Formation of a cultivated Spodosol in East-Central Finland

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The processes involved in Spodosol (Podzol) formation are still being debated. The pedogenic processes in a Spodosol, 10,700 years-old, at Sotkamo that has been cultivated for about 50 years were studied by characterizing the morphology and analyzing the major chemical properties, texture and mineralogy. Before cultivation, organic acids produced by decomposition of organic matter from pine litter in O and A horizons had weathered primary minerals in A and E horizons releasing Al and Fe. Percolating waters moved the organo-metallic complexes from A and E horizons to Bhsm and Bs horizons where the complexes coated and bridged sand grains eventually forming cemented ortstein. Because of the high biotite content of the parent material, the index of accumulation of Fe and Al in the Bhsm horizon (Al + 0.5 Fe = 4.1%) was the highest reported in Spodosols of Finland. The data support the theory of downward movement of Al and Fe as organo-metallic complexes with formation of some ferrihydrite but little or no formation of imogolite type materials. Little, if any, podzolization has likely occurred since the initiation of cultivation because, after agricultural liming and consequent increase of pH in the Ap horizon, organic compounds are likely to chelate Ca and Mg rather than Al and Fe.

Key words: podzolization, soil morphology, soil mineralogy, biotite, soil classification

Introduction

Spodosols (Soil Survey Staff 1999) or Podzols (FAO 1988, 1998) are an extensive group of soils in Finland, other Nordic countries and northern Rus-

sia, especially in sandy parent materials and glacial till. Acidic parent materials, high leaching potentials, and acid litter from coniferous trees are conducive to podzolization of these soils. The low cation exchange capacities and low base status of sandy soils also enhance podzolization. Spodosols are

characterized by light-colored eluvial horizons with bleached, uncoated sand grains and a dark, reddish-colored illuvial horizon with accumulated organic matter and Al oxides with or without Fe oxides. Since Spodosols form mostly under forest vegetation, several studies have investigated the formation and characteristics of Spodosols in forested areas in Finland (Aaltonen 1952, Jauhiainen 1972, 1973, Starr 1991, Petäjä-Ronkainen et al. 1992, Gustafsson et al. 1995, Lundström et al. 2000, Righi et al. 1997, Mokma et al. 2004) however no comprehensive studies have focused on cultivated Spodosols.

Two main theories have been proposed for the mechanisms of podzolization. The older and more widely accepted theory is the downward movement of organo-metallic complexes from eluvial zones to illuvial zones where they exceed solubility limits and are precipitated (Stobbe and Wright 1959, DeConinck 1980). The illuvial organo-metallic compounds form polygonally cracked coatings on sand grains (monomorphic organic matter) (McKeague et al. 1983). Biological activity was thought to incorporate illuvial organo-metallic compounds into pellets (polymorphic organic matter). The more recently proposed theory involves the downward movement of Al, Fe and Si as inorganic colloidal sols (Anderson et al. 1982, Farmer and Fraser 1982). A combination of the two theories has been proposed to explain formation of Spodosols in Nordic Countries (Gustafsson et al. 1995, Lundström et al. 2000). In this combination decomposition of organic matter in O and A horizons produces organic acids that weather primary minerals (Lundström et al. 1995, Raulund-Rasmussen et al. 1998) in A and E horizons thereby releasing Al, Fe, Ca, Mg, K, and P. Plant uptake reduces the concentrations of nutrients, such as Ca, Mg, K, and P, however, plants take up very little Al, Fe and Si. Formation of organo-metallic complexes and their subsequent eluviation from A and E horizons was found to enhance weathering of primary minerals in those horizons (Lundström 1993). Microbial degradation of the organic portion of some complexes in Bhsm and Bs horizons caused some Al and Fe to precipitate as imogolite type materials and ferrihydrite, respectively, in some Nordic soils (Gustafsson et al. 1995). In these Spodosols ammonium oxalate extractable Al and Fe exceeded sodium pyrophosphate Al and Fe in B horizons suggesting the presence of imogolite type materials and ferrihydrite. However, B horizons from 27 of 29 other Spodosols from several countries had equal or higher concentrations of pyrophosphate than oxalate extractable Al, and B horizons from 25 of the 29 soils had equal or higher concentrations of pyrophosphate than oxalate extractable Fe (Mokma and Buurman 1982, Mokma and Vance 1989) suggesting the presence of little or no imogolite type materials and ferrihydrite in Spodosol B horizons. Two studies of podzols in the Netherlands found no evidence for the inorganic colloidal sols theory nor for the combination theory (Jansen et al. 2004, 2005). Organic matter facilitated mobilization of Al and Fe from eluvial horizons to illuvial horizons. As the organo-metallic complexes accumulated in B horizons sand grains were coated and bridged by them. As more organo-metallic complexes accumulated in B horizon the coatings and bridges got thicker eventually cementing sand grains into ortstein.

Earlier studies have shown that Spodosols of Finland formed in glacial till have weakly developed E and Bhs horizons (Mount et al. 1995, Mokma et al. 2000, Yli-Halla and Mokma 2001) and these soils only marginally meet the criteria of Spodosols. By contrast, Spodosol formation in sand has resulted in more pronounced development of the horizons (Mokma et al. 2004). In the Sotkamo area, even ortstein has been found. In order to study the soil forming processes taking place in a cultivated soil in an advanced state of podzolization, a 10,700 years old pedon, in agricultural use for 50 years, at Sotkamo was characterized in detail. Support for either of the main theories of the podzolization process was sought for. This study also adds to the few published descriptions of cultivated coarse-textured pedons of Finland.

Material and methods

A sandy soil was selected for study in an area used for raising potatoes, ley and small grains at Sotka-

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mo, East-Central Finland. The field (64° 07' N, 28° 20' E) is located on the Kainuu Research Station, belonging to the MTT Agrifood Research Finland organization. The soil is about 10,700 years old, and thus represents close to the maximum time available for soil formation in Finland after the Weichselian glaciation. The native vegetation was Scotch pine (*Pinus sylvestris*). Three pits, in an area of 50 m × 50 m, were dug (two in 1999 and one in 2001) to facilitate describing the macromorphology and to obtain samples for laboratory analyses and micromorphological investigation. The depth to ground water was 189 cm on 10 August 1999 and 160 cm on 6 July 2001. The pits were morphologically similar, and the one dug in 2001 was studied for this paper. Organic C was determined using the Leco dry combustion apparatus (Laboratory Equipment, St. Joseph, MI). Soil pH was measured in water at a 1:2.5 soil to water ratio. Al and Fe were extracted with sodium citrate – sodium dithionite, ammonium oxalate (pH 3.0), and sodium pyrophosphate (Soil Survey Staff 1996). Silicon (Si) was also measured in the oxalate extract. The optical density of the oxalate extract (ODOE) was measured as an indicator of organic C associated with amorphous materials. Cation exchange capacity (CEC) was determined by extracting soil samples with four portions of 1 M ammonium acetate (pH 7.0) and analyzed for Ca, Mg, K and Na. Titratable acidity was determined by titrating the extract back to pH 7.00 with 0.02 M NaOH. The CEC was calculated as the sum of Ca, Mg, K, Na and titratable acidity, all expressed as cmol(+) kg^{-1}. Particle size distribution was determined using the pipette method after digestion with hydrogen peroxide. Bulk density, expressed on the basis of dry soil, was determined by the clod method (Brasher et al. 1966) using Saran resin to stabilize the clods.

Oriented samples for micromorphological examinations were collected from selected horizons using 8 × 16 × 5 cm Kubiëna tins. Samples were impregnated under vacuum (Ashley 1973) using a polyester resin diluted 2:1 with acetone. Hardening of the resin was accomplished using 8 × 10^{6} Rad gamma radiation (Drees and Drees 1997). Vertically oriented soil thin sections (40 × 60 mm)

were prepared from each sample. Sample blocks were polished, mounted on glass slides with epoxy and ground to a final thickness of 30 μm and described using the terminology of Bullock et al. (1985) and Stoops (2003).

Mineralogical composition of the sand (0.05–2 mm), silt (2–50 μm) and clay (< 2 μm) fractions was determined in three horizons (E, Bhsm, BCg) on a semi-quantitative basis by X-ray diffraction using Cu Kα radiation with a Philips X-ray diffractometer (XRD). Small amounts of clay recovered from the Bhsm horizon prevented its clay mineralogical examination. The clay suspensions were flocculated with 0.5 M MgC1$_2$. After washing the clays free of salts they were sedimented on ceramic-tile plates via suction. A sufficiently thick clay film (about 26 mg clay cm^{-2} plate area) was deposited on each tile to prevent any diffraction spectra from the ceramic tile.

Pretreatments used for Mg-saturated clays were air dry, ethylene glycol, and 350°C and 550°C heat treatments. Heated samples were maintained at respective temperatures for at least 2 hours before analysis. Clays were scanned from 2° 2θ to 32° 2θ at a scan speed of 2° 2θ min^{-1}. The sands (0.05–2 mm) and silts (2–50 μm) were ground for one minute in a disc mill grinder to reduce particle size. The powder was then front loaded into aluminum box mounts for X-ray analysis and scanned from 2° 2θ to 50° 2θ at a scan speed of 2° 2θ min^{-1}. Minerals were identified according to Brown and Brindley (1984).

The pedon was classified according to Soil Taxonomy (Soil Survey Staff 1999), the FAO-Unesco system (FAO 1988) and the World Reference Base for Soil Resources system (WRB) (FAO 1998). We assumed the pedon has a cryic soil temperature regime (Yli-Halla and Mokma 1998).

Results and discussion

Macromorphology

The sandy over loamy pedon had a typical Spodosol morphology with a gray colored E horizon

Fig. 1. Photo of pedon. The E horizon is more continuous and the lower boundary is less wavy in this part of the pit. Units on scale are 10 cm. (Photo: M. Yli-Halla.)

and dark, reddish brown colored B horizons (Fig. 1, Table 1). This color pattern suggests organic matter, Al and Fe have been translocated in this pedon from the surface horizons to subsoils where in the Bhsm they have cemented the sand grains together into ortstein. In the Bhsm horizon, the ortstein was not continuously cemented but consisted mostly of medium-sized platy chunks stacked vertically together. Firm chunks of 2.5YR 2.5/2 ortstein were also present in the Bs horizon indicating elevated levels of organic C, Al and Fe have accumulated in these parts of the Bs horizon.

The pit had a circumference of 762 cm, with the E horizon present in 364 cm or about 48% of the pit wall. In 52% of the pit wall the Ap horizon was in contact with the Bhsm horizon without an E horizon between them. The discontinuous nature of the E horizon in this pedon is the result of cultivation. The E horizon remaining was in the deeper portions of the wavy boundary that extend below the depth of plowing. The two other pits investigated in this field earlier had a continuous E horizon. An uncultivated Spodosol pedon, located 1400 m from the pedon of this study, had an 8 cm thick O horizon and a 26 cm thick continuous E horizon with a wavy boundary over a Bhsm horizon (Mokma et al. 2004). The wavy boundaries between the E, Bhsm, Bs, BC, BCg and Cg horizons are likely the result of preferential water flow

Table 1. Morphological properties of the pedon.

Horizon	Depth, cm	Color, matrix	Color, mottles	Texture	Structure	Boundary
Ap	0–25	10YR 3/2 10YR 6/1 dry		ls	1msbk	as
E	25–37	10YR 6/2 10YR 8/2 dry		ls	0sg	ab
Bhsm	37–46	2.5YR 2.5/2		s	0m/2mpl	aw
Bs	46–61	10YR 5/6		s	1msbk	aw
BC	61–104	2.5Y 6/3	c2p 7.5YR 4/4	fs	1mpl	as
BCg	104–160	2.5Y 5/2	c2p 7.5YR 4/4	fsl & sil	1mpl	as
Cg	160–193	2.5Y 5/2	c3p10YR 4/6	fsl & sil	1fpl	

Color, mottles: c = common (mottling 2–20%), 2 = medium (5–15 mm), 3 = large (>15 mm), p = prominent
Texture: ls = loamy sand, s = sand, fs = fine sand, fsl = fine sandy loam, sil = silt loam
Structure: 0 = structureless, 1 = weak, 2 = moderate, m = medium, f = fine, sg = single-grain, sbk = subangular blocky, pl = platy
Boundary: as = abrupt smooth, ab = abrupt broken, aw = abrupt wavy

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through differentially permeable sandy and loamy materials.

Plowing and secondary tillage have mixed materials from the O, A, E and Bhsm horizons into the Ap horizon. Chunks of ortstein from the Bhsm and white sand grains from the E horizon where observed in the Ap horizon. The origin of these chunks of ortstein is the Bhsm horizon that is currently in contact with the Ap horizon. The amount of B horizon material was much less than 85 percent, a criterion for a spodic horizon. The cementation in the Bhsm horizon was sufficient to resist complete breakdown by tillage.

The platy structure in the BC and C horizons (Table 1) resulted from the fluvial deposition of the original sandy parent materials. Rock structure was observed in thin sections of the BC, BCg and Cg horizons but not in the Ap, E, Bhsm and Bs horizons. Pedogenic processes have altered the structure in the upper horizons.

Chemical characteristics

Organic C was greatest in the Ap horizon, least in the E and Cg horizons and intermediate in the B horizons (Table 2). Dry bulk density was inversely related to the organic C contents of the horizons.

Cation exchange capacity was related to the organic C content. However, the highest value was measured in the Bhsm horizon in spite of the fact that the Ap horizon had a higher content of organic C. The high CEC is primarily the result of the amorphous material that accumulated in the Bhsm having a high CEC. Distributions of Al, Fe and organic C as indicated by ODOE (Table 3) support the interpretation of the macromorphology. The index of the accumulation of Al and Fe (Al_o + ½ Fe_o) greatly exceeded the 0.5% minimum value set for spodic materials in the Bhsm horizon, whereas it was slightly exceeded in the Bs horizon. The Al_o + ½ Fe_o value of 4.1% in the Bhsm horizon is the highest that has been reported in Finland, particularly attributable to the very high concentration of Fe_o in this soil. The Al_o content of the Bhsm horizon is similar to that of the Bhs and Bhsm horizons in other studies of Spodosols in Finland (e.g. Righi et al. 1997, Mokma et al. 2004) but the Fe content is much greater. Also the concentration of organic C (>>0.6%) and pH (<<5.9) in the Bhsm and Bs horizons and the ODOE (>>0.25) of the Bhsm horizon meet the criteria of spodic materials. The very low Fe_o concentrations in the BCg and Cg horizons may be attributable to illuvial materials not reaching these depths and to periodically water-saturated conditions.

Table 2. Selected physical and chemical properties of pedon. Sand, silt and clay indicate particles of 2–0.06 mm, 0.06–0.002 mm and <0.002 mm, respectively.

Horizon	Sand	Silt	Clay	Bulk density[1]	pH[2]	Org. C[3]	CEC[4]	BS[5]
	%	%	%	kg dm⁻³		%	cmol(+) kg⁻¹	%
Ap	83	15	2	1.30	5.7	4.3	13.5	51
E	83	16	1	nd	5.8	0.2	2.6	32
Bhsm	91	7	2	1.33	4.8	2.9	20.9	8
Bs	99	1	0	1.48	5.3	1.3	6.1	11
BC	93	7	0	1.68	4.8	0.3	3.3	7
BCg	42	57	1	1.68	5.1	0.4	4.5	8
Cg	51	49	0	nd	5.0	0.1	nd	nd

[1] bulk density of dry soil, standard deviation of the three replicates is 0.04 kg dm⁻³.

[2] Average mean deviation of the two replicates 0.09

[3] Long-time coefficient of variation of the results of a control sample 4.1%

[4] CEC = cation exchange capacity. Average mean deviation of the two replicates 0.13 cmol(+) kg⁻¹

[5] BS = base saturation

nd = not determined

Table 3. Aluminum, iron and silicon, extracted with citrate-dithionite (Al_d, Fe_d), ammonium oxalate (Al_o, Fe_o, Si_o) and sodium pyrophosphate (Al_p, Fe_p) and the optical density of oxalate extract (ODOE) values.

Horizon	Al_d	Al_o	Al_p	Fe_d	Fe_o	Fe_p	$Al_o + ½ Fe_o$	Si_o	ODOE
					%				
Ap	nd	0.11	nd	nd	0.36	nd	0.29	0.017	0.14
E	0.02	0.02	0.02	0.04	0.01	0.02	0.02	0.001	0.03
Bhsm	0.87	0.96	0.74	7.02	6.24	2.63	4.08	0.130	1.37
Bs	0.42	0.42	0.40	0.48	0.33	0.22	0.59	0.069	0.20
BC	nd	0.12	nd	nd	0.18	nd	0.21	0.024	0.05
BCg	nd	0.14	nd	nd	0.02	nd	0.15	0.022	0.05
Cg	nd	0.08	nd	nd	0.01	nd	0.08	0.017	0.02
Md, %	5.4	3.2	4.6	5.6	5.5	3.4	6.9	6.3	3.3

nd = not determined

Md = average mean deviation of the results of the two replicates, as percentage of the mean.

Most (77%) of the Al_o in the Bhsm horizon and all in the Bs horizon was extracted by sodium pyrophosphate. Therefore most of the Al was chelated with organic matter (McKeague et al. 1971) with some possible imogolite type materials in the Bhsm horizon. However, the $Al_o – Al_p$/ Si_o ratios of the Bhsm and Bs horizons were 0.17 and 0.03, respectively, indicating little imogolite type material that has an $Al_o – Al_p$/ Si_o ratio of about 2 (Anderson et al. 1982) was present in the B horizons. Most of the Fe_d in the B horizons (89% in Bhsm and 69% in Bs) was extracted by ammonium oxalate. Therefore it was chelated by organic matter or was amorphous ferrihydrite but not highly crystalline. About 42% of the Fe_o in the Bhsm horizon and 67% of that in the Bs horizon was extractable by pyrophosphate. This suggests Al and Fe were chelated by organic compounds in the A and E horizons and transported to the B horizon by percolating waters. In the B horizon some of the organo-metallic complexes may have been degraded by microbial activity and the Fe precipitated as ferrihydrite. The likely source of Fe accumulated in the Bhsm horizon is the biotite that was present in the lower horizon but completely weathered in the upper horizons.

Micromorphology

Sand grains in the Ap (Fig. 2a) and E (Fig. 2b) horizons did not have coatings or bridges except for several chunks of Bhsm materials that had been mixed into the Ap horizon. Organo-metallic complexes, imogolite type materials, and ferrihydrite coated sand grains and formed bridges between sand grains in the Bhsm (Fig. 2c and 2d) and Bs (Fig. 2e) horizons. The coatings and bridges in the Bhsm horizon thickened and cemented nearly all sand grains together (Fig. 2d). The coatings appeared to protect some weatherable mineral grains in the Bhsm horizon. The BCg horizon had few Al and Fe coatings and many weatherable minerals (Fig. 2f).

Mineralogy

Even though the BCg and Cg horizons have more silt than the upper horizons (Table 2), we assumed that the solum had been mineralogically rather homogeneous at the beginning of soil formation. According to the XRD analyses, all sand and silt-sized chlorite and mica had weathered completely in the E and Bhsm horizons (Table 4). From thin-section analysis the mica was identified as biotite (Fig. 2f), which ideally has a Fe content of about 6%. Most of the biotite was present in the BCg horizons but was not observed in Ap and E horizons, presumably because it had weathered out of these eluvial horizons. This may explain the presence of ferrihydrite in the B horizon and the high index of accumulation in this pedon. Some silt and clay-sized amphibole had weathered in the E hori-

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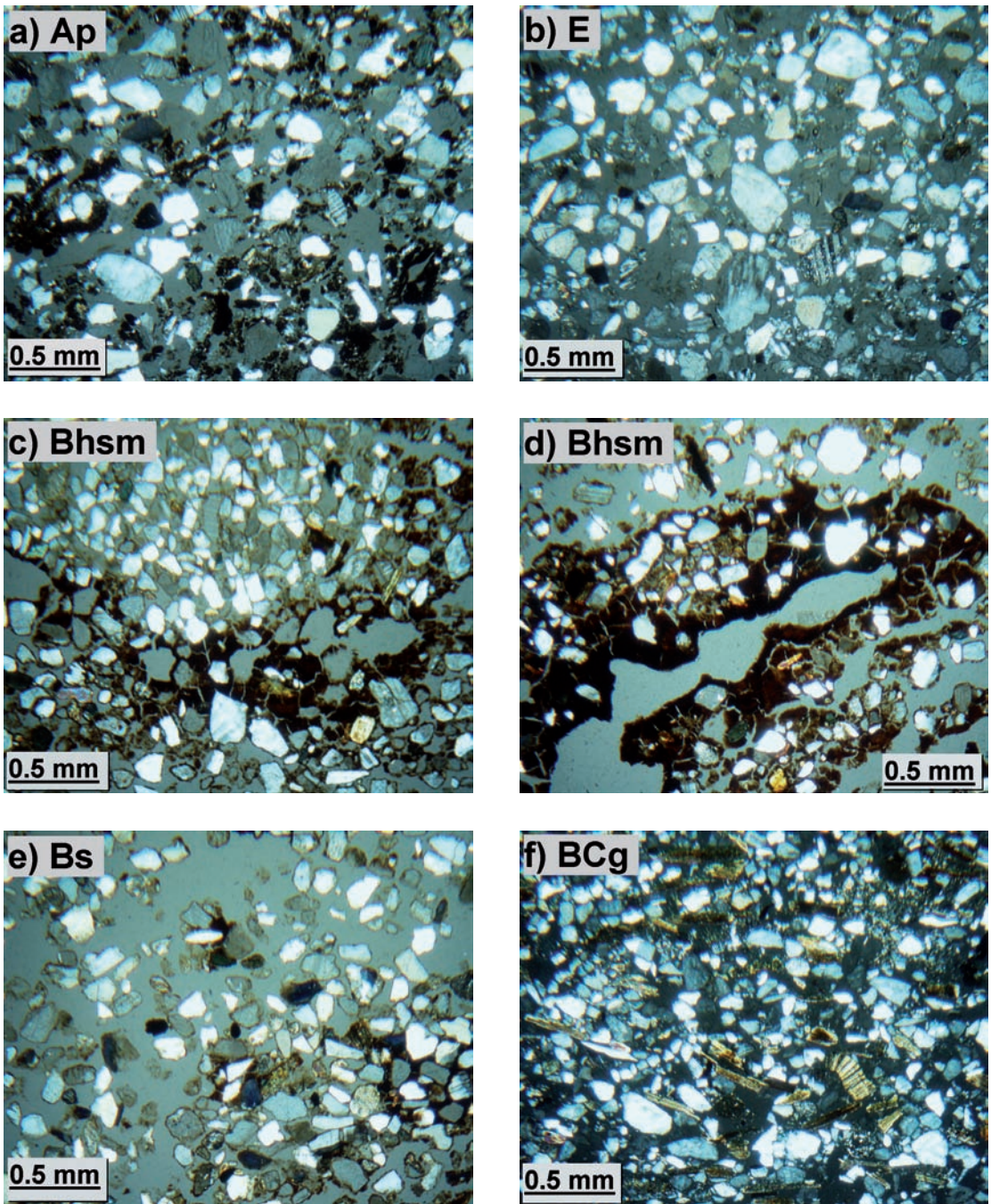*Yli-Halla, M. et al. Formation of a cultivated Spodosol in East-Central Finland*

Fig. 2. Micrographs of select micromorphological features in selected horizons. (a) organic particles and uncoated sand grains in Ap horizon, (b) uncoated sand grains in E horizon, (c) sand grains cemented by complexes in Bhsm horizon, (d) cracked coatings bridging sand grains in Bhsm horizon, (e) thin coatings on sand grains in Bs horizon, and (f) relatively unweathered and uncoated sand grains and plenty of biotite (brown) in BCg horizon. Photos taken in partially polarized light mode (half cross-polarized light). (Micrographs by the entire research group.)

Table 4. Semiquantative mineralogical composition (+ = least abundant, +++ = most abundant) of sand, silt and clay fractions of selected horizons.

Horizon	Quartz	Feldspar	Amphibole	Pyroxene	Chlorite	Mica	Vermiculite
Sand							
E	+++	+++	+	+			
Bhsm	+++	+++					
BCg	+++	+++	+		+	+	
Silt							
E	+++	+++	+	+			
Bhsm	+++	+++		+			
BCg	+++	+++	+	+	+	+	
Clay							
E	+++	++	+		+	+	+
BCg	+++	++	+		++	+	+

zon. Regularly interstratified vermiculite and biotite was present in the clay fraction of the BCg horizon but not in the E horizon. The irregular interstratified vermiculite and biotite suggests some of the biotite in the E horizon had weathered to vermiculite. The presence of a 1.54 Å 060 diffraction peak and the absence of a 1.49 Å 060 peak indicated chlorite and not kaolinite was present (Moore and Reynolds 1989). The mineralogy is similar to that presented earlier for coarse-textured soils in Finland (Mokma et al. 2004), quartz and feldspars being the dominant minerals. In the Bs3 horizon of the uncultivated Spodosol of Sotkamo, allophane was also detected (Mokma et al. 2004). The clay mineralogy of the E horizon of this pedon lacked smectite. This is different from two Spodosols chronosequences (up to 10,000 years old) in Finland, studied by Righi et al. (1997) and Gillot et al. (1999). The clay minerals in this pedon were dominantly trioctahedral (060 spacing of 1.54 Å). The smectite found in E horizons of other Spodosols in Finland was identified as dioctahedral (Righi et al. 1997, Gillot et al. 1999). All fine clay fractions were dioctahedral (Righi et al. 1997) indicating the parent material mineralogy of the tills in central Finland (Righi et al. 1977) is different from that of the pedon in this study. This may explain the lack of smectite in the E horizon of this pedon.

Cultivation-induced changes

Cultivation has likely terminated or certainly slowed podzolization in this pedon. Al and Fe are soluble and available for chelation under very acid conditions, <5.5, but not when the soils have been limed above this reaction. When the soil was cleared for agriculture, the trees and bushes were removed and Ca and Mg were added through liming, fertilization and manuring. Indeed, the Ap and even the E horizon had a higher pH and base saturation than the horizons below (Table 2). Lower pH values, between 3.5 and 4.5, are also typical for the E horizons of native Spodosols of Finland and a base saturation (BS) of only 8% has been found (Mokma et al. 2000, 2004). Particularly, the high values measured in the E horizon (pH 5.8, BS 32%) contrast with the E horizon of the forested Spodosol close by (pH 4.3), being the most acidic horizon in that entire pedon, indicating neutralizing components have been translocated downwards from the Ap horizon. Organic compounds which chelate Al and Fe will also chelate divalent cations such as Ca forming relatively insoluble calcium humates (McKeague et al. 1983, p. 241). The organic compounds that are produced by decomposition of organic matter in the Ap horizon, and would naturally chelate Al and Fe, will chelate

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the added Ca and Mg, whereas the Al and Fe remain in the Ap and E horizons. Small amounts of Ca will cause Al and Fe complexes to precipitate (Mokma and Buurman 1982, p. 5). The short period of cultivation, 50 years, has had little impact on the properties of this pedon. Cultivated Spodosols in Poland and Michigan, USA had less Al and Fe in Bhs and Bs horizons than nearby uncultivated Spodosols (Mokma and Szafranek 2001) indicating podzolization process were slowed or possibly terminated by cultivation.

Classification

According to Soil Taxonomy (Soil Survey Staff 1999) an albic or E horizon must be present in 50% or more of the pedon in order to qualify as a Spodosol. The pedon, studied in detail, had an albic horizon only in 48% percent of the pedon. Therefore, it did not quite meet the criteria for a spodic horizon (Soil Survey Staff 1999). The sand-textured Bhsm and Bs horizon did not meet the textural criteria for a cambic horizon. As a result, the pedon was classified as a Spodic Cryopsamment. If the albic horizon was in at least 50% of the pedon, like in the two other pedons of the same field and in an uncultivated otherwise similar pedon 1.4 km away, the pedon would be classified as Typic Duricryods. This subgroup was previously thought to not likely occur in Finland (Mokma and Yli-Halla 2000). According to the FAO system (FAO 1988) the pedon was classified as Haplic Podzols. The pedon was classified as Duric Podzols according to the WRB system (FAO 1998).

Conclusions

Before cultivation of the pedon in this study, organic acids produced by decomposition of organic matter from pine litter in O and A horizons had weathered primary minerals in A and E horizons releasing Al and Fe. Organic compounds chelated the Al and Fe and percolating waters translocated the organo-metallic complexes to the Bhsm and Bs horizons. Degradation of some of the complexes by microbial activity may have caused some Fe to precipitate as ferrihydrite, but little if any imogolite type materials formed. Weathering of biotite has likely contributed to the abundance of ferrihydrite. The Al and Fe complexes coat and bridge sand grains and eventually cemented the sand grains into ortstein. The data from the pedon in this study appear to support the older and more widely accepted theory of podzolization.

After initiation of cultivation of the pedon the O, A, E and parts of the Bhsm horizon were mixed into an Ap horizon. Organic compounds produced through decomposition of cultivated crop residues are not likely to chelate and translocate Al and Fe because they are not highly acidic and the pH has been elevated by liming. Any organic compounds that might be able to chelate Al and Fe will chelate, instead, Ca and Mg added by liming, fertilization and manuring. Therefore little, if any, further podzolization will occur as long as the study area is cultivated.

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SELOSTUS

Podsolimaannos karkealla hietamaalla Sotkamossa

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Karkeille hietamaille syntyneet podsolit ovat Suomen kehittyneimpiä maannoksia. Niitä tutkimalla saadaan uutta tietoa tämän koko pohjoisella havumetsävyöhykkeellä yleisen maannostyypin kehittymiseen johtaneista prosesseista, joista edelleenkin vallitsee erilaisia käsityksiä. Tämän tutkimuksen kohteena oli Sotkamossa karkealla hietamaalla oleva noin 50 vuotta viljelty maa, joka on ollut kuivillaan noin 10 700 vuotta. Muokkauskerroksen alapuolella oli huuhtoutumiskerros (valkomaa), joka sisälsi lähes pelkkää kvartsihiekkaa. Sen alapuolella oli noin 10 cm paksu rautapalsi eli iskostunut horisontti, johon ylempää orgaanisina kompleksiyhdisteinä huuhtoutuneet rauta ja alumiini ovat saostuneet. Mikroskoopilla voidaan nähdä, miten nämä saostuneet ainesosat peittävät kvartsihiekan jyväset ja sitovat ne yhteen. Tässä horisontissa oli erittäin runsaasti heikosti kiteytynyttä rautaoksidia, joka on uutettavissa ammoniumoksalaattiliuoksella, kun taas valkomaassa tällaista

rautaa oli erittäin vähän. Rikastumiskerroksen aluminista valtaosa oli pyrofosfaattiin uuttuvassa, oletettavasti orgaanisen aineksen sitomassa muodossa, mikä viittaa aineiden kulkeutuneen tähän horisonttiin nimenomaan kelaatteina eikä epäorgaanisina kolloideina. Syvä kyntö on nostanut valkomaata ja kappaleita rikastumiskerroksen iskostumasta myös muokkauskerrokseen. Rikastumiskerroksen alapuolella kvartsihiekkajyvästen pinnoilla ei ollut paljonkaan rautasaostumia, mutta mikroskoopilla näkyi runsaasti rapautumatonta biotiittia. Rikastumiskerroksen rauta lienee suureksi osaksi peräisin juuri biotiitista, joka on kokonaisuudessaan rapautunut pintamaasta. Vähemmän biotiittia sisältäviin maihin ei todennäköisesti kehity näin vahvaa rikastumiskerrosta maan pienemmän rautapitoisuuden takia. Podsoloituminen on luultavasti pysähtynyt sen jälkeen, kun maa on otettu viljelyyn ja sen pintaosien pH on kalkituksen seurauksena noussut.