The potential of gamma-ray spectrometry for soil mapping

Ludger Herrmann[A], Ulrich Schuler[B], Wanida Rangubpit[C], Petra Erbe[A], Adichat Surinkum[C], M. Zarei[A], K. Stahr[A]

[A] University of Hohenheim, Institute of Soil Science and Land Evaluation (310), D-70593 Stuttgart, Germany
[B] Federal Institute for Geosciences and Natural Resources (BGR), B2.2 Spatial Information Soil and Water, Stilleweg 2, D-30655 Hanover, Germany
[C] Department of Mineral Resources, Geotechnics Division, Bangkok 10400, Thailand.

Abstract
Soil mapping is an expensive exercise, especially in areas with high relief, low infrastructure (roads), and dense vegetation as given in Northern Thailand. However, for any development activity high resolution natural resource information is necessary. The DFG-funded -Uplands program- in Thailand is seeking for low cost soil mapping techniques in order to identify application zones for agricultural innovations. One evaluated option is the use of gamma-ray spectrometry, which measures the abundance of radio-nuclides in soils and parent materials. Gamma-ray spectrometry can be used ground based as well as remote (airborne), and offers this way application at different scales. This paper deals with the theory behind application for soil mapping, results of measurements at the profile to catchment scale in N-Thailand and potential other uses. The results show that gamma-ray spectrometry can support field identification of WRB Soil Reference Groups especially in the case of different parent materials or with different CEC as well as at the same time different base saturation. Future perspectives are mapping at regional scale with remotely sensed data as well as erosion mapping at the field scale.

Key words
Radiometry, rapid soil assessment, clay illuviation, mapping tools, northern Thailand.

Introduction
Radiometry is a well known methodology in geo-sciences, especially in geology, geomorphology and mineral resource mapping (Wilford 1995, Tulyatid 1997). It can be applied for remote as well as ground-based mapping. The radiometric fingerprint of a site mainly depends on the parent material, its mineralogy and geochemistry (Dickson and Scott 1997). In general, the radiometric fingerprint of the parent material is inherited to the soils which develop from them. However, from a theoretical perspective, soil formation processes should also alter the nuclide signature of soils (Taylor *et al*. 2002). This might be explained taking potassium as an example. In well draining soils from the semi-arid to the per-humid zones potassium is liberated from primary minerals like micas and feldspars by hydrolysis and protolysis. The liberated K can be incorporated in newly formed clay minerals, adsorbed by clay minerals or organic matter (CEC) or leached out of the profile with the soil solution. Since it is to be expected that different nuclides show a different behavior with respect to stability against weathering and transport depending on their size, weight and valency, the radiometric fingerprint should change with time due to preferential leaching of i.e. lighter and monovalent ions.
Another process, which can lead to a change of the fingerprint is redistribution of soil material by erosion processes. Especially, if several different parent materials, i.e. limestone and magmatic materials occur in the same landscape in different topographic positions, erosion can lead to a strong change of the signature, where eroded material is deposited (= relative landscape lows). Also the signal can be diluted by absolute enrichment of certain elements, like with ironpan formation in Gleysols. In semi-arid and arid landscapes salt, gypsum and carbonate accumulation can lead to dilution or change of single nuclide signals. Finally, also redistribution of elements within soil profiles can happen, predominantly by illuviation i.e. of clay minerals, which again concerns potassium.
These theoretical reflections give reason to test gamma-ray spectrometry as a potential tool for rapid soil assessment in the field, which has so far - with few exceptions - been neglected. An opportunity appeared in the collaborative „Uplands Program“ financed by Deutsche Forschungsgemeinschaft (DFG) in Northern Thailand. Within this framework one task was to establish a regional soil map in order to determine potential intervention zones for new agricultural practices. Since time and funds were restricted new means for rapid soil assessment needed to be developed among which gamma-ray spectrometry was one tested option. In the following experiences with this method will be presented.

Research area and materials

Research area

The intervention zone is limited by the Myanmar boarder in the north and west, the Doi Inthanon massive in the south and the Chiang Mai Basin in the east. So far mapping concentrated on three sites which represent the major parent materials in the region: Mae Sa in the NE (10.5 km^2, stressed granite), Bor Krai in the NW (8.5 km^2, limestone), and Huay Bong in the centre (6.8 km^2, sandstone)

Materials

As ground-based spectrometer a GRM-260 handheld device (Gf Instruments, s.r.o. Geophysical Equipment and Services, Czech Republic) was used. We tested the influence of the background radiation, measured rock samples, as well as soil profiles horizon-wise. For each soil profile the radiation of eU, eTh, and K were measured in 10 cm depth intervals with a sampling time of 3 minutes and 3 repetitions. A total of 547 measurements between 0 and 190 cm soil depth were conducted. The measured energy spectrum ranges from 0.401 to 3.001 MeV or for wavelengths between 0.03 x 10^{-4} to 4.13 x 10^{-4} nanometers. The respective sensitivity coefficients for yK, yU, and yTh were 0.01929, 16.5, and 10.2 mg/kg for counts/s. In order to avoid disturbances due to soil moisture, measurements were carried out during the dry seasons (October to May) of 2007 and 2008. Finally airborne radiometric data, which were provided by the Department of Mineral Resources in Bangkok and collected in the 1980ies are available for comparison reasons. Soil analysis for comparison reasons and classification of soils was executed according to Herrmann (2005).

Results and Discussion

Parent material radiation

As to be expected, parent material exhibit different radio signatures, with magmatic ones (i.e. latiteI generally emitting high and chemical sediments (limestone) emitting low radiation. Clastic sediments (claystone) show intermediate values (Table 1).

Table 1. Gamma-ray spectra of different rocks and soils derived in the Bor Krai area of northern Thailand.

Soil/Rock	K [dag/kg]	eU [mg/kg]	eTh [mg/kg]
Limestone (N=21)	0.2 ± 0.1	2.0 ± 0.9	4.0 ± 2.7
Alisols (N=42)	1.8 ± 0.9	4.5 ± 1.4	15.4 ± 4.1
Acrisols (N=105)	0.6 ± 0.2	7.1 ± 2.2	27.8 ± 5.1
Ferralsols (N=27)	0.4 ± 0.2	7.4 ± 1.9	25.2 ± 5.5
Umbrisols (N=21)	0.8 ± 0.2	6.4 ± 2.1	23.1 ± 4.2
Claystone (N=6)	2.5 ± 0.2	3.8 ± 1.7	12.9 ± 1.2
Luvisols (N=90)	2.1 ± 0.5	4.0 ± 1.4	16.0 ± 2.5
Alisols (N=258)	2.2 ± 0.5	4.5 ± 1.7	16.4 ± 3.2
Umbrisols (N=75)	2.8 ± 0.7	4.7 ± 1.5	15.4 ± 4.1
Latite (N=1)	17	9	131
Cambisols (N=19)	2.1 ± 0.8	1.2 ± 0.6	3.4 ± 1.1
Luvisols (N=30)	1.6 ± 0.4	1.6 ± 0.7	3.9 ± 0.9
Freshwater limestone (N=3)	0.1 ± 0.1	0.7 ± 0.4	1.4 ± 0.7
Chernozems (N=39)	0.7 ± 0.3	1.9 ± 1.0	5.0 ± 3.0

Soil reference group radiation and separation

Also WRB Soil Reference Groups (IUSS Working Group WRB 2006) show differences in radio signatures (i.e. Umbrisols vs. Chernozems, Table 1) if derived from different parent materials (limestone vs. freshwater limestone respectively). The picture becomes less clear for soils with similar genesis (i.e. clay illuviation) on the same parent material (i.e. Luvisols and Alisols on claystone). The rule that clearly appears is that differentiation must be based on multi-spectral measurements and cannot be executed based on one element alone.

In fact, field separation of illuviation type soils is of high interest to soil mapping, since the classification of the respective WRB Soil Reference Groups (Acrisol, Alisol, Luvisol, Lixisol) is based on chemical characteristics, which cannot be determined in the field. Therefore, we tried to exploit the radiometric data in more detail. Especially the K/Th ratio appeared to be very useful, whereas the behaviour of U is not well understood. The latter might be a general methodological problem using the 214 Bi nuclide for uranium estimation, since volatile radon occurs in the decay chain, which leads to a potential high estimation error. Figure 1 shows that it is possible to nearly completely separate Alisols and Acrisols in the limestone catchment based on radiometric data. For the cases where the separation does not work out, also results of chemical analysis are close to the threshold values of the WRB classification (24cmol$_{c+}$/kg clay, 50 % base saturation), and the distance to the threshold values is within the detection error of the analytical method.

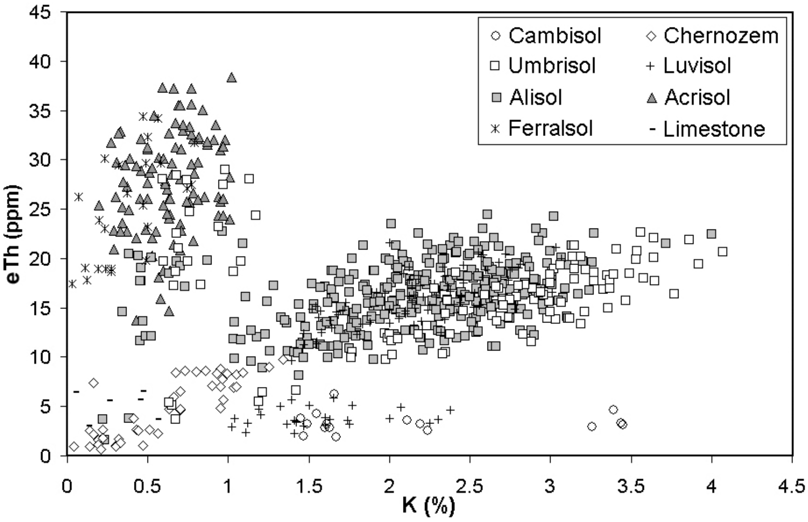

Figure 1. Binary plot of K and Th radiation of soil horizons from different WRB Soil Reference Groups for the limestone catchment Bor Krai

Behaviour of K, Th, and U nuclides during soil genesis in the Bor Krai limestone catchment in N-Thailand
Limestone, due to its high carbonate concentration, exhibits overall low radiation for the measured radio nuclides. During weathering carbonate is lost and clastic components are relatively enriched. This leads to an increasing radiation by an increasing concentration of radio-nuclides (Figure 2). The residual of limestone after dissolution of carbonate is a clay-rich clastic sediment, as it can also be found in the Bor Krai area. Under the given climatic conditions (seasonal tropical, semi-arid to sub-humid), clay illuviation is the dominant soil formation process, accompanied by base loss. Base loss by leaching leads to an absolute loss of elements including radio nuclides, which seems to affect predominantly K. Base loss is always accompanied by silica loss, which favours the formation of two-layer clay minerals with low substitution of central atoms and low cation exchange capacity. Consequently, total binding capacity for cationic nuclides is constantly reducing.

Apart from absolute loss, the radio signature is depending on redistribution within the soil profile by vertical particle movement, which mainly concerns finer particles (clay illuviation). Further on, erosion processes influence the surface signal at erosion sites (in case of illuviation type profiles through loss of depleted topsoil material) and the whole profile signal on depositional sites (depending on the origin of deposited material, which is in most cases topsoil material, as shown for Umbrisols).

Though also an absolute loss for U and Th nuclides must be suspected, our measurements show an increasing signal during terrestrial soil development, which we attribute to relative enrichment in sesquioxide components. However, this hypothesis will need further investigation.

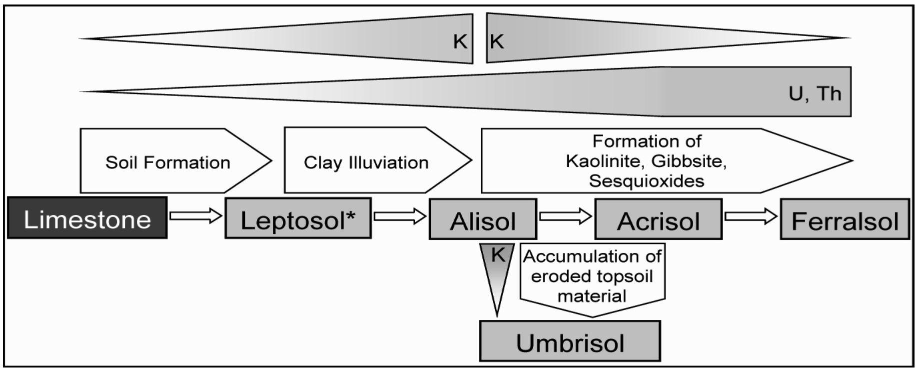

Figure 2. Conceptual model of radio nuclide behaviour during soil formation in the Bor Krai catchment in N-Thailand

Outlook

Apart from field scale mapping, gamma-ray spectrometry has also a potential for upscaling of results and mapping at the regional scale. Since airborne data are available for the whole of northern Thailand (Tulyatid & Ra-Nguppits 2004), the next step will be to correlate ground-based and airborne data and to search for the best upscaling algorithms, to connect the two scales. For potential mapping approaches which may integrate radiometric data see Schuler (2008) and Schuler *et al*. (this volume). Since erosion influences the topsoil radio signal, also erosion mapping is a potential, which is presently evaluated (see Erbe *et al*. this volume).

Conclusions

Ground-based gamma-ray spectrometry has a potential as tool for WRB Soil Reference Group distinction at the profile, field and (sub-)catchment scale. For illuviation type soils this is especially true if parent material differs or CEC and base saturation are significantly different. The measurements at profile scale are of special interest since they can replace high cost and time consuming chemical analyses (CEC and base saturation). Therefore, this potential should be further researched in other environments (parent materials, climates).

Further applications may concern in future erosion mapping at the field scale and regional soil and terrain mapping if airborne data are accessible (Tulyatid & Ra-Nguppits 2004, Wilford 1995).

Acknowledgements

This research was carried out within the framework of the Special Research Program 564 ("The Uplands Program", funded by Deutsche Forschungsgemeinschaft (DFG), whose support is gratefully acknowledged.

References

Dickson BL, Scott KM (1997) Interpretation of aerial gamma-ray survey – adding the geochemical factors. AGSO *Journal of Australian Geology and Geophysics* **17**(2), 187-200.

Herrmann L (2005) Das kleine Bodenkochbuch (Version 2005). Institute of Soil Science and Land Evaluation. University of Hohenheim, Stuttgart.

IUSS Working Group WRB (2006) World reference base for soil resources 2006. World Soil Resources Reports No.103. FAO, Rome.

Schuler U (2008) Towards regionalisation of soils in northern Thailand and consequences for mapping approaches and upscaling procedures. *Hohenheimer Bodenkundliche Hefte* **89**, 308p.

Taylor MJ, Smettem KRJ, Pracilio G, Verboom WH (2002) Relationships between soil properties and high-resolution radiometrics, central eastern wheatbelt, Western Australia. *Exploration Geophys*. **33**, 95-102.

Tuljatid J (1997) Application of airborne geophysical data to the study of Cenozoic basins in central Thailand. PhD Thesis. School of Earth Sciences, University of Leeds, UK, 325 p.

Tuljatid J, Ra-Nguppits W (2004) Airborne geophysical data and its application on surface mapping and land management. In 'Innovative techniques in soil survey' (Eds H Eswaran *et al.*) pp. 75- 86. (Land Development Department, Bangkok, Thailand).

Wilford JR (1995) Airborne gamma-ray spectrometry as a tool for assessing relative landscape activity and weathering development of regolith, including soils. *AGSO Research Newsletter* **22**, 12-14.