Empirical and simulated earth-friendly subsurface geothermal surveillance technology

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Summary

The deep geothermal development at the Eden Geothermal site has shown that, without an appropriate geophysical survey to delineate the resource target (a fluid bearing fault), it is very risky and may dissuade further investment and thus deep geothermal development in Cornwall. It is therefore worth investigating techniques which can reduce such a risk.

There are a number of such techniques available which uses change in the electrical properties of the rock mass to delimited storage of fluid and fault associated with it such as MT, AMT, Adrok and others. The Electromagnetic (EM) technology that Adrok has been developing aims to locate sources of geothermal heat prior to drilling. Through empirical fieldwork, the EM technology can non-invasively provide a proxy temperature measurement of the subsurface without physical drilling. Key aspects of the technology have been field tested, including depth and capacity to identify water. Furthermore, simulated models have been developed for different European geothermal settings.

This EM technology is based on the principle that different materials will reflect and absorb electromagnetic radiation (radio waves) at specific frequencies and energy levels. The system transmits a pulse of electromagnetic energy containing a multispectral wave packet that resonates and reacts with the sub-surface materials. The reflections from the subsurface are recorded as a time domain trace and provide information about the location and composition of the materials encountered. Given that radiowaves are good at identifying conductive water layers, the hypothesis is that radiowaves (high frequency electromagnetics) should be able to pick out the conductivity associated with hot rock layers in the ground associated with deep aquifers.

The EM techniques merit further investigation to enable efficient and optimal exploration of the natural resources useful for geothermal energy generation.

Introduction

Prior to such investment in deep geothermal, it is a traditional practice on the European continent to carry out an appropriate geophysical survey to delineate the local geothermal resource/deep fault, taking into consideration the geology involved, the depth of investigation and the resolution required.

Historically, in Rhine Graben 3D normal incident seismic reflection survey has proved to be very successful in delimiting the characteristics of the resource/fault because the interface is granite and sandstone giving sufficient impedance contrast to delineate it.

In Cornwall, this interface may consist of granite and killas (the metamorphic rock) where the mechanical impedance contrast between the two-rock type is not large enough to give clear reflectors and thus make the delineation of the fault more difficult. An example of such an investigation was carried in late 1980's where a 72 km normal incident seismic reflection survey was carried out in Cornwall to delineate faults suggested faults at around 6000 m depth. The survey was not successful as it did not reveal the presence of any such faults because of the lack of contrast between the suggested fault and surrounding rock. On the other hand, during the Hot Dry Rock Project development at the Rosemanowes site in 1980's, seismic monitoring indicated that the hydraulic stimulation fluid left the bottom of the injection and migrated downwards contrary to predicted direction horizontally to the production well. An AMT/MT survey was carried out by the British Geological Survey which showed that this was the case and that the fluid did migrate downwards and was stored up to a km below the injection well. This phenomenon was caused by the deviation of stress with depth. This demonstrated that a method which uses contrast in conductivity is perhaps a more appropriate technique for location of fluid in the rock mass in Cornwall.

There are a number of such techniques available which uses variations in the electrical properties of the rock mass to delimited storage of fluid and fault associated with it such as MT, AMT, Adrok and others. Most electrical based technique require laying of extensive cables across fields and it can be anything up to a km long. The advantage with Adrok method is that it does not require long cables as it uses electromagnetic pulse to investigate the conductivity of the rock mass.

Method

The Atomic Dielectric Resonance (ADR) technology is based on the principle that different materials will reflect and absorb electromagnetic radiation (radio waves) at specific frequencies and energy levels. The ADR geophysical system transmits a pulse of electromagnetic energy containing a multispectral, patented (Stove G.C. et al, 2023) wave packet that resonates and reacts with the sub-surface materials. The reflections from the subsurface are recorded as a time domain trace and provide information about the location and composition of the materials encountered.

The ADR signal generator produces a pulse of electromagnetic energy (frequencies typically range between 1MHz to 70MHz) that is fed to the antenna and is transmitted into the ground. Once the signal has been sent to the transmitting antenna a signal is sent to the receiving control unit to synchronise collection of the subsurface reflected data, which is collected through the receiving antenna and then digitized. The transmitted pulse is depicted in Figures 1 and 2, where we also show the power spectrum (Stove & Doel, 2015). It is not the usual localized pulse with a single centre frequency but a more complicated waveform. The higher frequency components allow accurate localization at shallow depths, but attenuate rapidly in the ground, while the lowest frequency component around 3Mhz can penetrate much deeper. We thus combine the advantage of high spatial resolution at high frequencies with the advantage of greater depth penetration at low frequencies at the expense of requiring more sophisticated analysis (Doel et al., 2014).

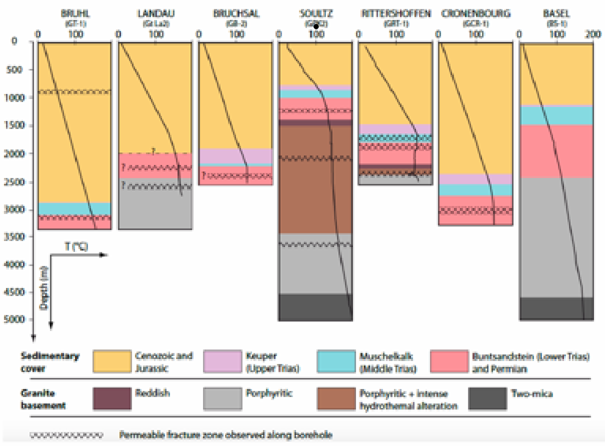
ADR is a time domain electromagnetic (TDEM) method but differs significantly from methods such as inductive polarization (IP) and resistivity methods. Those methods employ much lower frequencies and do not involve propagating waves but rely on measuring currents and polarizations induced by (relatively) slowly varying electric or magnetic fields. ADR on the other hand uses propagating wave packets and derives subsurface properties from the changes in spectral content and energy measured in the reflections. As such the data analysis resembles seismic methods more than the usual TDEM inversion techniques. However, ADR waves are electromagnetic which are governed by different physics than seismic pressure waves.

Adrok has developed ray tracing and finite-difference time-domain (FDTD) simulation software for numerical simulation of the ADR wave propagation through various subsurface materials (Doel & Stove, 2016). Simulated scans are used for preliminary feasibility studies and for experimental design of specific field scans using ground models based on known geology and/or borehole data if available. For example, in the case of simulated the Upper Rhine Graben effects on the EM waves, Figure 1 was used as input data to the model.

The ground is modelled as a stratified layer model with dielectric values according to the model in Figure 1, for example. The coupling to Maxwell's equations is modelled with the Debye model (Debye, 1929), which considers the materials as a mix of mobile charges, described by the static conductivity, and inertialess dipoles that lose energy due to friction. Parameters were taken from the measurements described in Doel et al., 2014 and Stove G. et al., 2023. In figure 2, the ADR wave packet (top) travels from surface (left z=0) into the ground. At each change in dielectric (lower plot), corresponding to material interfaces, part of the wave packet is reflected back up to the surface where it is detected by the surface receiver (Rx). Homogeneous regions generate continuous backscatter (small wiggles traveling up (left)) caused by granularity of the material. This backscatter contains spectral information regarding material composition, whereas the timings of the interface reflections can be used to compute velocity and thereby dielectric.

To account for observed backscatter in homogeneous regions, small random fluctuations are added to the dielectric values at random horizons. In the context of the simulations described here their only effect is a slight increase in energy loss due to the backscatter in addition to conductivity losses. This process is described in Doel & Stove, 2016 and Doel et al., 2020.

The depth of penetration of the transmitted ADR wave packets can be tuned to different transmission frequencies and energies (and two-way travel times) to suit different distance scales of propagation through solid objects. Adrok are keen to explore deep penetration applications for subsurface natural resource mapping at the geological scale as well as shallower penetration applications for close-range geotechnical imaging (for further explanations, refer to Doel & Stove, 2018; Doel et al., 2014). Depth is measured from time and velocity by ray tracing and Normal Move Out (NMO) computations, similar to the methods used in the seismic industry (Doel et al., 2014; Stove, G. D. C., Stove, G.C., and Robinson, M., 2018; Doel 2023).



Chronostrategrapy	Formation	Lithology	Top Depth (metres)	Bottom Depth (metres)	Adrok Dielectrics
Cenozoic and Jurassic	Sedimentary cover	Sand/Shale mixture	0	900	4
Triassic (upper)	Keuper	Dolomites, Shales or Claystones	900	1000	12
Triassic (middle)	Muschelkalk	Shell-bearing Limestone	1000	1100	10
Lower Triasic & Permian	Bruntsandstein (Bunter Standstone)	Sandstone	1100	1500	3
Granite Basement	Granites	Granites with porphyritic and intense hydrothermal alteration	1500	2000	5

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Figure 1 Example of simulated model input data based on Upper Rhine Graben geological data for drillhole Soultz 1 (Ledsert & Herbert, 2020) and theoretical dielectric values, based on Adrok's experience of similar rock types.

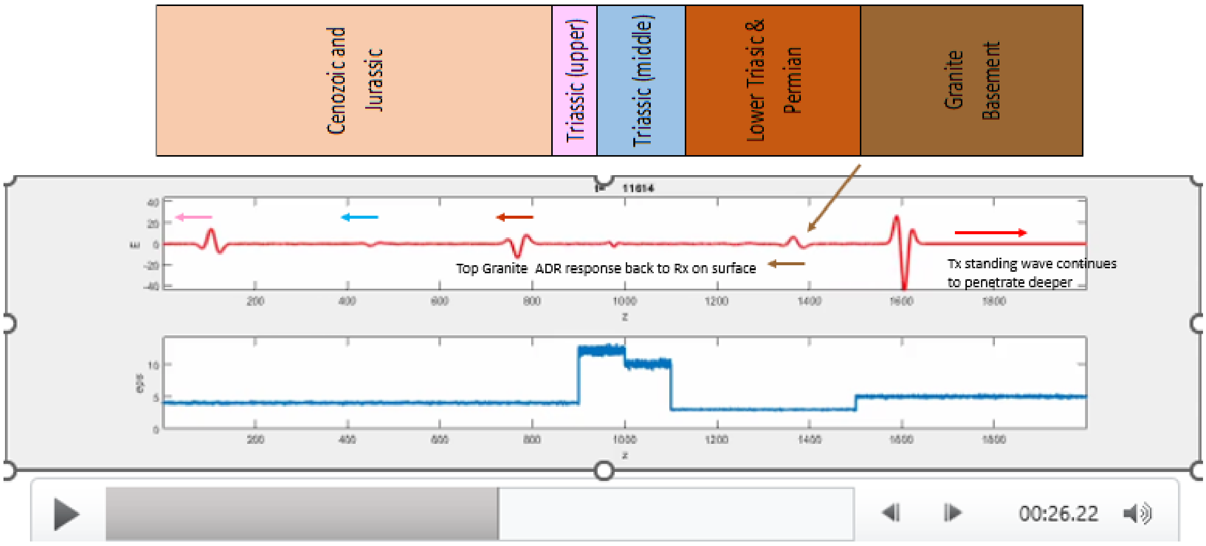

Figure 2 Simulated electromagnetic pulse and reflections (red line) modelled against dielectric values in the ground (blue line). Depth below ground level shown in the x-axis. The electromagnetic pulse emitted by Tx enters the ground and subsurface reflections are recorded at the receiver Rx. Noise level is defined as the ratio of the background noise at the receiver and the peak signal when entering the ground.

Results

Simulated models will be presented for the following three geothermal settings in the:

i. Upper Rhine Graben, France;
ii. North German Basin, Denmark (Fuchs, S., et al., 2020);
iii. Rhône Valley (Swiss Alps) near Lavey-les-Bains, Switzerland (Link, K., et al, 2020).

All these simulations show that the pulsed EM waves can propagate deeply into the earth.

Field measurements will be presented for the United Downs and Eden Project geothermal projects in Cornwall, United Kingdom.

Overall, the EM methods have demonstrated:

Measuring subsurface Temperature effects: The principal application for Adrok would be in the pre-drilling terrain to prospect-scale thermal characterization of the Earth's crust. Thermal maps could be easily generated which point towards the best target areas. Adrok requires some calibration work before providing absolute values.

Measuring water: Water has a high dielectric (>80). Due to this natural feature, the pulsed EM can measure peaks in relative dielectric values with depth. The identification of water-rich/aquifer layers at depth could be targeted in a similar way to the lithium brines in fracture hosted fluid pathways in Cornwall (UK) or thinner water-filled fractures in Switzerland.

Monitoring Temperature effects: Adrok can be used at key location around a geothermal borehole for example to monitor the change in temperature over time. If survey stations are established, ADR measurements could be made from the same station 12 months apart to provide a guide as to the annual change in temperature. This can, in turn, be used to better forecast the longevity of a geothermal field.

No special permits needed to deploy ADR: The ADR tool uses lower energy and transmits low power. The non-destructive, non-invasive nature of the technology means that 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. The portability and ease of manipulation of the equipment means it is very user friendly, cheap, and non-invasive.

References

Debye, P., 1929, Polar molecules: Chemical Catalogue Company.

Doel, van den, K., Stove, G., 2016, Modelling and Simulation of a Deeply Penetrating Low Frequency Subsurface Radar System, proc. EAGE, Vienna.

Doel, van den, K., and G. Stove, 2018, Modelling and Simulation of Low Frequency Subsurface Radar Imaging in Permafrost: Computer Science and Information Technology, 6(3), 40–45.

Doel, van den, K., Robinson M, Stove C, Stove G., 2020, Subsurface Temperature Measurement Using Electromagnetic Waves and Machine Learning for Enhanced Oil Recovery, Conference Proceedings, 82nd EAGE Annual Conference & Exhibition, Volume 2020, p.1 – 5

Doel, van den, K., 2023, Propagation and attenuation of EM waves in complex media, https://www.adrokgroup.com/technology/how-it-works

Doel, van den, K., Jansen, J., Robinson, M., Stove, G.C., Stove, G. D. C., 2014, Ground penetrating abilities of broadband pulsed radar in the 1-70MHz range, proc. SEG, Denver.

Fuchs, S., Balling, N., Mathiesen, A. (2020): Deep basin temperature and heat-flow field in Denmark – New insights from borehole analysis and 3D geothermal modelling. - Geothermics, 83. DOI: http://doi.org/10.1016/j.geothermics.2019.101722

Ledsert, B.A., & Herbert, R.L., 2020, How Can Deep Geothermal Projects Provide Information on the Temperature Distribution in the Upper Rhine Graben? The Example of the Soultz-Sous-Forêts Enhanced Geothermal System, Geosciences 2020, 10(11), 459.

Link, K., Lupi, N., Siddiqi, G., 2020, Geothermal Energy in Switzerland – Country Update 2015-2020, Proceedings World Geothermal Congress 2020 Reykjavik, Iceland, April 26 – May 2, 2020

Stove, G. D. C., Stove, G.C., and Robinson, M., 2018, Radiowave method for monitoring steam injection for Enhanced Oil Recovery (EOR) and for finding sources of geothermal heat, Geothermal Resources Council (GRC) Transactions Volume 42: pp1557-1567, ISBN: 0-934412-23-5

Stove, G., Doel, van den, K., Edwards, T.M., Paling, S.M., Scovell, P.R., 2023, Deep detection range test for a low frequency subsurface radar system (with reviewable data available online), Conference Proceedings,84th EAGE Annual 2023

Stove, G. C. et al, 2023, Method for determining material and/or subsurface temperatures, USA Patent No.: US11,604,302 B2, Edinburgh, GB: US Patent Office.