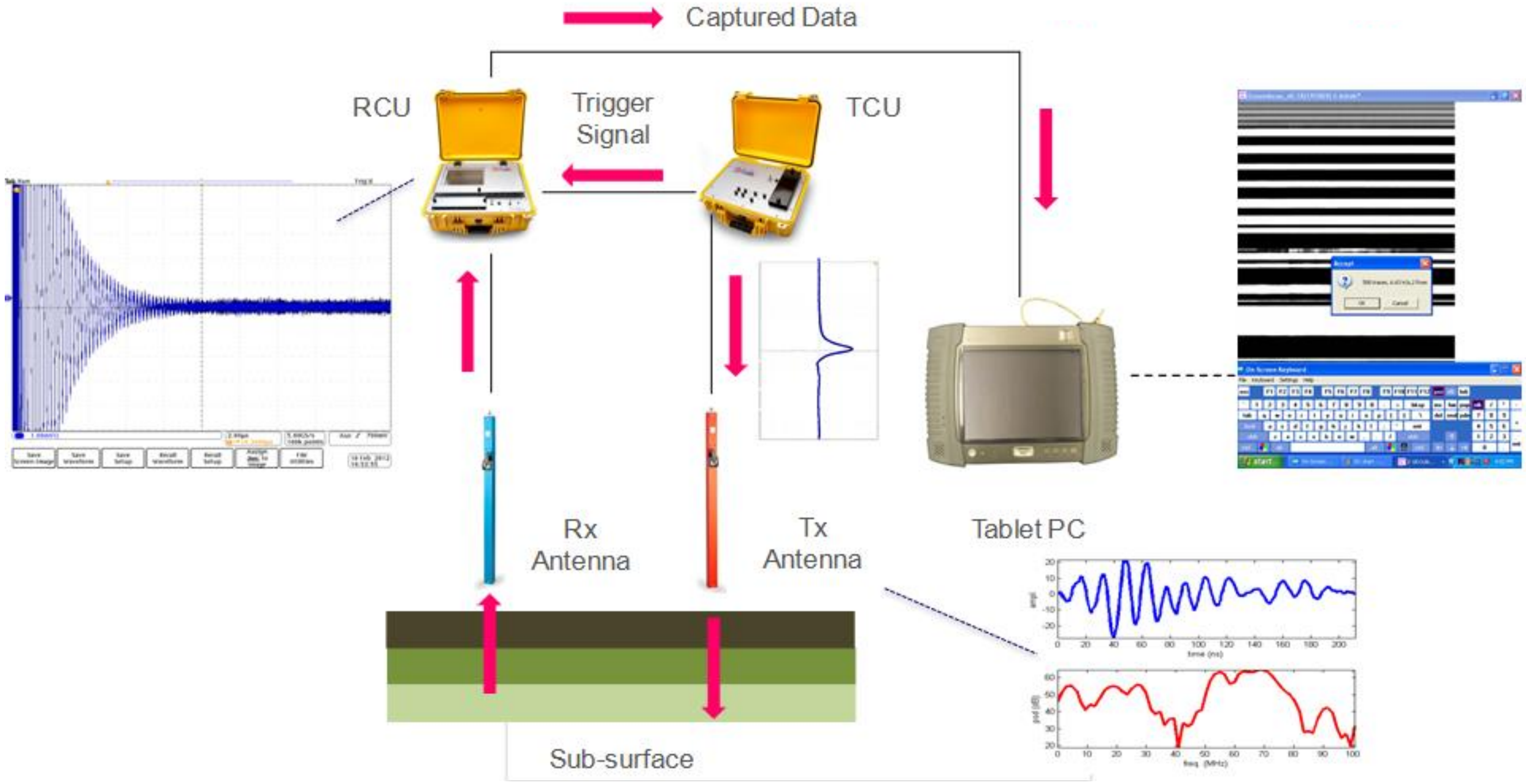
Field ADR Scanner



System Diagram



Field system specifications

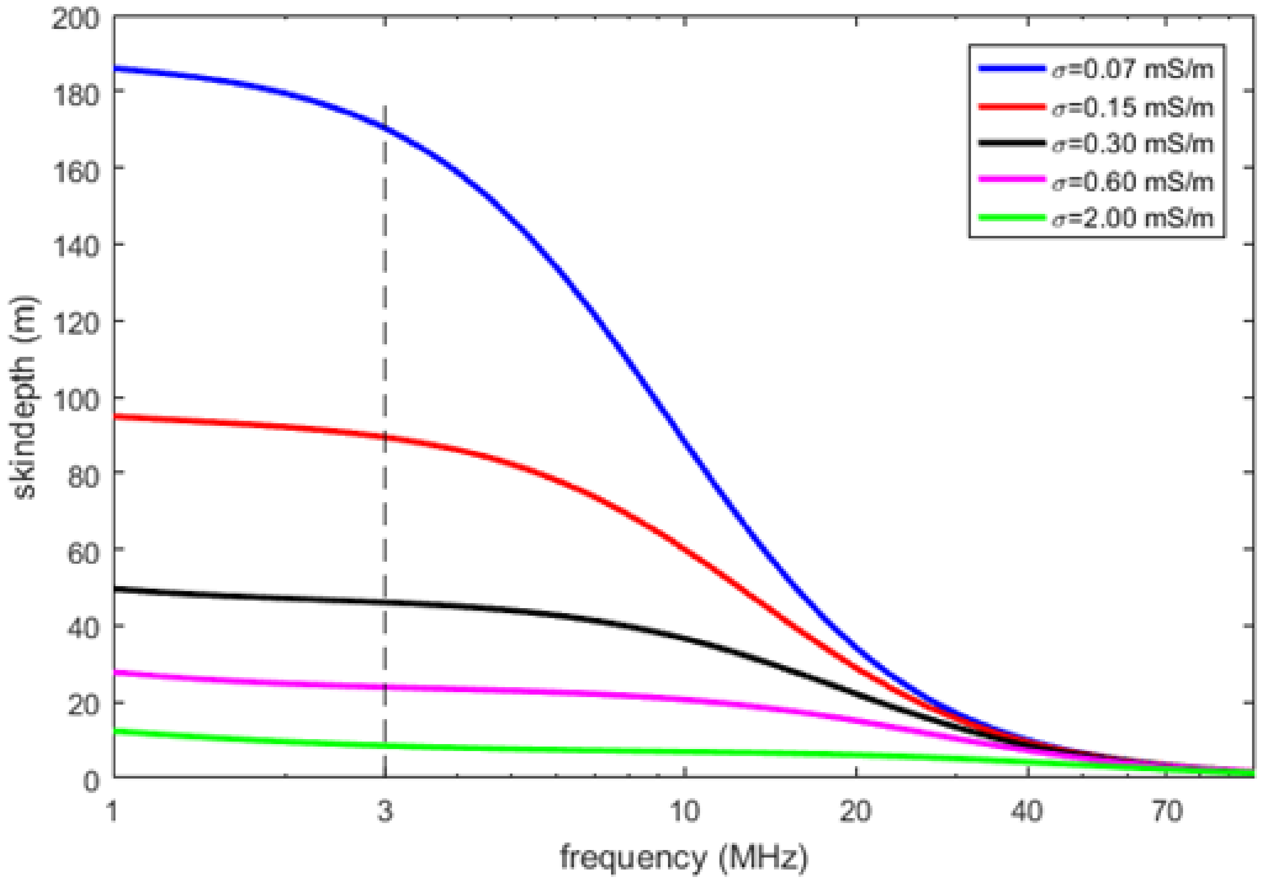
Sub-system	ADR Setting	Typical Range
TCU	Pulse width	~10ns
TCU	Pulse repetition frequency	< 10 kHz
TCU	Mean power	~ 5mW
TCU	Power supply	1 off 15 Vdc Li-Ion battery
TCU	Weight	7kg
Antenna	Tx pulse frequency	1 to 100 MHz
Antenna	Weight	5 kg
RCU:	Time Range (typical)	20,000ns, 40,000 & 100,000ns
RCU:	Number of samples/trace	100,000
RCU:	Power supply	4 off 30Vdc Li-Ion battery
RCU:	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. *Mega-stare is even better!*
- 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
  (Doel et al 2014 SEG conference paper).
- 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)

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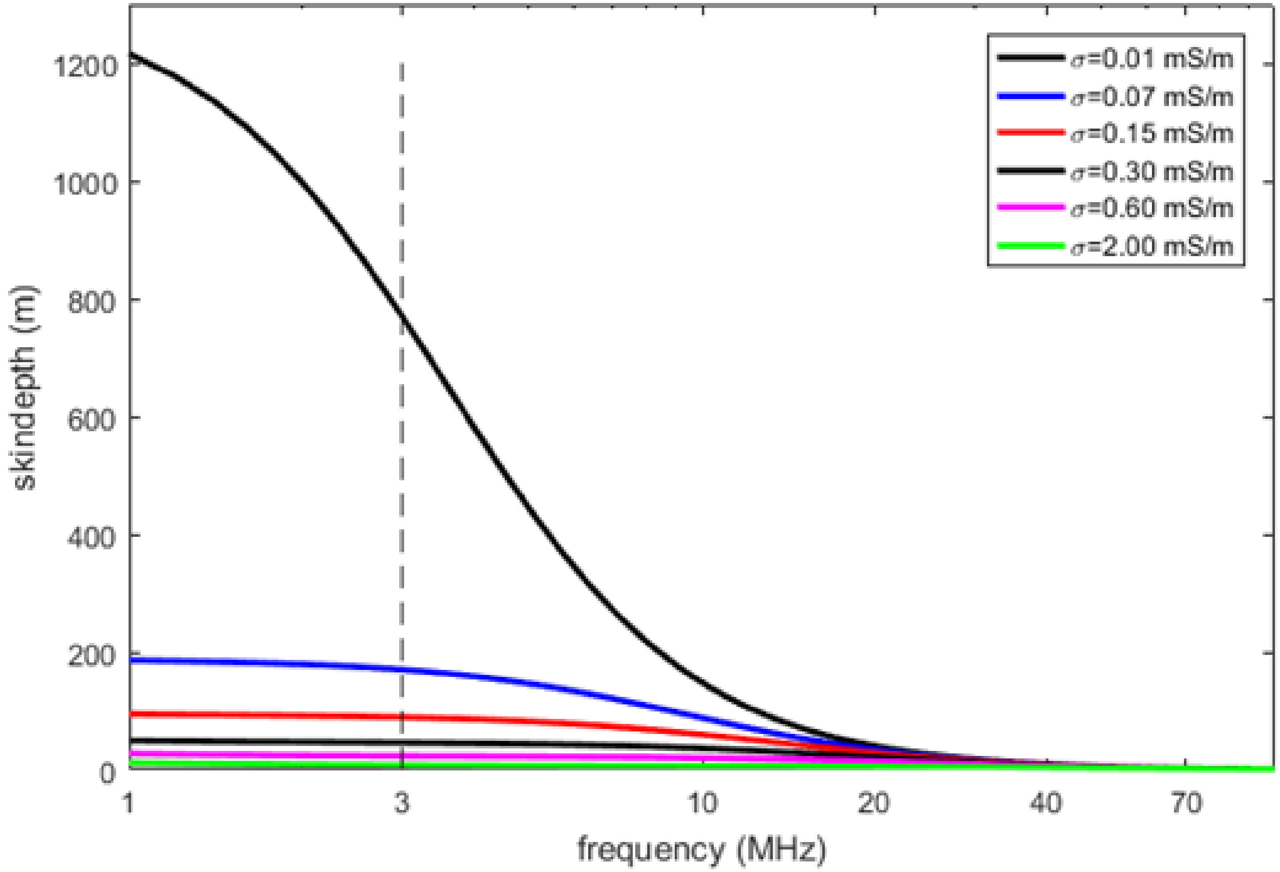
Skin depth versus frequency



- 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

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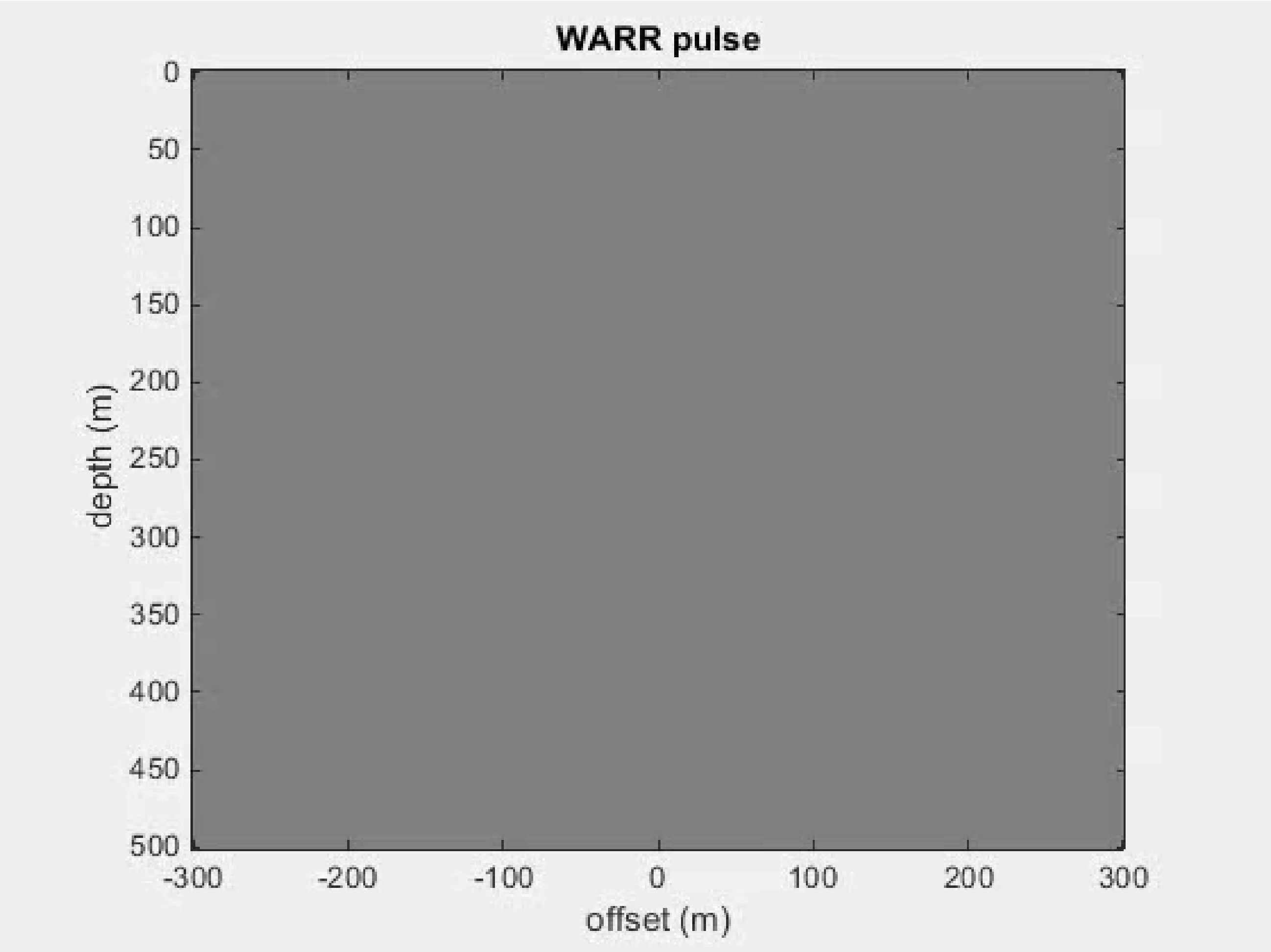
Pulse transmission

- 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: ϵ permittivity, σ conductivity and *P* polarization
  - *E* electric field, σ conductivity, τ Debye relaxation time, ε_r relative permittivity
- Resulting system of partial differential equations:

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

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

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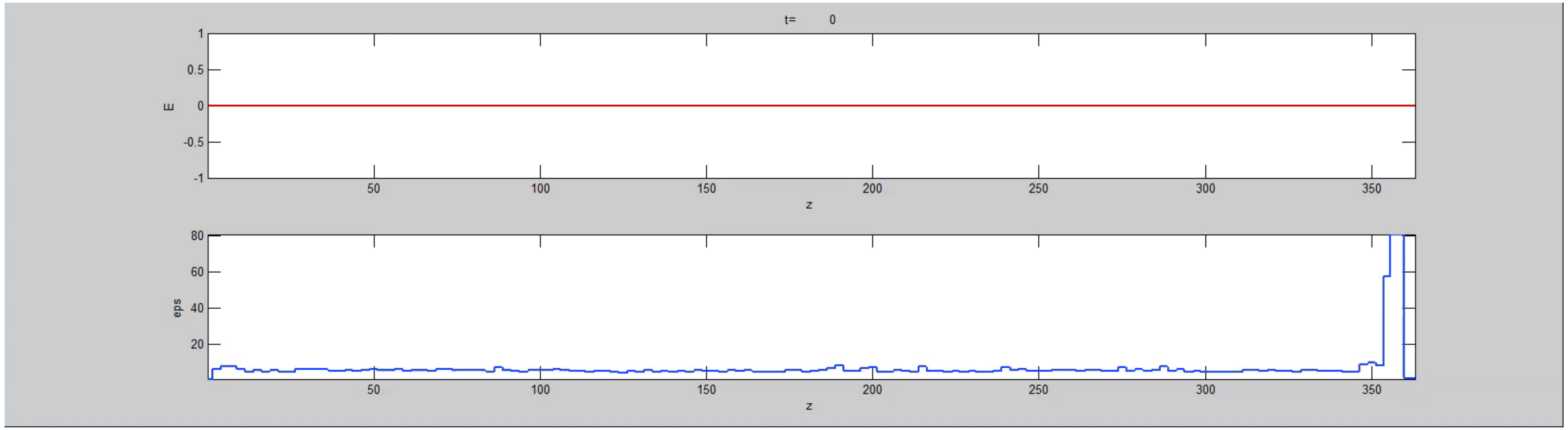
Simulation

- 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



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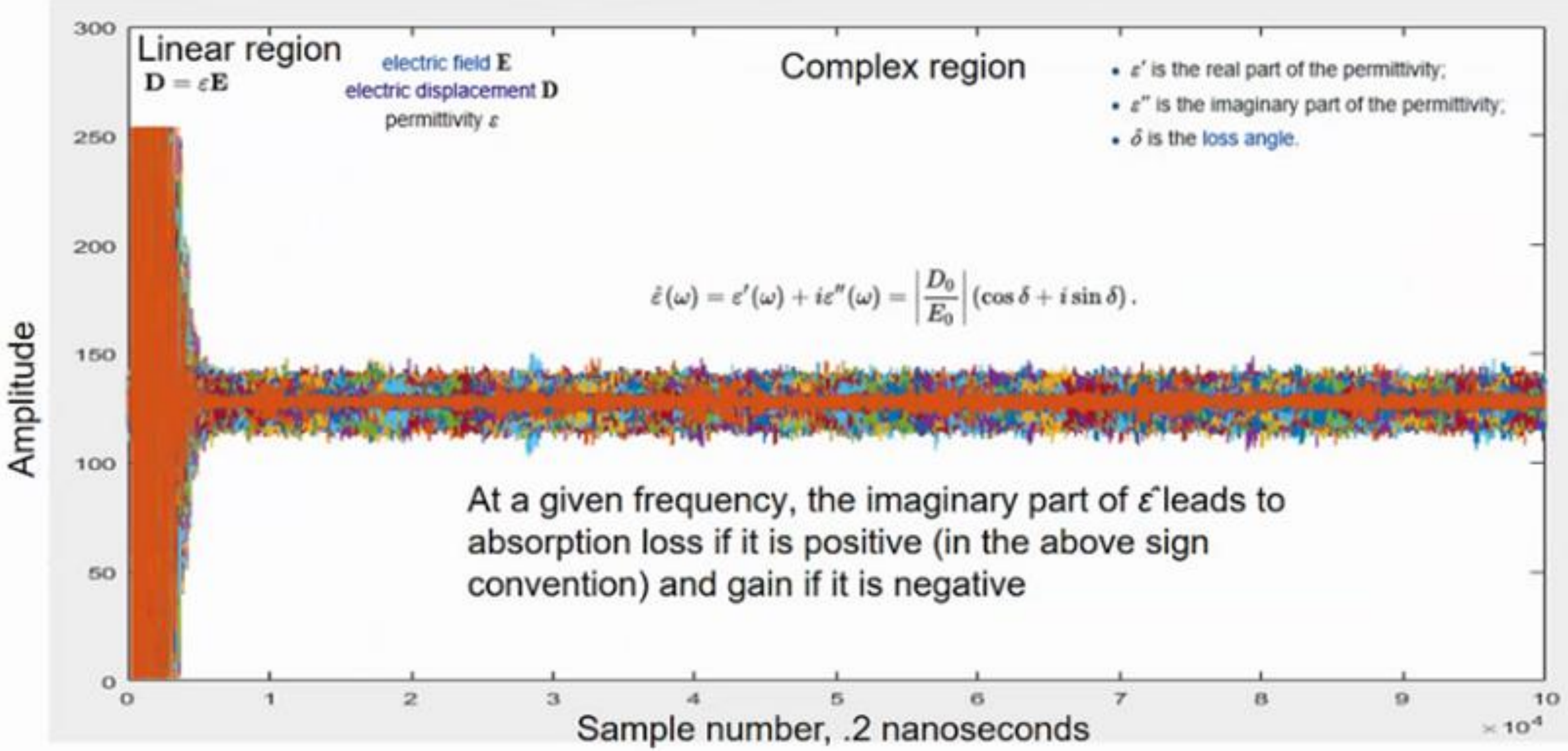
Received signals

Antenna is 1 meter above ground, To is from antenna at firing



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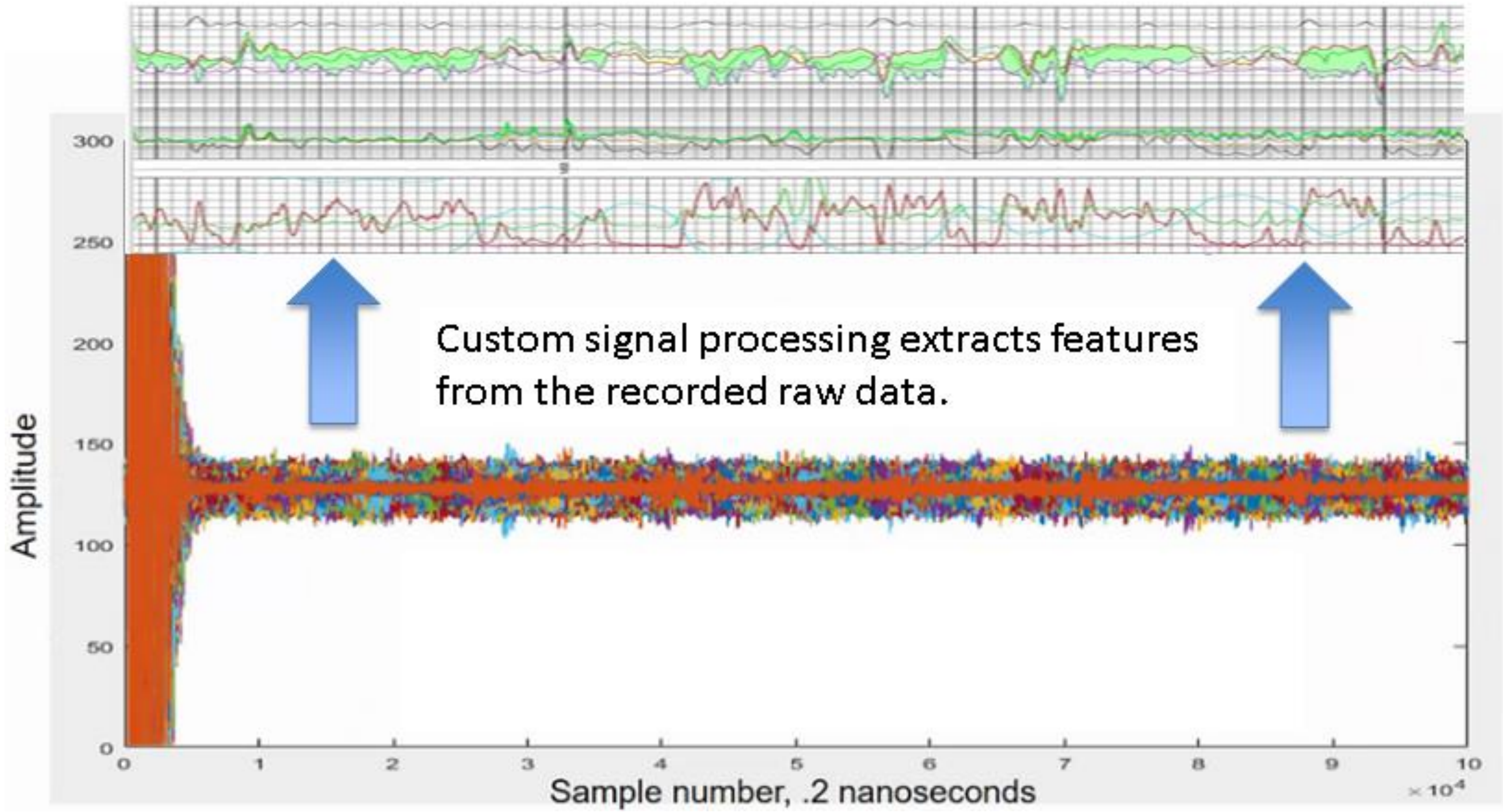
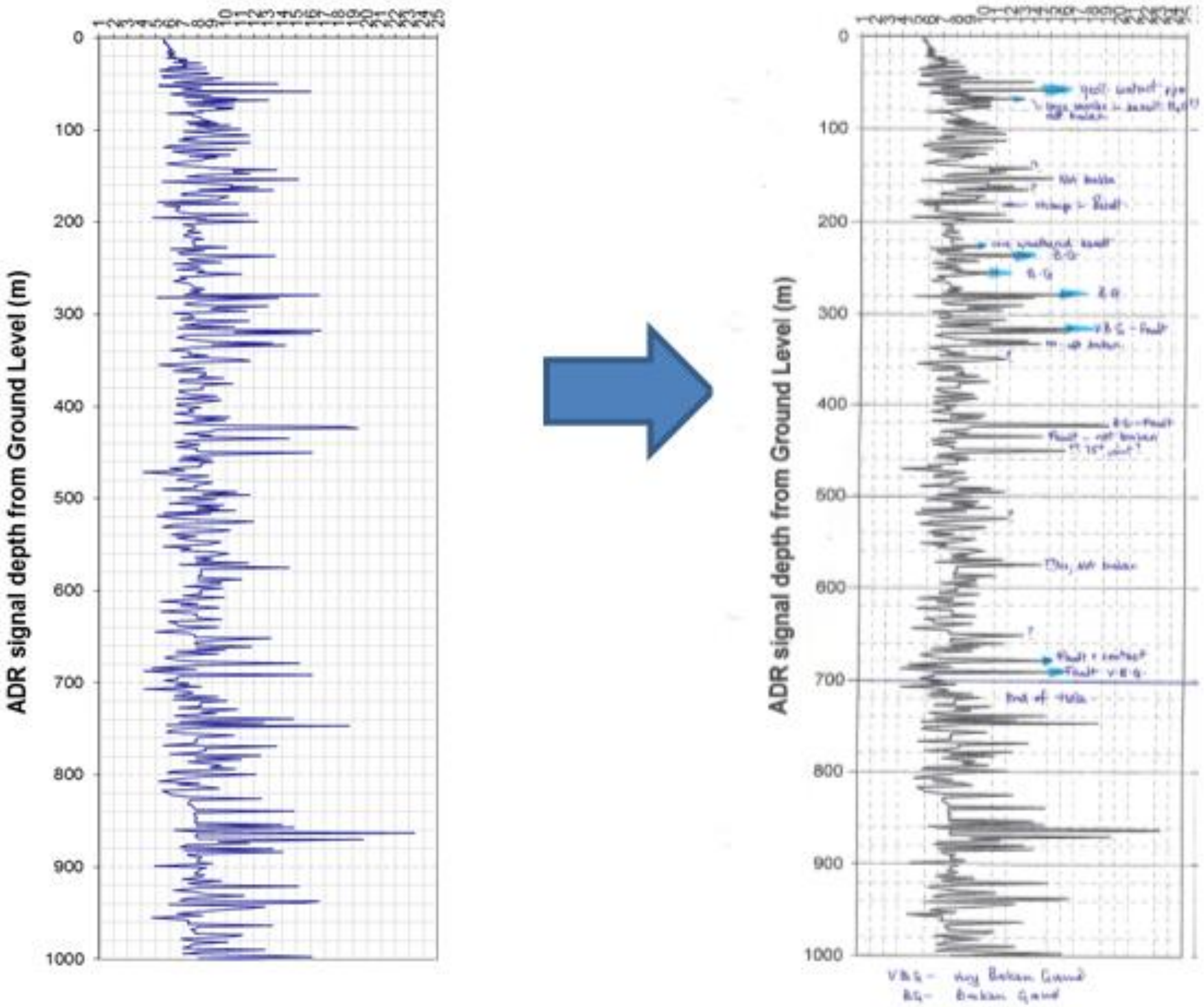

Custom signal processing extracts features from the recorded raw data.
Amplitude
Sample number, .2 nanoseconds
× 10⁴
0
50
100
150
200
250
300
1
2
3
4
5
6
7
8
9
10

Toolbox of ADR Measurements

Dielectrics (relative permittivity)



- 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)

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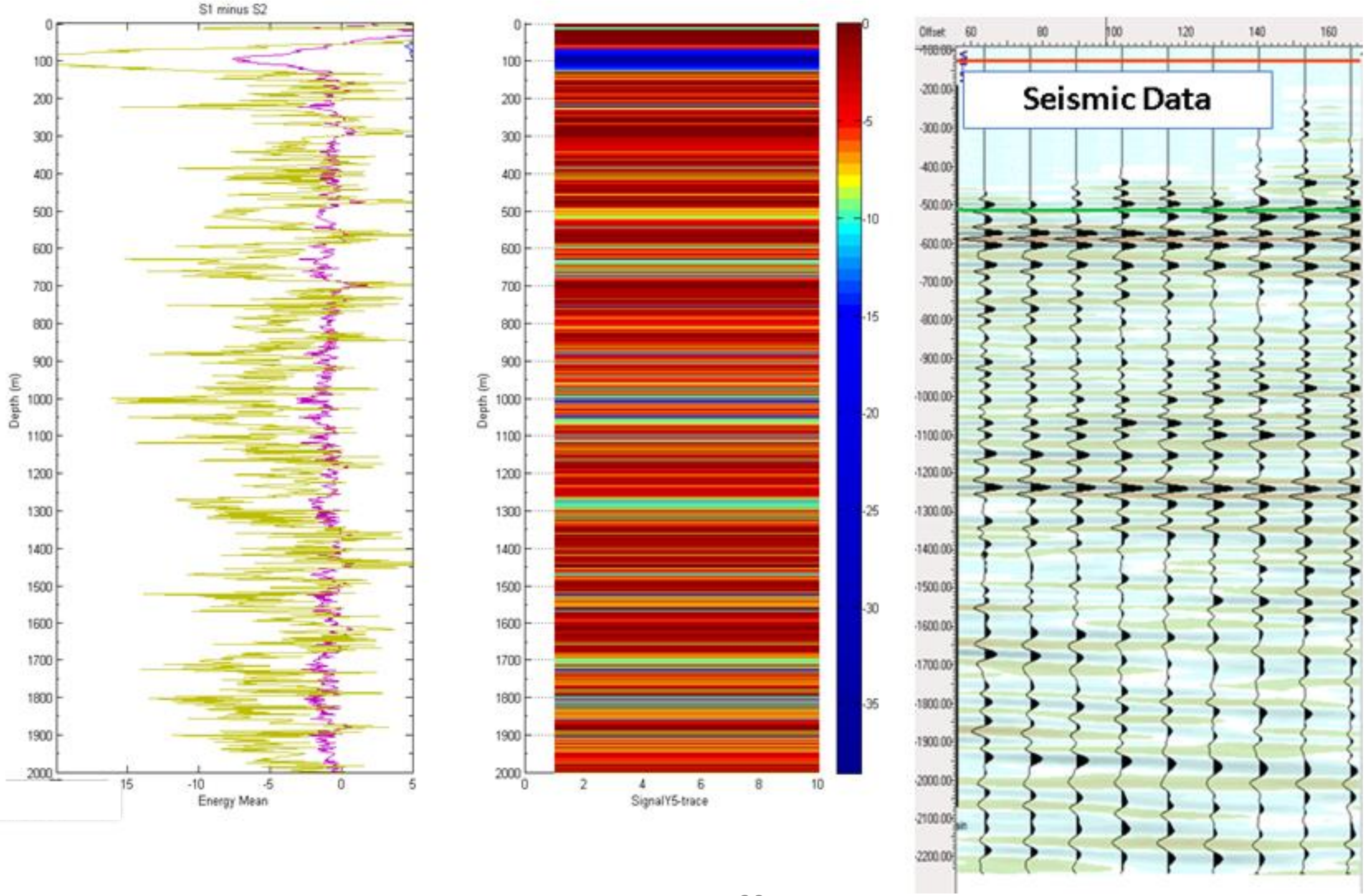
Energy log



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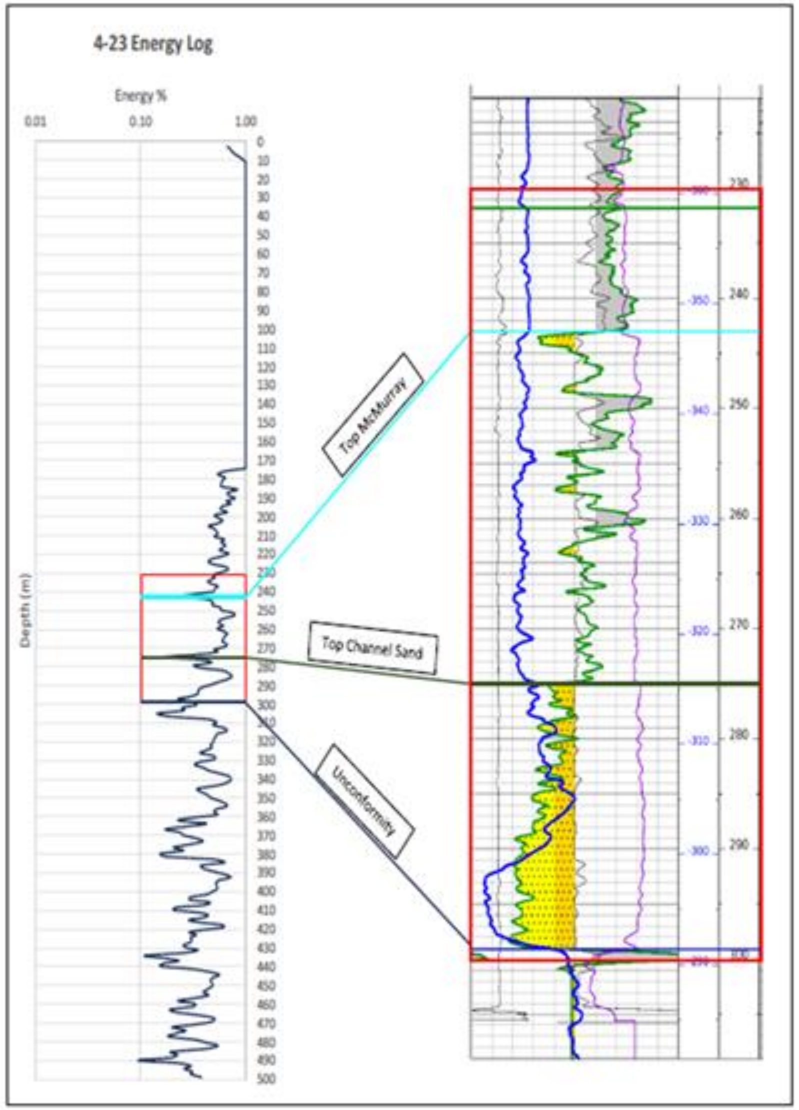
Energy log versus downhole logs

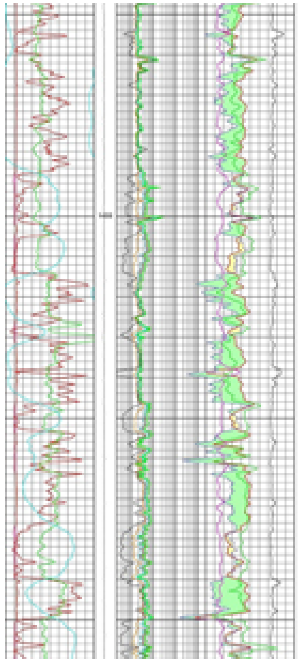


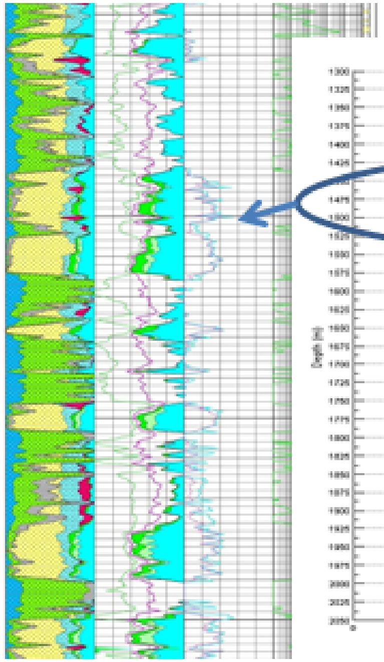
Frequency harmonics

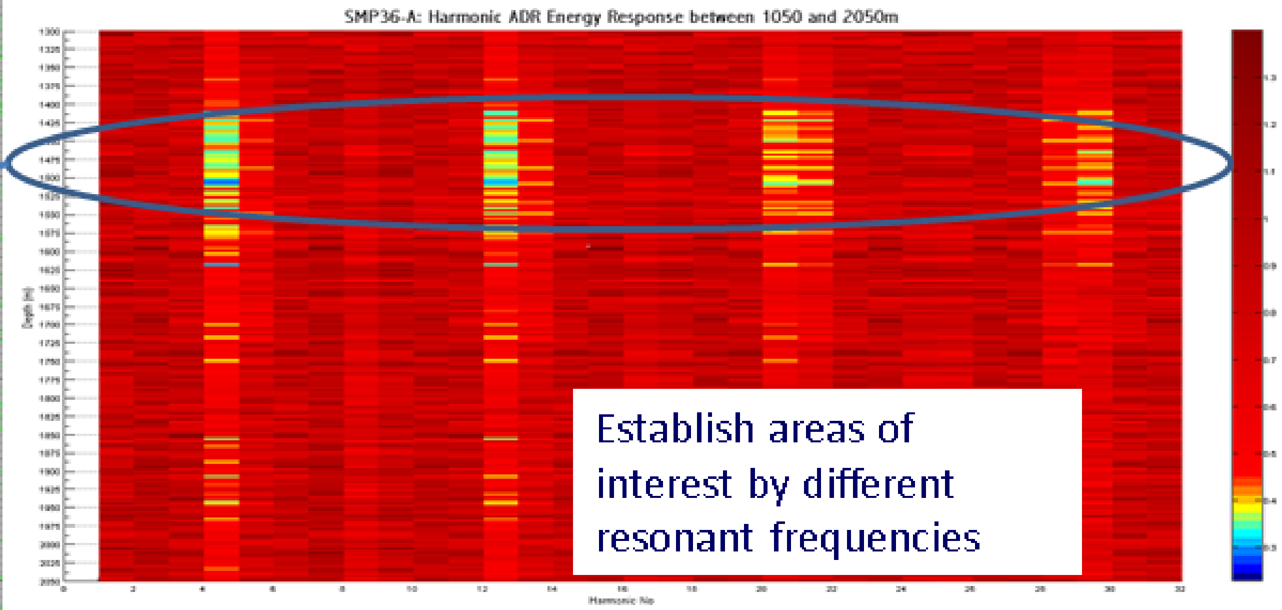
	Frequency															
Time (ns)	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16
51	100	59.2	22.9	77.4	89.5	71.5	31.9	8.1	20.1	28.1	30.3	27.7	13.9	11.2	4.9	10.3
102	100	52.1	22	25.5	21.8	14.3	8.4	10.6	14	14.5	12	8.3	6.6	6	5.3	3.7
153	100	46.2	34.9	29.2	26.5	22.3	15	7.5	3.4	3.8	6.4	8.9	9.6	8.4	6.3	4.7
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
255	11.4	34.2	5.2	91.4	100	22	51.1	22.9	21.8	15.1	6	21.7	17	11.1	24	24
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
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
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
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

	Frequency															
Time (ns)	H17	H18	H19	H20	H21	H22	H23	H24	H25	H26	H27	H28	H29	H30	H31	H32
51	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	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	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	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	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	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	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	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	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

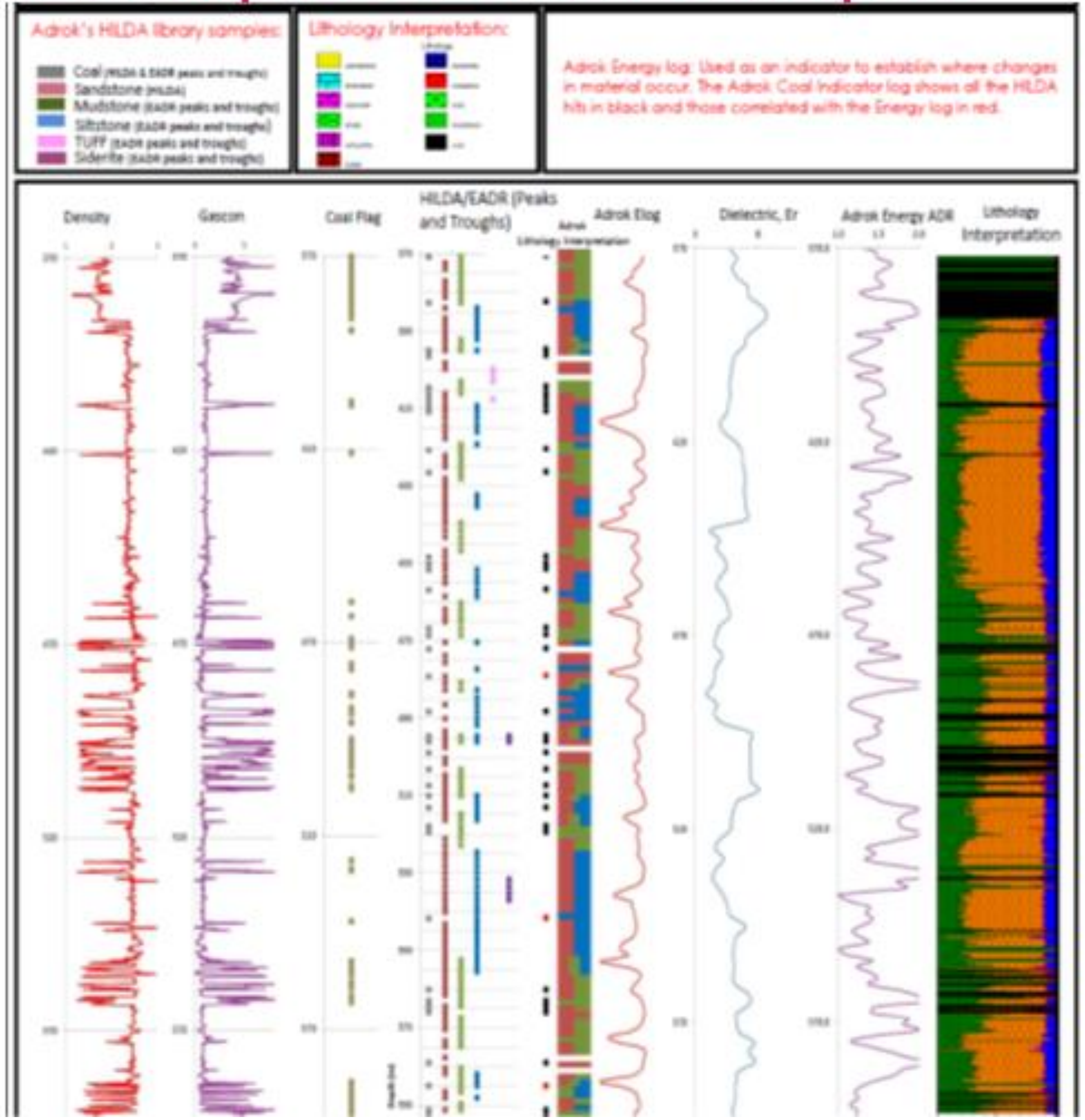
Create image of harmonic energies

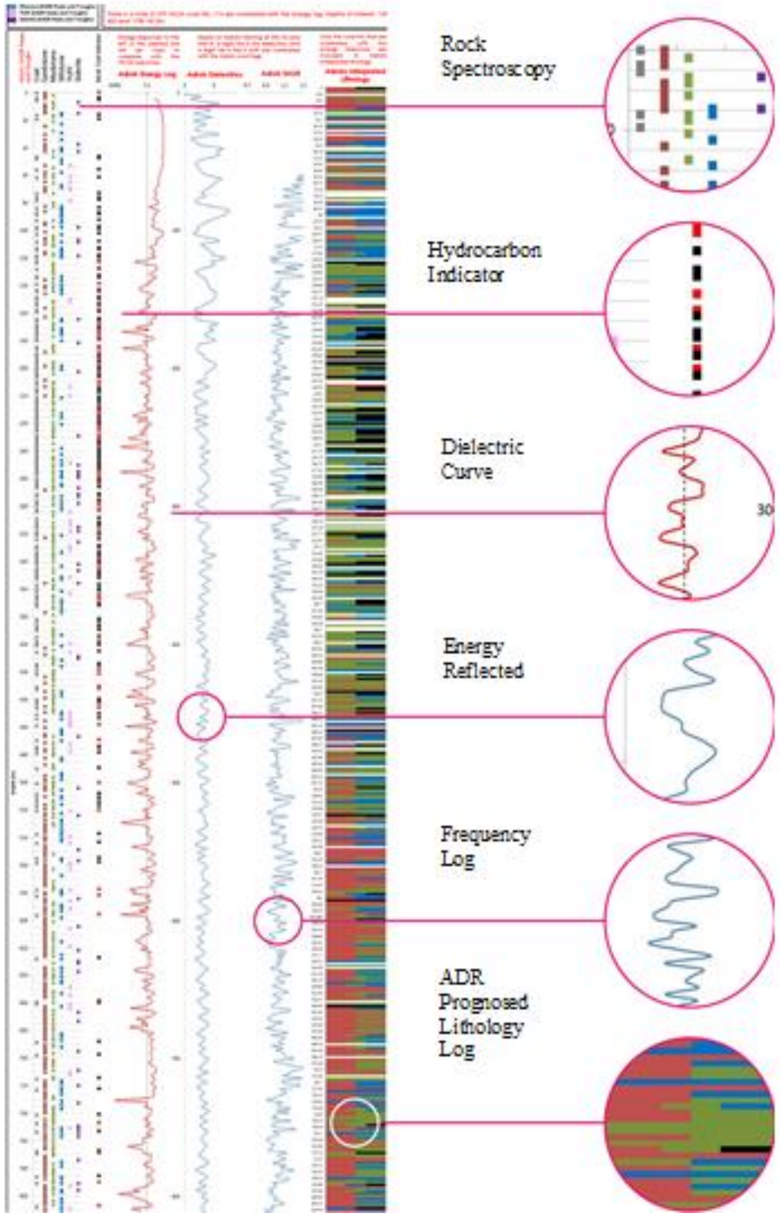






Examples of ADR Output





Case Studies

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

Case Study in Saskatchewan (Canada) with

Gensource
POTASH CORP

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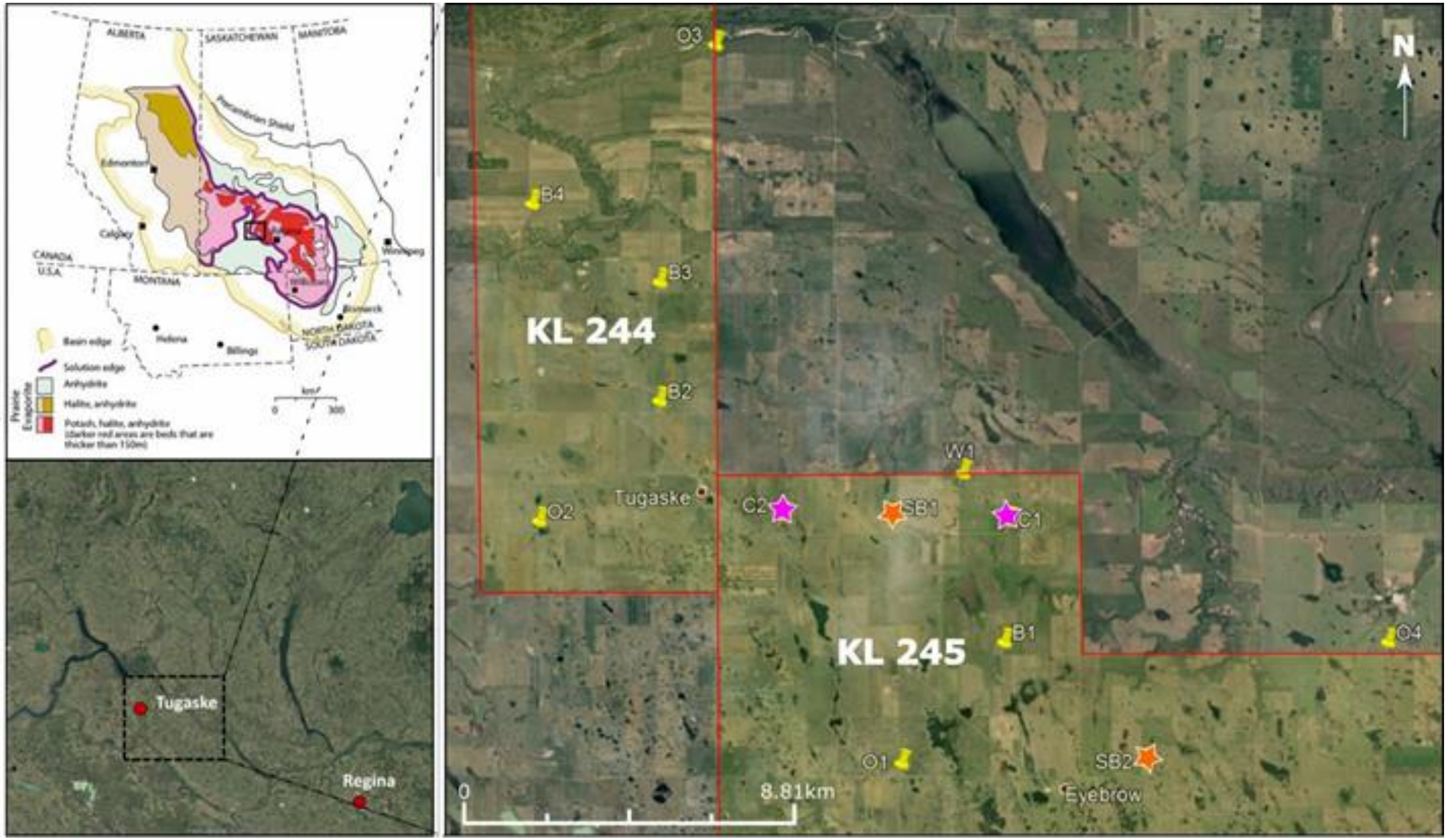

Figure 2 (right) location map displaying the location of Adrok's V-bores in relation to Gensource's two Potash leases in the Tugaske area of Saskatchewan. The pink stars denote training holes H1 (C1) and H2 (C2), and the orange stars represent the semi -blind V-bores H3 (SB1) and H4 (SB 2). (top left) 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) .

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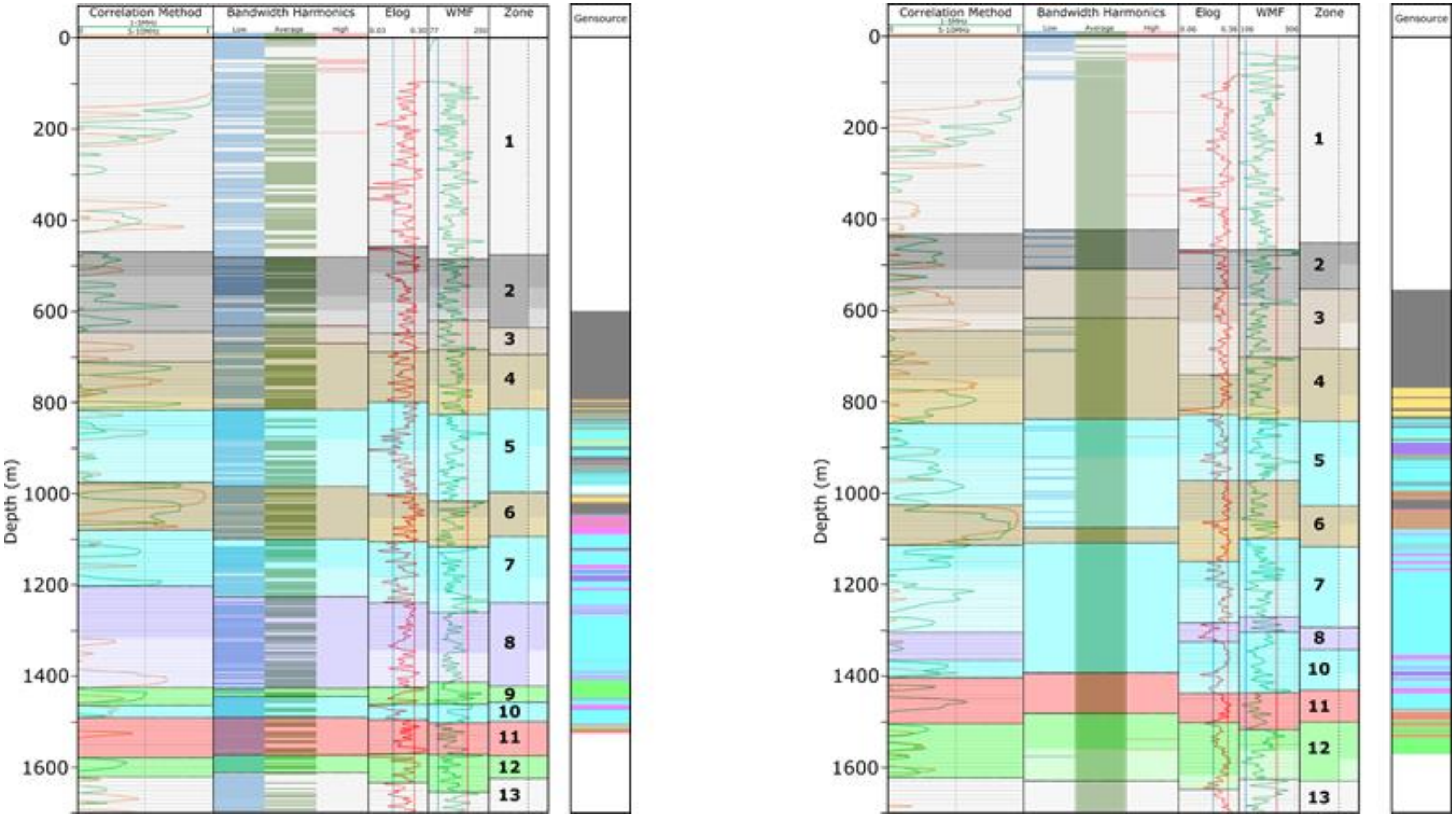


Figure 7: Lithological zonations for H3 (SB1) and H4 (SB2). These were interpreted "blindly" without any training lithology. The Gensource lithology displayed above was supplied to Adrok after interpretation was complete so that Adrok could determine the accuracy of the interpretation method.

Shale Siltstone Sandstone Limestone Chert Dolomite Anhydrite Halite Potash Mineralisation

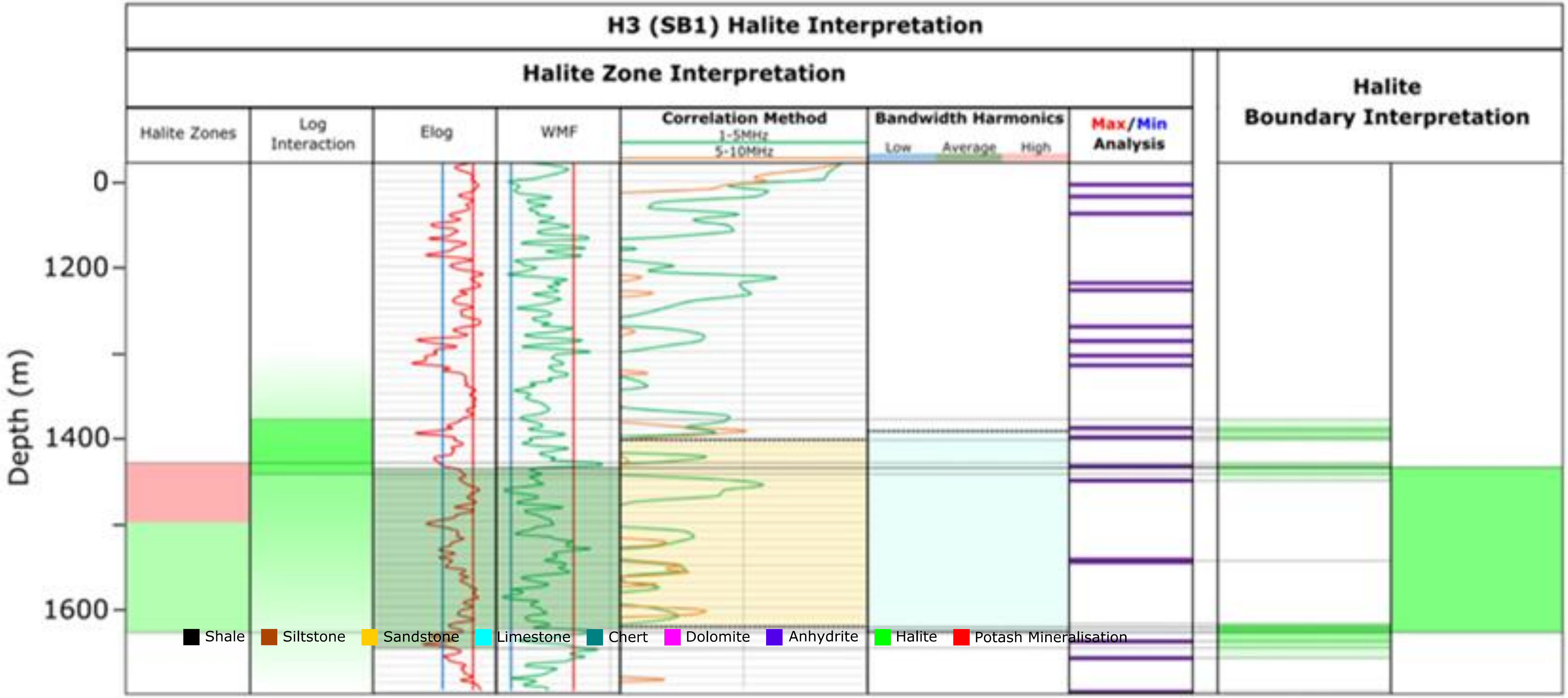
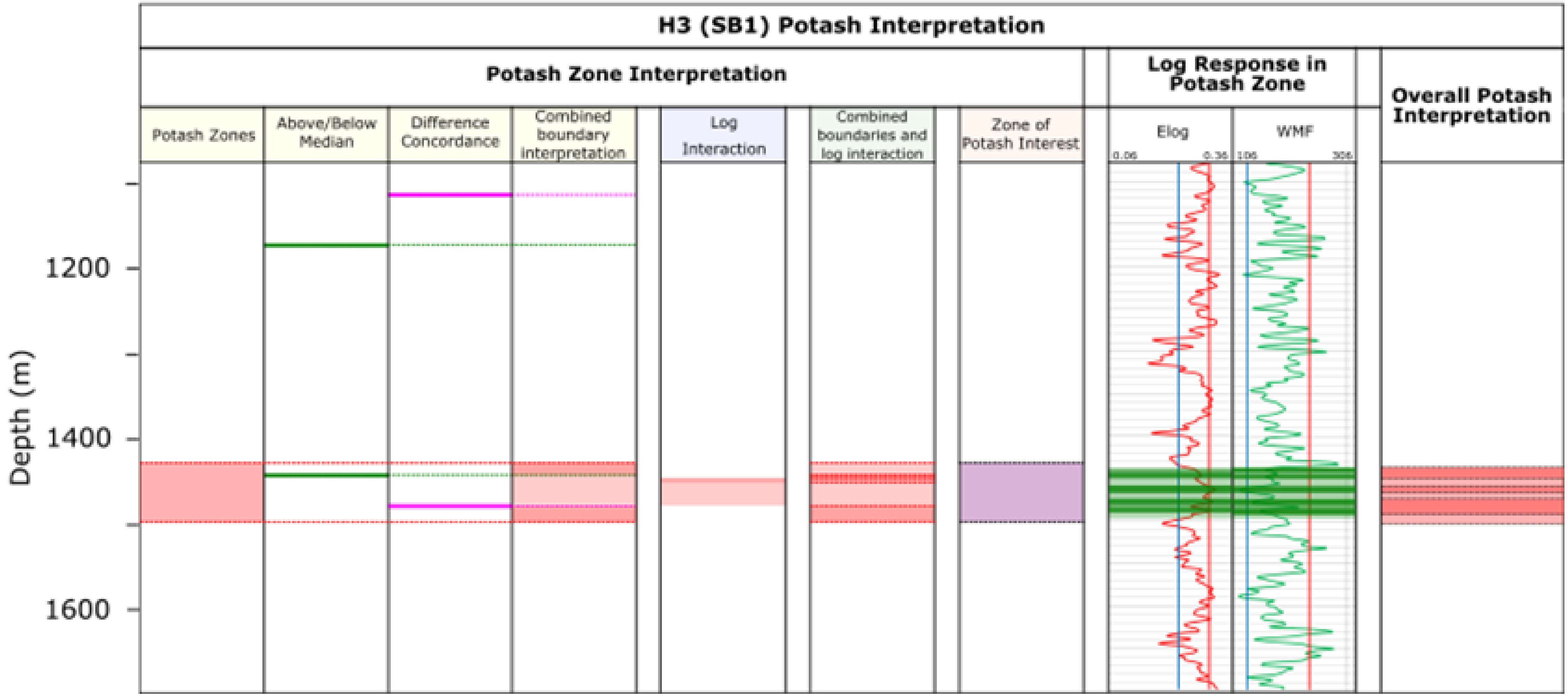


Figure 9: Example from H3 (SB1) of the full integrated interpretation approach for the presence of halite in the section.



<u>Figure</u> 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

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Case Study in near-surface water in Scotland in association with

Scottish Water

Always serving Scotland

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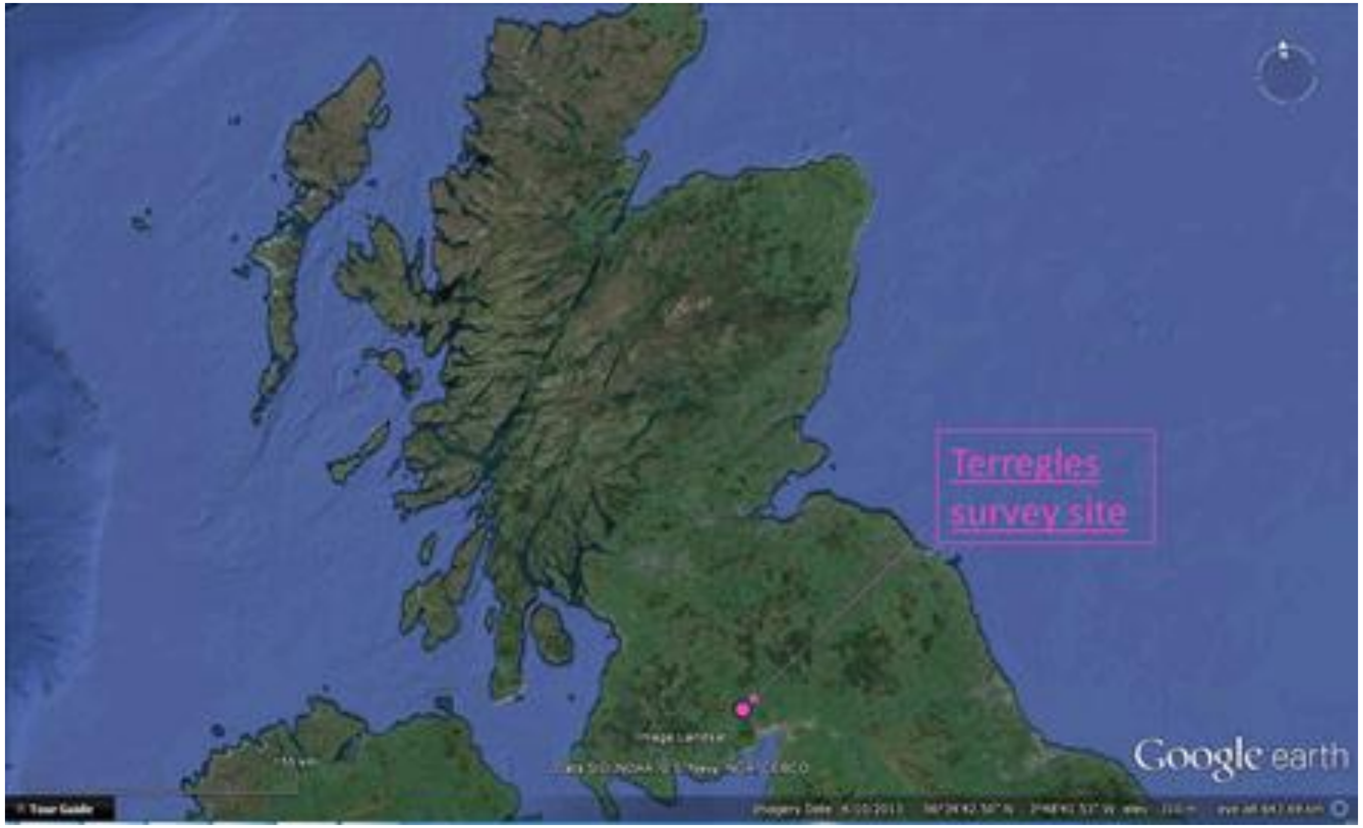

Map of Scotland showing the location of the Terregles survey site (Google Earth, 2013)

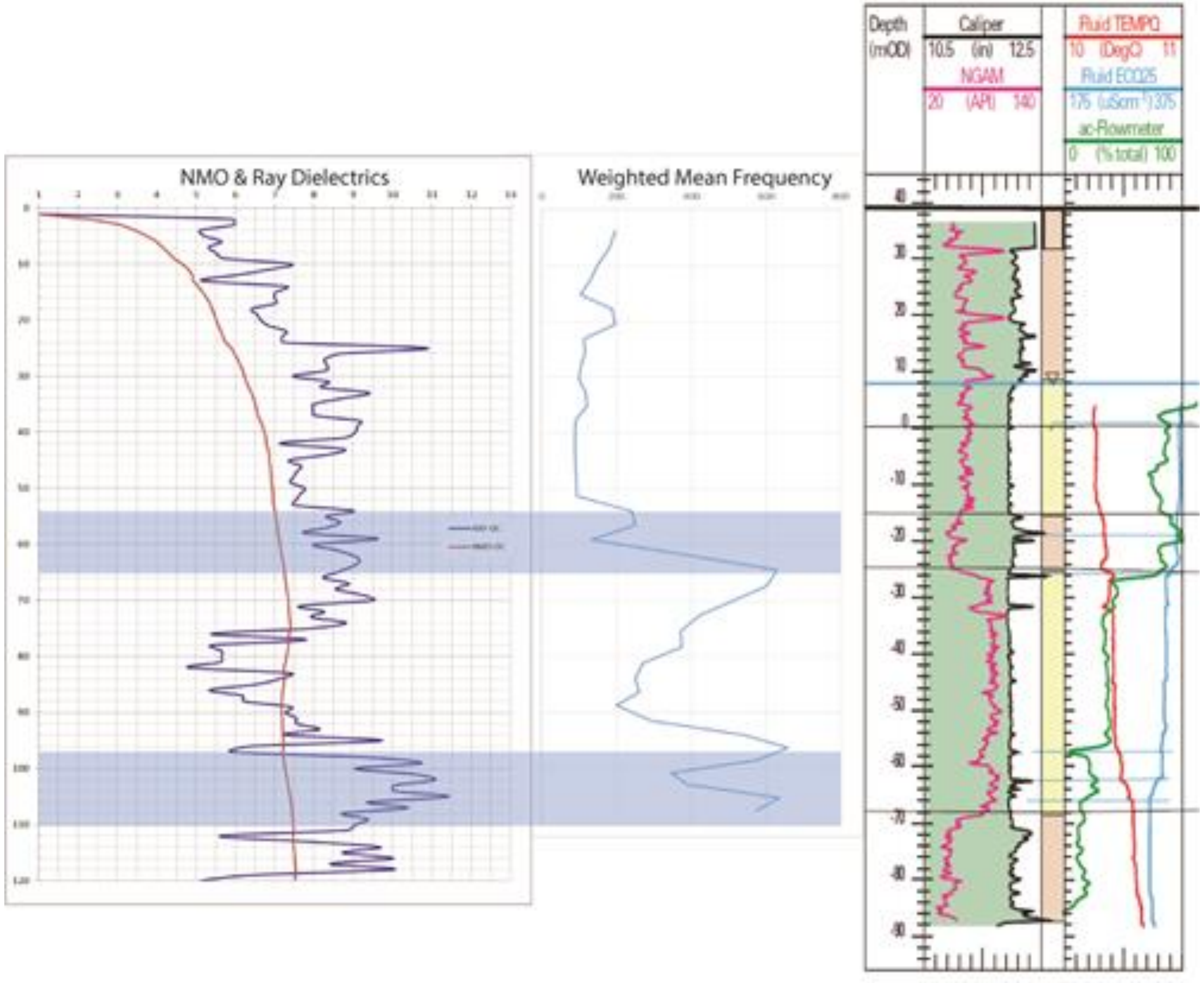

Figure 7. Comparison of TS3 ADR Stare scan Dielectric and Weighted Mean Frequency virtual logs (Adrok) with Terregles borehole logs (Robins and Ball, 2006).

- According to the geological information provided by Scottish Water, the two main aquifers are located in multiple fractures between 58-68 m and 98-110 m. This means that the aquifer is contained within in a less-permeable geological unit, confining the water to thin fracture networks.
- Adrok acquired three Stare scans (“virtual boreholes”) at Terregles: TS1, TS2, TS3. They were along a line, separated by 60 meters. The depths were obtained from the WARR scans at each Stare site.

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Case Study Gold Exploration in Queensland (Australia) with

www.citigold.com
CiTiGOLD
corporation

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Gold and sulphide targeting using Adrok's Atomic Dielectric Resonance (ADR) technique

AIM:

- To locate small (<50 x 50m) areas of high grade gold mineralisation hosted within a set of
- semi-predictable and semi-continuous fractures within granitic host rocks

SOME EXPLORATION CHALLENGES:

- Mineralization is located directly beneath the city of Charters Towers thereby limiting the
- Use of conventional drilling and other traditional geophysical techniques such as magnetics, gravity, IP, TEM, MT, Seismic reflection..
- The depth to mineralization is 400m to over 1500m.
- Drilling is extremely slow and expensive and there is a lack of drill pad sites within the city.
- The local granite is extremely hard resulting in an average drilling advance of 30-40m/day using conventional diamond drilling

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Tonalite host rocks

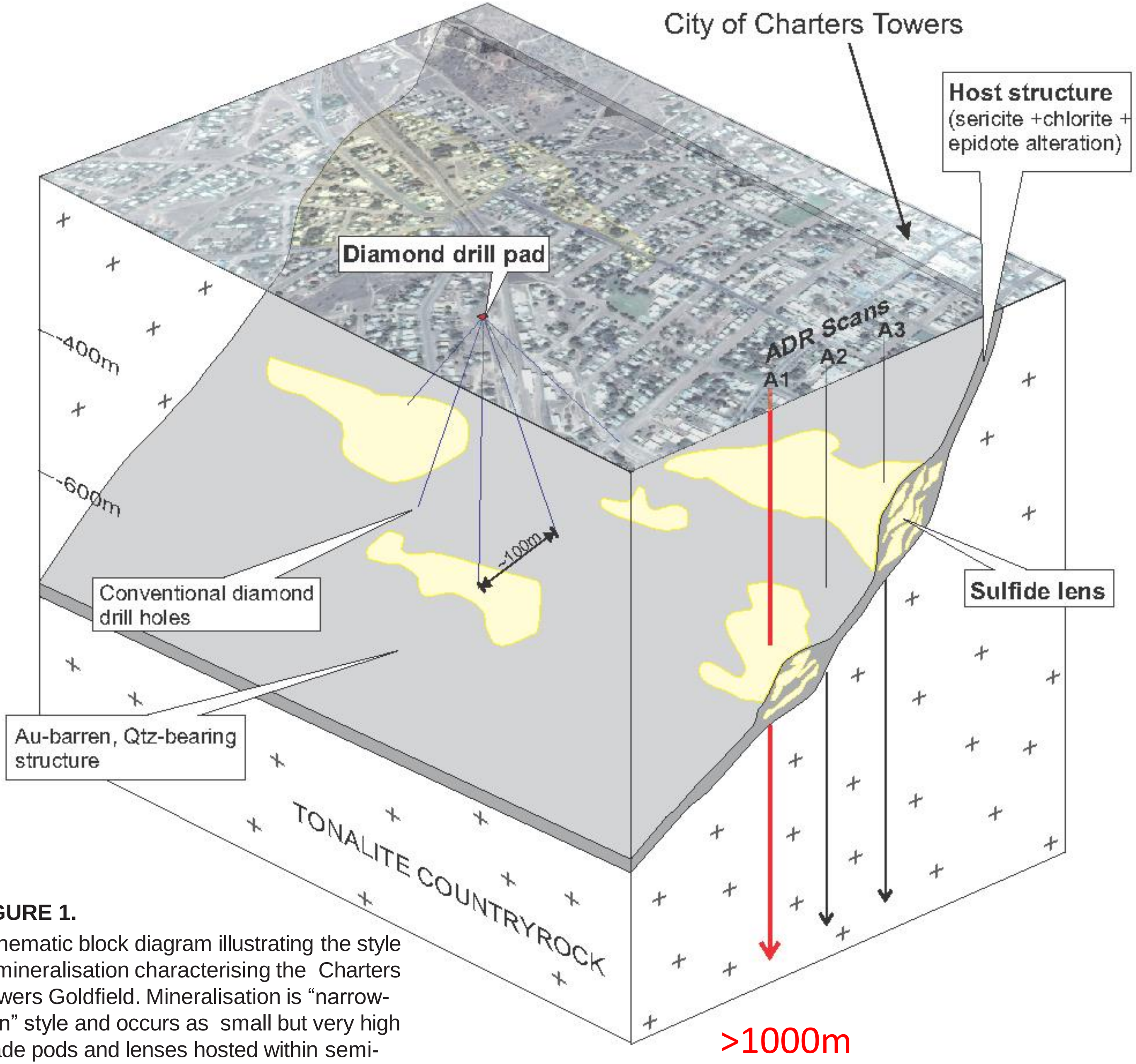
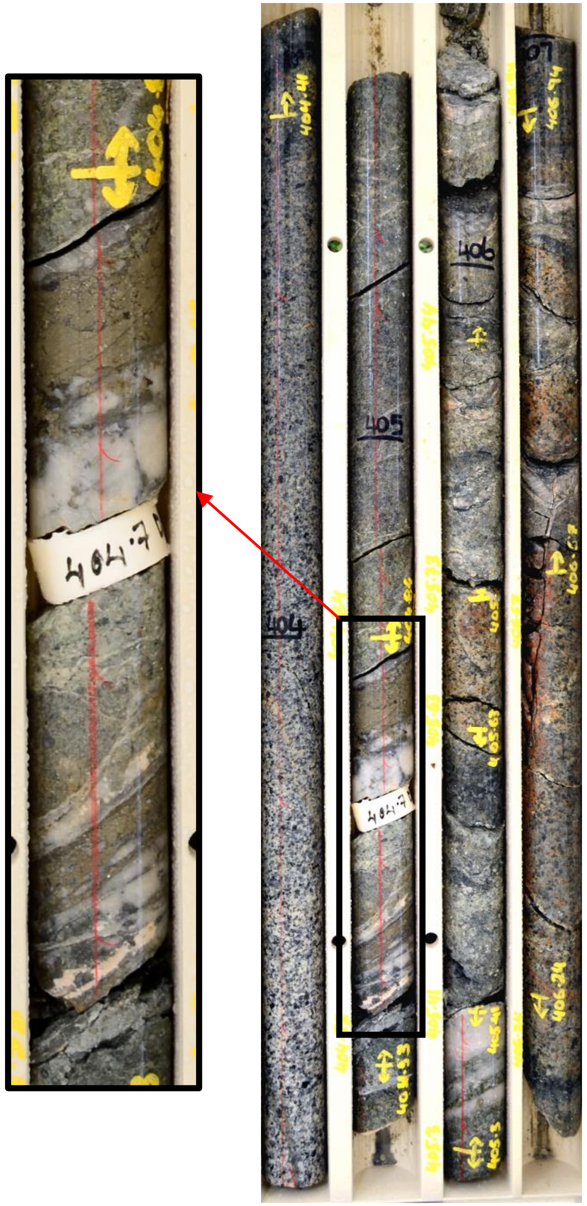


FIGURE 1.

Schematic block diagram illustrating the style of mineralisation characterising the Charters Towers Goldfield. Mineralisation is “narrow-vein” style and occurs as small but very high grade pods and lenses hosted within semi-continuous, planar - or NE-dipping dilatent fractures.



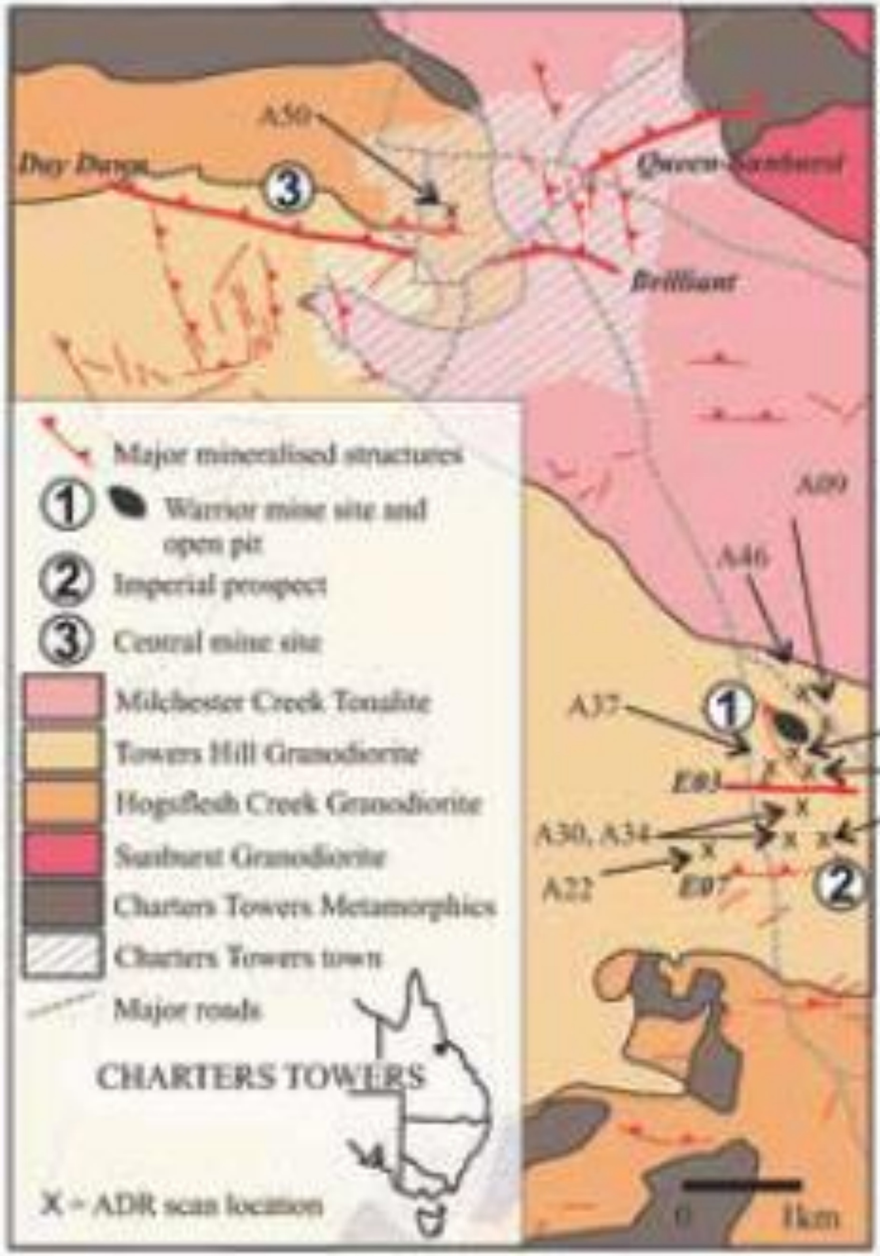
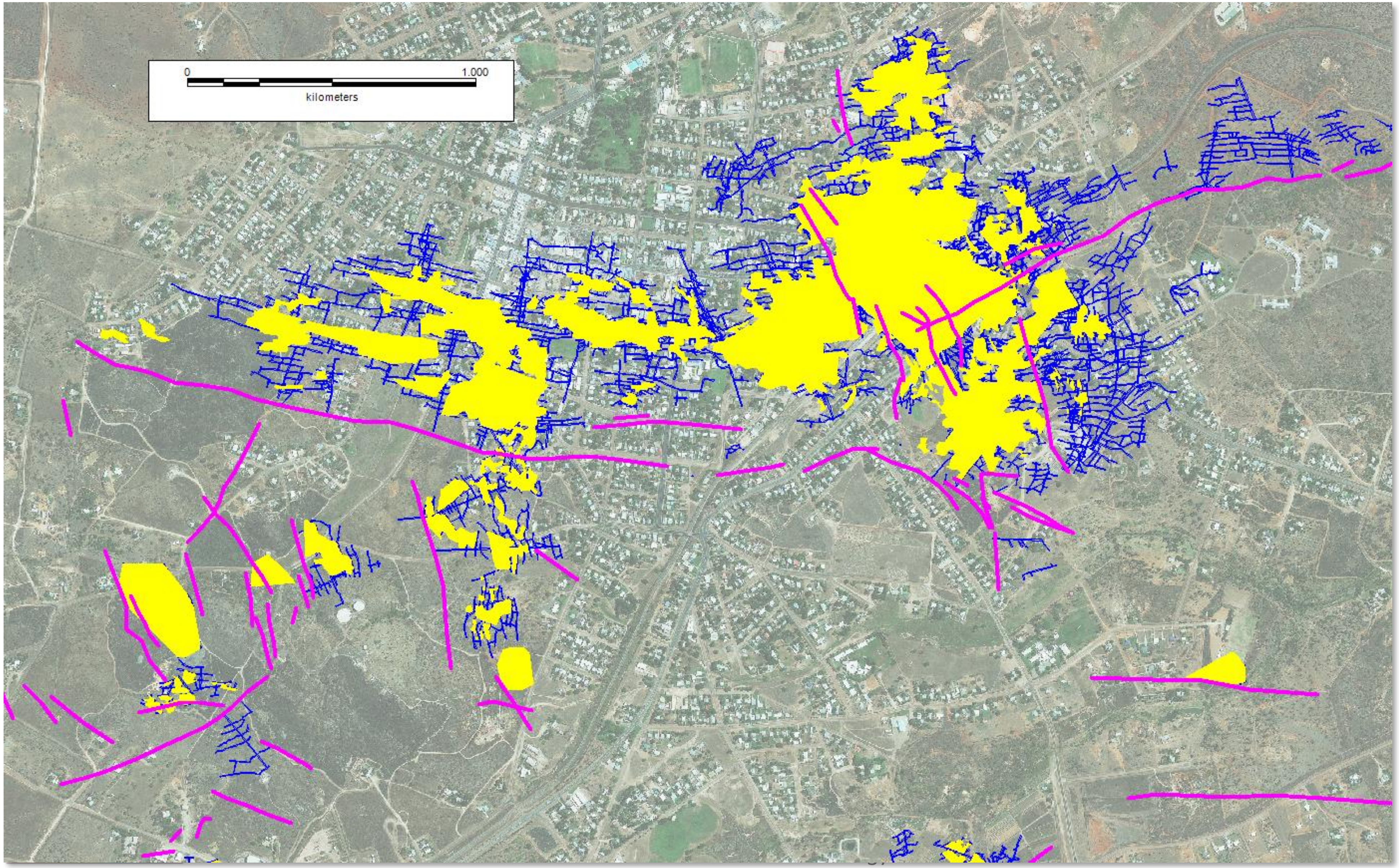


FIGURE 2.

Map of the Charters Towers area showing major rock type boundaries, major mineralised structures and the location of ADR scans discussed below. Citigold operates three areas of interest for ADR including Warrior (AREA 1), Imperial (AREA 2), and Central (AREA 3). Results are presented for Areas 1 and 2 below.

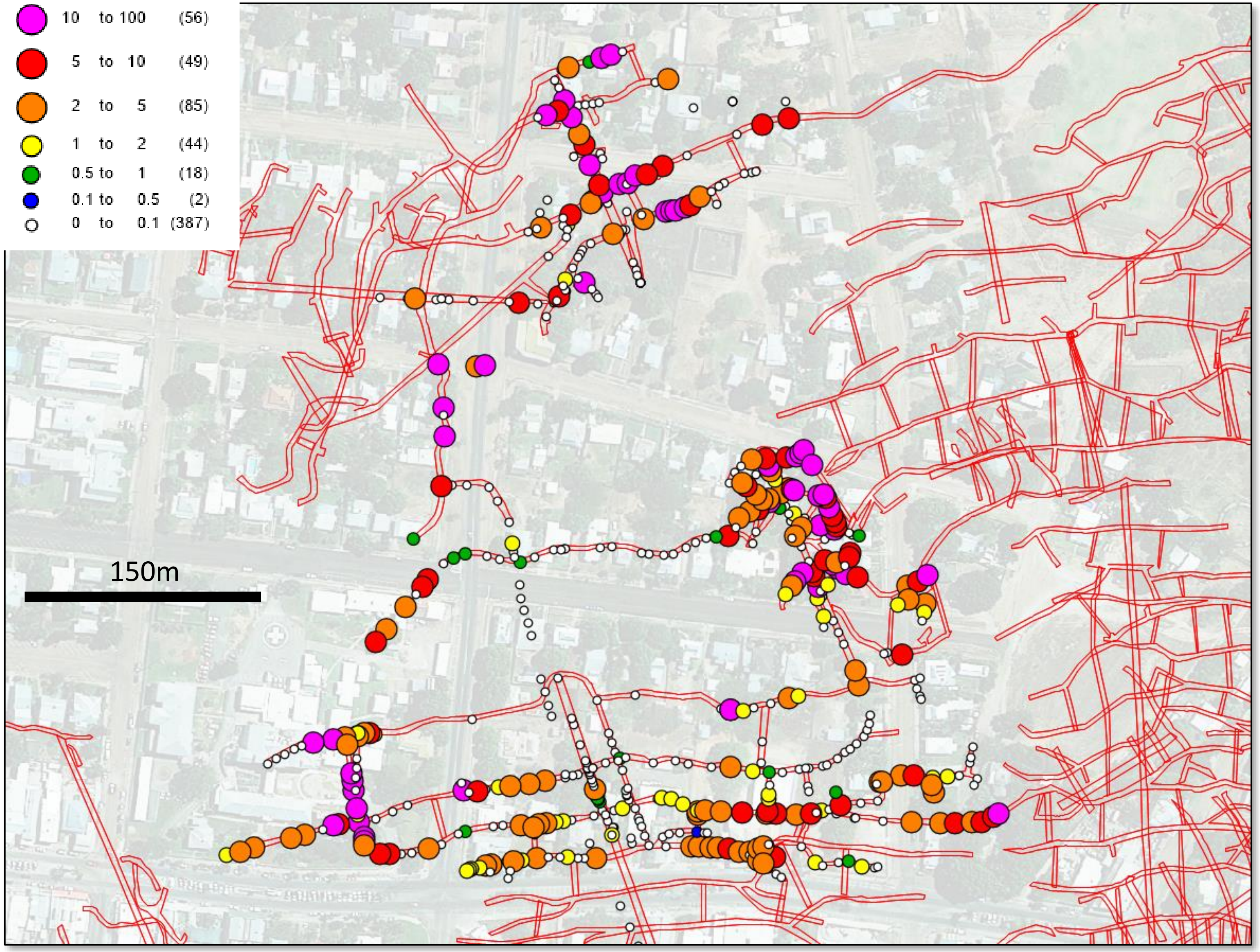
Area 1 - "PODDY" style mineralisation hosted by N-dipping and NE-dipping fractures



Surface expression of fractures

Historical development (drives, underlies etc)

Stopes (not all high grade)



THE PROBLEM WITH GRADE DISTRIBUTION

- Extremely irregular distribution of gold grades

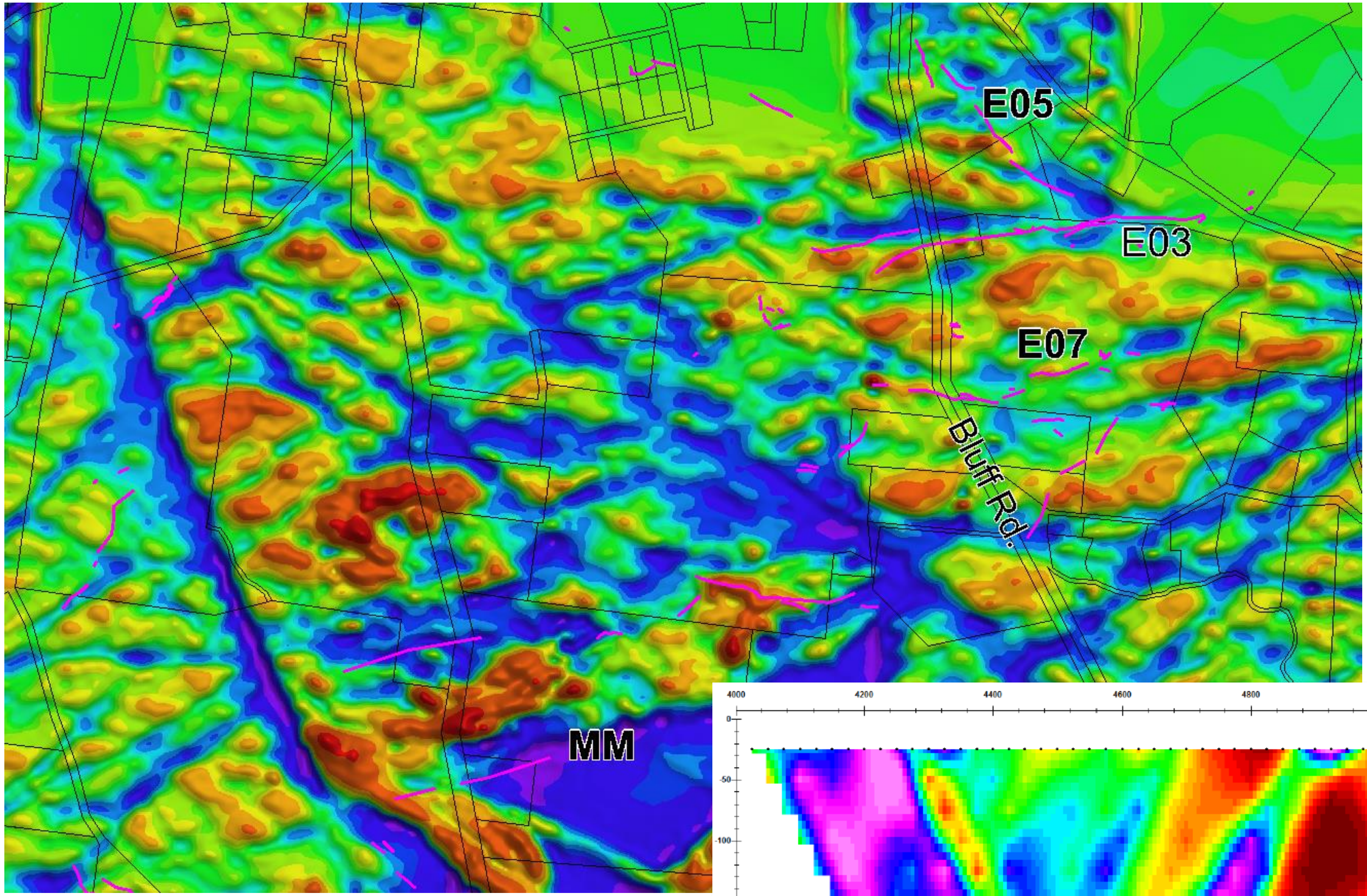
- High grade “pods” are typically <100m in longest dimension.

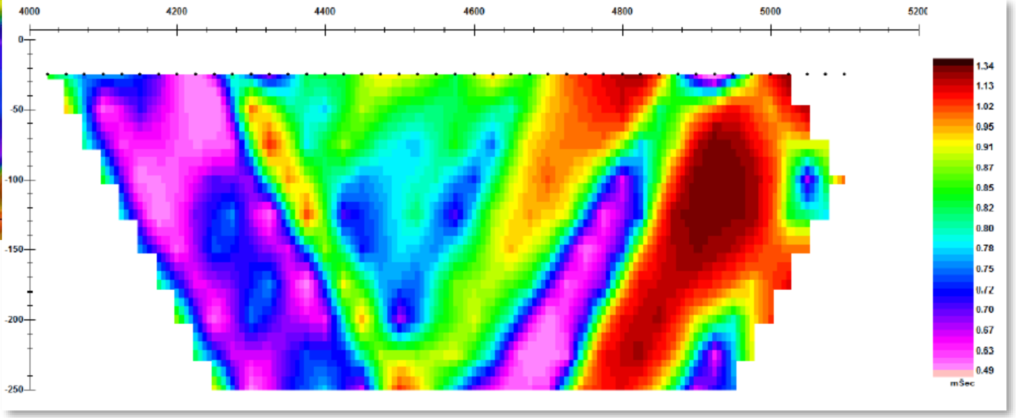
- Grade variable on the meter-scale

- Overall grade of the Charters Towers gold field is ~27g/t Au (average from drilling) to 32.3 g/t Au (average from historical production).

Even at 25m spacing, DRILLING IS UNRELIABLE, EXPENSIVE, INACCURATE and TIME CONSUMING.

Techniques trialed at Charters Towers





Aeromag (RTP) used to aid in the definition of possible host structures:

- No use in built up areas
- Variable results

DCIP Result: IP Data for C/S to a depth of -250m with a range of ~0.5 (purple) to 1.35 (red) mSec.

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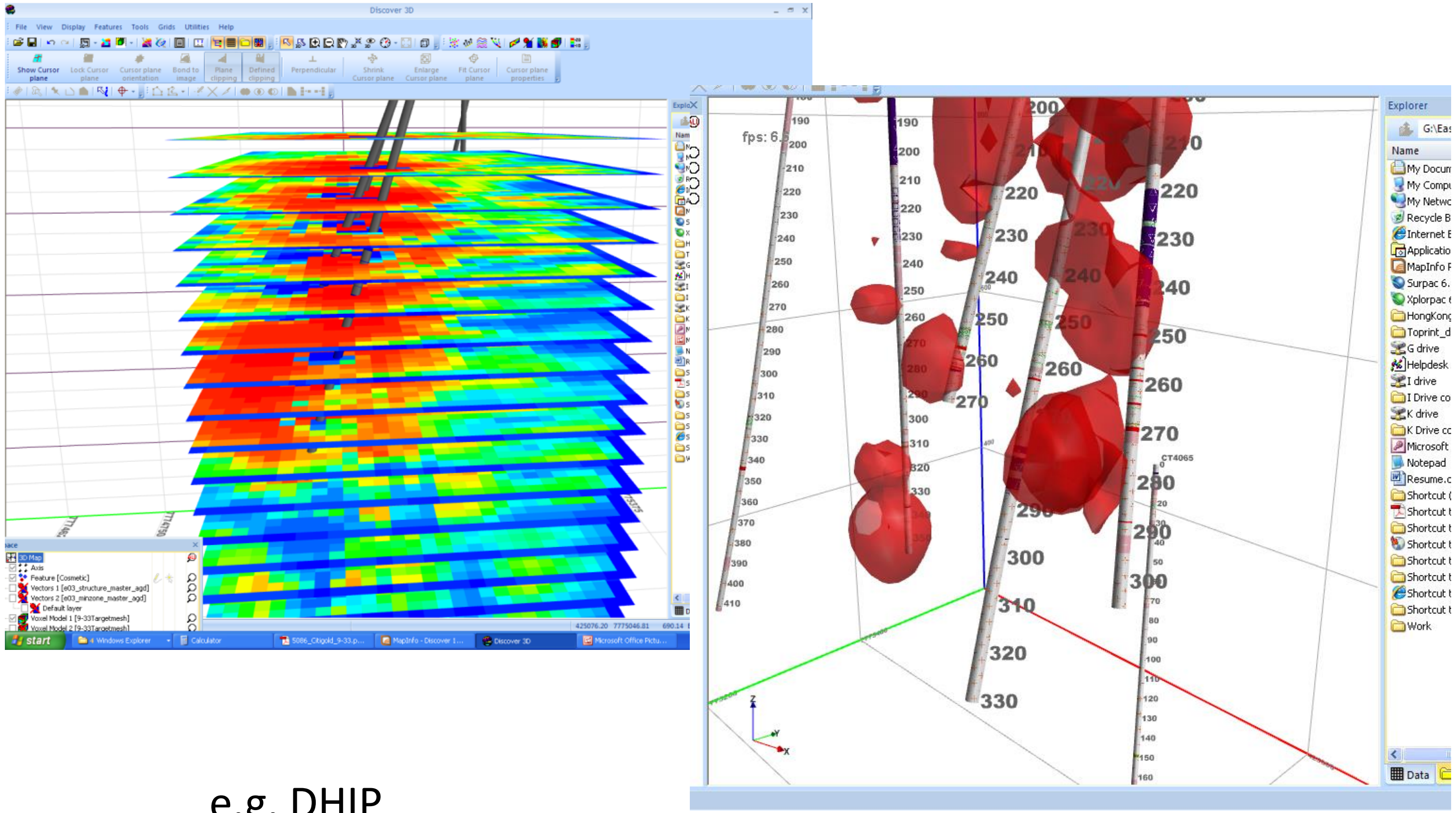
Techniques trialed at Charters Towers

- • = Requires drilling
- \- = Surface method

- • Borehole radar
- \- Surface magnetics
- \- Surface magnetics, radiometrics & gravity processing
- • Borehole induction, mag and gamma
- • DHIP
- • Sfc TEM, borehole TEM, DCIP
- \- Sfc TEM, DCIP
- \- Sfc TEM
- \- MT and Deep Seismic – Geoscience Australia (government funded)

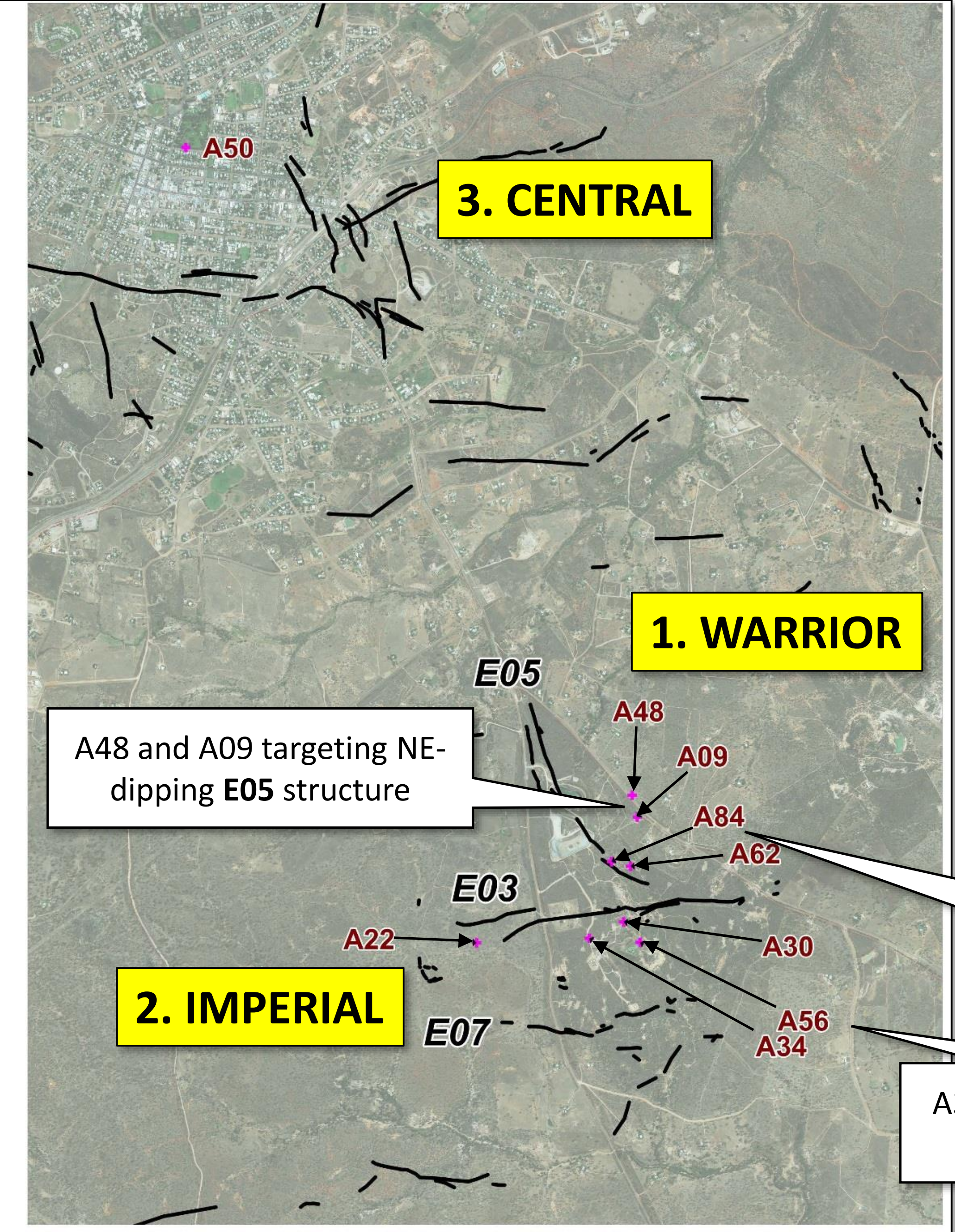
No use of Spectral IP?

And…..PETROS overseeing projects and data compilation/processing



e.g. DHIP
REQUIRES DRILLING & result = 52% anti-correlation

RESULTS



ADR SCAN LOCATION SELECTION

A84 and A62 targeting N-dipping **E03** structure

A30, A56, A34 and A22 targeting NE-dipping **E07** structure

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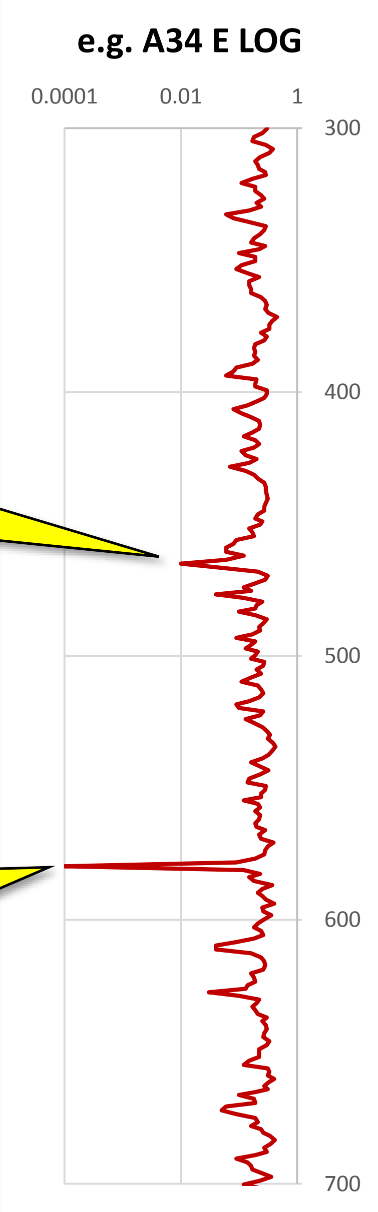
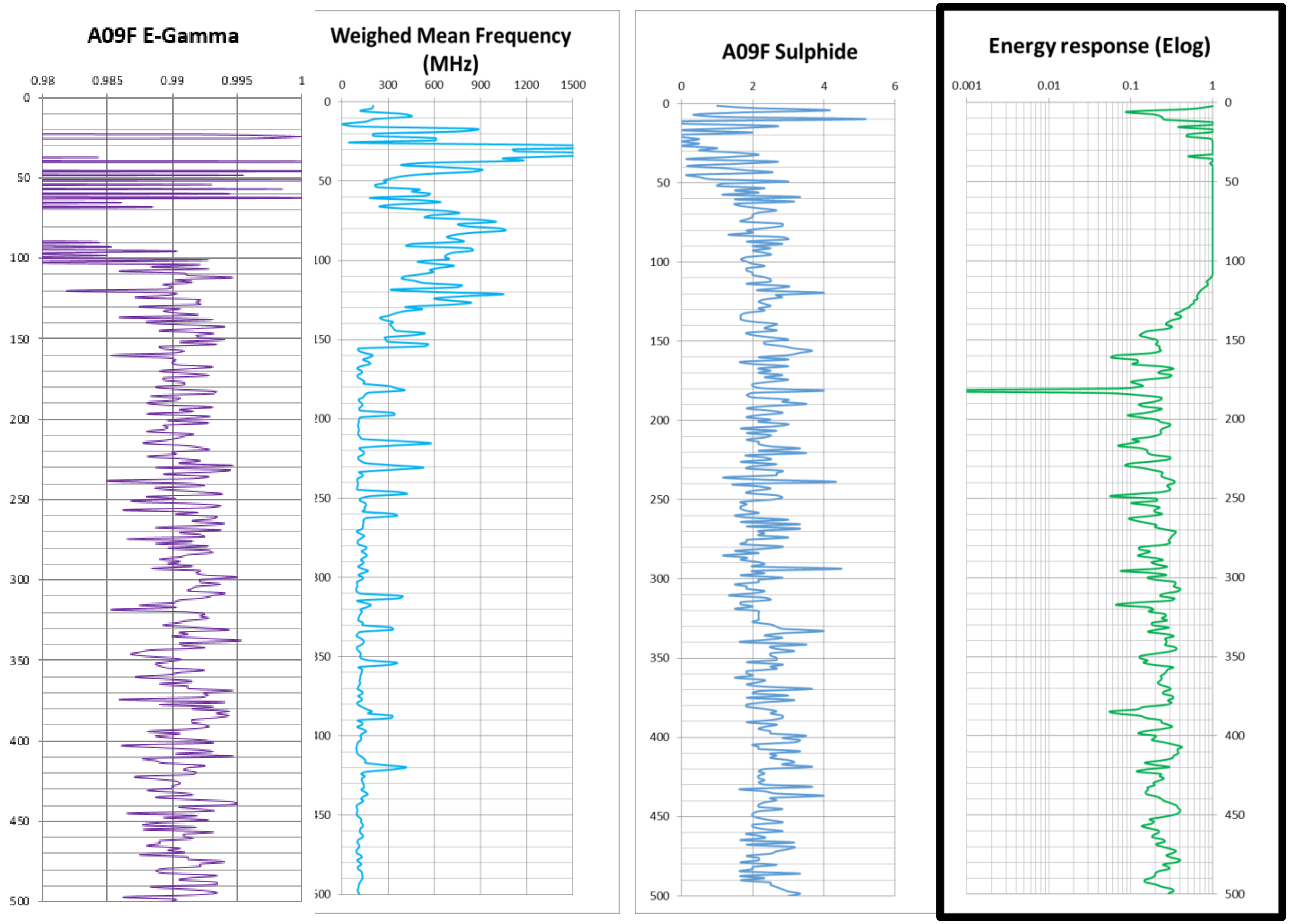
ADR RESULTS – how the results are presented and *interpreted*

0.01 considered "anomalous and significant"

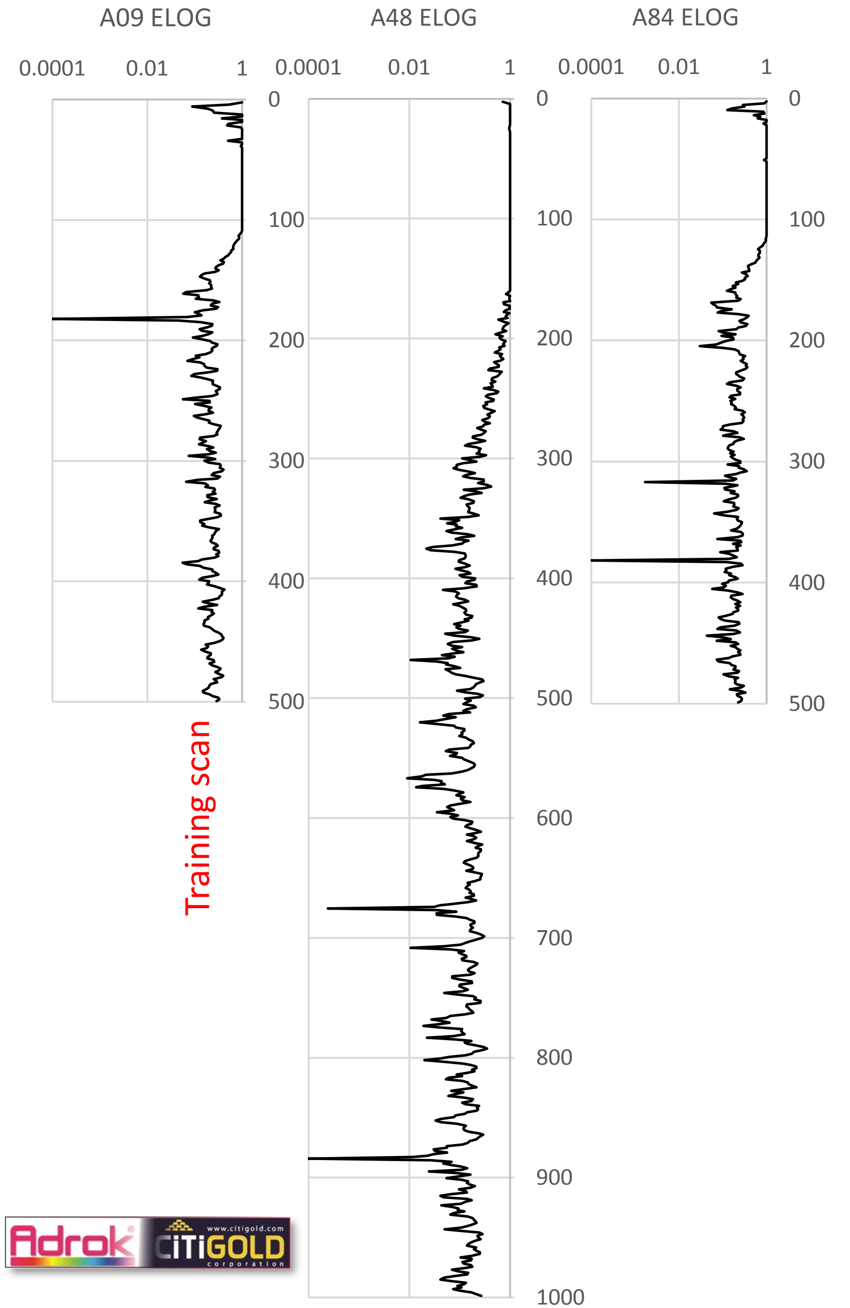
Lowest value(s) considered major anomalies

Lowest value assigned a value of 0.001 resulting in artificial exaggeration of apparent anomaly when plotted

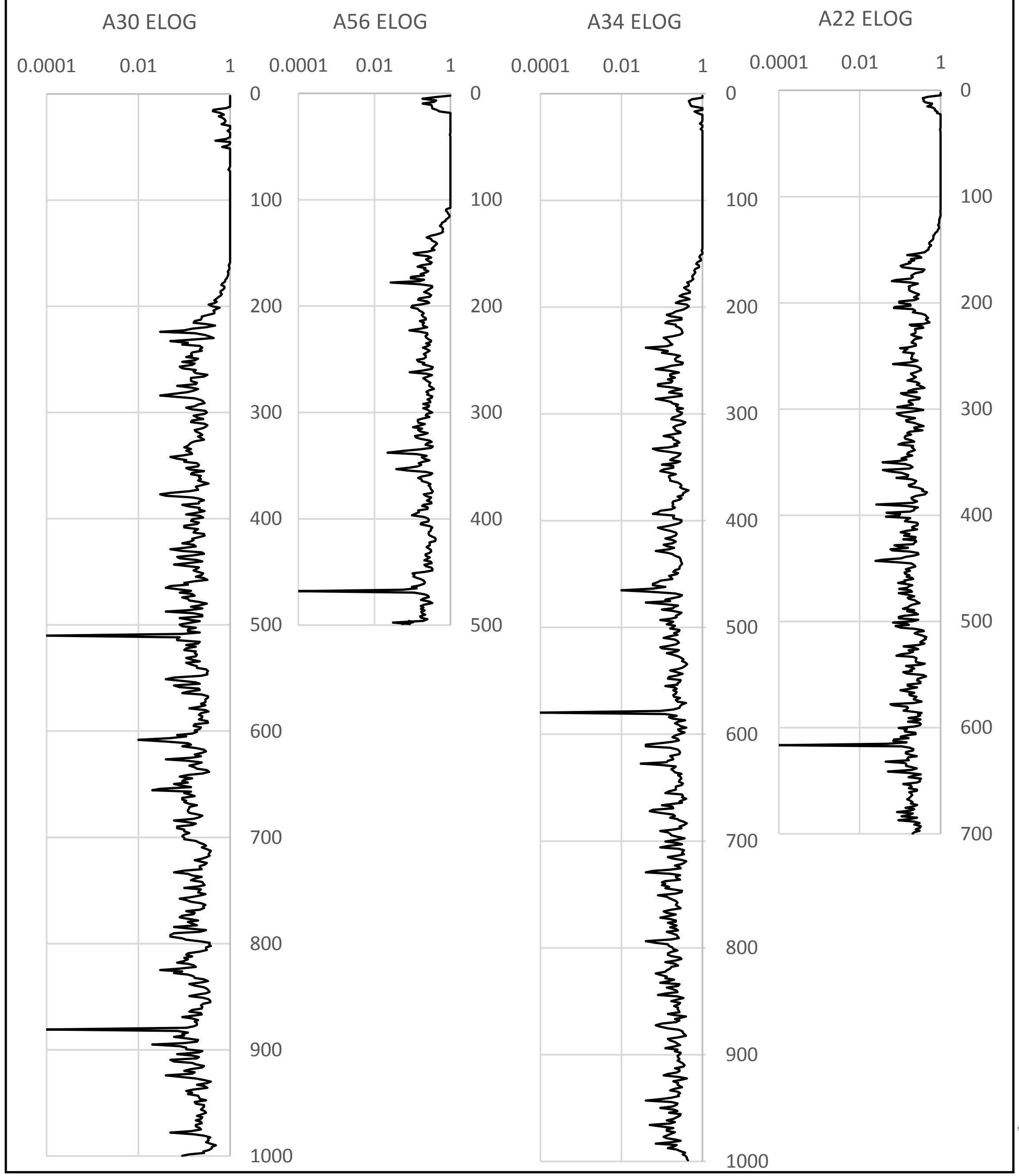


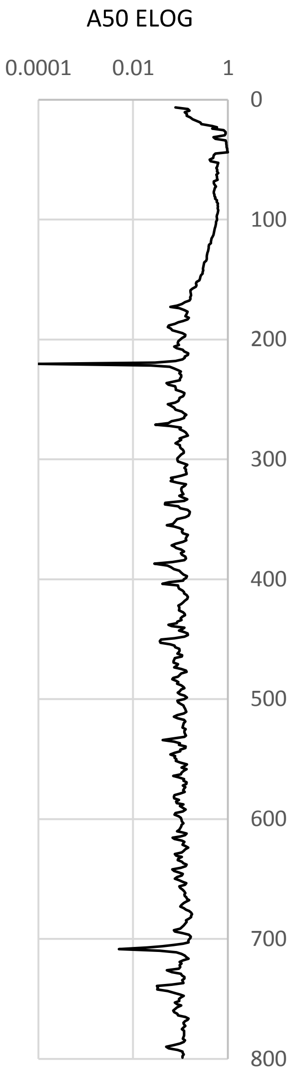


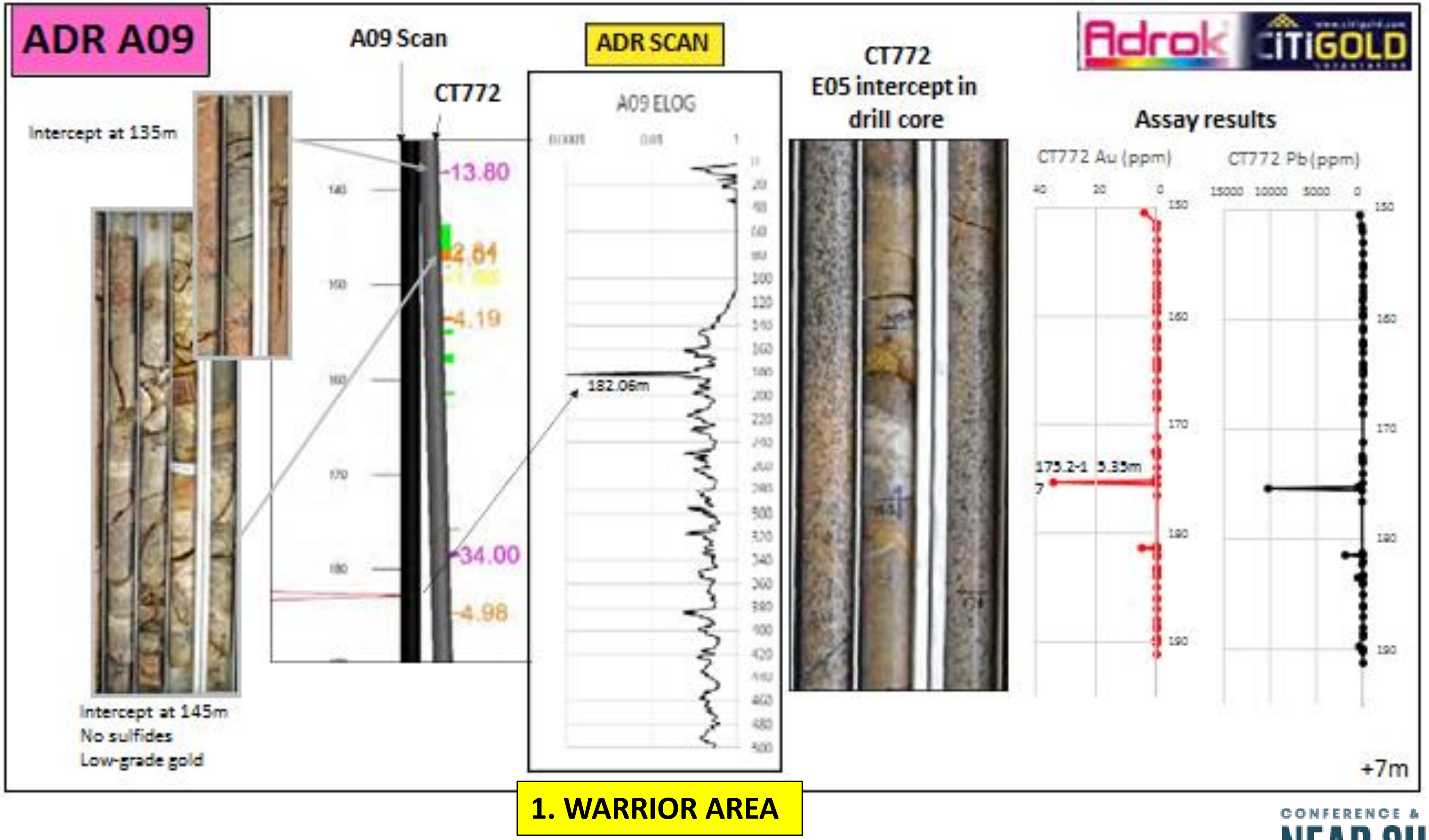
1. WARRIOR AREA



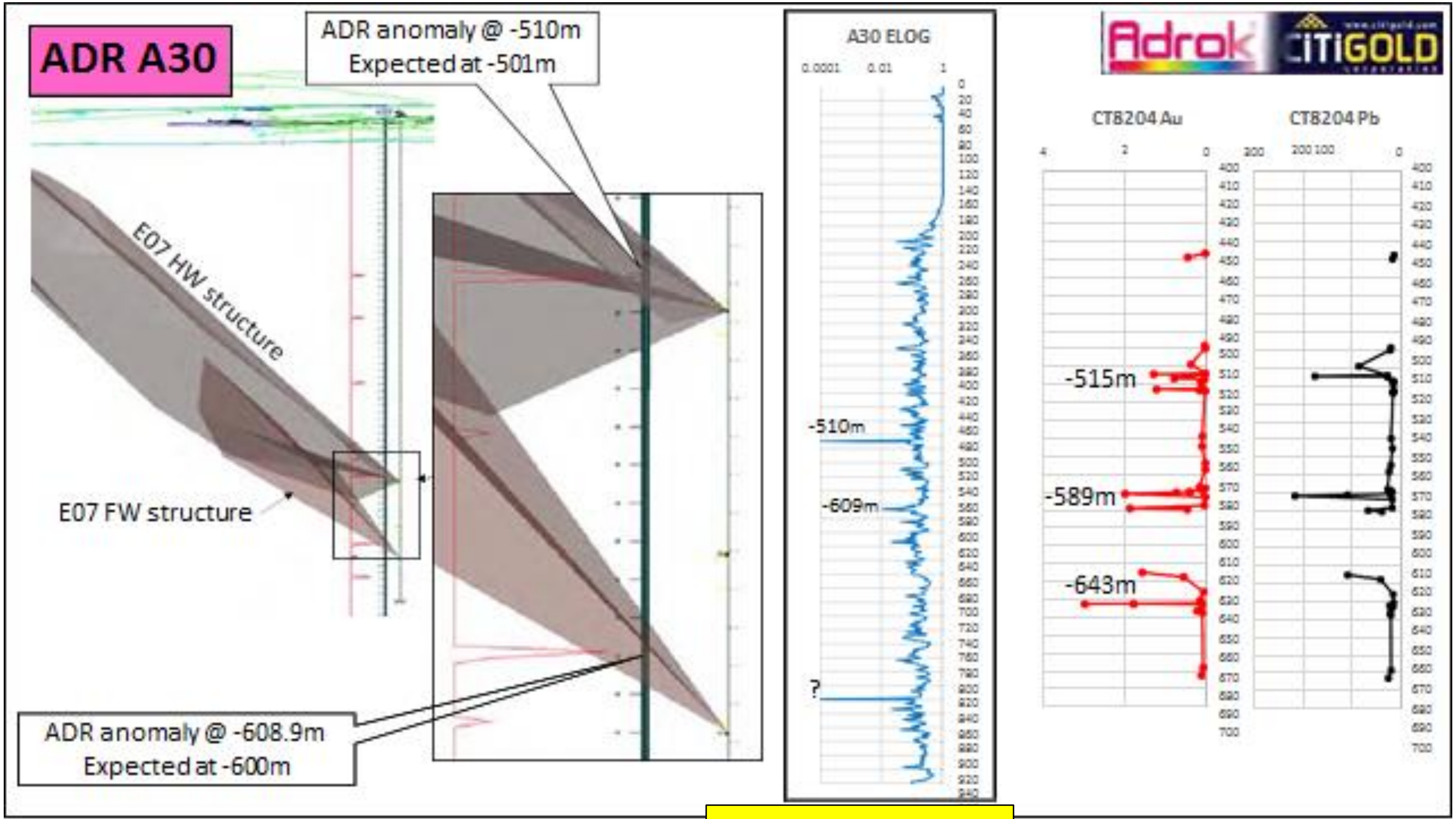
2. IMPERIAL AREA







ADR A09
A09 Scan
CT772
ADR SCAN
A09 ELOG
CT772
E05 intercept in
drill core
Assay results
CT772 Au (ppm)
CT772 Pb (ppm)
Intercept at 135m
Intercept at 145m
No sulfides
Low-grade gold
13.80
4.19
34.00
4.98
182.06m
173.2-1 5.35m
+7m
1. WARRIOR AREA



2. IMPERIAL AREA

Conclusions

Charters Towers type narrow vein gold is a relatively unique style of mineralisation

Traditional geophysical techniques are not suitable and have been unsuccessful due to:
1) the small size of gold-bearing lenses (meters to tens of meters scale),
2) the presence of a town over the primary target area,
3) the depth of mineralisation (>400m),
4) other masking factors including dykes, altered faults.

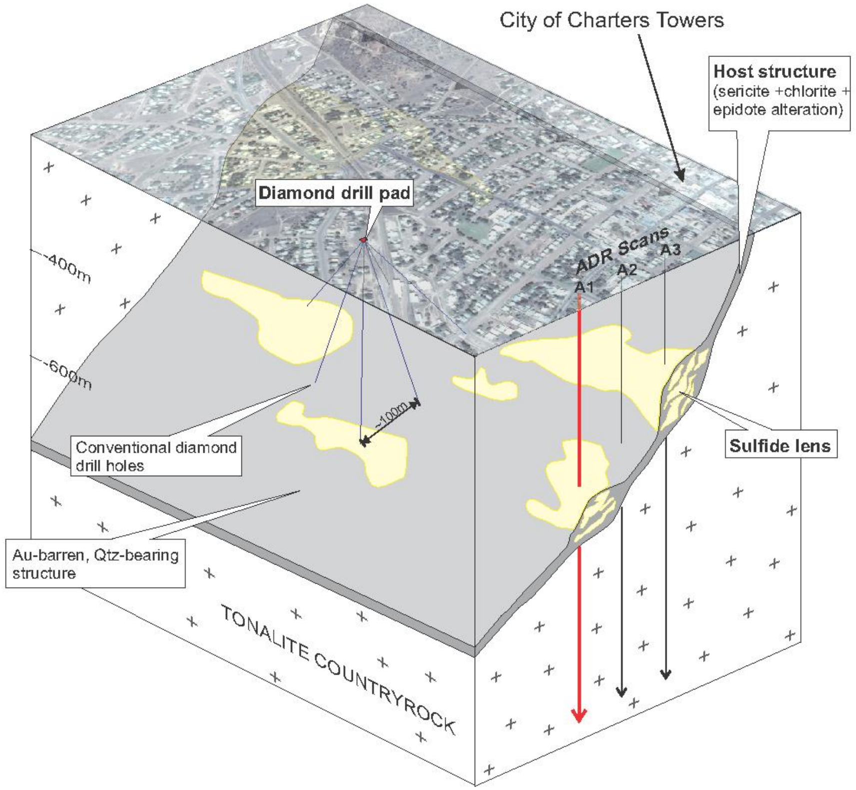
- The ADR technique appears to have successfully identified sulfides on target structures in three separate locations.

- **Averaging 8 scans per day with >80 scans completed in 2 weeks – equivalent to 80,000m of drilling (~2300 days (>6 years) of continuous drilling with one diamond rig).**

- **Testing** of the geophysics by drilling has **confirmed** the presence of gold and sulfides indicated by ADR.

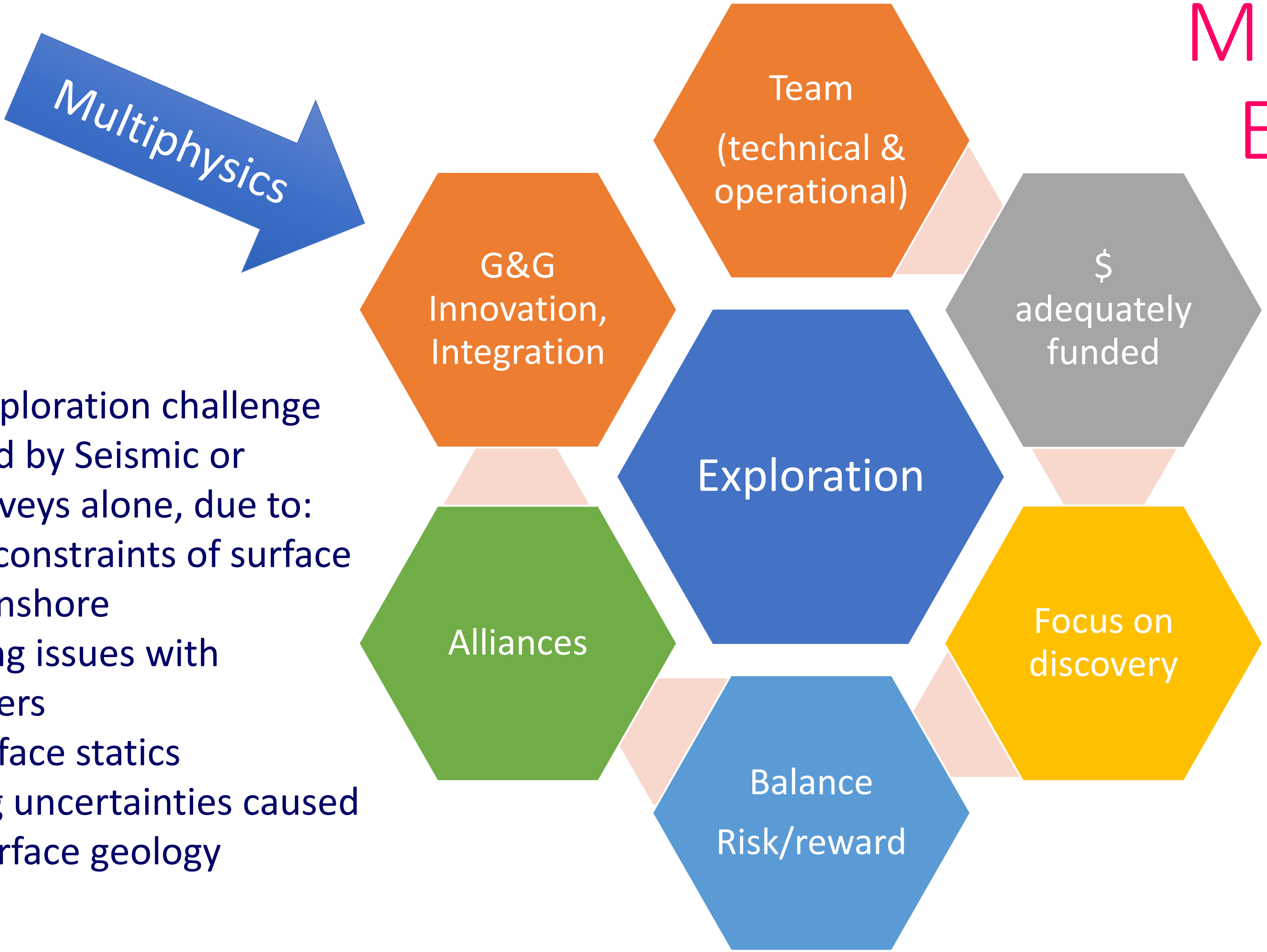
- NO FALSE ANOMALIES (yet).

- Simple geology and markedly different dielectric properties between the host granite and Galena (Pb)-bearing sulfides may be key to the success.



Closing thoughts

Multifaceted Exploration

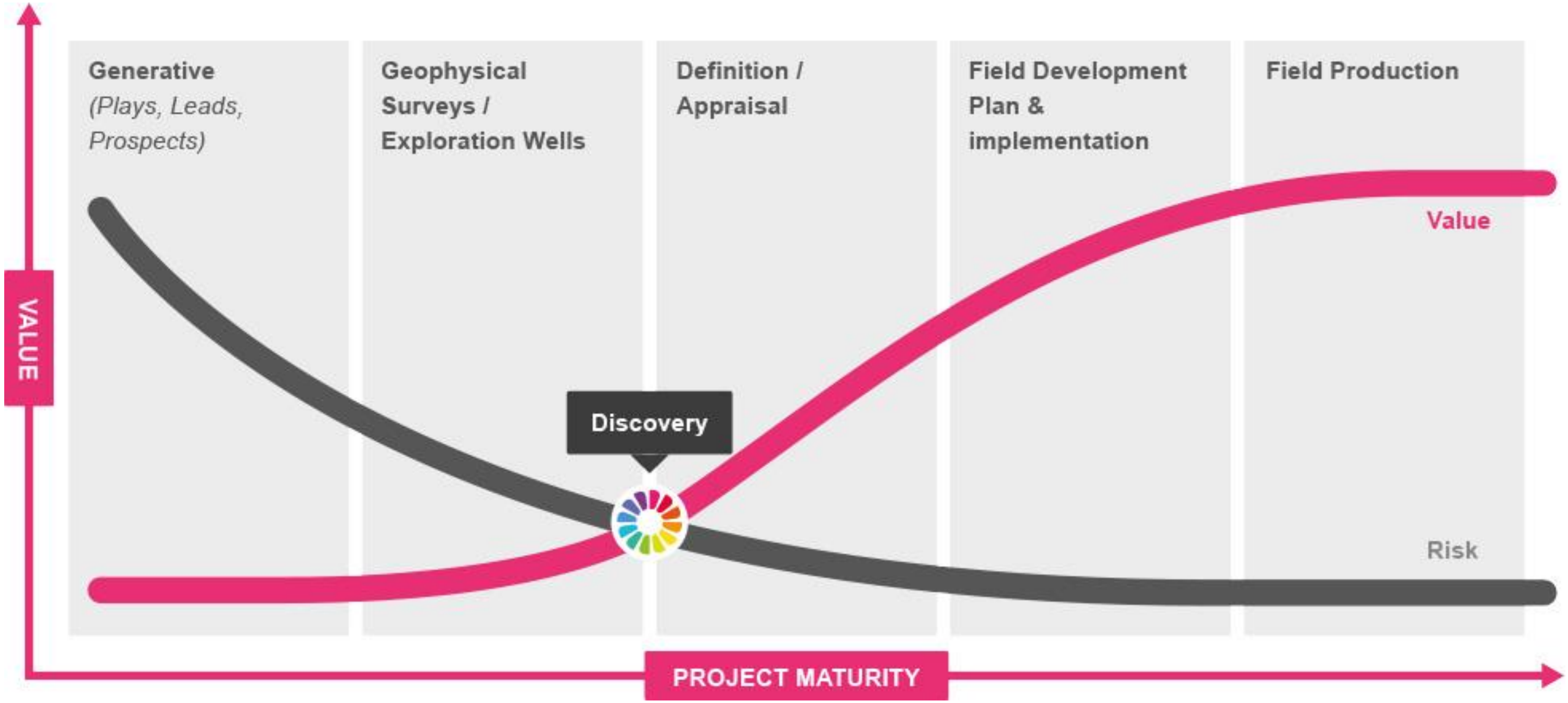


Not every exploration challenge can be solved by Seismic or Airborne surveys alone, due to:

- 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.



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Conclusions

- ADR is sub *m* scale resolution at *km* scale depth without holes or seismic
- Three projects using the ADR deep subsurface measurements have been presented as Case Studies
    - Gensource Potash – Saskatchewan, 1700m depth
    - Scottish Water – subsurface water detection, 150m depth
    - Citigold – Gold and sulfides, to 500m and 1000m depth
- "Digitally drilling" into the subsurface is the future of exploration

Sir Arthur C. Clarke

Revolutionary new ideas pass through 3 stages:

1. "It's crazy – don't waste my time"
2. "It's possible, but it's not worth doing"
3. "I always said it was a good idea"

Arthur C. Clarke. *Report on Planet Three and Other Speculations.* Harper & Row, New York, 1972, p. 70.

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Large depth exploration using pulsed radar electromagnetic technology

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September 2018