Clay and oxide mineralogy of different limestone soils in Southeast Asia

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Abstract

Limestone areas in the tropics are rare. However in South Asia they occur frequently. Soils derived from Palaeozoic and Mesozoic limestones in North Laos and Thailand, Vietnam were sampled. Dominant soils were Alisols and Acrisols in Thailand, Acrisols with few Luvisols in Laos and Luvisols with Alisols in Vietnam. The clay minerals show a sequence from illite to vermiculite and kaolinite. In strongly weathered profiles gibbsite is abundant while goethite and hematite occur sporadically. Chemical fertility is endangered in all areas, particularly in very weathered profiles of Thailand and the erosion problem is highest in Vietnam. Both are consequences of soil development and current land use.

Introduction

Limestone areas in Southeast Asia are characterized by unique landforms consisting of limestone towers with carstic depressions in between. Due to the deep and rugged slopes this areas is mostly inhabited by the socially disadvantaged groups like ethnic minorities. Fallow based farming systems without chemical fertilizer and pesticide applications are still prevailing in these areas. However recently a change from long time fallow system to short time fallow based farming systems including the application of agrochemicals is observed. This development is problematic as limestone areas are generally carstified and therefore are often characterized by high subsurface discharge. Tracer tests revealed very high transport velocities in the carstic underground, excluding significant degradation of agrochemicals. Downstream this affects the functionally of agrosystems and quality of human drinking water supply. On the other hand in areas with recent clearing of forest, high rates of erosion occur, which made sustainable agriculture impossible. The limestone soils are barriers between the surface and carstic underground. They play therefore a very important role in the ecosystems of these areas. This paper aims to highlight soil formation in limestone areas in three countries of Southeast Asia. The following questions will be addressed.

Which factors are influencing soil formation, how can differences can be explained and
how vulnerable are these soils to chemical and physical soil degradation.

Materials

Three carstic areas in Northern Thailand, Laos and Northern Vietnam have been selected.

Table 1. Research sites

Research area	**Bor Krai**	**Huay Sang**	**Muong Lum**
Country	Thailand	Laos PDR	Vietnam
Province	Mae Hong Son	Bokeo	Son La
District	Pang Ma Pha	Pha Udom	Yen Chau
Elevation [m asl]	550 - 1020	415 - 575	700 - 1300
Annual mean temperature [°C/a]	19.8 [a]	25.6 [b]	19.7 [c]
Mean annual precipitation [mm/a]	1197 [a]	1153 [b]	1427 [c]
Age of limestone	Permian	Carboniferous-Permian	Triassic
Ethnic group	Black Lahu	Hmong, Khamu	Black Thai, Hmong
Farming system	Subsistence	Subsistence	Subsistence, commercial
Main crops	Upland rice, maize	Paddy rice, maize	Paddy rice, maize, cassava

[a] Bor Krai – 770 m asl
[b] Chiang Rai – 394 m asl, 143 km WSW of Huay Sang, period 1971-2005
[c] Muong Lum – 780 m asl

They contain limestones of different ages the Carboniferous to Permian limestone of Laos being the oldest, then the Permian in Thailand and Triassic limestone in Vietnam. This limestone and the whole area has undergone cretaceous and tertiary orogeny as well as tectonic movements. This movements continued at least partially through the Pleistocene. However the age of the landscape is not well known. Intensive carstic phenomena have changed the land surface up to the decameter scale, thereby exposing limestone rocks with deep carstic depressions filled with residual material from limestone dissolution. All other carstic phenomena like dollines, underground rivers and dry valleys occur. All the research areas are placed in the outer tropics. The climate is subhumid tropical climate with marked dry humid phases. The mean temperature is about 20 degrees in the high mountain areas of Thailand and Vietnam. The farming system was shifting cultivation for subsistence but is moving in all areas towards more intensive landuse and more market orientation. There are hughe clearcuts and consequent tremendous erosion especially under upland rice and sweet corn cultivation. Beside other soils in the Thai area of Bor Krai Alisols and Acrisols are dominant. The development in the high altitudes also reaches the Ferralsol stage. In Laos Acrisols are the dominant soils, but under conditions were secondary lime is involved Luvisols are found. In the case of the Vietnamese area Alisols seem to be the most dominant soils. However in all areas the residues from limestone are rather thick covering the limestone in a thickness of several meters. A few meters away one can find places were the limestone crops out. That means the subsurface relief of the limestone is very rough (Figure 1-3).

Methods
The soils have been described according the FAO guide lines (2006) and the World Reference Base of Soil Resources (WRB 2006). The particle size, pH, carbon, nitrogen, CEC and carbonates have been analysed using the Institutes Standard Procedures (Schlichting *et al.* 1995). Bulk mineralogy was analysed using X-ray diffraction of powders specimens. The clay mineralogy was analysed after separating clay fraction and using oriented samples for X-ray diffraction with pretreatments of magnesium-, glycerol-, potassium-, saturation and heating to 50°C, 400°C und 600°C as well as ambient conditions. The qualitative analyses were done using standard minerals and a modified Rietveld analysis. The scanning electromicrographs are from natural aggregates of sand size, which have been coated with gold. The same sample have been also used for EDX-analysis.

Results
A relatively wide range of minerals has been obseverd in the bulk of the soil as well as in the clay fraction. A very clear but simple observation is that quartz was only found in the bulk soil but not in the clay fraction. This is a clear sign that we have no significant physical weathering. In temperate regions, we do find through physical cryoclastic weathering regularly in the topsoils also quartz in the clay fraction. Beside this the oxides, hematite and goethite as well as gibbsite are identified in several samples. The clay minerals are represented by illite, illite-vermiculite mixed layer, vermiculite, kaolinite and some chlorite.

Table 2. Clay minerals in three representative soils from limestone in Northern Thailand.

Soil	**Alisol**				**Acrisol**				**Ferralsol**	
Slope (%)	1.7				3.5				34.4	
Horizon	Ah (N=1)		Bt3 (N=1)		Ah1 (N=1)		Bt2 (N=1)		Bo4 (N=1)	
Depth (cm)	0-17		56-76		0-20		62-86		150-160	
Skeleton (%)	2-5		0-2		0		0		0	
Sand (%)	15		13		8		7		3	
Silt (%)	44		26		44		13		16	
Clay (%)	41		61		48		79		82	
Mineralogy:	Bulk	Clay	Bulk	Clay	Bulk	Clay	Bulk	Clay	Bulk	Clay
	(%)									
Gibbsite	0	0	0	0	36	18	37	20	58	45
Goethite	0	4	13	5	0	0	0	0	0	0
Hematite	8	5	8	5	19	15	18	13	14	22
Ilite	13	36	17	38	0	6	0	5	0	0
Illite/Vermiculite	0	26	0	22	0	0	0	0	0	0
Kaolinite	24	24	27	24	31	50	36	52	14	22
Quartz	54	0	48	0	12	0	5	0	4	0
Vermiculite	0	5	0	6	3	11	3	10	0	0
Chlorite	0	0	0	0	0	0	0	0	9	11

There is a clear tendency of mineral development when comparing the three Thai soils given in Table 2. The primary illite is not found in the Ferralsol and only in traces in the Acrisol and but it is abundant in the Alisol. Also the expanding clay minerals have their maximum in the Alisol and are reduced in Acrisols as well as Ferralsols. There is a tendency of desilification or ferralitisation, which is observed in the increasing kaolinite content from Alisols to the other soils. The tendency of desilification is further confirmed by the existence of gibbsite in the Acrisols and Ferralsols. Through the formation of iron and aluminium oxide cements, we find gibbsite as well as hematite in higher quantities in bulk soil, than in the separated clay fractions, especially in the Acrisol. Also rubification has its highest values in the Acrisol, and goethite is no detectable in Thai Acrisol and Ferralsols.

The findings of profiles from Laos and Vietnam confirm the results found in Thailand. With no exception an illitic clays mineral was found in the clay fraction in all soils. On the other hand the occurrence of gibbsite is only in very small amounts and could not be quantified. Also hematite was not found in samples from the two research sites but goethite was found in high quantities. Consistent with this finding is that in some of the Laostick profiles calcium carbonate could was present. The scanning electron microscope shows the presence of predominant kaolinite and gibbsite and especially kaolinite is not well crystallised having no idiomorphic shapes. The gibbsite crystals are very abundant however, they are extremely small and seem to cover all fragments and aggregates. This phenomenon, however, confirms the pedogenic origin and formation of these crystals insitu.

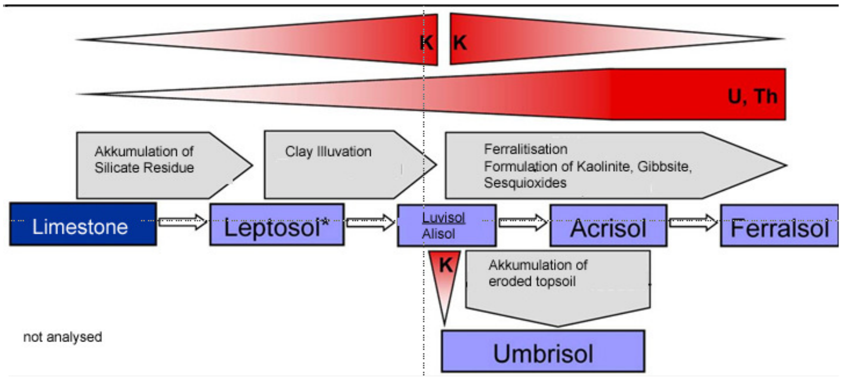

Figure 1. Mayor processes governing soil formation on limestone in SE-Asia

Discussion

Soil development especially the differentiation of clay minerals and oxides in the three analysed areas are different. Already the occurence of Ferralsols in Thailand points to the more advantaged development. This is confirmed through the overall presence of gibbsite and also by the occurrence of some chlorite. Both minerals are mainly absent in the other two areas. The major directions of soil formation and mineral formation are shown in (Figure 1). The development is in the beginning a formation of residual clays, which also gathers potassium. This improving the plant nutrition status of Luvisols and Acrisols. In the second phase of desilification and extreme base depletion the clay minerals are formed into kaolinite and finally gibbsite. This further development stage forms the aggregates and thereby the physical constitution of the soils, while the first process improves the nutrient situation of the soils. The ecological consequence is that in the areas analysed in Laos and Vietnam plant nutrition is still in an acceptable situation with exchange capacity and especially potassium nutrition at an acceptable level. However in this area the erosion problem is terrible. On the other hand the poor soils in Thailand, which have undergone rubification and strong decalcification have formed very stable aggregates and have a very good infiltration. Therefore these soils are more stable under cultivation. Sustainable landuse needs a management which stabilises the soil structure in Vietnam and Laos while in the North Thailand case especially the chemical situation has to be improved by specific fertilizer application.

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