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REGIONAL CARTOGRAPHY OF REGOLITH PARAMETERS USING AIRBORNE GAMMA RAY SPECTROMETRY

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Among the remote sensing techniques, the airborne gamma-ray spectrometry has been widely developed for several tens of years (e.g. IAEA, 1991), being nowadays almost systematically surveyed in regional mapping programs, for soil/regolith (e.g. Lacoste et al., 2011), solid geology reconnaissance (e.g. Metelka et al., 2011) or mineral potential assessment (e.g. Shives et al., 2000).
Gamma-ray surveys provide maps of concentration in K, U and Th chemical elements at the ground level. These data are primarily sensitive to the mineralogy and geochemistry of the parent material, as well as its weathering products, including residual and transported clays, sand and gravel (e.g.Minty, 1997).
In this study, instead of addressing complex concepts such as lithology, we chose to investigate these gamma spectrometric data by mapping parameters of the regolith, which are simple objective quantities. It is known that these parameters of the regolith: density, moisture, chemistry, all influence the natural gamma ray emissions (e.g. IAEA, 2003). Several papers assess correlations between gamma-spectrometric variables and one or few soil parameters including texture (e.g. Taylor et al., 2002), regolith chemical or mineral contents (e.g. ViscarraRossel et al., 2007), and other soil parameters such as soil depth, total phosphorus or total carbon (e.g. McKenzie and Ryan, 1999).

The first question we address in this study is whether or not various chemical, textural, or mineralogical parameters of the regolith can be related and quantitatively modeled vs. airborne gamma spectrometric variables U, K and Th. In the Sologne area, south-center of Paris basin, in a detrital sedimentary environment, we investigate as systematically as possible, whether statistical models can be inferred between gamma spectrometric data and regolith parameters.
The second issue we address is why, and how, these correlations would occur for certain regolith parameters and not for others. Our results provide information relating the gamma-spectrometric signals to geological and mineralogical gamma emitters.

The study uses a series of regolith sample measurements and analyses. Two independent sets of samples were used: i/ the first one was based on a systematic grid: the data have been extracted from the database of the French soil quality monitoring network RMQS (Réseau de Mesures de la Qualité des Sols) (Arrouays et al., 2003; Jolivet et al., 2006) performed by INRA, and ii/ the second one was based on a stratified sampling completed by BRGM for research purposes.
These field data were analyzed versus airborne gamma-ray data through multi-linear regression. Chemical, textural and mineralogical soil/regolith parameters were investigated. Predictive maps were produced and their accuracy was evaluated using the two BRGM and INRA independent sets of regolith samples and analyses.

We used multiple linear regressions to establish statistical models relating around 20 regolith parameters (chemical, textural and mineralogical) to the gamma-spectrometric variables as well as a morphological index. About 50% of the modeled regolith parameters were found to be predictable with an acceptable error ($R^2_{adj.}$ correlation coefficient being higher than 0.5 and p-value lower than 5%).
In addition, we tested the influence of adding very simplified 3-class geological information in the modeling: we showed that this improves slightly or sometimes greatly the models. This reasserts that in this kind of statistical modeling, the geological variability is one fundamental parameter that should be systematically considered: it should be taken into account in the design of the study and sampling and, if possible, in the modeling.
Qualitatively, predicted regolith parameter maps derived from the regression models display consistent patterns with known geology and soil maps. And quantitatively, the validation of predicted parameters (Sand and Clay contents) with respect to an independent set of samples, led to fairly good residuals: their average is close to zero and their standard deviation is 22% and 16 % respectively.

In the sedimentary environment studied, we further show that main gamma emitters are hosted in weathering products and leached detrital materials. A correlation matrix including chemical and textural parameters demonstrates that the most intense chemical signatures in this environment derive from 2 main mineralogical corteges: 1/ fine-grained weathering clays (with correlated Al, Fe, Mn, Mg, Pb and V elements), and 2/ residual K-rich minerals, interpreted as feldspar and/or muscovite (correlated with Na and Sr). These two families correlate with airborne gamma-spectrometric variables: first family with U and Th; second family with K.
Additionally, two chemical elements Si and Ca have specific behaviors and can hardly be characterized by the gamma data: Si (quartz) corresponds to rather coarse particles and may act as diluent of gamma signatures. Ca is neither correlated with other parameters, nor with gamma-spectrometric variables and is therefore unpredictable by the method.

Perspectives to use such modeling approach at local to regional scales are numerous: with high resolution gamma-ray surveys, this could be used in precision agriculture or to assess properties of the regolith, essential in mapping land hazards such as potentially erodible agricultural or shrinking-swelling potential areas. The usability of the method should however be tested in different geological environments (basement, volcanism, etc.), where very distinct mineralogy occur and where the geochemical source of gamma-rays and their relations with texture and other regolith parameters will be completely different from the detrital sedimentary environment we studied.

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