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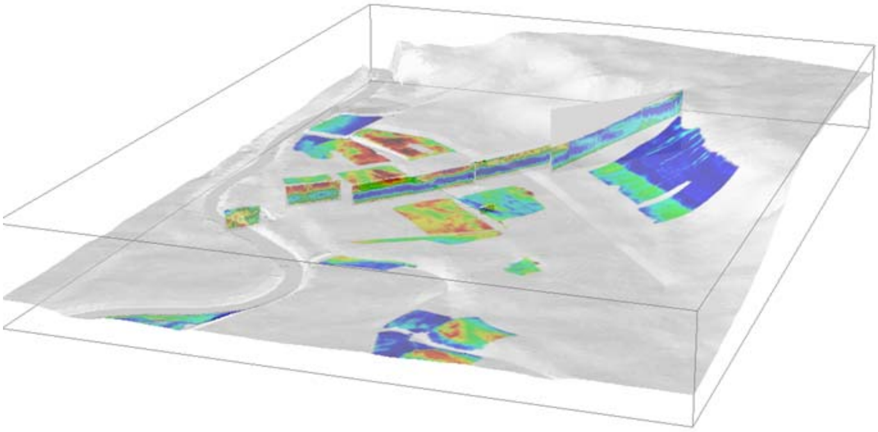
Application of near-surface geophysical data in GSI3D - case studies from Shelford and Talla Linnfoots

Land Use and Development

Internal Report OR/08/068



BRITISH GEOLOGICAL SURVEY

LAND USE AND DEVELOPMENT PROGRAMME

INTERNAL REPORT OR/08/068

Application of near-surface geophysical data in GSI3D - case studies from Shelford and Talla Linnfoots

J D O Williams and A J Scheib

Contributor/editor

O Kuras, M Raines and H Burke

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Near-surface geophysical data draped over Digital Terrain Model, Shelford

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British Geological Survey offices

BGS Central Enquiries Desk
Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG
Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA
Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE
Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE
Tel 029 2052 1962 Fax 029 2052 1963

Forde House, Park Five Business Centre, Harrier Way, Sowton EX2 7HU
Tel 01392 445271 Fax 01392 445371

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB
Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF
Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

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

Website www.bgs.ac.uk
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Summary

This report describes work that was carried out as part of the 3D Soils project of the former Sustainable Soils Programme. The work involved the acquisition of geophysical field data alongside traditional site investigation techniques to aid in 3D geological modelling of the shallow sub-surface. The first part of the report introduces the various geophysical techniques applied during site investigations, followed by a best practice guide to georeferencing geophysical data. It then goes on to describe how this data can be used in support of model development in GSI3D (Geological Surveying and Investigation in 3D).

This report can be consulted as a guide to how near-surface geophysics can be used as an aid to building site-scale soil-geology models using GSI3D, and suggests that work of this kind should be carried out using an integrated approach utilising appropriate geophysical techniques alongside standard geotechnical practices.

Geophysical techniques have demonstrated that Sand and Gravel (SAGR) deposits at Shelford are laterally variable in terms of their distribution and morphology, and a 3 m drop in-filled with SAGR has been mapped in 3D along with siltstone beds along the valley slopes.

Depth to the base of peat was identified using ground-truthed geophysical data at Talla Linnfoots, and demonstrates that the distribution and thickness of peat vary across the site. Information regarding the location of in-filled channels in the underlying glacial deposits has been used to add resolution to the 3D model and to suggest targets for further investigation.

Using a combination of geophysical and geotechnical data in GSI3D enabled the construction of 3D models showing the distribution of soil horizons, superficial deposits and bedrock geology. Various soil series/horizons were related to their parent materials by analysing their distribution in relation to the superficial and bedrock geology.

1 Introduction

Within the 3D Soils project, BGS has focussed on the development of geospatial 3 Dimensional (3D) models of the shallow sub-surface in order to visually describe the soil-geology continuum in a distributable manner. Understanding of the soil-geology transitional zone relies on investigating the distribution of various soil types (series) in relation to their parent materials.

Integrated geophysical and geotechnical site investigations have been carried out in order to create 3D models of the shallow sub-surface at two study sites at Shelford and Talla Linnfoots. Geophysical data was projected in 3D using GSI3D (Geological Surveying and Investigation in 3D) software, and was extensively used to model the geology and superficial deposits.

The methodology for georeferencing geophysical data in GSI3D has been examined, and is presented herein. Geophysical data from Shelford and Talla Linnfoots was used during the modelling process in order to add to the overall resolution of the 3D models for these sites. Several case studies are presented in order to convey various methodologies in which geophysical data can be used in GSI3D.

1.1 SHELFORD

The Shelford site is situated in the valley of the River Trent 5 km East of Nottingham centred at British National Grid (BNG) reference E 467238 N 342580. Covering an area of approximately 2 x 1 km, it is characterised by gently sloping river terraces, and a transition from Triassic mudstones and sandstones (Mercia Mudstone Group) to a flat and active alluvial system. The mudstones and sandstones are exposed on the north westerly dipping slope in the southern end of the site, while the River Trent marks the northern boundary of the study site. Data was acquired from Shelford during several field campaigns in 2006 and 2007.

1.2 TALLA LINNFOOTS

The Talla Linnfoots study area is an upland catchment in the Southern Uplands of Scotland 15.5 km north-east of Moffat (BNG E 315015 N 619836). The Talla Water stream runs through the centre of the site towards the north-west where it ultimately discharges into the Talla Reservoir. Underlain by Silurian Greywackes, this site covers an area of approximately 2.5 x 1.2 km, and is dominated by steep valley slopes with alluvium, peat and glacial deposits contained within the valley slopes. Data was acquired from Talla Linnfoots during two field campaigns in 2007.

2 Geophysical Site Investigation Techniques

2.1 ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

Electrical Resistivity Tomography (ERT) is a geophysical technique that can be applied to soil characterisation, and enables the generation of tomographic images of the sub-surface (Figure 1). This enables detailed structural evaluation, and the quantification of hydraulic and geotechnical parameters that are related to electrical properties. Features with a contrasting resistivity to that of surrounding materials may be located and characterised in terms of electrical resistivity, geometry and depth of burial (Figure 1). Interpretation can be 2D, 3D and also 4D (for time-lapse measurements).

At Shelford and Talla Linnfoots, data was acquired along transect lines perpendicular to the valley strike directions with the aim of traversing deposits of differing geologies. Surface topography was accounted for during inverse modelling of the data, with a maximum depth extent of the resistivity models being around 11 m below ground level.

ERT surveys require the installation of multiple electrodes along transect lines (Figure 2), making large-scale mapping surveys less practicable, but they are highly suitable for local reconnaissance, the evaluation of complex geological structures and the resolution of property variations with depth.

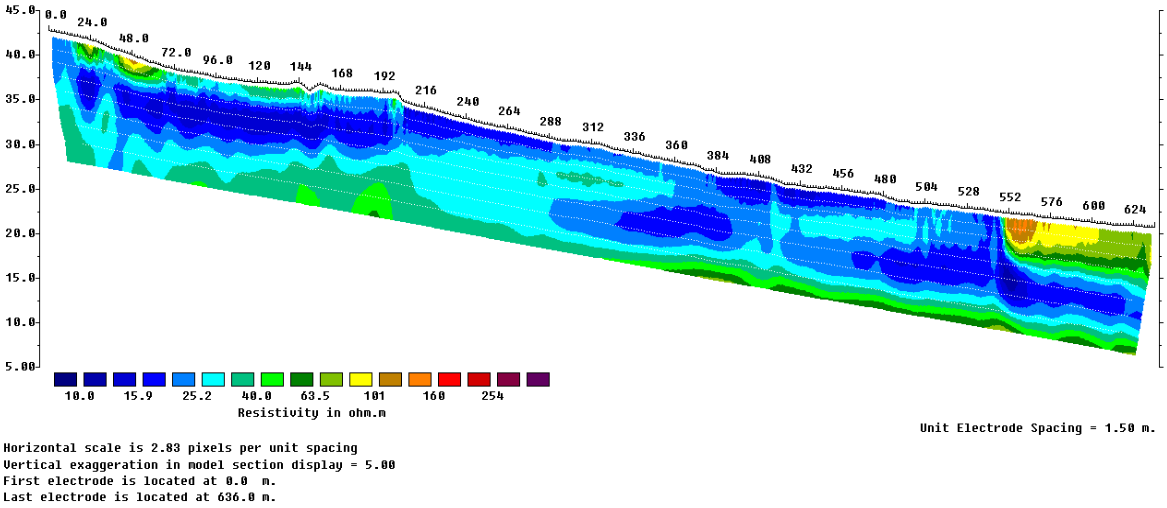

Figure 1: ERT section from Shelford showing a Triassic Mudstone (dark blue) slope with siltstone beds (light blue) and a buried cliff (orange, yellow, green) filled with sand and gravel to the right of the image

Figure 2: Installation of electrodes along ERT survey line at Talla Linnfoots facing north. Geophysicist in centre of image is installing an electrode in the stream bed

2.2 GROUND PENETRATING RADAR (GPR)

GPR is used to investigate the sub-surface by penetration and reflection of high-frequency electromagnetic waves in the ground. Reflections are generated by changes of the complex wave number of the soil or rock medium. At frequencies normally used for GPR (> 25 MHz), these changes are dominated by relative permittivity contrasts between two media, and determines the amplitude of any reflections generated (Davies and Annan, 1989).

The GPR surveys conducted at Shelford and Talla Linnfoots used the Pulse Ekko IV^{TM} (low frequency) system manufactured by Sensors & Software Ltd. Measurements were made with centre frequency 100 MHz antennae at 1 m separation, orientated broadside to the survey direction and moved in steps of 0.25 m (Figure 3). A Sample was recorded at each 0.25 m step. The transmitter voltage was 1000 V, with a sampling interval of 800 ps and signal stacking of 32 times.

The GPR data were processed and plotted using standard procedures as detailed in Annan (1993) using pulse EKKO^{TM} IV (version 4) software (Figure 4). A LIDAR (Light Detection and Ranging) Digital Terrain Model (DTM) was used to correct for topography and the results are plotted in section form as two-way travel time against sample position. Time-to-depth conversions are shown on the profiles by determining the electromagnetic wave propagation velocity at the sites. This velocity was determined by a Common Mid-Point (CMP) analysis (Annan and Davies, 1976) and was found to be 0.4 m/ns in the case of the Talla peat deposits and 0.1 m/ns for the sand and gravel at Shelford. This resulted in an observable signal penetration of approximately 5 m. The data are plotted in wiggle trace mode showing the actual waveform where the positive amplitudes are filled in (Figure 4). In this context, a wiggle trace represents the individual trace data at each sampling point.

Figure 3: GPR survey at Talla Linnfoots. Two antennae are moved along a transect line at regular intervals (0.25 m sampling). A pulse is transmitted from the leading antenna (left of image) and the reflected signal picked up by the receiving antenna (right)

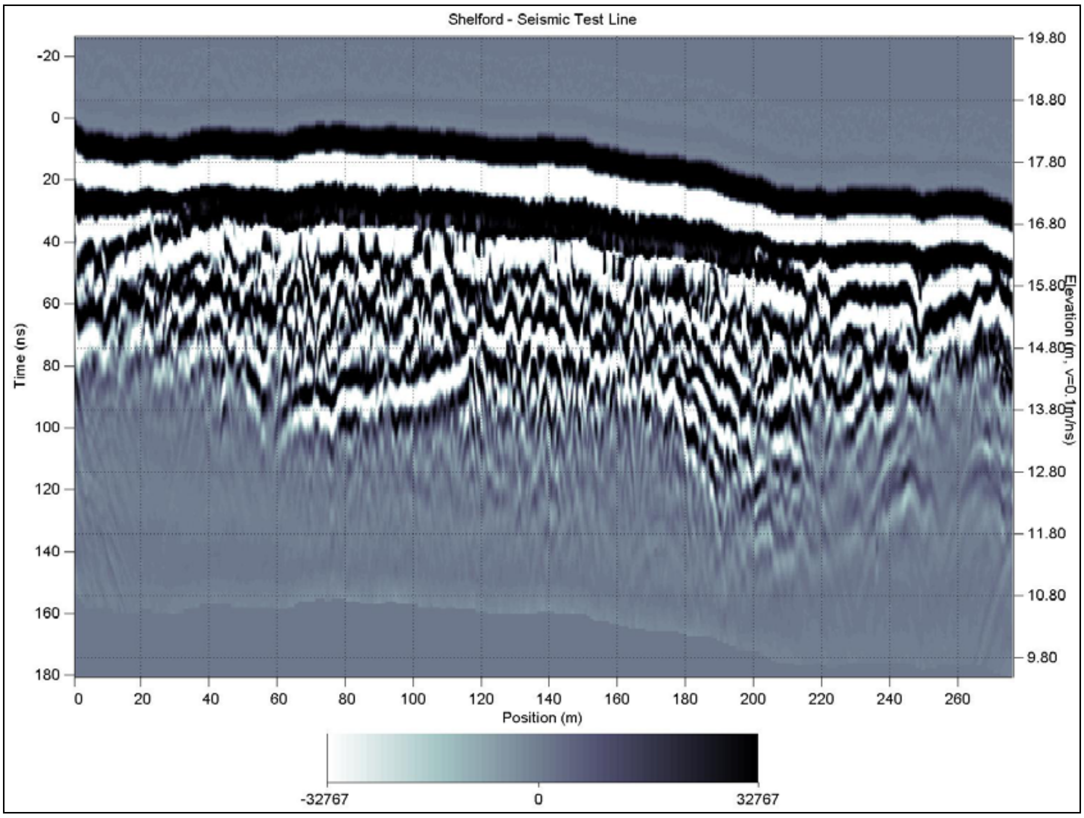

Figure 4: GPR section from Shelford showing depth of water table and structure of sand and gravel deposits

2.3 AUTOMATED RESISTIVITY PROFILING (ARP)

The Automated Resistivity Profiling (ARP) technique uses a patented multi-electrode device (provided by Geocarta SA, France), in which wheel-based electrodes are inserted in the ground and rolled along the surface (Dabas and Favard, 2007). An electrical current is injected into the ground using one pair of wheels, and resistance measured on three further pairs of wheels acting as potential dipoles. A typical sampling interval is 0.2 m. The system is mounted to a quad bike, which facilitates rapid data acquisition (~40 ha in 1.5 days at Shelford using a line spacing of 5 m). Use of differential GPS navigation within the system enables accurate surveying. Figure 5 shows the ARP system in operation at Shelford.

Figure 6 illustrates the setup of the system. Continuous electrical soil mapping is carried out at three different depths, with depth of investigation being determined by the electrode geometry. The dipole electrode pair with the widest spacing (furthest from injection point) acquires data at the greatest depth (See Figure 6). The three simultaneously obtained investigative depths are 0.5 m, 1 m and 2 m below ground surface level, and data is plotted as resistivity maps for each channel (Figure 7).

The horizontal property maps (Figure 7) obtained with ARP contain apparent resistivity values. They are not independent of the particular sensor geometry that was used to acquire the data. In contrast, the vertical sections obtained with ERT represent models of bulk sub-surface resistivity, which is an intrinsic physical property and independent of geometry. Both types of data can be compared in an approximate fashion, however a true quantitative comparison would require inverse modelling and a more accurate spatial localisation of the ARP results.

Figure 5: Geocarta ARP system in operation at Shelford moving towards left of image

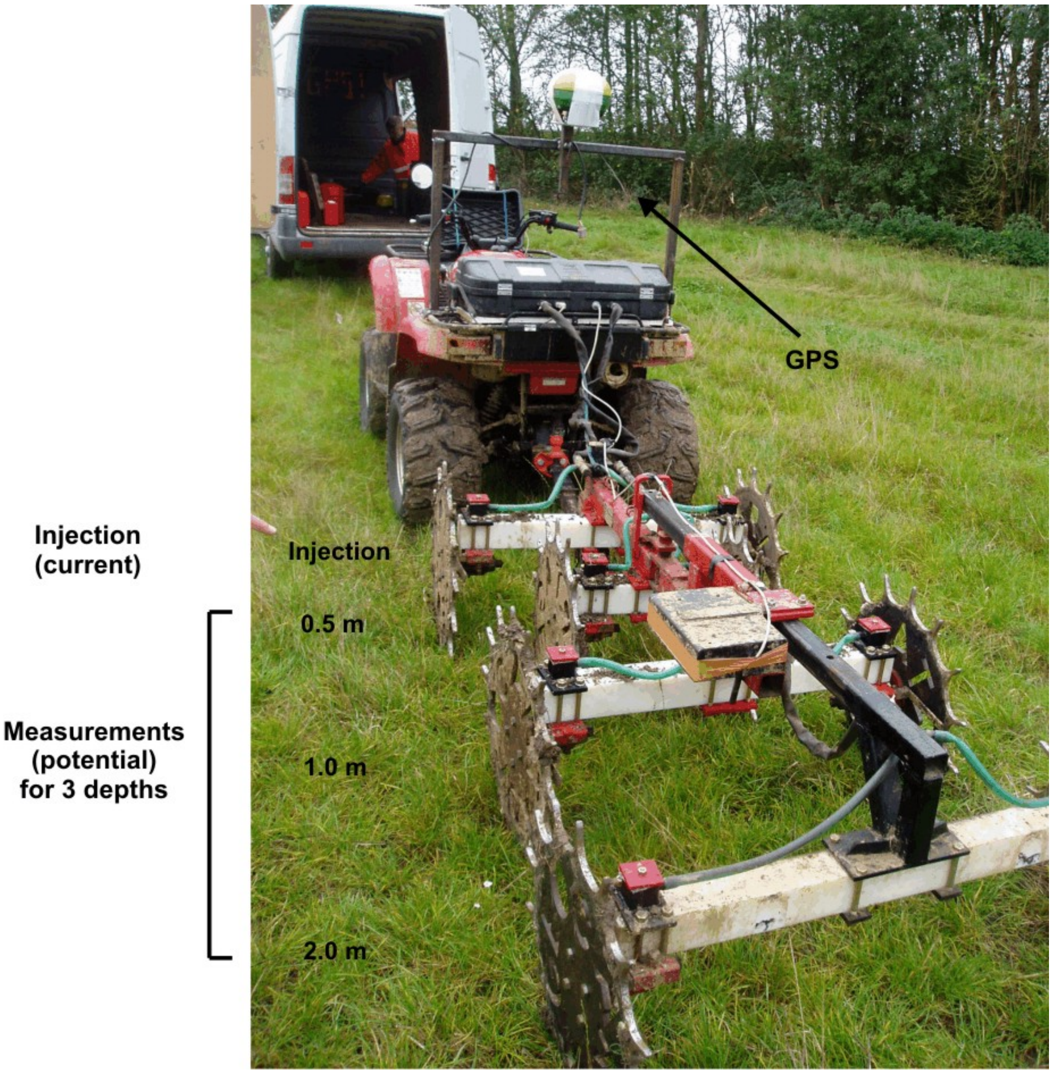

Figure 6: Basic setup of Geocarta ARP system showing depths of investigation at various electrode (wheel) spacing's. Depth of investigation increases with distance from injection point

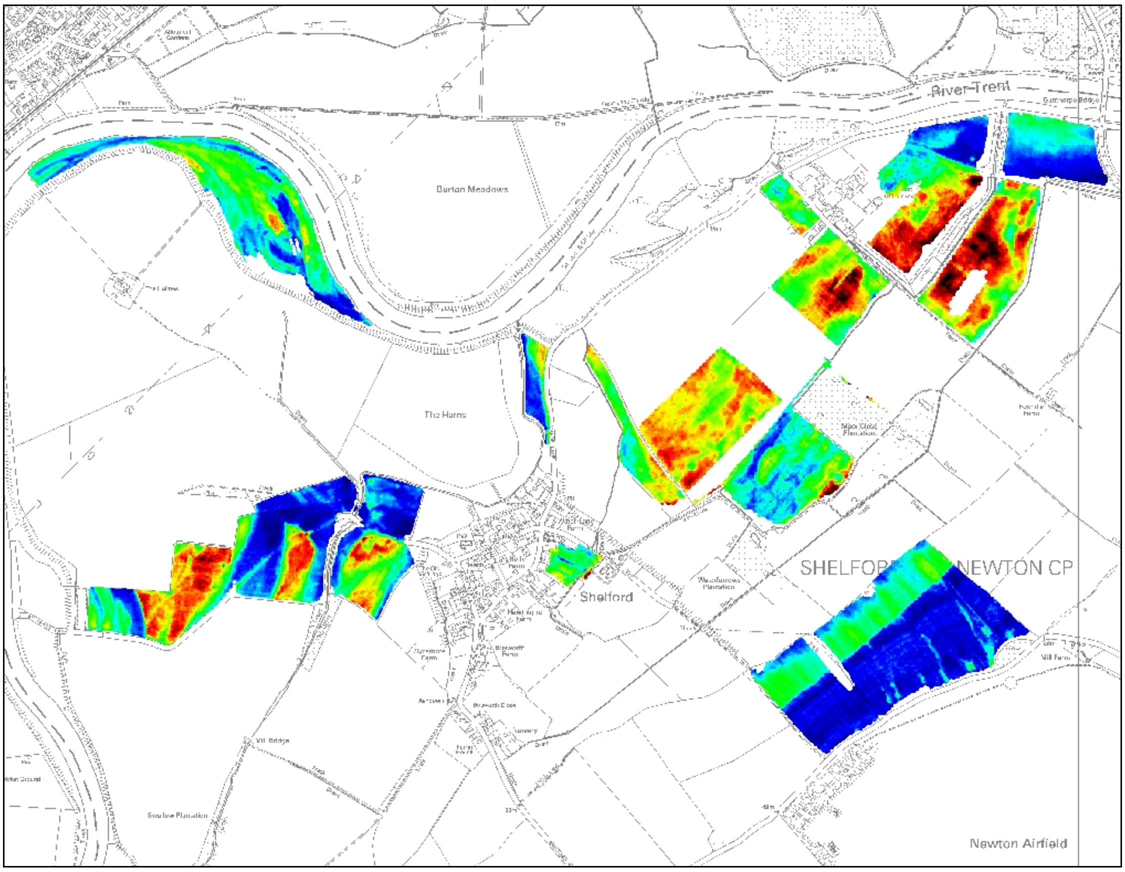

Figure 7: Geocarta ARP image (0.0 - 0.5 m; Channel 1) from 2007 survey at Shelford; blue areas show conductive sediments while red areas indicate electrically resistive sediments

3 GSI3D

This section aims to introduce the principals of GSI3D and to provide guidance on georeferencing and importing geophysical data. Although the basic principles of this procedure are similar to those used in other geoscientific modelling environments (Kuras, 2004), the specific capabilities of GSI3D need to be considered.

3.1 OVERVIEW OF GSI3D

GSI3D combines DTM, geological surface linework and downhole data to enable the scientist to construct intersecting geological cross-sections (Kessler and Mathers, 2004; Kessler *et al.*, 2008a). A brief description of the GSI3D workflow is given below and illustrated in Figure 8.

a) Geological map linework and downhole data is interpreted by the geoscientist and used to develop a Generalised Vertical Section (GVS) stating the order in which the geological units relate to one another. A legend (GLEG) file is produced to stipulate the colour properties (Red Green and Blue colour properties, RGB) of each unit

b) Geological cross-sections are constructed by correlating borehole data with the outcrop-subcrop of geological units

c) Regularly spaced intersecting cross-sections are combined to build a fence diagram

d) The distribution of each unit can be displayed and used to digitise distribution envelopes for each geological unit in turn. These envelopes define the subcrop/outcrop that is used during model calculation

e) A block model is calculated by mathematically interpolating between the nodes along sections and the outcrop/subcrop of the units. The top and basal surfaces and unit volumes are calculated automatically from a series of Triangulated Irregular Networks (TIN's)

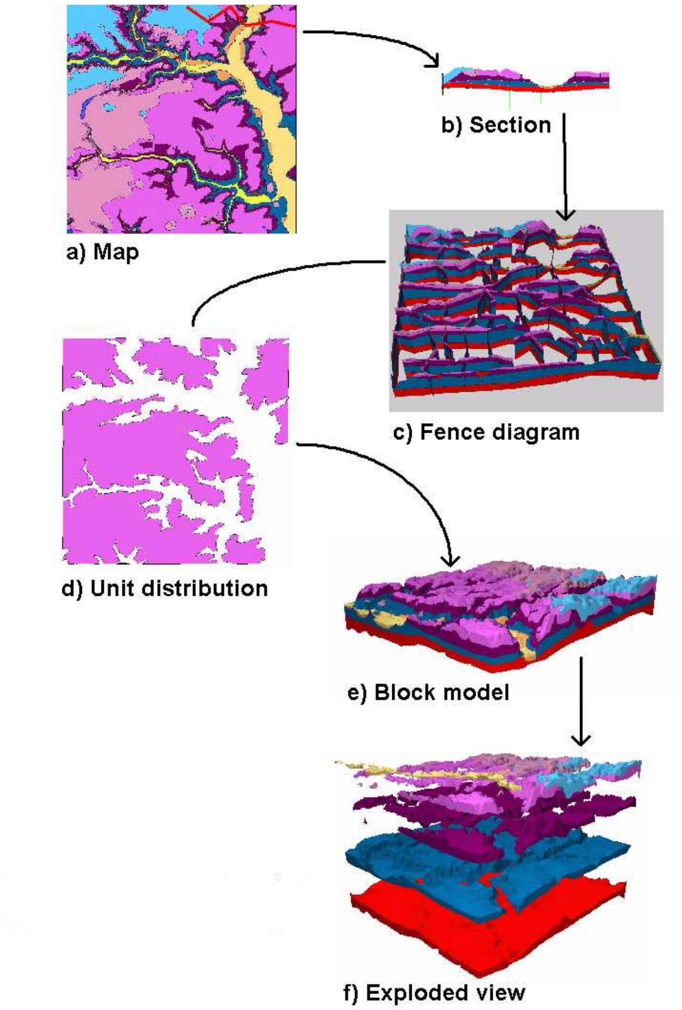

Figure 8: Workflow of 3D model construction in GSI3D

3.2 IMPORTING GEOPHYSICAL DATA INTO GSI3D

3.2.1 Vertical Geophysical Sections

ERT survey data from Talla Linnfoots will be used here as an example of how to prepare vertical sections for importing to 3D models in GSI3D. All manipulation and processing of data has been carried out prior to importing to GSI3D, i.e. colour scaling and vertical depth parameters have been pre-determined. Topographic corrections have also been applied to the data, as this cannot be achieved in GSI3D.

GSI3D imports bitmap images rather than raw geophysical data formats, and in order to georeference images correctly, requires an XYZ value for both the lower left and upper right hand corners. It is important that the start and end points of the survey line have accurate XY positions, and that the surface height, and profile depths are properly defined to provide accurate Z values. The software used for processing the ERT data is Res2Dinv© (Loke, 2007). This software can export files in *.bmp (bitmap) format that include a colour scale, horizontal and vertical scales and electrode numbers. An example of a typical output from Res2Dinv© is shown in Figure 9.

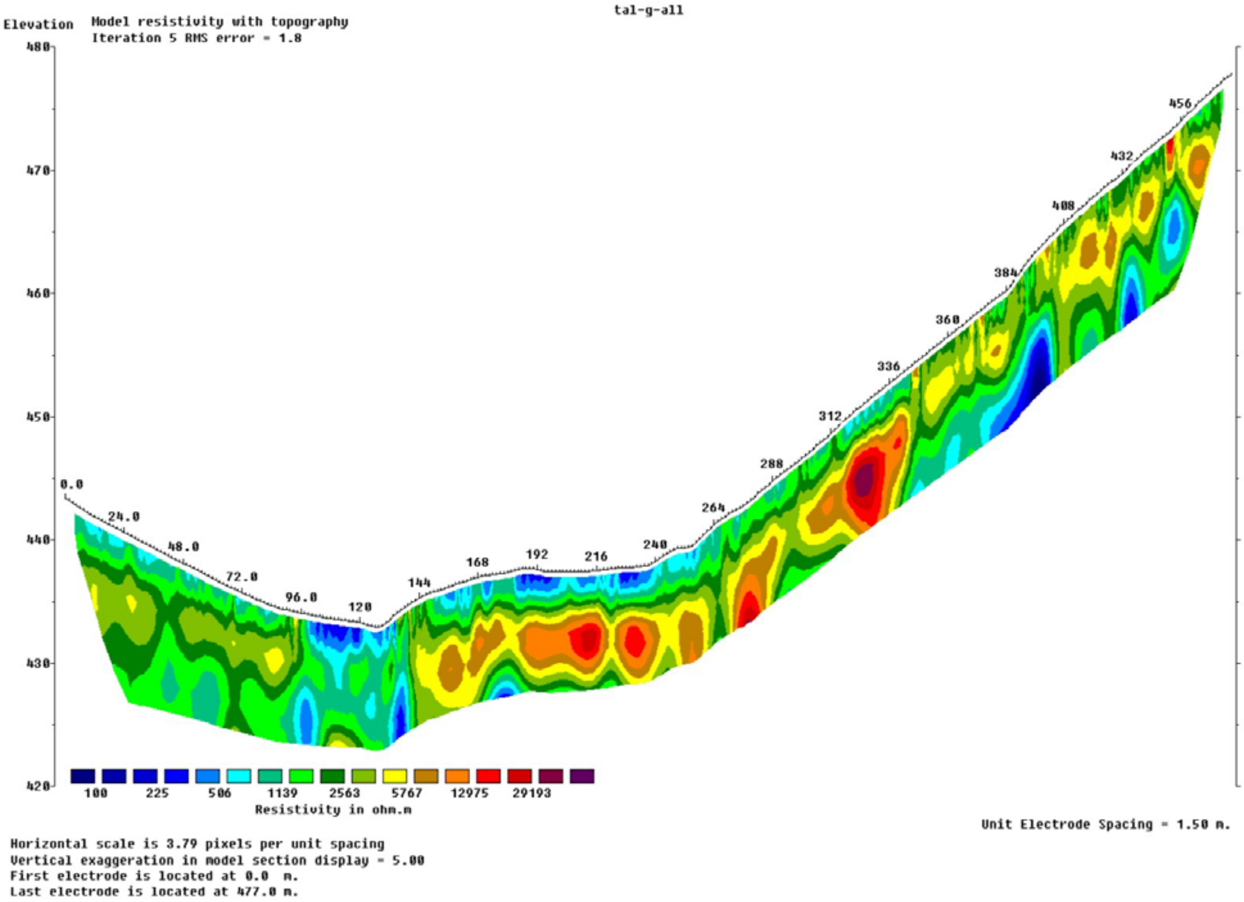

Figure 9: Example of unedited *.bmp output from Res2Dinv©

As the entire image is imported to GSI3D, only the data itself is required and so the image needs to be edited and cropped using appropriate graphics software such as Corel Photo-Paint©. The image should be cropped to the start and end points of the line, and to known heights above and below the data. Other information in the image such as colour scales etc. should be deleted manually using a delete/eraser tool available in the graphics software. An example of the area to be cropped is shown in Figure 10.

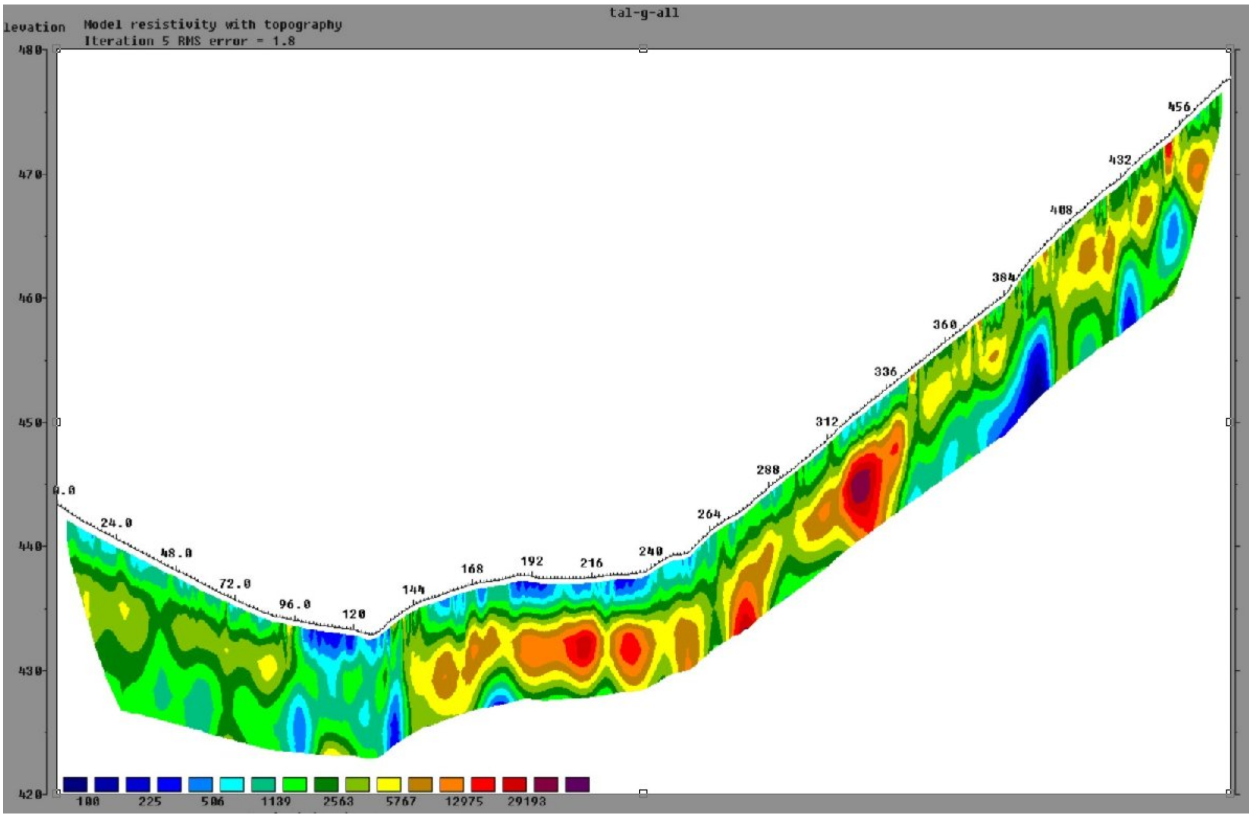

Figure 10: Example of cropped area (area greyed out will be cropped while the colour scale and electrodes positions should be erased manually)

Once the image has been cropped, and XYZ data recorded for the lower left and upper right hand corners, the image needs to be exported in a format compatible with GSI3D such as *.jpg or *.png. Before exporting the image from the graphics software, it is important to turn off any colour management tools that might affect the colour scaling of any images. In Corel Photo-Paint©, this option can be found under Colour Management tools, and the palette should be switched to 'Optimised' when exporting the file. This will ensure that the colour scaling and resolution of the image is not affected by the export functions of the graphics software. Once the image has been exported as a *.jpg or *.png, and is saved in an appropriate file space, it is ready for georeferencing using GSI3D.

The 'Georegister vertical geophysical sections' option in GSI3D is used to georeference vertical slices such as ERT data (Kessler *et al.*, 2008b). Using this option will allow the user to select the image to be registered from the file directory, and to define the XYZ positions of the lower left and upper right hand corners of the image. Once this has been done, the image should appear in the map and cross-section windows. Saving the project will save a *.gxml text file, which contains the XYZ information along with the file name and location of the image. If multiple sections are required, the *.gxml file can be edited using a standard text editor such as Microsoft Wordpad© to georeference other images by copying and pasting the text between the `</GSI3DMODEL>` header/footer, and updating the image name, location and XYZ information. An example of a *.gxml file georeferencing two images is shown in Figure 11.

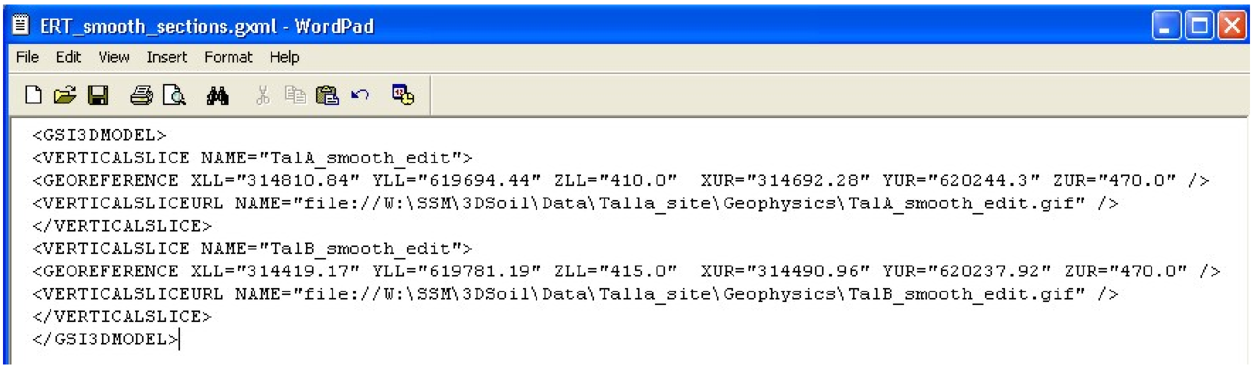

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Figure 11: Example of *.gxml file used to georeference two vertical geophysical images

If the image files are moved to a different file space to that specified in the *.gxml file, then the image cannot be viewed in GSI3D. If the file locations are changed, then the *.gxml file must be edited to specify the correct location of the geophysical image file.

3.2.1.1 IMPORTING VERTICAL GEOPHYSICAL SECTIONS – SUMMARY

a) Process data in appropriate specialist software, and export image as *.jpg or *.png format

b) Crop the image to the desired extent of data, and delete any unwanted scales etc.

c) Record XYZ positions for the lower left, and upper right hand corners of the image

d) Export cropped image to an appropriate file space

e) Use the ‘Georegister vertical geophysical sections’ option in GSI3D to georeference the image. Select the image from the file directory and specify XYZ positions for the lower left and upper right hand corners of the image

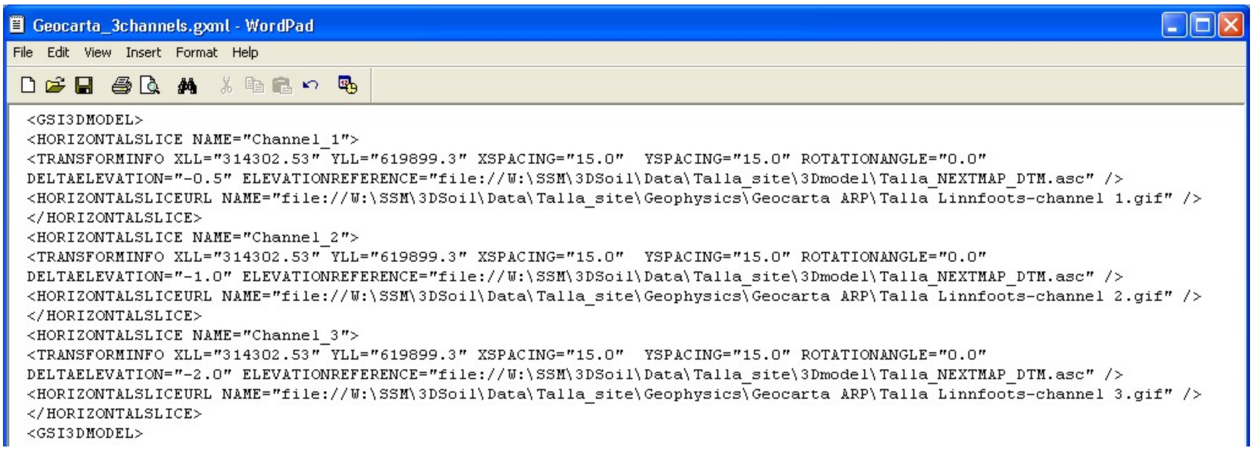
f) If georeferencing multiple geophysical sections, copy and paste the text in the *.gxml file for each image, and edit the XYZ positions and name of the images to be georeferenced

3.2.2 Horizontal Geophysical Slices (Property Maps)

Georeferencing horizontal geophysical slices is done in a similar way as with vertical geophysical sections. Unlike the vertical sections however, only the XY coordinates for the lower left hand corner of the image are required, along with the pixel size of the image. Resistivity maps created by Geocarta will be used here as an example of how to georeference horizontal images for use in GSI3D.

Map images for all three channels are provided by Geocarta as separate *.jpg files with associated *.jgw world files. These provide an XY location for the westernmost data point on the image, along with the image pixel size, which is required for georeferencing. This file is used for georeferencing the images for GIS products such as ArcGIS$^{©}$. GSI3D requires the XY coordinates of the lower left hand corner of the images, so viewing them in a GIS enables the user to obtain these coordinates. If images are provided without this information, it is still possible to obtain XY coordinates by georeferencing the image in a GIS and using the geographical extent to obtain the coordinates.

In GSI3D, the ‘Georegister horizontal geophysical sections’ option is used to georeference horizontal slices (Kessler *et al.*, 2008b). Using this option, the image is selected from the file directory, and the XY location of the lower left hand corner, and pixel size can be specified. Also, it is possible to select a DTM over which to drape the image, and to stipulate a depth relative to surface level. The various Geocarta channels are georeferenced in this way to ensure that the data is displayed in its correct vertical position relative to ground surface level. Figure 12 shows a *.gxml file georeferencing the three Geocarta channels.



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<GSI3DMODEL>
```

Figure 12: Example of *gxml file used to georeference three horizontal geophysical images

3.2.2.1 Importing Horizontal Geophysical Slices – Summary

a) Process the data in appropriate specialist software, and export image as *.jpg or *.png format

b) Crop the image to the desired extent of data, and delete any unwanted scales etc.

c) Record the pixel size, and XY coordinates for the lower left hand corner of the image

d) Export the cropped image to an appropriate file space

e) Use the ‘Georegister horizontal geophysical sections’ option to georeference the image. Select the image from the file directory and specify the pixel size and XY position of the lower left hand corner

f) If georeferencing multiple geophysical sections, copy and paste the text in the *.gxml file for each image, and edit the XYZ positions and name of the images to be georeferenced

4 Application – Case Studies

Once geophysical data slices have been georeferenced, GSI3D can be used as a tool for visualising and interpretating data in conjunction with other intrusive information such as borehole or auger data. Using geophysical data in this way enables the geoscientist to draw more accurate correlations and boundaries of geological units. Geophysical sections can guide a correlation line along the base of a geological unit between two borehole sticks in order to pick out the lateral variation of deposits between the two sample points, thus increasing the resolution of the cross-section. The horizontal geophysical slices can provide additional information when digitising the distribution envelopes of geological units within the stack.

4.1 CASE STUDY 1 – SHELFORD

4.1.1 Observations

Resistivity data acquired using the Geocarta ARP system displayed a high degree of lateral variation in the resistivity values of the near-surface across the site (Figure 7). Relatively high resistivity values (red) seem to correspond to slightly raised areas of coarse sandy gravel. The ERT data sections that run along the length of the site correlate with these areas while indicating that the relatively high resistive zones are restricted to the uppermost 4-5 metres (Figure 13).

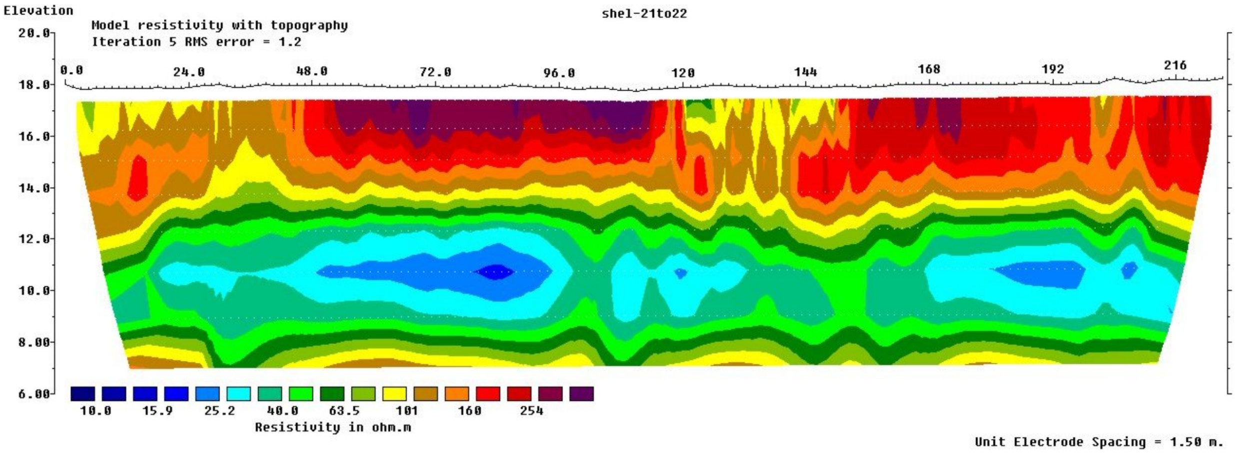


Figure 13: Example of ERT survey line at Shelford showing 4-5 metres of relatively high resistive sediments (red) overlying conductive Mercia Mudstone bedrock (blue/green).

These resistive zones did not extend further south than the base of the north westerly dipping slope that dominates the southern part of the site. Figure 14 illustrates how the south easterly limit of the relatively resistive zones appears to correspond with the onset of bedded subcrop within the conductive geology. Using the ARP data, these beds can be traced across the slope, appearing as linear resistivity contrasts.

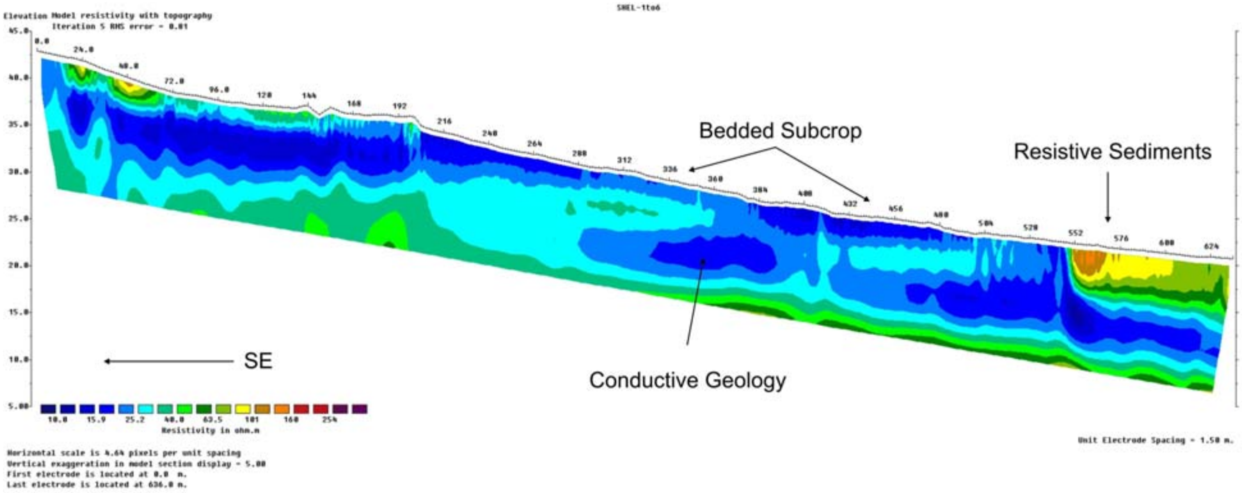


Figure 14: ERT section along slope at Shelford. Relatively resistive sediments on right side of image terminate at base of slope, while on the slope beds of conductive subcrop are observed within bedrock

4.1.2 Data Interpretations

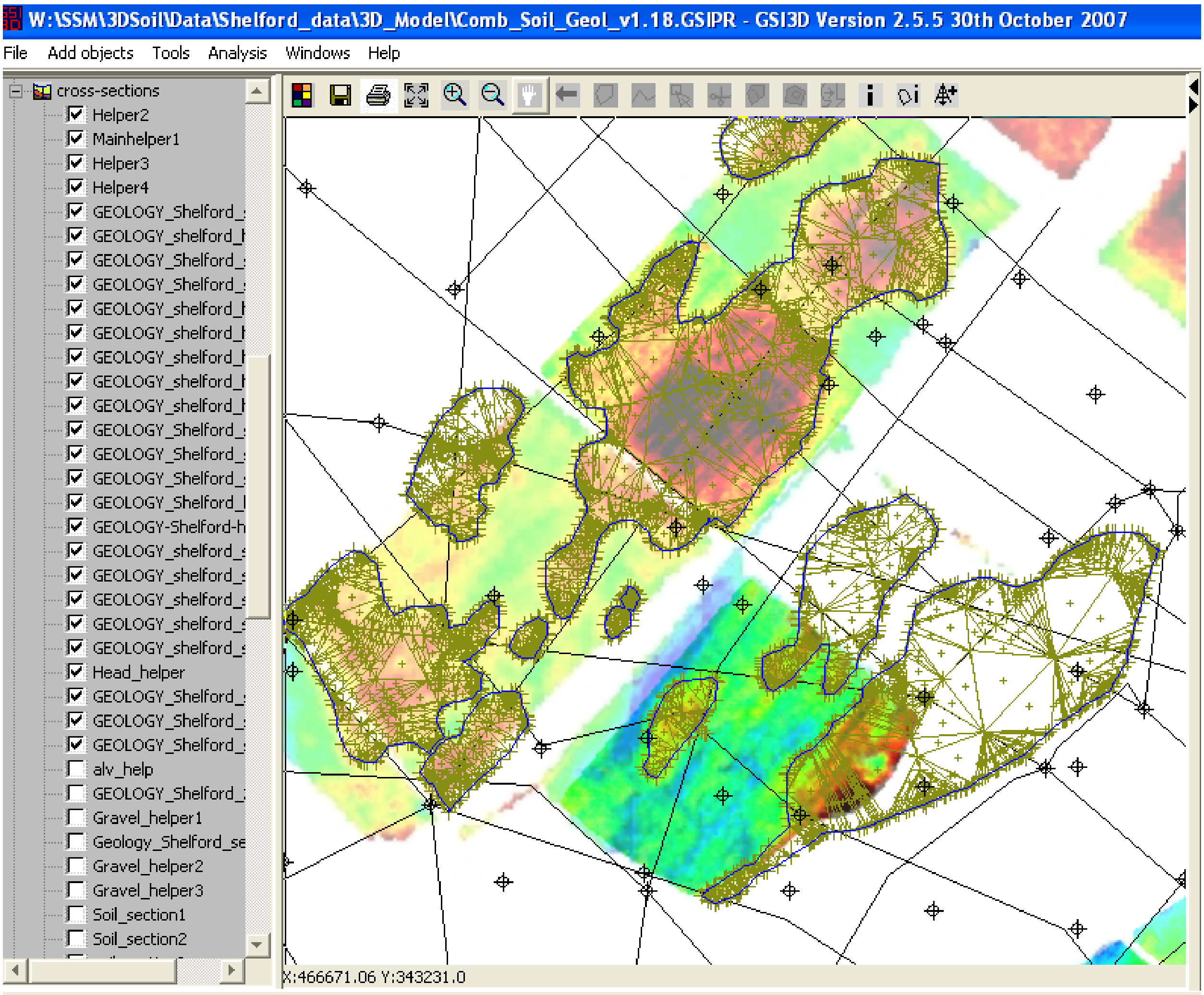
ARP results illustrate that there is heterogeneity within the river terrace deposits across the Shelford site (Figure 7). The distribution of various resistive zones displayed on the ARP maps have been attributed to the distribution of gravel-rich Sand and Gravel deposits (SAGR) in reds, and sandier SAGR deposits shown in yellow to green. Blue areas correspond to the finer textures of conductive alluvial clay and silts. Information on the lateral extent of gravel bars within the river terraces enabled the modeller to draw additional distribution envelopes (Figure 15).

As shown in Figure 14, the SAGR deposits at Shelford terminate at the base of slope, giving way to more conductive materials. This abrupt transition in electrical resistivity was interpreted as the maximum southern incision of the Trent, which created space for the deposition of SAGR bars and alluvial deposits. Figure 16 shows how different geophysical data (ARP maps and ERT sections) have been used together in order to map this 3 m vertical drop in 3D. The combination of geophysical sections and slices enabled the modeller to draw correlation cross-sections of the river terrace morphology.

The process of using geophysical data to assist with model construction in GSI3D is illustrated in Figure 17. This shows digitised distribution envelopes of the SAGR deposits in the 2D map window, a cross-section drawn using ERT data, and cross-sections along with ERT sections in the 3D window. The geological cross-section at the bottom of the image was drawn using a combination of borehole and ERT data.

Also displayed in the data are subcrops within the slope that appear to correlate with siltstone bands on the geological map of the Shelford site. These siltstone beds are more resistive than the surrounding Mercia Mudstone, and are clearly revealed in the ERT data (Figure 14) and mapped across the slope by the ARP data. Interpretation of the data suggests that these beds may have limited the southerly incision of the river as the siltstones will have been less prone to erosion than the surrounding mudstones.

The geophysical data acquired at Shelford was consulted during the planning of an additional drilling survey at the site, with various structures targeted for drilling. This additional downhole data was then used to further ground-truth the geophysical data.



W:\SSM\3DSoil\Data\Shelford_data\3D_Model\Comb_Soil_Geol_v1.18.GSIPR - GSI3D Version 2.5.5 30th October 2007

cross-sections
- ☑ Helper2
- ☑ Mainhelper1
- ☑ Helper3
- ☑ Helper4
- ☑ GEOLOGY_Shelford_
- ☑ GEOLOGY_shelford_I
- ☑ GEOLOGY_Shelford_
- ☑ GEOLOGY_Shelford_
- ☑ GEOLOGY_shelford_I
- ☑ GEOLOGY_shelford_I
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- ☑ GEOLOGY-Shelford-h
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- ☑ GEOLOGY_shelford_s
- ☑ GEOLOGY_shelford_s
- ☑ Head_helper
- ☑ GEOLOGY_Shelford_
- ☑ GEOLOGY_Shelford_
- ☑ GEOLOGY_Shelford_
- ☐ alv_help
- ☐ GEOLOGY_Shelford_
- ☐ Gravel_helper1
- ☐ Geology_Shelford_se
- ☐ Gravel_helper2
- ☐ Gravel_helper3
- ☐ Soil_section1
- ☐ Soil_section2

X:466671.06 Y:343231.0

Figure 15: Image from GSI3D 2D window showing ARP resistivity maps (transparency 30%) overlain by digitised distribution envelopes of coarse gravel bars within the terrace SAGR

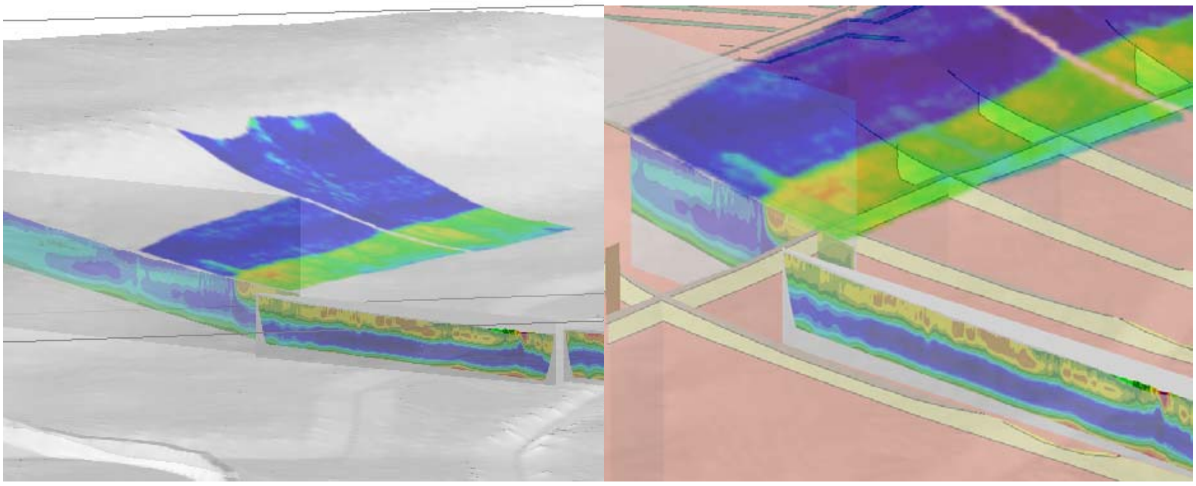

Figure 16: Image from GSI3D 3D window showing vertical drop of 3 m shown by ERT and ARP (left), and with correlated geological sections (right)

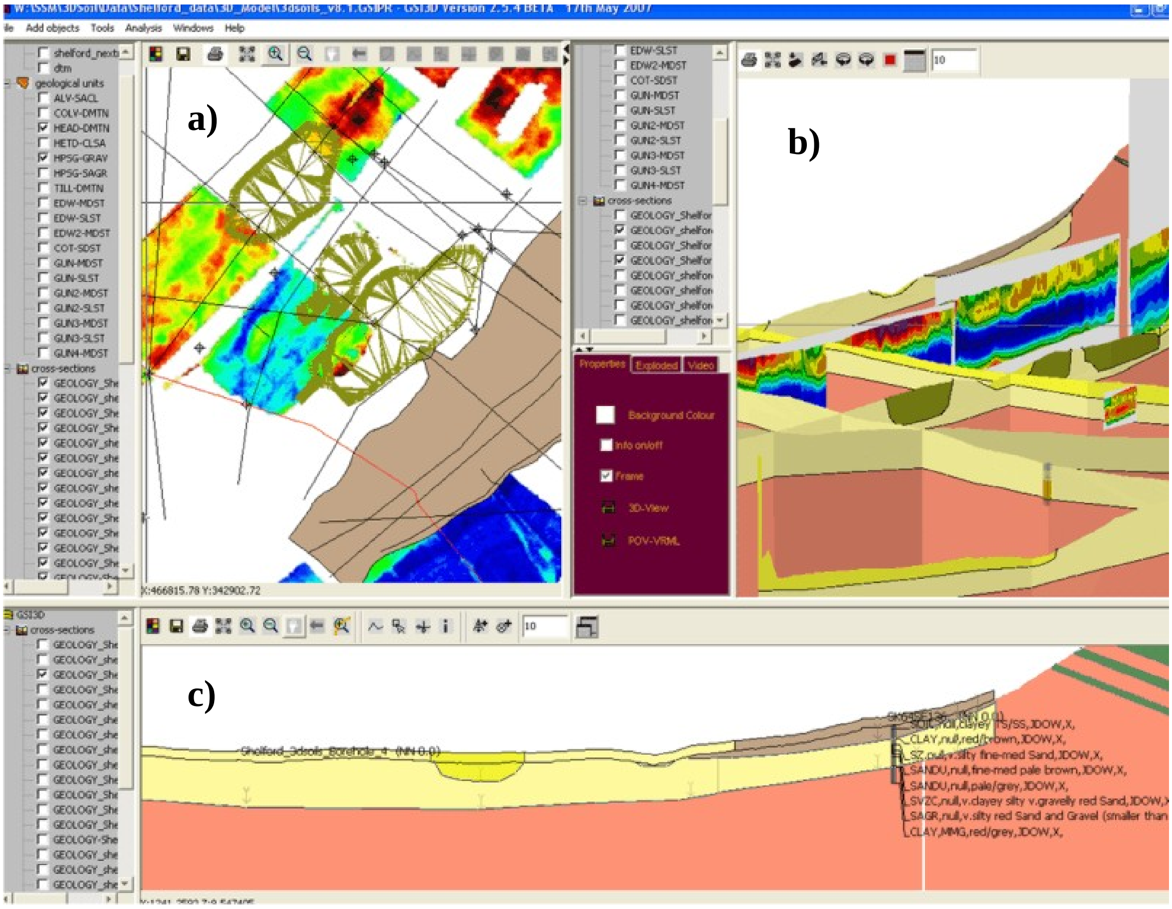

Figure 17: GSI3D showing a) Geocarta images, section and envelopes in 2D window, b) ERT sections in line with correlated geology sections in the 3D window and c) a geological cross section in the section window with borehole data to right hand side of image

4.2 CASE STUDY 2 – TALLA LINNFOOTS

4.2.1 Observations

Two major reflectors were seen in the GPR data acquired at the Talla Linnfoots site (Figure 18). The uppermost reflector is seen at <1 m depth, and is relatively consistent with respect to height below ground level. The second dominant reflector varies in depth across the profiles up to a maximum investigative depth of 4-5 m. Where the reflector sits at its maximum depth below ground level, it appears to form the base of channel like structures as shown in figure 18. Within these channels, some laterally inconsistent reflectors are observed that reflect variations within the structure of the channel fill deposits.

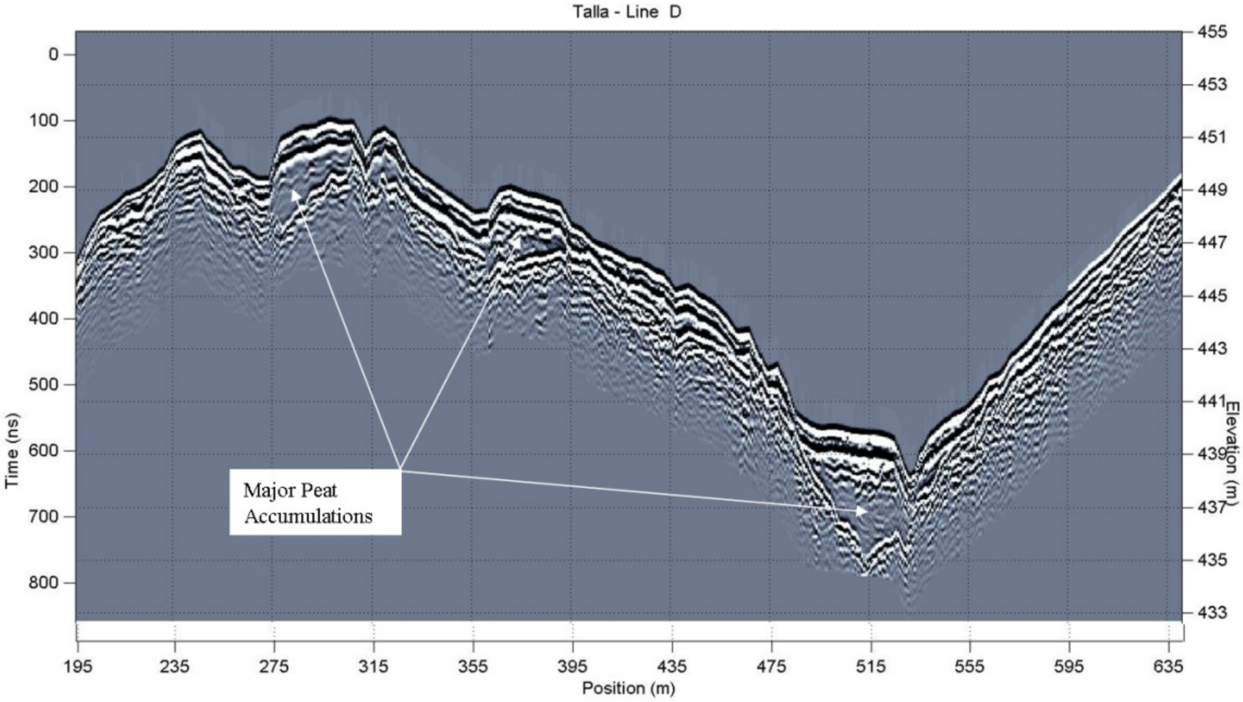

Figure 18: GPR section from Talla Linnfoots showing depth of investigation up to 4 m below ground surface level. The depth of the lower reflector is shown to vary across the section

4.2.2 Data Interpretations

Once an image has been imported to GSI3D, the modeller can generate a cross-section adjacent to this, and can pick along the interpreted horizon (Figure 17). GPR data from the Talla site was interpreted and annotations drawn on to the georeferenced images using standard graphical software (Figure 19). This is a way in which a geophysicist or geologist can pass on their interpretations to the 3D modeller. Once a geophysical image has been cropped and georeferenced in 3D, multiple copies of this can be made in order for various geologists and geophysicists to add their own interpretations. Interpreted images should be added to the *.gxml file in order that they be georeferenced. Annotations on a georeferenced image can be useful to avoid misinterpretation of data by the 3D modeller.

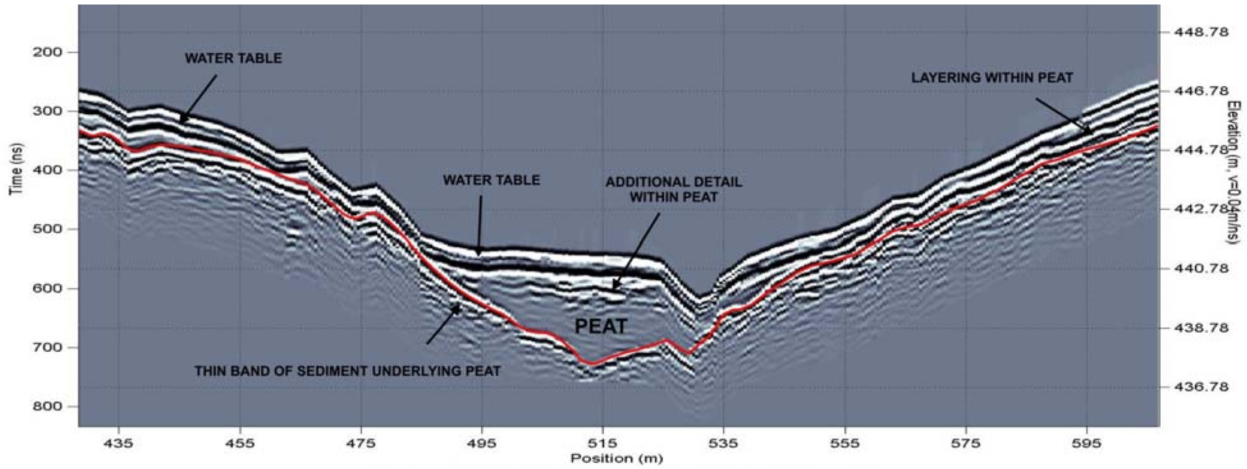

Figure 19: Example of interpreted GPR profile from Talla Linnfoots. The first dominant reflector represents the water table, while the red line represents the geophysicist's interpretation of the base of peat

Near-surface geophysical data should be interpreted in conjunction with other intrusive geological information such as borehole data. Geophysical and geotechnical data from Talla Linnfoots was imported into GSI3D for interpretation, and in order to refine the 3D model of the site. Geotechnical data should be used to ground-truth, refine and test geophysical interpretations and models. Figure 20 shows an ERT section in the 3D window of GSI3D, overlain by data acquired using a Panda Cone Penetrometer. This device measures the physical resistance of the sub-surface in Mega Pascal (MPa) units, and is effective in determining the depth of peat deposits due to the contrast in resistance between the underlying glacial deposits and the softer peats.

Panda Penetrometer data was acquired along similar transects as the geophysical datasets at 20 m sampling intervals. Figure 20 shows that the base peat profile line calculated using the Penetrometer data corresponds to a variation in electrical resistivity, though the ERT data offers a higher resolution due to the closely spaced electrode array. This higher resolution offers improved detail of peat thickness variability at the Talla site.

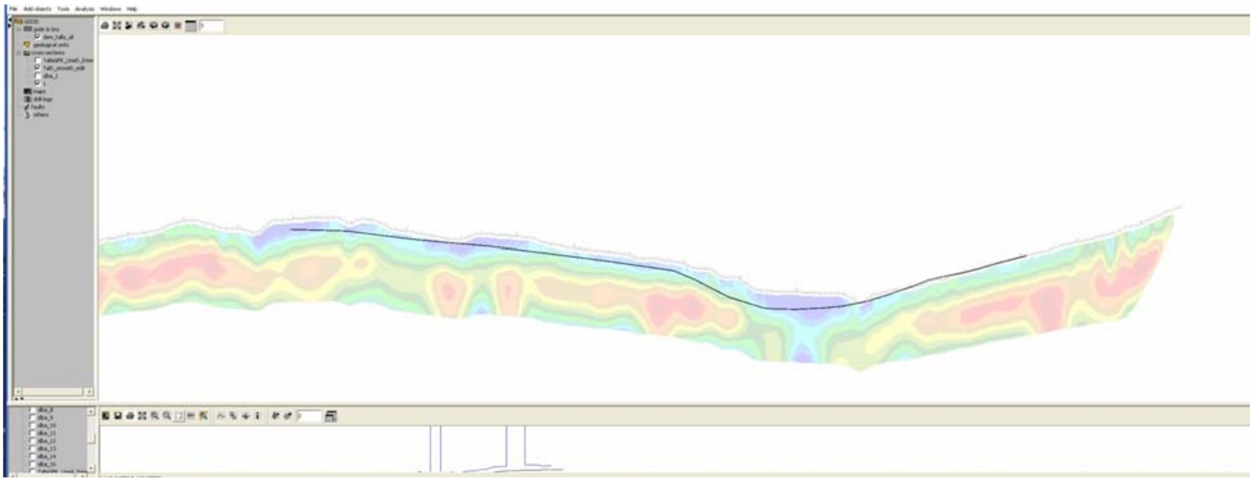

Figure 20: ERT section viewed in 3D window with Panda Penetrometer data (black line indicates base of peat profile)

Figure 21 shows how numerous datasets can be viewed simultaneously in 3D space using GSI3D. In this example, georeferenced ERT and GPR data have been viewed together along with borehole data. The base of peat has been interpreted using the GPR data, and this correlates with a transitional contour in the ERT data; from highly conductive peat, to the less conductive (resistive) underlying deposits. The interpreted horizon (red line) correlates with the borehole data.

The borehole data at the site was used to calibrate the radar data by refining the depth conversion. As GPR data is acquired in the time domain, it is necessary to stipulate a velocity value for the ground material (see Section 2.2). The initial depth conversion applied to the GPR did not produce a result that was supported by the borehole data, and thus was re-calculated accordingly using a value obtained from CMP velocity tests.

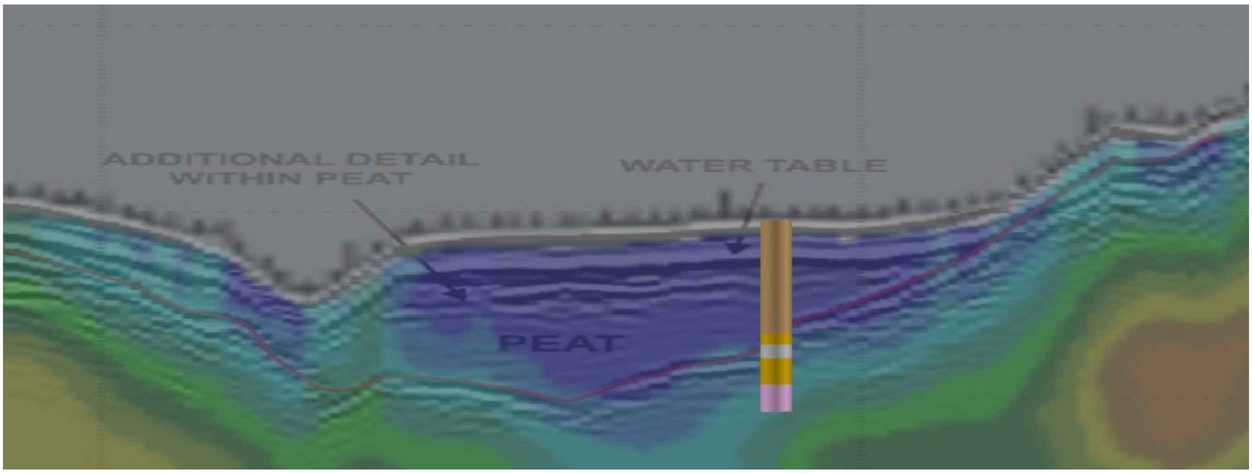

Figure 21: Image from 3D window of GSI3D showing ERT data superimposed on interpreted GPR section, with borehole log (Brown = Peat)

As the base of the peat horizon correlates with a transitional contour between two quantitative resistivity values in the ERT data, the data can be re-processed using a different scaling factor in order to emphasise this particular contoured transition. This allows the 3D modeller to digitise a contour that represents a given geological horizon and also provides a rough estimation of the resistivity ranges exhibited by the Talla peats. At the Talla site, some geophysical data was acquired in areas inaccessible to vehicles resulting in a lack of downhole data. Ground-truthed ERT profiles can be used as analogues for interpretating ERT data in areas of the site that lack suitable borehole coverage.

5 Conclusion and Recommendations

5.1 CONCLUSION

Geophysical techniques were deployed in order to aid in the production of site-scale 3D models of the shallow sub-surface at Shelford and Talla Linnfoots. 3D modelling of the study-sites was carried out using the GSI3D software tool for the purposes of relating the distribution of various soil series (types) to their parent-materials. The geophysical data provided information at a resolution that would have been impracticable using traditional site investigation techniques alone, and the data was used to suggest further targets for penetrative techniques such as drilling and soil augering.

At Shelford, ARP resistivity mapping and ERT sections indicated that SAGR deposits at the site show lateral variation in terms of their distribution and morphology. The presence of a 3 m drop in-filled with SAGR was established and mapped using geophysical data, while comparatively resistive beds were correlated with mapped siltstone beds along the slope.

Depth to the base of peat was identified using ground-truthed geophysical data at Talla Linnfoots. The distribution and thickness of peat varied across the site, and the information regarding the location of in-filled channels in the underlying glacial deposits was used to add resolution to the 3D model and to suggest targets for further investigation.

Using a combination of geophysical and geotechnical data in GSI3D enabled the construction of 3D models showing the distribution of soil horizons, superficial deposits and bedrock geology. Various soil series/horizons were related to their parent materials by analysing their distribution in relation to the superficial and bedrock geology.

5.2 FUTURE RECOMMENDATIONS

Further scope for development includes the potential to conduct 3D geophysical field surveys over smaller areas in order to increase model resolution in areas where deposits vary in terms of their distribution. Data would be acquired along regularly spaced (i.e. 10 m) transect lines, and the GSI3D methodology would remain the same. A survey of this nature over the peat deposits in Talla Linnfoots could allow for high resolution 3D mapping of channels/structures within the underlying glacial deposits.

Seismic refraction is another technique that may be used in order to acquire geophysical data for use in GSI3D models. Similar to GPR, seismic refraction is a technique used for defining discrete horizons. Preliminary data from Shelford indicate that the technique is effective in determining the depth to bedrock when overlying deposits are consolidated. A discrete horizon such as the top of bedrock can be modelled and imported to GSI3D as a series of coordinates and profile depth (XYZ) points. This data may provide the base of a soil-geology model.

A limitation of GSI3D is that it is unable to support native geophysical data formats. Advanced interpretation of geophysical data should therefore be carried out in other specialised software packages such as GOCAD®. These software packages are capable of exporting interpreted horizons as text format XYZ files, a format that can enable horizons to be read in GSI3D.

Glossary

ARP	Automatic Resistivity Profiling
BGS	British Geological Survey
BNG	British National Grid
CMP	Common Mid Point
DTM	Digital Terrain Model
EM	Electro-Magnetic
ERT	Electrical Resistivity Tomography
GPR	Ground Penetrating Radar
GSI3D	Geological Surveying and Investigation in 3-D
GVS	Generalised Vertical Section
LIDAR	Light Detection and Ranging
MPa	Mega Pascal
RGB	Red Green and Blue colour properties
SAGR	Sands and Gravels
TIN	Triangulated Irregular Network
3D	3 Dimensional

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