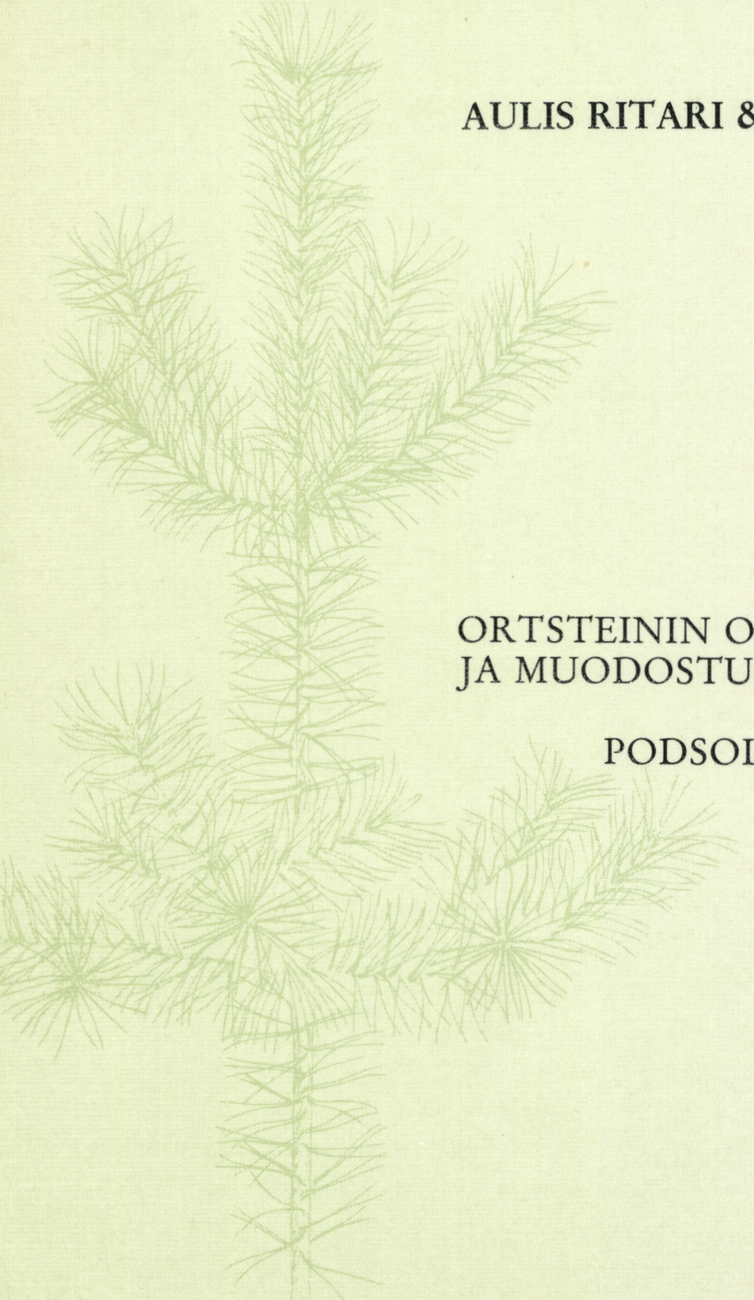
COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE 124

METSÄNTUTKIMUSLAITOS
JALOSTUSASEMA
01590 MAISALA

PROPERTIES AND FORMATION OF CEMENTED ORTSTEIN HORIZONS IN ROVANIEMI, NORTHERN FINLAND

AULIS RITARI & VESA OJANPERÄ



SELOSTE

ORTSTEININ OMINAISUUKSISTA JA MUODOSTUMISESTA ERÄISSÄ ROVANIEMEN PODSOLIMAANNOKSISSA

HELSINKI 1984

COMMUNICATIONES INSTITUTI
FORESTALIS FENNIAE

THE FINNISH FOREST RESEARCH INSTITUTE
(METSÄNTUTKIMUSLAITOS)

Unioninkatu 40 A
SF-00170 Helsinki 17
FINLAND

telex: 125181 hyfor sf
attn: metla/

phone: 90-661 401

Director:
Professor Aarne Nyyssönen

Head of Information Office:
Olli Kiiskinen

Distribution and exchange of publications:

The Finnish Forest Research Institute
Library
Unioninkatu 40 A
SF-00170 Helsinki 17
FINLAND

Publications of the Finnish Forest Research Institute:

— Communicationes Instituti Forestalis Fenniae (Commun. Inst. For. Fenn.)
— Folia Forestalia (Folia For.)
— Metsäntutkimuslaitoksen tiedonantoja

Cover (front & back): Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE
124

PROPERTIES AND FORMATION OF CEMENTED ORTSTEIN HORIZONS IN ROVANIEMI, NORTHERN FINLAND

AULIS RITARI & VESA OJANPERÄ

SELOSTE

ORTSTEININ OMINAISUUKSISTA JA MUODOSTUMISESTA ERÄISSÄ ROVANIEMEN PODSOLIMAANNOKSISSA

HELSINKI 1984

RITARI, A. & OJANPERÄ, V. 1984. Properties and formation of cemented ortstein horizons in Rovaniemi, Northern Finland. Seloste: Ortsteinin ominaisuuksista ja muodostumisesta eräissä Rovaniemen podsolimaannoksissa. Commun. Inst. For. Fenn. 124:1—32.

The ortstein layers which have been observed both in Finland an abroad usually occur in part of the B horizons of podzols. The ortstein which often develops on coarse sandy soils is clearly distinguished from other parts of the soil profile owing to its darker colour and compactness. The physical and chemical properties of cemented ortstein horizons were examined in this study on the basis of material collected from Rovaniemi, northern Finland. In addition, the phenomena involved in the formation of ortstein were also examined.

Ortstein consists of a skeleton of mineral grains which are cemented together by a substance called cutan. The formation of cutan results in an increase in the bulk density of the soil and a decrease in the hydraulic conductivity owing to the filling up of the pore space. In places, cutan was found to account for as much as 20 % of the surface area and the weight of the samples. Chemical analyses carried out on the material indicated that the skeletal grains were mainly cemented together by amorphous organic complexes and inorganic hydroxide compounds containing aluminium, iron and silicon. In podzolisation the phenomenon may be mainly associated with the translocation of material from the A horizon to the B horizon. One of the major differences between ortstein formation and soil formation not involving this cementing process, was found to be the movement of water which affects the translocation of material, and the pH-Eh conditions which affect the solubility of different compounds.

Cemented ortstein horizons have an indirect effect on the site conditions — the increased moisture conditions in the surface soil have, in certain cases, resulted in the onset of paludification. During wet periods the poor hydraulic conductivity of the ortstein layer has a negative effect as far as the vegetation is concerned, while during dry periods it may have a beneficial effect. According to the results of this study, the soil from the pure B horizon of an ortstein formation is not a very good growing substrate for tree seedlings owing to the low amounts of plant nutrients, a low base saturation and high content of iron and aluminium.

Ortstein-kerroksia on sekä Suomessa että ulkomailla todettu esiintyvän yleisesti eräissä podsolimaannosten B-horisonteissa. Usein karkeisiin hiekkamaihin kehittynyt ortstein eroaa maannoksen muusta osasta sekä kovuutensa että tummemman värinsä perusteella. Tässä tutkimuksessa selviteltiin Rovaniemen lähistöllä kerätyn aineiston pohjalta kovettuneiden ortsteinhorisonttien fysikaalisia ja kemiallisia ominaisuuksia ja arvioitiin ortsteinin syntymiseen johtaneita syitä.

Ortstein koostuu maan mineraalirakeiden muodostamasta rungosta ja rakeita sitovasta aineksesta, kutaanista. Seurauksena kutaanin muodostumisesta maan tilavuuspaino on lisääntynyt ja vedenläpäisevyys pienentynyt huokostilan täyttymisen myötä. Kutaania todettiin olevan paikoin jopa 20 % näytteen pinta-alasta sekä painosta. Kemiallisten kokeiden perusteella havaittiin, että runkorakeita sitoivat toisiinsa lähinnä alumiinia, rautaa ja piitä sisältävät amorfiset orgaaniset kompleksi- ja epäorgaaniset hydroksiyhdisteet. Edellä mainittujen ominaisuuksien perusteella voitiin eritellä ortsteinin kehittymiseen vaikuttavia tekijöitä. Podsolisaatiossa ilmiö liittynee läheisesti ainesten kulkeutumiseen A-horisontista B-horisonttiin. Merkittävimmiksi eroiksi tavalliseen ilman kovettumista tapahtuvaan maannostumiseen todettiin ainesten kulkeutumiseen vaikuttavat veden liikkeet ja eri aineiden liukoisuutta säätelevät pH-Eh-olosuhteet.

Kasvupaikan olosuhteisiin kovettuneilla ortsteinhorisonteilla on välillinen vaikutus — lisääntyneestä kosteudesta pintamaassa on ollut eräissä tapauksissa seurauksena soistumista. Sateisina aikoina heikosti vettä läpäisevä ortstein-kerros on kasvien kannalta negatiivinen, kuivina kausina mahdollisesti positiivinen. Tämän tutkimuksen antamien viitteiden mukaan ortsteinmaannosten puhdas B-horisontin maa ei ole saatavilla olevien kasviravinteiden niukkuuden, alhaisen emäskylläisyysasteen ja korkeiden rauta- ja alumiinipitoisuuksien takia erityisen hyvä kasvualusta puuntaimille.

ODC 114.36+114.441.2
ISBN 951-40-0668-2
ISSN 0358-9609

Helsinki 1984. Valtion painatuskeskus

CONTENTS

1. INTRODUCTION 5
2. MATERIAL AND METHODS 7
    21. Sites and soil pedons 7
    22. Soil samples 8
    23. Physical and chemical analyses 8
3. RESULTS 13
    31. Physical properties of orstein soils 13
    32. Thin-section analysis of the structure and formation of cemented bindings 14
    33. Chemical properties of ortstein soils 14
    34. X-ray microanalysis of the cementing agent 20
    35. Plant nutritional properties of ortstein soils 21
4. DISCUSSION 24
REFERENCES 29
SELOSTE 30

408401375W

1. INTRODUCTION

Ortstein, which occurs in podzolic soils, refers to the illuvial, ridigly cemented part of the B horizon. The cementing agent mainly consists of translocated aluminium and iron oxides, otherwise called sesquioxides (cf. Bates & Jackson 1980). In addition, the cemented layer should meet the thickness criteria and be located in the spodic part of the solum. When placed in water, clods of ortstein do not soften or dissolve.

Other forms of cemented podzols are duric horizons and fragipan horizons. Duric horizons differ from ortsteins as regards their colour. They are approximately the same colour as the C horizon, while ortstein horizons are clearly discernible parts of the brown B horizon (McKeaque & Sprout 1975). The cementing agent is usually similar in both types of podzol, although the proportion of silicon is usually higher in duripans (McKeaque & Protz 1980). Fragipan horizons are mainly cemented with clay minerals, which replace the sesquioxides of ortsteins (DeKimpe et al. 1971). However, even in these types of podzol the strength of the structure is due to the amorphic constituents of the horizon (Hallmark & Smeck 1979). In addition, clods of fragipan break up when placed in water.

Detailed pedological studies have been carried out on soils containing ortstein horizons by e.g. Moore (1976) in Quebec, Canada, and Wang et al. (1978) in the Maritime Provinces of Canada. Furthermore, the physical and chemical properties of ortsteins have been studied by, e.g. Altemüller & Klinge (1964) in the Rio Negro, Brazil, Karavayeva (1968) in Western Siberia, Lambert & Hole (1971) in Wisconsin, Miles et al. (1979) in the Maritime Provinces of Canada, and Zaydelman et al. (1979) in the Zagorsk area of the Soviet Union.

Ortstein is clearly distinguishable from the uncemented B horizon in the field. Its hardness makes digging difficult and it remains visible as an uneroded layer in the walls of a pit as the softer parts gradually wear away. Ortstein is often a darker brown colour than the material lying above and below it. This colour difference is further accentuated by the fact that ortstein does not dry out as quickly as the other layers.

The physical property which most clearly distinguishes ortstein from the adjacent soil layers is its greater hardness (Wang et al. 1978). Other distinquishing features are the lower hydraulic conductivity and larger bulk density. When thin sections are made from ortstein and examined under a polarizing microscope, the skeleton of mineral grains, bound together by cutan, is plainly visible (McKeaque & Guertin 1982).

As far as its chemical composition is concerned, ortstein does not differ very much from the uncemented B horizon. More extractable material, with a considerably variable composition, is obtained when the material cementing the grains together in cemented soils is extracted (Miles et al. 1979). In addition to the anionic constituents, the most important extractable elements in cutan are aluminium, iron and silicon. Microanalysis carried out on the binding agent between the skeletal grains indicates that the above three elements are in fact the most abundant ones in cutan (McKeaque & Wang 1980).

The most important questions investigated in studies concerning ortstein have concentrated on the mechanism of cement formation. In most cases it has been considered to be primarily a chemical process in which the material eluviated from the A horizon has precipitated in the B horizon to form a cementing layer of cutan on the surface of the skeletal grains. The chemical processes resulting in the formation of ortstein are to a great extent dependent on the mineralogical composition of the soil, the overlying vegetation, the pH-Eh conditions, and the composition and movement of the water present in the ground.

The cementing material has a mixed autochthonous-allochthonous origin (Karavayeva 1968). According to Karavayeva (1968), there are three ways in which material can accumulate to form an ortstein layer in the B horizon:

1) from above, due to intensive podzolization accelerated by a gradual rise in the ground water table,
2) from below, via the capillary fringe of the ground water, and a gradual rise in the ground water table especially during the early stages of paludification,
3) by lateral inflow, due to the location of the profile on a slope.

When studying the genesis of sesquioxide-cemented soil horizons, Moore (1976) proposed the hypothesis that iron and aluminium were released in the Ae horizon (eluviated part of the A horizon), translocated mainly in the form of inorganic compounds, and then precipitated in the B horizon as cutan which cements the skeletal grains together. According to the above, the released aluminium and iron in podzols are primarily derived from the weathering of unstable hornblende in coarse-textured soils where there is strong leaching by percolating water and a very acid soil environment. The precipitation of iron and aluminium can take place through oxidation, a change in the pH or adsorption by sesquioxides. In addition to the above, the cutan in ortsteins has been found to be formed of Al-organic complexed material (McKeaque & Wang 1980), and of organic binding agents, hydroxides and clay minerals in varying proportions (Page & Berrier 1983).

Ortstein layers are characterised by a relative poor nutrient status. The high levels of sesquioxides found in ortsteins have even been found to have a toxic effect on the growth of tree seedlings (Prusinkiewicz & Krzemien 1974). In addition, in the spring and during periods of intensive rainfall the soil may become partly waterlogged in strongly cemented areas as a result of the poor hydraulic conductivity. Thus ortstein makes the site conditions wetter and, in certain cases, brings about paludification.

The profiles of soils containing ortstein horizons located in the vicinity of Rovaniemi, Northern Finland, have been investigated in this study. Experience gained in, for instance, Canada (cf. Moore 1976, Wang et al. 1978) have also been applied in drawing up field notes. A number of methods used in the study of cemented soils, which differ from those usually used for uncemented soils, were applied in the study of the physical and chemical properties of the soils.

The aim of the study has been to elucidate the factors which bring about the formation of cementation, as well as to define the properties of ortstein. The persistance of ortstein and its role as a site factor, have also been touched on.

The study was carried out at the instigation of Aulis Ritari (Rovaniemi Research Station, the Finnish Forest Research Institute) as a joint effort with Vesa Ojanperä (Department of Geology, the University of Oulu). The idea of the study originated from the auhors' own observations concerning the occurence of ortstein, an earlier study carried out by V. T. Aaltonen in Finnish Lapland, and recent work done by J. A. McKeaque et al. in Canada.

The authors together planned and carried out the collection of the material and wrote the manuscript as a joint effort. Ojanperä also prepared a thesis based on the material. Professors Risto Aario and Eino Mälkönen have read this manuscript and made valuble comments. Their invaluable help is very much appreciated.

Kaarina Niska and Ilkka Aro assisted in the laboratory work at the Rovaniemi Research Station. Ilkka Aro also assisted in carrying out the field work. The plant coverage analyses were performed by Sirpa Pumpanen. Dr. Pirkko Ruostesuo, from the University of Oulu, instructed us in the use of the infra-red analyzer, Dr. Seppo Sivonen and Sinikka Komulainen assisted us in carrying out the microanalyses, Ulla Paakkola carried out the thin-section preparations. Seppo Kaakinen and Timo Kalenius performed the total analyses. The manuscript was translated into English by John Derome.

We wish to express our sincere thanks to the abovementioned persons and institutes, as well as to all those who contributed towards the completion of the present study.

2. MATERIAL AND METHODS

21. Sites and soil pedons

The study area is situated about 25 km to the west of the city of Rovaniemi (66°27′ N, 25°15′ W) (Fig. 1). The area lies within the middle boreal forest zone (Naturgeografisk... 1977), where the main mineral soil order is podzol. The mean annual temperature at the meteorological station situated about 30 km from the study area is 0.2 °C, and the annual precipitation 520 mm (30-year mean, 1951—1981). The climate in the area is humic. During the last 30-year period, a permanent snow cover developed on the average on 2.11. and melted on 8.5.

The study area was covered by water for 1000—2000 years after deglaciation about 9 500 years ago (Hyyppä 1966). The area is situated at an elevation of 100—160 m above the present sea level. In this region the highest shoreline reached a maximum of 210—215 m a.s.l., as can be seen from the washed bedrock and block concentrations on the slopes of the highest hills (Saarnisto 1981).

Study site No. 1 (Fig. 1) is a moist upland site of the *Vaccinium-Myrtillus* site type (VMT) (for site classification system, see Lehto 1978) on the southeastern slope of Kuusikkoselkä. The other two sites, site No. 2 on the northwestern slope of Kuusikkoselkä and site No. 3 on the southern part of Keski-Merkkivaara, are dryish upland sites of the *Empetrum-Vaccinium* site type (EMT). The tree stands are dominated by Scots pine (*Pinus sylvestris*), the field layer by blueberry (*Vaccinium myrtillus*) and lingonberry (*Vaccinium vitis-idaea*) and the bottom layer by the mosses, *Pleurozium schreberi* and *Hylocomium splendens* (Table 1).

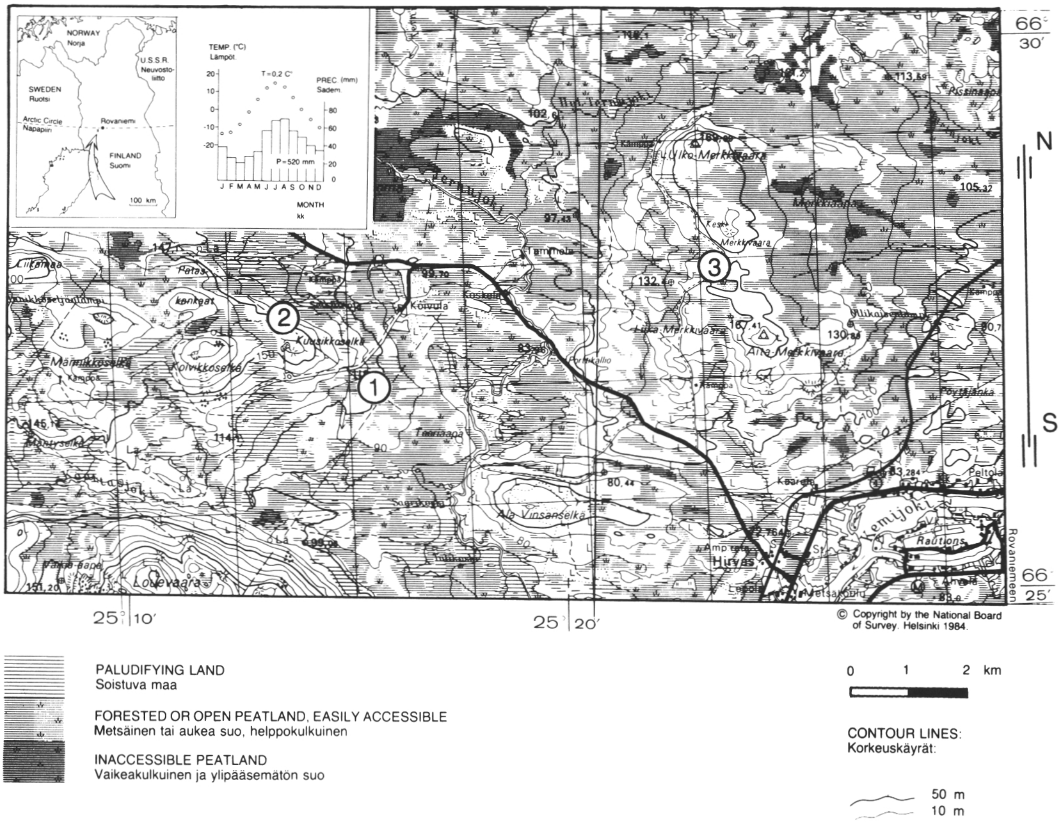


Fig. 1. Location of the study sites, and weather data from a nearby meteorological station (Lapland Research Station, Agricultural Research Centre) for the period 1951—1981. T = annual mean temperature, P = annual mean precipitation.

Kuva 1. Tutkimusalueiden sijainti sekä lähellä sijaitsevan ilmastoaseman säätietoja vuosilta 1951–1981 (Maatalouden tutkimuskeskuksen Lapin koeasema). T = vuoden keskilämpötila ja P = vuoden keskimääräinen sademäärä.

Table 1. Tree stand and ground vegetation (Study site No. 1 = southeastern slope of Kuusikkoselkä, site No. 2 = northwestern slope of Kuusikkoselkä, site No. 3 = southern part of Keski-Merkkivaara).

Taulukko 1. Tutkimusalueiden puusto ja pintakasvillisuus (alueet: 1 = Kuusikkoselkä, kaakkoisrinne, 2 = Kuusikkoselkä, luoteisrinne ja 3 = Keski-Merkkivaara, eteläosa).

Property *Ominaisuus*	Site — *Tutkimusalue*		
	1	2	3
Canopy *Latvuskerros*			
Mean height of trees (m) *Puuston keskipituus (m)*	13.3	13.3	15.1
Stand volume (m³/ha) *Kuutiomäärä kuorineen (m³/ha)*	170	120	120
Species composition (%) *Puulajisuhteet (%)*			
Pinus sylvestris	50	70	100
Picea abies	30	20	—
Betula (pubescens + pendula)	20	10	—
Field layer (coverage %) *Kenttäkerros (peittävyys %)*	70	60	50
Pinus sylvestris	—	—	1
Picea abies	—	1	1
Betula pubescens + pendula	—	1	—
Sorbus aucuparia	—	1	—
Vaccinium myrtillus	55	30	20
Vaccinium vitis-idaea	12	15	2
Vaccinium uliginosum	—	—	15
Empetrum nigrum	1	7	11
Ledum palustre	2	4	—
Linnea borealis	1	—	4
Lycopodium sp.	1	—	—
Deschampsia flexuosa	1	1	—
Melampyrum sp.	1	1	1
Other grasses *Muita heiniä*	1	—	—
Ground layer (coverage %) *Pohjakerros (peittävyys %)*	60	80	65
Hylocomium splendens	41	1	14
Pleurozium schreberi	17	66	34
Dicranum sp.	2	8	6
Polytrichum sp.	2	2	—
Other mosses *Muita sammalia*	1	1	7
Cladonia sp.	—	2	4
Other lichens *Muita jäkäliä*	—	—	1
Litter (coverage %) *Karike (peittävyys %)*	38	22	22

Ortstein layers up to 60 cm thick were found in sandy parts of the southeastern slope of Kuusikkoselkä. They occurred as a zone in which the uncemented layers were very thin (Fig. 2a). Clearly discernible light-coloured mottles were frequently visible in these ridigly cemented layers. During the wet summer (1981), the ground water (or perched water) table was so high that it reached the illuviated B horizon in the podzol profile, and in places even the eluviated part of the Ae horizon. During the dry summer (1982), the ground water table was considerably lower.

The soil texture was coarser on the northwestern slope of Kuusikkoselkä than on the southeastern slope, and stratified sand occurred in thin beds. The ortstein in these layers of sand had become rigider than in other places. The surface soil at the third study site, the southern part of Keski-Merkkivaara, consisted of beds of stratified sand and gravel, the sand being cemented into ortstein horizons (Fig. 2b). There is a boulder pavement underneath the stratified material, which depicts the erosion stage preceding deposition. The lowest horizon in the profile was composed of olive-green till, which included an ice age compression structure. Cemented ortstein was even found under peat at a point where mineral soil sloped gently under an adjacent bog (cf. Jauhiainen 1972).

A number of pits were dug in the study areas, more detailed examinations being carried out in four of them (Fig. 3, Table 2).

22. Soil samples

The material used in this study comprised the soil pits containing ortstein horizons (altogether 21 pits) dug in the above-described area, the observations made on the profiles, and samples removed from the pedons. The samples were taken as follows:

1) Fixed volume samples (using a cylinder) for determining dry bulk density and hydraulic conductivity.
2) Loose samples (in plastic bags) for determining particle size distribution, nutrient contents and various chemical properties.
3) Undisturbed clod samples used in carrying out physical analyses. Thin sections and polished sections were also prepared from these samples for microanalysis.

All the samples, apart from the clod samples used for making thin and polished sections, were taken from four pits only (1A, 2A, 3B and 3K). These four pits represented different types of pedons containing ortstein horizons. Samples of cemented ortsteins from a number of other pits dug in the study were included in the third group of clod samples.

23. Physical and chemical analyses

The profile descriptions carried out in the field were made on the basis of the Canadian classification system (Canada Soil Survey Committee 1978). The colour of the soil profiles were determined using Munsell colour charts (Munsell 1975).

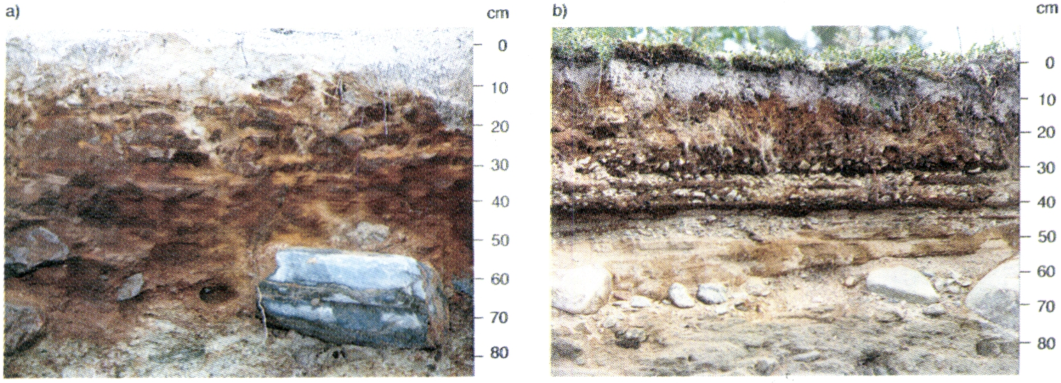


Fig. 2. a) Wall of a pit dug at SE-Kuusikkoselkä. Ortstein forms a thick layer in the profile. There are clearly distinct, usually coarse, light-coloured (10YR 8/6) mottles in the dark matrix (2.5YR 2/4). b) Wall of a pit dug at S-Keski-Merkkivaara. There is a washed stony layer (boulder pavement) between the upper stratum of sedimentaceous sand and gravel and the lower stratum of ice-compressed till. Ortstein has developed in the upper layer of sand.

Kuva 2. a) Sorakuopan seinämä Kuusikkoselän kaakkoisosassa, missä ortstein esiintyy maannoksessa paksuna vyöhykkeenä. Tummassa taustassa (2.5YR 2/4) on yleisesti karkeita, selvästi erottuvia vaaleita (10YR 8/6) täpliä. b) Sorakuopan seinämä Keski-Merkkivaaran eteläosissa. Yläosan lajittuneen hiekan ja soran sekä alaosan painumarakenteisen moreenin välissä on huuhtoutunut kivivyöhyke. Ortstein on kehittynyt yläosan hiekkaisiin kerroksiin.

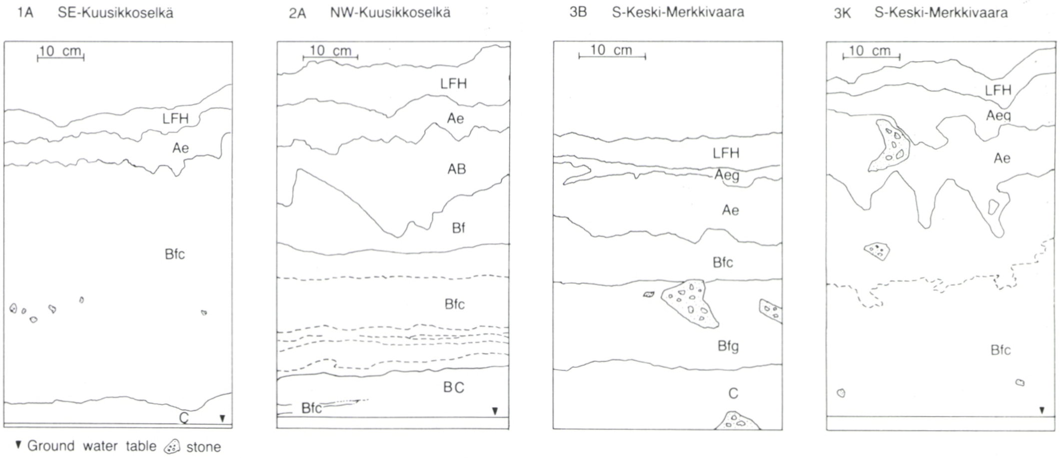


Fig. 3. Profile sketches of the pedons. See Table 2 for more detailed descriptions.

Kuva 3. Tutkimuskuoppien profiilit piirroksina. Tarkemmat kuvaukset maannoksista ovat taulukossa 2.

Determinations of particle size distribution were done by a combination of sieving and the Andreassen pipetting method (Elonen 1971). Wet and dry bulk densities were determined on samples taken with a brass cylinder. The proportion of the space occupied by water and air was also calculated from these measurements.

The resistance to penetration of the soil (kg/cm^2) was determined at different depths using a Proctor penetrometer (Davidson 1965). The needle was pushed in a vertical direction to a depth of 1 cm, a total of 30 measurements being made at each depth. The hydraulic conductivity of the saturated soil was measured under as natural conditions as possible from the fixed volume samples using the method developed by Guertin (1981).

The micromorphology of ortstein and its cementing agents were studied on thin sections cut from undisturbed, ovendried (105 °C) samples impregnated with polyester resin (Smith & Atkinson 1975). The descriptions were done using the terminology and classification of Brewer (1960, 1964 and 1979).

Total elemental analysis was done on melted samples by means of X-ray spectrometry. The elements studied were: Na, Mg, Ba, Ca, Al, P, Ti, Mn, K, Si, Cr and Fe. The clay fraction of the ortstein was studied by X-ray diffraction using undisturbed, oriented samples in order to determine the crystallity and the possible presence

Table 2. Description of the ortstein soils (cf. fig. 3). Color notations follow Munsell (1975) Soil Color Charts.
Taulukko 2. Ortsteinmaannosten ominaisuuksia (vrt. kuva 3). Väriluokittelu perustuu Munsellin (1975) väritauluihin.

Pedon *Kuoppa*	Site *Tutkimusalue*	Topography *Topografia*	Elevation (m) *Korkeus (m)*	Soil Class *Maannostyyppi*	Horizon *Horisontti*	Depth (cm) *Syvyys (cm)*	Colour (moist) *Väri (kostea)*	Texture *Maalaji*	Structure *Rakenne*	Consistence when moist *Konsistenssi*	Cementation *Iskostuminen*	Lower horizon boundary *Horisontin alaraja*	Other main features *Muita piirteitä*
1A	Kuusikkoselkä, SE	Lower slope *Alarinne*	107	Ortstein Humo-Ferric Podzol	LFH	8—0	2,5YR 2/2		Fibrous *Kuituinen*			Abrupt *Jyrkkä*	Abundant medium and fine roots *Runsaasti keskikokoisia ja hienoja juuria* Humus class fibrimor *Humusluokka fibrimor*
					Ae	0—20	5YR 7/2	Sand *Hiekka*	Structureless *Rakenteeton*	Loose *Löyhä*		Gradual *Vähittäinen*	Abundant fine roots *Runsaasti hienoja juuria*
					Bfc	20—70	5YR 5/8		Platy *Levymäinen*	Firm to very firm *Lujasta erittäin lujaan*	Strong to indurated *Lujasta hyvin kovaan*	Diffuse *Diffuusi*	Few coarse, prominent mottles (10YR 2/8), gravel beds *Muutamia kookkaita ja selvästi erottuvia täpliä, sorakerroksia*
					C	70—90	5YR 4/6	Sand *Hiekka*	Platy *Levymäinen*	Loose *Löyhä*			Some stones, groundwater level at 90 cm *Joitakin kiviä, pohjavesipinta 90 cm:ssä*
2A	Kuusikkoselkä, NW	Middle slope *Keskirinne*	157	Ortstein Humo-Ferric Podzol	LFH	5—0	2,5YR 2/2		Fibrous *Kuituinen*			Abrupt *Jyrkkä*	Abundant roots, fibrimor *Runsaasti juuria, fibrimor*
					Ae	0—10	10YR 8/2	Sand *Hiekka*	Structureless *Rakenteeton*	Loose *Löyhä*		Gradual *Vähittäinen*	Abundant fine roots *Runsaasti hienoja juuria*
					AB	10—15							Features from A and B horizons *A ja B-horisonttien piirteitä*
					Bf	15—25	7,5YR 6/8	Sand *Hiekka*	Platy *Levymäinen*	Loose *Löyhä*		Diffuse *Diffuusi*	Sand and gravel beds *Hiekka ja sorakerroksia*
					Bfc	25—35	5YR 3/6	Sand *Hiekka*	Platy *Levymäinen*	Firm to very firm *Lujasta erittäin lujaan*	Strong to indurated *Lujasta hyvin kovaan*	Clear *Selvä*	
					Bfc	35—60	7,5YR 6/8	Fine gravel *Hieno sora*	Platy *Levymäinen*	Loose to firm *Löyhästä lujaan*	Moderate *Vaihteleva*	Clear *Selvä*	Contains 3 Bfc gravelly beds, 2—5 cm thick *Sisältää 3 Bfc soraista kerrosta, 2-5 cm paksuja*
					BC	60—80	7,5YR 5/3	Gravel *Sora*	Platy *Levymäinen*	Very loose *Hyvin löyhä*			Gravel and sand beds, groundwater level at 71 cm *Sora- ja hiekkakerroksia, pohjavesipinta 71 cm:ssä*

3B	Keski-Merkkivaara, S	Crest *Laki*	150	Ortstein Humo-Ferric Podzol	LFH	7—0	5YR 3/6		Fibrous *Kuituinen*			Abrupt *Jyrkkä*	Abundant medium and fine roots, fibrimor *Runsaasti keskikokoisia ja hienoja juuria*
					Ae	0—10	5YR 6/1	Sand *Hiekka*	Structureless *Rakenteeton*	Loose *Löyhä*		Clear *Selvä*	Fairly abundant roots, upper part gleyish (Aeg) *Melko runsaasti juuria, yläosa savinen (Aeg)*
					Bfc	10—24	5YR 5/8	Sand *Hiekka*	Structureless *Rakenteeton*	Firm *Luja*	Strong *Luja*	Gradual *Vähittäinen*	Some stones, few coarse distinct mottles (5YR 3/4), gleyish *Muutamia kiviä, joitakin kookkaita, selviä täpliä (5YR 3/4), savinen*
					Bfg	24—30	5YR 4/6	Till *Moreeni*	Structureless *Rakenteeton*	Loose *Löyhä*		Diffuse *Diffuusi*	Common medium, distinct mottles (5YR 3/4), gleyish *Yleisesti keskikokoisia, selviä täpliä (5YR 3/4), savinen*
					C	24—40	5YR 4/2	Till *Moreeni*	Platy *Levymäinen*	Loose *Löyhä*			Common small, prominent mottles (10YR 4/1), consolidated structure *Yleisesti pieniä, hyvin erottuvia täpliä (10YR 4/1), painumarakennetta*
3K	Keski-Merkkivaara, S	Lover slope *Alarinne*	145	Ortstein Humo-Ferric Podzol	LFH	4—0	7,5YR 2/2		Fibrous *Kuituinen*			Abrupt *Jyrkkä*	Abundant roots, fibrimor *Runsaasti juuria, fibrimor*
					Ae	0—12	5YR 5/8	Sand *Hiekka*	Structureless *Rakenteeton*	Loose *Löyhä*		Gradual *Vähittäinen*	Abundant fine roots, lower boundary wavy, upper part gleyish (Aeg) *Runsaasti hienoja juuria, alaraja aaltoilee, yläosa savinen (Aeg)*
					Bfc	12—28	7,5YR 5/8	Sand *Hiekka*	Structureless *Rakenteeton*	Firm *Luja*	Strong *Luja*	Diffuse *Diffuusi*	Common coarse, distinct mottles (5YR 3/4) *Yleisesti kookkaita, selviä täpliä (5YR 3/4)*
					Bfc	28—58	7,5YR 5/8	Sand *Hiekka*	Structureless *Rakenteeton*	Firm to very firm *Lujasta erittäin lujaan*	Weak to indurated *Heikosta hyvin kovaan*	Diffuse *Diffuusi*	In the lower part dark, netlike structure *Alaosassa tumma, verkkomainen rakenne*
					C	58—70	7,5YR 5/6	Sand *Hiekka*	Structureless *Rakenteeton*	Loose *Löyhä*			Groundwater level at 62 cm *Pohjavesipinta 62 cm:ssä*

of clay minerals (cf. McKeaque 1981, Section 5.2.). The analysis conditions were: Cu K_α radiation and Ni filter, voltage 36 kV, current 20 mA and sensitivity 3000. The reactions taking place in the samples as a function of temperature were studied by differential thermal analysis (DTA). Changes in the weight of the samples as a function of temperature, in turn, were studied by means of thermogravimetric analysis (TGA). DTA and TGA were carried out on the unfractioned (total) samples using a heating rate of 10 °C/min and a sensitivity of 0.25 mV (MacKenzie 1970). Chemical bondings in the fine fraction of the ortstein samples were studied by infrared analysis using the potassium bromide pellet method (McKeaque 1981, Method 5.511). The analyses were carried out over the freqency range of 250—4 000 cm^{-1}.

The loss on ignition of the pedons containing ortstein was determined by heating between 105 and 1 000 °C. The pH of the samples was measured in water and in an aqueous solution of $CaCl_2$ (Lavkulich 1977). The electrical conductivity was also measured in the aqueous suspensions.

Extractable cations in the profiles were determined by extracting with aqueous solutions of dithionite-citrate-bicarbonate (McKeaque 1981, Method 3.51), acidic ammonium oxalate (McKeaque 1981, Method 3.52) and sodium pyrophosphate (Lavkulich 1977, p. 84). According to McKeaque (1981), these extractants give a rough estimate of the quality of the fine fraction as follows:

1) dithionite Fe − oxalate Fe = finely divided hematite and goethite,
2) oxalate Fe or Al − pyrophosphate Fe or Al = amorphous inorganic Fe or Al,
3) pyrophosphate Fe or Al = organic complexes of Fe or Al.

In addition to the extraction experiments, the slaking of the undisturbed ortstein clods in water and aqueous solutions of dithionite, oxalate and pyrophosphate was studied. The amounts of Al, Fe, Mn and Si extracted in the slaking test were also determined by atomic absorption spectrometry 14 and 28 days after the start of the experiment.

The content of exchangeable Ca, Mg, K and Al and easily soluble phosphorous were determined by extracting with ammonium acetate (pH 4.65). These results (me/100 g) were used to calculate the cation exchange capacity (Ca+Mg+K+Al) and base saturation (Ca+Mg+K/Ca+Mg+K+Al). The organic carbon content was determined by the Tyurin wet combustion method, and total nitrogen by the Kjeldahl method. In addition, the amount of easily soluble phosphorous in the ammonium acetate extract was determined by the molybdate-hydratzine method (the procedures are given in detail in Halonen et al. 1983).

Polished slides were made of the ortstein samples in order to study the binding material between the skeletal grains using a scanning electron microscope (SEM) combined with an energy-dispersive X-ray spectrometer (EDS). The conditions used in the analyses were: potential of 20 kV, beam current of about 0.5 nA and a measuring time of 100 seconds. The beam angle used in the analyses was 27° and the samples were untilted. The elemental content of the samples was determined by comparing the results obtained with the samples with the X-ray intensities produced by standard samples. The analyses were carried out under conditions in which the proportion of oxygen and other elements not included in the analysis was 60 %. This was considered to best correspond to the amount of oxygen present in the samples.

3. RESULTS

31. Physical properties of ortstein soils

The results concerning the particle size distribution, the soil composition, the dry bulk density and hydraulic conductivity of samples taken from the study pits are presented in Fig. 4. The particle size distribution in all the pedons showed that there was very clear stratification as regards the primary particles. The dominant fraction was coarse sand, accounting for over 90 % of all the particles in most of the samples, apart from pedon 3B where the fine fraction was dominant. The size of the fine fraction (< 0.002 mm) was always at its maximum level in the surface layer (the upper part of the A horizon) of the soil. There was another clear maximum in the cemented ortstein horizon.

In many cases the dry bulk density of the ortstein horizons was clearly greater than in the uncemented horizons (Fig. 4). The dry bulk density in the cemented layers varied, depending on the cementation strength, from 1.46 to 2.08 g/cm^3. The moisture content and air space was smaller in the ortstein than in other layers of the soil.

The ortstein horizons in these sandy soils had the lowest hydraulic conductivity. The hydraulic condutivity of the soil in strongly cemented samples was very low. However,

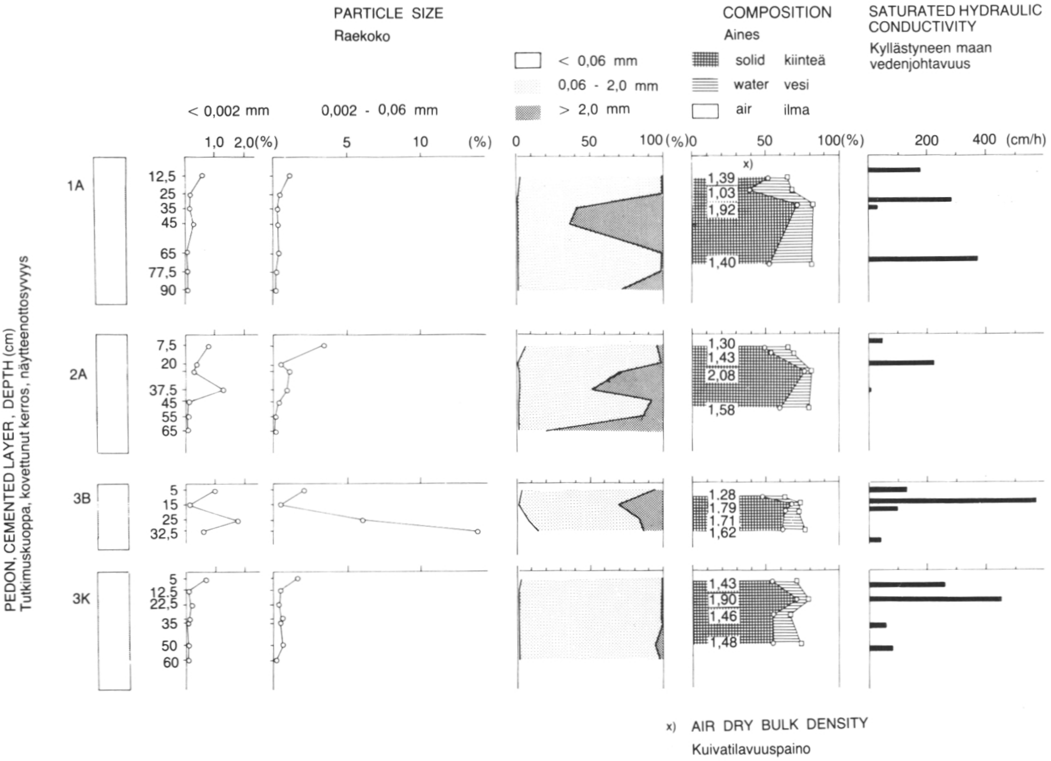


Fig. 4. Particle size distribution, air-dry bulk density, composition (solid/water/air) and saturated hydraulic conductivity of the soil pedons.

Kuva 4. Tutkimuskuopista määritetyt rakeisuusjakaumat, näytteiden kuivatilavuuspainot, maa-ainesten osuus (kiinteä/vesi/ilma) ja kyllästyneen maan vedenjohtavuus.

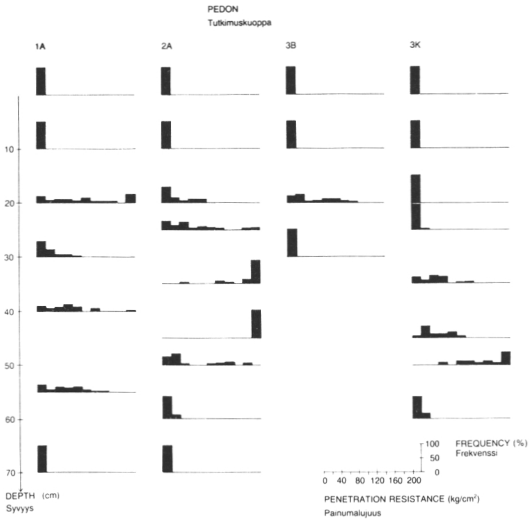


Fig. 5. Frequency distribution of the penetration resistance at different depths (in horizontal sections) in the pedons (30 measurements/section).

Kuva 5. Painumalujuuden arvot syvyyskerroksittain frekvenssijakaumina (30 mittausta/syvyyskerros).

there was great variation in the hydraulic conductivity, weakly cemented layers in some samples being just as pervious to water as uncemented ones.

The penetration resistance of ortstein was found to vary considerably when determined by the proctor penetrometer (Fig. 5). In cases where the cementation was at its most indurated, sandy and even gravelly soil attained a stonelike state, the penetration resistance being over 200 kg/cm². The cementation was so weak in places that the resistance did not differ at all from the eluviated A horizon or the underlying C horizon.

32. Thin-section analysis of the structure and formation of cemented bindings

The thin-section studies carried out on ortstein samples indicated that the material consists of a skeleton of mineral grains, brown cutan binding the grains, and pore space (Table 1). The mineral grains usually belonged to the sand fraction, and the most common minerals were quartz and feldspars. On the average, cutan accounted for 12.6 % of the surface area, at its greatest almost 20 %, and the free pore space sightly over 25 %.

The proportion of quartz in the skeletal grains remained constant throughout the profile (samples $3K_2$ – $3K_4$), but the proportion of feldspars decreased and that of dark minerals increased on moving downwards. Only slight weathering had occured in the minerals of the ortstein. The calculated value of 0.2 % for the organic matter content was considerably lower than, for instance, that obtained by thermogravimetry (about 1.5 %). The latter value is based on the loss in weight of the sample when heated over the range 200—470 °C, when part of the hydroxyl ions in the sample are also lost. The organic carbon content as determined by wet combustion was about 0.7 %.

The fabric class of the ortstein samples was chlamydic in 2/3 of the samples, and plectic in the other third. The surface of the mineral grains in the former class have a thin coating of cutan (Fig. 6a). The latter class was common in samples where thickened mottles of cutan were usually found (Fig. 6b).

Cutan can also occur as roll-shaped pellets (cf. Bullock 1974, Bunting & Fedoroff 1974). In this study the pellets had a mean diameter of 0.05 mm and were found to have a fibrous internal structure (Fig. 6c).

33. Chemical properties of ortstein soils

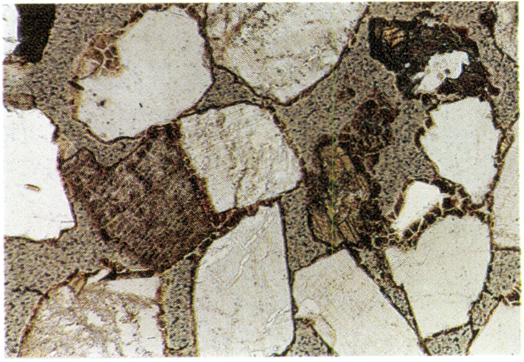
According to the results of the total elemental analyses, there is a clear maximum in the vertical distributions of iron, aluminium, phosphorous, and in places also of manganese, in the ortstein horizons of the pedons examined in this study (Fig. 7). The relative proportion of silicon, which is present in fairly large amounts in the skeletal grains, is at its minimum in the ortstein horizons. This indicates that Fe, Al, P and Mn have become enriched in these soils in the B horizon, and altered the element proportions. There was less regularity in the variation of other elements (Na, Mg, Ca, K) as a function of soil depth, and hence there does not appear to be any clear dependence on the illuviated layer.

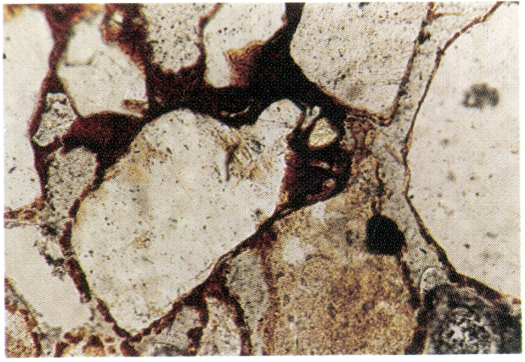
Table 3. Proportion of minerals, cutan, coarse organic plant material and pore space in the thin sections. N = 1000 points/thin section. The amount of organic material, as determined by thermogravimetry, is also presented.
Taulukko 3. Ortsteinnäytteiden ohuthieistä lasketut mineraalien, sideaineksen, karkeiden orgaanisten kasvinosien ja huokostilan prosenttiset osuudet. N = 1000 pistettä/hie. Lisäksi on esitetty termogravimetrisesti saadut orgaanisen aineksen määrät.

Material *Aines*	Pedon — *Kuoppa*												
	1A	1B	2A	2B	2D	3B	$3K_2$	$3K_3$	$3K_4$	3L	3M	$\bar{x}$	s
Quartz *Kvartsi*	37.5	35.9	38.9	35.2	27.0	32.1	29.6	32.0	34.3	33.0	35.8	33.8	3.3
Feldspars *Maasälvät*	20.5	21.6	24.5	19.0	21.2	24.2	21.0	22.6	15.6	25.6	20.7	21.5	2.7
Mica *Kiilteet*	0.6	1.0	1.3	3.1	0.6	0.7	0.3	0.7	0.8	0.2	0.5	0.9	0.8
Amphibols *Amfibolit*	2.1	1.9	1.1	4.4	2.1	0.8	5.2	2.7	7.4	1.2	1.8	2.8	1.9
Pyroxens *Pyrokseenit*	0.4	0.6	0.0	0.3	0.1	0.5	1.6	0.5	1.1	0.4	0.4	0.5	0.4
Aphatite *Apatiitti*	0.3	0.1	0.0	0.2	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.1	0.1
Titanite *Titaniitti*	0.0	0.0	0.0	0.1	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Carbonates *Karbonaatit*	0.0	0.0	0.0	0.3	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Opaque *Opaakki*	0.9	1.2	0.1	1.7	0.2	0.3	0.5	0.1	0.8	0.3	0.3	0.6	0.5
Other minerals *Muut mineraalit*	0.2	1.0	1.6	0.2	1.0	0.1	1.0	0.6	1.2	1.7	0.1	0.8	0.6
Cementing agent *Sideaines*	15.6	11.8	11.0	18.8	14.2	19.8	10.8	10.4	8.1	8.0	10.1	12.6	3.8
Organic particles *Orgaaniset palat*	0.1	0.0	0.0	0.2	0.0	0.0	0.1	0.3	0.6	0.3	0.4	0.2	0.2
Pore space *Huokostila*	22.1	25.9	21.5	16.8	33.6	20.9	29.3	29.0	30.4	29.3	30.0	26.3	4.9
Organic matter (TGA) *Orgaaninen aines (TGA)*	2.1	1.6	1.4	2.7	1.2	1.7	1.4	0.7	1.0	1.7	1.0	1.5	0.5

The clay fraction of ortstein was weakly crystalline, judging by the small peaks in the X-ray diffraction patterns obtained for the fine material in the undisturbed samples (Fig. 8a). The most important crystalline substances were quartz, K-feldspar, plagioclase and fibrous hornblende. As far as true clay minerals are concerned, only chlorite and illite peaks were obtained. In pedon 3K, the crystallity of the fine fraction clearly decreased on moving downwards from the Ae horizon (depth 13 cm).

As regards the results of differential thermal analysis, the ortstein was in most cases relatively featureless (Fig. 8c), apart from the reactions involving the loss of hygroscopic water (lost at a temperature of 200 °C) and ignition of the organic matter (200—470 °C). The differential thermal curves which were obtained represent samples containing a large amount of organic matter and hydroxide compounds containing easily decomposable hydroxyl ions. The only features of special interest were the reference temperature where the inversion of quartz ($\alpha \leftrightarrows \beta$ quartz) takes place (573 °C), the strong dehydration of amphiboles (about 700 °C) in sample 2B (depth 25 cm), and the allophane reaction (about 1000 °C) in sample B (depth 63 cm). This allophane reaction is most closely comparable to the reaction of aluminium-rich aluminium silica gel (cf. Wells et al. 1973). The magnitude of the peak produced by the reaction is a measure of the abundance of allophane in the sample, because this peak is usually





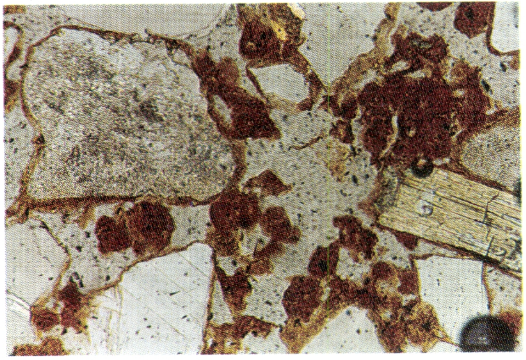


Fig. 6. a) Thin section of cemented ortstein soil (pedon 3K, depth 53 cm). The brown material around the grains is cutan. The areas which are darker than the light-coloured grains are the pore spaces (contain large number of organic fragments). Magnified 85 x. b) A mottle of reddish-brown cutan in a thin section (pedon 1A, depth 33 cm). Magnified 210 x. c) Pellets of brown cutan between skeletal grains in a thin section (pedon 2D, depth 18 cm). Magnified 210 x.

Kuva 6. a) Ohutkiehuva kovetuneesta ortsteinista (tutkimuskuoppa 3K, syv. 53 cm). Ruskea osa rakeiden ympärillä on sideainesta eli kutaania. Vaaleita runkorakeita tummempana näkyvä aines on huokostilaa, jossa on runsaasti orgaanisia siruja. Suurennos 85 x. b) Punaruskean kutaaniaineksen täplä (tutkimuskuoppa 1A, syv. 33 cm). Suurennos 210 x. c) Runkorakeiden välisiä ruskeita kutaaniaineksen palloja eli pellettejä (tutkimuskuoppa 2D, syv. 18 cm). Suurennos 210 x.

weak in total samples (cf. Campbell, et al. 1968). As far as the thermogravimetric analyses are concerned, the ortstein samples did not differ to any great extent from the uncemented B horizons of the podzols. The main feature was the large loss in weight, mainly due to the burning of organic matter and the decomposition of amorphic material between temperatures of 200 and 470 °C (Fig. 8d).

The most important features of the infrared spectra of the soils containing ortstein horizons were the absorption bands due to hydroxyl groups, organic complexes (-CO_3), Si-O-Al bonds, clay minerals and imogolite which absorbs at 345 and over the range 420—430 cm^{-1} (Fig. 8b). The absorption due to clay minerals was at its lowest, and that of imogolite at its greatest in those samples where the ortstein was not very well developed.

The soils were strongly acidic, the pH being at its lowest in the organic layer lying at the very top of the soil (Fig. 9). On moving downwards the pH rapidly rose to a value of 5, the increase then gradually levelling off until the start of the B horizon (depth 20 cm) where it remained steady. The electrical conductivity was fairly constant throughout the whole of the profile and there were hardly any variations at any depth. The loss in weight on ignition, which is primarily due to the burning or organic matter (200—470 °C), reached a clear maximum in the cemented part of the B horizon. The loss in weight on ignition of the soils containing ortstein was highly correlated with the amount of extractable iron and aluminium. This indicates that at least part of the decomposition of amorphic materials had taken place over the temperature range 200—470 °C.

According to the results of the extraction experiments, the ortstein layer in the profiles clearly had greater amounts of amorphous or crystalline material containing iron, aluminium, silicon and, in places, manganese, than the Ae and C horizons

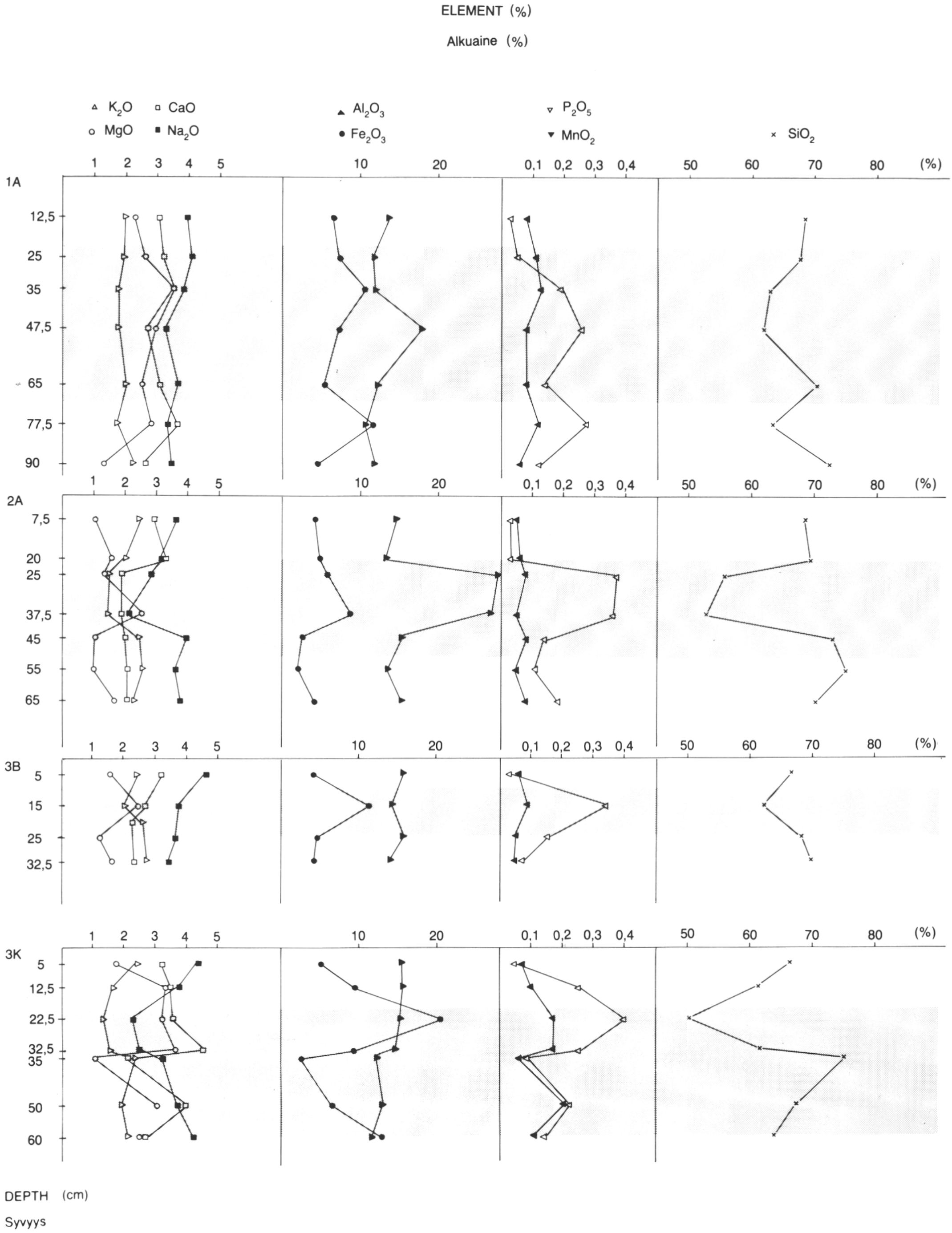


Fig. 7. Elemental distribution in the different pedons. The cemented layer is denoted by shading.
Kuva 7. Tutkimuskuopista otettujen näytteiden kokonaisalkuainejakautuma. Kovettunut ortsteinkerros on merkitty kuvaan varjostettuna.

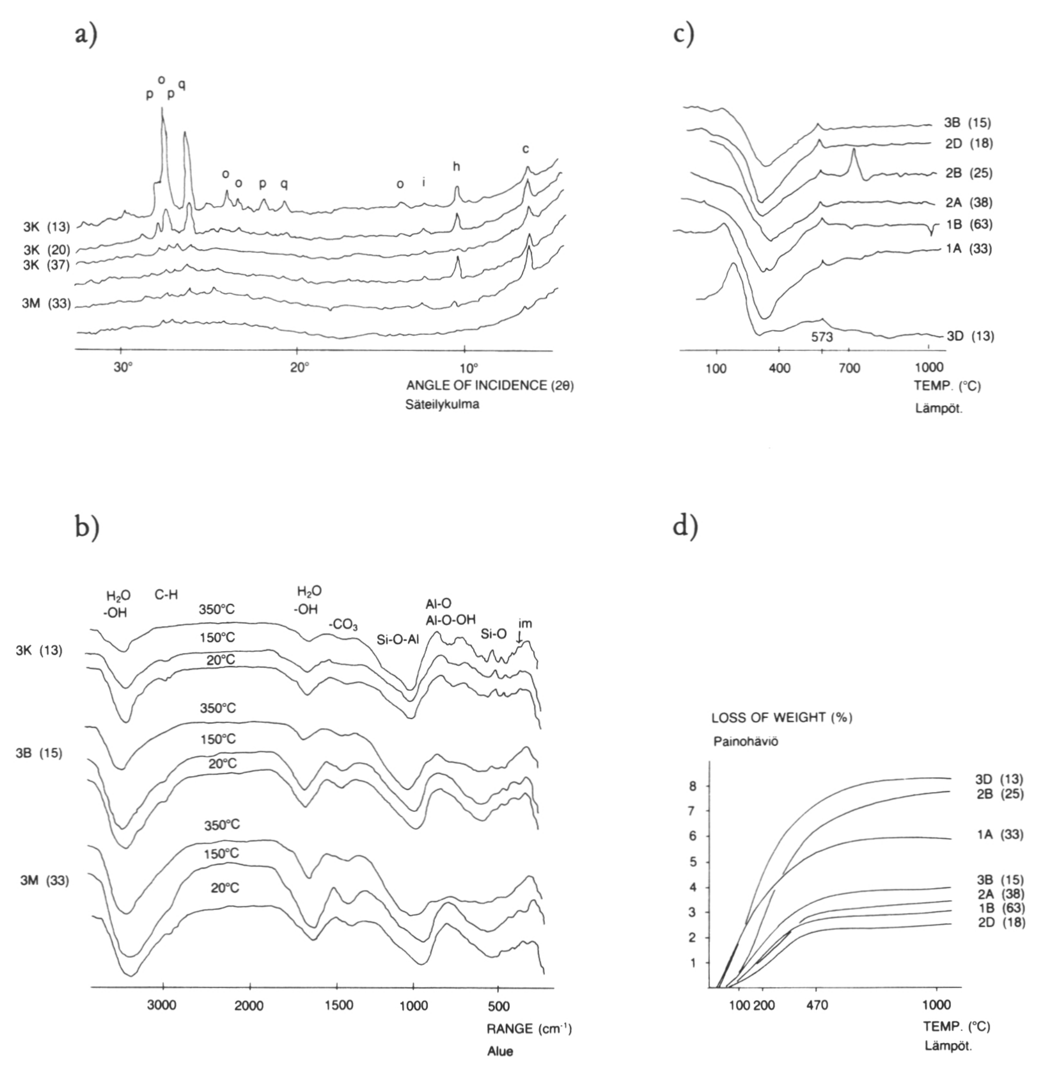


Fig. 8. a) X-ray diffraction curves (depth of samples in cm given in parentheses) representing different degrees of crystallization. Key to peaks given by different minerals: i = illite, h = hornblende, c = chlorite, q = quartz, p = plagioclase, o = orthoclase. b) Infrared spectra obtained when heating the fine material at different temperatures (im = imogolite). c) Differential thermal analysis (downwards slope in curve = exothermal reaction, upwards slope in curve = endothermal reaction). d) Thermogravimetric analysis.

Kuva 8. a) Eri kiteisyysasteita edustavia röntgendiffraktiokuvaajia (suluissa näytteiden keskisyvyys, cm). Mineraalien antamat piikit lyhenteinä: i = illiitti, h = sarvivälke, c = kloriitti, q = kvartsi, p = plagioklaasi, o = ortoklaasi. b) Näytteiden hienoaineksesta eri lämpötiloissa saatuja infrapunaspektrejä (im = imogoliitti). c) Differentiaalitermisiä analyysejä (käyrä alaspäin = eksoterminen reaktio, käyrä ylöspäin = endoterminen reaktio). d) Termogravimetrisia analyysejä.

(Fig. 9). These materials accounted for 2.5—8 % of the total weight of the ortstein, and even as much as 20 % when calculated as hydroxides. In other parts of the profile they usually accounted for less than 0.5 % of the total weight. The inorganic fraction of the extractable amorphous forms, obtained by substracting the values for the oxalate and pyrophosphate extracts from each other, was dominant in most cases. In addition, considerable amounts of iron were usually found to be present in the form of fine crystalline material (difference between the amounts extractable by dithionite and oxalate).

The results of the slaking test carried

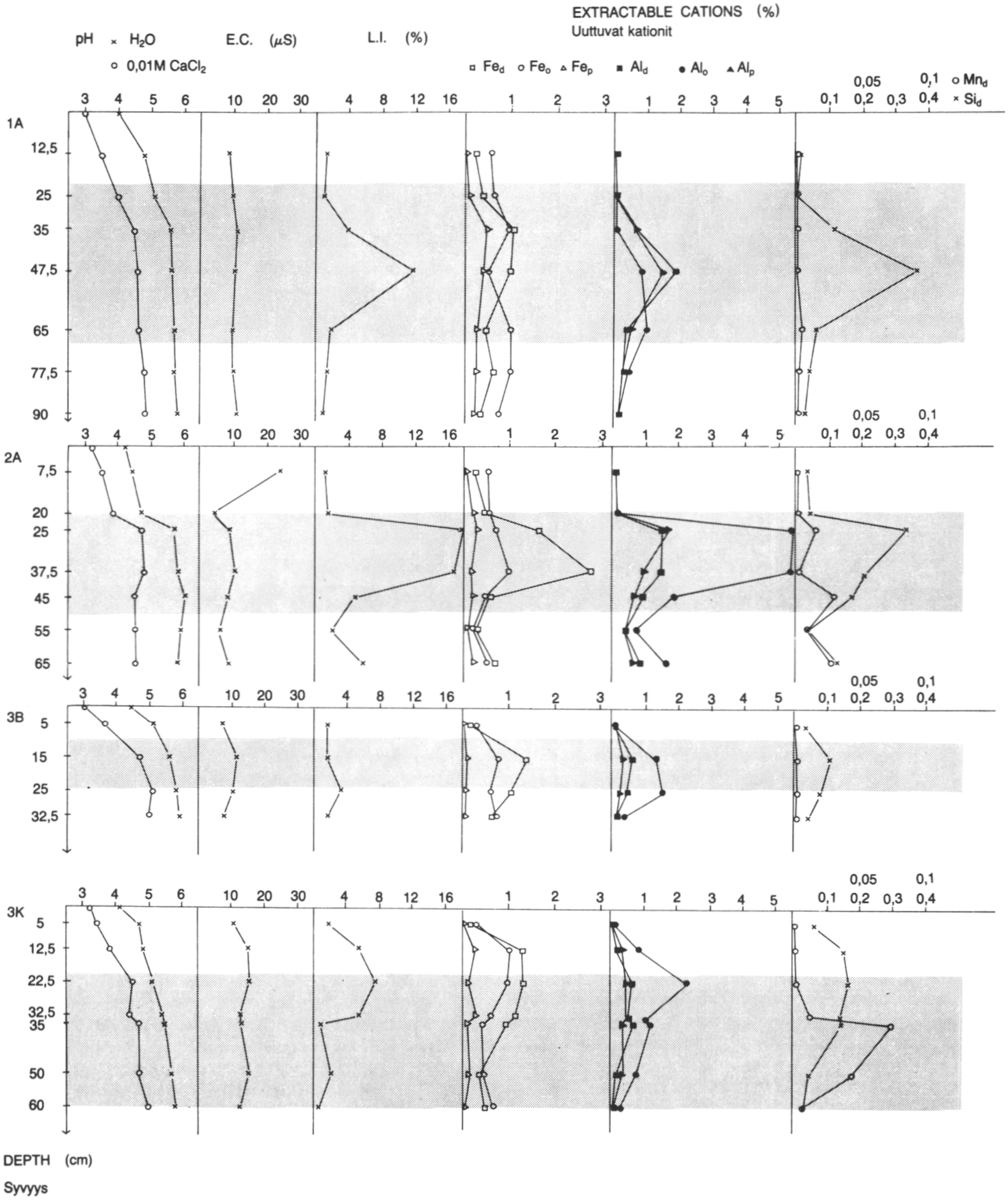


Fig. 9. Chemical properties of the pedons. Reading from the left: pH in water, pH in 0.01 M $CaCl_2$, electrical conductivity (E.C.), loss on ignition (L.I.) and extractable cations (lower case suffixes: d = dithionite, o = oxalate, p = pyrophosphate). The cemented layer is denoted by shading.

Kuva 9. Tutkittujen ortsteinmaannosten kemiallisia ominaisuuksia. Vasemmalta lukien: pH vedessä, pH 0.01 M $CaCl_2$*:ssa, ominaisjohtavuus (E.C.), hehkutushäviö (L.I.) ja uuttuvat kationit (alaviitteet: d = ditioniitti, o = oksalaatti, p = pyrofosfaatti). Kovettunut kerros on merkitty kuvaan varjostettuna.*

out with different extractants (Fig. 10) showed that the material which holds the grains together and makes the structure hard was composed of amorphous compounds of aluminium, iron and possibly silicon. This was determined by analysing the cations extracted during the slaking test (Table 3). No discernible amounts of the

Table 4. Amounts of cations extracted after slaking the ortstein clods for 14 and 28 days.
Taulukko 4. Hajoamistestin aikana 14 ja 28 vuorokaudessa liuokseen uuttuneet kationit.

Extractant *Uuttoliuos*	Extracted elements — *Uuttuneet alkuaineet*							
	In 14 days — *14 vrk:ssa*				In 28 days — *28 vrk:ssa*			
	Fe (%)	Al (%)	Si (ppm)	Mn (ppm)	Fe (%)	Al (%)	Si (ppm)	Mn (ppm)
Dithionite *Ditioniitti*	0.26	0.32	142	89	0.33	0.44	228	102
Oxalate *Oksalaatti*	0.25	0.32	208	40	0.26	0.57	224	52
Pyrophosphate *Pyrofosfaatti*	0.07	0.17	10	16	0.07	0.20	11	22
Distilled water *Tislattu vesi*	—	—	—	—	—	—	—	—

elements in question (Al, Fe, Si and Mn) were extractable with distilled water. The other extractants removed significant amounts of aluminium and iron, and small amounts of silicon and manganese. Slaking of the ortstein clods correlated the best with the amount of organic complexes containing aluminium and iron (extracted by pyrophospate), and the amount of inorganic amorphic compounds containing iron (difference between the amounts extractable by oxalate and pyrophosphate).

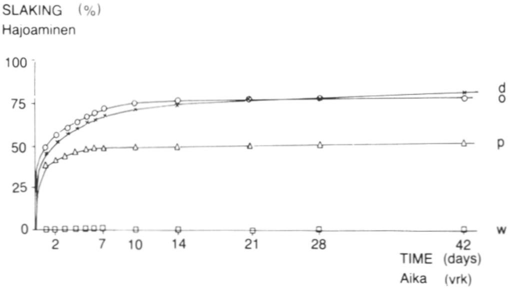


Fig. 10. Average slaking of ortstein clods in different solutions as a function of time. Extraction solutions: d = dithionite, o = oxalate, p = pyrophosphate, w = distilled water.
Kuva 10. Ortsteinin kokkareiden keskimääräinen hajoaminen eri liuoksissa ajan funktiona. Uuttoliuokset: d = ditioniitti, o = oksalaatti, p = pyrofosfaatti, w = tislattu vesi.

34. X-ray micronalysis of the cementing agent

Judging by the results of the microanalyses (SEM-EDS), the composition of the cementing agent in ortstein can vary considerably (Fig. 11 and Table 5). The continuous binding cutans almost always consisted of aluminium, iron and silicon compounds. The elemental (main elements) composition of the cementing agent was usually heterogeneous throughout the same sample.

The results also indicated that the composition of the pellets formed of cutan material was very similar to that of the coating cutan (sample 2D, Table 5). The composition of the mottles of cutan varied even more than that of the continuous cutan. Another interesting feature of these mottles was their relatively high content of manganese. Other elements present in cutan were potassium, calcium, phosphorus, titanium and chlorine, although usually in very small amounts. There were also differences in the density of the cutan, the material between the grains usually being loose. Such areas were apparent as a reduction in the number of the pulses when the background radiation was high. The assumption concerning the oxygen content (relative proportion of 60 % of the cutan weight) had no significant effect on the results, because when oxygen values of 50 and 70 % were used the ratios between the main elements (Al, Fe, Si and Mn) changed by only a few per cent.

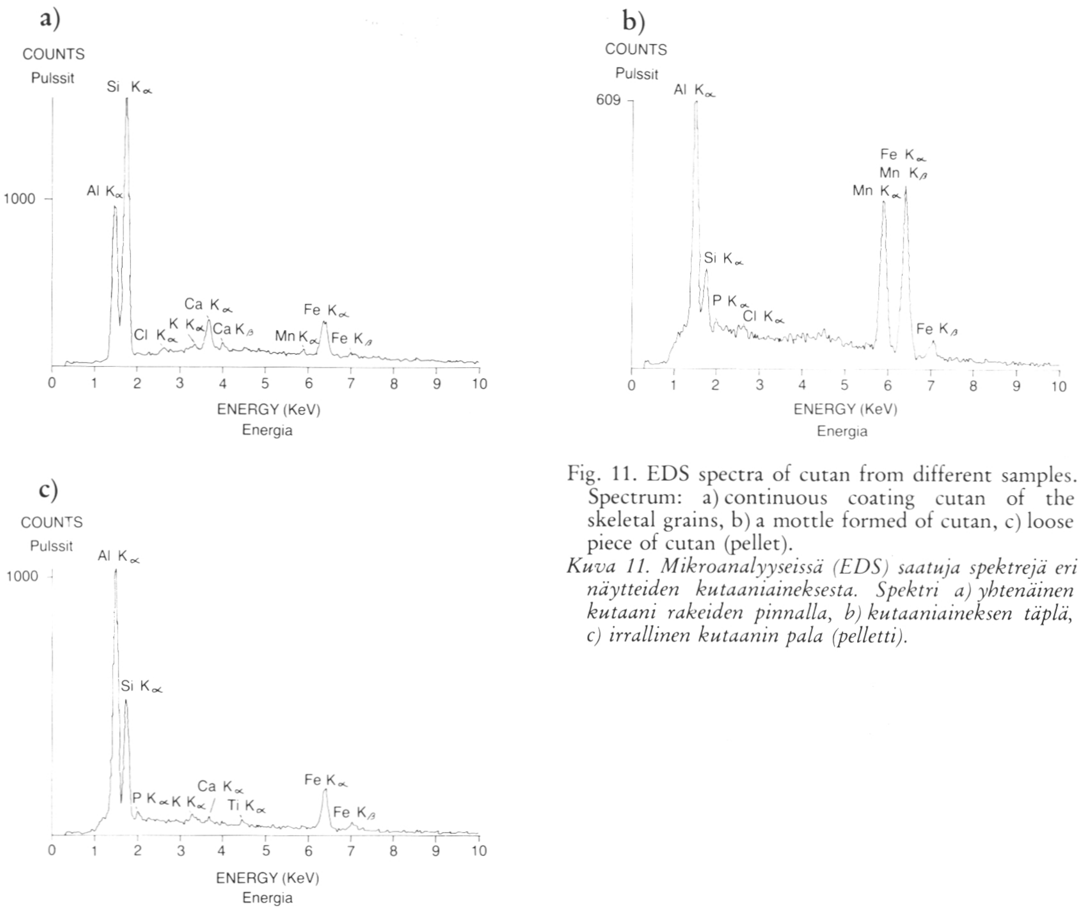


Fig. 11. EDS spectra of cutan from different samples. Spectrum: a) continuous coating cutan of the skeletal grains, b) a mottle formed of cutan, c) loose piece of cutan (pellet).

Kuva 11. Mikroanalyyseissä (EDS) saatuja spektrejä eri näytteiden kutaaniaineksesta. Spektri a) yhtenäinen kutaani rakeiden pinnalla, b) kutaaniaineksen täplä, c) irrallinen kutaanin pala (pelletti).

35. Plant nutritional properties of ortstein soils

The results for the amount of cations extractable with acetate show that the ortstein horizons contained only relative small amounts of exchangeable cations (Fig. 12). The amounts of plant nutrients, such as potassium, magnesium and calcium, were low, and were of the same order of magnitude throughout the soil profile. The amounts of calcium were higher than those of the other nutrients, and the variation in the amount of calcium was also greater. The highest calcium level was found in the upper part of the pedon 1A. The amount of aluminium extractable by acetate (= exchangeable aluminium) was many times that of the other nutrients, and was at its greatest in the B horizon. The cation exchange capacity (Ca+Mg+K+Al) was thus fairly well correlated and the base saturation (Ca+Mg+K/Ca+Mg+K+Al) inversely proportional with respect to the amount of aluminium. The low base saturation of the ortstein horizons weakens the fertility of this layer.

The soil profile contained only small amounts of organic carbon, reaching a maximum of only 0.9 % in the B horizon (Fig. 12). The amount of organic carbon in pedons 3B and 3K was even smaller than the minimum value proposed for podzols in the Canadian soil classification system (0,5 %). There was a clear maximum in the nitrogen content in the B horizon, which also had the highest C/N values (30—50). The distribution of phosphorous was less dependent on the soil horizons than the above mentioned elements.

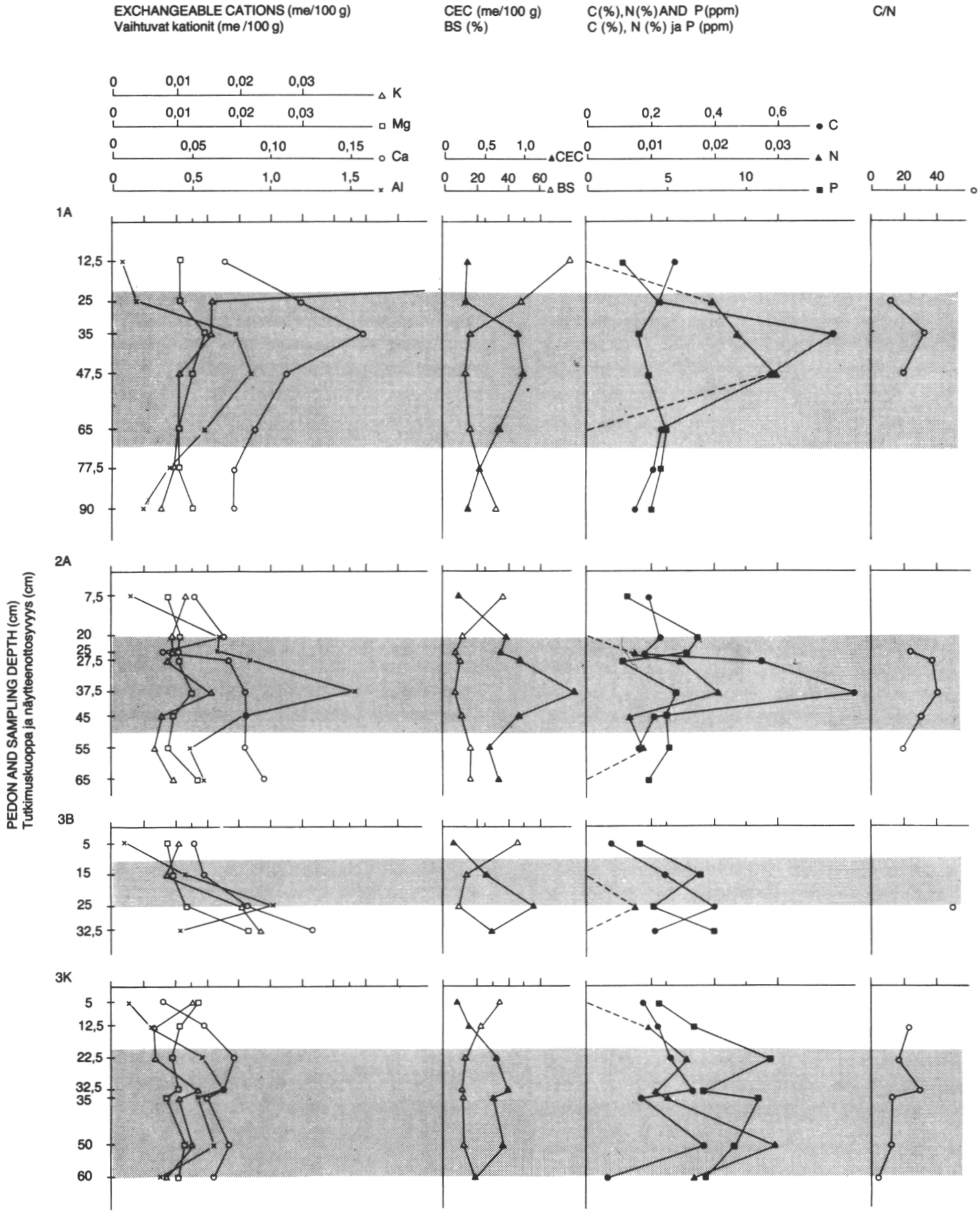


Fig. 12. Exchangeable cations, cation exchange capacity (CEC), base saturation (BS), organic carbon (C), total nitrogen (N), easily soluble phosphorous (P) and carbon/nitrogen ratio (C/N) of the ortstein soils. The cemented layer is denoted by shading.

Kuva 12. Ortsteinmaannoksista määritetyt kationit, kationinvaihtokapasiteetti (CEC), emäskylläisyysaste (BS), orgaaninen hiili (C), kokonaistyppi (N), helposti liukeneva fosfori (P) ja hiili/typpi suhde (C/N). Kovettunut kerros on merkitty kuvaan varjostettuna.

Table 5. Proportions of the main elements in the cutan of the ortstein samples as determined by x-ray microanalyis (SEM-EDS). A ratio of 60 % oxygen and 40 % measured elements (Al + Si + Mn + Fe) was used in the calculations.

Taulukko 5. Ortsteinin kutaanien (sideaineksen) röntgenmikroanalyysien (SEM-EDS) avulla lasketut pääalkuainepitoisuuksien suhteet eri näytteissä. Laskuissa on käytetty mitattujen aineiden (Al + Si + Mn + Fe) ja hapen suhteena 40 %/60 %.

Sample *Näyte*	Depth (cm) *Syv. (cm)*	Feature analyzed *Analysoitu piirre*	Elemental proportions, % (tot. = 40 %) *Alkuainesuhteet, % (tot. = 40 %)*								
			Coating cutan *Peitekutaani*				Mottles and pellets (p) *Täplät ja pelletit (p)*				
			Al	Si	Mn	Fe	Al	Si	Mn	Fe	
1A	33	yellowish brown, cracked, isotropic *kellanruskea, lohkeillut, isotrooppinen*	14	9	0	17	4	4	1	31	
1B	63	yellowish brown, uncracked, isotropic *kellanruskea, tasainen, isotrooppinen*	23	12	0	5	18	5	4	13	
2B	25	dark brown, cracked, isotropic *tummanruskea, lohkeillut, isotrooppinen*	22	10	0	8					
2D	18	redish brown, weakly anisotropic *punaruskea, heikosti anisotrooppinen*	10	15	0	15	11	12	0	17	(p)
3B	15	blackish brown, weakly anisotropic *mustanruskea, heikosti anisotrooppinen*	23	12	0	5	16	15	0	9	
3B	15	yellowish brown, isotropic *kellanruskea, isotrooppinen*	17	6	0	16					
3K	20	brown, weakly anisotropic *ruskea, heikosti anisotrooppinen*	25	13	0	2	13	1	26	0	
3K	37	blackish brown, isotropic *mustanruskea, isotrooppinen*	25	13	0	2	20	2	14	4	
3K	37	black, weakly anisotropic *musta, heikosti anisotrooppinen*	24	11	0	5					
3K	53	yellowish brown, isotropic *kellanruskea, isotrooppinen*	24	11	0	5	20	6	4	10	
3K	53	black, isotropic mottle *musta, isotrooppinen täplä*					18	4	12	6	
3L	36	yellowish brown, isotropic *kellanruskea, isotrooppinen*	25	6	0	9	20	6	0	14	
3M	33	yellowish brown, isotropic *kellanruskea, isotrooppinen*	24	13	0	3	22	13	0	5	
Mean value *Keskiarvo*			21	11	0	8	17	6	7	10	

4. DISCUSSION

The most important properties of the ortstein horizons in the podzols were found to be due to the physical and chemical changes taking place in the soil which bring about cementation. The cutan which covers the skeletal grains in ortstein was found to be responsible for the cemented structure, and to have filled up the pore space, increased the dry bulk density and reduced the hydraulic conductivity. A change in the moisture conditions and the movement of water which is responsible for translocating material, has had an effect on the course of soil formation and hence also on the further development of ortstein and on the growing conditions of the site. Cutan is primarily composed of organic complexes and inorganic hydroxides of aluminium, iron and silicon, which form a coating on the surface of the crystalline minerals. Cutan is thus also responsible for the most important chemical properties of ortsteins, such as the low fertility. The cementing of the ortstein horizons has taken place as a result of the cutan developing into a rigid form, mainly due to the seasonal changes in the pH-Eh conditions brought about by fluctuations in the ground water table.

Part of the ortstein horizons examined in this study fulfilled the requirements of the ortstein subgroup in humus iron podzols (group Humo-Ferric Podzols) of the Canadian classification system (Canada Soil Survey Committee 1978, Strong & Limbird 1981). In the soils of this group, the Bfh horizon is over 10 cm thick (or the Bf layer over 5 cm thick), has an organic carbon content of 0.5—5 %, and the total amount of pyrophospate-extractable iron and aluminium at least 0.4 % (sandy soils). In addition, the ortstein horizons are strongly cemented, over 3 cm thick and they occur in at least one third of the lateral extent of the pedon. Owing to the strong cementation, it is usually impossible to crush the hardened soil by hand.

The three morphological forms of cemented horizons presented by Moore (1976) were present in the study area: a platy structure following glacifluvial beds, a massive structure, and a reticulate pattern. In the bedded soils the formation of ortstein brings about platy structures (Fig. 2b). The different types of platy structures are usually a result of different grain sizes: fine-textured sand beds are usually more rigidly cemented than coarse-textured gravel beds. However, strongly cemented thin gravelly beds, 1—3 cm thick, occurred in places. This is presumably due to the fact that the ortstein developed in an upwards or downwards direction from fine-textured beds under favourable pH-Eh conditions. A massive structure occurs in soils where there is no clear bedded structure. This type is the most clearly developed in coarse grained soils. Poorly discernible reticulated cementation occurred in places where podzolization had progressed to a substantial depth.

In the study areas, ortstein had developed into a thick layer in coarse sands where podzolization had been intensive. According to the results of earlier studies, ortstein develops the most pronouncedly in acid soils in sandy areas (Wang et al. 1978). When looking at the results of this study it should be borne in mind that the organic material was removed from the samples before mechanical analysis. In this case the cutan was also decomposed (dissolved) and is not included in the particle size distribution of the primary material. In undisturbed samples the cutan coats the skeletal grains and increases their size.

The level of the ground water table varied in the study areas according to the weather and the time of year. This variation had brought about localized reducing and oxidising conditions in the soil, which appeared as mottling (see Fig. 2). In addition, the poor hydraulic conductivity of the soil as a result of ortstein formations increased the risk of waterlogging and further promotes the development of cementation (Karavayeva 1968). The reduced hydraulic conductivity may also restrict the movement of water in an upwards direction, thus deteriorating the uptake of water by plants (cf. Lambert & Hole 1971, Nikitin 1980).

McKeaque & Guertin (1982) have studied the fabric of ortstein in thin sections using Brewer's terminology (Brewer 1960, 1964 and 1979). They arrived at a fabric class of plectic for ortstein formations, this class being for a thick layer of cutan coating the skeletal grains. In this study the ortstein samples were, as opposed to the abovementioned, in most cases chlamydic, the cutan layer being thinner. Only the most strongly cemented samples had a clearly plectic fabric. This difference is mainly due to the low level of fine material (silt and clay) in the samples. In addition, drying the samples (at 105 °C) appeared to have caused the cutan to shrink and thus change the fabric class. Shrinking cracks are clearly visible in Figure 6a.

The properties of cutan closely resemble those of allophanic (non-crystalline) clay, which also exhibits a considerable amount of shrinkage on drying (Warkentin & Maeda 1974). The pellets observed in the thin sections have presumably become separated from the cutan that has earlier coated the skeletal grains. Their similar composition also supports this supposition. The cutan in the most ridigly cemented ortstein horizons has developed into a mottled structure, indicating that there are fluctuations in the level of the water table and changes in the aeration status. The most clearly discernible mottles occured in reticulated forms of ortstein, which have presumably been formed under moister conditions than those for other forms of ortstein. Large-sized indistinct mottles were found in cementations formed from sand with a uniform particle size distribution (Fig. 2a). Mottles have also been found to frequently occur as concentric concretions. These are considered to have been formed as a result of varying redox conditions (Sokolova & Polteva 1968, Childs 1975, Arshad & Arnaud 1980).

When the thermogravimetric curves for ortstein are compared with those for cemented fragipan, which is more easily slakable in water, it can be seen that there are many differences between the two (cf. DeKimpe et al. 1971). The greatest loss in weight in the case of ortstein is the burning of the organic matter (200—470 °C) and for fragipan the loss of hydroxyl ions from the clay minerals (470—1 000 °C).

The spectra of the air-dry ortstein samples were similar in infrared analysis to those of silica gel (where Si:Al is about 1) under acidic conditions (cf. Luciuk & Huang 1974, Farmer et al. 1979). The IR spectra for allophanic clays are also very similar (Lai & Swindale 1969, Warkentin & Maeda 1974, Wells et al. 1974, Ross 1980). The imogolite found in the IR analyses has earlier been observed in the B horizon of podzols in e.q. Scotland and British Columbia, and in brown forest soils developed in pyroclastic material (Ross 1980).

The cutan in the ortstein was amorphic, i.e. weakly crystalline, which is also a general feature in the ordinary fine material of non-cemented podzols (cf. Ross 1980). In studies concerning the phases of soil formation in podzolisation, imogolite-type material and iron oxides have been found to represent the early stages (Anderson et al. 1982). The absence of imogolite in the ortstein samples investigated here thus indicates that they are advanced forms of podzolization.

On the basis of the slaking experiments carried out with various extractants, the component which cements the ortstein and holds it together consists of amorphic compounds of aluminium, iron and possibly silicon. The major portion of these were found to be organic complexes, and the rest inorganic compounds. It has earlier been found that of these two components, organic complexes are the most important from the point of view of the cemented bindings (Miles et al. 1979). In comparison to uncemented podzol soils, ortstein soils contain much more extractable aluminium and iron (cf. Petersen 1976). However, the amount of extractable aluminium and iron can increase to a fairly high level in Humo-Ferric podzols containing predominantly fine material, without cementation developing in the soil (Nicholson & Moore 1977). Cementation is thus mainly due to the nature of the amorphic material and not at all to the amount of such material in the soil.

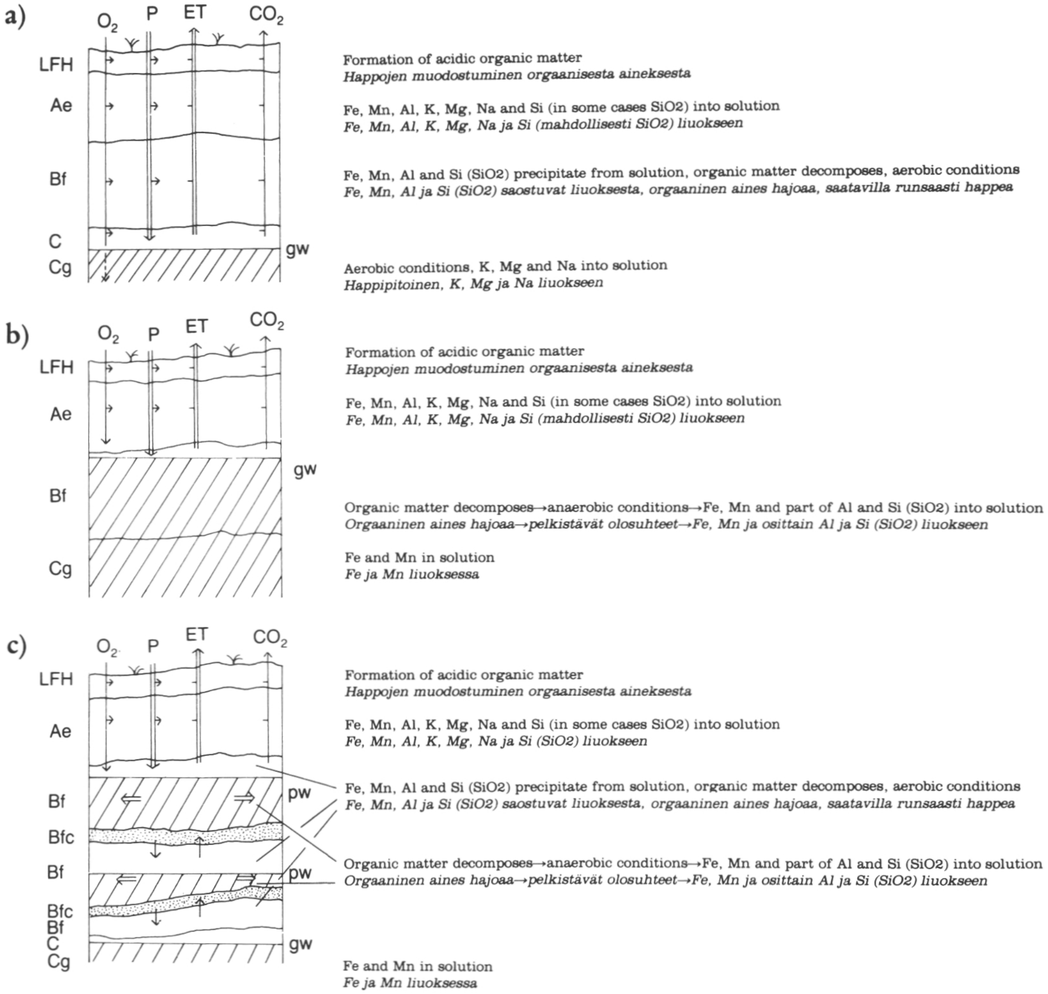
According to the results of the SEM-

EDS analyses, the composition and density of the cutan varied considerably, the most important elements being aluminium, iron and silicon. Thus the composition of the binding cutan can vary. Microanalyses carried out on the cutan of the ortstein horizons in podzols have also earlier shown that the composition of cutan is variable (McKeaque & Wang 1980). According to the above reference, the cementing agent is mainly composed of organic complexes of aluminium, and the importance of iron is, as was apparent in this study, only slight. Page and Berrier (1983) showed that the cutan coating the grains in the ortstein contains varying amounts of organic binding agents, hydroxides and clay minerals.

The formation of a cementation can be interpreted as a chemical process on the basis of its structure. The ortstein was mainly formed form skeletal grains belonging to the sand fraction, and a binding of cutan. The packing of the grains in the ortstein is relatively loose, and hence cementation is not a result of the consolidation of the soil due, for instance, to the weight of the ice and resulting increase in the forces of attraction between the grains (cf. Aario 1971). Other corresponding physical features are the coarseness of the skeletal grains and the non-coherence of repacked ortstein which had been broken up. The slaking tests, in which the ortstein was slaked by extracting the cutan between the skeletal grains, gave the strongest support for the hypothesis concerning the role of chemical processes in the formation of ortstein.

The pH-Eh conditions, which regulate the solubility of different materials, and the movement of water, which translocates material between the horizons, are the most important factors from the point of view of the formation of ortstein horizons in podzolic soils (Fig. 13). Humic and other acids produce a very low pH in the upper part of the profile. This, together with the high Eh due to the presence of air, results in weathering. Various forms of bacterial activity promote this process (e.g. Carlson et al. 1980, Foscolos & Kodama 1981). The weathered material is gradually carried down into the soil by the flow of water, the material passing through an environment in which the pH is increasing and the Eh decreasing. The change in these conditions results in the precipitation of the material translocated from the A horizon as a coating of cutan on the skeletal grains. This is a very complicated process and a large number of studies have been carried out on the phenomenon (e.g. Wright & Schnitzer 1963, Khan 1969, Farmer et al. 1980, Anderson et al. 1982). The precipitated cutan, owing to the reduced hydraulic conductivity of the soil, makes the conditions wetter and creates favourable conditions for the formation of compounds in the cutan which rigidly bind the skeletal grains of the ortstein. This process appears to presuppose fluctuations in the water conditions, which alternately create oxidising and reducing conditions in the horizon where the ortstein is formed. Anderson et al. (1982) found that a thin iron pan is formed at the interface between seasonally reducing conditions above and permanently oxidising conditions below. This takes place in the final stage of podzolization (stage c). According to Smith (1976), the better aeration (i.e. a more oxidising environment) in the soil below the pan was due to the diffusion of air into the soil under the pan via occasional fissures, followed by lateral diffusion below the pan. This type of hypothesis is well applicable to the thin, stongly cemented layers of the Bfc horizon of pedon 2A (marked with a dashed line in Fig. 3) and the platy horizon shown in Fig. 2b. The cemented part in both of these is in the form of thin layers, with coarse-grained material containing large pore spaces underneath that represent a highly aerobic environment.

Owing to the poor hydraulic conductivity of the iron pan layers, the soil above the layers freqently contains perched water (Fig. 13c). There are thus places in the soil where the pH-Eh conditions are such that cementation can again develop and form ortstein. The ortstein which develops in coarse sandy soils of equal grain size can form a uniform thick layer if the ground water level is high (cf. Karavayeva 1968). The conditions most favouring the development of this type of ortstein were found in the area around pedon 3K, where the fluctuations in the ground water table were also the greatest. Presumably it is just such fluctuations in the level of the ground or perched water that bring about the fluc-



Formation of acidic organic matter
Happojen muodostuminen orgaanisesta aineksesta

Fe, Mn, Al, K, Mg, Na and Si (in some cases SiO2) into solution
Fe, Mn, Al, K, Mg, Na ja Si (mahdollisesti SiO2) liuokseen

Fe, Mn, Al and Si (SiO2) precipitate from solution, organic matter decomposes, aerobic conditions
Fe, Mn, Al ja Si (SiO2) saostuvat liuoksesta, orgaaninen aines hajoaa, saatavilla runsaasti happea

Aerobic conditions, K, Mg and Na into solution
Happipitoinen, K, Mg ja Na liuokseen

Formation of acidic organic matter
Happojen muodostuminen orgaanisesta aineksesta

Fe, Mn, Al, K, Mg, Na and Si (in some cases SiO2) into solution
Fe, Mn, Al, K, Mg, Na ja Si (mahdollisesti SiO2) liuokseen

Organic matter decomposes→anaerobic conditions→Fe, Mn and part of Al and Si (SiO2) into solution
Orgaaninen aines hajoaa→pelkistävät olosuhteet→Fe, Mn ja osittain Al ja Si (SiO2) liuokseen

Fe and Mn in solution
Fe ja Mn liuoksessa

Formation of acidic organic matter
Happojen muodostuminen orgaanisesta aineksesta

Fe, Mn, Al, K, Mg, Na and Si (in some cases SiO2) into solution
Fe, Mn, Al, K, Mg, Na ja Si (SiO2) liuokseen

Fe, Mn, Al and Si (SiO2) precipitate from solution, organic matter decomposes, aerobic conditions
Fe, Mn, Al ja Si (SiO2) saostuvat liuoksesta, orgaaninen aines hajoaa, saatavilla runsaasti happea

Organic matter decomposes→anaerobic conditions→Fe, Mn and part of Al and Si (SiO2) into solution
Orgaaninen aines hajoaa→pelkistävät olosuhteet→Fe, Mn ja osittain Al ja Si (SiO2) liuokseen

Fe and Mn in solution
Fe ja Mn liuoksessa

Fig. 13. Effect of ground water and perched water on the geochemistry of the soil. Arrows indicate the flow of oxygen (O_2) and carbon dioxide (CO_2) in the soil water (P = precipitation, ET = evapotranspiration, gw = ground water, pw = perched water). Situation a) the ground water level deep down in the C horizon, b) ground water level high up in the B horizon, c) layers of perched water in the bedded soil.

Kuva 13. Pohjaveden ja orsiveden vaikutus maannoksen geokemiaan. Kuvassa on nuolilla merkitty veden hapen (O_2) ja hiilidioksidin (CO_2) virtaukset (P = sadanta, ET = haihdunta, gw = pohjavesi, pw = orsivesi). Tilanne a) pohjavesi syvällä C-horisontissa, b) pohjavesi korkealla B-horisontissa, c) orsivesikerroksia kerroksellisessa maassa.

tuation in oxidising and reducing conditions, which are characteristic of the formation of an iron pan layer, over a wide area in the soil profile. The large mottles found in the pedons are indications of such fluctuations in soils containing ortstein horizons. In this case, cementation of the ortstein does not presuppose that there are porous and oxidising fissures deeper in the soil, because the underlying soil can be merely till.

Cementation of the ortstein has taken place as a result of the conversion of the cutan between the skeletal grains into a rigid form when exposed to the conditions mentioned above. According to Anderson et al. (1982), the thin iron pan layer is mainly cemented together by iron oxides, and to a lesser extent by organic complexes. On the basis of the slaking tests and X-ray microanalyses carried out in this study, the ortstein differed from iron pans in that it was primarily cemented together by inorganic hydroxides and amorphic organic complexes of aluminium, iron and silicon. However, the composition of the cutan bringing about cementation in the ortstein varied considerably, e.g. the Al:Fe ratio varying between 10:1 to 1:2.

The ortstein horizons in the podzol soils held together well and retained their strength when both wet and dry. In its rigidist form the layer resembled frozen soil and it was difficult to excavate with a spade. Breaking up this type of ortstein is not even easy by mechanical means. Freezing of soil water during the winter does not appear to prevent the formation of ortstein nor its retention after it has been formed. Ortstein horizons are thus physically very stable. Reducing conditions can, over the long term, bring about the chemical weakening and gradual thinning of ortstein horizons (Karavayeva 1968). Such conditions may arise if the fluctuations in the level of the ground or perched water result in the soil above the ortstein layer becoming waterlogged for a long period, as was observed in this study.

The significance of ortstein from the point of view of plant growth is variable. The effect is usually indirect, the ortstein directing the flow of the ground water and affecting the movement of the surface water. If there is already too much water for the plants (poor aeration), then the effect will be negative during wet periods as the poor hydraulic conductivity of the ortstein further accentuates the wetness of the soil. If, on the other hand, the soil is too dry, then the effect will be positive. It is quite clear from this that ortstein has an effect on the site properties and, through this, on the tree stand and vegetation cover. Ortstein may also have played a role in the paludification of forest land in the study area, because cementation weakens the hydraulic conductivity of the soil. In this case, water-logging starts from the perched water formed above the ortstein horizons. This is further accentuated as a result of gleying, which brings about an increase in silicon in the cutan (Zaydelman et al. 1979). Furthermore, water-logging makes the tree stand more susceptible to wind throw. The soft soil lying above the ortstein horizons was found to have acted as a ripping zone in the Keski-Merkkivaara area as the trees fell during the autumn gale in 1982.

As is often the case with other types of very acid soil, the ortstein horizons studied here were low in nutrients. In comparison to the analysis results for the uncemented B horizons of soils developing on sand (Aaltonen 1935, Urvas 1973, Urvas & Erviö 1974) or poor quality cultivated land (Kurki 1982), the amount of exchangeable cations was low, the C/N ratio high, and the base saturation low. In addition, cemented ortstein horizons affect the aeration of the soil and may act as a mechanical barrier to the growth of tree roots.

Ortstein horizons in ploughed forest areas have, owing to their hardness, an effect on the actual ploughing itself. The furrows made in ploughed forest areas situated close to the study areas only went down as far as the upper part of the ortstein layer as a result of cementation of the soil. Some signs of erosion were also visible in the forest areas where the surface soil had been treated. This was due to the passage of water over the ortstein layer.

One important factor from the point of view of plant growth is the turning over, onto the top of the soil, of the B horizon of ortstein soils during soil preparation. Cemented material contains very low levels of nutrients and has been shown to be toxic in some growth experiments (cf. Prusinkiewicz & Krzemien 1974). In the case of forest ploughing, the cutan on the surface of the skeletal grains, which contains high levels of iron and aluminium, acts as the main source of exhangeable plant nutrients in the growing substrate. However, there is very little information available about wheather this has a harmful effect on transplantated tree seedlings or wheather the ortstein differs from the uncemented soil of the B horizon in this respect (cf. Aaltonen 1942). According to the results of a preliminary study (Ritari, A., unpublished data), however, the levels of aluminium and iron appear to be lower in the uncemented B horizons of podzols than in the cemented ortstein horizons examined in this study.

REFERENCES

Aaltonen, V.T. 1935. Zur Stratigraphie des Podzolprofils besonders von Standpunkt der Bodenfruchtbarkeit. I. Seloste: Valaisua podzolimaan kerrallisuuteen silmälläpitäen varsinkin maan viljavuutta. I. Commun. Inst. For. Fenn. 20(6):1—150.

— 1942. Muutamia kasvukokeita puuntaimilla. Referat: Einige Vegetationsversuche mit Baumpflanzen. Acta For. Fenn. 50(6):1—33.

Aario, R. 1971. Consolidation of finnish sediments by loading ice sheets. Bull. Geol. Soc. Finland 43:55—65.

Altemüller, H-J. & Klinge, H. 1964. Micromorphologische Untersuchungen über die Entwicklung von Podsolen im Amazonasbecken. In: Jongerius, A. (ed.). Soil Micromorphology. Ontario. P. 295—305.

Anderson, H.A., Berrow, M.L., Farmer, V.C., Hepburn, J.D. & Walker, A.D. 1982. A reassesment of podzol formation prosesses. J. Soil Sci. 33:125—136.

Arshad, M.A. & Arnaud, R.J. 1980. Occurrence and characteristics of ferromanganiferous concretions in some Saskatchewan soils. Can. J. Soil Sci. 60:685—695.

Bates, R.L. & Jackson, J.A. 1980. Glossary of Geology, 2nd ed., Virginia.

Brewer, R. 1960. Cutans: Their definition, recognition and interpretation. J. Soil Sci. 11:280—292.

— 1964. Fabric of Mineral Analysis of Soils, New York. 470 p.

— 1979. Relationships between particle size, fabric and other factors in some Australian Soils. Aust. J. Soil. Res. 17:29—41.

Bullock, B. 1974. The use of micromorphology in the new system of soil classification for England and Wales. In: Soil Microscopy. Ontario. P. 607—631.

Bunting, B.T. & Fedoroff, N. 1974. Micromorphological aspects of soil development in the Canadian High Arctic. In: Soil Microscopy. Ontario. P. 350—365.

Campell, A.S., Mitchell, B.D. & Bracewell, J.M. 1968. Effects of particle size, pH and organic matter on thermal analysis of allophane. Clay Minerals 7:451—454.

Canada Soil Survey Committee 1978. The system of soil classification for Canada. Ottawa. 255 p.

Carlson, L., Vuorinen, A., Lahermo, P. & Tuovinen, O.H. 1980. Mineralogical, geochemical and microbiological aspects of iron deposition from groundwater. In: Biogeochemistry of Ancient and Modern Environments. Australian Acad. Sci. P. 355—364.

Childs, C.W. 1975. Composition of iron-manganese concretions from some New Zealand soils. Geoderma 13:141—152.

Davidson, D.T. 1965. Penetrometer Measurements. In: Black et al. (ed). Methods of Soil Analysis, Part 1, p. 472—484. Am. Soc. Agron. Inc., Madison, Wisc.

De Kimpe, C.R., Baril, R.W. & Rivard, R. 1971. Characterization of a toposequence with fragipan; the Leeds-Ste. Marie-Brompton series of soils, province of Quebec. Can. J. Soil Sci. 52:135—150.

Elonen, P. 1971. Particle-size analysis of soil. Acta Agr. Fenn. 122. 122 p.

Farmer, V.C., Fraser, A.R. & Tait, J.M. 1979. Characterization of the chemical structures of natural and synthetic aluminosilicate gels and sols by infrared spectroscopy. Geochim. Cosmochim. Acta 43:1417—1420.

— , Russell, J.D. & Berrow, M.L. 1980. Imogolite and protoimogolite allophane in spodic horizons: evidence for a mobile aluminium silicate complex in podzol formation. J. Soil Sci. 31:673—684.

Foscolos, A.E. & Kodama, H. 1981. Mineralogy and chemistry of Arctic Desert soils on Ellef Ringnes Island, Arctic Canada. Soil Sci. Soc. Am. J. 45: 987—993.

Guertin, R.K. 1981. Clod method to determine the hydraulic conductivity. In: McKeaque, J.A. (ed.) Manual on Soil Sampling and Methods of Analysis. Agriculture Canada, Ottawa, Ont. P. 47—48.

Hallmark, C.T. & Smeck, N.E. 1979. The effect of extractable aluminium, iron, and silicon on strength and bonding of fragipans of northeastern Ohio. Soil Sci. Soc. Am. J. 43:145—150.

Halonen, O., Tulkki, H. & Derome, J. 1983. Nutrient analysis methods. Metsäntutkimuslaitoksen tiedonantoja 121. Helsinki. 28 p.

Hyyppä, E. 1966. The Late-Quaternary land uplift in the Baltic sphere and the relation diagram of the raised and tilted shore levels. Ann. Acad. Sci. Fenn. 90:153—168.

Jauhiainen, E. 1972. Structure, C-14 age and environment of an iron humus podzol under a peat layer. Ann. Acad. Sci. Fenn. 112:1—16.

Karavayeva, N.A. 1968. Formation and evolution of cemented ortstein horizons in the Taiga zone. 9th Intern. Cong. Soil Sci. IV:451—458.

Khan, S.U. 1969. Interaction between the humic acid fraction of soils and certain metallic cations. Soil Sci. Soc. Am. Proc. 33:851—854.

Kurki, M. 1982. Suomen peltojen viljavuudesta III. Viljavuuspalvelu Oy:ssä vuosina 1955—1980 tehtyjä viljavuustutkimusten tuloksia. Summary: On the fertility of Finnish tilled fields in the light of investigations of soil fertility carried out in the years 1955—1980. Helsinki. 181 p.

Lai, Sung-Ho & Swindale, L.D. 1969. Chemical properties of allophane from Hawaiian and Japanese soils. Soil Sci. Soc. Am. Proc. 33:804—808.

Lambert, J.L. & Hole, F.D. 1971. Hydraulic properties of an ortstein horizon. Soil Sci. Soc. Amer. Proc. 35:785—787.

Lavkulich, L.M. 1977. Methods Manual for Pedology Laboratory. Vancouver, B.C. 224 p.

Lehto, J. 1978. Käytännön metsätyypit. 3. painos. Helsinki. 98 p.

Luciuk, G.M. & Huang, P.M. 1974. Effect of monosilicic acid on hydrolytic reactions of aluminium. Soil Sci. Soc. Amer. Proc. 38:235—244.

MacKenzie, K.C. (ed) 1970. Differential Thermal Analysis. Parts 1—2, 775 + 607 p. London.

McKeaque, J.A. (ed.) 1981. Manual on Soil Sampling and Methods of Analysis. Can. Soc. Soil Sci. 212 p.

— & Guertin, R.K. 1982. Fabrics of some Canadian soils in relation to particle size and other factors. Soil Sci. 133:87—102.

— & Protz, R. 1980. Cement of duric horizons, micromorphology and energy dispersive analysis. Can. J. Soil Sci. 60:45—52.

— & Sprout, P.N. 1975. Cemented subsoils (duric horizons) in some soils of British Columbia. Can. J. Soil Sci. 55:189—203.

— & Wang, C. 1980. Micromorphology and energy dispersive analysis of ortstein horizons of podzolic soils from New Brunswik and Nova Scotia, Canada. Can. J. Soil Sci. 60:9—21.

Miles, N.M., Wang, C. & McKeaque, J.A. 1979. Chemical and clay mineralogical properties of ortstein from the Maritime provinces. Can. J. Soil Sci. 59:287—299.

Moore, T.R. 1976. Sesquioxide-cemented soil horizons in northern Quebec: Their destribution, properties and genesis. Can. J. Soil Sci. 56:333—334.

Munsell 1975. Soil Color Charts, Munsell Color, Baltimore, Maryland.

Naturgeografisk regionindelning av Norden 1977. NU B 1977:34. Stockholm. 130 p.

Nicholson, H.M. & Moore, T.R. 1977. Pedogenesis in a subarctic iron-rich environment: Schefferville, Quebec. Can. J. Soil Sci. 57:35—45.

Nikitin, Ye. D. 1980. Migration of iron in the soils of Taiga forest landscapes. Soviet Soil Sci. 9:23—33.

Petersen, L. 1976. Podzols and podzolization. Copenhagen. 293 p.

Prusinkiewicz, Z. & Krzemién, K. 1974. Toxic effect of free aluminium from the ortstein horizon of a podzol on the growth of Scots pine (*Pinus sylvestris* L.) seedlings. Roszniki Gleboznawcze 25:207—222.

Ross, G.J. 1980. Mineralogical, physical and chemical characteristics of amorphous constituents in some pedologic soils from British Columbia. Can. J. Soil Sci. 60:31—43.

Saarnisto, M. 1981. Holocene emergence history and stratigraphy in the area north of the Gulf of Bothnia. Ann. Acad. Sci. Fenn. 130:1—42.

Smith, K.A. 1976. Aeration status of upland soils. Forestry Commission Report on Forest Research 1976:56—59.

Smith, R.T. & Atkinson, K. 1975. Techniques in Pedology, a handbook for environmental and resource studies. London. 213 p.

Sokolova, T.A. & Polteva, R.N. 1968. The study of ironmanganese concretions from a strongly podzolic soil profile. 9th Intern. Congr. Soil Sci. IV:459—466.

Strong, W.L. & Limbird, A. 1981. A key for classifying soils to the subgroup level of the Canadian System of Soil Classification. Can. J. Soil Sci. 61:285—294.

Urvas, L. 1973. Rovaniemi. Summary: Soil map of Rovaniemi. Ann. Agric. Fenn. 12. Suppl. 2, 9 soil maps.

Urvas, L. & Erviö, R. 1974. Metsätyypin määräytyminen maalajin ja maaperän kemiallisten ominaisuuksien perusteella. Summary: Influence of the soil type and the chemical properties of soil on the determining of the forest type. J. Sci. Agric. Soc. Finland 3:307—319.

Wang, C., Beke, G.J. & McKeaque, J.A. 1978. Site characteristics morphology and physical properties of selected orstein soils from the Maritime Provinces. Canad. J. Soil Sci. 58:405—420.

Warkentin, B.P. & Maeda, T. 1974. Physical properties of allophane soils from the West Indies and Japan. Soil Sci. Soc. Am. Proc. 38:372—378.

Wells, N., Childs, W.C. & Downes, C.J. 1977. Silica springs, Tongariro National Park, New Zealand — analyses of the spring water and characterisation of the alumino silicate deposit. Geochim. Cosmochim. Acta 41:1497—1506.

Wright, J.R. & Schnitzer, M. 1963. Metallo-organic interactions associated with podzolization. Soil Sci. Soc. Am. Proc. p. 171—176.

Zaydelman, F.R., Nikiforova, A.S. & Sanzharov, A.I. 1979. Cutans and ortstein of nongleyed and gleyed sodpodzolic soils on a calcareous moraine and their diagnostic importance. Soviet Soil Sci. 2:1—8.

Total of 62 references

SELOSTE

Ortsteinin ominaisuuksista ja muodostumisesta eräissä Rovaniemen podsolimaannoksissa

Johdanto

Ortsteinilla tarkoitetaan kovaksi iskostunutta podsolimaannoksen B-horisonttia. Suomessa sen esiintymiseen on kiinnittänyt huomiota mm. Aaltonen (1935). Tässä käytetyn kanadalaisen maannosluokittelujärjestelmän mukaisesti kovettuneen ortsteinkerroksen tulee olla vähintään 3 cm paksu ja sen on sijaittava maannoksen spodisessa eli rikastuneessa osassa. Maakokkareet eivät saa pehmetä vedessä. Ortsteinin sideaineksen on todettu sisältävän pääasiassa huuhtoutuneita raudan ja alumiinin oksideja eli seskvioksideja.

Ortstein-horisontit ja niiden syntytavan selvittäminen on nykyään oleellinen osa maannosten kuvaus- ja luokitustyötä. Kovettuman syntyminen on katsottu useimmissa tapauksissa kemialliseksi tapahtumaksi, jossa pääasiassa A-horisontista uuttuneet aineet ovat saostuneet B-horisonttiin iskostavaksi sideainekseksi runkorakeiden pinnoille. Prosessiin vaikuttavia tekijöitä ovat mm. maan mineraloginen koostumus, pH-Eh -olosuhteet, maassa olevan veden koostumus ja liikkeet sekä kasvipeite.

Paitsi taksonomisen luokittelutyön kannalta, ortsteinilmiöllä on merkitystä etenkin silloin, kun kovettuma muuttaa veden virtausta pintamaassa ja vaikuttaa sitä kautta kasvualustan ominaisuuksiin. Ravinteisuudeltaan ortsteinin on todettu eräissä tutkimuksissa olevan huonon ja liukenevan alumiinpitoisuuden ylittävän tehtyjen kasvukokeiden perusteella jopa myrkyllisyystason puuntaimille.

Tämän tutkimuksen tarkoituksena oli selvitellä Pohjois-Suomessa varsin yleisesti tavattavien ortstein-horisonttien (kuva 2a ja b) ominaisuuksia ja muodostumista käyttäen apuna nykytekniikan mahdollistamia uusia sekä kovettuneiden maannosten tutkimisessa aikaisemminkin käytettyjä menetelmiä. Menetelmien valinnassa pidettiin tärkeänä mahdollisuutta vertailla saatavia tuloksia mm. kanadalaisten tutkijoiden vastaaviin tuloksiin.

Aineisto ja menetelmät

Tutkimuksen aineisto kerättiin ortstein-horisontteja sisältäviin maannoksiin tehdyistä kuopista, joista neljästä tehtiin tarkimmat kuvaukset (kuva 3 ja liite 2). Näytteet otettiin seuraavasti:

1) sylintereihin otetut näytteet, joista määritettiin maan tilavuuspaino ja kyllästyneen maan vedenjohtavuus
2) irtonäytteet muovipusseihin, joista määritettiin lajitekoostumus, ravinneominaisuudet ja muita kemiallisia ominaisuuksia
3) häiriintymättömät kokkarenäytteet, joista tehtiin fysikaalisia kokeita ja valmistettiin ohuthieet ja kiillotetut näytenapit mikroanalyysejä varten.

Muut paitsi kokkarenäytteet kattavat neljä tutkimusten kohteena ollutta kuoppaa.

Tutkimusalue (66° 27'P, 25° 15'I) sijaitsee n. 25 km länteen Rovaniemen kaupungista (kuva 1). Vuoden keskilämpötilaksi on alueelta n. 30 km:n päässä sijaitsevalla ilmastoasemalla (Apukka) saatu 0,2 °C ja vuotuiseksi sademääräksi 520 mm ajanjaksolla 1951—1981. Pysyvä lumipeite alueella muodostui keskimäärin 2.11. ja suli 8.5. Tutkimusalue sijaitsee 100—160 m nykyisen merenpinnan yläpuolella. Mannerjää perääntyi alueelta n. 9 500 vuotta sitten. Vedenpinta ulottui näillä seuduilla korkeimmillaan 210—215 metrin tasolle, josta merkkeinä ovat huuhtouneet rantakivikot korkeimpien vaarojen rinteillä.

Tutkimusalueista Kuusikkoselän kaakkoisrinne oli tuoreen kankaan *Vaccinium myrtillus* -tyyppiä. Kaksi muuta kohdetta, Kuusikkoselän luoteisrinne ja Keski-Merkkivaaran eteläosat, olivat kuivahkon kankaan *Empetrum-Vaccinium* -tyyppiä. Maannostyypiltään tutkitut alueet olivat kanadalaisen luokittelun mukaan useimmissa tapauksissa humus-rautapodsoleita (Humo-Ferric Podsols).

Rakeisuusmääritykset suoritettiin yhdistetyllä seulonnalla ja Andreanssenin pipettimenetelmällä (Elonen 1971). Tilavuuspainomääritykset tehtiin messinkisylintereihin otetuista näytteistä. Maannoshorisonttien painumalujuus määritettiin Proctor-neulalla. Kyllästyneen maan vedenjohtavuutta tutkittiin Quertinin (1981) kehittelemällä menetelmällä.

Ortsteinin rakennetta ja sidoksia tutkittiin ohuthieistä. Kuvauksessa käytettiin Brewerin (1960, 1964, 1979) terminologiaa ja luokittelua. Kokonaisalkuanalyysi tehtiin sulatemenetelmällä röntgenfluoresenssilaitteistolla. Savifraktiota tutkittiin röntgendiffraktion avulla. Differentiaalitermisellä analyysillä selvitettiin eri lämpötiloissa tapahtuvia reaktioita ja termogravimetrisellä analyysillä näytteiden painon muuttumista lämpötilaa nostettaessa. Ortstein-näytteiden hienoaineksen sidoksia tutkittiin infrapuna-analyysin avulla.

Vaihtuvat ravinteet määritettiin ammoniumasetaatti-uuttoa käyttäen atomiabsorptiospektrofotometrillä (Halonen, Tulkki & Derome 1983). Uuttuvien kationien määrä tutkittiin ditioniittisitraatti-bikarbonaatti -liuoksesta, happamasta oksalaattiliuoksesta ja natriumpyrofosfaattiliuoksesta (McKeaque 1981, Lavkulich 1977). Luonnontilaisten ortsteinkokkareiden hajoamista selvitettiin em. liuoksissa sekä tislatussa vedessä. Ortsteinin runkorakeiden välistä ainesta analysoitiin myös pyyhkäisyelektronimikroskooppiin liitetyllä mikroanalysaattorilla.

Tulokset

Ortsteinin havaittiin kehittyneen maakerroksiin, joiden lajitekoostumus oli pääosin hiekkaa. Yleisin ortsteinin esiintymismuoto oli levymäinen maan kerrosrakenteita seuraava tyyppi (kuva 2b). Lisäksi tavattiin massiivista ja lievästi verkkomaista esiintymää. Eri tyyppien syntyminen näyttää johtuvan pääasiassa maaperän kerroksellisuudesta ja muista rakenteista. Kovettuneiden ortsteinkerrosten tilavuuspaino oli ympäröivää maata suurempi huokostilan jäädessä pienemmäksi kuin muissa kerroksissa. Lujimmillaan ortstein muistutti routaantunutta maata. Kovettuneimmat näytteet johtivat vettä huonosti, vaikka ne olivat kehittyneet karkeisiinkin maalajeihin. Tutkimusalueilla todettiin pohjavesiolosuhteiden vaihtelevan suuresti. Tästä oli aiheutunut maannokseen vaihtelevia hapettavia ja pelkistäviä olosuhteita, mikä näkyi syntyneenä täpläisyytenä (kuva 2a). Normaalia sateisempana kesänä (1981) pohjavesi tai orsivesi kohosi paikoin A-horisontin tasolle. Maannosten fysikaalisia ominaisuuksia on esitetty kuvissa 4 ja 5.

Valomikroskoopilla tarkasteltuna ortstein koostui mineraalirakeiden muodostamasta rungosta, runkorakeiden päällä ja välialueilla esiintyvästä side- eli kutaaniaineksesta ja huokostilasta. Sideainesta oli keskimäärin 13 %, enimmillään 20 % näytteiden poikkipinta-alasta, ja runkorakeisen välisistä tiloista se täytti noin kolmanneksen. Taulukossa 1 on esitetty ortsteinnäytteiden eri ainesosien osuudet ohuthieistä laskettuina. Kutaania tavattiin tasaisina peitteinä, pieninä palloina (pelletit) tai täplinä rakeiden välissä (kuvat 6a, b ja c). Tasaiset ja yhtenäiset peitteet olivat yleisimmin esiintyvä muoto.

Kovettuneissa ortsteinkerroksissa yleisin alkuaine oli pii, joskin sen osuus jäi pienemmäksi kuin ympärillä olevissa kovettumattomissa osissa (kuva 7). Sen sijaan maannosten alumiinin, raudan, fosforin ja mangaanin korkeimmat pitoisuudet tavattiin ortsteinin alueella. Ortsteinin hienoaines oli heikosti kiteistä ja sisälsi runsaasti orgaanista ainesta (kuva 8). Heikko kiteisyys näkyi selvästi röntgendiffraktiokäyrissä (kuva 8a) eri kidepintojen aiheuttamina vähäisinä heijastumina. Orgaanisen aineksen ja muiden amorfisten yhdisteiden aiheuttamat piirteet hallitsivat lämpöanalyyttisia tuloksia (kuva 8c ja 8d). Sen sijaan märkäpoltolla saatu orgaanisen hiilen kokonaismäärä jäi suhteellisen alhaiseksi (kuva 12). Kuvassa 9 esitetyistä tuloksista nähdään, että B-horisontin ortsteinvyöhykkeissä Fe:n, Al:n, Si:n ja Mn:n määrät olivat suurimmillaan. Varsinkin alumiinia ja rautaa uuttui näytteistä runsaasti. Ortsteinista lohkotut kappaleet pehmenivät ja lohkeilivat liuottimissa, jotka hajottivat sideaineksen orgaanisia tai epäorgaanisia amorfisia osia (kuva 10). Näissä sitovissa aineissa tärkeimpinä kationeina olivat alumiini ja rauta (taulukko 2). Sen sijaan tislatulla vedellä ei ollut vaikutusta ortsteinkokkareiden lujuuteen. Röntgenmikroanalyysit osoittivat selvimmin runkorakeita yhdistävän sideaineksen koostumuksen vaihtelun (kuva 11). Tärkeimmät alkuaineet sideaineksessa olivat alumiini, pii, rauta ja joissakin näytteissä mangaani (taulukko 3). Kasviravinteiden suhteen tutkittuja ortsteinnäytteitä voidaan pitää vähäravinteisina (kuva 12). Etenkin ravinteisuuden kannalta tärkeä emäskylläisyysaste oli alhainen.

Tulosten tarkastelu

Kovettuneiden ortsteinhorisonttien olennaisimmat fysikaaliset ominaisuudet liittyvät runkorakeita sitovan kutaanin aiheuttamiin muutoksiin maassa. Sideaines lujitti B-horisontissa maan vaihtelevan kovaksi muusta maannostuneesta alueesta poikkeavaksi kerrokseksi. Tutkituissa näytteissä sideaines täytti runkorakeiden välisiä tiloja keskimäärin kolmanneksella, minkä seurauksena maan kuivatilavuuspaino oli noussut ja vedenjohtavuus heikentynyt.

Monet ortsteinin kemiallisetkin ominaisuudet johtuvat lähes yksinomaan sideaineksesta, koska se peittää runkorakeita ja estää näiden kemiallisia vaikutuksia. Sideaines koostui saatujen tulosten perusteella amorfisista orgaanisista kompleksiyhdisteistä ja epäorgaanisista hydroksiyhdisteistä, joissa oli runsaasti alumiinia, rautaa, piitä ja joskus myös mangaania. Näiden yhdisteiden ja alkuaineiden vaikutus tuli esille myös maannoksen tämän osan ravinteisuudessa kutaanin toimiessa kasvien ioninvaihtajana maassa olevan nesteen välityksellä.

Ortsteinin runkorakeita sitovan aineksen muodostuminen edellyttää vaihtelevia ilmavuus- ja kosteusolosuhteita. Tämä on mahdollista tutkimusalueella tavatun pohjaveden pinnan vaihtelun seurauksena (kuva 13). Lisäksi runsaiden sateiden tai kevättulvien aikana ortsteinin päälle voi jäädä kovettuman edelleen kehittymistä nopeuttavia orsivesiä.

Ortsteinin merkitys kasvien kannalta on usein välillinen. Kovettunut kerros estää veden virtauksen pintamaasta alaspäin (kosteana aikana negatiivinen ja kuivana positiivinen vaikutus) ja toisaalta rajoittaa kapillaarista vedennousua juuristovyöhykkeeseen (kuivana aikana negatiivinen vaikutus). Mahdollisesti ortstein-ilmiöstä on aiheutunut eräissä tapauksissa metsämaan soistumista maan vedenjohtavuuden heikennyttyä pystysuunnassa.

Tutkimusalueella myrskytuhot olivat syksyllä 1982 suuria. Puiden kaatumisalttius saattoi osaltaan olla seurausta ortsteinkerroksen yläpuolisesta kosteasta repeämisvyöhykkeestä.

Käsiteltäessä ortsteinmaannoksia sisältäviä alueita metsäauralla tuloksena on runsaasti alumiinia sisältävän maan (näytteiden kokonaiskoostumus kuvassa 7, amorfisen sideaineksen koostumus kuvassa 8) nousu aurauspalteeseen ja puuntaimien juuristovyöhykkeeseen. Onko tällä seikalla mahdollisesti haitallisia vaikutuksia kasvien kannalta, ja eroaako ortstein sementoitumattomasta B-horisontin maasta tässä suhteessa, on vielä näissä oloissa puutteellisesti tutkittu.

Ritari, A. & Ojanperä, V. 1984. Properties and formation of cemented ortstein horizons in Rovaniemi, Northern Finland. Seloste: Ortsteinin ominaisuuksista ja muodostumisesta eräissä Rovaniemen podsolimaannoksissa. Commun. Inst. For. Fenn. 124:1—32.

ODC 114.36+114.441.2
ISBN 951-40-0668-2
ISSN 0358-9609

RITARI, A. & OJANPERÄ, V. 1984. Properties and formation of cemented ortstein horizons in Rovaniemi, Northern Finland. Seloste: Ortsteinin ominaisuuksista ja muodostumisesta eräissä Rovaniemen podsolimaannoksissa. Commun. Inst. For. Fenn. 124:1—32.

The ortstein layers in the podzols were found to be hard, frequently rather impermeable to water and to have a higher dry bulk density than other parts of the profile. Ortstein is the result of cutan forming a cemented covering over the skeletal grains in a particular layer of the soil profile. Cutan is primarily composed of inorganic and organic amorphous compounds of aluminium, silicon and iron.

Variations in the moisture and pH-Eh conditions of the soil are the main factors affecting the formation of the cemented layer. In some cases the formation of ortstein has resulted in the waterlogging of the surface soil and a change in the site conditions. In addition, cementing affects the end result of silvicultural measures carried out on the site, as well as the potential uses for the soil.

Correspondence: Aulis Ritari, The Finnish Forest Research Institute, Rovaniemi Research Station, Eteläranta 55, 96300 Rovaniemi 30, Finland.

ODC 114.36+114.441.2
ISBN 951-40-0668-2
ISSN 0358-9609

RITARI, A. & OJANPERÄ, V. 1984. Properties and formation of cemented ortstein horizons in Rovaniemi, Northern Finland. Seloste: Ortsteinin ominaisuuksista ja muodostumisesta eräissä Rovaniemen podsolimaannoksissa. Commun. Inst. For. Fenn. 124:1—32.

The ortstein layers in the podzols were found to be hard, frequently rather impermeable to water and to have a higher dry bulk density than other parts of the profile. Ortstein is the result of cutan forming a cemented covering over the skeletal grains in a particular layer of the soil profile. Cutan is primarily composed of inorganic and organic amorphous compounds of aluminium, silicon and iron.

Variations in the moisture and pH-Eh conditions of the soil are the main factors affecting the formation of the cemented layer. In some cases the formation of ortstein has resulted in the waterlogging of the surface soil and a change in the site conditions. In addition, cementing affects the end result of silvicultural measures carried out on the site, as well as the potential uses for the soil.

Correspondence: Aulis Ritari, The Finnish Forest Research Institute, Rovaniemi Research Station, Eteläranta 55, 96300 Rovaniemi 30, Finland.

Tilaan kortin kääntöpuolelle merkitsemäni julkaisut (julkaisun numero mainittava).

Please send me the following publications (put number of the publication on the back of the card).

Nimi
Name ______________________

____

____

Osoite
Address ______________________

____

____

____

Metsäntutkimuslaitos
Kirjasto/*Library*
Unioninkatu 40 A
SF-00170 Helsinki 17
FINLAND

Folia Forestalia ______________________________

____

____

Communicationes Instituti Forestalis Fenniae ______________________________

____

____

Huomautuksia
Remarks ______________________________

____

____

____

____

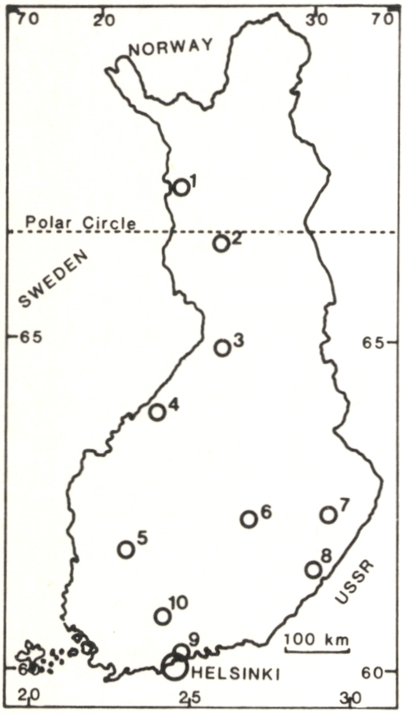
____

____

____

____

____



THE FINNISH FOREST RESEARCH INSTITUTE

DEPARTMENTS (Helsinki)

Administration Office
Information Office
Experimental Forest Office
Dept. of Soil Science
Dept. of Peatland Forestry
Dept. of Silviculture
Dept. of Forest Genetics
Dept. of Forest Protection
Dept. of Forest Technology
Dept. of Forest Inventory and Yield
Dept. of Forest Economics
Dept. of Mathematics

RESEARCH STATIONS

1 Kolari
2 Rovaniemi
3 Muhos
4 Kannus
5 Parkano
6 Suonenjoki
7 Joensuu
8 Punkaharju
9 Ruotsinkylä
10 Ojajoki

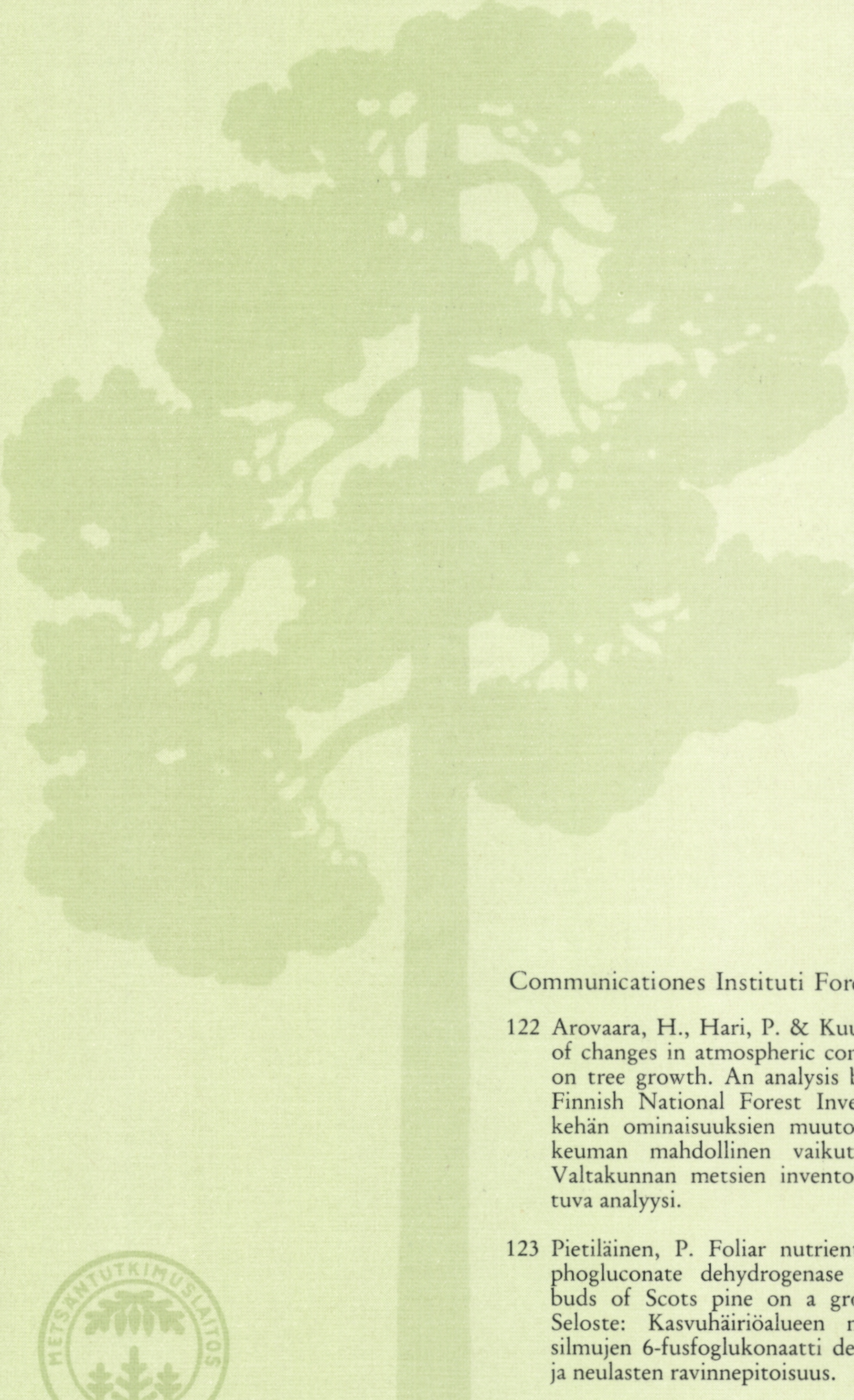
FACTS ABOUT FINLAND

Total land area: 304 642 km^2 of which 60—70 per cent is forest land.

Mean temperature, °C:	Helsinki	Joensuu	Rovaniemi
January	-6,8	-10,2	-11,0
July	17,1	17,1	15,3
annual	4,4	2,9	0,8
Thermal winter (mean temp. < 0°C):	20.11.—4.4.	5.11.—10.4.	18.10.—21.4.

Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens

THE FINNISH FOREST RESEARCH INSTITUTE ● METSÄNTUTKIMUSLAITOS



Communicationes Instituti Forestalis Fenniae

122 Arovaara, H., Hari, P. & Kuusela, K. Possible effect of changes in atmospheric composition and acid rain on tree growth. An analysis based on the results of Finnish National Forest Inventories. Seloste: Ilmakehän ominaisuuksien muutosten ja happaman laskeuman mahdollinen vaikutus puuston kasvuun. Valtakunnan metsien inventointien tuloksiin perustuva analyysi.

123 Pietiläinen, P. Foliar nutrient content and 6-phosphogluconate dehydrogenase activity in vegetative buds of Scots pine on a growth disturbance area. Seloste: Kasvuhäiriöalueen männyn vegetatiivisten silmujen 6-fusfoglukonaatti dehydrogenaasiaktiviisuus ja neulasten ravinnepitoisuus.

124 Ritari, A. & Ojanperä, V.: Properties and formation of cemented ortstein horizons in Rovaniemi, Northern Finland. Seloste: Ortsteinin ominaisuuksista ja muodostumisesta eräissä Rovaniemen podsolimaannoksissa.

ISBN 951-40-0668-2
ISSN 0358-9609