Characteristics and genesis of placic horizon in subalpine montane forest soils in northeastern Taiwan

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Abstract
Placic horizons occurred between the overlying E horizon and the underlying argillic or cambic horizon in the two subalpine forests, Chilanshan (CLS) and Szyuanyakou (SY) area. The thickness of the placic horizon in CLS area (Hapludults) was 20 mm, while that in SY area (Placorthods and Dystrudepts) was 30 to 60 mm. Redoximorphic features are evidence of wetness and of leaching and translocation of Fe. In both pedons, Fe_o/Fe_d ratios were much higher in the placic horizons compared with the other horizons. High clay contents in both pedons inhibited the downward movement of surface water. Reduction and oxidation processes associated with various favorable hydrological conditions are considered to be the main pedogenic processes that formed the placic horizons in soils in CLS area. Subsequent evolution of the landscape of the original soils in SY1 area, with partial truncation of the original soil and emplacement of a younger and deeper depositional material on the eroded surface, created the modern soil, which is classified as an Inceptisols. The environmental conditions, such as relatively flat landscape, clayey soil, and very high precipitation have enhanced this process.

Key Words
Placic horizon, temperate forest, soil characteristics, soil genesis, soil classification

Introduction
Placic horizons occur in a wide range of landscapes from temperate to tropical zones but are always associated with udic or perudic moisture regimes. Taiwan is located at the tropical and subtropical climatic zones. The subalpine forest regions are suitable for the formation of Podzolic soils, including Ultisols, Inceptisols, Entisols and Spodosols (Chen and Tsai, 2000). The Podzolic soils were formed at the elevation that is higher than 1900 m, cool and humid climate, high precipitation (3000 mm/year) mostly from April to October and with dominant coniferous vegetation type in Taiwan (Chen *et al*., 1989; 1995; Liu *et al*., 1994; Li *et al*., 1998; Hseu *et al*., 1999). However, in addition to sandstone, parent materials of subalpine forest areas of Taiwan also include shale or slate, which are easily weathered to a finer texture soil. In this condition, the water slowly flows into the soil and provides the cycling of reduced and oxidized (or wet and dry) conditions. The cycling of reduced and oxidized conditions is one of the important factors for the genesis of placic horizon in Taiwan (Chen *et al*., 1989, 1995; Clayden *et al*., 1990; Hseu *et al*., 1999). Therefore, the objectives of this study were (i) to evaluate and interpret the morphological and chemical characteristics of placic horizons occurring in subalpine forest in Taiwan and (ii) to explain the genesis of the placic horizons in these forest soils.

Methods
Site description
In northeastern Taiwan, three Ultisols with placic horizons in the Chilanshan (CLS) area and one Inceptisols and one Spodosols with placic horizons in the Szyuanyakou (SY) areas were selected (Table 1). The major parent materials of soils in the area are sandstone and shale, with minor amounts of slate. The slope of selected subalpine forest soils ranged from 3° to 20°, and the elevation of five soils ranged from 1840 to 1940 m above sea level (asl). The soil temperature regime in both pedons is mesic. The moisture regime in CLS area is perudic having a mean annual precipitation (MAP) of 3700 mm and in SY area is udic with 2280 mm MAP. However, the microrelief of the sampling sites appears to have modified the moisture regime toward perudic or aquic. The dominant vegetation in both sites is coniferous, composed of Taiwan red cypress (*Chamaecyparis formosensis* Matsum), Taiwan cypress [*Chamaecyparis obtusa* (Siebold & Zucc.)], Ranta fir (*Cunninghamia konishii* Hayata), and Willow fir (*Cryptomeria japonica* Hassk.). An herbaceous plant, Alpine silver grass (*Miscanthus transmorrisonensis* Hay.), is also common around SY area. In each study site, soil pits were excavated for the description of macromorphological soil characteristics as well as for the collection of soil samples according to standard procedures (Soil Survey Staff, 1993).

Table 1. Environmental characteristics and soil classification of five selected soil pedons in this study.

Pedon	Elevation (m)	Slope (degree)	Landscape position	Soil drainage	Parent material	STR[a]	SMR[b]	Soil classification[c]
				Chilanshan				
CLS-1	1840	3	summit	good	slate	mesic	udic	Typic Hapludults
CLS-3	1840	31	shoulder	good	slate	mesic	udic	Typic Hapludults
CLS-4	1880	20	shoulder	good	slate	mesic	udic	Typic Hapludults
				Szyuanyakou				
SY1	1940	10	summit	good	slate	mesic	udic	Typic Dystrudepts
SY3	1940	9	summit	good	slate	mesic	udic	Typic Placorthods

[a] STR = soil temperature regime
[b] SMR = soil moisture regime
[c] Based on Keys to Soil Taxonomy (Soil Survey Staff, 2006)

Laboratory analysis

Soil samples were collected from each horizon of five soil pedons for physical and chemical analyses. Soil samples were air dried and slightly ground to pass a 2-mm sieve. Bulk density was measured by cold method. Particle size distribution was determined by pipette method. Soil pH was determined with a soil/water ratio of 1:1 and soil/1 M KCl ratio of 1:2.5. Organic C was determined by the Walkley-Black wet combustion method. Cation exchange capacity (CEC) and exchangeable bases were measured using ammonium acetate extraction. Different forms of Fe and Al were extracted by dithionite-citrate- bicarbonate (DCB, Fe_d and Al_d), ammonium oxalate (pH 3.0, Fe_o and Al_o) and sodium pyrophosphate (pH 10.0, Fe_p and Al_p). Optical density of the oxalate extract (ODOE) of soils was also determined by ammonium oxalate. Potassium, Na, Ca, Mg, Fe, and Al were quantified by atomic absorption spectrometry.

Results

Soil macromorphology

All pedons have soil properties associated with Podzols and suggest strong eluviation and illuviation of soluble salts, Fe, Mn, and other materials. All albic E horizons have a massive structure that is enhanced by wet soil conditions and was identified as a redoximorphic feature. The poor drainage condition was further enhanced by current climate conditions characterized by high annual rainfall, low air temperature, and low evapotranspiration rate. The abundant coniferous vegetation is believed to have contributed to the climate. Gleyzation of the albic material was apparently affected by the poor drainage resulting from the underlying placic horizon (Hseu *et al*., 1999; Wu and Chen, 2005).The thickness of the placic horizons ranged from 2 to 6 cm. The placic horizon had colors of 2.5YR 5/8 in pedon CLS-1, 5YR 4/6 in pedon CLS-3, 7.5YR 5/8 in pedon CLS-4, and 5YR 5/8 in pedon SY1 and SY3. Two distinct phases were found in these placic horizons. A dark hard iron pan occurred in the upper part of the Bs horizon of pedon CLS-1, 3, and 4 accompanied by less-dense plasma immediately below the main pan. In the placic horizon of pedons SY1 and SY3, darker red iron bands and lighter dense plasma paralleled each other. The placic horizon in SY area was more brittle than the one in CLS area, as revealed by field test. The placic horizon is too dense to be penetrated by roots. The soil between E horizon and Bw horizon have an abrupt texture change. This change of clay content may affect vertical water movement and relate to the formation of the placic horizons of three pedons.

Pedogenesis of placic horizon in CLS and SY area

In soil of CLS area, the original dense plasma formed a thin layer that grew progressively as a result of Fe accumulation in the upper margins of the Bs horizons (Table 2). This probably reduced the percolation rate of surface water. The generally flat land surface (with minor irregularities and a 5% slope) and its continuity across the landscape could have enhanced perching of water on the surface of the clay soil. This may have in turn produced the irregular surface of albic horizon as well as the abrupt and wavy lower boundary of the placic horizon. These site and soil morphological features help to explain why water could have perched on top of the soil, saturating it and reducing Fe, which was then translocated vertically down through the E horizon. Reoxidization and precipitation of Fe occurred in the placic horizon. The chroma the Bs horizon of Pedon CLS-1, 3, and 4 suggests that the water did not stay long in this horizon. The growth of iron pan gradually impeded the normal water flow into the Bs horizons. Thus, the reducing condition occurred only within the eluvial horizon above the placic horizon and not in the Bs horizons. This is supposed by the barrier imposed by the pan to have retarded further precipitation of Fe, and this may account for the limited thickness the placic horizon in Pedon 1. In addition, the placic horizon further impeded the deposition of Fe, Al, or Mn in the lower B horizon.

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Table 2. Results of selective dissolution analysis of selected soils in Chilanshan and Szyuanyakou area.

Horizon	DCB		Oxalate		Pyrophosphate		Al_o +1/2Fe_o	$Fe_{p/o}$	$Fe_{o/d}$	$Al_{p/o}$	$Al_{o/d}$	ODOE[a]
	Fe_d	Al_d	Fe_o	Al_o	Fe_p	Al_p						
	g/kg						%					
					CLS-1							
A	8.40	2.64	4.06	1.90	3.72	2.62	0.39	0.91	0.48	1.38	0.72	1.67
E	2.08	2.07	0.89	1.79	0.40	2.53	0.22	0.45	0.43	1.41	0.86	0.40
Bsm	123	8.72	80.3	5.18	43.6	5.71	4.53	0.54	0.65	1.10	0.59	2.01
Bt	36.4	9.28	10.2	3.65	8.18	5.43	0.87	0.80	0.28	1.49	0.39	0.60
BC	33.4	10.8	7.31	3.08	6.16	3.27	0.67	0.84	0.22	1.06	0.29	0.36
Saprolite	18.7	6.78	7.73	4.40	5.99	4.36	0.83	0.77	0.41	0.99	0.65	1.27
					CLS-3							
OA	ND	1.26	2.55	1.41	1.70	2.05	0.27	0.67	ND[b]	1.45	1.12	0.29
A	25.3	3.49	27.2	2.51	23.9	2.91	1.61	0.88	1.08	1.16	0.72	2.69
AE	4.36	2.03	6.24	2.20	4.82	2.86	0.53	0.77	1.43	1.30	1.08	0.85
Bsm	195	10.8	161	7.96	94.3	7.02	8.85	0.59	0.83	0.88	0.74	--[c]
Bt	27.2	8.32	23.6	5.99	30.8	7.71	1.78	1.31	0.87	1.29	0.72	1.27
2E	17.9	2.49	5.29	1.55	8.10	2.52	0.42	1.53	0.30	1.63	0.62	0.40
2Bsm	122	10.1	115	7.27	56.3	6.61	6.48	0.49	0.94	0.91	0.72	0.78
2Bt	25.6	7.97	21.6	5.35	22.1	8.08	1.62	1.02	0.84	1.51	0.67	0.97
2BC	27.1	5.50	17.4	4.06	17.1	5.50	1.27	0.98	0.64	1.36	0.74	1.58
					CLS-4							
A	11.3	3.37	6.76	3.04	7.17	3.84	0.64	1.06	0.60	1.27	0.90	1.87
E1	5.19	0.59	4.25	1.14	4.14	1.21	0.33	0.98	0.82	1.06	1.93	0.42
E2	8.20	0.98	3.48	1.36	1.97	1.33	0.31	0.57	0.42	0.98	1.38	0.67
Bsm	111	4.82	75.8	3.05	41.9	2.75	4.10	0.55	0.68	0.90	0.63	--
Bt1	40.9	3.38	10.6	2.36	9.35	2.78	0.76	0.89	0.26	1.18	0.70	1.85
Bt2	27.0	7.34	15.5	5.11	16.8	5.76	1.29	1.08	0.57	1.13	0.70	2.92
BC	24.0	6.90	12.1	4.86	10.2	4.98	1.09	0.84	0.51	1.02	0.70	2.53
					SY1							
O	11.7	1.97	6.17	1.52	3.76	2.21	0.46	0.61	0.53	1.45	0.77	1.76
A	21.4	3.96	12.0	3.03	8.86	4.94	0.90	0.74	0.56	1.63	0.77	1.43
Bw	24.9	2.92	6.34	1.63	3.78	2.07	0.48	0.60	0.25	1.27	0.56	0.25
2E1	22.0	3.97	6.80	2.49	5.42	3.25	0.59	0.80	0.31	1.30	0.63	0.44
2Bsm	155	7.26	40.3	2.28	3.28	1.42	2.24	0.08	0.26	0.63	0.31	1.71
2E2	34.1	4.36	3.16	2.04	4.16	3.00	0.36	1.31	0.09	1.47	0.47	1.59
2Bw1	35.2	5.67	3.80	1.72	3.91	2.00	0.36	1.03	0.11	1.16	0.30	0.30
2Bw2	32.3	4.90	6.28	1.64	3.49	1.65	0.48	0.56	0.19	1.00	0.33	0.58
2BC	33.7	4.44	7.38	1.79	3.84	1.75	0.55	0.52	0.22	0.97	0.40	0.26
					SY3							
O	16.5	2.74	4.87	1.67	3.32	1.84	0.41	0.68	0.30	1.10	0.61	--
A	22.3	4.06	5.33	1.94	4.15	2.30	0.46	0.78	0.24	1.19	0.48	0.69
E	22.0	4.83	7.53	2.92	6.72	3.78	0.67	0.89	0.34	1.29	0.61	0.66
Bsm	--	--	--	--	--	--	--	--	--	--	--	--
Bw	34.3	4.86	6.85	2.35	7.66	3.24	0.58	1.12	0.20	1.38	0.48	0.24
BC	31.9	4.20	7.88	2.73	7.27	3.50	0.67	0.92	0.25	1.28	0.65	0.17

[a] optical density of oxalate extraction.
[b] ND = not detected
[c] -- = no data

In SY area, the landscape once had fairly uniform parent materials beneath it, much like the soil materials found in the horizons below the Bsm horizons. Classic podzolization processes, complexing of Fe, Al, and organic matter in well drained, very acid soil environments, mobilized Fe and C and translocated them together into subsoil horizons. A spodic horizon began to form in the original soils. Then, the landscape became unstable, perhaps due to climate change. Erosion stripped away the surface soils above the 2E1 horizon. The placic horizon effectively armored the landscape and prevented erosion from removing any of the soil beneath the placic horizon. New soil materials, perhaps colluvium washed down from higher landscapes, blanketed the landscape and rested above the erosion surface. The hydrological barrier caused by the placic horizon created a perched water table, saturating the younger soils above it, and leading to the reduction of Fe in 2E horizons of Pedon SY1. Lateral flow through the soil landscape above the placic horizon caused much of the reduced, mobile Fe to be removed via downslope leaching process. The 2Bsm horizon and the weakly developed 2Bw horizons beneath it are relic feature of an earlier cycle of soil genesis and landscape evolution. The soil horizons that provided the source of Fe to concentrate in the placic horizon are long gone. Therefore, the horizons currently above the placic horizon are much younger soil materials, and the development of redoximorphic features in them is also a much younger phenomenon.

Conclusion

Placic horizons occurred between the overlying E horizon and the underlying argillic or cambic horizon in the two subalpine forests, Chilanshan and Szyuanyakou area. Bifurcated iron pans occurred mixed with dense plasma within the placic horizon. The thickness of the placic horizon in CLS area (Hapludults) was 20 mm, while that in SY area (Placorthods and Dystrudepts) was 30 to 60 mm. Organo-Fe complexes in the placic horizon of Pedon CLS-1, 3, and 4 formed isotropic plasma separated by planar voids. Redoximorphic features are the evidence of wetness and by leaching and translocation of Fe. Pedons in CLS area had maximum Fe and organic C content in the placic horizon, whereas in SY area had only a maximum Fe content in the placic horizon. In both pedons, Fe_o/Fe_d ratios were much higher in the placic horizons compared with the other horizons. High clay contents in both pedons inhibited the downward movement of surface water. Reduction and oxidation processes associated with various favorable hydrological conditions are considered to be the main pedogenic processes that formed the placic horizons in soils in CLS area. Subsequent evolution of the landscape of the original soils in SY1 area, with partial truncation of the original soil and emplacement of a younger and deeper depositional material on the eroded surface, created the modern soil, which is classified as an Inceptisols. The environmental conditions, such as relatively flat landscape, clayey soil, and very high precipitation have enhanced this process.

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