Characteristics and genesis of Inceptisols with placic horizons in the subalpine forest soils of Taiwan

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Abstract

Three pedons of Inceptisols with placic horizons were selected to study the characteristics and genesis of subalpine forest soils located in Shang-Hsing Mountain in Ilan county, northeastern Taiwan. The selected pedons were elevated from 1900 to 2100 m and derived from slate formed in the late Quaternary age. The vegetation types are dominated by red cypress (*Chamaecyparis formosensis* Matsum) and Taiwan Chinese fir (*Taiwania cryptomerioides* Hay). The annual rainfall is about 3000 mm and mostly falls from April to October. The soil moisture regime is perudic, and the soil temperature regime is mesic. Three Inceptisols can be classified as Lithic Dystrudept and Oxyaquic Dystrudept based on USDA *Soil Taxonomy* or Cambisol based on World reference base system. Clear illuvial pedogenic processes were observed by the bleached albic (E) horizon and the underlain placic (Bs) horizons, which were characterized on the changes of soil morphology, micromorphology, soil texture and chemical compositions. The placic horizon appeared to be dominated by amorphous iron and free iron oxides, with lesser amounts of amorphous aluminum and free aluminum oxides. The genesis of the placic horizons in the study area was proposed as two stages. In the first stage, the perched water was located between albic horizon and cambic horizon after a storm owing to the texture changes of these two horizons. In the second stage, Fe of the upper part of the pedon was reduced, then be mobilized and reoxidized it in the boundary of E and Bw horizon. Therefore, the boundary of placic horizon has a wavy or irregular boundary. In addition, the genesis of placic horizon may also relate to the precipitation of mobile Fe at higher soil pH value and oxidizing soil contacts below the mineral soil surface. Although we do not find the argillic horizon formed below the placic horizon, Ultisols are a major soil order formed in the level landscape position of the study area.

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1. Introduction

The placic horizon has been defined as a thin, black to dark reddish pan that is cemented by iron (or iron and manganese) and organic matter. It has a

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minimum thickness of 1 mm and, where associated with spodic materials, is less than 25-mm thick (Soil Survey Staff, 1999). A placic horizon is relatively impermeable to water and plant roots. It occurs in the sola of some Spodosols as a thin wavy or convoluted horizon that transgresses several subhorizons (McKeague et al., 1967). In some regions, it occurs within or immediately below the albic E horizon (Soil Survey Staff, 1975). Placic horizons are usually associated with perudic to aquic soil moisture regimes in coastal regions (McKeague et al., 1983).

Soils with a placic horizon are classified as Spodosols or Inceptisols. The placic horizon, however, is also found in Histosols (McKeague et al., 1968; Clayden et al., 1990). The genesis of placic horizon is still not completely understood. Several hypotheses have been proposed to explain this genesis (Crompton, 1952; Conry et al., 1996; Chen et al., 1989, 1995; Clayden et al., 1990; Hseu et al., 1999; Lapen and Wang, 1999). Placic horizons are formed in a wide range of landscapes from temperate to tropical zone but are always associated with the climate condition under udic or perudic soil 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 dominant with the 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 dried) 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).

The objectives of this study are (i) to study the soil characteristics and soil classification of three Inceptisols with placic horizons, (ii) to investigate the micromorphology of placic horizon and (iii) to propose the genesis of placic horizon of these pedons.

2. Materials and methods

2.1. Soil and environmental conditions

Three Inceptisols with placic horizons were selected in the Shang-Hsing Mountain area (around 24°32' N, 121° 56' E) of Ilan county, northeastern Taiwan (Fig. 1). The slope of selected subalpine forest soils ranged from 20% to 60%, and the elevation of three soils ranged from 1900 to 2100 m above sea level (asl). The parent material of study area consists of slate formed in the late Quaternary. The vegetation types are dominated by red cypress (*Chamaecyparis formosensis* Matsum) and Taiwan Chinese fir (*Taiwania cryptomerioides* Hay). Some environmental characteristics of the soil pedons are listed in Table 1. The mean annual air temperature is 10.7 °C, and the mean annual precipitation is 3000 mm. The rainfall mostly occurs from April to October.

2.2. Laboratory analysis

Soil samples were collected from each horizon of three soil pedons for physical and chemical analyses. Soil samples were air dried and slightly ground to

Fig. 1. The location of pedons studied in Taiwan.

Table 1
The environment condition of three pedons in the study area

Location	Physiographic position	Elevation meter	Slope degree	Facing direction	SMR ^a	STR ^a	Parent materials
<i>Pedon SH1: fine, mixed, mesic, Lithic Dystrudept</i>							
24° 32' 49" N 121° 35' 18" E	Summit	2000	<5	210	Udic	Mesic	Slate
<i>Pedon SH2: fine, mixed, mesic, Lithic Dystrudept</i>							
24° 29' 45" N 121° 31' 40" E	Summit	1920	<5	180	Udic	Mesic	Slate
<i>Pedon SH3: fine, mixed, mesic, Oxyaquic Dystrudept</i>							
24° 31' 51" N 121° 37' 01" E	Shoulder	1940	21	115	Perudic	Mesic	Slate

^a SMR—soil moisture regime, STR—soil temperature regime.

pass a 2-mm sieve. Bulk density was measured by paraffin method (Blake and Hartge, 1986). Particle-size distribution was determined by pipette method (Gee and Bauder, 1986). Soil pH was determined with a soil/water ratio of 1:1 and soil/1 M KCl ratio of 1:2.5 (McLean, 1982). Organic C was determined by the Walkley-Black wet combustion method (Nelson and Sommers, 1982). Cation exchange capacity (CEC) and exchangeable bases were measured using ammonium acetate extraction (Thomas, 1982). Different forms of Fe and Al were extracted by dithionite-citrate-bicarbonate (DCB, Fe_d and Al_d; Mehra and Jackson, 1960), ammonium oxalate (pH 3.0, Fe_o and Al_o; McKeague and Day, 1966) and sodium pyrophosphate (pH 10.0, Fe_p and Al_p; Loveland and Digby, 1984). Optical density of the oxalate extract (ODOE) of soils was also determined by ammonium oxalate (Daly, 1982).

2.3. Thin section analysis

For soil micromorphological studies, Kubiena boxes were used to collect undisturbed soil blocks in the field. After air drying, vertically oriented thin sections (5×7 cm) with thickness of 30 µm were prepared by Spectrum Petrographics (Oregon, USA). Thin sections were examined under a polarized microscope (AFX-II Type, Nikon), and the micromorphology was described according to the terminology of Bullock et al. (1985).

3. Results and discussion

3.1. Soil morphology

Soil morphological characteristics of the three pedons are listed in Table 2. All pedons have soil properties associated with Podzols and suggest strong eluviation and illuviation of soluble salts, Fe, Mn, and other materials. All pedons have a dark organic and mineral (O/A) surface, a gray albic (E) horizon, a dark red placic (Bs) horizon and a brownish yellow B horizon. The color of the albic E horizon is gray (10YR 6/1, 7.5YR 6/1 or 10YR 7/1). All albic E horizons have a massive structure that is enhanced by wet soil conditions and was identified as a redox-imorphic feature. Gleyzation of the albic material was apparently affected by the poor drainage resulting from the underlying placic horizon (Hseu et al., 1999).

The thickness of the placic horizons ranged from 2 to 5 mm (Fig. 2). The placic horizon had colors of 2.5YR 4/6 in pedon SH1, 2.5YR 5/8 in pedon SH2 and 2.5YR 4/8 and 2.5YR 2.5/1 in pedon SH3 (Table 2). 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 SH1 accompanied by a less-dense plasma immediately below the main pan (Fig. 2a). In the placic horizon of pedons SH2 and SH3, darker red iron bands and lighter dense plasma paralleled each other (Fig. 2b and c).

The thickness of placic horizon is about 5 mm and has an abrupt and wavy boundary (Fig. 2). The placic

Table 2
The morphological characteristics of three pedons

Horizon	Depth (cm)	Munsell color	Texture ^a	Structure ^b	Consistence ^c	Rootsd	Boundary ^e
<i>SH1, elevation 2000 m</i>							
O/A	0–3	10YR 3/1	L	1vf and fgr	fri	mm and c	gs
E	3–12	10YR 6/1 7.5YR 5/8(mot) ^f	SiL	massive	fm, ss and sp	cf and m	aw
Bs	12–12.5	2.5YR 4/6	—	—	h	—	aw
Bw	12.5–40	10YR 6/8	SiCL	2m and cabk	fm, ss and sp	ff and m	d
C	>40	2.5Y 6/6	SL	2fsbk	fm	fvf	—
<i>SH2, elevation 1920 m</i>							
O/A	3–0	7.5YR 2.5/1	L	mucky	—	—	—
AE1	0–18	10YR 5/1	SiL	massive	sfm, ss and sp	sm and c	gs
AE2	18–27	10YR 5/1	SiL	massive	fm, ss and sp	svf and f	ds
E	27–36	7.5YR 6/1	SiCL	massive	fm, s and p	sm and c	aw
Bs	36–36.5	2.5YR 5/8	—	—	h	—	aw
Bw	36.5–56	10YR 6/8	SiCL	2vf and fabk	sfm, s and p	—	d
C	>56	2.5Y 6/6	SL	2fsbk	—	fvf	—
<i>SH3, elevation 1940 m</i>							
O	5–0	7.5YR 3/2	—	mucky	—	—	cs
A	0–10	5YR 2.5/2	L	2vf and fgr	—	mvf, sm	aw
E1	10–15	10YR 4/2	L	massive	fm, ss and sp	fvf and f	aw
E2	15–25	10YR 7/1	CL	massive	s and p	fvf and f	aw
Bs	25–25.3	2.5YR 4/8(70%) 2.5YR 2.5/1(30%)	—	—	h	—	aw
Bw1	25.3–55	10YR 6/8	SiCL	2vf and fabk	fm, ss and sp	fvf and f	d
Bw2	55–75	10YR 6/8	SiCL	2vf and fabk	fm, ss and sp	fvf and f	d
BC	75–100	10YR 6/8	SiCL	2vf and fabk	fm, ss and sp	fvf and f	d
C	>100	2.5Y 6/6	SL	2fsbk	—	fvf	—

^a SiCL—silty clay loam, SiL—silt loam, CL—clay loam, SL—sandy loam, L—loam.

^b 1—weak, 2—moderate, vf—very fine, f—fine, m—medium, gr—vgranular, abk—angular blocky, sbk—subangular blocky.

^c fm—firm, fri—friable, s—sticky, p—plastic, ss—slightly sticky, sp—slightly plastic, vs—very sticky, vp—very plastic, h—hard.

^d c—common, m—many, s—some, f—few, c—coarse, m—medium, f—fine, vf—very fine.

^e a—abrupt, c—clear, s—smooth, g—gradual, d—diffuse, w—wavy, i—irregular, b—broken.

^f mottle color.

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.

3.2. Soil micromorphology

In the boundary area between albic (E) and placic (Bs) horizon, the soils showed an abrupt change in micromorphological characteristics (Fig. 2). The lower part of E horizon have a large amount of crystalline quartz materials, but the upper part of Bs horizon have cracked, parallel and isotropic iron and manganese matrices (Fig. 3a). The general micro-

morphological characteristics of the placic horizons for the three pedons are similar. Brewer (1964) reported that iron pans originally have a granular fabric that has been modified by various degrees of cementation. They indicated grain coatings that could be found in the placic horizon. In contrast, all the fabrics in the placic horizons in the present study are isotropic.

Some different micromorphological characteristics were found between the upper part and lower part of placic (Bs) horizon (Fig. 3b). The upper part of placic horizon showed a dark red isotropic Fe oxide material (Fig. 3b and c), and the lower part of the placic horizon showed a black to a reddish dense plasma with soil matrixes (Fig. 3b and d). The fabric of the

Fig. 2. Morphological characteristics of placic horizon of (a) SH1, (b) SH2 and (c) SH3. These photos were copied from the glass specimen of thin section. Scale of bar is 1 cm.

placic horizons mainly consisted of dense plasma and was cemented by oxidized Fe and Mn materials. Intergranular voids (v) were found in the hard portion of the placic horizon in the three pedons (Fig. 3b and c).

The micromorphology of the placic horizons indicated higher bulk density and a maximum accumulation of Fe oxides (Tables 3 and 4). This

character indicated that the soluble Fe and Mn was leached from O/A and E horizons and then accumulated in the upper part of the placic horizon.

We did not find significant evidence of oriented illuvial clay in the cambic horizons (Bw). This indicates that clay illuviation did not occur in the cambic horizon after the formation of placic horizon. Owing that the illuviation of clay is not sufficient to promote the formation of an argillic horizon, we propose that the clay content of cambic (Bw) horizon was derived from its parent material. This situation is also consistent with the formation of placic horizons. After our survey in the study area, we found that some forest soils can be classified as Typic Hapludults based on *Soil Taxonomy* if the soils have illuvial clays, especially on the level topographic surfaces. If clay illuviation does not occur under steep landscape positions, the cambic horizon will be easily formed, also providing good conditions for placic horizon formation.

3.3. Physical and chemical properties

The soil physical and chemical properties of the selected pedons are listed in Table 3. Because slate is the parent material, the soils have fine soil texture compared with coarse-textured Podzolic soils formed in temperate regions (Clayden et al., 1990). The albic horizon (E) above the placic horizons have a coarser soil texture (such as silt loam or clay loam), but the cambic horizon (Bw) immediately underlying the placic horizons has finer soil textures (silty clay loam; Table 3). The clay content changes abruptly between the E and Bw horizons. Clay skins were not found in cambic horizon as determined by thin section analysis. This implies that clay illuviation does not occur, and the high clay contents of B horizons are from in situ weathering of the parent material. The changes of soil texture between AE2 and E horizon of SH2 pedon maybe result from the illuviation of clay moving from AE2 horizon downward to E horizon after formation of the placic horizon.

The placic horizon has a higher bulk density (1.30 to 1.98 Mg/m^3) compared to other soil horizons of the pedon. This suggests that placic horizons are relatively impermeable in the subalpine forest region although there is a very high precipitation in the study area.

Fig. 3. (a) The picture showed the boundary area between E and Bs horizons of pedon SH1. The lower part of E horizon includes crystalline materials, and the upper part of Bs showed cracked and isotropic Fe matrices. Scale of bar is 0.5 mm (plane-polarized light). (b) The picture showed the micromorphological characteristics of the Bs horizon in pedon SH2. The upper part of placic horizon showed a red isotropic inorganic Fe oxide material (Fe), and the lower part of the Placic horizon showed dense plasma (P) with skeleton grains. Scale of bar is 0.5 mm (plane-polarized light). (c) The picture showed the micromorphological characteristics of the upper part of Bs horizon in pedon SH1. Voids (V) existed between cracked Fe matrices. Scale of bar is 0.01 mm (plane-polarized light). (d) The picture showed the micromorphological characteristics of the lower part of Bs horizon in pedon SH1. Dense plasma mixed with skeleton grains (P). Scale of bar is 0.01 mm (plane-polarized light).

The O/A and E horizons of the pedons have lower soil pH than the B horizons (Table 3). This provides a suitable environment for the formation of placic horizons (Clayden et al., 1990). The placic horizons have higher pH values than those above the E horizon (0.6–1.0 unit; Table 3), which is consistent with previous reports that placic horizons appears to be related to the precipitation of Fe or Mn that occurred under oxidizing conditions and higher soil pH (Lapen

and Wang, 1999). Very low base saturation (except O/A) was found in the three pedons and was presumed to be caused by strong leaching conditions associated with very high precipitation (3000 mm/year) in the study area. Organic C content of the placic horizon, only 2.3 g/kg, was almost equal to or slightly higher than that of upper E or lower Bw horizon of the pedons (Table 3). The distribution of cation exchange capacity (CEC) of the placic horizons was consistent

Table 3
The physical and chemical properties of three pedons

Horizon	Depth (cm)	Total			Soil texture	Bulk density (Mg/m ³)	pH		Organic C (g/kg)	CEC ^a (cmol(+)/kg soil)	BS ^b (%)
		Clay (g/kg)	Silt (g/kg)	Sand (g/kg)			H ₂ O	KCl			
SH1, elevation 2000 m											
O/A	0–3	210	503	287	L	–	5.9	4.5	7.0	13	78
E	3–12	205	603	192	SiL	1.21	4.7	2.9	1.8	4.2	15
Bs	12–12.5	–	–	–	–	1.66	5.6	4.1	2.3	13	3
Bw	12.5–40	296	552	152	SiCL	1.28	5.7	3.7	1.3	10	2
C	>40	185	255	560	SL	–	5.7	3.7	0.7	4.2	6
SH2, elevation 1920 m											
O/A	3–0	257	453	318	L	–	3.8	2.6	19	45	35
AE1	0–18	218	682	100	SiL	1.19	4.1	2.9	3.2	8.9	4
AE2	18–27	215	688	98	SiL	1.22	4.4	3.1	4.3	8.7	2
E	27–36	390	478	132	SiCL	1.27	5.0	3.4	2.4	15	2
Bs	36–36.5	–	–	–	–	1.98	5.4	4.2	2.3	20	3
Bw	36.5–56	385	508	107	SiCL	1.26	5.2	3.6	1.2	9.1	3
C	>56	190	230	580	SL	–	5.9	3.9	0.3	3.8	8
SH3, elevation 1940 m											
O	5–0	–	–	–	–	–	4.4	4.1	270	–	–
A	0–10	242	473	285	L	–	4.0	3.5	22	60	9
E1	10–15	236	432	332	L	1.20	4.0	3.5	9.8	14	1
E2	15–25	314	481	205	CL	1.25	4.1	3.5	2.0	16	1
Bs	25–25.3	–	–	–	–	1.30	4.7	4.5	2.2	28	1
Bw1	25.3–55	379	444	177	SiCL	1.18	4.9	4.3	1.4	19	1
Bw2	55–75	390	414	196	SiCL	1.20	5.1	4.4	0.7	17	1
BC	75–100	370	439	191	SiCL	1.26	5.1	4.4	0.9	14	1
C	>100	180	250	570	SL	–	5.8	4.0	0.2	6	5

^a CEC—cation-exchange capacity.

^b BS—base saturation percentage.

Table 4
The contents of Fe and Al of three pedons

Horizon	Depth (cm)	Dithionite			Oxalate		Pyrophosphat		Al _o +1/2Fe _o (%)	Fe _o /Fe _d	Fe _p /Fe _o	Al _p /Al _o	ODOE ^a
		Fe _d (g/kg)	Al _d (g/kg)	Mn _d (g/kg)	Fe _o (g/kg)	Al _o (g/kg)	Fe _p (g/kg)	Al _p (g/kg)					
SH1, elevation 2000 m													
O/A	0–3	26	2.6	1.1	7.2	2.9	3.7	2.5	0.65	0.28	0.51	0.86	0.32
E	3–12	3.0	0.4	n.d ^b	0.9	1.3	0.2	0.8	0.18	0.30	0.22	0.62	0.11
Bs	12–12.5	185	8.5	0.2	115	7.6	44	6.2	6.51	0.62	0.38	0.82	1.35
Bw	12.5–40	30	6.6	0.2	16.9	7.5	7.1	7.1	1.60	0.56	0.42	0.95	0.34
C	>40	17	2.9	n.d	9.1	4.3	3.5	3.7	0.89	0.54	0.38	0.86	0.16
SH2, elevation 1920 m													
O/A	3–0	1.5	0.3	0.2	1.5	1.1	0.3	0.5	0.19	1.00	0.20	0.45	0.08
AE1	0–18	3.0	0.4	n.d	1.4	1.4	0.6	1.0	0.21	0.47	0.43	0.71	0.36
AE2	18–27	0.8	1.1	n.d	0.8	2.2	0.3	1.8	0.26	1.00	0.38	0.82	0.58
E	27–36	24	6.2	n.d	7.0	5.8	7.8	5.8	0.93	0.29	1.11	1.00	0.74
Bs	36–36.5	101	4.5	n.d	44	2.0	36	2.6	2.40	0.44	0.81	1.30	1.94
Bw	36.5–56	51	7.4	n.d	19.2	4.7	30	5.9	1.43	0.38	1.56	1.26	0.56
C	>56	–	–	–	–	–	–	–	–	–	–	–	–
SH3, elevation 1940 m													
O	5–0	1.7	1.0	0.8	2.0	1.4	1.0	1.5	0.24	1.18	0.50	1.07	0.08
A	0–10	6.0	1.8	n.d	8.5	3.3	5.8	3.4	0.76	1.42	0.68	1.03	0.96
E1	10–15	0.3	1.1	n.d	0.4	2.0	0.3	2.0	0.22	1.33	0.75	1.00	0.17
E2	15–25	0.4	1.2	n.d	0.3	1.9	0.2	2.0	0.21	0.75	0.67	1.05	0.19
Bs	25–25.3	159	5.5	0.1	109	4.7	37	4.8	5.92	0.69	0.34	1.02	1.48
Bw1	25.3–55	27	3.9	0.1	28	8.5	33	8.7	2.25	1.04	1.18	1.02	0.80
Bw2	55–75	23	3.8	0.2	20	7.3	26	15	1.73	0.87	1.30	2.05	0.58
BC	75–100	21	4.6	0.3	16	6.2	21	8.4	1.42	0.76	1.31	1.35	0.35
C	>100	–	–	–	–	–	–	–	–	–	–	–	–

^a ODOE—optical density of oxalate extraction.

^b n.d.—not detectable.

with the distribution of soil organic C. The C distribution of pedons implies that there is no significant podzolization processes occurring in this study area (Hseu et al., 1999).

The distribution of different forms of Fe and Al in the three pedons is shown in Table 4. The maximum accumulation of iron (Fe_d , Fe_o and Fe_p) was found in the placic horizon (Table 4). The placic horizons appear to be dominated by free iron oxides (Fe_d) and range from 101 to 185 g/kg. The depth distribution of Fe_d indicated that large amount of Fe were eluviated from the E horizon and accumulated in the placic horizon. Extractable Al ranged from 5 to 15 g/kg and was found in the B horizons (Bs and Bw) of the three pedons and was less than other forms of Fe in the Bs or Bw horizons (Table 4). The depth distribution of Fe and Al implies that there is no evidence on the formation of organo-iron or organo-aluminum complexes materials. This suggests that Spodosols are not present in the study area.

The ratio of Fe_o/Fe_d in the placic horizons was 0.62 in pedon SH1, 0.44 in pedon SH2 and 0.69 in pedon SH3 (Table 4). This value is very similar to the ratio of other Inceptisols with placic a horizon, ranging from 0.7 to 0.8 (McKeague et al., 1967; De Coninck, 1980; Righi et al., 1982). This wide range of Fe_o/Fe_d ratio suggests that some placic horizons are likely dominated by poorly crystalline goethite, lepidocrocite and ferrihydrite whose occurrence is enhanced by high amount of organic matter, as well as by wet moisture regimes (Chambell and Schwertmann, 1984; Chiang et al., 1994). Clayden et al. (1990) and Hseu et al. (1999) evaluated the formation of placic horizons and concluded that the reducing conditions required to mobilize the ferrous ion in the upper part of the profile resulted from high rainfall, cool temperature and low evapotranspiration of perudic regions. The reducing conditions were caused by seasonal saturation resulting from the formation of a slowly permeable subsurface horizon.

3.4. Pedogenesis of placic horizon

Several hypotheses have been proposed to explain the genesis of placic horizons (Crompton, 1952; Clayden et al., 1990; Conry et al., 1996; Hseu et al., 1999; Lapen and Wang, 1999). Clayden et al. (1990)

concluded that placic horizon formed from Fe, which was reduced and mobilized from the upper part of the pedon and then reoxidized and precipitated in the Bs horizon. Lapen and Wang (1999) proposed that the formation of placic horizon appears to be linked to the precipitation of mobile ferrous ion at higher pH and oxidizing soil conditions below the mineral soil surface. Besides, the perched water could provide the reducing conditions in the placic horizon to reduce Fe (Crompton, 1952). The genesis of placic horizons is quite different from the podzolization process. Spodic horizons are base on the accumulation of organic C, Al, with or without Fe (Soil Survey Staff, 1999). Conry et al. (1996) and Hseu et al. (1999) also concluded that podzolization and placic horizon development were fundamentally different processes.

Significant accumulation of Fe and Mn in the placic horizons indicate that inorganic ferrous Fe can be leaching from E horizon and accumulating in the B horizons. Because Fe was the dominant cation of the pedon, this may explain why the placic horizons were present in the study area. Conversely, spodic materials or organic-metallic complexes were not formed in the study area because of the absence of Al and organic C in the pedons.

The perched water appears to provide the essential preliminary condition for the development of placic horizons. The major reason for perched water formation is the abrupt texture changes of the pedons. The particle-size distribution of three pedons indicated that the clay content of horizon below the placic horizon was higher than that of the albic horizon (Tables 2 and 3). The micromorphological features also indicated that there is no significant clay illuviation in the cambic (Bw) horizons. We speculate that the perched water table should remain on the albic (E) horizon for several weeks to reduce Fe. The evidence of this reduction is the white color and massive structure in albic (E) horizon. When the soil condition changed to oxidizing with respect to Fe after the perched water drained, the reduced Fe will be reoxidized and accumulate at the boundary of the E and Bw horizon to form the placic horizon. Therefore, we find the boundary of placic horizons always have a wavy or irregular boundary, and the placic horizon occurs as a very thin layer (2–5 mm) above the Bw horizon.

3.5. Soil classification

The soil color of the plagic horizon are red (2.5YR 5/8) or dark red (2.5YR 4/6). Although the soil chemical analysis of $Al_0+1/2Fe_0$ and ODOE of plagic horizon is more than two times of those in the Albic E horizon (Table 4), the depth of the plagic horizon was too thin to identify as a spodic horizon. The horizon below the plagic horizon can be identified as a cambic horizon. The soil moisture regime in the study area is perudic. Thus, the selected three pedons can be classified as Lithic Dystrudept or Oxyaquic Dystrudept based on *Soil Taxonomy* (Soil Survey Staff, 1999) or Dystric Cambisol based on World reference base for soil resources system (WRB system; ISSS Working Group WRB, 1998). For these three pedons, we cannot find a suitable Soil Great Group, or a Subgroup for Inceptisols that have the characteristics of plagic horizons. Therefore, we propose that a Plagic Dystrudept should be included in the Subgroup of Dystrudepts in the *Soil Taxonomy* (Soil Survey Staff, 1999) or a Plagic Cambisol should be included in the Subgroup of Cambisols in the WRB system.

4. Conclusion

The development of podzolization and plagic horizons are fundamentally different processes. From the soil macro- and micromorphological, physical, and chemical characteristics, we hypothesize the genesis of plagic horizon in the study area occurs as two stages. In the first stage, E horizon is saturated with perched water due to the textural changes between albic (E) horizon and cambic (Bw) horizon. This may have in turn produced the irregular surface of the albic horizon as well as the abrupt and wavy lower boundary of the plagic horizon. In the second stage, soluble Fe is reduced and mobilized from upper part of the pedon into the Bw horizon and re-oxidized and precipitated at the boundary of the E and Bw horizons after the perched water has drained. In this condition, the plagic horizons have a wave or irregular boundary and are expressed in a very thin layer (2–5 mm). Plagic horizon genesis may also relate to the precipitation of mobile Fe at higher soil pH value

(0.6–1.0 unit) and oxidizing soil contacts below the mineral soil surface. The plagic horizons appear to be dominated by amorphous iron and free iron oxides.

There is no evidence of the illuviation of clay particles in the B horizon formed in the study area. The selected three pedons can be classified as Lithic Dystrudept or Oxyaquic Dystrudept based on *USDA Soil Taxonomy* or can be classified as Cambisols based on World reference base system. We propose that a Plagic Dystrudept should be included in the subgroup of Dystrudepts in the *Soil Taxonomy*.

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