Micromorphological and chemical characteristics of placic and ortstein horizons in subtropical subalpine forests

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Abstract
Pedons with a placic or ortstein horizon are commonly occurred in the subalpine and alpine forests in Taiwan. We selected a representative pedon with well-developed placic horizon in subalpine forests in northeastern Taiwan and another with a well-developed ortstein horizon in subalpine forests in central Taiwan to compare the differences between these two horizons. Micromorphological observations indicated that the placic horizon was characterized by vughy microstructure and was composed of iron oxides, whereas ortstein horizon was characterized by granular and bridge microstructures between quartz grains. Analytical results of cementing materials between skeleton grains in these two horizons by using energy dispersive spectrometry (EDS) further indicated that Fe, O and C were predominant elements in the placic horizon, whereas Al, Si and C were major elements of the cementing materials in the ortstein horizon. The elemental mapping determining by electron probe micro-analyses (EPMA) also indicated that organically complexed-Al was the dominant material, which was present between soil aggregates and coated on quartz grains in the ortstein horizon as compared with those of the placic horizon. Chemical analytical results showed that pedogenic Fe (Fe_d) was the dominant Fe fraction in both placic and ortstein horizons; however, the Fe_d contents were much higher in the placic horizon than in the ortstein horizon. Dominant Al fractions were different between the two horizons, organically complexed-Al (Al_p) was predominant in the ortstein horizon, and pedogenic Al (Al_d) was dominant in the placic horizon. We concluded that different formation mechanisms occurred between these two horizons; the placic horizon was related to redox processes, and the ortstein horizons related to podzolization.

Key Words
Energy dispersive spectrometry (EDS), micromorphology, placic horizon, ortstein horizon.

Introduction

Hardened soil layers, placic or ortstein horizons common occur in the subalpine or alpine forest soils, and their genesis is not fully understood, especially in subtropical or tropical forest ecosystems in Taiwan. The definition of the placic horizon in US soil taxonomy is a thin (< 25 mm), black to dark reddish pan which cemented by iron (or iron and manganese) and organic matter (Soil Survey Staff 1975). The ortstein horizon is commonly an illuvial hardened horizon such as Bh and Bs horizons in Spodosol or Podzol, and these horizons are at least 25 mm thick (Soil Survey Staff 1975). Both of these horizons are severely influence the drainage and plant growth of forest ecosystems and their management. Several hypotheses have been proposed for the formation of the placic horizon, including translocation and precipitation of organic Fe complexes (Conry *et al.* 1996; Clayden *et al.* 1990), and mobilization of reduced Fe in the upper parts and then oxidation in lower soil horizons (Lapen and Wang 1999; Pinheiro *et al.* 2004). With regard to the formation of the ortstein horizon; the translocation and precipitation of organic Fe and/or Al complexes is a dominant mechanism (Lee *et al.* 1988; Lapen and Wang 1999).

Taiwan is located at the tropical and subtropical climatic regions, and more than 70% of the lands is mountain covered by various forests. In the subalpine and alpine forest ecosystems, clear illuvial processes and strong chemical weathering prevail in these soils due to the great amount of annual rainfall (≥ 3000 mm). Podzolic soils and soils with placic horizon have been found by Li *et al.* (1998), Hseu *et al.* (1999) and Wu and Chen (2005) in the subalpine cloud forests of northern Taiwan. However, clearly comparison of genesis between these soils is rare. The objectives of this study are to combine micromorphological observations, EDS analyses, electron probe micro-analyses (EPMA) and bulk soil chemical extraction to determine the geochemical characteristics of the placic and ortstein horizons and to deduce the differences of the formation processes between the placic and ortstein horizons in the subtropical subalpine ecosystem.

Methods

Environmental setting and soil characteristics

The TPS site (around 24°32' N, 121° 56' E) is located at Mt. Taiping with altitude of 2200 m, where mean annual air temperature is 10 °C and total annual rainfall is 3200 mm, in northeastern Taiwan (Figure 1). The parent materials are comprised shale and slate (Ho 1986). Cypress forest of Taiwan red cypress (*Chamaecyparis formosensis* Matsum), Taiwan Chinese fir (*Taiwania cryptomerioides* Hay.) and Willow fir (*Cryptomeria japonica* Hassk.) are dominant vegetation. In addition, the placic horizon was common characteristics within the soils at this site (Wu and Chen 2005). Based on previous investigation studies (Hseu *et al.* 1999; Wu and Chen 2005), we selected a representative pedon with well-developed placic horizons on the summit position, and it was classified as Typic Hapludults with placic horizon based on US Soil Taxonomy (Soil Survey Staff 2006). The SLS site is located at Mt. Fenghuang with altitude of 1700 m (around 23°38' N, 120° 47' E), where mean annual air temperature is 16 °C and total annual rainfall is 2600 mm, in central Taiwan. The parent material of this site is mainly composed of sandstone. Based on pre-investigation of soil distribution, the soils with distinct eluvial and ortstein horizons were commonly found on the summit position at this area. Accordingly, we selected a representative pedon with well-developed ortstein horizons on the summit position, and it was classified as Typic Haplorthod based on US Soil Taxonomy.

Soil analyses

Soil samples were collected from each horizon of the two pedons for physical and chemical analysis. Soil analyses included pH, total organic carbon (TOC) contents, cation exchange capacity (CEC), dithionite-citrate-bicarbonate (DCB) extracted Fe and Al (Fe_d and Al_d), ammonium oxalate extracted Fe and Al at pH 3.0 (Fe_o and Al_o), and sodium pyrophosphate (pH 10) extracted Fe and Al (Fe_p and Al_p).Total contents of major metal elements in soils were determined by X-ray fluorescence spectrometry (XRF) (RIGAKU, ZSX Primus II, Japan) with Rh target and a beam voltage of 20 kV. Analytical quality of the XRF measurements was controlled by analyzing standard reference material (NIST-2709) certified by National Institute of Standards and Technology (NIST), USA.

Soil micromorphology

Kubiena boxes were used to collect undisturbed soil blocks in the field for making thin section. Vertically oriented thin sections which 5 × 8 cm and with a thickness of 30 μm were prepared by Spectrum Petrographics, Inc., Winston, Oregon, USA. The thin sections were observed for all soil horizons using a polarized microscope (AFX-Ⅱ Type, Nikon Precision Instruments, Belmont, CA). Meanwhile, we also made the polished slides for soil placic horizon. The selected samples were mounted in cold-mounting epoxy resin (EpoFix, Struers Co.) with 1-inch diameter mold at the room temperature for over night. The mounted samples were ground by SiC and then polished by alumina paste (up to 0.3 μm) until surface exposed well. Each polished sample was initially observed by an optical microscope with the reflection light, and then, a scanning electron microscope (SEM; JEOL JSM-6360LV) was used to observe micro-scale texture. Back-scattered electron image, which represents mean atomic abundance by contrast in back and white image, were observed from the surface of the polished section. Identification of mineral phases were made by an energy dispersive spectrometer (EDS; Oxford Instruments Ltd., INCA-300) which equipped with SEM, under the beam conditions of 15 kilovolt (kV), and 180 picoampere (pA) for the acceleration voltage, and beam current, respectively, in the vacuum condition of 25 Pascal (Pa) without carbon coating.

Results

The placic horizon

The placic horizon of Typic Hapludults at the TPS site exhibited hard structure and undifferentiated fabric with small voids and plane channels, which reflected dense structures of the placic horizon (Figure 2a and b). The above-mentioned micomorphological features are commonly observed in thin section. The placic horizon was characterized by high contents of Fe_d and Fe_t (≥ 330 g/kg), low contents of organically complexed-Fe (≤ 70 g/kg) and Al (≤ 5 g/kg), and low ratio of Fe_p/Fe_d (≤ 0.25) (Table 1). Additionally, high content of Fe oxides and Fe/Al ratio of the cementing materials between skeleton grains were estimated by EDS (Table 2). The results indicated that inorganic Fe was dominantly distributed in the soil matrix and cementing materials between quartz grains (Figure 3a, b, c and d), which also indicated that redox processes were dominant pedogenic processes in the placic horizon.

The ortstein horizon

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The ortstein horizon of Typic Haplorthods at the SLS site is characterized by bridge and granular microstructures, and with high proportion of large voids such as chamber and channels (Figure 2c and d). The above-mentioned micomorphological features are commonly observed in the thin sections. The ortstein horizon also has much lower contents of Fe_d and Fe_t (≤ 80 g/kg), compared to those of placic horizon, whereas slightly higher contents of organically complexed-Al (about 10 g/kg) and high ratio of Al_p/Al_d (≥ 0.54) were present in the ortstein horizon (Table 1). Meanwhile, EDS results also showed that relatively low Fe/Al ratio in the cementing materials between soil aggregates and coatings on the quartz grains (Table 2). We conclude that aluminosilicates and pedogenic Fe were distributed in the soil matrix, however, the cementing materials between soil aggregates and coatings on the quartz grains of the ortstein horizon were composed of organically complexed-Al, which were further supported by the elemental mapping of EPMA (Figure 3e, f, g and h). The formation of the ortstein horizon is considered as a process related to podzolization.

Table 1. DCB-, oxalate- and pyrophosphate-extractable Fe and Al in two pedons.

Pedon	Horizon	Depth	Fe_d	Al_d	Fe_o	Al_o	Fe_p	Al_p	Fe_t	Fe_p/Fe_d	Al_p/Al_d	Fe_p/Fe_o	Al_p/Al_o	Al_o +1/2Fe_o
		(cm)	(---------------------------g/kg-----------------------)											
TPS	O	5-0	3.73	1.16	2.02	1.06	0.85	0.81	4.37	0.23	-	-	-	-
	A	0-7	5.13	2.11	2.86	1.92	2.52	1.65	5.94	0.49	0.78	0.86	0.88	0.34
	E	7-21	0.38	2.23	0.18	3.15	0.17	2.43	3.79	0.45	1.09	0.77	0.94	0.32
	Bsm	21-22.7	327	10.2	174	4.73	71.3	4.49	331	0.22	0.44	0.95	0.41	9.17
	Bt1	22.7-45	61.0	9.24	18.0	4.39	38.1	8.27	62.0	0.62	0.90	1.88	2.12	1.34
SLS	O	13-0	-	-	-	-	-	-	-	-	-	-	-	-
	A	0-4	3.49	1.08	0.85	0.74	1.00	0.95	6.63	0.29	0.88	1.28	1.18	0.12
	2E	4-11	4.16	0.67	0.95	0.53	0.93	0.44	5.39	0.22	0.66	0.83	0.98	0.10
	2Bh	11-32	79.3	17.8	12.0	5.32	22.3	9.59	63.8	0.28	0.54	1.80	1.86	1.13
	2Bs	32-47	40.6	7.21	2.68	2.20	11.5	4.17	45.2	0.28	0.58	1.90	4.29	0.35
	2BC	>47	28.4	9.99	1.50	2.12	1.71	2.46	-	0.06	0.25	1.16	1.14	0.29

Table 2. Elemental composition of the cementing materials in the placic and ortstein horizon.

	Placic (Bsm) value (%)	standard deviation	Ortstein (2Bh) value (%)	standard deviation
SiO_2	19.6	1.54	21.5	6.07
Al_2O_3	10.2	0.53	15.8	3.07
FeO	48.3	4.56	8.62	2.57
K_2O	1.15	0.10	1.02	1.18
MgO	-	-	0.33	0.20
TiO_2	-	-	0.70	1.28
Total	79.2		48.0	
Sample number	7		12	
SiO_2/Al_2O_3	1.92		1.36	
FeO/Al_2O_3	4.74		0.55	

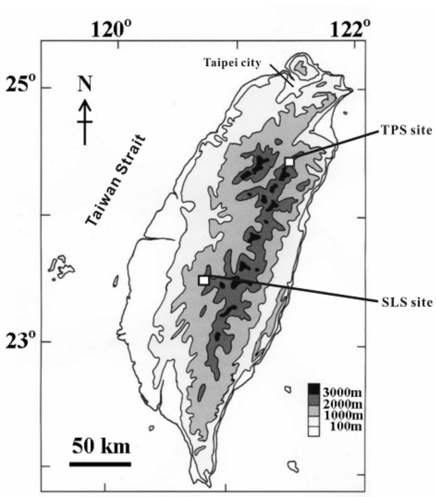

Figure 1. The studied sites in Taiwan.

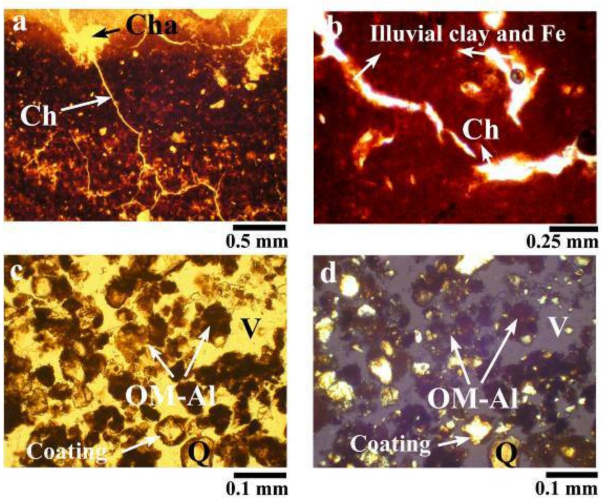

Figure 2. The micromorphological photos of the placic horizon (a: with a plane polarized light (PPL); b: with a PPL) and ortstein horizon (c: with a PPL; d: with a cross polarized light (XPL)). (OM-Al: organically complexed-Al; Cha: chamber; Ch: channel; V: void; Q: quartz).

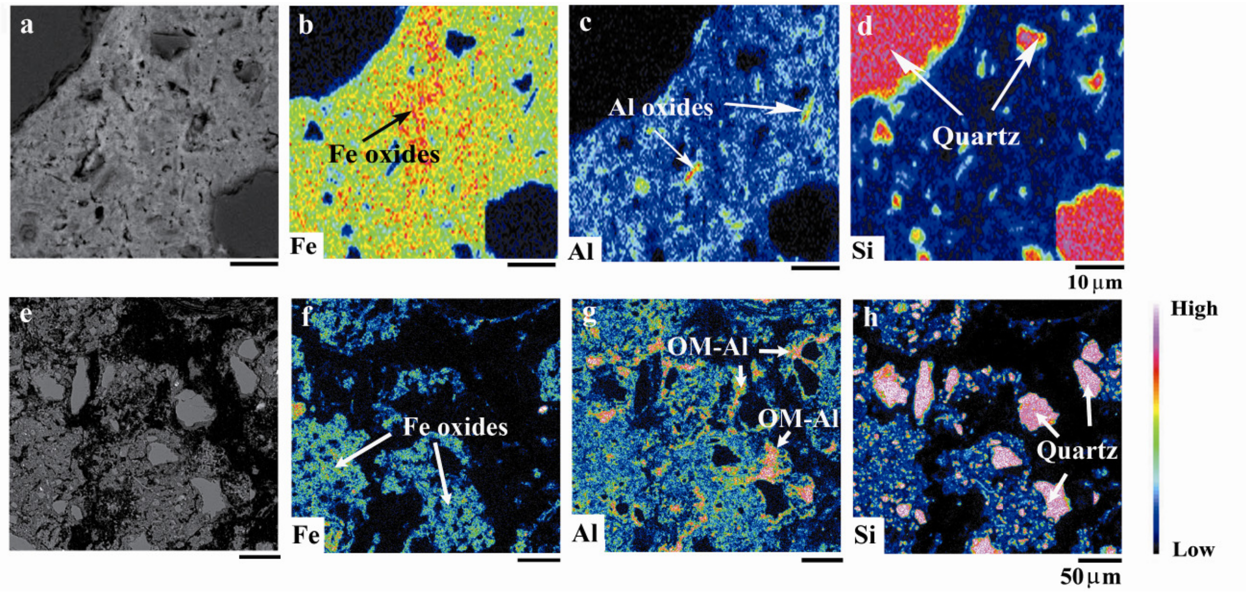

Figure 3. The spatial distribution of Fe, Al and Si in the placic horizon (a, b, c and d) and ortstein horizon (e, f, g, and h); a and e are back electron image of the placic and ortstein horizon, respectively. (OM-Al: organically complexed-Al).

Conclusions

Significant differences were present between the placic horizon and ortstein horizon; denser microstructure and less porosity were found in the placic horizon as compared to the ortstein horizon. Predominant pedogenic Fe were found in the placic horizon and predominant organically complexed-Al was found in the ortstein horizon, which indicated that different formation processes occurred between the two horizons. The formation of placic horizon reflects the redox process, whereas the ortstein horizon is due to the podzolization. Additionally, we conclude that poor drainage of clayey pedons located in TPS subalpine forests led to saturated and reduced conditions in the surface soils; textural difference and pH gradient enhanced the accumulation and oxidization of Fe above the B horizon and formed the placic horizon rather than an ortstein horizon. Texture is a critical factor controlly the formation of placic and ortstein horizons in the humid subalpine forests in Taiwan.

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