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Contents of Elements in Some Flooded Soils as Related to Their Origins in Northeast Thailand

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ABSTRACT

The contents of elements in two flooded soils in Northeast Thailand were studied. Aeric Endoaqualf (P1) was derived from fine-grained sedimentary rocks and Typic Endoaquert (P2) developed on basalt. The concentration of elements (Ti, Fe, Ca, Mg, K, Mn, P, Li, Cs, As, Cr, V, Ni, Rb, Cu, Zn, Ga, Co, Pb, Mo, Zr, U, Sr) in the fine-earth, sand, silt and clay fractions was measured by using XRF and ICP-MS techniques. The results revealed that both soils were deep and alkaline. The 2:1 phyllosilicate clay dominated in clay fraction with minor amount of kaolin. Illite and smectite were major clay minerals in P1 and P2, respectively, which were influenced by their parent materials. Authigenesis of clay and carbonate was evident. The amount of elements was quite low throughout the profiles. This was probably due to the shallow water table and these soils had been saturated with water where the reducing condition restricted the weathering rate of the parent rocks. Additionally, there was limited vertical leaching as compared to lateral water flow. However, P1 showed a larger variation of element compositions than did P2, reflecting a more uniform composition of basalt. The distribution of elements showed that their concentrations were generally high in the clay fraction indicating that the clay played an important role as a reservoir for these elements and heavy metals in soils.

Key words: trace elements, flooded soils, geochemistry, pedogenesis, water activity, tropical soils

INTRODUCTION

Rock weathering is mainly a natural source of elements in soils and the element concentrations can generally be predicted from the element abundance in the parent material. The soil processes in accumulating or mobilizing elements are of interest in environmental science due to the central position of soil in the hydrological cycle and in ecosystems (Kabata-Pendias and Pendias, 2001). The extent to which pedogenesis affects heavy metal distribution varies according to the prevailing factors affecting soil processes. Redox conditions, pH and water content affect the rate of transformation of elements in soil (Alloway, 1995). Birkeland (1999) proposed that elements released by weathering might or might not be redistributed down slope as a function of their mobility under constant or changing geochemical environments. Under slightly acid with oxidizing conditions, Fe and Al are residual, and mobile cations (some Si,

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Ca, Mg, Mn, K, Na) move to the lower parts of the slope (Tardy *et al.*, 1973). Yaalon *et al.* (1971) studied the amount of Mn increases downslope in three soil catenae formed on basalt, dolomite and limestone and indicated that there was an active transportation downslope rather than the relative enrichment from *in situ* weathering.

This paper presents results of an attempt to examine the distribution of elements in flooded soils developed from different parent materials to highlight the different role of inheritance parent rock and pedogenic processes in controlling element distribution and its content in soils.

MATERIALS AND METHODS

Two studied areas were located in Northeast Thailand (Figure 1). P1 was derived from fine-grained sedimentary rocks and P2 from basalt. They have been used for paddy rice cultivation. The soils were classified as Aeric Endoaqualf (P1) and Typic Endoaquert (P2) based on soil taxonomy (Soil Survey Staff, 1999). Pedon analysis in soil pits was carried out, including detailed profile descriptions and sampling soil from each genetic horizons using standard field study method (Kheoruenromne, 2004). Laboratory analyses of soil samples were conducted according to standard method (National Soil Survey Center, 1996). The elements (Ti, Fe, Ca, Mg, K, Mn, P, Li, Cs, As, Cr, V, Ni, Rb, Cu, Zn, Ga, Co, Pb, Mo, Zr, U and Sr) in soils, clay (<0.02 mm), silt (0.02-0.05 mm) and fine sand (0.25-0.1 mm) fractions were determined by a combination of X-ray fluorescence spectrometry (XRF) and inductively coupled plasma-mass spectrometry (ICP-MS). Semi-quantitative determination of minerals was by X-ray diffraction analysis. Soil, sand, silt and clay were analyzed as random powders and clays were also analyzed as oriented aggregates.

Thin sections of selected horizons were analyzed under a polarizing microscope using standard micromorphological techniques (Bullock *et al.*, 1985). Selected areas defined under the polarizing microscope were examined by scanning electron microscopy with energy dispersive X-ray analysis (SEM/EDS) to determine the composition of the soil matrix.

RESULTS AND DISCUSSION

Field morphology and environmental setting

All soils were deep and moderately

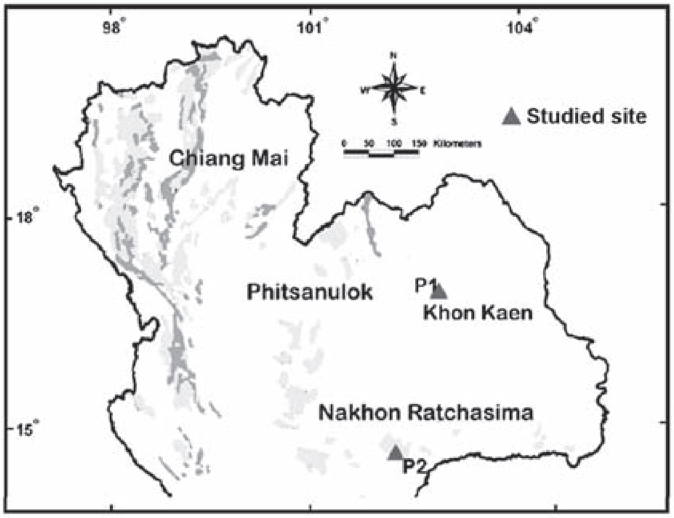

Figure 1 Sampling sites of flooded soils in the study.

weathered. They were poorly drained with slow permeability. Their texture reflected the inheritance of parent rock. P1 on toeslope position was sandy loam to silty clay loam with an evidence of clay accumulation with depth. Nevertheless, P2 on the valley floor position was clay but did not show clay accumulation. This was possible due to its saturation by water throughout the profile retarding clay translocation (Buol *et al.*, 2003). The color ranged from yellow, olive brown and dark olive gray with many mottles throughout the profiles. The soils had very shallow water table with some seasonal fluctuation. Secondary minerals releasing iron and manganese further induced a presence of mottles in the soils (Weitkamp *et al.*, 1996). In addition, Fe, Mn-oxide nodules occurred at 5-30 cm depth in P1 reflecting the wetting and drying periods in their pedogenesis (Acquaye *et al.*, 1992).

Physico-chemical properties

All soils had high clay content as influenced by their parent materials (Figure 2). The high clay content of the B-horizon further suggested a moderate to high degree of the transformation of primary minerals to clay (Beckmann *et al.*, 1974). The soil chemical properties are summarized in Table 1. All soils generally showed trend of having the highest organic matter content in the surface and a decrease of organic matter with depth. They were alkaline (pH>7) with high extractable bases, especially Ca and Mg which were attributed to a lower intensity of weathering and leaching. This also indicated that there was a removal of the basic cations from the upper position to accumulate in the soil on the

Table 1 Chemical properties of the flooded soils[1/].

Depth	Horizon	pH	OM	Total N	Available		Extractable				CEC	Extractable Fe	
		(H_2O)			P	K	Ca	Mg	K	Na		Fe_d	Fe_o
(cm)			(--- g kg^{-1}---)		(--- mg kg^{-1}---)		(------------------ cmol kg^{-1}				------------------)	(--- g kg^{-1}---)	
P1: Aeric Endoaqualf													
0-5	Apg	6.00	5.50	0.21	3.90	14.58	3.39	0.76	0.19	0.46	19.98	2.69	1.15
5-23/30	Btcg	7.00	3.30	0.14	0.52	12.26	13.60	2.79	0.15	2.25	16.71	15.34	1.33
30-48	Btg1	8.50	1.24	0.11	0.79	15.38	18.62	3.90	0.19	0.08	20.36	9.98	0.78
48-80	Btg2	8.90	1.03	0.11	0.95	15.60	27.03	4.81	0.19	4.71	22.23	10.43	0.62
80-113	Btg3	9.20	0.93	0.11	4.63	17.97	18.91	5.01	0.22	0.22	24.48	10.68	1.04
113-143	Btg4	9.10	1.00	0.12	19.01	20.55	17.67	5.66	0.25	0.28	27.80	10.05	0.85
143-162	BCg1	9.20	1.07	0.13	77.06	21.59	21.79	6.35	0.27	1.61	27.38	11.37	0.86
162-195+	BCg2	9.10	0.69	0.12	89.28	23.07	22.79	6.23	0.28	0.35	28.58	10.93	0.73
P2: Typic Endoaquert													
0-15	Apg	7.6	31.12	0.90	2.00	20.91	18.14	13.44	0.27	1.11	40.04	34.69	8.55
25-50	Bssg	7.8	12.84	0.38	0.15	7.83	12.92	15.28	0.10	4.82	40.67	25.34	7.32
50-76	Bg1	8.0	8.80	0.30	0.15	5.69	11.38	18.56	0.07	4.94	37.17	20.17	5.85
76-100/110	Bg2	8.0	7.00	0.25	0.50	5.30	11.90	21.09	0.07	4.14	41.07	17.95	4.94
110-133	BCg1	8.3	10.41	0.31	1.25	5.82	17.28	31.27	0.07	2.09	42.48	3.38	3.43
133-160	BCg2	8.3	6.24	0.22	2.50	4.15	19.44	25.41	0.05	0.78	46.66	4.16	2.46
160-180+	Crg	8.4	5.39	0.24	3.00	1.99	17.25	23.63	0.03	0.78	47.53	3.95	1.39

[1/] The analytical methods were done according to standard method: soil pH (National Soil Survey Center, 1996), organic matter (Walkley and Black, 1934), total nitrogen (Jackson, 1965), available P (Bray and Kurtz, 1945), available K (Pratt, 1965), extractable bases (Ca, Mg, K, Na) (Thomas, 1982), CEC (Chapman, 1965), Fe_d (Mehra and Jackson, 1960), Fe_o (McKeague and Day, 1966).

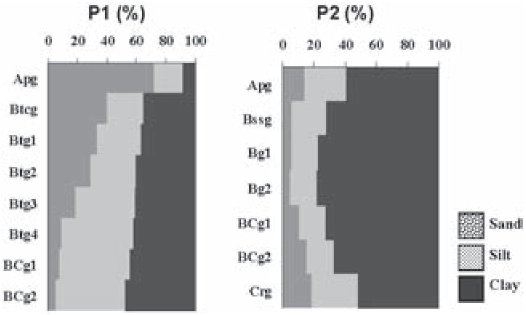

Figure 2 Depth function of soil particle size distribution.

lowest position of the landscape. The high contents of Ca and Mg with depth reflected the remaining of primary minerals inherited from the parent rock. This was confirmed by a presence of some feldspar in silt and fine sand fractions. The low amounts of free iron (Fe_d) in soils reflected their poorly drained nature (Ogg and Smith, 1993). This might be due to the repeated removal of dissolved free iron oxides from the soil, possibly in laterally seeping ground water (Ojanuga *et al.*, 1976). In addition, the high iron content in P2 without a presence of iron oxide minerals suggested high amount of amorphous and organic forms of iron because under poorly drained condition the amorphous iron could not dehydrate to the crystalline form (Ogg and Smith, 1993).

Sand, silt and clay mineralogy

The 2:1 clay minerals dominated the clay fraction along with minor amount of kaolin. Their 2:1 clay mineral type depended on the basic cation in soil solution. The relatively high K and Mg in the soil solution induced the formation of illite and smectite, respectively. For P1 where leached material from upslope accumulated a higher pH and geochemical environment favor retention of illite (Fanning *et al.*, 1989). Additionally, the soil had formed upon a fine grained illitic sediment that could contribute much illite to the profile (Thompson and Ukrainczyk, 2002). P2 on the valley floor was poorly drained and saturated with water for at least some time of the year. Reduced iron together with dissolved ions (Si, Al, Mg) leached from the profiles upslope might have reacted to form smectite (Harder, 1972).

Quartz was a main constituent in the silt and sand fractions due to its relative resistance to weathering. Traces of feldspar and the 1.4 nm mineral occurred in silt and sand fractions. The persistence of these minerals might be the consequence of the less intense weathering under alkaline condition at this position (Buol *et al.*, 2003).

Elements geochemistry

The factor analysis of the element concentrations showed about 70% of the variation in the data. Elements could be allocated into two main groups of similar geochemical behavior, with other elements not belonging to any group (Figure 3a). The first group was composed of As, U, Mn, K, Cs, Rb, Li and Zn. The reason for elements being in this group was unknown as these elements could be classified as mobile (Korte *et al.*, 1976). The second group was Fe, Ti, Sr, Cu, Mg, Ca, P, Ga, Cr, V, Ni and Co. Many metals were associated with Fe as members of the secondary oxide group as the metals could substitute for Fe in oxide structure. Iron and P were positively related as was commonly observed for basalt derived soils (Marques *et al.*, 2004) due to P being sorbed by sand-sized iron oxide aggregates. Vanadium and Ni were frequently associated with Fe as these elements formed structural analogues to goethite and hematite, and thus readily substituted for Fe in natural hematite and goethite (Singh and Gilkes, 1992).

Generally, the trace and heavy elements in soils were released from their parent material during the weathering process. In this case, the shallow water table level induced saturation condition for these soils. This was then possible that the reducing condition could restrict weathering rate of the parent rocks. There was very limited vertical leaching because only the lateral water flow occurred. Hence the amount of trace and heavy elements were quite low throughout the profiles. However, P2 that derived from basalt had a very uniform element composition throughout the profile as indicated by the tight grouping of samples in the factor plot whereas P1 that derived from sedimentary rock showed more diversity in its composition (Figure 3b). This reflected that basalt had a more uniform chemical composition than did the fine-grained sedimentary rock.

In general, the distribution of minor elements between size fractions showed that most of elements were located in the clay fraction (Figure 4) which, therefore, had an important role as a reservoir for heavy metals and plant nutrient elements (Song *et al*., 1999).

The spatial distribution of elements in soil matrix

The Al, Si, Fe and Ca mapping (Figure 5) of P1 revealed that this soil also contained much Si. Also, most of data points were located away from the 'kaolin line' towards the SiO_2 apex. This corresponded to the presence of predominant illite and the very fine-grained quartz in this soil. In addition, the authigenesis of clay and carbonate

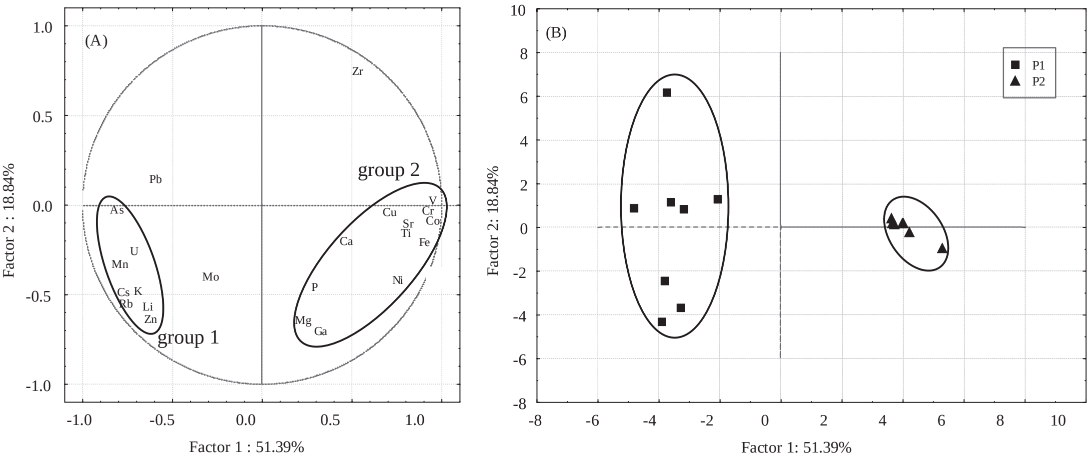

Figure 3 Factor analysis for element concentrations in whole soils: (A) distribution of elements; (B) distribution of soil samples, where elements were superimposed in (A) they had been slightly displaced for clarity.

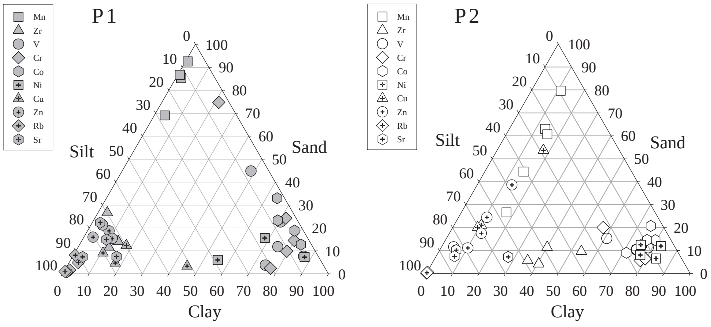

Figure 4 Triangle graphs based on the content of elements located within the sand, silt and clay fractions.

were recognized. P2 showed data points that were located off the kaolin line towards the SiO_2 apex (Figure 6). This was a consequence of the presence of smectite (dioctahedral) as a major constituent of the matrix. The smectite contained a higher concentration of SiO_2 than did kaolin and the octahedral cation site of smectite was occupied by Mg and Fe in addition to Al thus further reducing the Al_2O_3 concentration (Borchardt, 1977). Very small quartz grains were abundant although quartz was not a primary mineral in basalt, Beckmann *et al.* (1974) proposed that it could be a product of weathering or geological alteration.

CONCLUSION

Dominant characteristics of these soils included being deep, fine-textured with alkaline condition. Illite and smectite were major clay minerals in P1 and P2, respectively, which inherited from their parent materials. Quartz was the main constituent in the silt and sand fractions due to its resistance to weathering. In addition, these soils were on the lowest position of the landscape where stagnant water prohibiting Fe to form crystalline iron oxide minerals even though they had quite high iron content.

The element distribution patterns of these

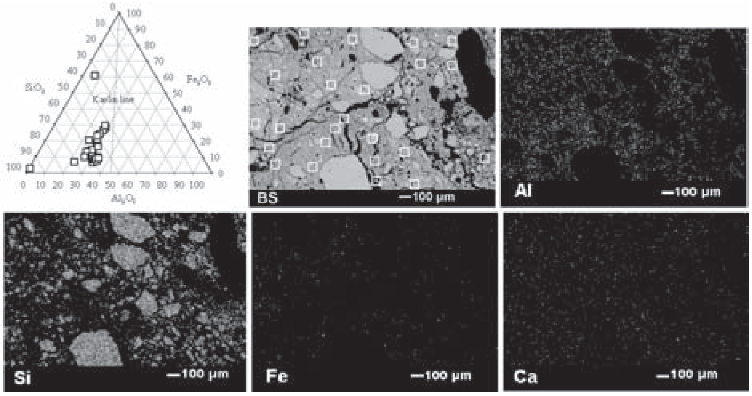

Figure 5 Backscattered electron micrographs, EDS element (Al, Si, Fe and Ca) maps and normalized composition triangular graph for the Btcg (5-23/30 cm) horizon of Aeric Endoaqualf (P1).

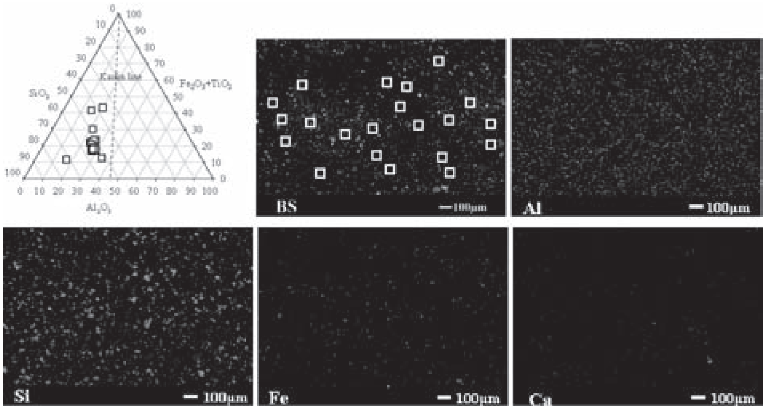

Figure 6 Backscattered electron micrographs, EDS element (Si, Al, Fe and Ca) maps and normalized composition triangular graph for the Bg2 (50-76 cm) horizon of Typic Endoaquert (P2).

soils showed little variation within soil profile. However, P1 was more variable than P2. This was due to the saturation of soils induced by the shallow water table level. The reducing condition restricted the rate of weathering of the parent rocks. There was also limited vertical leaching as compared to the action of the lateral water flow, hence the amount of elements was low throughout the profiles. The concentrations of most elements were generally high in the clay fraction indicating that the clay fraction played an important role as a reservoir for these elements and heavy metals.

The elements in these soils were probably inherited from parent rock during pedogenesis. Chemical weathering of the parent rock under tropical climate gave rise to the element distribution in soils that reflected the presence of clay minerals and iron oxide minerals. However, the low position on the landscape could restrict the degree of weathering as related to the water activity and it was the key of the element distribution in flooded soils.

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