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Relationships between gamma-ray attenuation and soils in SW England

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ABSTRACT

Soil studies using radiometric data typically employ one or more of the main, naturally occurring radioelement estimates (potassium, thorium and uranium) to undertake a variety of soil property assessments. This study concerns an *attenuation* assessment of high-resolution radiometric data obtained by a recent airborne geophysical survey in SW England. These data provide continuous measurements over a wide-range of region-specific soils and their parent bedrock materials. A prime motivation for this study is the observed complexity of the spatial variance in the radiometric signal level. Although such data may be jointly classified according to soil and bedrock types, variable attenuation levels in the signal levels remain to be explained. The data appear to carry information on soil properties additional to that of texture or other available soil descriptors. Existing gamma-ray theory indicates that the attenuation behaviour of radiometric data is jointly controlled by soil density and wetness in the upper ~60 cm of the soil profile. Low density, highly organic soils (e.g. peat) produce readily identifiable and variable attenuation zones. All soil types are predicted to attenuate radiometric signal levels but at lower density–wetness sensitivities. The broad radiometric response level is, as expected, found to be controlled by bedrock. Clay mineral soils provide the most uniform response behaviour with respect to bedrock type. Peat soils display the lowest amplitude and most variable signal levels. The data from similar bedrock formations, even with the same lithological descriptor (e.g. argillaceous), can display distinctly different geostatistical behaviour when the same soil type is considered. A variety of inferred attenuation zones are discussed in relation to supporting information on soil property and soil and land-use classifications. Spatial inconsistencies in existing database descriptors of organic rich zones are demonstrated and it is evident that the radiometric data can assist in resolving such ambiguities. The supporting control information has been found to be often ambiguous or unavailable at a scale appropriate to the field-of-view of the airborne measurements. Within this wider context, it is suggested that an observational database, such as that supplied by the radiometric data, may assist in providing enhanced spatial assessments of the soils and soil properties encountered

1. Introduction

Geophysical gamma-ray spectroscopy, both ground-based and airborne, is increasingly being used for the digital mapping of soil properties. The subject has a considerable historical pedigree (Talibudeen, 1964; Hyvönen et al., 2005) in terms of early studies. Ground-based studies at the field scale, using soil-sampling to control interpretation, have defined relationships between the measured radioelements and soil properties such as clay content (Van der Klooster et al., 2011), soil pH (Dickson and Scott, 1997), SOC (Wong and Harper, 1999), plant available potassium (Wong and Harper, 1999; Dierke and Werben, 2013) and CEC (Rodrigues et al., 2015). More extensive airborne data sets may also be used in soil property assessments (Cook et al., 1996) although control information is inevitably more sparse. The airborne data are also distinct in having a much larger field-of-view (i.e. a lower spatial resolution) but are invariably more extensive and data may be obtained continuously and uniformly over most terranes. The existing soil studies using radiometric data typically employ one or more of the main, naturally occurring radioelement estimates (potassium, thorium and uranium), together with their ratios and Total Count (TC), to undertake soil assessments (Schwarzer and Adams, 1973; Cook et al., 1996; Taylor et al., 2002). More complex studies, in more arid environments, also deal with the relationship between the erosional characteristics of regolith and radiometric survey data (Wilford et al., 1997).

In contrast to the above, we here consider the behaviour of the *attenuation* of airborne radiometric data in relation to the soil properties that control this behaviour. The attenuation of radiometric signal due to water or soil moisture is well-established (Carroll, 1981; Grasty, 1997). Repeat (time-lapse) airborne radiometric surveys have the capability to provide assessments of snow-water equivalent and/or soil moisture by estimation of the variation in attenuation, from a known calibrated baseline (Peck et al., 1971; Lougens, 1980). While studies of

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airborne data sets may note or discard unwanted attenuation features due to water or water-content, extensive studies of the radiometric signal attenuation levels in single baseline (meaning one-off) survey data sets are uncommon.

The present study considers a recent airborne radiometric data set from SW England with the purpose of assessing the attenuation characteristics of the data. It is acknowledged that one-off survey data do not provide an absolute reference for the degree of attenuation so only relative assessments (e.g. same soil and bedrock types) can be carried out. The primary purpose of the study is to evaluate the degree to which attenuation effects may be observed as a function of both soil and bedrock types. A prime motivation for the study is the observed complexity of the spatial variance in the radiometric signal levels. The data clearly carry soil information additional to that of texture or classification but without detailed study the behaviour remains unexplained. In order to carry out the assessment, a wide range of secondary information on soils, parent material, land-use and vegetation height is examined. The behaviours identified by the analysis should then inform other field-scale and airborne-scale studies of the type of attenuation effects that may be present in the data sets considered.

As discussed later, the physical properties that control attenuation in soils are the bulk density and moisture content; however, such parameters are not routinely available at the appropriate scale and extent of an airborne survey. The two controlling factors are distinct from the soil properties typically examined at the field-scale although bulk density and soil texture are related (Saxton and Rawls, 2006).

The airborne radiometric data (TellusSW) obtained across SW England are shown in Fig. 1. The full survey is extensive (10,929 km^2) and the study presented is focussed on a main area of 29 × 20 km. Three additional subareas are then examined in detail. The main area partially contains one of the main outcropping, highly radiogenic granites that occur across the region. A series of Devonian and Carboniferous argillaceous sediments form the main bedrock units. These are interspersed with a series of lava and Dolerite (microgabbro) intrusions. Mineral (clay) soils across the area are limited in extent with the main soil type being loam. Loam soils generally contain more moisture and humus than sandy soils and have better drainage and infiltration of water and air than silty soils.

A joint classification of the radiometric data by soil and bedrock types is undertaken. A GIS-based geostatistical assessment reveals the behaviour of different bedrock types with respect to soil type. The assessment of low count (attenuation) behaviour of the distributions obtained is however difficult. This is due to the fact that the 'attenuation level' for any single or joint classification is arbitrary (there is no absolute baseline reference) and the fact that the classified distributions typically display non-parametric behaviour. Additionally, studies using low count inevitably employ data values that may approach the noise level of the data.

The TC data along with combined radioelement concentrations (Ternary images) are presented and discussed across the whole survey and within the selected subareas. It is evident that at the larger scale primary radiometric control is provided by bedrock units that may require assessment by their lithological or lithostratigraphic characteristics. At the more detailed scale, a series of attenuation zones, within the framework of primary bedrock control can be identified. The zones identified are then assessed using the extensive supporting information on soils and parent materials together with other land and landform characteristics.

2. Theory

It is assumed that bedrock material acts as a radionuclide parent to any derived (overlying) superficial (i.e. unconsolidated) sediments and soils. The bedrock is therefore considered to provide the primary radiometric response. The soil material, where present, attenuates the observed in-air gamma-ray flux primarily through density when the material is dry (Løvborg, 1984). Additional secondary attenuation effects are introduced when the material contains free or absorbed water (Grasty, 1997). The standard dry-material attenuation (an exponential decay) within the material is increased by the addition of water. The subsurface attenuation scale length (e.g. the depth across which 90% of the flux is attenuated) therefore depends on density and water content. The attenuation scale lengths may typically vary between 20 cm (highly intact bedrock) and 60 cm (wet peat) as discussed by Beamish (2013). For the majority of moist soils we anticipate a scale length of between 40 and 60 cm (Beamish, 2013). It therefore follows

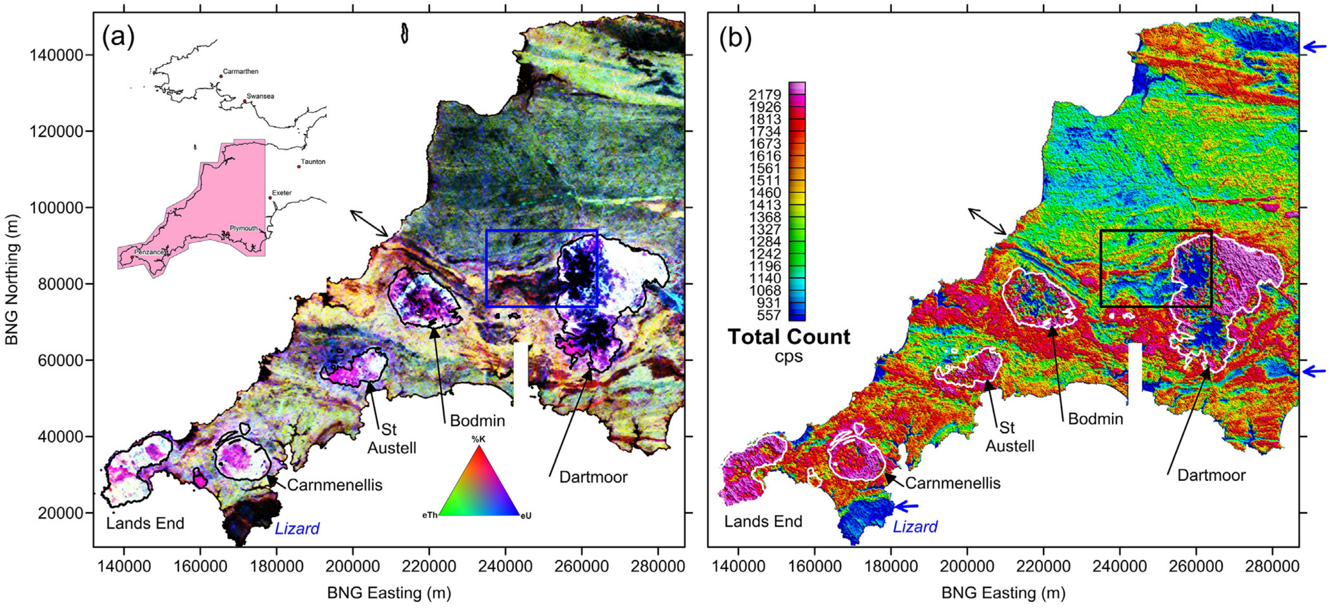

Fig. 1. Radiometric survey data (cut to coast) obtained from the TellusSW survey of SW England. Insert shows survey location. Five outcropping Variscan granites are identified and outlined. The double-arrow denotes a transition from Devonian (in the SW) to Carboniferous rocks (in the NE). The central rectangle (29 × 20 km) denotes the main case study area considered here. BNG refers to British National Grid. (a) The ternary colour image obtained using the 3 radioelement ground concentrations. (b) The Total Count values shown using a linear colour scale. Blue arrows denote locations noted in the text. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)