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Pedology

Distribution and Genesis of Ortstein and Placic Horizons in Soils of the USA: A Review

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Soils with ortstein cover 2.2 million ha in the USA, 87% of which occur in Michigan and Florida. Of the 650 soils in the National Soil Survey database classified as Spodosols, 47 contain sufficient ortstein to be classified in the ortstein rupture-resistance class; another 42 soils contain materials that are <50% cemented and, therefore, not officially recognized as ortstein. Well-developed ortstein averages 41 cm in thickness and is moderately cemented, dense (bulk density 1.60 g cm^{-3}), massive, very firm to extremely firm, predominantly in sandy particle-size classes, and may contain living roots. Because soils with and without ortstein often occur on the same landforms, soils containing >5% ortstein (89 series) were compared with geographically associated and competing soil series (59) that lack ortstein, using analysis of variance. Soils with ortstein occur on lesser slopes ($p = 0.001$) and at lower elevations ($p = 0.015$) than soils without ortstein. The lower depth boundary and thickness of the spodic horizon were significantly greater ($p = 0.001$) in soils with ortstein than in those without ortstein. The data suggest that soil water transporting cementing materials (Fe, Al, Si, and dissolved organic C) moves more slowly in landscape positions where ortstein eventually forms than in those where it is absent. However, ortstein is not restricted to soils with poor drainage as only 39% of the soils with ortstein have an aquic soil moisture regime. From a weight-of-evidence assessment, ortstein is cemented by Al-organic complexes and short-range-order compounds, and placic horizons are cemented by Fe as ferrihydrite or as Fe-organic complexes.

Abbreviations: DXRD, differential x-ray diffraction; EDS, energy dispersive spectrometry; ODOE, optical density of the oxalate extract; SEM, scanning electron microscopy; SMR. Soil moisture regime; ST, *Soil Taxonomy*; STR, soil temperature regime.

Ortstein horizons are relatively common in the USA, but placic horizons are less common. Soils bearing ortstein and placic horizons are used for cranberry and blueberry (*Vaccinium* spp.) culture, truck crops, and forestry operations but have many limitations for other kinds of land use. The factors influencing the distribution and formation of these cemented horizons are poorly understood. According to *Soil Taxonomy* (ST), ortstein consists of spodic materials and occurs in a layer that is ≥25 mm thick and ≥50% cemented (Fig. 1A-1C; Soil Survey Staff, 2010a). In ST, ortstein is both a diagnostic subsurface horizon and the only rupture-resistance class recognized in the system. In contrast, a placic horizon does not require spodic materials and ranges between 1 and 25 mm in thickness. Unlike the ortstein horizon, the placic horizon is not penetrated by roots except in fractures.

In the USA, ortstein has been studied in soils in the "flatwoods" of Florida (Lee et al., 1988a, 1988b), on sandy drift in New England and New York (Freeland and Evans, 1993), on outwash in northern Michigan (Mokma et al., 1990; Mokma, 1997; Barrett, 1997), and on uplifted marine terraces in Oregon (OR; Bockheim et al., 1991, 1996). Soils with ortstein have been reported throughout the world, including eastern and western Canada (Lavkulich et al., 1971; Lapen and Wang, 1999), Finland (Yli-Halla et al., 2006), Great Britain, Germany and Poland (Kaczorek et al., 2004), Russia (Karavayeva, 1968), and in tropical regions such as northern Queensland, Australia (Farmer et al., 1983) and the People's Republic of Congo (Schwartz, 1988).

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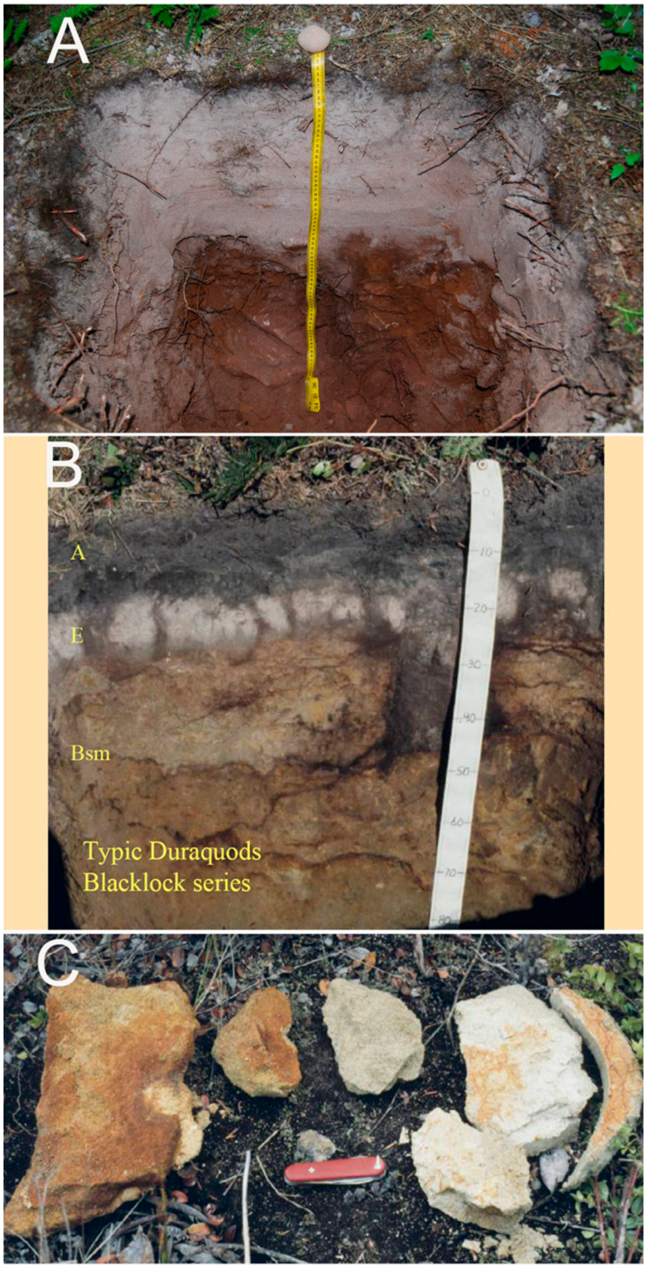

Fig. 1. Photographs of ortstein: A. Finch soil series (Typic Duraquods) from the Upper Peninsula of Michigan; B. Blacklock series (Typic Duraquods) from coastal Oregon; and C. fragments of ortstein from the Blacklock series (photos by the author).

The primary objective of this study is to utilize the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) database, and data from the published literature to identify the factors influencing the distribution of soils with ortstein and placic horizons. A secondary objective is to determine the cementing materials of ortstein and placic horizons from a weight-of-evidence assessment of data from the literature.

MATERIALS AND METHODS

The USDA-NRCS "soil classification database" (http://soils.usda.gov/technical/classification/scfile/index.html) was queried at the family level for soil series with ortstein and at the great group and subgroup levels for soil series with placic horizons. Because ortstein may occur in spodic horizons that are <50% cemented, "official soil series descriptions" (http://soils.usda.gov/technical/classification/osd/index.html, verified 12 Jan. 2011) were examined for the entire database on Spodosols (approximately 650 soil series) to determine whether or not they contained reported ortstein. Official soil descriptions also were used to obtain data on the soil-forming factors, soil properties such as the proportion and degree of cementation, properties of the spodic horizon, and soil-extent maps. Soil laboratory data were obtained from the NRCS website for the various soil series (Soil Survey Staff, 2010b).

Soil description and sampling methods generally followed those of Schoeneberger et al. (2002). For the majority of the pedons, methods described in the *Soil Survey Laboratory Methods Manual* (Soil Survey Staff, 1996) were used for the determination of pyrophosphate-extractable Al (Method 6C4), oxalate-extractable Fe, Al and Si (Method 6C6) and citrate-dithionite-bicarbonate-extractable Fe and Al (Method 6C5), optical density of the oxalate extract (ODOE; Method 8J), pH in water (Method 4C1a), organic C (Method 6A1c), cation-exchange capacity (Method 5A3), extractable base cations (Method 6N2e, Method 6O2d, Method 6P2d, Method 6Q2b) and acidity (Method 6H5), base saturation (Method 5C), and Al saturation (Method 5G1).

Three groups of soils were delineated: (i) soils with extensive ortstein (i.e., soil series with ≥50% ortstein in the spodic horizon), (ii) soils with less extensive ortstein (i.e., soil series with <50% ortstein), and (iii) geographically associated and competing Spodosols without ortstein to identify key site factors influencing their distribution. These factors included mean annual precipitation, mean annual air temperature, slope, elevation, coded soil depth class, and coded drainage class. Properties of the spodic horizon were compared among the three groups, including the upper boundary, lower boundary, thickness, and color development equivalents. Properties of horizons containing ≥50% ortstein were compared with those with <50% ortstein, including upper boundary, lower boundary, thickness, proportion of cementation, and degree of cementation (coded). Finally, analytical properties of the spodic horizon were compared for all three groups, including organic C, pH, sum of exchangeable cations, Al saturation, percentage of base saturation, extractable Fe, Al and Si, ODOE, coarse fragment content, and bulk density. The data were analyzed using analysis of variance (Minitab Inc., 2000). There were insufficient data to include placic horizons in the analysis.

RESULTS

Properties of Soils with Ortstein or Placic Horizons

Ortstein

The soil depth classes for soil series with and without ortstein were deep (1–1.5 m) or very deep (>1.5 m) (Table 1). The lower boundary of the spodic horizon and the thickness of the spodic horizon were significantly greater in soils with ≥50% ortstein. However, there were no significant differences between the upper or lower boundaries or the thickness of ortstein for soils with ≥50 and <50% ortstein. The ortstein horizon averaged 41 and 32 cm in thickness for soils with ≥50 and <50% ortstein, respectively. The degree and proportion of cementation were significantly greater in soils with ≥50% ortstein than in those with <50% ortstein (Table 1). Spodic horizons with

≥50% ortstein commonly were moderately cemented; spodic horizons with <50% ortstein were weakly cemented. Whereas 70% of the spodic horizon in soils classified with ≥50% ortstein was cemented, only 16% of the spodic horizon of soils with <50% ortstein was cemented. There were no differences in coded Munsell color (color-development equivalents) among the three soil groups with spodic horizons. Whereas soils with ≥50% ortstein commonly had a massive structure (64% of soil series), soils with <50% ortstein and those lacking ortstein often had a subangular blocky structure (74 and 54%, respectively; Table 2). Soils with ≥50% ortstein generally had a hard to extremely hard dry consistence (57%), whereas soils with <50% ortstein and those without ortstein had a consistence of slightly hard or less.

Other morphologic features of ortstein horizons include sand grains coated with organic material in Bhm horizons of ortstein soils from Florida. In 18 of the series, all of which occur in Michigan, ortstein exists in columns up to 45 to 60 cm wide and 15 to 50 cm apart. Tonguing of ortstein into underlying horizons is common in 13 of the series, all of which occur in Michigan. Rinds of 5- to 15-mm cemented material may occur in horizons not sufficiently cemented to be identified as ortstein. The ortstein horizon limits but does not preclude rooting; a few fine roots were reported in ortstein horizons of 11 pedons that were ≥50% cemented.

All three groups of Spodosols commonly occurred in sandy, sandy-skeletal, or sandy over loamy particle-size classes (Table 2). However, the proportion of soil series in these classes was greater for soils with some form of ortstein. A predominance of soils in the three groups had udic rather than aquic soil-moisture regimes (SMR). However, the proportion of soils with an aquic SMR was greatest in soils with ≥50% ortstein in the spodic horizon. Orstein occurs in soils with soil temperature regimes (STR) ranging from cryic or frigid to hyperthermic as well as isomesic. However, soils with ortstein most commonly had a frigid STR. Soils with ortstein occurred in four soil mineral classes, including mixed, siliceous, isotic, and amorphic but were most common (56%) in the mixed class (Table 2).

Ortstein and placic horizons are extracted with Na pyrophosphate for Fe_p and Al_p, acid NH_4 oxalate by Fe_o and Al_o, and Na citrate-dithionite-bicarbonate for Fe_d and Al_d to determine the nature of the cementing agents. Parfitt and Childs (1988) used Mössbauer spectroscopy to estimate forms of Fe and Al from these extractions. Key findings were (i) Fe_p does not relate to any particular form of Fe; (ii) Al_p corresponds to Al in humus complexes; (iii) Al_o minus Al_p yields allophane and imogolite, if large amounts of ferrihydrite are not present; and (iv) Fe_d minus Fe_o yields crystalline forms of Fe such as hematite, but also yields ferrihydrite.

Table 1. Statistical comparison of analytical properties of soils with ≥50% ortstein, <50% ortstein in the spodic horizon, and geographically associated Spodosols without ortstein. Data for seven soils with placic horizons are included.

Property	Ortstein	Some ortstein	No ortstein	*p* value	Placic
Soil depth class (coded)†	3.3ab	3.8a	3.6ab	0.024	1.3
Upper boundary spodic, cm	38a	35a	26a	0.11	30
Lower boundary spodic, cm	95a	78ab	63b	0.001	43
Thickness spodic, cm	57a	43ab	38b	0.001	13
Upper boundary ortstein, cm	52a	44a	na	0.35	na
Lower boundary ortstein, cm	93a	75a	na	0.283	na
Thickness ortstein, cm or placic, mm	41a	32a	na	0.173	15
Color development equivalents	21a	19a	19a	0.407	21
Proportion of cementation, %	70a	16b	na	0	100
Degree of cementation (coded)‡	3.3a	2.3b	na	0	5
Fe_d, %	1.0a	0.97a	1.4a	0.268	5.5
Al_d, %	0.65a	0.37a	0.69a	0.177	1.4
Al_p, %	0.43a	0.31a	0.60a	0.483	0.93
Fe_o, %	0.46a	0.42a	0.74a	0.348	5.5
Al_o, %	0.69a	0.37a	0.69a	0.227	7.74
Al_o-Al_p, %	0.34a	0.26a	0.35a	0.933	6.8
Fe_d-Fe_o, %	0.58a	0.49a	0.50a	0.865	2.71
Si_o, %	0.18a	0.07a	.21a	0.162	3.2
ODOE	0.41a	0.60a	0.62a	0.741	0.45
OC, %	1.7a	1.7a	3.0a	0.108	2.98
pH	5.0a	4.9a	4.9a	0.83	4.9
Sum cations , cmolc kg^{-1}	20a	16a	24a	0.134	45.8
Al saturation, %	62a	61a	52a	0.394	68
Base saturation, %	6a	9a	8a	0.461	4
Bulk density, g cm^{-3}	1.60a	1.55a	1.38a	0.162	1.7
Coarse fragments, % >2 mm	7a	8a	11a	0.342	12

† Soil depth class: 4 = very deep (>150 cm); 3 = deep (150–100 cm); 2 = moderately deep (50–100 cm); 1 = shallow (<50 cm).

‡ Degree of cementation: 5 = indurated; 4 = strongly cemented; 3 = moderately cemented; 2 = weakly cemented; 1 = very weakly cemented.

Spodic horizons in all three soil groups contained comparable amounts of Al-humus (Al_p), amorphous compounds (Al_o–Al_p) and Si_o, and crystalline forms of Fe (Fe_d–Fe_o) (Table 1). There were no significant differences in ODOE or any of the other analytical properties reported in Table 2. Spodic horizons in all three groups of soils contained abundant organic C (1.7–3.0%), were very strongly acidic (pH 4.9–5.0 in water), had abundant exchangeable cations (16–24 $cmol_c\ kg^{-1}$) with exchangeable Al (52–62%), and were depleted in base cations (6–9%). There were no significant differences in the amount of coarse fragments (>2 mm) among the three soil groups. Although the differences were not significant, average bulk densities could be arrayed: ≥50% ortstein, <50% ortstein, and no ortstein (Table 1).

Placic

Soils with placic horizons generally were shallow (Table 1). The placic horizons ranged from 5 to 17 mm in thickness and averaged 12 mm (data not shown). A spodic horizon occurred in two of the soil series and was considerably shallower than those for the other three soil groups. The surface of the placic horizon ranged from 25 to 117 cm in depth and averaged

Table 2. Frequency distribution by class of morphological features of soils containing ≥50% ortstein, <50% ortstein in the spodic horizon, and geographically associated Spodosols without ortstein. Percentage of total is given in parentheses. Data for seven soils with placic horizons are included.

Soil property	Category						
Structure grade	Massive	Platy	Subangular blocky	Other or not reported			
Ortstein	30 (64)	3 (6)	3 (6)	11 (24)			
Some ortstein	7 (26)	1 (2)	21 (74)	13 (31)			
No ortstein	3 (5)	0	32 (54)	24 (41)			
Placic	2	1	1	3			
Moist consistence	Extremely firm	Very firm	Firm	Slightly hard or less	Not Reported		
Ortstein	10 (21)	10 (21)	7 (15)	1 (2)	19 (41)		
Some ortstein	0	1 (2)	2 (5)	32 (76)	7 (17)		
No ortstein	0	1 (2)	4 (7)	53 (89)	1 (2)		
Placic	4	2	0	0	1		
Particle-size class	Sandy	Sandy-skeletal	Sandy/(other)	Coarse-loamy	Loamy	Clayey or finer	Other
Ortstein	31 (66)	4 (9)	2 (4)	3 (6)	3 (6)	0	4 (9)
Some ortstein	26 (62)	6 (14)	6 (14)	2 (5)	0	0	2 (5)
No ortstein	28 (47)	4 (7)	5 (9)	10 (17)	0	0	12 (20)
Placic	0	0	0	0	1	3	3
Soil moisture regime	Udic	Aquic					
Ortstein	25 (53)	22 (47)					
Some ortstein	30 (71)	12 (29)					
No ortstein	42 (71)	17 (29)					
Placic	2	5					
Soil temperature regime	Cryic	Frigid	Mesic	Hyper-thermic	Isomesic	Other	
Ortstein	4 (8)	14 (30)	12 (26)	11 (23)	6 (13)	0	
Some ortstein	0	24 (57)	8 (19)	5 (12)	1 (2)	4 (10)	
No ortstein	9 (16)	33 (56)	2 (3)	12 (20)	3 (5)	0	
Placic	1	0	0	0	1	5	
Soil mineralogy class	Isotic	Mixed	Siliceous	Amorphic	Other		
Ortstein	9 (19)	23 (49)	12 (26)	3 (6)	0		
Some ortstein	6 (14)	27 (64)	9 (22)	0	0		
No ortstein	17 (29)	27 (46)	12 (20)	3 (5)	0		
Placic	0	3	0	1	2		
Parent material	Sandy marine	Sandy drift	Dunes, beach sand	Sandy fluvial, lacustrine	Loamy marine or till	Residuum	Other
Ortstein	13 (28)	16 (34)	3 (6)	7 (15)	5 (11)	0	3 (6)
Some ortstein	11 (26)	29 (69)	0	1 (2)	1 (2)	0	0
No ortstein	14 (24)	21 (36)	0	8 (14)	10 (17)	0	6 (10)
Placic	0	1	0	0	2	3	1

59 cm (data not shown). Placic horizons are indurated with laminar ironstone and have a "troweled" upper surface. The ironstone sheet is impermeable to roots except through cracks. The texture of placic horizons is highly variable, ranging from clay to extremely gravelly loamy sand.

Extractable Al_p averaged 0.93% (three pedons only; Table 1). The placic horizon from the Kahanui series (Hawaii; Placorthods) and Halbert series (Washington; Petraquepts) contained 1.0 and 0.35% Al, respectively, in allophane or imogolite forms. The dominant Fe minerals were goethite, hematite and ferrihydrite, with values of 6.28 and 2.35% for the Kahanui and Halbert soils, respectively.

Placic horizons contained an average of 2.98% organic C, a pH of 4.9, 46 $cmol_c\ kg^{-1}$ exchangeable cations, 68% Al saturation, and an average base saturation of 4% (Table 1). No bulk density values were available from the NRCS dataset, but values from the literature ranged widely from 1.00 to 2.20 with most values around 1.70 g m^{-2} (Lavkulich et al., 1971; Ping et al., 1989; Hseu et al., 1999; Wu and Chen, 2005).

Factors Influencing the Distribution of Ortstein and Placic Horizons

Ortstein

Statistical comparisons of site factors were made among the three soil groups: ≥50% ortstein, <50% ortstein, and no ortstein in the spodic horizon. The percentage of slope was significantly less ($p = 0.001$) on soils with ortstein than in those lacking ortstein (Table 3). In addition, soils with ortstein tend to occur at lower elevations than those without ortstein ($p = 0.015$). The drainage (coded class) was significantly less ($p = 0.024$) in soils with ≥50% ortstein than in soils of the other two groups.

Despite some differences in mean annual precipitation, the climates of areas with Spodosols with and without ortstein are comparable (Table 3). The mean annual precipitation in areas with the three groups of soils averages between 1000 and 1300 mm but ranges from 380 to 2790 mm. The mean annual air temperature averages 10°C but ranges from −2.8 to 23°C. As is typical of Spodosols in general, the vegetation was dominated by coniferous trees in the overstory and ericaceous vegetation (e.g., *Vaccinium*) in the understory and included slash pine (*Pinus elliottii* Engelm.) in the "flatwoods" of FLorida, northern hardwoods (*Acer-Tilia-Fagus-Betula*) and mixed conifers (*Tsuga-Pinus*) in the Great Lakes region and northeastern USA, and western conifers (*Pseudotsuga-Tsuga-Thuja-Picea*) in western Washington and Oregon and southeastern Alaska. The three soil groups were derived from a variety of parent materials. However, the most prevalent parent materials in soils with ortstein (79%) were outwash sands, sandy till, and sandy marine terrace deposits of crystalline origin.

Table 3. Statistical comparison of site factors for soils with ≥50% ortstein, <50% ortstein in the spodic horizon, and geographically associated Spodosols without ortstein. Data for seven soils with placic horizons are included.

Property	Ortstein	Some ortstein	No ortstein	*p* value	Placic
Drainage (coded)†	3.3b	3.8a	3.6ab	0.024	2.4
Mean annual precipitation, mm	1218a	944b	1279a	0.008	3177
Mean annual air temperature, °C	10.7a	9.8a	9.9a	0.782	12.8
Slope, %	10b	12b	20a	0.001	15
Elevation, m	162b	183b	290a	0.015	495

† Drainage code: 7 = excessively drained; 6 = somewhat excessively drained; 5 = well drained; 4 = moderately well drained; 3 = somewhat poorly drained; 2 = poorly drained; 1 = very poorly drained.

Placic

There were insufficient data to identify key factors influencing distribution of soils with placic horizons in the USA (Table 4). However, these soils tended to be in areas with abundant precipitation (ca. >2400 mm yr^{-1}), restricted internal drainage because of a lithic or paralithic contact, and textural discontinuities.

Classification of Soils with Ortstein or Placic Horizons

Aquods accounted for 49% of the soil series classified with ≥50% ortstein, followed by Orthods (40%), Cryods (9%), and Humods (2%) (Table 4). The dominant great groups were Duraquods (13 pedons), Haplorthods (10), Alaquods (8), and Durorthods (6). Soils with <50% ortstein were classified primarily as Orthods (71%) and Aquods (29%). Dominant great groups were Haplorthods (26 pedons), Alaquods (6), and Endoaquods (6). Geographically associated Spodosols lacking ortstein were arrayed: Orthods (53%), Aquods (32%), Cryods (12%), and Humods (3%). Dominant great groups included Haplorthods (24 pedons), Alaquods (12), and Fragiorthods (6).

Sixty-two percent of the soils containing some form of ortstein have a udic soil moisture regime and 38% have an aquic SMR (Table 3). Soils with some form of ortstein were classified primarily into four soil temperature classes, including frigid (38 soil series), mesic (20), hyperthermic (16), and isomesic (7). The dominant mineralogy class was mixed (50 soil series), followed by siliceous (21), isotic (15), and amorphic (3).

The seven soil series with placic horizons occurred in three orders with four great groups: Petraquepts, Cryaquods, Placorthods, and Placudands (Table 4). Nearly three quarters of the placic soils have an aquic SMR. Soils with placic horizons are all classified into iso-soil temperature classes, including isothermic (4 pedons), isofrigid (2), and isomesic (1 pedon) and into four mineralogy classes, including mixed (4 pedons), isotic, amorphic, and parasesquic (1 pedon each).

Geographic Extent of Soils with Ortstein and Placic Horizons

A total of 47 soil series with ≥50% ortstein in the spodic horizon are contained in the USDA- NRCS database. These soils comprise 257,000 ha in the USA and occur primarily in MI (134,000 ha), and Florida (74,000 ha) (Table 5). However, there are an additional 42 soil series that contain spodic materials that are <50% cemented but were identified in official soil descriptions as ortstein. These soils occur primarily in Michigan (863,000 ha combined), Florida (761,000 ha), and Wisconsin (135,000 ha). These data suggest that there are at least 2.2 million ha of soils with some form of ortstein, 87% of which occur in Michigan and Florida (Fig. 2). Smaller areas of soils with ortstein occur in the Pacific Northwest (Oregon and Washington), New England–New York, and Alaska. There are at least three soil series classified as Andisols that have ortstein-like horizons that are <50% cemented with Fe, Al and Mn. These include the Getchell, Hoquiam, and Hoko series, which are classified as Haplocryands, Fulvudands, and Durudands, respectively. These series account for 71,000 ha on the Olympic Peninsula of western Washington.

Seven soil series with a placic horizon comprise 15,600 ha in Hawaii, 8600 ha in western Washington, and 1700 ha in Alaska for a total area of 25,900 ha (Table 1). Two additional soils contain thin, Fe-cemented horizons that could be recognized as placic horizons, including the Copalis (Durudands) and Tokul (Vitrixerands) series, which account for 100,000 ha in western Washington. Soils with ortstein horizons and those with placic horizons occur on the same landscape in only a few localities, such as the Russian taiga (Karavayeva, 1968) and southeastern Newfoundland (Lapen and Wang, 1999).

Table 4. Distribution by taxa of soils with ≥50% ortstein, <50% ortstein in the spodic horizon, and geographically associated Spodosols without ortstein. Data for seven soils with placic horizons are included.

Suborder/Great group	Subgroup	No. of soil series		
Ortstein		Full ortstein	Some ortstein	No ortstein
Aquods				
Alaquods	Alfic	1	2	1
	Aeric	0	1	1
	Alfic Arenic	1	0	1
	Arenic Ultic	1	0	0
	Arenic	2	0	1
	Arenic Umbric	0	1	0
	Ultic	3	2	5
	Typic	0	0	2
	Oxyaquic	0	0	1
Duraquods	Typic	13	0	0
Endoaquods	Typic	1	5	4
	Andic	1	0	0
	Argic	0	1	1
Epiaquods	Alfic	0	0	1
	Histic	0	0	1
Aquods subtotal		**23**	**12**	**19**
Orthods				
Alorthods	Entic Grossarenic	0	2	0
	Grossarenic	2	1	0
	Oxyaquic	1	0	0
Durorthods	Typic	5	0	0
	Andic	1	0	0
Haplorthods	Alfic	0	4	3
	Aquic	0	2	4
	Oxyaquic	2	4	0
	Entic	2	6	3
	Typic	5	7	10
	Alfic Oxyaquic	1	0	2
	Lamellic	0	2	1
	Aquentic	0	1	1
Fragiorthods	Oxyaquic	0	1	4
	Alfic	0	0	2
	Typic	0	0	1
Orthods, subtotal		**19**	**30**	**31**
Cryods				
Duricryods	Typic	1	0	0
	Humic	1	0	0
Haplocryods	Typic	2	0	2
	Andic	0	0	1
Humicryods	Typic	0	0	2
	Andic	0	0	1
	Lithic	0	0	1
Cryods, subtotal		**4**	**0**	**7**
Humods				
Haplohumods	Typic	0	0	2
Durihumods	Andic	1	0	0
Humods, subtotal		**1**	**0**	**2**
Spodosols, total		**47**	**42**	**59**
Placic				
Aquepts				
Epiaquepts	Humic	1		
Petraquepts	Placic	2		
	Histic Placic	1		
Aquods				
Cryaquods	Placic	1		
Orthods				
Placorthods	Typic	1		
Udands				
Placudands	Typic	1		
Total		7		

DISCUSSION

Site Factors Related to Ortstein and Placic Horizon Development

Ortstein Horizons

Table 6 lists soil-forming factors commonly cited in the literature that favor ortstein development. The present review supports many of these suggested factors. The present summary identified elevation as a key factor distinguishing between soils with ortstein and geographically related soils without ortstein; in the USA soils with some form of ortstein often occur below 200 m elevation (Table 4). About a third of the soils occurred in the Great Lakes region on sites with a seasonally high water table, primarily in the spring following melting of a thick snowpack. In addition, soils with ≥50% ortstein had more restricted drainage than soils with <50% ortstein or soils lacking ortstein in the spodic horizon.

Because rooting depth is restricted in soils with ortstein, the lack of bioturbation may be important in the development and preservation of an ortstein horizon (Lapen and Wang, 1999). Ortstein typically is found in areas with sparse or different tree cover than in adjacent areas supporting soils without ortstein (Wang et al., 1978). In the Great Lakes region, ortstein occurs in areas containing primarily northern hardwoods and hemlock but commonly is restricted to specific sites with red maple (*Acer rubrum* L.), red pine (*Pinus resinosa* Aiton), and other less nutrient demanding species. In coastal Oregon soils containing ortstein support sparse stands of shore pine (*Pinus contorta* var. *contorta*) within an area with western conifers. Both regions contain an abundance of blueberry, leaf extracts of which have been employed to experimentally re-cement crushed ortstein (Bronick et al., 2004). Ortstein often occurs adjacent to and down slope from peat deposits, not only in the Maritime Provinces of Canada (Wang et al., 1978), but also in the Great Lakes region, western Oregon and Washington, and Florida. Lapen and Wang (1999) noted that ortstein tends to form in soils on gentle slopes. In the present review, slope was one of the few site factors that differed significantly among the three broad soil groups considered in the analysis. Soils with ortstein were most common on slopes averaging 10 to 12% (Table 3).

There is considerable disparity in the literature regarding the drainage conditions related to ortstein development. Whereas many investigators report ortstein horizons in soils with free internal drainage (Karavayeva, 1968; Moore, 1976; Kaczorek et al., 2004), some cite the occurrence of ortstein in depressions with restricted drainage (Wang et al., 1978; Lapen and Wang, 1999), or in areas with a fluctuating water table (Dubois et al., 1990). In the present study, ortstein was common not only in poorly drained soils of Florida and soils with a seasonally high water table in all of the regions, but also in well-drained to excessively drained soils derived from relatively uniform outwash sand in northern Michigan.

Parent materials such as till, glaciolacustrine deposits, and beach sediments composed primarily of medium and coarse sands are particularly prone to ortstein formation (Moore, 1976; Wang et al., 1978). In the present study 84% of the soil series containing ortstein were derived from sandy materials of all sand-size classes. Materials enriched in ferromagnesian minerals, such as hornblende and olivine, are a key source of Fe, Al, and Si and are important not only in the podzolization process but also in cementing ortstein (Moore, 1976). A few studies stress the importance of fines, largely clay-size particles, in bridging sand grains to form ortstein (McKeague and Wang; 1980; Kaczorek et al., 2004). However, many of the soils included in the present study have <2% clay content.

Lapen and Wang (1999) suggested that coarse fragments (>2 mm), which are abundant in soils containing ortstein in southeastern Newfoundland, may serve as "nuclei" for precipitation of cements that eventually bind these

Fig. 2. Areas containing soils with ortstein horizons in the conterminous USA and Alaska.

Table 5. Areas of soil series containing ortstein by region in the USA.†

Region	Soil series, > 50% ortstein	Area	Soil series, < 50% ortstein	Area	Total area
		ha		——ha——	
Alaska	Fanshaw, Toklat, Tsadaka	8154		0	8154
Florida	Ankona, Delks, Jonathan, Lawnwood, Nettles, Pendarvis,	73730	Chaires, Deland, Duette, Hobe, Kingsferry, Lynne, Sapelo,	730,671	804401
	Pepper, Salerno, Susanna, Tantile, Waveland		Smyrna, Wabasso		
Michigan/Wisconsin	Borgstrom, Copemish, Crowell, Garlic, Healylake, Mcivor,	133616	Battlefield, Battydoe, Bete Grise, Blue Lake, Brethren,	998,337	1131953
	Paquin, Proper, Pullup, Skeel, Spot, Voelker, Whittemore,		Cheboygan, Copper Harbor, Croswood, Duel, East Lake,		
	Saugatuck, Finch, Jebavy, Wallace, Ogemaw		Furlong, Gilchrist, Guardlake, Hartwick, Ingalls, Ishpeming,		
			Islandlake, Kaleva, Kalkaska, Keweenaw, Ocqueoc,		
			Pequaming, Pipestone, Velvet, Wainola		
New England/New York	Success, Constable, Duane	6429	Colton, Flackville, Occur, Pipestone, Redstone, Waumbek	241,797	248226
Oregon/Washington	Bandon, Cashner, Depoe, Joeney, Nelscott, Whetstone,	35062	Netarts	5479	40541
	Blacklock, Custer, Edmonds, Klaus, Philippa, Woodlyn				
Total		256991		1976,284	2233275
	Soil series with placic horizon				
Washington	Halbert, Salmonriver	8570			
Hawaii	Amalu, Hulua, Kahanui, Olokui	15,647			
Alaska	Isidor	1708			
Total		25,925			

† For the suborder, great group,and subgroup affiliated with each soil series please see appendix.

Table 6. Site conditions favoring ortstein development from the literature and this review.

Soil-forming factor	Description of condition	References	Favored here†
Climate	Ortstein in the Black Forest only occurs below 900 m	Kaczorek et al., 2004	X
	A seasonal desiccation period enables dehydration and hardening of a subsoil layer	McKeague and Wang, 1980	=
Organisms	Minimal bioturbation to break up pan.	Lapen and Wang, 1999	X
	Adjacent to and upslope from areas with peat cover	Wang et al., 1978	X
Relief	Free drainage	Karavayeva, 1968; Moore, 1976; Kaczorek et al., 2004	X
	Restricted drainage	Wang et al., 1978; Lapen and Wang, 1999	X
	Fluctuating water table	Dubois et al., 1990	X
	Gentle slopes	Lapen and Wang, 1999	X
Parent material	Medium and coarse sandy material	Moore, 1976	X
	Materials enriched in ferromagnesian minerals	Moore, 1976	X
	High amount of coarse fragments to act as "nuclei" for precipitation of Fe, Al, Si, OC	Lapen and Wang, 1999	–
	Availability of fines to bridge sand grains and slow water movement	McKeague and Wang, 1980; Kaczorek et al., 2004	–
Time	Soils older than approximately 4000 yr	Moore, 1976	X

†Favored: X = favor under most conditions; = favor under some conditions; '- = do not favor.

fragments into ortstein. However, there were no significant differences in coarse fragment contents among the three soil groups. Furthermore, soils with ortstein contained on average <10% coarse fragments (Table 3). Ortstein requires a minimum of 2000 to 6000 yr to form (Moore, 1976; Barrett, 1997). Most of the soils examined in the present study are of late Wisconsinan age, approximately 10 to 14 kyr BP or older (Bockheim et al., 1991, 1996).

In summary the key factors accounting for the occurrence of soils with ortstein within the Spodosol regions of the USA appear to be: (i) low elevations in coastal areas or areas with large lakes, (ii) the bottoms or edges of depressions in areas with complex relief, (iii) gentle slopes, (iv) a sparse vegetation cover with minimal bioturbation, and (v) a soil age in excess of approximately 2000 yr.

Placic Horizons

The site conditions leading to the formation of placic horizons are poorly understood. Climate appears to play a major role in that placic horizons are observed in soils with extremely high precipitation, ranging from 2400 to 3900 mm yr^{-1} and averaging 3200 mm (Lavkulich et al., 1971; Valentine, 1969; Shoji et al., 1988; Ping et al., 1989; Hseu et al., 1999; Pinheiro et al., 2004; Wu and Chen, 2005; Schawe et al., 2007). This is the same as the 3200 mm yr^{-1} recorded for the seven soils with placic horizons in the USA (Table 4). Soils with a placic horizon generally occur in depressions on the landscape and have a seasonally high water table (Crampton, 1963; Lapen and Wang, 1999; Pinheiro et al., 2004; Wu and Chen, 2005). In the present study, five of the seven soil series with a placic horizon have an aquic soil moisture regime (Table 3). In Europe placic horizons occurred in areas where the groundwater was <70 cm from the soil surface (Kaczorek et al., 2004).

Soils with placic horizons occur in one of three predominant vegetation types: tropical montane forest (Pinheiro et al., 2004; Wu and Chen, 2005; Schawe et al., 2007), western conifers (Valentine, 1969; Shoji et al., 1988; Ping et al., 1989), or bog (Crampton, 1963; Lavkulich et al., 1971; Lapen and Wang, 1999). Of the seven soil series with a placic horizon examined in this study, three support western conifers and four feature tropical montane forest (data not shown). Placic horizons are common in soils derived from volcanic ash (Shoji et al., 1988; Ping et al., 1989; Pinheiro et al., 2004). One of the soils in the present study is derived from volcanic ash; three are developed from basaltic or andesitic residuum. Jien et al. (2010) reported an argillic horizon below the placic horizon and suggested that clay migration leads to restricted drainage and the development of a placic horizon. In the present study six of seven pedons were underlain by either saprolite or dense till.

Origin of Ortstein and Placic Horizons

Ortstein

There are at least four conditions necessary for the formation of ortstein: (i) a supply of Fe and Al from weathering of ferromagnesian minerals, (ii) a supply of dissolved organic C, particularly fulvic acids, for complexing with the Al and Fe, (iii) restricted drainage in the profile for at least part of the year to enhance the complexation process, and (iv) a period of drying whereby the cementing compounds dehydrate and harden (Moore, 1976; McKeague and Wang, 1980; Lapen and Wang, 1999; Kaczorek et al., 2004). To these conditions Lapen and Wang (1999) would add the condition of a strong soil pH gradient that would enable hydrolysis and precipitation of Al compounds.

In addition to being Spodosols, the majority (89%) of the soils in this study containing ortstein had one or more of three conditions that cause restricted internal drainage, including (i) a textural discontinuity at or immediately below the ortstein, (ii) a seasonally or permanently high water table immediately below the ortstein, or (iii) bedrock or hard till several decimeters below the ortstein layer. More than half of the pedons have a textural discontinuity, including a coarse layer over a finer layer or a fine layer over a coarser layer. Textural discontinuities are important for holding up water and increasing the time for soil particles to react with the soil solution. About a third of the pedons had either a seasonally or semi-permanently high water table.

The presence of a water table at depth enables coprecipitation in the Bh horizon of organic compounds and Al, especially in soils containing ortstein in FL (Lee et al., 1988a, 1988b) and in tropical regions (Farmer et al., 1983). Four of the pedons with ortstein in the present study had bedrock with 100 cm of the surface. Since these soils were somewhat excessively or well drained, the bedrock serves to temporarily restrict internal drainage to increase the time for soil particles to react with the soil solution.

Eight of the soils are developed under excessively to well-drained conditions in relatively uniform sandy outwash, and yet they contain ortstein. These include the Copemish, Crowell, Garlic, Pullup, Wallace, Kaleva, Kalkaska, and Netarts series. All of these series occur in northern Michigan except for the Netarts which exists along the Oregon coast. These soils warrant further investigation as they do not reflect the drainage conditions for ortstein formation.

The NRCS data suggest that ortstein begins to form in discrete areas of the spodic horizon as nodules, "bodies," or "pockets" and that eventually they form isolated "chunks" of ortstein. The distance between columns or chunks of ortstein varied from 10 cm to as much as 150 cm. In that the extent of cementation varied from <5 to 100%, it is possible that these chunks eventually coalesce to form a continuous ortstein horizon.

Most of the soils examined in this study occur on relatively young landforms, approximately <200 kyr. These data may suggest that ortstein eventually degrades with continued pedogenesis. Bockheim et al. (1996) examined a chronosequence of soils on uplifted marine terraces along the Oregon coast and provided a model illustrating the stages in development leading to the conversion of Spodosols containing ortstein to Ultisols. An argillic horizon forms beneath the ortstein and eventually builds upward, destroying the ortstein. They found relict pieces of ortstein with clay coatings in Typic Haplohumults approximately > 600 kyr in age.

Placic Horizons

Textural discontinuities or organic-rich horizons may be important in arresting the Fe in the placic horizon (Lapen and Wang, 1999; Pinheiro et al., 2004; Wu and Chen, 2005). These layers cause perching of the water table which enables the Fe to become temporarily reduced; with drying the Fe is mobilized and reoxidized at the textural break. Some investigators suggest that clay eluviation followed by podzolization creates the textural discontinuity that leads to episaturation (Jien et al., 2010). The precipitation of Fe may be due to higher oxidation potential and pH at depth in the profile (Lapen and Wang, 1999). The time required for forming placic horizons is not known.

Cementing Agents of Ortstein and Placic Horizons

There were no significant differences in concentrations of Fe, Al, and Si extracted by Na pyrophosphate, acid NH_4 oxalate, and citrate-dithionite-bicarbonate among the three groups of Spodosols (Table 2). However, only small concentrations of these constituents are necessary to cause cementation (Moore, 1976). From the literature Fe and Al extractions yield the following results with regards to ortstein cementing agents: (i) pieces of ortstein do not slake in water but do dissolve in reagents commonly used to extract Al and Fe (Lee et al., 1988b); (ii) narrow Fe_o/Al_o indicate that Al is more abundant in ortstein horizons than Fe (Moore, 1976; Lee et al. (1988a, 1988b; Mokma, 1997; Lapen and Wang, 1999); (iii) Al_p is particularly abundant in the Fe-Al extractions, suggesting the existence of Al-humus compounds (Miles et al., 1979; Farmer et al., 1983; Barrett, 1997; Lapen and Wang, 1999; Kaczorek et al., 2004); and (iv) wide Al_o/Al_p and Fe_o/Fe_p indicate that allophane and ferrihydrite, respectively, may be involved in the cementation (Freeland and Evans, 1993; Barrett, 1997) (Table 7). Based on energy dispersive spectrometry (EDS), scanning electron microscopy (SEM), differential X-ray diffraction (DXRD), micromorphology, and proximate analysis of organic C, ortstein likely is cemented by Al-fulvic-acid gels or short-range-order compounds containing dissolved organic C, Al, and some Fe that bridge sand grains (McKeague and Wang, 1980; Farmer et al., 1983; Lee et al. (1988a, 1988b); Freeland and Evans, 1993; Kaczorek et al., 2004).

Major findings with regards to cementing agents in placic horizons include: (i) a wide Fe_o/Al_o indicates that Fe is more abundant than Al in placic horizons (McKeague et al., 1967; Valentine, 1969; Lapen and Wang, 1999; Pinheiro et al., 2004; Bonifacio et al., 2006); and (ii) abundant Fe_o suggests that ferrihydrite and goethite are dominant (McKeague et al., 1967; Ping et al., 1999; Pinheiro et al., 2004; Wu and Chen, 2005; Bonifacio et al., 2006) (Table 7). The existence of ferrihydrite and goethite, along with some lepidocrocite, has been verified with differential XRD, SEM, EDS, micromorphology, and selective dissolution techniques (Campbell and Schwertmann, 1984; Jien et al., 2010). These data suggest that placic horizons are cemented by amorphous or weakly crystalline Fe minerals such as ferrihydrite, goethite, and lepidocrocite. However, some investigators suggest that Fe-organic complexes are also important in cementation (McKeague et al., 1967; Hseu et al., 1999; Lapen and Wang, 1999).

In summary, ortstein appears to be cemented primarily by Al-humus gels that bridge sand grains and placic horizons are cemented by amorphous or weakly crystalline Fe minerals with or without organic complexes.

CONCLUSIONS

Ortstein and placic horizons form under aquic or udic soil moisture conditions, a variety of STRs, coniferous or ericaceous

Table 7. Nature of cementing agents and origin of ortstein and placic horizons from a review of the literature.

Nature of cementing agents	Cementing process	Genesis of horizon	Reference
Ortstein horizons			
Organic C bridges quartz sand grains; Al humates dominant	micromorphology; extractable Fe, Al	Bh forms at upper level of water table and complexes downward moving Al	Farmer et al., 1983
Organic-complexed Al based on narrow Fe_o/Al_o and high Al_p	Extractable Fe, Al		Lapen & Wang, 1999
High organic-bound Fe and Al; OC bridges quartz grains	Extractable Fe, Al, micromorphology, energy dispersive X-ray		Kaczorek et al., 2004
Fe_o and Al_o dominant based on narrow Fe_o/Al_o and high Al_p	Extractable Fe, Al, Mn, C_p	Fe & Al released from E horizon, translocated in inorganic forms to B horizon and precipitated as cementing agent	Moore, 1976
High Al_o–Al_p = allophane; allophanic grain cutans bridge grains in BCm	Extractable Fe, Al, Si, OC; micromorphology	Two phases: (1) inorganic oxhydroxides & allophanic sols deposited in Bsm and BCm; (2) translocation of organic compounds to form overlying Bhm and Bhsm	Freeland & Evans, 1993
1. Feo-Fep, Alo-Alp in Bsm. 2. Fep, Al_p in Bhsm	Extractable Fe, Al		Barrett, 1997
Abundant Al_o, Al_p; Fe_o/Al_o narrow	Extractable Fe, Al		Mokma, 1997
Narrow Fe_o/Al_o; high Al_p; wide C_f/C_h; Al-fulvates gels predominant	Extractable Fe, Al; XRD; SEM; organic fractionation		Lee et al., 1988a,b
Al, Fe-humus (fulvic acids) cement sand grains	energy dispersive spectrometry; differential XRD; extractable Fe, Al; micromorphology		McKeague & Wang, 1980
High Al_p; Al-organic cementing substance	micromorphology; energy dispers sive spectrometry		Miles et al., 1971
Al-organic complexes from Vaccinium leaf extracts cause re-cement ation of ortstein			Bronick et al., 2004
Placic horizons			
Fe_d–Fe_o dominant = ferrihydrite; some Al_o–Al_p and Al_d–Al_o	Extractable Fe, Al; micromorphology	Two stages: (1) water is perched between E and B due to textural discontinuity; (2) Fe in upper part of pedon is reduced, then immobilized and reoxidized at E-Bsm interface	Wu & Chen, 2005
High Fe_o/Al_o; ferrihydrite and goethite dominant	Extractable Fe, Al; micromorphology	Fe reduced in organic-rich horizon under wet conditions then reoxidized in drier horizon below	Pinheiro et al., 2004
High Fe_o–Fe_p = ferrihydrite	Extractable Fe, Al		Ping et al., 1999
Wide Fe_o/Al_o; high Fe_o	Extractable Fe, Al; elemental composition of C_h, C_f		Valentine, 1969; Bonifacio et al., 2006
Ferrihydrite, goethite > lepidocrocite from DXRD	Differential XRD; selective dissolution		Campbell & Schwertmann, 1984
Fe-C_f complex; wide Fe_o/Al_o; abundant Fe_o	micromorphology; differential thermal analysis, extractable Fe, Al; functional analysis SOM		McKeague et al., 1967
Narrow Fe_o/Al_o; high Al_o	Extractable Fe, Al, SOC		Lavkulich et al., 1971
Fe-OC complexes; isotropic microfabric; wide Fe_o/Al_o; high Fe_o	micromorphology; extractable Fe, Al	Forms due to redox processes enhanced by high water table	Hseu et al., 1999
Lepidocrocite & ferrihydrite from DXRD; wide Fe_o/Al_o	scanning electron microscopy; energy dispersive spectrometry; differential XRD; extractable Fe, Al; micromorphology	Clay eluviation followed by podzolization creates textural discontinuity that enforces episaturation; topsoil Fe is reduced and mobilized, then illuviated with clay & organics	Jien et al., 2010
High Fe_o; wide Fe_o/Al_o	extractable Fe, Al, Si	Fe precipitates at depth in profile due to higher oxidation, pH potential	Lapen & Wang, 1999

vegetation, and in sandy materials 3000 yr in age or older. Based on data from 47 soil series, ortstein averages 42 cm in thickness, has a coarse platy structure, is massive, is extremely firm when moist and very hard when dry, and varies in degree of cementation. Although ortstein occurs in all four suborders of Spodosols, nearly half of the soils were Aquods. Eighty-seven percent of the soils with ortstein occur in Michigan and Florida. Placic horizons are by definition <25 mm in thickness. They are invariably indurated and preclude rooting except in cracks. Placic horizons occur in three orders and four great groups: Petraquepts, Cryaquods, Placorthods, and Placudands and are most abundant in Hawaii and western Washington.

Ortstein appears to be cemented illuvial humus and Al in a hyperthermic environment in southern Florida and by short-range-order compounds from illuvial humus, Al and Fe elsewhere in the USA. In contrast, placic horizons are cemented primarily by amorphous Fe and in some cases by organic-bound Fe.

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APPENDIX

Classification of Soils mentioned in Table 5 to the subgroup level.

No.	Suborder	Great Group	Subgroup	Soil series
1	Aquepts	Epiaquepts	Humic Epiaquepts	Olokui
2	Aquepts	Petraquepts	Histic Placic Petraquepts	Amalu
3	Aquepts	Petraquepts	Placic Petraquepts	Hulua
4	Aquods	Alaquods	Arenic Ultic Alaquods	Ancona
5	Aquods	Alaquods	Ultic Alaquods	Delks, Susanna, Tantile, Lynne, Sapelo
6	Aquods	Alaquods	Aeric Alaquods	Lawnwood, Waveland, Smyrna
7	Aquods	Alaquods	Alfic Aeric Alaquods	Nettles
8	Aquods	Alaquods	Oxyaquic Alaquods	Pendarvis
9	Aquods	Alaquods	Alfic Alaquods	Pepper, Chaires, Wabasso
10	Aquods	Alaquods	Glossarenic Alaquods	Salerno
11	Aquods	Alaquods	Arenic Umbric Alaquods	Kingsferry
12	Aquods	Cryaquods	Placic Cryaquods	Isidor
13	Aquods	Duraquods	Typic Duraquods	Spot, Whittemore, Saugatuck, Jebavy, Cashner, Depoe, Joeney, Woodlyn
14	Aquods	Endoaquods	Typic Endoaquods	Custer, Battlefield, Bete Grise, Ingalls, Pipestone, Wainola
15	Aquods	Endoaquods	Andic Endoaquods	Edmonds
16	Aquods	Endoaquods	Argic Endoaquods	Pequaming
17	Cryods	Duricryods	Typic Duricryods	Toklat
18	Cryods	Duricryods	Humic Duricryods	Tsadaka
19	Cryods	Haplocryods	Typic Haplocryods	Fanshaw, Whetstone
20	Humods	Durihumods	Andic Durihumods	Philippe
21	Orthods	Alorthods	Glossarenic Alorthods	Jonathan, Deland, Duette, Hobe
22	Orthods	Durorthods	Typic Durorthods	Borgstrom, Mcivor, Paquin, Voelker, Wallace, Ogemaw, Nelscott
23	Orthods	Durorthods	Andic Durorthods	Klaus
24	Orthods	Fragiorthods	Oxyaquic Fragiorthods	Velvet
25	Orthods	Haplorthods	Oxyaquic Haplorthods	Healylake, Proper, Brethren, Copper Harbor, Croswood, Gilchrist
26	Orthods	Haplorthods	Alfic Oxyaquic Haplorthods	Skeel
27	Orthods	Haplorthods	Typic Haplorthods	Success, Constable, Duane, Bandon, Battydoe, Furlong, Guard Lake, Kaleva, Kalkaska, Colton, Redstone
28	Orthods	Haplorthods	Lamellic Haplorthods	Blue Lake, Island Lake
29	Orthods	Haplorthods	Alfic Haplorthods	Cheboygan, Keweenaw
30	Orthods	Haplorthods	Entic Haplorthods	Duel, East Lake, Hartwick, Ishpeming, Ocqueoc
31	Orthods	Haplorthods	Aquic Haplorthods	Flackville, Waumbek
32	Orthods	Haplorthods	Aquentic Haplorthods	Occur
33	Orthods	Placorthods	Typic Placorthods	Kahanui
34	Udands	Placudands	Typic Placudands	Salmonriver

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