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Sand and Gravel Deposit Evaluation Using Electrical Resistivity Tomography

J.E. Chambers* (British Geological Survey), P.B. Wilkinson (British Geological Survey), A.L. Weller (British Geological Survey), O. Kuras (British Geological Survey), P.I. Meldrum (British Geological Survey), R.D. Ogilvy (British Geological Survey), J. Aumonier (Mineral Industry Research Organisation (MIRO)), S. Penn (CEMEX), D.R. Wardrop (Lafarge), E. Bailey (Aggregate Industries), P. Joel (Tarmac) & N. Griffiths (Hanson)

SUMMARY

In this study, we assess the suitability of ERT for UK sand and gravel deposit assessment. To this end, we have reviewed the characteristics of deposits in terms of geological setting, thickness and heterogeneity to inform our survey design strategy. We have collated existing data on the electrical properties of UK sand and gravel, reviewed previous examples of ERT sand and gravel surveys, and undertaken detailed geophysical studies at seven potential or active sand and gravel extraction locations in East Anglia and the East Midlands.

INTRODUCTION

Electrical Resistivity Tomography (ERT) is a rapidly developing geophysical imaging technique that is now widely used to visualise subsurface geological structure, groundwater and lithological variations. It is being increasingly applied to environmental and engineering site investigations, but despite its suitability and potential benefits, ERT has yet to be routinely applied by the minerals industry to sand and gravel deposit assessment and quarry planning. The principal advantages of ERT for this application are that it is a cost-effective non-invasive method, which can provide fully 2D spatial or 3D volumetric models of the subsurface at the site scale. This is in contrast to intrusive sampling methods, which typically provide information only at discrete locations. We anticipate that ERT has the potential to reveal mineral and overburden thickness (if a sufficient resistivity contrast exists between the overburden, sand and gravel, and bedrock), quality variations within the body of the deposit, archaeological features and information on the level and quality of groundwater.

In this study, we assess the suitability of ERT for UK sand and gravel deposit assessment. To this end, we have reviewed the characteristics of deposits in terms of geological setting, thickness and heterogeneity to inform our survey design strategy. We have collated existing data on the electrical properties of UK sand and gravel, reviewed previous examples of ERT sand and gravel surveys, and undertaken detailed geophysical studies at seven potential or active sand and gravel extraction locations in East Anglia and the East Midlands.

BACKGROUND

The most widely exploited sand and gravel deposits in the UK are from river terrace and glacial sources. River terrace deposits are, in most cases, less than 10 m thickness, whilst glacial deposits tend to be more heterogeneous, and with thicknesses up to 30 m, with most falling within the 10 to 20 m range. Nearly all the economic deposits for which electrical data exists display good contrasts in resistivity between bedrock and mineral (Chambers et al, 2007). The relatively shallow nature of most UK deposits (i.e. <10 m), and the good resistivity contrasts between mineral and bedrock in the geological settings for which information is available, are favourable indicators for the future success of ERT for this application.

One of the earliest references to the use of 2D ERT for sand and gravel resource studies is by Barker (1997), in which he describes a survey from the Trent Valley, UK. Other published examples are rare, but include Beresnev et al. (2002), Hill (2004) and Lucius et al. (2006). To the best of our knowledge, there are currently no published examples of the application of 3D ERT.

CASE STUDIES

A set of field sites for controlled testing were chosen to include a range of geological settings and geological complexity. All of the sites are associated with existing sand and gravel quarries and are well characterized with good ground truth data (e.g. boreholes and trial pits) with which to calibrate and assess the ERT models.

2D Surveys

2D ERT surveys were undertaken at Ingham (Suffolk), Broom (Bedfordshire), Wimblington Fen (Cambridgeshire) and Trafford Estate (Norfolk). These surveys were intended to demonstrate 2D ERT as a rapid sand and gravel reconnaissance tool, and to extend our knowledge of the electrical properties of the deposits and bedrock in these areas. In all cases 2D ERT was successful in imaging the thickness of the sand and gravel due to the good resistivity contrasts between the sand and gravel and bedrock materials (i.e. clay and chalk) (Figure 1). The Ingham survey included a substantial thickness of boulder clay overburden, which was successfully identified in the resistivity image as a low resistivity zone.

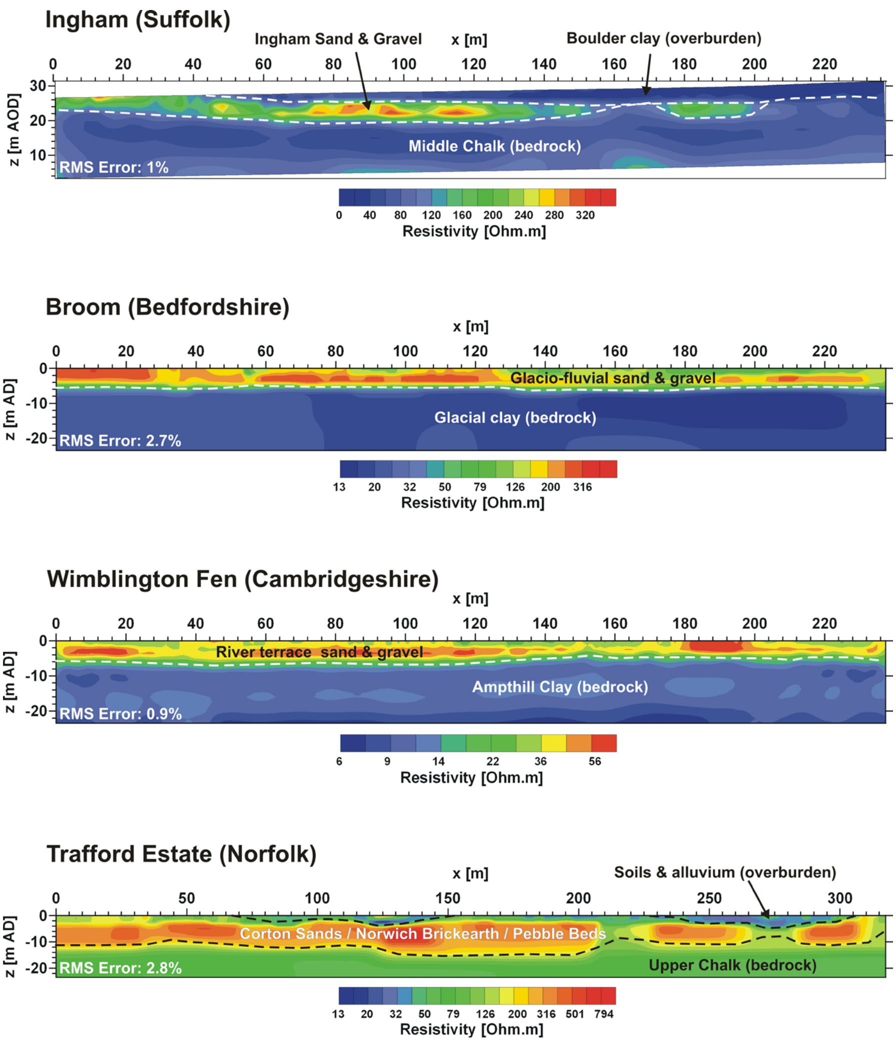

Figure 1. 2D ERT images from study sites in eastern England.

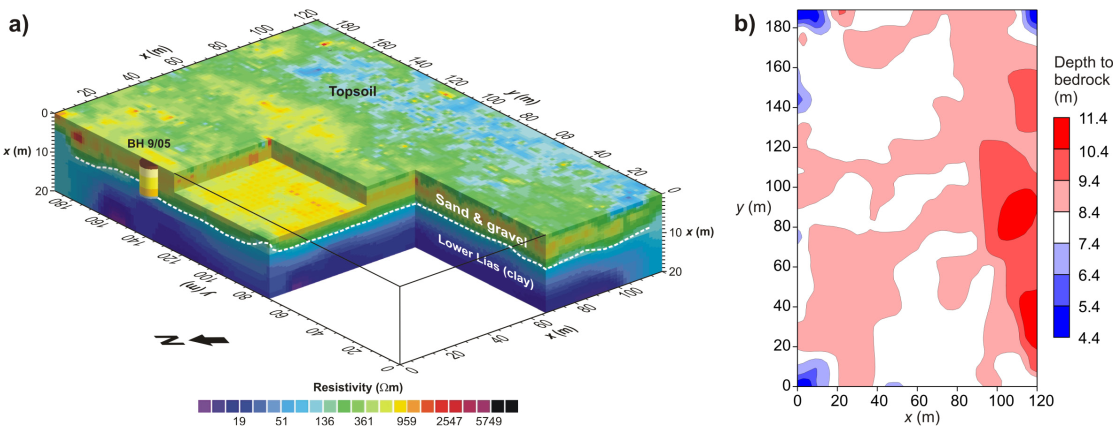

Figure 2. Norton Disney (a) 3D ERT model and (b) calculated bedrock surface.

3D Surveys

Validation surveys using 3D ERT were undertaken at Norton Disney (Lincolnshire), Chelmsford (Essex) and Masham (North Yorkshire).

Norton Disney was chosen as a simple case, with relatively homogenous river terrace sand and gravel overlying Lower Lias clay bedrock, and little or no overburden. The 3D resistivity model (mean misfit error = 3.2%), shown in Figure 2a, revealed a strong resistivity contrast between the sand and gravel and clay bedrock. An automated bedrock detection algorithm, which was calibrated using borehole data, was used to determine depths to bedrock across the 3D resistivity model. These data were used to calculate the bedrock surface shown in Figure 2b.

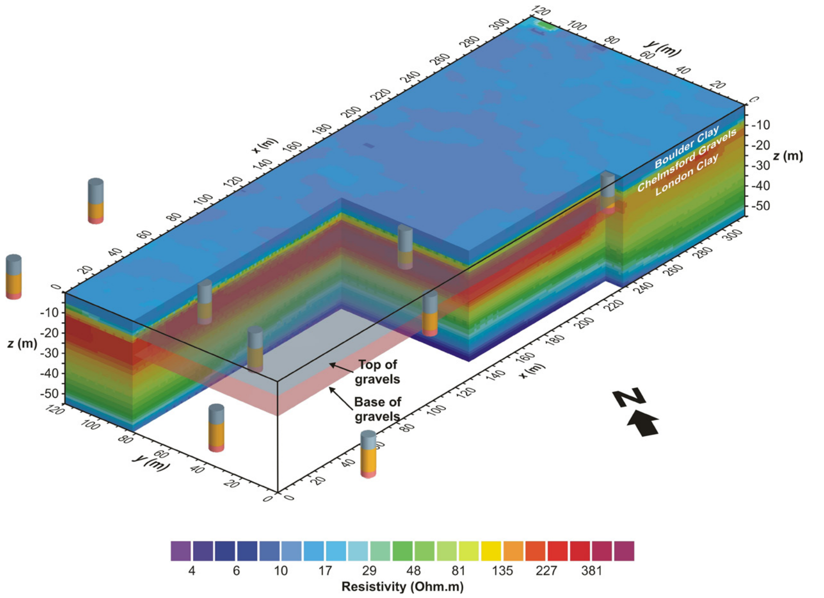

Figure 3. Chelmsford 3D ERT model, including geological model.

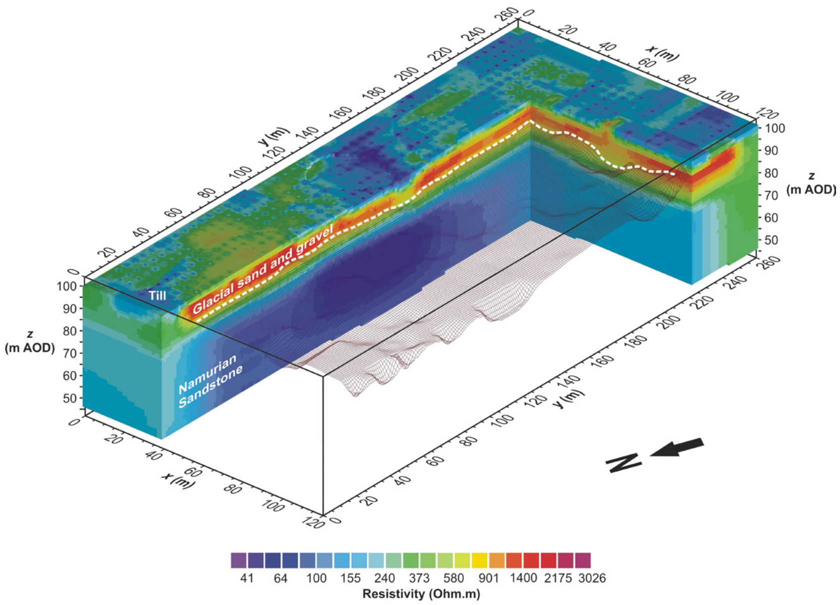

Figure 4. Masham 3D ERT model, including calculated bedrock surface (wireframe).

The Chelmsford deposit consists of glacial gravels overlying London Clay bedrock. The gravels are covered with a thick layer of till. In this case the thickness of the till overburden is well resolved in the 3D ERT model (mean misfit error = 2.14%), but the base of the sand and gravel is poorly resolved (Figure 3). The failure of ERT in this case was due to the high overburden to mineral thickness ratio, and current channeling in the very low resistivity till – thereby illustrating the limitations of surface 3D ERT. Synthetic modelling studies carried out to assist in the interpretation of this survey have revealed that the dipole-dipole array, as used for this survey, is unlikely to be successful where the overburden is thicker than the mineral layer. However, the use of higher power imaging systems, buried electrodes or alternative array types, such as the gradient array, has the potential to improve significantly the depth of investigation in areas where current channeling in conductive overburden is a problem.

The Masham site represents a relatively simple geology, which consists of Namurian sandstone or mudstone bedrock, overlain by fluvio-glacial sand and gravel, which in turn are overlain by a thin variable cover of clay till. However, it is essentially unproven due to the failure of conventional drilling methods, which have been rendered almost useless due to the high proportion of cobbles and boulders in the deposit. The 3D ERT model (mean misfit error = 1.65%) is successful in identifying the distribution of overburden across the area and revealing the thickness of the gravel deposit (Figure 4). A 2D surface defining the base of the gravel was calculated from the ERT model; as with the Norton Disney survey this surface was in a form that could be directly incorporated into terrain modelling packages for reserve calculation.

CONCLUSIONS

ERT was proved to be an effective ground investigation technique for all but one of the sites investigated during the study, and good resistivity contrasts between mineral and bedrock were observed in all the geological settings considered. When viewed in the broader geological context this increases our confidence that ERT will be more generally applicable to UK sand and gravel resources. Economic sand and gravel deposits are by definition relatively clean (i.e. low clay content), and are therefore typically more resistive than weathered mudstone (e.g. Mercia Mudstone Formation) and chalk (Chalk Formation), and clay (e.g. Oxford & London Clay) bedrock that underlies many important UK deposits.

ERT was used to provide additional ground-truth information that was not identifiable from borehole data alone. This was particularly important for deposits that were difficult to drill (e.g. Masham), and for complex deposits (e.g. Ingham) where ERT could reveal geological variations between intrusive sample points. Initial comparisons have shown that ERT survey costs are likely to be broadly similar to those of drilling (assuming a 100 m spaced grid of boreholes). Whilst ERT should not replace drilling, it has the potential to reduce the number of intrusive sample points required, and will enable better targeting of boreholes.

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