Silva Fennica 1988, vol. 22 n:o 2: 113–133

Podzolization as studied from terraces of various ages in two river valleys, Northern Finland

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TIIVISTELMÄ: PODSOLISAATIO KAHDEN JOKILAAKSON ERI-IKÄISISSÄ TERASSEISSA POHJOIS-SUOMESSA

Koutaniemi, L., Koponen, R. & Rajanen, K. 1988. Podzolization as studied from terraces of various ages in two river valleys, Northern Finland. Tiivistelmä: Podsolisaatio kahden jokilaakson eri-ikäisissä terasseissa Pohjois-Suomessa. Silva Fennica 22(2): 113–133.

The study was made in the Ivalojoki and Oulankajoki valleys, consisting of terraces of well sorted sandy material aged 9500–300 B.P. The vegetation is characterized by dry and moderately dry forest types with Scots pine as the dominant tree species. The study included: forest site types, particle size and sorting of mineral horizons, thicknesses of horizons, amount of organic material, pH, electrical conductivity, and NH_4OAc (pH 4.56) extractable Fe, Al, P, K, Mg, Mn and Zn concentrations. The principal aim was to study the interrelationships between all these properties with special reference to the age of the soil.

The results allowed a distinction to be made between the following categories: (1) features typical of podzolization (e.g. increase in leaching of Fe and Al with age of soil from the A_2), (2) certain factors showing higher values in the north (Ivalo) than in the south (Oulanka), principally Fe and Mg, (3) declining trends in P, Mg, Mn and Zn content with age, which may partly be due to the geological history, and (4) declining trends in amount of organic material and electrical conductivity with age, these both being factors arising from the geological history rather than from podzolization.

Tutkimus tehtiin Ivalo- ja Oulankajokien laaksoissa, joissa on eri korkeudella olevia 300–9500 radiohiilivuotta vanhoja lajittuneen hiekan terasseja. Kasvillisuutta luonnehtivat kuivat ja kuivahkot mäntyvaltaiset kangasmetsät. Maannoksista määritettiin aineksen raekoko ja lajittuneisuus, horisontin paksuus, orgaanisen aineksen määrä, happamuus, sähkönjohtavuus sekä raudan, alumiinin, fosforin, kaliumin, magnesiumin, mangaanin ja sinkin pitoisuudet. Pääongelma oli näiden väliset riippuvuussuhteet erityisesti iän suhteen.

Tulokset voitiin luokitella seuraaviin ryhmiin: (1) podsolisaatiolle tyypilliset piirteet (esim. mitä vanhempi maannos, sitä suurempi raudan ja alumiinin huuhtoutuminen A_2-horisontista, (2) rauta- ja magnesiumpitoisuuksien kasvu pohjoiseen (Ivalo) mentäessä, (3) maannoksen iän mukaan pienenevät fosfori-, magnesium-, mangaani- ja sinkkipitoisuudet, joilla voi olla yhteyttä geologiseen historiaan, (4) maannoksen iän mukaan pienenevät orgaanisen aineksen määrä ja sähkönjohtavuus, jotka tässä tapauksessa johtunevat enemmän geologisesta historiasta kuin podsolisaatiosta.

Keywords: Podzolization, podzol, boreal forest, taiga
ODC 114, 441.2+(480.9)

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Accepted February 29, 1988

1. Introduction

Podzolization is one of several soil formation processes, and is involved in the development of the soil type called podzol. Podzol is the typical soil type in the taiga, the northern coniferous forest zone encircling the Northern Hemisphere.

There are a number of ways of distinguishing the various horizons in the podzol profile. The more detailed survey given in this paper follows the division presented e.g. by Kubiena (1953, p. 30). The principal horizons are A, B and C. The A horizon is divided into three sub-horizons. Uppermost is A_0, consisting of undecomposed plant remains, i.e. litter. This is underlain by A_1, the humus layer, which consists mainly of decomposed organic material, and below this is A_2, the eluvial horizon, the greyish colour of which makes it easy to recognize a podzol from other soil types. The B and C horizons will be dealt with as such without any subdivision.

The most characteristic features of a podzol profile are (a) the acidity of the A_0 and A_1 horiszons, and (b) the leaching of the A_2. The acidity originates from the acid needles of the coniferous trees, i.e. Norway spruce (*Picea abies* (L.) Karsten) and Scots pine (*Pinus sylvestris* L.) in this case, while the leaching is caused by rain and surface water permeating through the upper layers and resulting in mobilization and eluviation of Al and Fe compouds, which accumulate in the illuvial B horizon.

The mineralogical and particle size compositions of the surface layers, climate, type of vegetation, the amount and nature of precipitation and perculating water, topography and time are among the most important factors controling podzolization. According to Jauhiainen (1973, p. 30) it takes 200−300 years at least for any differences between the horizons to become distinguishable by chemical analysis, and 400−500 years for them to become visible. In the area studied here these figures may be even higher, since the speed of decomposition of forest litter in Northern Finland is less than a half of that in Southern Finland (Mikola 1960, p. 166).

Because of differences in analytical methods, it is often not possible to compare the results of podzolization studies. Consequently the comparisons made in this paper concentrate mainly on work done following much the same principles as used here and in relatively closely situated areas. All dates given in the text and figures are uncorrected radiocarbon years B.P.

2. Material and methods

Climatologically the areas studied fall into the Dfc-type of Köppen's classification. Mean annual temperatures are of the range 0−−1°C, and precipitation sums 450−550 mm. Snow and ice cover the ground and lakes about half of the time. In normal winters the ground freezes to a depth of 20−100 cm depending on local conditions (Koutaniemi 1983a).

The sites studied are located in the valleys of the rivers Ivalonjoki and Oulankajoki (Ivalo and Oulanka in the following: Fig. 1). Material collected from the valley of the river Kitkajoki, a short tributary of the river Oulankajoki, is included in the Oulanka material. Geologically the Ivalo area belongs to the Presvecokarelian granulite complex and the Oulanka area to the Svecokarelides, which are rich in various schists, aged 1. 8−1. 9 Ga.

The valleys became ice-free during the Preboreal, about 9500 B.P. The valley bottoms contain huge amounts of well sorted sandy glaciofluvial drift, most of which the postglacial river activity has rearranged into unpaired river terraces (Koutaniemi 1979, pp. 51−52; Koutaniemi & Luoma-aho 1983, pp. 175−176).

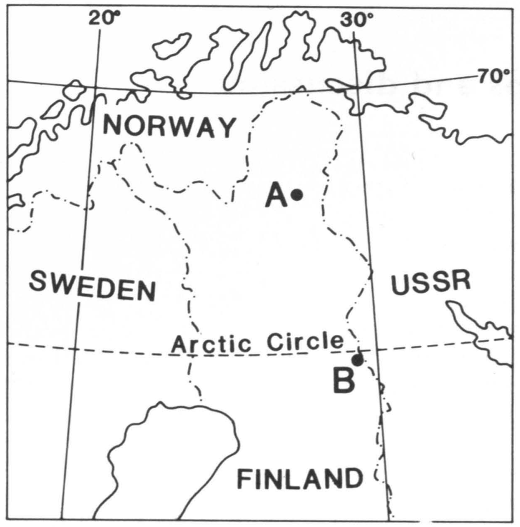

Fig. 1. Locations of the areas studied. (A) Ivalo, (B) Oulanka.

Numerous radiocarbon dates from the Ivalojoki and Oulankajoki valleys have given a general framework for the ages of terraces at various levels. It is this information, as pictured in Fig. 2 and listed in Appendix 1, which is used in determining the ages of the sites studied.

Twenty-nine podzol profiles each comprising five samples from eight valley cross-sections were chosen for the study. Seven of the points examined in this way were located on the glaciofluvial valley fill aged 9500−9300 B.P., the rest on lower levels of fluvial origin and of an age between 7800 and 300 B.P. (Appendix 1). The main idea when sampling each level was to avoid exceptional conditions.

Samples were taken from pits 75×75 cm wide dug down until the C horizon was clearly visible. The samples for each horizon comprised material from three walls of the pit in order to minimize the effects of local variability.

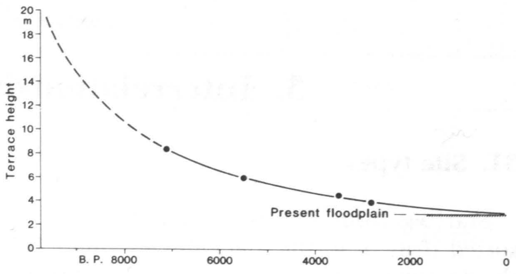

Fig. 2. Heights of river terraces of various ages in the Ivalojoki valley as calculated from the material presented in Koutaniemi (1987). Corresponding values in the Oulankajoki valley are 0−0.5 m higher, while in its tributary valley, the Kitkajoki valley, these figures are 1−1.5 m lower.

Electrical conductivity and pH were determined soon after sampling by preparing extracts of fresh samples with distilled water in a ratio of 1 to 2.5. Those parts of the samples which were preserved for chemical analysis were kept deep-frozen (−18°C).

The particle size distribution was determined by dry-sieving. If the proportion of the <0.053 mm fraction was greater than 10 %, a hydrometer test was performed. The equation $(Q_3/Q_1)^{1/2}$ was used to calculate sorting values (S_0). Organic material in cases where this exceeded 2 % was removed with H_2O_2. The amount of organic material (loss on ignition) was determined by burning the sample at a temperature of 800°C.

The concentrations of soluble Al and Fe and exchangeable K, Mn, Mg and Zn were determined by extracting fresh volumetric samples with acid ammonium acetate (NH_4OAc, pH 4.65) in a ratio of 1 to 10. To avoid contamination, three extractions were performed in each case. After shaking (1 h), standing (2 h) and filtering the samples were measured by atomic absorption spectrophotometer. Total phosphorus (PO_4) was measured colorimetrically from the same extracts using a spectrophotometer.

3. Interrelationships and discussion

31. Site types

Starting from the uppermost level of the sorted drift, i. e. the glaciofluvial valley fill, the dominant site type is the collective ErC1T in Ivalo, and CC1T (*Calluna-Cladina*) in Oulanka. Going down to the lower levels of fluvial origin the most common site types are the following, classified according to decreasing elevation (cf. Appendix 1): UVET (*Uliginosum-Vaccinium-Empetrum*) and UEMT (*Uliginosum-Empetrum-Myrtillus*) in Ivalo, and EVT (*Empetrum-Vaccinium*), EMT (*Empetrum-Myrtillus*) and HMT (*Hylocomium-Myrtillus*) in Oulanka. For a comprehensive discussion of these site types, the reader is referred to Cajander (1916, p. 453; 1949, p. 35), Lakari (1920, p. 56) and Kalela (1949, p. 70; 1961, pp. 78–79).

The above-mentined shows that there is a definite tendency towards less arid conditions at the lower levels, the main contributory factor being the groundwater table (cf. Koutaniemi 1984, pp. 51–52). The relationships between elevations/ages and the coverages of the field layer, mosses and lichens demonstrate the situation well: the higher/older the level, the more dominant the lichens are, while at the lower levels there is an increasing coverage of mosses and dwarf shrubs (Appendix 2).

32. Physical properties of the soil

Particle size distribution and sorting

In terms of their median particle size (Md) the surface layers consist mainly of medium sand (Table 1). There is an increase in coarseness with depth, especially in between the B and C horizons, a feature which has been noted by many research workers in other connections (e.g. Eyre 1968, p. 53; Jauhiainen 1969, pp. 72–73; Hinneri 1974, p. 28).

Sorting values are of the order of 1.2–2.1 (Table 1) indicating a high degree of sorting due to glacial meltwater and later fluvial activity. Typical of podzol profiles, the best sorted material is that of the B horizon, whereas the higher degree of sorting in the C horizon than in A_2 differs from the findings of Jauhiainen (1972, p. 38). As a whole, the surface layers of Ivalo are of finer composition than those of Oulanka, the origin of this difference lying in the glaciofluvial activity depositing the parent material.

The statistically significant interdependences between median particle size and sorting, i.e. the coarser the material, the poorer the sorting, is the only feature shared by all the horizons (Appendix 2). As above, the reason for this and the positive correlation between the median particle sizes and relative elevations/ages of the B horizons must lie in the geological history rather than in the podzolization itself. The negative correlation between the median particle sizes and the amount of organic material has a natural explanation in the principles of soil formation, viz. the coarser the material, the lower its capacity to stop organic matter from penetrating any deeper (e.g. Millar et al. 1965, p. 248; Jauhiainen 1969, p. 73; Copponen 1985, p. 34).

Thickness of horizons

The illuvial horizon (B) is the thickest and the litter horizon (A_0) the thinnest (Table 1). The A_1 and A_2 horizons feature much the same values in both areas. The figures for the A_2 horizon, for example, are of the same order as measured by Hinneri (1974, p. 28), and slightly lower than those of Jauhiainen (1969, p. 83).

The thicknesses of the upper sub-horizons A_0 and A_1, both of which are rich in organic material, are clearly dependent on the type of ground vegetation. An increase in moss and field layer coverage results in thicker A_0 and A_1 horizons, while the opposite is true as the coverage of lichens increases (Appendix 2). This is quite logical since lichens typify the poorest vegetation communities, producing minimal amounts of litter and organic material for the humus layer (e.g. Aaltonen 1940, p. 210; 1949, p. 87; Jauhiainen 1969, p. 69; Söyrinki et al. 1977, p. 42; Rajakorpi 1984, pp. 306–307).

Table 1. Values of various physical soil properties in different horizons.

Property	Horizon	Ivalo		Oulanka	
		range	mean	range	mean
Particle size (mm)	A_2	0.114–0.356	0.158	0.093–0.679	0.226
	B	0.073–0.396	0.168	0.114–0.569	0.224
	C	0.109–0.506	0.230	0.112–0.637	0.296
Sorting (S_o)	A_2	1.30–2.00	1.45	1.20–2.10	1.49
	B	1.20–1.50	1.31	1.20–1.60	1.39
	C	1.20–1.50	1.36	1.20–1.80	1.48
Thickness of horizons (cm)	A_0	1–3	1.5	1–5	1.9
	A_1	1–9	3.5	1–6	3.1
	A_2	1.5–5	2.5	2–7	4.1
	B	6–33	19.4	4–36	16.4
Amount of organic material (%)	A_0	66.4–94.5	82.0	56.2–95.6	79.5
	A_1	38.5–90.2	70.7	1.8–86.9	60.1
	A_2	1.4–19.7	6.8	0.8–6.2	2.3
	B	1.8–5.8	3.6	1.7–10.1	3.1
	C	0.7–2.2	1.3	0.1–1.5	0.7

The thickness of the A_2 and B horizons both show statistically significant positive correlations with age and negative correlations with the amount of organic material (Appendix 2). This means that both horizons tend to become thicker with age, whereupon they contain a lower proportion of organic material. Corresponding results have been presented by Aaltonen (1937, p. 29), Jauhiainen (1969, p. 36) and Mälkönen (1974, p. 43), but only concerning the B horizon, viz. the drier the conditions (meaning at the same time a greater age and less productive vegetation communities in this case) the thicker the B horizon. The increase in particle size with relative elevation/absolute age in the valleys studied here also tends to promote this kind of development.

Aaltonen (1940, fig. 56) and Jauhiainen (1969, p. 29) note that the younger the soil and the damper the conditions the thicker is the A_2 horizon. As shown above, all our results indicate the opposite. Insofar as the present results hold good only for the valleys studied, the explanation is to be found in the postglacial history of these valleys rather than in any other external factor.

Amount of organic material

The amount of organic material is in the range 56.2–95.6 % in the A_0 horizon, 0.5–3.5 % in the C horizon, and is characterized by a step-wise decline between A_1 and A_2 (Table 1). All these, together with higher values in the B horizon than in A_2 are features which very often typify podzol profiles which have developed under cool, damp conditions (Aaltonen 1949, p. 87; Ponomareva 1969, p. 121).

Organic content shows a negative correlation with age in all cases, including two values which are of statistical significance (Appendix 2). This, as well as similar reverse correlations with the thickness of the horizon and the median particle sizes and sorting values, show the effects of the geological history of the valleys on the results, i.e. the higher/older the level the coarser and less sorted the material, resulting in drier vegetation communities with lower organic production at higher levels. The same is clearly demonstrated by the correlation coefficients between the amount of organic material and other factors associated with the A_0 horizon, viz. the lower/younger the level, the higher the coverage of the field layer, which is an indication of more productive vegetation types.

The slightly higher values in Ivalo than in Oulanka (Table 1) may be due to the difference in surface material composition. In Ivalo the valley fill consists of finer particles, thus favouring a more productive vegetation and a higher organic material content. On the one hand, it is possible that the macroclimatic features have had their own effects. The climate in Ivalo is more oceanic than that of the Oulanka area (Koutaniemi 1983b, pp. 9–10), and an increase in oceanity has been observed to favour a higher humus content (cf. Jauhiainen 1976, pp. 27–28; Rajakorpi 1984, p. 320). On the other hand, forest fires may have influenced the results achieved.

33. Chemical properties of the soil

Acidity (pH)

The A_1 horizon is the most acid of all (Fig. 3). There is no definite trend in the pH values when arranged according to either the site type (Table 2) or particle size (Table 3) (cf. Söyrinki et al. 1977, pp. 42–44), but the Oulanka values are slightly more acid than those for Ivalo. Altogether the results are at the more acid end of the range typical of Finnish conditions (Aaltonen 1940, p. 161), and abnormally acid as compared with the results of Viro (1951, pp. 31–35), Jauhiainen (1972, pp. 38–39) and Sepponen (1985, p. 22), for instance.

A decrease in pH with depth between horizons A_2 and B is a widely accepted feature of podzol profiles (e.g. Aaltonen 1940, p. 163; Hinneri 1974, p. 32; Urvas & Erviö 1974, p. 312; Rajakorpi 1984, p. 32). Okko (1964, p. 289) mentions a peak in pH in A_1, as was also the case in the present results. An increase in

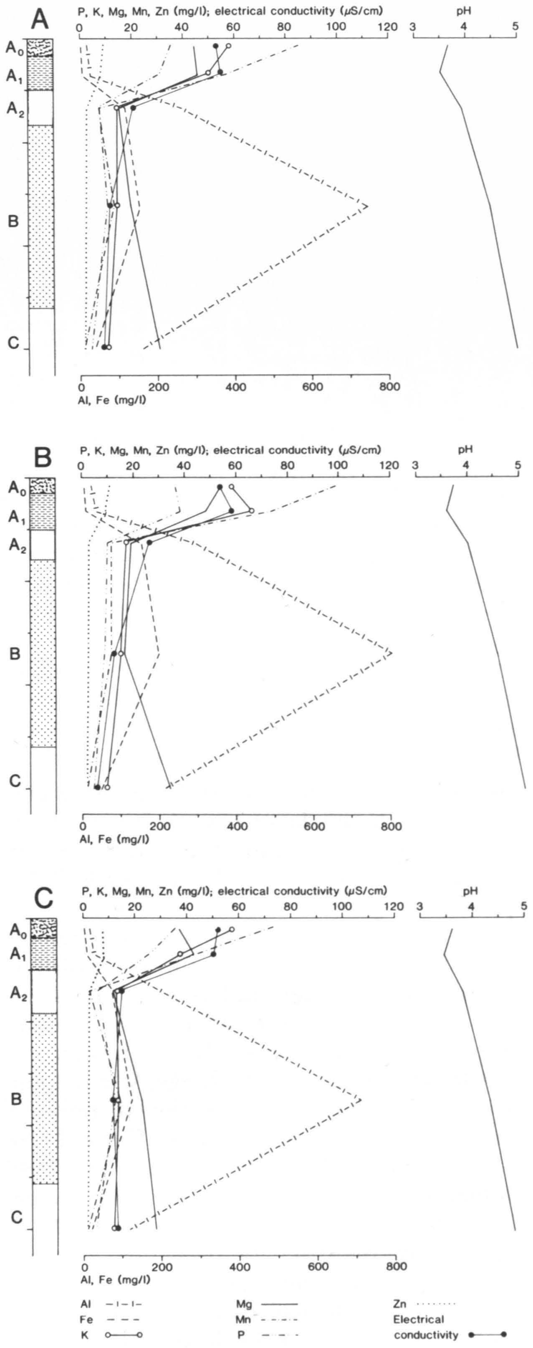

Fig. 3. Mean thicknesses and chemical properties of the podzol profiles studied. (A) Total material, (B) Ivalo, (C) Oulanka.

Table 2. Mean values of chemical properties in different horizons and site types. The arrangement of site types means that generally speaking the productivity of the vegetation communities increases from left to right (cf. section on Site types).

Property	Horizon	Site type						
		CCIT (Oulanka)	ErCIT (Ivalo)	UVET (Ivalo)	EVT (Oulanka)	EMT (Oulanka)	UEMT (Ivalo)	HMT (Oulanka)
Acidity (ph)	A_0	3.61	3.67	3.78	3.80	3.50	3.81	3.53
	A_1	3.36	3.56	3.52	3.65	3.42	3.76	3.38
	A_2	3.87	4.13	3.87	3.90	3.75	4.15	3.65
	B	4.36	4.57	4.42	4.45	4.33	4.86	4.05
	C	4.76	5.03	5.19	4.87	4.76	5.20	4.85
	mean	3.99	4.19	4.16	4.13	3.95	4.36	3.90
Electrical conductivity (µs/cm)	A_0	36.8	38.4	59.4	43.0	55.5	62.1	72.9
	A_1	53.3	49.2	58.2	42.9	46.7	71.2	73.4
	A_2	13.1	12.1	37.2	15.6	14.5	22.0	23.9
	B	9.5	8.5	15.5	9.9	10.0	11.7	15.8
	C	5.1	4.4	5.8	18.3	15.0	5.8	6.8
	mean	23.6	22.5	35.2	25.9	28.3	34.6	38.6
Iron (Fe) (mg/l)	A_0	2.4	4.2	2.2	3.8	3.0	2.7	1.9
	A_1	1.7	5.0	1.9	18.1	8.5	27.8	3.8
	A_2	27.5	108.8	165.2	80.1	102.2	170.9	34.1
	B	74.4	92.9	202.0	164.1	85.6	325.7	225.7
	C	17.6	30.8	65.2	20.0	26.6	46.0	30.2
	mean	24.7	48.3	87.3	55.6	45.2	114.6	61.9
Aluminium (Al) (mg/l)	A_0	15.2	30.2	19.4	19.3	19.7	22.1	16.9
	A_1	20.9	44.6	16.3	28.1	33.4	59.2	24.6
	A_2	124.9	196.7	383.5	273.7	239.2	252.9	74.7
	B	614.3	823.8	843.9	467.8	780.0	657.6	871.4
	C	121.6	302.4	215.3	47.1	145.0	77.9	66.5
	mean	179.4	279.5	295.7	159.6	243.6	213.9	225.9
Phosphorus (P) (mg/l)	A_0	24.8	25.6	40.3	34.6	36.6	41.7	46.4
	A_1	30.9	33.4	44.0	28.9	17.9	32.1	42.9
	A_2	3.4	5.1	14.7	8.3	5.6	7.2	4.5
	B	13.5	8.2	7.2	14.6	11.7	11.1	9.2
	C	4.9	3.5	6.2	2.2	5.3	2.7	5.1
	mean	15.5	15.2	22.5	18.4	15.4	19.0	23.5
Potassium (K) (mg/l)	A_0	36.3	39.1	55.9	69.9	53.0	85.1	95.7
	A_1	42.0	69.9	62.2	25.1	35.8	66.8	54.7
	A_2	16.1	11.6	18.9	16.3	11.6	18.3	9.5
	B	15.3	15.2	14.1	10.4	15.0	17.6	8.9
	C	10.4	10.0	9.0	12.4	10.9	10.1	14.4
	mean	24.0	29.1	32.0	27.6	25.3	39.6	39.7
Magnesium (Mg) (mg/l)	A_0	23.6	35.2	61.6	50.6	36.9	63.5	36.2
	A_1	42.0	42.4	49.8	49.1	41.3	53.9	41.0
	A_2	7.3	9.2	23.1	8.7	12.7	26.0	9.8
	B	9.2	4.0	22.1	36.3	16.5	21.5	46.1
	C	22.5	8.1	53.6	32.5	19.3	29.2	64.8
	mean	20.9	19.8	42.0	37.4	25.4	38.8	42.9
Manganese (Mn) (mg/l)	A_0	63.5	50.8	120.0	128.7	60.0	118.5	51.7
	A_1	52.6	54.4	90.0	60.2	33.5	59.7	42.6
	A_2	3.3	6.5	13.0	1.9	3.2	15.4	2.6
	B	6.8	6.0	15.5	12.2	12.3	7.9	39.8
	C	2.1	1.3	1.5	1.3	1.1	1.1	1.3
	mean	25.6	23.8	48.0	43.6	22.0	40.5	30.4
Zinc (Zn) (mg/l)	A_0	7.4	8.3	11.5	8.4	7.4	14.6	7.2
	A_1	8.5	8.6	9.5	7.3	6.8	11.5	9.5
	A_2	2.4	2.8	3.1	2.1	2.4	2.5	2.2
	B	1.7	2.0	3.3	1.9	1.8	2.1	4.1
	C	1.8	1.7	2.4	2.2	1.7	1.7	2.1
	mean	4.4	4.7	5.9	4.5	4.0	6.5	5.3

Table 3. Mean values of chemical properties in different horizons and particle size fractions.

Property	Horizon	Fraction (mm)			
		< 0.125	0.125–0.177	0.177–0.25	>0.25
Acidity (pH)	A_2	3.84	3.94	3.96	3.85
	B	4.34	4.57	4.41	4.40
	C	4.98	4.98	4.92	4.94
	mean	4.39	4.50	4.43	4.40
Electrical conductivity (μs/cm)	A_2	21.2	22.1	21.0	13.7
	B	11.9	6.2	11.1	9.3
	C	6.1	11.7	4.9	4.9
	mean	13.1	13.3	12.3	9.3
Iron (Fe) (mg/l)	A_2	131.0	149.4	40.6	17.9
	B	171.6	74.0	106.6	86.3
	C	62.0	35.8	31.4	15.5
	mean	121.5	86.4	59.5	39.9
Aluminium (Al) (mg/l)	A_2	270.0	325.1	140.3	104.9
	B	729.9	924.9	942.7	645.2
	C	234.0	91.1	234.9	107.6
	mean	411.3	447.0	439.3	285.9
Phosphorus (P) (mg/l)	A_2	8.5	9.3	5.0	2.8
	B	9.1	13.6	23.1	9.8
	C	6.5	3.9	6.5	2.9
	mean	8.0	8.9	11.5	5.2
Potassium (K) (mg/l)	A_2	13.5	17.7	15.2	13.6
	B	14.9	17.3	16.4	12.4
	C	10.3	13.6	12.5	8.8
	mean	12.9	16.2	14.7	11.6
Magnesium (Mg) (mg/l)	A_2	19.0	13.7	8.5	6.3
	B	24.7	3.7	6.9	5.3
	C	44.5	45.8	21.7	13.6
	mean	29.4	21.1	12.4	8.4
Manganese (Mn) (mg/l)	A_2	9.7	4.8	0.9	5.3
	B	11.5	5.1	22.8	5.5
	C	1.6	1.1	1.2	1.3
	mean	7.6	3.7	8.3	4.0
Zinc (Zn) (mg/l)	A_2	2.6	2.8	2.2	2.3
	B	2.4	1.9	1.8	1.7
	C	2.1	1.8	1.6	1.9
	mean	2.3	2.2	1.9	2.0

pH values with fresher and more luxurious vegetation types, a feature not noted here, has been reported by Urvas & Erviö (1974, p. 312) and Rajakorpi (1984, p. 321; cf. Viro 1951, p. 46). Opinions are divided on the effects of particle size, some people reporting a decrease in pH with increased particle size (e.g. Rajakorpi 1984, p. 321) and others the opposite (Urvas & Erviö 1974, pp. 313–314).

Of the properties used in this study, pH most often shows a statistically significant correlation with Mn, which is positive in the two uppermost horizons and negative in the B and C horizons (Appendix 3). In A_2 there is a clear tendency for an increase in pH with a decrease in lichen coverage and an increse in mosses.

As regards age relationships it seems that the older the soil profile is, the more acid are the A_0 and A_1 horizons, while the opposite is true in A_2 and B (Fig. 4). In all cases the statistical significance is low, however.

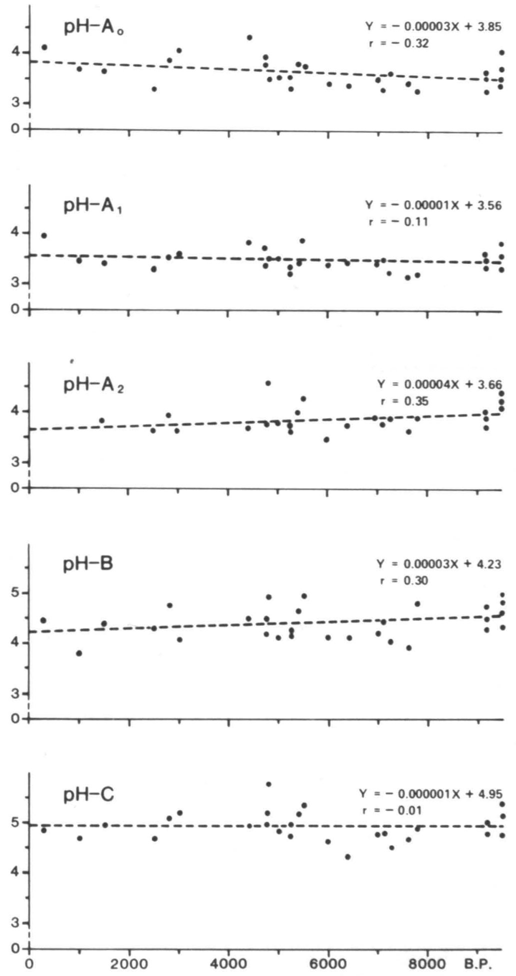

Fig. 4. pH values for the horizons, arranged according to age. Points with exactly the same x and y coordinate values are presented as a single dot (hence the horizons may have different numbers of dots).

Electrical conductivity

The values for the horizons rich in organic material are roughly 3–4 times higher than those for the mineral horizons (Fig. 3), and the same horizons have a definite tendency for higher conductivity at more fertile sites, whereas this feature is not equally clear in the mineral horizons (Table 2). An increase in particle size appears where electrical conductivity values are lower (Table 3). Of the electrolytes it is those of K and Mg in the A_0 horizon, P in A_1, Fe, K, Mg, P and Zn in A_2, and Mn and Zn in the B horizon which are of the greatest importance for electrical conductivity.

In all the horizons there is a tendency towards a decrease in electrical conductivity with the age of the soil (Fig. 5). The steepest decline, with the highest statistical significance, is in A_2, which is clear proof of one of the basic principles in podzolization, the effect of leaching. On the other hand, it should be noted that many of the horizons of the driest (oldest) site types (on the left in Table 2) with the coarsest material composition (on the right in Table 3) feature the lowest values of all, a pattern which may have had an effect of its own on the results.

Iron (Fe)

The vertical distribution of soluble Fe provides a maximum in the B horizon and minimum in A_0 (Fig. 3). The A_2 values are 2–3 times higher than those for the C horizon. The Fe content values are in general twice as high in Ivalo as in Oulanka. The different site types yield wide ranges of values and an irregular increase with fresher vegetation types (Table 2). As regards particle size,

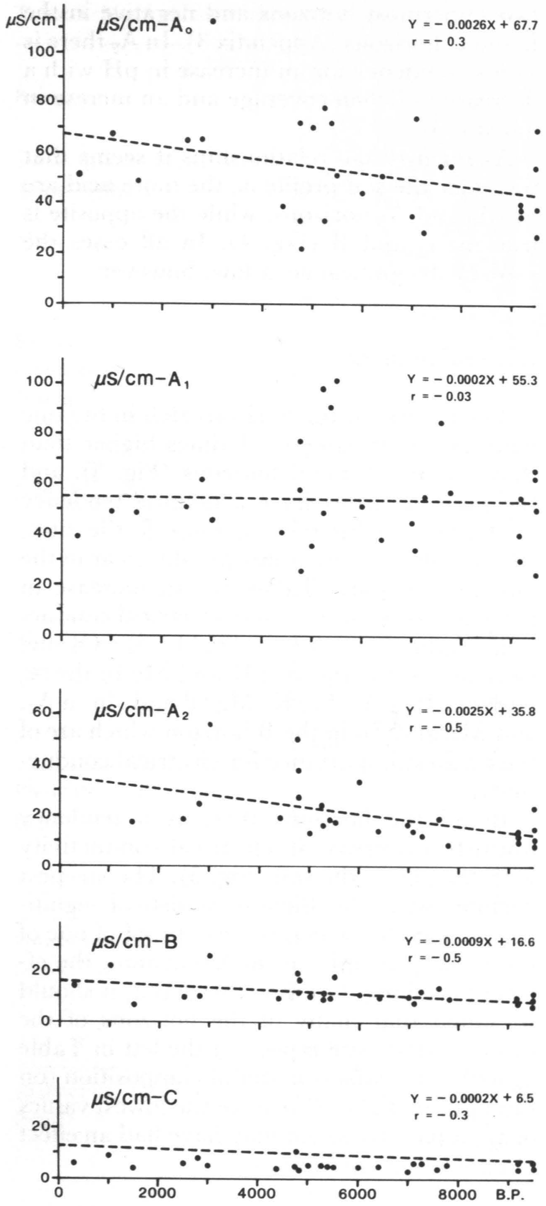

Fig. 5. Electrical conductivity in the horizons, by age (cf. Fig. 4).

a definite trend is visible for smaller particle sizes to be associated with a higher Fe content (Table 3).

All the features mentioned here have much in common with previous results, i.e. it is quite normal to have Fe concentrated in the B horizon, to find higher values in the north (Ivalo) than further south (Oulanka) and to have higher values associated with decreasing particle size (e.g. Aaltonen 1935, p. 71; 1939, p. 51; Jauhiainen 1969, p. 109; Vasander et al. 1979, pp. 69–70; Rajakorpi 1984, p. 315).

The high correlations between Fe and A_1 and A_2 (Appendix 3) show the close interdependence between these elements in podzolization. The higher amount of organic material found alongside higher Fe values in the C horizon and the reverse situation in A_0 are features mentioned by Sepponen (1985, p. 31), for example. Furthermore, the Fe values show statistically signifcant correlations with Mg in the A_2 and C, with pH in A_0, and with P and electrical conductivity in A_2.

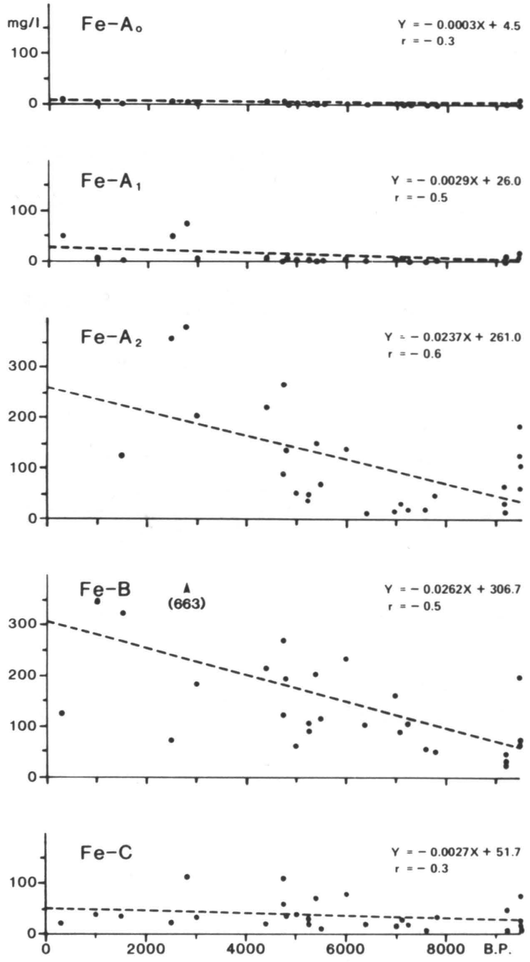

Fig. 6. Fe content of the horizons, by age (cf. Fig. 4).

All the horizons, and especially A_2 and B, feature a decrease in Fe content with age (Fig. 6). This is to be expected in A_2, since leaching of Fe from this horizon is one of the principles of podzolization. On the other hand one might assume the values in the B horizon to increase with the age of the soil due to the tendency of Fe to become accumulated here, as also shown above. This discrepancy can at least partly be explained by the specific features of the valleys studied, i.e. the drier the site type, the older it will be and the coarser its material composition providing lower than normal iron content (cf. Tables 2 and 3).

Aluminium (Al)

The pattern of soluble Al content is much the same in vertical distribution as that of Fe above (Fig. 3), with the only difference that the peak in Al in the B horizon is 4–5 times higher than that for Fe content. As a whole the values in Ivalo are about 100 mg/l higher than those in Oulanka. Various site types and particle sizes provide large ranges of values in which it is difficult to find any systematic changes (Tables 2 and 3). All these are normal features in the behaviour of Al in prodzol profiles (e.g. Jauhiainen 1972, p. 56; 1973, p. 20). The ratios of Al in relation of Fe in the B horizon are approx. double as compared with those recorded by Jauhiainen (1969, p. 80).

There are also similarities with previous studies in the interrelationships. Positive correlations with the amounts of organic material in the A_2 and B, and the opposite in the A_1 (Appendix 2) are observations made e.g. by Sepponen (1985, pp. 25–26). Apart from its correlations with Fe, Al also has statistically significant correlations with P in the A_2 and C horizons, and with Mg in A_2.

As regards age relationships, the leaching of Al from A_2 is by far the most visible feature (Fig. 7). Contrary to the normal case, Al shows an accumulation in the C, instead of in the B. The former is up to expectations (e.g. Jauhiainen 1973, p. 24), the latter may be an indication of the tendency of Al to become deposited at a lower level than Fe (cf. Okko 1964, p. 290). In other respects attention should be paid to the possible effects of the specific features of the valleys, in the same way as presented above for Fe (cf. Fig. 7 and Tables 2–3).

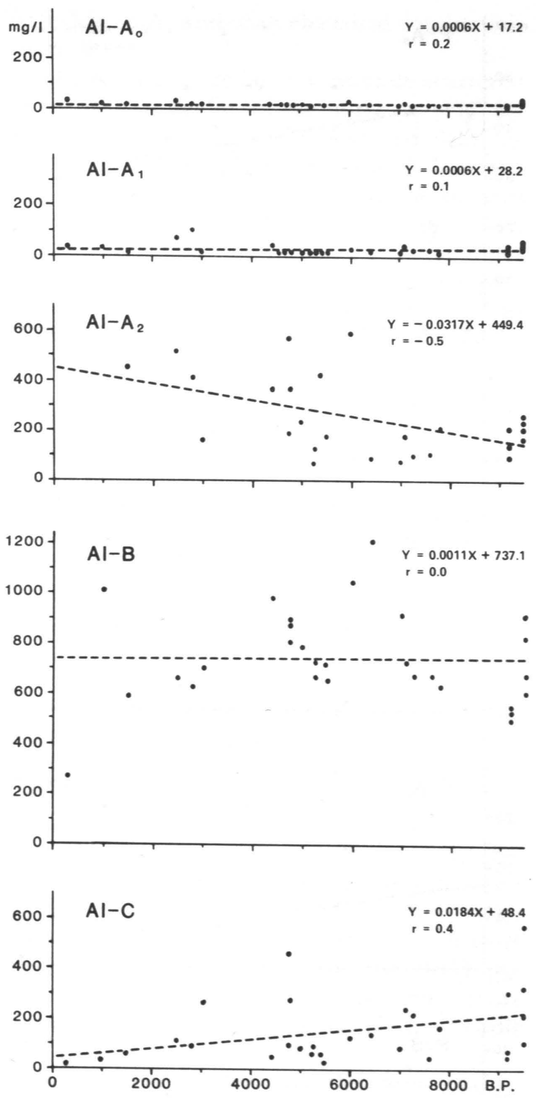

Fig. 7. Al content of the horizons, by age (cf. Fig. 4).

Phosphorus (P)

It is common to find P maxima in horizons rich in organic material, either A_0 or A_1 (Fig. 3) (e.g. Hinneri 1974, p. 28; Urvas & Erviö

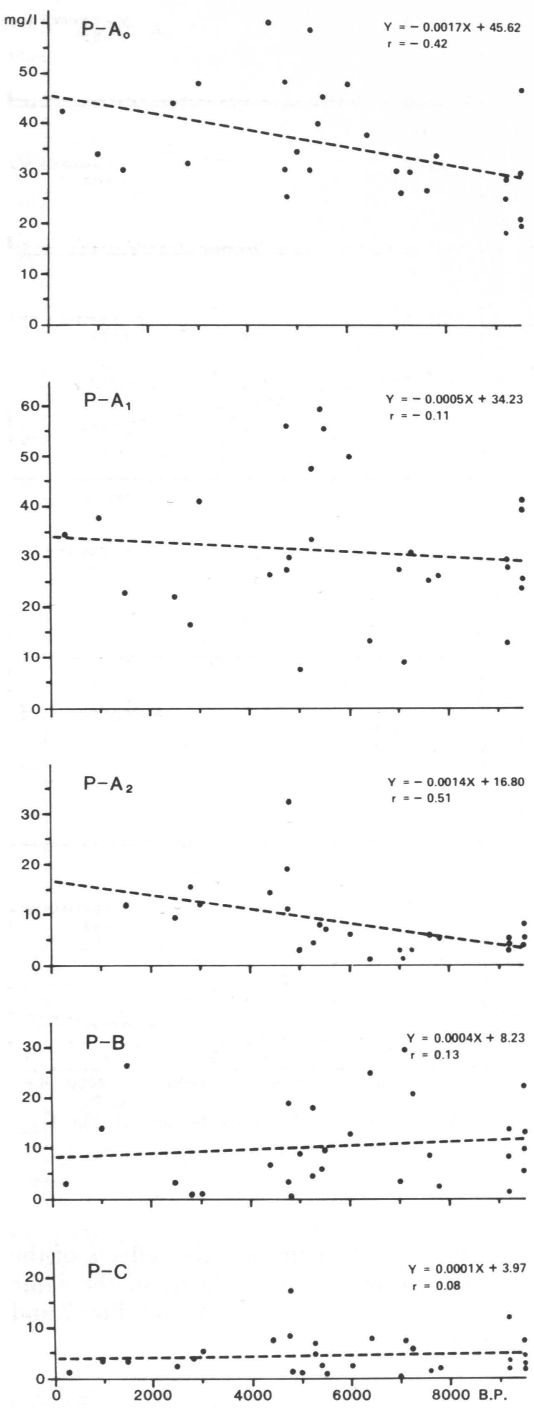

Fig. 8. P content of the horizons, by age (cf. Fig. 4).

1974, p. 316; Rajakorpi 1984, p. 318). Deeper down, the B horizon very often has a lower peak, this being present here only in the Oulanka results (cf. Jauhiainen 1969, p. 42; 1973, p. 21). Increased values in fresher site types, although not very regular in this case (Table 2), have been reported by Malmström (1949, pp. 107–109) and Jauhiainen (1969, p. 43), for example. There is also a tendency to have higher P values with a finer material composition (Table 3; cf. Sepponen 1985, p. 84). As such, the values achieved are much the same as those reported by Rajakorpi (1984, p. 315), and higher than those of Urvas & Erviö (1974, p. 316).

Positive correlation between P content and the coverages of the field layer and mosses in the A$_0$ and A$_1$, and the reverse situation as to the lichens in the A$_0$ (Appendix 3), are facts to support the importance of the site type, i.e. the more productive vegetation, the higher the P values (see Mälkönen 1974, p. 54). This results in increased electrical conductivity associated with a higher number of P, K, Mn and Zn cations in this case. There is also a tendency to have higher P values with an increase in amount of organic material and in Fe, Al, Mg and electrical conductivity values in the A$_2$ (cf. Viro 1951, pp. 15–18), and with the rise of Al values in the C.

The P values show declining trends with age in the A$_0$ and A$_2$ (Fig. 8). In other horizons the situation is more or less neutral. It is possible that the same geological factors which may have contributed to similar declining trends in the case of Fe and Al above have had their own effects on the present declining trends. On the other hand, Jauhiainen (1973, p. 23) reports the same declining trend, measurements in his case having been made in the humus layer.

Potassium (K)

The distribution of exchangeable K in the podzol profiles is basically the same as that of P (Fig. 3). Maximum values are in either A$_0$ or A$_1$, followed by a steep decline deeper down. This is a situation described by many researchers (e.g. Jauhiainen 1972, p. 39; 1973, p. 20; Hinneri 1974, p. 28). The figures as such are of the same order as those of Rajakorpi (1984, pp. 312–315) from Southern Finland in the mineral horizons, but only a half of his figures in the organic horizons. Fresher vegetation types and smaller particle sizes both have tendencies, although not very clear one, to give higher K values (Tables 2 and 3), features also noted by Viro (1951, p. 34) and Urvas & Erviö (1974, p. 318).

The positive correlations with the coverage of the field layer and electrical conductivity in A$_0$ (Appendix 3) indicate that K favours the more productive vegetation communities. The close connections with the P values in A$_1$ and with the amount of organic material in A$_2$ are findings similar to those of Sepponen (1985, p. 25). K also has positive correlation with Mn in A$_1$ and with electrical conductivity in A$_2$.

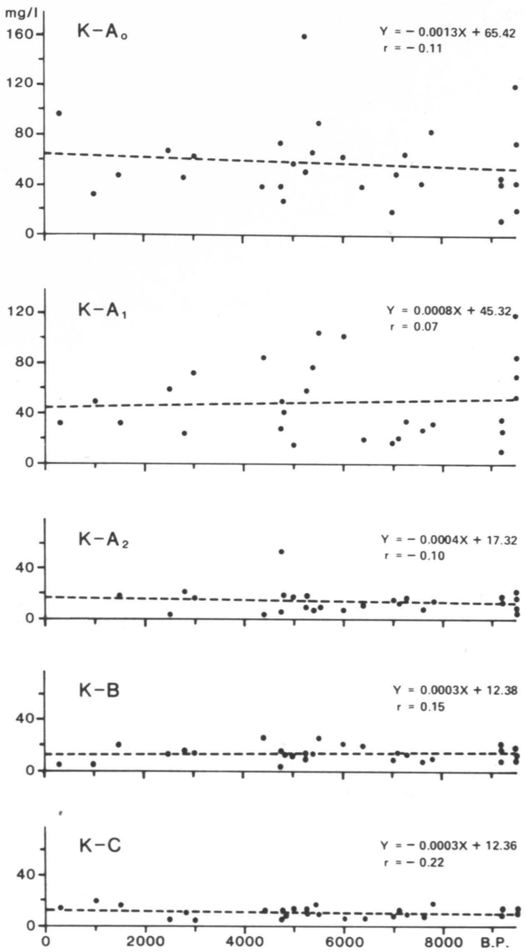

Fig. 9. K content of the horizons, by age (cf. Fig. 4).

The K values are fairly randomly scattered in relation to age in all the horizons (Fig. 9). Jauhiainen (1969, p. 41) observed that his values grew higher the older the A$_0$ horizon was. The lack of this feature in the present results is perhaps explained by the same fact mentioned many times above, that the older site types are drier, and therefore their production of K does not reach the same level as is the case with the younger sites with higher productivity.

Magnesium (Mg)

Mg features maximun values in the uppermost layers (A$_0$/A$_1$), minimum in the A$_2$ or B, and a lower peak in the C deeper down (Fig. 3). The general picture achieved by different analytical methods in various sources (e.g. Lehtonen et al. 1976, p. 187; Rajakorpi 1984, pp. 312–315) is much the same as in the present study, although differences in detail exist. Higher values in the north than further south were also noted by Sepponen (1985, p. 28). The values for the horizons rich in organic material are of the same order as reported in Southern Finland (Rajakorpi 1984, pp. 312–315) and those for the mineral horizons 5–10 times higher than in the latter area. Site types of higher productivity feature higher Mg values (Table 2; cf. Viro 1951, pp. 11, 34), a tendency which becomes more definite with decreasing particle size (Table 3).

Positive correlation with electrical conductivity, amount of organic material and coverage of the field layer and the negative one with the lichen cover, all affecting many of the horizons (Appendix 3), are facts which indicate that the amount of Mg in the soil increases towards the fresher site types. The Mg values also show similar trends with pH, P, Mn and Zn in A$_0$, with Fe, Al and P in A$_2$, and with Fe in the C horizon.

There is a clear decline in Mg content in all horizons as the age of the soil increases (Fig. 10). As above, the vegetational characteristics of the valleys may have contributed to this.

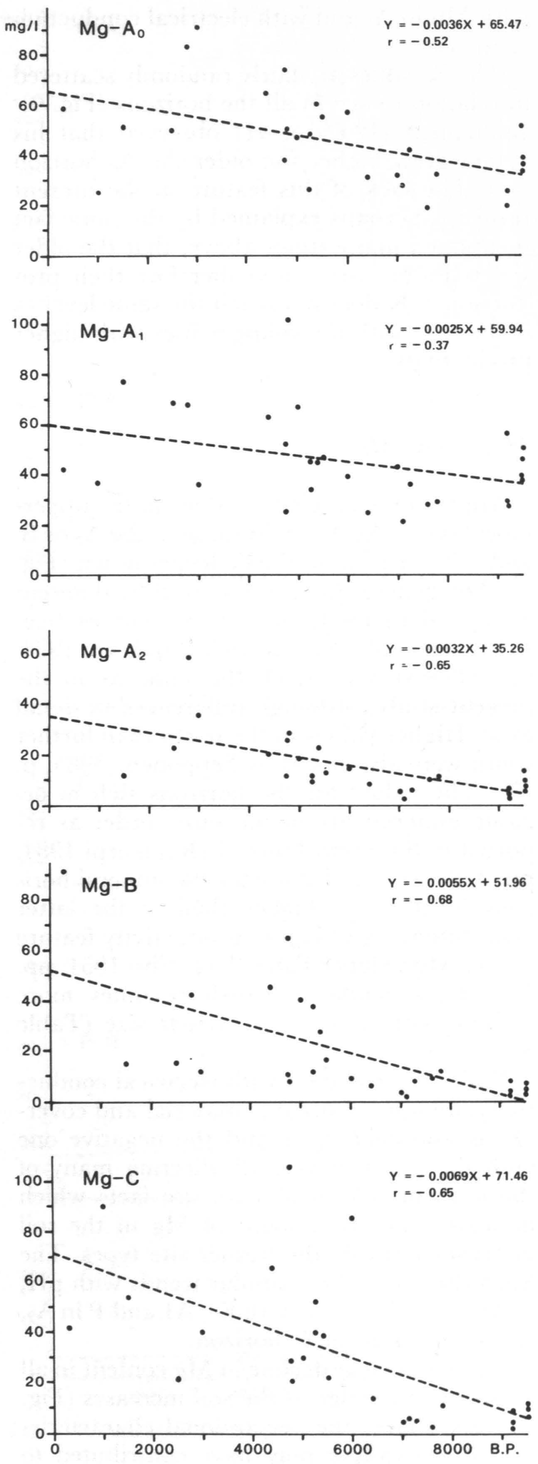

Fig. 10. Mg content of the horizons, by age (cf. Fig. 4).

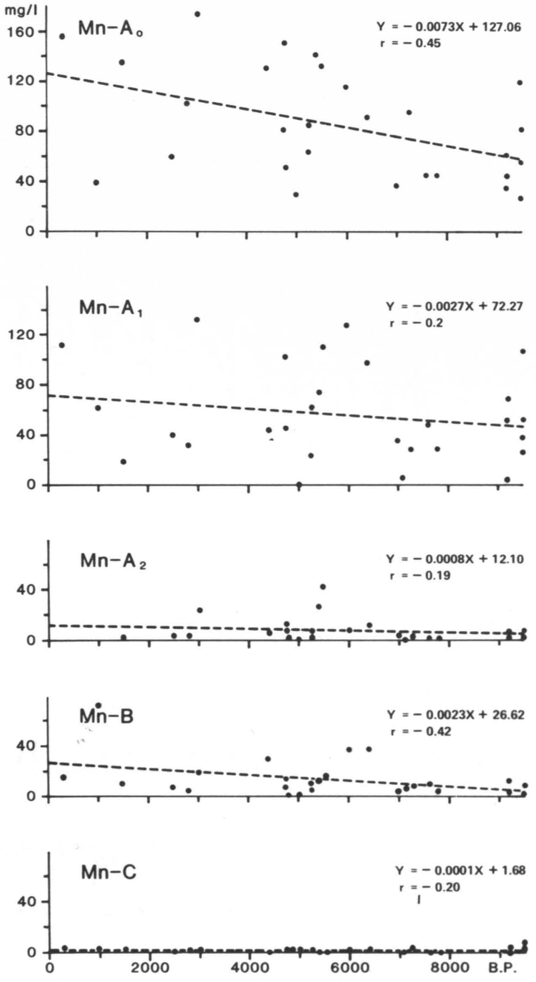

Fig. 11. Mn content of the horizons, by age (cf. Fig. 4).

Manganese (Mn)

The vertical distribution of Mn is very similar to that of P (Fig. 3). Surface maxima are reported in numerous works, e.g. by Hinneri (1974, p. 29) and Vasander et al. (1979, p. 29), while higher values in the fresher site types (Table 2) are also found by Rajakorpi (1984, p. 314). There is also a somewhat irregular tendency for a decline with decreasing particle size (Table 3), a feature mentioned by Vuorinen (1958, p. 35).

The postive correlation with the coverage of the field layer together with the opposite relation to the lichen cover (Appendix 3) both support the above-mentioned idea that more productive site types have a higher Mn content. Further support is provided by the positive correlations with P, Mg and Zn, all of which are favoured by higher organic productivity. There is also a tendency to have higher Mn values in the B horizon the greater the amount of organic material.

Mn content shows lower values with increasing age in all horizons, statistically more significant correlations being those found in the A$_0$ and B horizons (Fig. 11). As is the case with all the factors regulated by the site type (cf. above), the specific features of the valleys may also have contributed to these trends.

Zinc (Zn)

Zn content is at its highest in horizons rich in organic material, followed by a step-wise decline when going deeper down (Fig. 3). This is a picture shared by many studies (e.g. Erviö & Virri 1965, p. 183; Kurki 1974, p. 208; Rajakorpi 1984, pp. 312–315). The Ivalo material indicates a more definite increase in Zn in the fresher site types than do the values as a whole (Table 2). In mineral horizons, especially in the B horizon, a decrease in particle size results in a higher Zn content (Table 3). Vuorinen (1958, p. 32) and Kurki (1974, p. 213), for example, found the same trend.

Positive correlations with the coverage of the field layer, electrical conductivity and the amount of organic material in the A$_0$, A$_2$ and B horizons all show high Zn content to favour more productive vegetation communities (Appendix 3). Positive correlations with Mg and Mn in A$_0$, with P in the A$_1$ and with Mn in the B horizon point to the same fact. An increase in Zn content with pH in A$_0$ is strange in the sense that Zn cations are known to decrease with increasing pH (see Kurki 1974, p. 209).

The age relationships give various pictures (Fig. 12). In the cases of higher statistical significance, in the B and C horizons, Zn shows decreasing values with increasing age of the soil. As with most of the factors dealt with above, the present declining trends may have been favoured at least in part by the vegetational characteristics of the valleys studied.

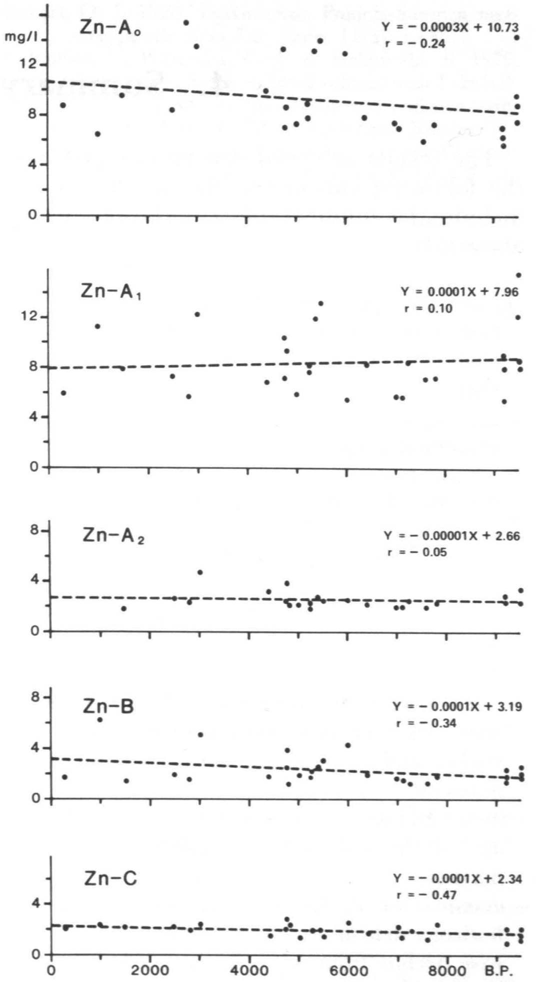

Fig. 12. Zn content of the horizons, by age (cf. Fig. 4).

4. Summary of the results

The results achieved can be grouped into the following categories (the details do not include the innumerable correlations listed above):

(1) Features typical of podzolization
- best sorted material in the B horizon and coarsest particle size composition in the C horizon
- the higher the productivity of the vegetation community, the thicker the horizons rich in organic material
- the older the soil the thicker the B horizon
- a step-wise decrease in the amount of organic material between A_1 and A_2
- an increase in the pH is seen with more productive site type
- the increase in pH with depth is retarded below A_2
- highest electrical conductivity values in the horizons rich in organic material together with the fresher and more productive vegetation communities
- increased leaching of Fe and Al from A_2 with the age of the soil and accumulation in the B horizon
- maxima for P, K, Mg, Mn and Zn in the horizons rich in organic material, with a step-wise decline from A_1 to A_2, and a lower peak deeper down in the B horizon in the case of P and Mn
- increase in P, K, Mg, Mn and Zn with fresher site types and decreasing particle size

(2) Factors showing systematically higher values in the north (Ivalo) than further south (Oulanka) these being Fe and Mg.
(3) Declining trends in P, Mg, Mn and Zn with the age of the soil, which may partly have been brought about by the valley characteristics, i.e. the higher the level the older it is, being associated with drier site types of lower organic productivity. This is possibly the explanation for the unexpected decrease in Fe content with age in the B horizon.
(4) Declining trends in the amount of organic material and electrical conductivity with the age of the soil. Both factors have been greatly affected or totally controlled by the valley characteristics mentioned above.
(5) Some interdependences, (a) the older the soil, the thicker the A_2 horizon, and (b) an increase in the accumulation of Al with age in the C horizon, which seem highly exceptional in the light of other studies. Mg in the mineral horizons also gave very high values in relation to those measured in Southern Finland.

A lot of the information achieved is in accordance with the principles of the physico-chemical reactions typical of podzolization (category 1 above). On the other hand, there are a number of time-dependent events (category 4) which find their natural explanation in the geological history of the valleys studied, and another group of correlations (category 3), especially those connected with the role of time in podzolization, in which the details regarding podzolization are overshadowed by the vegetational characteristics of the areas themselves. By interrupting podzolization many times in the past, as evidenced by numerous findings of charcoal in the A_1 horizon, forest fires may have had their own effects on the results.

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Total of 41 references

Appendix 1. Ages, site types, source material and locations of podzol profiles studied.

No of podzol profile	Terrace height (m)	Approximate radiocarbon age	Site type	Parent material	Coordinates (Finnish national grid reference)
1	24	9 200	EMT	glaciofluvial (Oulanka)	N = 7353.42 E = 482.39
2	9	7 800	EMT	fluvial (Oulanka)	N = 7353.49 E = 482.41
3	7	7 100	EMT	fluvial (Oulanka)	N = 7353.59 E = 482.43
4	4	5 000	EMT	fluvial (Oulanka)	N = 7353.79 E = 482.49
5	5	2 500	EMT	fluvial (Oulanka)	N = 7355.00 E = 483.94
6	3	1 000	HMT	fluvial (Oulanka)	N = 7355.31 E = 483.91
7	6	5 250	HMT	fluvial (Oulanka)	N = 7355.37 E = 483.90
8	24	9 200	CClT	glaciofluvial (Oulanka)	N = 7355.59 E = 483.88
9	4	300	EVT	fluvial (Oulanka)	N = 7356.81 E = 481.57
10	9	7 250	EVT	fluvial (Oulanka)	N = 7356.85 E = 481.84
11	5	4 400	EMT	fluvial (Oulanka)	N = 7356.91 E = 481.89
12	4	1 500	EVT	fluvial (Oulanka)	N = 7357.13 E = 482.09
13	24	9 200	CClT	glaciofluvial (Oulanka)	N = 7357.26 E = 482.20
14	7	6 400	EMT	fluvial (Oulanka)	N = 7355.71 E = 482.81
15	9	7 600	EMT	fluvial (Oulanka)	N = 7355.75 E = 482.85
16	6	5 250	CClT	fluvial (Oulanka)	N = 7355.89 E = 482.97
17	22	9 500	ErClT	glaciofluvial (Ivalo)	N = 7613.03 E = 518.57
18	5	5 500	UEMT	fluvial (Ivalo)	N = 7613.17 E = 518.25
19	26	9 500	ErClT	glaciofluvial (Ivalo)	N = 7613.25 E = 518.23
20	20	9 500	UEMT	glaciofluvial (Ivalo)	N = 7617.05 E = 518.89
21	6	4 800	UVET	fluvial (Ivalo)	N = 7616.87 E = 518.83
22	7	6 000	UVET	fluvial (Ivalo)	N = 7616.71 E = 518.77
23	18	9 500	ErClT	glaciofluvial (Ivalo)	N = 7614.73 E = 522.33
24	9	7 000	ErClT	fluvial (Ivalo)	N = 7614.98 E = 522.18
25	2	2 800	UEMT	fluvial (Ivalo)	N = 7615.17 E = 522.08
26	4	3 000	UVET	fluvial (Ivalo)	N = 7616.14 E = 520.09
27	6	4 750	UVET	fluvial (Ivalo)	N = 7616.27 E = 519.88
28	6	5 400	UVET	fluvial (Ivalo)	N = 7616.39 E = 519.72
29	6	4 750	UVET	fluvial (Ivalo)	N = 7616.42 E = 519.68

Appendix 2. Correlation coefficient values between various physical properties used in the study. (1) Thickness of horizon, (2) relative elevation, (3) age, (4) coverage of the field layer, (5) coverage of mosses, (6) coverage of lichens, (7) mean particle size, (8) sorting of material, (9) amount of organic material. Values of over 99 % statistical significance underlined.

A_0	1	2	3	4	5	6	9
1	1.00						
2	–0.06	1.00					
3	–0.13	$\underline{0.83}$	1.00				
4	0.35	$-\underline{0.46}$	$-\underline{0.46}$	1.00			
5	$\underline{0.43}$	$-\underline{0.49}$	$-\underline{0.45}$	$\underline{0.65}$	1.00		
6	$-\underline{0.44}$	$\underline{0.54}$	$\underline{0.53}$	$-\underline{0.74}$	$-\underline{0.95}$	1.00	
9	0.36	–0.22	–0.36	$\underline{0.57}$	0.30	–0.30	1.00

A_1	1	2	3	4	5	6	9
1	1.00						
2	–0.30	1.00					
3	–0.31	$\underline{0.83}$	1.00				
4	$\underline{0.45}$	$-\underline{0.46}$	$-\underline{0.46}$	1.00			
5	0.36	$-\underline{0.49}$	$-\underline{0.45}$	$\underline{0.66}$	1.00		
6	–0.40	$\underline{0.53}$	$\underline{0.53}$	$-\underline{0.74}$	$-\underline{0.95}$	1.00	
9	0.20	$-\underline{0.48}$	–0.39	0.35	0.08	–0.10	1.00

A_2	1	2	3	4	5	6	7	8	9
1	1.00								
2	0.33	1.00							
3	0.42	$\underline{0.86}$	1.00						
4	–0.04	$-\underline{0.43}$	–0.41	1.00					
5	0.05	$-\underline{0.47}$	$-\underline{0.43}$	$\underline{0.65}$	1.00				
6	–0.08	$\underline{0.50}$	$\underline{0.51}$	$-\underline{0.73}$	$-\underline{0.95}$	1.00			
7	0.14	0.26	0.30	–0.20	–0.08	0.04	1.00		
8	0.21	0.38	0.22	0.05	0.03	–0.09	$\underline{0.45}$	1.00	
9	$-\underline{0.46}$	–0.39	$-\underline{0.52}$	0.39	0.12	–0.16	–0.28	0.15	1.00

B	1	2	3	4	5	6	7	8	9
1	1.00								
2	0.39	1.00							
3	$\underline{0.48}$	$\underline{0.83}$	1.00						
4	–0.05	$-\underline{0.46}$	$-\underline{0.46}$	1.00					
5	–0.04	$-\underline{0.49}$	$-\underline{0.45}$	$\underline{0.66}$	1.00				
6	0.04	$\underline{0.53}$	$\underline{0.53}$	$-\underline{0.74}$	$-\underline{0.95}$	1.00			
7	0.22	$\underline{0.44}$	$\underline{0.46}$	–0.27	–0.18	0.12	1.00		
8	0.13	0.36	0.29	–0.24	–0.23	0.15	$\underline{0.72}$	1.00	
9	$-\underline{0.47}$	–0.39	$-\underline{0.46}$	0.38	0.25	–0.24	–0.25	$-\underline{0.47}$	1.00

C	2	3	4	5	6	7	8	9
2	1.00							
3	$\underline{0.83}$	1.00						
4	$-\underline{0.46}$	$-\underline{0.46}$	1.00					
5	$-\underline{0.49}$	$-\underline{0.44}$	$\underline{0.66}$	1.00				
6	$\underline{0.53}$	$\underline{0.53}$	$-\underline{0.74}$	$-\underline{0.95}$	1.00			
7	0.13	0.21	–0.07	–0.10	0.02	1.00		
8	0.22	0.24	–0.13	–0.11	0.00	$\underline{0.69}$	1.00	
9	–0.21	–0.15	0.12	0.09	–0.01	$-\underline{0.65}$	$-\underline{0.57}$	1.00

Appendix 3. Correlation coefficient values between various physical and chemical properties used in the study. (1) Coverage of the field layer, (2) coverage of mosses, (3) coverage of lichens, (4) iron, (5) aluminium, (6) phosphorous, (7) potassium, (8) magnesium, (9) manganese, (10) zinc, (11) amount of organic material, (12) acidity, (13) electrical conductivity. Values of over 99 % statistical significance underlined.

A_0	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00												
2	0.66	1.00											
3	–0.74	–0.95	1.00										
4	–0.20	–0.04	0.05	1.00									
5	–0.16	–0.25	0.34	0.32	1.00								
6	0.65	0.47	–0.56	0.31	–0.05	1.00							
7	0.54	0.36	–0.36	–0.08	0.19	0.59	1.00						
8	0.54	0.30	–0.34	0.32	0.01	0.50	0.32	1.00					
9	0.65	0.37	–0.45	0.17	–0.07	0.49	0.30	0.76	1.00				
10	0.56	0.26	–0.25	0.12	0.11	0.35	0.30	0.81	0.72	1.00			
11	0.57	0.30	–0.30	–0.53	–0.10	0.08	0.30	0.21	0.22	0.24	1.00		
12	0.32	0.01	–0.09	0.43	–0.05	0.30	–0.10	0.56	0.67	0.44	–0.04	1.00	
13	0.46	0.50	–0.45	–0.10	–0.08	0.36	0.45	0.51	0.31	0.43	0.41	0.05	1.00

A_1	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00												
2	0.66	1.00											
3	–0.74	–0.95	1.00										
4	0.10	0.19	–0.18	1.00									
5	–0.17	–0.10	0.15	0.72	1.00								
6	0.45	0.02	–0.03	–0.20	–0.29	1.00							
7	0.29	–0.10	0.09	–0.14	0.11	0.67	1.00						
8	–0.01	–0.15	0.10	0.28	0.09	–0.02	0.09	1.00					
9	0.36	0.03	–0.08	–0.03	–0.22	0.64	0.47	–0.08	1.00				
10	0.36	0.07	0.02	–0.24	–0.05	0.44	0.42	0.04	0.30	1.00			
11	0.35	0.08	–0.11	–0.24	–0.48	0.36	0.25	0.13	0.21	0.09	1.00		
12	0.23	–0.19	0.09	0.15	0.13	0.25	0.38	0.19	0.48	0.29	–0.05	1.00	
13	0.47	0.39	–0.33	–0.04	–0.07	0.52	0.30	–0.18	0.05	0.31	0.07	–0.18	1.00

A_2	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00												
2	0.65	1.00											
3	–0.73	–0.95	1.00										
4	0.19	0.21	–0.18	1.00									
5	0.22	0.22	–0.21	0.75	1.00								
6	0.10	–0.16	0.11	0.50	0.53	1.00							
7	0.18	0.01	–0.05	0.18	0.24	0.30	1.00						
8	0.32	0.21	–0.24	0.79	0.51	0.55	0.25	1.00					
9	0.49	0.15	–0.16	0.12	0.06	0.10	–0.03	0.20	1.00				
10	0.19	0.14	–0.08	0.30	0.02	0.15	–0.24	0.23	0.31	1.00			
11	0.39	0.12	–0.16	0.58	0.47	0.68	0.45	0.65	0.30	0.50	1.00		
12	–0.22	–0.61	0.65	–0.08	–0.12	0.28	0.01	–0.02	0.20	–0.10	–0.14	1.00	
13	0.56	0.26	–0.32	0.43	0.36	0.52	0.43	0.52	0.31	0.44	0.92	–0.30	1.00

Appendix 3 cont.

B	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00												
2	0.66	1.00											
3	–0.74	–0.95	1.00										
4	0.39	0.21	–0.26	1.00									
5	–0.01	–0.08	0.08	0.15	1.00								
6	0.00	0.00	–0.06	0.01	0.19	1.00							
7	0.00	–0.04	–0.01	0.09	0.22	0.15	1.00						
8	0.45	0.41	–0.46	0.30	–0.14	–0.33	–0.39	1.00					
9	0.45	0.41	–0.46	0.30	–0.14	–0.33	–0.39	0.29	1.00				
10	0.44	0.23	–0.24	0.26	0.34	0.02	–0.02	0.15	0.76	1.00			
11	0.38	0.25	–0.24	0.41	0.55	–0.08	–0.04	0.31	0.83	0.83	1.00		
12	–0.11	–0.41	0.42	0.02	–0.31	–0.23	0.29	–0.10	–0.48	–0.40	–0.36	1.00	
13	0.44	0.21	–0.26	0.26	0.13	–0.23	–0.12	0.24	0.47	0.70	0.62	–0.33	1.00

C	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1.00												
2	0.66	1.00											
3	–0.74	–0.95	1.00										
4	0.27	0.33	–0.23	1.00									
5	–0.31	–0.22	0.38	0.24	1.00								
6	0.11	0.25	–0.23	0.30	0.58	1.00							
7	0.10	0.20	–0.13	0.17	–0.23	–0.18	1.00						
8	0.50	0.41	–0.46	0.60	–0.33	0.06	0.30	1.00					
9	0.15	0.34	–0.25	0.35	0.36	0.35	0.00	0.18	1.00				
10	0.18	0.18	–0.13	0.33	0.03	0.04	–0.05	0.41	0.24	1.00			
11	0.12	0.09	–0.01	0.81	0.42	0.39	0.04	0.50	0.26	0.34	1.00		
12	0.11	–0.39	0.36	0.12	0.08	–0.17	0.02	0.04	–0.44	0.04	0.22	1.00	
13	–0.03	0.22	–0.27	0.06	–0.04	0.34	0.28	0.18	–0.03	–0.20	0.00	–0.07	1.00