New method for monitoring steam injection for Enhanced Oil Recovery (EOR) from ground level without drilling

Introduction

This presentation displays Atomic Dielectric Resonance (ADR) methods for remotely monitoring steam injection for Enhanced Oil Recovery (EOR) and for subsurface lithology. Adrok has developed a Forward Model in collaboration with the University of British Columbia. In theoretical modelling and empirical field measurements, Adrok have observed that the high frequencies of its transmission pulses into the ground were found to penetrate very little, but the low frequency component had very low losses. Results were analyzed to estimate the skin depth and interpreted in terms of a constitutive model incorporating Maxwell's equations with conductivity and polarization losses.

In a separate experiment we successfully detected the reflection of the radar pulse from a body of water through 350m of rock. A numerical simulation of the model confirmed that these results do not contradict theoretical expectations. The directional radar pulse was emitted and recorded using equipment provided by Adrok Ltd (Stove, 2015) as shown in Figures 1. We recorded the pulse in air and show its temporal and spectral shape The dominant frequency components are between 1MHz to 100MHz. We verified the directionality of the pulse by additional measurements in air. Figure 2 shows subsurface behaviour. Table 1 shows ADR Scanner settings and specifications.

Experiments have been performed to quantify the depth penetration possible with the system, and to explain the results theoretically with a propagation model based on Maxwell's equations coupled to a ground model (Doel et al., 2014) . Working with Chevron, empirical evidence of the technology's efficacy in monitoring steam injection for Enhanced Oil Recovery (EOR) has been demonstrated and warrants further investigation.

Specifications

ADR Setting	Typical Range
Tx frequencies for geology	100kHz-200MHz
Time Range	2ns to 250,000ns
Number of pixels per trace	40 to 4000
Pulse Repetition Frequency (PRF)	10-100kHz
Pulse Width	0.1ns to 10ns
Power supply	4 off 24Vdc Li-Ion batteries
Power consumption	150W for ADR equipment *plus 100W for tablet PC*
Power transmission	< 5 miliwatts (mW)

Table 1: Specifications of ADR Scanner systems

Field ADR Scanner

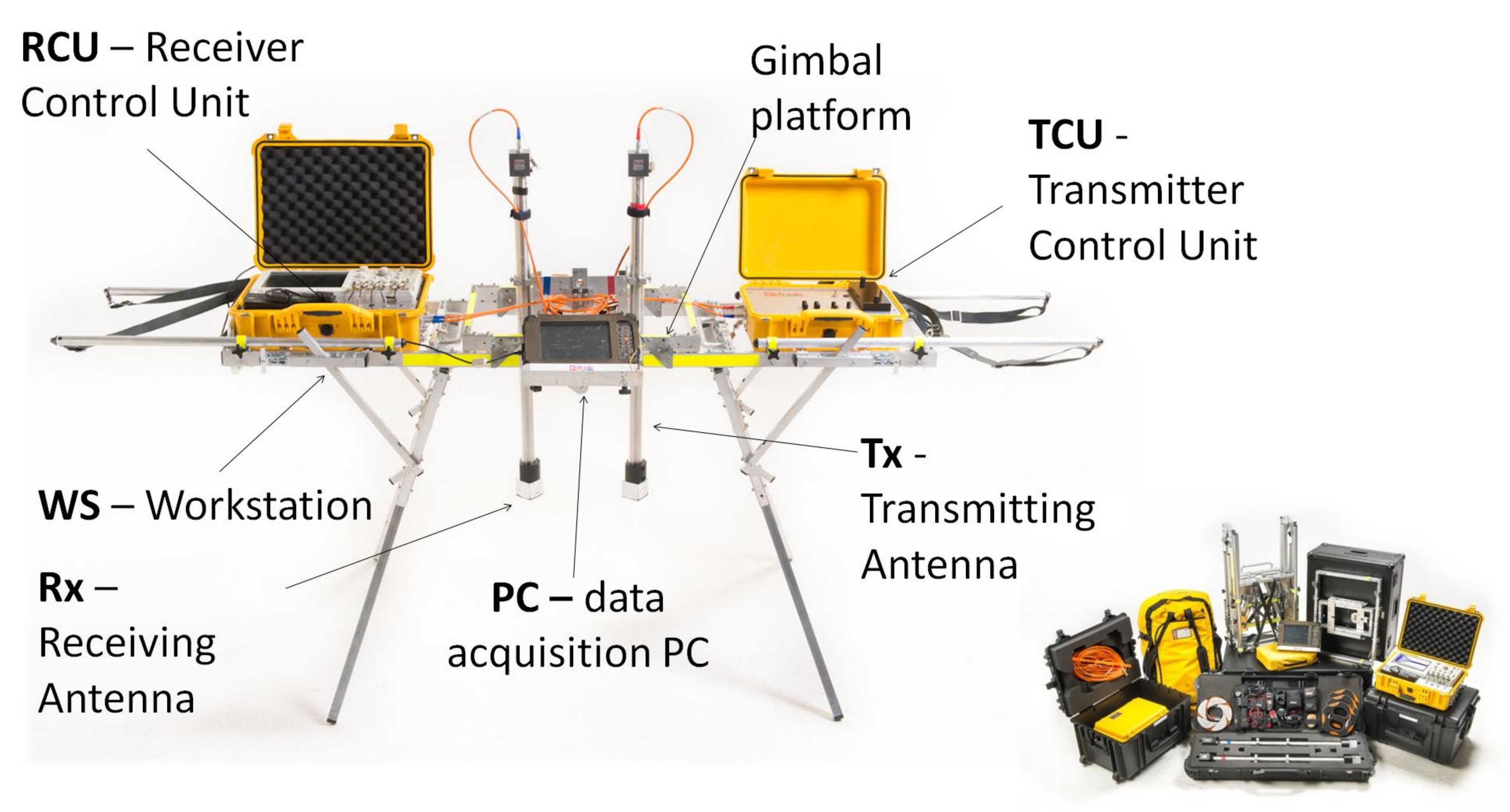


Figure 1 Field ADR scanner

Temperature Measurements using ADR

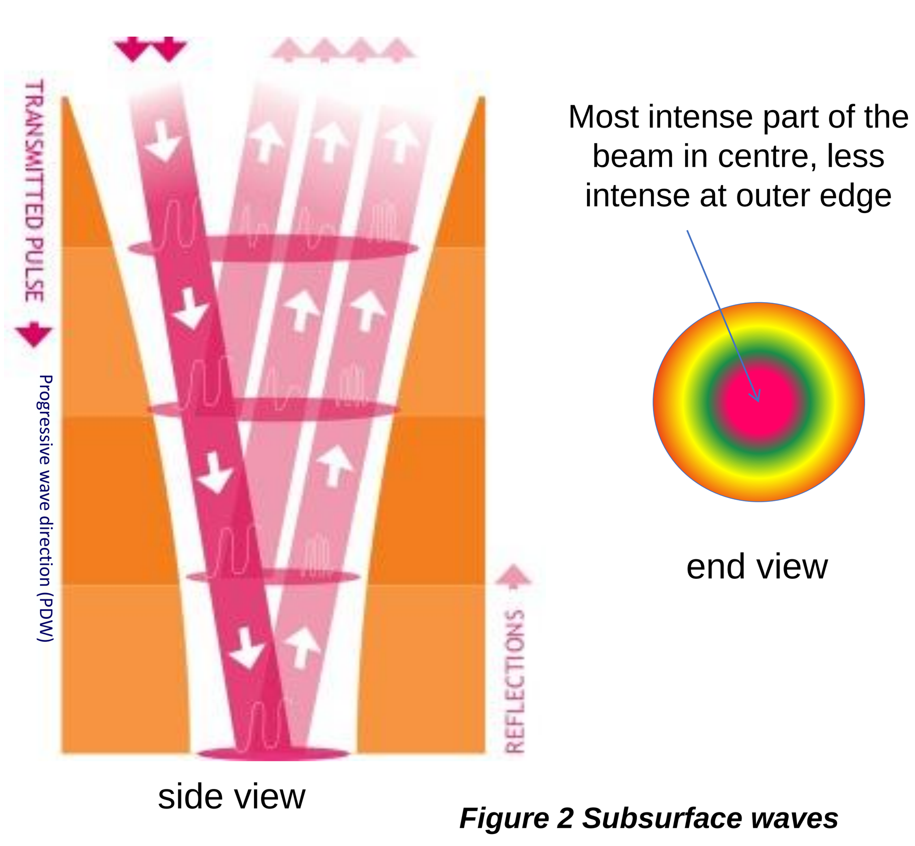


Figure 2 Subsurface waves

- The Beam Wavenumber (Bn) of the beam is: $Bn=kx\sqrt{|DC|}$

Where: $k = 2\pi/\lambda$ and $\sqrt{|DC|}$ is the square root of the modulus of the dielectric constant, which is a measure of the electrical permittivity of the medium through which the beam is being propagated by transmission through the Radar Cross Section (RCA).

- This formula clarifies the relationship between Bn, λ and DC
- Considering a two dimensional RCA where the x-direction is horizontal to the surface of the ground and the z-direction is vertical $Bn=2\pi x/\lambda\sqrt{|DC|}=2\pi x\sqrt{((1/\lambda_x)^2+(1/\lambda_z)^2)|DC|)}$

- The energy density (ρ) of ADR radiation through a layered RCA medium should increase with the absolute temperature in accordance with **Stefan Boltzmann's Law**: $\rho=\sigma T^4$
- The ADR 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: $\alpha=(\sigma\lambda_x T^4)/(Ed(S))$

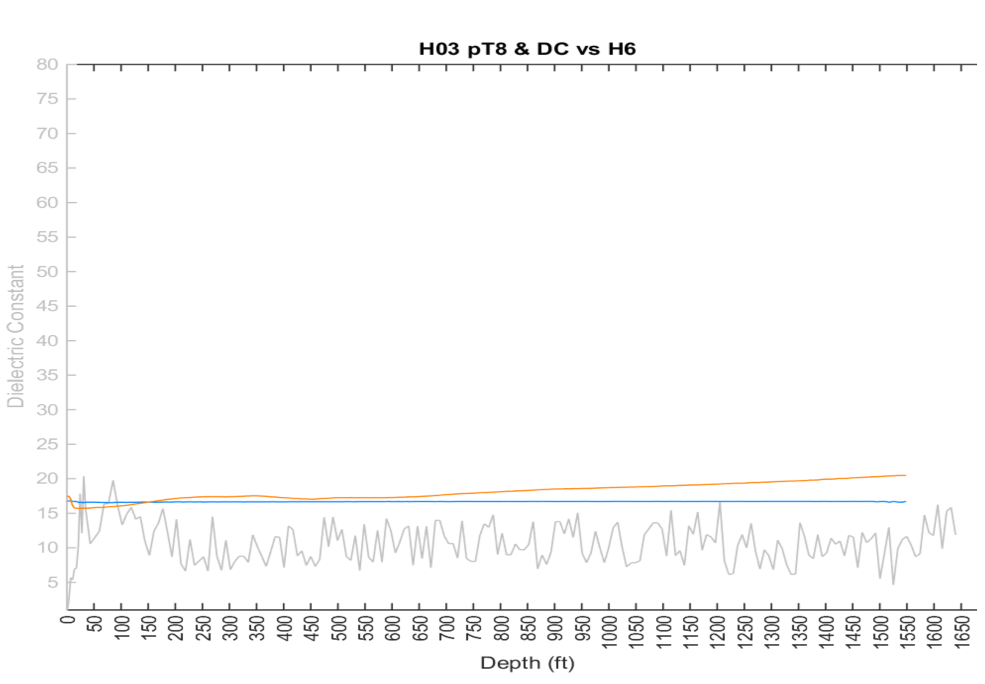
And, rearranging, it can be seen that the **temperature T** can be calculated by: $T=\sqrt[4]{((Ed(S)\alpha)/(\sigma\lambda_x))}$

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

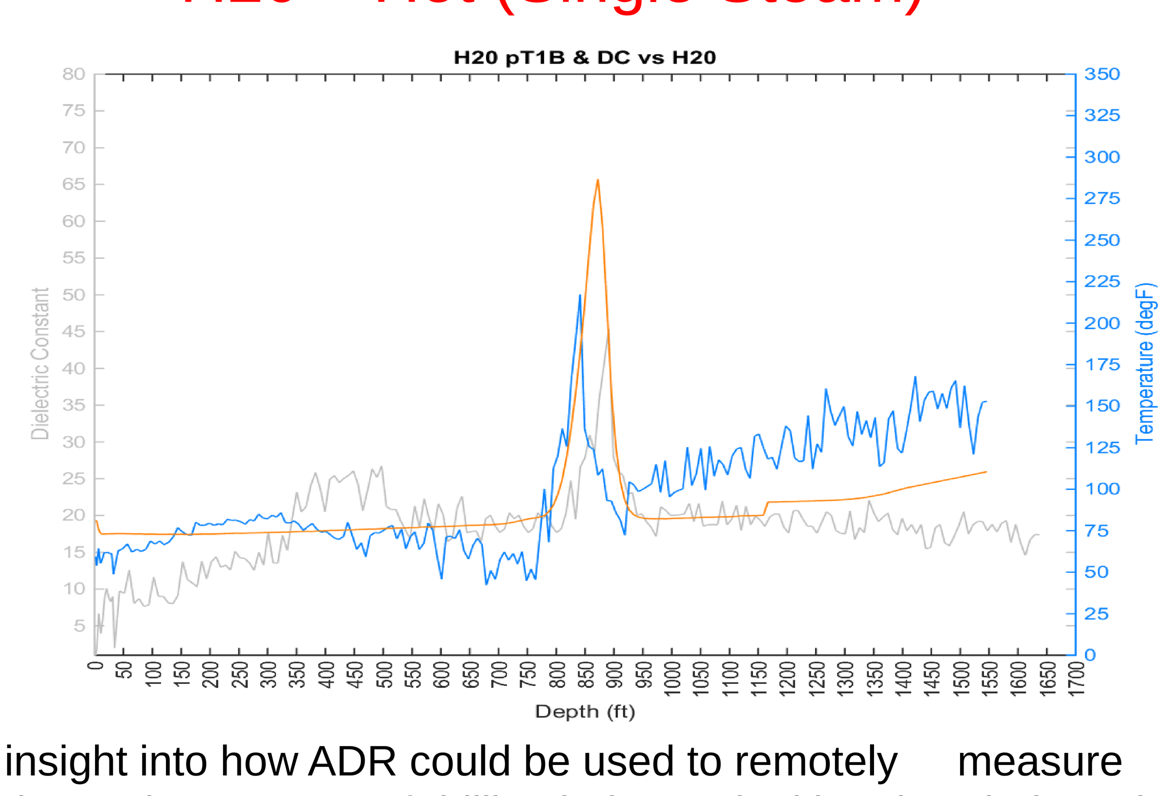
Case Study - California

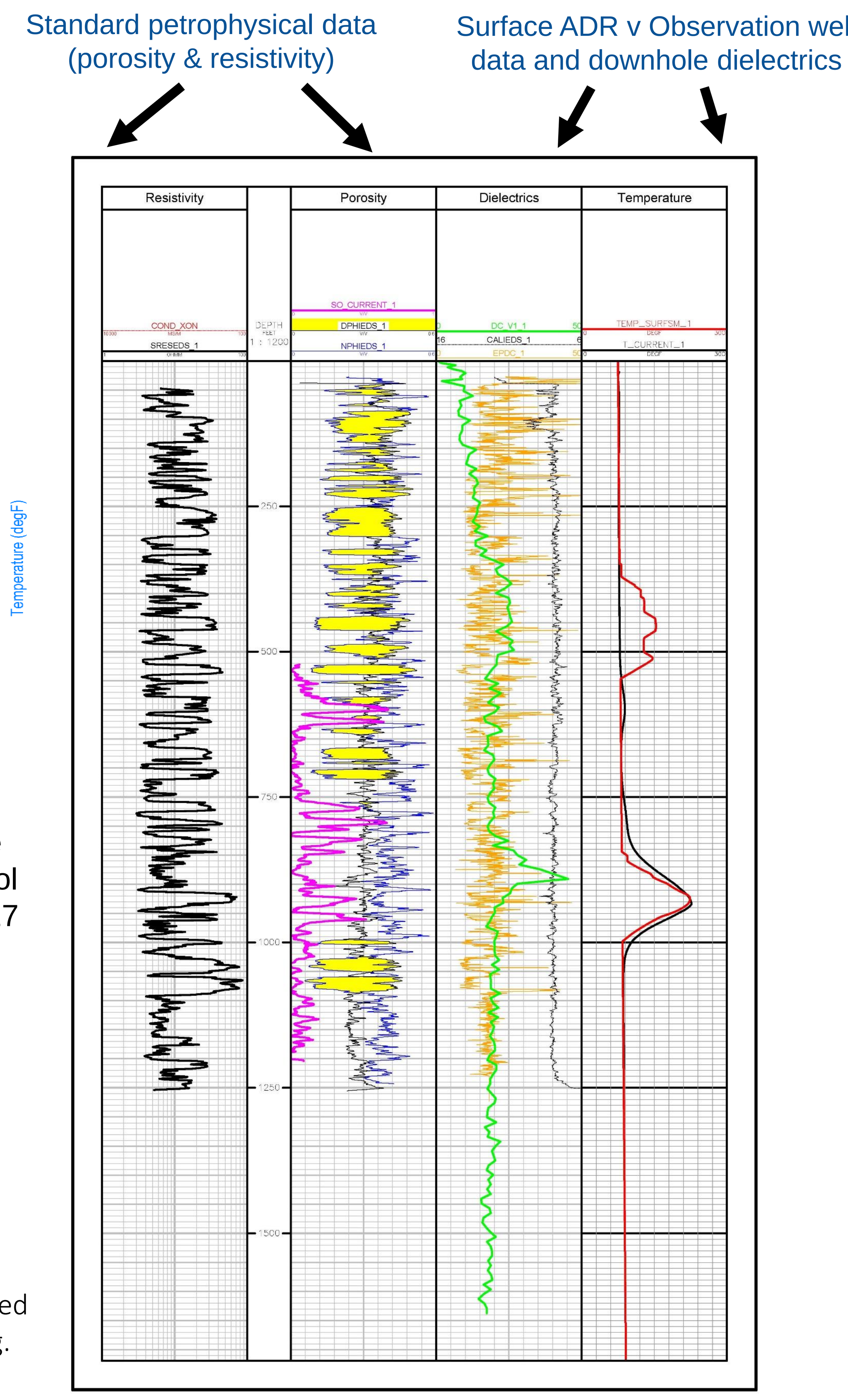
A database of over 10,000 wells with open hole logs, of which over 600 wells are dedicated surveillance wells with whole core, time lapse Carbon/Oxygen, Neutron, and Temperature data is being used for evaluating a deep penetrating radar system. The database is from the thermally operated Kern River Super Giant oilfield in Kern County California, USA. The technology being tested is ADROK 's deep penetrating radar system (ADR). The Kern River field and dataset thru-out its history has provided a robust environment for training and blind testing of various technologies (time lapse Carbon Oxygen, EM, cross well tomography to name a few).

H3 – Cold



H20 – Hot (Single Steam)





In conclusion, this research has proven to be a valuable insight into how ADR could be used to remotely measure subsurface temperature changes in the ground before going to the expense of drilling holes and taking downhole tool measurements. The research is still ongoing. Our initial studies will be supplemented by additional surveys in 2017 and 2018 to investigate:

- repeatability,
- asset time-lapse potential,
- a new acquisition geometry to improve time to depth conversion, and
- test depth capability by recording down the Lower Vedder Sands at ~ 6000feet.

Our expectations are to increase the current success rate of 80% to 95% or better, which would put this technology into a commercial product.

References

.Doel, van den, K., Jansen, J., Robinson, M., Stove, G. C., and Stove, G. D. C., 2014 Ground penetrating abilities of broadband pulsed radar in the 1-70MHz range. SEG Technical Program Expanded Abstracts 2014: pp. 1770-1774. SEG Denver 2014 Annual Meeting.

.Stove, G. D. C., and Doel, van den, K., 2015, Large depth exploration using pulsed radar. In: ASEG-PESA Technical Program Expanded Abstracts 2015, Perth. 1–4.