Introduction

Geophysical methods are playing an increasingly important role in the investigation and monitoring of landslides (e.g. Jongmans and Garambois, 2007); such methods are proving to be particularly effective for revealing the 3D structure, failure surfaces, and the hydrogeological regimes associated with rock and earth slides.

In this paper we present the results of a geoelectrical reconnaissance survey of the Hollin Hill landslide, UK. This work was undertaken in advance of the installation of a permanent geophysical and geotechnical monitoring system, and was designed to assess the suitability of resistivity and self-potential (SP) methods for investigating and monitoring this site. In particular, we were concerned to assess the electrical property contrasts and the magnitude of SP response across the study area.

Site Description

The Hollin Hill research site [SE 6807 6883] lies 11 km to the west of Malton, North Yorkshire, occupying an elevation of between 55 and 100 mAOD. It is located on the south facing side of a degraded Devensian ice-marginal drainage channel, with a slope of approximately 12^{o}. The unstable ground extends for a distance of 200 m down the slope, and for a width of several hundred meters. Mapping of the geological and geomorphologic features at the site has been carried out by BGS. The bedrock geology of the slope comprises Redcar Mudstone Formation (Lower Lias) at the base, above which are the Staithes Sandstone and Cleveland Ironstone formations (referred to here as "Staithes Sandstone") (Middle Lias), which in turn are overlain by the Whitby Mudstone Formation (Upper Lias) (Figure 1). The superficial geology of the site is represented by a thin (<1 m) drape of sandy, gravelly clay (hillwash) derived from the highest bedrock unit, the Dogger Formation (Ravenscar Group) and degraded lobes of Liassic landslide material. The instability at the site is largely caused by the movement of the Whitby Mudstone Formation, which is highly prone to landsliding. The landslide is characterized by shallow rotational failures at the top of the slope, that feed into four larger-scale slowly moving (i.e. tens of centimeters per year) lobes of slumped material (Figure 2). Relatively little is known about the hydrogeology of the site. However, a spring line extends across the base of the slope where the Staithes Sandstone gives way to the underlying Redcar Mudstone Formation. Runoff from the valley floor and sides appears to drain into the stream located at the valley centre (Figure 1).

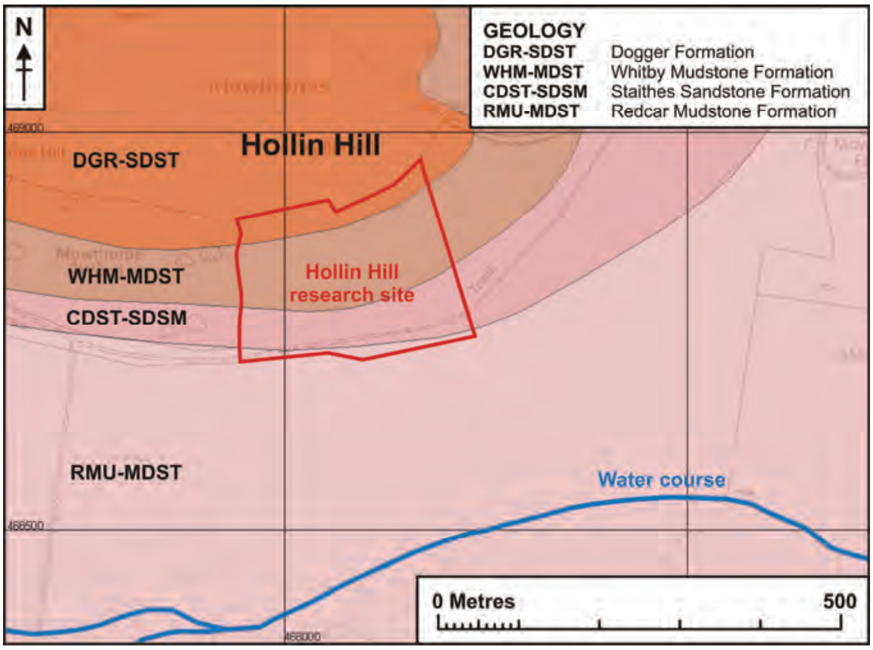

Figure 1. Location and geology of the Hollin Hill research site (Geological map, BGS © NERC 2008. Base map, Ordnance Survey © Crown copyright. All rights reserved. Licence number 100017897/2008).

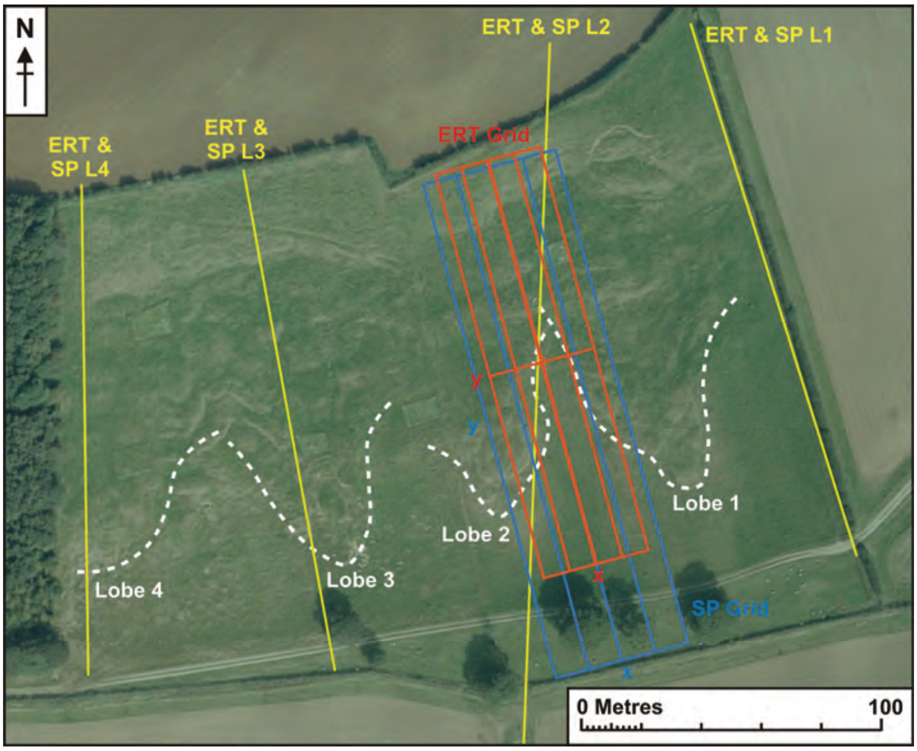

Figure 2. Hollin Hill geophysical survey plan. (© UKP/Getmapping Licence No. UKP2008/01)

Methodology

The reconnaissance geophysics included a Geocarta mobile resistivity mapping survey, four 2D ERT survey lines, four SP profiles, a 3D ERT grid and an SP grid for 2D mapping (Figure 2). The resistivity methods were chosen to provide information on the bedrock geology, and the dimensions and the structure of the landslide (e.g. Friedel et al., 2006); SP surveys were undertaken to identify groundwater seepage pathways associated with the slide (e.g. Perrone et al., 2004). In terms of coverage, the purpose of the resistivity mapping survey, the 2D ERT lines and SP profiles was to provide geophysical data across the whole of the Hollin Hill research site. The ERT and SP grids were designed to provide detailed 3D and 2D spatial information relating to the area on and between the two eastern lobes, which has been identified as a preferred location for the monitoring system.

The 2D ERT lines were surveyed using electrodes at 3 m intervals, and a dipole-dipole array configuration (a = 3, 6, 9, 12, and 15 m, n = 1 – 8). The SP profiles were generated using 5 m electrode spacings; a base electrode (negative) was installed a short distance from the midpoint of each line, and a roving electrode (positive) was moved up and down each line in a closed loop, so that repeat measurements were made for each electrode location. The 3D ERT survey consisted of a grid of 5 (x) x 32 (y) electrodes arranged in five lines, with an interline spacing of 9.5 m and an along line spacing of 4.75 m. The 2D SP mapping utilized a grid of 5 (x) x 38 (y) electrode positions, with an electrode separation of 12 m in the x-direction, and 5 m in the y-direction.

Results

The resistivity map revealed the extent of the in-situ and slipped Whitby Mudstone Formation (low resistivity), and in-situ Staithes Sandstone (high resistivity). These data were complemented by the ERT models (Figures 3 & 4) in which the lobes of slipped mudstone could be distinguished from the underlying sandstone bedrock; in particular, slip surfaces can be seen in the resistivity models where the mudstone lobe has overridden the sandstone bedrock (Figure 4). Improved resolution of the geology and structure of the landslide should be achieved when a fully 3D ERT model is produced from the data. The success of the resistivity methods in characterizing the geology and the geometry of the slipped material was due to the strong resistivity contrast between the Whitby Mudstone Formation and the Staithes Sandstone.

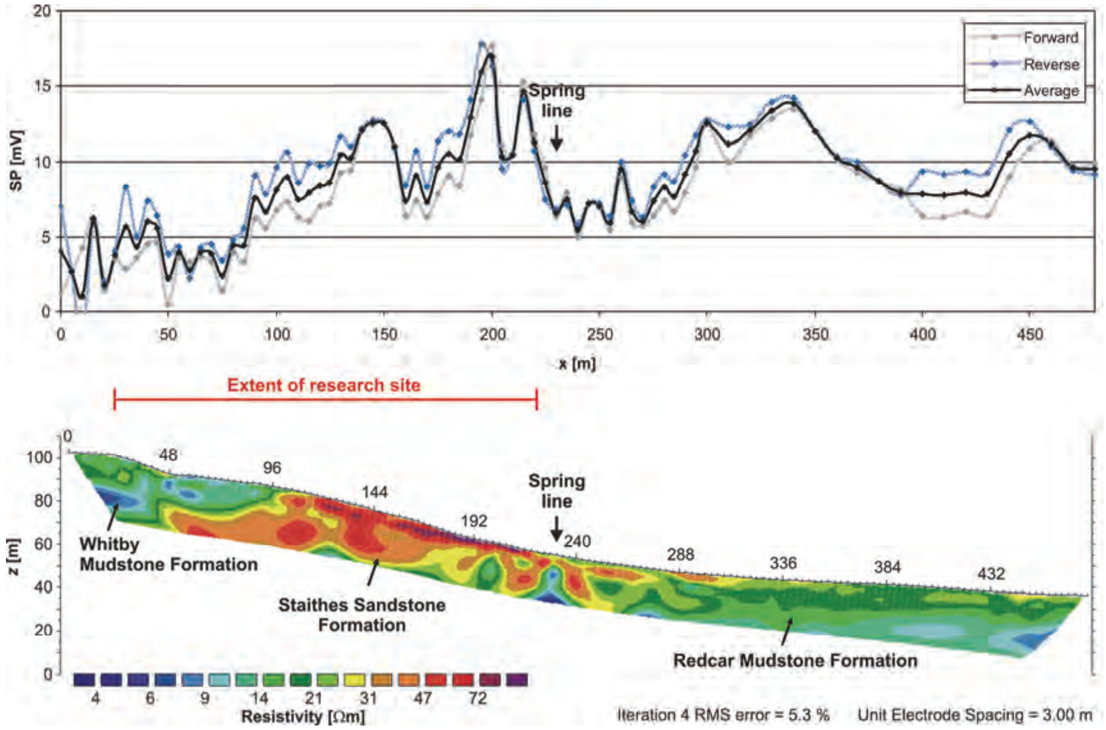

Figure 3. 2D ERT model and SP profile for ERT and SP L2.

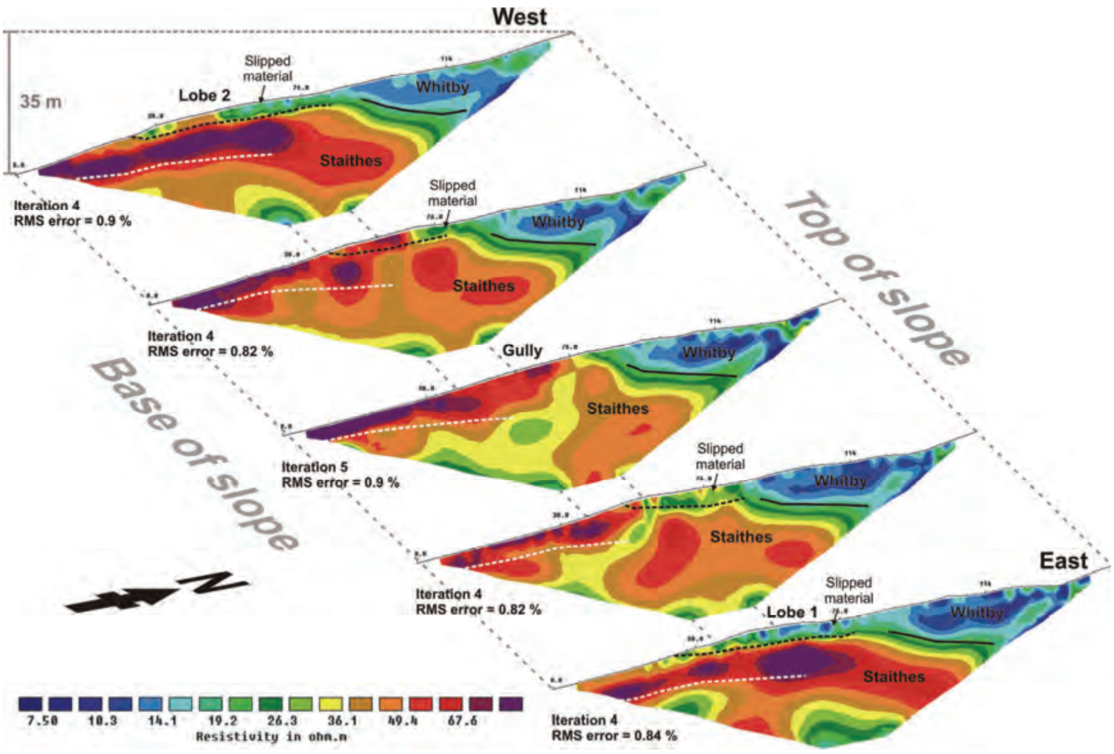

Figure 4. 2D ERT models generated from the five lines comprising the ERT survey grid over the two eastern lobes. (Interpretation: dashed black line – slip surface; dashed white line – water table; solid black line – stratigraphic boundary).

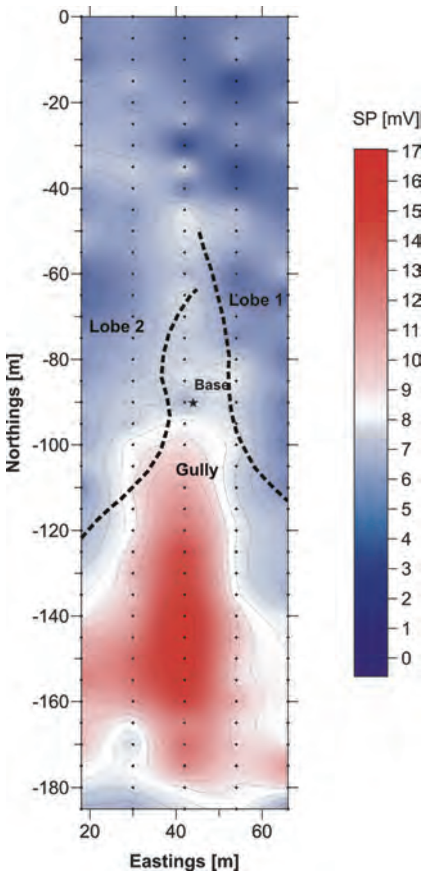

Figure 5. SP map generated from the SP survey grid over the two eastern lobes.

The Staithes Sandstone displayed a highly resistive near surface layer, and in general became less resistive with depth. This may reflect a change from unsaturated to saturated conditions. This interpretation is supported by the presence of the spring line a short distance to the south, at the base of the Staithes Sandstone, which indicates that the water table could be near the surface towards the base of the hill.

The magnitude of the measured SP response varied over a range of approximately 20 mV from the top to the bottom of the research site, with measured potentials becoming increasingly positive towards the base of the slope (Figures 3 & 5). We suggest that the SP signatures observed at the site were due to electrokinetic coupling (streaming potentials), arising from the infiltration of water on higher ground, seepage, and discharge towards the base of the slope. This is particularly clear in Figure 5, where preferential drainage appears to be causing an accumulation of positive charge in the gully. Other processes that would produce measurable SP effects, such as cultural noise, thermoelectric, or electrochemical effects, are not thought to have made a significant contribution to the measured potentials.

Future Work

Following the successful completion of the reconnaissance phase, a permanent SP and 3D ERT monitoring system is being installed across the two eastern lobes of the research site. The primary focus of the ongoing research will be to use time-lapse ERT and SP to monitor hydrogeological changes (i.e. water table (Revil et al., 2003), moisture content, seepage pathways), and investigate the link between these changes and the movement of the landslide.

Conclusions

In this study we describe the combined application of 2D mobile resistivity mapping, ERT and SP to the investigation of an active landslide. Good resistivity contrasts between the slipped material and sandstone bedrock allowed us to use resistivity mapping data and ERT models to define the geometry of the landslide. An SP signature consistent with the movement of groundwater through the landslide was observed at the site, and was used to identify seepage patterns associated with two of the lobes.

Acknowledgements

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