# Deep detection range test for a low frequency subsurface radar system (with reviewable data available online)

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## Summary

Applications of ground penetrating radar are currently mostly limited to shallow depths of a few tens of meters, because of the strong attenuation of radio waves in most subsurface materials at a typical frequency range of 30 1000MHz. Losses are caused by conductivity and polarization effects due to moisture content or inherent material properties. Deeper penetration has been achieved with much lower frequencies (1 - 5Mhz) using very large antenna's in resistive environments such as Martian rock, ice, and permafrost.

We test the ground penetrating ability of a low frequency pulse radar system with a centre frequency around 3MHz. We previously reported experimental results measuring the in-situ attenuation rates through limestone and a reflection mode scan of the surface from 350m below ground. In this study we use this radar system to detect a reflection from the ground surface from 1100m below the ground using reflection mode scans. The main difference with the previous study is an increase of stacking by three orders of magnitude. Previously we stacked 500 traces, with our current setup we stack almost 500,000 traces. Results show a clear reflection in the full stack near 21,500 ns. Data from this project can be reviewed at https://www.adrokgroup.com/data.

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We test the ground penetrating ability of a low frequency pulse radar system with a center frequency around 3MHz. We previously (van den Doel et al., 2014) reported experimental results measuring the in-situ attenuation rates through limestone and a reflection mode scan of the surface from 350m below ground. In this study we use this radar system to detect a reflection from the ground surface from 1100m below the ground using reflection mode scans. The main difference with the previous study is an increase of stacking by three orders of magnitude. Previously we stacked 500 traces, with our current setup we stack almost 500, 000 traces. Results show a clear reflection in the full stack near 21, 500 ns.

The data gathered for this experiment is freely available at (ADROK, 2023).

## Experimental setup

*Boulby Underground Laboratory*

Boulby Underground Laboratory is a multidisciplinary deep underground science facility located at Boulby Mine, between Saltburn and Whitby on the north-east coast of England and on the edge of the North Yorkshire moors. The facility, operated by the Science and Technology Facilities Council (STFC), hosts a range of studies from low background particle physics (the search for Dark Matter) to studies of geology, geophysics, life in extreme environments and planetary exploration technology development (https://www.boulby.stfc.ac.uk). Boulby mine is a working polyhalite and rock-salt mine that previously also mined potash and is operated by ICL-UK. The salt (NaCl) and potash (KCl) seams mined here are left over from the evaporation of an ancient sea (the Zechstein Sea) during the Permian geological period, some 260 million years ago (Duff and Smith, 1992). The laboratory resides underneath 1,100 meters (3,600 feet) of solid rock below the Earth's surface. Boulby Mine is Europe's second deepest mines. Boulby potash occurs at depths between 1,100 and 1,350m in a seam ranging from 0-20m but averaging 7m in thickness. Within a Permian evaporate sequence, sylvinite ore comprises 40% Sylvinite, 40% Halite 15% silts and other impurities. The sedimentary strata above the evaporites include the Triassic Sherwood and Bunter sandstones, which contains substantial volumes of brine under high pressure (https://www.mining-technology.com/projects/boulby). Above the sandstones lie Marls (600m to 365m below ground level) and Shales from 365m (bgl) to ground level. See Figure 1 for a diagram of the lab and surrounding geology.

*Experimental setup*

Transmitter and receiver were placed in close proximity in the underground excavation and electromagnetic wave packets approximately 200ns long and containing frequency components from 2 70MHz with significant peaks at 3, 20, 30, and 65MHz (van den Doel et al., 2014) were emitted in 15 sets of 32, 000 at a rate of 10, 000 pulses per minute. Such a set will be referred to as a STARE. The return (and clutter) signals were recorded as digital waveforms at a sampling rate of 2.5GHz, resulting in 480, 000 traces. Due to space restrictions in the underground facility, it was not possible to obtain a velocity model with a triangulation (WARR/CMP) scan (Stove and van den Doel, 2015), so we use a theoretical velocity model based on dielectric estimates of the materials involved.

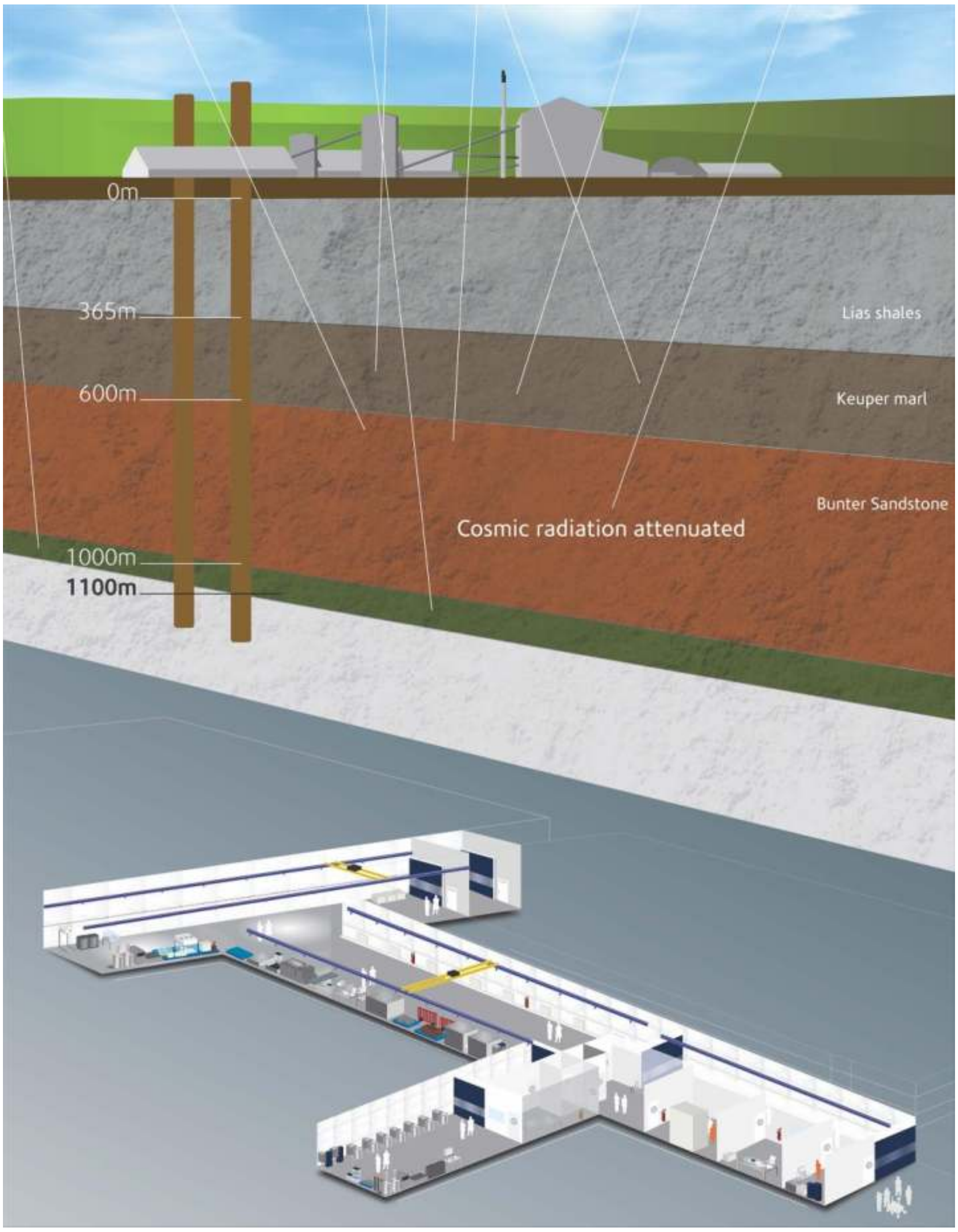


***Figure 1*** *Boulby Underground Laboratory.*

**Results**

Figure 2 shows a simple plot of the partially and fully stacked data in the time domain. Horizontal scale is in nanoseconds, vertical scale is relative amplitude normalized to $[-128\ 128]$. The reflection from the ground surface can be seen in the upper figure, which is the fully stacked data, around $22,\ 000$ns. However, using just one STARE set (lower figure) is not sufficient to reduce the clutter for an unambiguous identification of the ground surface. Velocity $v$ is determined by the relative permittivity or dielectric $\varepsilon_r$ by $v = \frac{c}{\sqrt{\varepsilon r}}$ with $c$ the speed of light in vacuum. From the time of the reflection and distance covered (1100m) we derive a bulk relative permittivity of around 8.6. In Table 1 we show a dielectric (velocity) model based on the geology that is consistent with this.

In Figure 3 we show the result of applying the stacked correlation method (van den Doel, U.S. Patent 10,444,390 B2) to detect the reflector using the velocity model mentioned above to migrate the data to the spatial domain. Indicators are stacked correlations that indicate how coherent the stack is and an associated standard deviation. An example of use of this method for determining critical noise levels can be found in van den Doel and Stove (2019, 2018).

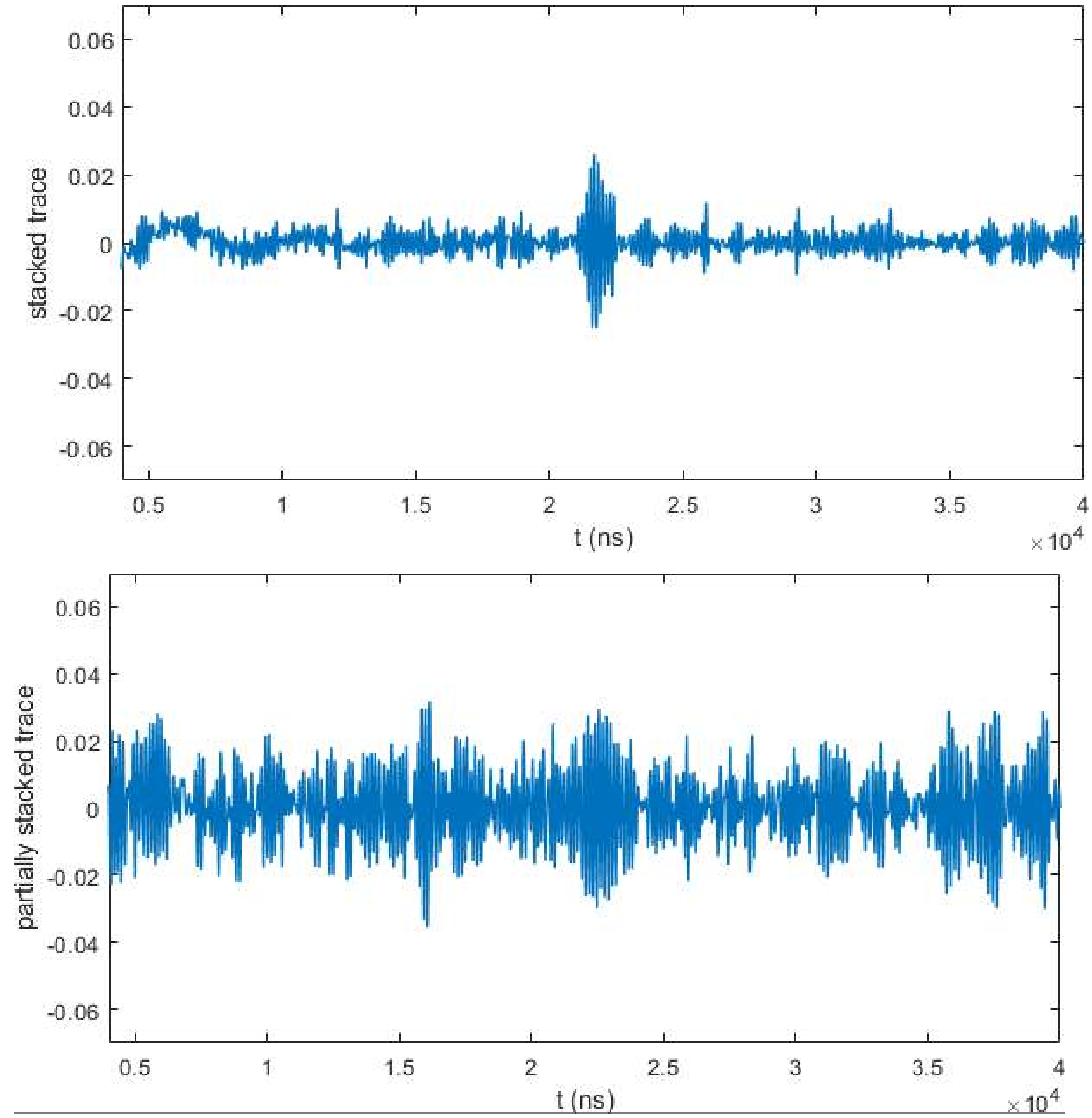


***Figure 2*** *The lower figure displays the (denoised) stack from a single STARE, the upper figure displays the full stack of all* 15 *STARES.*

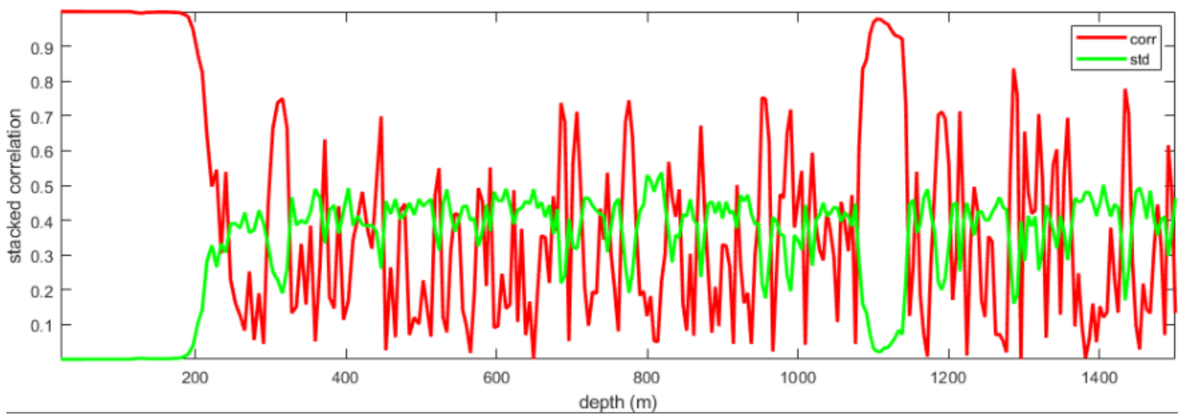


***Figure 3*** *Stacked correlations plot. Peaks of stacked correlation (blue) above the stacked standard deviation (green) indicate coherent reflected signal. The ground reflection is very prominent around* 1100*m.*

| Depth (m) | Material | $\varepsilon_r$ |
|---|---|---|
| 0-365 | Lias Shales | 12 |
| 365-600 | Keuper Marl | 10 |
| 600-1000 | Bunter Sandstone | 7 |
| 1000-1100 | Polyhalites (Potash) | 2.5 |

***Table 1*** *Illustrative dielectric model values for various layers. Mean bulk dielectric from transmitter to ground surface level is* 8.6.

## Conclusions

We demonstrate the detection of the ground-air interface from a low frequency radar scan 1100m below the surface. The detection is possible by using a very low center frequency for the pulsed radar wave packet, and extensive stacking to reduce noise and clutter.


## Acknowledgements

We are grateful for Boulby Underground Laboratory to allow us access to perform the experiment.


## References


ADROK [2023] https://www.adrokgroup.com/data

Angelopoulos, M.C., Pollard, W.H. and Couture, N.J. [2013] The application of CCR and GPR to characterize ground ice conditions at Parsons Lake, Northwest Territories. *Cold Regions Science and Technology*, **85**, 22–33.

Berthelier, J.J., Bonaime, S., Ciarletti, V., Clairquin, R., Dolon, F., Gall, A.L., Nevejans, D., Ney, R. and Reineix, A. [2005] Initial results of the Netlander imaging ground-penetrating radar operated on the Antarctic Ice Shelf. *GEOPHYSICAL RESEARCH LETTERS*, **32**(L22305), L22305, doi:10.1029/2005GL024203.

Ciarletti, V., Martinat, B., Reineix, A., Berthelier, J.J. and Ney, R. [2003] Numerical simulation of the operation of the GPR experiment on NETLANDER. *JOURNAL OF GEOPHYSICAL RESEARCH*, **108**(E4, 8028), doi:10.1029/2002JE00186.

Daniels, D.J. [2004] *Ground penetrating radar*. The Institution of Electrical Engineer, London.

van den Doel, K. [U.S. Patent 10,444,390 B2, Oct. 2019] Method Of Identifying Reflected Signals.

van den Doel, 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. In: *SEG Technical Program Expanded Abstracts 2014, Denver*. 1770–1774.

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

van den Doel, K. and Stove, G. [2019] Calculation of optimal noise levels for the detection of conductive lenses in permafrost with radar scans. In: *EAGE 2019*. European Association of Geoscientists and Engineers, 1–5.

Duff, P.M.D. and Smith, A.J. [1992] *Geology of England and Wales*. Geological Society of London.

Jol, H.M. [2009] *Ground Penetrating Radar Theory and Applications*. Elsevier, Amsterdam.

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