Characterization of Placic Horizons in Central Louisiana, USA

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Abstract
Placic horizons, indurated subsoil horizons of cemented iron and organic matter, have been scarcely recognized in soils of the United States. They have been described in highly leached, acid soils of Alaska, Washington, and Hawaii. A soil with similar morphology and physicochemical properties in central Louisiana was evaluated for possible placic recognition. Results conclusively indicate that the described pedon contains placic horizons. The moisture regime of the sampling location is important to its taxonomic classification. Presently, *US Soil Taxonomy* would define the soil as a Fine-loamy, siliceous, subactive, thermic, Placic Petraquept. However, if the site is found to be udic, adjustments to *US Soil Taxonomy* may be warranted to recognize this soil's unique properties within the taxonomic structure.

Key Words
Placic horizon, ironstone, ortstein, petroferric contact

Introduction
The placic horizon is defined by the Soil Survey Staff (2006a) as "a thin, black to dark reddish pan that is cemented by iron (or iron and manganese) and organic matter." A petroferric contact represents "a boundary between soil and a continuous layer of indurated material in which iron is an important cement and organic matter is absent or present only in traces (Soil Survey Staff, 2006a)." Ortstein is essentially an indurated spodic horizon or spodic materials of >25mm in thickness (Soil Survey Staff 2006a).
A query of 23,543 soil series in the Soil Survey Staff's (2009) official soil series description database identified only seven soil series in the United States containing placic horizons; all occurring in Washington, Alaska, or Hawaii. While disparate in their location, they share several common features: 1) moderately to very strongly acid conditions, 2) average annual precipitation >177 cm, and 3) similar soil colors (very red). The thickness of the placic horizons in the seven soil series ranges from 2.5 cm to 10 cm, with finite gradations in hardness and color.

The presence of plinthite, fractured ironstone ledges, strong leaching conditions, and acidic, sandy soils in parts of Louisiana are conducive to placic horizon formation. The objectives of this study were to: 1) evaluate and interpret the morphological and chemical characteristics of suspected placic horizons occurring in a pedon in central Louisiana, 2) explain the pedogenesis of this soil, and 3) propose an appropriate classification of such soils per *US Soil Taxonomy* (Soil Survey Staff, 1999).

Methods
Description of study area
The study was conducted in Vernon Parish, LA in the Kisatche National Forest. The area falls within major land resource area (MLRA) 133B, the Western Coastal Plain (Soil Survey Staff, 2006b). The pedon described occurs along the high wall of a large sand/gravel pit at 31.0599 °N and 92.8954°W. Elevation at the site is ~95 m (LSU CADGIS, 2006). Climate of the area is characterized as moist subtropical, with both continental and marine influences. Summers are hot and humid and winters are cool with precipitation often caused by frontal passage. Average annual precipitation is approximately 150 cm. Soils mapped in the area include the Malbis (Fine-loamy, siliceous, subactive, thermic Plinthic Paleudult) and Ruston (Fine-loamy, siliceous, semiactive, thermic Typic Paleudult) soil series (Soil Survey Staff, 2009). Parent materials in the area consist of sandy and gravelly Pleistocene alluvium. The described pedon was on a convex, linear shoulder slope with a gradient of 1-5%. The site appears to be moderately well drained, with no evidence of flooding and none to slight erosion of natural habitat. The area is dominated by mixed hardwood (post oak) and coniferous (loblolly pine and longleaf pine) forest and mixed mid- and tall grasses such as little bluestem. Coarse fragments, in the form of gravel and cobbles, were estimated to cover ~35% of the surface.

Laboratory analysis
Particle size analysis was conducted using the hydrometer method with 24 h clay determination and sieved

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sands (53 μm) (Gee and Bauder, 1986). Sands were fractionated using nested sieves on a Ro-Tap sieve shaker. Bulk density was determined using ring cores for disaggregated soil, and volume displacement for indurated horizons (Blake and Hartge, 1986). Soil reaction (pH) was determined via saturated paste, after equilibration for 24 h, using an Orion 2 Star pH meter (Thermo Scientific, Waltham, MA)(Salinity Laboratory Staff 1954). Electrical conductivity was evaluated on the soil paste using a model 4063CC digital salinity bridge (Traceable Calibration Control Company, Friendswood, TX)(Salinity Laboratory Staff, 1954). Loss on ignition organic matter was determined after 16 h at 400°C (Nelson and Sommers, 1996). Organic carbon was determined via titration following the Walkley-Black dichromate oxidation method (Nelson and Sommers, 1996; Walkley and Black, 1934). Poorly crystalline Fe (Fe_o) and Al (Al_o) were extracted via acid ammonium oxalate (Loeppert and Inskeep, 1996; McKeague and Day, 1966). Elemental quantification was conducted using a Ciros model inductively coupled plasma atomic emission spectrometer (Spetro Analytical, Marlboro, MA).

Results

Physical properties

Condensed results of soil physicochemical analysis are presented in Table 1. A number of key differences were observed between placic horizons (Bsm, Bsm', Bsm'', and Bsm''') and noncemented horizons. In the Bsm, Bsm'', and Bsm''' horizons, sand percentage was higher and clay percentage was lower than the immediately overlying horizons. Fractionated sands showed similar trends. Very coarse sand increased by >13% for each Bsm horizon compared to each overlying horizon. Given the macropores present in very coarse sands, the contrast in particle size between Bsm horizons and immediately overlying horizons likely served as a restrictive layer, limiting soil solution percolation. With downward movement of the soil solution stalled, dissolved iron and organic compounds would have begun to precipitate, triggering placic horizon formation. This mode of formation supports Clayden *et al.'s* (1990) theories on placic horizon genesis. The contrasting particle sizes within the pedon are relic features of ancient alluvial deposition. Soil bulk density was higher in the Bsm (3.25 Mg/m^3) and Bsm''' (2.84 Mg/m^3) horizons than the adjacent Bv2 (1.45 Mg/m^3) and 2C (1.59 Mg/m^3) horizons. Soil color varied dramatically throughout the pedon due to stratification of alluvial materials, plinthite, and differential oxidation of iron in relation to the Bsm horizons. With the exception of the A and Bw horizons, all other horizons were structureless (massive or single grain). Consistency of all Bsm horizons was very rigid as these horizons had to be broken from the profile with a hammer.

Chemical properties

Soil reaction (pH) ranged from extremely acid in the A (4.46) and Bv2 horizons (4.31) to very strongly acid in all other disaggregated horizons (4.60 to 4.86). A general trend of increasing pH with depth was observed (4.46 to 4.86). However, pH of each Bsm horizon was substantially higher than adjacent horizons above or below it. The placic nature of Bsm horizons in this pedon, however are dramatically defined by the loss on ignition organic matter (LOI_{OM}) levels. In each Bsm horizon, LOI_{OM} increases by ~3% to 6% compared to the overlying horizon. Organic carbon (OC) levels determined via Walkley Black methodology show the same pattern among horizons as the LOI_{OM} levels, but at a different magnitude. Cation exchange capacity (CEC) was low throughout the pedon, with all horizons ≤3.76 $cmol_c/kg$, and generally decreased with depth. The Bsm', Bsm'' and Bsm''' horizons, however, all showed higher CEC than adjacent horizons above or below them, owing to the elevated levels of organic material in these horizons. Acid ammonium oxalate extractable Fe and Al were inversely proportional to one another. In each Bsm horizon, Fe levels increased and Al levels decreased compared to overlying and underlying adjacent horizons.

Morphological properties and taxonomic classification

The wavy nature of the Bsm horizon formed semi-polygon features (large, rounded, oblong-shaped segregations of soil surrounded by hardened Bsm material) within the pedon (Figure 1A); the interiors of which were characterized by 7.5YR or 10YR hues while the exteriors (most susceptible to downward wetting fronts) were much redder with hues of 2.5YR or 10R. The indurated organo-Fe placic horizon varied in thickness from 0.5-4.0 cm and extended laterally for ~ 25 m. Scanning electron migrographs of the placic horizon show a nodular surface lamination (Figure 1B). Classification of the soil at this site rests largely on moisture regime. If the site is locally aquic, the proposed *US Soil Taxonomy* classification of the pedon would be Fine-loamy, siliceous, subactive, thermic, Placic Petraquept. Conversely, if the site is found to be udic, a larger quandary presents itself. Under the Udepts suborder in *US Soil Taxonomy*, Durudepts is a possible great group. However, examination of the language defining Durudepts clearly favors duripan recognition. It is noteworthy that 'Durudepts' occupy the same taxonomic position under Udepts that 'Petraquepts' occupy under Aquepts. Results from this study indicate that the introduction of a 'Petraudepts' great group (between Sulfudepts and Durudepts) may be warranted.

Table 1. Physicochemical soil properties of a pedon containing placic horizons in central Louisiana, USA.

Horizon	Depth	Munsell color Soil	REDOX	Gravel	Texture†	Structure	Dry Consistence	Boundary
	----cm----			---%---				
A	0-51	2.5YR 4/6		4.4	SCL	W,M,SBK	MH	CW
Bv1	52-122	10R 4/8	7.5YR 6/8	-	SCL	MA	VH	CW
Bv2	123-267	2.5YR 5/6	7.5YR 6/8	7.2	SCL	MA	VH	AS
Bsm	268-274	2.5Y 2.5/1		-	LS	MA	VR	AW
C	275-280	10YR 5/8		12.9	S	SG	SH	AW
Bsm'	281-282	2.5Y 6/6		-	S	MA	VR	AW
Bw	283-301	5YR 5/6		2.3	LS	W,F,PL	SH	AW
Bsm''	302-303	10YR 4/4		-	S	MA	VR	AW
C'	304-332	5YR 5/6		3.2	LS	SG	SH	AS
Bsm'''	333-335	5YR 4/6		-	S	MA	VR	AS
2C	336-390	5YR 6/4		5.6	S	SG	SO	-

Horizon	pH	EC	OC	LOI_{OM}	CEC	BS	Fe_o	Al_o
		µs/cm	-------------%----------		$cmol_c$/kg	------%-----	------------mg/kg----------	
A	4.46	227	0.017	1.45	3.45	32.4	921	1280
Bv1	4.74	173.5	ND	0.84	2.65	20.0	507	1472
Bv2	4.31	134	ND	0.82	3.29	18.2	866	1378
Bsm	4.96	285	0.055	3.84	0.55	42.4	2034	665
C	4.72	150	ND	0.29	1.46	25.8	643	1149
Bsm'	5.87	444	0.151	6.48	2.37	10.9	1573	668
Bw	4.72	145.7	ND	0.43	1.04	42.1	624	940
Bsm''	5.11	260	0.119	6.44	2.58	7.9	1784	858
C'	4.60	74.5	ND	0.50	2.29	22.7	879	1565
Bsm'''	5.15	265	0.032	6.98	3.76	7.9	1691	599
2C	4.86	61.4	ND	0.18	0.54	59.5	256	711

†Soil Survey Staff (2002)

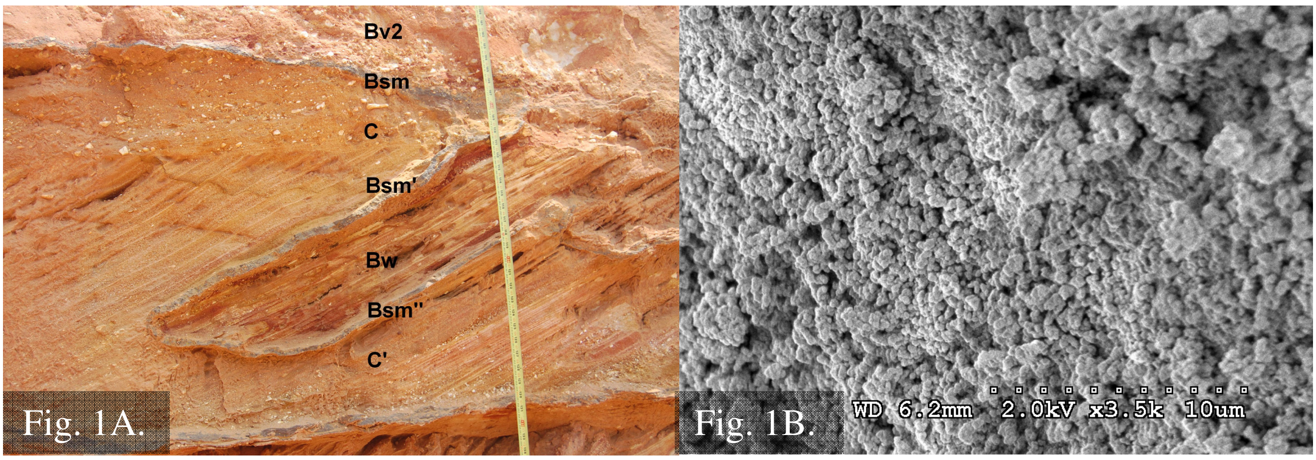

Figure 1. A) Soil profile containing wavy placic horizons, and B) scanning electron micrograph of the Bsm horizon in a pedon from central Louisiana, USA.

Conclusion

A pedon containing ironstone features in Vernon Parish, LA was evaluated to determine if its properties qualify as placic horizons. Results from soil physicochemical analysis confirm that multiple horizons within the pedon do qualify as placic horizons. This is highly significant since no soils with placic horizons have been mapped in the southern United States. The mode of formation is similar to findings by previous researchers (i.e. strong leaching conditions of acidic soils with placic horizon formation triggered by discontinuity in soil physical or chemical properties). Future research will focus on the spatial distribution of such soils in Louisiana and the southern United States to determine their extent.

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