Geological geophysics: the bedrock conductivity structure of the UK from AEM data

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SUMMARY

Geological geophysics essentially refers to any geophysical map that is based on, or classified according to, existing geological knowledge. Here the geological classification of UK bedrock conductivity, derived from 5 airborne EM surveys conducted over 10 years is assessed. At a scale of 1:625k the UK digital bedrock geological lexicon comprises just 86 lithological classifications. The lowest common AEM frequency of 3 kHz is found to provide an 87% coverage (by area) of the UK lithologies. The geological classification is then extended to provide a new and complete 1:625k UK map of the near-surface bedrock conductivitity. Geological classifications inherently address grain size and clay/silt content of rock and these parameters also underpin theoretical descriptions of the materials electrical properties. When AEM conductivity data are examined on the basis of geological classification, they are found to be information rich. The challenge remains to successfully relate the bulk geophysical property variations to potentially more revealing lithological and physical characteristics.

Introduction

Geological geophysics refers to the potential relationship between the geological classification of rock formations and their geophysical properties. Airborne electromagnetic (AEM) surveys are capable of providing a dense sampling of geological units and, when regionally extensive, may sample a wide-range of geological units. Such surveys provide estimates of bulk electrical conductivity and at sufficiently low frequencies they assess bedrock. Existing UK geological lexicons provide both lithostratigraphical and lithological classifications. The latter classification is simpler and provides an inherent association with grain-size and clay content that also underpins theoretical descriptions of the electrical properties of rocks. Here the geological/lithological classification of UK bedrock is used together with the results from 5 fixed-wing geophysical surveys conducted between 1999 and 2009 to assess the bedrock conductivity structure of UK. Half-space conductivity estimates at a common frequency of ~3 kHz are used to form statistical distributions for each geological unit. The central moments of these distributions allow a baseline geological/conductivity map to be constructed. The baseline data, when evaluated, then allow assessments/interpretations of data exhibiting departures from the norm.

The largest study (the entire UK) takes place at 1:625k scale and involves 86 lithological categories defined from the Precambrian through to pre-Quaternary (superficial) deposits. In order to construct the final fully attributed 625k model, it was necessary to involve additional lithological classifications provided by 250k lexicons and the inherent lithological associations between formations. The potential influence of superficial deposits was also assessed using existing superficial thickness estimates within the 'control' survey areas.

At the most basic level, geological geophysics allows an assessment of the detailed geophysical properties of each geological or lithological formation. These are the data that form the norms and dispersion statistics of the summary baseline assessment. The major rock types in the UK (by area) are associated with Mudstone and mixed lithology formations such as Sand-Silt-Clay. An example of the detailed conductivity assessment of two shale formations from the geophysical survey of Northern Ireland is provided. One of the formations is a current hydrocarbon prospect for tight hydrocarbons (shale-gas) at deeper levels in the adjacent Carboniferous basin.

The 625k conductivity map of the UK

The conductivity map was constructed using the framework of the BGS DiGMapGB-625 bedrock product. Further details and data download can found at http://www.bgs.ac.uk/products/digitalmaps/DiGMapGB_625.html. The digital product contains 11,244 polygons identified by a two-part 'LEX_RCS' code such as MMG_MDST (Mercia Mudstone Group Mudstone). The first part, Lexicon code, refers to the name of the unit, as listed in the BGS Lexicon of Named Rock Units. The second part, Rock Characterisation Scheme code, refers to the composition or lithology of the unit in a BGS hierarchical database. The lexicon contains 244 categories under the LEX-RCS code that would provide the basis for the production of a standard lithostratigraphic geological map. The simpler RCS characterisation, used here, provides 86 categories.

Prior to geological attribution, the AEM survey data were conditioned (screened to remove outliers due to cultural interference). The procedures include applying a maximum value of 500 to 1000 mS/m to the data and restricting the data to locations where the survey altitude is less than 120 to 180 m. This second condition also has the equivalent effect of restricting the data set to non-urban areas. The data still contain significant outliers that are collected in the tails of the distributions obtained. The first-pass procedure resulted in the attribution of 54 of the 86 lithological units as defined by the 625k lexicon. The number of samples obtained ranges from 198 (PELITE) to 1,196,650 (MAFIC LAVA AND MAFIC TUF).

The unsampled lithological units cover an area of only 33,267 km^2 (13.6% of the total). In a number of cases the remaining lithologies represent very small, localised occurrences of particular units (e.g. RCS=ANORTHOSITE, 8 km^2 and RCS=MAFITE, 11 km^2). Fourteen of the 32 units have spatial areas of less than 100 km^2 and a significant proportion of the lithologies are confined to Scotland. The two largest unsampled lithologies are CONGLOMERATE, SANDSTONE, SILTSTONE AND MUDSTONE and LIMESTONE, SANDSTONE, SILTSTONE AND MUDSTONE. Many of the unsampled units comprise multi-lithological components and natural associations with other sampled lithologies exist. A reassignment strategy was defined that resulted in the full statistical attribution of DiGMapGB-625.

The statistical distributions of the classified conductivity data are often revealing and have undergone detailed analysis (e.g. Beamish & White, 2012). The distributions range from unimodal and close to log-normal behavior through to highly peaked, highly skewed, multimodal behavior that would be expected of multi-component mixtures. The complex behavior confirms the classified data are, in general, not stochastic but often take the form of spatial clusters responding to changes in conductivity across each formation (see later example). The analysis of central moments takes place using logarithmically transformed data and here the medians are used to define the conductivity map of the UK as shown in Figure 1.

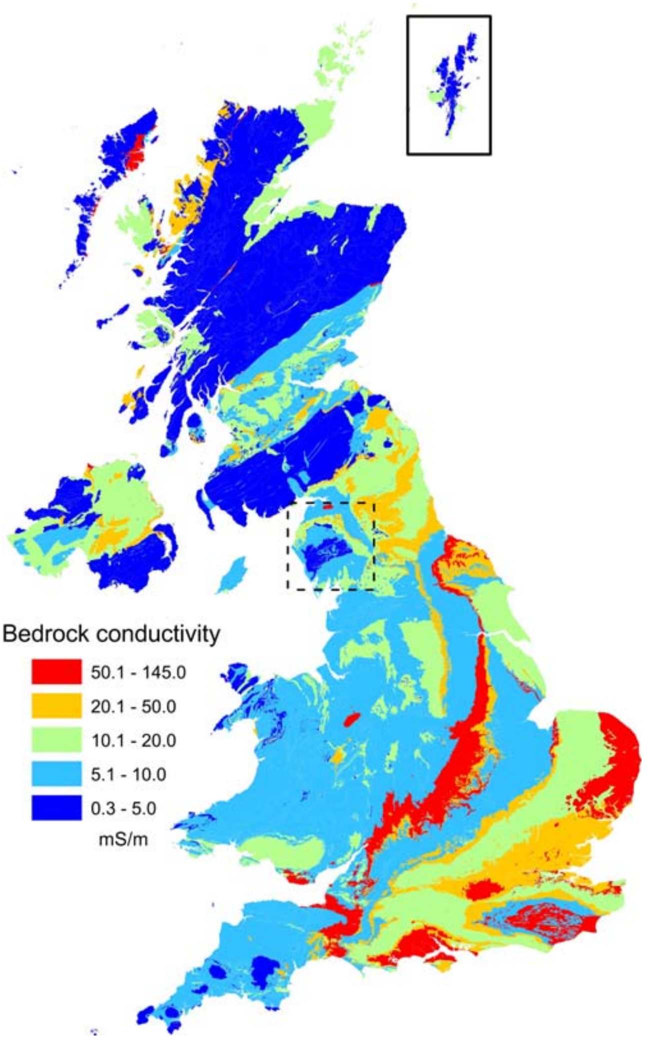


Figure 1 *The 1:625k near-surface bedrock conductivity distribution of the UK produced by lithological classification of AEM survey data*

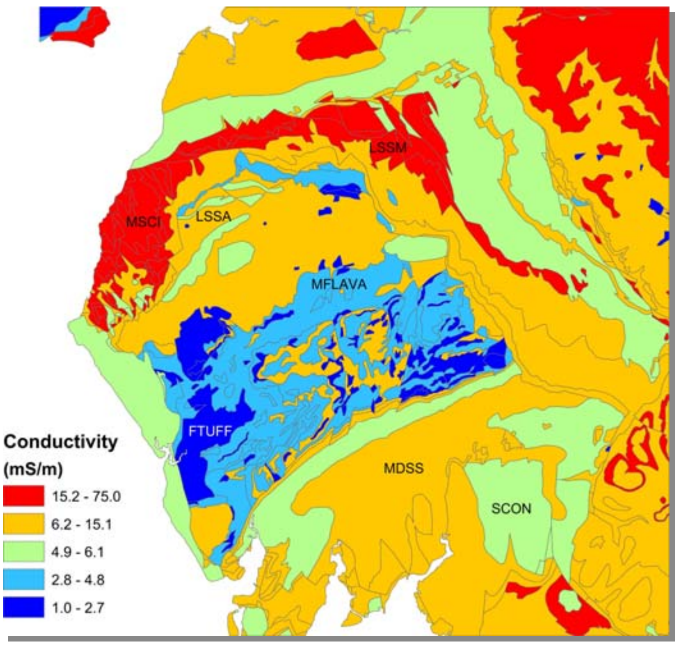
The three most conductive lithologies are associated with mylonitic fault zone rock (145 mS/m), Sandstone-Siltstone (129 mS/m) and Clay-Silt-Sand (126 mS/m). The three most resistive lithologies are obtained for Pyroclastic rock (0.32 mS/m), Psammite (0.69 mS/m, a metamorphic/metasedimentary rock) and Felsic Lava (1.02 mS/m, a fine grained volcanic rock). The lower limit on the conductivity values (e.g. 0.32 mS/m) is influenced by the signal/noise limits (low conductivity aperture at 3 kHz) of the AEM system employed.

At the scale shown, there is an evident association between the larger scale terranes found in northern Scotland (omitting the Midland Valley), the Southern-Uplands-Down-Longford terrane (Southern Scotland and Northern Ireland), the Lake District (see below), NW Wales (particularly Anglesey) and the south west granitic terrane which are all associated with the lowest conductivities (<5 mS/m). The general areas of eastern and southern England, associated with younger formations are generally associated with much higher conductivities.

Detailed Studies

The 625k conductivity map is digital and capable of further manipulation. In order to demonstrate some of the detail available within the map, a 90 x 90 km area cantered on the Lake District (see Fig. 1) was selected. The conductivity data is displayed in Figure 2 using a 5 range colour scheme with natural breaks.

Figure 2 *Conductivity distribution across a 90 x 90 km area centred on the Lake District (see Fig. 1)*



The highest conductivity range is from 15.2 to 75 mS/m and thus this large area is predominantly resistive (< 15 mS/m). The large central area is dominated by the Lake District volcanics (lavas and tuffs) across which conductivities are < 4.8 mS/m. The highest conductivities derive from a combination of Limestone-Sandstone-Siltstone-Mudstone (LSSM) and Mudstone-Siltstone-Sandstone-Coal-Ironstone (MSCI) lithologies.

The AEM data from the Tellus survey of Northern Ireland (Beamish & Young, 2009) warrant classification at a scale of 250k or less. The 250k scale digital bedrock map of Northen Ireland provides 218 LEX-RCS units and 56 RCS lithological classifications. The data, after screening, provide 5,336,890 samples across the onshore geology. The detailed conductivity behaviour of a single lithology (MUDSTONE AND LIMESTONE, INTERBEDDED) is shown in Figure 3 across a 50 x 38 km area adjacent to a Carboniferous basin in the SW of the survey area. The lithology can be subdivided into 2 formations: (i) the extensive BUNDORAN SHALE and (ii) the less extensive DRUMGESH SHALE (DHSH) identified as 2 labeled polygons in the SE of the area (Fig. 3).

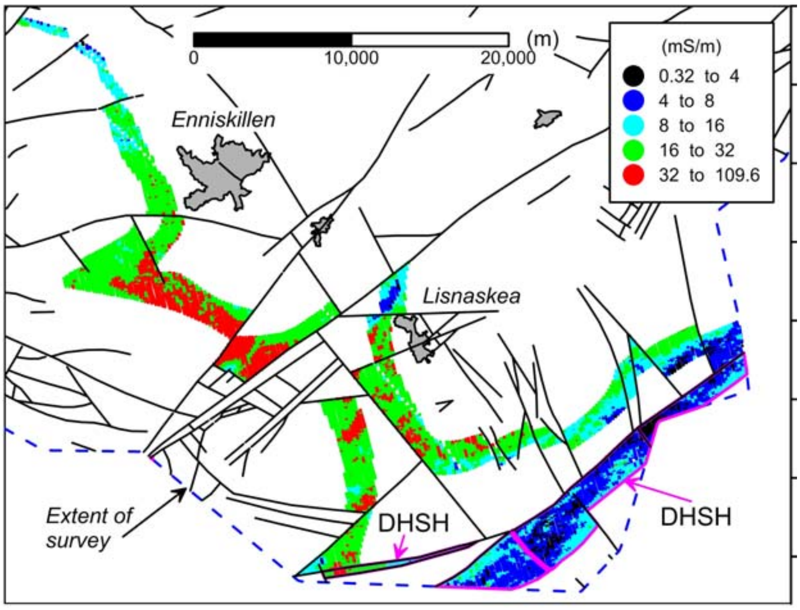


Figure 3 *A 50 x 38 km area in the SW of Northern Ireland showing conductivity values across the BUNDORAN SHALE (not labelled) and the DRUMGESH SHALE (DHSH). Grey zones are towns and lines are faults.*

Both formations display the full range of conductivities however it is clear that the DHSH unit would be largely classified as a tight formation with little or no clay content. By contrast the BUNDORAN shale displays a level shift to higher conductivities and extensive zones of conductivities > 32 mS/m indicating increased clay content. It is evident that the data are information-rich and would typically relate to the depositional conditions controlling grain size, silt content and laminations in the mudstone.

Summary and Conclusions

A geological classification of apparent electrical conductivity obtained from high-resolution AEM surveys conducted between 1999 and 2009 has been conducted. The classification uses the current 625k DiGMapGB bedrock lithological map of the UK. The classification, and inherent lithological associations between formations, has provided a new 625k scale map of the near-surface bedrock conductivity structure of the UK. This initial baseline map is capable of further refinement.

When examined in detail, geologically classified AEM data appear information rich. The challenge remains to successfully relate the bulk geophysical property variations to potentially more revealing lithological and physical characteristics of the formations. Ultimately this will only be achieved with at least some degree of borehole/geophysical log control.

References

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