

Assessing soil wetness with airborne radiometric data

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Extended Abstract

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SUMMARY

A valid interpretation model for UK radiometric data requires a joint assessment of both soil and bedrock variations. Although the geological bedrock (the parent material) provides a specific radiogenic level with associated radiochemical attributes, attenuation of the signal level is controlled by soil wetness in conjunction with the density and porosity of the soil cover. Peat soils, in particular, produce readily identifiable attenuation zones. Other soil types are also predicted to attenuate radiometric signal levels but at lower wetness sensitivities. The amount of water stored in the soil is of fundamental importance to agriculture

Studies of soil attenuation zones have now been undertaken using a number of modern UK radiometric data sets. Case studies are presented which highlight the procedures and results obtained. A variety of implied increases in wetness, at the scale of the airborne measurements, have been identified across a range of soil types, including those categorized as freely draining. The level of attenuation (and hence wetness scale) remains uncalibrated since ground information on wetness is not generally available at the appropriate scale.

Introduction

Conventionally, airborne radiometric survey data are used in a bedrock exploration context. Radiometric ground concentrations, typically obtained from the upper 30-50 cm of the soil profile, are understood to be derived from the parent bedrock material. In the UK, attenuation zones have been found to be a pervasive feature of modern airborne radiometric data sets. Peat soils, in particular, produce readily identifiable attenuation zones. The radiometric data can therefore be used for peat mapping and hence assessments of the lateral extent of the carbon store (Beamish, 2014). Although the bedrock provides a specific radiogenic level with associated radiochemical attributes, attenuation of the signal level is controlled by soil moisture content in conjunction with the density and porosity of the soil cover. A valid interpretation model for UK radiometric data therefore requires a joint assessment of both soil and bedrock variations.

A geostatistical assessment of radiometric signal levels with both soil and bedrock types can be undertaken across a survey area. This typically identifies multi-modal behaviour in the classified distributions, often with significant low-value tails which potentially indicate attenuation effects due to enhanced soil wetness. The amount of water stored in the soil is of fundamental importance to agriculture. Here we illustrate general soil-wetness assessments by considering the detailed attenuation behaviour of radiometric data from a recent airborne geophysical survey in SW England (<http://www.tellusgb.ac.uk>). The 29 x 20 km case study area contains a highly radiogenic granite.

Theory

Løvberg (1984) discusses the general principles of gamma-ray attenuation and the effect of moisture content of materials. The theory of radiometric attenuation in soils was further reassessed by Beamish (2013). In the absence of water, soil, superficial and bedrock materials will have comparable attenuation coefficients at a given source concentration. Attenuation in dry materials is controlled by density alone. Any hydrogen supplied to the material as absorbed or free water (e.g., pore water) then generates an additional attenuation provided by the additional electron content (Compton scattering). Methods of making routine airborne soil moisture measurements are described by Carroll (1981). The methods are large scale and use reference, ground-calibrated flight lines. The attenuation sensitivity of various soils to the degree of saturation was evaluated by Beamish (2013). Mineral soils typically provide only 15 to 20% attenuation towards full saturation. Clay-rich soils appear more sensitive and 60% attenuation may be achieved towards full saturation. As has already been noted, wet peat readily provides >90% attenuation even at low wetness levels.

The case-study area: bedrock

Figure 1a shows the 1:250k bedrock distribution across the 29 x 20 km study area along the western margin of the Dartmoor granite. The area in the north is dominated by a Carboniferous (C), argillaceous sandstone formation. To the south a complex sequence of units involving both Carboniferous and Devonian formations are interspersed with intrusive Carboniferous Lava (L) and Dolomite (D).

The Ternary radiometric image across the area is shown in Figure 1b, alongside the bedrock line-work from Figure 1a. The Ternary image is a 3-way colour stretch formed from the distributions of Potassium (red), Thorium (green) and Uranium (blue). The highest values in all 3 radioelements are shown in white while the combined -lowest values tend to black. It is very evident that the highly radiogenic granite has an extensive attenuation zone (i.e. a largely black response) which masks the high bedrock values. This is formed by the presence of an extensive upland blanket bog as discussed below.

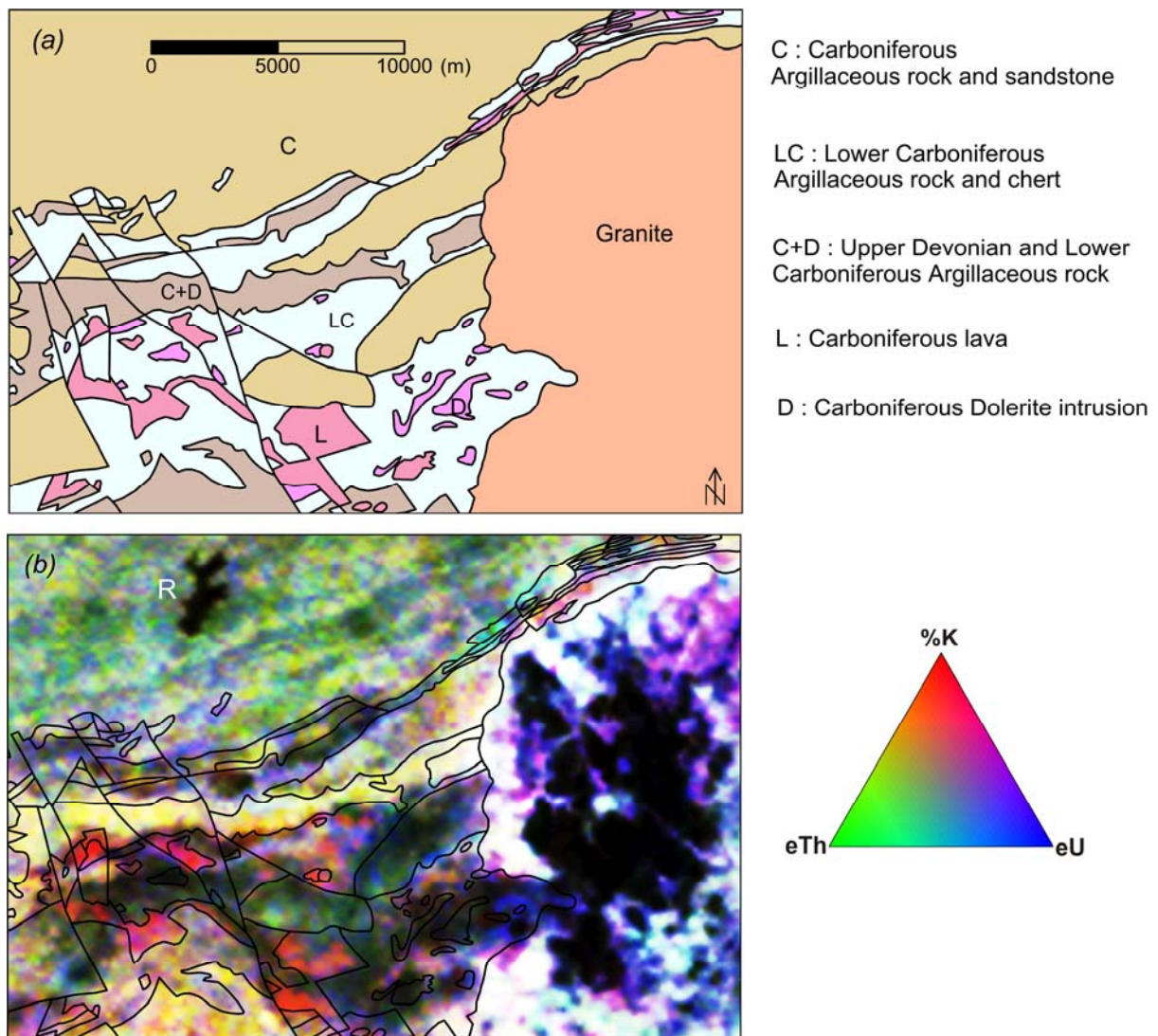


Figure 1 29 x 20 km study area from the TellusSW airborne geophysical survey of SW England. (a) 1:250k bedrock polygons with a simplified geological lexicon. (b) Ternary radiometric image with 1:250k bedrock line-work superimposed. Black response R is a water reservoir.

A modern water reservoir, producing a largely null response, is labelled R. The northern Carboniferous formation displays a strong Thorium response and subtle changes in the response reveal detailed changes in lithology. To the south, this same unit shows different characteristics and significant masking by attenuated (black) responses is evident. The Lava (L) units are associated with a strong Potassium response while the Upper Devonian and Lower Carboniferous (C+D) unit displays an intermediate Potassium-Thorium response. While such features would form the basis for an evaluation of bedrock radiochemistry, it is evident that a considerable amount of attenuation exists at a wide-range of scales. These zones are not a function of bedrock geology and therefore require an assessment using soil information.

The case-study area: soil

There exist a large number of descriptors of soil information but relatively few include information directly related to soil wetness. Here we use a simplified derivative map (NATMAP SOILSCAPES) developed from the national mapping of soils (NATMAP, England and Wales) by NSRI (<http://www.landis.org.uk/>).

The SOILSCAPE information is shown in Figure 2a with 6 soil units of direct relevance to the study identified from the complete lexicon. The SOILSCAPE information does not identify the water body since the mapping predates the construction of the reservoir (1989). Also shown on the map are the contours (cross-hatch infill) of the radiometric Total Count data restricted to low values (i.e. values < 800 cps). It is evident that three of the soil units associated with low value behaviour are defined as having free draining behaviour.

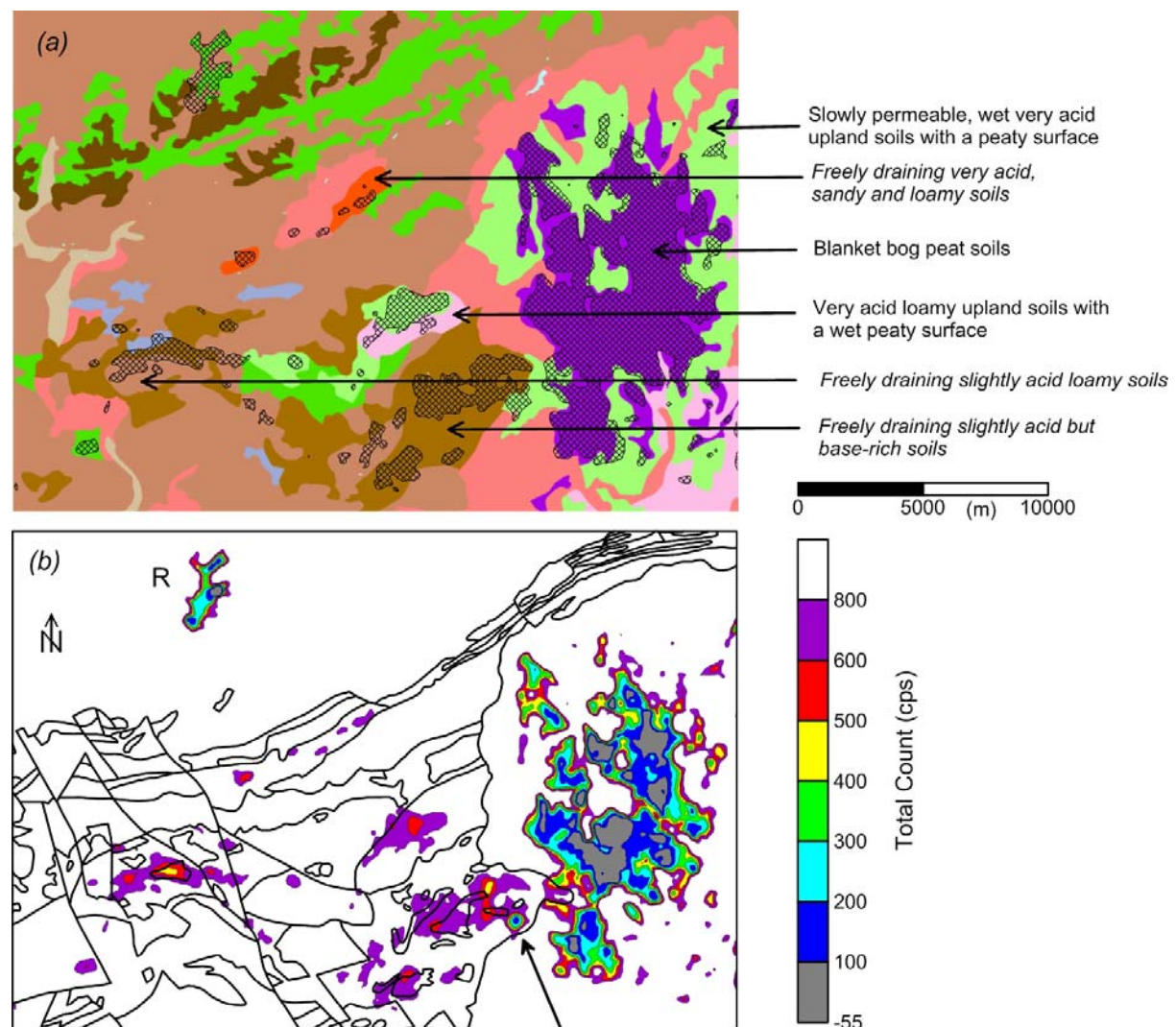


Figure 2 Soil, bedrock and radiometric relationships across the 29 x 20 km study area. (a) SOILSCAPE polygons with 6 soil types containing attenuation zones. Cross-hatch areas denote Total Count < 800 cps. (b) Contours of Total Count < 800 cps with 1:250k bedrock line-work superimposed. R is a water reservoir.

The low value behaviour of the Total Count data is shown in more detail in the contour map of Figure 2b. The bedrock line-work from Figure 1 is overlaid. The data range across the area is from -55 to 4724 cps. The threshold of 800 cps is used since it largely outlines the extent of the Blanket Bog as defined in Figure 2a. As is usual in radiometric peat studies (Beamish, 2014), intra-peat variations are observed and the lowest interval (e.g. < 100 cps) would imply 100% saturation. The low response behaviour also indicates the ability of the radiometric data to distinguish between Blanket Bog soils and the adjacent slowly permeable, wet, very acid upland soils with a peaty surface. Water bodies, such as the reservoir (R) should offer a local control in relation to 100% saturation. The low value response outlines the rather complex water body precisely but only portions of the response are < 200 cps. The effect may be due to limited sampling of the water body in relation to edge (non-water) effects.

The threshold of 800 cps used here is arbitrary and it can be seen that the off-granite, off-blanket bog responses shown in Figure 2b are typically > 400 cps. One particular localised zone with an implied 100% saturation is arrowed. In order to provide a normalised attenuation analysis, it is necessary to classify the data set according to the bedrock (parent material type) as was undertaken in the study by Beamish (2013).

Summary

The detailed analysis of attenuation effects in airborne radiometric data is a relatively new subject. In the UK, and at similar temperate latitudes, soil attenuation effects must be taken into account to permit a valid interpretation of the data. The most visible attenuation effects are observed in case of peat soils due to their high sensitivity to wetness. Other soil types are also predicted to attenuate radiometric signal levels but at lower wetness sensitivities. The case study discussed here indicates that attenuation effects and hence implied increases in wetness are observed across a number of soil types. The soil categories include freely draining soil types.

It is worth noting that the radiometric data provide a physical measure of soil properties, at the lateral scale of the airborne measurement. The level of attenuation (and hence wetness scale) remains uncalibrated since ground information on wetness is not available. The amount of water stored in the soil is fundamentally important to agriculture and is an influence on the rate of evaporation, groundwater recharge, and generation of runoff. Further work to clarify the nature of radiometric attenuation zones observed in UK soils is clearly warranted.

Acknowledgement

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