Environmentally friendly low impact, low carbon footprint, low power electromagnetic technique for shallow geothermal exploration

Introduction

Geophysicists in the 21st century now accept their commitment to being a sustainable and responsible surveyor of the Earth's subsurface. Reducing our carbon footprint on our route to Net Zero in the face of the challenges presented by the global pandemic and the subsequent return to work, fieldwork and international air travel is not an easy task. Whatever our geophysicist tool of choice we can take some basic steps to help, such as:

1. Protect the environment by lessening our impact through monitoring and reducing our carbon emissions
2. Raise awareness without our own organisation of things that colleagues can do to reduce their personal carbon emissions as well as reducing carbon emissions within our organisations
3. Engage colleagues in environmental issues and initiatives
4. Identify environmental causes that we can support; and
5. Publicly hold ourselves accountable for our carbon footprint by publishing our carbon impact on our websites and public domain media channels.

Above all, we can develop and use our geophysics tools and technology in an environmentally way. We have been developing a low carbon, low impact geophysics offering for the past two decades. Over the past five years we have been letting our clients know what our carbon footprint levels are for each geoscientific survey. Multiple surveys have been performed in Northeast England for a geothermal and lithium brine exploration using its novel electromagnetic (EM) technologies. This paper will explore this survey in more detail through a geophysical lens and an environmental lens.

Method and/or Theory

The EM technology used for this project is known as Atomic Dielectric Resonance (ADR) technology and is based on the principle that different materials will reflect and absorb electromagnetic radiation (radio waves, microwaves) at specific frequencies and energy levels. The ADR system transmits a pulse of electromagnetic energy containing a multispectral (patented) wave packet that resonates and reacts with the sub-surface materials (Stove 2020). 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 transmitted ADR wave packet contains several frequency components in the range of 1-100 MHz where the low frequencies achieve deep penetration whereas the higher frequencies enhance vertical resolution (Stove 2018). The technology measures the dielectric permittivity of the subsurface as well as characterizing the nature of the rock types based on analysis of both the spectroscopic and resonant energy responses (Doel et al, 2020). The ADR system is non-destructive and non-ionising that transmits EM wave signals directed at the ground to penetrate the Earth's subsurface. The system's transmission of EM waves should therefore not pose any harmful threats to persons, flora and fauna in its transmission path.

Specification of the ADR transmitting sensor in the field:

- transmits pulsed EM waves into the ground in the frequency range of 500kHz to 30MHz
- power emitted is less than 5 milliwatts (mW). This is extremely low power and does not damage the solid material it propagates
- power supply to transmitter is 15v DC Li-Ion battery; batteries are rechargeable and recyclable
- majority of raw materials used in the system are selected based on recyclability and reusability.

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. We 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).

Northeast England Survey (Case Study)

This research and development project for subsurface geothermal heat identification was conducted in various onshore sites in the UK. There are two different types of geothermal energy; low enthalpy (low temperature) resources that can provide warm water for direct applications, and high enthalpy (high temperature) resources that can yield hot water that is capable of driving turbines and generating electricity (Gillespie et al., 2013).

Within the sites selected in NE England (Figure 1), there are two different geological settings that have a large impact on the geothermal scenarios that may be encountered. Science Central and Bishop Auckland are both situated within successions of Carboniferous Limestones and Sandstones. This means that the geothermal setting is likely to be a deep aquifer related to heat transfer from the many granite batholiths in NE England. Drilling at Science Central has confirmed a high geothermal gradient of 39°C/km (13°C/km higher than the UK average), with a potential reservoir in the Fell Sandstone at 1418m deep (Younger, 2016). Rookhope and Eastgate are both situated directly above the Weardale Granite, which drilling has pinpointed at depths of 390m & 270m, respectively (Manning et al, 2007). The Weardale Granite is expected to be a strong source of heat in the area, with post-drilling logging at Eastgate showing temperature of 46.2°C at 995m (10-15°C higher than the UK average). Significant volumes of hot saline water were also encountered during drilling at Eastgate, particularly at 411m depth (PB Power, 2005).

Statistical signal processing techniques were developed to assist information extraction of the resonant signal returns obtained from their ADR sensors following transmission through soil, sediment and rock layers and reception by a matched bistatic ADR receiver. The resulting processed data suite is a specific set of logs which display signal frequency returns and a specific set of logs which display signal energy returns. To evaluate mathematically and statistically the exact nature of the signal oscillations through time and space (distance), we have developed a series of precise “measures” which examine the degree of Reflectivity of the signal. E-Gamma is the basic measure of Energy Reflectivity. Mathematically it is described as follows: **E-Gamma = ((Emax –Emin)/ (Emax+Emin))**

This means that the Relectivity of the signal energy is simply the ratio of the maximum signal difference parameters (Maximum Energy (%) minus Minimum Energy (%)) divided by the sum of the maximum signal energy (%) plus the minimum signal energy (%). The analogy is the E-Gamma, also called “modulation” in the literature, of a photographic film in terms of grey level returns. The E-Gamma results showed the most promising correlation to ground-truthing (by way of drill log results comparison) across all of the drill locations.

When the three Eastgate 2 (EG2) sites’ E-Gamma’s are averaged, all three low E-Gamma anomalies are identified. The most significant low E-Gamma anomaly in EG2 is at a depth of 400-490m, within the Weardale Granite. This correlates well with drilling, as a strong influx of warm, saline water was encountered at a depth of 411m (PB Power, 2005). The other two E-Gamma anomalies are located at depths of 530-610m & 640-690m.

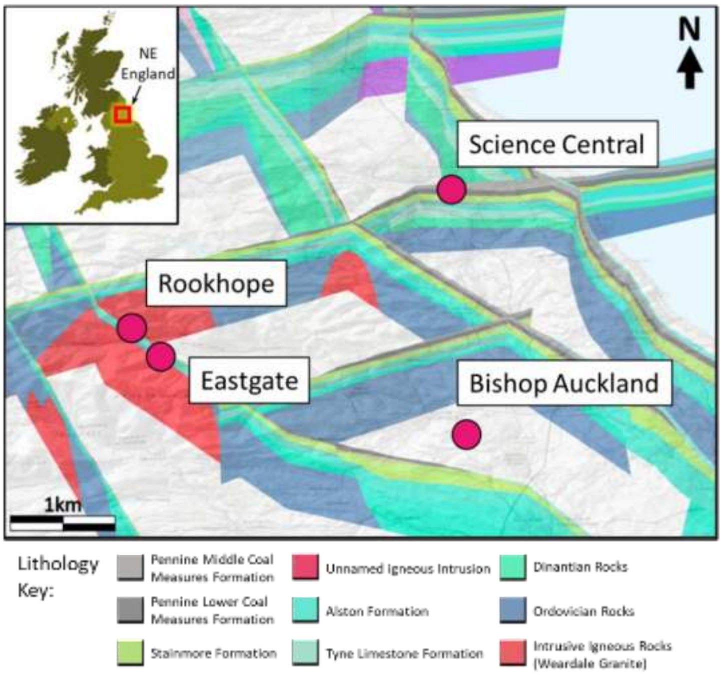

Figure 1 *Location map and geology of NE England sites*

A new method has been developed in order to pinpoint the "hottest" horizons with more precision and accuracy. The top 20 "troughs" or low values of E-Gamma for each V-Bore (below the beam saturation) have been selected and plotted together with depth in order to gain greater insights into the areas that yield the most heat (Figure 2).

Conclusions

This paper describes the deployment of an EM technology that is an environmentally friendly non-destructive way to see below the ground surface for geology. The method of deployment, on the ground, as opposed to airborne or downhole, means that there are zero emissions generation. The only carbon footprint is created by the transportation of the two-person survey crew and equipment to and from survey location (ideally not be aeroplane, preferably by car or train) and a small amount of carbon generation from computer data processors.

Regarding the Case Study, the interpreted results show that the technology can identify the highest temperatures below the ground and prognose their depths with reasonable accuracies. Moreover, the technology demonstrates repeatability in measurements. The field measurements show encouraging potential for the technology to be applied as a pre-drilling tool in onshore geothermal plays around the world, given the ease of survey deployment and low environmental footprint.

We acknowledge that this technique is still in its infancy and requires more work to explain the relationships. Is this method picking up changes in temperature or changes in water or brine or a mixture of both? We do not (and cannot) claim to fully understand why it works at this stage, but the case studies we have worked on have shown consistent matches to reality. It would be interesting to apply this methodology to other electromagnetic (EM) subsurface measurement methods such as resistivity surveys which should also be able to see a relation between resistivity and temperature which perhaps could be disentangled from the geological features. We would probably need to visit an oilfield to obtain fuller subsurface measurements, where downhole tools and temperature and fluid measurements are readily available for calibration and corroboration against ADR measurements. The geoscience surveys for this project generated a small footprint of only 1.02 tCO_2e.

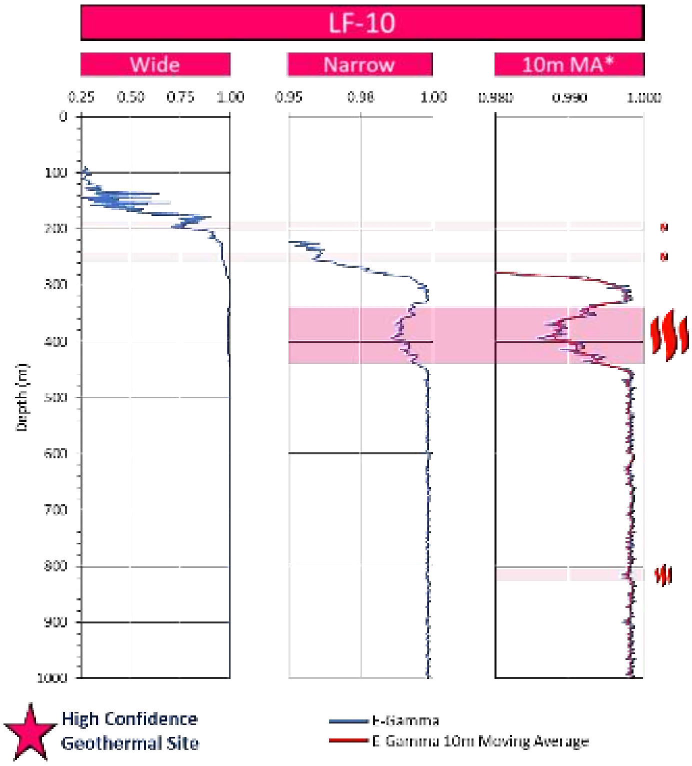

***Figure 2** The strongest thermal impact at the site from 340-440m depth. After the signal stabilisation point it presents a very intense trough.*

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