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Analysis of spectra from portable handheld gamma-ray spectrometry for terrain comparative assessment

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ABSTRACT

Geological characteristics can have impacts on societal development by, e.g., geotechnical issues and radiological hazard levels. Due to urban sprawl, there is an increasing need for detailed geological assessment. In this work are analysed data from portable handheld gamma-ray spectra (K, eU and eTh) obtained in granitic and Silurian metaclastic outcrops as well as in an profile, roughly N–S, on soil covered terrains transecting a mapped contact between these rock types (the profile's northern extremity is at locations mapped as granite). Estimations from gamma-ray spectra were studied by univariate and multivariate analyses. K, eU and eTh values were higher on granite in relation to Silurian metaclastic rocks. The northern extremity of the profile showed clearly higher contents of eTh and this contrast was supported by univariate statistical tools (normality plot and Wilk–Shapiro test; boxplots). A ternary plot with the contribution of the elements to gamma-ray absorbed dose showed the separation of granite from Silurian metaclastic rocks with the former being nearer the eTh vertex. The points in the northern extremity of the profile are nearer the eTh vertex than the other points on the profile. These visual suggestions were supported by hierarchical cluster analysis, which was able to differentiate between granite and metaclastic outcrops and separate portions of the profile located on different terrains. Portable gamma-ray spectrometry showed, hence, the potential to distinguish granite and metaclastic terrains at a scale useful for engineering works. These results can also be useful for a first comparative zoning of radiological hazards (which are higher for granite).

1. Introduction

The growing concentration of people in urban centres implies the development in terrains at the outskirts of such centres and in the spaces between the current existing constructions. Regarding urban planning, and in terms of Engineering Geology projects, the distinction of rock types can have practical significance as, for example, igneous and metamorphic terrains can imply different kinds of geotechnical issues (Goodman, 1993). Lithological variations can also imply different hazard levels not only by physical mechanisms (e.g. slope failure) but also in relation to geochemical contamination, including natural radioactivity.

Radioactive decay hazards include the emission of gamma ray photons within a range of energies. The main producers of gamma ray emissions from rock and soil minerals are ^{4}K and isotopes of the uranium and thorium decay series. Hence, hazards related to external gamma-ray dose are linked to specific activity of these isotopes and will be different for terrains with geochemical differences that depend on mineral components. This means that different geologic materials will have different hazard levels in relation to external gamma radiation (Markkanen, 1995) and that the background dose that must be considered on this assessment can also be variable. Additionally, radon levels hazards are related, among other factors, to uranium contents.

Among several methods employed to assess gamma radiation, *in situ* gamma ray spectrometry is commonly used in surveys related to geological and geochemical mapping, mineral prospecting, structural geology, and agricultural and environmental

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studies (IAEA, 2003). It consists of obtaining spectra recording the counts of photons with energies that can be attributed to certain radioactive isotopes. This technique is sensitive to several factors such as water and organic matter content in soils but is relatively easy to perform.

Measurements performed by portable handheld spectrometers are among ground radiometric methods referred by IAEA (2003) and consist of a probe that is transported by foot. It belongs to the class of geophysical methods (Kearey et al., 2008) that depends on a natural signal of the terrain without needing the use of additional sources of energy. It has clear operational advantages for on ground surveying of soils and rocks in relation to other exploration methods such as electrical resistivity or seismic refraction since there is no need to deploy a complex array of receivers, cables, etc., a feature that can be a plus in surveys of small, complex areas. It could be performed by a small team (even by one person) and in a relatively fast way (namely when compared with other geophysical methods).

Several examples of the application of portable gamma-ray spectrometry can be found. Cassidy (1981) presents a study of geological mapping of magmatic units. Walsh and Satkoski (2005) performed 1:24000 geological mapping of terrains with limestones and metamorphic rocks aiming to determine which rock types were potential sources of radionuclides. Lizurek and Dorda (2006) performed *in situ* surveys to evaluate radioisotope levels of geological units used as building materials. Trindade et al. (2014) investigated the distribution of radionuclides in relation with weathering processes of igneous and metamorphic rocks. Portable gamma spectrometry has also been used for soil mapping (Wong and Harper, 1999; Roberts et al., 2003; Herrmann et al., 2010; Priori et al., 2013, 2014). Portable systems have shown the potential for mapping radiation levels with a resolution of a few metres or less (Cresswell et al., 2013), even in complex urban environments with enclosed geometries and building materials variations.

In this study it is attempted the use portable gamma spectrometry for distinction between signals from granites and metaclastic (Silurian) rocks, namely in conditions where these rocks do not outcrop, a distinction that can be relevant for several issues in ancient (older than Mesozoic) terrains. In this way it will be assessed the usefulness of this technique for two main goals of geophysical exploration (USACE, 1995): i) gathering geological information of the terrains, i.e. whether it can distinguish terrains of different lithologies and, hence, contribute to detailed mapping in a scale suitable for engineering works; (ii) detecting cultural features with a contrast in relation to the surrounding material. Regarding these purposes, one of the classical issues of geophysical (and geochemical) exploration is data interpretation. In that perspective it is attempted the use of data interpretation tools that can be considered as objective in the sense that anybody that considers the same original data will arrive at the same classification. However, as any other scientific observation (see Popper, 1983), results are only significant in the context of a given hypothesis (which, in this context, corresponds to a given geological model, e.g. arisen from a geological map in a smaller scale). For that end will be compared also the spectra from outcrops of different rock types, hence contributing to another goal of geophysical exploration (USACE, 1995): the assessment of engineering properties of materials, in the sense that it could be used for comparative assessment of radiological hazards of materials (both in relation to gamma external dose and radon emissions).

2. Materials and methods

The data discussed here are of the type described by IAEA (2003) as static measurements (recording a spectrum in a given point during a certain amount of time). Measurements were made on two main situations:

- On a roughly N–S profile in a terrain where no outcrops were visible but that, according to the available geological mapping (Ferreira et al., 2000), straddles a contact between the Braga granite (biotitic, fine to medium grained, porphyric granite) and Silurian (metaclastic, schistous) rocks (see simplified geological cartoon in Fig. 1). The north extremity of the profile corresponds to its beginning (point herewith referred as 1 with the last point being the 24th, in the south extremity). This one profile was studied as an exploratory survey to assess the potential usefulness of this technique for this kind of issue.
- Outcrops of granite and Silurian metaclastic rocks (Fig. 1).

It was used a portable gamma spectrometer GF Instruments GRS-2000, equipped with a probe BGO (Bi4Ge3O12) having a 51 mm × 51 mm detector and a shielded photomultiplier (Fig. 1). The analyser has 512 channels and measures up to 70.000 pulses per second, being the energy range up to 3 MeV. Each spectrum corresponds to a counting period of 3 min.

Besides the abundance of the radioelements, several issues can have influence on the results obtained such as (IAEA, 2003) the irregularity of the terrain, soil moisture and the position of the probe above the ground (raising the probe above the ground increases the diameter of the effective source that affects the recorded signal). Measurements on the profile were made with the probe 1 m above the ground in order to sample a larger volume. Measurements on the outcrops were made with the probe directly in contact with the rock surface in order to restrict the sample volume and obtain signatures of the rocks.

The recorded spectra allowed estimations of K (%) from the peak of ^{4}K. For the uranium and thorium decay series there are several radioactive isotopes and, assuming that there is secular equilibrium, one of them, which is considered to give more reliable estimations, is selected to represent the series. Hence, results are expressed as equivalent of uranium (eU, in ppm), which is calculated from the peak of the ^{214}Bi radionuclide (emitting the energy of 1.764 MeV) and in equivalent of thorium (eTh, in ppm), which is calculated from the peak of the ^{208}Tl radionuclide (with the energy of 2.615 MeV).

Data analyses and graphs were supported by the statistics software *STATISTICA* 11 (*Statsoft*, Inc.). Standardized values (z-scores) were used in several analyses in order to compare parameters with different scales and were obtained (Sá, 2007) by subtracting the mean and dividing by the standard deviation (in this way all considered variables have a mean equal to zero and a standard variation equal to one). Normal probability plots (Sá, 2007) of the original data were also done to assess the distribution of the values in relation to the normal distribution, which defines a straight line in this kind of plots (deviations from the straight line correspond to deviations from normality). The Shapiro–Wilk Test for Normality (Sá, 2007) was used to assess the probability (*p*-value) of data deviations from the normal distribution being due to random variations (as a non parametric test is more robust, namely for small sets of measurements).

With the original data were also prepared “box and whiskers” plots or boxplots. The boxplot is a robust statistical tool for data exploration analysis that besides allowing the comparison of several collections can be used to flag potential outliers (Emerson and Strenio, 1983). The criteria used for demarcation of the potential outliers and the interpretation of those outliers have been a matter of extensive discussion.

In relation to the criterion of demarcation of possible outliers, the boxplot shows limits defined by a certain factor of the