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Time-lapse resistivity analysis of Quaternary sediments in the Midlands of Ireland

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ABSTRACT

Electrical Resistivity Tomography (ERT) data are influenced by a number of factors associated with the subsurface such as porosity, moisture content and lithology; as well as external factors such as rainfall and temperature. Two time-lapse ERT profiles with 5 m and two with 2 m electrode spacings were acquired over a range of Quaternary sediment types encompassing till, esker gravel, glaciofluvial sand and silt and glaciolacustrine silt/clay. Data were collected on a monthly basis during 2006 at a site located in the Midlands of Ireland in order to evaluate the influence of such conditioning factors on the resistivity of the subsurface. Effective recharge, the depth of investigation, the texture and the internal architecture of the different sediment types and temperature variation are the main factors influencing the resistivity seasonal variation. The shallow subsurface (<3 m depth) showed a direct relationship between resistivity variation and effective recharge, whereas, an increasing time-lag between effective recharge and resistivity was recorded at increasing depths. As a result of the time-lag, it was possible to determine the rate of movement of the wetting/drying front for the unconsolidated relatively sorted coarse sediments recorded on the site at 7.8 cm/day. Conversely, poorly sorted and fine sediments show little resistivity variation and the velocity of the wetting front could not be estimated. Other factors influencing the electrical response of the subsurface are the electrode spacing used for data collection and the seasonal temperature variation of the subsurface. Two methods for temperature correction of electrical resistivity data were tested in this study — both gave similar results. Resistivity values recorded in the shallow subsurface (<5 m) show variations of over 15% subsequent to temperature correction. The results illustrate that seasonal temperature changes and their influence on subsurface temperature have to be accounted for in data interpretation and emphasise the potential of this technique for the estimation of the rate of movement of the wetting/drying front in soft sediments.

1. Introduction

Time-lapse resistivity imaging allows changes in the nature of the subsurface through time to be monitored. The lithology and the internal architecture of a site located in the Irish Midlands were characterised using the geophysical techniques Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) in combination with geomorphological, lithostrastigraphic and geotechnical investigations (Pellicer and Gibson, 2011). However, electrical resistivity research shows that porosity, moisture contents and temperature of the subsurface strongly influence the resistivity of soft sediments (Bernstone et al., 2000; Chambers et al., 2009; Guerin et al., 2004; Harmon and Hajicek, 1992; Hayley et al., 2009). Bulk resistivity of the subsurface is dependent on its fluid electrical conductivity (EC), temperature, saturation, porosity, and cation exchange capacity (CEC) or clay content (Hayley et al., 2007; Revil et al., 1998). On this basis, a year long time-lapse ERT experiment was carried out on the site to observe the seasonal resistivity variation for four ERT profiles. A range of glacial and postglacial sediments with differing lithological and sedimentological settings were investigated in order to recognise their response to the shifting weather conditions throughout the year.

Time-lapse ERT is a methodology which attempts to detect variations in the electrical properties of the subsurface with time introducing an additional dimension into the data collection. This technique can be carried out through short time periods (several days with readings taken every few hours) to evaluate the migration of contamination plumes (Radulescu et al., 2007), detection and monitoring of concentration of a conductive contaminant within aquifers (Cassiani et al., 2006; Chambers et al., 2004; Oldenborger et al., 2007), quantification of superficial water infiltration rates into the subsurface (Barker and Moore, 1998) and tracer test monitoring (Monego et al., 2010; Ward et al., 2010). Long term time-lapse resistivity surveys have been applied to monitor seasonal variations on seepage rates (Johansson and Dahlin, 1996; Sjödahl et al., 2008), monitoring salinity within aquifers in coastal areas (de Franco et al., 2009; Leroux and Dahlin, 2006; Ogilvy et al., 2009), safety assessment for storage of

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nuclear waste (Yaramanci, 2000), estimation of subsurface temperature variation (Morard et al., 2008), observing changes in liquid water saturation and temperature in frozen ground (Hauck, 2002) and monitoring permafrost active layer thickness variation (Kneisel, 2006). In the Irish context, the use of time-lapse resistivity is limited; Gibson (2003, 2005) used this technique for monitoring seasonal effects on limestone bedrock and the movement of contamination plumes in a landfill.

The results of a time-lapse ERT experiment carried out on a monthly basis from January 2006 to December 2007 are presented in this paper. The aims of this study are twofold: to assess the seasonal variation of the resistivity values for a range of Quaternary sediments and to evaluate the seasonal evolution on the resistivity of the surveyed sediments at different depths. Such an experiment should aid in the understanding of the response of unconsolidated sediments to electrical resistivity surveys under changing weather conditions.

2. Study area

The study area is located in the Irish Midlands, 9 km east–southeast of Tullamore (Fig. 1a). A broad range of subsurface sedimentological

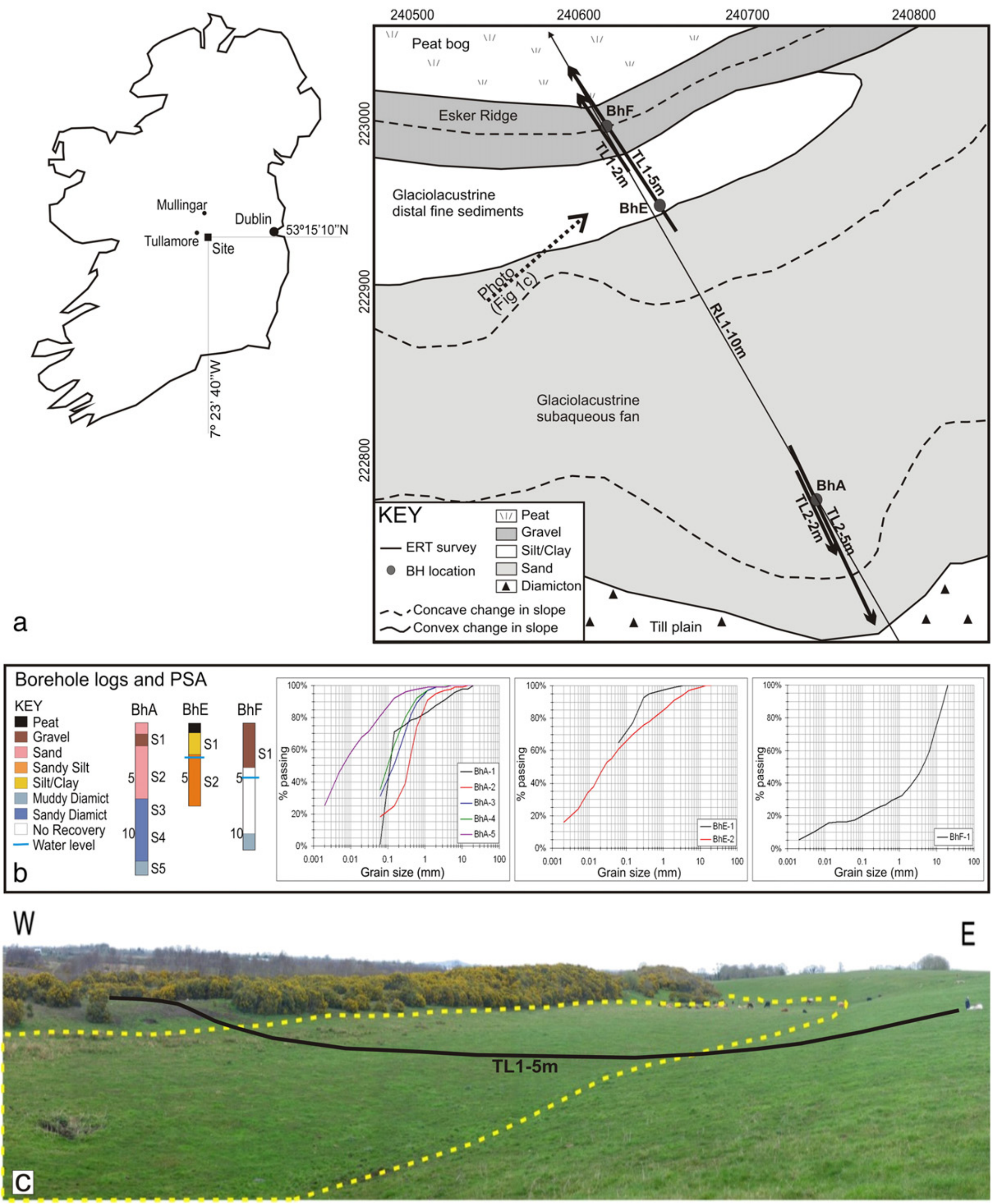

Fig. 1. (a) Location of the study area, geological characterisation of the site and location of time-lapse ERT profiles. (b) Description of borehole logs and particle size distribution analysis of collected samples. (c) Three main geomorphological features within the site. Esker ridge running east–northeast to west–southwest covered with bushes. Lacustrine flat outlined with dashed line. Glaciolacustrine fan is located to its right. ERT profile TL1 — 5 m cuts across the three geomorphological features.