Geophysical investigation of a badger sett located in a flood embankment on the River Ouse

.Keywords

Report; ERT, GPR, Badgers, Badger sett, voids.

National Grid Reference

SW corner 466627,430212
Centre point 466681,430229
NE corner 466734,430245

Front cover

Picture of the badger sett and Drax power station in the background

Bibliographical reference

White, A., Boyd, J. Wilkinson, P. B., Chambers, J. E. 2022. Geophysical investigation of a badger sett located in a flood embankment on the RIver Ouse. *British Geological Survey*.

Geophysical investigation of a badger sett located in a flood embankment on the River Ouse

White, A., Boyd, J. Wilkinson, P., Chambers, J.

Keyworth, Nottingham British Geological Survey 2022

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of UK Research and Innovation.

British Geological Survey offices

Nicker Hill, Keyworth,
Nottingham NG12 5GG
Tel 0115 936 3100

BGS Central Enquiries Desk
Tel 0115 936 3143
email enquiries@bgs.ac.uk

BGS Sales
Tel 0115 936 3241
email sales@bgs.ac.uk

The Lyell Centre, Research Avenue South,
Edinburgh EH14 4AP
Tel 0131 667 1000
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road,
London SW7 5BD
Tel 020 7589 4090
Tel 020 7942 5344/45
email bgslondon@bgs.ac.uk

Cardiff University, Main Building, Park Place,
Cardiff CF10 3AT
Tel 029 2167 4280

Maclean Building, Crowmarsh Gifford,
Wallingford OX10 8BB
Tel 01491 838800

Geological Survey of Northern Ireland, Department of Enterprise, Trade & Investment, Dundonald House, Upper Newtownards Road, Ballymiscaw,
Belfast, BT4 3SB
Tel 01232 666595
www.bgs.ac.uk/gsni/

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU
Tel 01793 411500   Fax 01793 411501
www.nerc.ac.uk

UK Research and Innovation, Polaris House,
Swindon SN2 1FL
Tel   01793 444000
www.ukri.org

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report is the published product of a study by the British Geological Survey (BGS). It describes the results of geophysical investigations with the aim of determining the structure of a known badger sett in a flood embankment. The site had previously been remediated with sheet piling.

Acknowledgements

This work was commissioned by the Environment Agency. We are grateful to Kim Ryan and her colleagues for their assistance and cooperation with the fieldwork.

Contents

FIGURES

Summary

Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) are two near-surface geophysical methods that are well suited to mapping air-filled cavities (e.g. burrows) in the shallow subsurface. They both have the advantage that they are non-intrusive, so can image the subsurface targets without disturbing them, which is advantageous for detecting, characterising, and monitoring animal burrows.

GPR is a very rapid technique that can survey large areas relatively quickly; however, flood embankments often have a clay component that can limit the depth of investigation of GPR surveys, with tunnels beyond the penetration depth of the instrument. ERT surveys are typically slower but are not limited by clay-rich ground. Both techniques are affected by metal objects in the ground, such as sheet piling and wire mesh, which are installed at the stie to prevent animal burrowing.

A desk study of badger sett morphology found that:

- Badgers rarely dig beyond 10 m from an entrance
- The tunnels are 30 cm wide and 20 cm tall
- Tunnels rarely go deeper than 2 m below the surface.

At the badger sett north of Drax power station, entrances were found within an area extending along 75 m of the flood embankment. The location of the sheet piling was confirmed using the GPR, and all badger tunnel entrances were found to be within this reinforced section of the embankment. However, the entrances at the site's eastern end were very close to the end of the sheet piling, making this area the focus of the geophysical survey.

In summary, the results of the geophysical survey (Figure 5) are as follows:

- Two areas of extensive tunnelling were found in the GPR data, matching tunnel entrances' locations.
- GPR could only detect tunnels in the first three lines, beyond which the tunnels likely continued but were over 1.5 m deep, deeper than the penetration depth of the GPR signal.
- Most of the tunnelling seems to be concentrated in the floodplain and embankment toe.
- ERT focused on the eastern area but was partially affected by sheet piles, especially the lines perpendicular to the embankment.
- Tunnels interpreted from the ERT data head towards the crest of the embankment close to where the sheet pilling ends.
- We are unsure if we imaged the full extent of the tunnels or if they continued in to the embankment, but they were beyond the detectability of the instruments at these depths. Furthermore, the proximity of sheet piling at these locations caused significant noise in the data.

This report concludes that ERT and GPR could successfully image areas of tunnelling in the embankment northwest of Drax power station. Useable data could be collected despite the sheet piling, which makes interpretation of the data significantly more difficult. While GPR could only find tunnels in the first three lines, it provided some confidence to the ERT interpretation and was able to investigate a much larger area. This highlights the potential benefits of combining ERT and GPR for future badger investigations.

1 Introduction

The flood embankment north of Drax Power Station protects the access roads to the power station, local farms and the surrounding farmland from flooding. A badger sett has been present in a section of this embankment for many years, and it was last remediated in 2013 with the installation of metal sheet piles. During a recent inspection, new excavations were found further along the embankment to the east.

The Environment Agency commissioned a geophysical survey to investigate the extent and subsurface distribution of the badger tunnels, with a particular focus on the eastern expansion of the sett.

1.1 SCOPE AND OBJECTIVES OF THE INVESTIGATION

The objective of this study was to map the location of the badger tunnels with respect to the embankment and sheet piling. This report addresses the following objectives:

- Determine the location of the sheet piling installed in 2013.
- Assess if badgers have gone around the sheet piling.
- Find the maximum distance tunnels have entered the embankment.
- Test two geophysical methods, Ground Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT), to image badger tunnels with known metal sheet piles.

1.2 BADGER SETT MORPHOLOGY

Design of the geophysical surveys requires estimates of the target's dimensions, properties and location, in this case, badger tunnels. Key characteristics of a badger sett (Fischer and Dunand, 2016; Roper, 1992; Roper et al., 1991):

- Multiple curving burrows that intersect.
- Burrows are 30±5 cm wide and 20±5 cm high.
- Chambers are typically 50-60 cm in diameter and 45 cm high but may be smaller and can be located at the end of the burrow or centrally, connected by multiple burrows.
- Tunnels typically drop steeply down from the tunnel entrance before continuing horizontally.
- Tunnels are typically between 0.5 and 1.5 m below the ground surface and are not documented to exceed 2 m depth.
- Badger tunnels have not been documented to extend more than 8-10 m from the nearest entrance.

As most of the burrows are air-filled, a suitable survey technique should be able to detect/image a 30 cm wide air-filled void at depths of up to 2 m. In terms of electrical properties, these void spaces are electrical insulators with effectively infinite resistivity (or, equivalently, zero conductivity), providing a strong contrast with the surrounding ground.

2 Site Details

2.1 SITE LOCATION AND DESCRIPTION

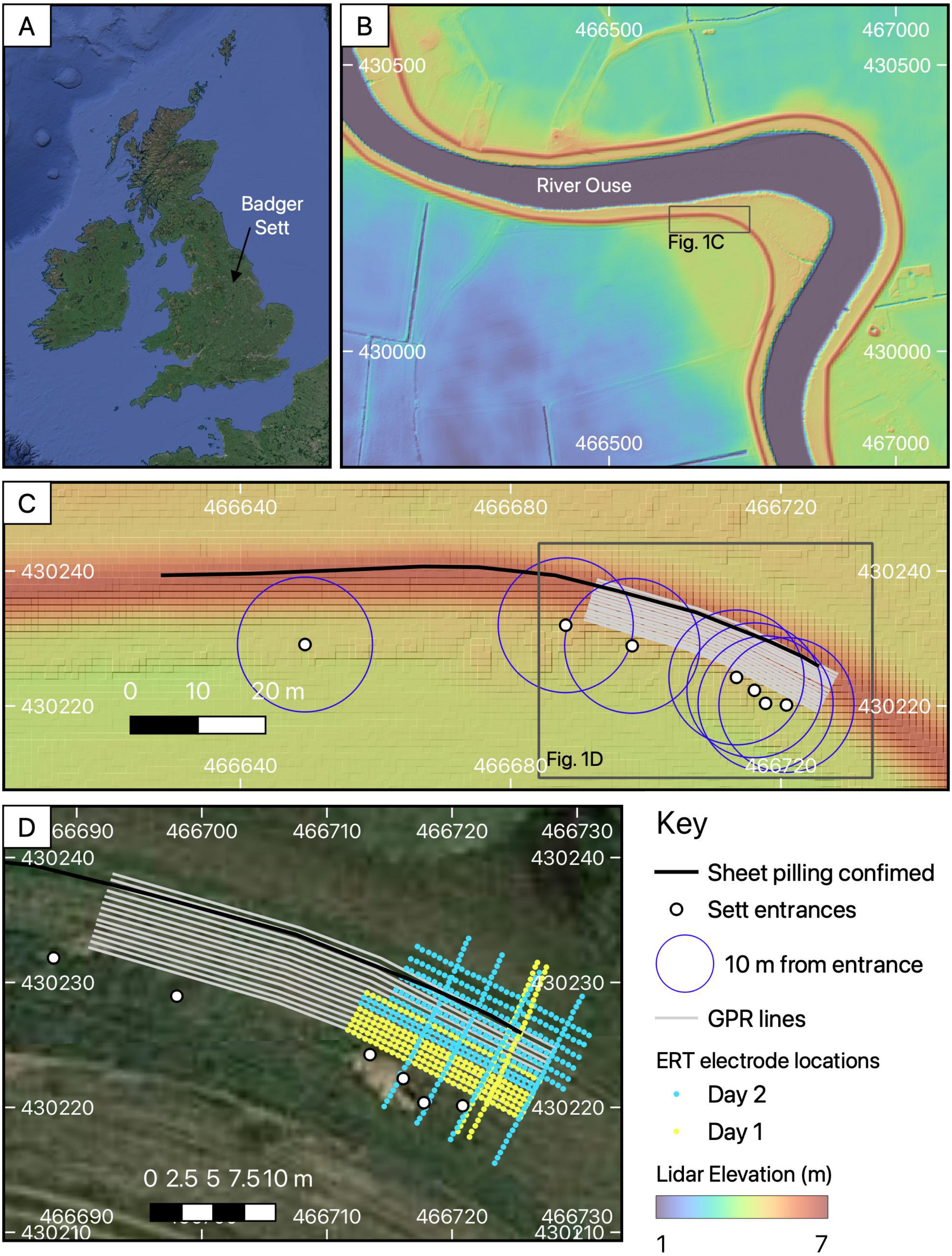


Figure 1. Overview of the survey site. A) Location of the badger sett in the UK, B) Local topography of the surrounding area, showing that the sett is located in a part of the flood embankment higher than most of the surrounding farmland. C) Close-up of the site, showing the location of the embankment, the metal sheet piling (location confirmed during our survey), the badger sett entrances and their associated 10 m radius beyond which tunnels are not anticipate. D) Survey plan of the collected GPR and ERT lines. The ERT lines have been split into day one and day two due to differences in data quality. Google satellite imagery for A and C ©2022 CNES / Airbus, Getmapping plc, Infoterra Ltd & Bluesky, Maxar Technologies, Map data ©2022.) LiDAR data from the National Lidar Program collected 11/2020 *"© Crown copyright, released under the Open Government Licence v3.0*" (Open Government Licence (nationalarchives.gov.uk)

The badger sett is next to a flood embankment on the river Ouse northeast of Drax power station (Figure 1). Entrances to the sett are located on the dry side of the embankment and were found to extend over 75 m (Figure 1C). The grid references of the affected embankment are SE 66649 30229 in the west to SE 66721 30220 in the east. The embankment is about 1.6 m high and 16 m wide at this location.

A badger sett at this location has previously been remediated with the installation of sheet piles along the crest of the embankment. Before the survey, there was some uncertainty about the location and efficacy of the sheet piles in protecting the embankment from burrowing. The location of the sheet piles could be seen in both geophysical surveys, confirming the 'as built' drawing provided and demonstrating that all the known badger entrances are located behind the sheet piling. Sheet piling was confirmed between grid references SE 66628 30239 to the west and SE 66725 30226 to the east (Figure 1C).

We mapped the most prominent badger entrances that were close to the embankment. However, there were many entrances that we did not map between the embankment and the fence. These were mostly hidden by tall vegetation, and there was a significant risk of falling into them, so this area was avoided.

2.2 GEOLOGICAL AND GEOPHYSICAL DATA

At depth, the site is underlain by the Sherwood Sandstone Group, which is overlain by alluvium comprising clays, silts, and gravels. Interpretation of an electromagnetic geophysical survey in 2016 indicates that the embankment is likely to be sand with silt and clay, with the section adjacent to the sheet piles interpreted as clay with silt and high moisture content. We suspect this interpretation may be erroneous and that the whole embankment could be of similar composition. Still, the sheet pilling increased the measured conductivity giving the impression that it was wetter and more clay-rich. If the embankment is sandy, the GPR may have a sufficient penetration depth to image the tunnels.

3 Ground Penetrating Radar Investigation

3.1 SURVEY DESIGN

The GPR survey was designed to cover a larger area than ERT due to its faster data collection speed. Fourteen GPR lines parallel to the embankment, each about 38 m long, were carried out starting at the embankment toe and working up the embankment to the crest where the sheet pilling was found. The line spacing was 0.5 m, the width of the GPR cart. The survey used the Sensors & Software Noggin 250 MHz antenna, which was expected to be the best trade-off between depth penetration and resolution.

The GPR data was processed in ReflexW as 2D lines following a standard procedure (Jol, 2009, chap. 5; Reynolds, 2011, chap. 13). The processing steps for the 250 MHz radargrams were: (1) each file was imported, correctly aligned to the local grid and any erroneous files were removed; (2) Dewow filter was applied with a four ns window; (3) data collected before the start time was removed; (4) a Bandpass Butterworth filter with a low cut-off of 50 MHz and high cut-off 450 MHz; (5) a background removal filter was applied to highlight hyperbola in the data; (6) an energy decay gain was applied to remove the effect of geometric spreading to enhance the reflections from greater depths. The velocity of the site was estimated to be 0.075 m/ns using diffraction analysis, assuming each hyperbola was caused by a burrow 0.3 m in diameter (Jol, 2009, chap. 5).

Each radargram was visually inspected to map the burrow network, and all the hyperbolae seen were traced using ReflexW. Reflectors with similar characteristics, depth and reflection strength, were also picked as they were assumed to be tunnels parallel to the survey line. Reflections that were not related to the tunnel network were not interpreted. The highest point of each hyperbola was extracted to pinpoint the centre of the suspected tunnel.

3.2 RESULTS

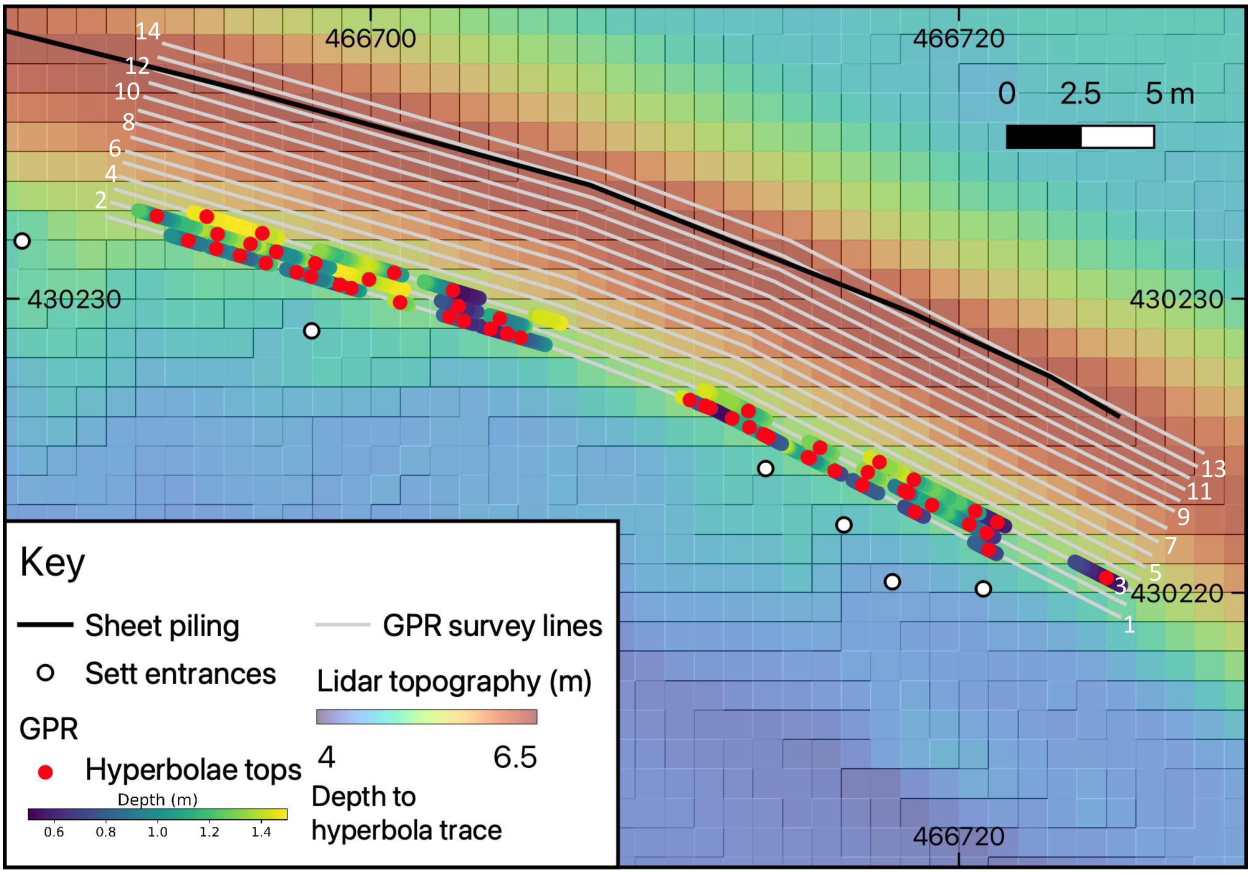


Figure 2. Results of the GPR Survey. Hyperbolae caused by badger burrows can only be interpreted in the first three lines of the survey. In the subsequent lines, any tunnels present are too deep to interpret (over 1.5 m deep). Two distinct regions of burrowing can be seen and appear to be separate from each other within the survey area. GPR line number in white. LiDAR data from the National Lidar Program collected 11/2020 *"© Crown copyright, released under the Open Government Licence v3.0"* (Open Government Licence (nationalarchives.gov.uk)

The results of the GPR survey are shown in Figure 2 and Figure 5, and the individual radargrams are presented in Appendix 1. Each radargram was interpreted in turn, picking any hyperbola thought to be caused by badger burrows. These hyperbolae could only be found in the first three lines and form two distinct groups in the area investigated (Figure 2). These hyperbolae deepen from 0.5 m to 1.5 m over these first three lines before disappearing by line four. It is likely that some of the tunnels continue beyond this point but are too deep to be detected, and the depth of investigation may be reduced if the embankment material is more clay-rich. In lines 12 and 13, regular hyperbolae can be seen close to the surface; these are likely caused by the sheet piling at the site and allowed us to quickly identify their location (Figure 1C).

4 Electrical Resistivity Tomography Investigation

4.1 SURVEY DESIGN

The ERT survey was designed to address the key objectives of the survey to find out how far the tunnels have extended into the embankment, whether the badgers have dug around the end of the sheet piles, and whether this is possible with the presence of the metal sheet piles. To achieve these objectives, ERT survey lines were carried out parallel and perpendicular to the embankment. The lines parallel with the embankment were co-located with part of the GPR lines to aid the comparison of the two data sets.

The survey was carried out using the AGI SuperSting with eight channels that simultaneously address up to eight pairs of potential electrodes. The dipole-dipole configuration was used with dipole lengths, *a*, of 1-4 times the actual electrode spacing and dipole separations *na, where n* = 1-8. Dipole-dipole was used for all survey lines due to the short acquisition time (20 min for a 32 electrode line), more excellent horizontal coverage benefitting 3D surveys, ease of collecting reciprocal measurements for error modelling and better resolution for localised objects (Dahlin and Zhou, 2004; Gharibi and Bentley, 2005).

Data processing and filtering were done using the open-source software ResIPy (Blanchy et al., 2020). Each line was processed in turn to remove: all negative apparent resistivities, measurements with transfer resistances below 0.001 Ω caused by a faulty connector while collecting data on day 1, data with no reciprocal measurements, and measurements with reciprocal errors greater than 20%. A power law error model was fitted to the data (Blanchy et al., 2020). Finally, measurements with a reciprocal error of less than 5% were kept (Chambers et al., 2012). The average of the transfer resistance was calculated for each reciprocal pair and then weighted based on the error model. The data was then inverted in 2D using the ResIPy software

Line number	Day	Reciprocal Measurements	Measurements post-processing	Chi^2
101	1	516	90	0.86
102	1	516	89	0.87
103	1	516	90	1.03
104	1	516	90	1.02
105	1	516	90	0.99
106	2	516	510	1.27
107	2	516	511	1.00
108	2	516	511	1.00
109	2	516	508	1.03
110	2	516	503	1.01
111	2	516	198	1.01
112	2	516	219	1.12
113	2	516	513	1.00
114	2	516	507	1.01
201	2	516	513	1.07
202	1	516	50	1.01
203	2	516	400	1.00
204	2	516	378	1.00
205	2	515	371	1.00

Table 1 Summary of each ERT measurement line. Day 1 data was of poorer quality due to a cable connection issue. Reciprocal measurements were the number of data pairs collected and the number remaining post-processing. The power-law parameters describe the fitted error model and Chi^2 describes the fit of the inversion. $Chi^2=1$ indicates a perfect fit assuming that the error models accurately represent the data noise.

4.2 RESULTS

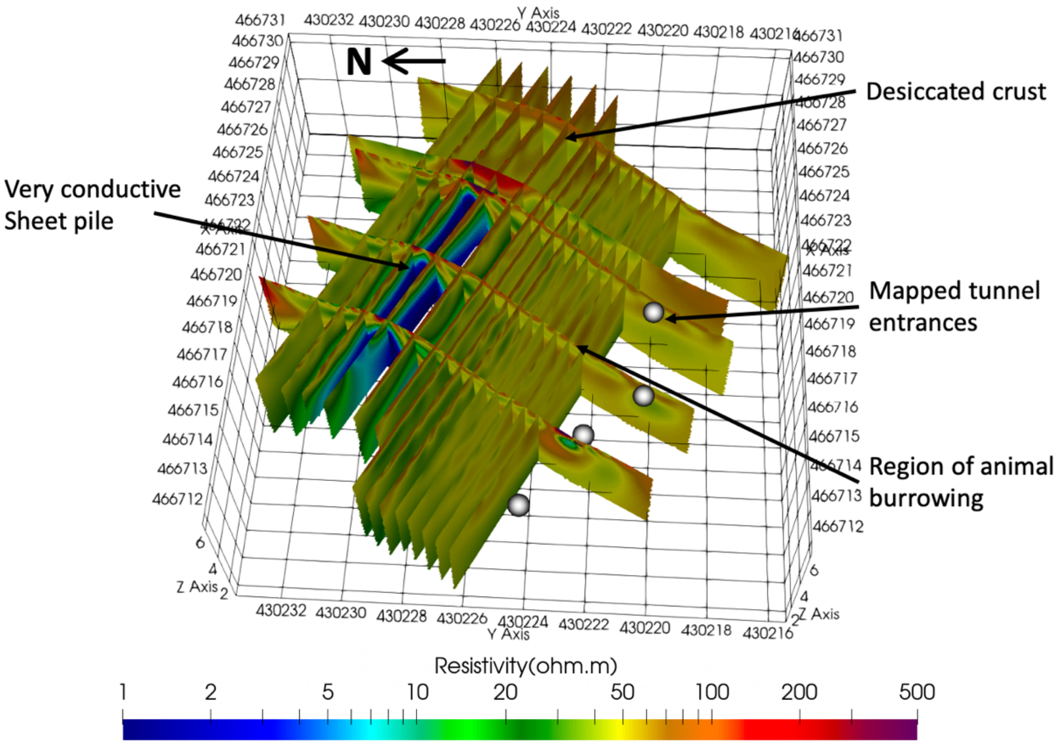


Figure 3. ERT survey of the badger sett close to the end of the sheet piles, with the four measured entrances shown as spheres. The large blue conductive anomaly is caused by the sheet piling present at the site and can be clearly seen to end. The ERT lines perpendicular to the embankment contain several large resistive anomalies that are thought to be artefacts caused by the sheet piling. The location of the survey is shown in Figure 1D.

In total, 19 ERT surveys were carried out at the site, 14 parallel and 5 perpendicular to the embankment (Figure 3). The parallel lines allow us to track any tunnels leading from the entrances into the embankment, while the perpendicular lines tie the parallel lines together and check that we have not missed any tunnels running parallel.

The ERT data is affected by the presence of the sheet piling (the blue conductive anomaly in Figure 3), which is seen to end at grid reference 466724 430226. The anomalies associated with the metal sheet piling would likely prevent the detection of any tunnels within a couple of meters.

By adjusting the colour scale in Figure 3 and by removing the resistive upper layer caused by a desiccated soil layer covering the embankment, we can see ‘bullseye’ resistive anomalies in the ERT sections that can be followed from line to line, suggesting that they are caused by the badger tunnels (Figure 4). These anomalies appear to coincide with the mapped tunnel entrances.

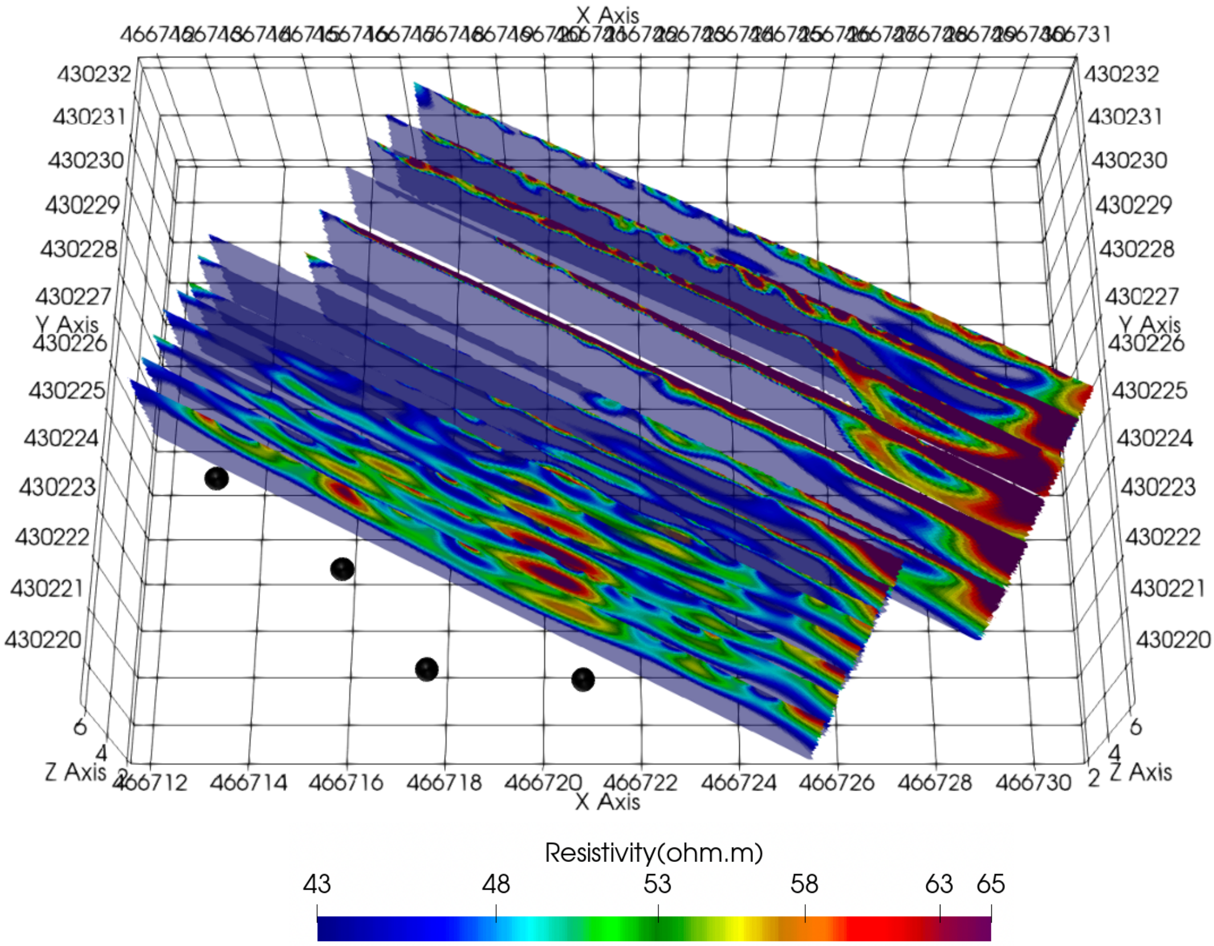


Figure 4. Processed ERT data to show the potential tunnel network. The desiccated layer 0.5 m thick was removed to improve the visualisation of the tunnels below.

5 Discussion and Conclusion

Using the location of the badger tunnel entrances, resistivity anomalies in the ERT data, and the picked hyperbola in the GPR data, a joint interpretation of the data can be made to estimate the tunnel structure (Figure 5). There is some agreement between the GPR and the ERT results, with the largest resistive anomalies also associated with a cluster of hyperbolae. However, some of the more minor resistive anomalies do not correspond to any hyperbolae, and some hyperbolae do not correspond with any resistive anomalies. It is likely that closely spaced tunnels are poorly resolved and have combined into a single resistive anomaly which may explain why several hyperbolae are associated with a single resistivity anomaly.

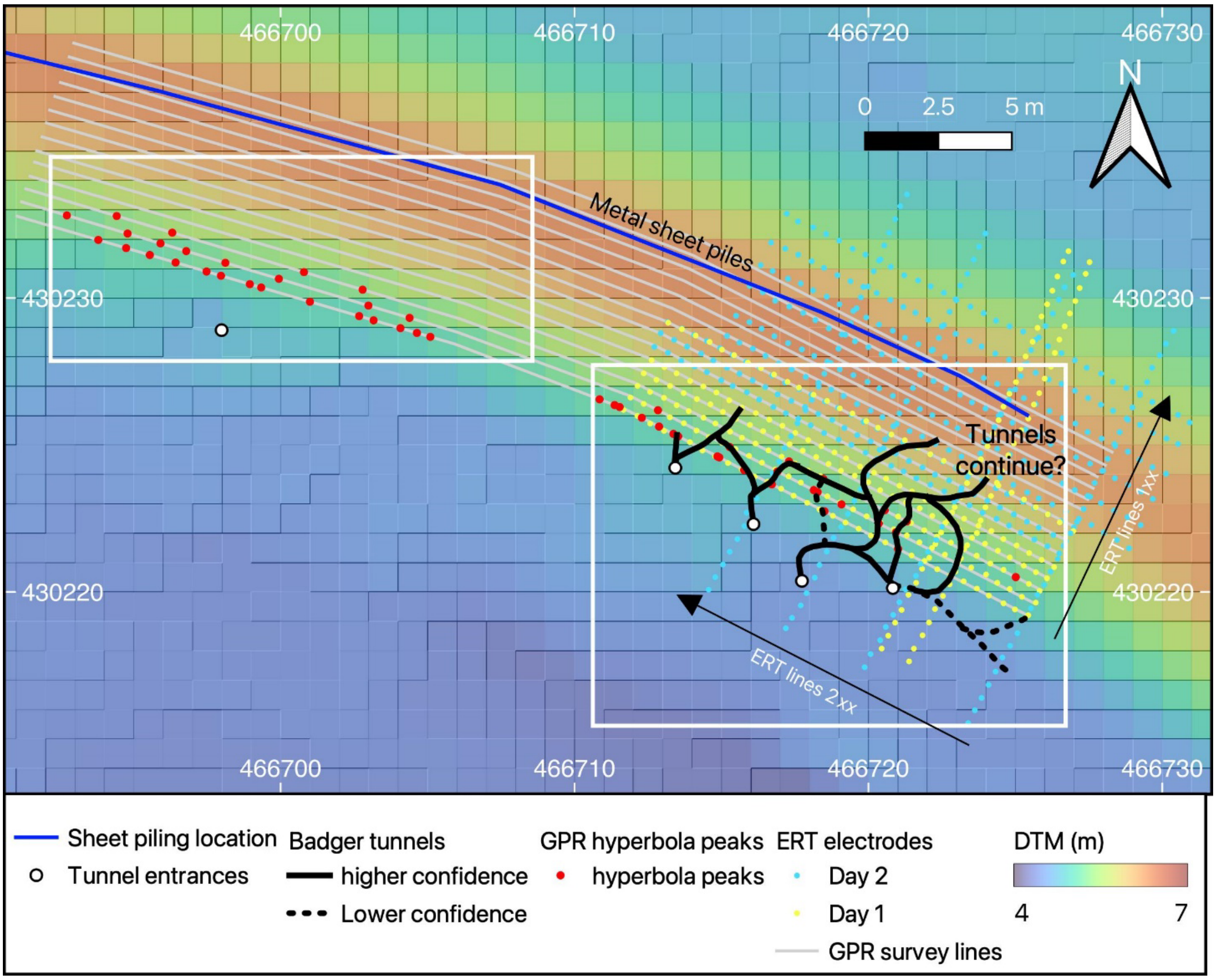


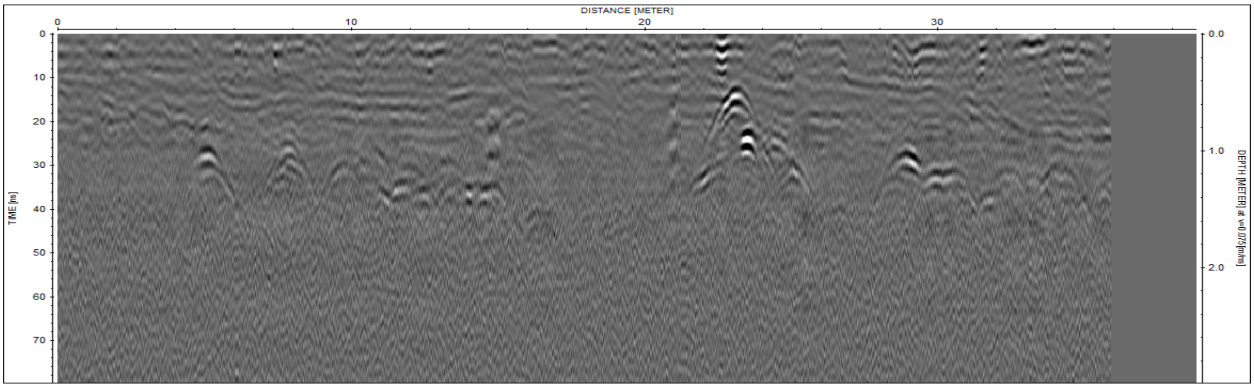
Figure 5. Map interpretation of the GPR and ERT data, showing an estimated spatial extent of the tunnel network (black dashed lines are low confidence). These tunnel location estimates are a qualitative interpretation and are therefore only indicative of where tunnel-like anomalies in the ERT data were seen. LiDAR data from the National Lidar Program collected 11/2020 *“© Crown copyright, released under the Open Government Licence v3.0*” (Open Government Licence (nationalarchives.gov.uk)

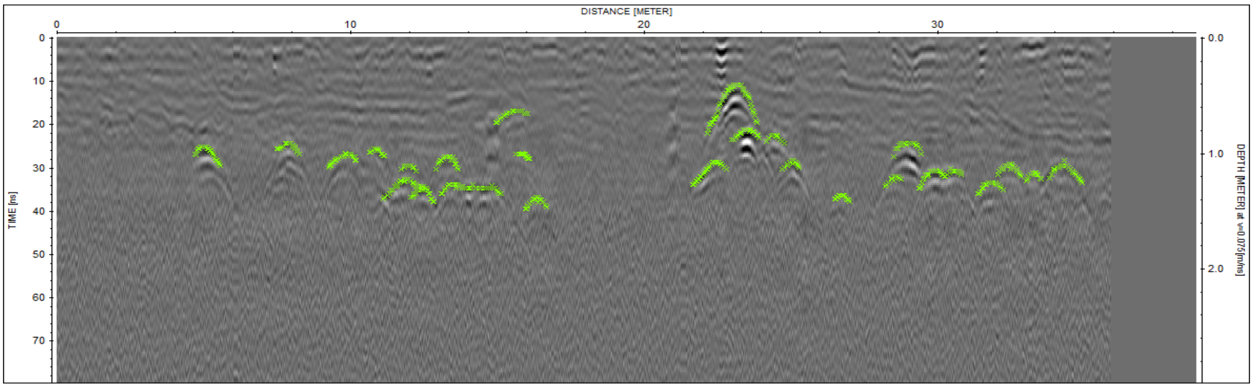
The final interpretation finds a complex network of tunnels at the site's eastern end. Summarising the results of the geophysical survey (see Figure 5):

- Two areas of extensive tunnelling were found in the GPR data, matching tunnel entrances' locations.
- GPR could only detect tunnels in the first three lines, beyond which the tunnels likely continued but were over 1.5 m deep, deeper than the penetration depth of the GPR signal.
- Most of the tunnelling seems to be concentrated in the floodplain and embankment toe.
- ERT focused on the eastern area but was partially affected by sheet piles, especially the lines perpendicular to the embankment.
- Tunnels interpreted from the ERT data head towards the crest of the embankment close to where the sheet pilling ends.
- We are unsure if we imaged the full extent of the tunnels or if they continued in to the embankment, but they were beyond the detectability of the instruments at these depths. Furthermore, the proximity of sheet piling at these locations caused significant noise in the data.

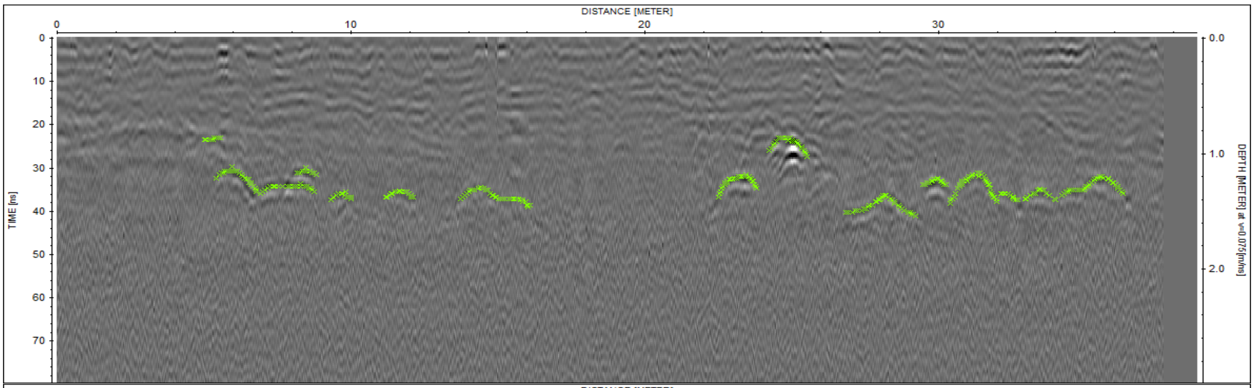
Appendix 1 Processed GPR Radargrams

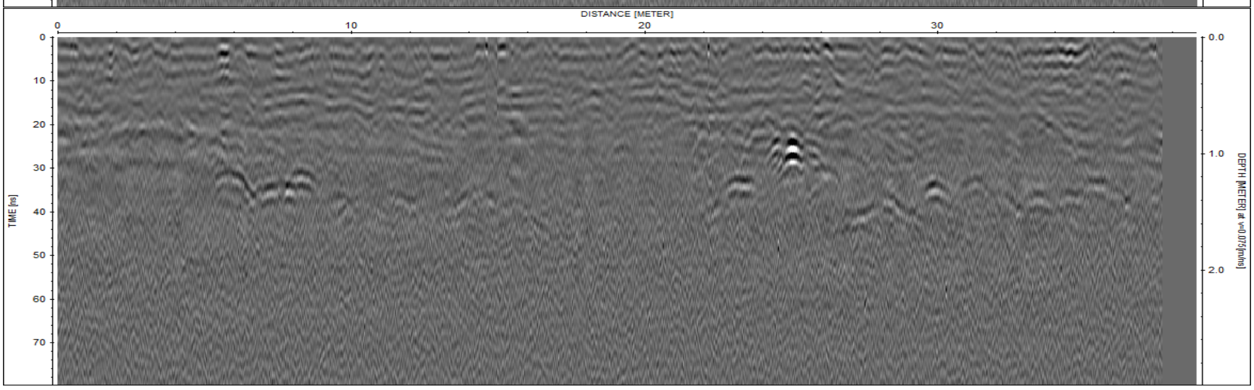
Line 1



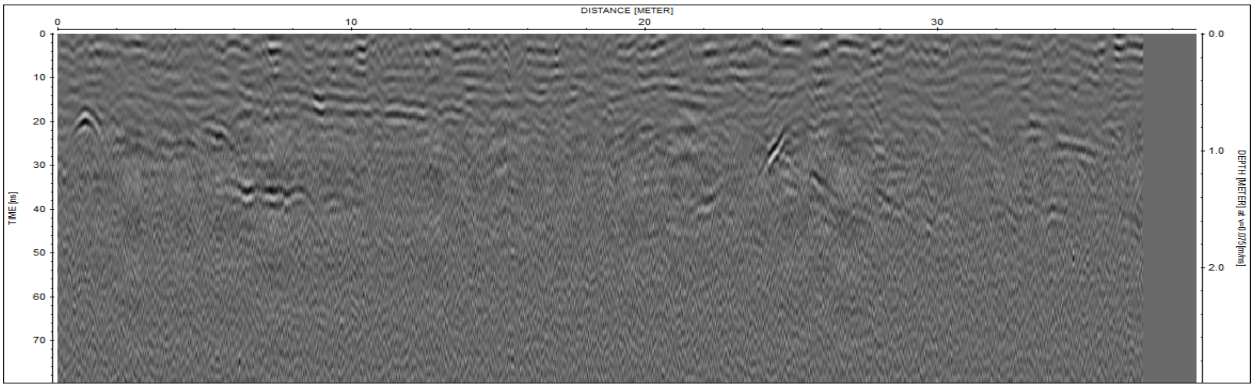


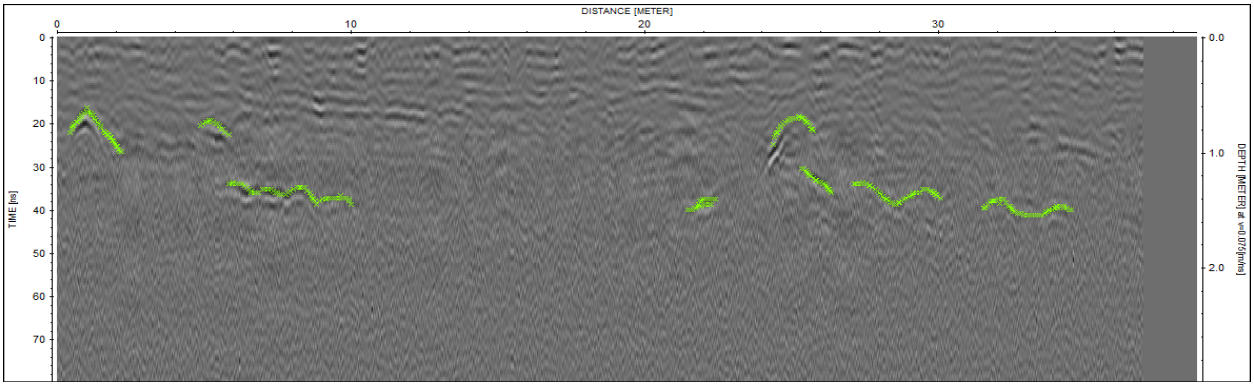
Line 2



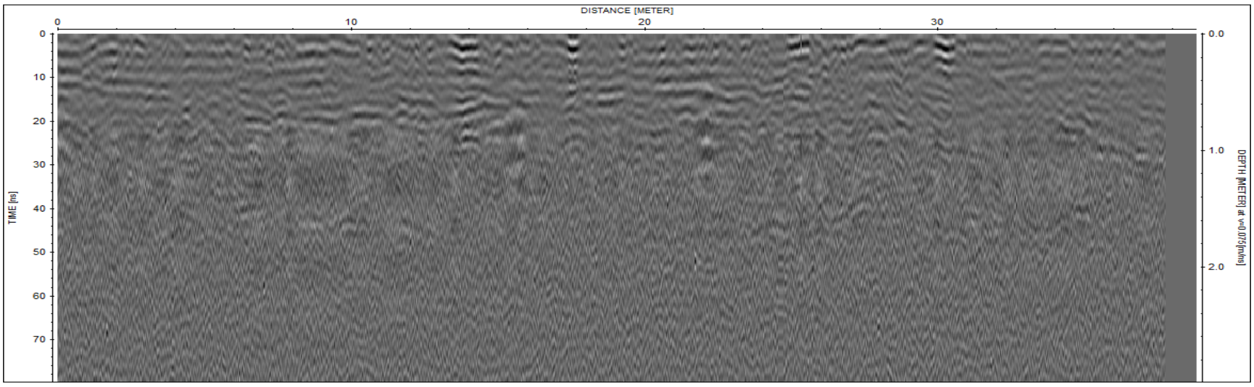


Line 3

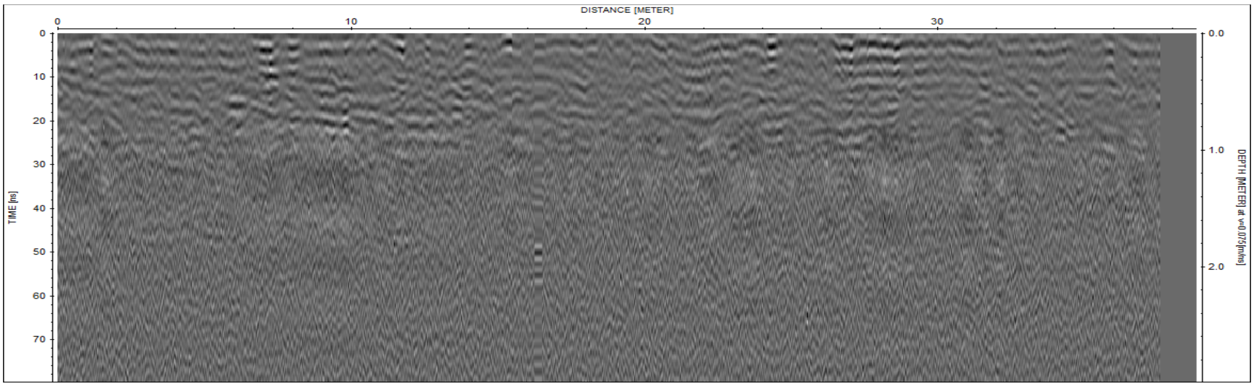




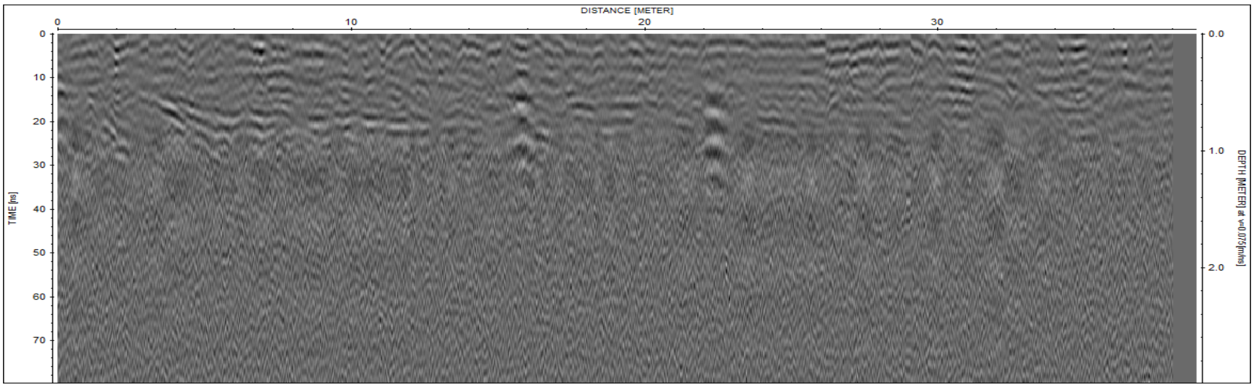
Line 4



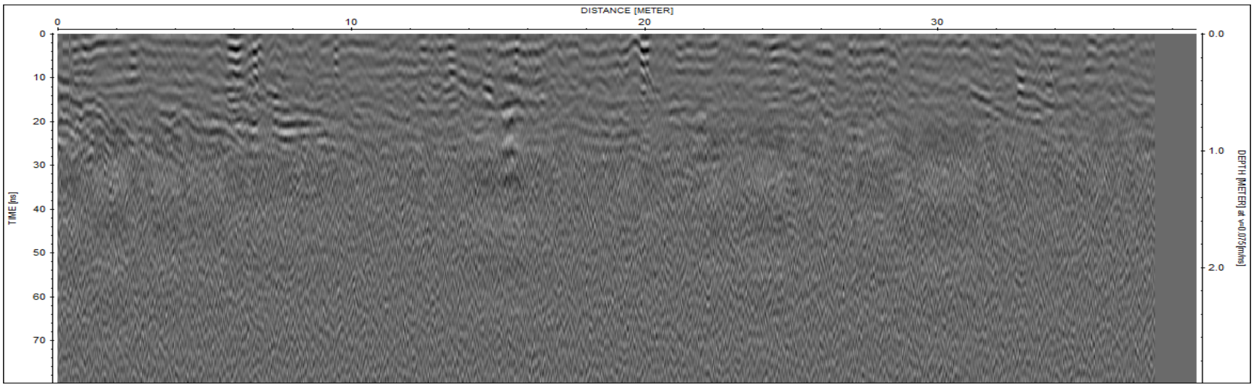
Line 5



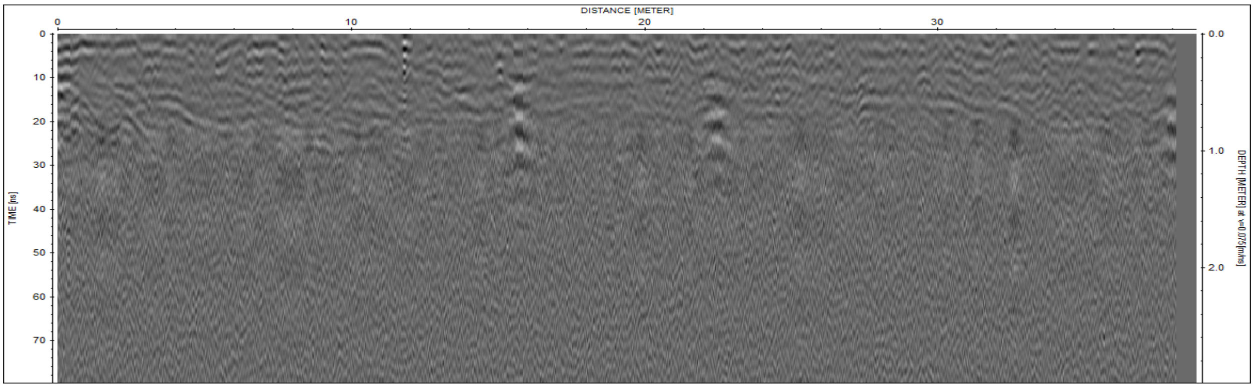
Line 6



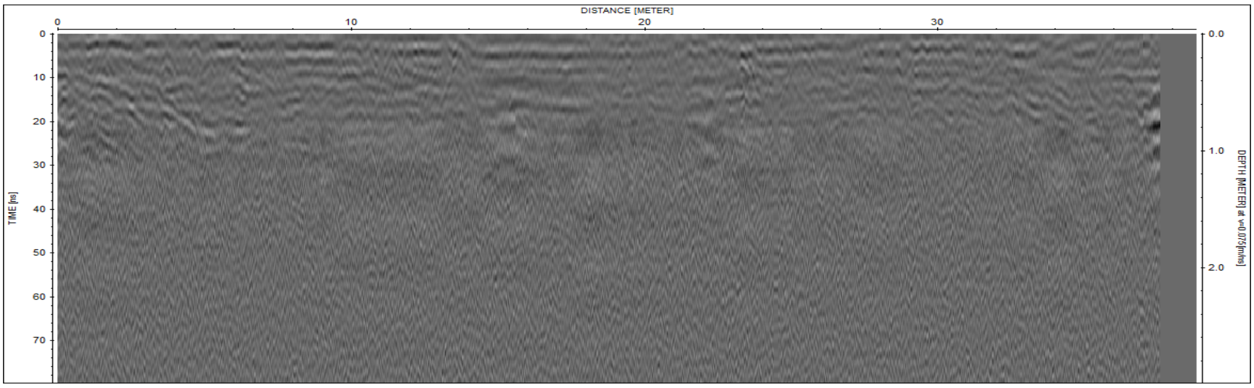
Line 7



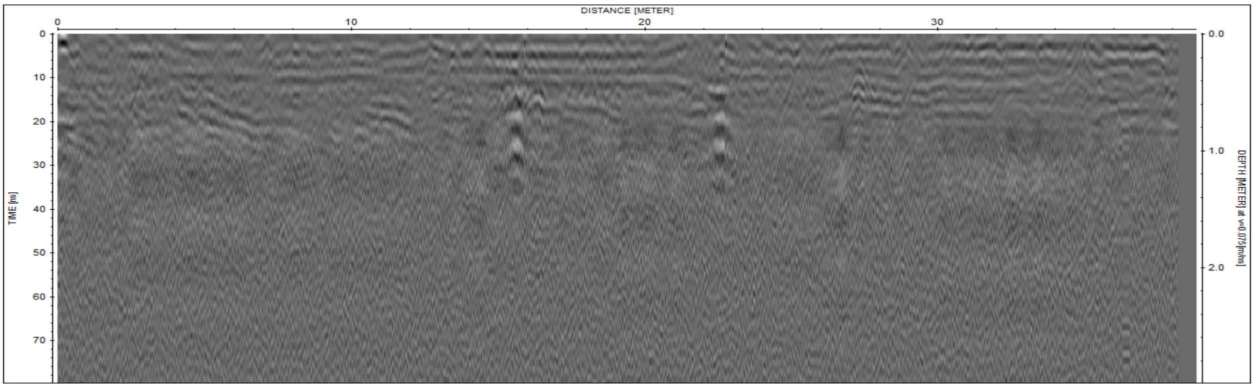
Line 8



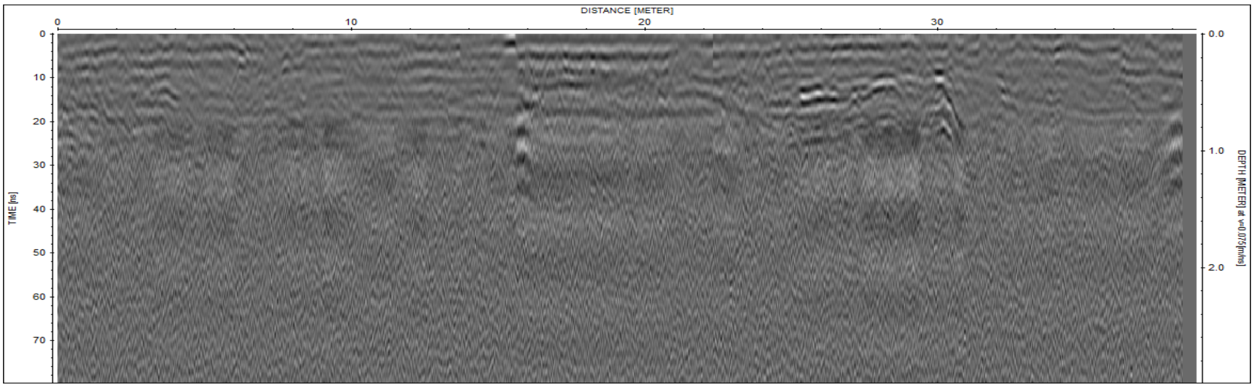
Line 9



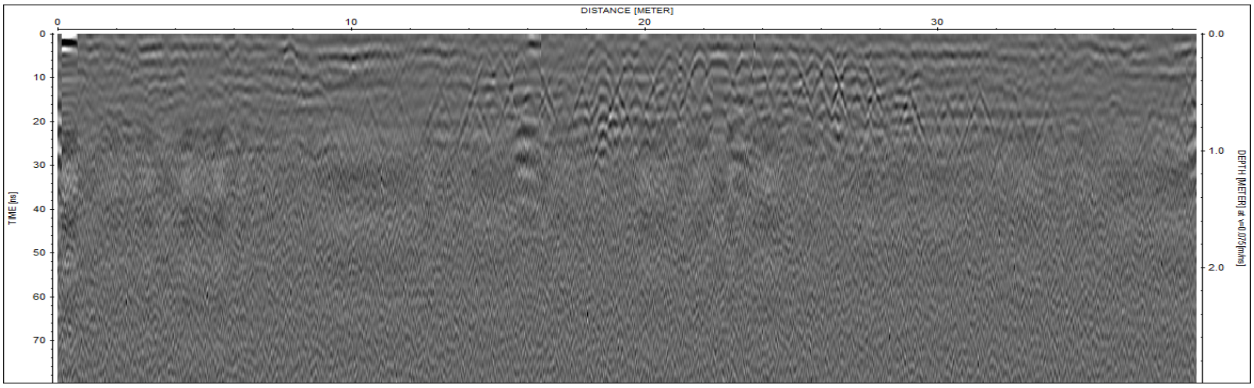
Line 10



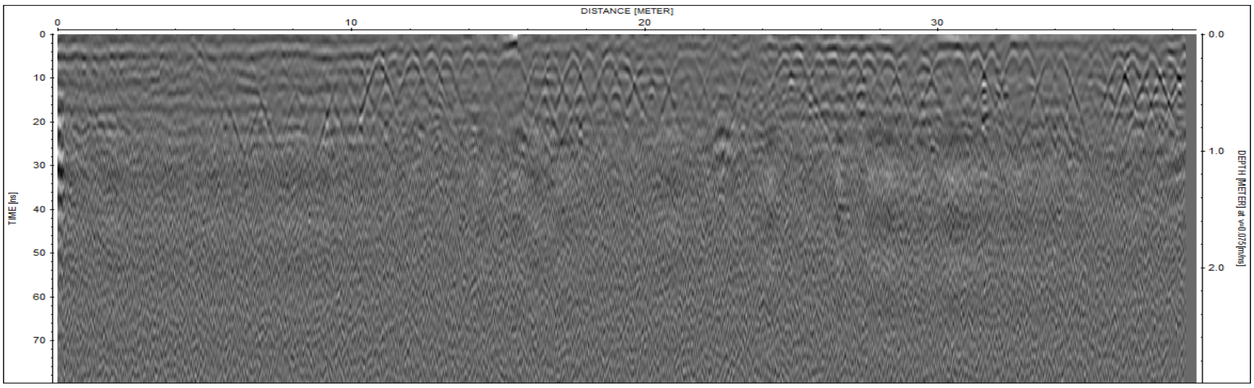
Line11



Line 12



Line 13



Line 14

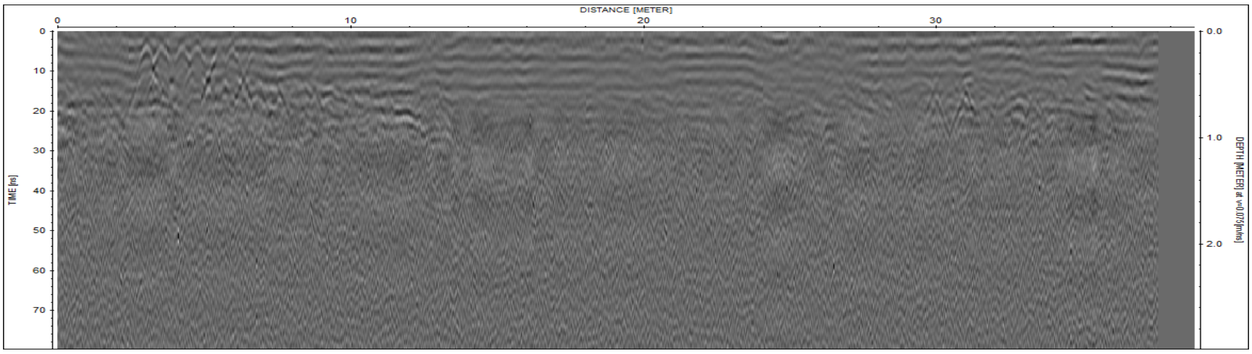
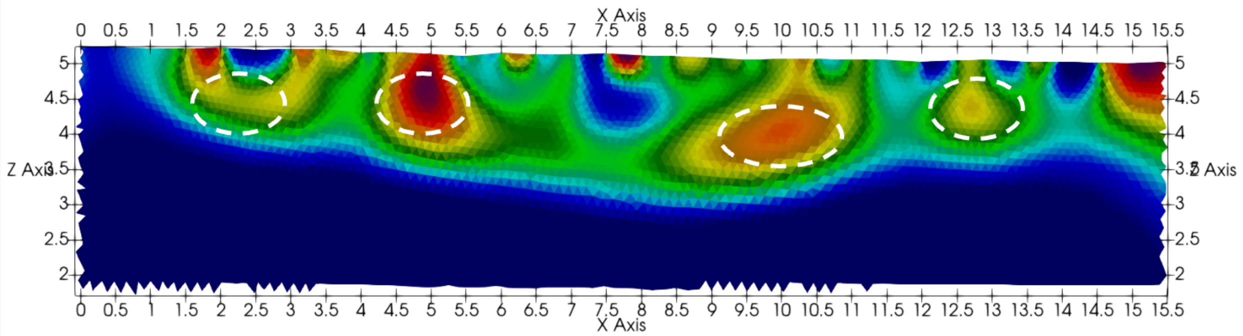


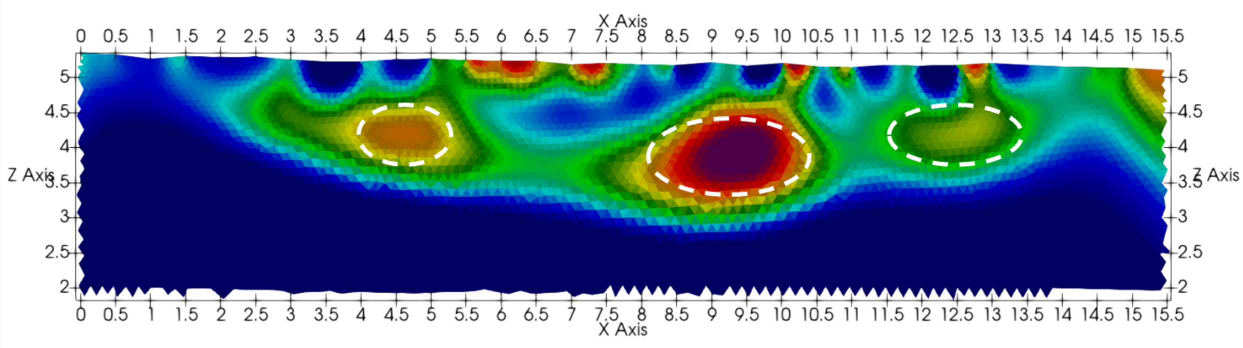
Figure 6. Processed radargrams from the 14 lines. Lines 1 to 3 are shown twice firstly blank and secondly with interpretation, where tunnels could be interpreted. Note that all radargrams are orientated west to east, i.e. distance=0 is at the eastern end of the line.

Appendix 2 Processed 2D ERT lines

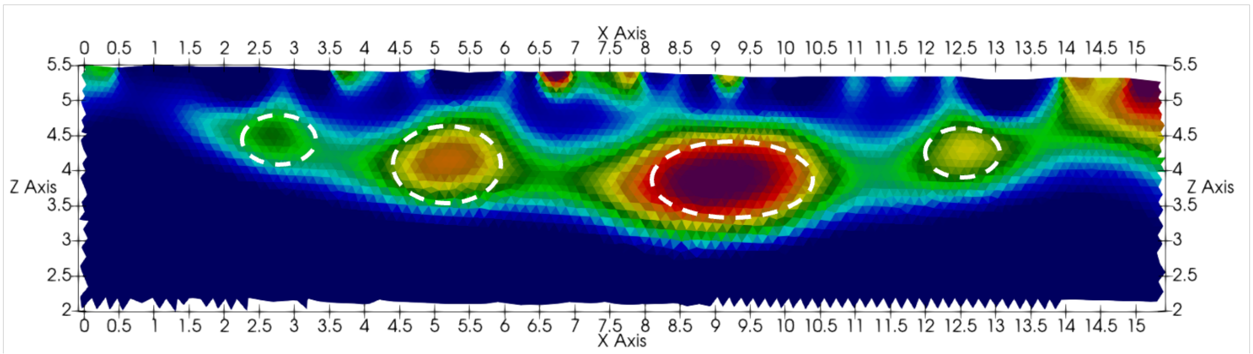
Line 101



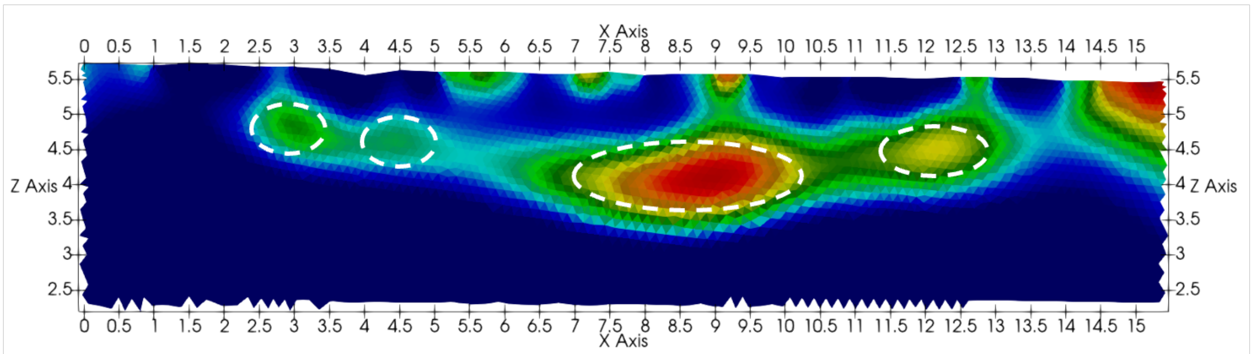
Line 102

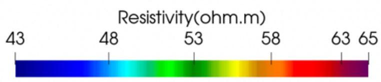


Line 103

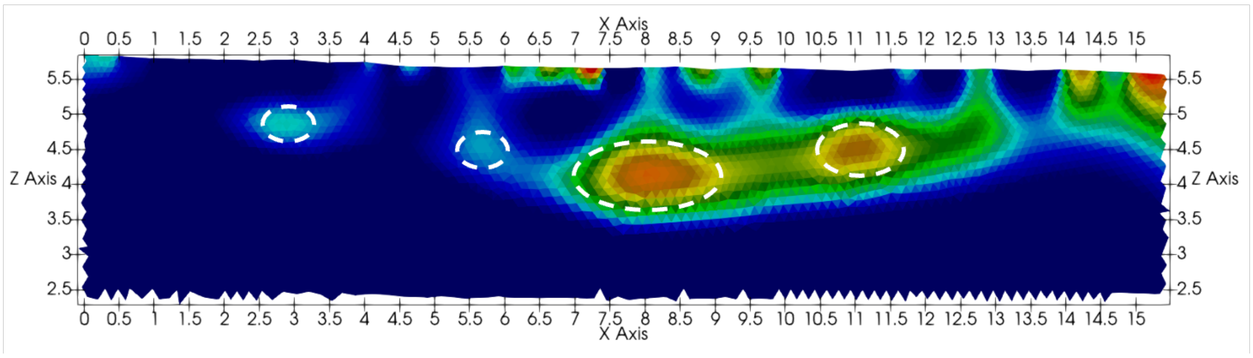


Line 104

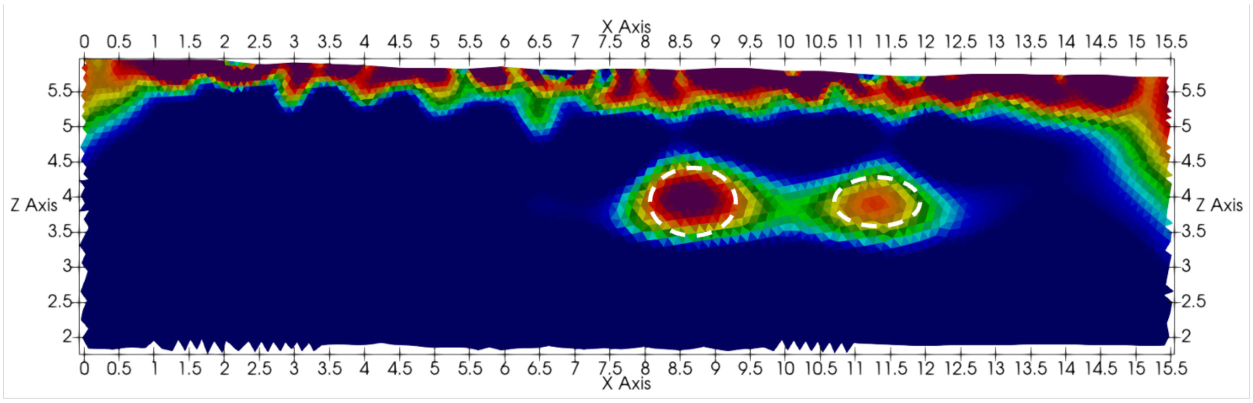




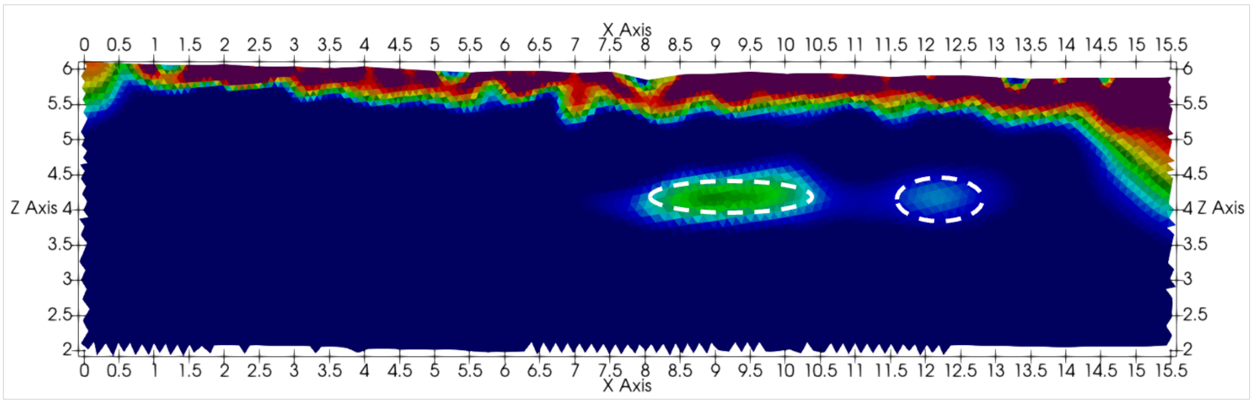
Line 105



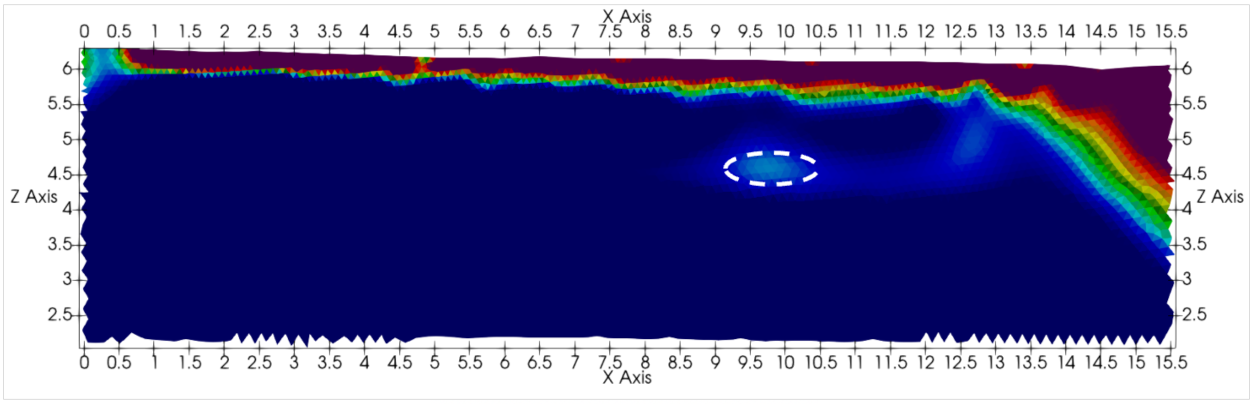
Line 106

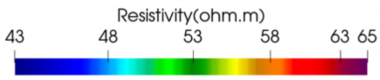


Line 107

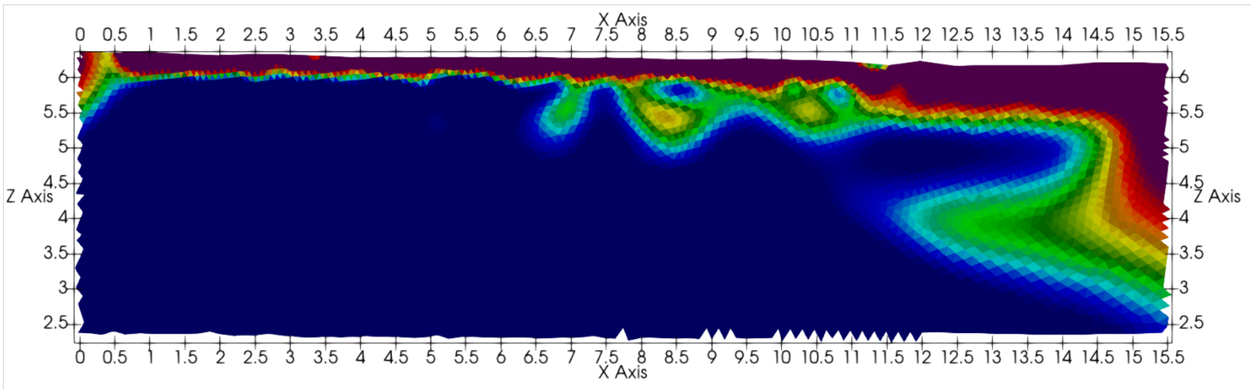


Line 108

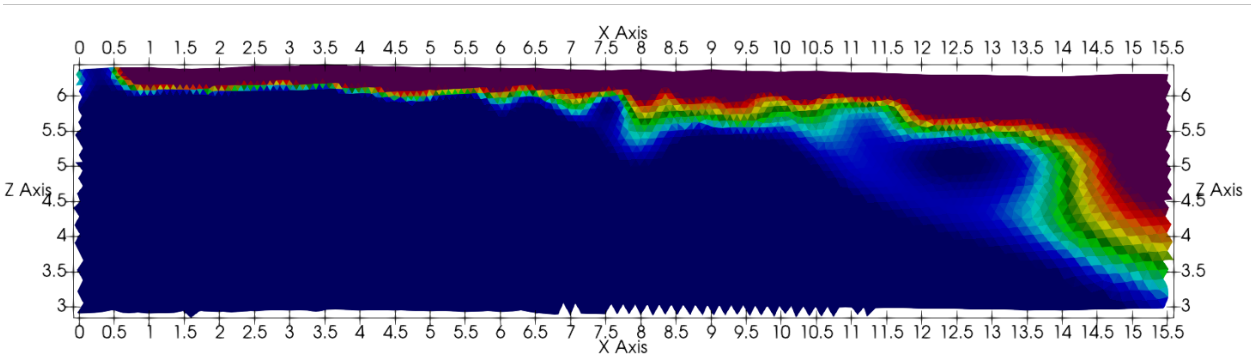




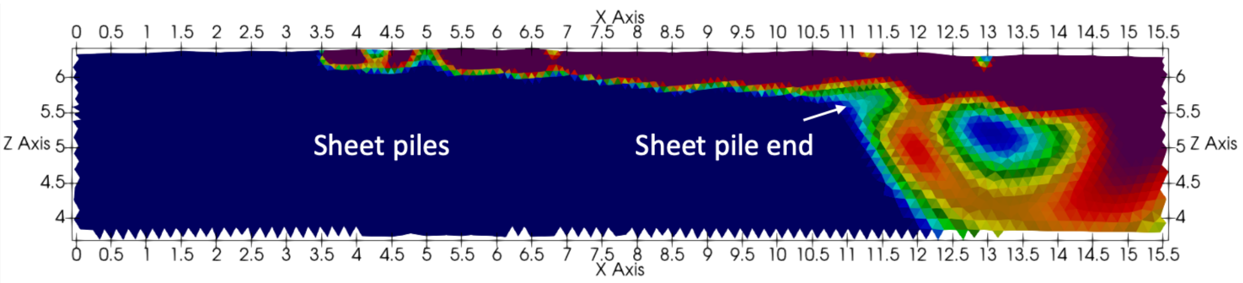
Line 109



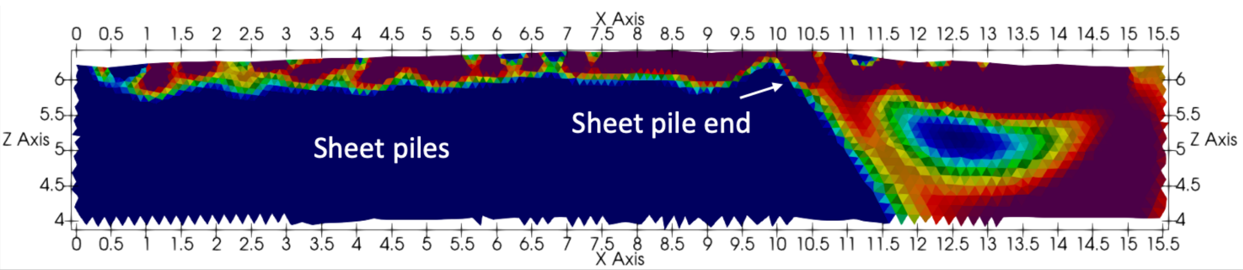
Line 110

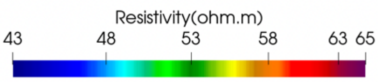


Line 111

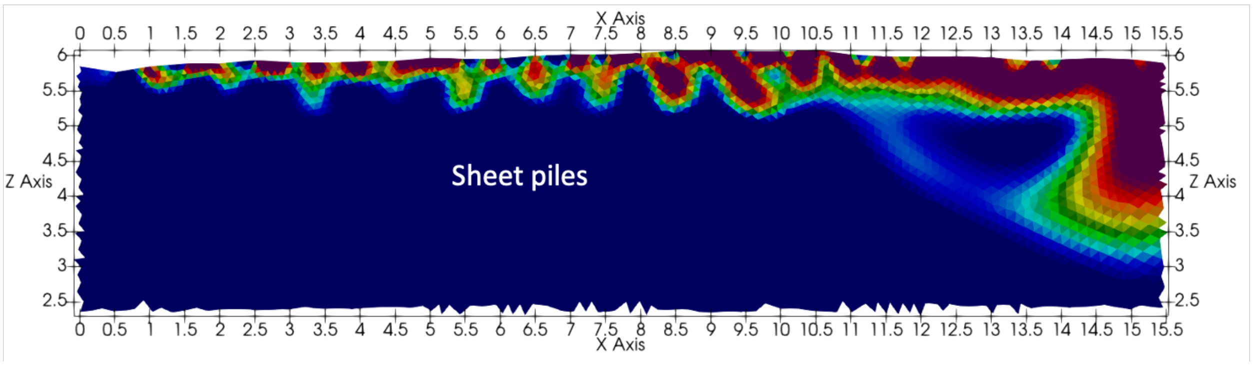


Line 112

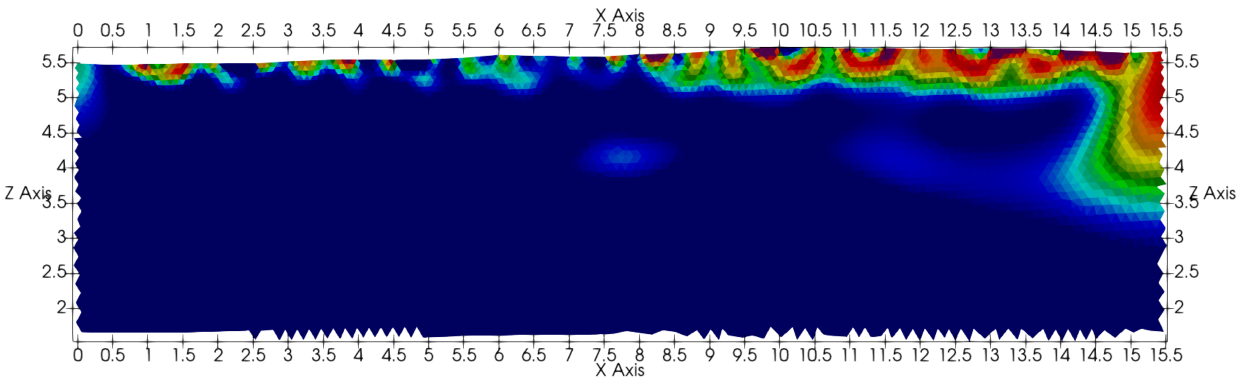




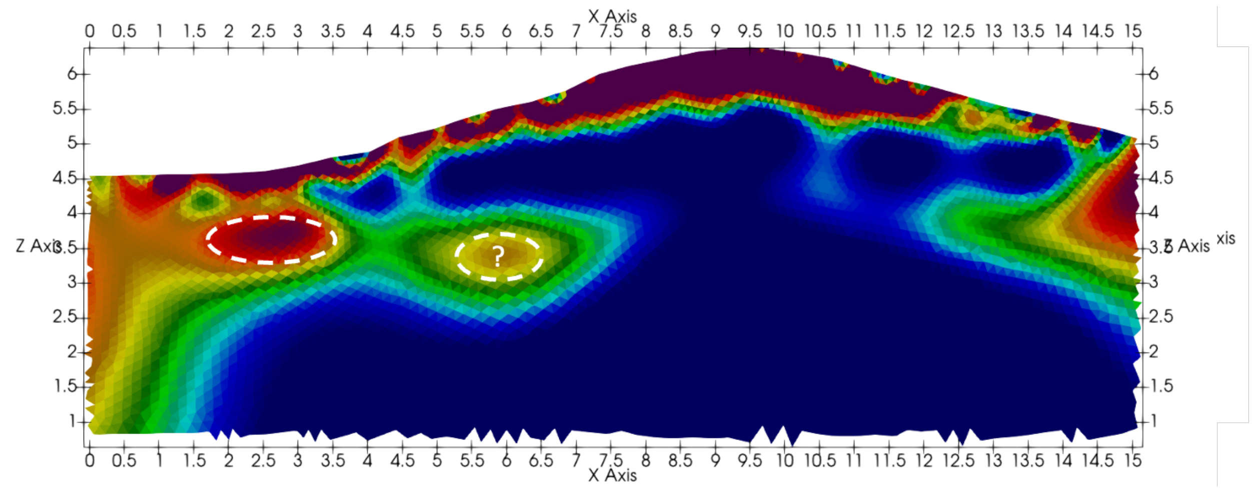
Line 113



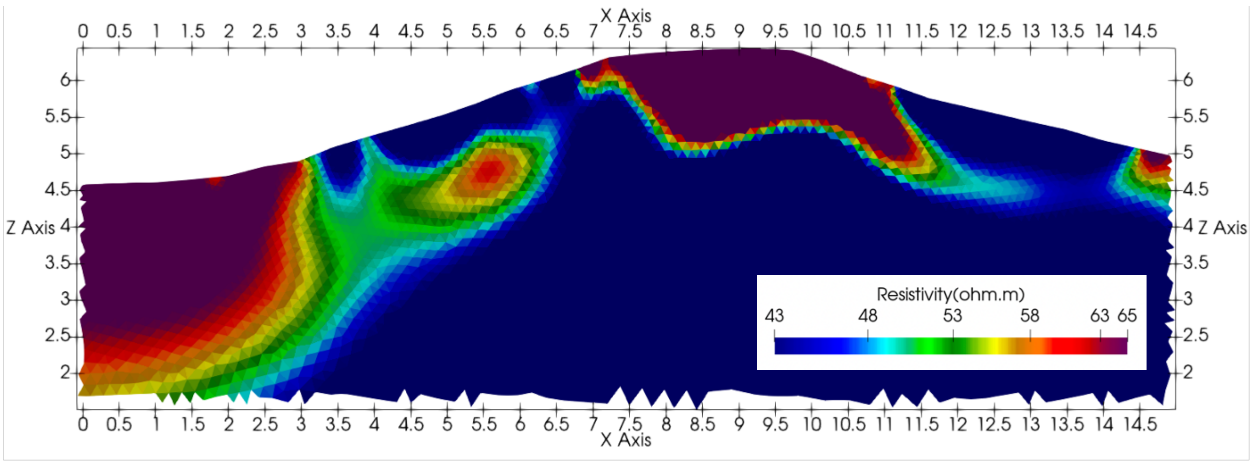
Line 114



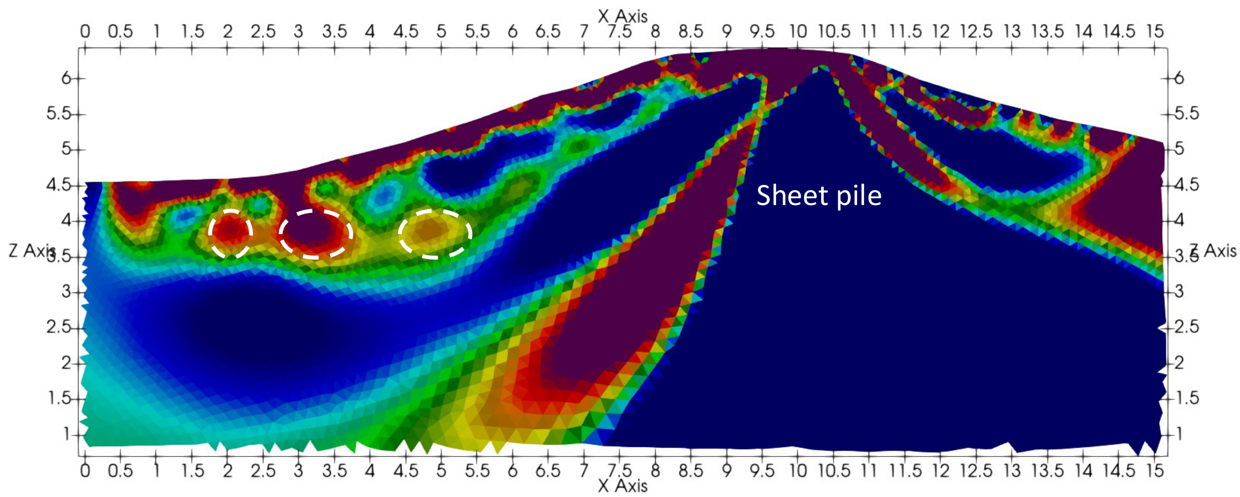
Line 201



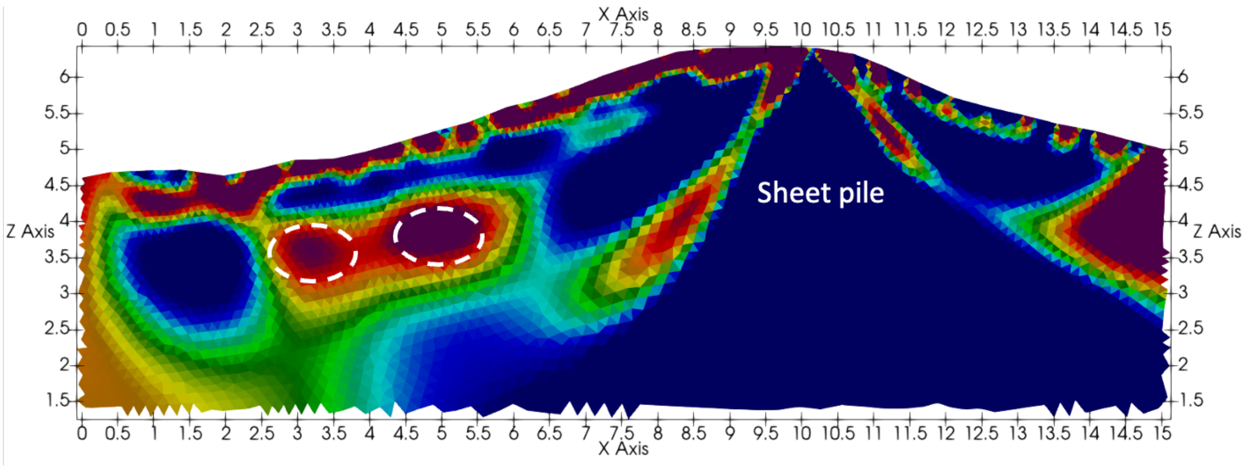
Line 202



Line 203



Line 204



Line 205

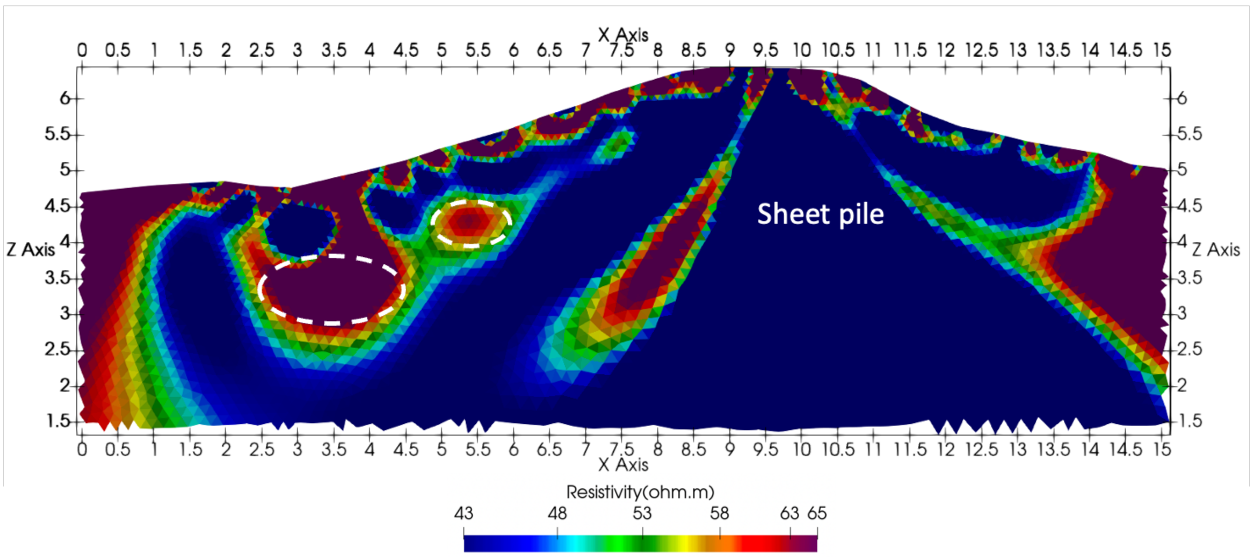


Figure 7. ERT profiles with annotations of burrows and sheet piles. The white dashed circles are possible badger tunnels. Lines 1xx are orientated east-west, i.e. (0 is at the east end of the line). Lines 2xx are orientated north-south with 0 at the line's southern end. In lines 203-5 the sheet piling label shows their influence on the ERT data. For line locations and numbering, see Figure 5. Where lines from day one and day two overlap only the line from day two is shown due to the better data quality

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

Blanchy, G., Saneiyan, S., Boyd, J., McLachlan, P., Binley, A., 2020. ResIPy, an intuitive open source software for complex geoelectrical inversion/modeling. Computers and Geosciences 137. https://doi.org/10.1016/j.cageo.2020.104423

Chambers, J.E., Wilkinson, P.B., Wardrop, D., Hameed, A., Hill, I., Jeffrey, C., Loke, M.H., Meldrum, P.I., Kuras, O., Cave, M., Gunn, D.A., 2012. Bedrock detection beneath river terrace deposits using three-dimensional electrical resistivity tomography. Geomorphology 177–178, 17–25. https://doi.org/10.1016/j.geomorph.2012.03.034

Dahlin, T., Zhou, B., 2004. A numerical comparison of 2D resistivity imaging with 10 electrode arrays. Geophysical Prospecting 52, 379–398. https://doi.org/10.1111/j.1365-2478.2004.00423.x

Fischer, C., Dunand, F., 2016. 3D topography and structure analysis of three European badger (Meles meles) setts from western Switzerland. Wildlife Biology in Practice 12, 26–35. https://doi.org/10.2461/wbp.2016.eb.3

Gharibi, M., Bentley, L.R., 2005. Resolution of 3-D electrical resistivity images from inversions of 2-D orthogonal lines. Journal of Environmental and Engineering Geophysics 10, 339–349. https://doi.org/10.2113/JEEG10.4.339

Roper, T.J., 1992. Badger Meles meles setts - architecture, internal environment and function. Mammal Rev. 22, 43–53.

Roper, T.J., Tait, A.I., Fee, D., Christian, S.F., 1991. Internal structure and contents of three badger (Meles rneles) setts. Journal of Zoology 225, 115–124. https://doi.org/10.1111/j.1469-7998.1991.tb03805.x