Why electromagnetics have the potential to massively add value to seismic exploration

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CEO & Co-founder

9th March 2017

Differences between Seismic and Electromagnetics (EM)

What is Geophysics?

- Remote sensing of the internal structure of the earth
- Data collected respond to physical property <u>contrasts</u>

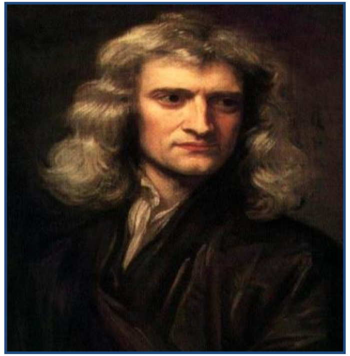
Petrophysical property	Geophysical survey
Magnetic susceptibility	Magnetic
Density	Gravity, neutron activation, muon geotomography
Resistivity Conductivity	DC resistivity ElectroMagnetic
Chargeability **Dielectric permittivity**	Induced Polarization **Atomic dielectric resonance**
Radioactivity	Gamma ray spectrometry
Acoustic impedance	Seismic

Geophysics Brain Trust

Magnetics

William Gilbert
1544 - 1603

Gravity

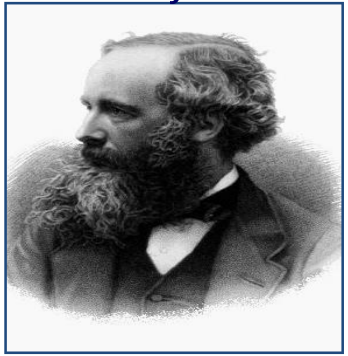


Isaac Newton
1642 - 1727

EM Induction

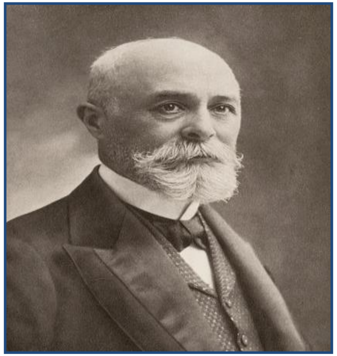
Michael Faraday
1791 - 1867

Classical Electrodynamics



James Clerk Maxwell
1831 - 1879

Radioactivity



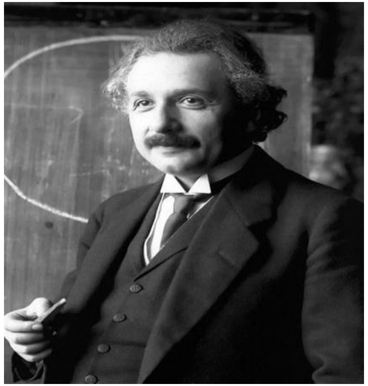
Henri Bequerel
1852 - 1908

The quantum age

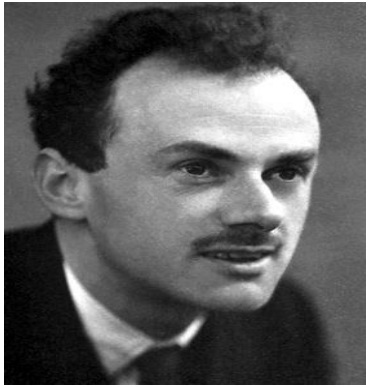
Photons and Quantum Field Theory

Masers, Lasers, Mw Spectroscopy

Max Planck
1858 – 1947



Albert
Einstein
1879 - 1955

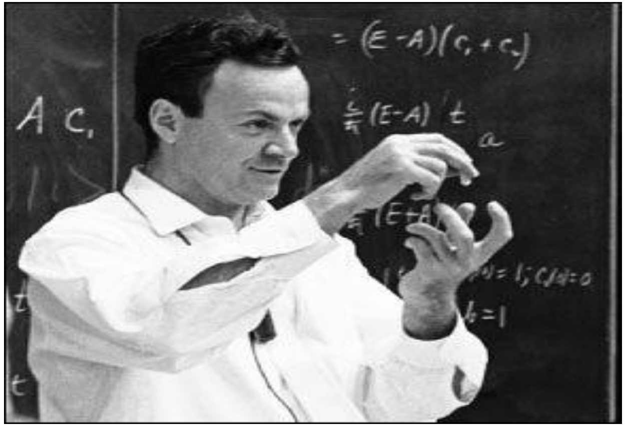


Paul Dirac
1902 - 1984

Arthur
Schawlow
1921 - 1999

Charles Townes
1915 – present
(age 96)

QED: “the jewel of physics”



Richard Feynman
1918 - 1988

Quantum ElectroDynamics mathematically describes all phenomena involving electrically charged particles interacting by means of exchange of photons and represents the quantum counterpart of classical electrodynamics giving a complete account of matter and light interaction.

Radiowave Penetration

- Dr G. Colin Stove

- Inventor of Atomic Dielectric Resonance (ADR)
- Dr. Stove is a remote sensing specialist who has been a principal investigator with ESA, NASA, and NATO.
- The early use of SAR and LIDAR systems from aircraft and space shuttles revealed the ability of the signals to penetrate the ground surface.
- $\lambda / 2$ was the conventional theory
- Dr Stove discovered something different in 1983 by changing polarisation and from planar waves. Publishing his findings with the Royal Society of London:

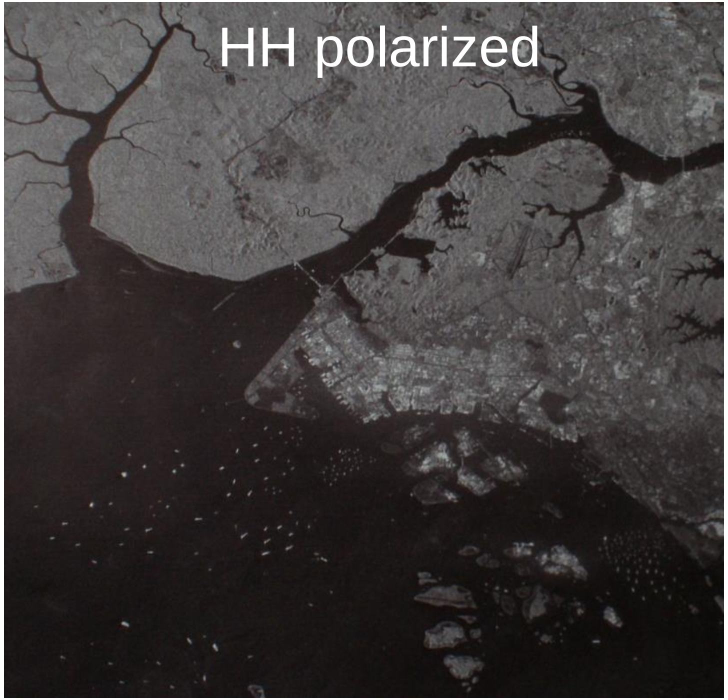
  Stove, G.C. 1983 The current use of remote-sensing data in peat, soil, land-cover and crop inventories in Scotland. Phil. Trans. R. Soc. Lond. A 309, 271-281
- Industry geophysicists, still today, erroneously dispute radiowave systems depth of penetration based on an incorrect application of the skin depth concept derived from Maxwells equations for planar waves in a conductor

Radar imagery from space

- From Classical Electrodynamics can be derived the concept of "skin depth", which describes the depth penetration of high-frequency EM waves into matter:

$$skin\ depth \approx 503\sqrt{\frac{resitivity}{frequency}}$$

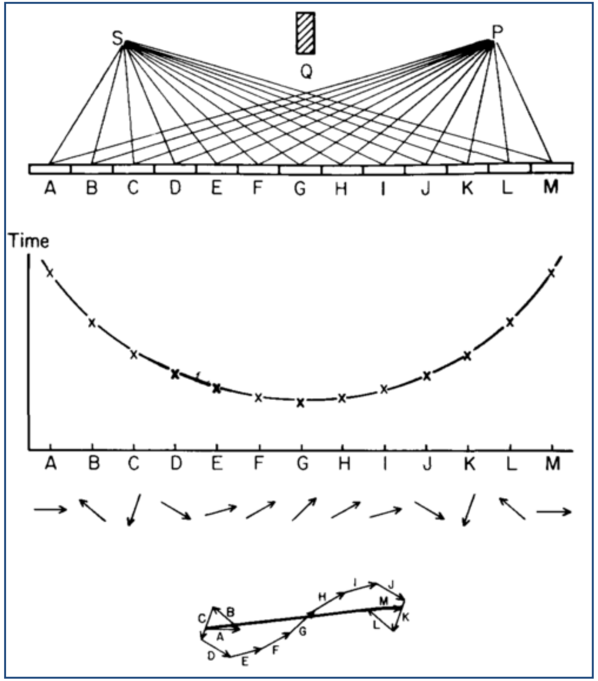
- The skin depth of microwaves in seawater is on the order of cm



Credit: RADARSAT

Radar imagery from space

QED: focused, polarized radar waves can indeed penetrate conductive sea water

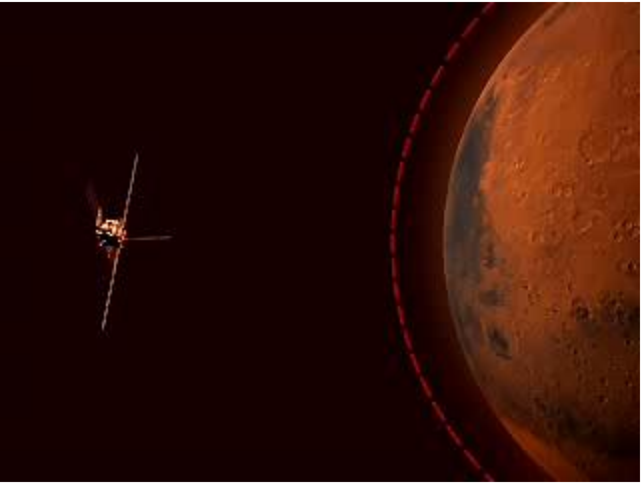


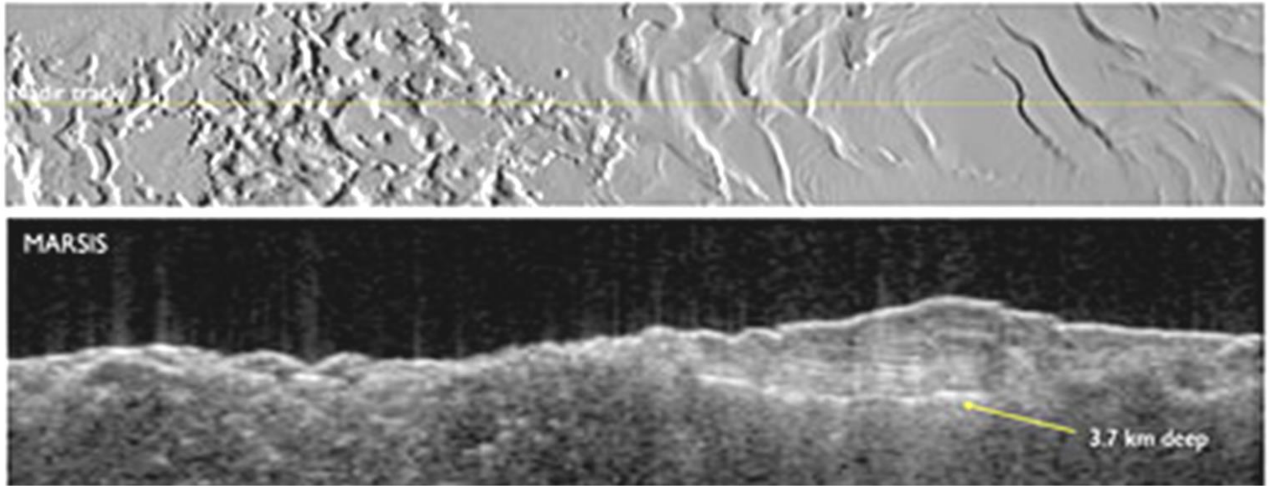
Credit: ESA

Adrok

esa mars express European Space Agency

- The Mars express radar experiment (MARSIS) in 2008 penetrated solid ground to 3.7km using low frequency radar systems (1-5MHz) on a total power payload of 500watts



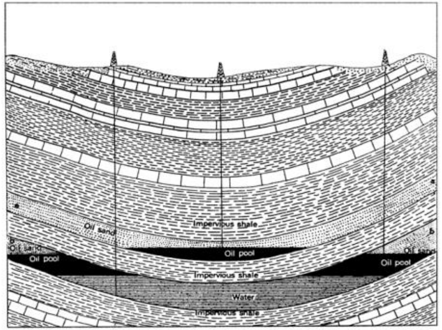


Credits: MARSIS: ESA/NASA/ASI/JPL-Caltech/University of Rome; SHARAD: NASA/JPL-Caltech/ASI/University of Rome/Washington University in St. Louis
Source: http://www.esa.int/SPECIALS/Mars_Express/SEMIF74XQEF_1.html#subhead1

Atomic Dielectric Resonance (ADR)	Seismic
Electromagnetic pulse	Pressure pulse
Multi-spectral wavelet	Single centre frequency wavelet
Propagation velocity ~100,000km/s	Propagation velocity ~1km/s
Acquisition time tens of µs per trace	Acquisition time tens of s per trace
Massive (100,000+) zero-offset stacking	Limited zero-offset stacking
Source: Antenna + dielectric resonance tube	Source: thumpers (ground) or explosions (water)
Easy deployment (crew of 3, minimal cabling)	Complicated deployment (large field crews, thumper trucks, vast cabling)
Low cost, typically 90% the cost of physically drilling a well	High cost, typically $’000s per line km per scan
Detects conductivity and dielectric contrasts	Detects density contrast
Material identification of targets using dielectrics, and spectral analysis of returns	Only density measured. No direct material classification.
Exploration depth up to several km. Depth measured.	Exploration depth up to several km. Depth estimated against velocity.

Electromagnetics (EM) versus Seismic

It is fluid…



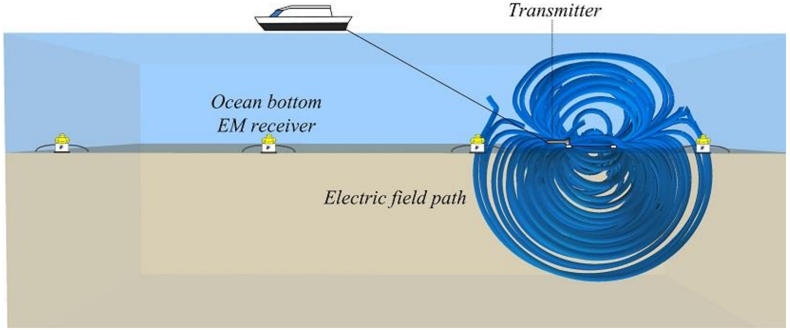
- Seismic properties of oil-filled strata and water-filled strata do not differ significantly
- However, their electromagnetic resistivities (permittivities) do differ.
- An EM surveying method can be deployed to show these differences.
- The success rate of EM in predicting the nature of a reservoir can be increased significantly; providing potentially enormous cost savings.

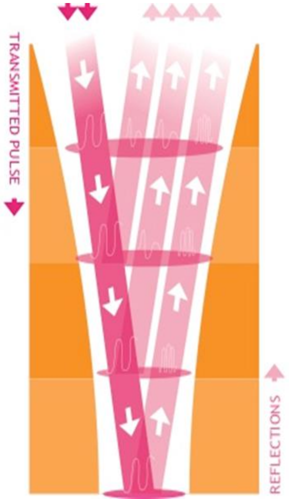
Electromagnetics (EM) versus ADR

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

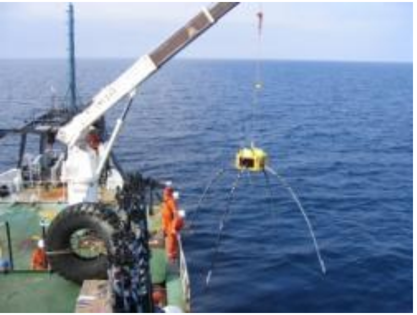
- ADR utilizes propagating waves in the MHz range.

- 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.

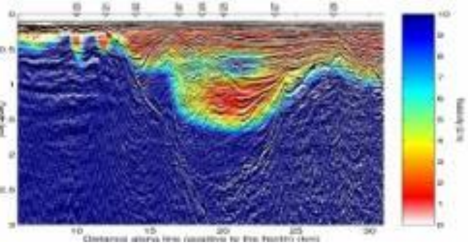


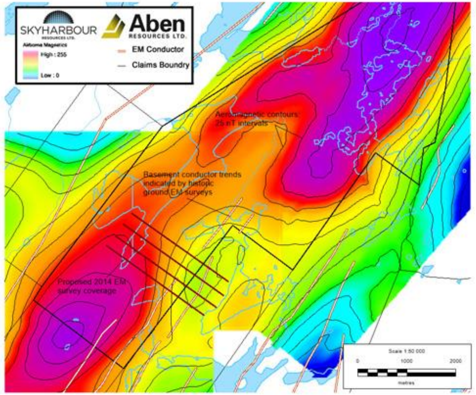


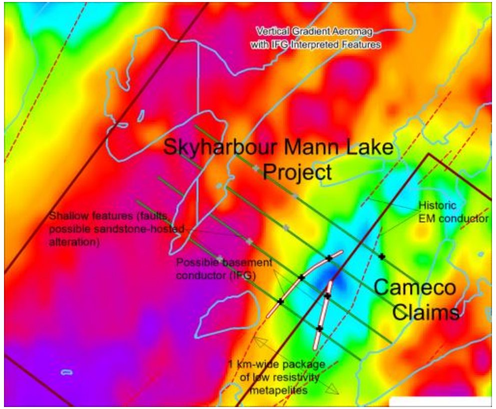
EMpulse Geophysics of Dalmeny, Saskatchewan

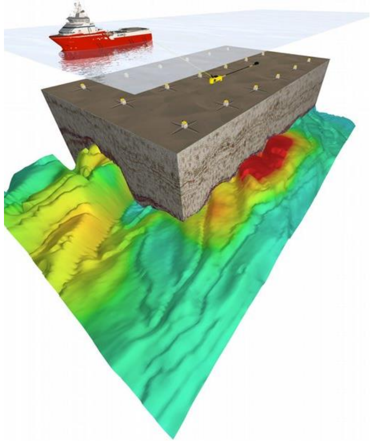


OHM Surveys

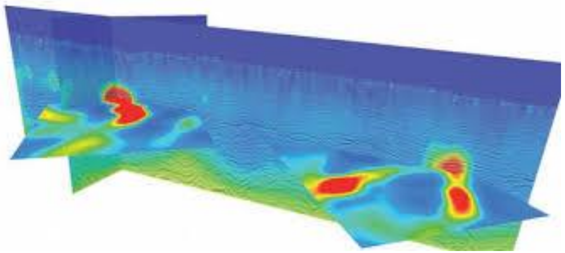




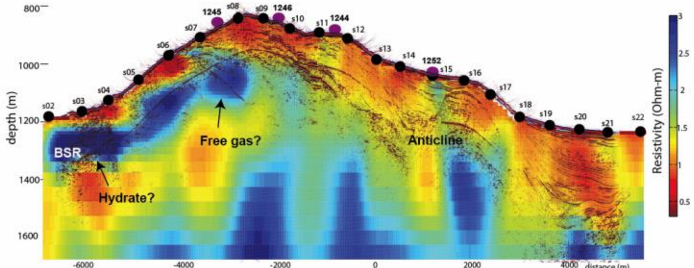


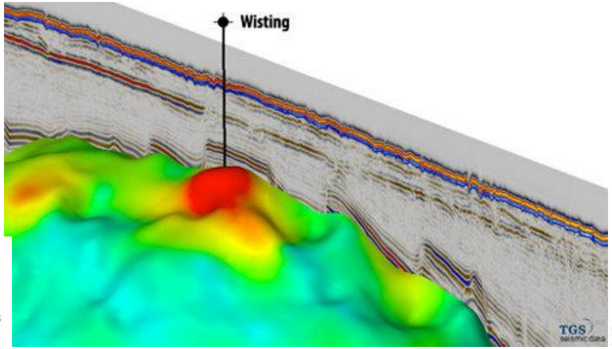


EMGS

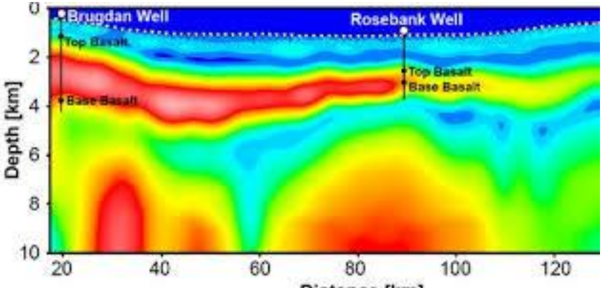


Seafloor Electromagnetic Methods Consortium at the Scripps Institution of Oceanography





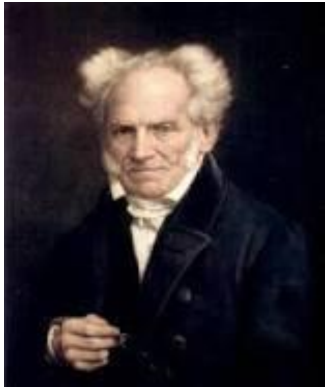
3D EM resistivity surface and 2D seismic (courtesy TGS) at the Wisting Central well location



Changing the status quo

There are specialists that have surely worked their entire life with the techniques & science [geophysics] being revolutionized, so expressing change to their reality is a sensitive affair.

"All truth passes through three stages.
First it is ridiculed.
Second, it is violently opposed.
Third, it is accepted as being self-evident."



Arthur Schopenhauer. *Die Welt als Wille und Vorstellung.* 1818. English translation by E. F. J. Payne in *The World as Will and Representation*, Volume I, Falcon's Wing Press, Indian Hills, Colorado, 1958.

We just have to remember that ultimately, skepticism makes technology better ☺

Why has EM not been given a fair chance?

Service Companies are entrenched in Seismic and are very protective:

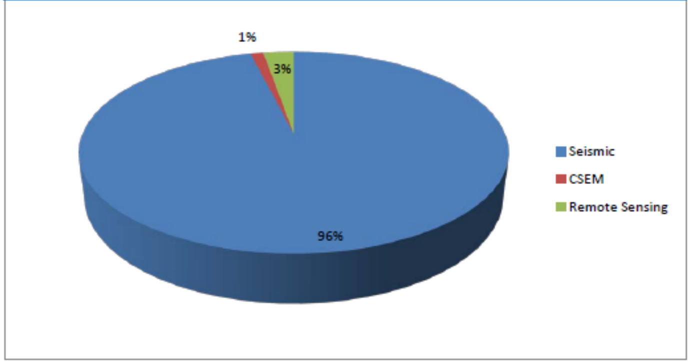
- PGS bought out MTEM in 2007 and has not commercialised its technology widely
- Schlumberger has been wrestling with EMGS through the patent courts

Oil Companies have:

- strong bargaining position on price, despite EMGS 90% success rate
- a lack of in-house EM expertise to interpret & integrate EM data sets (secondments would help)

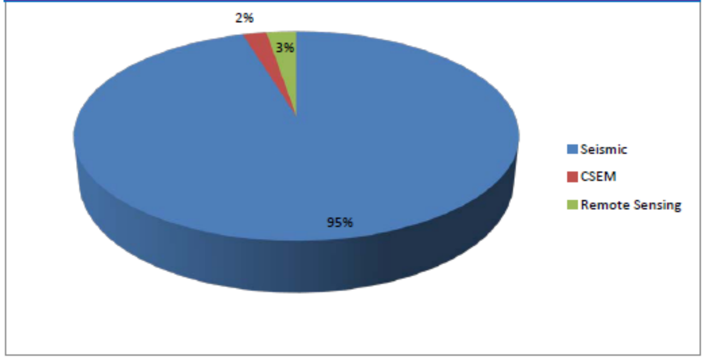
(refer to Mari Danielsen Lunde, 2014, Masters Thesis, Norwegian School of Economics)
https://brage.bibsys.no/xmlui/bitstream/handle/11250/221553/Masterthesis.pdf?sequence=1

Figure 3.9 Advanced Oil & Gas Exploration Technologies Submarket Share, 2010 (%)



Source: *Visiongain 2010*

Figure 3.10 Advanced Oil & Gas Exploration Technologies Submarket Share, 2020 (%)

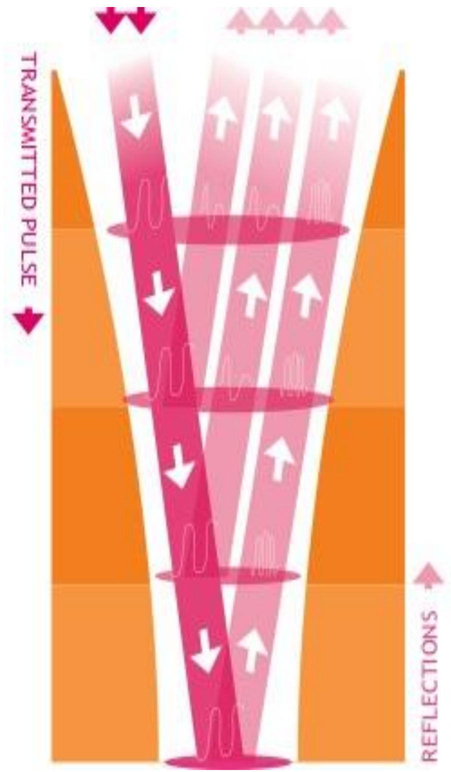


Source: *Visiongain 2010*

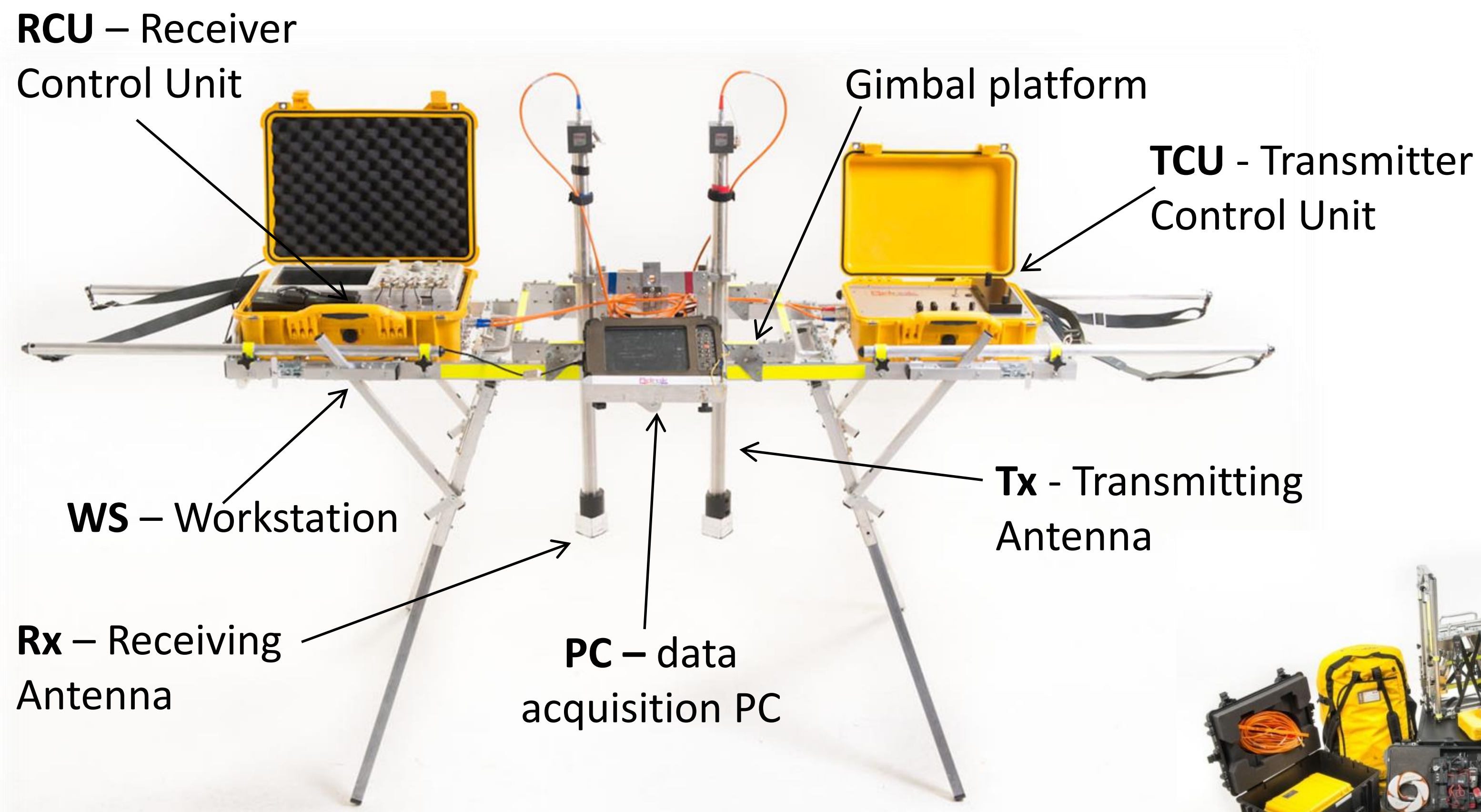
A revolution in Electromagnetics
- using radiowaves

Atomic Dielectric Resonance (ADR)

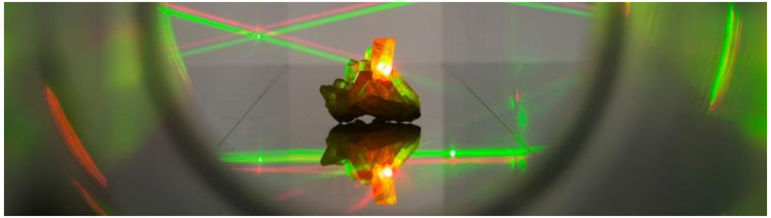
- RAdio Detection And Ranging in visually opaque materials
- Transmit pulsed broadband of radiowaves and microwaves
- Depending on depth of investigation transmit between 100kHz to 1GHz
- For large depth geo exploration typically transmit between 1MHz to 100MHz
- ADR sends broadband pulses into the ground and detects the modulated reflections returned from the subsurface structures
- ADR measures dielectric permittivity of material
- ADR also uses spectral content of the returns to help classify materials (energy, frequency, phase)



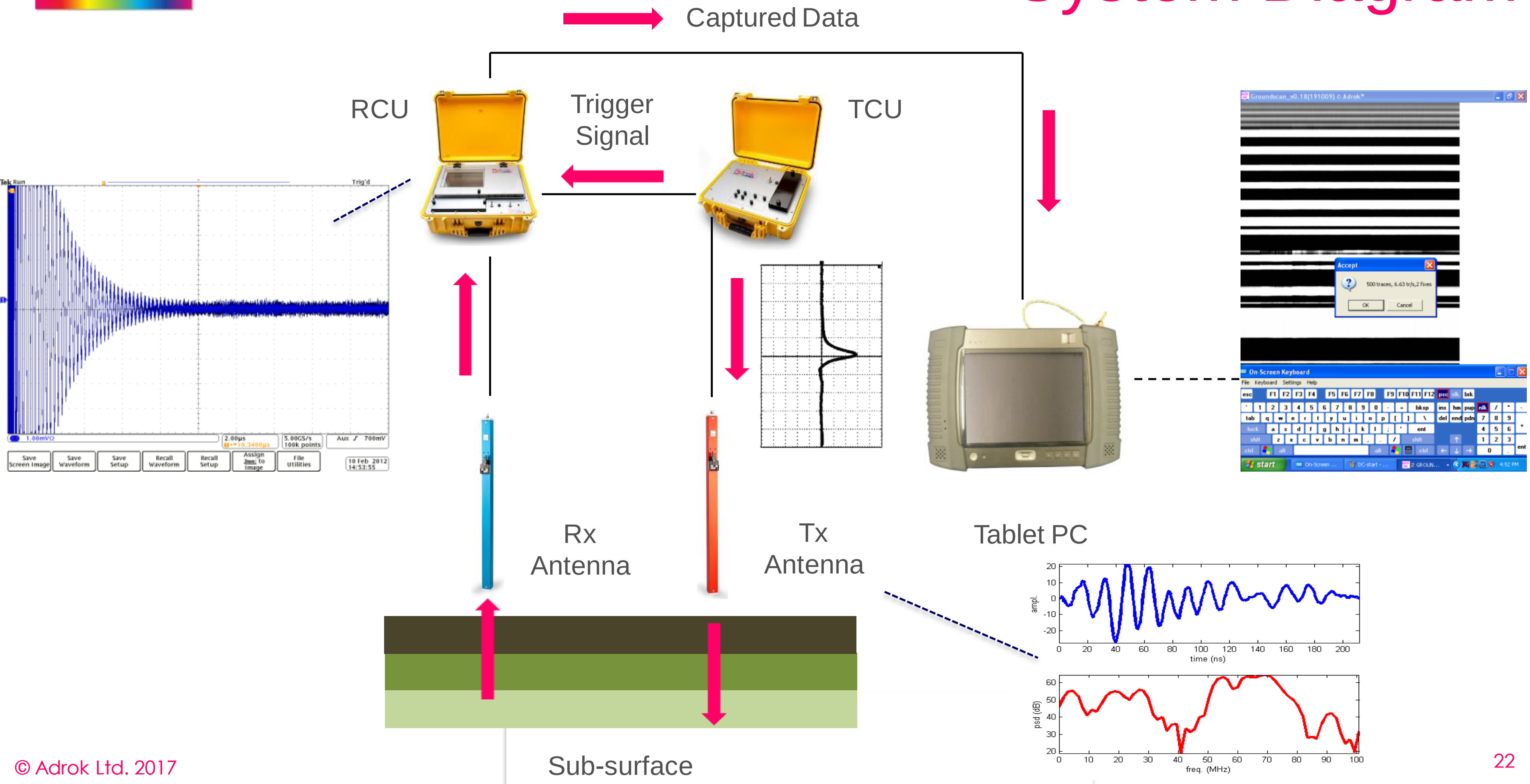
Field ADR Scanner



Laboratory ADR Core Scanner



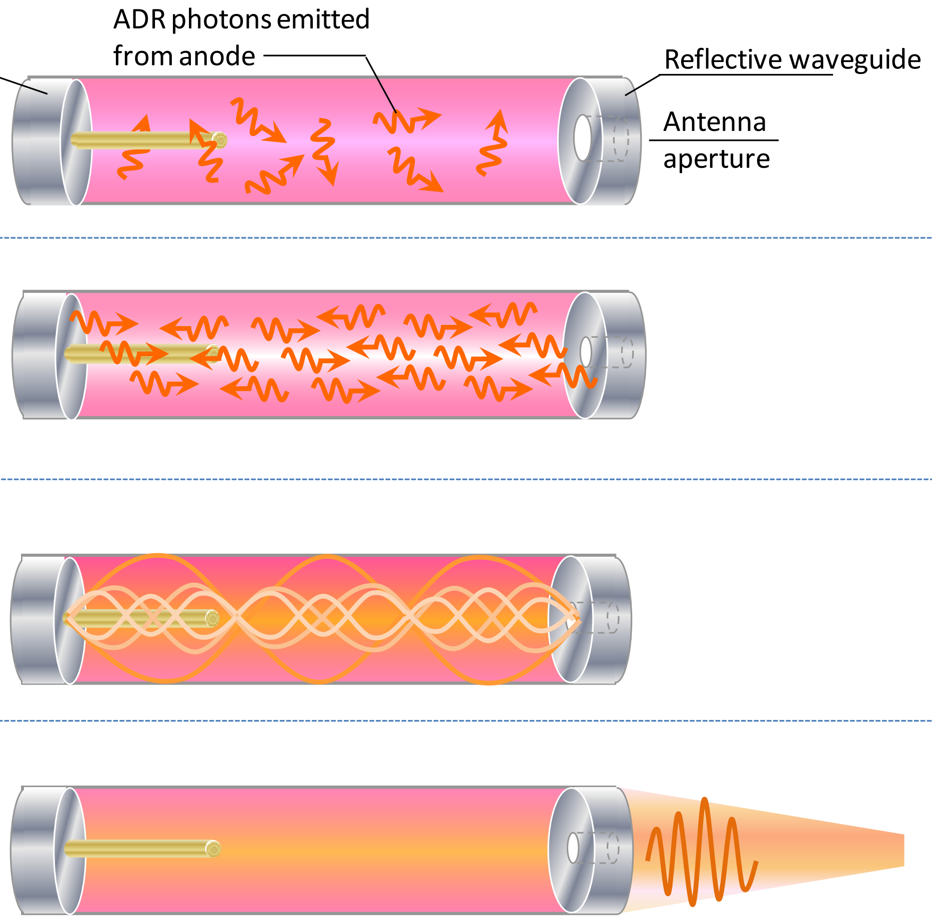
System Diagram



Specifications

ADR Setting	Typical Range
Tx frequency maximum	12.5MHz-10GHz
Tx frequency minimum	100kHz-1GHz
Time Range	2ns to 250,000ns
Number of pixels per trace	40 to 4000
Pulse Repetition Frequency (PRF)	10-100kHz
Pulse Width	0.1ns to 10ns
Power supply	4 off 24Vdc Li-Ion batteries
Power consumption	150W for ADR equipment *plus* 100W for tablet PC
Power transmission	< 5 miliwatts (mW)
Type of transmission	Continuous pulsing of a wide range of frequencies. Propagating waves.

Transmission Beams



Step 1.

ADR antenna pulsed signal input into chamber. Initially, the ADR photons travel in random motion

Step 2.

Material inside waveguide (i.e. dielectric) polarises the ADR photons and in turn concentrates and amplifies the energy within the chamber

Step 3.

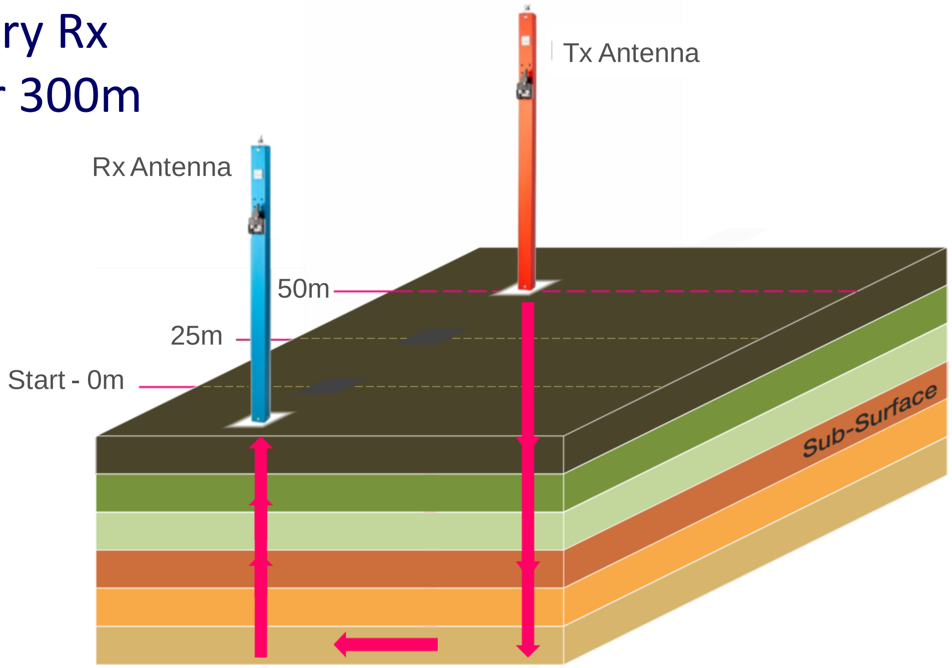
Standing wave generated inside chamber further enhancing the signal amplification

Step 4.

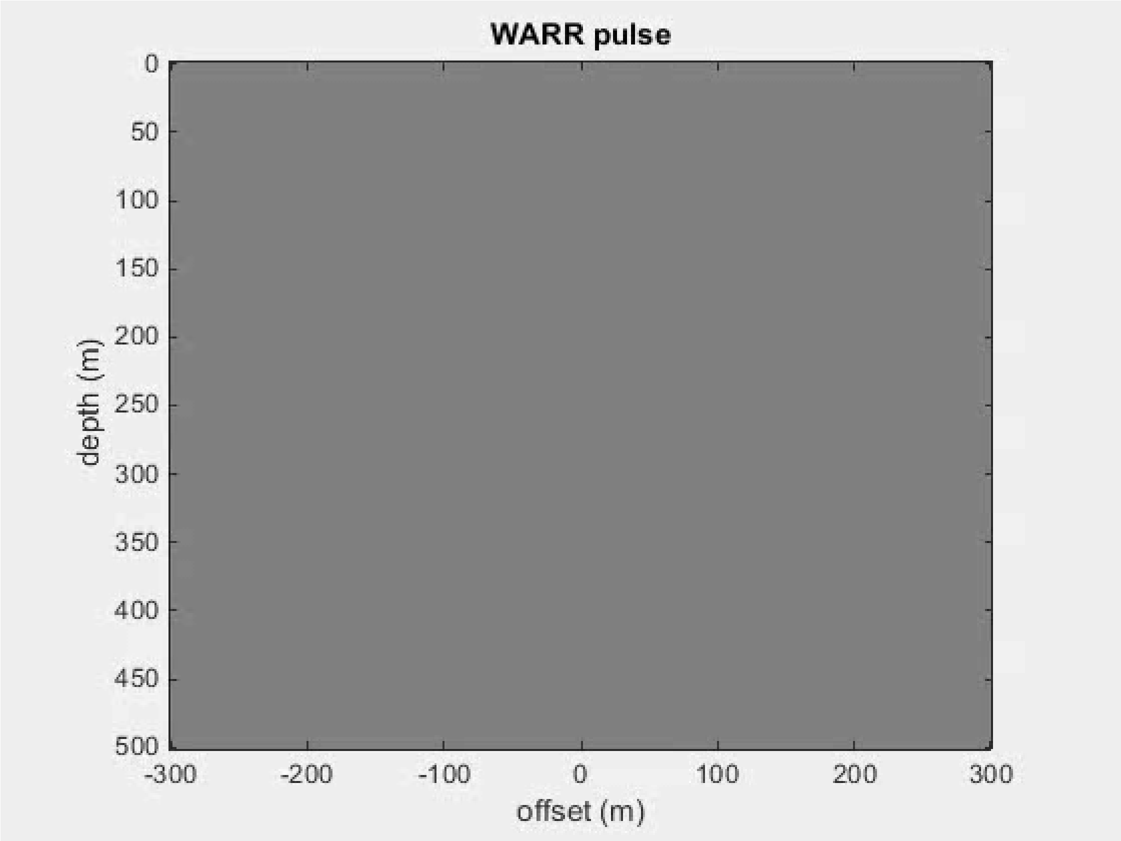
Antenna aperture allows polarised progressive standing wave to exit the Tx chamber

Types of ADR Scanning in Field (1) “WARR”

- Wide Angled Reflection & Refraction
- Triangulation for conversion of time into depth
- Tx antenna moves away from stationary Rx
- Tx moves continuously to say 100m or 300m
- Rx stays at start of scan line at 0m

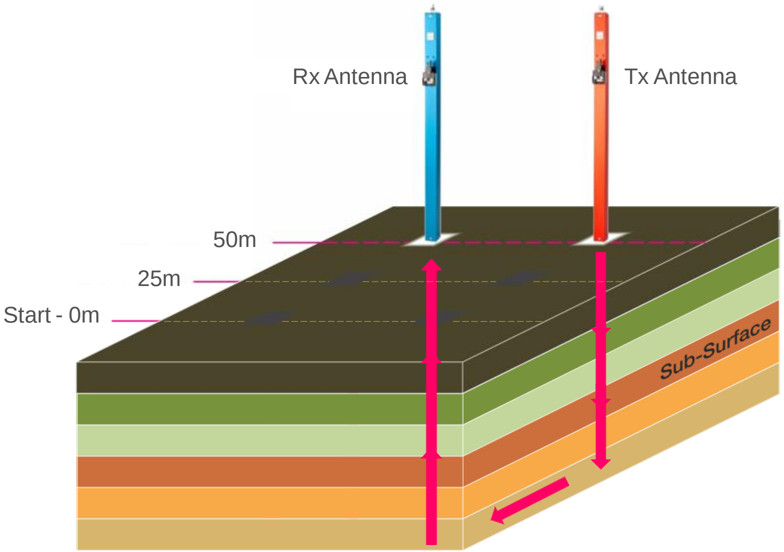


WARR beam forming



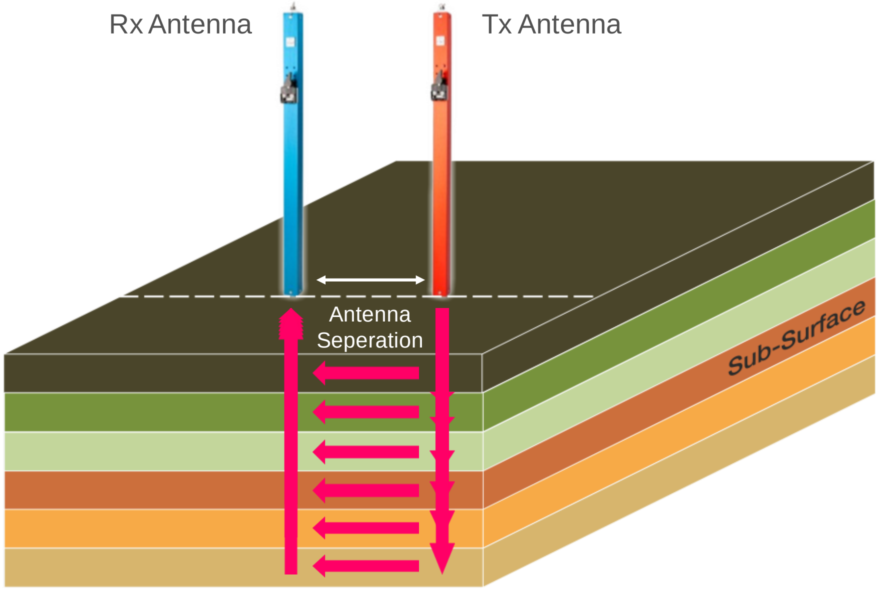
- Line of transmitters in WARR creates beam (Synthetic Aperture Radar, SAR)
- Note in animation pulse wavelet stays coherent

Types of ADR Scanning in Field (2) "P-Scan"



- Profile Scan (2-d cross-section)
- Continuous scanning on the move over short scan line distance (e.g., 50m)
- Tx & Rx antennas at fixed separation distance (e.g. 0.3m)
- Typically, 1 pulsed Tx ping every 5cm, repeatedly over entire length of scan line

Types of ADR Scanning in Field (3) "STARE"



- Tx & Rx antennas at fixed separation (e.g., 0.3m) and whole system stationary
- Active (Tx on) and Passive (Tx off) stares gathered to quantify noise levels
- Stack traces to enhance signal to noise ratio
- Up to 100,000 traces used in current stack

STARE Forward Model

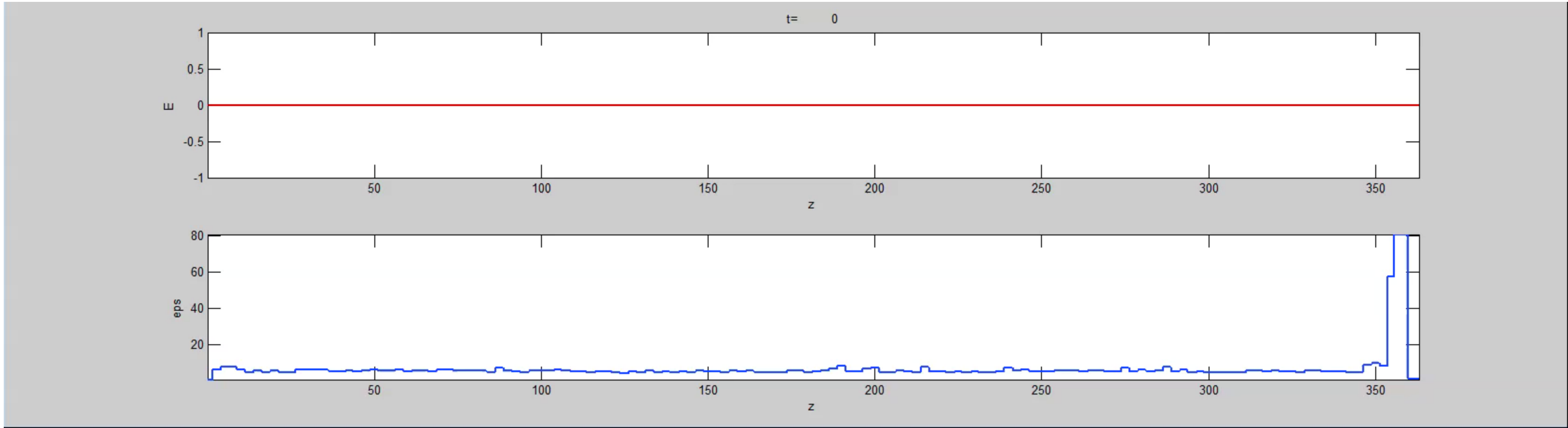
- Maxwell equations coupled to ground model
- Ground model: permittivity, conductivity and polarization (*P*)
  - E electric field, σ conductivity, τ Debye relaxation time, ε_r dielectric
- Resulting system of partial differential equations:

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

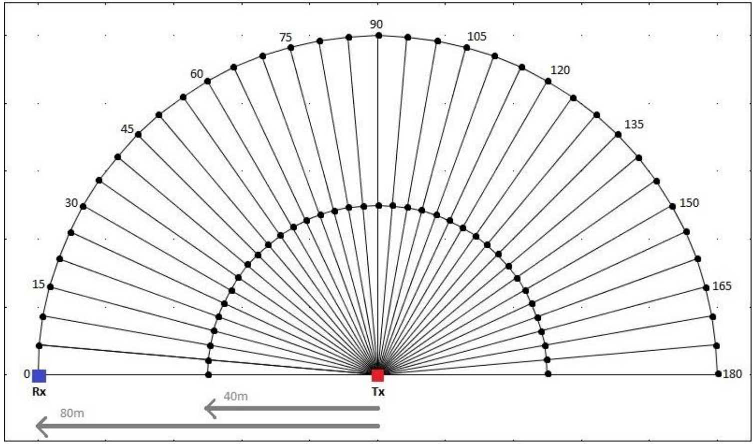
$$\tau(x)\frac{\partial P(t,x)}{\partial t} + P(t,x) = \epsilon_0(\epsilon_r(x) - 1))E(t,x). \qquad (2)$$

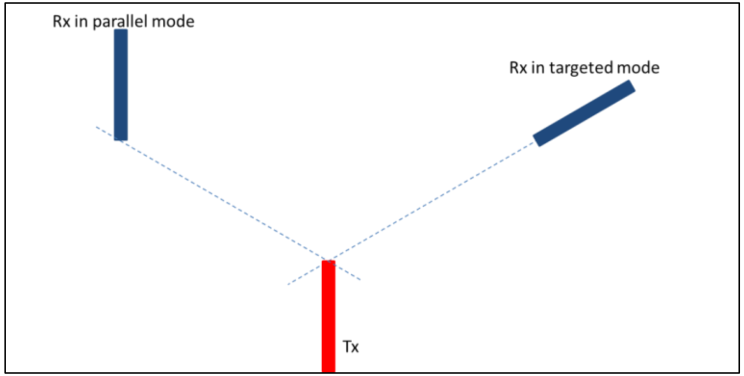
STARE Simulation Example

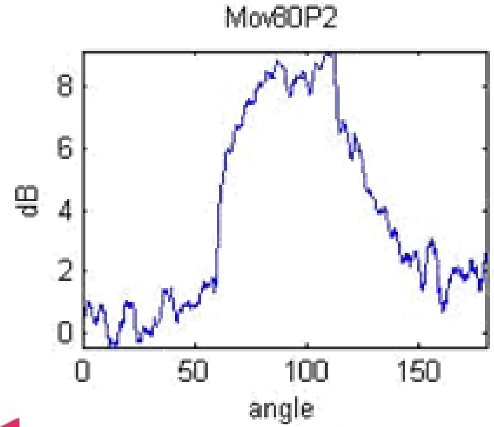
- Dielectric Constant (DC) profile (bottom graph) take from WARR data
- Other parameters from transillumination experiments
- Peak in dielectric at 350m down represents a water body
- Electric field animated in top graph
  - We observe pulse traveling down (left to right)
  - Small irregularities in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



Types of ADR Scanning in Field (4) "Transillumination" (no targets)

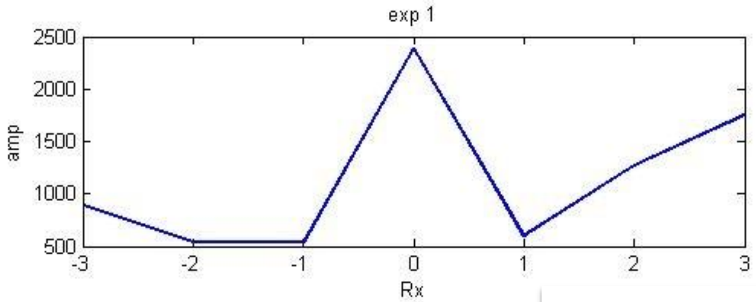


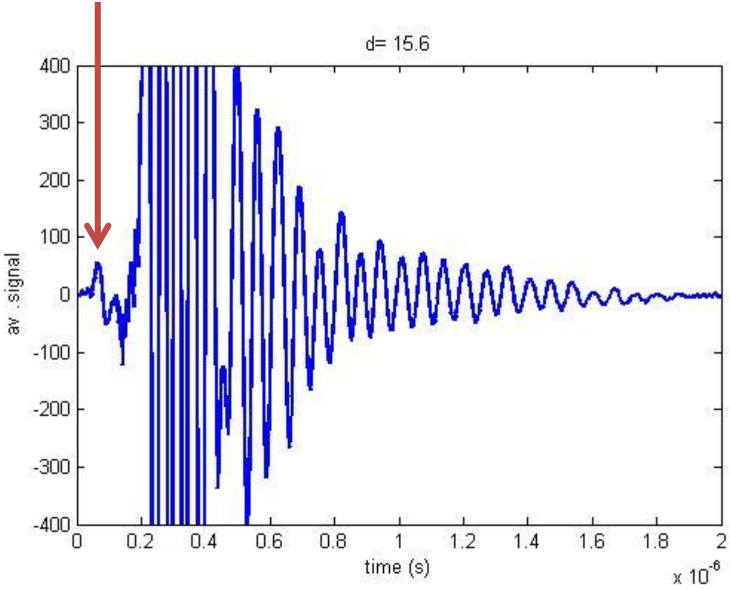




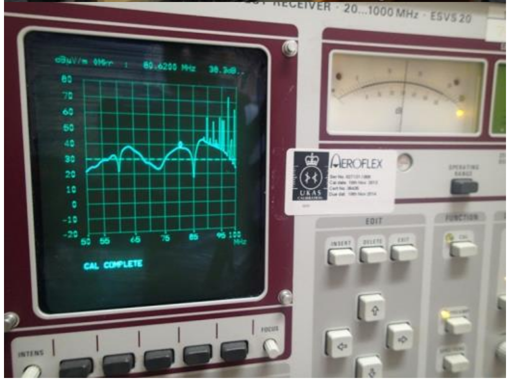
Types of ADR Scanning in Field (4) "Transillumination" (with targets)

Early signal at the arrow at t = 66ns. This corresponds to a signal traveling about 20m through air at c=3e8m/s, corresponding nicely with expectations for an air wave. Since we can see the air wave , the rest is not the air wave.



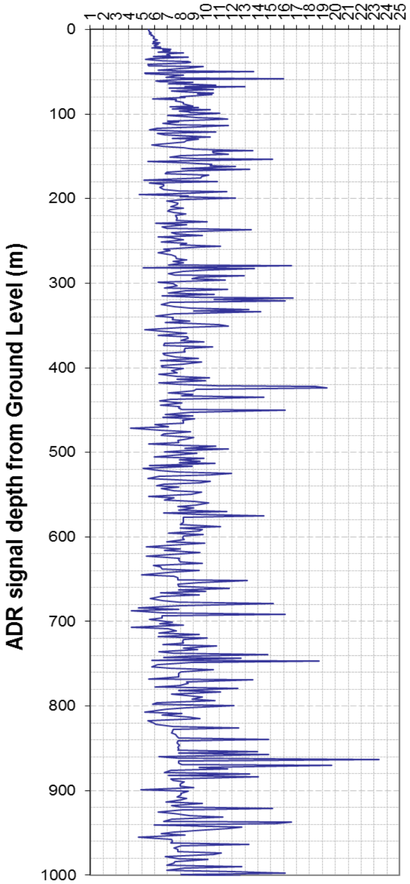


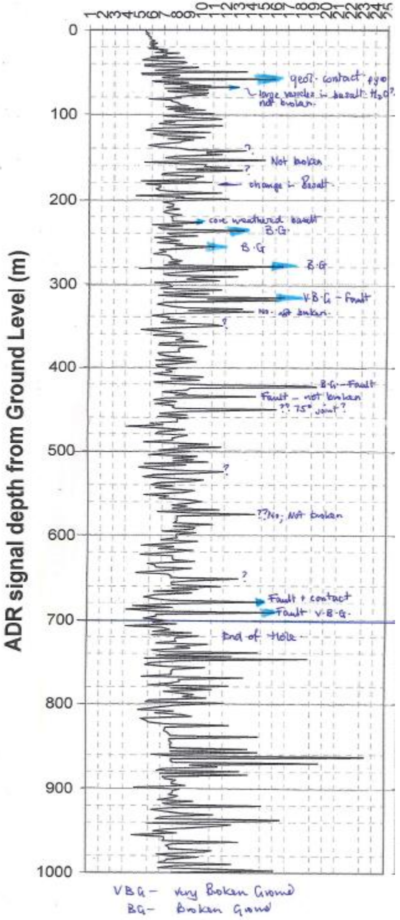
Equipment sensitivity measured in lab



Toolbox of ADR measurements

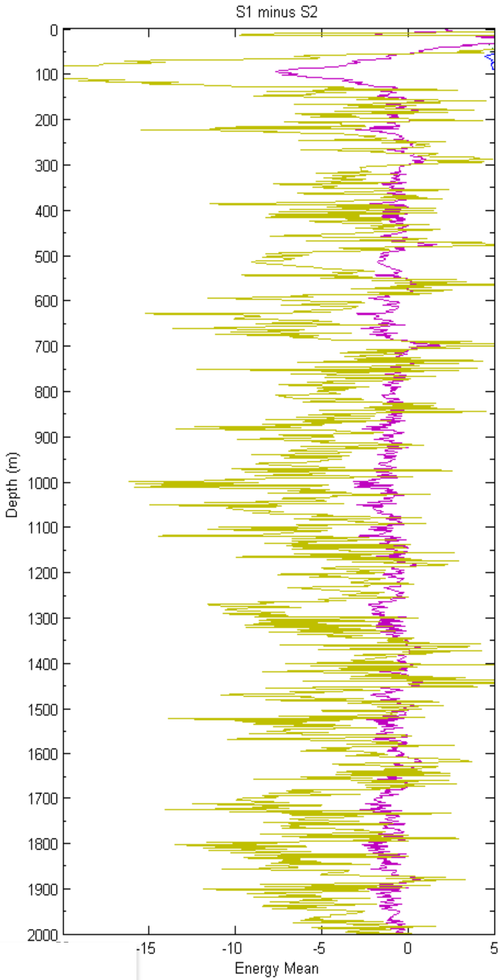
Dielectrics

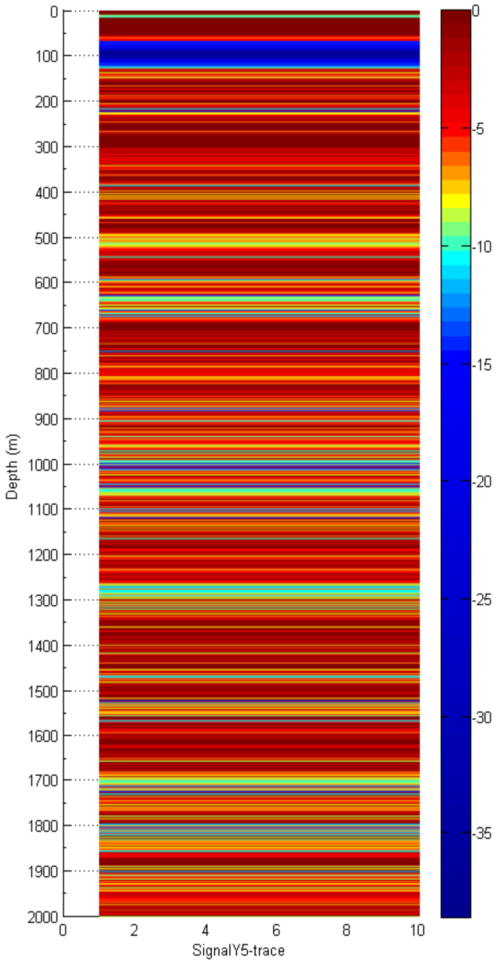




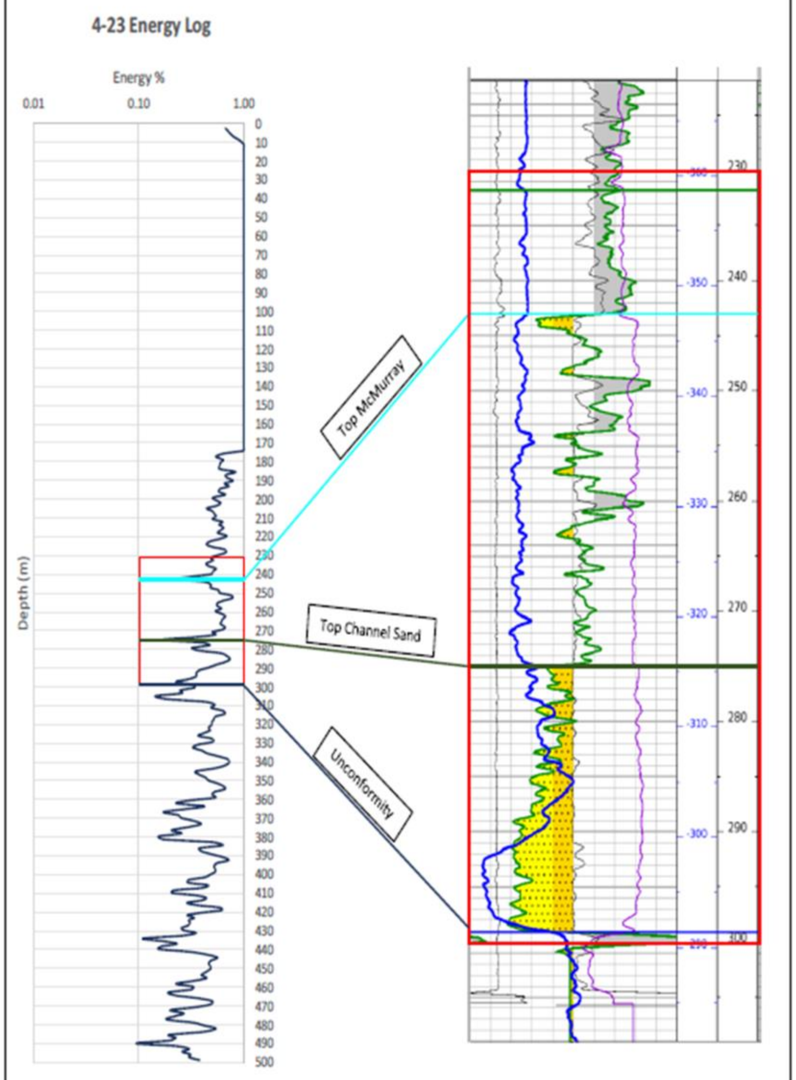
- Dielectric survey log
- In this example, high dielectrics verified by client from core inspection to be broken ground, very broken ground or faulting (caused by moisture)

Energy Harmonics





Energy Log

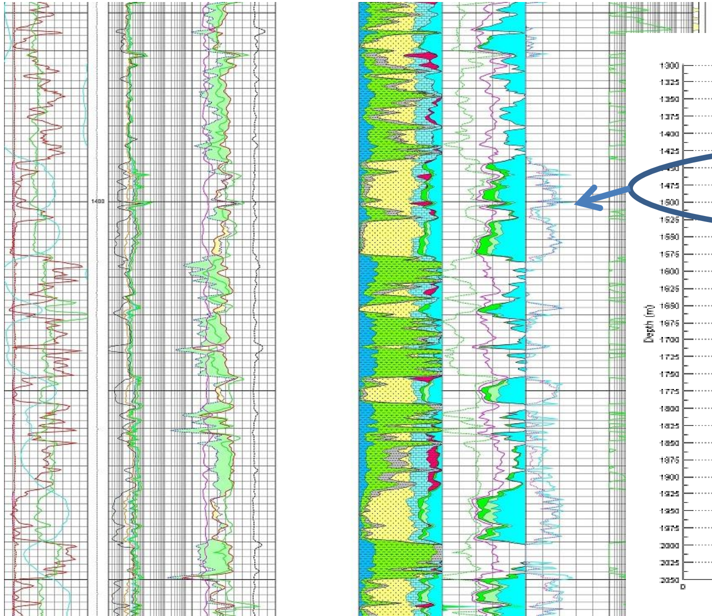


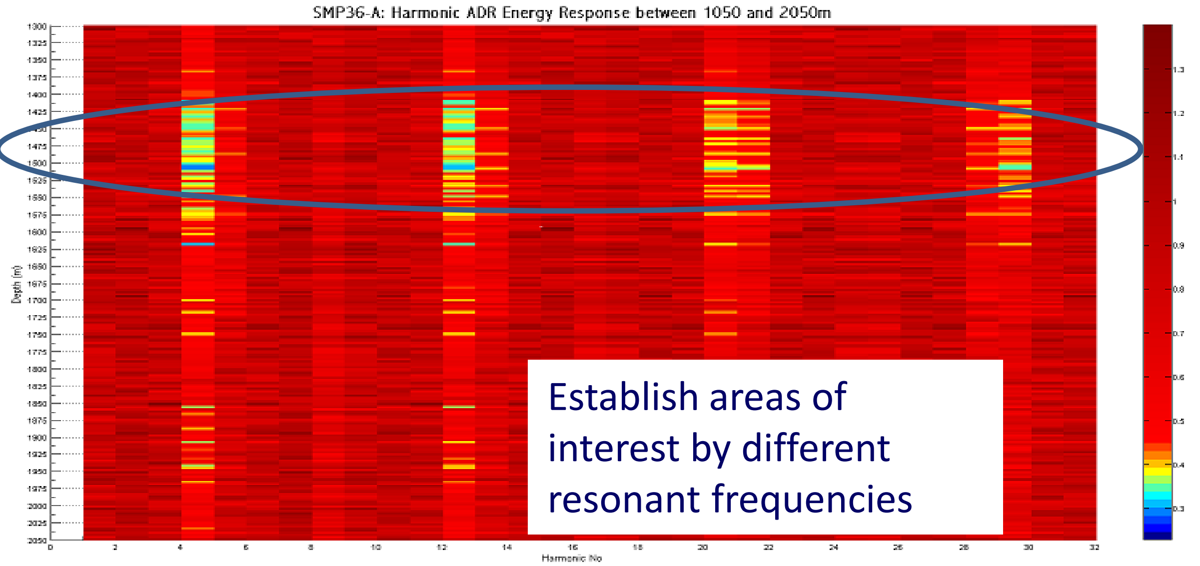
4-23 Energy Log
Energy %
0.01
0.10
1.00
Depth (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
460
470
480
490
500
Top McMurray
Top Channel Sand
Unconformity
-350
-340
-330
-320
-310
-300
230
240
250
260
270
280
290

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

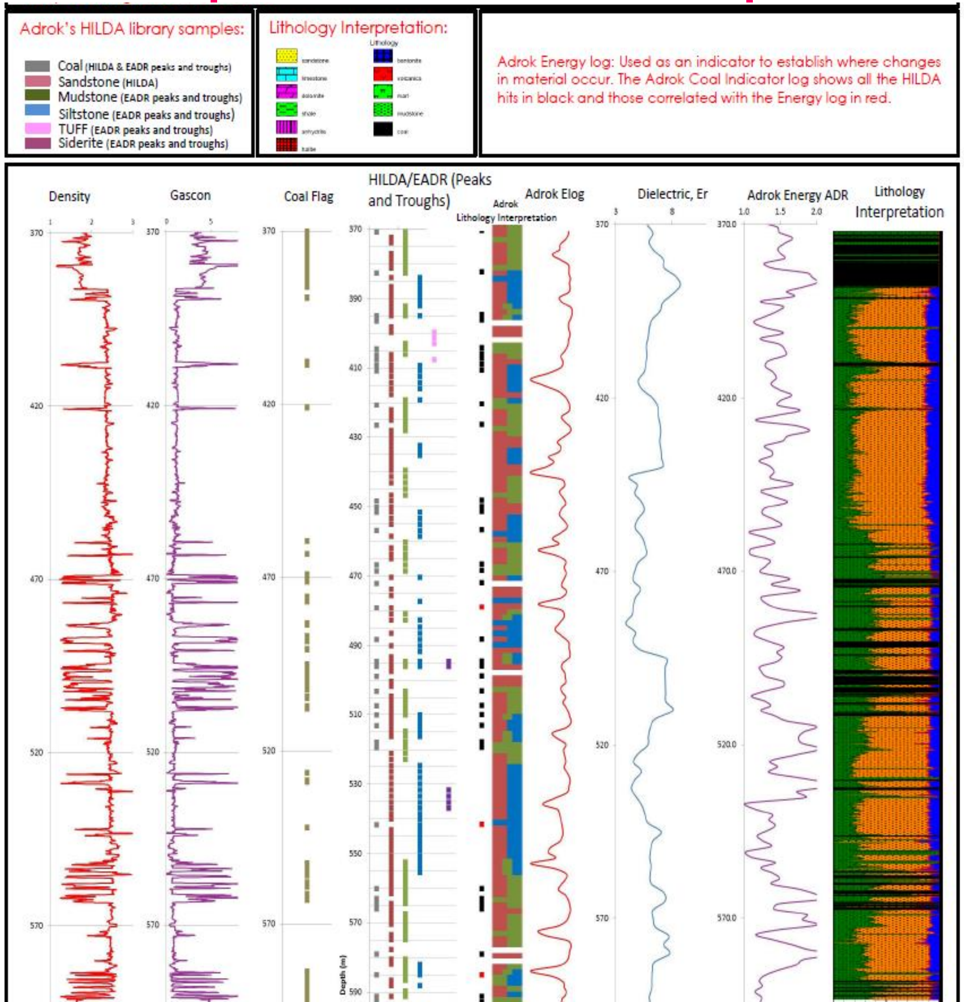
Create image of harmonic energies

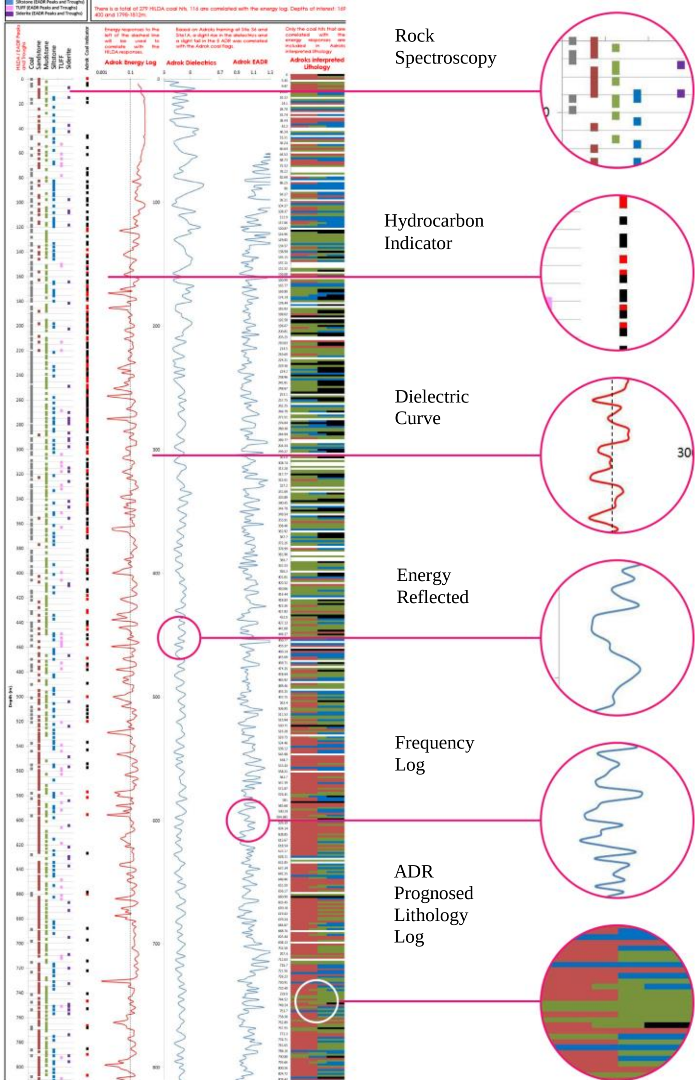




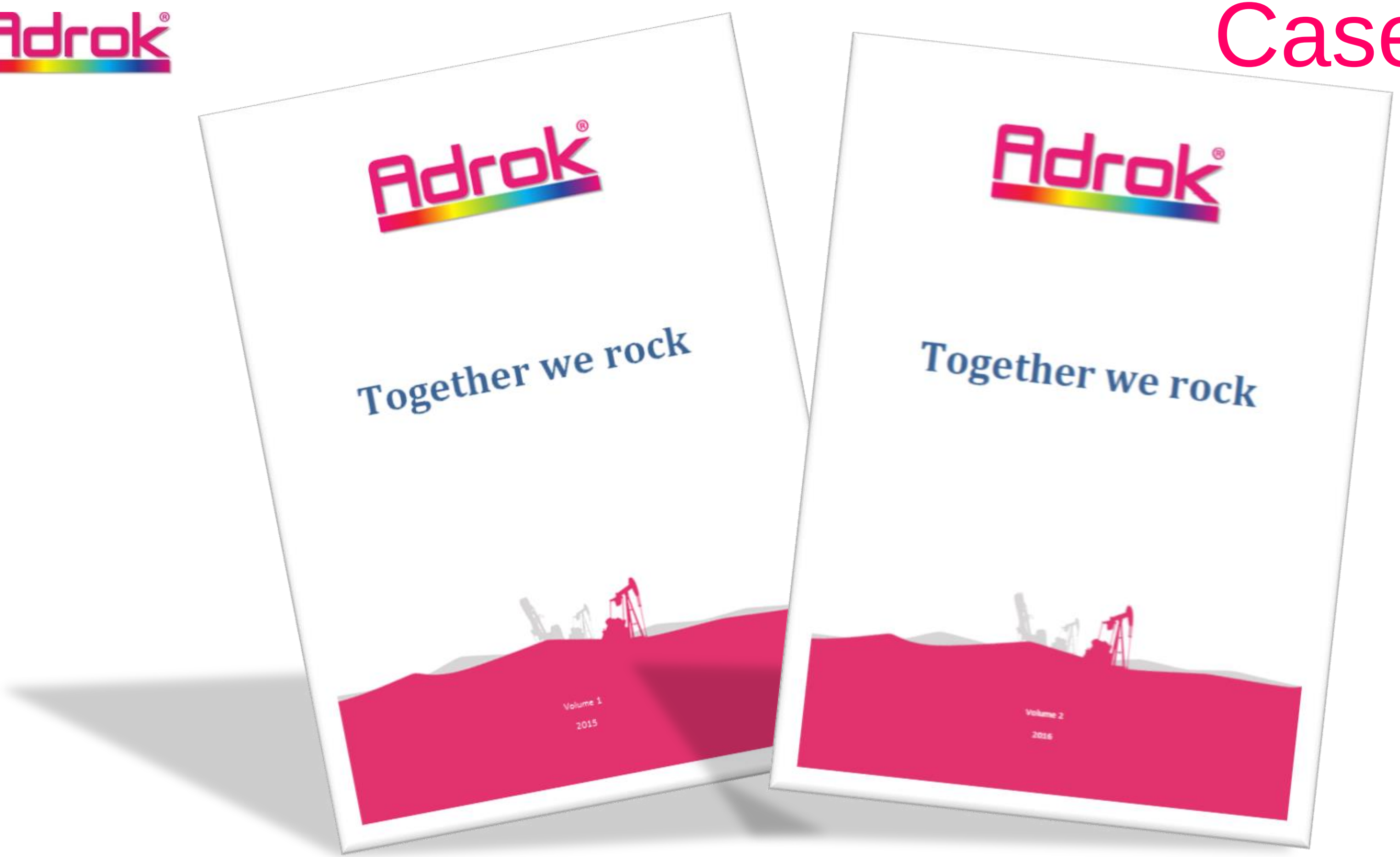
Establish areas of interest by different resonant frequencies

Examples of ADR Output





Case Studies

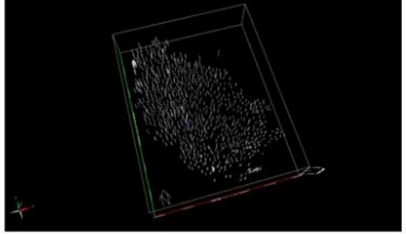


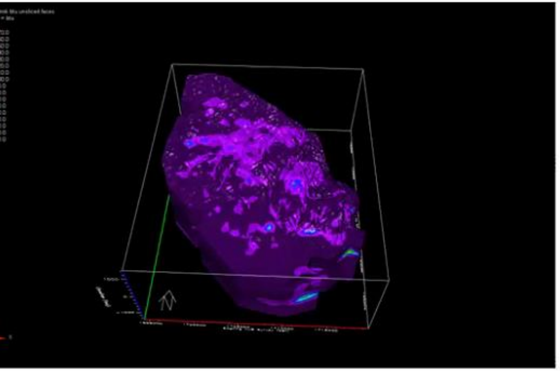
http://adrokgroup.com/case-studies/together-we-rock-vol-1.html

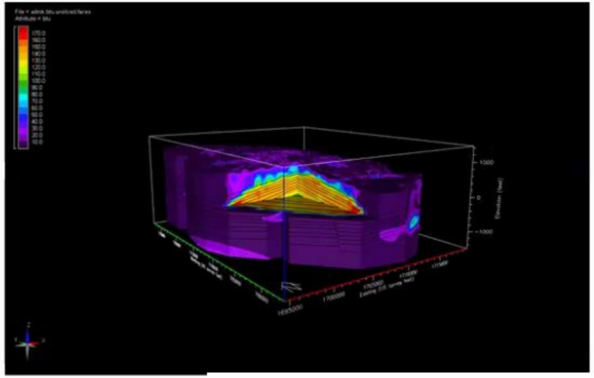
Case Study of ADR 2D imagery in California with

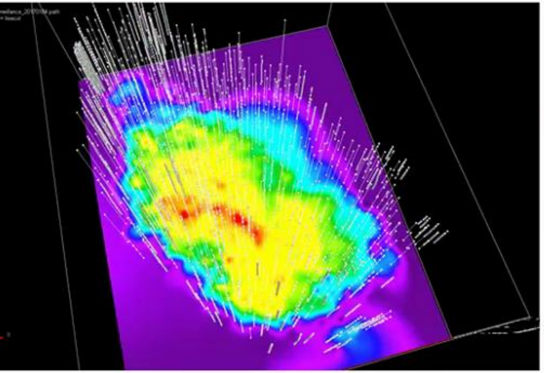
Chevron

Case Studies

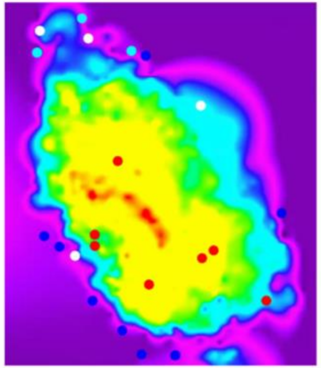


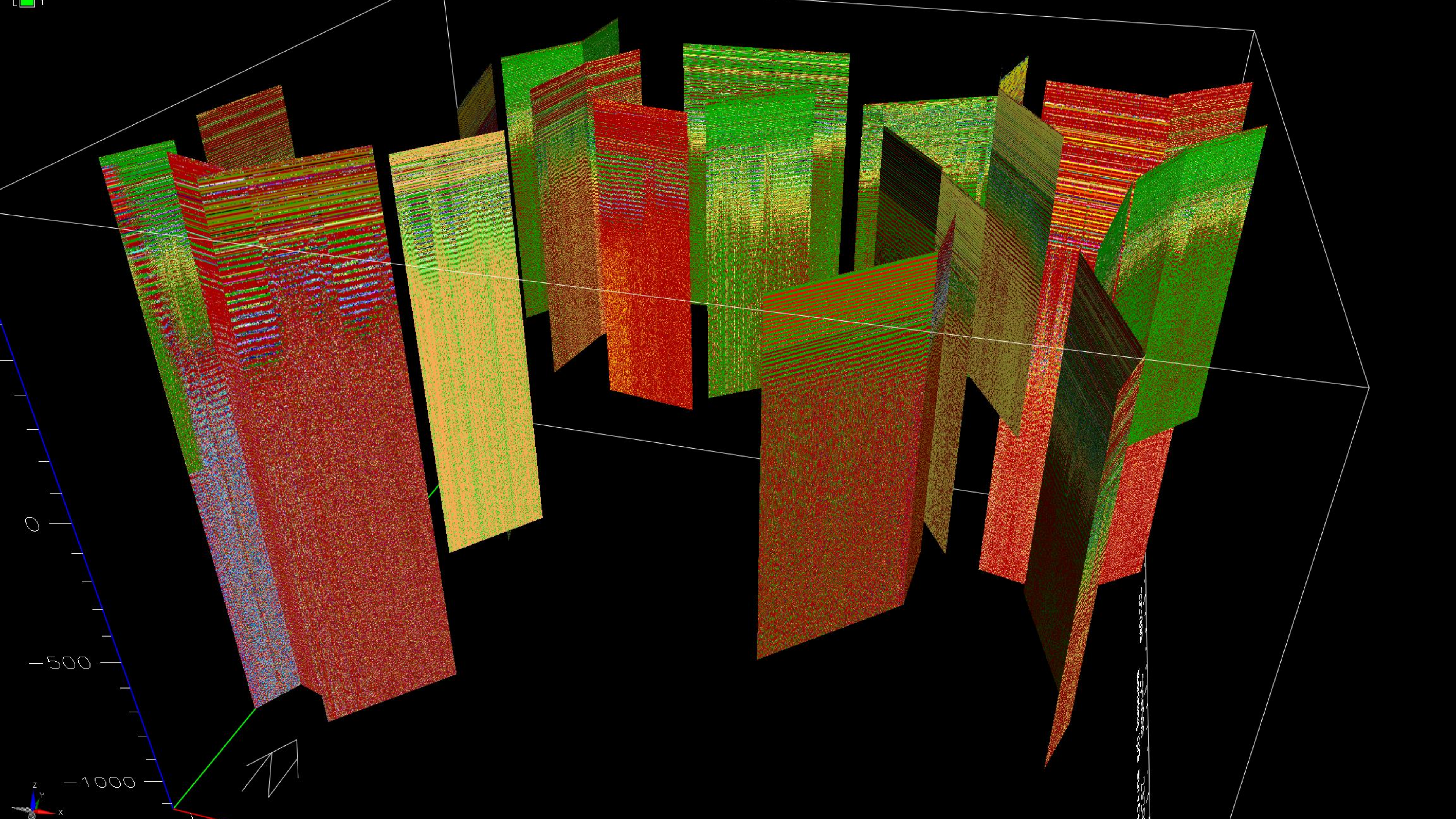




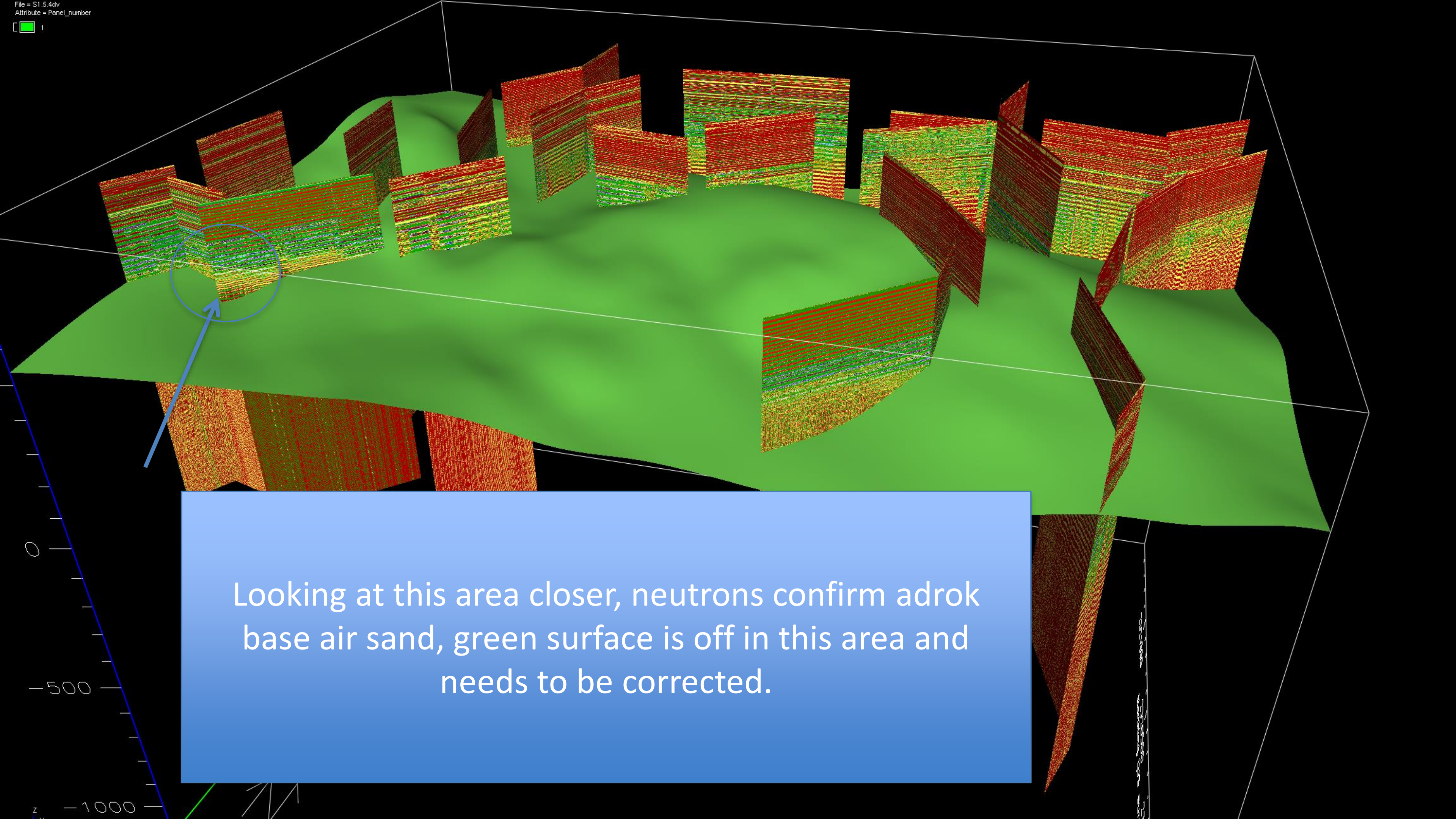


Adrok locations across KR

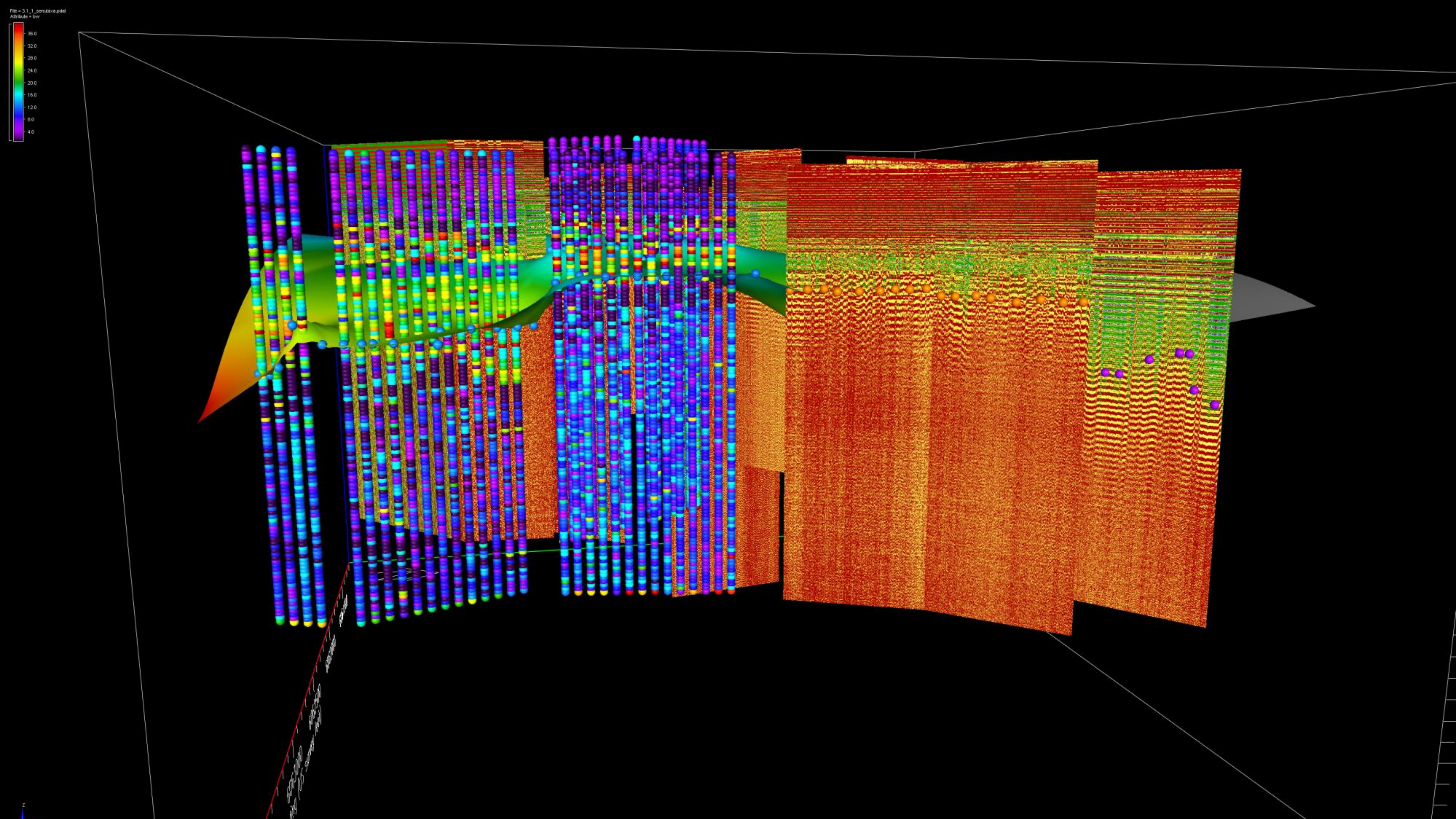




0
−500
−1000



Looking at this area closer, neutrons confirm adrok base air sand, green surface is off in this area and needs to be corrected.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20.0
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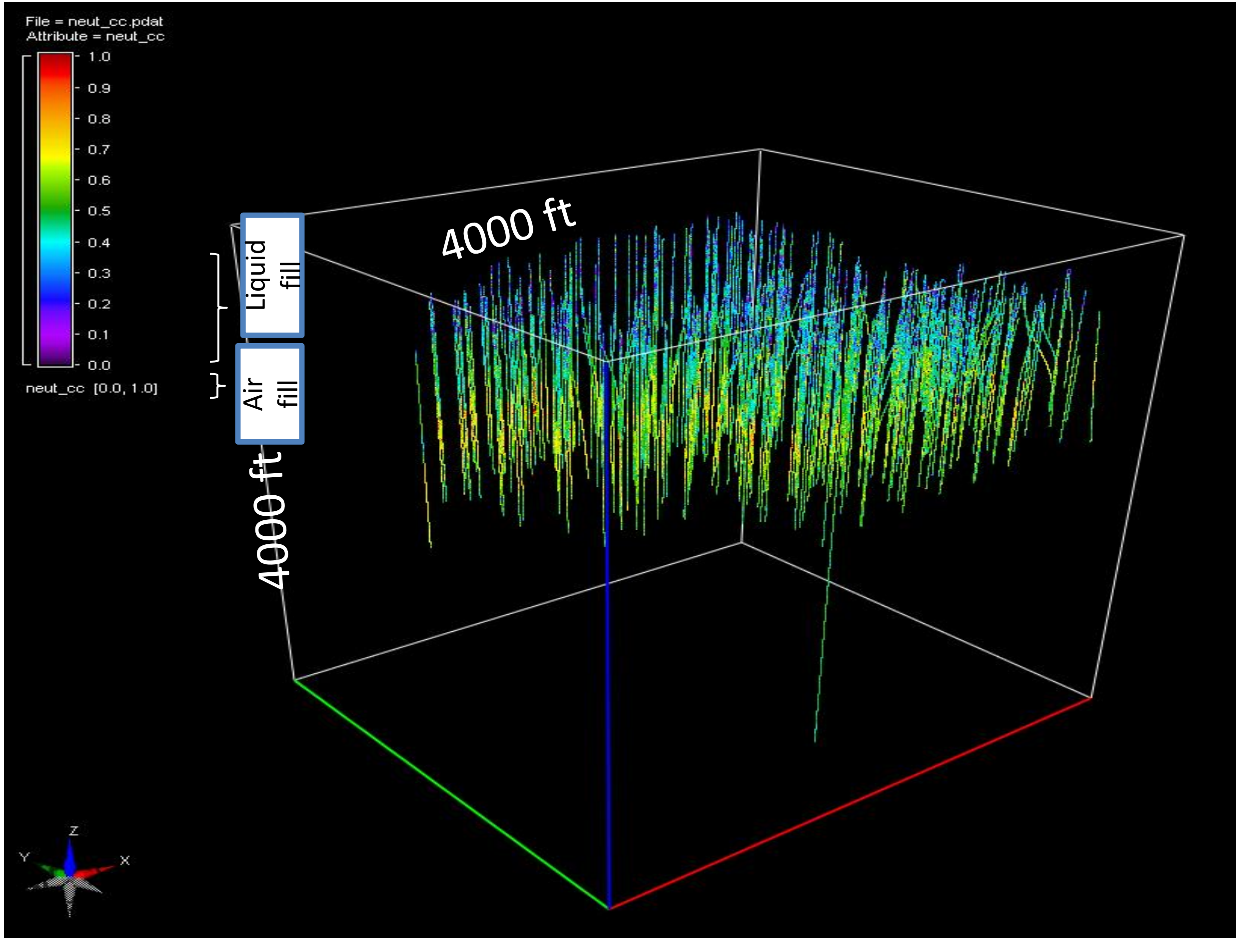
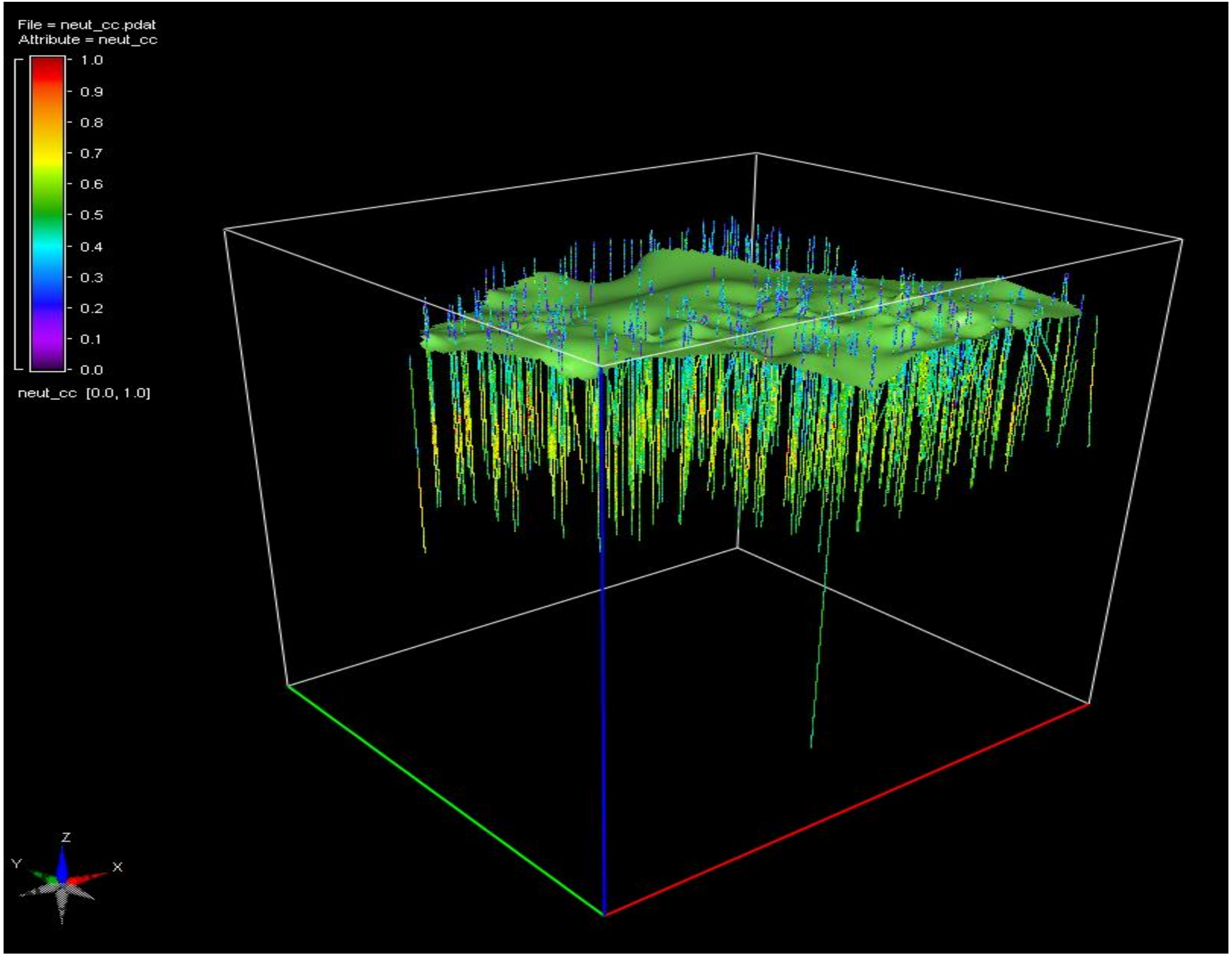
4.0

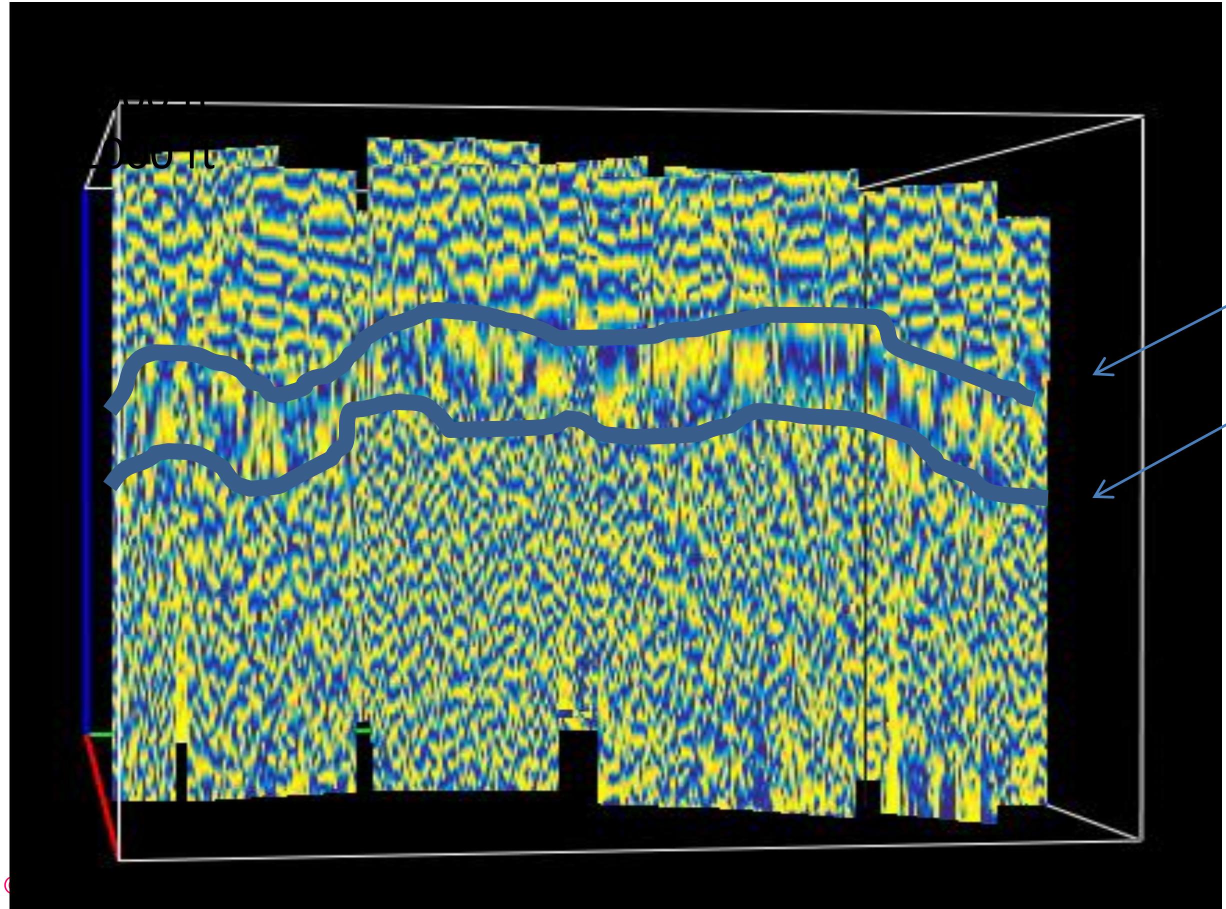
700 neutron logs used to map water table





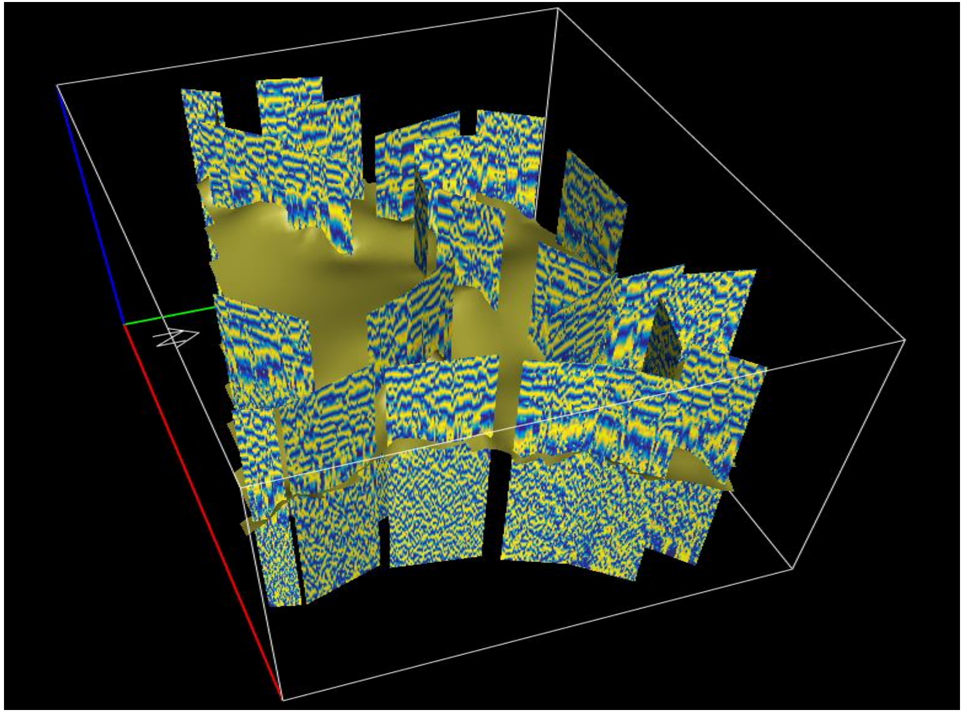
Water table from base air fill

Adrok phase panels
23 x 100 meter x-sections

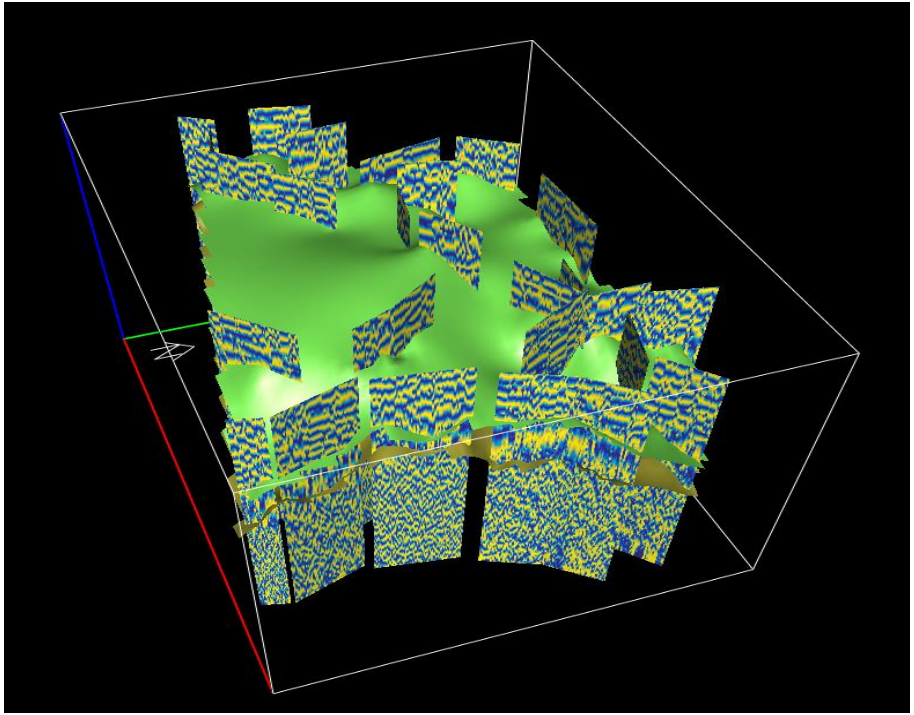


Mapped top surfaces

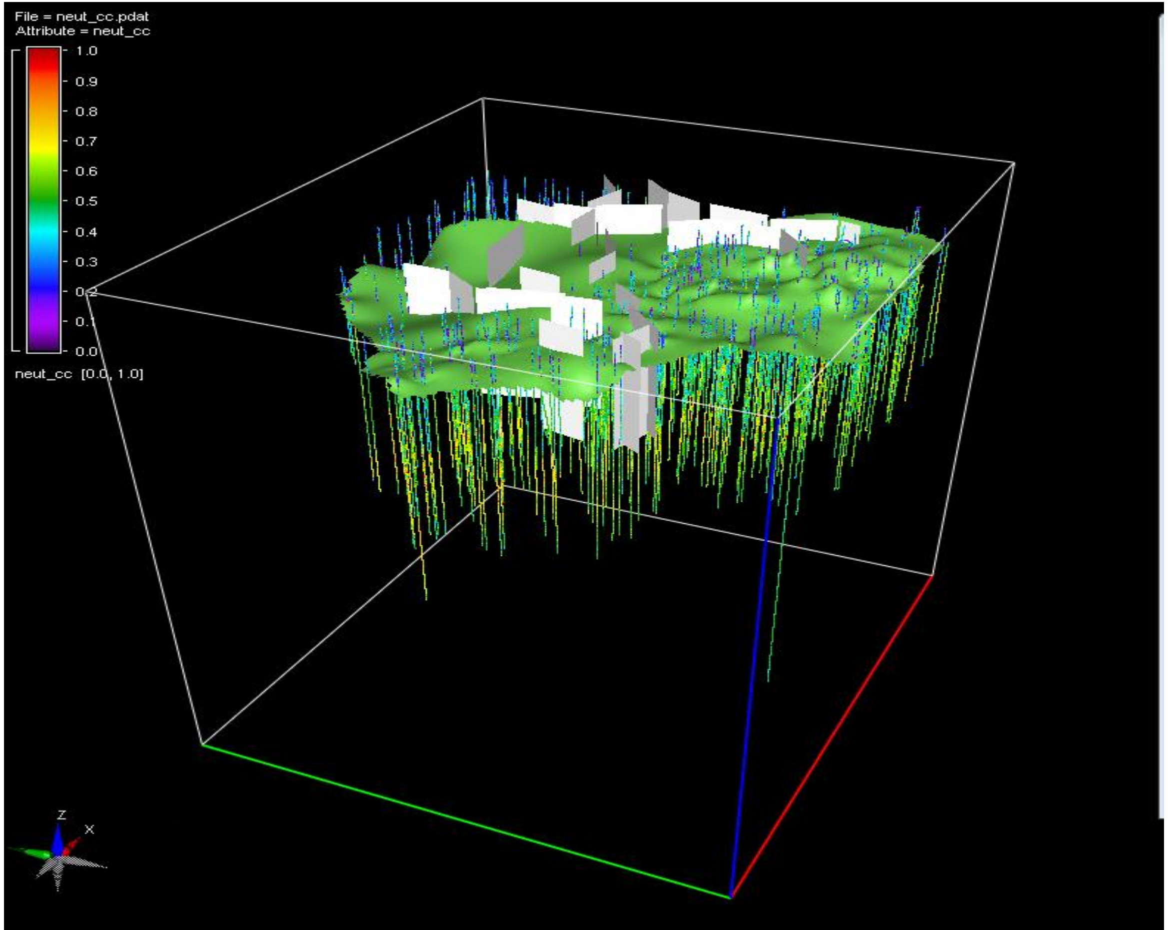
Lower surface



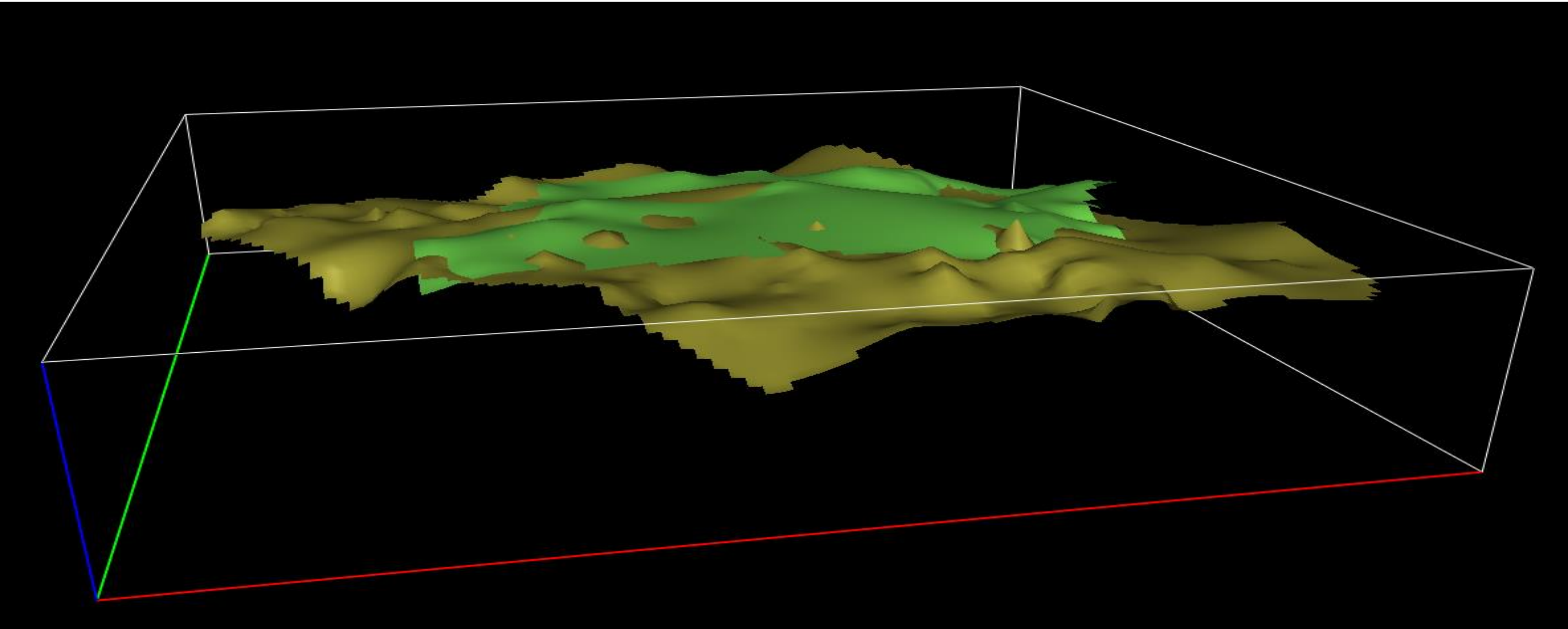
upper surface



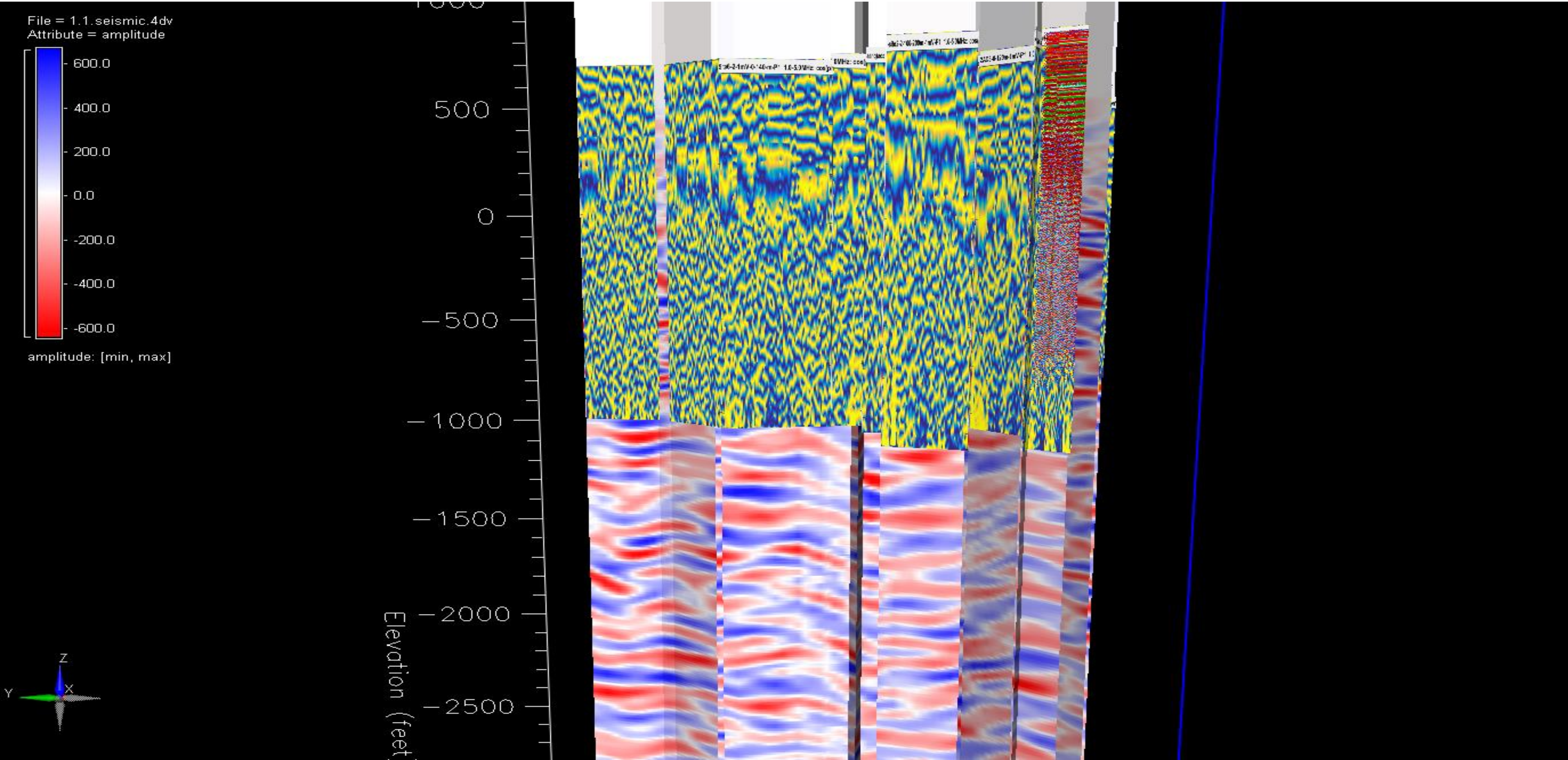
Water table with Adrok x-sections

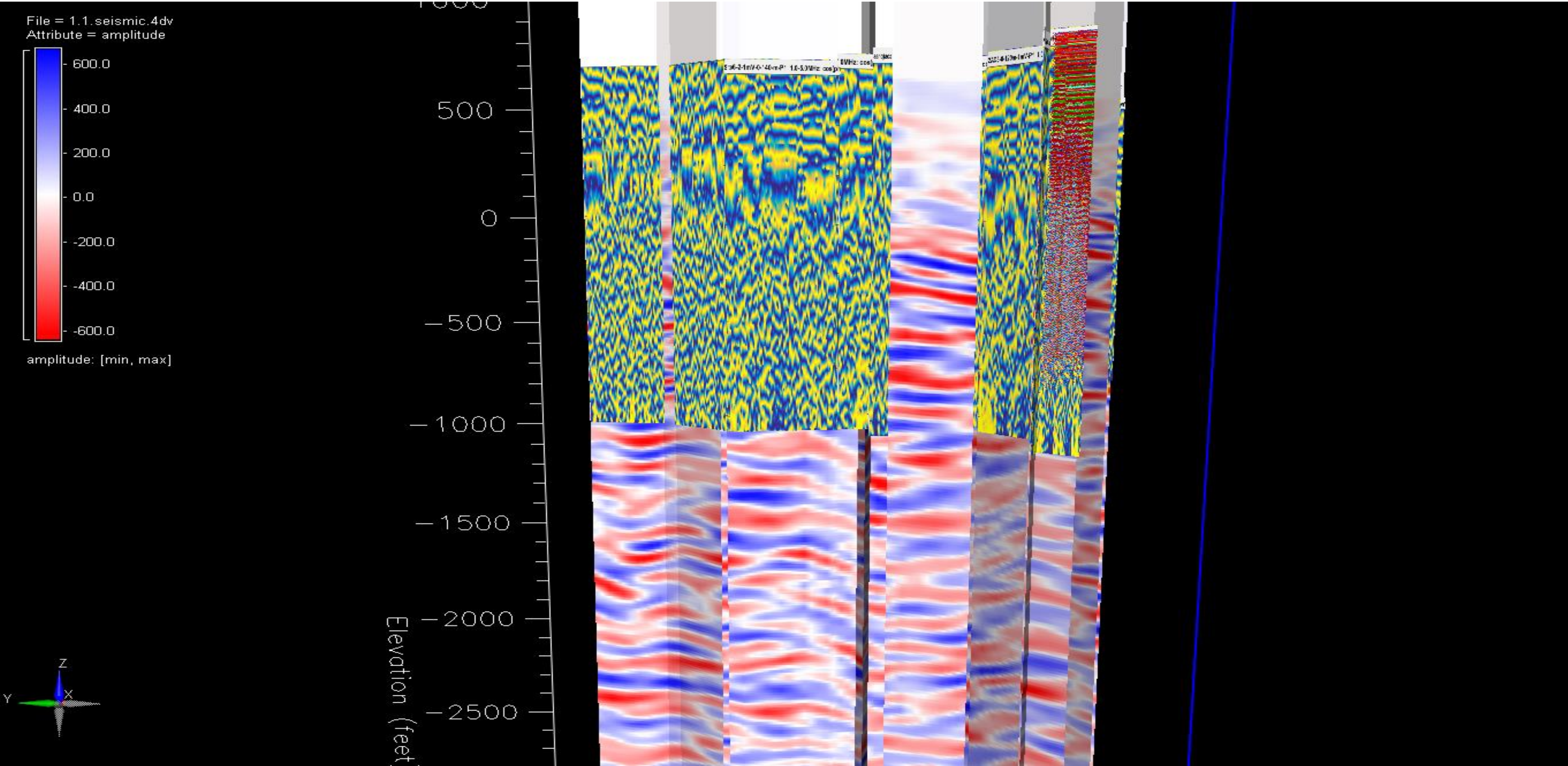


Comparison of Adrok surface with water table surface



Adrok x-sections plotted over seismic

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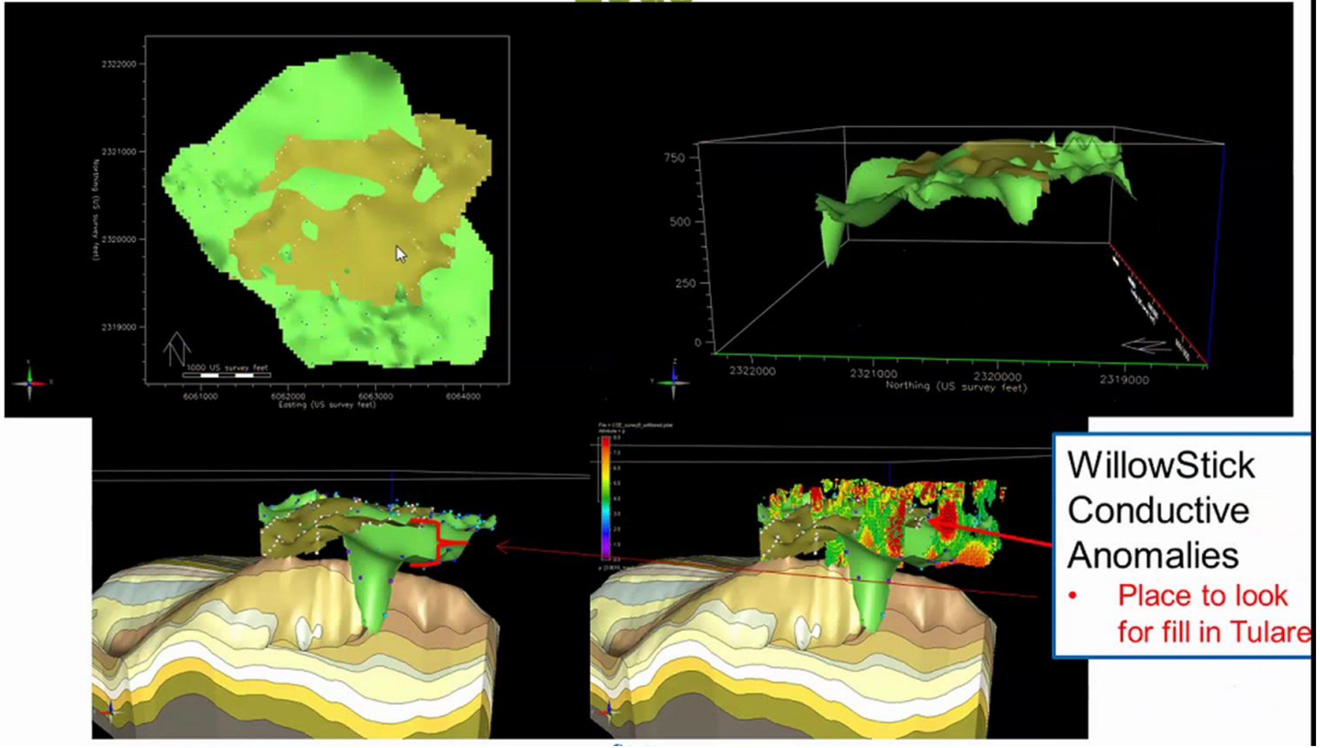
0.0
-200.0
-400.0
-600.0
amplitude: [min, max]
500
0
−500
−1000
−1500
−2000
−2500
Elevation (feet)
Z
Y
X

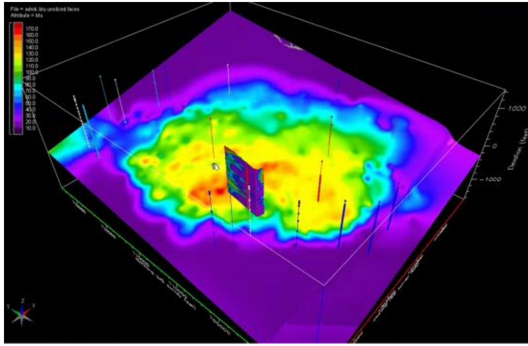
Observation Adrok supports change in water table

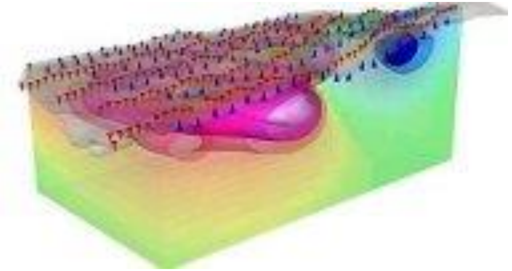
Water Table Surface: ADROK Pscans, Neutron Logs

Temporal Change in Water Table

Integration

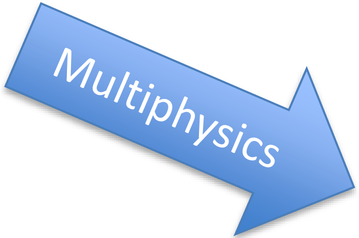






Closing thoughts

Exploration



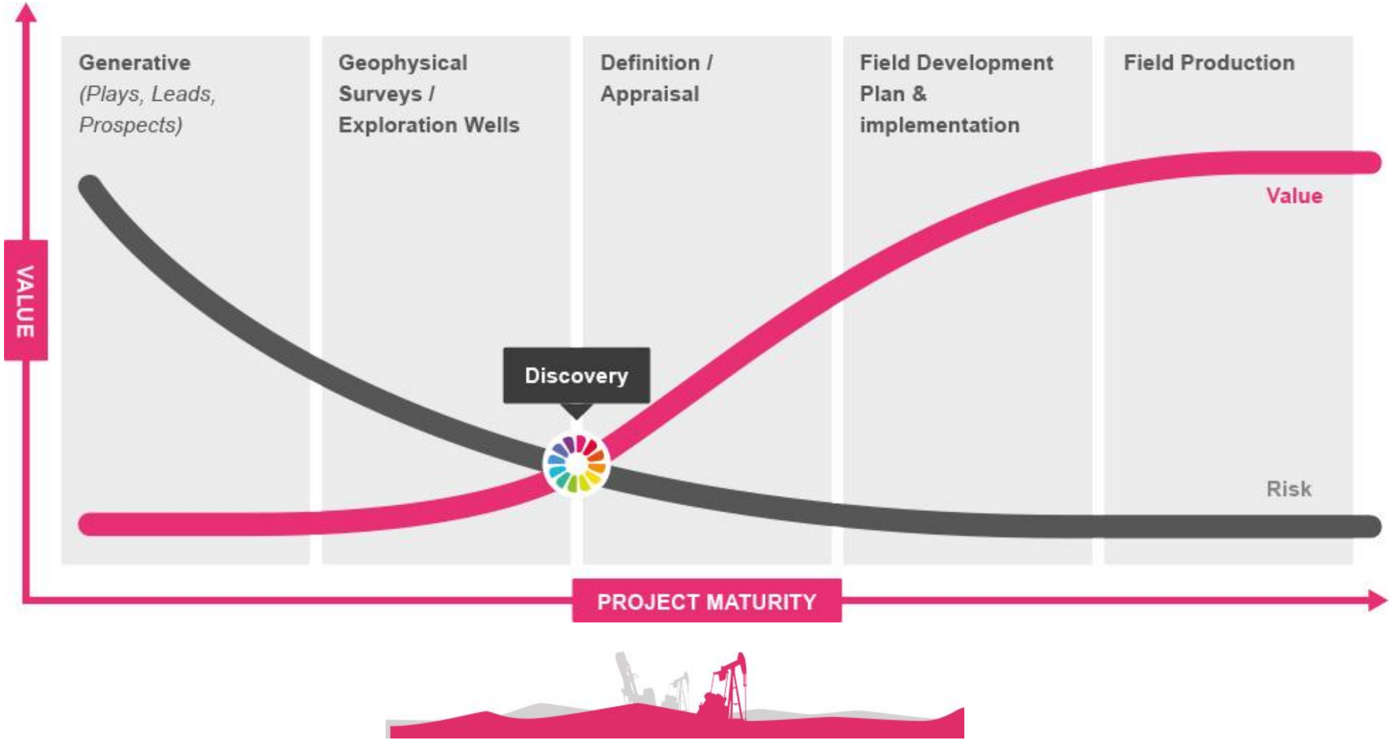
Not every exploration challenge can be solved by Seismic alone, due to:

- Physical constraints of surface terrain onshore
- Permitting issues with landowners
- Near-surface statics
- Salt-dome masking
- Basalts

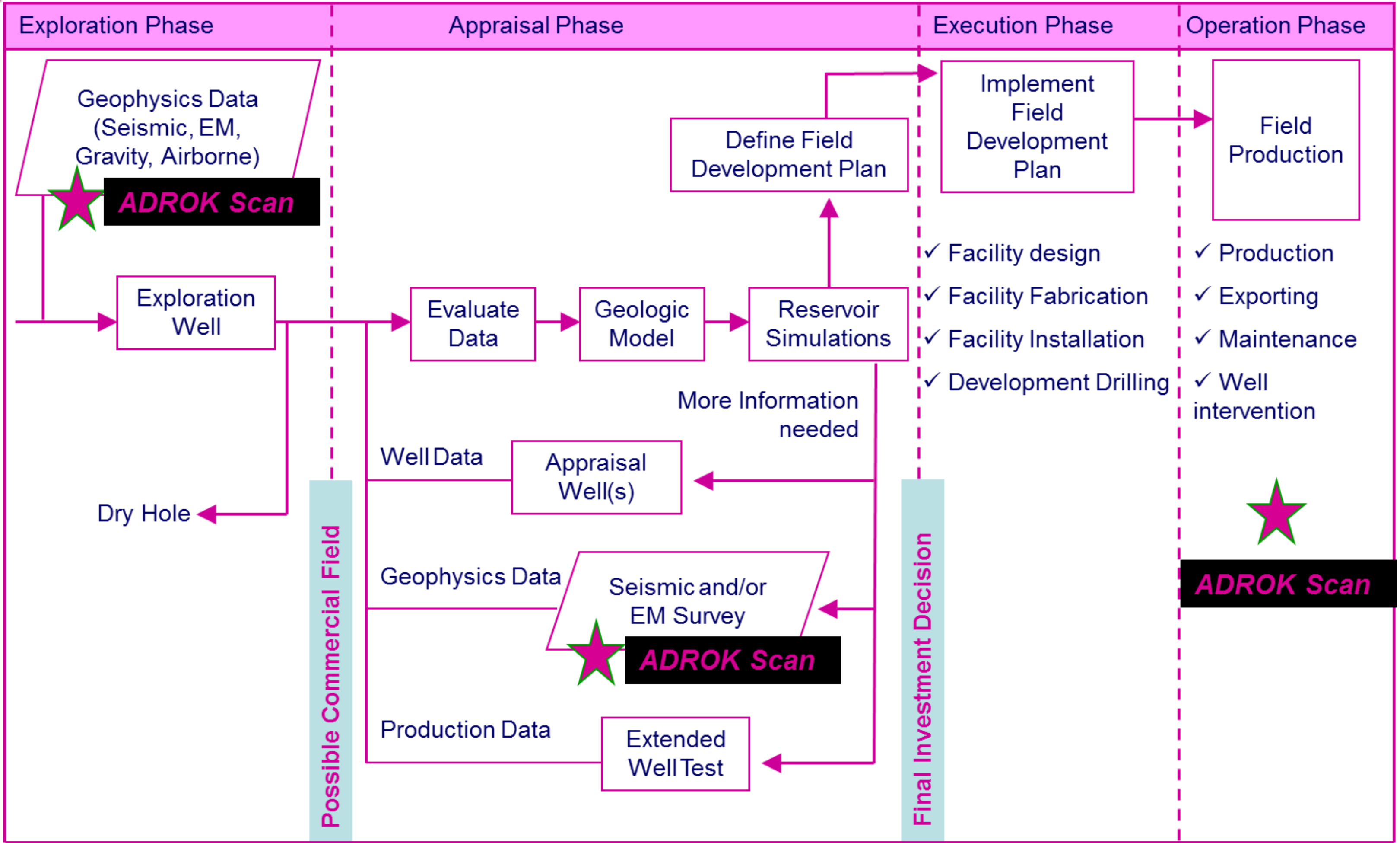
- Haliburton
- Schlumberger
- Neos Geosolutions
- CGG

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.

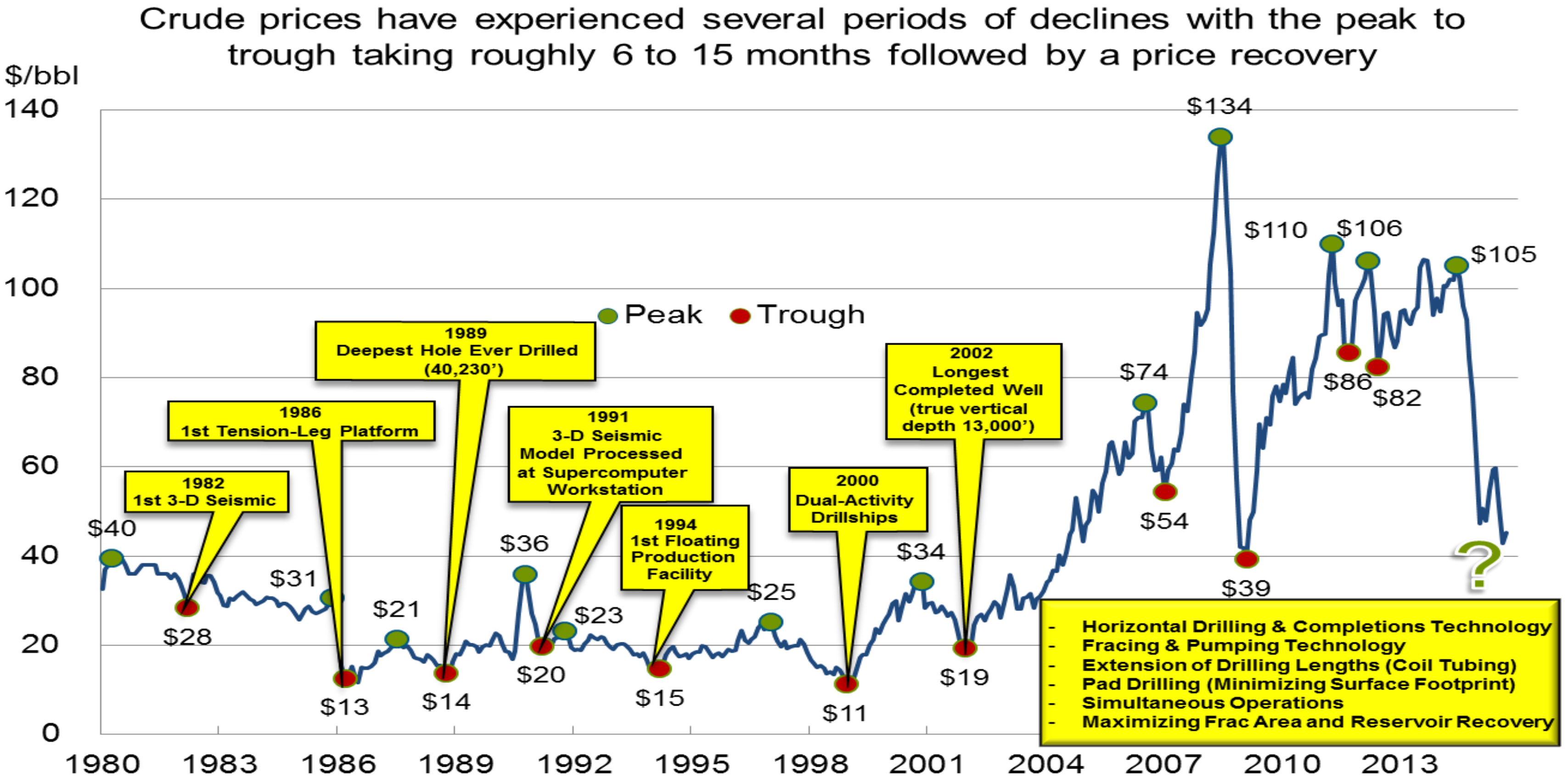


Workflows


Exploration Phase
Appraisal Phase
Execution Phase
Operation Phase
Geophysics Data (Seismic, EM, Gravity, Airborne)
ADROK Scan
Exploration Well
Dry Hole
Possible Commercial Field
Evaluate Data
Geologic Model
Reservoir Simulations
Define Field Development Plan
More Information needed
Well Data
Appraisal Well(s)
Geophysics Data
Seismic and/or EM Survey
ADROK Scan
Production Data
Extended Well Test
Final Investment Decision
Implement Field Development Plan
✓ Facility design
✓ Facility Fabrication
✓ Facility Installation
✓ Development Drilling
Field Production
✓ Production
✓ Exporting
✓ Maintenance
✓ Well intervention
ADROK Scan

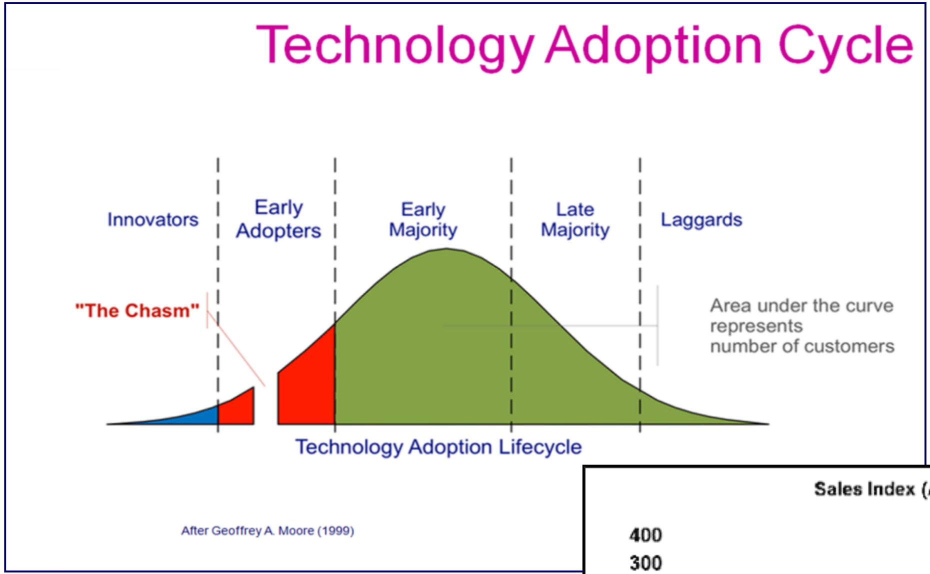
WTI Crude Price History and Innovation

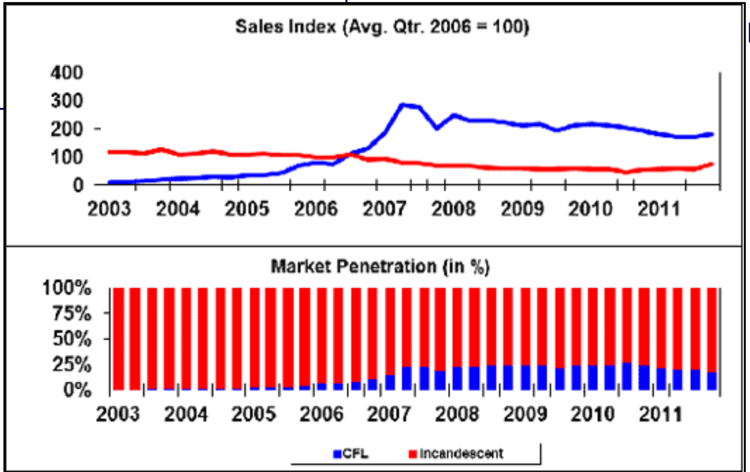
1980 - Present



Source: Encana Fundamentals, BP, CME, Economagic, EIA

Technology adoption



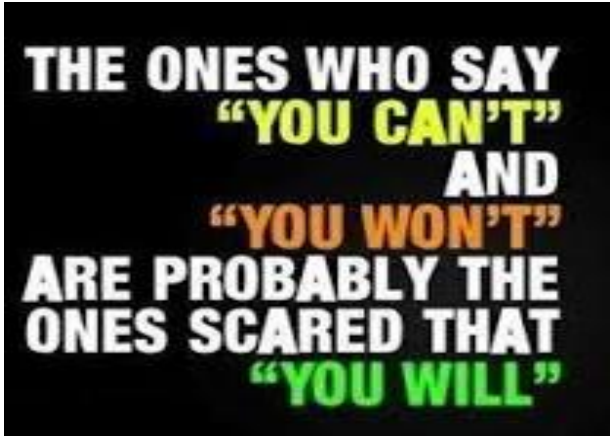


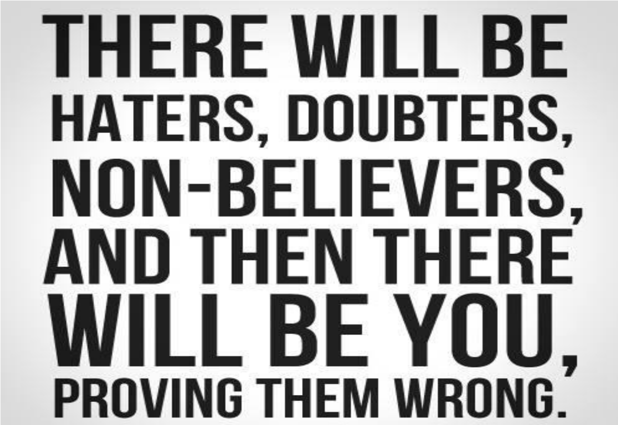
nt lamp

Martin Bett, *CEO,Stingray, Finding Petroleum presentation 2012*

Source: http://freedomlightbulb.blogspot.co.uk/

Beware the cynics & critics





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"

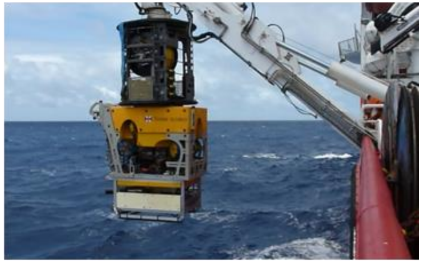
Arthur C. Clarke. *Report on Planet Three and Other Speculations.* Harper & Row, New York, 1972, p. 70.

What's next for Adrok?

Energy Catalyst – Early Stage Feasibility – Round 3

Feasibility study for innovative remote sensing to increase onshore UK gas production (kicked-off October 2016)

Subsea ADR deployed from ROV launched May 2016



Why electromagnetics have the potential to massively add value to seismic exploration

Q&A

Gordon D.C. Stove
CEO & Co-founder
gstove@adrokgroup.com

9th March 2017