Helping DE-RISK the EXPLORATION for suitable GEOTHERMAL drill targets

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Adrok®

Adrok is DELOPING NEW TECHNOLOGY FOR A GEOTHERMAL FUTURE

Just imagine if we can significantly reduce the number of high-risk geothermal exploration drill holes by adopting technology from the oil and gas industry to measure a proxy for temperature from the surface?

Some Key Capabilities

1) Technology and processing adopted from the oil industry and being applied to the geothermal exploration industry. Adrok can help map out the best target areas for geothermal boreholes prior to drilling thereby significantly reducing financial, social and environmental risk.
2) Small, compact, surface-based geophysical equipment setup requiring no land clearing and no special permits. Surveys take around 2 hours each and data can be collected to >1000m.
3) Surveys can be carried out almost anywhere including built up areas, in farmland, or in forests. Adrok leaves nothing but footprints. The ability to carry out geophysics in built up areas is an advantage as many potential geothermal drill sites are located near towns and communities, therefore the technology offers a viable option to test numerous drill locations/targets prior to committing to highly disruptive and expensive drilling.
4) Temperature estimates have been carried out to depths of 3000m (see case study provided for Perth Basin, Australia) without the need for drilling.
5) Fully processed results can be obtained within weeks rather than months or even years thereby saving time and money.

Testing Adrok's geothermal capabilities around the world
Case studies are growing rapidly!

SOME BACKGROUND TO THE TECHNIQUE

Typical SURVEY PARAMETERS

- Surveys 1MHz – 70MHz
- Typically >4 scans per day
- Pulse penetration depths of up to and over 1000m deep depending on geology
- Training site desirable (vertical drill hole with target sulfide type).
- 3-person field operation

BORROWING SOME PRINCIPALS FROM GROUND PENETRATING RADAR (GPR):

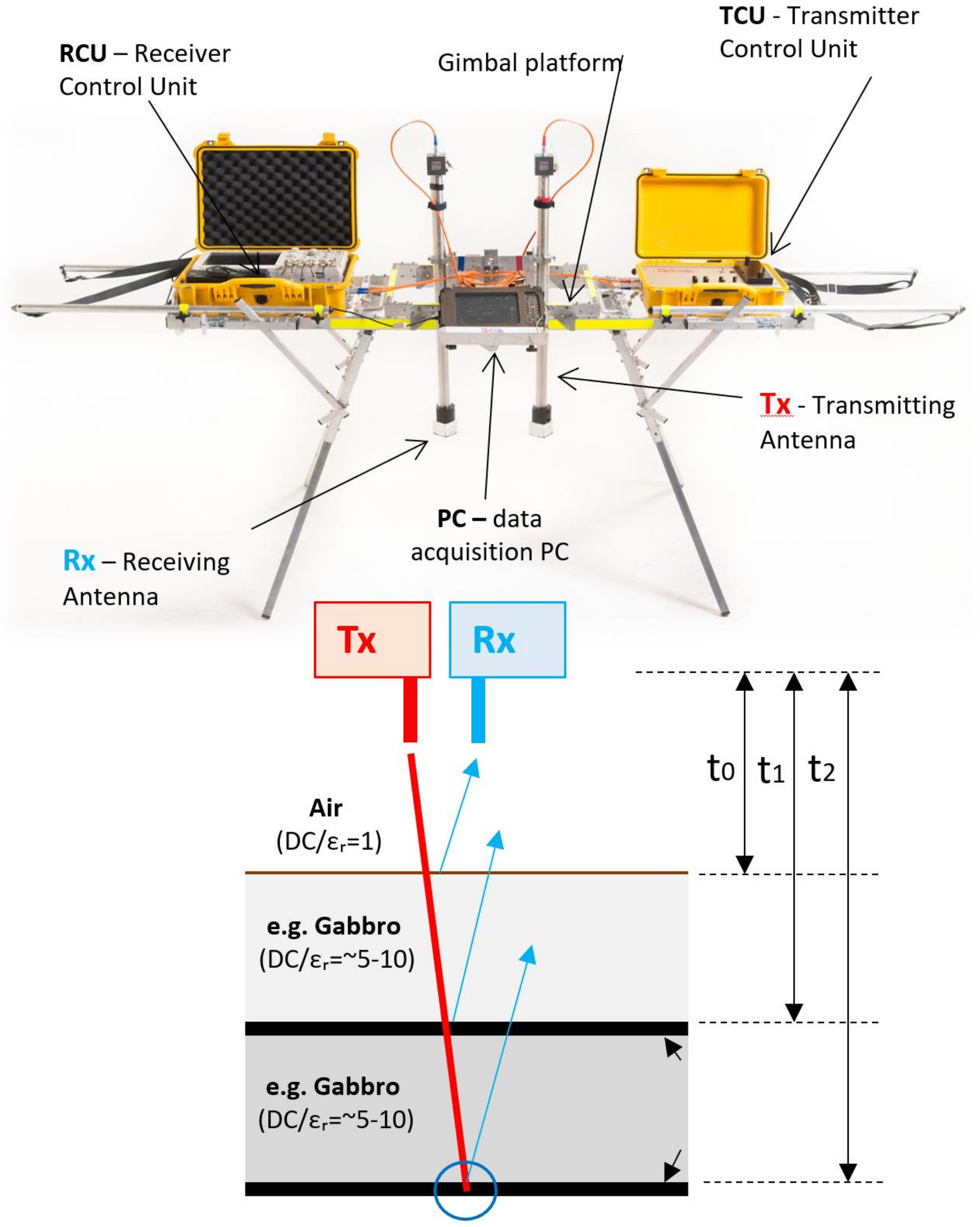
GPR (1-1000MHz) uses similar frequencies to the ADR tool used for detecting different materials (1-70MHz). There are, however, some fundamental differences in the technology, particularly in the transmitter and antenna design, but many of the physical principals for GPR are the same as those for ADR.

"GPR *for example* consists of an antenna that produces short duration electromagnetic pulses that penetrate…materials. The radar pulses are reflected at interfaces where the dielectric constants of material layers change. The reflected amplitude depends on the change in dielectric constant, while the arrival time of a reflected wave at a detector also depends on the depth at which the discontinuity is encountered. Layer material's dielectric property is used for pulse velocity and thickness calculation."

Exert taken from:
https://www.researchgate.net/publication/318152161_Ground_Penetrating_Radar_for_Measuring_Thickness_of_an_Unbound_Layer_of_a_Pavement

ALSO BORROWING PRINCIPALS FROM SEISMIC REFLECTION:

"When a seismic wave encounters a boundary between two materials with different acoustic impedances, some of the energy in the wave will be reflected at the boundary, while some of the energy will be transmitted through the boundary. The amplitude of the reflected wave is predicted by multiplying the amplitude of the incident wave by the seismic *reflection coefficient*, determined by the impedance contrast between the two materials."
Source: https://en.wikipedia.org/wiki/Reflection_seismology



PROVING DEPTH OF PENETRATION – CASE STUDY FOR TECK RESOURCES

Upwards-directed pulsed radar test in an underground mine

The following experiment was carried out in collaboration with Teck Resources as a test of Adrok's technology to be able to penetrate significant thicknesses of rock and detect materials with different Dielectric Permittivities.

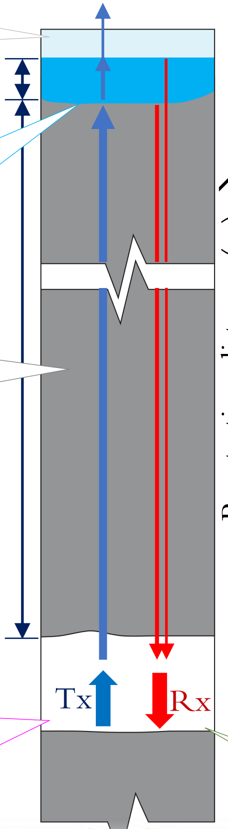
EXPERIMENT DESIGN

AIR
Dielectric Permittivity (ε_r) or Dielectric Constant (DC) equals **1**

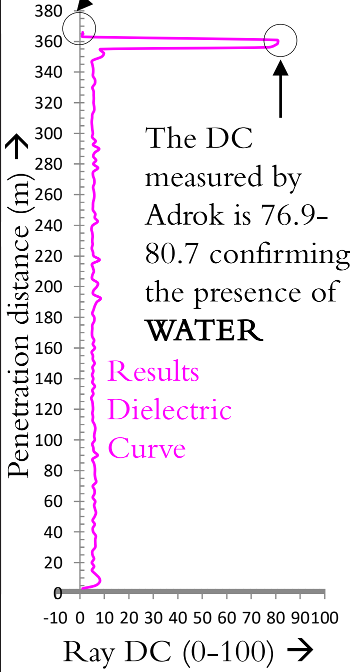
WATER BODY
Dielectric Permittivity (ε_r) or Dielectric Constant (DC) equals **80**

ROCKS
Dielectric Permittivity (ε_r) or Dielectric Constant (DC) between **5-15**

SETUP
Transmitter (Tx) and Receiver (Rx) antennas setup underground and pointed upwards towards the base of the waterbody



The DC measured by the ADR tool is 1 confirming the presence of **AIR**



The DC measured by Adrok is 76.9-80.7 confirming the presence of **WATER**

Portable ADR equipment

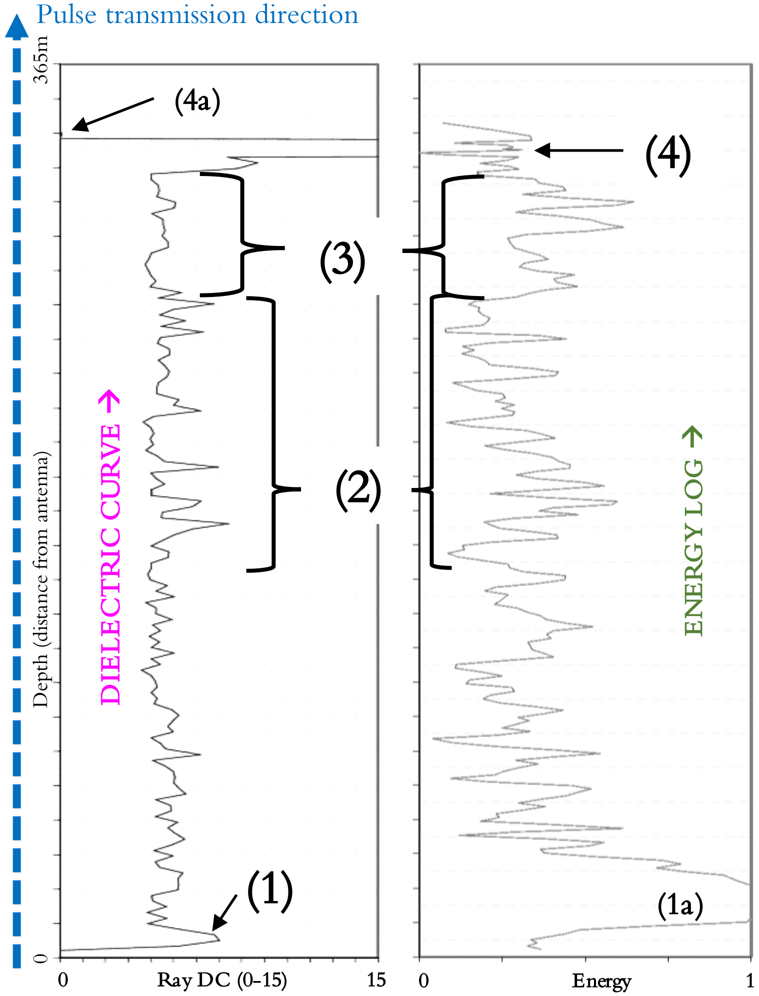
UNDERGROUND MINE
Equipment setup in active underground mine tunnel approximately 380m below the surface.

(4) (water-rock interface) The lowest energy (strongest relative energy return) is recorded at the boundary between rock (DC=3-12) and the overlying waterbody (DC=80). The sharp boundary between rocks with contrasting DC acts as a strong reflector at the 1-70MHz range (refer to GPR overleaf). The ADR measurements record the thickness of the body of water (approximately 5.2m thick) as a section of continuously high DC. At point **(4a)**, the DC measurements return to a value of 1, consistent of the known DC of Air (DC=1).

(3) Relatively smooth DC curve suggests few changes in rock type and, with consistently higher energy values. This section **(3)** is interpreted as a separate unit of rock than below **(2)** where DC values are variable and energy response is generally lower.

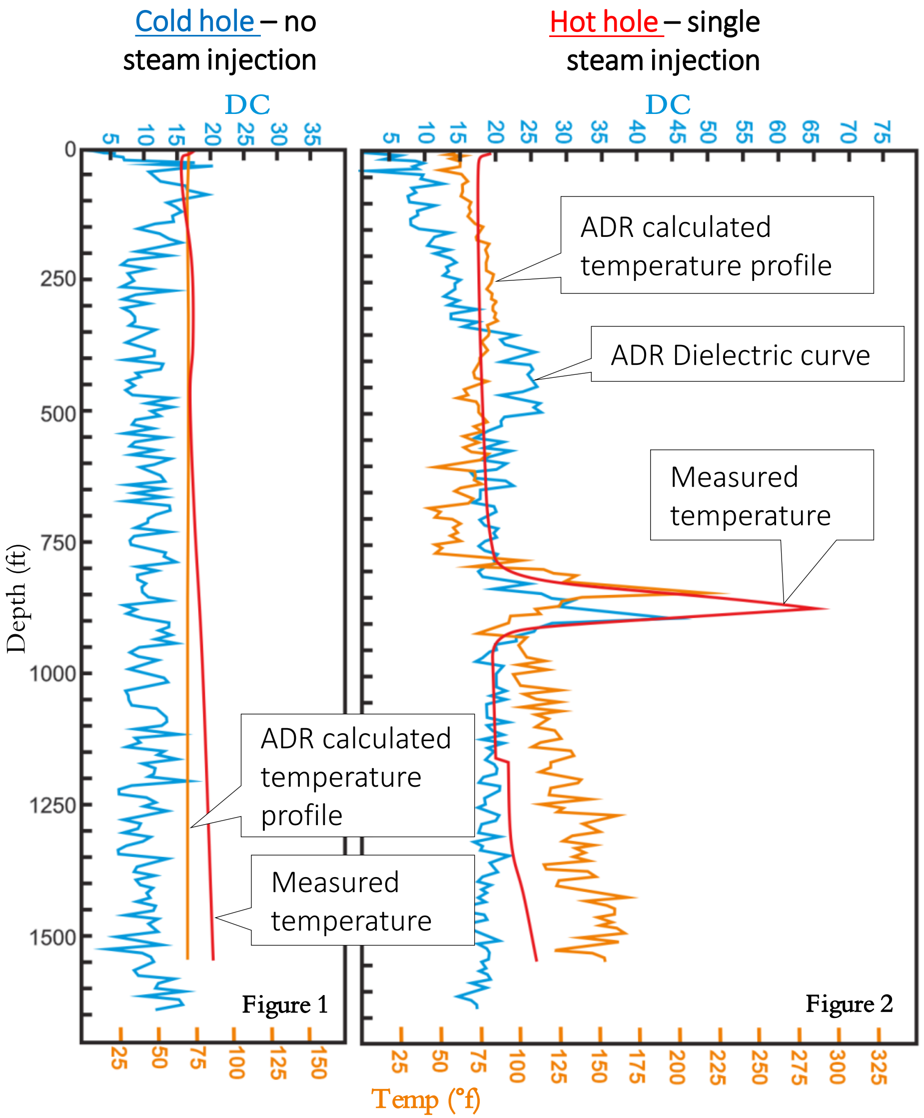
(2) Changes in DC (Δ < 5 units) and fluctuations in returned energy indicate that the pulse is reflecting small amounts of energy from boundaries between rock types with small differences in (ε_r).

(1) The rapid increase in measured DC from 0 (air) to DC=8 occurs when the transmitted pulse passes from air (DC=1) into the overlying rock. The transition is marked by an equivalent jump in energy **(1a)** marking the absorption of energy by the country rocks.



The information presented here is a current snapshot of the recent adaptation and development of Adrok's surface-based, ADR geophysics technology for **measuring temperature** at depths of over 1000m without the need for drilling. The technology is under rapid development with some extremely promising results, just a few of which are presented here.

Oilfield Steam Injection – field results, USA



Relative Dielectrics Permittivity (ε_r presented here as DC) is a measure of the relative change in the dielectric permittivity (ε_r) value of the material at each depth interval measured. The ε_r of rock is generally around 3-10 whereas the ε_r of water and steam is over 80. As the water saturation of rock increases towards 1, the DC measurement also increases. Higher values in DC tend to correspond closely with occurrences of steam and increases in temperature.

Results figure 1: Shown here (left) are results from temperature measurements of basal geothermal gradient (1) and steam injected layer (2). There is a good match between both ADR calculated temperature (orange) and the measured temperature (red).

Changes in subsurface temperature will affect conductivity and permittivity (Kummerow and Raab, 2015), which will affect the radar returns.

Adrok uses a combination of results from an ADR scan including Energy Returns (E-Gamma, E-ADR) Weighted Mean Frequency (WMF) and DC to estimate temperature in °C.

How to derive temperature proxy from radiowaves:

• The energy density (ρ) of radiowaves through a layered medium should increase with the absolute temperature in accordance with **Stefan Boltzmann's Law**:

$$\rho=\sigma T^4$$

• The radiowave Spectral Energy Density Ed(S) is the product of the energy density and the wavelength:

$$Ed(S)=\rho\lambda$$

• Consider the horizontal component α of vector Progressive Wave Direction (PWD) of the ADR beam, this is a function of spectral energy density, more specifically:

$$\alpha=(\rho\lambda_x)/(Ed(S))$$

Then: $(Ed(S)\alpha)/\lambda_x=\rho$

Therefore: $\alpha=(\sigma\lambda_x T^4)/(Ed(S))$

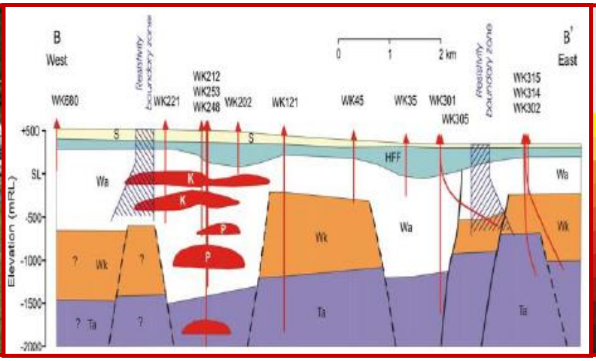
And, rearranging, it can be seen that the **temperature T** can be calculated by:

$$T=\sqrt[4]{(Ed(S)\alpha)/(\sigma\lambda_x)}$$

Where: α the horizontal component of vector PWD of the ADR beam.

New Zealand Geothermal - Pilot Study

The Wairakei-Tauhara geothermal system has developed over two million years on the North Island of New Zealand. The system is bisected by a series of faults. The Wairakei-Tauhara has been generating geothermal power since 1958 using the underground water with temperatures up to 248°C. It currently generates at least 300MW1 of electricity p.a. The sedimentary basement is thought to occur 2250m below sea level beneath a series of ignimbrites and rhyolite lavas. The main geological controls on temperature are thought to be at 1000m below the surface. Project carried out for Contact Energy (www.contact.co.nz).



Results figures 4, 5 & 6:
Temperature and dielectrics at WK271 and TH11. Red line is measured temperature. Orange lines are Adrok interpreted temperatures from DC. The orange dots indicate the presence of steam.

Measured (Adrok)
ADR DC
ADR DC NMO

Calculated (Adrok)
ADR interpreted temp
ADR interpreted temp 6pt moving av (best estimate of sub-surface temp)

Measured (Client)
Measured temp

Single temp measurement
Steam

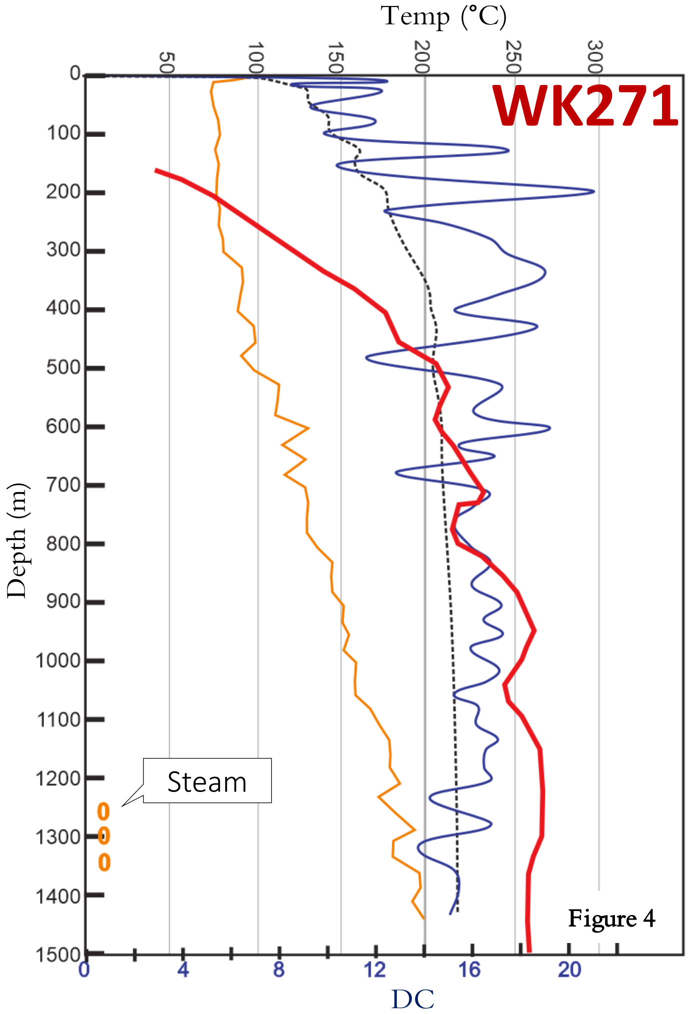


Figure 4

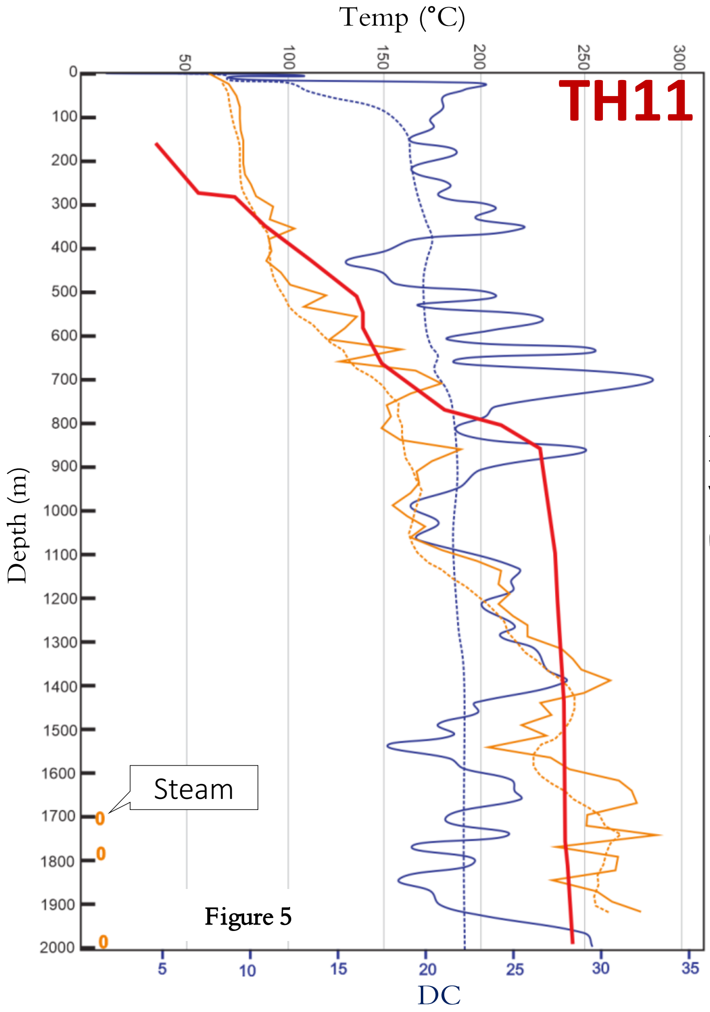


Figure 5

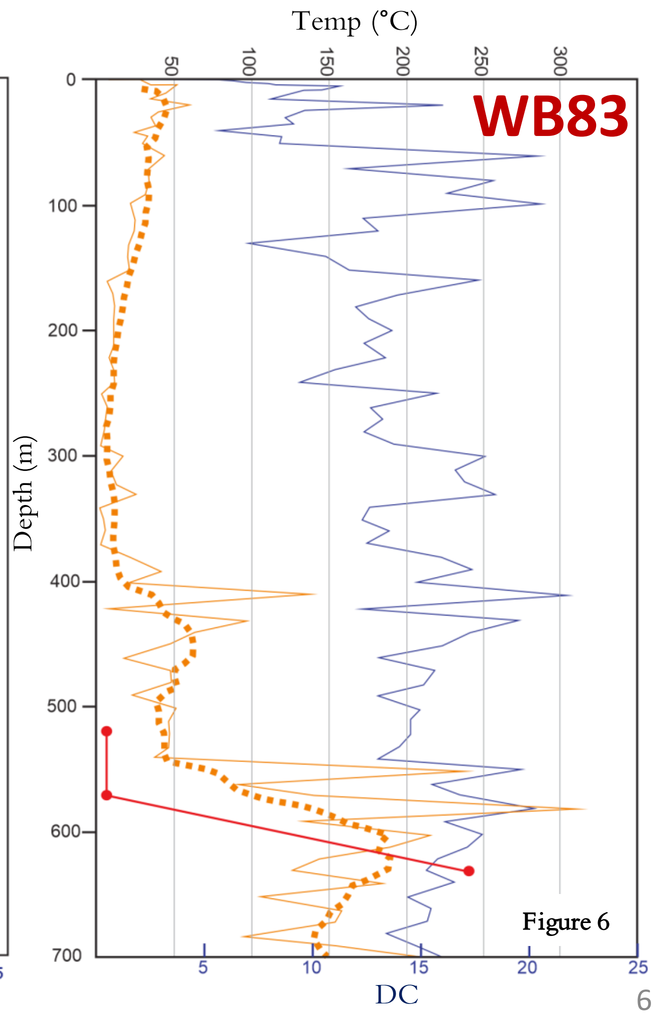


Figure 6

Temperature and oil measurement, Jingemia oil Field, Perth, Western Australia

The overall objective of the survey was to test the applicability of Adrok's ADR Scanner for the geological mapping of potential reservoirs and hot sandstone aquifers. The geothermal potential of the area appears to be primarily associated with the High Cliff Sandstone(sst) (~3km depth). The formation was encountered in the petroleum exploration well Jingemia-1 and exhibited maximum porosities in excess of 20% and an associated corrected temperature of approximately 123°C.

Figure 9: The orange line line is Adrok's predicted temperature proxy based on **pT1** model. The red line is the downhole tool temperature measurement (provided by Origin Energy). The light blue curve is the relative dielectric permittivity (presented here as DC relative to depth). High DC generally indicates the presence of water, low DC can be associated with oil such as found within the Wagina Shale.

Seismic section over the project area in the Perth Basin. Image provided by Green Rock Energy

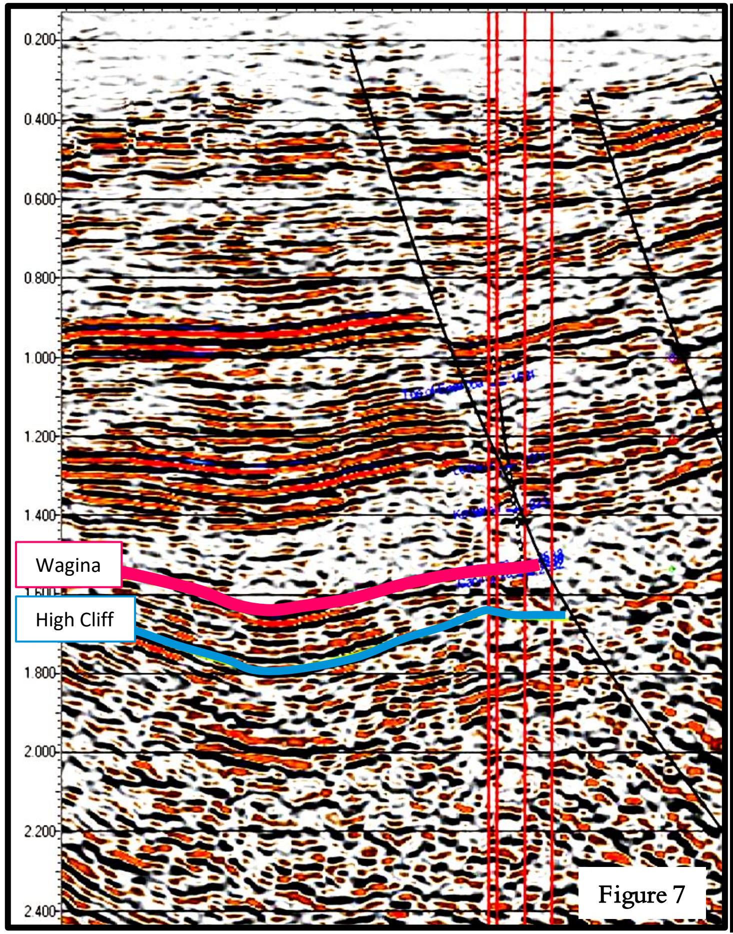


Figure 7

ADR scan results (E-ADR) overlain over selected lithologies provided by Green Rock Energy

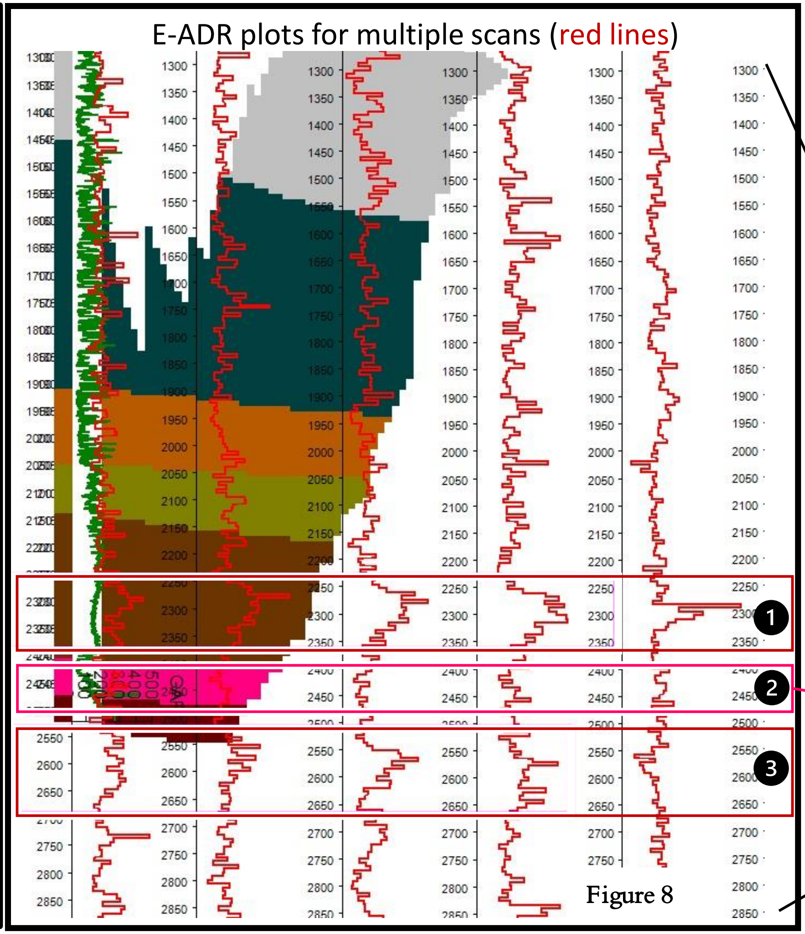


Figure 8

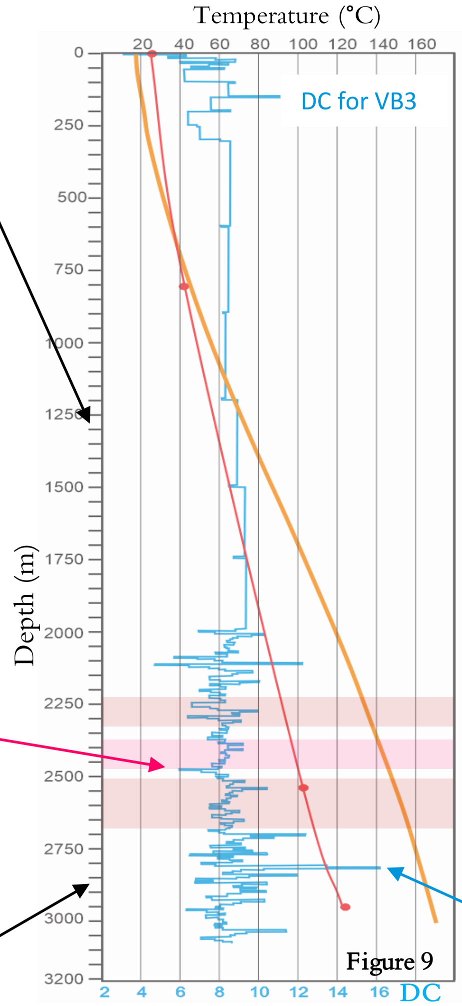


Figure 9

H2O-bearing High Cliff sst.

Results

The field-based test carried out by Adrok in 2012 was successful in highlighting the Kockatea sst. which exhibits consistently high E-ADR results. The results also demonstrated excellent repetition in adjacent scans.

Low DC values at the base of the Wagina sst may indicate the presence of the oil-water contact (OWC) as anticipated in the Wagina Sandstone.

High DC (>16)2825m depth is interpreted to be the water-bearing High Cliff sandstone.

The temperature estimate for at the depth of the High Cliff sst. is approximately 160°C.

(1) Kockatea Shale
(2) Wagina Sandstone
(3) Caryngina Shale

Exploration for Geothermal Resources shares many of the same risks as exploring for minerals or oil. As such, the geothermal industry is also seeing the adoption of technologies developed in the oil exploration industry. De-risking the early phase of exploration for suitable geothermal sites requires the early adoption of new technology. While drilling offers a direct way of measuring temperature at depth, it also shares extremely high financial and environmental risk. Indirect, geophysical methods are the most cost-effective, environmentally friendly and technically feasible methods of exploring. Accordingly, surface-based, low- to no-impact geophysical techniques present a much more sustainable option for exploring and, in some cases monitoring geothermal prospects.

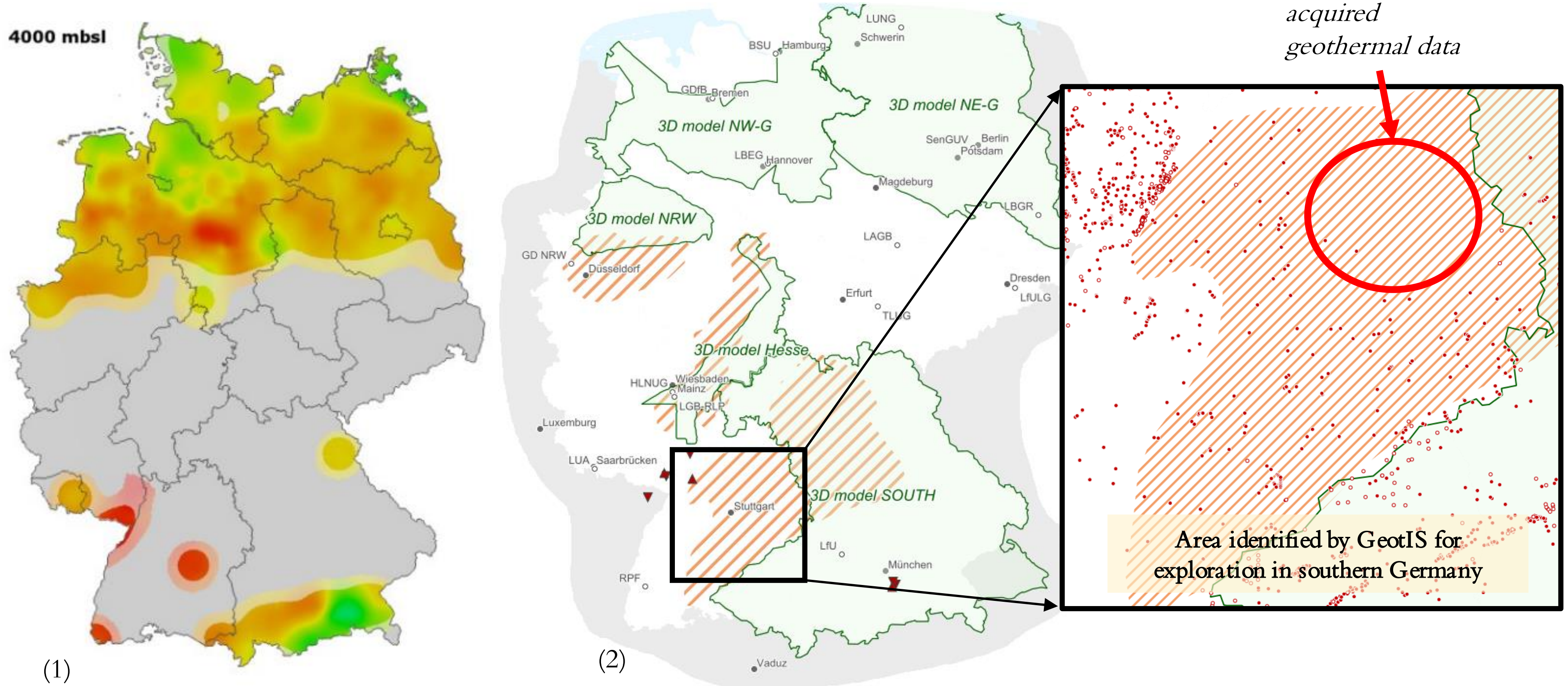
Where to from here? Field-based testing and further development – Using adaptive technology, Adrok has the potential to be able to rapidly increase the existing geothermal maps of regional areas where drilling is sparse and where measurements are lacking. A great example is southern Germany, highlighted by GeotIS (https://www.geotis.de/geotisapp/geotis.php) as an area of possible exploration. This area presents an ideal potential future case study area where thermal mapping could be carried out by Adrok without need for surface disturbance. The technology will be developed further, specifically for the needs of the geothermal exploration and monitoring industry.

Figure 10

An example of how ADR can be applied to geothermal exploration

Under explored geothermal potential in Germany

Identify areas requiring quickly acquired geothermal data



Potential advantages of ADR technology for geothermal prospecting

- ✓ Currently at TRL 8 and advancing quickly.
- ✓ Can be used in residential areas.
- ✓ Low- to no-impact at scan site.
- ✓ Fast data acquisition (approximately 2 hours per scan to >1000m).
- ✓ Extremely low cost when compared with drilling.
- ✓ No clearing or other environmental impact required.
- ✓ No noise pollution, no potential aquifer contamination and no risk of drilling-induced seismicity.
- ✓ Data processing and interpretation (thermal profiles) provided.
- ✓ Extremely environmentally friendly.
- ✓ Small, low power portable scanning unit.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Agemar, T., Weber, J., & Schulz, R., (2014). *Deep Geothermal Energy Production in Germany*. Energies. 7. 4397-4416. 10.3390/en7074397.
(2) GeoTIS - https://www.geotis.de/geotisapp/geotis.php
(3) Doel, K., Robinson, M., Stove G., & Stove, G., (2020). *Subsurface Temperature Measurement Using Electromagnetic Waves and Machine Learning for Enhanced Oil Recovery.* Conference Proceedings, 82nd EAGE Annual Conference & Exhibition Workshop Programme, Dec 2020, Volume 2020, p.1 – 5
(4) Kummerow, J. & Raab, S., (2015). *Temperature Dependence of Electrical Resistivity Part II: A New Experimental Set-up to Study Fluid-saturated Rocks.* Energy Procedia, 76, 247–255.
(5) Stove, G., Stove, C., Robinson, M., (2018). *Radiowave method for monitoring steam injection for Enhanced Oil Recovery (EOR) and for finding sources of geothermal heat*, GRC Transactions Volume 42. pp1557-1567
(6) Stove, G., Stove, C., Robinson., (2018). *New method for monitoring steam injection for Enhanced Oil Recovery (EOR) and for finding sources of geothermal heat.* AEGC2018, Sydney, Australia 18-21 February 2018

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