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Atomic Dielectric Resonance (ADR): Lighting a way through the subsurface

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for Adrok Ltd (Edinburgh)

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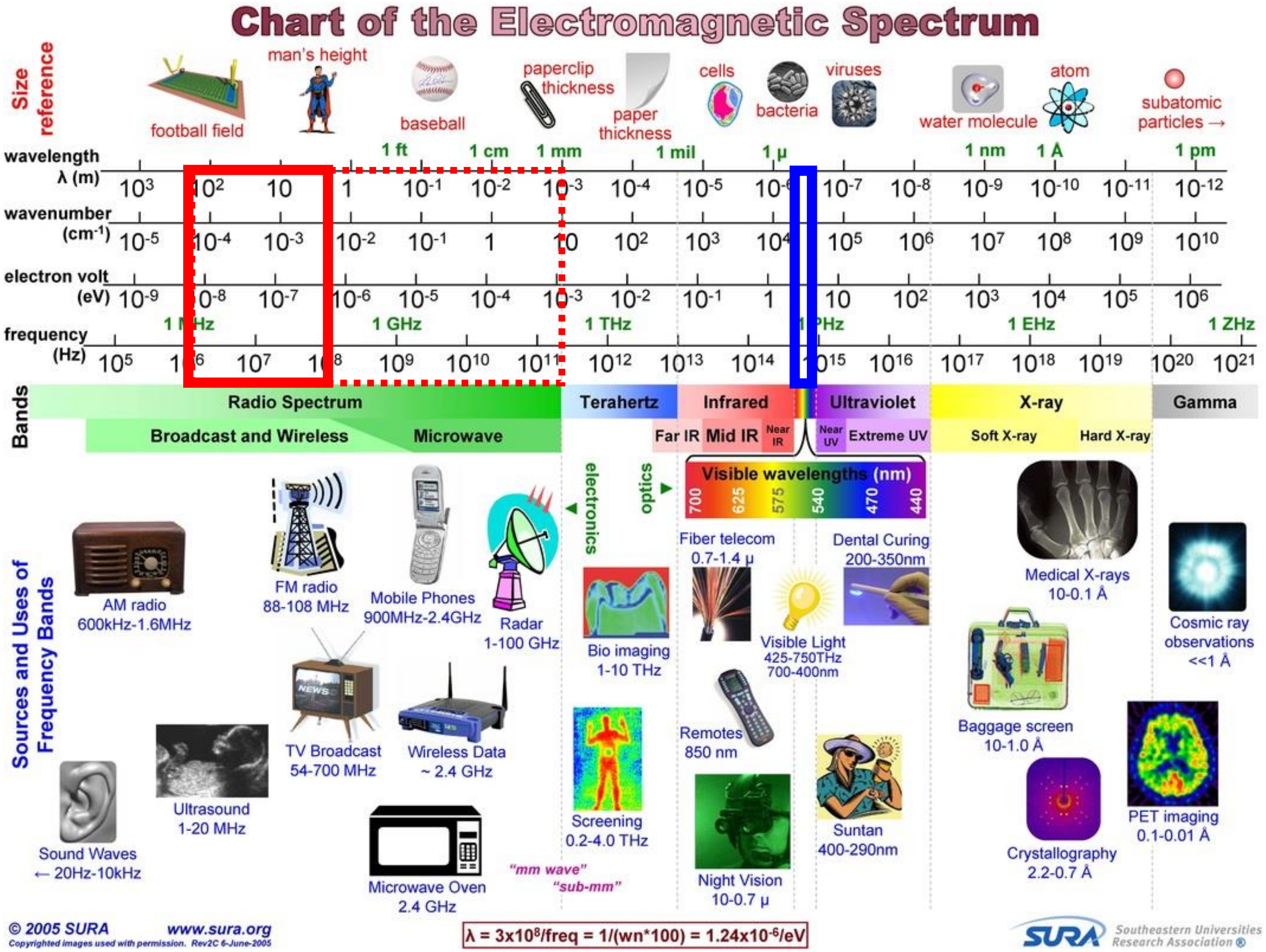
1) The Technology

Slides with custom animations

Light!

- Poetic licence to think of "light" as the full EM spectrum
- Not just the tiny bit we see with our eyes
- Adrok tools mainly operate at 1-100 MHz (radio waves)
- But also up to radar frequency (300 MHz to 300 GHz)



Penetrating the subsurface further: directionality and coherence

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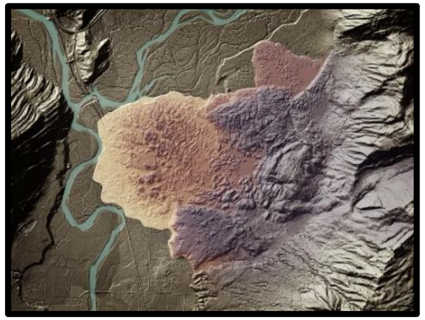
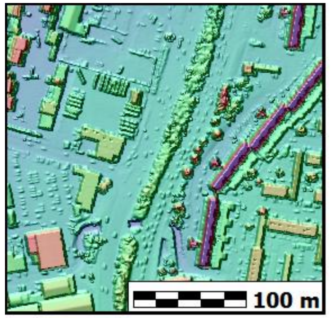
- A streetlight in the fog acquires a certain penetration, more or less omnidirectionally.
- We get greater penetration when focussing the light, using reflective materials, as in torches.
- ADR scanning shines a radio wave torch into the subsurface, achieving similar directionality.
- It's tempting to call these "beams", like lasers. In practice "beams" in the strict sense have precise physical width, wavelength and aperture definitions that aren't quite met by ADR scanning.
- Nevertheless, like lasers and LIDAR, the ADR scanner produces a coherent source.
- This means the source signals have the same wave form, frequency and phase difference.
- This character allows greater optical manipulation to achieve directionality, and shine the radio torch at a specific part of the subsurface, detecting material contrasts.



DSM 1m


"Light" and solids

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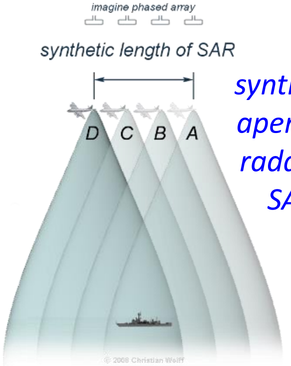
- **But can "light", or EM radiation ever penetrate deeply into solids?**
- **The fly in a cathedral analogy helps:**
  - The atomic nucleus in an atom
  - Even solids are lots and lots of nothing
  - The barriers to passage are ones of force, not "stuff"
- **When "light" encounters a barrier, one or more of three things happen:**
  - reflection
  - transmission
  - absorption
- **How much of each happens depends on:**
  - wavelength & frequency
  - intensity
  - the barrier :
    - chemistry
    - physical microstructure
    - thickness

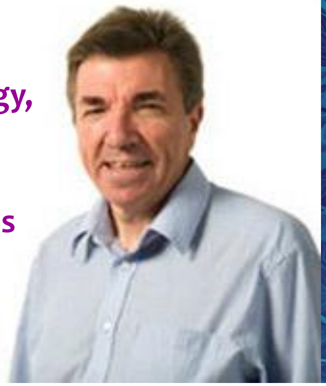
- **Visible light doesn't travel through solids as easily**
  - Its wavelengths are of a size that interacts readily with the molecules and chemical structures
- **Gamma rays and X-rays travel better through solids**
  - Their wavelengths are too small to care – they can go through most atom's gaps
- **Radio waves have wavelengths that travel better through solids**
  - Their wavelengths are too large to care - they are a cruise ship on a choppy sea – with enough push they sail on through

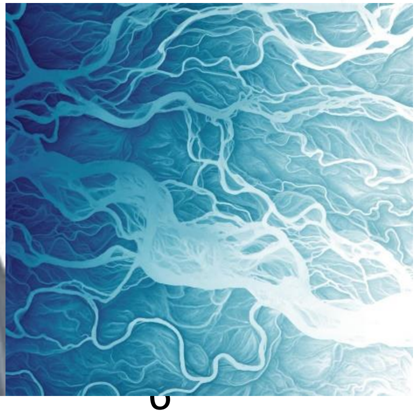
ADR – a history

- Subsurface penetration of radar signals – first recognised 1910
- Glacier depth estimates 1920's
- Advent of ground penetrating radar (GPR) in 70's
- 80's & 90's military and space experiments with aircraft & spacecraft moving directed radar pulses over an area (SAR)
- Proof of concept for detection of shallow subsurface geology using this method – Scotland, North Sea, Egypt
- Development of LIDAR technologies suggested similar approaches might be applied to radio waves
- Following on from experience in SAR & GPR & remote sensing, founding of Adrok by Colin Stove in 1994
- Development of the Adrok technologies for greater depth penetration - with multiple patents issued since.
- Application of Adrok technologies in medicine, mining, hydrogeology, archaeology, hydrocarbons, & geothermal
- Notably Chevron is now using the technique to assist with tracking injection fluids
- 2016/2017 innovate project to look at onshore UK petroleum geology



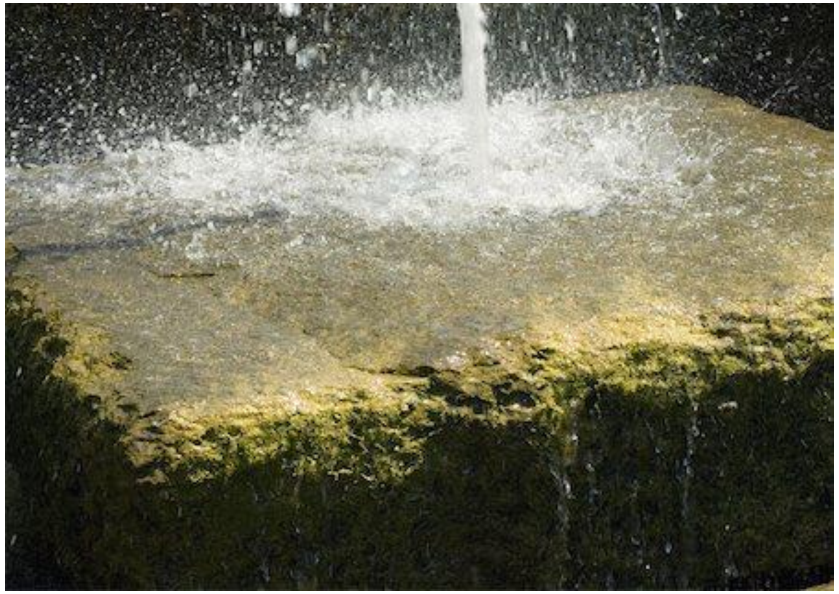
synthetic aperture radar or SAR





Absorption – a window into relative permittivity (dielectric constant)

- **Pouring water onto a material, it is absorbed in different ways by different materials**
- **Pouring " light" or electromagnetic waves onto a material also creates different absorption responses**
- **Atomic dielectric resonance technology exploits this material specific response**
- **Radio waves from X-band and C-band radar have resonance properties that facilitate the technique**
- **Any subsurface reflections from the scanner's pulses are recorded in time, collated, and spectrally analysed**
- **Energy, frequency, and phase**

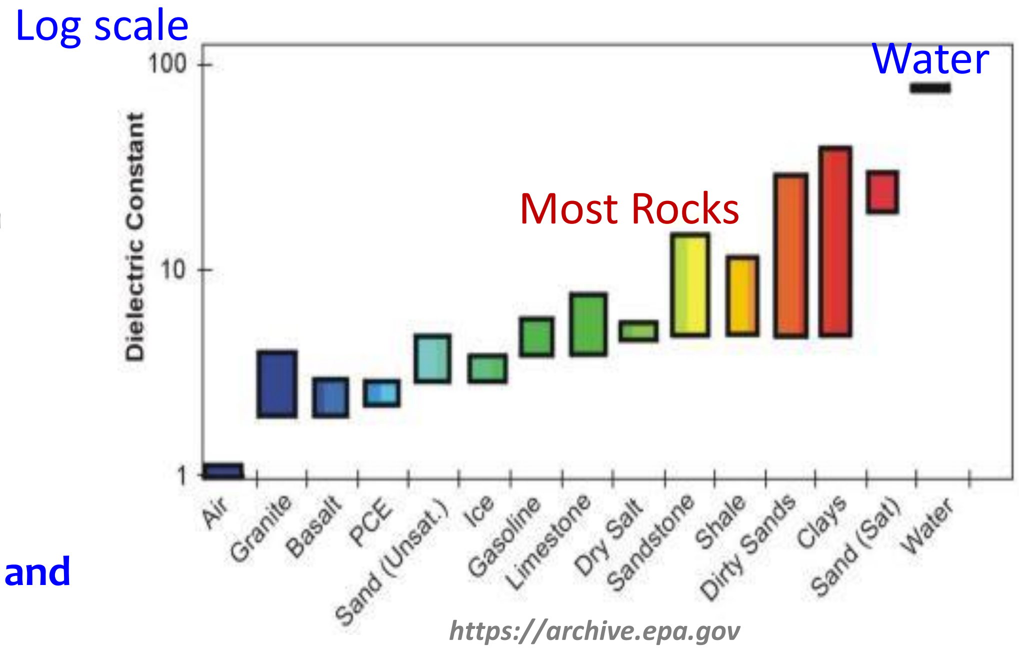


- **Using Maxwell's equations for EM propagation, and Debeye* polarisation models, three key variables of the material can be studied:**
  - Relative (dielectric) permittivity (ε)
  - Magnetic permeability (μ)
  - Electric conductivity (σ)
- **Of these, the most interesting to us for subsurface geology is the relative permittivity (dielectric constant)**

**Debeye is used over Cole-Cole as it lends itself more to time domain solutions*

Relative permittivity (dielectric constant or DC)

- Defined relative to that of a vacuum, set at 1
- It's related to the electric susceptibility
- Dictates *how polarised* a dielectric material (i.e. an insulator that will polarise) becomes in an applied electric field
- A variety of rocks share a similar value – but note that:
- Water ~ 81, HC's 1-2, most rocks 4-12
- The tool should therefore be sensitive to porosity and water saturation
- Devil is in detail of discerning mixtures of rock types, porosity, and pore-fluids
- Non uniqueness is the enemy
- Requires the creativity to bring in other calibrating information



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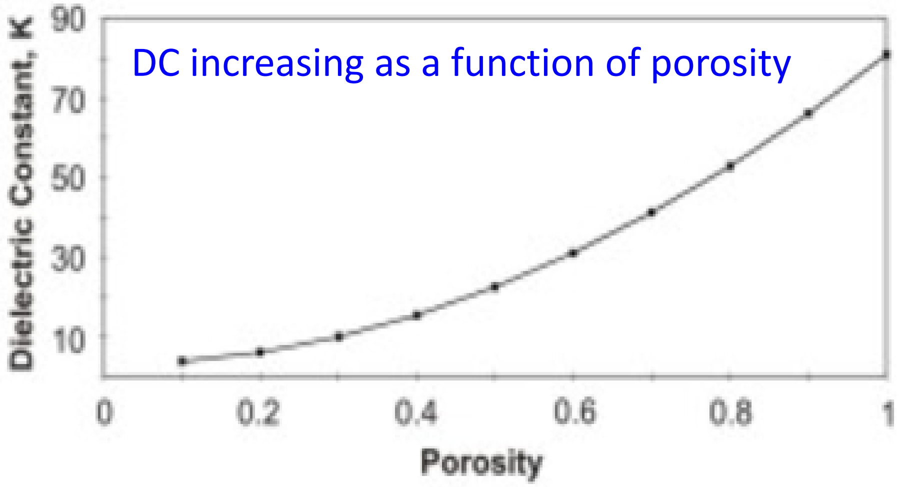

Water Content

With a dielectric constant of 80, water dominates the permittivity of rock water mixtures. There does not appear to be one widely accepted model for water-saturated rocks. One model, proposed by Calvert (1987), is:

$$K_f = (1-\phi^2)K_m + \phi^2 K_w,$$

ADR – is it like GPR?

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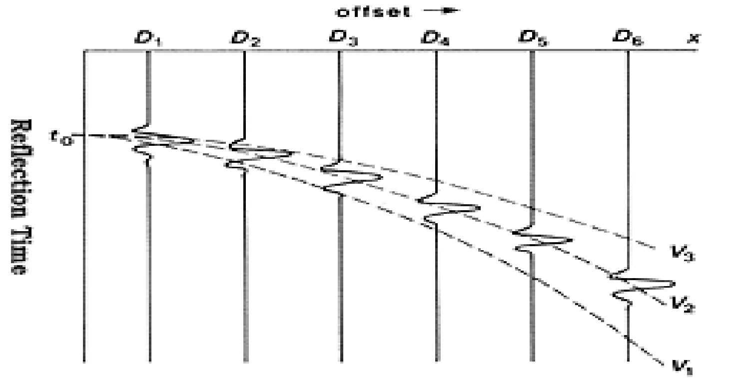
- **It is a time domain electromagnetic method – but this is a big bucket describing lots of very different methods**
- **It has some similarities with seismic –**
  - Observations made at a variety of distances from the transmitter
  - These deliver two independent NMO and ray tracing derived dielectric constant curves
  - EM velocities are related to the DC, and are used to **convert time to depth**
- **It is not GPR (Ground penetrating radar)**
  - They do both use utilise reflections of radio waves
  - GPR's higher frequencies and cm scale wavelength don't penetrate as deeply, and are useful only for the top few m of the earth's surface
  - ADR uses different wavelengths to achieve km scale penetration.
  - GPR doesn't use the resonant element of a wave packet to look at the material
  - GPR isn't normally concerned with discerning the relative permittivity (dielectric constant).
- **Unlike seismic and GPR, ADR is not waving the energy about omnidirectionally**
  - it is a focussed, intense ray, up to a max of 0.4 m wide
  - Actually a lot narrower (<0.1 m) at its most intense centre
  - Not significantly affected/deflected by structural dip

Velocity and Travel-time

EM wave velocity α $1/\sqrt{\varepsilon}$

The velocity (V) at which electromagnetic waves travel through low-loss materials is described by the relationship:

$$V = c \,/\, (\varepsilon_{r\text{-}bulk})^{0.5}, \qquad (5)$$



Transmitter & Receiver **N**ormal **M**ove **O**ut (**NMO**) with increased distance

ADR - is it like CSEM/MT?

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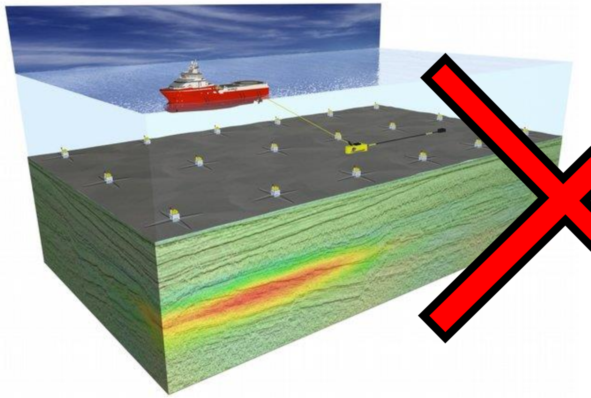
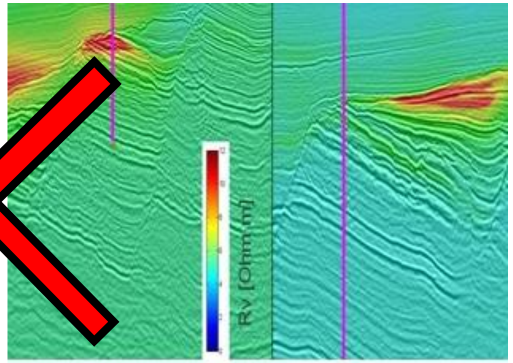
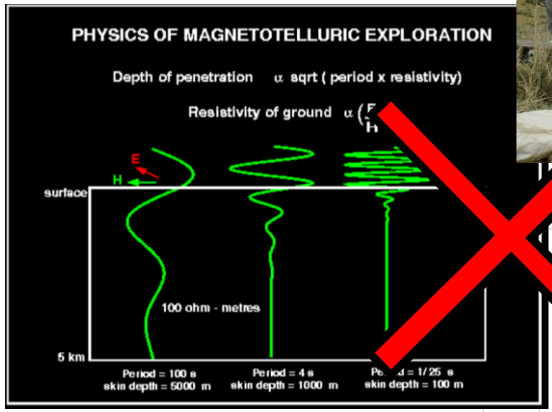
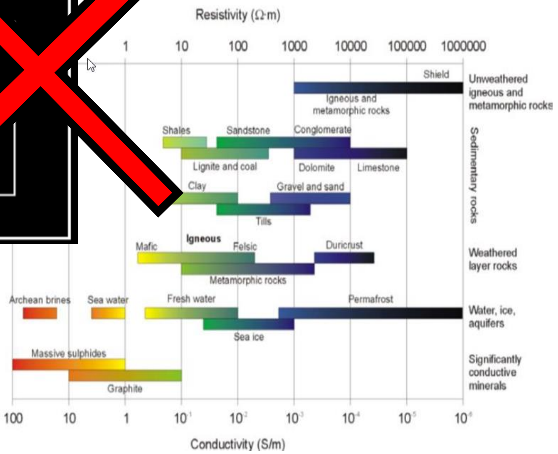
- **It’s not using inductive polarisation or resistivity (e.g. like marine CSEM or magnetotelluric)**
  - Those techniques employ lower frequencies that don’t see high detail
  - They measure changes created by externally sourced ***induced*** electric & magnetic fields (natural or controlled)
  - Happen relatively slowly compared to what the ADR tool does instantly
- **These other EM methods have a very useful and important place, but ADR is FUNDAMENTALLY different from them**
  - It endeavours to give m-scale resolution at km scale depths
  - Using directional radio wave illumination and resonance
  - To highlight dielectric permittivity and other contrasts in the subsurface









Not a question of whether it works...

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- **Adrok today is not testing whether the fundamental technology works – it does**
- **It's seeing how far it can be taken and developed in a deep subsurface geological context**
- **Including petroliferous sedimentary basis**

Adroks' radar image of a horse and cart buried in the ***Loch-nan-Uamh viaduct in Scotland****, seen through several m of concrete*

-Several m,
- Hundreds of m,
- It works,
- So can we take it to km scale level?

Adroks' signal transmission being tested through a 160m limestone pillar of the ***Washington State Pend Oreille lead-zinc mine****, and by detection of an overlying river 350m above*

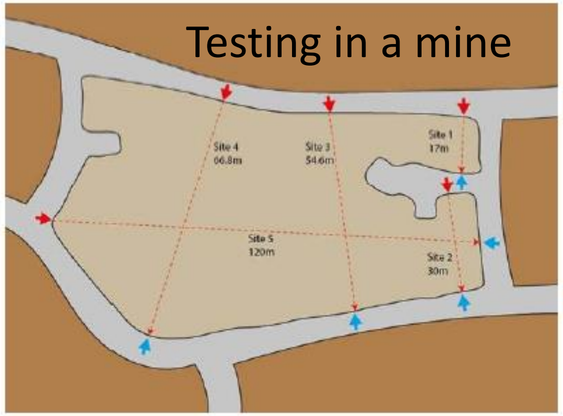


Figure 1: Location of emitters (red) and receivers (blue) for the trans illumination experiments.

Experiment 1

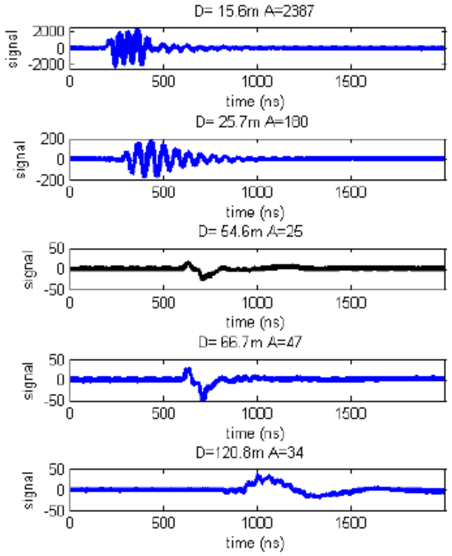
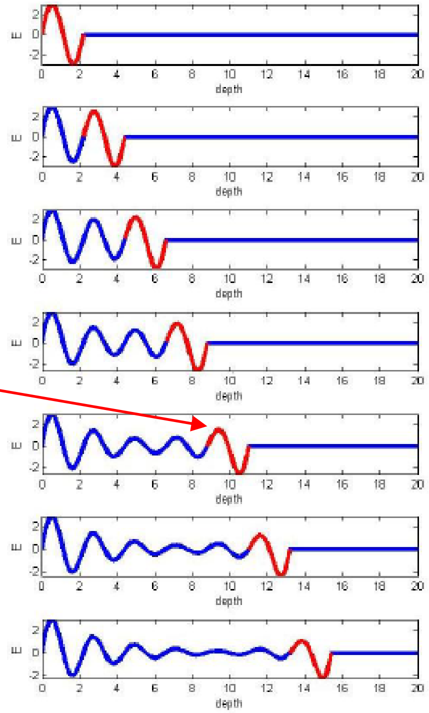
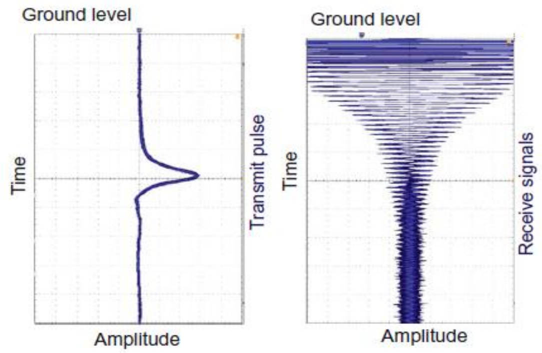


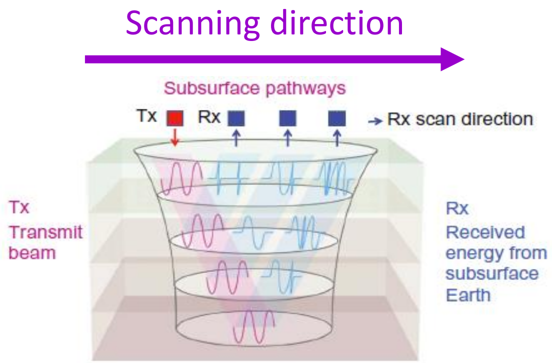
Figure 3: Measured signal amplitudes (mV) after stacking through the 5 paths in the trans illumination experiment. Indicated are the distance *D* through rock and the maximum amplitude *A* received.

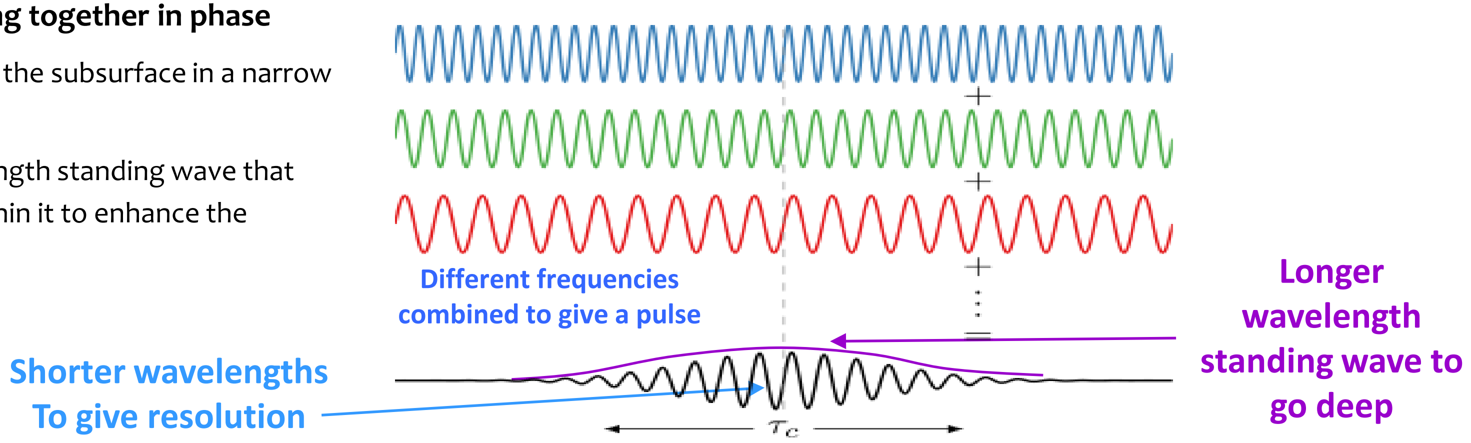
Signal design for depth

- **Adrok has developed a number of approaches to optimise depth penetration**
- **The lower the frequency, the greater the penetration**
- **Conductive losses in soil or mud with free ions is a limiting factor – if you can steer away from these areas you see deeper (also why onshore is the focus)**
- **Attention is focussed on the head of the wave, where the least energy is lost**
- **EM waves of different frequency are combined to form directed packets of energy in a fixed pulse with a fixed phase relationship**
    - Unlike monochromatic lasers, ADR is multi-spectral i.e., "multi-coloured" in the radio wave domain, to capture more response
    - Because it is coherent and multi-spectral, loss of energy to the surroundings is minimised
- **The scanner applies two synchronised waves working together in phase**
    - They are transmitted in confocal rays, illuminating the subsurface in a narrow downward converging cone.
    - The pulses have two components – a long wavelength standing wave that helps to go deep, and shorter resonant waves within it to enhance the vertical resolution









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Other subsurface applications

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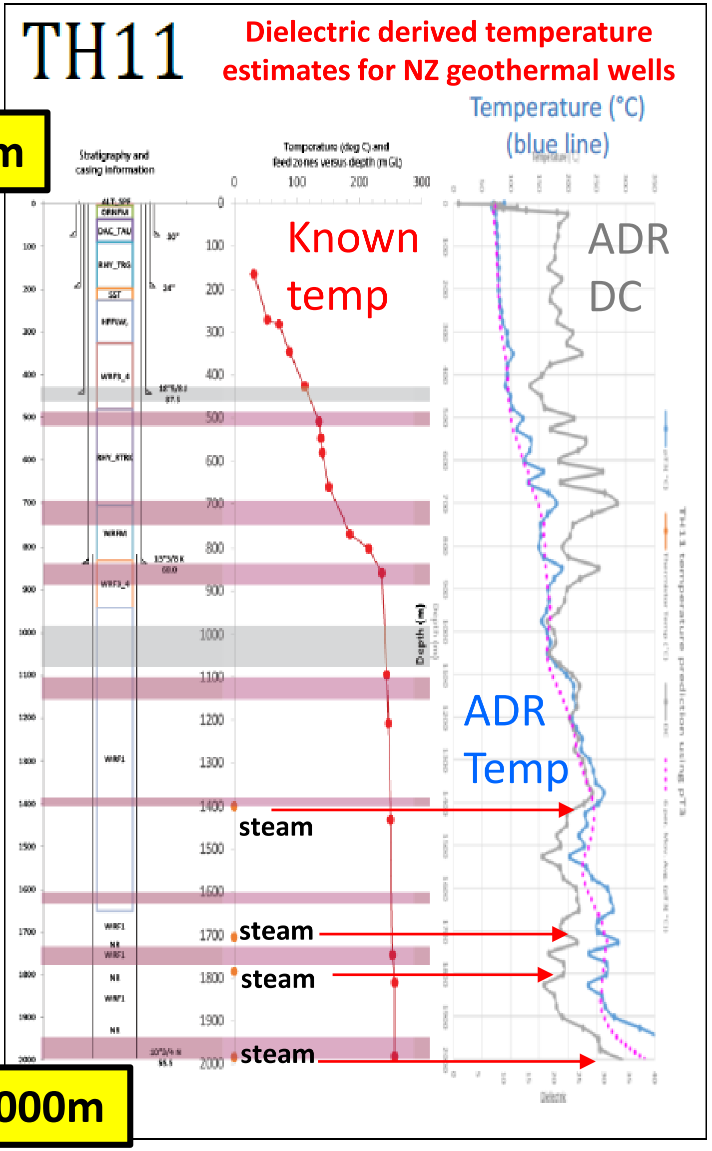
MINERALS

- Iron Sulphide deposits in Australia
- Identification of distinct energy and frequency trends at mineral body interfaces

GEOTHERMAL & HYDROGEOLOGY

- Detection of thick permeable aquifers as per HC – DC sees poroperm water
- DC is a function of temperature
- Steam highlighted in the DC curve



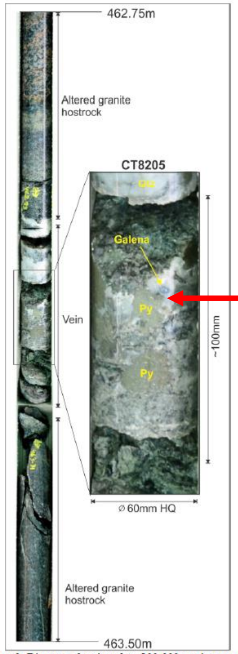


Figure 2. Diagram showing the ~100-200mm intercept in diamond drill hole CT8205 pinpointed by ADR scan A56.

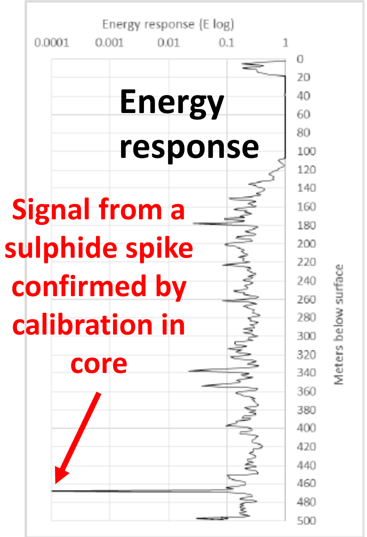
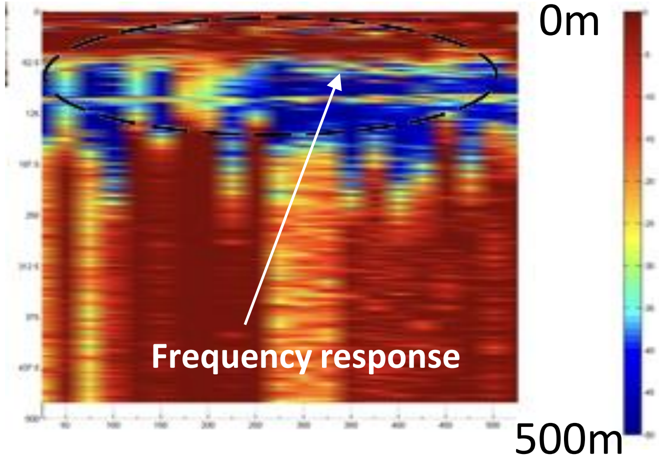
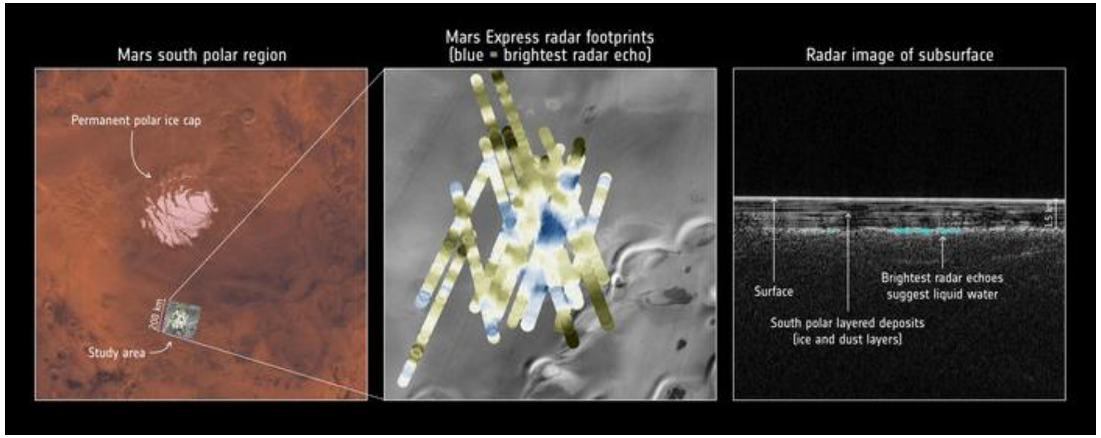


Figure 3. Plot of ADR energy response for scan A56. The anomaly at 462.93m corresponds with a sulfide ore pod contained within the E07 structure.

Sulphide responses from two different Australian deposits

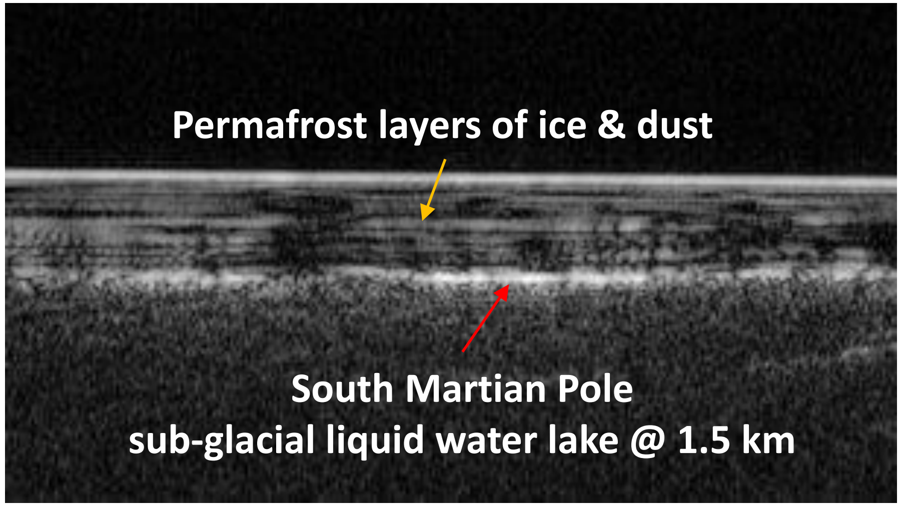


Not the only ones getting deeper



- **Orbitally based planetary exploration is also using radar to see deep geology**
- **But Adrok is taking it to new places, with specially engineered techniques for deep subsurface resource exploration**
- **Undertaken remotely from the ground surface.**
    - ESA's Mars Express has used radar signals to find evidence of a lake of water buried below the south polar cap, using the **Mars Advanced Radar for Subsurface and Ionosphere Sounding instrument**, MARSIS.
    - At bottom right, the bright horizontal feature represents the icy surface of Mars. The south polar layered deposits – layers of ice and dust – are seen to a depth of about 1.5 km. Below is a base layer that in some areas is even much brighter than the surface reflections
    - The reflected signals from the base layer yields properties that correspond to liquid water.
    - The brightest outline a well-defined, 20 km-wide zone.

The tech is for real and increasingly used



0m

1500m

Physical Versatility

- **The tool is back pack portable**
  - Remote locations and difficult terrain, urban or industrial environments, negligible impact
- **Lab calibration of samples**
- **Survey's are effectively point ones, 1D**
  - But sections of a few hundreds of metres from sites can be undertaken, taking it into the realms of 1.5-2D
- **Duration**
  - Field work typically completed in a few weeks
  - Processing takes some months and is the most time consuming aspect
- **Cost is a fraction of wells or seismic**
  - Might not totally replace them, but goal is to help place them much more efficiently.
  - Another arrow in the de-risking quiver

IT'S ALL REMOTE SENSING DONE FROM THE SURFACE – NO NEW HOLE IS NEEDED

2) UK onshore case study

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The Paetoro Role (that's me)

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- **Asked by Adrok to review their results obtained as part of an INNOVATE UK project with a client in three UK onshore basins**
- **Invited as a geologist to suggest workflow improvements**
- **Non-theoretical empirical approach with a geologist hat on – does it respond to geology?**
- **Yes or no...does it do what it says on the tin?**
- **If yes, does it do so reliably enough to facilitate use in a predictive context?**
- Petrophysical assistance from **David Sendra**
- Physics questions – it's involved - I'll deflect those to the experts at Adrok

Assemble, digitise, view

MATLAB coding

Data preparation, CDP interpolation, normalisation, averaging

David Sendra

Petrophysical analysis

Synthetic dielectrics

The Paetoro-refined workflow

ADR-Log-Petrophysics calibration

MATLAB coding

MATLAB coding (work in progress)

Lith Metric calculation

Compilation, "genome" calibration, prediction

Post Mortem, Conclusions, Workflow adjustments

Seeking: Objectivity, Auditability, Repeatability

MATHS more than **EYES**

So clients can verify and check

An honest appraisal, warts and all

What data is recorded?

- **Focus is on 17 different key curves**
- **Many thousands of repeated measurements taken to increase S/N ratio, up to ~ 100 000**
  - The EM world isn't a noise free one…
- **Statistical processing looks at +/-1.5 m intervals or a 3 m window**
- **Resonant energy & frequency of interval (8)**
  - 4 energy curves, EADR (~ Emean/ESD) & Egamma
  - 4 frequency curves FADR (~ Fmean/FSD) & Fgamma
  - ADR = resonant E&F of the interval
  - Gamma = the E&F reflectivity or "shininess"
  - FFT (Fast Fourier Transform) processing
- **Other E & F related logs (6)**
  - ElogA or E% – normalised total energy response
  - WMF – weighted mean frequency – average frequency response for a given depth, weighted towards most energetic responses
  - Correlation logs & their st. dev over ~ 50 m depth and 5 MHz frequency bins, 1-5 and 5-10 MHz the most commonly useful
- **Dielectric Constant curves (2)**
  - NMO DC curve – the dielectric constant is directly related to the velocity and travel time, so can be obtained through NMO processing similar to seismic
  - RAY DC – interpreted dielectric constant curve using ray tracing & NMO independently – (only when both agree is the depth measurement accepted)
- **Band Width Harmonics (1)**
  - Spectral analysis resolves the time domain signal into key resonant frequency harmonic constituents and the number of harmonics is recorded

14 curves related to various aspects of energy and frequency, including reflectivity and statistical analysis of the repeated measurements

2 curves directly and independently estimating the dielectric constant

1 curve counting the number of harmonics present in the resonant frequency response

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Uniqueness & lack of

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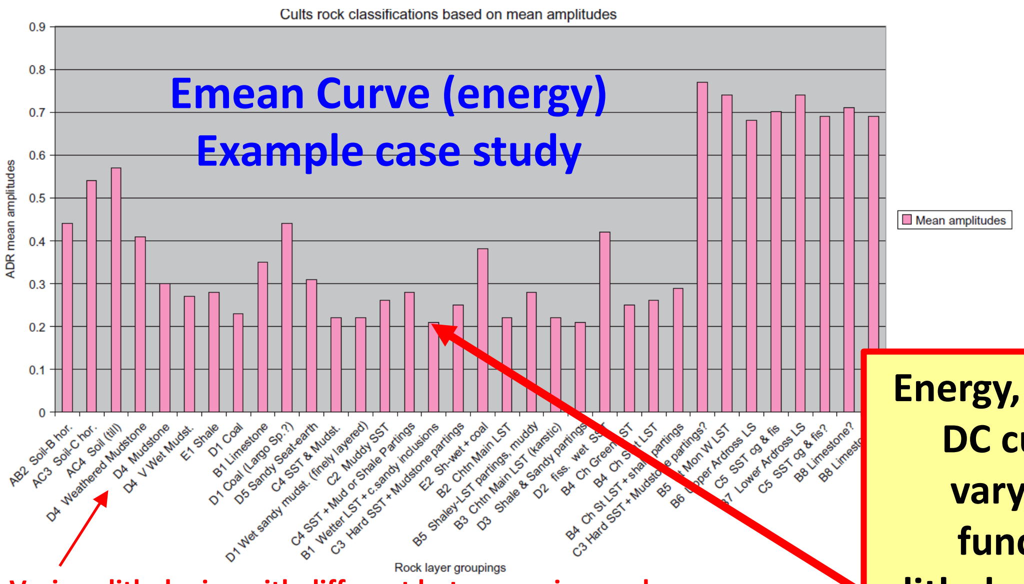
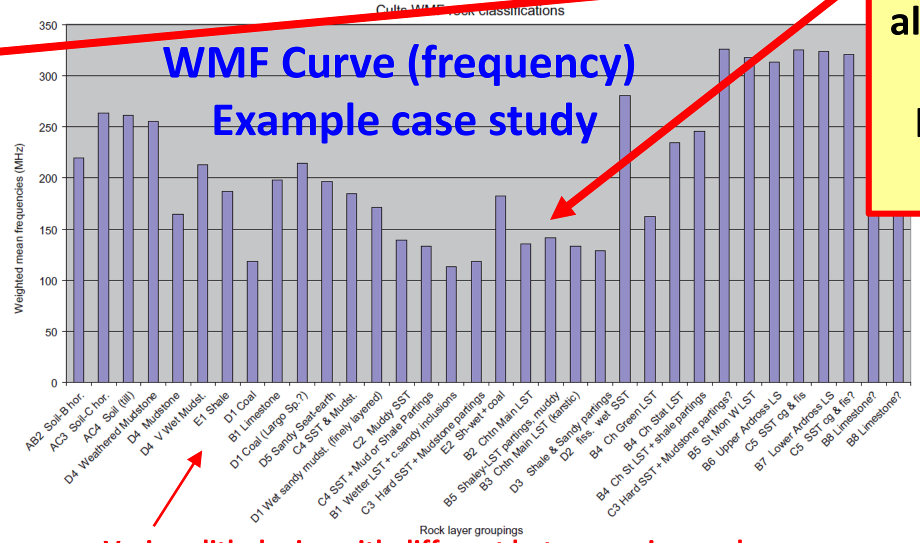
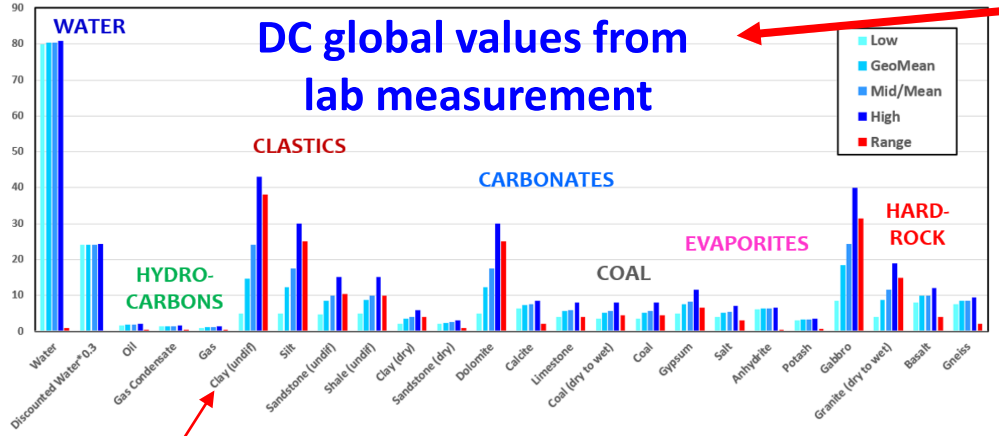
- Any individual parameter from those 17 curves will vary according to composition/lithology
- One parameter alone won’t be always be unique enough to unambiguously identify a lithology
- So we need to use the curve *combinations* to help build uniqueness
- And local well calibration/stratigraphic knowledge



Various lithologies with different but non-unique values



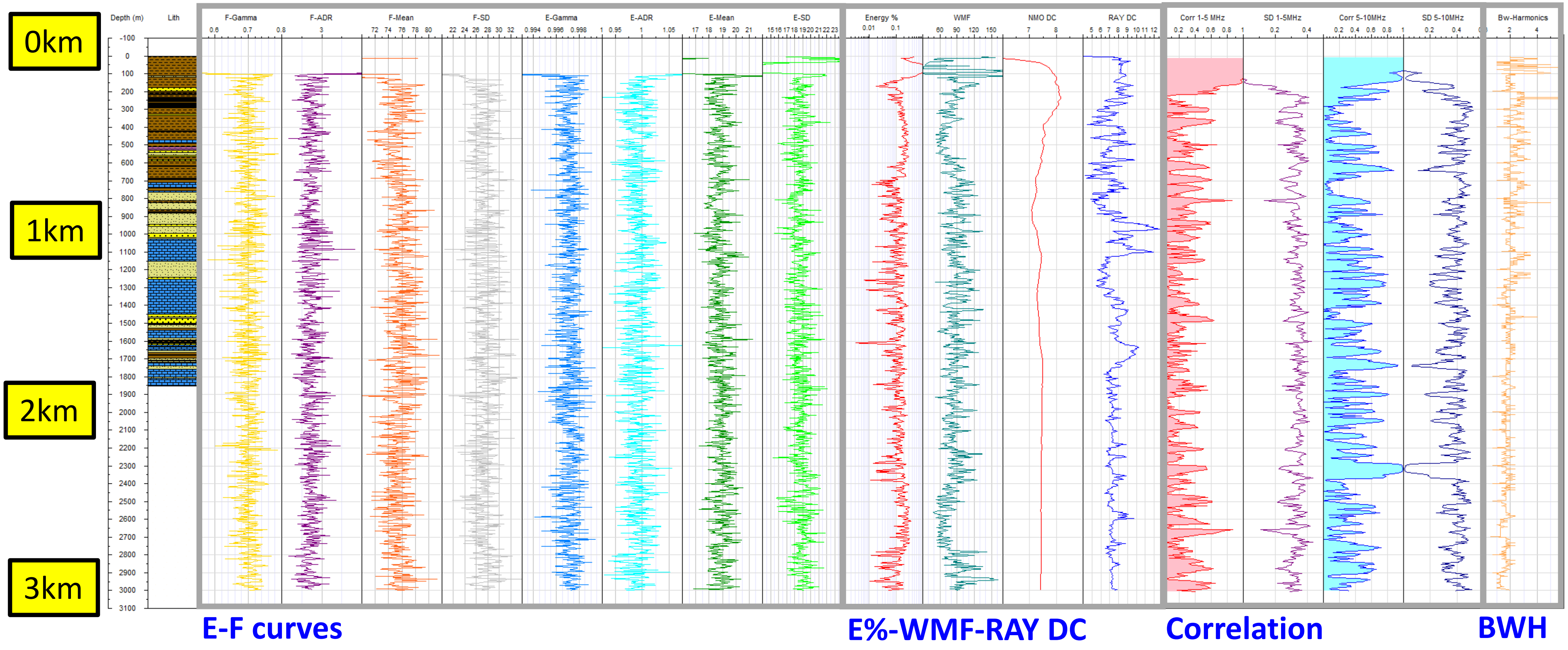
Various lithologies with different but non-unique values



Various lithologies with different but non-unique values

Energy, frequency, DC curves all varying as a function of lithology, but not always with *unique* values for each lithology for any one curve

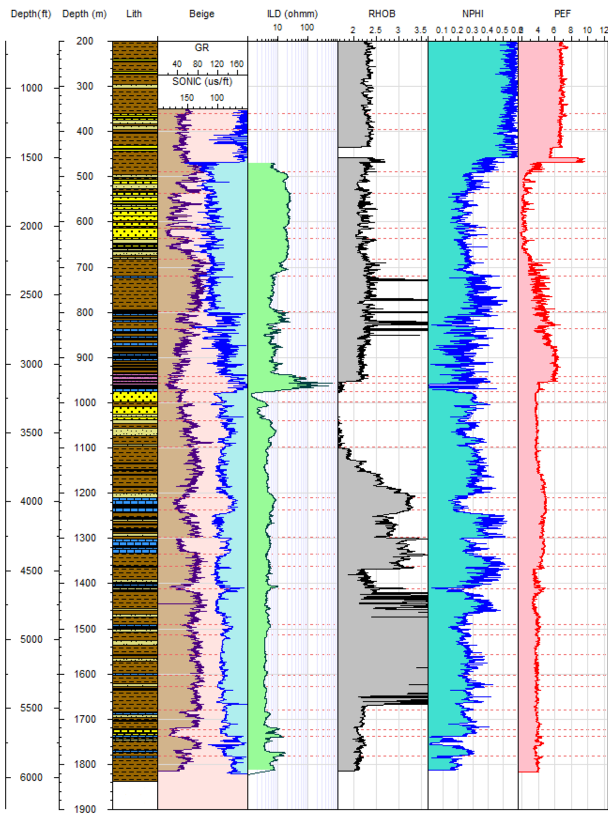
What the raw data looks like



- Managing expectations – it's not like a GR – it's not going to tell you everything at a glance
- E%, WMF, RAY DC, Fgamma, probably hold the most direct relation to lithology...
- ...but interpretation and analysis takes a detailed look at ALL the log responses, in calibration with local info

The ability to calibrate

200m



1900m

Log data & Interp Lith

Petrophysics

ADR data

- **The tool can be taken very close to a historical well site, and data acquired, for comparison with historically acquired logs and associated petrophysical interpretation.**
- **Important to base calibration on continuously varying log and petrophysical curves and not just a discrete and subjective interpreted lithology – nature isn't like that – it is gradational.**

The ability to calibrate

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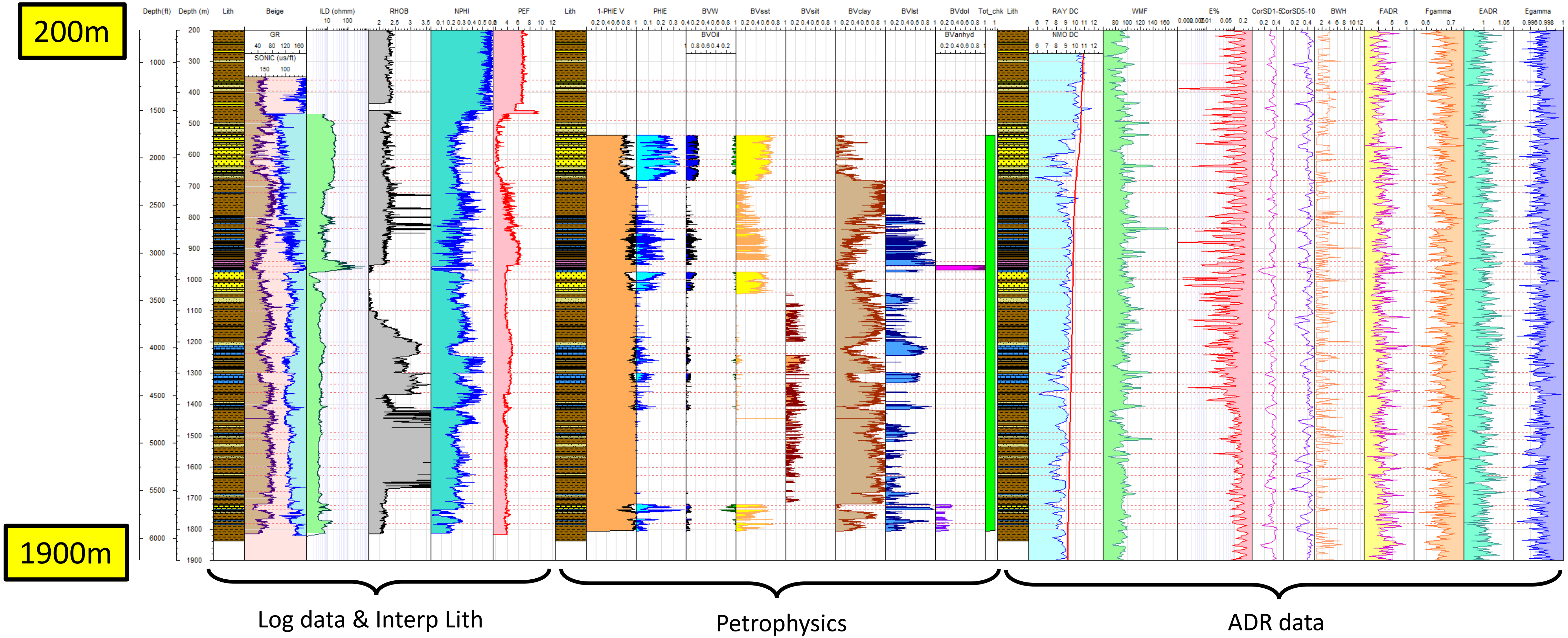

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What to expect, compare & contrast: dielectric forward modelling

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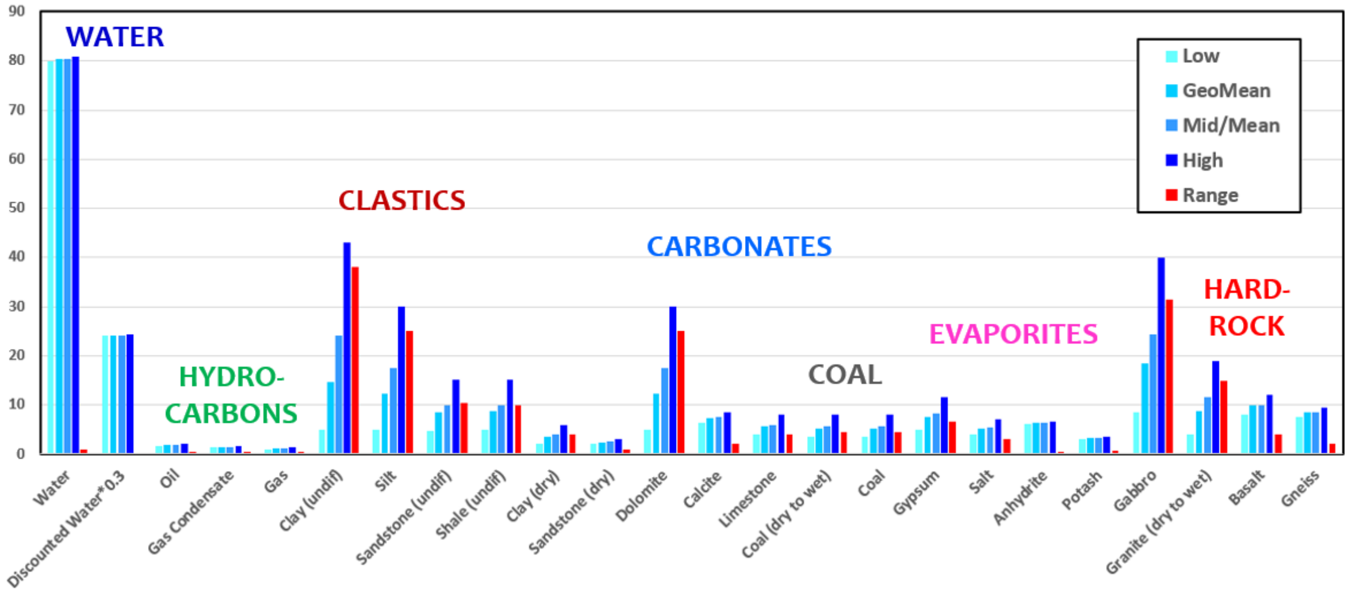
- We already know theoretical ranges of the dielectric constant for various minerals & fluids
- Many lab experiments in published literature
- This allows us to model the dielectric constant of a lithological mixture from calibrating well petrophysics, according to defined rules & assumptions (e.g. Martinez and Byrne 2001)
- Not trivial – still evolving this process
- But it can serve to highlight the main contrasts we are likely to see
- All this ahead of, and independently of, any ADR data acquisition
- i.e. pre-acquisition feasibility and post-acquisition QC studies



What to expect, compare & contrast: dielectric constant (DC) forward modelling

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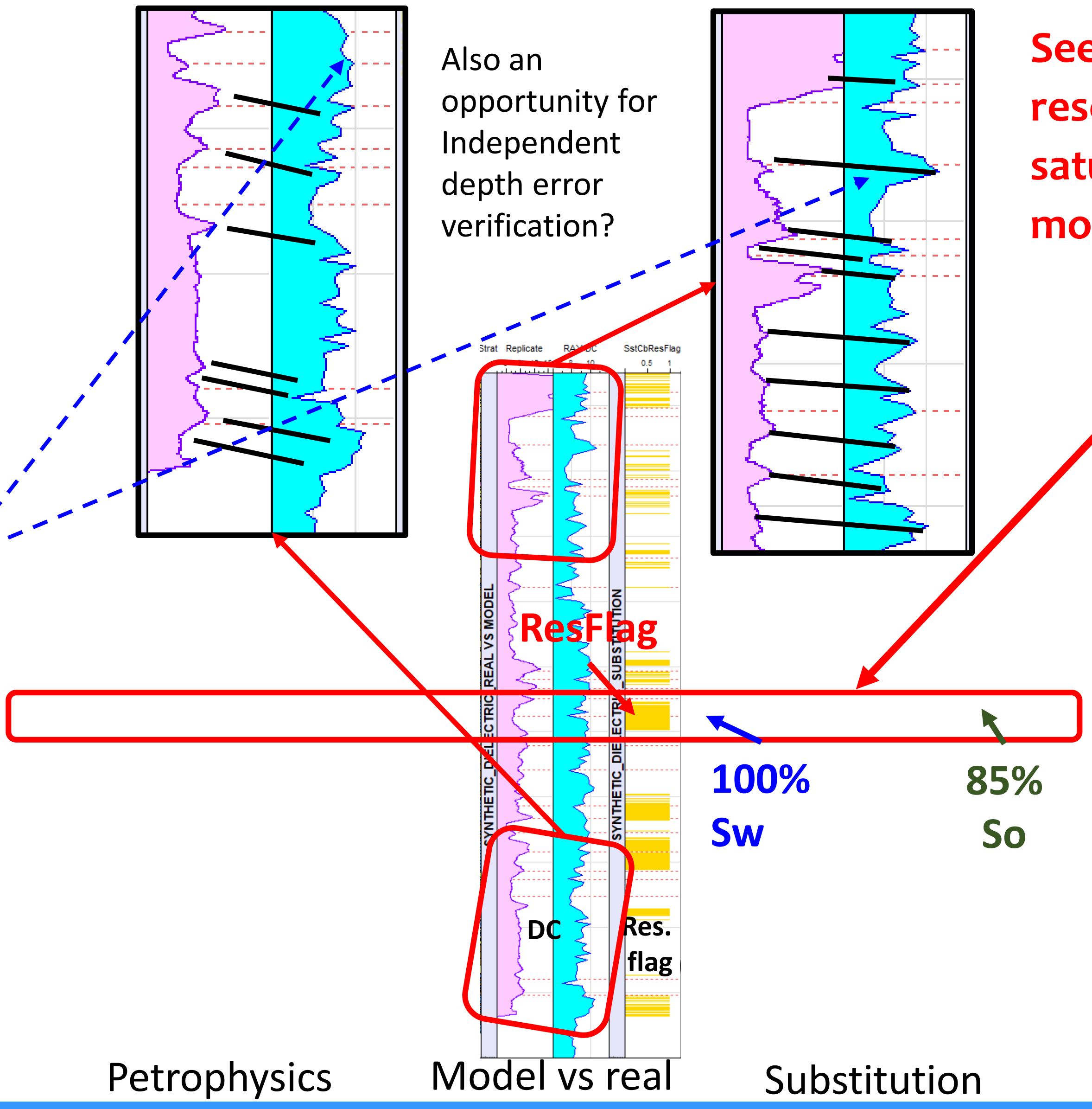
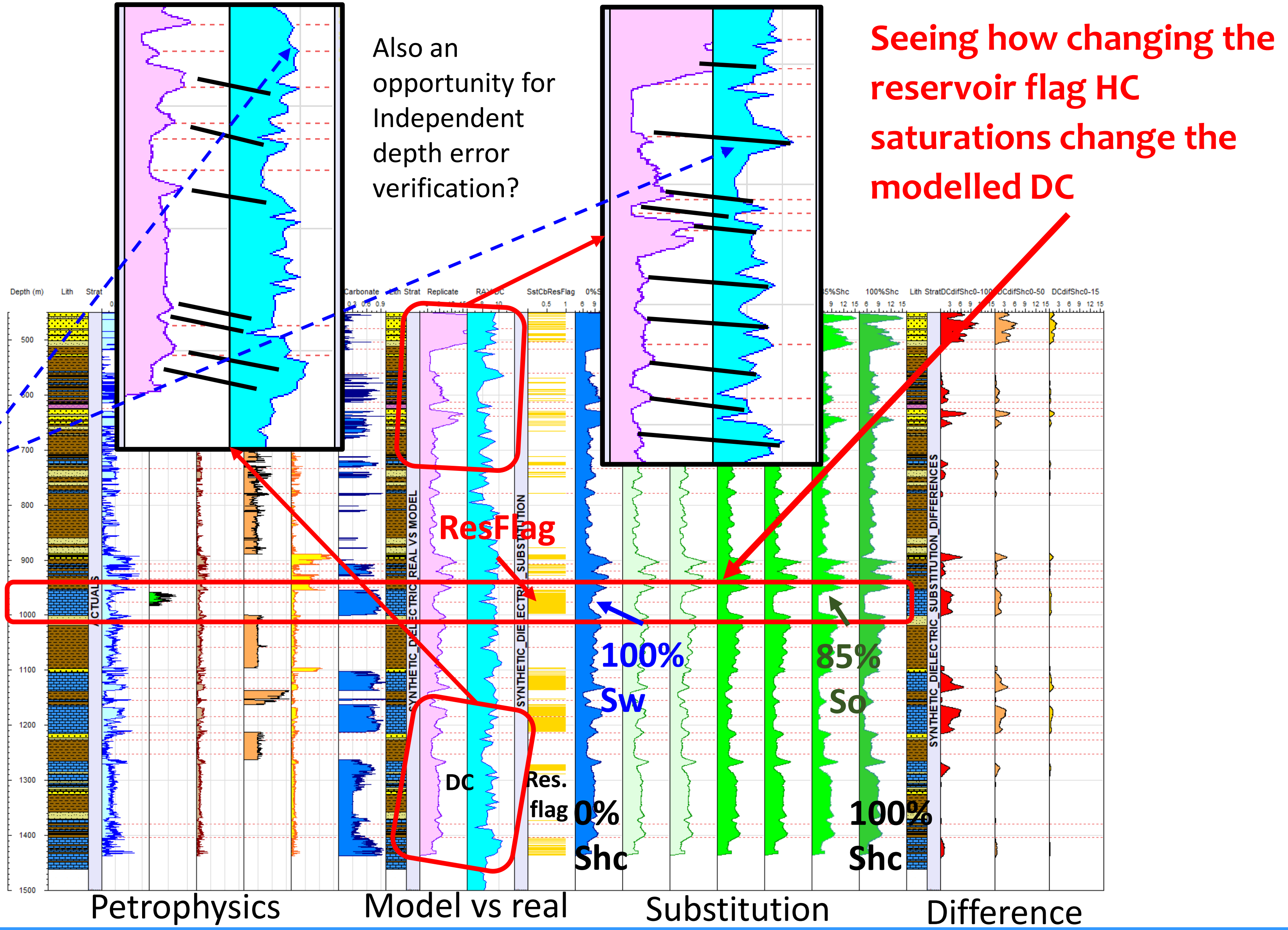
- Early results suggest forward modelling does have some success replicating gross form of the DC
- A decent match gives independent verification the tool is seeing real stuff at depth
- Where the match is decent, it can also provide independent estimate of any depth error
- Sometimes things are just different or much more dramatic than the modelled DC –understanding this better is a work in progress
- Not too stressed by that – early days
- But sufficient encouragement to develop workflows further
- We can also forward model the dielectric effect of HC saturation with reservoir fluid substitution
- To help recognise HC indicators we are looking for at those levels



Seeing how changing the reservoir flag HC saturations change the modelled DC

What to expect, compare & contrast: dielectric constant (DC) forward modelling

- Early results suggest forward modelling does have some success replicating gross form of the DC
- A decent match gives independent verification the tool is seeing real stuff at depth
- Where the match is decent, it can also provide independent estimate of any depth error
- Sometimes things are just different or much more dramatic than the modelled DC –understanding this better is a work in progress
- Not too stressed by that – early days
- But sufficient encouragement to develop workflows further
- We can also forward model the dielectric effect of HC saturation with reservoir fluid substitution
- To help recognise HC indicators we are looking for at those levels



Utilising the calibration – Lith metrics

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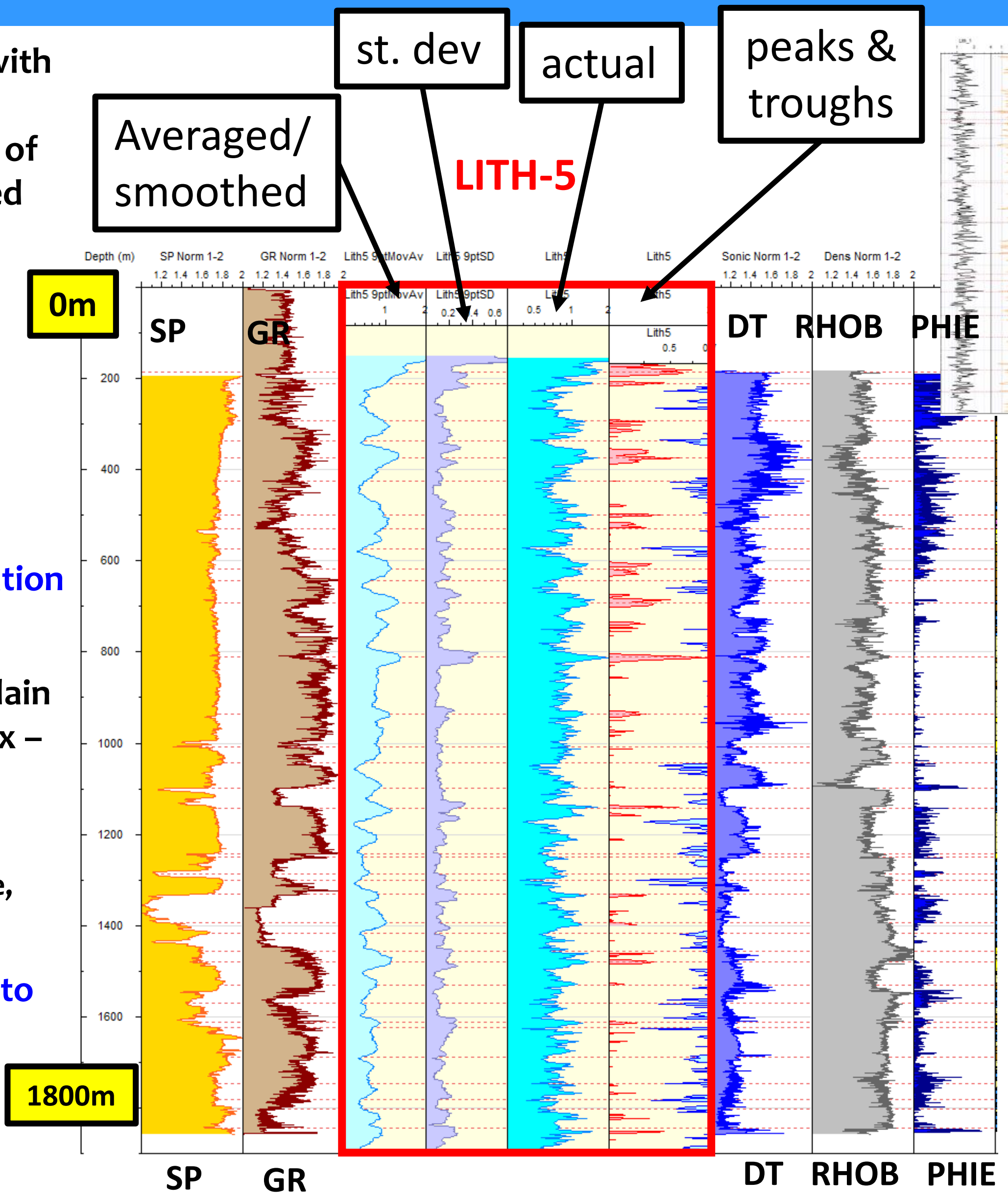
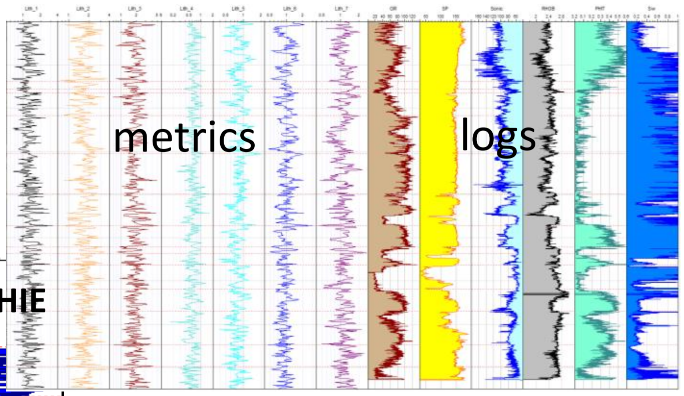
- **From empirical calibration with lithology can design mathematical combinations of curve to accentuate observed responses – “lith-metrics”**
- **Not diagnostic, just a guide**
- **Good news: Many (not all) peaks and trough responses coincide with geological contrasts**
- **Beware the spurious correlation**
- **Bad news: not always a systematic relationship to plain lithology – it’s more complex – recall:**
  - **Atomic level responses**
  - **Chemistry, microstructure, thickness of the barrier**
- **This means local calibration to stratigraphy is required**
- **Means it’s good to have a variety of different metrics**





Where metric and log curves responses coincide: good L5 peak, good L5 trough, other L5 possible, no match

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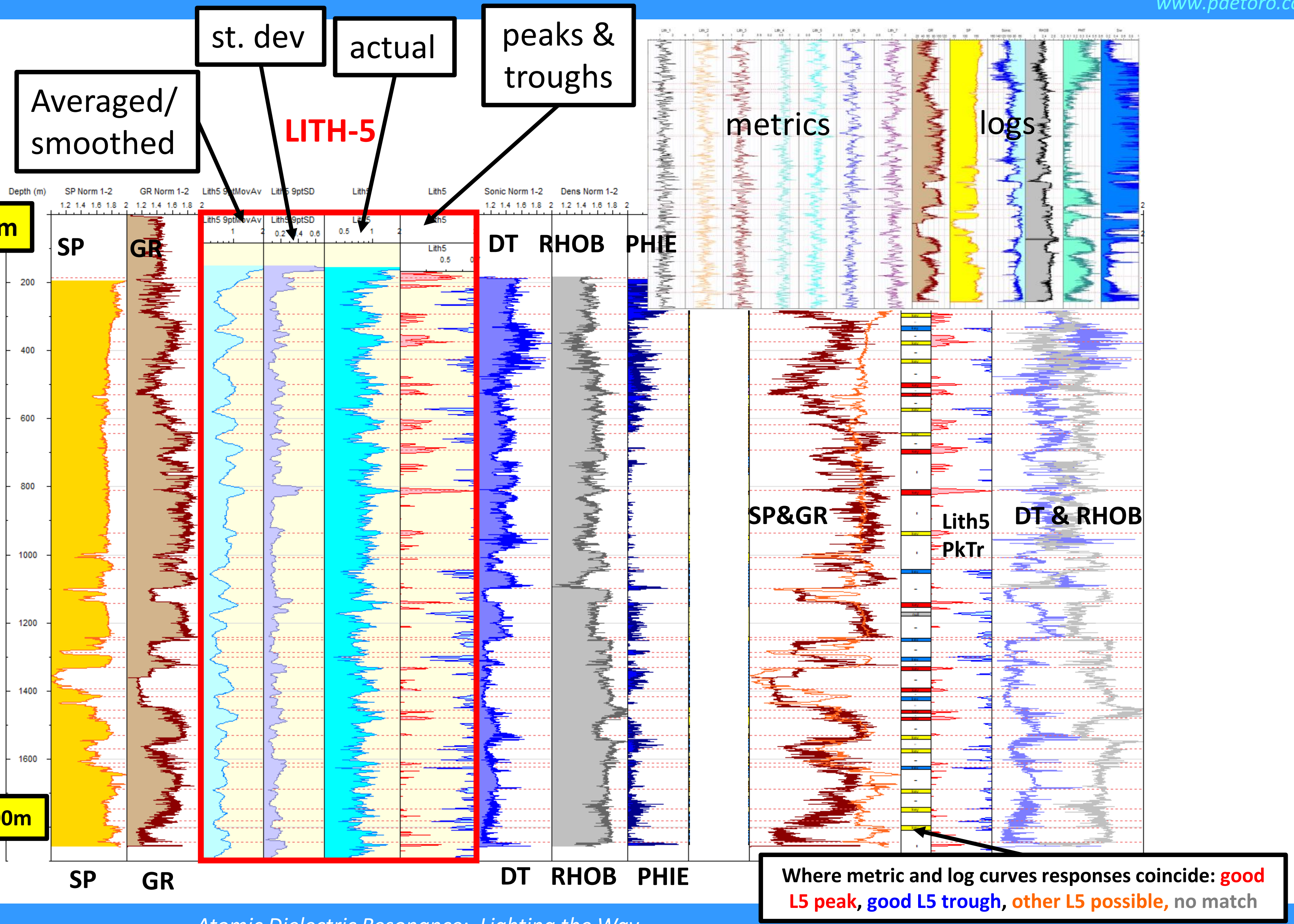
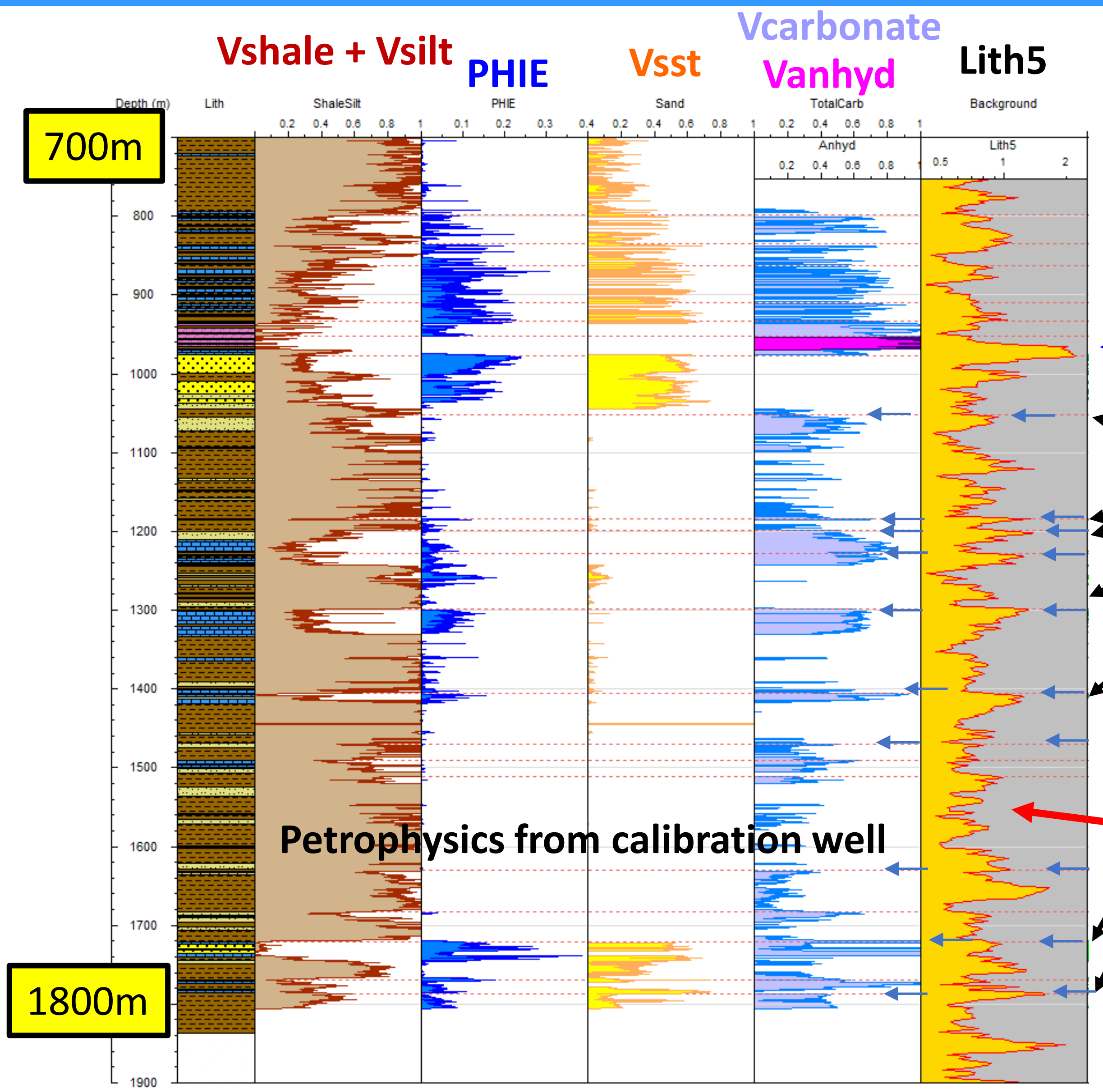


Seeing the geology



- **In some wells a response to lithology is clearly apparent**

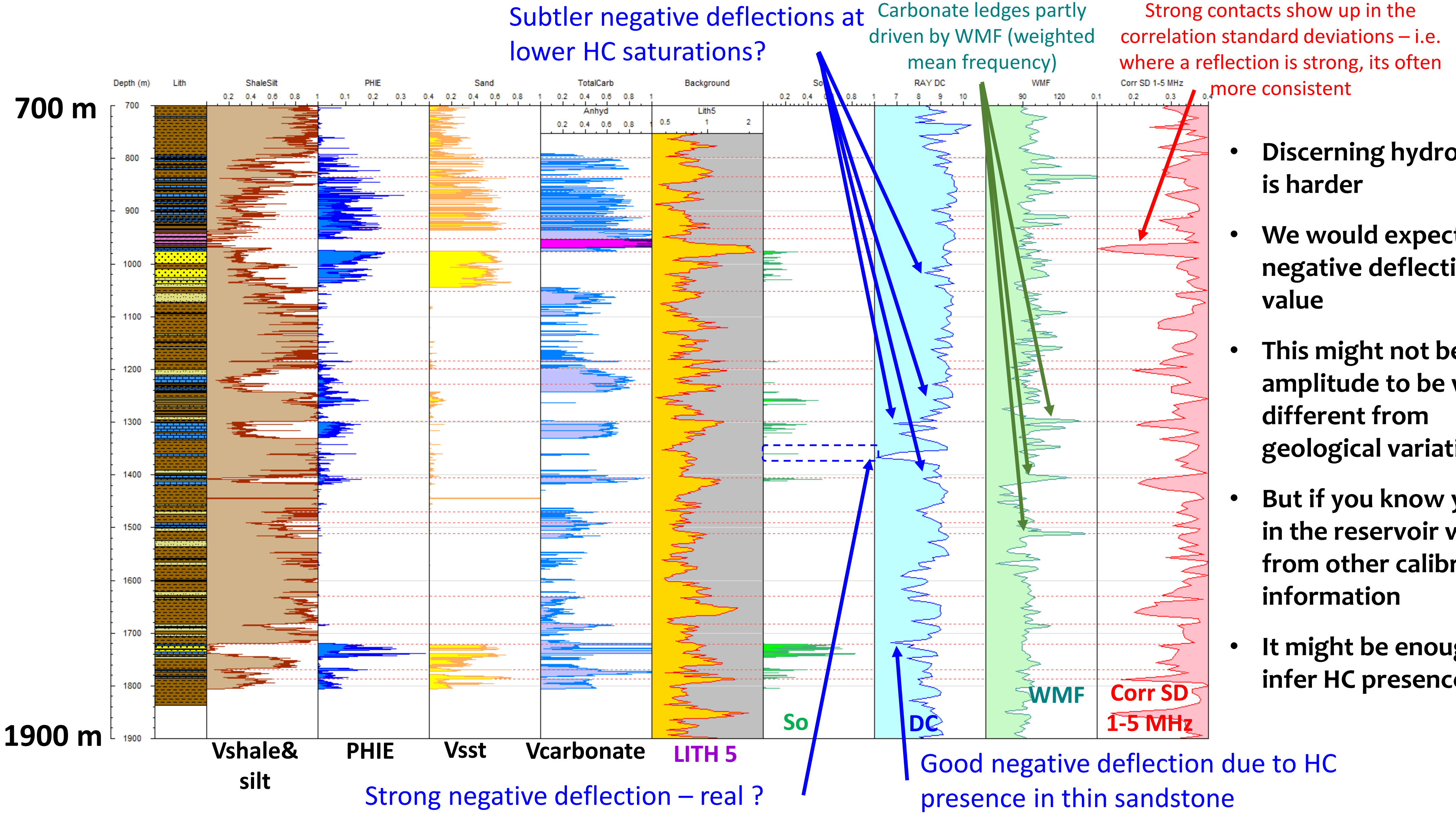
Big peak at a strong anhydrite-limestone/sandstone poroperm contrast

Carbonate "ledges"

ADR derived lith metric

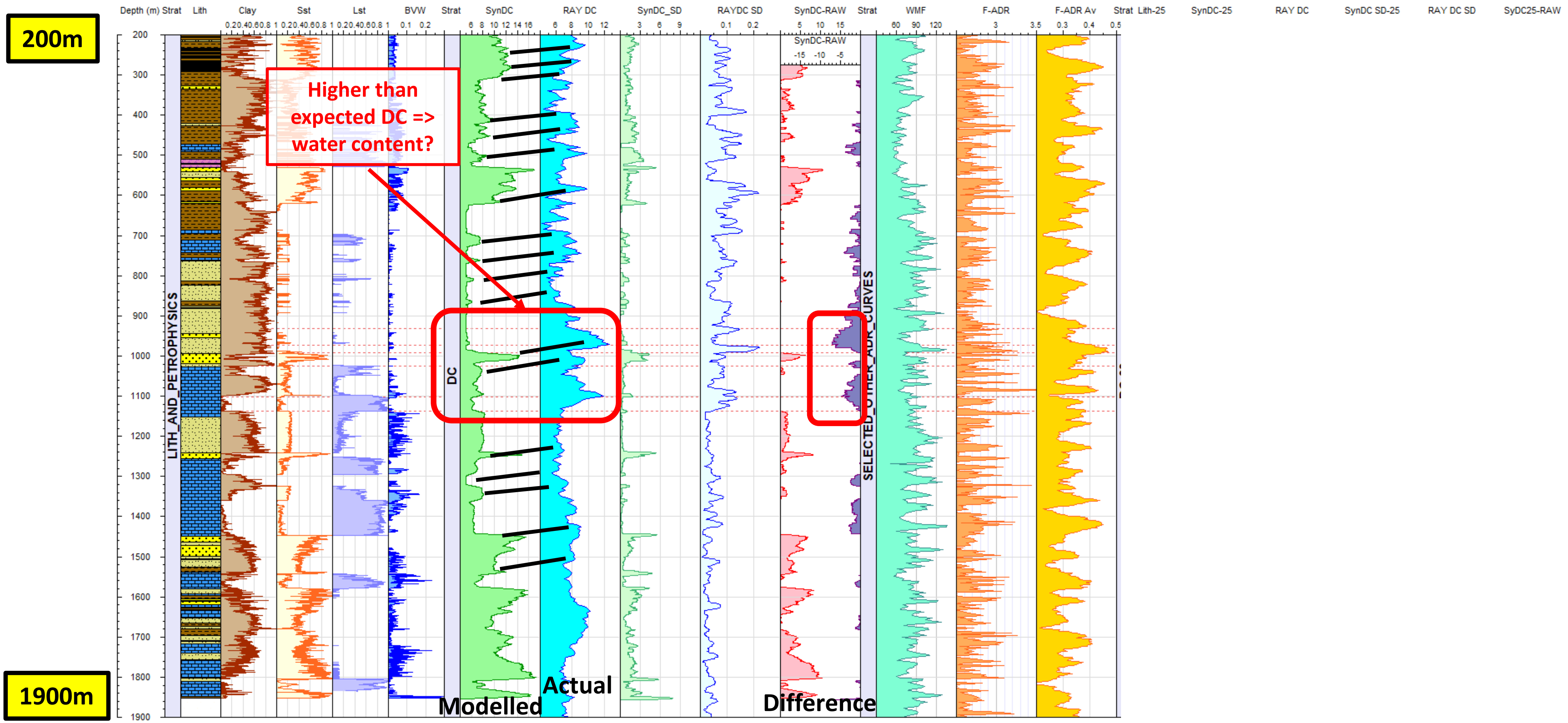
Notice also lack of appreciable depth error here

Seeing the hydrocarbons



- **Discerning hydrocarbons is harder**
- **We would expect a negative deflection in DC value**
- **This might not be of an amplitude to be very different from geological variations**
- **But if you know you are in the reservoir vicinity from other calibrating information**
- **It might be enough to infer HC presence**

The things we just can't explain



- Sometimes get blips hard to explain
- These two happen to roughly coincide with two good hydrocarbon bearing reservoirs in the area – coincidence?
- Could it be production related water front migration between log and ADR acquisition? – discussions with operator seem to rule that out
- 25 m depth error? – perhaps related to ADR acquisition a bit offset from the well – but even so the blips remain anomalous

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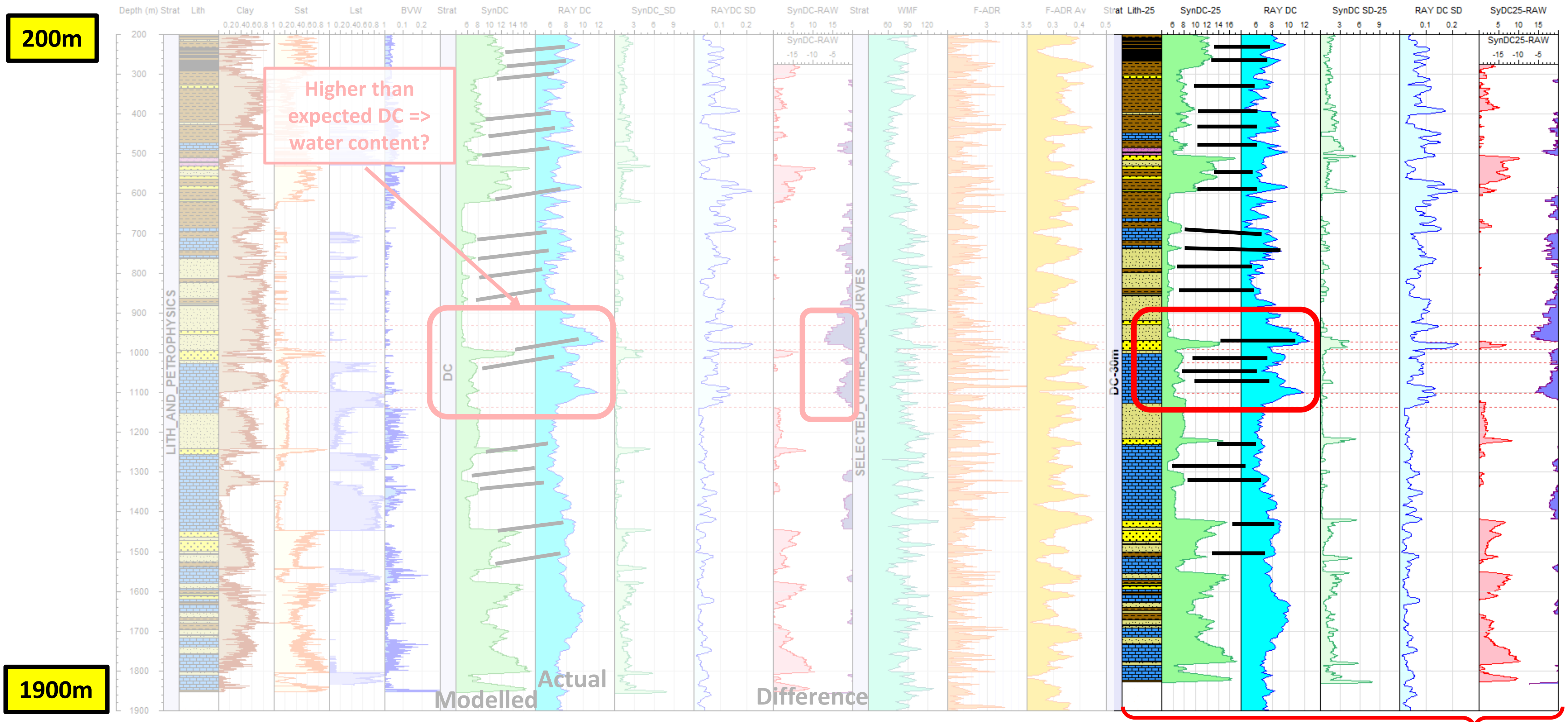

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The things we just can't explain

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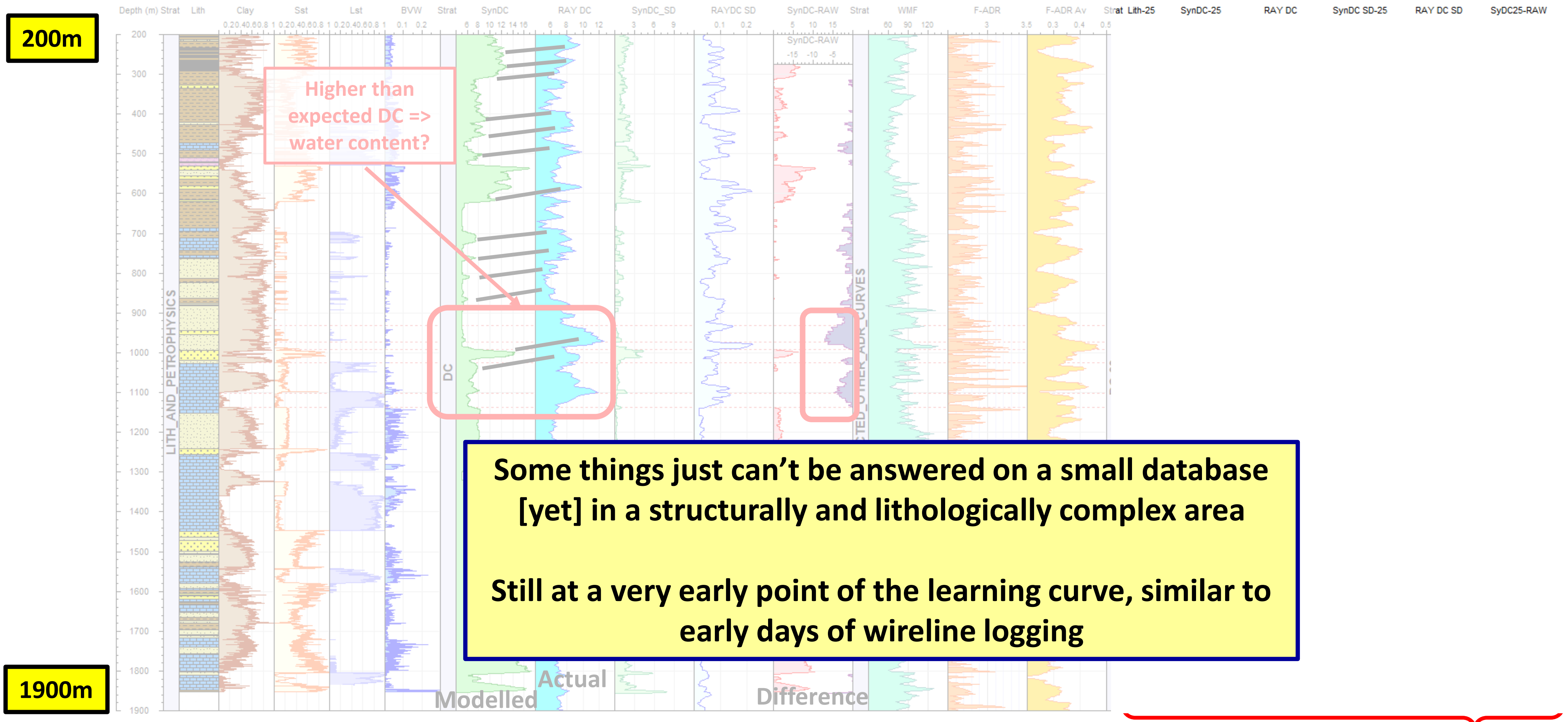

Some things just can't be answered on a small database [yet] in a structurally and lithologically complex area

Still at a very early point of the learning curve, similar to early days of wireline logging

Version with – 25 m depth correction

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An ADR stratigraphic "genome"

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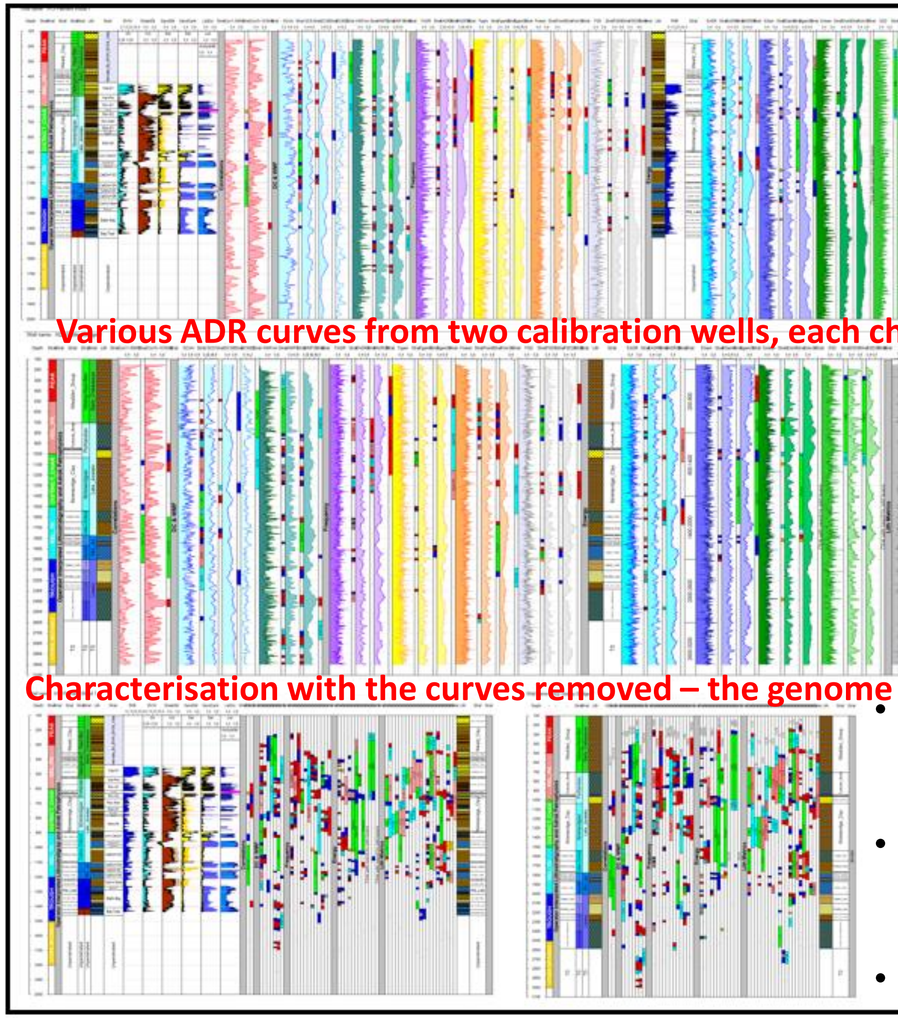
- *We don't need to fully understand a geophysical response, to use it* empirically for calibration...
- ...as long as it is consistent
- Understanding helps – but it can come second – like seismic – don't need to know *why* we have a response to map it
- If you have two calibration wells, you can see what character of responses they have in common at various points of the stratigraphy
- And for every ADR curve build a shared ADR "genome" for that lithostratigraphy and well pair
- Provides a reference framework for application at new sites
- For now, qualitative and subjective, but perhaps ways of making it more mathematical, objective – e.g. AI



- Look at the character of each curve for each well in a pair
- See what aspects they share at various points in the stratigraphy
- Create a genome

Well 1

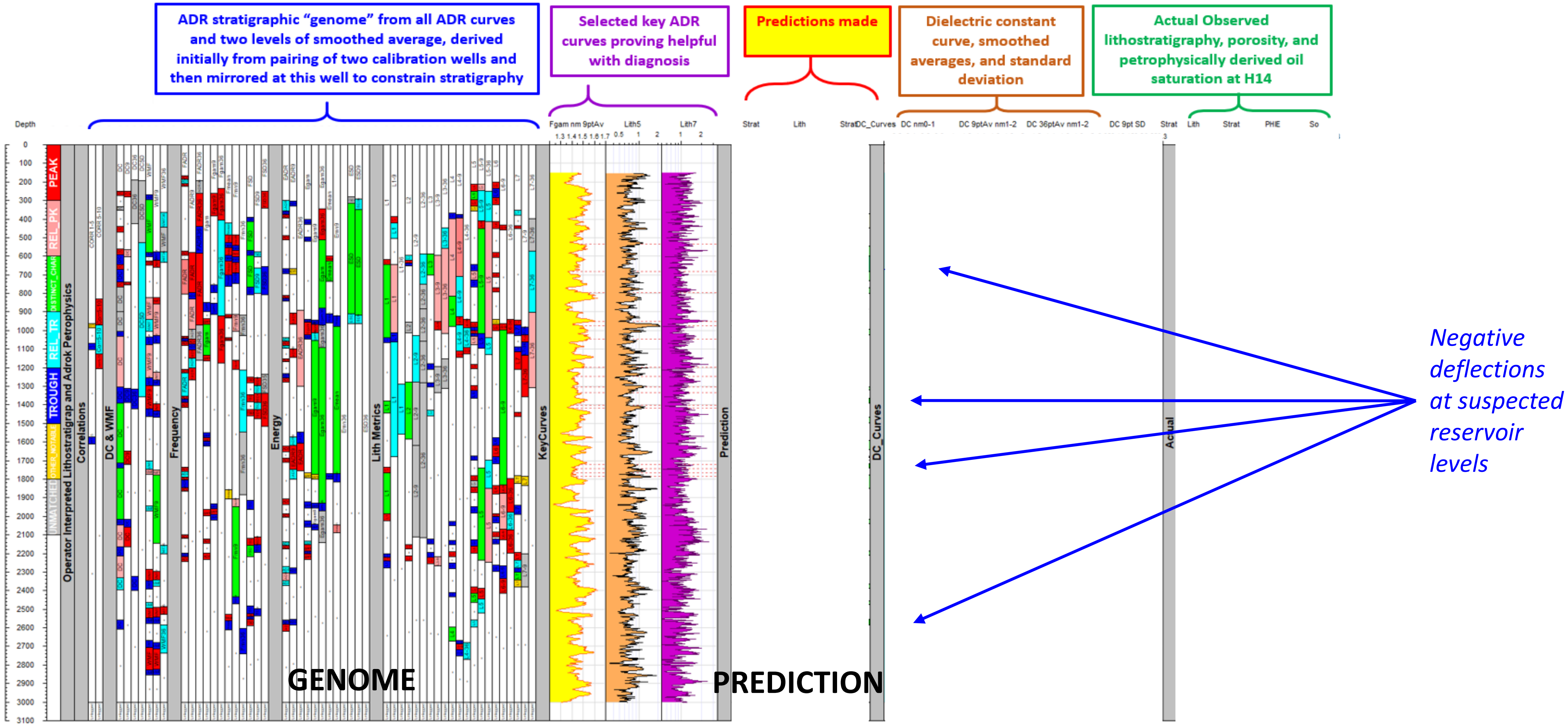
Well 2

Condensed versions of well 1 & 2 with curves removed and just the similar "genome" left

UNMATCHED	OTHER_NOTABLE	TROUGH	REL_TR	DISTINCT_CHAR	REL_PK	PEAK

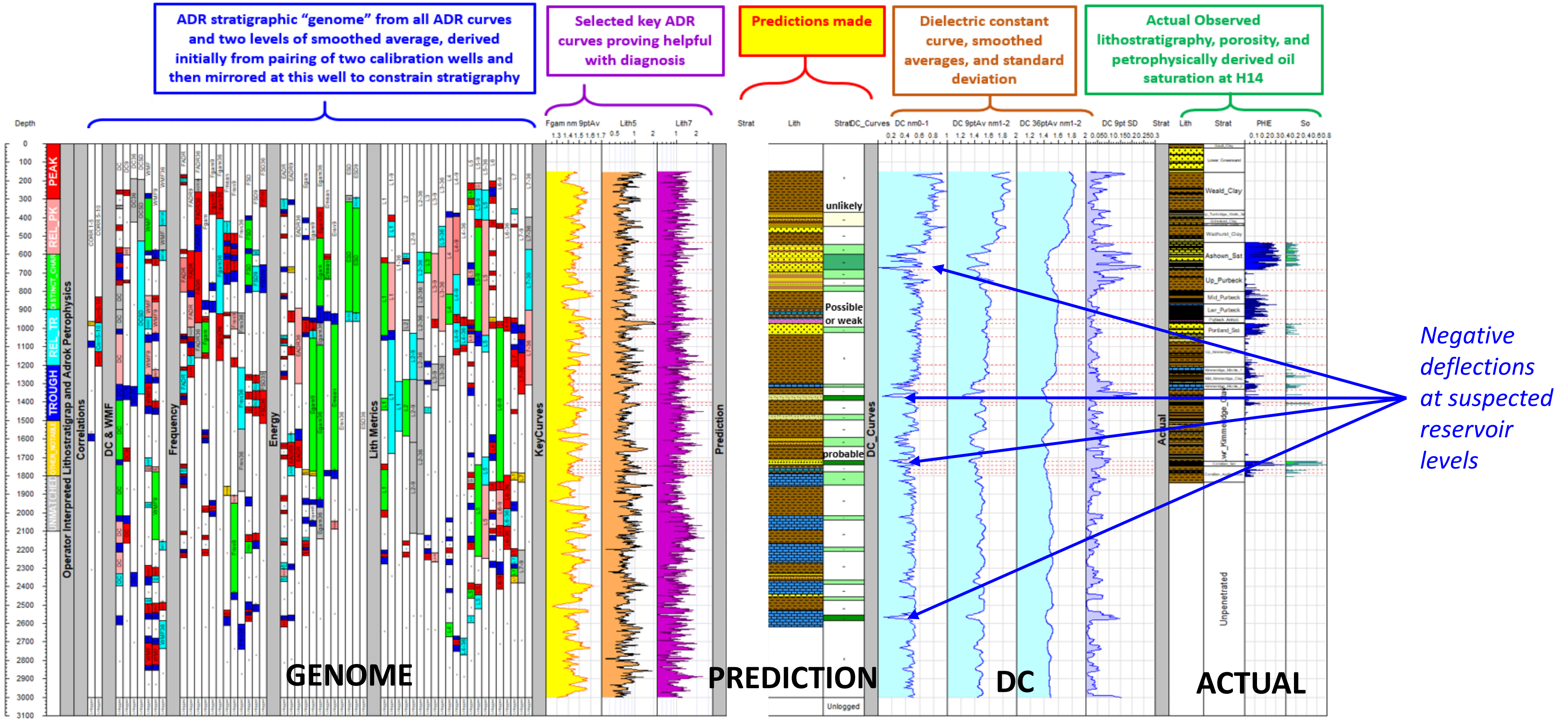
stratigraphic response character types matched between well pairs

Prediction



- Using this "genome" anchors a new well in the local stratigraphy, allowing a framework stratigraphic prediction
- The dielectric constant can then be examined for negative deflections to assess for likelihood of HC presence in that reservoir, with extra guidance provided by the dielectric modelling & associated fluid substitutions

Prediction



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Case study implications

- Subsurface geology is being seen by the ADR techniques.
- Not *all* subsurface geology is.
- Detection is best where there are strong poroperm and fluid saturation contrasts. I.e. it readily sees high water content.
- Purely lithological changes are sometimes discernible, but in a sedimentary basin context are typically non-unique and can require careful local calibrations to progress.
- Forward modelling of relative permittivity (dielectric constant) can provide advance indication of what should be detected, and assist with stratigraphic placement of ADR results.
- Detecting hydrocarbons in a known reservoir using the dielectric response alone is trickier, but also feasible, and the higher the saturation the easier it is.
- Complex or poorly-calibrated geology, stratigraphic variability, low HC saturations, old and sparse calibrating logs, aren't show stoppers, but will hamper interpretations.
- Simpler situations with less structural and lithological variability are most helpful (initially) for ongoing verification and use in a petroleum basin context.

Adrok

3) The Future

★Data processing – possible advances

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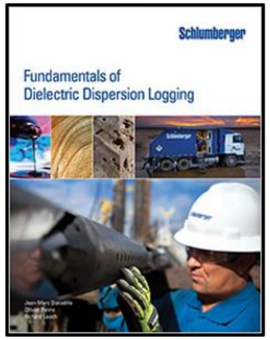
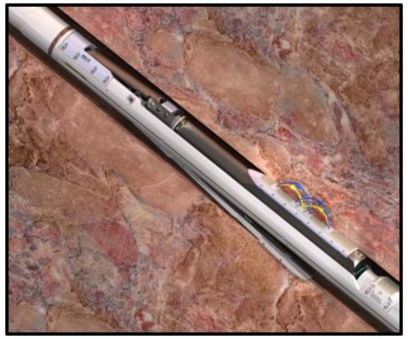
- **Downhole calibration**
  - Ability to calibrate much more closely with real downhole assessment
  - Several big logging companies have a dielectric tool and Adrok are designing their own
  - Will help understand detail of signal propagation in porous rocks via direct comparison of distal versus proximal sensing
- **Qemscanning Calibration?**
  - **Q**uantitative **E**valuation of **M**inerals by **SCAN**ning electron microscope
  - Understanding the dielectric detail of rock mixtures further in lab calibration of samples
- **Deep/Machine learning etc**
  - **Pattern recognition from multiple data sets & theoretical constraints:**
    - 17 raw logs
    - Numerical combinations of the above to derive metrics
    - Calibration with well logs and lab samples
    - Calibration with petrophysics
    - Calibration with any downhole dielectric tool
    - Calibration with regional stratigraphic and seismic
    - Theoretical models of expectation
  - **Seems a good problem for AI techniques**

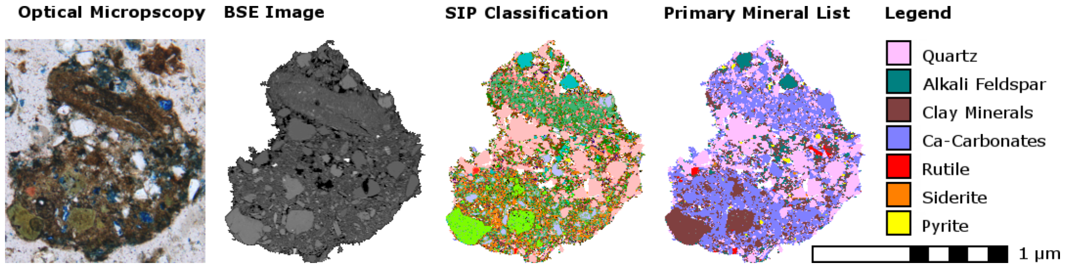
Schlumberger



Baker Hughes

Haliburton





Applying the learnings

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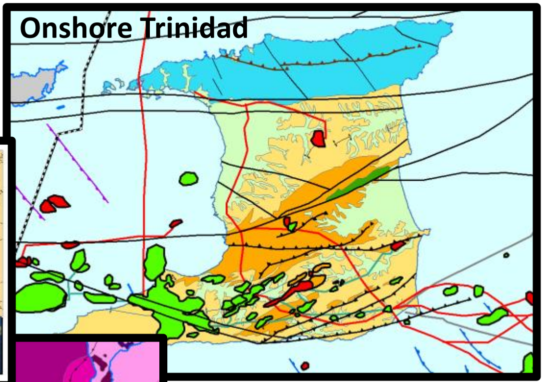
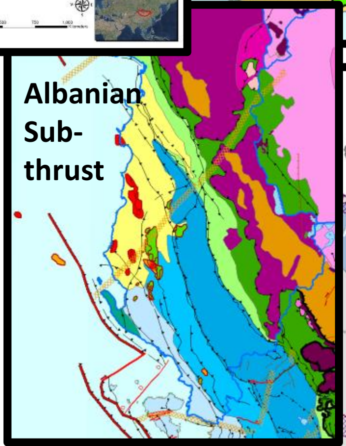
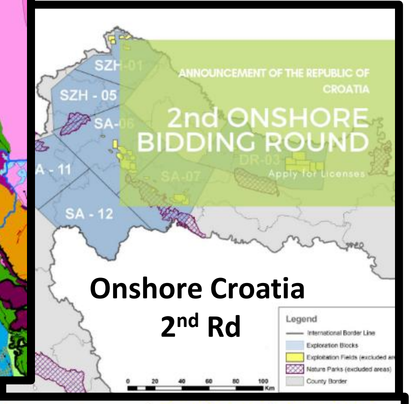
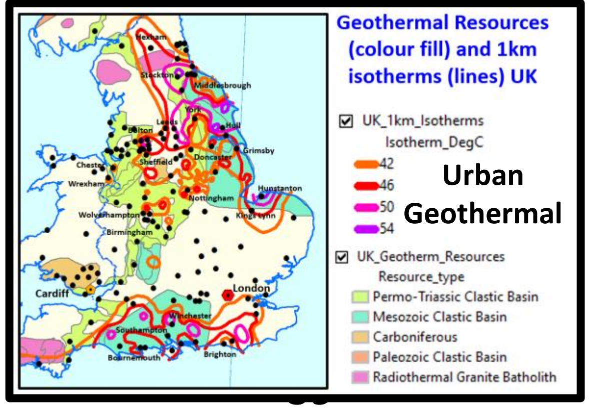
- **Production & EOR : water front propagation due to production & injection**
- **Working onshore where lithological variations are limited, so effects of fluid saturation are more easily distinguishable from lithology**
  - **sand/shale sequences – deltaic and turbiditic environments**
    - E.g., Pannonian Basin, Trinidad
  - **marine carbonate-shale sequences**
    - E.g. Middle East
  - **Base evaporite contrasts – perhaps for detection of sub-evaporite carbonate & clastic traps in thrust belts**
    - E.g., Albania, Zagros
- **Working where a good density of calibrating well information is available**
  - true of most onshore basins these days anyway, more modern log data better
- **Targets involving a significant thickness (>5 m) and strong poroperm contrast**
  - This is generally a desirable feature in geothermal, hydrogeological, and hydrocarbon reservoirs anyway
- **Where access via other techniques is limited**
  - Urban, industrial, remote, rugged environments
  - Here the value of information provided by ADR is increased
- **Where hard rock mineralisation is targeted**
  - In these lithologically "drier" environments, changes due to lithology, and particularly minerals with diagnostic dielectric constants like sulphides, will be more prominent



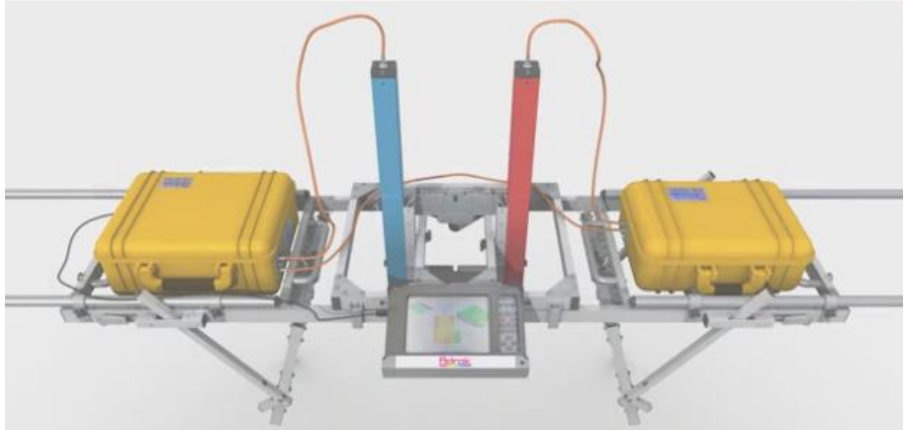


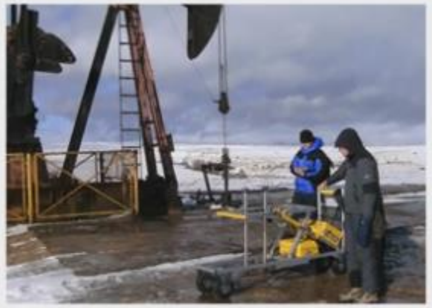




Closing comment

- Young technology still under development and nobody is pretending everything is understood – the physics is involved
- Non-uniqueness of subsurface responses can be an issue, and it doesn't see everything – strong dielectric contrast is needed
- Yet with a backpack portable surface tool, some geological contrasts are being detected to verifiable depths of at least 2 km, probably more, and apparently with m-scale resolution
- If that doesn't prick our ears up as geoscientists, we probably aren't thinking about it hard enough.
- With calibration - getting better at predicting in advance the contrasts it will see
- It might not replace onshore seismic or drilling totally but it can help place those things more sensibly before the serious spend starts
- A new cost-saving technology in the de-risking arsenal - especially where terrain, infrastructure, or population density hinders other subsurface techniques like seismic
- Applications for almost any subsurface resource. The time seems ripe to deploy more widely, increasing understanding of the tool
- Does it work everywhere, all the time? Nope? Is it perfected now? Nope. Is EM noise a challenge? Yes. Does it puzzle still? Yes.
- But where mankind sees that sometimes something does work – as a species we have a good track record of refining & bettering that in our service.





Where was the first wireline was one hundred years ago?
Perhaps the scope for advance is comparable.
No guarantees, but let's find out.

Any questions?

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We don't bite

(normally)

More info at:

https://adrokgroup.com

The questions: presenter's summary

Fair to say robust discussion was had. The highest priority questions arising I think can be summarised as:

- Repeatability
  - demonstrating the response can be repeated at different times, different seasons - signal to noise compensations are most effective if done over a time that captures different noise conditions
- The detail of the physics
  - my role thus far has been mainly as an empirical observer - i.e. is there a response to geology - but clearly there is (rightly) a thirst to understand fully the physics of how things can be possible, be that in a Maxwellian or a Quantum realm - especially how can shorter wavelength be maintained for resolution at depth given attenuation etc
- Curve similarity
  - when comparing curves, such comparison needs to be demonstrated mathematically with statistical tests to ensure that our own positive interpretation bias is not at play

These are questions I accept the validity of wholeheartedly and look forward to addressing in further review.

Adrok has more information on some of them on their website, but the need to communicate these further, for vigorous peer review is recognised and welcomed.

Best, D.