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The bedrock electrical conductivity map of the UK☆

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ABSTRACT

Airborne electromagnetic (AEM) surveys, when regionally extensive, may sample a wide-range of geological formations. The majority of AEM surveys can provide estimates of apparent (half-space) conductivity and such derived data provide a mapping capability. Depth discrimination of the geophysical mapping information is controlled by the bandwidth of each particular system. The objective of this study is to assess the geological information contained in accumulated frequency-domain AEM survey data from the UK where existing geological mapping can be considered well-established. The methodology adopted involves a simple GIS-based, spatial join of AEM and geological databases. A lithology-based classification of bedrock is used to provide an inherent association with the petrophysical rock parameters controlling bulk conductivity. At a scale of 1:625k, the UK digital bedrock geological lexicon comprises just 86 lithological classifications compared with 244 standard lithostratigraphic assignments. The lowest common AEM survey frequency of 3 kHz is found to provide an 87% coverage (by area) of the UK formations. The conductivities of the unsampled classes have been assigned on the basis of inherent lithological associations between formations. The statistical analysis conducted uses over 8 M conductivity estimates and provides a new UK national scale digital map of near-surface bedrock conductivity. The new baseline map, formed from central moments of the statistical distributions, allows assessments/interpretations of data exhibiting departures from the norm. The digital conductivity map developed here is believed to be the first such UK geophysical map compilation for over 75 years. The methodology described can also be applied to many existing AEM data sets.

1. Introduction

Over the past decade, a number of high-resolution airborne geophysical surveys have been conducted across onshore UK (Beamish and Young, 2009; Peart et al., 2003). These High Resolution Airborne Resource and Environmental (HiRES) surveys have typically acquired radiometric (gamma-ray spectroscopy), magnetic and electromagnetic (conductivity) measurements at 200 m line spacings and at low altitude (<60 m). The airborne electromagnetic (AEM) data were typically acquired at four frequencies and the highest frequency provides information on the bulk electrical conductivities of near-surface formations. Progressively deeper information is then provided with decreasing frequency. Due to their systematic coverage, the airborne conductivity data provide almost continuous information across each survey area with a nominal along flight line sampling of less than 15 m.

The HiRES survey areas, flown between 1998 and 2009 are shown in Fig. 1 and summarised in Table 1. The original North Midlands survey of 1998 was largely acquired at lower spatial resolution (400 m line spacing) and at a higher elevation (90 m) than later surveys. The survey did not include active frequency domain EM measurements. AEM data converted to half-space apparent conductivity (e.g. Fraser, 1978) from the remaining 5 surveys are used here. Such data provide a consistent conductivity mapping capability across surveys provided identical/similar frequencies are maintained. Data from most time-domain AEM systems are also capable of transformation to an equivalent estimate of half-space conductivity (Huang and Rudd, 2008).

The term apparent conductivity is used to denote that a vertically uniform, half-space conductivity is assumed. The AEM system used in the UK surveys is described by Leväniemi et al. (2009). Two common EM acquisition frequencies of ~3 kHz and 12–14 kHz were maintained from 1999 onwards. The lower frequency of 3 kHz (3025 Hz prior to 2005 and 3005 Hz thereafter) provides the larger depth of investigation.

The UK surveys necessarily cover a range of UK geological formations. Geological classification is accomplished using a GIS-based scheme and this, in the first instance, defines the range of bedrock formations encountered, together with the AEM data sampling statistics associated with each formation.

The behaviour of geologically classified values of apparent conductivity has previously been presented for the IoW survey by Beamish and White (2011, 2012). The IoW formations provided the youngest bedrock lithologies (Palaeogene and Cretaceous formations) encountered

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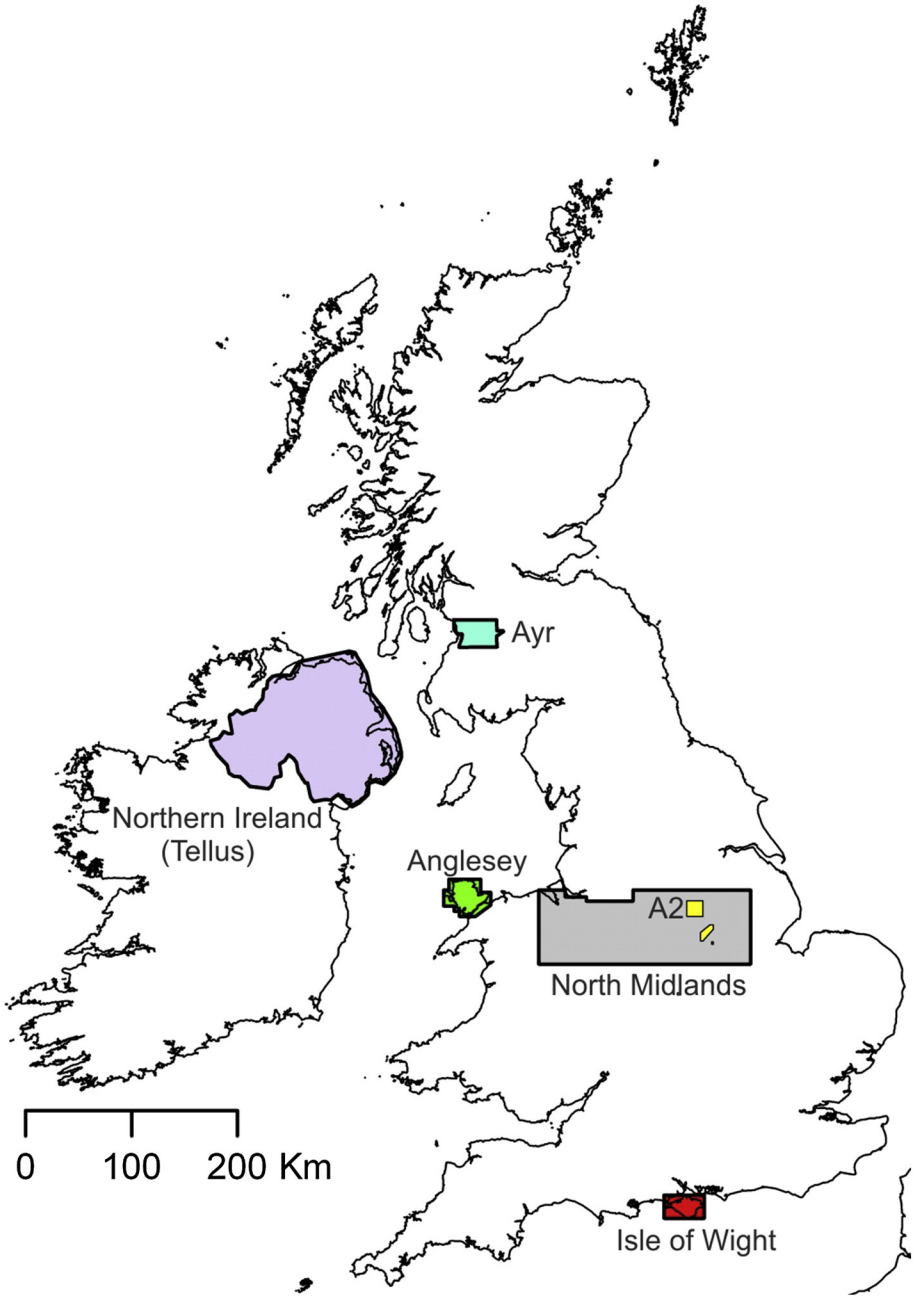

Fig. 1. Six HiRes UK survey areas (1998–2009). The North Midlands survey did not acquire active EM data.

during the HiRES surveys. The 1:50k map information when attributed with the central moments (a measure of the norm) of the apparent conductivity distributions was referred to as baseline data. Such baseline data then allow assessments/interpretations of data exhibiting departures from the norm. Beamish and White (2012) compared procedures and results obtained for both LEX-RCS (a lithostratigraphic code description) and RCS (a lithological code description) attributions at a 1:50k scale. It was noted that the lithological scheme may be considered more appropriate to geophysical attribution in that it represents a more generic description of the rock materials present (e.g. chalk, sandstone, limestone, together with mixed lithologies). This observation is based on the dependence of the bulk electrical conductivity on porosity and grain size and packing as embodied in Archie's law (Archie, 1942) together with an additional term to include enhanced conductivity (surface conduction at the pore scale) typically related to the presence of conducting clay/silt materials.

Table 1
HiRES AEM surveys conducted in the UK from 1998 to 2009.

Code	Description	Area (km^2)	Year
HiRES-1	Survey across North Midlands	13,408	1998
A2-Thorseby	Surveys in the East Midlands (Area A2, Thorseby). 4 trial areas surveyed.	329	1999
AYR	Survey across west Ayrshire	977	2004
NI	Tellus survey of Northern Ireland	16,089	2005–06
IoW	Survey of Isle of Wight	836	2008
ANG	Survey of Anglesey	1198	2009

The lithological classification of all the 3 kHz apparent conductivity data across the 5 HiRES survey areas indentified above is considered here. The classification is largely undertaken at a 1:625k scale in order to predict near-surface bedrock properties across the whole of the UK. The potential influence of superficial deposits (when sufficiently thick in terms of EM skin-depth) was examined by Beamish and White