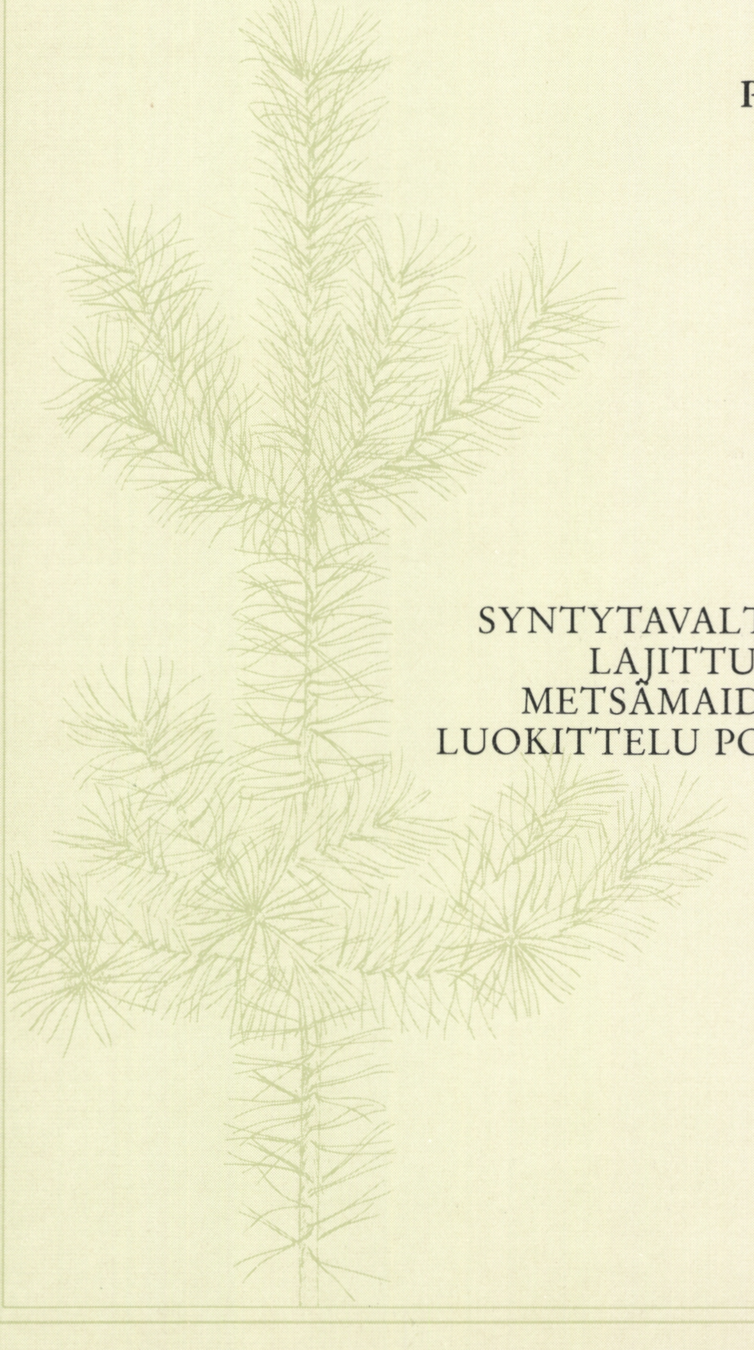
COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE 129

THE ECOLOGICAL CLASSIFICATION OF SORTED FOREST SOILS OF VARYING GENESIS IN NORTHERN FINLAND

PENTTI SEPPONEN



SELOSTE

SYNTYTAVALTAAN ERILAISTEN LAJITTUNEIDEN KANGASMETSÄMAIDEN EKOLOGINEN LUOKITTELU POHJOIS-SUOMESSA

HELSINKI 1985

COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE

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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.

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THE ECOLOGICAL CLASSIFICATION OF SORTED FOREST SOILS OF VARYING GENESIS IN NORTHERN FINLAND

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University of Oulu

To be presented, with the permission of the Faculty of Science of the University of Oulu, for public discussion in the Auditorium YB 210, Linnanmaa, on October 11th, 1985, at 12 o'clock noon.

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SYNTYTAVALTAAN ERILAISTEN LAJITTUNEIDEN KANGASMETSÄMAIDEN EKOLOGINEN LUOKITTELU POHJOIS-SUOMESSA

HELSINKI 1985

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The processes involved in the development on different types of site type on soil formations sorted by the action of wind or water were studied in nothern Finland. The tree stands, ground vegetation and a number of physical and chemical soil properties (parameters describing the particle size distribution of the soil, and the pH and Ca, Mg, K, P, N, and Na content of the soil) were studied on a total of 285 sample plots in northern Finland. The soil formations included in the study were divided into aeolian (formed by the action of the wind), fluvial (formed by the action of large rivers) and glaciofluvial soils (soils formed by the melt water from the continental ice sheet).

Statistically significant differences were found between the nutrient status of the humus in the different soil types but not between the values for the sub-soil. As the physical properties of the mineral soil were found to be different in the different soil types, this result was interpreted to indicate that the differences in the nutrient status arise during the development of the site types, the physical properties being the controlling factor, since, in turn, the physical properties are at least partly a product of the particular geological processes in question, these processes can therefore be considered to control the development of the nutrient status on the different site types.

A number of correlations were found between the coverage of various plant species and soil parameters. These supported the above mentioned conclusions. Mosses, especially *Pleurozium schreberi* and *Hylocomium splendens,* were found to be the best indicators of a good nutrient status and a fairly high proportion of fine soil fractions. On the other hand, lichens, especially species of *Cladonia* and *Stereocaulon spp.,* were the best indicators of a low nutrient content and a uniform soil texture.

The results of the study were interpreted as indicating that different geological processes can produce mineral soils wich differ clearly from each other, and also soils that initially resemble each other, and that subsequently can also develop into forms which closely resemble each other. For this reason, the soil formations alone are not usually sufficient to act as the basis of an ecological classification. Classification done using the ground vegetation is a rather good and workable method for classification in stands which are in a rather natural condition and which have developed on sorted mineral soils, such as those investigated in this study. However, different soil parameters can also be used to provide additional information in vegetation classification.

Tutkimuksessa selvitettiin kasvupaikkojen erilaistumisprosessia eräillä tuulen ja virtaavan veden lajittamilla kivennäismaamuodostumilla Pohjois-Suomessa. Tutkimus toteutettiin mittaamalla eri puolilta Pohjois-Suomea 285 näytealaa, joilta tutkittiin puusto, aluskasvillisuus ja joukko maan fysikaalisia ja kemiallisia tunnuksia (maan raekokoa kuvaavat tunnusluvut, Ca-, Mg-, K-, P-, N- ja Na-pitoisuus ja maan happamuus). Tutkitut maaperämuodostumat luokiteltiin tuulen kerrostamiin l. eolisiin, mannerjään sulamisvesien kerrostamiin l. glasifluviaalisiin ja suurten jokien kerrostamiin l. fluviaalisiin muodostumiin.

Eri maatyypit erosivat toisistaan tilastollisesti merkitsevästi humuskerroksen ravinteisuuden suhteen. Koska eri maatyypit oli todettu kivennäismaan fysikaalisten ominaisuuksien suhteen erilaisiksi, tätä tulosta tulkittiin siten, että ravinteisuuserot syntyvät kasvupaikkojen kehittyessä fysikaalisten ominaisuuksien ohjailemina. Koska fysikaaliset erot taas ainakin osittain ovat geologisten prosessien aikaansaamia, on näiden prosessien katsottava ohjailevan tällä tavoin myös kasvupaikkojen ravinteisuuskehitystä.

Kasvilajien peittävyyden ja maan tunnusten välillä todettiin useita korrelaatioita, jotka vahvistivat edellä esitettyjä havaintoja. Sammalet, etenkin *Pleurozium schreberi* ja *Hylocomium splendens* todettiin selvimmin maan hienoja lajitteita ja ravinteikkuutta indikoiviksi ja jäkälistä etenkin *Cladonia*-lajit ja *Stereocaulon spp.* taas niukkaravinteisuutta ja maan tasarakeisuutta indikoiviksi.

Tuloksia tulkittiin siten, että erilaiset geologiset prosessit voivat tuottaa paitsi selvästi toisistaan poikkeavia myös samankaltaisia kivennäismaita, jotka myös jatkossa kehittyvät toisiaan muistuttaviksi. Tästä syystä maaperämuodostumat eivät yksin yleensä riitä ekologisen luokittelun perustaksi. Aluskasvillisuuden avulla tapahtuva luokitus on varsin hyvä ja käyttökelpoinen menetelmä tässä tutkitun kaltaisissa lajittuneille kivennäismaille syntyneissä, puustoltaan melko lähellä luonnontilaa olevissa metsissä. Kasvillisuusluokituksen apuna voidaan kuitenkin käyttää luokituksen käyttötarkoituksesta riippuen erilaisia maaperätunnuksia.

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PREFACE

This study forms part of a project being carried out at the Rovaniemi Research Station of the Finnish Forest Research Institute into the classification of upland soil site types. I started working on this study in summer 1978 while employed by the Academy of Finland as a research assistant at Rovaniemi Research Station. Since 1979 I have continued to work on the theme while employed as a researcher at the Finnish Forest Research Institute.

I received invaluable advice during the planning stage from Dr. Erkki Lähde, research specialist in silviculture for North Finland at the time, and from Dr. Pentti Roiko-Jokela, researcher in forest production. Both of them have helped me with numerous problems during the course of the study. Following my transfer to the Finnish Forest Research Institute as a researcher, Prof. Erkki Lähde provided, as head of the Department of Silviculture, considerable assistance in completing the study.

I have received considerable help in carrying out the field work for the study from Mr. Antti Heikkinen, Mr. Pentti Pikkupeura and Mr. Raimo Pikkupeura. Mr. Raimo Pikkupeura has also assisted in the numerous tasks involved in handling the material throughout the course of the study. Technical and expert advice has also been provided by Mr. Kimmo Linnilä, M.Sc. and Mr. Kari Mikkola. Other sources of help during the handling of the material include Mr. Markku Pänttäjä and the staff of the computing section of the Rovaniemi Research Station. The computing section has created ideal conditions for the flexible and expert treatment of the material.

I have received invaluable assistance in drawing the figures and setting up the photos from Mr. Tapani Vartiainen who, together with Mr. Raimo Pikkupeura and Mrs. Sointu Nenola, have helped in all aspects concerned with the completion of this work.

Professors Paavo Havas and Erkki Lähde and assistant professor Seppo Eurola have read the manuscript and made valuable comments. The manuscript was translated into English by Mr. John Derome.

I would like to thank those responsible for providing funds for the study, the persons mentioned above, and all who have contributed towards the successful completion of the work.

Rovaniemi, March 1985

Pentti Sepponen

1. INTRODUCTION

11. Factors affecting the determination of site type

Forests and their vegetation can be classified in many different ways. The internationally most famous classification system, developed in Finland, is Cajander's (1909, 1925 and 1949) site type calssification. It is used for a wide range of purposes: as well as in practical forestry, also for forest taxation and in ecological research. The studies carried out by Ilvessalo (1920, 1922 and 1937) provided the main foundation for the taxatorial use of forest site types (see also Cajander & Ilvessalo 1921 and Ilvessalo Y. and Ilvessalo M. 1975).

The site type system has been considered to work well in practice, especially in forests which have not been subjected to intensive management such as cuttings or other silvicultural measures. However, the active management of forests has brought about problems in determining the forest site type, partly for the reason that the effect of different silvicultural measures on the ground vegetation is not sufficiently well known, and partly because the succession series of the vegetation in each site type have not been studied very much in different climatic zones (Ilvessalo Y. & Ilvessalo M. 1975 and Vuokila 1980). The soil treatment methods which have been widely used in conjunction with forestation in recent years (Pohtila 1977) have brought about a need for the further development of the classification system, or at least the development of substitute or supplementary systems. One system used frequently in the field of forestry is the so-called site index system (e.g. Ebeling 1978, Fries 1974, Gustavsen 1980 and Hägglund 1981).

The crucial problem in ecological site type research is still to elucidate which environmental factors affect the determination of the site type, and what kind of process is involved in the creation of site types. Cajander (1925, p. 25) stated the following about the factors determining the forest site type: "...The forest site type thus usually only reflects the primary site factors — climatic ones and those associated with the soil — which can be considered to remain in force even if plants are totally absent from the site". The secondary site factors, above all the changes brought about by the tree stand in the local (the stand's own) climate (illumination etc.) and the soil, each impart their own additional stamp on the vegetation, while on the other hand creating their own variation due to the age of the stand, the site index etc. which brings about temporary differences in the vegetation of the site type.

This principle difference between primary and secondary site factors has more recently been emphasized in the discussion centered, for instance, on the nature of HMT spruce stands in northern Finland (Sirén 1955 and Keltikangas 1959). As the site type consequently depicts the factor constellation of all the climatic and soil factors (Keltikangas 1959 and Kotilainen 1927), the contribution of an individual ecological variable as a factor determining the site type is difficult to measure. A forest vegetation zone division (e.g. Kalela 1961 and Ahti et al. 1968 etc.) and parallel climatic types (also Kujala 1936 and 1938) have been formed primarily on the basis of climatic differences. Climatic differences thus cause variation in the groups of vegeation types, as well as in the distribution of site types in different areas. Climate has received attention in many studies as a factor causing variation in the vegetation (Aario 1943, Vasari 1962, Solantie 1974 and Tuhkanen 1980).

The particle size distribution of mineral soil is a factor which affects many properties of the soil (Aaltonen 1941, Viro 1949, Lakanen et al. 1970, Kurki 1972 and Sepponen 1981), and thus indirectly affects the plant cover (Kujala 1938 and Sepponen et al. 1979). The fine fractions, in particular, have been found to improve water and nutrient retention in the soil (Sepponen 1981). As regards the relationship between the site type and the textural class of the soil, however, the soil type distribution and the distribution of site types have usually been found to differ to some extent from each other, although the same site type can occur on many different types of soil (Aaltonen 1941, Ilvessalo 1933, Granlund & Wennerholm 1934, Teivainen 1952, Urvas & Erviö 1974, Söyrinki et al. 1977). On the average, damp site types occur most frequently on fine-textured soils, and the infertile site types in turn on coarse-textured and sorted soils (Sepponen et al. 1982).

The chemical properties of the soil, which are dependent on the bedrock and on the structure and texture of the soil (Erviö 1970, Lakanen et al. 1970, Urvas et al. 1978 and Sepponen 1981), also affect the development of the plant cover and the formation of the site type. Valmari (1921), Cajander (1925) and Urvas & Erviö (1974) found that there is a clear dependence between the site type and the nitrogen and calcium contents of the soil. The acidity of the soil, being strongly correlated with the calcium content of the soil, is also clearly correlated with the site type. On the other hand, no clear correlation was found between the site type and the phosphorus content. The correlation between the site type and the potassium content has also been found to be weak.

In many respects the quaternary development may have a decisive effect, from the point of view of the formation of the site type, on what sort of soil conditions are created. It determines the distribution of soil types in the area and also to a large extent the structure of forest soils. The quaternary development in northern Finland was elucidated already at the beginning of the century (Tanner 1915, 1930 and 1958), and a number of studies have since been carried out (e.g. Kujansuu 1967, Kurimo 1979, Mansikkaniemi 1970 and Seppälä 1971).

The flat coastal region in the northern part of the Gulf of Bothnia forms, owing to the rapid land uplift and relative youth of the forest soils in the region, a distinctive uniform region (Eronen 1974 and Sauramo 1958). The youngest soils in this region are certain sand dunes, which Aartolahti (1976) estimated as being only 300—500 years old.

The historical development of the vegetation in northern Finland during the Quaternary Period has also been studied (e.g. Auer 1927, Lappalainen 1970, Vasari 1962 and 1974), although so far least attention has been paid to how the history of the quaternary geology has affected soil formation and the creation of the present-day site types (e.g. Okko 1944 and Jauhiainen 1969). This, as well as the classification of soils in general, has been studied more elsewhere (e.g. Catt 1979 and Evans 1980).

Soil formation, which is a process that affects the properties of the surface layers of the soil, may also have an importance in explaining the variation in the forest vegetation (Aaltonen 1933, 1935, 1939, 1941b, 1947 and 1951 and Jauhiainen 1969, 1970, 1973 and 1976). In his studies on regional variation in soil formation, Aaltonen (1941a and 1951) distinguishes the flat coastal region of the northern part of the Gulf of Bothnia from geologically older soils on the basis of the fact that they are less leached. Aaltonen (1941a) did not find any clear differences between site types as regards the thickness of the A horizon in the soil profile, but observed that the horizon is thicker in the case of geologically young soils (Aaltonen 1935, p. 104). He concluded that this was due to the fact that the B horizon was first formed at a greater depth, and then grew upwards while producing at the same time a corresponding thinner A horizon. Later on, however, he did become rather doubtful about his hypothesis when analysing a new, more extensive material. Jauhiainen (1969, p. 109) also drew attention to differences in the thickness of the horizons in different parts of the country. The A horizon, according to Aaltonen (1941a), is thicker on coarser soils than on finer-textured ones. The texture of the soil thus also has a clear effect on the development of the structure of the soil profile.

The vertical distribution of plant nutrients in podzolic soils has been studied by Jauhiainen (1969) and Urvas & Erviö (1974), as well as Aaltonen. The clearest trends are considered to be the increase in the pH on moving downwards, and the strong precipitation of aluminium and iron in the B horizon. Such clear trends have not been found as regards phosphorus and potassium, for instance. There is still a lot to be learnt about the behaviour of these nutrients, as well as other elements, in the soil.

12. The problems associated with measuring and explaining the variation in the vegetation

The main problem encountered in ecological vegetation studies is to find a suitable means of describing the plant cover, and of analyzing its ecological explaining value. One way of analysing a stand is to collect a sample of the coverage of different plant species from a sample square of known size. The frequency of a species thus also depicts its occurrence frequency (Greig-Smith 1964 and Kershaw 1964). The above method has the added advantage that the values (percentages) which are obtained can also be subjected to parametrical tests. Multivariate methods have been used to an increasing extent in recent years for classifying plant communities (see e.g. Hinneri 1972, Pakarinen 1976, Pakarinen & Ruuhijärvi 1978 and Jukola-Sulonen 1983).

Attempts to explain the variation in the vegetation and its ecological trends by means of single variables are faced with problems which are partly caused by the complicated interactions between different factors, and partly to the "random" proportion of the total variation formed by factors not included in the study (see Sepponen et al. 1979).

The aim of this study is to determine the role of quaternary development in determining the processes resulting in the formation of site types, as well as the present properties of forest soils and the vegetation, on formations of certain types of sorted soil material. The problem is approached by first considering certain formations of quaternary geological origin, an attempt being made to analyse the extent to which the plant communities and soils of each formation are typical of the type of formation in question, and whether there are differences between the different types of formation with respect to botano-ecological factors. This will help to make the site type formation theory more exact, and to provide a better basis for site classification. At the same time an attempt is made to create a classification system based on ecological premises for the forest soils examined in this study. The soil types are divided into deposits formed by the action of the wind (aeolian soils e.g. dunes), deposits formed by water draining from the melting of continental ice sheets (glacio-fluvial soils, e.g. eskers) and deposits formed over time by present-day large rivers (fluvial soils, e.g. beach ridges and river banks).

2. MATERIAL AND METHODS

Sorted mineral soil formations, whose mode of formation was clearly identifiable, were chosen as the study objects. Deposits formed from sorted soil material were selected because they were considered to be easier to master in this sort of study than, for instance, till deposits which occur in a wide range of forms and which are more heterogeneous as regards the texture and structure of the soil.

The soils were classified according to their formation process into wind deposits, i.e. aeolian soils, and soils formed from deposits produced by running water. The latter group was further divided into soils formed from deposits left by the melting of continental ice sheets, i.e. glaciofluvial soils, and fluvial soils formed from deposits left by present-day large rivers in northern Finland. The possible contributory role of glaciofluvial processes could not be ruled out in the group of deposits called fluvial soils. This, however, is not considered to be of primary importance from the point of view of this study; it is more important to know that both glaciofluvial and fluvial soils are both sorted and deposited by flowing water. The term fluvial soil is thus used to refer to those sorted soils which occur as bank formations along the present-day large rivers. Glaciofluvial soils are in most cases sorted eskers, but the group also includes deltas and came formations (for the classification see e.g. Donner 1965). Aeolian soils are dunes or the more uniform wind-blown sand fields which occur along their edges (e.g. Aartolahti 1976).

21. Selection of the sample plots and the field and laboratory measurements

The sample plots were sited on typical deposits of aeolian, glaciofluvial and fluvial material. They were located in the stands as clusters of three sample plots. The position of the first plot was chosen, and the other two plots then marked out at spacings of 40 m to the north. In cases where the deposits occupied only a small area, an attempt was made to select the site for the first sample plot in such a way that the different sample plots would lie on different expositions of the deposit and the ecological variation caused by the topography thus be described as well as possible. The conditions in each study area were examined as thoroughly as possible so as to obtain an overall picture of the variation in the vegetation before choosing the deposits to be included in the study. An attempt was thus made to pay particular attention to the representativeness of the sample.

Measurements were made on the tree stand, ground vegetation and soil on the sample plots. General observations were made at the same time of the topography, the possibility of thinnings, forest fires, erosion of the site and the surrounding plant communities. The tree stand was estimated using a relascope, increment cores being taken from the socalled centre tree at the same time. However, no increment cores were taken from the tree stand on the dune sample plots measured in summer 1978. Four 1 m^2 square blocks were marked out at a distance of 5 m from the centre point of the sample plot at half cardinal points of the compass. The ground vegetation on the sample plots was described using these blocks. The coverages (as percentages) of the plant species were noted down. In addition, notes were also made of species growing on the sample plot which did not happen to be growing in the blocks. A square soil sample pit was dug in the centre of each plant cover sample block. The horizons in the soil profiles were classified in this study as follows: the humus layer (i.e. the A_0 horizon), the leached layer (i.e. the A horizon), the enriched horizon (i.e. the B horizon) and the sub-soil (i.e. the C horizon). The samples taken from each layer in the four separate pits were combined to form one sample for each layer per sample plot. The size of the samples was about 1 litre. The thickness of the humus and the A and B horizons was measured (from the center of one of the walls in the pit) in each pit to an accuracy of one centimetre. The means of these values were calculated to give the horizon thicknesses for each sample plot.

In addition to the above-mentioned parameters, a few general measurements were made on the vegetation, such as the mean height of the lichens, on each plant cover square. The stoniness of the soil was determined in the field using the rod method described by Viro (1952 and 1958).

The particle size distribution of the mineral soil samples was determined in most cases by dry sieving, using sieves with a mesh size of 20, 6, 2, 0.6, 0.2 and 0.06 mm. In cases where more than 10 % of the dry weight of the sample passed through the finest sieve, particle size analysis was carried out on the < 2 mm material by the pipetting method described by Elonen (1971) (see also Lipas 1983). The material with a particle diameter of less than 20 mm was taken into account when depicting the particle size distribution. The moisture content of the samples was determined by drying the samples overnight in an oven (temperature 105°C), and the moisture content was expressed as the relative proportion (%) of the difference between the fresh and dry weights out of the dry weight. Loss in weight on ignition was determined by ashing the oven-dry samples (3—5 g) in a muffle furnace at 550°C for 1—2 hours. The loss in weight on ignition was expressed as a percentage of the dry weight.

Ca, Mg, K, P and Na were extracted from the soil samples using hot 2N HCl in the ratio 2 g of soil to 50 ml of HCl. Ca, Mg, K and Na were determined from the extract using atomic absorption spectrophotometry, 5 % La_2O_3 being added before the determination of Ca and Mg. Phosphorus was determined colorimetrically from the extract by the molybdenum blue method. Total nitrogen was determined by the Kjeldahl method on the humus samples only. Aluminium and iron were determined colorimetrically using the so-called Tamm's (1922) extraction method (for HCl as the extracting agent see Andersson 1975). Acidity was determined in two ways using water and an aqueous solution of 0.02 N $CaCl_2$ (for the significance of the extractant see e.g. Lierop 1981). The slurries were prepared in the ratio 1:2.5 (v/v).

A total of 285 sample plots were studied, the distribution of the plots into different soil formations being as follows: aeolian soils 106, glaciofluvial soils 110, and fluvial soils 69. A total of 1 140 soil samples were analysed in the laboratory, being equally divided into humus samples and samples from the A, B and C horizons.

22. Treatment of the material

The mean particle size (Md), two parameters depicting the degree of sorting (S and S_0), and the parameters depicting the shape of the particle size distribution, K (Curtosis) and Sk (Skewness), were calculated on the basis of the results from the particle size distribution analyses. The sorting parameter (S) was calculated directly from the relative proportion of different fractions according to Sindowski (1938). The other parameters depicting the particle size were calculated from the values obtained from the particle-size curve using the equation presented by Folk (1969, see also Sepponen 1981). A millimeter scale was used in the calculations. The particle size values corresponding to different penetration percentages were calculated by interpolation instead of reading them from the curve.

The dependences between the different ecological variables were tested using computer programmes for correlation and regression analysis developed at the Rovaniemi Research Station, the Finnish Forest Research Institute. The differences between different areas and soil types with respect to different ecological variables were tested by means of variance analysis. The programmes for this were also devised at the Rovaniemi Research Station.

Multivariate methods were used for stratifying the material and for determining a number of different variable combinations: factor analysis, DECORANA ordination and TWINSPAN clustering. Factor analysis (e.g. Überla 1977) was used in the same way as in an earlier study (Sepponen et al. 1982) for ranking the ecological variable groups as factors. Factor analysis was also used for stratification. The sample plots were awarded factor scores on the basis of four different factors, the sample plots then being clustered on the basis of these scores.

DECORANA ordination and TWINSPAN clustering were done in the manner presented by Gauch (1982) (see also Hill and Gauch 1980 and Oksanen 1983). Percentage coverage values for the plant species were used in the analyses, the values being subjected to logarithmic transformation before ordination analysis. Variance standardization of the variables was used in treating the soil analysis data.

3. THE STUDY AREAS

An attempt was made to select areas which contained as many sorted soil formations as possible. The aim was to obtain two study areas from each of the three forest vegetation zones of the northernmost coniferous forest area (Kalela 1961, Ahti et al. 1968 and Kalliola 1980), the study areas being representative of the different natural conditions within each zone. Since no uniform extensive dune area was found in the western part of the Peräpohjola area, the dune samples and also a large part of the esker samples had to be collected from a very wide area. However, it was possible to follow the selection criteria described here in the other areas. Another of the selection criteria for the study areas was that there should be sufficient sample plots in as natural a state as possible in the area. However, a certain amount of compromise had to be made in practice in this respect, since there were not enough forested nature protection areas or completely uncut areas in northern Finland for the purposes of this study.

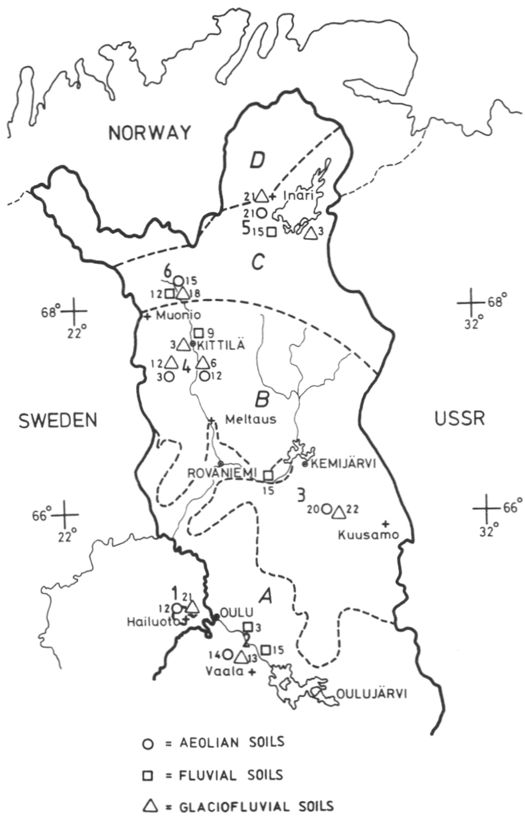

Fig. 1. The location of the study areas and the distribution of the sample plots into different soil types in the different study areas. The numbers next to the soil type symbols indicate the number of sample plots. The borders of the forest vegetation zones have also been marked on the figure: A = Ostrobothnia-Kainuu, B = Peräpohjola, C = Forest Lapland and D = Fell Lapland.

The location of the study areas and dispersed sample plots are presented in Fig. 1. The height above sea level and latitude of the study areas are presented in Fig. 2. The Hailuoto and Rokua areas thus represent the Northern Ostrobothnia area (Ostrobothnia — Kainuu zone). No study area was selected in the eastern part of this zone, and these study areas have primarily been included to act as comparison areas representing more southern and geologically younger areas. It was estimated that such a comparison of different aged soils is needed when studying, for instance, the properties of the soil profiles. The sand and esker area to the south of the Lake Livojärvi (in Posio) represents the eastern part of the Peräpohjola region, and in the western part of the Peräpohjola region the sample plots had to be selected from those places where it was possible to find dunes. An attempt was made to concentrate the esker samples in this area in the vicinity of Kittilä. There are two clear concentrations in the Forest Lapland zone: the dune and esker area between Raattama and Ketomella to the north of Pallasjärvi, and the other to the west of Lake Inari. An attempt has been made to describe the forests developing on fluvial soils along the banks of the largest rivers as close as possible to the study areas.

31. Hailuoto

The Hailuoto study area, referred to in the text as No. 1, is the lowest-lying and geologically the youngest of all the study areas. Land uplift is also the rapidest in this area; about 9 mm per year (Kääriäinen 1953). Hailuoto is very flat: the highest point on the island, Hyypänmäki reaches to a height of about 31 m asl (Alestalo 1979). The receding edge of the continental ice sheet reached this area about 8 800—9 000 years ago (Alestalo 1979). Alestalo claims that the highest points on Hailuoto did not rise above sea level until about 1 650 years ago. According to Aartolahti (1976), at least some of the dunes in the area are only perhaps about 300—500 years old. Even considerably younger drifts of aeolian sand occur close to the edge of the sea. They are either completely vegetationfree or only weakly bound by vegetation (Sepponen 1979).

Of the sample plots described in the area, 12 were classified as being mainly formed from aeolian material, and 21 of the sites were considered to be mainly glaciofluvial. Demarcation is rather difficult because the effect of soil sorting by the wind is also evident in the large number of beach ridges which occur in the area, while on the other hand aeolian material may sometimes occur in such narrow layers in the ridges, that soil samples taken from greater depths always include glaciofluvial material. The border between aeolian sand and so-called shore sand is in this respect very unclear — the action of the wind in every case has a noticeable effect on the formation of almost all the reliefs described here (see also Kukal 1971, p. 124).

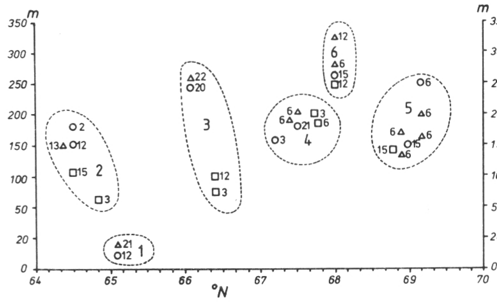

Fig. 2. The height of the study areas and sample plots above sea level (vertical axis) plotted against their latitude. The areas are numbered as in Fig. 1.

As regards the bedrock in Hailuoto, at least most of the area belongs to the region of unmetamorphosed sedimentary rocks (Simonen 1980, Figs. 2 and 3). Most of the area studied in Hailuoto is covered with lichen Scots pine forest (see Fig. 3). Most of the forests have been managed rather conservatively, although the ground vegetation has been to some extent affected by the lichen gathering which is practiced on a commercial scale in the area (Kauppi 1979 and Sepponen 1979). The soil in the study area mainly consists of sorted mineral soil, although small patches of shallow peatland do in fact occur to some extent in the area (Alestalo 1979). Owing to the absence of large rivers, it was naturally not possible to describe any river sediments in the area.

32. Rokua

Rokua, the other research area representing the Ostrobothnia-Kainuu zone (Fig. 1) and which is referred to in the text as No. 2, is situated above the edge of the Litorina Sea (Aartolahti 1973). While the edge of the Litorina Sea is about 100 m asl in the Northern Ostrobothnian area (Eronen 1974), Pookivaara, the highest point in Rokua, reaches to a height of 193.7 m. On the average Rokuanvaara rises to a height of about 50—70 m above its surroundings. The height of the surrounding plains is 100—200 m asl (Aartolahti 1973).

Rokuanvaara is an esker and dune complex (Aartolahti 1973) with deposits of aeolian and esker material, and in places also vegetation-free deflation surfaces. According to Aartolahti, there are no moraines in the area. There are large numbers of beach ridges along the edges of the formations, some of which have become dunified. In this respect the area has some similarities with Hailuoto.

Since, according to Aartolahti (1976), the formation of aeolian deposits ceased almost

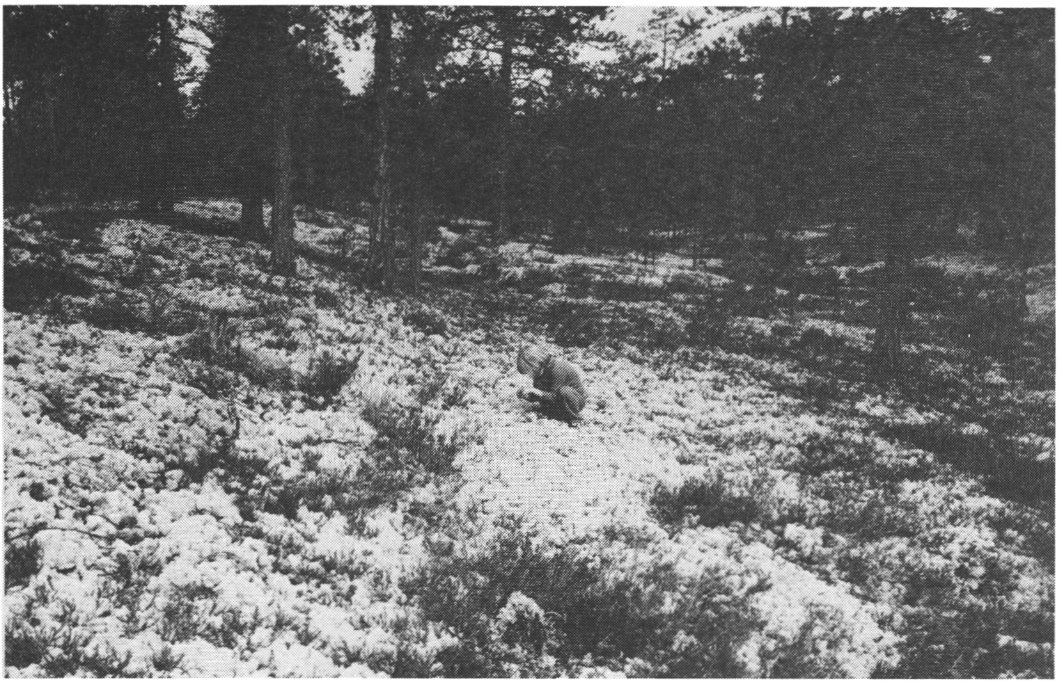

Fig. 3. The lichen pine stands and hillocks typical of the topography of the Hailuoto study area.

completely about 8 000 years B.P., the dunes at Rokua have presumably been formed before then. They are thus considerably older than the dunes in Hailuoto, as is the case with regards to the other soils treated in this study.

The forest vegetation in the area is dominated by lichen, although forests growing on moister mineral soil sites, as well as peatland and grassland vegetation, do occur (Jalas 1953 and Aartolahti 1973). The bedrock comprises phyllite and mica schists, as well as quartzite and granite gneiss (Simonen 1980). There is also a national park at Rokua, the virgin forests growing in the park having been utilized in this study. It is known that extensive parts of the area were burnt during the latter half of the last century, as well as a number of smaller areas at the beginning of this century (Jalas 1953). This may have some effect on some of the features of the vegetation and forest soils in the area.

14 of the sample plots were classified as dunes, and 13 as being formed of esker material. In addition, 18 sample plots were described as river deposits along the banks of the River Oulujoki (Fig. 1). The sediments of the River Oulujoki have not been studied very much in this area, although they have been described further down river starting from the Muhos area (Gibbart 1979).

33. Posio

The study area to the south of Posio, referred to in the text as No. 3 (Fig. 1), belongs to the great glacier river period, to the Kolari—Rovaniemi—Posio—Kuusamo esker (Niemelä 1979, p. 41). The esker material has spread over an extensive area at Posio (Kurimo 1979a, Appendix 1). Observations made in the field indicated that there are plenty of dunes in the area, the depressions between the dunes being covered in places by bogs.

According to Kurimo (1979a, Fig. 4), the border of the highest shore in this region is at a height of about 195—205 above present sea level. Thus all the sample plots are in a subra-aquatic area, as opposed to the others so far described. According to Kurimo

(1979b), the edge of the continental ice sheet receded from this area about 9 500—9 200 years B.P., and hence the soils are obviously older than the ones in both of the areas so far described (see also Kurimo 1978).

The bedrock mainly consists of granite gneiss, although quartzite, unmetamorphised sedimentary rocks and siliconrich intrusive rock also occur (Hackman 1918 and Simonen 1980). Most of the forests are growing on dry or dryish upland sites, although there are considerably more bogs than in the vicinity of the sample plots of the previously described areas. 15 of the plots were classified as dunes and 21 as esker material. 15 sample plots in the River Kemijoki area (Fig. 1) were classified as fluvial soils.

The material from which these river deposits have been formed is presumably derived from the same esker period as in the area to the south of Posio. However, it is assumed that the river has eroded and deposited the soil material in these sample plots. For this reason, they have been considered to be genetically different forest soils compared to the previously described esker soils.

34. The western part of the Peräpohjola region

In the western part of the Peräpohjola region, referred to in the text as No. 4, the dune samples especially had to be selected from different parts of an extensive area (Fig. 1). This accounts for the greater variation in the bedrock, as well as in other environmental conditions, compared to the earlier described areas (for information about the bedrock in the area, see e.g. Mikkola 1941 and Simonen 1980).

Most of the area has been covered by water (Kujansuu 1967 and Sauramo 1928, Fig. 85). The sea and lake stages have earlier covered part of the area, and various ice lakes other parts. Judging by the information presented by Kurimo (1979a, Fig. 1), it would appear that the continental ice sheet receded from the area about 9 000—8 500 years B.P.

There are 24 sample plots classified as aeolian soils in the area, and 12 classified as glaciofluvial soils. It was so difficult to find sufficient river sand sample plots with a cover of virgin vegetation along the bank of the River Ounasjoki, that only 9 are in the study. They are situated above the highest bank along the river (e.g. Kujansuu 1967, Appendix 1).

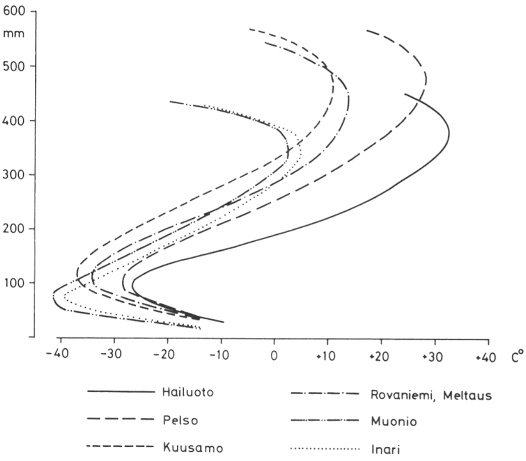

Fig. 4. The mean monthly temperatures and yearly precipitation, expressed as cumulative curves, from six meteorological stations close to the study areas (see also Fig. 1).

35. The area close to Lake Inari

The sample plots furthest to the north and to the east of Forest Lapland, referred to as No. 5 in the text, are situated in the area close to Lake Inari (Fig. 1). There are two clearly distinct dune fields in the area: most of the sample plots are at the southern end of Mutusjärvi (15 sample plots), and only 6 are situated along the River Kaamasjoki. The former field lies completely within the coniferous forest zone, while the area around the River Kaamasjoki extends across the border region between the birch zone and the coniferous forest zone.

18 of the sample plots comprising glaciofluvial material are clearly in the coniferous forest zone, and 6 on the border of the birch zone. All the sample plots situated on river deposits (altogether 15) are within the coniferous forest zone.

The bedrock in the study area comprises granulitic complexes formed mainly of granite-cordierite gneisses and small-grained granate-quartz-feldspar gneisses (Hörmann et al. 1980 and Meriläinen 1965). The Kiellajoki and Kaamasjoki area has earlier been a lake dammed by the continental ice sheet. Glaciofluvial material has become sorted in the area, the texture of the material ranging from medium sand to gravel. The dunes in the area presumably started to form immediately after the ice receded and the water flowed away about 9 700 years B.P. (Seppälä 1971, p. 73). No corresponding research material is available concerning the area to the south of the southern end of Mutusjärvi, but the proximity of the two areas permits the assumption to be made that there are no decisive temporal differences in their developmental history.

The developmental history of the area also differs from area No. 4 in that Lake Inari has earlier been constricted off from the Arctic Ocean (Alhonen 1969). In fact the maritime stage in the lake has been short. The close proximity of the Arctic Ocean may introduce other features which differentiate it from the earlier-described areas. The northern location of the area is also demonstrated by the palsa bogs found in the vicinity (Seppälä 1971 and Ruuhijärvi 1963).

36. The upper reaches of the River Ounasjoki

The southernmost study area in the Forest Lapland zone, and which is also the highest, is the esker area between Ketomella and Raattama to the north of Pallasjärvi (Figs. 1 and 2). This area is referred to as No. 6 in the text. According to Kurimo (1979a, Fig. 1), the edge of the continental ice sheet receded from this area between about 8 800—8 400 years B.P. The area is subra-aquatic, but it has been at least partly covered by a lake dammed by the ice during the receding stage of the continental ice sheet (Kujansuu 1967, Appendix 1).

The bedrock mainly consists of granite, quartz diorite and ganodiorite (Kujansuu 1967, Fig. 4). The bedrock has a decisive effect on the large surface forms. The dune area here is rather uniform and is situated in the height zone 200—300 m. Kujansuu (1967, Figs. 8 and 9) found that there was great variation in the particle size of the glaciofluvial and aeolian material.

Dry and dryish mineral soil sites are the predominant site type in the area. Considerably more luxuriant vegetation occurs along the banks of the river and in stream hollows, although on rather small areas. There are also treeless, grassy patches in places on the aeolian soil, the vegetation being characterized by a lot of heather *(Calluna vulgaris)* and low juniper bushes *(Juniperus communis)*.

15 of the sample plots represent aeolian formations, 12 fluvial and 18 glaciofluvial soils. Reindeer husbandry and tourism have left their mark in this highly susceptible area.

37. The macroclimate

Information about the macroclimate in the different study areas has been collected from the meteorological stations situated closest to the areas in question. The data presented here are for the period 1931—1960. The reason for this was that the network of weather stations reporting weather

Table 1. Weather data from meteorological stations close to the study areas. Source: Kolkki (1966).

	Temperature (°C)						Effective temperature sum	Precipitation		Length of growing period
	Year			Growing period				Year	Growing period	
	$\bar{x}$	min.	max.	$\bar{x}$	min.	max.	(d.d.)	(mm)	(mm)	(days)
Hailuoto	+2.1	—14.1	+19.6	+11.3	+1.1	+19.6	1 060	454	229	150
Pelso, Vaala	+1.5	—15.6	+20.2	+11.2	+1.2	+20.2	1 050	568	315	149
Kuusamo	—0.3	—18.4	+18.9	+ 9.7	—0.7	+18.9	800	567	315	129
Rovaniemi, Meltaus	—0.1	—17.4	+18.7	+ 9.9	+0.1	+18.7	850	546	279	130
Muonio	—1.5	—21.0	+18.6	+ 9.1	—0.7	+18.6	700	438	254	117
Inari	—1.1	—19.3	+17.6	+ 8.6	—1.1	+17.6	650	428	262	123

conditions for this period was considered to best represent the macroclimate in the study areas. The data from six meteorological stations, primarily consisting of temperature and humidity information, are presented in Table 1 (see Fig. 1 for the location of the weather stations).

It can be seen from the table that there are clear differences in the temperature conditions in the different research areas. There is a difference of 1—2°C in the annual mean temperature, as well as in the mean temperature during the growing season, between the study areas representing different forest vegetation zones. Although the weather stations were not always situated right in the study area, their data may depict the mean climatic differences between the study areas. There is also a difference of 100—200 d.d. units between the effective temperature sum in the different vegetation zones.

The differences in the temperature and precipitation recorded at the different weather stations are presented in Fig. 4 using sum curves which have been plotted using the coordinates formed by the monthly amount of precipitation and the mean temperature. The curves representing each forest vegetation zone lie close to each other, and the different zones are clearly distinguishable from each other. On the average, the highest amount of precipitation was recorded at the Kuusamo and Meltaus weather stations representing Peräpohjola, and the smallest amount at the stations representing Forest Lapland. The temperature differences between the zones are also clearly visible in the figure.

The Martonne index (see Tuhkanen 1980), which is used to depict the humidity of the climate, also varies from region to region. It can be seen from the sum curves in Fig. 5 that the highest index value for the year is reached at the stations situated in Peräpohjola, and the lowest value in Hailuoto where the amount of precipitation is relatively low and where, owing to the fact that the temperatures are higher than in other areas, evaporation is the greatest. According to the curves, the climate is the most humid during May — October in Kuusamo, and the least humid in Hailuoto. The data for the time of the year when the ground is not frozen has been used in the study because the amount of water left in the soil after evaporation and surface runoff has presumably an important effect on the occurrence of podzolisation, and the differences in humidity between the areas can thus bring about differences in soil formation in the different areas (see also Aaltonen 1933).

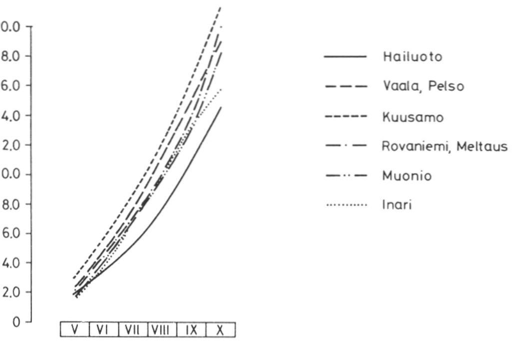

Fig. 5. The Martonne index (Tuhkanen 1980) depicting the humidity of the climate, expressed as cumulative curves, measured at six meteorological stations close to the study areas.

The winter severity index presented by Mansikkaniemi (1979), which takes into account the strength and occurrence of the wind and the number of days with snowfall, as well as the above climatic parameters, varies to the extent that the value for the two southernmost study areas is slightly below 1000, in Peräpohjola zone and in Forest Lapland about 1200, and in Inari slightly below 1200.

The climatic regions presented by Solantie (1980) for northern Finland approximately follow the boundaries of the forest vegetation zones, apart from a few exceptions. According to this division, the Inari study area belongs primarily to the Inari—Teno Lapland climatic zone, and the whole of Forest Lapland to the Saariselkä climatic zone. The other study areas belong to the Southern Lapland and Northern Ostrobothnia climatic zones, which follow the boundaries of the corresponding forest vegetation zones. The hydrological area division of northern Finland also follows the same borders (Gottschalk et al. 1979).

4. RESULTS AND DISCUSSION

41. Forest soil

411. Particle size and stoniness

The aeolian, glaciofluvial and fluvial formations clearly differ from each other as regards the particle size distribution of the soil. It was evident already in the field that the variation in the soil type is smallest in the case of the aeolian formations, and much greater in the glaciofluvial ones. The fluvial sediments more resemble the aeolian material in this respect than the glaciofluvial material. The particle size distribution measurements presented here were carried out on the subsoil (the C horizon) samples. The analyses were done on the C horizon because it was assumed that the soil formation processes would have had the least effect on this horizon in the soil profile. Soil formation is treated later on in the paper. The soil types are initially treated here using the classification presented by Aaltonen et al. (1949), which is close to Atterberg's (1912) soil type classification.

The aeolian material was mainly composed of pure sand. The glaciofluvial deposits included a certain amount of gravel material. This was also the case in the fluvial deposits, although to a lesser extent. There was hardly any material belonging to the finest fractions, i.e. silt and clay, in the samples. In this study the finest fractions are depicted by the total amount of the fractions smaller than 0.06 mm. There are also differences in this combined fraction between the different soil types. The cumulative particle-size curves for all the soil types studied are presented in Fig. 6. The above-mentioned features are clearly visible: the higher proportion of coarse particulate material in the glaciofluvial soil material, and the similarity between the composition of the aeolian and fluvial deposits.

The distribution of the samples with respect to their degree of sorting is presented in Fig. 7 in the form of a two-dimensional distribution using two different sorting parameters. It can be seen that the correlation between the sorting values measured in two different ways is not complete, and some deviation occurs. Neither is the dependence linear. The shape of the dependence in fact becomes linear when a logarithmic transformation is carried out on the S_0 variable. The variation in the degree of sorting as measured using these parameters is rather large, even in this material comprising sorted soils.

The distribution of the whole material in the coordinates formed by the degree of sorting (S_0) and the mean particle size (Md) can be seen in Fig. 8. There appears to be positive correlation in the material between the mean particle size (Md) and the sorting parameter (S_0). This means that the samples with a more mixed particle-size composition are, on the average, coarser than the more sorted samples — this being due to the effect of the gravel fraction.

Table 2 gives a more detailed picture of the variation in particle size to be expected

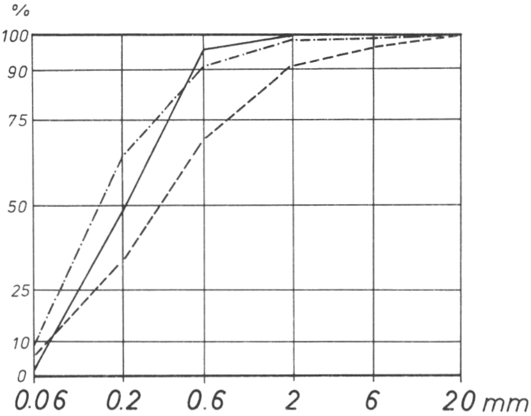

Fig. 6. Particle size curves for the aeolian (——) fluvial (· — ·) and glaciofluvial (— — —) soils.

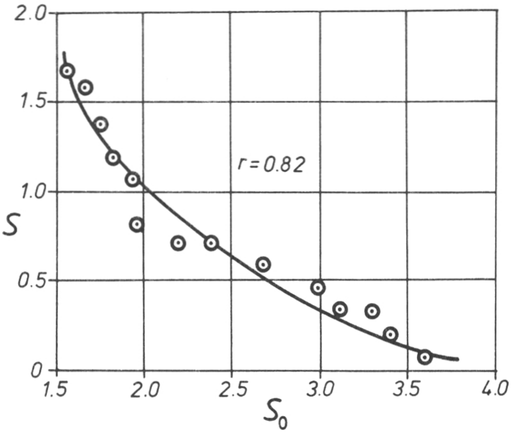

Fig. 7. The distribution of the soil sample material from the subsoil plotted in a graph formed from two sorting parameters. The points are cluster averages.

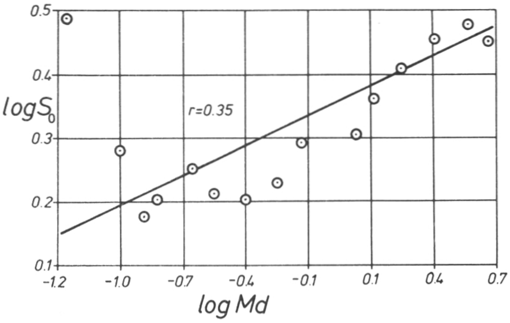

Fig. 8. The distribution of the soil sample material from the subsoil plotted in a logarithmic graph formed from the sorting parameter (S_0) and the mean particle size (Md). The points are cluster averages.

from formations with a different genesis. The values depicting the particle size have been read from the particle size curves of the individual samples, or the corresponding values have been estimated mathematically by interpolation. It can be seen from both of the parameters depicting the degree of sorting (S and S_0), that the aeolian material is the most sorted (uniform textured) and the glaciofluvial material the least. The aeolian and fluvial soil material are closer to each other in this respect. They both differ statistically from the glaciofluvial material at the 0.1 % risk level.

The same conclusion also holds true as regards the mean particle size (Md) of the different types of soil material. The arithmetical mean of the mean particle size values calculated from the individual soil samples (Table 2) differs to some extent from the median of the particle size read from the particle-size curve in Fig. 6. The greatest difference is in the values for the glaciofluvial material, and clearly the smallest in those for the aeolian material. The explanation for this phenomenon lies in the particle size distribution of the different types of soil material. Since the texture of the glaciofluvial material is the most mixed (see Table 2), it is natural that the medians of the particle size determined graphically, and as the arithmetic mean, differ the most from each other in this respect. The amount of finer fractions (< 0.06 mm) is greatest

Table 2. The particle size parameters of the aeolian, glaciofluvial and fluvial soil material. S and S_0 = sorting parameters, Md = mean particle size (the median of the particle size), K = curtosis of the particle size distribution of the sample, Sk = skewness of the particle size distribution. The proportion of fine fractions in the samples is depicted by the relative proportion of the < 0.06 mm fraction in the soil sample.

	Aeolian soils	Fluvial soils	Glaciofluvial soils	F
	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	
K	0.22 ± 0.01	0.24 ± 0.01	0.22 ± 0.01	1.83
(in Phi scale)	(+2.18)	(+2.00)	(+0.71)	
Sk	0.99 ± 0.02	0.92 ± 0.03	0.99 ± 0.02	2.82°
(in Phi scale)	(+0.01)	(+0.12)	(+0.01)	
S	1.39 ± 0.03	1.29 ± 0.05	0.97 ± 0.04	38.43^{***}
S_0	1.57 ± 0.02	1.64 ± 0.04	2.00 ± 0.06	29.78^{***}
Md	0.23 ± 0.01	0.22 ± 0.02	0.59 ± 0.06	26.50^{***}
< 0.06 mm (%)	1.37 ± 0.17	1.51 ± 1.37	6.03 ± 1.03	18.75^{***}

Table 3. The particle size parameters of the aeolian soil material in the different areas. See Table 2. for explanation of symbols.

Area	< 0.06 mm (%)	S	S_o	Md (Ø)
	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$
1 (n = 12)	0.2 ± 0.1	1.50 ± 0.09	1.54 ± 0.05	0.31 ± 0.02
2 (n = 14)	0.6 ± 0.2	1.52 ± 0.04	1.46 ± 0.03	0.37 ± 0.01
3 (n = 20)	1.5 ± 0.2	1.28 ± 0.04	1.64 ± 0.02	0.18 ± 0.02
4 (n = 24)	2.4 ± 0.7	1.41 ± 0.07	1.57 ± 0.04	0.19 ± 0.01
5 (n = 21)	1.1 ± 0.1	1.30 ± 0.04	1.55 ± 0.04	0.21 ± 0.02
6 (n = 15)	1.7 ± 0.3	1.39 ± 0.08	1.60 ± 0.04	0.16 ± 0.01
F	3.65**	2.33*	2.28*	28.48***
Significant			3 > 2	1 > 3, 4, 5, 6
differences	1 < 4			2 > 3, 4, 5, 6
($p < 0.05$)	2 < 4			5 > 6

in the fluvial material, and the smallest in the aeolian material.

The aeolian soils

On the average, the amount of fine material (< 0.06 mm) was smallest (only about 0.2 %) in the aeolian samples collected in Hailuoto (Area 1), and second to smallest in the samples from Rokua (Area 2) (Table 3). The greatest amounts were found in samples (2.4 %) from the western part of Peräpohjola (Area 4).

The mean values depicting the degree of sorting of the soil material are presented in Table 3. It can be seen from the values for both parameters that the aeolian material in the Hailuoto and Rokua areas was the most sorted. The samples collected from the Posio area proved to have the most mixed texture in the whole aeolian part of the material. However, the differences between the samples of aeolian origin were not very large when compared to the variation in the other types of soil examined in this study.

The mean particle size (Md) is largest at Rokua (Md = 0.37) and at Hailuoto (Md = 0.31), and smallest in Area 6 to the north of Kittilä (Md = 0.16). The difference between the first and second area with respect to the other study areas was statistically significant (Table 3).

No fractions coarser than sand were found in the aeolian soil material from any of the areas. Most of the formations were clearly developed dunes. In addition to the aeolian material, Area 6 to the north of Kittilä was also the most uniform deposit. However, no precise classification based on the form of aeolian deposits has been made in this study.

The glaciofluvial soils

The amount of fine fractions (< 0.06 mm) in the glaciofluvial soil material is clearly the smallest in the samples taken in Hailuoto (Table 4). These samples differ significantly (at the 5 % risk level) in this respect from the samples taken in Inari (Area 5). On the other hand, the difference was not statistically significant in comparison to any of the other areas. The same feature is apparent in the glaciofluvial soil material as in the aeolian samples: the amount of fine material is smallest at Hailuoto, and second to smallest at Rokua.

The soil material at Hailuoto and Rokua is also the most sorted (Table 4). The mean particle size is smallest at Rokua, although these samples contain the smallest amounts of the finest fractions (< 0.06 mm), not counting Hailuoto, out of all the areas. This is due to the fact that there is more medium sand and fine sand in the glaciofluvial material in these samples than in any of the other areas. The mean particle size and the proportion of the finest fractions were thus not completely intercorrelated.

The effect of outwashing shore forces has clearly played a major role in the samples taken in Hailuoto and Rokua. Both the aeolian and glaciofluvial reliefs are associated with a considerable number of beach ridges, from which the finest soil material has been washed out either by the action of water or the wind.

Table 4. The particle size parameters of the glaciofluvial soil material in the different areas. See Table 2. for explanation of symbols.

Area	<0.06 mm (%)	S	S_o	Md (Ø)
	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$
1 (n = 21)	0.7 ± 0.4	1.34 ± 0.08	1.60 ± 0.06	0.46 ± 0.06
2 (n = 13)	2.4 ± 0.7	1.14 ± 0.05	1.62 ± 0.05	0.29 ± 0.03
3 (n = 22)	4.8 ± 2.4	0.96 ± 0.07	1.96 ± 0.11	0.66 ± 0.12
4 (n = 12)	7.5 ± 2.1	0.82 ± 0.15	2.31 ± 0.29	0.58 ± 0.11
5 (n = 24)	11.2 ± 3.5	0.67 ± 0.06	2.35 ± 0.13	0.67 ± 0.11
6 (n = 18)	8.5 ± 1.9	0.91 ± 0.13	2.09 ± 0.13	0.78 ± 0.31
F	2.93*	7.88***	5.83***	1.12
Significant differences ($p < 0.05$)	1 < 5	1 > 3, 4, 5, 6 2 > 5	1 < 4, 5, 6 2 < 4, 5	

Table 5. The particle size parameters of the fluvial soil material in the different areas. See Table 2. for explanation of symbols.

Area	<0.06 mm (%)	S	S_o	Md (Ø)
	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$	$\bar{x} \pm s_{\bar{x}}$
1 —	—	—	—	—
2 (n = 18)	6.6 ± 2.2	1.67 ± 0.06	1.43 ± 0.03	0.13 ± 0.01
3 (n = 15)	16.2 ± 3.3	1.00 ± 0.08	1.99 ± 0.13	0.17 ± 0.02
4 (n = 9)	21.8 ± 4.7	1.24 ± 0.05	1.61 ± 0.07	0.12 ± 0.01
5 (n = 15)	2.5 ± 1.1	1.10 ± 0.06	1.60 ± 0.05	0.45 ± 0.03
6 (n = 12)	5.0 ± 0.9	1.38 ± 0.10	1.57 ± 0.07	0.18 ± 0.02
F	8.96***	15.07***	8.40***	51.81***
Significant differences ($p < 0.05$)	2 < 3, 4; 3 > 5, 6; 4 > 5, 6	2 > 3, 4, 5; 3 < 6; 5 < 6	2 < 3; 3 > 4, 5, 6	2 < 5; 3 < 5; 4 < 5; 5 > 6

The fluvial soils

No fluvial samples were available from Hailuoto. There are no rivers in the area whose river banks would have provided samples comparable with those taken in the other study areas.

The river sand samples taken in the Inari area (Table 5) contain the smallest amount of fine material (< 0.06 mm), and the samples taken in the western part of Peräpohjola — the deposits along the River Ounasjoki — contain the largest amounts. However, the mean particle size is of almost the same order of magnitude in both areas: 0.12—0.13 mm. The degree of sorting is greatest in the samples taken from the deposits along the River Oulujoki, and the samples with the most mixed texture are those taken from the upper reaches of the river Kemijoki.

The most finely textured soils in the material are found from among those representing the fluvial material. As well as the abundance of fine fractions, this is also apparent in the mean particle size (Fig. 6 and Table 5).

Soil type classification of the soils

All the soils included in the study are thus sorted, and many of them consist of pure sand. They were reclassified into soil type classes on the basis of their mean particle size (Md):

Gravel soils	Md	20—2	mm
Coarse sand soils	Md	2—0.6	mm
Medium sand soils	Md	0.6—0.2	mm
Fine sand soils	Md	0.2—0.06	mm
Silt soils	Md	<0.06	mm

There were no pure silt soils in the material. There were also very few gravel soils. Most of the samples had a mean particle size corresponding to the textural composition of various forms of sand or fine sand, and gravel or silt may be present as a significant additional fraction. The distribution of the samples representing different soil formation groups is presented according to the mean particle size in Fig. 9.

Stoniness

It is self-evident from the way in which such soils have been formed that aeolian soils are completely stone-free. Only in places where the aeolian soil material is so thin that the rod used to determine stoniness penetrates the underlying layer of soil of different origin, could it even in theory be possible that aeolian material present as topsoil would turn out to be stony. However, no such cases occurred in this study. Hence in Viro's (1952 and 1958) three-class soil stoniness classification, all aeolian soils belong to the stone-poor Class I.

All the fluvial soils studied here also belonged to stonepoor Class I, and resemble in this respect aeolian soils. The variation in the stoniness of the glaciofluvial soils was to some extent greater. However, most of them (at least 89 %) belonged to stone-poor Class I, and 11 % to the stony Class II.

Discussion

The particle size parameters differ rather clearly from each other in soil formations of different genesis. Perhaps the most important feature from the point of view of an ecological study is the difference in the content of the fine fractions, referred to in this study as silt (< 0.06 mm) (Table 2). The differences are very small in this material and, on the average, there are only very small amounts of fine fractions in all the types of soil studied here. The average value in the fluvial soils is only 9.5 % (Table 2). According to Virkkala (1969), the mean value is between 19.6—35.8 % of the dry-weight of the soil in the most common types of till in Finland — fine sand and sand tills (see also Granlund & Wennerholm 1935, Okko 1944, Teivainen 1952, Lähde 1974. Lähde et al. 1981 and Sepponen et al. 1979).

Although the only physical property of the soil measured in this study was the particle size distribution, some conclusions can be drawn on the basis of these results when they are combined with the results from earlier studies. For example, the field capacity of the soil has been shown to be correlated with the mean particle size (Md) and the amount of fine fractions (< 0.06 mm) in laboratory studies (Sepponen 1981). Similarly, the amount of fine fractions has been found to be correlated with the coverage of specific plant species and the condition of Scots pine plantations (Lähde 1974 and Sepponen et al. 1979). Although the differences between the soil formations studied here are on the average small as regards these parameters, the proportion of silt in these formations may be of importance in the development of the site type. The group includes individual sample plots whose substrate clearly contains greater amounts of fine fractions.

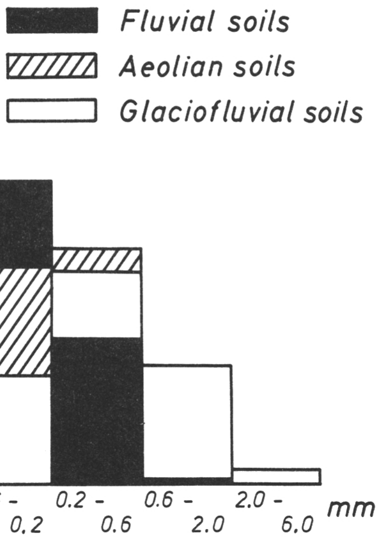

Fig. 9. The relative distribution of the soil sample material from the subsoil in mean particle size classes by different soil type.

Aartolahti (1973) has earlier published information about the particle size parameters of sorted soil material in the Rokua area (Area 2). He states that the mean particle size (Md) of aeolian material varies over the range 0.17—0.32 mm. The mean particle size obtained in this study is only a slightly higher (Table 3), as is also the case when the S_0 value is compared with the range of 1.27—1.39 presented by Aartolahti. On the other hand, the mean particle size (Md) of the glaciofluvial material falls within his presented variation range (0.06—0.33 mm). However, none of the finer glaciofluvial soils described by Aartolahti were included in the study. The arithmetical mean of the S_o values (Table 4) is also slightly higher than that presented by Aartolahti. Aartolahti had not calculated the sorted parameters presented by Sindowski (1938), which were used in the study in hand, for his samples taken in Rokua. On the other hand, the values calculated in this study also fell well within the variation range for his Sk parameter.

Aartolahti (1976) has presented particle-size data for aeolian soils in different parts of Finland. He also presented Sindowski's (1938) S values for dunes in Urjala, the values ranging between 1.12 and 1.20 (Aartolahti 1967). The value indicates a slightly lower degree of sorting than the S value obtained in this study for dunes in northern Finland (Table 3). In general, the differences between the parameters obtained in different studies are relatively small. This is also to be seen in Seppälä's (1969) comparison of particle size parameters of aeolian soils in Central Europe and different parts of Finland (see also Ilvessalo, L. 1927, Jauhiainen 1970, 1972a and b, Seppälä 1971 and Sepponen 1979).

There is greater variation in the particle size parameters of glaciofluvial and fluvial material than in the corresponding parameters of aeolian soils. This was found to be the case in this study as well as in earlier studies (Aartolahti 1973, Mansikkaniemi 1970, Kujansuu 1967, Gibbart 1979, Koutaniemi 1979 and Pöykäri 1979). In the fluvial soils along the River Oulanjoki described by Koutaniemi (op. cit.), for instance, the mean particle size varies between 0.06—0.60 mm. The values obtained for the different areas in this study come well within this variation range. However, it is difficult to compare the particle size values obtained in different areas.

While the particle size parameters described here have been treated illustratively from the point of view of sedimentology by, for instance, Folk (1966), litle is known about the ecological meaning of such parameters (Sepponen 1981). Since the particle size distribution of the soil (e.g. through determination of the soil type) is used in many different types of study (Sepponen 1982), it is also interesting to study the suitability of using particle size parameters for other purposes. In this study, for instance, an attempt is made to find correlation between the particle size parameters of the soil and other soil parameters. The classification of the studied soils into soil types has also been done with this in mind (Fig. 9).

A logarithmical transformation has sometimes been used before calculating the particle size parameters, the particle size scale thus being converted into the so-called Phi scale (e.g. Pöykäri 1979). The transformation has often been excluded and millimetres used instead as the parameter (Koutaniemi 1979 and Aartolahti 1973). A similar decision was made in this study because, bearing in mind that many parameters have to be expressed, it is more illustrative from the point of view of ecological studies.

Statistically significant regional differences were only found in the mean particle size of the aeolian soils (Table 3). However, these differences were very modest, and it is highly unlikely that such small differences would have had much effect on the ecological properties of aeolian soils as a substrate. As far as the glaciofluvial soils are concerned, the regional differences were mainly in the degree of sorting of the soil material. On the other hand, the differences in the proportion of fine fractions and in the mean particle size were only small (Table 4). The degree of sorting did not exhibit quite the same sort of trends in the fluvial soils, although the most sorted soils were also found in fluvial material in Area 2. On the other hand, there were such large differences in the amount of fine fractions in the fluvial soils that it can be assumed to have resulted in ecological differences. The most finely textured fluvial soils were found in Area 4, along the banks of the River Ounasjoki. Since there were no fluvial soil samples in the Hailuoto study area, the fluvial soils will not be included in the following examination of the regional differences between the soils.

The stoniness of the soils in the material of this study clearly differ from the average stoniness of forest soils in northern Finland. Viro (1958), who studied the stoniness of forest soils, found that 41.6 % of the upland forest soils in the Province of Oulu belonged to stone-poor Class I, and only 30.6 % of the upland forest soils in the Province of Lapland. The lower degree of stoniness is clearly apparent in the values calculated from old national forest inventory data, as Viro (1958, p. 19) points out. Aaltonen (1941a) has presented stoniness data from the IInd National Forest Line Inventory, and Sepponen et al. (1982) from the IIIrd Line Inventory in northern Finland.

412. The chemical properties of the soil

The distribution of the chemical factors measured on the soil samples is examined separately for the humus layer and for the mineral soil. The sub-soil layer (the C horizon) has been chosen to represent the mineral soil in this part of the study since the podzolisation process and the subsequent formation of different layers in the soil is examined separately later on in the paper.

The sub-soil samples from different soil classes do not differ statistically significantly from each other as regards a number of chemical factors (Table 6). On the other hand, there were highly significant differences in the humus samples — the humus in aeolian soils being relatively poor in nutrients and the humus samples from the fluvial soils being, on the average, the most nutrient rich. This feature was most clearly evident in the electrical conductivity and in the phosphorus, calcium and potassium contents. Sodium also followed a similar distribution. Aluminium and iron, on the other hand, behaved in quite a contradictory fashion: the differences between the soil types were statistically the most significant in the sub-soil samples.

It was not possible to determine the amount of total nitrogen in the mineral soil owing to the very low nitrogen content. On the other hand, the differences in the nitrogen content of the humus in the different soil types are highly significant. The greatest amount of nitrogen is in the humus of the fluvial soils, and the smallest in the humus of the aeolian soils (Table 6).

Iron and aluminium behave in quite a different fashion to the above-mentioned nutrients. On the average, the mineral soil of the fluvial soils contains the most aluminium and iron, and correspondingly the mineral soil of the aeolian soils the least. In addition, one striking observation in the aeolian soils is that there is more iron and aluminium in the humus than in the mineral soil — the situation in the other types of soil being quite the opposite.

The pH values measured in different ways clearly differ from each other. The pH measured in a water suspension is about 0.7 pH-units higher in the case of the mineral soil samples, and as much as 1.0 pH-units

Table 6. The mean values of the chemical soil properties in the humus (A_o) and the subsoil (C) of the different soil types.

		Aeolian soils	Glaciofluvial soils	Fluvial soils	F
pH (H_2O)	A_o	4.22 ± 0.03	4.14 ± 0.02	4.09 ± 0.03	7.25***
	C	5.71 ± 0.03	5.54 ± 0.03	5.70 ± 0.03	14.19***
pH ($CaCl_2$)	A_o	3.22 ± 0.02	3.13 ± 0.02	3.21 ± 0.02	5.98**
	C	5.01 ± 0.02	4.90 ± 0.03	4.90 ± 0.03	5.73**
Electrical conductivity index	A_o	1.28 ± 0.11	2.33 ± 0.16	3.59 ± 0.28	39.48***
	C	1.01 ± 0.01	0.98 ± 0.02	0.97 ± 0.03	1.14
N_{tot} (%)	A_o	0.66 ± 0.03	0.88 ± 0.02	0.95 ± 0.03	34.11***
	C	—	—	—	—
P ($mg \cdot 100g^{-1}$)	A_o	22 ± 1	28 ± 1	38 ± 1	51.57***
	C	29 ± 2	25 ± 2	29 ± 2	1.66
K „	A_o	48 ± 2	66 ± 2	79 ± 3	42.41***
	C	58 ± 4	57 ± 4	57 ± 5	0.03
Ca „	A_o	138 ± 8	225 ± 9	232 ± 10	33.63***
	C	101 ± 6	89 ± 5	100 ± 6	1.52
Mg „	A_o	70 ± 6	56 ± 4	66 ± 5	2.09
	C	195 ± 12	211 ± 15	226 ± 20	0.95
Fe „	A_o	374 ± 18	287 ± 14	522 ± 44	21.93***
	C	269 ± 12	336 ± 33	660 ± 58	31.87***
Al „	A_o	648 ± 22	561 ± 21	584 ± 26	4.34*
	C	628 ± 27	938 ± 60	997 ± 47	16.52***
Na „	A_o	13.6 ± 0.6	14.8 ± 0.6	19.3 ± 1.4	12.12***
	C	11.2 ± 0.6	11.0 ± 0.4	10.5 ± 0.3	0.36

Table 7. Correlations between the chemical soil properties in the humus (A_0) and in the subsoil (C).

		1	2	3	4	5	6	7	8	9	10	11
1. pH (H_2O)	A_0	1.00										
	C	1.00										
2. pH ($CaCl_2$)	A_0	0.69	1.00									
	C	0.53	1.00									
3. Electrical conductivity index	A_0	0.01	0.20	1.00								
	C	0.01	–0.05	1.00								
4. N_{tot}	A_0	–0.29	–0.17	0.22	1.00							
	C	—	—	—	—							
5. K	A_0	–0.26	–0.10	0.49	0.62	1.00						
	C	0.23	0.08	0.01	—	1.00						
6. P	A_0	–0.17	0.08	0.48	0.71	0.74	1.00					
	C	0.19	0.14	0.01	—	0.46	1.00					
7. Ca	A_0	–0.14	–0.02	0.27	0.64	0.56	0.55	1.00				
	C	0.24	—	0.09	—	0.53	0.69	1.00				
8. Mg	A_0	0.47	0.51	0.04	–0.23	–0.01	–0.01	–0.09	1.00			
	C	0.27	0.01	0.01	—	0.72	0.29	0.35	1.00			
9. Fe	A_0	0.09	0.27	0.13	–0.22	0.01	0.11	–0.10	0.42	1.00		
	C	0.18	–0.10	–0.01	—	0.12	0.17	0.13	0.36	1.00		
10. Al	A_0	0.19	0.17	–0.08	–0.40	–0.22	–0.20	–0.37	0.32	0.64	1.00	
	C	0.18	0.09	–0.04	—	0.13	0.12	0.04	0.42	0.69	1.00	
11. Na	A_0	–0.04	–0.06	0.09	0.08	0.06	0.09	0.02	–0.01	0.17	0.07	1.00
	C	—	—	—	—	—	—	—	—	—	—	—

higher in the humus. The correlation (Table 7) between the pH values measured in two different ways in the mineral soil samples is r = 0.53***. The values for the humus were more strongly correlated (r = 0.69***). The amounts of all the different mineral nutrients determined in both the humus and mineral soil samples are small, apart from the values for iron and aluminium.

Calcium is not correlated with the pH in this material. On the other hand, magnesium is more strongly correlated with the pH of the humus (Table 7). The intercorrelations between the nitrogen, potassium, phosphorus and calcium contents are highest in the humus. There is clear correlation between iron and aluminium in both the humus and the mineral soil layers.

The correlations between the individual elements are, in some cases, clearly different in the humus than in the mineral soil. For example, there is strong positive correlation between potassium and magnesium in the mineral soil, although they are not correlated at all in the humus. The Ca:Mg ratio in the humus is 3.0, and in the mineral soil 0.5. This shows that the nutrient ecological picture obtained on the basis of the humus measurements is rather different from that given by the results for the sub-soil.

The dependence of the chemical properties on the particle size distribution of the soil

Combined samples were prepared from the mineral soil samples taken from the C horizon. The following fractions were then separated out by dry sieving: 1 = 2—0.6 mm, 2 = 0.6—0.2 mm, 3 = 0.2—0.06 mm and 4 = < 0.06 mm. The phosphorus, potassium, calcium and magnesium content of each fraction was determined in order to study how the different textural fractions retain nutrients.

It can be seen from Fig. 10 that there are statistically significant differences between the amounts of three of the nutrients bound by the different fractions. The situation as regards potassium is clearly different. The greatest amount of potassium was in the finest fraction, but there were no statistically significant differences between the amounts retained by the other fractions. The greatest amounts of nutrients are found in the finest fraction, and the smallest in the two coarsest fractions. The two coarsest fractions do not differ statistically significantly from each other as regards their nutrient contents. The amount of phosphorus and potassium are clearly smaller than the amounts of calcium and magnesium in the corresponding fractions. There is clearly more magnesium than the other nutrients in the finest fraction: there is about eight times the amount of phosphorus and potassium, and about three times the amount of calcium.

An attempt was made to analyse the ecological factors in the soil using factor analysis (Table 8). Factor analysis was carried out separately on the humus layer and on the subsoil layer in an an attempt to gain a more detailed picture of the dependences and combinations between the variables measured on the soil samples. A three factor model appeared, in this case, to give a rather clear and easily interpretable structure. The factors used in the factor analysis carried out on the sub-soil were named as follows:

1. Gravel factor
2. Silt factor
3. Fine sand factor

The gravel factor is characterised by the fact that the coarse fractions receive the largest loading. The same is true for the mean particle size and the sorting parameters. This shows that gravel and coarse sand is the factor in the material which is responsible for the mixed texture of the soil material, and of course for the increase in the mean particle size. All the nutrient factors receive a low loading in this factor, although none of them receive a strong negative loading.

The silt factor is clearly different to the first factor. The silt and humus content, and of the nutrients the magnesium, iron and aluminium contents, receive the highest loading. This shows that there is clear correlation between the factors in question. This is also in agreement with the observation made earlier: there are abnormally high amounts of magnesium in the silt fraction (Fig. 10). All the different nutrients do not behave in the same way. The loadings given by the parameters depicting the degree of sorting show that silt, just as gravel, is a factor causing mixed texture in the material.

The fine sand factor in turn differs clearly from the previous ones. It depicts the abundance of the fine sand fraction in a certain part of the material, and it can be concluded from the loadings of the parameters depicting fractionation that fine sand is of uniform texture, and thus a factor causing a high degree of sorting. Phosphorus and calcium receive their highest loadings in this factor, and hence their contents appear to be dependent on the amount of fine sand.

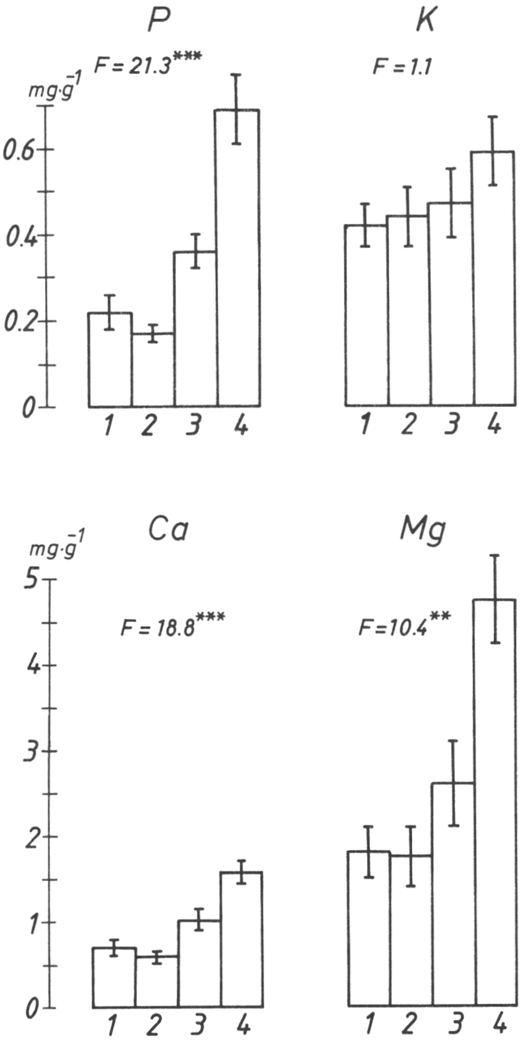

Fig. 10. The nutrient contents of the different particle size fractions of the soil. Fractions: 1 = 2.0—0.6 mm, 2 = 0.6—0.2 mm, 3 = 0.2—0.06 mm and 4 = <0.06 mm (N = 14).

The three factors of the humus layer are named as follows:

1. The macronutrient factor
2. The pH-magnesium factor
3. The iron-aluminum factor

Table 8. Three factor factor analysis carried out separately on the humus layer (A_0) and on the subsoil (C). C (%) = proportion of total variance.

	FACTORS					
	A_0 horizon			C horizon		
	1	2	3	1	2	3
2—6 mm	—	—	—	0.84	0.10	–0.07
6—2 mm	—	—	—	0.94	0.04	–0.19
2.0—0.6 mm	—	—	—	0.53	–0.02	–0.54
0.6—0.2 mm	—	—	—	–0.31	–0.40	–0.76
0.2—0.06 mm	—	—	—	–0.29	0.06	0.95
< 0.06 mm	—	—	—	–0.14	0.79	0.08
S	—	—	—	–0.49	–0.38	0.41
S_o	—	—	—	0.52	0.51	–0.20
Md	—	—	—	0.85	–0.05	–0.23
Humus-%	0.76	–0.49	–0.18	0.09	0.78	0.12
pH (H_2O)	–0.18	0.75	–0.08	–0.06	0.16	0.27
pH ($CaCl_2$)	0.06	0.94	0.06	–0.03	–0.05	0.20
Elect. conduct. index	0.48	0.17	0.12	–0.02	–0.03	0.02
K	0.79	–0.14	0.06	0.21	0.18	0.28
P	0.87	0.03	0.12	–0.03	0.11	0.52
Ca	0.71	–0.06	–0.11	0.04	0.07	0.41
Mg	–0.03	0.54	0.32	0.22	0.50	0.11
Fe	–0.01	0.23	0.91	–0.12	0.81	0.23
Al	–0.32	0.18	0.65	0.17	0.81	0.12
Na	0.09	–0.08	0.19	0.12	0.17	0.04
N_{tot}	0.82	–0.22	–0.18	—	—	—
C (%)	31.8	21.0	13.9	20.5	17.6	14.2

Examination of the loadings given to different factors in the macronutrient factor shows that the loss in weight on ignition, the total nitrogen, potassium, phosphorus and calcium contents are given high loadings of the same sign. This indicates that they are dependent on each other. This is also apparent from the correlation coefficients in the correlation matrix (Table 7).

Only the pH measured in two ways and magnesium receive a high positive loading in the second factor. The loss in weight on ignition receives a highish negative loading in this factor. The pH-magnesium factor depicts the humus samples with the lowest acidity in the material. The proportion of organic matter in these samples also appears to be the smallest.

As its name suggests, the iron-aluminium factor characterizes the highest loadings received by aluminum and iron. No other factors receive very high loadings — neither positive nor negative ones. The factor can be considered to characterize those humus samples where the iron and aluminium contents are the highest. In addition, it shows that iron and aluminium are strictly bound to each other.

The dependence of the chemical factors on the particle size parameters and the humus content of the soil were examined, on the basis of the hints provided by factor analysis, using more detailed regression analysis. The loss in weight on ignition, depicting the amount of organic matter, is strongly positively correlated with many other factors in the humus layer, as well as in the mineral soil layer. For example, the total nitrogen content of the humus is the parameter most clearly dependent on the loss in weight on ignition (Fig. 11). The loss in weight on ignition is also strongly correlated with the potassium, phosphorus and calcium contents in the humus layer. On the other hand, the magnesium, iron and aluminium contents are negatively correlated, to a highly significant degree, with the loss in weight on ignition.

The situation as regards the last-mentioned three nutrients (Mg, Fe and Al) was quite the opposite in all the mineral soil layers: they were positively correlated, to a highly significant degree, with the loss in weight on ignition. When the humus and mineral soil layers are compared, the correlation coefficients between these nutrients and the loss in weight on ignition were (the C horizon represents the mineral soil):

	Mg	Fe	Al
Humus	—0.32	—0.28	—0.42
Mineral soil	0.41	0.66	0.75

On the other hand, the dependence between the potassium, phosphorus and calcium contents and the loss in weight on ignition showed a similar trend in all the soil layers, although the correlation was clearly higher in the humus layer than in the mineral soil.

The highest correlations between the measured nutrients and the particle size parameters of the soil are presented in Table 9. Only the strongest correlations for each nutrient have been included in the table. The correlation analysis has been done on the results of the C horizon of the mineral soil. Different nutrients appear to be correlated in different ways with the particle size parameters of the soil. Potassium, phosphorus and calcium are positively correlated with the size of the fine sand fraction. All the nutrients are clearly negatively correlated with the size of the medium sand fraction. Medium sand is, at least in this material, clearly a factor causing a low nutrient status.

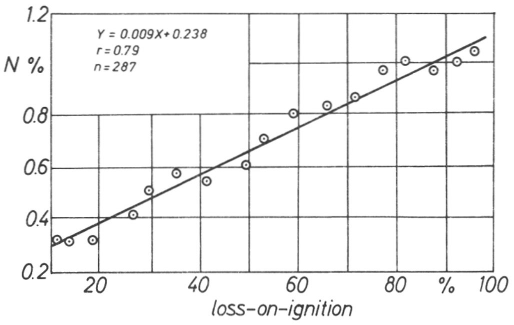

Fig. 11. The dependence of the total nitrogen content on the loss in weight on ignition of the humus layer. The points are cluster averages.

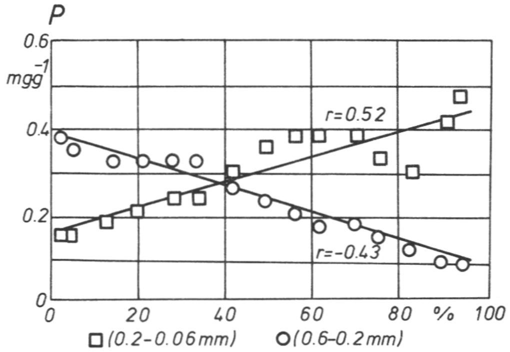

Fig. 12. The dependence of the phosphorus content of the subsoil samples on the relative proportions of the fine sand fraction (0.2—0.06 mm) and the medium sand fraction (0.6—0.2 mm). The points are cluster averages.

The dependence of the nutrients on different particle size parameters was also examined on the basis of the regression figures in order to get a better picture of the form of the dependence. The dependence of phosphorus on the amount of fine sand and medium sand is clearly linear (Fig. 12), as is the case with the dependence between magnesium, iron and aluminium and the size of the < 0.06 mm fraction (Fig. 13). On the other hand, the dependence between the amount of nutrients and the mean particle size and the sorting parameter, S_o, is not

Table 9. The strongest correlations between certain particle size parameters and soil nutrient contents in the subsoil.

	K	P	Ca	Mg	Fe	Al	Na
20—6 mm							
6—2 mm							+0.13
2.0—0.6 mm							
0.6—0.2 mm	—0.35	—0.42	—0.35	—0.35	—0.47	—0.45	—0.12
0.2—0.06 mm	+0.22	+0.51	+0.38				
<0.06 mm				+0.45	+0.72	+0.60	
Md							
S							
S_o				+0.34	+0.28	+0.50	

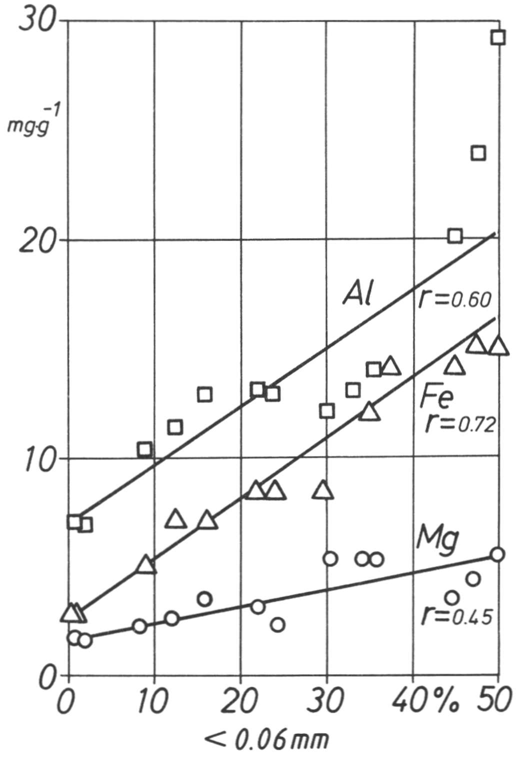

Fig. 13. The dependence between the aluminium, iron and magnesium contents on the relative proportion of fine fractions (<0.06 mm) in the mineral soil (C horizon). The points are cluster averages.

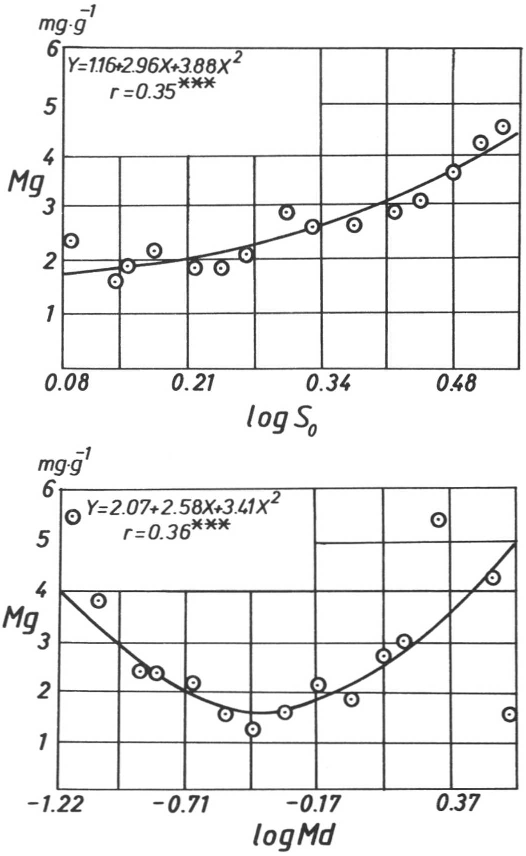

Fig. 14. The dependence between the magnesium content and the mean particle size (Md) and degree of sorting (S_O) of the soil. The points are cluster averages.

linear. Only the dependence between magnesium and the particle size parameters are discussed here as an example of this type of dependence relationship (Fig. 14).

The dependence between the amount of magnesium and the mean particle size or sorting parameter, S_O, is not linear (Fig. 14), and the material appears, especially with respect to the mean particle size, to be "two-storied" in the sense that the magnesium content initially decreases as the mean particle size increases, but then starts to rise. A decrease in the degree of sorting correspondingly brings about an initially slow, but then accelerating rise in the magnesium content. As it is known that the glaciofluvial soils with the most mixed texture have the largest mean particle size (Table 2), this phenomenon probably indicates that the most mixed textured soils are the soils with the highest magnesium content, as is probably also the case with the most finely textured soils.

The following models were obtained for the dependence between the magnesium content and the particle size parameters using regression analysis of the two independent variables:

$$Y = 1.03 + 0.06X_1 + 3.24X_2,$$

where Y = the magnesium content, air-dry soil ($mg.g^{-1}$), X_1 = the proportion of < 0.06 mm fractions in the soil (weigh-%) and X_2 = log S_O,

and

$$Y = -0.12 - 1.16X_1 + 6.61X_2,$$

where Y = as above, X_1 = log Md and X_2 = log S_O.

The coefficient of determination for the first model is 0.24, and for the second model 0.13.

The models where the parameter depicting the particle size parameters were combined with the parameter depicting the degree of sorting thus give a fairly better coefficient of determination than either of the two parameters separately.

Regional variation in the nutrient status

The samples from the fluvial soils were not included in the examination of the regional differences in the occurrence of certain plant nutrients. This was because there were no fluvial samples from Area 1 (Hailuoto). Statistically highly significant regional differences were apparent in the contents of the nutrients studied (N_{tot}, K, P, Ca, Mg and Na).

It can be seen from the results of the analyses (Fig. 15) carried out on the humus samples that, apart from sodium, the content of all the other nutrients is clearly the smallest in the Rokua area (Area 2). The magnesium content is clearly the highest in the humus samples from the two northernmost study areas (Areas 5 and 6), while on the other hand the highest levels of nitrogen, phosphorus and sodium are found in the Posio region (Area 3). In fact there was just as much phosphorus in the samples taken from the study area to the north of Pallasjärvi, and clearly the highest calcium content in Hailuoto (Area 1). The different nutrients appear to behave, as regards their regional differences, in rather a varying fashion.

There were also statistically significant differences with respect to all the nutrients in the samples taken from the C horizon of the mineral soil (Fig. 16). The differences between the nutrient contents in different areas diverge slightly from the corresponding trends for the humus samples. For instance, the amount of potassium is lowest in the samples taken from the two southernmost study areas, second to highest in the samples taken in the two study areas situated in the Peräpohjola forest vegetation zone, and clearly the highest in the samples taken in the study areas situated in the Forest Lapland zone. There is a similar trend as regards the variation in the amount of magnesium. There is clearly more sodium in the samples taken in the Inari area than in the other areas, but otherwise the other areas included in the study do not differ significantly from each other as regards the amount of sodium. The only nutrient which appears to vary to approximately the same extent in both the humus and the mineral soil samples is magnesium (cf. Figs. 15 and 16).

Discussion

When the values for the samples taken from the humus layer were tested, the different soil classes differed, to a statistically highly significant degree, from each other as regards the most important macronutrients (N, P, Mg and also Na). On the other hand, when the values for the samples from the C horizon were tested, no statistically significant differences were found (Table 6). This lends considerable support to the hypothesis concerning the development of site types.

As has already been shown (Table 2), the soils of different geological genesis differ from each other as regards their particle size parameters. There are also structural different types of genesis. However, such features have not been studied here. A different particle size distribution also results, in turn, in different physical properties. These physical properties presumably regulate, in turn, the processes fashioning the site. This is apparent in the results of this study (Table 6) as follows: there are no significant differences in the sub-soil as regards the chemical growth factors in different types of soil, but because they differ from each other as regards their physical factors, chemical differences develop during the development of different types of site. This is especially apparent as chemical differences in the product of the site formation process — the humus layer. As the physical differences are derived from geological processes, these processes are in the end also the causal agents for the differences in the chemical properties of the humus layer.

The above-described processes can also be approached by studying the dependence between the chemical factors and the particle size parameters of the soil. This type of analysis is used to determine how the development of the chemical properties of the site are coupled to the particle size distribution

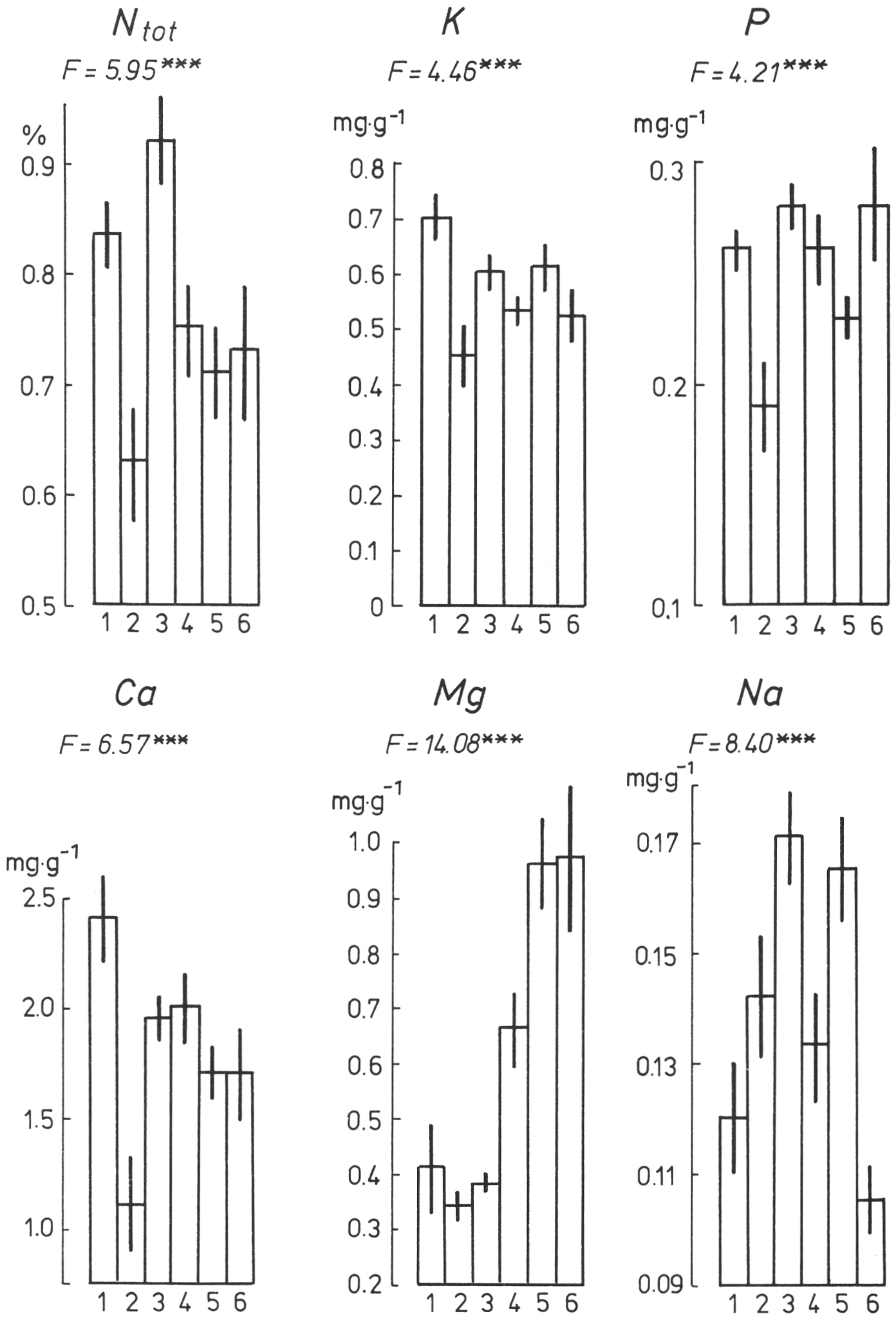

Fig. 15. The variation in the nutrient contents of the humus in the different study areas. The numbers of the study areas are the same as in Figs. 1 and 2.

of the soil.

The phosphorus, potassium, calcium and magnesium contents (Fig. 10) of the different particle size fractions were examined in this study. In general, the finest fractions contained clearly the greatest amount of nutrients. Potassium was the only nutrient where the differences between the different

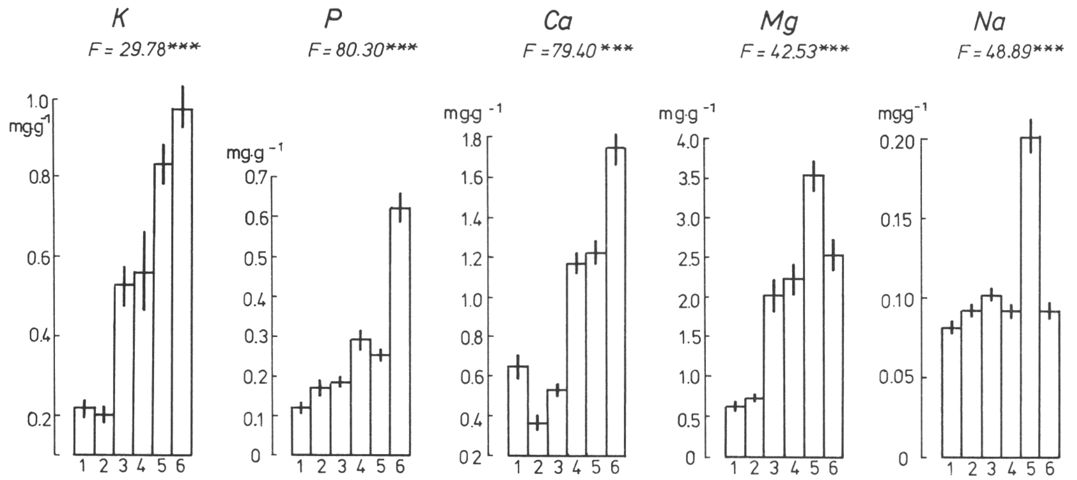

Fig. 16. The variation in the nutrient contents of the subsoil (C horizon) in the different study areas. The numbers of the study areas are the same as in Figs. 1 and 2.

fractions were not statistically significant. This illustrates the great importance of the fine fractions in retaining nutrients in the soil (also Sepponen 1981). Very few studies have been carried out concerning the effect of the particle size of the mineral soil on the nutrient status in medium coarse and coarse forest soils. Urvas and Erviö (1974) have examined the formation of site types on the basis of the soil type and the chemical properties of the soil. However, the effect of the particle size distribution on the concentration of nutrients in the soil has primarily been studied in agricultural soils only, where attention has mainly been paid to the importance of the clay and silt fractions as binders of nutrients (Salminen 1931, Kaila and Ryti 1968, Lakanen and Hyvärinen 1971, and Urvas et al. 1978). The interdependence between fertility factors in different soil types has also been studied (Lakanen et al. 1970 and Kurki 1972). The finest soil fractions have generally been found to be of great importance in retaining nutrients.

The proportion of the clay fraction in the different soil types has not been analysed in this study. It has been estimated to be so small in these soils that the relative proportion of the fractions of as large a particle size of < 0.06 mm only was considered to be a possible ecological explainer since this fraction occurred in an amount which could be reliably measured. In addition, this fraction has been shown to be a rather useful ecological explainer in a number of earlier studies (Lähde 1974, Wilde 1958, Sepponen et al. 1979 and Sepponen 1981). In this study the potassium content of the finest fraction was not found to differ statistically significantly from that of the other fractions (Fig. 10). Urvas et al. (1978) have shown that in fact potassium is positively correlated with the size of the clay fraction. The soils investigated in their study are completely different from those studied here. The amounts of phosphorus, calcium and nitrogen were found in this study to be higher, to a statistically highly significant degree, in the silt fraction (< 0.06 mm) than the corresponding values in the other fractions.

There was also clearly more phosphorus in the fine sand (0.2—0.06 mm) fraction than in the coarser fractions. The same result was also found in the correlation analysis (Fig. 12), and even in the factor analysis where phosphorus clearly received the highest loading in the factor called the "fine sand" factor (Table 8). Although, according to the analyses, phosphorus is thus bound (as is the case with the other nutrients studied) best to the silt fraction, the amount of phosphorus is not strongly correlated with the amount of silt in coarse soils of this sort, but rather with the amount of fine sand. The explanation for this can be found from the particle size distribution of the material. On the other hand, for instance, Urvas et al. (1978) have found that phosphorus is clearly negatively correlated with the very finest fractions. The main reason for the correlation phenomenon observed in this material appears, however, to be that there is so little silt present that it is not the main factor responsible for binding phosphorus in soils of this type, but rather fine sand which is present in considerably greater amounts.

Phosphorus and its behaviour as a major plant nutrient have been studied extensively in different types of soils (e.g. Kaila 1963a, 1963b, 1964, and 1965, and Hartikainen 1979). However, there is not yet much information available about the dependence between the texture of the soil and phosphorus in the type of soils included in this study.

At first sight it perhaps appears to be contradictory that on the one hand both the P, K, Ca and Mg concentrations are greatest in the silt fraction (Fig. 10), although in the whole material the silt content does not explain the greatest amount of the variation in the P, K and Ca concentration (Table 9). Of these four nutrients, the silt concentration appears to be clearly correlated only with magnesium. This may be simply explained by the fact that magnesium is the only one of these nutrients present in such large amounts that its variation usually becomes large enough to explain the small variation in the amount of silt. The variation in the low concentrations of the other nutrients are also small. However, the sensitivity of the analytical method was perhaps not sufficient to reveal the variation in the concentrations of these nutrients which follow the variation in the actual silt content. Another explanation may however, lie in the particle-size fractionation method.

Some of the phosphorus, potassium and calcium may be "lost" from the coarser fractions to the finest fraction in the bottom of the rack of sieves during dry sieving. These nutrients would thus be determined from a different fraction to which they are bound in a natural undisturbed sample. In nature, on the other hand, the concentration of these nutrients is most clearly correlated with the fraction of the soil where the nutrient is before sieving. A better idea of the nutrient-binding capacities of the different fractions is obtained by examining the results obtained with both methods.

Use of the other particle size parameters to explain the amounts of the individual nutrients in question proved to be clearly more complicated. For example, the dependence between the amounts of these nutrients and the mean particle size and sorting index was not linear (Fig. 14), the best coefficient of determination being obtained only when a clearly more complicated model, and transformations done on the parameters, were used (see also Sepponen 1981). The use of these particle size parameters to explain the variation in the amounts of the nutrients requires a profound knowledge of the particle size distribution of the material being analysed. There was a clear negative correlation between the amount of medium sand and all the nutrients, and hence it can perhaps be estimated to be a factor causing clear low nutrient status in soils of this type (Table 9 and Fig. 10).

The loss in weight on ignition is used here to depict the amount of organic matter in the soil. It has also been found to be clearly correlated with the contents of a number of different nutrients. The loss in weight on ignition and the amount of total nitrogen in the humus layer were the most strongly correlated (Fig. 11). Their correlation is so clear that it is possible, on the basis of the function calculated in this study, to estimate the amount of nitrogen in the humus sufficiently accurately when the loss in weight on ignition is known. The latter parameter is clearly easier to determine in a small laboratory than the total nitrogen content. There is a negative correlation between the amounts of magnesium, iron and aluminium in the humus layer and the loss in weight on ignition, while in the mineral soil it is strongly positive. The phenomenon may be partly associated with the leaching processes of these nutrients, and partly to the different extractability of the nutrients from the humus than from the mineral soil (for extractability see e.g. Mäkitie 1956, Viro 1965, Andersson 1975, Stålberg 1980 and Åresund 1980). However, comparison of different extractants could not be included in this study, nor was it possible to study the abovementioned phenomenon in detail.

The above-described correlations indicate that different soil formations differ from each other with respect to the development in the nutrient status of the sites. As has already been shown (Fig. 6), aeolian soils contain the greatest amount of medium sand, which causes low fertility, and the smallest amount of material finer than 0.06 mm. On the other hand, fluvial soils contain the smallest amount of sand and the greatest amount of fine fractions. As was earlier pointed out, however, what is significant is the fact that the differences in nutrient status do not come to light in analyses carried out on the C horizon of the mineral soil, but only when the humus layer, which better represents the secondary site factors, is analysed.

The nutrient contents of aeolian soils have in fact already been presented for the outer archipelago of the Gulf of Finland by Ilvessalo (1926), although they are not very comparable with the results obtained in this study. The most work in this field has been done by Jauhiainen (e.g. 1970 and 1972b) on dunes in both southern and northern Finland. The nutrient values which he has presented are clearly smaller than those obtained in this study. This is mainly due to the different extraction methods used in the two studies. This is also valid when comparing the results presented about brown soils in Poland (Jauhiainen 1970) and the nutrient values for loess in the Lammi area (Jauhiainen 1972a).

In general, rather few results have been presented about analyses made on forest soils in northern Finland which woul be comparable with the results obtained in this study. The main aim in this study was to determine the nutrient reserves of the soil which, according to the results obtained, appear to be larger than the amounts of easily soluble nutrients determined by, e.g. Jauhiainen (1969, 1970, 1972a and 1972b). However, the pH values he obtained are close to those obtained in this study.

Clear regional differences were also found in the nutrient contents of both the humus (Fig. 15) and the mineral soil (Fig. 16) in the soils studied here. The differences occurring in the humus and the mineral soil did not show the same trends. As far as the humus layer is concerned, the smallest amounts of almost all the nutrients were found in the Rokua area. The values for the mineral soil were also generally small in the same area. According to Viro (1969 and 1974), forest fires may reduce the amount of organic matter and nutrients in the humus layer for many decades after the fire. It is known that there were many forest fires in the Rokua area before the last war, and even after the war some local prescribed burning (Jalas 1953). It is possible that the effect of forest fires, and subsequent leaching of nutrients, may be visible in permeable, sorted soils for a long time. In addition, it should be remembered that Rokua, as well as Hailuoto, was found to be the most sorted soil in the material, and to contain only a small amount of fine fractions (Tables 3 and 4).

The greatest amounts of potassium, phosphorus and calcium occur in the C horizon of the mineral soil in the area to the north of Pallasjärvi. A clear ”fertility series”, stretching from south to north, was evident in the amount of potassium measured in the C horizon: the smallest amount of potassium in the southernmost study area, the second lowest amount in the areas situated in Peräpohjola, and the most in the areas situated in Forest Lapland. The phenomenon may be explained by the different rate of leaching of nutrients in the milder conditions in the south, where the period when the ground is not frozen is also shorter (for leaching see Viro 1953, Hartikainen 1978, Haynes and Goh 1980 and Rosen 1982). The geochemical differences in the bedrock and soil, and the geological age of the soils, may also have a certain effect on the regional differences. However, the role of these factors has not been studied in more detail here.

413. Soil organic matter and the properties of the soil profiles

The humus layer (A_0 horizon), the leached layer (A horizon) and the enriched layer (B horizon) are examined as whole layers in this part of the study, without dividing them up into smaller sections.

The thickness of the humus and A and B horizons were measured *in situ* in the soil sample pits dug in the field. Judging by the external appearance of the soil profiles, all the profiles included in the study belong, according to Aaltonen's (1951) classification, to iron podzols. The amount of organic matter in the soil is examined on the basis of the loss in weight on ignition.

There are statistically significant regional differences in the amount of organic matter in all the layers of the soil profile (Fig. 17). The relative proportion of organic matter is

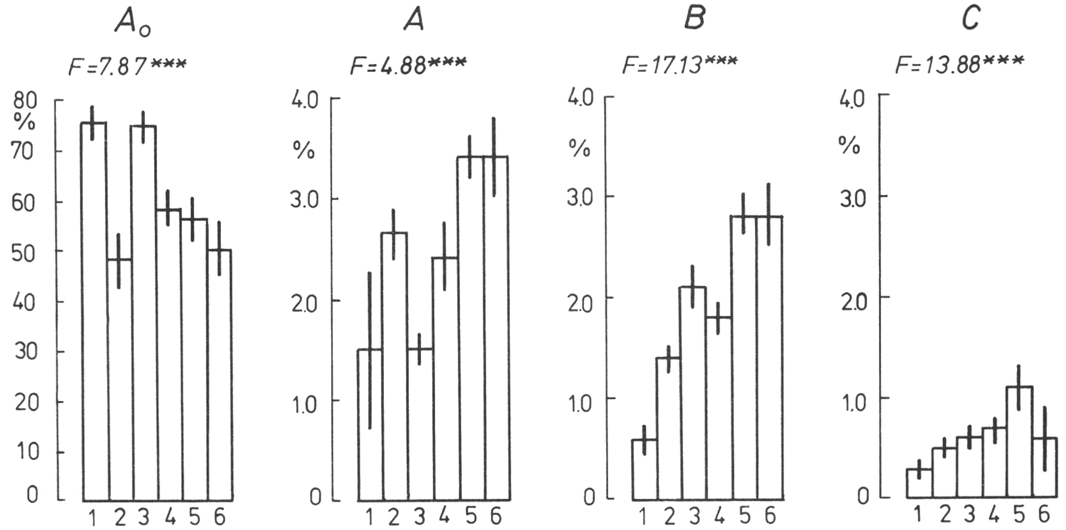

Fig. 17. The loss in weight on ignition (as per cent of the dry weight of soil) of the individual soil layers in the different study areas. The numbers of the study areas are the same as in Figs. 1 and 2.

very small in the mineral soil: the highest value measured in the C horizon was 3.5 %, and in the B horizon 7.8 %. Only in the A horizon, which is in immediate contact with the overlying humus horizon, was the organic matter content in one case as much as 27.3 % of the dry weight of the soil sample. The highest organic matter content in the humus layer was 96.4 %, and the lowest only 6.6 %.

The large regional differences in the loss in weight on ignition of the A_0 horizon stand out clearly (Fig. 17). It was greatest in Hailuoto and Posio (Areas 1 and 3), smallest at Rokua (Area 2), and almost as small in the area to the north of Pallasjärvi (Area 6). However, the regional trend as regards the A horizon is quite the opposite. This is especially pronounced in the case of the ratio between the loss in weight on ignition of the humus layer and that of the mineral soil layers: in places where the humus layer is thin, the loss in weight on ignition in the A horizon is fairly large (Fig. 17).

There are also clear differences in the loss in weight on ignition between different genetic soil classes. The difference was the most apparent in the humus layer, although it is statistically significant also in the B horizon as follows (values as percentages):

	Aeol. soils	Glaciofluv. soils	Fluvial soils	F
A_0	48.3 ± 0.3	75.2 ± 0.2	75.2 ± 0.2	48.15
A	2.5 ± 0.0	2.5 ± 0.0	1.8 ± 0.0	2.28
B	1.5 ± 0.0	2.4 ± 0.0	2.5 ± 0.0	16.51

However, in this respect only the aeolian soils differ significantly from the other soils as far as the A_0 and B horizons are concerned, while the glaciofluvial and fluvial soils do not differ significantly from each other at all. The loss in weight on ignition was greater in the humus layer of the fluvial soils than in the corresponding layer in the aeolian soil, but smaller than the others in the A horizon.

The thickness of the humus horizon was also greatest in the fluvial soils (mean 5.2 ± 0.3 cm), the second thickest in the glaciofluvial soils (3.5 ± 0.2 cm) and smallest in the aeolian soils (2.5 ± 0.1 cm). The difference between all the soil types was statistically significant. The thickest humus layer measured in the study (14 cm) was lying on top of fluvial material. Very thin humus layers, of about 1 cm thick, were found on all types of soil.

The thickness of the A horizon also followed the same trend as for the thickness of the humus horizon: aeolian soils 4.7 ± 0.3 cm, glaciofluvial soils 5.7 ± 0.3 cm, and fluvial soils 7.9 ± 0.6 cm. All the soil types differed, to a statistically significantly degree, from each other. The trend in the thickness of the B horizon was also the same: aeolian soils 19.0 ± 0.6 cm, glaciofluvial soils 22.1 ± 0.8 cm, and fluvial soils 23.2 ± 1.0 cm. The last two soil types do not differ significantly from each other, but the aeolian soils do differ significantly from both the other two. It thus appears that soils of different genesis differ, to a statistically significant degree, from each other as regards the thickness of the different horizons, as well as in the organic matter content of the podzol horizons.

There were also statistically significant regional differences in the thickness of the humus layer (Fig. 18). The greatest thicknesses were measured in Areas 1 and 3, in other words in Hailuoto and the Posio district. The thickest A and B horizons were also found in Hailuoto, the geologically youngest of the study areas. The A and B horizons were clearly the thinnest in Area 5 (Inari district). The thickest individual humus layer in a glaciofluvial soil occurred in Area 3: 10 cm. Very thin layers of < 1 cm occurred in all the study areas.

The thickest individual A horizon (16 cm) was measured in a glaciofluvial soil in Area 4, and the thickest B horizon (49 cm) in Area 2. However, it was difficult in many cases to distinguish accurately between the B horizon and the subsoil. There was one dune formation in the northernmost area (Area 5) where wind erosion had completely removed the humus and A horizon from the plots. There were no significant differences between the particle size parameters of the different horizons in this case. Only the proportion of gravel (particulate diameter 2—20 mm) was to some extent smaller in the A_0 horizon than in the other horizons of the mineral soil. The mean particle size (Md) of the A horizon was therefore, on the average, significantly smaller than that in the other horizons. The difference as regards the mean particle size even was small: the mean particle size of the A horizon was 0.1 mm smaller than the mean particle size of the C horizon. There was at least 1 %-unit more silt (diameter < 0.06 mm) in the C horizon than in the B horizon (the silt content of the C horizon was on the average 6.2 %). These differences were not statistically significant and naturally their ecological significance was also very small.

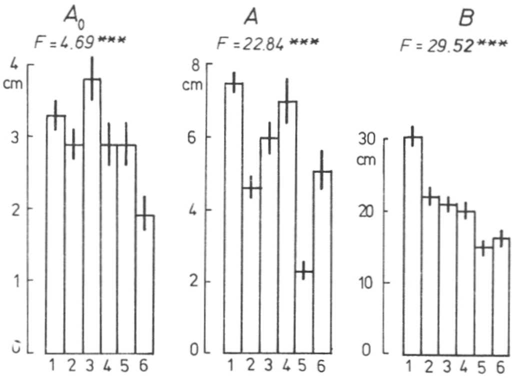

Fig. 18. The thickness of the soil horizons in the different study areas. The numbers of the study areas are the same as in Figs. 1 and 2.

Those soils with the highest silt content appear to have the clearest differences between the amount of silt in the different horizons. The maximum value for the silt content in the A horizon was 30.1 %, in the B horizon 38.8 %, and in the C horizon 50.5 %. There are very few cases of such finely-textured soils in the material of this study, which perhaps explains why podzolisation was not found to have had any effect on the particle size distribution in different horizons.

The particle size parameters were not correlated with the thickness of the mineral soil horizons. On the other hand, the amount of fine fractions (< 0.06 mm) in the sub-soil is correlated, to a highly significantly degree, with the thickness of the humus layer (r = 0.24). Some of the chemical factors in the humus layer were positively correlated with the amount of fine fractions in the subsoil. These factors were the total nitrogen content (r = 0.23), the potassium content (r = 0.24), the phosphorus content (r = 0.28) and the calcium content (r = 0.22). On the other hand, there was no such correlation between the magnesium content of the humus layer and the fine fractions of the mineral soil. The sorting parameter, S_0, was also found to be slightly correlated with some of the properties of the humus layer. This would suggest that the humus layer of soils with the most mixed texture are also the richest in nutrients, although no such correlations were found in the case of the other

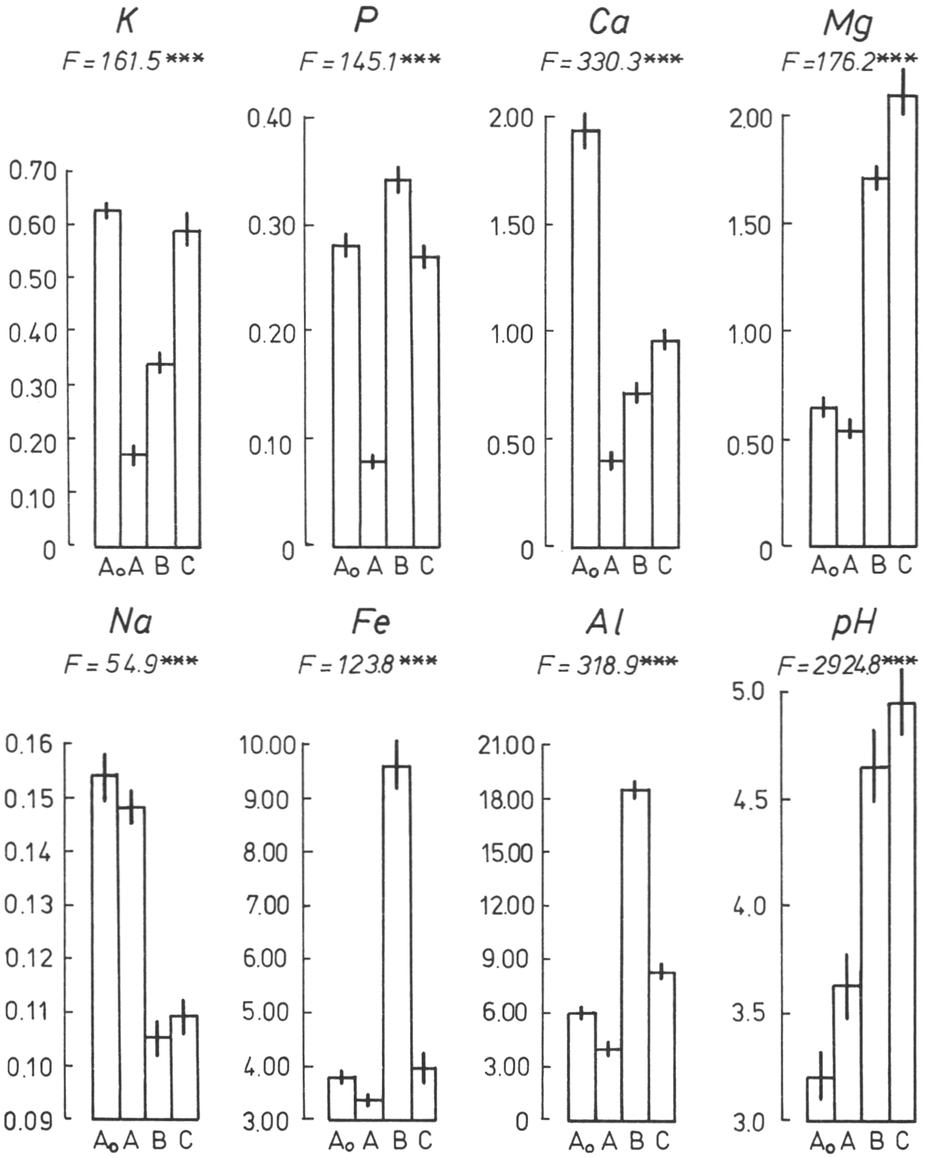

Fig. 19. The variation between the nutrient contents of the different horizons ($mg \cdot g^{-1}$).

particle size parameters.

There are very clear differences between the chemical factors determined in the different horizons (Fig. 19). The amount of potassium is highest in the A_0 horizon (humus layer) and lowest in the A horizon, from where it gradually increases on moving deeper. The different vertical distribution of calcium and magnesium in the different horizons can be clearly seen in the figure.

The B horizon, which is also called the enriched horizon, is characterized by a build up of aluminium and iron, as well as of phosphorus. No such accumulation is apparent as far as the other nutrients are concerned (Fig. 19). There is highly positive correlation between iron and aluminium, and the dependence appears to be linear (Fig. 20). There is also a clear dependence between iron and phosphorus, and between aluminium and phosphorus, which follows approximately the shape of the logarithmic curve in the figure.

Since iron and aluminium appear to be the elements which accumulate to the greatest extent in the B horizon, the sum of their contents was used to depict the degree of podzolisation. The ratio between the combined amount of aluminium and iron in the B horizon and that in the C horizon = B (Fe+Al) : C (Fe+Al) was used for this purpose. These horizons were selected for calculating the ratio because the B horizon represents the extent to which the podzolisation process, which results in the accumulation of these nutrients, has progressed, and the C horizon is the horizon which best represents the properties of the soil material from which the podzol profile has originally developed.

Highly significant regional differences were found in the values of this ratio (Fig. 21). The ratio is clearly the smallest in Area 1 (Hailuoto), where the A and B horizons were also found to be the thickest. The highest ratio values were found in Areas 3 and 6, and values significantly smaller than these in Areas 2 and 5. The A horizon in Areas 2 and 5 was in turn the thinnest. According to observations made in the soil sample pits in the field, the B horizon in Area 3 was abnormally strongly coloured. There was highly significant positive correlation between the ratio and the height of the sample plot above sea level (Fig. 22). It does not vary in either direction in any of the horizon thicknesses measured. No statistically significant differences were found between the ratio values of genetically different soil types, nor were any of the particle size parameters correlated with it.

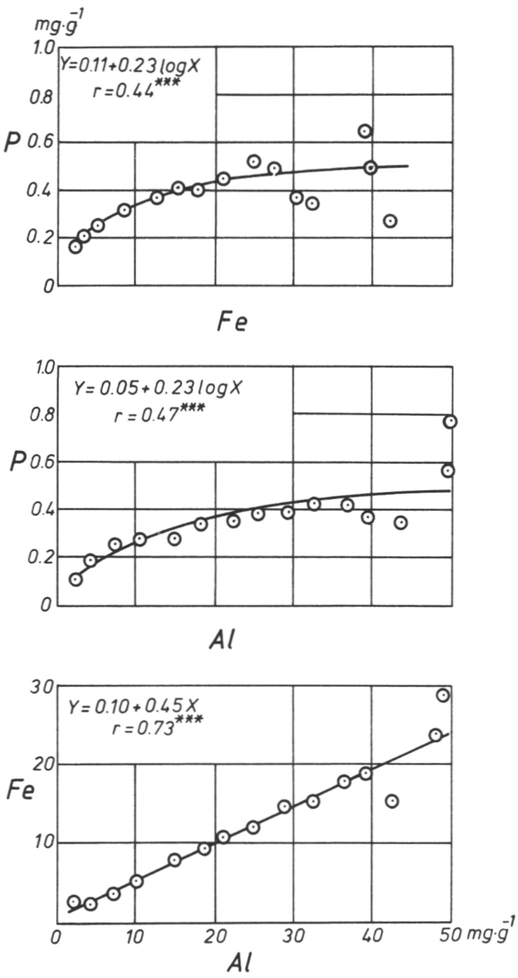

Fig. 20. The correlations between iron, aluminium and phosphorus in the whole material. The points are cluster averages.

Discussion

The amount of organic matter in the aeolian soils described by Jauhiainen (1970 and 1972a) in northern Finland is approximately the same as that measured in this study. In addition, he found clear differences in the amount of organic matter in each dune, just as was observed in this study. He stated that the amount of organic matter decreases rather clearly when moving down from the border of the A horizon, and he reported almost as small humus contents for the A_0 horizon as were found in this study.

The differences between the amount of organic matter in the different soil types followed approximately the same trends as were found for the differences in the nutrient levels. The loss in weight on ignition in both the A and the B horizons were largest in the two northernmost study areas (Fig. 17). This may be partly explained by the fact that the decomposition of organic matter in the mineral soil is slower under the colder climatic conditions in the north (see Fig. 3). However, the differences are rather small, and no far-reaching conclusions can be made on the basis of these results. The loss in weight on ignition of the humus layer is smallest in the Rokua area (Area 3, Fig. 17). Although it is difficult to find an explanation for this, one tentative reason may

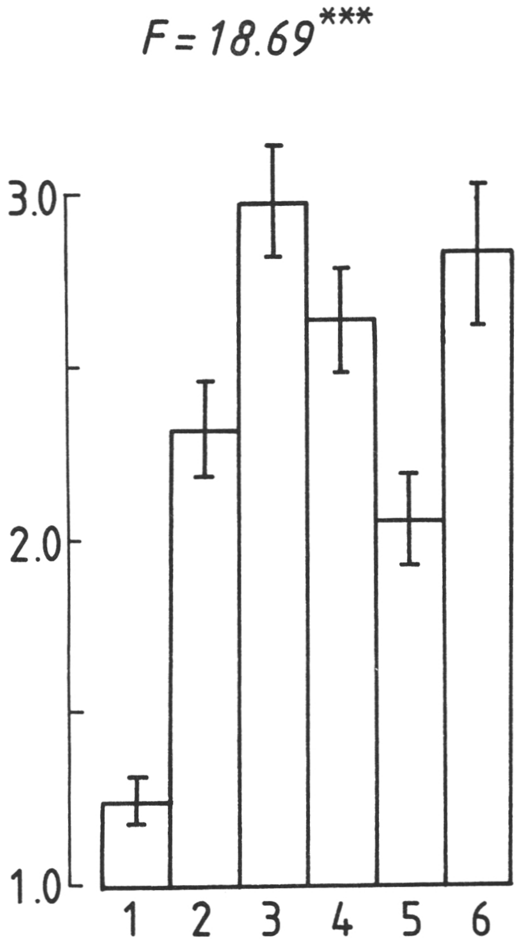

Fig. 21. The variation in the parameter depicting the degree of podzolisation in the different study areas. The numbers of the study areas are the same as in Figs. 1 and 2.

be the ecological effect of forest fires, as was discussed earlier.

The regional differences in the thickness of the horizons are important from the point of view of gaining an understanding of the podzolisation process. The humidity curves for the period when the ground is not frozen (Fig. 5), presented earlier, show that Koillismaa (represented by Area 3) is clearly more humid than the other areas, i.e. the amount of water remaining in the soil during the growing season is greater there than in the other study areas. This is presumably the main reason for the thickness of the humus layer in this area. The cumulative curve depicting the amount of rainfall (Fig. 4) also supports this assumption. These areas have been studied from the point of view of the precipitation and evaporation during the summer by e.g. Solantie (1974). The thin humus layer in Area 6 can be explained by the low mean temperature and low temperature sum in the area (Table 1). This results in a low biomass production and thus also a low accumulation of dead organic material.

The A and B horizons are clearly thicker in Area 1 (Hailuoto). It represents the youngest soils in this study and is situated below the edge of the Litorina Sea (Eronen 1974). According to Aartolahti (1976), for instance, the age of the dunes situated along the shore may be only 300—500 years, while the older dunes appear to have been formed 9 000—10 000 years ago. He assumes that formation of the dunes ceased about 8 000 B.P., and so the ages of the dunes examined in this study, apart from the dunes in Hailuoto, appear to be about the same as the figure mentioned above. As the dunes were formed in most cases in connection with the receding of the ice sheet and the drop in the water level, the age of the glaciofluvial soils as regards their soil formation is of approximately the same order as the dunes — it being assumed that the glaciofluvial soils were released from the water or the ice cover at approximately the same time as the dunes were formed. The study area at Rokua (Area 2) is completely above the edge of the Litorina Sea (Aartolahti 1973). The above discussion concerns the aeolian and glaciofluvial soils only, and a regional comparison of podzolisation in these two soil types is done here.

Aaltonen (1933) drew the following main conclusions concerning podzolisation:

- the thickness of the humus and A horizon increase as the wetness of the soil increases (on moving from dry upland soils to moist ones), and the B horizon is presumably the thinnest in the moistest and driest soils.
- The A horizon, B horizon and possibly the humus horizon become thinner as the age of the soil increases.

He also estimated that podzolisation is in different stages, or takes place in different ways, depending upon whether or not the soil has been formed before the subatlantic stage or during it. He divided Finland into five podzolisation zones. Zone I covers the subra-aquatic soils of northernmost Lapland,

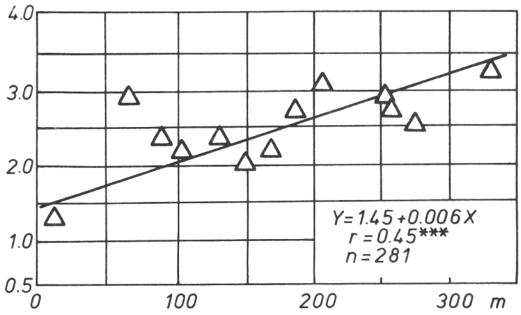

Fig. 22. The dependence of the parameter depicting the degree of podzolisation (vertical axis) on the height of the sample plots above sea level (horizontal axis). The points are cluster averages.

Areas 5 and 6 in this study falling within this zone. Zone II includes Peräpohjola and eastern Finland. Areas 3 and 4 are in this zone, Area 2 being situated astride this zone and Aaltonen's III podzolisation zone. Zone III is the coastal region which includes the geologically youngest soils. Aaltonen also drew attention to the same feature which can be seen in this study: the A horizon in the soils of Zone III is unusually thick.

Aaltonen (1935) presented the hypothesis that the accumulation layer (B horizon) is initially formed at a greater depth, and as the amount of certain compounds (primarily compounds of iron and aluminium) accumulate the horizon gradually becomes thicker in an upward direction — the A horizon becoming correspondingly thinner. However, he mentions that there are studies which indicate that the A horizon is initially formed as a very thin layer which then gradually becomes thicker. After reaching a maximum thickness it then starts to become thinner in the way described above.

Later on, however, Aaltonen (1941a) was no longer so certain about the statement that the A horizon of the youngest soils would be as a rule thicker than that of older soils, and stressed that the type of soil also has a major effect on the degree of podzolisation, just as the chemical properties have.

The particle size parameters of the mineral soil were not found to be significantly correlated in this study with the thickness of the mineral soil layer, and hence the thicker horizons in Hailuoto cannot be due to differences in the soil type. Neither was it possible to demonstrate any trends in the chemical factors at Hailuoto which would show that the soil is more susceptible to podzolisation than that in other areas. In the light of the results of this study, it appears that Aaltonen's (1933 and 1935) hypothesis concerning the thicker podzol layer of young soils is logical and based on firm grounds. Franzmeier and Whiteside (1963) have compared the thickness of podzol layers in different parts of the world.

Jauhiainen (1969) has also arrived at results similar to those described above. He states that the A horizon is thicker in young soils in central Finland than in old soils, and thinner in the northern study areas than in the ones in central Finland. The A horizon in northern Finland (the area studied by Jauhiainen is mainly Area 6 in this study) is, according to Jauhiainen, thinner in dry soils than in moist ones. This observation is also in agreement with the results obtained in this study. Jouhiainen's (1970 and 1972a) observations about the thickness of the horizons in aeolian soils agree rather well with the results obtained in this study (also Seppälä 1971).

Highly significant differences were found between the chemical properties of the different horizons. The amounts of potassium, calcium and magnesium were the greater in the mineral soil, the deeper the horizon in question (Fig. 19). Jauhiainen (1969), who used 1N ammonium acetate as the extractant, obtained different results in this respect. According to Jauhiainen, the amount of exchangeable potassium and calcium is at its greatest in the A horizon, and decreases on moving downwards. The difference between the results can be explained by the different extraction methods, and at the same time shows how decisive the choice of extractant is from the point of view of the interpretation of analysis results.

One of the most significant differences between Jauhiainen's (1969) results and those obtained in this study is in the quality of the elements which accumulate in the B horizon. According to Jauhiainen, the amount of phosphorus is approximately independent of the depth along the profile (Jauhiainen 1969, Figs. 14 and 26). In this study phosphorus was found to have accumulated in the B horizon, there being significantly more than in the subsoil. The enriched horizon is thus not only characterized by the accumulation of iron and aluminium, but also of phosphorus. The differences between the results obtained in these two studies is explained by the differences between the extraction methods used. Phosphorus has also been found to be only weakly extracted from peat soils by acidic ammonium acetate (Sepponen and Haapala 1979). Viro (1965) has also drawn attention to the different extractability of various nutrients (see also A. Valmari 1970 and Lähde et al. 1981).

The ratio depicting the accumulation of iron and aluminium in the B horizon also shows that the podzolisation process in the Hailuoto study area has not progressed very far in comparison to, for instance, Area 3, where the corresponding ratio was almost three times larger (Fig. 21). Aaltonen (1935) also suggests that the precipitation of iron and aluminium occurs at a greater depth in young soils than in old soils, and that real hardpans (i.e. stronger B horizons) are only to be found in old soils (see Aaltonen 1939 and 1951).

The accumulation of iron and aluminium in the B and C horizons was highly significantly correlated with the height of the sample area above sea level (Fig. 22). This confirms the conclusion that the length of time during which the processes has been taking place affects the size of the ratio value. This conclusion is also further strengthened by the fact that the ratio is largest in high and old soils, and smallest in geologically young soils. The humidity differences between low-lying and high areas may also be of some significance.

The dependences between the height and the thickness of the horizons in the podzol profile were not as clear as those in the case of the ratio value, apart from the clearly thicker A and B horizons in Hailuoto. It may well be that very many factors regulate the thickness of the horizons. This material is too restricted to permit a detailed investigation of these features. On the other hand, the ratio value calculated on the basis of the iron and aluminium concentrations appears to be a rather good indicator of the age of the podzol formation.

414. Classification of the sample plots according to the soil properties

Classification of the sample plots on the basis of soil parameters can be done in many ways. One method is that used earlier on in this study, i.e. classification according to the geological mode of formation. In order to be able to examine the classification potential on the basis of the results of the soil analyses, a data-set was formed which included the chemical properties of the humus, the most important particle size parameters of the subsoil (C horizon), and the thickness data for the horizons in each sample plot (Table 10). The list of variables was drawn up on the basis of the conclusions concerning the results presented earlier on in this paper.

The data-set was initially analysed using factor analysis. The four factor model was selected that would best take into account the trends in the material from the point of view of the classification (Table 10). The factors were named according to the strength of the loadings received by the variables as follows:

1. The nutrient factor
2. The pH and magnesium factor
3. The gravel factor
4. The iron and aluminium factor

The loss in weight on ignition of the humus, the humus thickness, the N, P, K and Ca contents of the humus, as well as the amount of fine fractions (< 0.06 mm) in the subsoil, receive the very strongest loadings in the first factor. The pH of the humus determined in two ways, the magnesium content of the humus and, as in the previous factor, also the amount of fine fractions, received the highest loadings in the second factor. The third factor is clearly the factor for the large amount of gravel fractions — the mean particle size (Md) and the sorting parameter (S_0) also receiving high loadings. The fourth factor is the factor for the high amount of iron and aluminium in the humus.

In order that ordination analysis could be done on as natural a clusteringness as possible, a two factor model was formed and factor points were awarded for each sample plot on the basis of both factors. The first factor in this factor model was interpreted as being almost identical to the first factor of the earlier-presented model (Table 10), i.e. the fertility factor. On the other hand, the second factor corresponded to the third factor of the model in question and was interpreted as being the gravel factor in which the mean particle size and the sorting value also received high loadings (cf. Table

Table 10. Four factor factor analysis carried out on a selected variable group in the humus layer and in the subsoil. Only those loadings whose eigenvalue is greater than 0.2 are included. C (%) = proportion of total variance.

	FACTORS			
	1	2	3	4
Thickness of A_0 horizon	0.55	–0.38		0.25
Thickness of A horizon	0.41	–0.52		
Thickness of B horizon		–0.68		
Loss-on-ignition	0.75	–0.36		–0.30
pH$_{(H_2O)}$		0.75		
pH$_{(CaCl_2)}$		0.74		0.33
N_{tot}	0.82	–0.21		–0.20
K	0.81			
P	0.86			
Ca	0.76			
Mg		0.54		
Fe				0.89
Al	–0.35			0.67
Na		–0.25		0.34
20—2 mm fraction			0.96	
<0.06 mm fraction	0.49	0.32		
Md			0.93	
S_0	0.23	0.22	0.68	
C (%)	23.1	15.2	13.1	11.7

10, Factor 3). The ordination of the sample plots formed from this factor model (Fig. 23) depicts the position of the sample plots in a two-dimensional figure plotted using the fertility factor and the particle size factor.

Ordination analysis (Fig. 23) shows that the sample plots representing different types of soil intermingle with each other in the centre of the figure. On the other hand, the gravelly glaciofluvial soils, which also lie in the central part of the fertility axis (horizontal axis), are situated in the upper part of the figure. The sample plots representing aeolian material, which are rather poor in nutrients and lacking gravel fractions, are situated in the lower left corner. The gravel-free fluvial soils, which are the most nutrient-rich soils in the material, are situated in the lower right corner. Ordination analysis thus does not divide the soil types of different genetical origin into fully distinct groups, although it does stress their grouping in different parts of the figure formed from the fertility factor and the gravel fraction axes.

The sample plot material was grouped by means of cluster analysis using the factor points awarded to the sample plots by the four factor model (Table 10) as the starting values. After the sample plot material had been divided by clustering into smaller parts, there was still a group comprising 102 sample plots in the six-cluster model. However, it was considered that this could not be divided into smaller parts owing to the large number of clusters. The clusters were ranked according to how high a factor point score the sample plots received on the average in the fertility factor. Thus the first cluster in Fig. 24 comprises the most fertile sample plots, and the sixth cluster the most nutrient-poor ones.

The first cluster receives the highest factor score in both the fertility factor and the pH and magnesium factor, and the second cluster overwhelmingly the highest point score in the iron and aluminium factor (Factor 4, Table 10). Altogether there are only two sample plots situated on aeolian soil in both these clusters, and clearly most of the sample plots (68 %) are on fluvial soil.

The third cluster is a ”mixed cluster” as regards the soil type and, with regard to the number of sample plots, also the largest in the material. The sample plots in this cluster are not geographically concentrated in any special study area or vegetation zone. This is quite opposite to the situation as regards the sample plots of the two clusters mentioned above. The sample plots of the cluster represent the middle level as regards nutrient

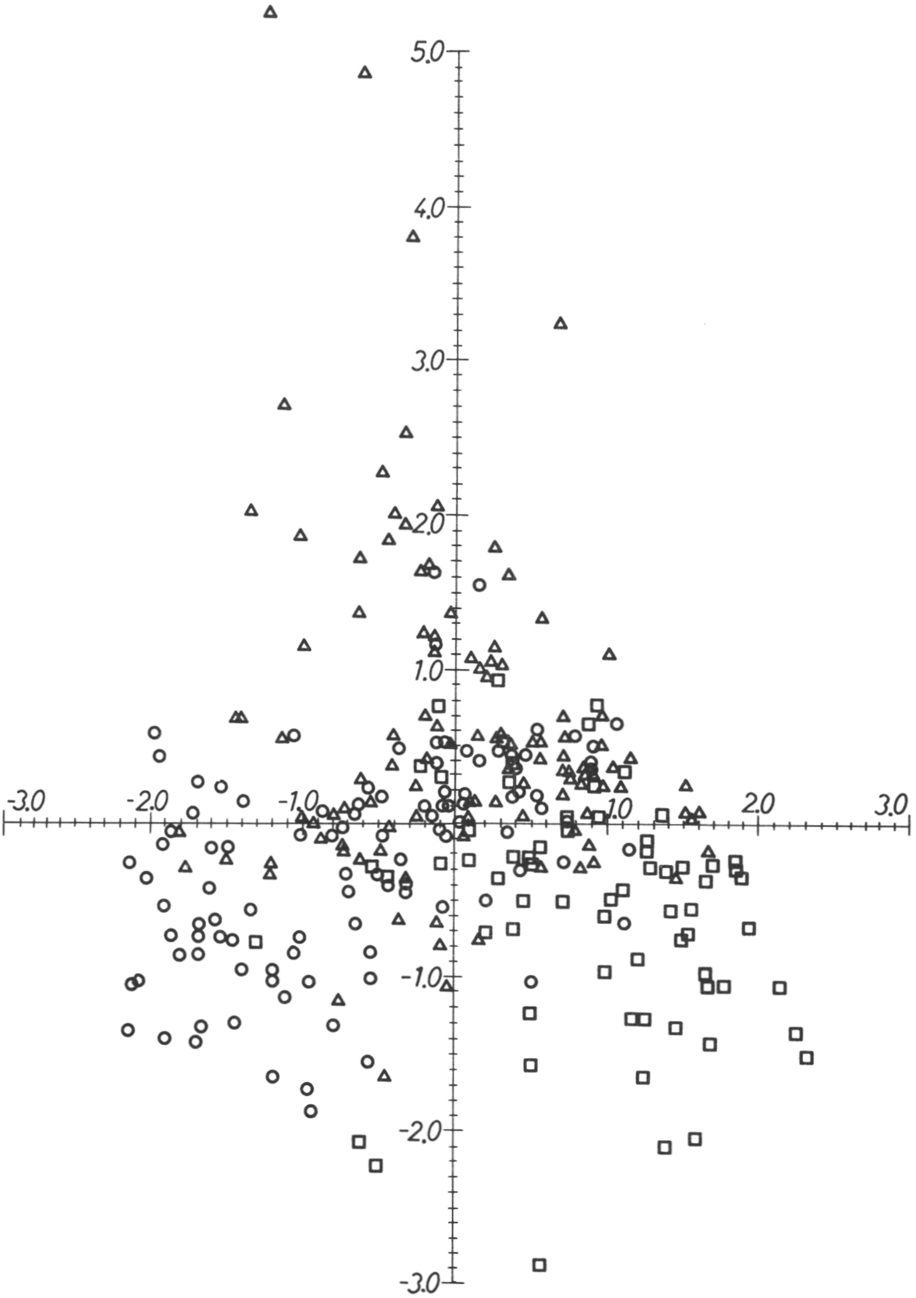

Fig. 23. The position of the sample plots in the two factor ordination according to their factor scores. The horizontal axis closely resembles the fertility factor, and the vertical axis the particle size factor. Symbols for different soil types: ○ = aeolian soils, △ = glaciofluvial soils and □ = fluvial soils.

status in this material, as is the case for the mean particle size of the mineral soil.

The fourth cluster represents only the glaciofluvial soils, which have a high proportion of gravel fractions. These sample plots have a poorer nutrient status than the previous cluster. The proportion of sample plots representing aeolian soils is considerably large in the fifth and sixth clusters. The sample plots of the sixth cluster are, in addition, concentrated in the northernmost study areas, only three of them representing the southernmost vegetation zone. The amount of magnesium and the pH are, however, relatively high in the humus of the sample plots of this cluster, although the nutrient status in other respects is the lowest in the material. A very sorted type of forest soil and the effect of the cold climate on the nutrient status of the humus are thus combined in the cluster containing soils with the poorest nutrient content.

The different types of soil are not put into completely different groups in this clustering. Even the largest cluster in the material is such that all the soil types are almost equally represented. However, there are clear stresses on different soil types in the cluster series (Fig. 24) — the fluvial soils dominate the clusters with the best nutrient status and the aeolian soils, together with the most rough-textured glaciofluvial soils, the most nutrient-poor clusters. However, the intermixing of the different soil types in the middle cluster shows that soils formed as a result of different geological processes can, over a long period of time, develop into forms which resemble each other very much as regards their nutrient status.

DECORANA ordination analysis gave a somewhat similar picture about the positioning of the sample plots as did factor analysis. However, as it did not add any additional information to the factor analysis described above, it is not examined further in this connection. TWINSPAN clustering gave a rather different sample plot division than the above-described clustering done on the basis of the factor scores. Six clusters were formed in the TWINSPAN clustering and an attempt was made to rank them in such a way that the grouping of the sample plots corresponded as far as possible to the clustering done using the factor scores. The classifications were not in complete agreement with each other with respect to the positioning of

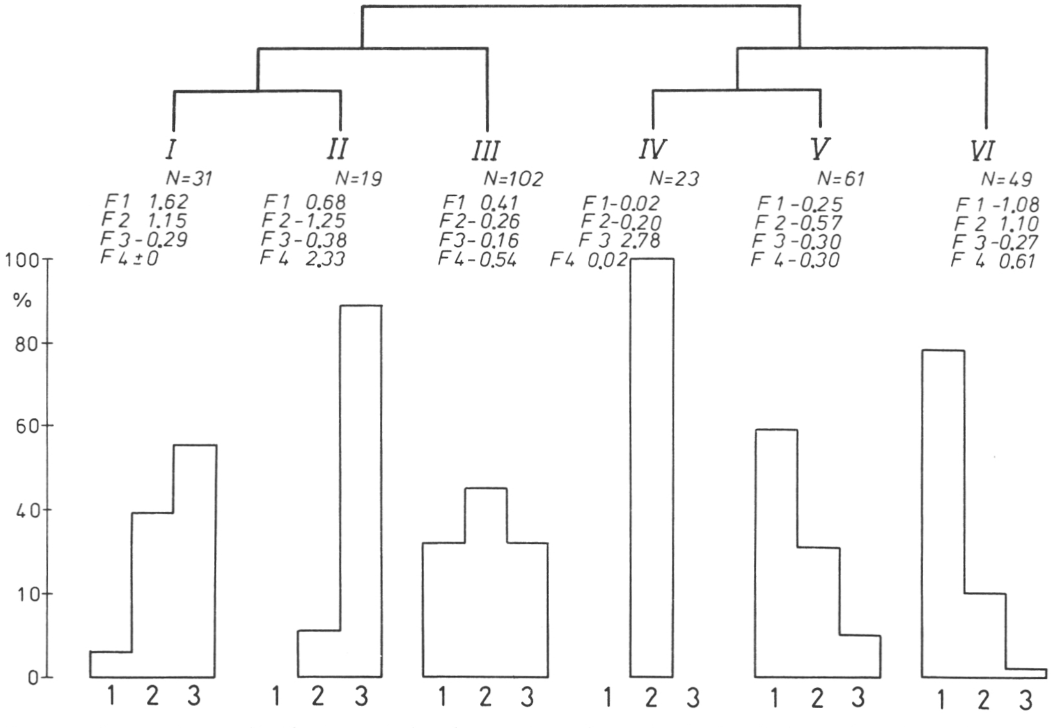

Fig. 24. The soil type distributions of the clusters formed on the basis of the soil analysis data. 1 = aeolian soils, 2 = glaciofluvial soils, and 3 = fluvial soils. The mean factor scores received by the sample plots of each cluster for different factors (F1, F2, F3 and F4). The dendrogramme depicts the proximity between the clusters and their formation as clustering progresses.

the sample plots (Fig. 25), although some clear correspondence was evident. The very nutrient-poor sixth cluster was formed in both classifications, which in this synthesis examination of the classifications still comprises only aeolian soils. The joint IV group representing pure glaciofluvial soils was also formed. There was some divergence between the classifications as regards all the groups. There were even two sample plots in the material which, in the factor analysis classification, were placed in the first group, but in the TWINSPAN clustering in the fifth group.

Discussion

Very little classification has been practiced in an ecological sense in Finland, and it is usually considered sufficient to use the plant cover as an aid in classification. The strong Cajanderian tradition (e.g. Cajander 1909, 1925 and 1949) has directed the classification of forest soils in this direction. The soil has been used much more in other parts of the world as the basis of classification (e.g. Cline 1949, Gerasimov 1978, Gennadiyev & Gerasimova 1980, Schlichting & Schwekle 1980, Stromg & Limbird 1981 and Wiechmann 1981). Attention has also sometimes been paid to the importance of the quaternary history in the formation and use of present day soils (Mitchell & Howard 1978 and Catt 1979).

The soils in Finland are also much less variable than those in many parts of the world. The predominant soil formation type in Finland is podzol (Aaltonen 1951). As the age of the soils also varies very little within the framework of the geological timescale — our upland forest soils are in fact products of the last ice age — the differences in age do not cause any large variation. Aaltonen (1951) in fact divided the country up into zones on the basis of soil formation using the duration of podzolisation as one of the criteria. Differences do occur in this respect, such as those already pointed out earlier on in this paper. However, the differences do not become as large within this timescale as they do in areas where the forest soils can represent different geological eras. There are exceptions to this in Finland, such as the land uplift along the Ostrobothnian coast (e.g. Siira 1970).

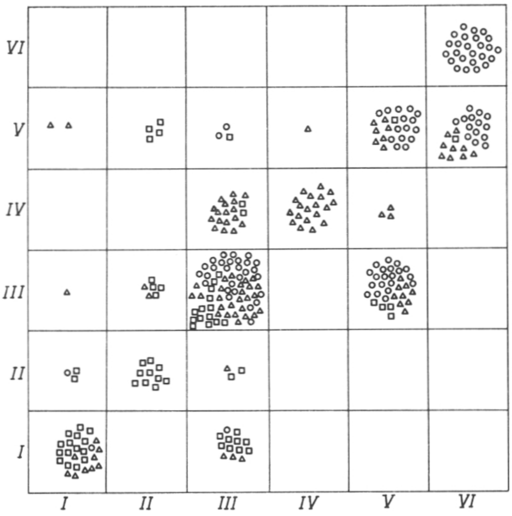

Fig. 25. The dependence between the soil classifications made on the basis of the factor scores (horizontal axis) and on the basis of TWINSPAN clustering (vertical axis). See Fig. 23 for the symbols for the sample plots by soil types.

There have been very few attempts in Finland to use geological soil formations as a starting point for a botano-ecological classification (Okko 1944 and Sepponen et al. 1979). On the other hand, geological soil formations are taken into account in the interpretation of soil types using aerial photography (Penttilä 1960), and they have been utilized — as an aid in soil type classification — in the planning of soil data systems (Rahkila 1980). The upland soil classification system developed by Atterberg (1912), and more recently the system developed for our conditions by a Finnish working group (Aaltonen et al. 1949), have been regularly employed in agriculture and forestry, as well as in botano-ecological studies (also Sepponen 1981).

It has usually been sufficient to divide podzol soils in Finland into iron and humus podzols (Aaltonen 1951). Since all the soils examined in this study were considered to belong, according to this classification, to the iron podzol group, parameters other the external appearance of the soil profile had to be taken as the classification criteria. The thickness of the horizons measured in the field and the fertility and particle size parameters determined in the laboratory were used as such criteria. There appeared to be clear variation in the material with respect to these parameters (Fig. 23).

A similar type of multivariate analysis has earlier been applied to the analysis of soil parameters by Jauhiainen (1976). He examined a group of sixty variables using a fivefactor model. The samples were collected from soil profiles in southern Norway and Denmark. Most of the variables he used were different from those employed in this study, and hence it is difficult to make comparisons between the results of the two studies. However, he found for instance that plant nutrients and the particle size parameters of the soil received high loadings in certain factors, just as was observed in the study in hand (Table 10).

In this study the list of variables used in the multivariate analyses was drawn up on the basis of earlier results: the chemical values of the humus layer were best considered to depict the chemical differences between the site types (cf. Table 6), and the particle size values of the sub-soil in turn best represented the primary site factor which podzolisation has not had any effect on. The trends in the textural parameters clearly separated the gravelly glaciofluvial soils from the other sample plots in the factor analyses (Figs. 23 and 24). The geological history of the soils is thus visible in the ordination. It is also indirectly apparent in the variation according to the fertility axis: the fluvial soils, being on the average more finely-textured, were situated at the more fertile end of the axis than the aeolian soils. However, there is a group of soils formed by different geological processes which are intermixed in the middle of the figures based on the results of the cluster and ordination analyses (Fig. 23).

The above-described features were also apparent in the clustering based on the factor scores and the standardised variable values (Fig. 25). A synthesis of both classifications is thus formed when examining, for instance, the class of pure aeolian soils, which were the most nutrient-poor soils of the material, and a class of pure glaciofluvial soils, which differed from the others as regards their coarse-textured sub-soil. However, it can also be seen in the clustering that genetically different soil types are mixed up with each other in a number of groups.

It can be concluded from the above that although the geological history of the soils clearly has an effect on the development of the properties of their surface layers, different geological processes can produce also soils with analogous ecological properties. A knowledge of the geological background is thus of very great help in the ecological classification of soils, but cannot usually be used as the sole classification criterion.

42. The vegetation

The forest ground vegetation is the most precisely described compartment of the vegetation growing on the sample plots. The tree stand has been measured with a relascope, and the shrub layer has been almost completely ignored. This part of the study, i.e. the vegetation analysis, is thus based on the one hand on the species composition and species coverage of the ground vegetation, and on the other hand on the parameters measured in the tree stand. Another reason why these parameters were measured is because they are the most easy to measure in practice in site classification work. On the other hand, the use of the shrub layer is to some extent more difficult.

421. The tree stand

The tree stand is examined only rather roughly in this study on the basis of the tree species composition, and the mean height, basal area and volume over bark of the tree stand. The aim is merely to obtain an overall picture of the tree stand as a component together with the other vegetation on the site.

Scots pine *(Pinus sylvestris)* was clearly the predominant tree species on almost all the sample plots, irrespective of the soil type on which the trees were growing. This was most clearly evident in stands which had developed on aeolian soils, the proportion of pine in the tree stand being 97 % of the basal area. The corresponding value for glaciofluvial soils was 96 %, and on fluvial soils 86 %. The stands on the last-mentioned soil type thus usually contained the greatest admixture of other tree species.

The proportion of Norway spruce *(Picea abies)* was small on all the soil types, on the average its proportion being highest on the fluvial soils — even in this case only 4.2 %. There were a number of cases of individual

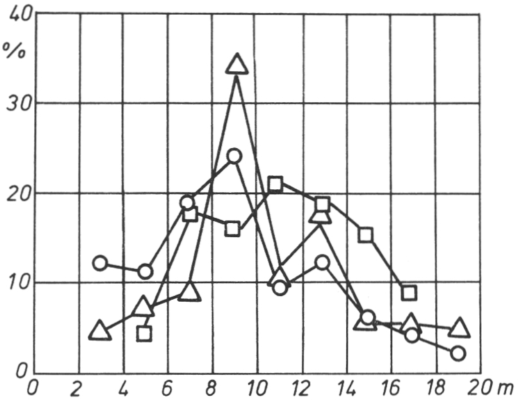

Fig. 26. The distribution of the tree stands growing on different types of soil into mean height classes. ○ = aeolian soils, △ = glaciofluvial soils, and □ = fluvial soils.

sample plots with a slightly higher proportion of spruce — the highest value on aeolian soils being 20 %, on glaciofluvial soils 50 %, and on fluvial soils 58 % of the basal area of the tree stand.

Birch *(Betula pubescens* and *B. pendula)* was rather uncommon apart from the northernmost dune sample plots which were partly located in the birch forest zone. The mean proportion of birch on aeolian soils was 2.3 %, on glaciofluvial soils 2.0 %, and on fluvial soils 8.9 % of the basal area of the tree stand. The occurrence of other tree species was considerably less on all the soil types. Only on rare occasion were there any aspen *(Populus tremula)* or goatwillow *(Salix caprea)*.

The height class distributions of the mean trees on the sample plots of different soil type differ only slightly from each other (Fig. 26). The mean trees on the fluvial soil sample plots fell in most cases in the 10 to 12 m height class, and in the case of the glaciofluvial and aeolian soils in the 8 to 10 m class. Of course any silvicultural measures carried out in the stands will have an effect on these distributions and it is almost impossible to remove this effect from the material. However, the overall impression to be gained from the measurement results, as well as the visual observations made in the field, is that on the average the tallest pine stands are most frequently growing on fluvial soils, and least frequently on aeolian soils.

The variation in the volume over bark of the tree stand follows the same trend as for the height distribution of the mean trees: on the average it is 101.5 m^3/ha for pine on the fluvial soils, 89.7 m^3/ha for pine on the glaciofluvial soils, and 78.3 m^3/ha for pine on the aeolian soils. The soil types are in the same order as for the height class distribution. Silvicultural measures also have an effect on this parameter. The volume of birch is also highest on the average on the fluvial soils (4.6 m^3/ha), the second highest on the glaciofluvial soils (1.2 m^3/ha), and lowest on the aeolian soils (0.7 m^3/ha). The mean volume of spruce on the fluvial soils was 6.4 m^3/ha, on the glaciofluvial soils 1.6 m^3/ha, and on the aeolian soils only 0.5 m^3/ha.

Discussion

The tree stand measurements made in this study are so superficial that they should only be used to provide a rough overall picture of the species composition and structure of the tree stands growing on the different types of soil. The measurements show that the tree stand growing on aeolian soils was clearly the most dominated by pine, although the glaciofluvial soils do not differ very much in this respect. On the other hand, the tree stands growing on the fluvial soils were to some extent more mixed.

The mean height and mean volume of the tree stands were greatest on the fluvial soils, and smallest on the aeolian soils. Although the growth and wood production has not been examined in more detail on the sample plots, the structure of these stands does suggest that the productivity follows the ascending order: fluvial soils — glaciofluvial soils — aeolian soils. This also fits in well with the results presented earlier concerning the nutrient status of these types of soil.

According to the results of the National Forest Inventory (1971—1976), the mean volume of the tree stand in old thinning stands and mature stands in the northern half of the country was 102 m^3/ha (Metsätilastollinen vuosikirja 1981). Thus the stand volume of the fluvial soils is rather close to the mean for northern Finland, while the other two soil types are clearly below the average level. This sort of comparison is of course not very valid since the northernmost glaciofluvial and aeolian sample plots reduce the mean volume of the tree stand on these soils, while the mean for the fluvial soils is not affected since they were not found quite so far to the north (see Fig. 1). However, the comparison does give a rough picture of where the sample plots are placed as regards their tree stands. They are thus to a large extent stands that are poorer than the average, despite the fact that an attempt was made to site them at points where the tree stand was in as natural a state as possible. This of course was not always successful, but the overall picture given by the stand measurements can be mainly explained by the infertile and poor nutrient status of most of the soils studied here.

422. *The ground vegetation*

In order to get an overall picture of the variation in the vegetation on the sample plots, the sample plots were classified in the field, on the basis of the plant cover, into the following site types. The vegetation ranged from the poorest to the most luxuriant as follows: barren sites, dry sites, subdry sites and damp sites.

The different soil types differ rather clearly from each other as regards their site type distribution estimated on the basis of the vegetation (Fig. 27). There are no damp sites on the aeolian soils at all. The sub-dry and damp sites are clearly the most common on the fluvial soils. The most common site type on the aeolian soils is the barren site type, on glaciofluvial soils the dry site type, and on fluvial soils the sub-dry site type. On the other hand, the dry site type especially, as well as the sub-dry site type, occur on all three soil types included in this study. The most common site type in the whole material is the dry site type (52 % of the sample plots), and the least common the damp site type (6 %).

Observations made in the field indicated that the effect of exposition on the development of a particular site type is such that the southern and western slopes on the aeolian dunes, for instance, were the most infertile, and the subdry site type, which was rare in the material, occurred on the northern slopes of this soil type.

The different soil types also differ clearly from each other as regards the occurrence frequency of individual plant species (Table 11). On the average, the coverage of dwarf shrubs is the highest on the fluvial soils, and the lowest on the aeolian soils. The situation as regards the coverage of mosses is the same. Herbs, grasses and sedges are also the most abundant on the fluvial soils, although the coverage of their species groups is very small on all the soil types. The coverage and species number of lichens is also high on all the soil types; the highest on the aeolian soils, and the lowest on the fluvial soils.

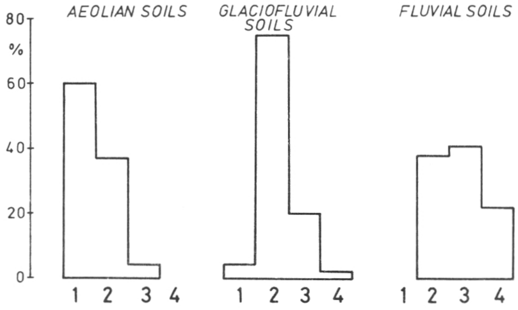

Fig. 27. The distribution of the different types of soil into Lehto's (1969) site type classes. 1 = barren sites, 2 = dry sites, 3 = sub-dry sites, and 4 = damp sites.

The most common species of dwarf shrub on all the soil types are *Vaccinium vitis-idaea, Empetrum nigrum coll.* and *Vaccinium myrtillus* (Table 11). *Arctostaphylos uva-ursi* and *A. alpina* are missing from the fluvial soils. The most common species of moss are *Pleurozium schreberi* and *Hylocomium splendens,* which are most abundant on the fluvial soils, and least abundant on the aeolian soils.

The coverage of mosses is greater than the coverage of lichens only in the bottom layer on the fluvial soils, lichens being overwhelmingly the dominant species in the bottom layer on the other soil types. *Cladonia stellaris* has the largest mean coverage, followed by *C. rangiferina* and *C. sylvatica coll.* Approximately all the lichen species occur in greater amounts on the aeolian soils than on the other types of soil. A number of species typical of the aeolian soils, which rather frequently occur on this type of soil with small coverages, did not occur at all on the fluvial soils. These species are *Cetraria nivalis, Cladonia coccifera, C. fimbriata* and *C. verticillata.* All these species were also found on the glaciofluvial soils. *Stereocaulon spp.* were found rather abundantly especially on the aeolian soils. This species occurred almost without exception in places where

Table 11. The plant species composition on the different soil types. D = mean coverage of a species (%), F = occurrence frequency of the species (%), + = coverage of < 1 %.

	Aeolian soils		Glaciofluvial soils		Fluvial soils	
	D	F	D	F	D	F
Alnus incana	+	7	+	5	+	2
Betula nana					+	4
B. pubescens	+	7	+	5	+	4
B. pubescens ssp. tortuosa	+	1	+	4		
Juniperus communis	+	9	+	3	+	16
Picea abies	+	9			+	6
Pinus sylvestris	+	71	+	67	+	35
Populus tremula	+	1	+	2	+	2
Salix glauca	+	4				
S. phylicifolia					+	2
Arctostaphylos alpinus	+	1	+	2		
A. uva-ursi	+	29	+	12		
Calluna vulgaris	1	32	2	58	+	25
Diphasium alpinum	+	1	+	3		
D. complanatum	+	21	+	11	+	4
Empetrum nigrum coll.	6	78	8	87	7	65
Ledum palustre	+	9	+	21	+	23
Lycopodium annotinum	+	3	+	2	+	10
L. clavatum	+	1				
Phyllodoce caerulea			+	7		
Thymus serpyllum	+	1				
Vaccinium myrtillus	+	34	3	67	7	68
V. uliginosum	+	5	+	15	3	33
V. vitis-idaea	9	95	11	100	18	100
Calamagrostis phragmitoides					+	6
C. spp.	+	4	+	2	+	10
Carex brunnescens	+	1				
C. globularis	+	1				
C. spp.			+	1	+	3
Deschampsia flexuosa	+	21	+	26	2	39
Festuca ovina	+	26			+	13
Luzula pilosa					+	6
Ceratodon purpureus	+		+	1	+	2
Dicranum bergerii	+	16	+	34	+	19
D. drummondii	+	3	+	18	+	16
D. fuscescens	2	42	+	54	+	23
D. majus			+	6	+	15
D. polysetum	+	31	1	50	+	61
D. scoparium	2	64	3	79	2	87
D. spurium			+	5	+	3
D. spp.	+	3				
Hepaticae spp.	+	9	+	12	+	25
Hylocomium splendens	+	6	1	6	6	57
Pleurozium schreberi	8	72	15	96	35	100
Pohlia nutans	+	33	+	33	+	10
Polytrichum commune	+	29	+	12	1	33
P. juniperinum	+	57	+	47	+	29
P. piliferum	1	45	+	16	+	2
Antennaria dioica	+	3	+	1		
Cornus suecica					1	7
Epilobium angustifolium	+	2			+	3
Equisetum arvense	+	3			+	4
E. hyemale	+	1				
E. pratense					+	3
E. sylvaticum	+	2			+	4
Hieracium spp.	+	3				
Linnaea borealis	+	6	+	6	+	15
Maianthemum bifolium					+	20
Melampyrum pratense					+	10
Rubus arcticus					+	3
R. chamaemorus					+	3
Solidago virgaurea	+	17	+	1	+	21
Trientalis europaea	+	1	+	1	+	13
Barbilophozia hatcheri	+	1				
B. lycopodioides	+	1	+	3	+	4
Brachythecium spp.					+	2
Bryum spp.	+	1				
Buxpaumia aphylla			+	1		
Ptilidium ciliare	+	26	+	15	+	15
Ptilium crista-castrensis	+	2	+	2	+	7
Sphagnum russowii					+	2
Tetraplodon spp.			+	1		
Cetraria crispa	+	46	+	22	+	4
C. islandica	+	22	+	23	+	19
C. nivalis	+	29	+	8		
Cladonia stellaris	16	83	12	91	5	48
C. botrytes	+	5	+	1	+	2
C. cenotea	+	29	+	11	+	2
C. coccifera	+	29	+	16		
C. cornuta	+	54	+	22	+	20
C. crispata	+	24	+	14	+	9
C. deformis	+	69	+	69	+	51
C. degenerans			+	2	+	2
C. fimbriata	+	4	+	6		
C. gracilis	+	67	+	46	+	31
C. pyxidata	+	3				
C. rangiferina	11	96	12	98	9	84
C. sylvatica coll.	12	100	10	97	7	86
C. uncialis	3	85	+	66	+	38
C. verticillata	+	5	+	2		
C. spp.	+	4				
Nephroma arcticum	+	6	+	12	+	19
Peltigera aphthosa	+	13	+	8	+	38
P. canina	+	4			+	3
P. malacea	+	1				
Solorina crocea	+	1				
Stereocaulon spp.	6	57	+	36	+	16

the ground had been compacted or there were other marks of soil erosion, or else the lichen cover was otherwise incompletely closed. *Cladonia stellaris* was, in turn, most abundant in the very densest lichen stands.

There were tree seedlings growing in the dwarf shrub layer on most of the sample plots on aeolian soil. The relative occurrence frequency of Scots pine *(Pinus sylvestris)* seedlings was 71 % on the sample plots on this type of soil (Table 11). The corresponding figure for the glaciofluvial soils was 67 %, and for the fluvial soils only 35 %. These percentages express the capacity

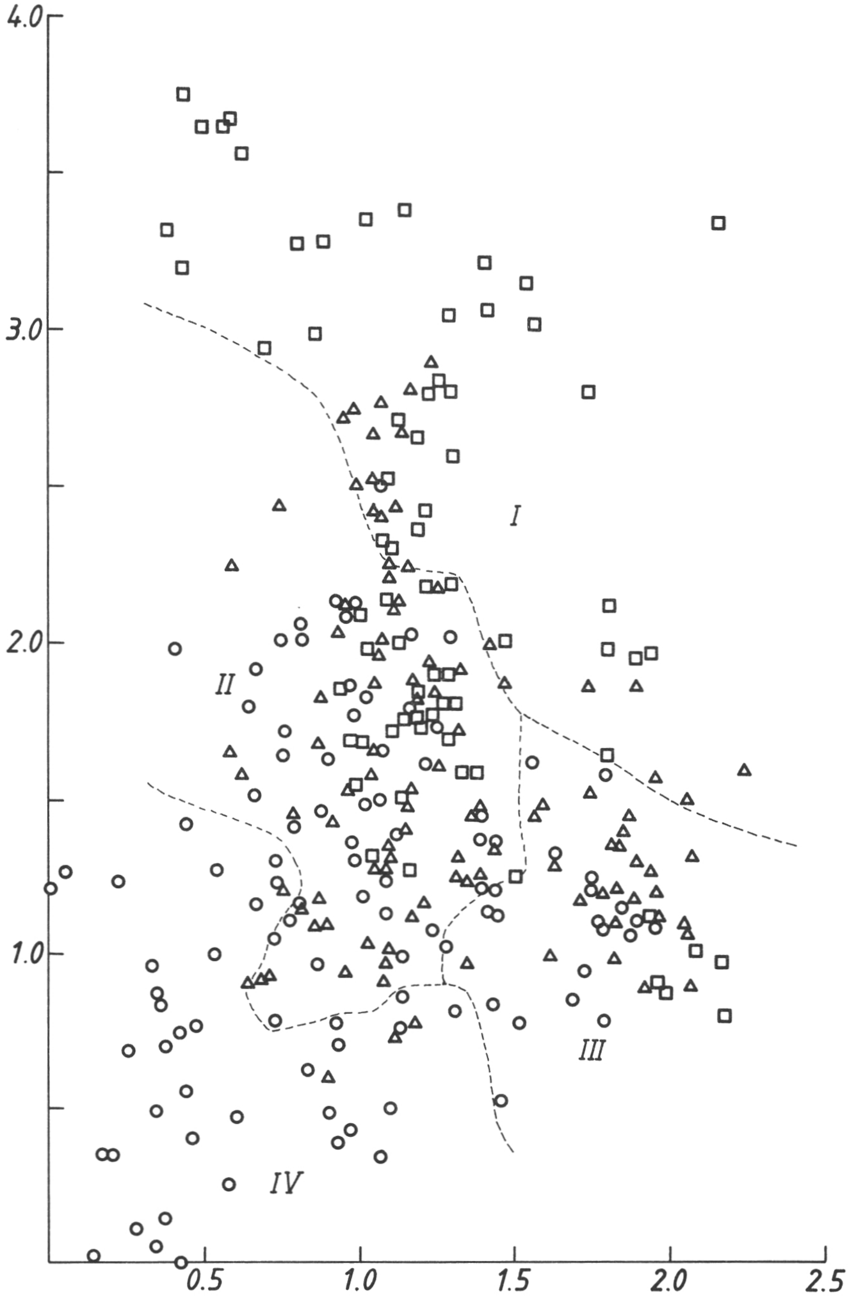

Fig. 28. The position of the sample plots when plotted against the two main trends in DECORANA ordination done on the basis of the coverage of the different plant species. The symbols for the different types of soil are the same as those in Fig. 23

of these soil types to sustain seedling growth, which thus appears to be clearly better on the aeolian and glaciofluvial soils than on the fluvial soils.

In the ordination analysis of the vegetation (so-called DECORANA ordination), the sample plots belonging to the different soil types were placed as shown in Fig. 28. The

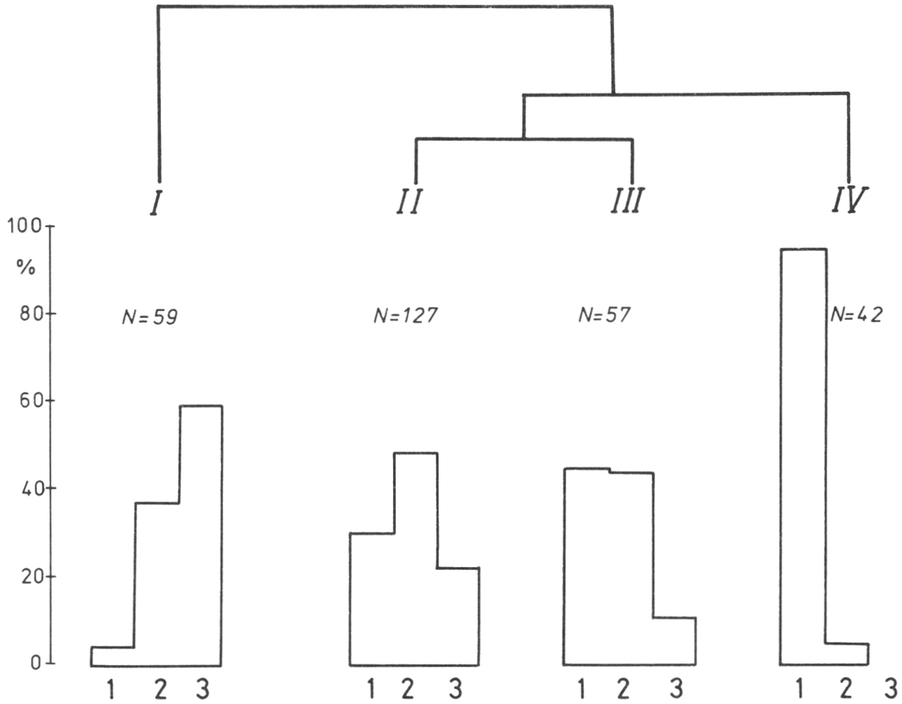

Fig. 29. The distribution into soil types of the sample plot clusters formed using TWINSPAN clustering on the basis of the coverage of the different plant species. 1 = aeolian soils, 2 = glaciofluvial soils, and 3 = fluvial soils. The dendrogrammes depict the formation of the clusters as the division of the sample plot groups progresses.

coordinates of the figure comprise the two strongest main trends in the material. The aeolian soils are concentrated in the left-hand lower corner of the figure, but are also mixed together with the other two soil types in the centre of the figure. The fluvial soils are concentrated in the upper half of the figure, and the glaciofluvial soils are mixed together with the other two soil types in the centre of the figure.

Although the soil types do not form any clear natural groups in the ordination analysis done on the basis of the vegetation, their partial grouping in the figure (Fig. 28) does however illustrate the mean difference between the vegetation of the different soil types. Their position in the figure lends support to the impression given by the mean coverage values (Table 11) about the differences between the vegetation of the different soil types: the aeolian soils represent the most lichen-covered and least dwarf shrub and moss-covered type of soil. The fluvial soils represent the opposite extreme in this material. The vegetation on the glaciofluvial soils represents a transition group between these two types of soil.

The sample plot material was classified using TWINSPAN cluster analysis into four clusters (Fig. 29). A cluster of 59 sample plots (Group I in Fig. 29) was separated out in the first division of the material, the sample plots on fluvial soil being predominant. In the second division of the larger group, a cluster of 42 sample plots was again separated out, almost all of which represented aeolian soil (Group IV in Fig. 29). There are only two sample plots on glaciofluvial soil in this cluster, and no fluvial soil sample plots. On the other hand, Clusters II and III contain sample plots equally representing all three soil types. The clusters have been presented in Fig. 29 in numerical order according to how close to each other they are as regards their soil type distribution. The dendrogramme shows the order of division as clustering progresses. This can be interpreted as some form of "family tree" of the clusters.

In cluster analysis, the first cluster differed from the other groups above all due to the abundant occurrence of *Vaccinum myrtillus* and *Hylocomium splendens.* However, *Vaccinium vitis-idaea* and *Pleurozium schreberi* are the most abundant in this cluster. In the figure drawn on the basis of the results of ordination analysis (Fig. 28), the sample plots of the first group are placed on the upper edge of the figure. *Melampyrum pratense* also occurs on some of the sample plots in this cluster, while it is totally lacking from the other groups. The most abundant of the lichen species are *Cladonia rangiferina* and *C. arbuscula.* This is also the only group where *Vaccinium uliginosum* occurs in moderate amounts.

The second group contains the greatest number of sample plots, being placed across the middle of the ordination figure (Fig. 28). The most abundant species in the dwarf shrub layer are *Vaccinium vitis-idaea* and *Empetrum nigrum coll.* There is a lot of *Pleurozium schreberi* in the moss cover, but the amount of *Hylocomium splendens* is very low in comparison to the sample plots of the previous cluster, as is the case with *Vaccinium myrtillus.* Lichens, especially the species *Cladonia arbuscula, C. rangiferina* and *C. stellaris,* are clearly more abundant than in the previous group.

The third group also has a heterogeneous soil type distribution and is placed next to the previous group on the ordination analysis (Figs. 28 and 29). *Cladonia stellaris* and *C. rangiferina* occur the most abundantly in this group. The most abundant species in the dwarf shrub layer are *Vaccinium vitis-idaea* and *Calluna vulgaris.*

The fourth cluster is characterized by the abundance of *Cladonia stellaris,* although the species is not quite as abundant as in the previous group. On the other hand, *Stereocaulon spp.* is the most abundant of the lichen species. *Cladonia uncialis,* as well as the mosses *Polytrichum piliferum* and *Polytrichum juniperinum,* are also at their most abundant in this group. This is the only group where *Empetrum nigrum coll.* occurs abundantly as a dwarf shrub. The most abundant dwarf shrub in all the other groups is *Vaccinium vitis-idaea. Vaccinium myrtillus* is almost completely lacking from the sample plots in this group.

The clusters were named after the typical plant species in each group as follows:

I *Hylocomium-Myrtillus-Uliginosum* group
II *Vaccinium-Pleurozium* group
III *Vaccinium-Cladonia-Stellaris* group
IV *Empetrum-Cladonia-Stereocaulon* group

As far as the soil type distribution is concerned, there are two "divergent" sample plots, both representing aeolian soil, in the first group. All the other sample plots were on glaciofluvial or fluvial soils. Correspondingly, there are two sample plots on glaciofluvial soil in the fourth group, all the other sample plots representing, aeolian soil.

Of the two sample plots on aeolian soil in the first cluster, one of them is situated in the western part of Peräpohjola (Area 4), and the other in the Posio area (Area 3). The former plot is situated on a northern slope and the vegetation is characterised by abundant *Empetrum* and an almost completely closed cover of mosses. There are very few lichens. The moss cover is dominated by *Pleurozium schreberi.* The latter sample plot also has a luxurious moss cover, the dominant species being *Pleurozium schreberi* and *Hylocomium splendens.* There are also very few lichens on this plot. The plot is situated in a small hollow on top of a sand dune, its position presumably having an effect on the moisture status and through this on the plant cover. The other sample plots in this group are widely distributed over a large geographical area, all the study areas being represented in this group. One interesting observation is the fact that all the fluvial soils in Area 6 are included in this group.

There are two sample plots representing glaciofluvial soil, as opposed to the rest of the sample plots in the fourth cluster. They are both situated in the Inari area (Area 5). One of them is located on the top of an esker formation where there are clear signs of an earlier forest fire. The fire, together with the topographical location of the sample plots, may be the reason for the development of an exceptionally poor plant cover. The dwarf shrub layer was very scant, the dominant species being *Vaccinium vitis-idaea.* The moss cover was almost completely absent. The lichen cover was dominant, the most abundant species being *Cladonia stellaris.* There were also clear signs of a forest fire on the other "different" sample plot. The plot is located on a flat deposit of coarse gravel, lichens being the dominant species represented by abundant *Stereocaulon spp.* There were also clear signs of felling on both these sample plots — this may also have had some effect on the plant cover.

The regional distribution of the sample plots in group four is characterised by the fact that there are no aeolian sample plots for Hailuoto (Area 1), and only two sample plots for the Rokua area (Area 2). As well as an exceedingly sorted and nutrient-poor substrate, this also indicates the northern location of the sample plots.

The third cluster is composed almost entirely of sample plots from the southernmost study areas. The only exception to this are the four aeolian sample plots from Inari, the almost uniform cover of *Cladonia stellaris* on these plots resembling the lichen stand in Hailuoto (Area 1). All the sample plots on aeolian soil in Hailuoto, and most of the aeolian sample plots in Rokua, belong to this group. Apart from the Inari sample plots already mentioned, all the other sample plots are from Areas 1 and 2 (Fig. 1).

The geographical variation in the second group, which also contains the largest number of sample plots, is large. However, it would appear that the sample plots are clearly concentrated in the two northernmost vegetation zones included in this study — Peräpohjola and Forest Lapland. Although the number of sample plots in this group is large (127 sample plots), only five of them are located in the Ostrobothnia-Kainuu zone, and none of them in Hailuoto.

The geographical distribution of the groups is thus as follows: Cluster III primarily represents the Ostrobothnia-Kainuu zone, and Clusters II and IV the two more northern vegetation zones. Cluster I is geographically indifferent and the vegetation in this group appears to be more dependent on edaphic factors.

It can be seen from the above-presented distribution of the sample plots into groups, and the description of their plant cover, that there is rather large variation between the vegetation of the sample plots on the different types of soil. As well as being due to geographical features, the variation is also due to the trampling of the vegetation on the sample plots by reindeer grazing and during cuttings, as well as to the local developmental history of the vegetation. Eliminating the effect of such features in the comparison of substrates done on the basis of the plant cover is very difficult under the conditions prevailing in northern Finland.

The ordination diagramme shown in Fig. 30 is obtained when the effect of exposition

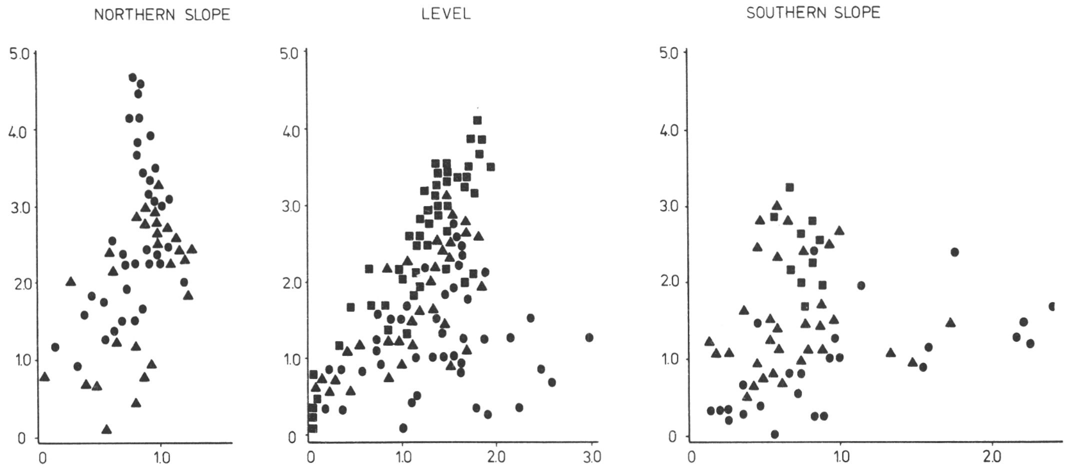

Fig. 30. The position of the sample plots when plotted against the two main trends in DECORANA ordination done on the basis of the coverage of the the different plant species. The sample plots have been classified into three groups on the basis of the aspect of the slope. ● = aeolian soils, ▲ = glaciofluvial soils and ■ = fluvial soils.

Table 12. The mean coverage of *Cladonia stellaris* and that of all the lichens. The mean height of the lichens on the aeolian and glaciofluvial soils in the different study areas ($\bar{x} \pm s_{\bar{x}}$).

	1	2	3	4	5	6
Coverage of lichen (%)	69 ± 4	75 ± 3	19 ± 2	31 ± 3	45 ± 4	38 ± 6
Height of lichen (cm)	5.9 ± 0.2	5.1 ± 0.2	1.6 ± 0.1	2.5 ± 0.2	3.0 ± 0.2	1.6 ± 0.1
Coverage of *Cladonia stellaris* (%)	50 ± 3	7 ± 2	< 1	1 ± 1	19 ± 3	10 ± 2

on the results of ordination analysis is removed by dividing the group of sample plots into sites with a southern exposition (S, SW, W and NW slopes), those with a northern exposition (N, NE, E, and SE slopes) and flat sites where the direction of the slope has no effect. None of the fluvial soil sample plots were on northern slopes. Comparison of the different soil types is most successful when the division representing the flat sites is used. The fluvial soils appear to be concentrated in the left-hand edge of the figure, while the glaciofluvial and aeolian soils are again intermixed. The division according to exposition thus did not bring very much additional information in comparison to the results presented in Fig. 28.

The differences between the vegetation in the different study areas are most evident in the total coverages of lichen species, and especially in the coverage of *Cladonia stellaris.* When the regional variation in the coverage of lichens was examined, only the glaciofluvial and aeolian soils were included. The fluvial soils were omitted because they did not occur in all the study areas, and because their lichen populations were not plant communities in the same way as those on the other two soil types.

The lichen coverage is clearly the highest in the southernmost study areas (Table 12). The mean height of the lichen stands is also highest in these areas. The differences as regards the coverage of *Cladonia stellaris* are even more clear: Hailuoto differs very clearly from the other study areas. The occurrence of this species was especially low in Areas 3 and 4 (see also Figs. 31 and 32).

Ordination analysis was also carried out by forest vegetation zones: the two southernmost study areas were considered to be in the Ostrobothnia-Kainuu vegetation zone, Areas 3 and 5 in the Peräpohjola vegetation zone, and Areas 5 and 6 in the Forest Lapland vegetation zone. As this analysis did not provide any additional information to the earlier-mentioned analysis, the sample plots were not clustered separately by vegetation zones.

The four sample plot clusters obtained here were compared to traditional forest site types as reported by two different sources (Kalela 1973 and Sepponen et al. 1979). The percentage similarities between all the types to be compared and the clusters presented here were calculated using percentage similarity analysis in the comparison. The forest site types ranging from dry to damp sites in the Ostrobothnia-Kainuu, Peräpohjola and Forest Lapland vegetation zones were included in the comparison. The results are presented as similarity percentages in Table 13.

The first cluster (I) is floristically closest to both the sub-dry site types (EVT and EMT) and the damp site types (VMT, HMT and LUT). This indicates that the cluster lies floristically somewhere between the damp and sub-dry site types, since it has features characteristic of both types. Its floristic similarity to the second cluster is only 50 %, and to the third and fourth clusters only slightly more than 20 % (Table 13).

The second cluster (II) is in turn floristically closest to the dry and sub-dry site types — ErClT, ECT and MCClT, and UEMT, EMT and EVT. It thus appears to have features characteristic of both groups of site type. However, it should be pointed out that its similarity to any of the traditional forest site types does not even approach 60 %, the closest being ErClT (a similarity of 58 %).

The third cluster (III) is closest to the dry site types ErClT, ECT, MCClT and UVET, as is the case with the fourth cluster (IV). They are clearly much further away from the sub-dry site types than the first two clusters. The floristic similarity between the third and fourth clusters is only 51 %. They clearly represent the most infertile cases of the dry site types.

Fig. 31. The lichen stands on the sample plots situated to the south of the reindeer husbandry region were sturdy and well developed in places. Picture from Hailuoto.

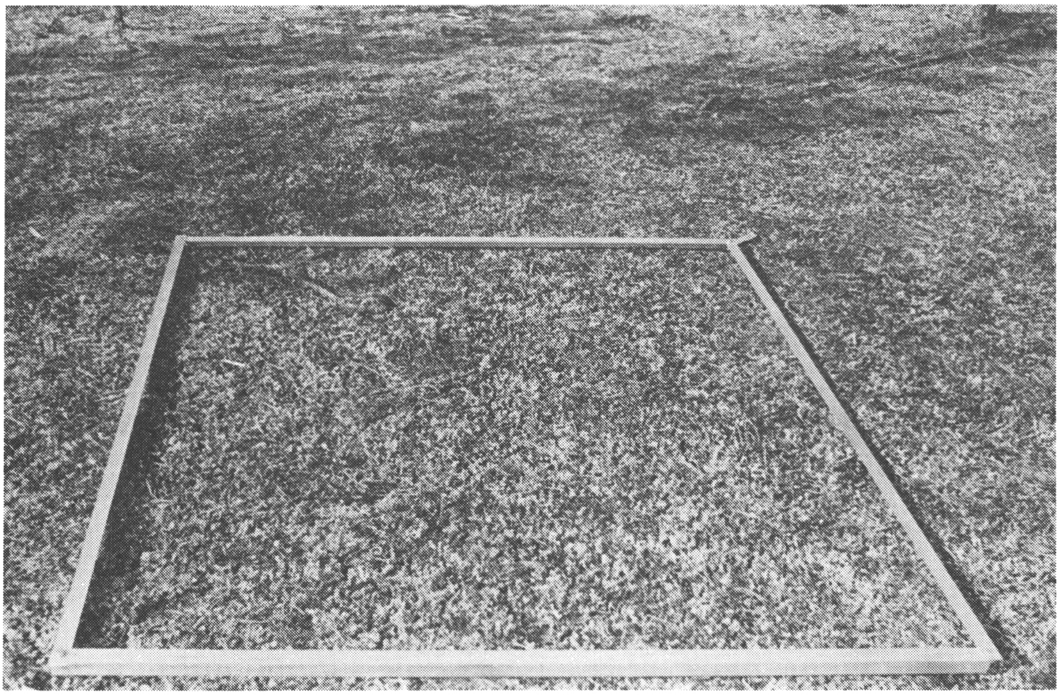

Fig. 32. The lichen stands in the reindeer husbandry region were very heavily eroded in places. The dominant species in such stands was usually *Stereocaulon spp.* The sort of aluminium frame used in the plant cover analyses can be seen in the picture.

Table 13. The percentage similarities between the sample plot clusters (I—IV) and the forest site types of northern Finland. The forest site types from dry to damp sites according to two sources: (K) = Kalela (1973) and (S) = Sepponen et al. (1982).

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.
1. I	100																				
2. II	50	100																			
3. III	24	52	100																		
4. IV	21	48	51	100																	
5. ErClT (S)	43	58	51	42	100																
6. ECT (K)	43	55	56	38	70	100															
7. MCClT (K)	40	53	51	45	79	71	100														
8. UVET (K)	41	51	52	47	66	61	80	100													
9. EVT (S)	57	32	15	19	31	30	24	26	100												
10. EVT (K)	66	47	30	24	55	63	53	52	50	100											
11. EMT (S)	64	39	23	20	48	42	42	43	56	60	100										
12. EMT (K)	63	49	32	25	54	58	55	61	48	74	68	100									
13. UEMT (K)	57	51	36	32	57	58	57	66	47	64	63	81	100								
14. VMT (S)	63	32	16	14	36	34	32	34	58	51	66	66	56	100							
15. VMT (K)	62	29	16	10	32	37	30	30	50	63	61	67	55	84	100						
16. HMT (S)	65	31	15	13	33	32	29	30	58	51	65	65	53	94	83	100					
17. HMT (K)	52	30	15	13	32	34	32	34	49	45	56	60	55	81	76	80	100				
18. DeMT (K)	49	24	12	7	26	31	24	24	40	45	51	54	46	78	80	79	85	100			
19. LUT (S)	66	34	19	15	42	37	35	42	70	59	72	69	69	77	69	75	63	58	100		
20. LMT (K)	60	34	18	16	37	39	37	44	63	58	64	71	71	77	74	73	73	66	79	100	
21. pMT (S)	57	32	17	12	33	32	28	28	48	43	58	53	49	78	72	80	69	71	69	63	100

It can also be seen from Table 13 that the forest site types classified as being of the same type according to the two different sources are nowhere near floristically similar. For instance, the floristical structure of the EVT site type calculated from the sample plots classified as EVT in the IIIrd National Forest Inventory (Sepponen et al. 1982) has a similarity of only 50 % to the floristical structure of the same site type described by Kalela (1973). On the other hand, the similarity to the floristical structure of the HMT and VMT site types from one of these sources (Sepponen et al. 1982) is much closer (as high as 94 %). This shows that there is great floristical variation in the practical application of the forest site type system, and hence the mathematical comparison done here between site types is mainly of indicative value only and indicates the mean position of the sample plot groups formed in this study in the forest site type classification system.

The validity of the above-presented interpretation was tested by calculating the site type distribution of each cluster according to how the site type was classified in the field. It became apparent from this that the majority (59 %) of the sample plots of the first cluster were classified already in the field as sub-dry sites, and the second most frequent classification was damp site (25 %). The rest were classified as dry sites (15 %). Damp sites occurred only in this cluster.

Most of the sample plots in the second cluster had been classified as dry sites (76 %), followed by sub-dry sites (14 %). All of the sample plots in the third cluster had been classified in the field as being of the dry (61 %) or barren (39 %) site types. The barren (79 %) and dry (17 %) site types were predominant in the fourth cluster.

Although there is variation in every group, the determinations carried out in the field strongly support the statistical interpretation of the grouping of the vegetation presented above.

Discussion

In analysing the vegetation of the sample plots, an attempt has been made to determine the extent to which the differences between the different types of soil are also visible as differences in the plant cover. Very few systematic comparisons of the vegetation of different types of sorted soils, starting from the genetical aspects of the soil, have been done in Finland, and only a few studies have been made using this type of approach for till soils (e.g. Okko 1944).

Aartolahti (1973) has presented some vegetation data for soil formations of different genesis at Rokua, which is one of the study areas included in this paper (Area 2, Fig. 1). He obtained similar results to those obtained in this study: the driest site types with a lichen cover occur on aeolian sand dunes, and the moistest site types with the most developed moss cover occur most freqently on glaciofluvial soil material. This latter type also occurs on knolls and in hollows on northern slopes where the snow melts later than on southern slopes, the ground thus remaining wetter for a longer period in the spring and early summer. However, he concluded that the mossy vegetation on knolls and in hollows is more due to topographical features than to the properties of the soil (Aartolahti 1973, p. 39).

The most extensive comparison of the vegetation on esker and sand formations in Finland has been done by Jalas (1950). However, his study concentrated to some extent on different types of soil than those treated in this study, and it does not cover fluvial soils. Eskers especially are strongly represented. The flora dealt with in Jalas' study is thus also rather different from that encountered in this study. Jalas (1953) has since published the results of an extensive floristic and vegetation survey carried out in the Rokua area.

Some of the features observed in this study were similar to those reported by Jalas (1950 and 1953). For instance, the observations concerning the effect of exposition are similar: northern and eastern expositions are more mossy than southern expositions on corresponding soils, which usually develop into pure lichen stands. He also found that stands of *Cladonia stellaris* form part of the final succession stage of the strongest lichen stands. On the other hand, *Stereocaulon* and *Polytrichum piliferum* stands form the initial stages of younger lichen stands. Aartolahti (1973) reports corresponding observations in Rokua. The observations made in this study are very similar.

When the two southernmost study areas (Areas 1 and 2) are compared, it can be seen that *Cladonia stellaris* is more abundant in Hailuoto than at Rokua (also Sepponen 1979). Jalas (1953, pp. 20—23) estimated that forest fires at Rokua are the reason why the lichen stands are in many cases dominated by *Cladonia rangiferina* and *C. silvatica.* He states further that *Cladonia stellaris* is the dominant species in the oldest lichen stands (over 80 years old) (also Sarvas 1937, Ahti 1959, p. 23 and Helle & Aspi 1983). The effect of forest fires is thus presumably still evident in the vegetation on dunes and eskers at Rokua, although this sample plot network is not so comprehensive that the problem could be examined in more detail here.

The northern lichen populations belonging to Group IV were, in addition to *Cladonia stellaris,* also dominated by *Stereocaulon,* and *Cladonia* species of the youngest succession stages. This clearly demonstrates the effects of reindeer grazing on the lichen vegetation (e.g. Kärenlampi 1973, Mattila & Helle 1978 and Mattila 1981). The two sample plots susceptible to damage on aeolian soils at Rokua are also placed in this group. There is no reindeer grazing to wear down the lichen stands at Rokua (this area, as well as Hailuoto, is outside the rendeer husbandry region), but the area is popular with hikers and lichen is also collected there (see Kauppi 1979).

The primary aim of this vegetation analysis was to determine how soil types of different genesis differ from each other as regards their vegetation cover. The clustering and ordination analyses showed, however, that the soil type in fact affects the weighting of the sample plots into different sample plot classes. However, clustering also appears to have been clearly affected by many other factors, e.g. the forest vegetation zone of the sample plots (Kalela 1961, Ahti et al. 1968 and Eurola 1978).

Of course there are many reasons for this variation. Part of the variation can be explained by cuttings, reindeer grazing and other forms of activity which damage the forest vegetation. But even if these factors were to be removed, mere edaphic factors, not to speak of factors derived from the genetical background of the soil types, could not alone explain the variation in the vegetation, which in fact is affected by a combination of geographical, climatic and biotic factors (e.g. Sarvas 1952).

The use of statistical multivariate methods has been practiced for rather long, both abroad (e.g. Goodall 1954, Pritchard & Andersson 1971, Gauch & Whittaker 1972, Gauch, Whittaker & Wentworth 1977, Maarel 1979 and Gauch, Whittaker & Singer 1981) and in Finland (e.g. Hinneri 1972, Kärenlampi 1972, Pakarinen & Ruuhijärvi 1978, Oksanen & Ahti 1982, Oksanen 1983a and Jukola-Sulonen 1983). The aim of this study was not to carry out a comparison of different classification methods nor to study the dissimilarity or reliability of the results given by these methods. The aim was only to classify the vegetation material by statistical means in such a way that it would be possible to compare the genetical soil types and the classification of the soils carried out on the basis of the results of soil analyses. The DECORANA ordination and TWINSPAN cluster analyses used here appear to work well together, as can be seen from the distribution of the sample plots into groups in Fig. 28. It shows that both ordination and classification analyses give similar results with this material.

The differences between the different areas are most evident in the lichen stands. One logical explanation for this is grazing by reindeer (Mattila & Helle 1978), but the climatic differences between the areas may also have had an effect on these results. One reason for the unusually small amount of lichen in Area 3, which is situated in Koillismaa (Fig. 1), may be the exceptionally high humidity of the climate in this area (Figs. 4 and 5) which has permitted the development of an abundant moss cover at the expense of the lichens.

The vegetation clusters presented here cannot be directly equated with the traditional forest site types (Cajander 1909, 1925 and 1949, Kalela 1961 and 1973 and Sepponen et al. 1982). On the other hand, Oksanen and Ahti (1982) have presented a vegetation classification for lichen pine stands, which includes certain plant populations that are obviously close to those obtained in this study. For instance, the *Stereocaulon-Cladina* nodum they describe resembles the *Empetrum-Cladonia-Stereocaulon* populations described in the study in hand. It may only be a case of a difference in stress as regards the significance of different species. The *Calluna-Cladina* and *Empetrum-Cladina* noda described by Oksanen and Ahti may also be close to this. Lakari (1929) has presented sub-types of the *Cladina* type with the same name. Oksanen (1983b) has published a study on the vegetation of fossil dunes in North Karelia. In the study he paid attention to the same type of variation in the vegetation as has been done in the study in hand.

Similar stratification features to those found in this study (Sepponen et al. 1982) are to be seen in the traditional forest site type classification system, for which the largest vegetation material covering northern Finland was collected during the IIIrd National Forest Inventory (1951—1953). The most luxuriant cluster (I) obtained in this study has features characteristic of both the damp site types, VMT, HMT, LUT and pMT, and the sub-dry site types, EVT and EMT (Table 13). The rather abundant occurrence of *Hylocomium splendens* suggests a damp site, but in other respects the flora follows rather closely the sub-dry forest site types. The second cluster is placed close to the dry site types (e.g. ErClT), and the two most infertile clusters are close to the *Cladina* type described by Lakari (1920).

The forest type system used in the IIIrd National Forest Inventory was devised by Prof. Viljo Kujala. In his forest site type descriptions (Kujala 1979) he puts the pure lichen (ClT) sites in the Kainuu vegetation zone in the collective site type MCClT, and further to the north in the collective site type ErClT, and separates a pure *Cladina* site type in southern Finland. Cajander and Ilvessalo (1921) and Cajander (1925) also separated out a pure lichen site type.

Aaltonen (1919) and Lakari (1920) divided it into sub-types in a slightly different way, but close to each other were: the "typical" lichen site type, the *Empetrum-Cladina* sub-type and the *Calluna-Cladina* sub-type. The division into subtypes appears to have been especially popular in the early days of the development of the forest site type classification system.

Oksanen and Ahti (1982), in their study involving the analysis of lichen communities, have arrived at the same conclusions as were made in this study: the sample plot clusters which are formed are not usually completely equivalent to the traditional forest site types, but may be situated in the border area between the various site types. They proposed that the area between the *Cladina* type and the group of dry site types is one such border area.

ClT was not included in the similarity index calculations presented in this study because descriptions of this site type were missing from the material used for comparison. However, it is quite clear that if we want to equate the clusters obtained in this study with the traditional forest site types, then Cluster III mainly represents the Ostrobothnia-Kainuu variant of the *Cladina* type, and Cluster IV the northern variant of the same site type. However, both groups, but especially Cluster III, contain more general features of ErClT. This, as is the case with the data obtained from earlier studies (e.g. Oksanen and Ahti 1982), reflects the indistinct and non-static nature of the borders between the forest site types.

423. Correlation between the properties of the vegetation and the soil

The correlation between certain properties of the humus and the sub-soil and the coverage of the most common plant species in the material was calculated in the study (Table 14). The results of correlation analysis confirmed the conclusions made earlier on in this study concerning the dependence between the vegetation and the properties of the soil.

Vaccinium myrtillus and *Pleurozium schreberi* are positively correlated with the amounts of the most important nutrients in the humus. These two species are also positively correlated, to a highly significant degree, with the loss in weight on ignition of the humus layer, and the thickness of the humus and A layers. Only those correlation coefficients which are significant at the 0.1 % risk level are presented in Table 14. Furthermore, they are generally positively correlated with the amount of fine soil fractions (< 0.06 mm), and negatively correlated with the size of the medium sand fraction (0.6—0.2 mm). On the other hand, they are either negatively correlated with the pH or not correlated at all.

A number of herbs which are positively correlated with the nutrients in the humus *(Maianthemum bifolium, Melampyrum pratense* and *Trientalis europea)* are, on the other hand, positively correlated to a varying degree with the pH. These are the plants associated with the more fertile, thin humus-layered soils in the material.

While the above species are positively correlated with the nutrient content and in many cases also with the fine soil fractions, certain species of lichen have just as clear a negative correlation with the same variables. Such species include *Cetraria nivalis, Stereocaulon spp., Cladonia stellaris, C. sylvatica, C. uncialis* and *C. gracilis.* Although they are negatively correlated with a number of macronutrients, they are also frequently positively correlated, to a highly significant degree, with the magnesium content and the pH (Table 14).

Of the lichens, *Peltigera aphthosa* appears to be positively correlated with the finer soil fractions. The other lichen species are either negatively correlated with this variable, or else are not significantly correlated with it at all.

There are also differences in the properties of the soil in the correlations of the above lichen species. *Stereocaulon* is a species which is found on soils that have a slightly finer texture than those where the above *Cladonia* species grow. *C. stellaris* and *C. rangiferina* especially favour the amount of medium sand (0.6—0.2 mm) in the soil, and are negatively correlated with the soil fractions finer than medium sand. *C. uncialis* also behaves in a similar way to *Stereocaulon,* although its correlation coefficients with the same soil fractions are smaller and hence are not shown in Table 14.

The correlations between certain lichen species (above all *Cladonia stellaris)* and the properties of the soil can be considered to be an even more interesting result since it is known from the foregoing that its abundance on the sample plots varies very much for reasons other than edaphic ones (see e.g. Table 12). Despite such large variation in the coverage values, there is still statistically significant correlation with certain soil parameters (Table 14).

The extent to which the sample plot clusters, formed earlier on the basis of the vegetation, differed from each other as regards the properties of the soil was examined in order to obtain an even more comprehensive understanding of the correlation between the plant cover and the soil (for the clusters see Fig. 29). There are statistically significant differences between the different sample plot groups as regards all the soil parameters measured (Table 15).

The sample plot clusters formed a clear fertility series, ranging from the first to the

Table 14. The coefficient values for significant (0.1 % risk level) correlation between the coverages of the plant species and certain soil parameters.

	Thickness of horizons			Loss-on-ignition (A_o)	Contents of A_o horizon							Particle size parameters of C horizon							
	A_o	A	B		pH_{H_2O}	pH_{CaCl_2}	N_{tot}	K	P	Ca	Mg	20—6	6—2	2—0.6	0.6—0.2	0.2—0.06	< 0.06	Md	S_o
Pinus sylvestris				–0.25			–0.26	–0.23	–0.27	–0.21									
Ledum palustre	0.31																		
Vaccinium myrtillus	0.68	0.43					0.25	0.27	0.31	0.22					–0.34				
V. vitis-idaea	0.46	0.29	0.22	0.34	–0.35	–0.25	0.22	0.36	0.23	0.27									
V. uliginosum	0.29	0.35					0.23		0.33										
Calluna vulgaris											–0.21				0.25				
Empetrum nigrum														0.20					
Deschampsia flexuosa		0.21				0.33	0.24		0.34										
Cornus suecica		0.26	0.25																
Maianthemum bifolium						0.20			0.23										
Melampyrum pratense		0.26					0.24		0.35										
Solidago virgaurea				–0.25	0.22	0.23					0.20								
Linnaea borealis									0.20										
Trientalis europea		0.23					0.22		0.35										
Pleurozium schreberi	0.55	0.33		0.41			0.40	0.45	0.44	0.33							0.38		
Hylocomium splendens	0.45	0.20							0.21	0.24					–0.22	0.22			
Dicranum polysetum			0.29							0.22									
D. scoparium						–0.22						0.25							
D. bergeri												0.23		0.23				0.23	
Barbilophozia lycopodioides							0.23		0.28										
Hepaticeae spp.										0.22									
Polytrichum piliferum			–0.21	–0.22	0.29	0.26													
Cetraria crispa				–0.22															
C. nivalis				–0.28	0.27	0.26	–0.28		–0.20	–0.21	0.24								
Nephroma arcticum											0.29								
Peltigera aphthosa																	0.39		0.21
Stereocaulon spp.	–0.31			–0.49	0.40	0.39	–0.39	–0.27	–0.26	–0.32	0.38					0.20			
Cladonia stellaris	–0.26						–0.23		–0.28						0.39	–0.22	–0.26		
C. sylvatica (coll.)	–0.34	–0.27		–0.27			–0.30	–0.33	–0.36	–0.32									
C. rangiferina						–0.21									0.29				–0.20
C. uncialis	–0.34	–0.23	–0.22	–0.40	0.23	0.24	–0.33	–0.36	–0.31	–0.31									
C. gracilis	–0.22			–0.28	0.21		–0.28		–0.20	–0.21	0.23								

Table 15. The mean values (± the standard error of the mean) of the properties of the humus layer (A_o) and the subsoil (C) in the sample plot clusters formed on the basis of the plant cover.

Particle size parameters (C hor.)		I	II	III	IV	F
20—6 mm (%)		1.2 ± 0.7	2.3 ± 0.5	0.5 ± 0.3	0.3 ± 0.3	2.9*
6—2 mm (%)		2.1 ± 0.7	3.2 ± 0.5	1.2 ± 0.4	0.6 ± 0.5	3.8**
2— 0.6 mm (%)		9.1 ± 1.8	16.3 ± 1.7	10.2 ± 1.5	3.5 ± 1.7	8.2***
0.6— 0.2 mm (%)		26.3 ± 3.2	35.6 ± 1.8	62.6 ± 3.2	38.7 ± 3.1	29.3***
0.2—0.06 mm (%)		49.4 ± 3.9	37.6 ± 2.6	24.4 ± 3.5	55.4 ± 3.7	12.4***
<0.06 mm (%)		12.0 ± 1.9	5.0 ± 0.7	1.1 ± 0.2	1.4 ± 0.2	19.5***
Md		0.3 ± 0.1	0.5 ± 0.1	0.3 ± 0.0	0.2 ± 0.0	3.5*
S_o		1.9 ± 0.1	1.8 ± 0.0	1.5 ± 0.0	1.6 ± 0.0	8.0***
loss-on-ignition (%)	A_o	81.7 ± 1.4	66.6 ± 1.9	63.3 ± 3.1	34.0 ± 3.4	47.3***
	C	1.0 ± 0.1	0.7 ± 0.0	0.4 ± 0.0	0.7 ± 0.0	17.1***
pH (H_2O)	A_o	4.1 ± 0.0	4.1 ± 0.0	4.1 ± 0.0	4.4 ± 0.0	21.6***
	C	5.6 ± 0.0	5.7 ± 0.0	5.4 ± 0.0	5.8 ± 0.0	24.3***
pH ($CaCl_2$)	A_o	3.1 ± 0.0	3.2 ± 0.0	3.1 ± 0.0	3.4 ± 0.0	20.5***
	C	4.9 ± 0.0	5.0 ± 0.0	4.8 ± 0.0	5.1 ± 0.0	11.2***
N (%)	A_o	1.05 ± 0.02	0.84 ± 0.02	0.75 ± 0.03	0.52 ± 0.04	45.9***
K ($mg \cdot 100g^{-1}$)	A_o	86 ± 3	60 ± 2	59 ± 3	44 ± 3	33.9***
	C	59 ± 5	63 ± 4	24 ± 2	84 ± 7	21.2***
P ”	A_o	40 ± 1	28 ± 1	23 ± 1	20 ± 1	40.3***
	C	26 ± 1	28 ± 2	16 ± 1	42 ± 4	20.2***
Ca ”	A_o	260 ± 9	203 ± 7	171 ± 16	108 ± 10	26.1***
	C	99 ± 7	96 ± 5	63 ± 6	140 ± 8	18.3***
Mg ”	A_o	61 ± 4	59 ± 3	40 ± 5	116 ± 12	25.4***
	C	235 ± 26	234 ± 10	87 ± 13	259 ± 19	19.2***
Fe ”	A_o	438 ± 44	357 ± 22	300 ± 20	457 ± 27	5.0***
	C	730 ± 76	351 ± 20	199 ± 16	287 ± 16	32.3***
Al ”	A_o	526 ± 26	590 ± 18	587 ± 29	746 ± 39	9.0***
	C	1086 ± 83	938 ± 39	502 ± 46	638 ± 43	20.8***
Na ”	A_o	18 ± 1	16 ± 1	14 ± 1	14 ± 1	2.7*
	C	11 ± 0	10 ± 0	10 ± 1	14 ± 1	6.6***

fourth cluster, as regards the nutrient contents in the humus. For instance, the total nitrogen content of the first cluster is double that of the fourth cluster. The situation as regards potassium, phosphorus and calcium is the same. However, the behaviour of magnesium is quite different: the magnesium content of the humus in the fourth cluster is the highest. Aluminium and iron do not follow the fertility series.

The amount of fine fractions (< 0.06 mm) is clearly the highest in the sub-soil of the first sample plot group; almost ten times the amount in the sample plots of Groups III and IV. On the other hand, the amount of fine sand (0.2—0.06 mm) is greatest in the sub-soil of the sample plots of Group IV, and that of medium sand clearly the greatest in the sub-soil of the sample plots in Group III. The sample plots in Group II contain more than average amounts of gravel, and those of Group IV less (Table 15). These observations concerning the particle size composition of the sample plot groups are in agreement with the results for the correlation between the plant species and the soil parameters: *Cladonia stellaris* is positively correlated with the medium sand fraction, and *Stereocaulon* in turn with the fine sand fraction (Table 14). The former is the most typical species of Group III, and the latter of Group IV (Table 16).

The type of soil on each sample plot was determined using the so-called d_{50} method, i.e. the type of soil is named after the fraction whose particle size area is bisected by the penetration curve at the 50 % abscissa (for penetration curve see Fig. 6). The sample plot clusters formed on the basis of the plant cover were then examined with respect to their soil type distribution.

The soil type distribution of the clusters supports the conclusions made on the basis of the mean proportions of the different fractions (Table 15). Those fine sand soils where the proportion of fine fractions

Table 16. The most common species in each cluster. D = mean coverage, F = occurrence freequency, as in Table 11.

	CLUSTER I		CLUSTER II		CLUSTER III		CLUSTER IV	
	D	F	D	F	D	F	D	F
Pinus sylvestris	+	48	+	60	+	68	+	71
Calluna vulgaris	1	32	1	35	4	83	+	10
Empetrum nigrum	7	78	8	88	4	60	7	76
Ledum palustre	1	37	+	21	+	2	—	—
Vaccinium myrtillus	11	95	1	59	+	42	+	2
V. uliginosum	3	41	+	13	+	2	+	7
V. vitis-idaea	17	100	12	100	10	100	4	88
Deschampsia flexuosa	2	58	+	23	+	2	+	33
Cornus suecica	2	9	—	—	—	—	—	—
Linnaea borealis	+	19	+	4	—	—	+	10
Maianthemum bifolium	1	24	—	—	—	—	—	—
Melampyrum pratense	+	12	—	—	—	—	—	—
Solidago virgaurea	+	25	+	2	+	2	+	33
Trientalis europaea	+	17	—	—	—	—	+	2
Barbilophozia lycopodioides	+	12	—	—	—	—	—	—
Dicranum bergeri	+	12	+	44	+	7	—	—
D. drummondii	+	17	+	17	+	4	—	—
D. fuscescens	+	14	2	67	+	25	+	29
D. polysetum	2	61	+	34	1	83	+	7
D. scoparium	5	86	3	81	+	72	1	48
Hepaticae spp.	+	31	+	11	+	5	+	10
Hylocomium splendens	9	66	+	9	—	—	+	2
Pleurozium schreberi	44	100	16	97	4	9	1	36
Pohlia nutans	+	3	+	45	+	16	+	24
Polytrichum commune	3	53	+	12	+	9	+	38
P. juniperinum	+	20	1	69	+	9	1	64
P. piliferum	—	—	+	27	+	4	2	74
Cetraria crispa	+	2	+	32	+	19	1	52
C. islandica	+	24	+	15	+	33	+	21
C. nivalis	+	3	+	10	—	—	2	60
Cladonia botrytes	—	—	+	2	—	—	+	10
C. gracilic	+	9	+	71	+	23	1	83
C. rangiferina	3	80	9	99	27	100	7	91
C. sylvatica (coll.)	1	78	13	100	13	100	11	100
C. uncialis	+	19	2	91	+	35	5	100
Nephroma arcticum	+	25	+	11	—	—	+	7
Peltigera apthosa	+	29	+	21	—	—	+	12
Cladonia stellaris	3	41	4	82	38	100	16	86
Stereocaulon spp.	+	5	1	51	+	4	16	98
Luzula pilosa	+	7	—	—	—	—	—	—
Cladonia coccifera	—	—	+	20	+	4	+	50

(< 0.06 mm) represents an additional factor in the soil type of 30 %, are included as a class of their own in the soil type classification. Such types of soil were most common in the sample plots of Cluster I, there also being a few cases in the sample plots of Cluster II (Fig. 33). They were completely absent from the other clusters, as was the case with gravel soils. Clusters III and IV are clearly plant communities of sandy and fine sand soils, some of which occurred on slightly more finely textured soils in Cluster IV (cf. also Table 15 and Fig. 29).

The variations in the nutrient contents of the sub-soil do not follow the same trends as in the nutrient contents of the humus samples. For instance, the contents of potassium, phosphorus and calcium were greatest in the sub-soil of Cluster IV. The loss in weight on ignition in the humus layer follows the earlier described fertility series. However, the loss in weight on ignition in the sub-soil was so small that the differences between the groups have no ecological meaning, even though they are statistically significant (Table 15).

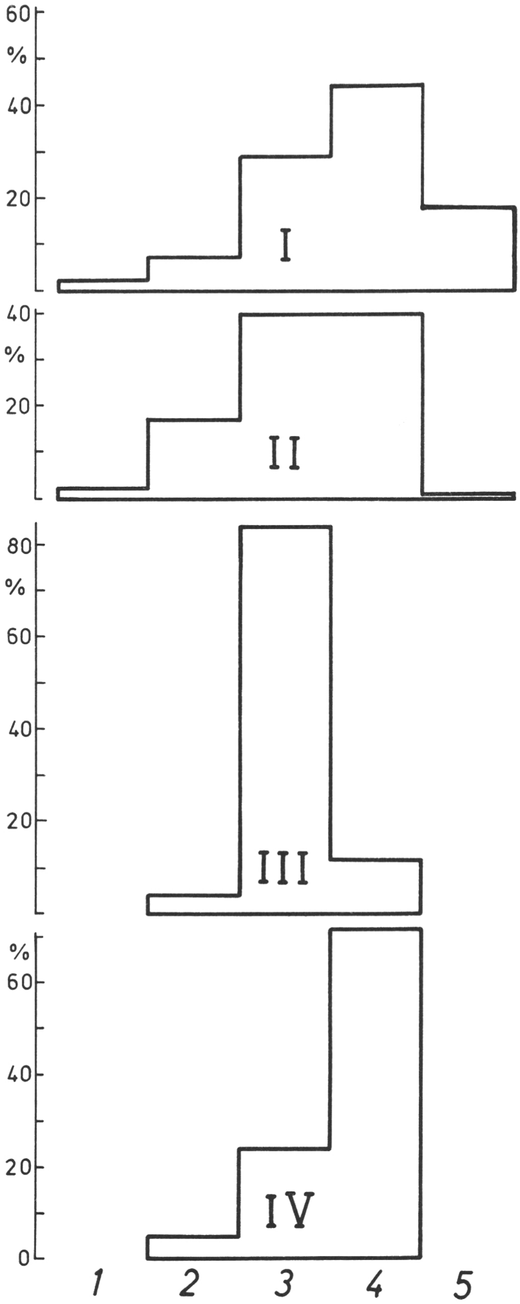

Fig. 33. The soil material distributions of the sample plot clusters formed on the basis of the vegetation. 1 = gravel soils, 2 = coarse sand soils, 3 = medium sand soils, 4 = coarse silt soils where the proportion of fine material (< 0.06 mm) is over 30 %.

Now that the value of different species in explaining the properties of the site type has been studied in this way, the floristic structure of the four sample plot clusters is presented as the mean coverages of the plant species and the occurrence frequencies of the species. Only those plant species which were found to be statistically significantly correlated with the soil parameters have been included in Table 16. In addition, a few species which were not significantly correlated with the soil parameters at the 0.1 % risk level, but which were very common in the material (e.g. *Cetraria islandica, Polytrichum commune* etc), were also included.

The soil classification done on the basis of the soil parameters (Table 10) is not completely correlated with the classification done on the basis of the vegetation (Fig. 34). In fact, for instance, a group of aeolian sample plots is formed in the most infertile clusters in both classifications, and the fluvial soils again are mainly placed in the first group of clusters in both classifications. However, there is very much variation.

Discussion

Determination of the forest site type on the basis of the soil has been earlier studied in a large number of investigations. Its dependence on the soil type (Ilvessalo 1933, Grannlund & Wennerholm 1934, Aaltonen 1941a, Okko 1944, Teivainen 1952, Söyrinki et al. 1977 and Sepponen et al. 1982) and on the chemical properties of the soil (Valmari 1921, Dahl et al. 1967, Viro 1962 and Urvas & Erviö 1974) have both been studied. In general, it has been concluded that the more fertile site types are to be found on soils with a finer than average texture, and the more infertile ones on the more coarse-textured soils. However, this dependence is only a general one and almost all the studies in this field state that each site type can occur on almost any type of soil, at least under certain conditions.

As far as the nutrient status of the different forest site types is concerned, these studies have shown that in the humus layer especially the pH and the nitrogen and calcium contents follow the fertility series of the forest site types. Potassium also often follows this series, but not the amount of phosphorus extractable with ammonium acetate (Urvas

& Erviö 1974). Similar results were found in this study as regards the humus layer: the particle size values of the sub-soil differed rather clearly from each other in the different sample plot clusters, and a clear series was found in the nutrient contents of the humus especially that extended from the most fertile to the most infertile cluster (Table 15). On the other hand, the nutrient contents for the sub-soil do not follow the same order.

There may be many reasons for the last-mentioned result. Comparison with the earlier studies is first of all made difficult by the fact that it is a question of so-called nutrient reserves which perhaps behave in a slightly different way from nutrients extracted with ammonium acetate and, as they are more readily available to the plants, may thus adapt better to the prevailing plant cover. Since the humus layer is itself a product of the plant community, it is only natural that its nutrient contents are well adapted to the composition of the plant community. Urvas and Erviö (1974) found that the nutrient contents of the mineral soil also vary by soil type within the same forest site type. Such trends make the comparison of the results of different studies difficult.

The dependence between the occurrence abundance of individual plant species and the particle size parameters of the soil has not earlier been studied very much in Finland. Sepponen et al. (1979) have examined the dependence between the coverages of certain plant species and species groups (grasses, dwarf shrubs, mosses and lichens) and the particle size parameters of the soil in spruce, pine and pine-dominated mixed stands separately. In the study, the correlation between the plant species and the soil fraction was found to change from negative to positive when the main tree species in the stand changes. So, for instance, the total coverage of the dwarf shrubs was found to be negatively correlated with the fine soil fractions (< 0.06 mm) in pure spruce stands, but highly positively correlated in pine stands.

The stands included in this study are almost pure pine stands and so it is not possible to study the effect of the tree species in the same way. The soil type distribution of the material in this study differs from that of the abovementioned studies in that all the sample plots in the study in hand are on sorted forest soil, while those in the other studies have been primarily on till soils. This causes problems in the comparison. For instance, *Vaccinium myrtillus* was not significantly positively correlated with the fine fractions in the other studies, but it was in the study in hand. This result appears to reflect the importance of the fine fractions for the abundance of *V. myrtillus* stands especially on sorted forest soils. On the other hand, a significant negative correlation was found between the coverage of *V. myrtillus* and the sand and fine gravel fractions in the study in question. This result is partly in agreement with the result obtained in the study in hand (Table 14).

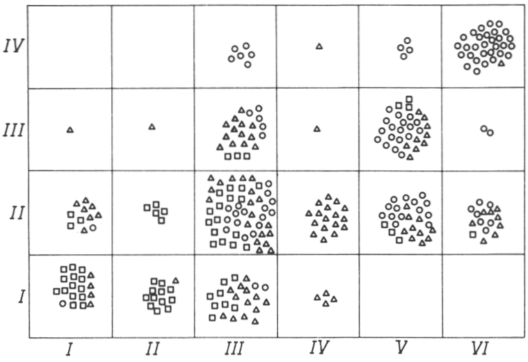

Fig. 34. The dependence between the sample plot clusters formed using TWINSPAN clustering on the basis of the plant cover analysis, and the sample plot clusters formed using factor scores on the basis of the soil analysis data (horizontal axis).

The results obtained in this study for the total coverage of mosses and lichens are to some extent similar to the results obtained in an earlier study (Sepponen et al. 1979). In fact it was apparent in this study that different species of lichen and moss have clear differences with respect to the particle size of the soil (Table 14).

In general, the thickness of the humus layer has been found to increase on moving from dry to moister site types. The humus thickness is greatest on damp site types (Aaltonen 1941a and Söyrinki et al. 1977). In this study, the species of damp soil sites (*Vaccinium myrtillus, V. uliginosum, Hylocomium splendens* and *Pleurozium schreberi)* which favour a high moisture content, are also positively correlated with the thickness of the humus layer (Table 14). However, the pH value has been found to increase on moving from dry to moister sites in earlier studies (Urvas & Erviö 1974). In this study these species are not positively correlated with the pH of the humus layer since, for instance, *V. myrtillus* and *Pleurozium schreberi* are even slightly negatively correlated with the pH (not shown in Table 14 since the correlation is not statistically significant at the 0.1 % risk level). This can be explained by the fertility and site type distributions of the soils included in this study. The increase in the thickness of the humus layer on infertile sorted soils presumably mainly results in an increase in the amount of humic acids and humidity to the extent that the soils with the thickest humus layer are also the most acidic. The amount of calcium in such soils is, for instance, not large enough to regulate to an appreciable extent the pH of the soil (see also Table 15).

Classification of the sample plots on the basis of the vegetation in this study proved to correspond rather well to the trends in certain properties of the soil (Table 15). Comparison with earlier studies (e.g. Sepponen et al. 1979) shows that the occurrence of such a parallelity is mainly dependent on the choice of ecological variables. As sorted soils which have a very similar tree species composition have been examined in this study, it has obviously been easier to find such dependences. Till soils, and soils with stands of variable species composition, would presumably have been more difficult to analyse in this respect.

5. CONCLUSIONS AND APPLICABILITY OF THE RESULTS

The main aim of the study was to determine which processes are involved in the differentiation of mineral soil formations sorted by wind and water into different site types in northern Finland. The hypothesis tested in the study is that the geological history of the soil formations, i.e. their mode of formation, also determines their development into different forest site types.

There were clear differences in the particle size parameters of soil formations of different genesis. The particle size values were used in this study to depict the differences which the different geological processes cause in the texture and structure of the soil. No parameters depicting the structure were actually measured, but it is assumed that the texture also reflects differences in the structure of the soil. The results of chemical soil analyses showed that although the different types of soil formation do not differ significantly from each other as regards the chemical properties of the sub-soil, there are differences in the chemical properties of the humus. This was considered to reflect the fact that the processes determining the chemical properties of the humus layer are regulated by the physical factors of the soil.

The vegetation cover also has a great effect on the composition of the humus. Clear correlations were found between the coverage of various plant species and the physical properties of the soil. The physical factors can presumably also regulate the properties of the humus indirectly by regulating the vegetation. Since the physical properties are at least partly determined by the geological processes which have brought about the formation of the soil, these processes are thus involved, via the physical processes, in the development of the chemical properties of the site. The results obtained in this study concerning the variation in the chemical properties of different types of soil provide empirical evidence for these phenomena and, in turn, support the hypothesis made at the beginning of the study about the effect of geological processes on the site properties of the soil.

When the soil sample material was classified on the basis of parameters measured in the laboratory using statistical multivariate methods, it became apparent that the classification did not exactly follow the geological division of the soils in question, although the clusters were concentrated in certain geological formations. The same feature was found in the classification done on the basis of the plant cover. This result shows that the geological history of the soils does not always unambiguously channel soils formed by different geological processes along the road of diverging development in ecological terms, but rather that the different geological processes can often create the basis for the development of soils which are ecologically similar. Thus under certain conditions deposits formed by wind and by water can develop into soils which resemble each other in the ecological sense.

Climatic differences can produce considerable variation in the chemical and biological site factors, as was apparent in this study. The climate and other factors causing variation make it difficult to determine precisely the real effect of geological factors with the method employed here. There is also reason to assume that the sorted soil formations examined in this study are to some extent easier to examine than till soils, whose wide range of forms makes their site properties more laborious to study by this method.

It has been possible to trace to some extent the effect of geographical differences on the variation in the parameters depicting the site. This is clearly evident in the vegetation classification, but above all in the parameter used to describe podzolisation, which in this study was the ratio between the combined amounts of aluminium and iron in the enriched horizon (B horizon) and in the subsoil (C horizon).

A rather important part of this study has been to examine the ecological explaining power of the particle size parameters of the soil on rather infertile and very infertile sorted mineral soils. The correlations obtained here can be generalized to cover sorted infertile forest soils only, since the mixed texture and subsequent different structure of till soils perhaps have a different effect to that of the sorted soils studied here.

The different correlations between different nutrient contents and the different soil fractions are of central importance: clear positive correlation between magnesium, iron and aluminium and the fine fractions (< 0.06 mm), positive correlation between phosphorus and the proportion of fine sand (0.2—0.06 mm), and negative correlation between phosphorus and the proportion of medium sand (0.6—0.2 mm). Until this feature has been studied in more detail on different types of soil, we can perhaps only make generalizations about the behaviour of phosphorus in sorted forest soil with a coarsish or medium particle size fraction. However, the results of this study do show that medium sand is the mineral soil fraction which most clearly accounts for a poor nutrient status. Soils containing abundant medium sand can in this respect be called "real sandy soils". For instance, the gravel content does not generally appear to be a factor causing a poor nutrient status. Use of the behaviour of the other parameters depicting the particle size for explaining the nutrient variation can only be recommended in cases where the fraction distribution of the soils to be studied is known in detail. Such parameters include the mean particle size (Md) and the degree of sorting (S_o).

Tracing Cajander's "primary site factors" on the basis of the plant cover is difficult to do in detail. As the plant cover is assumed to depict all the primary site factors simultaneously, it is impossible to use it for making very profound conclusions about individual site factors, e.g. the amount of different nutrients, soil type etc. Only the correlations between individual plant species and the properties of the soil provide some possibilities for drawing conclusions about the quality of the soil on the basis of the plant cover. However, there is still the problem that the correlations between the soil and the plant species may vary considerably in areas with a different climate. In this study there was found to be considerable variation in the lichen cover on sites with a very uniform soil, e.g. aeolian sand, in the different study areas. Reindeer have a considerable effect, especially on lichen stands: the study areas lying outside the reindeer husbandry region clearly differed from those within this region. This feature should always be taken into account when classifying infertile upland sites using the plant cover.

The results concerning the indicator value of certain species on sorted mineral forest soils in northern Finland can be summarised as follows:

Vaccinium myrtillus: prefers soils with a thick humus layer, the loss in weight on ignition and the amount of macronutrients in the humus being relatively high. The amount of medium sand in the mineral soil is low. The amount of fine fractions (< 0.06 mm) is important, and hence the species prefers moist sites.

Vaccinium vitis-idaea: behaves rather similarly to the above species, but prefers to some extent more acidic soils and is more indifferent as regards the particle size composition of the mineral soil.

Grasses and *sedges* in general: they usually prefer rather fertile soils with a less acidic humus layer. Most of them are indifferent as regards the particle size composition of the mineral soil.

Pleurozium schreberi: behaves in very much the same way as *V. myrtillus,* i.e. it prefers fine fractions and moist soils.

Hylocomium splendens: similar to the previous species in that it prefers moist soils with a thick humus layer. However, there is no clear positive correlation with the nutrients in the humus. The negative correlation with the amount of fine sand is stronger than that of the previous species.

Cladonia stellaris prefers nutrient-poor soils with a thin humus layer. The mineral soil contains a high proportion of medium sand, and as little as possible of fractions finer than this.

C. rangiferina: similar to the previous species, but the negative correlation with the pH and degree of mixed texture is stronger. Most species of *Cladonia* exhibit similar correlation with the soil properties.

Stereocaulon spp.: clearly prefer nutrient-poor soils with a thin humus layer. They prefer slightly finer-textured soils than the *Cladonia* species since they are positively correlated with the fine sand fraction. The positive correlation with the pH and the amount of magnesium in the humus is stronger than that for the *Cladonia* species.

Peltigera apthosa: prefers less sorted, finer-textured soils than the other species of lichen described here.

It is difficult to make even rough estimates of the sort presented above about the indicator value of other plant species on sorted soils. It is clear, owing to the different nature of till soils, that it is not yet possible to apply the general conclusions about a number of indicator species to till soils.

Classification could not be based on the variation in the tree species since Scots pine *(Pinus sylvestris)* was present on almost all the sample plots and other tree species were predominant in a few isolated cases only. The ground vegetation was selected as the criterion for developing the classification.

The whole plant cover proved to be a suitable basis for classification in this study. It was possible to form sample plot groups on the basis of the vegetation cover by means of multivariate methods. These groups appeared to differ clearly from each other as regards both the soil geological distribution of the substrates, and the nutrient status of the soil. This shows that the plant cover best depicts the state of the forest ecosystem at the time when the measurements are made: the humus is itself a product of the forest system and is best correlated with the vegetation, while the nutrient values measured in the sub-soil follow different trends from the corresponding values for the humus.

To sum up the conclusions made in this paper, the results of this study have demonstrated to some exent that the geological processes act as the determinator of site types. However, it has also become clear that different processes can produce sites which are ecologically very similar. The use of information about the genetical background of the soils alone is not a suitable basis for ecological classification. However, it does provide valuable information for an ecological classification.

Classification done on the basis of the vegetation, including additional information about the forest soil, thus appears to be the method most applicable in practice. However, one alternative that should be considered when the classification is being further developed is to initially divide the soils roughly into sorted soils and till soils, and then to carry out a more detailed classification using for instance the ground vegetation and soil data: humus thickness, soil type etc. The other possibility, which has already been suggested earlier in a number of connections, is to roughly classify the stands according to the dominant tree species (e.g. Brenner 1921, 1922 and Sukatšev 1960). However, the stands included in this study have such a onesided species composition that it was not possible to test such a classification with this material.

6. SUMMARY

The main aim of the study was to analyse the differentiation of soils of different genesis into specific site types, and the factors affecting this process, on wind and water-sorted mineral soils in northern Finland. Another aim was to study the possibilities of developing an ecologically suitable classification system for the stands which develop on such soils. A total of 285 sample plots situated in different parts of northern Finland (Fig. 1) were established for this purpose. The sample plots were located on wind-blown deposits (aeolian soils, 106 sample plots), deposits formed by the melt water flowing from the continental ice sheet (glaciofluvial soils, 110 sample plots), and deposits laid down by the action of large rivers (fluvial soils, 69 sample plots). The distribution of the sample plots into different soil types and their height above sea level are shown in Figs. 1 and 2. The differences in the climatic conditions in the different study areas are depicted by means of the longterm mean in Figs. 4 and 5.

The tree stands on the sample plots were measured using the relascope principle, and the ground vegetation characterized by coverage analysis on four 1 m^2 squares. In addition, soil samples were taken from the A_0, A, B and C horizons in the podzol profiles. The thickness of the different horizons was measured. The particle size parameters of the mineral soil samples were determined by dry sieving or, in the case of more finely textured samples, by the pipette method. The most important plant nutrients (Ca, P, K, Mg and Na) were determined by extracting the humus and mineral soil samples with HCl. The total nitrogen content of the humus samples was determined by the Kjeldahl method, and the iron and aluminium content of all the samples by the so-called Tamm's extract. The iron and aluminium contents were utilized in studying the degree of podzolisation. A total of 1 140 soils samples were analysed.

The dependences between the different variables and between the different classes were tested using correlation, regression and variance analysis, and the material classified using factor analysis.

The aeolian, glaciofluvial and fluvial soils were found to differ clearly from each other as regards the particle size distribution of the mineral soil (Fig. 6). The aeolian soils were the most sorted (Table 2), and the glaciofluvial soils had the most mixed texture. The soils were divided on the basis of the mean particle size into gravel soils, coarse sand soils, medium sand soils, fine sand soils and silt soils. There were no samples belonging to the last class (a mean particle size of < 0.06 mm) in the material. The groups of sand and fine sand soils (mean particle size ranging from 0.6—0.06 mm) were clearly the largest. Most of the aeolian soils, for instance, belonged to this class (Fig. 9).

Clear differences were found in the variations in the chemical properties of the different soil horizons. Strong intercorrelation was found between the nitrogen, potassium, phosphorus and calcium contents in the humus, for instance (Table 7). The Ca:Mg ratio was 3.0 in the humus layer, and only 0.5 in the mineral soil.

The different soil types differed statistically significantly from each other as regards the nutrient contents of the humus, but not with respect to the nutrient contents in the sub-soil (Table 6). This was interpreted to mean that the nutrient status of the forest ecosystems differentiate as succession progresses, and that the physical differences in the sub-soil at least partly regulate this development. The humus layer in the fluvial soils was found to be the most fertile, and that of the aeolian soils the most infertile.

The dependence of the nutrient contents of the mineral soil on the particle size fractions of the soil was studied by two different methods. The following fractions were separated from some of the soil samples by sieving: 2—0.6 mm, 0.6—0.2 mm, 0.2—0.06 mm and < 0.06 mm. The P, K, Ca and Mg contents of each fraction were determined. No statistically significant differences were found between the two coarsest fractions, but the finest fractions appeared to contain greater amounts of most of these nutrients (Fig. 10). In the second approach, the correlations between the nutrient contents and the relative proportion of different fractions in the mineral soil were examined. The clearest positive correlations were found between the iron, aluminium and magnesium contents and the amounts of fine fractions (< 0.06 mm) in the soil (Fig. 13). On the other hand, phosphorus was positively correlated with the fine sand fraction (0.2—0.06 mm) (Fig. 12). Factor analysis (Table 8) indicated that the macronutrients form their own factor in the humus layer, as was the case with the pH and magnesium, and with iron and aluminium. This observation is supported by the dependence between the different factors.

Clear variation was found between the nutrient status in the different study areas, although the trends were different in the humus and in the mineral soil layers (Figs. 15 and 16). For instance, the calcium and potassium contents of the humus were highest in the Hailuoto study area (Area 1, Fig. 1), but the contents of these nutrients in the sub-soil were considerably smaller in Hailuoto than the corresponding values for Areas 4, 5 and 6 further to the north. The variation in the humus especially was estimated to be at least partly due to climatic differences between the areas.

The soil in all the study areas belonged to the group of iron podzols. Statistically significant differences were found between the organic matter content, determined as the loss in weight on ignition, in all the soil horizons (A_0, A, B and C) of the different study areas. The highest loss in weight on ignition of the humus layer was found in Areas 1 and 3 (Fig. 17). Clear differences were also found in the loss in weight on ignition of the different soil types, being smallest in the humus of the aeolian soils, and highest in the fluvial soils.

The degree of podzolisation was studied on the basis of the thickness of the horizons, and also using the ratio between the combined iron and aluminium contents in the B and C horizons. The thickness of the horizons varied in the different soil types as follows: the A_0 and A horizons were thinnest in the aeolian soils, and thickest in the fluvial soils. On the other hand, there were no statistically significant differences between the iron and aluminium ratios of the different soil types. This parameter was not significantly correlated with any of the particle size parameters of the mineral soil.

Regional variation was found in the thickness of the different horizons (Fig. 18). The podzolisation index (aluminum and iron ratio) described above was also found to vary regionally (Fig. 21). It was highly significantly correlated with the height of the sample plots above sea level (Fig. 22), thus indicating that podzolisation is further advanced on elevated soils than on low-lying ones. Clear differences were found between all the nutrient contents of the different horizons (Fig. 19). Iron and aluminium, as well as phosphorus, were most clearly concentrated in the B horizon. Iron, aluminium and phosphorus were statistically highly intercorrelated in the material (Fig. 20).

The sample plots were classified on the basis of the soil parameters using statistical multivariate methods. A data set comprising the most important nutrient parameters of the humus layer and the most important particle size parameters of the mineral soil was formed for this purpose (Table 10). The data set was initially subjected to factor analysis. The two strongest trends were found to be the variation in the amount of macronutrients and the mean particle size of the soil. When the sample plots were plotted in a factor ordination (Fig. 23) based on the factor scores, the different soil types were found to be partly clumped in the two halves of the figure, as well as being intermixed in the centre of the figure.

A six cluster model was obtained when clustering was done on the basis of the factor scores. Although almost every cluster contained sample plots representing the three soil types, there was differentiation between the soil types since the most fertile clusters were dominated by the fluvial soils, and the least fertile ones by the aeolian soils (Fig. 24). The results of classification were interpreted as indicating that soils with different geological histories are not in fact completely separated in a classification based on soil parameters, but that the geological history only determines to some extent their physical and chemical properties.

The tree stands on all the three soil types were found to be almost without exception pure pine stands. The purest pine stands occurred on the aeolian soils, while in most cases spruce or birch were present as an admixture on the fluvial soils. The mean height of the tree stand on the sample plots on fluvial soil was of the order of 10—12 m, and on the other two types of soil around 8—10 m. The volume of the stands was greatest on the fluvial soils, and smallest on the aeolian soils (see also Fig. 26).

When classified according to the vegetation cover, most of the aeolian sample plots (about 60 %) were found to be of the barren site type (Fig. 27). The predominant site type on the glaciofluvial soils was the dry site type, and on the fluvial soils the sub-dry site type. The aeolian soils were thus more lichen-dominated, and only the fluvial soils had a moss coverage that was greater than that of the lichens. The most common species of lichen were *Cladonia stellaris, C. rangiferina* and *C. sylvatica coll.* (see Table 11).

In ordination analysis (DECORANA ordination) the different soil types were placed to some extent in different parts of the figure, as well as being intermixed in the centre of the figure (Fig. 28). Ordination analysis done on the basis of the plant cover gave similar results in this respect to the ordination done on the basis of the soil data (cf. Fig. 23). When the sample plots were clustered using so-called TWINSPAN clustering, four sample plot clusters were formed in which the different soil types were also concentrated in different ways in the different clusters. However, no "pure" soil type clusters were formed (Fig. 29). The clusters were called after the typical plant species in each cluster:

I *Hylocomium-Myrtillus-Uliginosum* group
II *Vaccinium-Pleurozium* group
III *Vaccinium-Cladonia-Stellaris* group
IV *Empetrum-Cladonia-Stereocaulon* group

Regional differentiation was also found in the clusters, Cluster IV being clearly more northern than Cluster III, which in turn is almost entirely the cluster of the two southernmost study areas. Cluster II represents northern sample plots, Cluster I is indifferent and its vegetation appears to be primarily determined by edaphic factors.

Of the clusters formed on the basis of the vegetation, the first cluster was mainly placed with the forest site types of the sub-dry type (EVT and EMT) and the damp type (VMT, HMT and LUT). The second cluster was apparently situated between the dry and sub-dry site types. The last two clusters appeared to be the most infertile variants of dry site types (Table 13).

Individual plant species were found to be clearly correlated with a number of the soil parameters (Table 14). The strongest correlations were between certain species of lichen (e.g. *Cladonia* species and *Stereocaulon spp.)* and moss (e.g. *Pleurozium schreberi)* and the nutrient status and particle size parameters of the soil. Generally speaking the lichens were indicators of coarsish soil fractions and a poor nutrient status, and the mosses of quite the opposite. Highly significant differences were found between both the particle size and nutrient status of the soil in the different sample plot clusters formed on the basis of the plant cover analysis. The plant cover can thus be considered to depict rather well the variation occurring in the properties of the soil. The floristic structure of the classes formed on the basis of the vegetation are presented in Table 16.

It can thus be concluded that the hypothesis presented at the beginning of the study concerning the effect of the geological processes of the soils in determining their site properties is supported by the results of this study. However, these geological processes do not determine the site properties to the extent that soils formed by different geological processes would always be of a different site type, but that the different processes can produce soils whose properties resemble each other. This phenomenon was evident in this study in the case of site types where the soil deposits that had been formed by the action of wind or water had rather similar soil properties and vegetation cover.

As can be concluded from the above, it is very difficult to use geological processes as the sole criterion in classification. The plant cover is a very useful basis for classification if cuttings or other human activities have not changed it to a great extent. On the other hand, information about the soil, soil type, soil profile etc, could be used as an additional parameter in ecological classification.

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SELOSTE

Syntytavaltaan erilaisten lajittuneiden kangasmetsämaiden kasviekologinen luokittelu Pohjois-Suomessa

Johdanto

Meillä on totuttu luokittelemaan metsiä A. K. Cajanderin (1909, 1925 ja 1949) kehittämää metsätyyppijärjestelmää apuna käyttäen. Cajander määritteli primääriset kasvupaikkatekijät — ilmaston ja maan ominaisuudet — ratkaiseviksi metsätyypin synnylle. Hän esitti myös, että metsätyyppi on näiden kasvupaikkatekijöiden muodostaman kokonaisuuden ilmentäjä. Yksittäiset kasvupaikkatekijät, esimerkiksi maalaji, voivat sensijaan vaihdella samankin metsätyypin sisällä. Metsätyypistä on näinollen myös vaikea päätellä yksittäisten kasvupaikkatekijöiden luonnetta.

Metsien käsittely ja samalla niiden luokittelutarve on Cajanderin ajoista muuttunut. Tämä on synnyttänyt keskustelun siitä, tulisiko metsätyyppiluokitusta edelleen kehittää, tai korvata se uudella luokituksella. Näitä kysymyksiä pohdittaessa yhden lähestymiskulman tarjoaa kasvupaikkojen syntyprosessin tuntemus ja Cajanderin primääristen kasvupaikkatekijöiden tarkempi tutkiskelu. Esimerkiksi maan kasvupaikkatekijöitä voidaan lähestyä monin tavoin luokitukselle asetetusta tavoitteesta ja käyttöalueesta riippuen.

Kivennäismaiden metsien kasvualustan ovat synnyttäneet erilaiset geologiset prosessit, jotka meillä liittyvät läheisesti jääkauteen. Maaperämuodostumat on tunnistettavissa ja luokiteltavissa niiden syntytavan mukaan. Erilaisten prosessien synnyttämät maaperämuodostumat ovat myös rakenteeltaan ja monilta ominaisuuksiltaan erilaisia; paitsi maalaji, niille on tyypillistä myös määrätynlainen maan rakenne. Tämän tutkimuksen tarkoituksena oli ensisijaisesti analysoida kasvupaikkojen erilaistumisprosessia tuulen ja veden lajittamilla kivennäismetsämailla Pohjois-Suomessa. Toisena tavoitteena oli tutkia ekologisesti mielekkään luokituksen kehittämismahdollisuutta näille maille syntyneisiin metsiin. Tutkimuksen hypoteesina oli, että geologisilla prosesseilla on määräävää vaikutusta maiden kasvupaikkaominaisuuksiin.

Aineisto ja menetelmät

Tutkimuksessa mitattiin 285 näytealaa, jotka sijoittuivat eri puolille Pohjois-Suomea kuvan 1 osoittamalla tavalla. Ne sijoitettiin syntytavaltaan erilaisille maille seuraavasti: 106 näytealaa tuulen kerrostamille eli eolisille maille, 110 näytealaa mannerjään sulamisvesien kerrostumille eli glasifluviaalisille maille ja 69 näytealaa suurten jokien kerrostamille eli fluviaalisille maille.

Näytealoilta mitattiin puusto relaskopoimalla, kasvillisuudesta tehtiin lajikohtainen peittävyysanalyysi neljältä 1 m^2:n ruudulta ja otettiin maanäytteet podsolimaannoksen A_0-, A-, B- ja C-horisonteista. Horisonttien paksuudet mitattiin. Maanäytteistä määritettiin kivennäismaan raekokotunnukset seulomalla tai hienojakoisimmista maista liettoanalyysiä käyttäen. Kaikista näytteistä mitattiin Ca-, P-, K-, Mg- ja Na-konsentraatio suolahappouuttoa käyttäen ja Fe- ja Al-konsentraatio ns. Tammin uuttoa käyttäen. Kokonaistyppi määritettiin vain humusnäytteistä ns. Kjeldahl-menetelmällä.

Aineiston käsittelyyn käytettiin korrelaatio-, regressio- ja varianssianalyysejä eri luokkien välisten erojen ja muuttujien välisten riipuvuuksien testaamiseen sekä faktorianalyysiä etenkin maanäyteaineiston luokitteluun. Kasvillisuuden analysointiin käytettiin DECORANA-ordinaatiota ja TWINSPAN-klusterointia.

Metsämaa

Eolisten, glasifluviaalisten ja fluviaalisten maiden todettiin poikkeavan toisistaan selvästi maan raekokojakauman suhteen (kuva 6). Eoliset maat olivat lajittuneimpia ja glasifluviaaliset sekarakeisimpia (taulukko 2). Aineistossa esiintyi selvästi eniten hiekka- ja hietamaita, soramaita ja kaikkein hienojakoisimpia silttimaita oli sen sijaan vähän. Nimenomaan eoliset maat olivat tyypillisimpiä hienohiekka- ja hietamaita (kuva 9).

Kaikki tutkitut maannokset luokiteltiin rautapodsoleihin kuuluviksi. Joissakin tapauksissa maannoksen B-horisontti oli heikosti kehittynyt ja raudan rikastuminen siihen oli silminnähden vähäistä. Useimmissa tapauksissa rikastumiskerros oli kuitenkin hyvin selvä. Podsoloituneisuutta tarkasteltiin horisonttien paksuuden ja raudan ja alumiinin yhteisestä konsentraatiosta lasketun indeksiarvon avulla. Indeksi laskettiin B-horisontin ja C-horisontin raudan ja alumiinin yhteiskonsentraatioiden suhdelukuna.

Horisonttien paksuudet vaihtelivat maatyypeittäin siten, että A_0- ja A-horisontti oli ohuin eolisissa maissa ja paksuin fluviaalisissa maissa. Sensijaan mainittu indeksiarvo ei eronnut merkitsevästi eri maatyyppien välillä. Se ei korreloinut merkitsevästi minkään raekokotunnuksen kanssa. Molemmilla tarkastelutavoilla todettiin sensijaan selviä tutkimusalueiden välisiä eroja (kuvat 18 ja 21).

Paksuin A-horisontti todettiin geologisesti nuorimmilla mailla Hailuodossa. Humuskerros taas oli paksuin Koillismaata edustavalla tutkimusalueella 3. Raudan ja alumiinin konsentraatioiden avulla laskettu indeksi korreloi erittäin merkitsevästi maaston korkeuden kanssa (kuva 22) osoittaen, että korkeilla alueilla sijaitsevat maat ovat tässä suhteessa podsoloituneempia kuin alavammat maat.

Eri maatyypit erosivat toisistaan erittäin merkitsevästi humuskerroksesta mitattujen ravinnearvojen suhteen (taulukko 6). Perusmaasta mitatuissa arvoissa ei sensijaan ollut havaittavissa samaa ilmiötä. Tämän tulkittiin kuvastavan sitä, että metsäekosysteemit erilaistuvat humuksen ravinnetalouden suhteen sukkession edetessä siten, että kivennäismaan fysikaaliset ominaisuudet ainakin osittain pystyvät ohjailemaan tätä erilaistumista. Koska eri tavoin syntyneet maaperämuodostumat poikkeavat toisistaan maan fysikaalisten ominaisuuksien suhteen, ne kehittyvät myös humuksen ravinnearvojen osalta eri suuntiin vaikka kivennäismaassa ei alunalkaen merkitseviä kemiallisia eroja esiintyisikään. Humuskerrosten osalta ravinteikkaimmiksi todettiin fluviaaliset maat ja eoliset maat taas olivat karuimpia.

Tutkimuksessa selvitettiin kivennäismaan ravinnearvojen riippuvuutta maan raekokotunnuksista kahdella tavalla. Osasta maanäytteitä seulottiin erilleen seuraavat fraktiot, joista tehtiin P-, K-, Ca- ja Mg-analyysi: 2—0,6 mm, 0,6—0,2 mm, 0,2—0,06 mm ja alle 0,06 mm. Kahden karkeimman fraktion välillä ei todettu merkitsevää ravinteisuuseroa, sensijaan hienommat fraktiot näyttivät sisältävän useimpia ravinteita selvästi enemmän (kuva 10). Toiseksi tarkasteltiin eri lajitteiden suhteellisen osuuden vaikutusta maan ravinnekonsentraatioihin. Raudalla, alumiinilla ja magnesiumilla todettiin selvimmät positiiviset korrelaatiot hienojen lajitteiden (alle 0,06 mm) määrään maassa (kuva 13). Sensijaan fosforilla todettiin vahvin positiivinen korrelaatio karkean hiedan (0,2—0,06 mm) kanssa (kuva 12).

Faktorianalyysissä (taulukko 8) todettiin keskeisimpien ravinteiden muodostavan oman faktorinsa humuskerroksessa, samoin käyttäytyivät pH-arvo ja magnesium sekä rauta ja alumiini. Humuskerroksen typpipitoisuuden vaihtelusta selitti hehkutuskevennys regressioanalyysitarkastelussa 62 % (kuva 11). Maan ravinteisuudessa todettiin selviä eroja maannoksen eri horisonttien (kuva 19) ja eri tutkimusalueiden (kuvat 15 ja 16) välillä. Tutkimusalueiden väliset erot todettiin — kuten maatyyppienkin väliset erot — erilaisiksi riippuen siitä minkä horisontin suhteen niitä tarkasteltiin.

Näytealat luokiteltiin maatunnusten perusteella monimuuttujamenetelmiä käyttäen. Tätä varten muodostettiin tiedosto, jossa olivat humuskerroksen keskeiset ravinnearvot ja perusmaasta mitatut raekokotunnukset kultakin näytealalta (taulukko 10). Faktorianalyysitarkastelussa todettiin aineistossa vahvimmiksi vaihtelusuunniksi pääravinteiden määrän ja maan raekokotunnusten mukainen vaihtelu. Faktoripisteiden avulla toteutetussa ordinaatiossa näiden vaihtelusuuntien mukaan eri maatyypit painottuivat jonkin verran eri puolille kuvaa (kuva 23), mutta sekoittuivat vahvasti toisiinsa kuvan keskiosassa. Myös faktoripisteiden perusteella tehdyssä klusteroinnissa todettiin, että jokaiseen klusteriin tuli jonkin verran kaikkia maatyyppejä edustavia näytealoja, mutta selvää edelläkuvatunkaltaista painottumista tässäkin tarkastelussa esiintyi. Luokituksen tulosta tulkittiin siten, että laboratoriossa mitattujen tunnusten perusteella ei geologiselta historialtaan erilaisia maita saada yksiselitteisesti erilleen toisistaan, mutta maan geologinen historia näyttää kuitenkin selvästi ohjaavan metsämaan myöhempää fysikaalis-kemiallista kehitystä.

Kasvillisuus

Puustoltaan kaikki tutkitut maatyypit olivat lähes puhtaita mäntymetsiä. Puhtaimpia männiköitä olivat eoliset maat, useimmin taas esiintyi sekapuuna kuusta tai koivua fluviaalisilla mailla. Näytealojen puuston keskipituus oli eolisilla ja glasifluviaalisilla mailla 8—10 m:n ja fluviaalisilla mailla 10—12 m:n pituusluokkaa (kuva 26). Myös puuston kuutiomäärä oli pienin eolisilla ja suurin fluviaalisilla mailla. Eolisten maiden useimmat näytealat (60 %) todettiin kasvillisuuden perusteella jo maastossa kasvupaikkatyypiltään karukkokankaisiin kuuluviksi (kuva 27). Glasifluviaaliset maat olivat useimmiten kuivia kankaita ja fluviaaliset maat kuivahkoja kankaita. Jäkälien peittävyys oli suurin eolisilla mailla ja ainoastaan fluviaalisilla mailla sammalen peittävyys oli keskimäärin jäkälän peittävyyttä suurempi (taulukko 11). Yleisimpiä jäkälälajeja olivat *Cladonia stellaris, C. sylvatica coll.* ja *C. rangiferina.*

DECORANA-ordinaatiotarkastelussa (kuva 28) todettiin sama ilmiö kuin edellä maa-analyysitietojen perusteella tehdyssä ordinaatiotarkastelussa: eri maatyypit painottuvat myös kasvillisuutensa suhteen eri puolille ordinaatiokuvaa, mutta sekoittuvat toisiinsa kuvan keskiosassa. TWINSPAN-klusterianalyysillä muodostettiin näytealaryhmiä, joissa eri maatyypit niinikään painottuivat eri klustereihin, mutta maatyyppien puhtaita klustereita ei tässäkään syntynyt (kuva 29). Ryhmät eli klusterit nimettiin niille tyypillisten lajien mukaan:

I *Hylocomium-Myrtillus-Uliginosum*-ryhmä
II *Vaccinium-Pleurozium*-ryhmä
III *Vaccinium-Cladonia-Stellaris*-ryhmä
IV *Empetrum-Cladonia-Stereocaulon*-ryhmä

Ryhmissä todettiin alueellista painottuneisuutta siten, että ryhmän IV näytealat sijoittuivat keskimäärin selvästi pohjoisemmaksi kuin ryhmän III, joka taas oli lähes puhtaasti kahden eteläisimmän tutkimusalueen ryhmä. II ryhmä edusti myös jonkinasteista pohjoisuutta, mutta I ryhmä oli maantieteellisesti indifferentti ja sen kasvillisuutta näyttivät säätelevän ennenkaikkea edafiset tekijät.

Muodostettuja klustereita vertailtiin perinteisiin metsätyyppeihin niiden floristisen rakenteen perusteella. I eli kasvillisuudeltaan rehevin klusteri sijoittui kuivahkojen kankaiden tyyppien EVT ja EMT sekä tuoreiden kankaiden tyyppien VMT, HMT ja LUT välimaastoon ja siinä oli selvästi piirteitä kaikista näistä tyypeistä. II klusteri näytti taas sijoittuvan kuivahkojen ja kuivien kankaiden välimaastoon ja klusterit IV ja V edustivat selvästi kuivien kankaiden karuinta osaa (taulukko 13).

Kasvilajeilla todettiin selviä korrelaatioita mitattuihin maatunnuksiin. Selvimpiä korrelaatioita todettiin eräiden jäkälien (esim. *Cladonia-* ja *Stereocaulon*-lajit) ja sammalien (esim. *Pleurozium schreberi*) ja maan ravinteisuus- ja raekokotunnusten kesken. Jäkälät olivat odotetusti karkeita maalajitteita ja niukkaravinteisuutta suosivia sammalten käyttäytyessä päinvastoin. Kasvipeitteen perusteella muodostettujen näytealaklustereiden välillä todettiin tilastollisesti merkitseviä eroja sekä maan raekoko- että ravinteisuustunnuksissa (taulukko 15) ja niiden maalajijakaumat olivat myös selvästi erilaiset (kuva 33). Kasvipeitteen todettiin näinollen kuvastavan varsin hyvin maan ominaisuuksissa esiintyvää vaihtelua. Klustereiden floristinen rakenne on esitetty taulukossa 16.

Johtopäätökset

Tutkimuksen alussa asetetun hypoteesin geologisten prosessien määräävästä vaikutuksesta maiden kasvupaikkaominaisuuksien kehitykseen todettiin saaneen tutkimuksen tuloksista vahvistusta. Kuitenkaan nämä geologiset prosessit eivät näytä määräävän kasvupaikkaominaisuuksien kehitystä siten, että erilaiset prosessit tuottaisivat aina täysin erilaisia kasvupaikkoja, vaan geologiselta historialtaan erilaiset maat voivat olla ekologisilta ominaisuuksiltaan myös hyvinkin toistensa kaltaisia. Tässä tutkimuksessa ilmiö näkyi siten, että sekä virtaavan veden että tuulen kerrostamat metsämaat osoittautuivat monissa tapauksissa sekä maan kemiallis-fysikaalisten ominaisuuksien että kasvillisuuden suhteen hyvin samankaltaisiksi. Toisaalta taas löytyi joukko kullekin geologiselle prosessille "tyypillisiä" metsämaita.

Geologisia muodostumia on näinollen vaikea käyttää yksinomaisina luokitusperusteina esimerkiksi kasvupaikkoja luokiteltaessa. Toisaalta on selvää, että maan geologisen historian tuntemuksesta on apua maan fysikaalisia ominaisuuksia arvioitaessa ja näinollen maaperämuodostumia voidaan käyttää luokituksen apuvälineinä joko muilla luokituskriteereillä täydennettynä tai muiden kriteereiden lisämääreenä. Tämänkin tutkimuksen tulosten perusteella kasvipeite osoittautuu varsin käyttökelpoiseksi luokitusperustaksi, mikäli sitä ei ole hakkuin tai muilla toimenpiteillä voimakkaasti muutettu. Kasvillisuusluokituksen lisämääreenä ovat käyttökelpoisia tiedot maaperämuodostumasta, maalajista, maannoksen ominaisuuksista jne. luokituksen käyttötarkoituksesta riippuen.

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The processes involved in the development on different types of site type on soil formations sorted by the action of wind or water were studied in northern Finland. The vegetation and a number of physical and chemical soil properties were studied on a total of 285 sample plots. Statistically significant differences were found between the nutrient status of the humus in the different soil types (aeolian, glaciofluvial and fluvial soils), but not between the values for the sub-soil. A number of correlations were found between the coverage of various plant species and soil parameters.

The results of the study were interpreted as indicating that different geological processes can produce mineral soils which differ clearly from each other, but also soils that develop into forms which closely resemple each other. For this reason the classification done using the vegetation is rather good method for classification in stands which are in a rather natural condition, but different soil parameters can also be used to provide additional information in vegetation classification.

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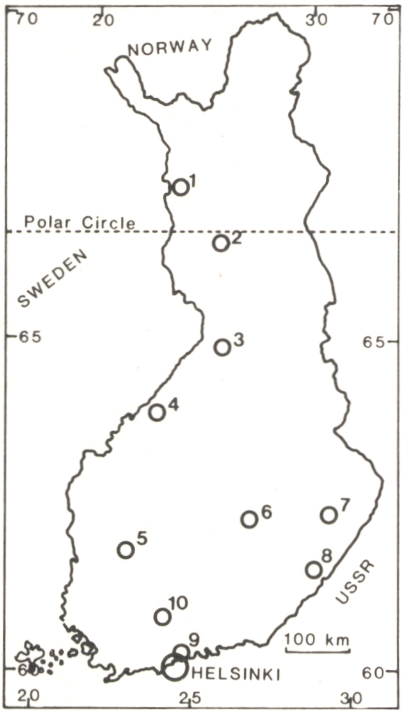

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FACTS ABOUT FINLAND

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

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