Onshore UK detection of subsurface geology to metre scale resolution and km scale depth, without drilling or seismic

www.adrokgroup.com

www.paetoro.com

Gordon Stove[1], Dave Waters[2]

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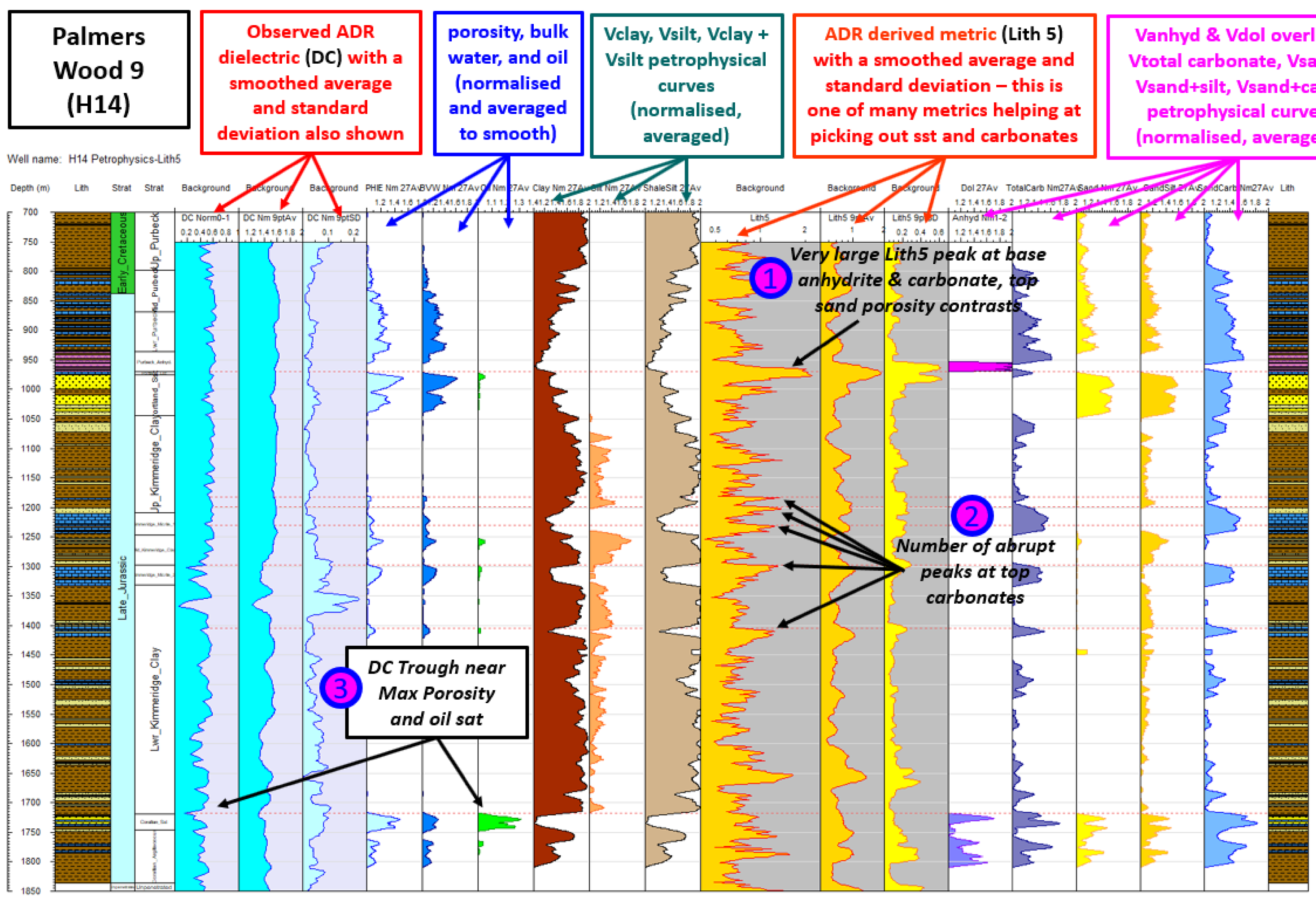
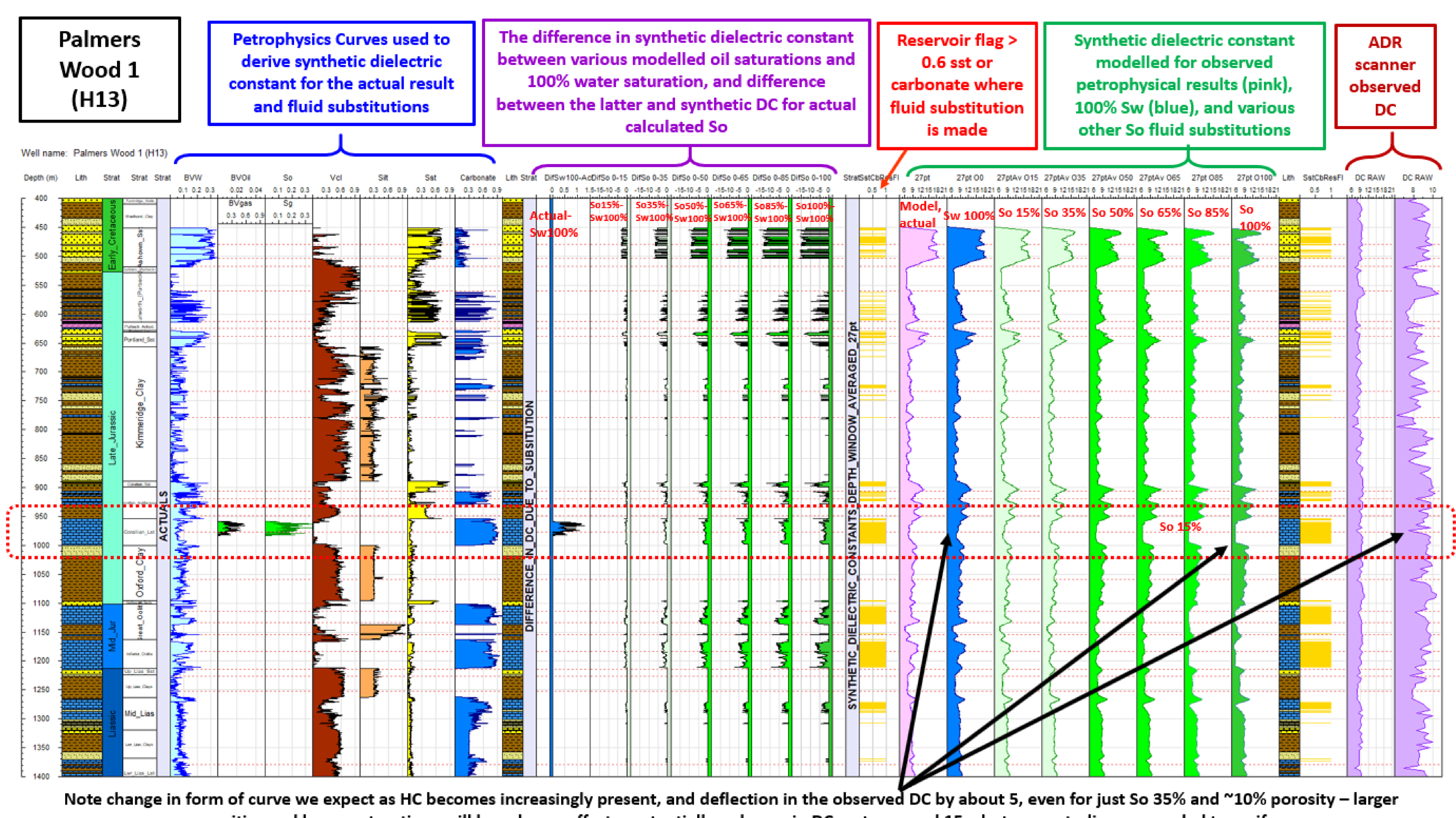
Petroleum Geoscience Collaboration Showcase

If you can see this

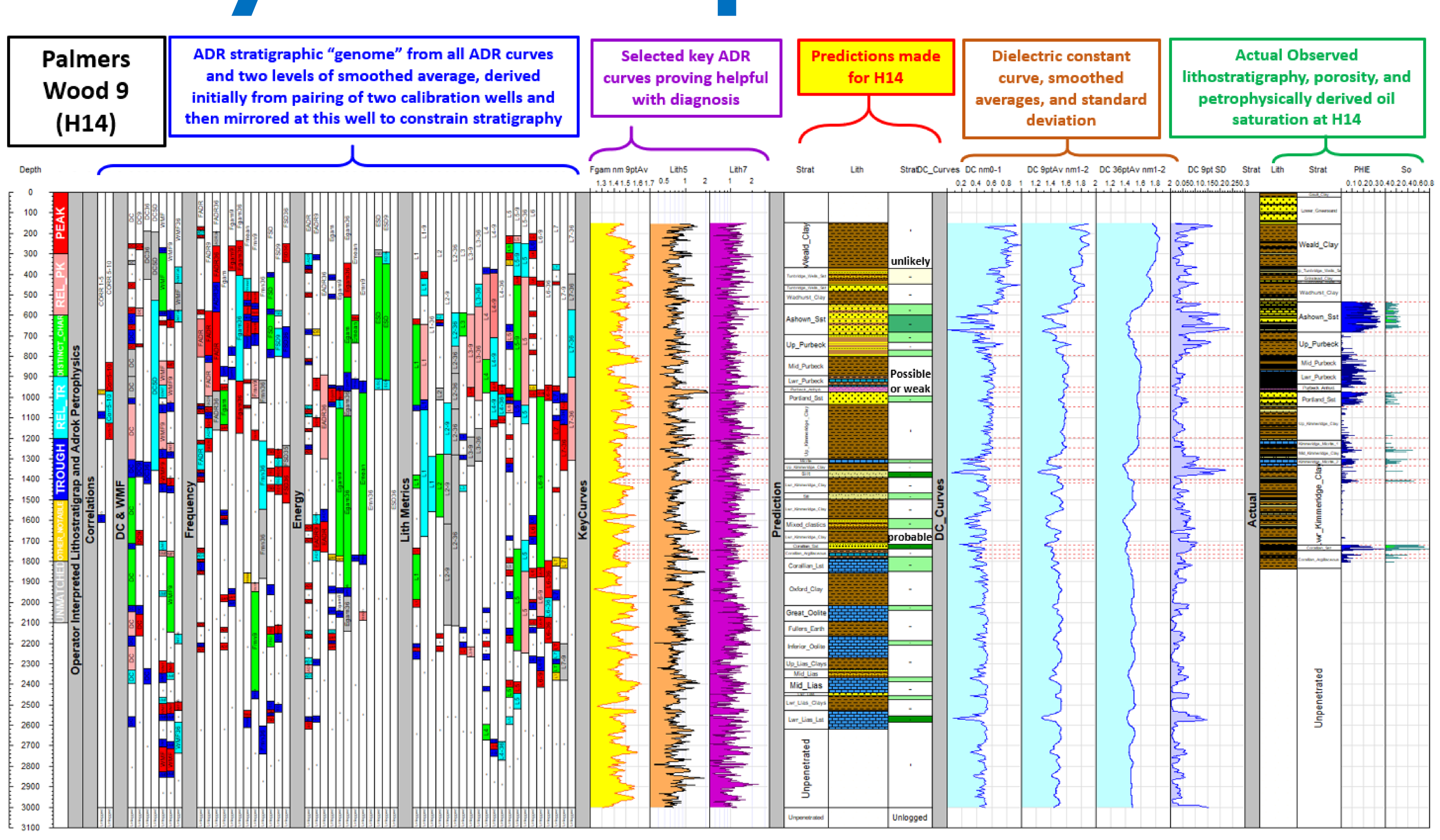


If you can model this



Note change in form of curve we expect as HC becomes increasingly present, and deflection in the observed DC by about 5, even for just So 35% and ~10% porosity – larger porosities and larger saturations will have larger effect – potentially a change in DC up to around 15 – but more studies are needed to verify

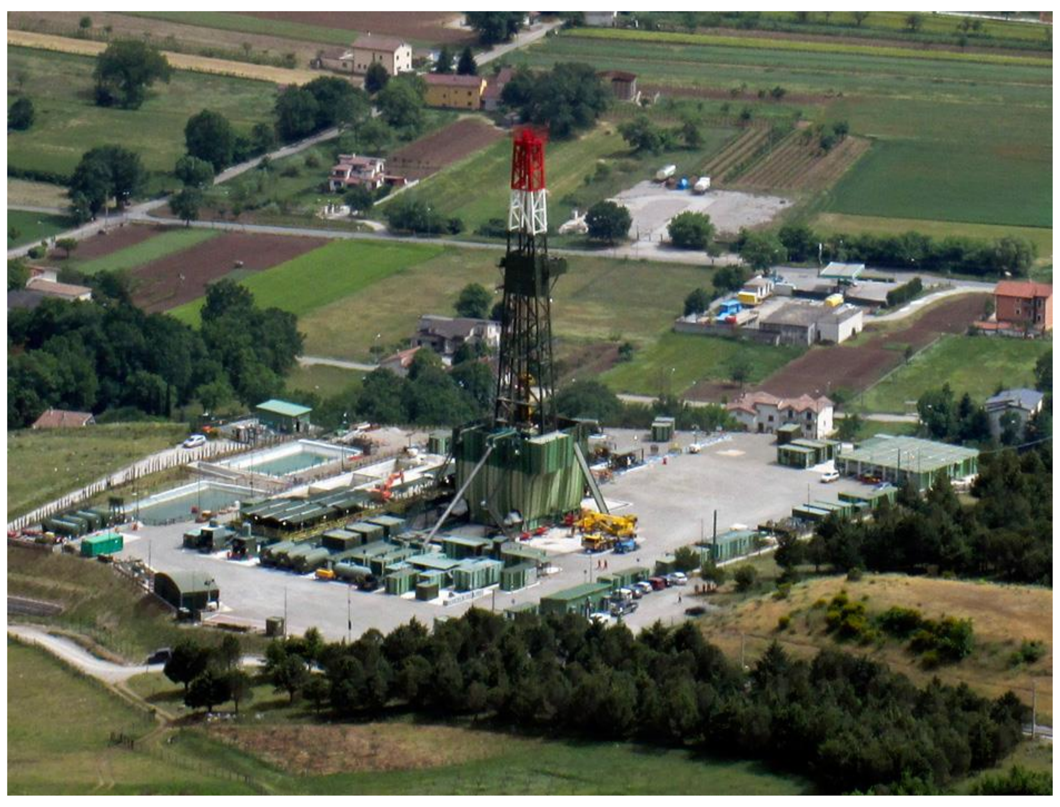
If you can predict this



By just using this

Then you can use less of this

Be much cleverer with this



And save a whole caboodle of this

While trying to find this

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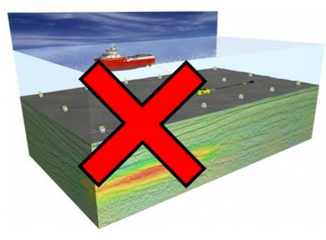
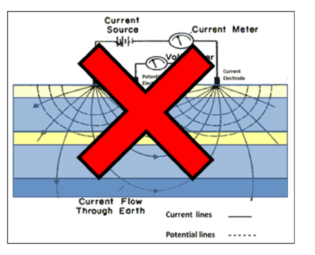
Atomic Dielectric Resonance (ADR): what it is, and what it's not



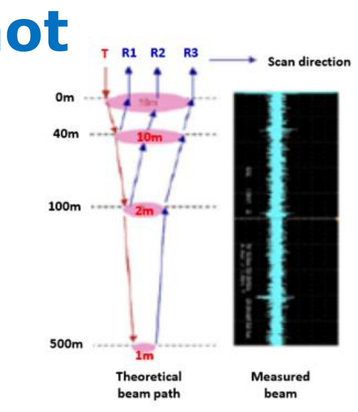


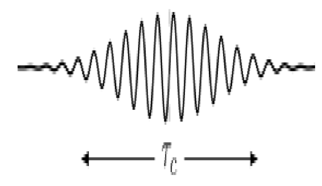
A new electromagnetic (EM) tool

- Atomic dielectric resonance is an Adrok Ltd patented electromagnetic technique for resolving subsurface geology.
- It operates in the 1 MHz to 300 GHz range of radio & radar.
- A similar approach is employed by the ESA (European Space Agency) Mars Express probe, which recently used comparable methods to find evidence of a sub-glacial lake on Mars.

Not CSEM, not GPR – It's Hi-Res & Deep

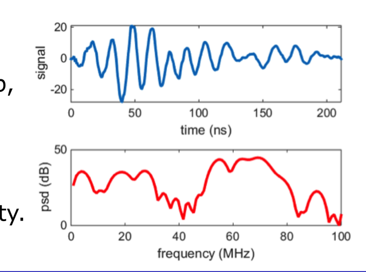
- Unlike other electromagnetic techniques including ground penetrating radar (GPR) and marine CSEM (controlled source electromagnetic methods) it sees both at depth and with high depth resolution, and is ***not*** measuring slow changes from induced electric and magnetic fields.
- Instead it uses propagating waves that respond quickly to materials in the subsurface, reflecting and transmitting in a way that can be time recorded and depth converted similar to seismic.





Double Whammy

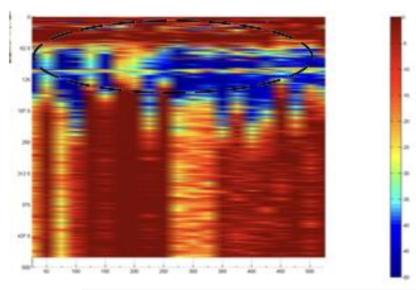
- The Adrok scanner applies two synchronised multi-spectral coherent waves, working together in-phase, transmitted through the ground in a pulsed confocal beam.
- The beams have two components – a long wavelength standing wave that helps to go deep, and shorter resonant waves within it to enhance the vertical resolution.
- Because it is coherent, the loss of energy to the surroundings (dispersion) is minimised.
- The energy and frequency resonant response of the material depends on a fundamental material property, varying with geology – the dielectric constant (DC) or relative permittivity.
- The tool resolves these changes in the dielectric constant – a function of the geology.

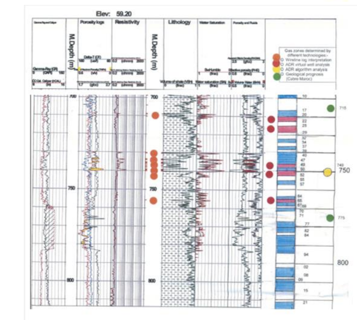


The ADR Tool: Practicalities, advantages, costs, development

Backpack-portable

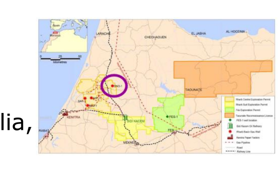
- The scanning process is achieved at the surface, non-intrusively through a backpack portable tool.
- Where old wells and seismic exist, they can be used for calibration, but a new borehole or new seismic is not required.
- This makes an ADR survey cheap in comparison, and field work is typically achieved in a matter of weeks.
- Laboratory equivalents also exist, where core and samples can be scanned for further calibration, producing a library of real-rock responses.





Going where others can't

- The very portability and non-intrusiveness of the tool means it can go where others can't:
- Including in built up areas, remote areas, or in mountainous areas where effective seismic penetration is difficult.
- For deep HC applications, for now it's an onshore tool.



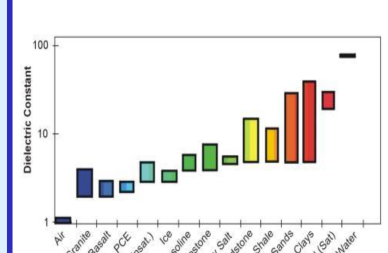
Ongoing development

- The scanner is always in ongoing development, and various case studies available on the Adrok website (www.adrokgroup.com) show something of the evolution
- Successes have already been notable in mineral cases studies, including sulphide deposits in Australia, and successful application to hydrocarbons has already been achieved onshore Morocco.
- The more studies in petroliferous basins that are achieved, the more HC prediction can be understood.

The dielectric constant – what it can (& can't) tell us

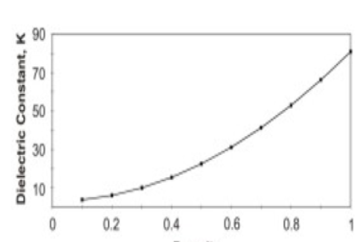
Absorption

- When we pour water onto different materials, it absorbs them in different ways, that are unique to that material.
- The same kind of thing happens when we "pour" electromagnetic waves onto a material.
- Different EM absorption responses are dictated by the dielectric constant (DC).
- They manifest as different energies and frequencies of the transmitted and reflected waves.
- The Atomic Dielectric Resonance (ADR) scanner tool exploits this to detect the DC induced contrasts.



Water is special

- The dielectric constant of many materials has been measured in labs and published.
- It varies a bit as a function of frequency and temperature, but not too much.
- One of the most important features is that water has a DC value much higher (~81) than almost all other materials found in the subsurface, including hydrocarbons (1-2)
- Important geological boundaries – especially HC bearing ones, often have a change in water content, opening an important route for geological mapping, if the DC can be discerned from the surface.



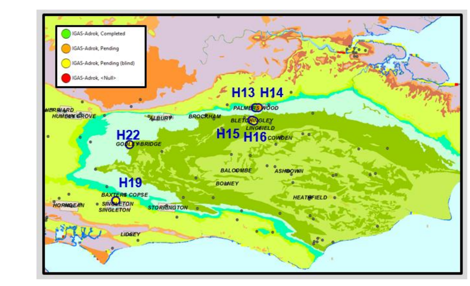
The non-uniqueness issue

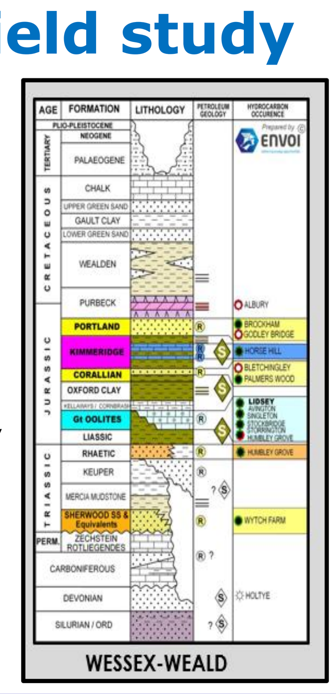
- Just like any log measuring the subsurface that attempts to relate responses to lithology, there is a uniqueness of solution question.
- The ranges of DC value possible globally for some lithologies often overlap – so extra information is required to discern which lithology is present.
- Locally the range for each might be much narrower, but it is still an issue.
- The best way to do so is calibrating a surface ADR scan at a historical well site & matching results to wireline, petrophysics, shows, and interpreted lithology.

Rocks will be rocks – empirical versus theory

- Observing the dielectric constant of complex lithological mixtures in this manner is still not 100% theoretically understood – e.g. differential attenuation in fluid pores versus matrix.
- Where empirical calibration with historical wells is available though, we don't need to know this, to simply extrapolate observed contrasts relating to known stratigraphy, through a basin.

Weald Basin Field study

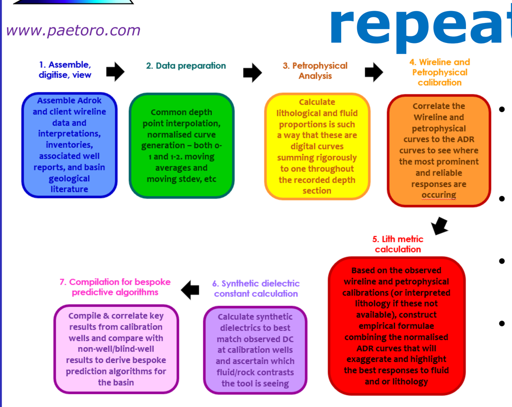




Weald Basin – a foothold

- The Weald Basin study is one of three petroleum producing areas onshore UK which IGAS originally asked Adrok to evaluate.
- The current study conducted internally by Adrok & Paetoro has picked up that baton and run with it further.
- At it's heart it is using three calibration wells to see if subsurface geology is indeed being detected, and if so whether it can usefully be extrapolated to three "blind" wells.

Objectivity, auditability, repeatability



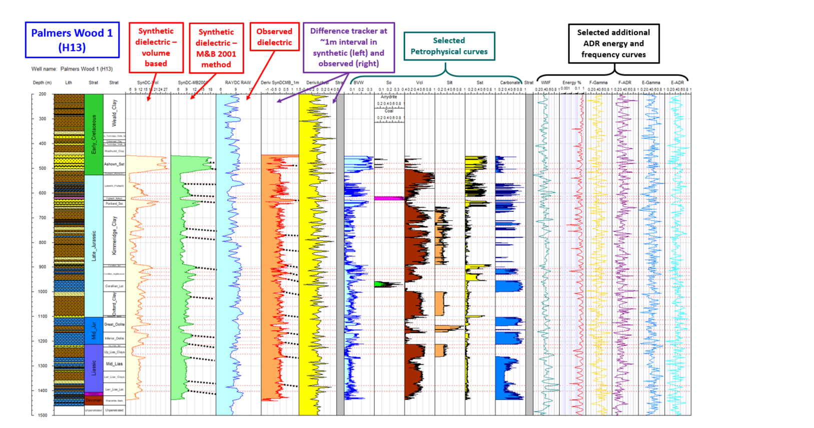
Is it for real?

- Paetoro Consulting UK Ltd became involved as an independent reviewer
- Our role has been to ask the question of Adrok's tool:
- Is it really detecting subsurface geology? Hydrocarbons?
- Is it detecting these things with sufficiently reliability to use predictively?

Yes, but can we prove it?

- It's one thing to get a qualitative sense of a tool's success, but at Paetoro we wanted to illustrate the ADR tool's success in ways that were mathematically rigorous and objective – depending on raw data, not subjective interpretation.
- With Adrok we set out to achieve apply workflows that are mathematical, auditable and repeatable by clients, so that they don't have to take our word for any success, but can check for themselves. It's an ongoing evolution.

Petrophysics for a synthetic dielectric constant



Petrophysics – empowering the resolution of the tool

- One way in which historical analysis of the ADR data has had problems – is in trying to match interpreted lithologies provided by clients for the calibration wells – but interpreted lithologies are subjective and artificially discrete.
- Paetoro has instead used petrophysical evaluation of well wireline data. Although this is subjective too – this is only in the context of the mathematical algorithms applied to wireline, which can be audited.
- This provides a continuous function of various lithological and fluid proportions and is much better at matching the real variations in lithology that the tool detects – otherwise masked when using a discrete interpreted lithology.

With thanks to David Sendra for Petrophysics

The Dielectric Constant – can we predict what will be seen?

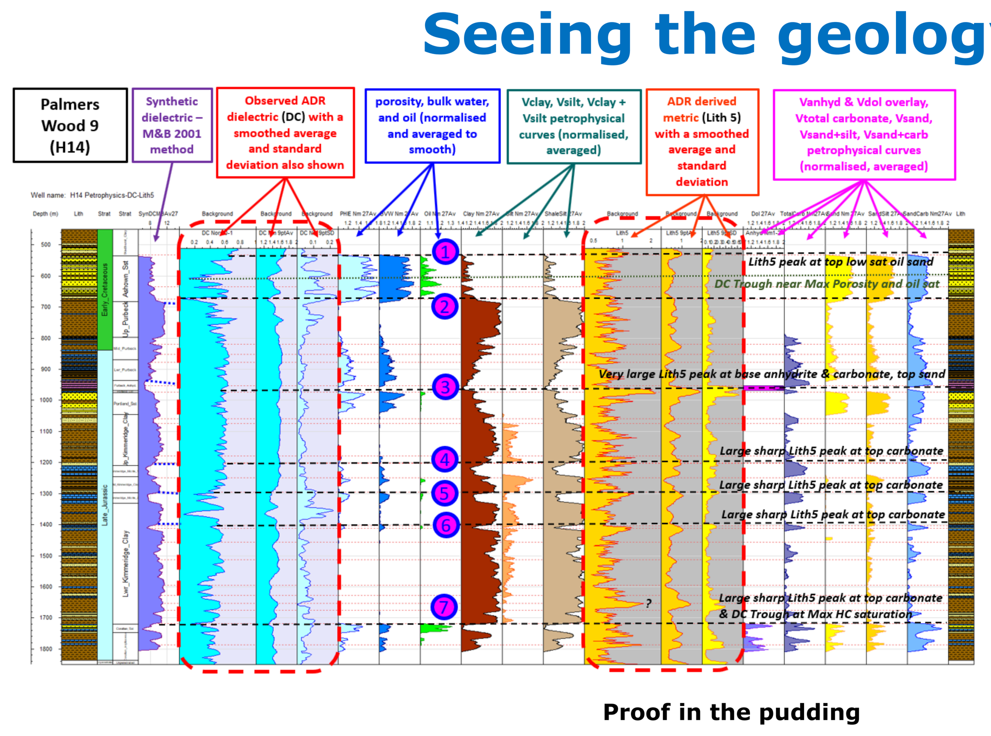
- Once we have petrophysical proportions and a knowledge of the range of dielectric constant values for the component parts, we have the capability to derive a synthetic dielectric constant curve from the well's petrophysics.
- This can be compared with the observed.
- There are a variety of methods for calculating the synthetic – volume pro-rata-ing and the method of Martinez & Byrne (2001) are two we have used.
- Though the match is not perfect, the forms of the curve and locations of key contrast occurring in both the observed and synthetic curves provides independent confirmation that the Adrok tool is indeed discerning this aspect of the subsurface.

Work in progress

- The observed DC to date seems to be a "muffled" version of the modelled – we are working to understand this and refine the models further.

CHOSEN COMPONENTS							
Tot	Category	Type	Low	Geomean	Mid/Mean	High	Range
water	fluid	liquid	80.00	80.50	80.50	81.00	1.00
limestone (undif)	lithology	carbonate	4.00	5.66	6.00	8.00	4.00
calcite	mineral	carbonate	6.40	7.38	7.45	8.50	2.10
dolomite	lithology	carbonate	7.20	7.45	7.45	7.70	0.50
anhydrite	mineral	evaporite	6.10	6.30	6.30	6.50	0.40
salt (rock, dry)	mineral	evaporite	4.00	5.29	5.50	7.00	3.00
coal	lithology	organic	3.50	5.29	5.75	8.00	4.50
shale (undif)	lithology	clastic	5.00	8.66	10.00	15.00	10.00
silt	lithology	clastic	5.00	12.25	17.50	30.00	25.00
sandstone (dry)	lithology	clastic	2.00	2.45	2.50	3.00	1.00
oil (general)	fluid	hydrocarbon	1.60	1.79	1.80	2.00	0.40
gas condensate	fluid	hydrocarbon	1.31	1.48	1.49	1.67	0.36
methane (gas)	fluid	hydrocarbon	1.01	1.16	1.18	1.34	0.33

Seeing the geology



Depth of investigation

- At present the tool routinely scans to 3km. That's deep enough to do some useful exploration & appraisal geology.

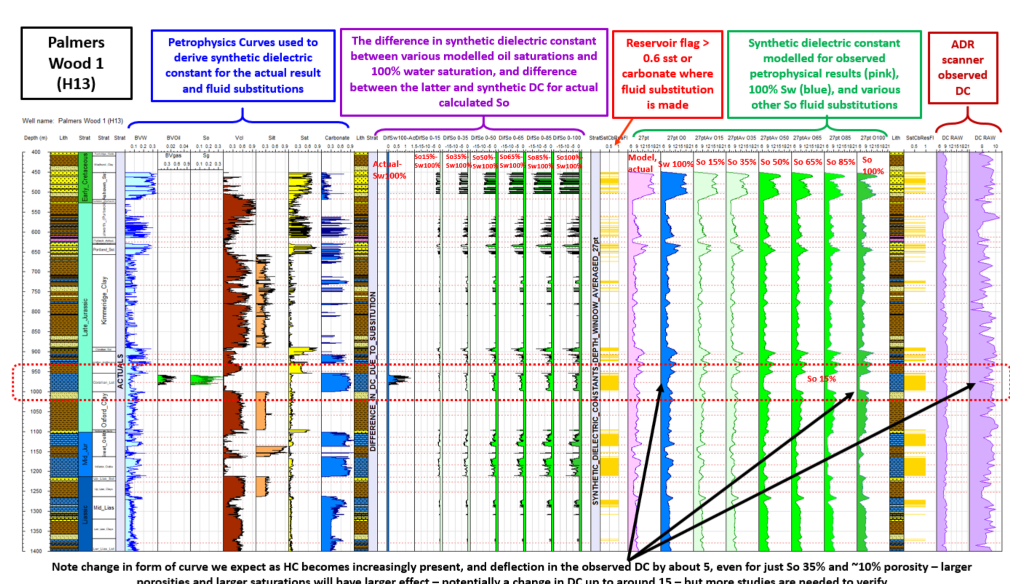
Lithological metrics

- The ADR scanner tool actually produces about 16 initial curves as a function of depth, all measuring different aspects of energy and frequency and their correlation and variation, and inferring a dielectric constant from them.
- These different curves respond to geology in different ways. Metrics can be mathematically (i.e. objectively) calculated through their combination to exaggerate responses to geology that are observed in the various curves.
- This is done empirically rather than on any theoretical basis.

Proof in the pudding

- The figure above is just one clear example, where the tool is clearly responding to changes in subsurface geology, with good depth precisions, at depths to 1.8 km. This is without any seismic or need for a borehole – the well data is just for calibration prior to extrapolation in undrilled areas.
- In particular, marker 3 above shows a very large response of the calculated "Lith-5" metric (yellow orange) to a change in lithology and porosity at a carbonate-anhydrite contact with a porous sandstone, and markers 4,5,6,7, consistently shows quite sharp contacts at the top of carbonate beds.
- DC troughs (left, pale blue) are associated with the best (most porous) sandstones and limestones, and as might be expected, especially those with highest HC saturation.

Seeing the hydrocarbons



What about the pay-dirt?

The contrast in dielectric constant of water and hydrocarbons, should result in a signature in a porous rock with decent saturations – that's the theory – but does it?

Where we have calibration wells with known hydrocarbons, we can take their reservoirs, and replace observed porosity with varying degrees of water and HC saturation – and observe the effect on modelled dielectric constant.

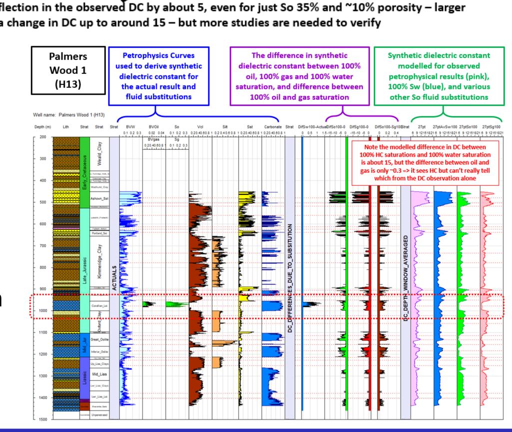
This can help tell us whether detection is likely and occurring. It tells us what to expect in other locations away from wells, and also where the geology is sufficiently constrained by the tool to highlight areas of suspected HC saturation.

There are still many questions about how the signal from the pores and the rock matrix differentially attenuate and combine to give our overall DC observation at surface. More studies are needed to progress questions like this.

HC vs water, oil versus gas

While the DC modelling still needs work, the substitutions suggest a real deflection in DC value is discernible even for the Palmers Wood-1 oil saturations of 35%, in porosity of about 10%. Larger saturations and larger porosities will work even better.

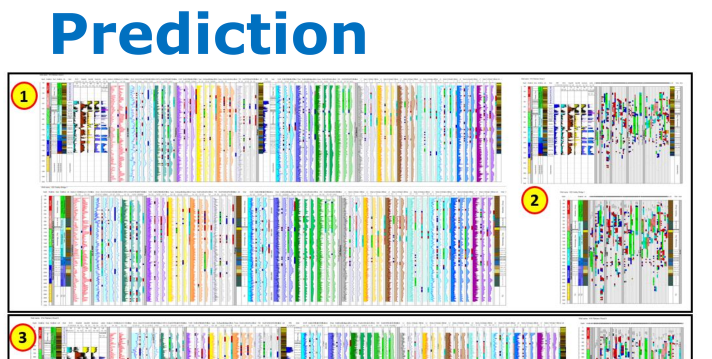
Distinguishing oil and gas is harder, because the difference in DC value is much less than between HC and water, but work continues on the tool's other measurements to see if there is a gas effect.

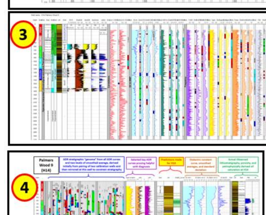


Prediction

Can we predict?

- It's one thing to recognise that the tools are responding to subsurface geology and fluids.
- It's another to do this reliably and consistently enough to predict these things in a new location.
- We're not going to lie – it's hard – there are two enemies – noise, and non-uniqueness.





1) Examine ADR curves (and averaged versions) of two calibration wells and highlight intervals of shared character present in both
2) Extract the shared ADR "stratigraphic genomes" that result at each well
3) See where the "genome" can likewise be applied at a third site to constrain stratigraphy.
4) Use this with selected key curves useful in that particular instance, and the dielectric constant curve, to make predictions of stratigraphy, lithology, and fluid fill

Tackling the enemy-calibration pairs

- To combat the noise – from cosmic, solar, atmospheric, and man-made sources, the scanner makes tens of thousands of measurements to increase the signal to noise ratio.
- To combat non-uniqueness, we need to bring in as many variables as we can to help. This means utilising all curves we have, and all calibration data we have.
- Initially we focus on two calibration wells of known petrophysics and lithostratigraphy and extract intervals of shared character – peaks, throughs, plateaus, ramps, ledges, etc. across all their curves.

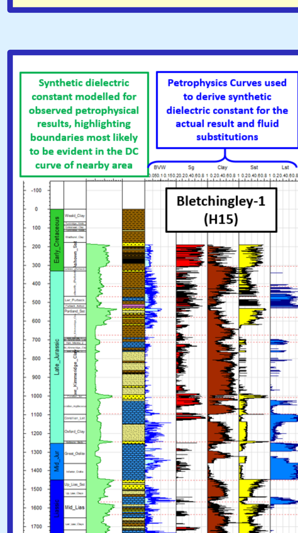
Extending the bridge

- This "bridge" of shared characteristics in two wells creates a template we call the "ADR stratigraphic genome".
- Applying it to a third site for a match helps constrain stratigraphy.
- It is a guide, not fool-proof, but it is used with the most helpful curves and the dielectric curves to constrain lithostratigraphy.
- Once this is achieved, the dielectric curves also allow characterisation of the likely fluid fill.
- We are investigating ways to take this from the purely human realm into more automated mathematical processes such as machine learning.

SUMMARY

- **ADR tools are still developing but they are resolving subsurface geological features at km scale depth with m-scale resolution.**
- **They can do so with a back-pack portable tool that can access built-up, or remote inaccessible areas that seismic can't reach, and complete field studies from the surface in weeks.**
- **No intrusive seismic or borehole is required, making the tool cheap and quick to operate –though historical drilling and seismic efforts are useful for calibration, especially when good petrophysics is available.**
- **They are not wireline logs, take an bit of analysis to interpret, and do not resolve every geological contact - those with major water content contrasts are most easily resolved.**
- **Yet they hold great promise for helping de-risk hydrocarbon, geothermal, and mineral exploration in onshore areas - to inform decisions before making more costly investments in seismic or drilling**

Can it work for you? Feasibility studies



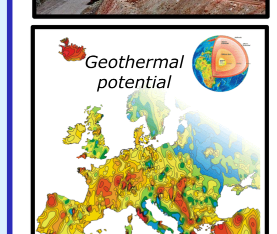
Dielectric contrast

- The tool works well where there are subsurface contrasts in dielectric constant to help flag and map subsurface units – do you have them? We can help.
- Not every geological interface has this kind of contrast - so not everything is going to "light up".
- Being able to construct synthetic dielectric curves from petrophysics on calibration wells enables Adrok to say at the start, whether the targets sought in the area of interest are likely to show up.
- Clients can then use an initial feasibility study in their areas, with their data, to give an advance indication of the likely usefulness of an ADR study.

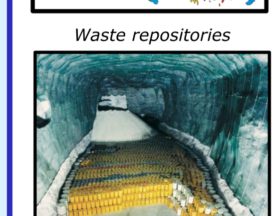
Future studies, future promise

Mineral extraction

Geothermal potential



Waste repositories



The Best testing grounds

- The Weald Basin has have a very varied stratigraphy and hydrocarbon distribution, with sandstones, carbonates, evaporites, shales, coals, oil&gas, all present. Coupled with rapid variations in stratigraphy – this makes uniqueness of solution from just three calibration wells more challenging.
- The best testing grounds for the future are onshore areas with abundant historical drilling & good infill potential, that have relatively bimodal lithology and fluid presence – e.g. sand/shale sequences with one of just gas or oil – such as deltaic and turbiditic sediments (e.g. Hungary, Trinidad).
- Similarly carbonate-shale sequences of the Middle East would be good to test. An ability to detect evaporite-carbonate and evaporite-clastic interfaces in the petroliferous basins of onshore Tethyan fold belts (e.g. Iran, Albania) would also be great to investigate. It may help de-risk exploration & appraisal in these structurally complex and difficult to seismically image areas.
- Time-related depletion and water flood of onshore field reservoirs is another potential application.

AI

- A suite of logs from the ADR tool, if calibrated with wireline and petrophysics logs, and then applied to new sites - is a great machine & deep-learning predictive analytics problem.

Not just hydrocarbons – minerals, geothermal, nuclear waste

- The tool is already being applied in mineral exploration successfully – case studies for gold and coal exist on the Adrok website www.adrokgroup.com.
- Geothermal aquifers typically require good quality and good lateral extent sandstones at least 100m thick to be commercial – this is just the kind of thing that will show up well on ADR transects. It can help map units in onshore built-up areas where a nearby hot water market is required for commerciality, but where intrusive exploration techniques like seismic are undesirable or difficult.
- Another interesting field for consideration is whether the tool can be used to monitor long term, the integrity of geologically-disposed radioactive-waste sites.