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THE GEOBOTANICAL DEVELOPMENT OF SPRING-FED MIRES IN FINNISH LAPLAND

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WITH 23 FIGURES AND 8 TABLES IN TEXT AND FOUR PLATES

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Surficial groundwater conditions, especially spring-fed mires in Central Finnish Lapland, are geobotanically interpreted with the aid of black-and-white and infra-red colour aerial photographs, together with field analyses of the vegetation at nine selected case study sites. In addition, the effect of the composition of ground water on mire vegetation, and the structure and development of spring-fed mires during the Holocene are evaluated. The seeping springs situated on sloping mires characteristically form "crater"-like hummocks rising 0.5 to 1.5 metres above the mire environment. They are composed mainly of *Bryales* or *Carex-Bryales* peat and in the light of pollen and ^{14}C analysis they began to form at the end of the Pre-Boreal and beginning of the Boreal c. 8 800 years ago.

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CONTENTS

INTRODUCTION

The aim of this study is to give some representative examples of the interpretation of surficial groundwater conditions, especially spring-fed mires or spring fens, with the aid of black and white and infra-red colour aerial photographs. Furthermore, the authors want to shed light on the internal structure and the development of spring fens during the Holocene, likewise on the effect of the quality of ground and surface water on fen vegetation in Central Finnish Lapland (Fig. 1).

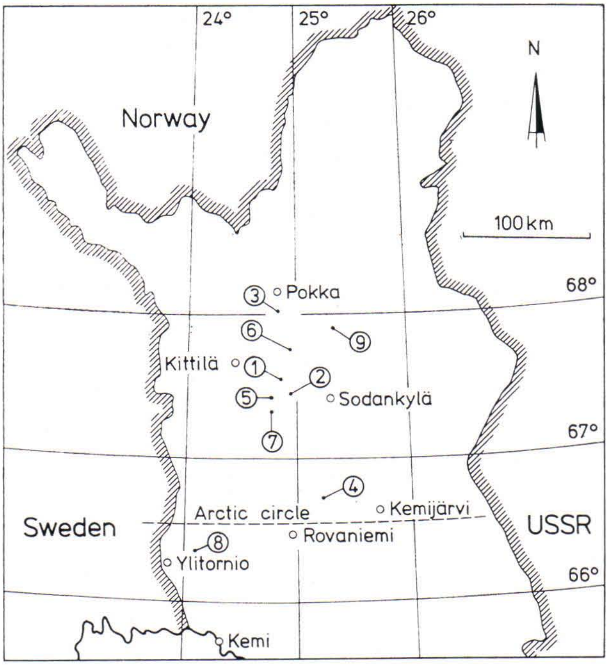

Fig. 1. The case study sites in Central Finnish Lapland. 1. Värttiövaara in the commune of Kittilä; 2. Sulaskaltionoja, Kittilä; 3. Arabiankangas, Kittilä; 4. Liinastenharju in the rural commune of Rovaniemi; 5. Sotkavuoma, Kittilä; 6. Tuorenaakiselkä in the commune of Sodankylä; 7. Säynäjäjärvi, Kittilä; 8. Sammaljoensuo in the commune of Ylitornio; 9. Karjala-aapa, Sodankylä.

The spring fens in northern Finland have been dealt with in only a few papers, the most comprehensive of them being the study of Havas (1961) concerning the hill-slope fens of Kuusamo, south of the present investigation area. The corresponding springs on mires, described by the present authors, are now presented in detail for the first time.

Aerial photography has been employed in the interpretation of surficial geological features particularly in sparsely populated and remote areas. In Finland, where until recently the most important indicators were geomorphological features, aerial photographs have been used mainly in the mapping of Quaternary deposits, in reconstructing the course of deglaciation and in structural geological investigations of Pre-Cambrian bedrock. The tones and colours in aerial photographs have only rarely been used for geobotanical analyses. These indicators would, however, provide a good means of establishing surficial groundwater geological conditions (see, e.g., Preobrazhenskaya 1965, Romanova 1965, Meyer and Markovskiy 1965). In this country the advantages afforded by the vegetation in the interpretation of black and white aerial photographs have been described only in a few general studies, one of them concerning the groundwater conditions in Lapland (Lahermo 1973).

Black and white aerial photographs as paper prints, are the most widely used material in Finland, little use having been made in routine geological reconnaissance of true colour photographs with the exception of a few comparative studies. This is mainly because in small-scale colour aerial photographs taken from a high altitude (scale 1: 60 000) the tones are commonly overall blueish or greenish and the contrasts poor. The advantages of colour over black and white photographs have, therefore, seldom compensated for the greater expenditure involved, even though, some of the comparative studies show clearly that the scope of colour photographs (especially at low altitude) outweighs that of black and white in geological investigations, e.g. in the mapping of surficial deposits (*cf.* Allum 1970, Lappalainen 1972). Where stress is laid upon geobotanical indicators, colour photographs are indispensable (*cf.* Kihlbom *et al.* 1974), owing to the clarity with which different tones can be distinquished, thus making the objects for study stand out more clearly from their surroundings. To date this technique has only been used in an experimental sense, however.

Infra-red colour aerial photographs (so called false colour photographs) have been used in Finland primarily as an aid to the structural geological investigation of Pre-Cambrian bedrock (*cf.* Paarma, Raevaara and Talvitie 1968, Paarma and Talvitie 1968, Talvitie and Luoma-aho 1973), and more recently also in Quaternary investegations (*cf.* Aario, Forström and Lahermo 1974). No detailed geobotanical analyses have yet been attempted.

Infra-red colour photographs offer a greater potential for geobotanical interpretation than black and white ones and possibly even than ordinary colour ones to the same scale. Differences in tone due to variations in vegetation cover, and thus reflecting differences in the soil, bedrock and surficial groundwater conditions, are more readily discernible in the former. Hence they are well suited to the interpretation of waterways and areas of variable moisture and vegetation such as zones of ground water discharge and mires with their network of streams (e.g. Marshall 1968, Norman 1968, Sowers and Asce 1973, Newton 1971).

The present study, in which surficial groundwater conditions are interpreted with the aid of aerial photographs, is based lagerly on the use of geobotanical indicators, the focus of attention being upon spring-fed mires on zones of ground water discharge, where the films employed are a most versatile aid to the reconnaissance of areas marked by large variations in moisture and vegetation.

The photographs employed in the study were taken at a scale of 1: 60 000. For the field investigations, paper colour prints enlarged 6—9 times were made from the original slides, 23 × 23 cm (Ektachrome IR Aero Film, type 8443) for each of the sites. On the basis of these aerial photographs five sites representing the transitions from zones of ground water recharge to discharge were selected for investigation. From these, test areas visible as uniform tones were delineated whose surficial and ground water conditions made them suitable key sites. The choise of representative sites was impeded by the fact that infra-red colour protographs are available for only a limited area of Lapland. The general features of the vegetation at the sites, studied in the field during the summers of 1972—75, are presented as tables, in which the plant species are given in their estimated order of abundance in the tree layer, field layer and ground layer respectively.

Four sites with typical spring-fed mires were also selected from the several thousand black and white photographs available at a scale of 1: 20 000 or 1: 30 000 (sometimes 1: 60 000), covering the whole of Central Lapland. For the field investigations paper prints at a scale of 1: 5 000 or 1: 10 000 were made of the actual sites. Only the main features of the vegetation are shown in the context of text and the species are not listed separately.

Borings were taken in four of the spring-fed mires to establish the evolution and origin of the peat deposits. The results of these stratigraphical investigations are presented in the form of long profiles and pollen diagrams. The onset of paludification was dated at these four sites by pollen analysis and ^{14}C determinations.

CASE STUDIES

1. Värttiövaara, Kittilä

On the basis of the infra-red colour photographs seven test areas at the Värttiövaara site (Plate I) were selected for vegetation analysis. The general features of the vegetation are presented in Table 1.

The tops and flanks of the hills constitute the zone of groundwater recharge, and the low-lying areas between the hills the zone of groundwater discharge (see p. 40). In the lower part of the recharge zone, the groundwater table is just beneath the surface, whereas on the upper slopes it is often as much as 5 to 20 meters below. This upper zone supports a dry heath vegetation. In the discharge zones, the groundwater table practically coincides with the surface of the ground. These low-lying wet areas are occupied by water courses, mires and springs.

The hill of Värttiövaara is largely covered by sandy till (see Fig. 4, curve 6) with block fields, that is, outrops of Pre-Cambrian bedrock, occurring particularly in the upper parts. Block fields without vegetation or with sparse pine stands are indicated by a light blue colour (area 1). In the vicinity of the block fields on the upper slopes of the hill, where there is a thin till covering and the groundwater table at a depth of more than 10 meters, a somewhat more densely forested dry pine heath vegetation predominates. These areas show up sligthly less blue than do the barren block fields. The minor hollows with somewhat larger stands of deciduous trees are visible as reddish spots or elongated streaks (frequentely determined by the fracture tectonics).

On the lower slopes of the hill (area 2) the depth of the ground water nowhere exceeds 0.5—1.5 meters. The till cover is usually thicker and the average content of fines higher. These moist heaths are marked by a predominance of coniferous and deciduous trees and more luxuriant undergrowth. The tone in infra-red photographs is reddish or an intense magenta.

Fig. 2. Birch-dominated fen which is seen as a yellowish patch in aerial photograph, (see area 5 in Plate I and Table 1) Line A—B runs across a small seeping spring with some *Saxifraga hirculus* vegetation (marked x). In the background a large spring pool is visible.

Table 1
The Värttiövaara site, Kittilä.

Area	Geological environment, mire type and colour in photograph	Dominant vegetation
1	Block fields, thin till deposits in depressions. Dry heath. Deep groundwater table. Blue and light blue with reddish spots and patches.	Block field: *Pinus* dominant, *Betula* sparse, scattered *Salix caprea* and *Sorbus aucuparia*. Lichens: *Parmelia, Cetraria, Cladoria*. Till: young *Pinus, Betula* and *Sorbus, Empetrum nigrum, Vaccinium vitis-idaea, V. myrtillus, Salix caprea*.
2	Till deposits. Moist heath. Medium groundwater table. Red (magenta).	*Pinus* dominant, abundant *Betula, Picea, Salix caprea* and *Juniperus. Vaccinium uliginosum, V. myrtillus, Carex globularis, Linnaea borealis, Ledum palustre, Empetrum nigrum, Pleurozium schreberi, Hylocomium proliferum*.
3	Till deposits covered by a thin peat bed. Damp, herb-rich forest with speckled alder. High groundwater table. Red (magenta).	*Alnus incana* 50 %, *Picea* 30 %, *Betula* 20 %, *Filipendula ulmaria, Saussurea alpina, Calamagrostis neglecta, Phalaris asundinacea, Geranium silvaticum, Saxifraga hirculus, Chamaenerium angustifolium, Dryopteris linnaeana, Rubus saxatilis, Pyrola secunda, Trientalis europaea, Vaccinium vitis-idaea, Majanthemum bifolium, Equisetum palustre, Viola epipsila, Sphagnum girgensohnii, S. warnstorfianum, Mnium punctatum*.
4	Till deposits at the margin of groundwater discharge zone. Red (magenta).	*Alnus incana, Filipendula ulmaria, Calamagrostis purpurea, Potentilla palustris, Chamaenerium angustifolium, Linnaea borealis, Sphagnum rubellum, Calliergon stramineum, Cinclidium stygium, Mnium punctatum*.
5	Eutrophic birch fen with *Saxifraga hirculus* (see Fig. 2). Reddish-yellow and yellow.	*Equisetum fluviatile, Pedicularis sceptrum-carolinum, Saxifraga hirculus, Melampyrum pratense, Solidago virga-aurea, Viola epipsila, Sphagnum warnstorfianum, S. teres, Aulacomnium palustre, Tomentypnum nitens*.
6	Thinly wooded spruce mire. Red.	*Picea* 60 %, *Pinus* 40 %, *Salix clauca, Betula nana, Empetrum nigrum, Vaccinium uliginosum, V. vitis-idaea, Rubus chamaemorus, Equisetum silvaticum, Carex globularis, Sphagnum parvifolium, S. fuscum, S. robustum, Polytrichum strictum, P. commune*.
7	Treeless *Sphagnum* bog. Yellowish-red.	*Betula nana, Vaccinium uliginosum, Empetrum sp., Oxycoccus quadripetalus, Chamaererium angustifolium, Sphagnum fuscum, S. rubellum, S. parvifolium, Plaurozium schreberi*.

At the foot of Värttiövaara, at the border of the zone of groundwater discharge, there are two large elongated spring pools that branch out into numerous smaller arms and channels (Plate I). The large amount of ground water discharged from these springs, especially from the bottom of the shallow pools, forms the stream Manto-oja which is several meters wide. This stream

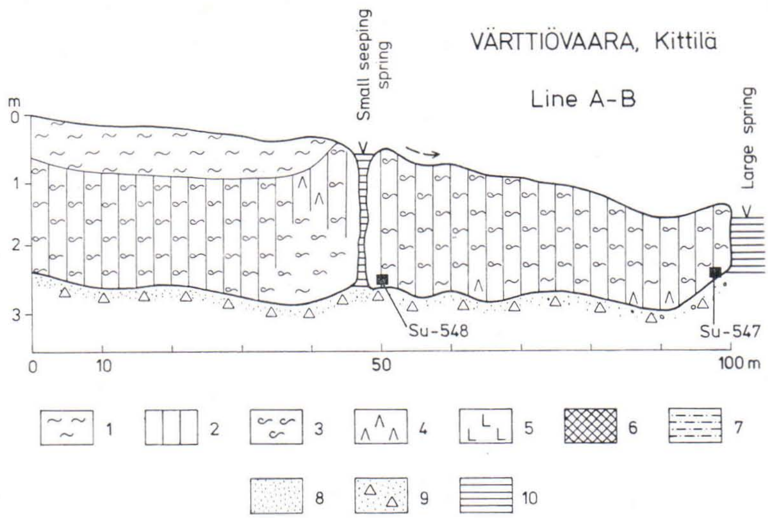

Fig. 3. The long profile A—B through the small birch-dominated fen presented in Fig. 2. Legend: 1. *Sphagnum* peat; 2. *Carex* peat; 3. *Bryales* peat; 4. Wood; 5. *Equisetum* peat; 6. Gyttja; 7. Silt; 8. Sand; 9. Till or partly sorted sandy till; 10. Open water body. Radiocarbon-dated samples: Su-547, 4660 ± 40 (2710 B.C.); Su-548, 8810 ± 50 (6860 B.C.).

is readily discernible as a blue-black or black streak against the reddish colour of the mire, which is partly wooded with birch. The discharge of Manto-oja is calculated at about 50 litres per second (18. 3. 1977, Plate I).

The rich fen which thrives on the moist soil near the springs and in the transitional zone between the foot of the hill and the mire assumes an intense magenta in the infra-red colour photographs (areas 3 and 4).

The colours of the mires in the photographs vary conspicuosly depending on their vegetation type and degree of wetness. On the edge of the westernmoust spring pool there is a small birch fen (Fig. 2) which shows up as a small yellowish fanlike spot (area 5) in a reddish environment. Here the nutrient-rich groundwater seeping from a small spring pool (marked x) has led to the development of eutrophic vegetation. The characteristic plant species are *Saxifraga hirculus* and *Pedicularis sceptrum-carolinum*. The line A-B running through the birch fen and small spring pool to the large spring pool was bored to its base (Plate I, broken line). The long profile (Fig. 3) shows how groundwater seeping from the bottom of the rich fen, which is resting on till, has led to the formation of eutrophic *Bryales* and *Carex-Bryales* peat, especially in the vicinity of the small spring pool. Beyond the influence of seeping groundwater, in the upper part of the sequence oligotrophic *Sphagnum* peat predominates.

Farther away from the spring zone the rich fen grades into a thinly wooded mire (area 6) and an open treeless *Sphagnum* bog (area 7). The former shows up reddish in the photographs, primarily owing to the abundance of *Betula nana,* whereas the latter is more yellowish.

2. Sulaskaltionoja, Sodankylä

Nine test areas for vegetation analysis were selected from the Sulaskaltionoja site (Plate II) on the basis of the infra-red colour photographs. This site has previously been investigated by Lahermo (1973). The general features of the vegetation are presented in Table 2.

A comparison of the black and white aerial photograph (Lahermo 1973, Fig. 33) and the infra-red colour photograph (Plate II) indicates the superior interpretative potential of the latter, the versatility of which is especially evident in interpreting the details of a mire surface.

The soil and surficial groundwater conditions are very similiar to those found at Värttiövaara. The bedrock exposed as block fields is readily distinguished (area 1) from the till-covered shallow hollows with their more luxuriant vegetation (area 2).

The ground water discharges at an estimated rate of at least 5 litres per second through Sulaskaltionlähde, a spring at the foot of the hill. The stream originating from the spring is clearly seen on the photographs. Around the spring, along the boundary between the block fields and the rich fen (area 3), there is a narrow zone of damp herb-rich forest. South of Sulaskaltionlähde, at the foot of the hill, there are numerous seepage zones. The runoff and the groundwater seeping into the mire together allow the formation of some waterlogged patches of *Carex* that show up as dark streaks on the photographs (area 4) and exhibit small transverse peat strings perpendicular to the direction of flow. They are only visible on highly enlarged aerial photographs. Sometimes small greenbluish spots (area 5), probably mainly due to dry sedges, are also visible.

The drier parts of the mire, e.g. the parts thinly wooded with pines and dwarf shrubs, show up as a light reddish colour (area 6), whereas the more open parts which support *Sphagnum* bog are more yellowish (area 7). Further out and in the southern part of the bog, the waterlogged area shows up a dark patch and forms a background against which the peat ridges are readily discernible as reddish bands (frame 8). The fairly wide belt of birch fen associated with Sulaskaltionoja, is seen as a red strip on the infra-red colour photograph (area 9), as at Värttiövaara.

Table 2
The Sulaskaltionoja site, Sodankylä.

Area	Geological environment, mire type and colour in photograph	Dominant vegetation
1	Block fields, thin till deposits. Dry heath. Deep groundwater table. Blue or light blue.	A patch of till with *Pinus* as dominant species, some *Betula* and a few *Picea*. Field layer (thin): *Vaccinium vitis-idaea*, *V. myrtillus*, *Empetrum nigrum*.
2	Till deposits. Fairly dry heath. Medium groundwater table. Red (magenta).	Equal abundances of *Betula*, *Picea* and *Pirus*. *Vaccirium myrtillus*, *V. uliginosum*, *Empetrum nigrum*, *Ledum palustre* (a few), *Hylocomium parietinum*.
3	Zone of groundwater discharge around the spring. Red (magenta).	*Deschampsia caespitosa*, *Potentilla palustris*, *Equisetum limosum*, *E. silvaticum*, *Parnassia palustris*, *Epilobium palustre*, *Mnium cinclidioides*, *Calliergon cordifolium*, *Climacium dendroides*, *Sphagnum squarrosum*, *S. riparium*.
4	Long, narrow, wet sedgefens crossed by small, peat ridges strings or ridges. Dark with red or reddish white peat strings or ridges.	*Ledum palustre-Betula nara* peat ridges: *Andromeda polifolia*, *Rubus chamaemorus*, *Vaccinium uliginosum*, *Oxycoccus quadripetalus*. Between ridges: *Scheuchzeria palustris*, *Eriophorum vaginatum*, *E. angustifolium*, *Oxycoccus quadr.*, *Scirpus caespitosus*, *Sphagnum balticum*.
5	A long, narrow, sedge fen strip with patches of dry hay. Light or yellowish red with bluish patches.	Young *Pinus* trees with older dead trees. *Equisetum limosum*, *Carex chordorrhiza*, *Betula nana*, *Juniperus communis*, *Eriophorum vaginatum*, *Potentilla palustris*, *Ledum palustre*, *Salix myrtilloides*, *Campylium stellatum*, *Drepanocladus revolvens*.
6	Pine bog with *Sphagnum*. Red or light red mixed with light or yellowish spots.	*Betula nana*, *Vaccinium uliginosum*, *Rubus chamaemorus*, *Ledum palustre*, *Andromeda polifolia*, *Sphagnum fuscum*, *Pleurozium schreberi*.
7	Open pine bog. Yellowish or light red.	*Filipendula ulmaria*, *Solidago virga-aurea*, *Potentilla palustris*, *Equisetum limosum*, *Betula nana*, *Carex caespitosus*, *Eriophorum angustifolium*, *Parnassia palustris*, *Geranium silvaticum*, *Vaccinium uliginosum*, *Saussurea alpina*, *Eriophorum vaginatum*.
8	Waterlogged treeless *Sphagnum dusenii* poor fen with peat ridges. Dark with reddish or yellowish peat ridges.	Peat ridges: *Betula nana*, *Ledum palustre*, *Eriophorum vaginatum*, *Menyanthes trifoliata*, *Sphagnum fuscum*. Between peat ridges: *Carex limosa*, *Eriophorum angustifolium*, *Sphagnum dusenii*, *S. balticum*.
9	Birch and spruce fen with herbs and grasses. Red (magenta).	*Filipendula ulmaria*, *Equisetum silvaticum*, *Potentilla palustris*, *Parnassia palustris*, *Menyanthes trifoliata*, *Pirola minor*, *Deschampsia caespitosa*, *Calamagrostis purpurea*, *Salix lapponum*, *S. phylicifolia*, *Juniperus communis*, *Sphagnum apiculatum*, *S. parvifolium*, *Polytrichum commune*.

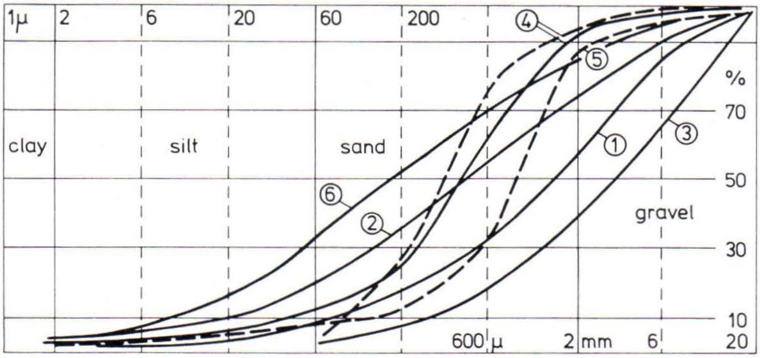

Fig. 4. Cumulative curves indicating the grain-size composition of surficial deposits at the Arabiankangas site (see Plate III). Curve 1. Coarse, partly sorted till (area 1); 2. More fine-grained till (area 2); 3. Sandy gravel (area 3); 4. Medium and fine sand (area 4); 5. Coarse sand (area 5); 6. Sandy till from the Värttiövaara and Sulaskaltionoja sites (3 analyses).

3. Arabiankangas, Kittilä

On the basis of the colour photographs, six test areas were selected from the Arabiankangas site (Plate III) for vegetation analysis. The general features of the vegetation are presented in Table 3.

The sand and gravel deposits bordering on the till-covered hill are suggestive of a sandur or a flattish esker. These were deposited by glaciofluvial meltwaters flowing from the northwest through a fracture valley just beyond the picture. North of Arabianjärvi, the till cover is thin and in many places the bedrock is visible in the form of blocks (area 1). There is a somewhat richer growth of vegetation in the moister till-filled hollows, which show up as small reddish spots or streaks on a light blue background to the west of area 1. To the southwest the till deposits grade gradually into sand and gravel, but the vegetation remains unaltered (area 3). Consequently, thinly-covered till areas cannot always be distinguished on the basis of vegetation in the photographs, despite the differences in the grain size of the material (Fig. 4, curves 1 and 3).

In the eastern part of the region, the till cover is thicker and has a higher concentration of fine material (area 2, curve 2). The undergrowth is more luxuriant, and decidious trees are more abundant than in the sand and gravel areas. Here the more reddish tone of the till distinguishes it from the sorted material (*cf.* Paarma, Raevaara and Talvitie 1968, Figs. 13 and 17).

There is an elongated shallow depression trending from northeast to southwest by the side of Arabianjärvi. The groundwater table is close to or level with the surface of the ground. The soil is medium sand (curve 4) and provides a fertile, sheltered site for a distinctly rich forest vegetation and undergrowth.

Table 3
The Arabiankangas site, Kittilä.

Area	Geological environment, mire type and colour in photograph	Dominant vegetation
1	Block fields, thin till cover in shallow hollows (Fig. 4, curve 1). Dry pine heath. Deep groundwater table. Blue and light blue.	*Pinus* dominant scattered. *Betula, Empetrum nigrum, Vaccinium vitis-idaea, V. myrtillus*, some *V. uliginosum, Cladonia rangiferina.*
2	Thicker till-cover than in area 1. Material more finely graded (curve 2). Fairly dry heath. Deep groundwater table. Red mixed with bluish spots.	*Picea, Pinus* and *Betula* are equally abundant; while *Ledum palustre, Empetrum hermaphroditum, Vaccinium myrtillus, V. vitis-idaea, V. uliginosum, Juniperus communis, Hylocomium proliferum, Pleurozium schreberi* are also present.
3	Sand and gravel (curve 3). Dry pine heath. Deep groundwater table. Blue and light blue with some reddish spots.	*Pinus* dominant, some low *Picea* and a few *Betula, Calluna vulgaris, Empetrum hermahproditum, Vaccinium vitis-idaea, V. myrtillus, Cladonia rangiferina.*
4	Sand and fine sand (curve 4). Moist heath with luxurious forest vegetation and undergrowth. High groundwater table. Bright red (magenta).	Old tall *Picea, Prunus padus* and *Sorbus aucuparia, Ribes rubrum, Paris aquilina, Filipendula ulmaria, Actea erythrocarpa, Triticum caninum, Chmaererium angustifolium, Dryopteris phegopteris, D. linnaeana, Rubus saxatilis, Equisetum silvaticum, Viola selkirkii.*
5	Sand (curve 5). Moist pine, spruce and birch heath. Border of discharge zone of groundwater. Red (magenta).	*Vaccinium myrtillus, V. uliginosum, V. vitis-idaea, Ledum palustre, Rubus chamaemorus, Hylocomium proliferum, Pleurozium schreberi, Dicranum undulatum, Sphagnum rubellum.* Around the seeping spring: *Potentilla palustris, Carex canescens, Epilobium palustre, Salix lapponum, S. phylicifolia, Equisetum fluviatile, Betula nana, Juncus sp., Calamagrostis neglecta, Paludella squarrosa.*
6	Oligotrophic *Sphagrum* bog with small scattered pines. White and yellowish.	*Empetrum nigrum, Rubus chamaemorus, Vaccinium vitis-idaea, V. myrtillus, V. uliginosum, Eriophorum vaginatum, Betula nana, Sphagnum fuscum, S. apiculatum, Cladonia rangiferina.*

This area is visible in the photographs as a striking magenta patch (area 4) surrounded by the bluish area of the barren dry heath which is composed of coarser sand and gravel. The fertility of the place is evident from the exceptional brownness of the soil and the variety of plant species (Table 3), in contrast to the surrounding barren land with its podsol soils and sparse vegetation.

The influence of groundwater conditions on vegetation, and thus also on the colours recorded in aerial photographs, is striking. So, variations in soil composition can be interpreted with reliability on the basis of geobotanical indications only in hydrogeologically analogous areas.

The groundwater disharged from the sand and gravel collects into small streams flowing along the margin of the minerogenic and peat soils, which then join the river Seurujoki flowing farther out on the mire (Plate III). The discharge of groundwater is calculated at about 5 to 7 litres per second (22. 3. 1977). The zone of groundwater discharge, a swampy area with a rich stand of deciduous trees, shows up as a fairly narrow reddish belt bordering on the sand and gravel area (area 5). The material here is somewhat coarser than in the depression described earlier (Fig. 4, curve 5).

The tones of the mire display great diversity. The rather dry bog with thin pine forest is visible as light reddish or yellowish tones (area 6), whereas the wet sedge bog in the southwestern part of the area is dark with numerous light-coloured peat ridges. Seurujoki is flanked by a narrow belt of birch fen similar to that noted at Sulaskaltionoja.

4. Liinastenharju, rural commune of Rovaniemi

One test area for vegetation analysis was selected from the Liinastenharju site (Fig. 5). The general features of the vegetation are presented below.

Northwest of the esker, there is an extensive seeping spring zone that discharges about 1.5 to 2 litres per second into the stream which collects the ground water (Fig. 5, A). The vegetation in the seeping spring zone is much richer (B) than in the nearby mire and shows up in the infra-red colour photographs as bright magenta (see colour of area 4 in Plate III). Owing to the sparse pine forest and poor undergrowth, the esker itself shows up as pale blue (see colour of area 1 in Plate I), forming a striking contrast to the spring zone. Consequently, spring zones with eutrophic vegetation covering a sufficiently large area may be detected by means of their bright colour.

The dominant vegetation on the edge of the esker is *Betula-Picea* mixed forest with *Salix caprea* and *Sorbus aucuparia. Equisetum silvaticum, Solidago virga-aurea, Chamaenerium angustifolium, Trientalis europaea, Pyrola secunda, Vaccinium vitis-idaea, V. myrtillus* and *Dryopteris phegopteris* are also present. The following zone more near the spring is composed of *Climacium dendroides, Drepanocladus badius, Sphagnum warnstorfi, Hylocomium splendens* and *Tomentypnum nitens.* The next zone nearest the springs has *Potentilla palustris, Equisetum palustre, Carex canescens, Epilobium palustre* and *Poa pratense,* while immediately surrounding the springs grow *Salix phylicifolia, Potentilla palustris, Epilobium palustre, Equisetum palustre* and *Mnium cinclidioides.*

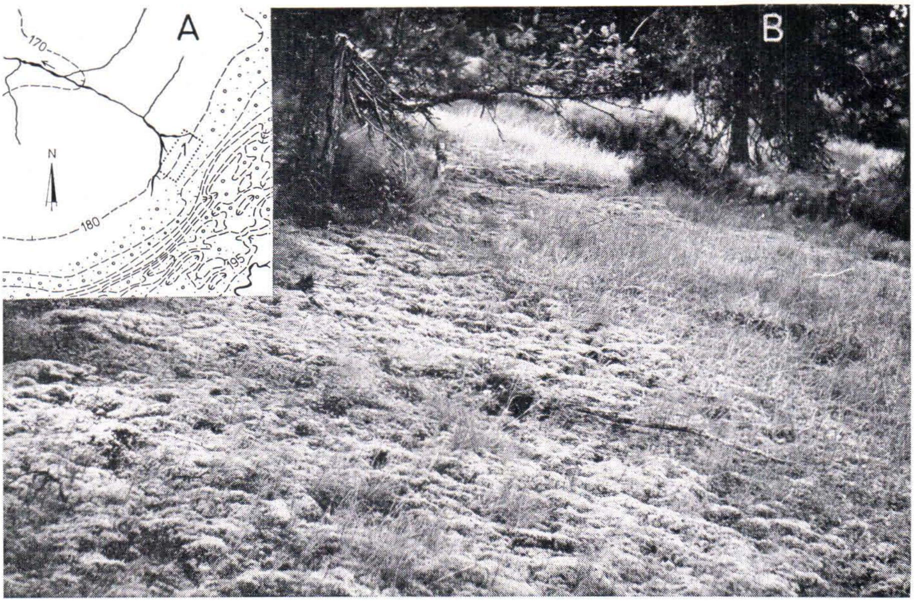

Fig. 5. The Liinastenharju (A) site about 8 km E of Ala-Nampa, a village in the rural commune of Rovaniemi (topographic map 3623/4). The site consist of a spring zone (B, area 1) in the lower slope of the esker.

The acid peat layer covering the gently sloping spring zone on the lower slope of the esker is only 10 to 30 cm thick (Fig. 5 B).

5. Sotkavuoma, Kittilä

Five test areas for vegetation analysis were selected from the Sotkavuoma site (Plate IV) on the basis of of the aerial photographs. The general features of the vegetation are presented in Table 4.

The till cover of the gently sloping hill is thin and the bedrock is exposed locally in the form of block fields (area 1). Near the edge of the discharge zone, along the margins of the hill, the moist till provides the conditions for a somewhat richer vegetation (area 2). The mire has several seeping springs, the immendiate vicinities of which show up as light yellowish and reddish elongated patches (areas 3 and 4). The spring localities are islands of eutrophic vegetation or wooded peat hummocks rising to a maximum of 0.5 to 1.0 m above their surroundings, and with a spring pool in the centre (p. 41). In some of the springs, the vegetation has overgrown the whole pool.

Some of the islands are partly superimposed on others (area 4), in which case there may be a considerable time difference in their stage of development. Some of the hummocks are small and irregular, and without detectable springs.

Table 4
The Sotkavuoma site, Kittilä.

Area	Geological environment, mire type and colour in photograph	Dominant vegetation
1	Block fields, local thin till cover. Dry pine heath. Medium groundwater table. Blue and light blue with reddish spots	as Värttiövaara, area 1.
2	Till deposits at the junction of a gently sloping hill and mire. Moist pine and spruce heath with deciduous trees. High groundwater table. Red, some bluish spots.	Clear-felled area, originally with *Betula*, *Pinus* and *Picea* (in the aerial photograph it occurs in the natural state). *Vaccinium myrtillus*, *V. vitis-idaea*, *Ledum palustre*, *Agrostis tenuis*, which has increased since clear-felling, *Pleurozium schreberi*, *Hylocomium proliferum*.
3	Wooded peat island surrounded by open sedge fen. Reddish and yellowish patch on a darker background.	Trees: *Pinus*, *Picea* and *Betula*. On peat ridges: *Empetrum nigrum*, *Rubus chamaemorus*, *Betula nana*, *Vaccinium myrtillus*, *V. vitis-idaea*, *Ledum palustre*, *Sphagnum fuscum*, *S. apiculatum*. At the edges of the seeping springs: *Calamagrostis neglecta*, *Poa pratensis*, *Potertilla palustris*, *Equisetum palustre*, *Epilobium palustre*, *Paludella squarrosa*, *Philonotis fontana*, *Bryum duvalii*, *Sphagnum riparium*, *S. squarrosum*.
4	Larger island of sedge fen around the hummock of a seeping spring, partly connected with another island. As area 3. The edge of the island is yellowish, with some blueish spots.	Around the seeping spring some dead *Picea*. *Potentilla palustris*, *Salix phylicifolia*, *Epilobium palustre*, *Calamagrostis neglecta*, *Equisetum palustre*, *Paludella squarrosa*, *Philonotis fontana, Bryum duvalii*. The island is bordered by a narrow belt of *Sphagnum* bog: *S. fuscum* hummocks, *Empetrum sp.*, *Eriophorum vaginatum*, *Betula nana* and *Andromeda polifolia*.
5	Mostly open bog with»rimpi» pools and peat ridges with herbs and grasses. Dark with light peat ridges (see Fig. 6).	Peat ridges: *Betula nana*, *Menyanthes trifoliata*, *Solidago virgaaurea*, *Tofieldia palustris*, *Andromeda polifolia*, *Potentilla palustris*, *Trientalis europaea*, *Oxycoccus microcarpum*, *Calamagrostis purpurea*, *Empetrum nigrum* (a little), *Sphagnum fuscum*, *S. apiculatum*. Wet area between ridges: *Scheuchzeria palustris*, *Carex limosa*, *Eriophorum angustifolium*, *Drosera longifolia*, *Utricularia intermedia*, *Sphagnum balticum*, *S. papillosum*, *Drepanocladus fluitans*.

The oval or ellipsoidal form of the mounds (Plate IV) is the result of percolating ground water which seeps in a fan-like manner following the gradient of the mire surface (broken arrows). The peat strings on the wet open bog between the spring hummocks are perpendicular to the direction of runoff (*cf.* Lappalainen 1970, Lahermo 1973). In the immediate vicinity of the seeping springs the strings are small and close together (thick lines), but further out in the poor fen, where percolation is slower owing to the gentler gradient, they are larger and more widely spaced (thin lines, Fig. 6).

Fig. 6. Peat ridges with *Betula nana* on the treeless poor fen of Sotkavuoma (see test area 5 in Plate IV, Table 4).

6. Tuorenaakiselkä, Sodankylä

The Tuorenaakiselkä site has been described earlier by Lahermo (1973). A hill-slope fen, investigated for a distance of 1.5 km, contained more than ten small seeping springs 40 to 110 m away from the slope of the hill. Two of these are presented in an enlargement of a black and white aerial photograph (Fig. 7). As at Sotkavuoma, ground water seeping from the bottom of the mire has presumably caused the eutrophic fen adjacent to the spring to develop into a low hummock supporting a small stand of spruces and surrounded by waterlogged open fen. The hummocks and their nearest surroundings at downwards direction show up as elongated, virtually symmetrical patches on black and white photographs, the streamlined shape being due to the direction of flow (broken arrows). The actual spring pools are situated near the upper edge of the patch.

Two coring lines were established crossing the seeping springs (Fig. 7) in order to obtain a general vegetation profile and to establish the influence of seeping ground water on paludification. The coring data are compiled in long profiles in Fig. 8.

Line A-B runs approximately from east to west across the hill-slope fen. Its eastern end is on the slope of the hill where moist wooded heath prevails

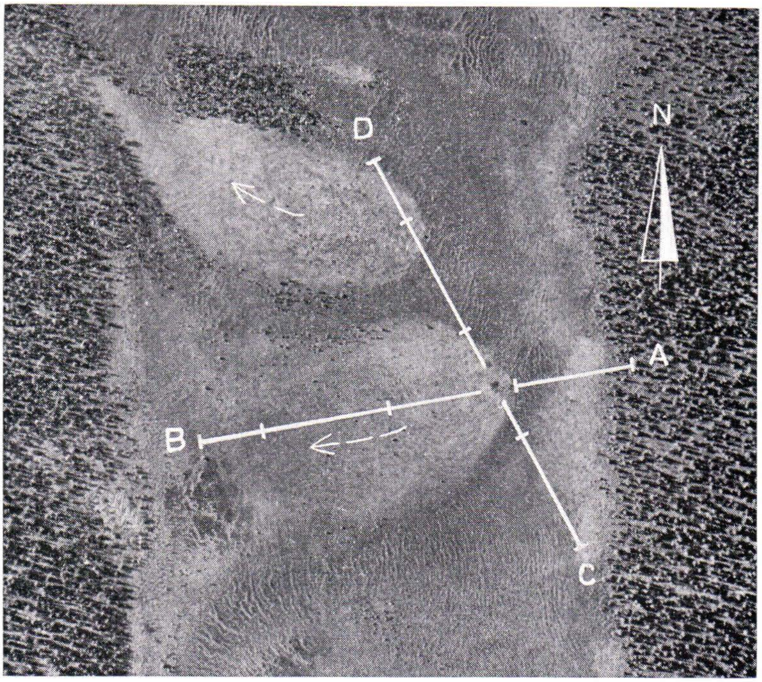

Fig. 7. A black and white aerial photograph of the Tuorenaakiselkä site about 13 km NW of Rajala, a village in the commune of Sodankylä. The site consists of part of a hill-slope fen bordering a till-covered hill (right side of the picture). The long profiles A—B and C—D are shown (see Fig. 8). There are some seeping springs (black dot) in the fen, which have encouraged more eutrophic vegetation than in the surrounding mire. Two such zones are seen on the aerial photograph as lighter elongated patches. Aerial photo 63231/30. By courtesy of the Army Map Service (Topografikunta).

and the groundwater table is near the surface. The dominant vegetation is composed of spruce, with a few pines and *Salix aurita*. Also present are *Vaccinium uliginosum, V. myrtillus, V. vitis-idaea, Ledum palustre, Rubus channaemorus, Polytrichum commune, Pleurozium schreberi, Sphagnum girgensohnii* and *S. rubellum* (light in photograph). The above types grade downwards in accordance with the gradient through wet sedge fen, rushes and brown moss (dark in photograph) into a spring hummock proper (light in photograph). The vegetation of the mound consists of about twenty small spruces, *Salix phylicifolia, S. lapponum, Equisetum fluviatile, Cares rostrata, C. aquatilis, Calamagrostis neglecta, Menyanthes trifoliata, Potentilla palustris, Caltha palustris, Vaccinium uliginosum, Ledum palustre, Sphagnum riparium, S. squarrosum, Paludella squarrosa* and *Calliergon stramineum* (*cf.* Lahermo 1973, Fig. 22).

West of the spring, lower down the line, the mire is a typical open rich

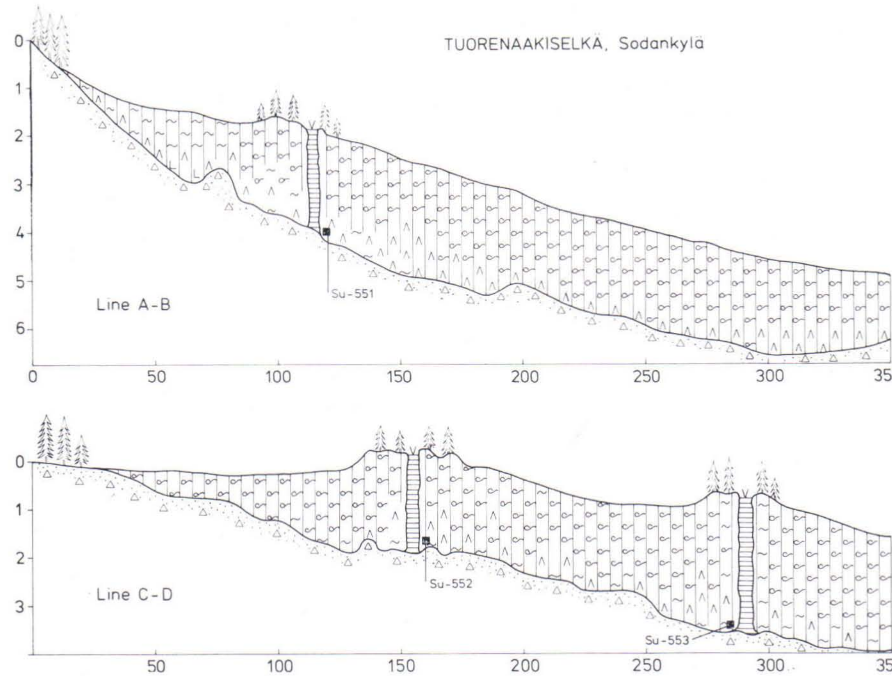

Fig. 8. Long profiles A—B and C—D through seeping springs and patches of eutrophic vegetation (see Fig. 7). The "crater"-like hummocks of the springs show up clearly. Legend: As in Fig. 3. Radiocarbon-dated horizons: Su-551, 8640 ± 120 (6690 B.C.); Su-552, 7910 ± 60 (5960 B.C.); Su-553, 8790 ± 70 (6840 B.C.).

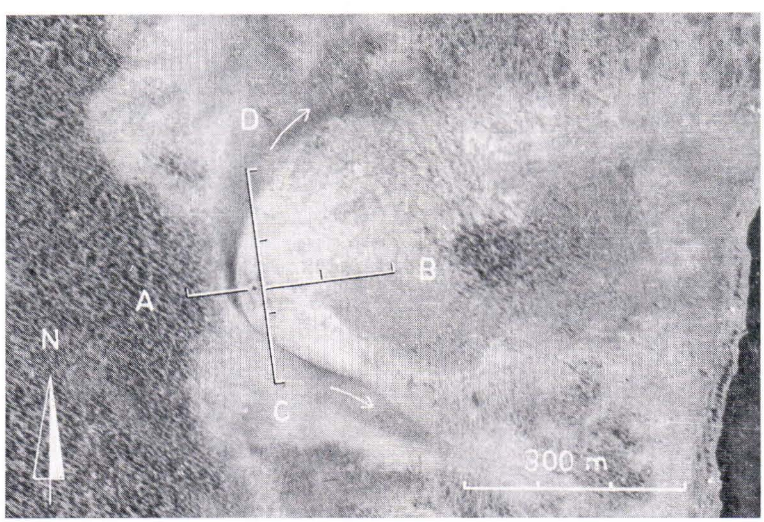

Fig. 9. A black and white aerial photograph of the Säynäjärvi site, about 3 km E of Maunujärvi, a village in the commune of Kittilä. The site consists of part of a mire bordering a till-covered hill (left side of picture). About one hundred metres from the slope of the hill there is a seeping spring hummock. Profiles A—B and C—D are shown (see Fig. 10). Aerial photo 5712/38. By courtesy of the Army Map Service (Topografikunta).

fen with the following vascular plants: *Saxifraga hirculus, Stellaria grassifolia, Pedicularis sceptrum-carolinum, Parnassia palustris, Tofieldia pusilla, Molinia coerulea, Menyanthes trifoliata, Eriophorum angustifolium, Selaginella selaginoides* and *Saussurea alpina.*

The plant species on the line C-D, which runs across two spring hummocks, are roughly similar to those on line A-B, although in some places the former display features characteristic of *Molinia* moss fens, containing, in addition to *Molinia coerulea, Betula nana, Andromeda polifolia, Carex chordorrhiza, C. lasiocarpa, Menyanthes trifoliata, Potentilla palustris, Sphagnum subsecundum, S. warnstorfianum, Calliergon stramineum* and *Drepanocladus sp.*

The profiles from Tuorenaakiselkä indicate that the mire is a typical hill-slope fen whose surface follows the contours of the underlying land. The seeping springs are located on the sloping till basement. A higher rate of peat formation in the spring hummocks may be inferred form the abundance of wood remnants in the lowest peat layers. These sections of the mire represent a paludified forest, which has partly been brougth about by discharging ground water. Elsewhere the peat bed contains mainly sedge-brown moss peat.

7. Säynäjäjärvi, Kittilä

The Säynäjäjärvi site (Fig. 9) is part of the hill-slope fen containing one seeping spring described earlier by Lahermo (1973, Fig. 22). The spring pool (black spot on aerial photograph) is a few metres in diameter and about 60 m from the gentle slope of a till-covered hill. As at the Tuorenaakiselkä site, the seeping ground water has created a peat hummock which rises about 1 meter above the surrounding mire. This is indicated by two long profiles levelled and cored across the spring (Fig. 10). The runoff from the hill to the surface of the fen has been forced to flow around the spring hummock by the waterlogged sedge-dominated stripes that show up as a dark curve on the black and white aerial photograph (see also Fig. 11).

Line A-B starts in moist heath on the gentle slope of the till-covered hill, where pine, spruce and birch are present in almost equal proportions. Other plants are *Vaccinium myrtillus, V. vitis-idaea, Empetrum nigrum, Carex globularis* and *Polytrichum commune.* On the edge of the open, waterlogged, treeless bog there are strings of *Sphagnum fuscum* interspersed with *Equisetum fluviatile, Carex canescens, C. limosa, Sphagnum balticum* and *S. papillosum.* The pool of the seeping spring is surrounded by a zone of shrubs: *Salix lapponum, S. phylicifolia, Betula nana, Ledum palustre, Rubus chamaemorus, Vaccinium uliginosum* and *Carex aquatilis.* The plants of the spring hummock comprise

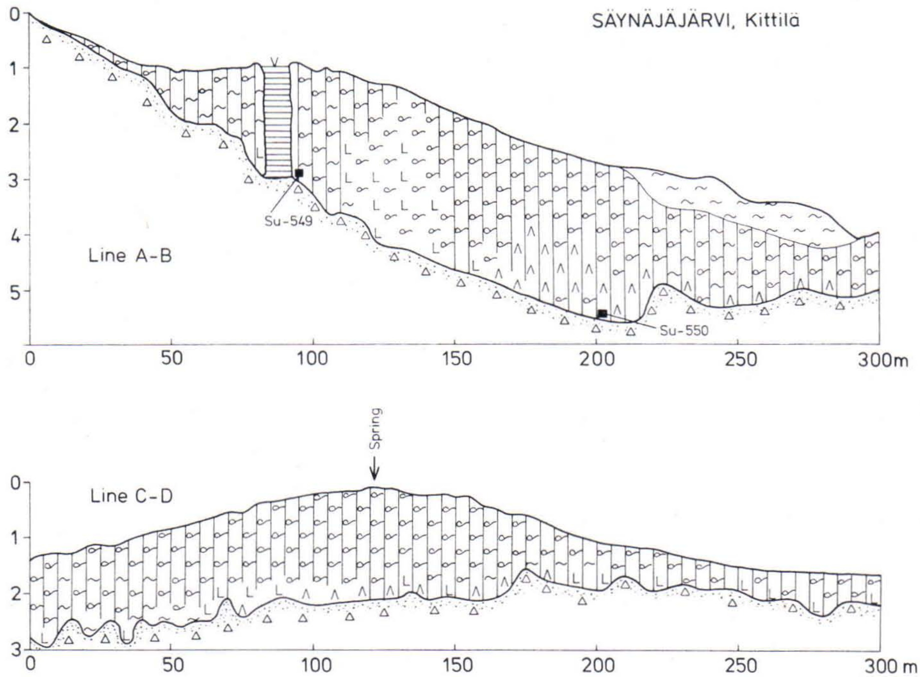

Fig. 10. Long profiles A—B and C—D through the seeping spring hummock (see Fig. 9). Legend: As in Fig. 3: Radiocarbon-dated horizons Su-549, 4530 ± 40 (2580 B.C.); Su-550, 7920 ± 70 (5970 B.C.).

the following species: *Salix phylicifolia, Carex aquatilis, C. canescens, Calamagrostis purpurea, Equisetum fluviatile, E. palustre, Menyanthes trifoliata, Potentilla palustris Sphagnum squarrosum, S. girgensohnii, S. teres, Helodium lanatum, Mnium punctata* and *Paludella squarrosa.* The profile continues downwards from the spring into a *Carex rostrata* fen with shrub-dominated ridges that grade into brown moss fen and finally into *Sphagnum* bog.

Line C-D runs across the spring hummock but does not intersect the spring pool proper. Along its whole length the profile displays a complex of *Bryales* and *Carex* fen types, e.g. *Drepanocladus* and *Paludella* sedge fen. This vegetation is typical for such fens.

The stratigraphy of long profiles A-B and C-D (Fig. 10) is roughly similar to that of the Tuorenaakiselkä profile described above. The peat deposit is composed predominantly of *Bryales* and *Carex,* but the basal layers contain an abundance of wood and remnants of *Equisetum.* The influence of seeping ground water is most clearly seen in the occurrence of *Bryales* peat downstream from the spring proper.

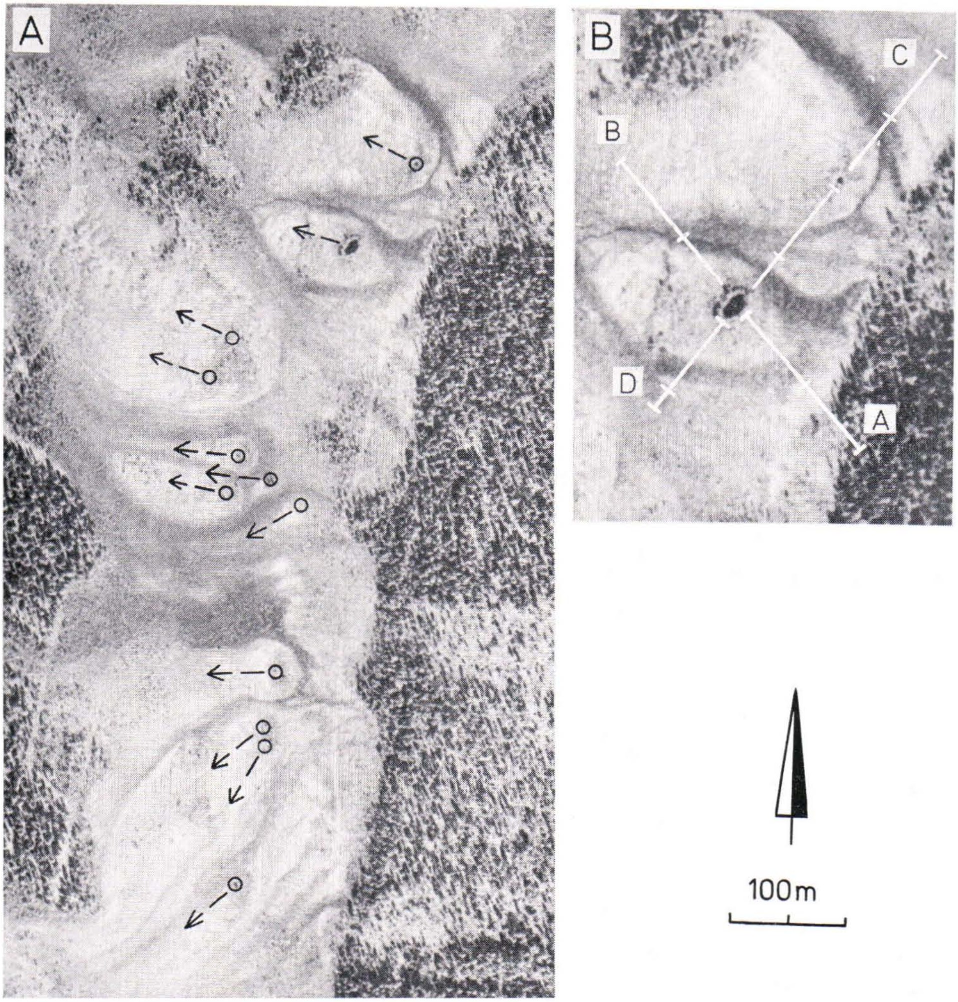

Fig. 11. Black and white aerial photographs of the Sammaljoensuo site about 7 km E of Kauliranta, a village in the commune of Ylitornio. The site comprises part of a hill-slope fen and a till-covered hill, Kalliolaki (right side of the photo A), with numerous seeping springs (small circles, arrows indicate the direction of flow). There is one exceptionally large pool (detailed photo B; see Fig. 12), which is seen as a black spot. The scale refers to photograph A. Lines A—B and C—D are shown. Aerial photo 71187/103. By courtesy of the Army Map Service (Topografikunta).

8. Sammaljoensuo, Ylitornio

The Sammaljoensuo site lies at the edge of a hill-slope fen situated in the Sammaljoki valley. The 1 km stretch of fen investigated, borders on a till-covered hill, and includes about twelve small seeping springs (Fig. 11, A, circles and arrows) and some exceptionally large spring pools. The diameter of

Fig. 12. The large pool of the seeping spring which is also illustrated in Fig. 11. In the background is Kalliolaki hill.

the largest pool is c. 15 metres and its depth more than 4 metres. The base is composed of till and silt (Fig 13). A pool of this size will show up clearly on an enlargement made from a 1: 60 000 aerial photograph (Fig. 11, B).

Two lines were studied to establish the vegetation cover of the fen and to eludicate the role of seeping ground water in paludification. Line A-B runs from the till-covered slope across the largest spring pool in the direction of the gradient of the fen. Line C-D runs through the two largest springs (Fig. 11, B).

Line A-B begins in moist heath on the lower slopes of the till-covered hill. The groundwater table is close to the surface, which is covered by a peat layer 10 to 30 centimetres thick. Spruce dominates, and birch is also present.

The terrain between the hill-slope and the spring is occupied by a belt of open, waterlogged sedge fen, which surrounds the spring hummock (light in the aerial photograph), as at Säynäjäjärvi. From the edge of the spring the following zones of vegetation can be discerned: *Andromeda polifolia, Carex lasiocarpa-Menyanthes trifoliata, Equisetum fluviatile, Salix phylicifolia-S. myrsinites-Betula nana, Potentilla pal.* and *Epilobium palustre,* while discrete patches

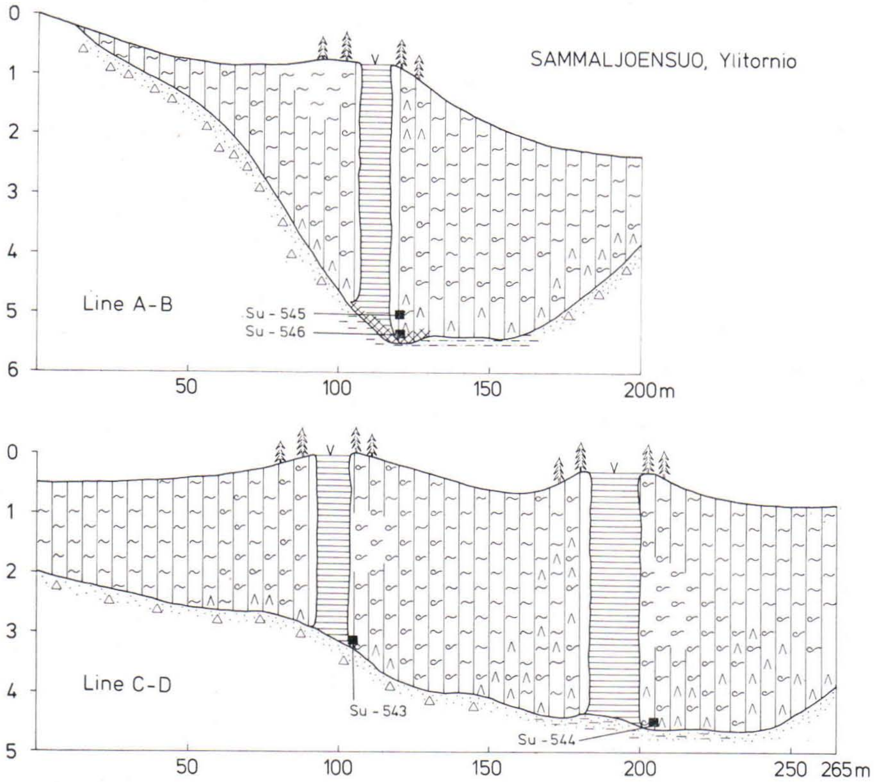

Fig. 13. Long profiles A—B and C—D though "crater"-like hummocks (see Fig. 11 and 12). Legend as in Fig. 3: Radiocarbon-dated horizons: Su-543, 6230 ± 60 (4280 B.C.); Su-544, 6830 ± 120 (4880 B.C.); Su-545, 7150 ± 50 (5200 B.C.); Su-546, 7900 ± 150 (5950 B.C.).

of *Drepanocladus badius, Paludella squarrosa, Sphagnum riparium, S. squarrosa* and *S. girgensohnii* also occur.

Some isolated spruces and pines grow on the spring hummocks. This is a characteristic feature of seeping springs (Fig. 12) and enables the site of a spring hummock to be located from a long way off. *Empetrum sp.* is the dominant species on the spring hummocks, with *Carex globularis, Equisetum silvaticum, Sphagnum girgensohnii* and *S. wulfianum*.

Line C-D begins in *Carex* fen in which the dominant species are *Carex rostrata* and *Menyanthes trifoliata*. This gradually alters to *Bryales-Carex* fen with, in addition to the species listed above *Paludella, Drepanocladus badius, Sphagnum subsecundum* and *S. teres*. The oval patches connected with the seeps are seen as light areas in the aerial photographs, largely because of the lower moisture content of the mire surface rather than the composition of the vegetation cover. The patches are drier *Sphagnum-Bryales* fens surrounded by waterlogged sedge fens.

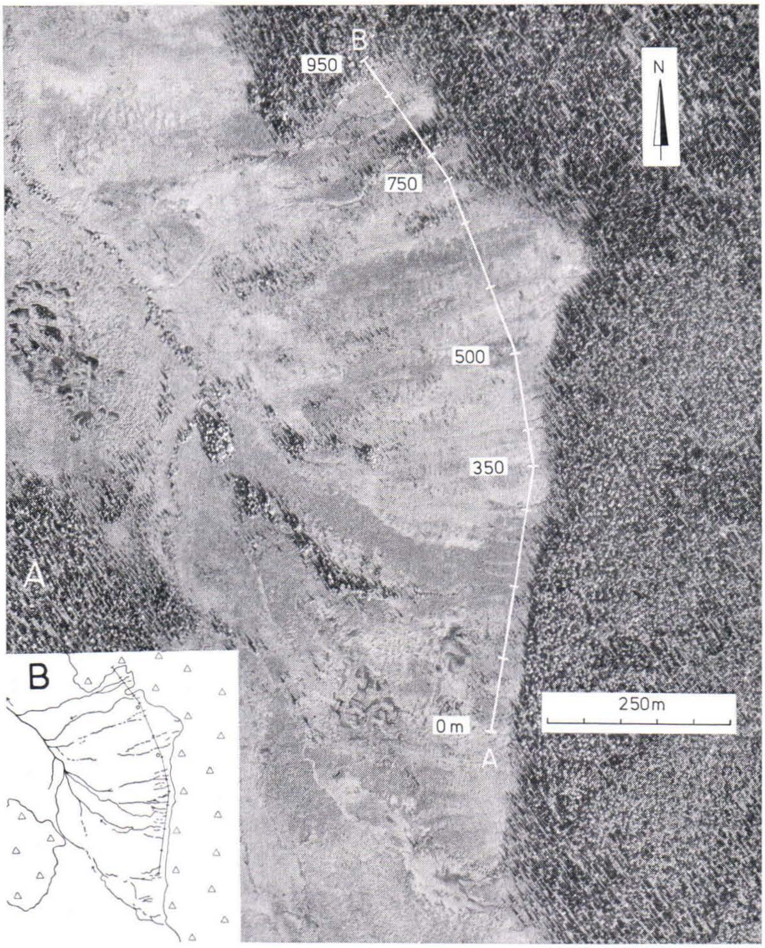

Fig. 14. Black and white aerial photograph (A) of the Karjala-aapa site about 24 km NW of Peurasuvanto, a village in the commune of Sodankylä. The site consists as part of a hill-slope fen bordering the till-covered hill of Karjalavaara (right in the photograph). The fen has numerous streams originating from springs at the foot of the hill and some seeping springs farther out in the mire (drawing B in left-hand lower corner). Line A—B is shown. Aerial photo 63243/42. By courtesy of the Army Map Service (Topografikunta).

The long profiles indicate that the fen has a fairly thick peat substrata (Fig. 13), the deepest level reached by coring being 4.35 m. The peat types exhibit the same sequence as at the Tuorenaakiselkä and Säynäjäjärvi sites, the majority being composed of *Bryales* and *Carex* with local remnants of eutrophic *Sphagnum* species. An abundance of woody remains is visible here and there lower down in the peat, especially around the springs. *Sphagnum-Carex* peat dominates in the sedge-rich regions. In a few localities there are lenses of pure *Sphagnum* and *Bryales* peat.

In the bottom of the trough-like depression parallel to the hill slope, silt overlies the till basement (Fig. 13, line A-B) and it is the seeping of ground water over the edge of this bed that may have led to the abundance of springs on the hill-slope fen (see Fig. 11).

9. Karjala-aapa, Sodankylä

The Karjala-aapa site (Fig. 14 A) is a hill-slope fen bordering onto a till-covered hill. The stretch investigated, which is almost 1 km in 'eng·h, contains at the foot of the hill roughly 15 springs or seeps, from which streams originate (Fig. 14 B). The streams are clearly distinguishable as narrow bands on black-and-white aerial photographs, and are situated in shallow "gorges" from ½ to 1 m deep. In addition there are some seeping springs with peat hummocks farther out on the mire (Fig. 16).

One coring line A-B was set up through the sloping part of the fen to establish the influence of discharging ground water on paludification (Fig. 14). The coring data are compiled in the long profile presented in Fig. 15.

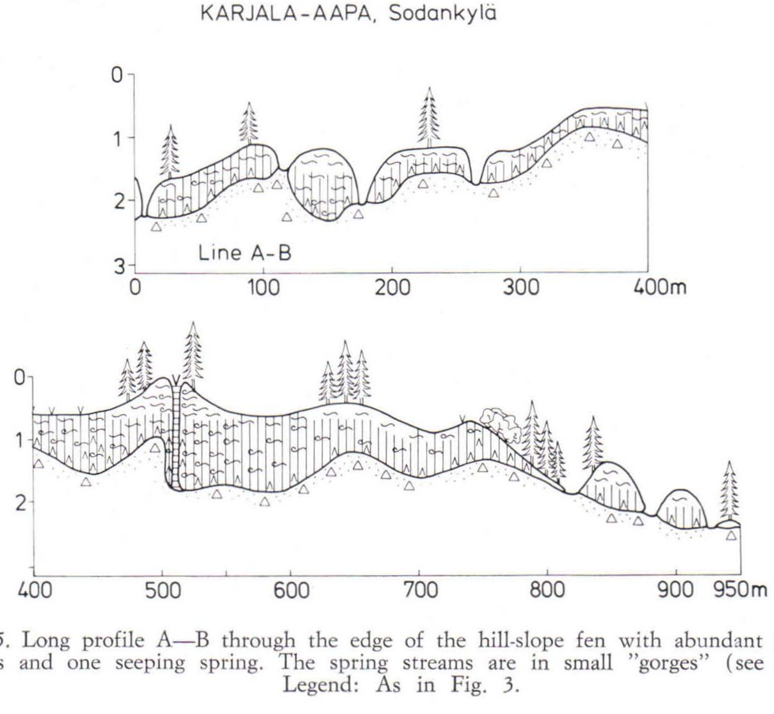

Fig. 15. Long profile A—B through the edge of the hill-slope fen with abundant spring-fed streams and one seeping spring. The spring streams are in small "gorges" (see Fig. 17). Legend: As in Fig. 3.

Fig. 16. Typical small "crater"-like seeping spring. The point is 500 m along the line A—B (Fig. 15). The photograph has been taken looking towards the collective stream bordered with line of spruces in the middle of the mire (see Fig. 14 B).

Line A-B begins in a *Carex rostrata* fen with hummocks of *Sphagnum fuscum,* which grades into dry *Sphagnum* bog with scattered spruces, willows and dwarf birches (175 to 300 m, dark grey in the aerial photograph). The line investigated continues as drier sedge fens with *Salix, Equisetum* and *Bryales* (300 to 640 m, light in aerial photograph). This area is followed by *Sphagnum fuscum* bog with hummocks and ridges (640 to 680 m, dark grey in aerial photograph). The line continues through a partly infilled spring pool (700 m) with *Salix, Equisetum, Paludella* and *Campothecium.* At the end of the line the mire types grade into an area with Sphagnum bogs, paludified forest, fens and three spring streams, the largest of which is surrounded by spruces.

Fig. 17. Spring-fed stream on the Karjala-aapa mire flowing in a shallow "gorge". The point is 200 m along the line A—B (Fig. 15). In the background gently sloping hill slope.

The till-covered base of the mire is very uneven (Fig. 15) and since streams have repeatedly cut into the peat, the surface of the mire is similarly uneven. Brown moss-sedge peat is the most common, while the surface-leyers of the mire are mostly composed of *Sphagnum* peat. The lowest horizons are of woody sedge peat.

INFLUENCE OF THE CHEMICAL COMPOSITION OF GROUND WATER ON THE VEGETATION OF SPRING-FED MIRES.

The bedrock has an indirect influence on the vegetation cover through the lithological composition of the soil and the chemical content of both ground and surface water. Hydrogeological conditions determine the extent to which

Table 5

Composition of the bedrock and specific conductivity values for the discharging and seeping ground water in the spring-fed mires.

Site	Composition of bedrock	Sp. conductivity of discharging or seeping ground water ($\mu S/cm$)
Tuorenaakinselkä	greenstone	70—213
Värttiövaara	greenstone, arkose-quartzite	89—118
Sulaskaltionoja	quartzite, greenstone to the north of site	60—104
Säynäjäjärvi	granite	20—29
Sotkavuoma	porphyritic granite	17—31
Arabiankangas	Hetta granite, with greenstone and amphibolite in the surrounding area	15—37
Sammaljoensuo	granite and gneiss	22—29
Liinastenharju	granite	17—21

the composition of the ground water reflects that of the soil and, thus, indirectly that of the underlying bedrock (Lahermo 1970). Because plants ultimately obtain their nutrients from water, there is every justification for assuming that the difference in the quality of the water is reflected in the mire vegetation in the vicinity of springs.

Table 5 shows that the composition of the underlying bedrock is strongly reflected in the concentration of electrolytes (expressed as specific conducivity) in the ground water discharged from the springs. The concentrations are five to six times higher in the greenstone than in the granite areas. Similarly, the concentrations are slightly higher in the ground water from till deposits (Sammaljoensuo) than in that percolating through sorted sands and gravels (Liinastenharju). Although the differences are small in this latter case, they are clear enough when a sufficiently large amount of data are accumulated and there are no large differences in lithological composition.

In many cases, the water in seeping springs on the same mire may differ conspicuously, the differences being largest at sites with basic bedrock (Tuorenaakiselkä). The quality of the water in the deep spring pools does not differ appreciably between the surface and the bottom. Sometimes, however, the electrolyte concentrations are slightly higher at the bottom than at the surface. The composition of the spring water also shows some seasonal variation (Lahermo 1970), with the samples collected in the spring, although poorer in electrolytes, usually containing more humus in solution (Arabiankangas, fairly high $KMnO_4$-consumption value, Table 6) than do the samples taken later on in the summer or winter.

At the subsilicious rock sites (Värttiövaara, Tuorenaakiselkä) the ground water contains 4 to 6 times more calcium and magnesium (Table 6) than does that at the silicious sites (Liinastenharju, Säynäjäjärvi, Sammaljoen-

Table 6
Chemical composition of ground and surface water (arithmetical mean values) at the different sites.

Site	Location of water sample	number of determinations	pH	Specific conductivity, $\mu S/cm$	Alkalinity, meq	Total hardness, dH°	$KMnO_4$-consumption, mg/l	SiO_2 mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Temp. C°
1. Värttiö-vaara	spring	3—5	7.9	100	1.00	3.1	2.9	9.7	12.6	5.9	1.2	0.4	3.5
2. Sulaskal-tionoja	spring	2	7.2	70	0.54	2.0	7.2	13.2	11.4	1.8	1.5	0.9	3.2
3. Arabian-kangas	springs	4—8	6.3	20	0.19	0.5	10.8	8.6	2.1	0.7	1.0	0.2	2.5
	gravel pit	1	6.6	14	0.12	0.4	6.0	8.1	1.8	0.5	1.0	1.4	—
	brook	1	6.8	27	0.30	0.6	18.2	8.8	3.2	0.6	—	—	—
4. Liinasten-harju	spring	3	6.4	19	0.20	0.4	4.6	11.4	1.7	0.6	1.2	0.3	—
5. Sotka-vuoma	seeping springs	2—4	6.2	27	0.21	0.8	4.5	11.1 (12.8)	3.0	1.6	1.3	0.7	—
	surface water	1—2	6.1	17	0.17	0.5	47.9	0.5	2.0	0.9	0.8	0.2	—
6. Tuorenaa-kiselkä	seeping springs	3—5	7.1	113	0.66	3.0 (2.3)	6.0	12.7	18.5	1.7	1.8	1.5 (0.7)	5.2
	surface water	1	5.7	33	0.34	—	—	9.2	—	—	1.5	0.6	—
7. Säynäjä-järvi	seeping spring	4—5	6.2	26	0.24	0.7	3.7	14.5	2.5	1.4	1.5	0.5	3.5
	surface water	2	6.4	18	0.17	0.4	29.1	9.5	2.1	0.7	1.4	0.2	—
8. Sammal-joensuo	seeping springs	4—5	6.7	23	0.24	0.5	6.6	10.0	2.1	0.7	1.2	0.7	—
	surface water	1	5.7	24	0.17	0.4	47.9	11.5	1.3	1.0	1.5	0.2	—
9. Karjala-aapa	springs	3	6.6	40	0.35	1.1	3.5	13.4	4.2	2.4	1.8	1.5	3.9
	brook	1	6.6	60	4.50	1.9	42.3	12.3	9.7	2.4	1.9	1.7	—

suo). At the silicious sites which are located near large areas of subsilicious bedrock (Sulaskaltionoja, Arabiankangas) the amount of dissolved material is something between these two. The sodium and potassium concentrations change little in relation to the composition of the bedrock, and the same is true of SiO_2, whose average concentration is often a little higher in the nutrient poor waters of silicious sites. Of the nitrogen compounds, the concentrations of NH_4^+ are usually below 0.1 mg/l, those of NO_2^- below 0.0025 mg/l and those of NO_3^- below 0.1 mg/l. These low concentrations of nitrogen compounds show that the ground water is still entirely in its natural state.

The surface water of a wet treeless mire adjacent to seeping spring hummock is usually poorer in electrolyte that is the seeping ground water (Sotkavuoma, Säynäjärvi, Sammaljoensuo, Table 6). The concentrations of the principal nutrients, Ca, Mg, Na and K, and the amounts of Si are lower in the surface water than in the ground water. On the other hand, the surface water contains distinctly more humus than does the ground water. The surface water in a mire is derived partly from rain water and partly from the runoff from the lower slopes of surrounding hills. In the most sloping parts of hill-slope fens, in particular during dry seasons, surface water may originate primarily from ground water seeping from the soil.

In Central Lapland there are various types of spring-fed mires. However, even quite major differences in the nature of the ground water of the various sites have little effect on the macro-vegetation of large mire areas. The vegetation is only locally a eutrophic fen vegetation as long as it comes under the influence of the ground water seeping from the springs. Beyond the influence of the ground water, the mire changes into an oligotrophic open *Spagnum*-peat bog (Sulaskaltion-oja and Arabiankangas).

There is, however, fairly distinct correlation between the specific conductivity of spring water and the vegetation in the investigated spring fens. It is true, in more eutropfic cases (Tuorenaakiselkä and Värttövaara) the range of variation of the specific conductivity is large (*cf.* Table 5). The flora of the mentioned mires reflects a fairly electrolyte-rich as well as calcareous soil. Among lime-favouring plants may be mentioned *Saxifraga hirculus, Stellaria grassifolia, Pedicularis sceptrum-carolinum, Tofieldia pusilla, Saussurea alpina* and *Selaginella selaginoides.*

The proper spring areas are often discerned as spruce-grown hummocks and abundant *Salix* vegetation is typical. Among herbs the most common are *Potentilla palustris, Equisetum palustris, Epilobium palustris, Carex canescens, Calamagrostis purpurea* and *Menyanthes trifoliata.* The most often appearing species of moss are *Paludella squarrosa, Campylium stellatum, Drepanocladus revolvens, Mnium punctatum, Sphagnum squarrosum* and *S. girgensohnii.* In spring areas and in their close neighbourhood there are, in addition to the mentioned plants, several species of plants characteristic of mineratropfic mires.

The presence or absence of a certain plant species or even peat type is mainly due to differences in the nutrient content the surface water of the mire from that of the ground water. Hence, *Saxifraga hirculus* grows only on those fens (Värttiövaara and Tuorenaakiselkä) where the water exhibits higher concentrations of electrolytes, Ca, Mg and higher pH values than do the waters at the other investigation sites. According to Kotilainen (1944, p. 132), *Saxifraga*

Table 7
pH-values of peat in spring-fed mires and at points further removed from the springs and beyond the influence of discharging or seeping ground water. The peat samples were collected from a depth of 20—30 cm, and the measurements were made both in the field and in the laboratory.

Site	Spring fen		Mire farther away from spring	
	test area	pH	test area	pH
Värttiövaara	4	6.4—6.7	5	3.7—4.1
Sotkavuoma	4	5.3—5.7	5	4.7—5.0
Arabiankangas	—	—	6	3.6—3.7
Liinastenharju	1	5.6—5.8	—	—

hirculus thrives on birch-dominated fens nourished by vivianite and ferro-carbonate. The moss cover composed of *Scorpidium* and *Drepanaocladus intermadium-Campylium sellatum* common on other mires is absent or rare on birch dominated fens, presumably because these species cannot thrive in a iron-rich environment. Sjörs (e.g. 1952, p. 255) states, that a high salt content (at least calcium bicarbonate) in the mire water is generally connected with a rich fen vegetation, but the latter is not always dependent on the former. Havas (1962) also notes the relationship between the electrolyte content of mire water and the mire type, *viz.* the transitional change from nutrient poor water with oligotrophic bog vegetation to nutrient rich water with mesotrophic and eutrophic vegetation.

Fig. 18. The ice-covered stream originating from Sulaskaltio spring at Sulaskoltionoja investigation site (see Plate II) photographed 21st April 1976 towards the central part of the mire. The location of ground water discharges on the bottom of the large stream is indicated by ice-free, rounded spots in the foreground.

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According to Kivinen (1935, p. 56) bog vegetation seems to be more dependent on pH level than on the electrolyte content of the bog water. Kotilainen (1933), again presents that the general vegetation is more accurate indicator of the acidity of mire than single plant species.

The same mire can exhibit both a eutrophic vegetation and peat type fed by the ground water and an oligotrophic vegetation and peat type which is beyond the influence of the ground water, the eutrophic vegetation and peat being concentrated around springs. This difference is reflected in the pH values of the peat (Table 7). Havas (1961, p. 135) establishes a corresponding relationship in the spring-fed hill-slope fens of Kuusamo.

The temperature of the ground water in a spring and its surroundins is practically constant throughout the year, which encourages the growth of an eutrophic fen vegetation. Measurements made in summer in the large springs (Värttiövaara, Sulaskaltionoja and Liinastenharju) indicate that the temperature of the water varies from 2.5 to 3.8° C, while in winter the temperature at some of the sites may even be a few tenths of a degree higher than i summer (3.1—4.3° C) owing to the time-lag in the changing heat content of the ground (see Fig. 18). In the pools of the seeping springs (Tuorenaakiselkä, Sotkavuoma, Säynäjärvi, Sammaljoensuo) the temperature of the ground water varies from 3.4 to 5.2° C in summer from 2.6 to 3.8° C in winter. The seepage is so slow that the surface of the spring pool down to a depth of several metres has time to warm up slightly. According to Havas (1961, p. 134) the avegage summer temperature of the spring water in the hill-slope fens of Kuusamo is 4.6° C.

THE GEOLOGICAL DEVELOPMENT OF SPRING-FED MIRES

In Lapland spring-fed mires or spring fens are characterised by a uniformity of the peat bed. The prevailing peat types are *Bryales-Carex, Sphagnum-Carex* and *Sphagnum-Bryales* peat, important additional components being remnants of wood and *Equisetum,* the wood is being mainly encountered in the lower part of the peat layers.

Four sets of samples for pollen and ^{14}C analyses were obtained from spring fens to establish the development of the springs and the fens induced by them as well as the date when the paludification process started (Figs. 3, 8, 10 and 13).

Domination by *Pinus* is a common feature in all the pollen diagrams (Figs. 19, 20 and 21) except in that of Sammaljoensuo (Fig. 22), where the dominance of *Betula* is marked. In the Säynäjärvi (Fig. 21) diagram the dominance of *Pinus* pollen is interrupted by a comparatively high peak in *Betula.*

The pollen diagrams can be divided into those with *Picea* pollen and those without, a division which has proved to be a good basis for dating the peat

VÄRTTIÖVAARA, Kittilä

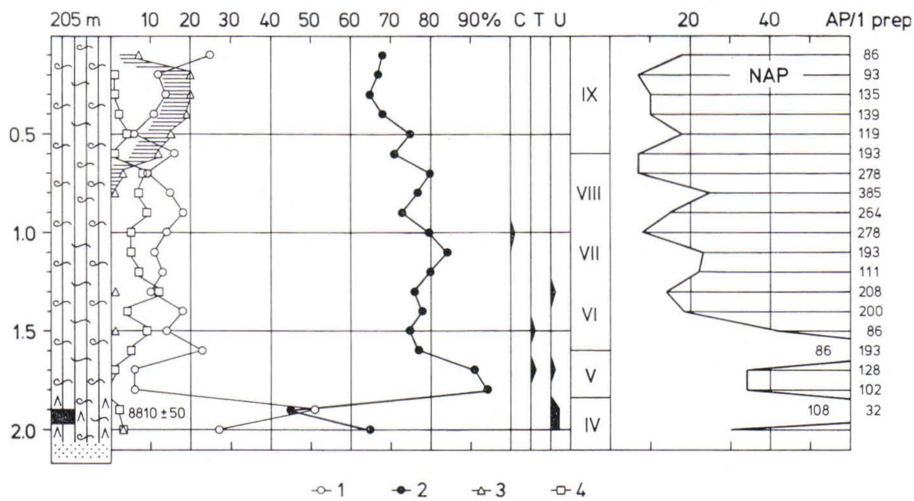

Fig. 19. Pollen diagram from the peat sequence investigated at Värttiövaara site (Plate I). The coring point is near the small spring (50 m in profile A—B in) Fig. 3. Legend: 1. *Betula;* 2. *Pinus;* 3. *Picea;* 4. *Alnus;* C. *Corylus;* Q. *Quercus;* T. *Tilia;* U. *Ulmus;* NAP. Non-arboreal pollen. IV—IX division of zones indicate forest-historical and climatic variations.

sequences. Another factor pertinent to the dating is in the *Pinus* curve in the lower parts of the diagrams. According to Lappalainen (1970, p. 70), this period correspands to the Boreal period (zone V), whose opening stage was characterised by a *Betula*-dominated one. The two diagrams (Säynäjärvi, Sammaljoensuo) indicate that the paludification of the spring site started in the final stage of Boreal period.

Lappalainen (1970) maintains that in North Finland widespread paludification set in as early as the Pre-Boreal period (zone IV), which according to ^{14}C analyses began at approximately 9500 B.P. The Värttiövaara (Fig. 19) and Tuorenaakiselkä (Fig. 20) diagrams indicate that paludification nearby springs started at the end of the Pre-Boreal period. The aforementioned diagrams suggest that towards the end of that period atmospheric humidity led to an increase in wetness and thus triggered of the paludification process.

The Säynäjärvi diagram shows that the proportion of *Betula* pollen was higher than that of *Pinus* at the end of the Atlantic period (zone VII), when the climate was warmer and more humid. This is supported in the Säynäjärvi diagram by the relative abundance of *Corylus, Ulmus* and *Alnus.* The diagrams suggest that the Sub-Boreal period did not differ significantly from the preceding periods, althoug *Picea* pollen begins to appear in deposits from that period. The amount

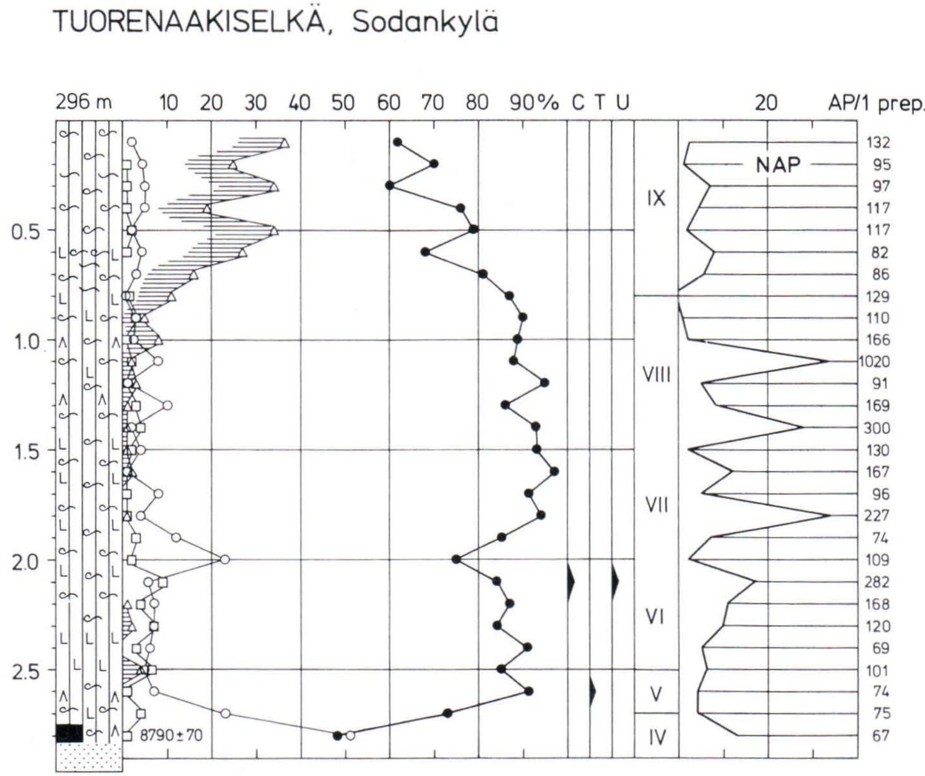

Fig. 20. Pollen diagram from Tuorenaakiselkä (Fig. 7). The coring point is near the spring (5 m) in profile A—B in Fig. 8. Legend: As in Fig. 19.

of *Picea* gradually increased until, during the last stage of forest history, i.e. the Sub-Atlantic period (zone IX), it had become a significant component of the pollen assemblages. During that time *Picea* attained approximately its present status in the forest of North Finland.

The proportion of pollen of herbaceous plants (NAP) in the diagram varies from 10 % to 40 % AP. At Värttiövaara the high frequency of NAP in the lower part of the diagram is largely due to the abundance of *Cyperaceae* pollen.

The pollen diagrams may also be dated on the basis of the relative abundance of tree pollen per preparation.

A sample of 1 cm^3 of fresh peat was boiled in 10 percent KOH, filtered and centrifuged. Twenty drops of stained glycerine were added to the centrifugate, and an aliquot of 0.5 cm^3 was brought to the boil on a metal sheet. One drop of the liquid was transferred to a microscope slide with a pipette and covered with a coverslip measuring 32×24 mm. The whole area of the preparation was examined. The concentration of tree pollen is given in the diagrams in numbers.

The tree pollen concentration remained comparatively low during the Sub-Atlantic period (zone IX), i.e. during the period marked by the dominance of

SÄYNÄJÄJÄRVI, Kittilä

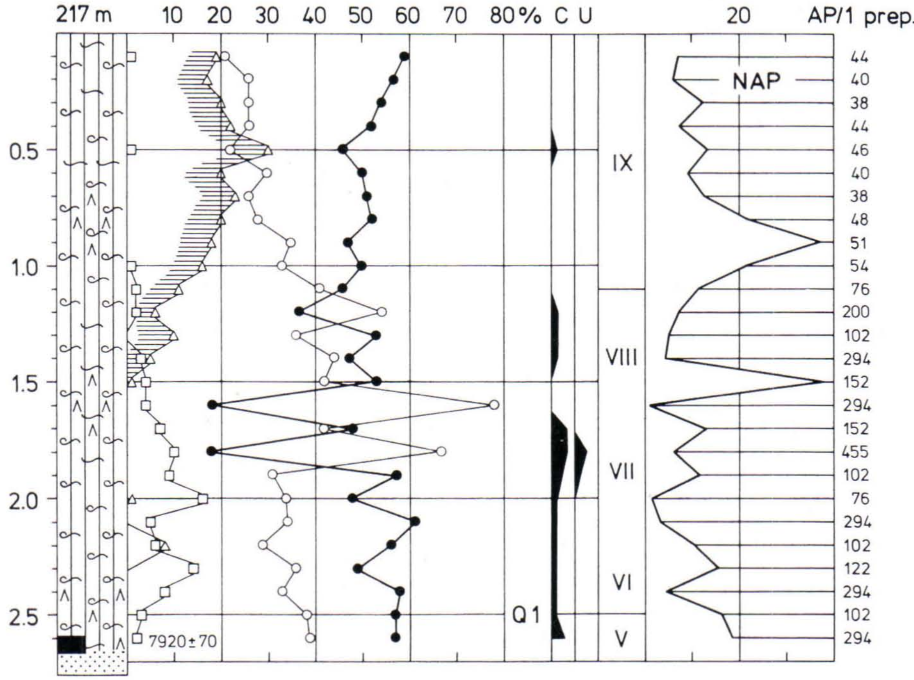

Fig. 21. Pollen diagram from Säynäjäjärvi (Fig. 9). The coring point is near the spring (3 m) in profile A—B in Fig. 10.

Picea. At the zone boundary VII/IX, the tree pollen frequency increased markedly and remained fairly high, although some fluctations are apparent, until the zone boundary V/VI when it decreased to approximately the level of the Sub-Atlantic period. Thus the Postglacial hypsithermal interval comprising zones VI to VIII can be recognised with the aid of tree pollen data.

The ^{14}C datings, which were carried out in the Laboratory of the Geological Survey of Finland, Otaniemi, are listed in Table 8.

The ages of the spring-fed mires were estimated on the basis of the four pollen diagrams and the eleven ^{14}C dates given above. It appears that the sites of those spring fens were originally forested (*viz.* the abundant wood remnants in the basal peat horizons). Thus, ar early as the Pre-Boreal period spring fens were developing mainly as a result of the paludification of heath forest the accumulation of peat being accelerated by ground water discharging or seeping from springs. The pollen diagrams suggest that the peat which contains wood remains dates from the Pre-Boreal and Boreal periods (zone IV—V), and it

SAMMALJOENSUO, Ylitornio

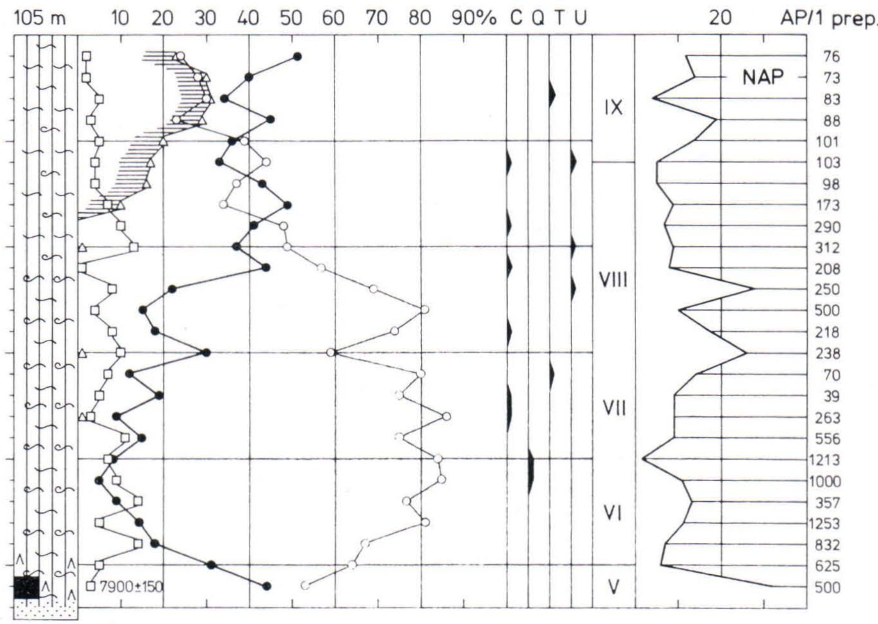

Fig. 22. Pollen diagram from Sammaljoensuo (Fig. 11). The coring point is near the large pool (3 m) in profile A—B in Fig. 13.

was only after that the woodless peat containing *Equisetum, Carex* and *Bryales* remains (zone VI) began to form. Paludification of the area surrounding the spring started an the beginning of the Atlantic period, and in spite of the 2 to 4 m thick peat bed, the springs are still open today.

SUMMARY AND CONCLUSIONS

The geobotanical interpretation of surficial groundwater conditions in Lapland by means of aerial photographs, especially in the zone of groundwater discharge, is based on observations of colours or sades of black and white, which in turn reflect the composition of the vegetation. The interpretation is often complicated, however, by the difficulty of specifying the mutual interdependence between soil and groundwater conditions and vegetation cover. In addition to these geological conditions, the vegetation is also affected by topography, exposure and microclimate, the significance of which factors it is often difficult to evaluate.

Infra-red aerial photographs are more rewarding than black and white photographs for this purpose. However, the high altitude copies (scale 1: 60 000)

Table 8
Radiocarbon-dated samples. Datings were carried out by Mr. Aulis Heikkinen at the Radiocarbon Laboratory of the Geological Survey of Finland.

Sample	Depth, m	Age B.P.	Age B.C.
Sammaljoensuo, Ylitornio			
Su-543: Lignin-*Bryales-Sphagnum* peat	3.72—3.83	6 230 ± 60	4 280
Su-544: Lignin-*Sphagrum-Carex* peat	4.20—4.24	6 830 ± 120	4 880
Su-545: Lignin-*Sphagnum-Carex* peat	4.35—4.41	7 150 ± 50	5 200
Su-546: Lignin-*Sphagnum-Carex* peat	4.58—4.63	7 900 ± 150	5 950
Värttiövaara, Kittilä			
Su-547: *Bryales-Sphagnum-Carex* peat	0.95—1.00	4 660 ± 40	2 710
Su-548: Lignin-*Sphagnum-Carex* peat	1.90—1.95	8 810 ± 50	6 860
Säynäjärvi, Kittilä			
Su-549: *Bryales-Carex* peat	1.95—2.00	4 530 ± 40	2 580
Su-550: Lignin-*Sphagnum-Carex* peat	2.76—2.80	7 920 ± 70	5 970
Tuorenaakinselkä, Sodankylä			
Su-551: Lignin-*Sphagnum-Bryales* peat	2.06—2.11	8 640 ± 120	6 690
Su-552: Lignin-*Sphagnum-Bryales* peat	1.95—2.00	7 910 ± 60	5 960
Su-553: Lignin-*Carex-Bryales* peat	2.76—2.80	8 790 ± 70	6 840

and the enlargements made from them which were employed in the present study allow for no more than a general interpretation to be made of the individual features of plant communites, in particular those in the zone of groundwater discharge. Field experience is essential before the photographs can be interpreted with sufficient reliability to enable specification of vegetation types and how they reflect the groundwater conditions.

Hydrogeological conditions (especially the moisture content of the soil) rather than grain size have the greatest effect on the nature of the vegetation and thus on its colour or shade in the photographs. These hydrogeological factors have more effect in areas of sand and gravel than in areas covered by till, where the water content is often higher irrespective of the position of the groundwater table. Although the composition of the bedrock has both a direct effect on the vegetation and an indirect effect through the lithological composition of the soil, its impact it always less pronounced than that of the water conditions.

The interpretation of aerial photographs allows a crude distinction to be drawn between zones of groundwater recharge and discharge (Fig. 23). The former are relatively high areas such as till-covered hills and eskers and the latter consist of the intervening low-lying areas occupied by mires and water courses. The border between these two zones is transitional (intermediate zone) and partly dependent on seasonal changes in the position of groundwater table. The zones of recharge, where the groundwater table is well below the surface, are comparatively barren dry heaths and support a fairly small number of plant

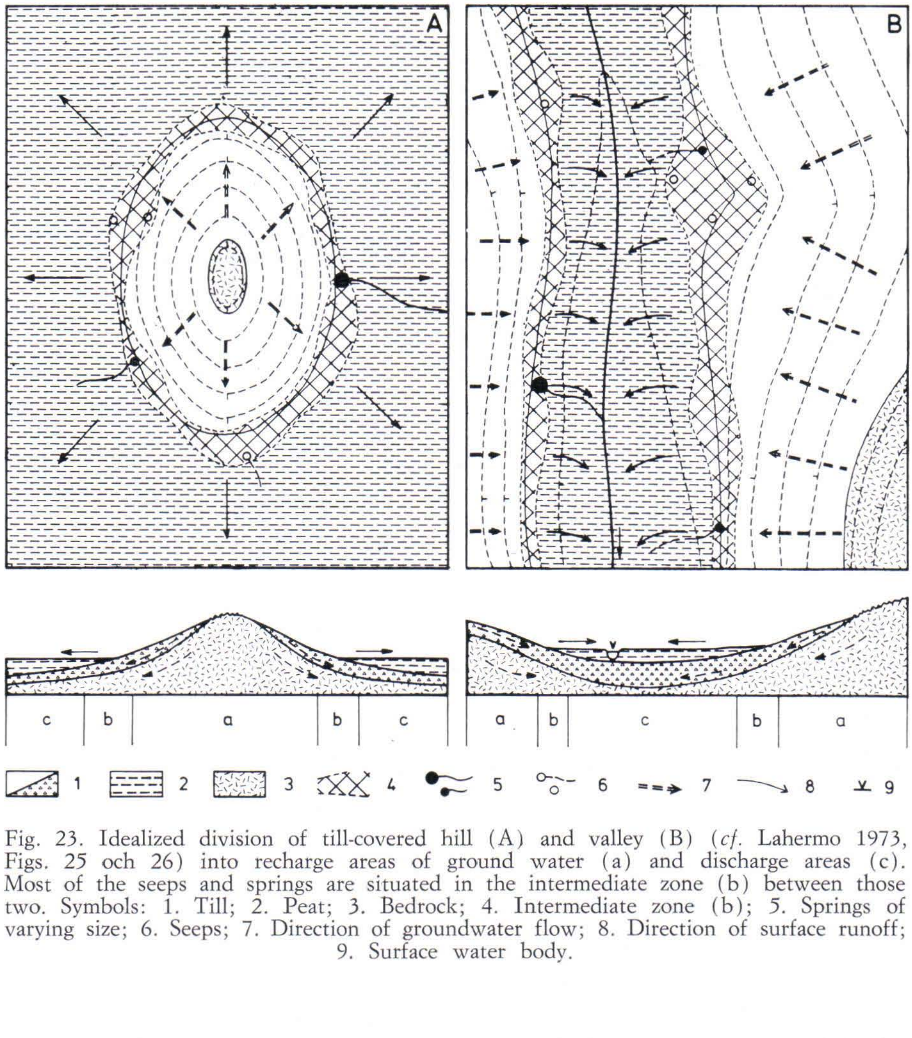

Fig. 23. Idealized division of till-covered hill (A) and valley (B) (*cf.* Lahermo 1973, Figs. 25 och 26) into recharge areas of ground water (a) and discharge areas (c). Most of the seeps and springs are situated in the intermediate zone (b) between those two. Symbols: 1. Till; 2. Peat; 3. Bedrock; 4. Intermediate zone (b); 5. Springs of varying size; 6. Seeps; 7. Direction of groundwater flow; 8. Direction of surface runoff; 9. Surface water body.

species. On the upper slopes of the hills the till deposits are thin and bedrock outcrops occur frequently, so that the vegetation is sparse. On the lower slopes the deposits are thicker and generally contain more fines. Consequently, on forested hills, the vegetation is usually more diversified and richer towards the lower parts of slopes, owing to the increased moisture made available by the proximity of the water table and as a consequence of grain size distribution too.

The gradation of vegetation zones is not always as regular as described above. High up on the slope of a hill a finer-grained soil may give rise to patches of rich vegetation which are distinctly more luxuriant than that of the surroundings. Furthermore the vegetation of depressions and gullies on the slopes of a hill into which runoff is concentrated is frequently more luxuriant than that of the surrounding area, irrespective of the composition of the soil and the hydrogeological conditions.

Most of the springs are situated in the transitional belt between minerogenic soils and adjacent mires (Fig. 23). The interpretation of infra-red photographs of this belt where both the hydrogeological conditions and the vegetation is more variable, is most rewarding. The zone of groundwater discharge, especially at the spring sites, is moist and hence the vegetation is more luxuriant and contains a greater variety of species. On the other hand, the abundance of details makes interpretation a difficult task. In zones of ground water discharge such as spring-fed mires and the paludified margins of hills a wide vartiation is exhibited, not only in the vegetation, but also in the surficial structure and composition of the peat. Even in areas such as these, the great diversity of shade in infra-red aerial photographs is due rather to variation in moisture conditions at the surface of the mire than to variations in the vegetation.

The margins of the ground water discharge zones bordering on the slopes of hills appear on the infra-red photographs as narrow, reddish bands of trees, and at the edges of mires, as pale, somewhat wider zones of pine bog. These pine bogs are not always present and the wet sedge communities may extend right to the margin of the bog. The waterlogged parts of the mires are generally dark in colour.

The ground water discharges are generally located at the junction between the zones of recharge and discharge or slightly lower down on the mire. If the spring is on a very gentle slope or in a low depression, *Bryales*-dominated eutrophic peat will have started to grow at the site of seeping or discharge. The formation of this minerotrophic peat is restricted to the area affected by the ground water, there being hardly any *Bryales* peat above the spring. This indicates that groundwater has been discharged from the same site throughout the evolution of the spring-fed mire.

The seeping springs situated further out on the mire are usually marked by wooded peat hummocks or islands of eutrophic vegetation rising above their environment, and having a spring pool in the middle of the hummock. In some of the spring the pool has been completely grown over. Similar "crater" -like spring hummock, although different in internal structure, have been encountered in Sweden (*cf.* Osvald 1937, pp. 190—191; Lundquist and Granlund 1957, p. 570) and in the Leningrad region of the Soviet Union. In the latter area, they may be as high as 2.5 m, with a diameter of from 50 to 60 m (Bogdanowskaya—Guihéneuf 1926), and are thought to have developed as the result of the felling of alders on slopes rich in springs.

Pollen analysis suggests that peat began to form at the oldest spring sites 8 800 years ago (Fig. 19), at the end of the Pre-Boreal and beginning of the Boreal period. The intense paludification may possibly be attributed to the change in climate, the increasing humidity being accompanied by a rise in average temperature. The higher rainfall probably served to raise the ground water table and cause the ground water to discharge through springs on the lower slopes of the hills, thus hastening the process of paludification. However, the rise of a few degrees the average temperature and the increased rainfall during the Pre-Boreal period need not necessarily have led to rise in the groundwater table. The higher temperature could have speeded up the rate of evaporation so that the formation of ground water was even reduced (*cf.* Aario 1966; Lahermo 1971). Ground water had probably started to discharge at the same spring sites before the groundwater table began to rise and the forests started becoming paludified in the Boreal period. Even so climatic conditions in Finland did not change sufficiently to favour paludification until the Atlantic period and after.

The ground water which discharged onto the surface of a minerogenic soil before paludification, nowadays rises on the top of a peat layer several metres thick in the case of many spring fens. Consequently the paludification of spring areas has caused a corresponding local rise in the groundwater table. Since the Atlantic period, this rise has been of 3 to 4 m at maximum on the lower slopes of some hills and eskers. The discharge from most of the seeping spring hummocks is very slow or partically nil. In summer the temperature of the spring waters (2,5° to 4° C) is lower than that of the surface water in the surrounding mire, which indicates that seepage is, however, taking place. Moreover the composition of the seeping water is typical of ground water and differs appreciably from that of surface water on the mire, the latter frequently containing less material in solution but more humus than the former (high $KMnO_4$ consumption value, Table 6).

Although the discharge rate of the ground water is low, it is sufficient, when one considers the total evolution of the spring fen, to prevent the spring pool from being completely covered by peat. It appears, however, that most of the seeping springs will eventually be covered by a floating peat layer, this process already being well beveloped in many of them. One explanation for this may be the decrease in the hydrostatic pressure of the water and smaller discharge resulting from the thickening of the peat layer. Another explanation may be the slight areal lowering of the ground water table in recent times. In the experience of the present authors, several springs have diminished or dried up in the last 10 to 15 years, a fact which is, however, frequently attributed to the artificial draining of mires and paludified forests.

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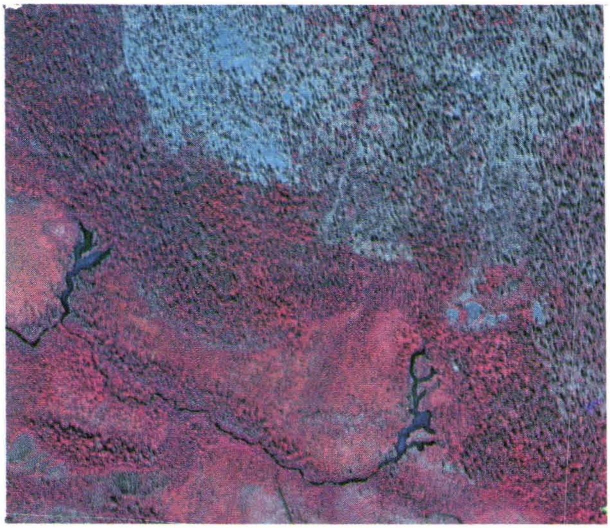


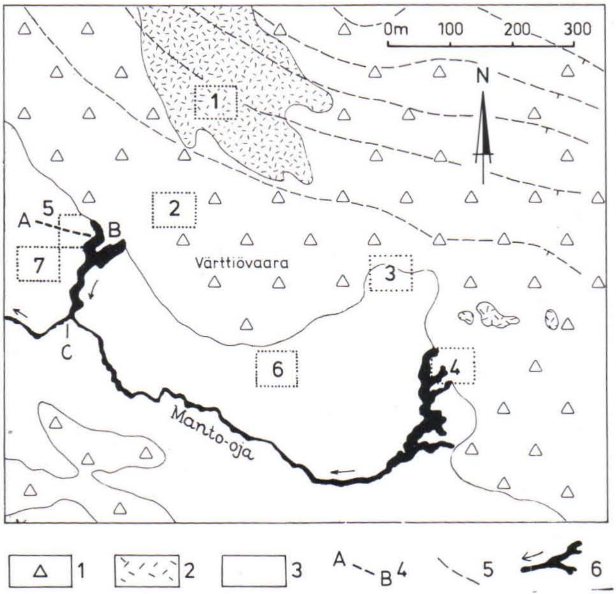
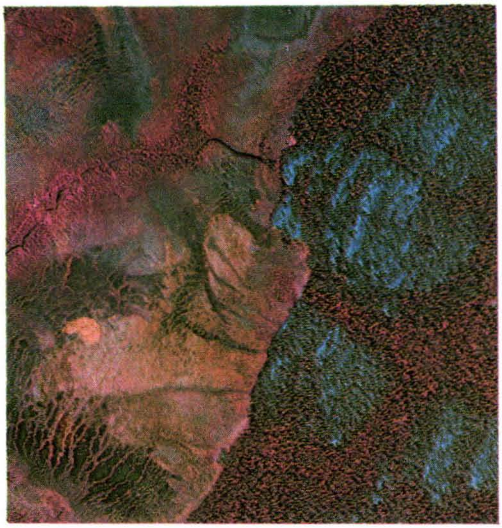


Plate I. Upper: Infra-red aerial photograph of the Värttiövaara site about 3 km NE of Tepsa, a village in the commune of Kittilä (topographic map 3712/07). See text for additional details. By courtesy of the Army Map Service (Topografikunta).

Lower: The interpretation of the photograph. The Värttiövaara site comprises part of the WSW slope of a till-covered hill and the hill-slope fen at the foot of it. Test areas 1—7 for vegetation analysis (*cf.* Table 1) and line A—B are indicated. The site at which discharge was measured is marked C. Legend: 1. Till; 2. Block field (physically weathered bedrock); 3. Mire; 4. Levelled and cored line A—B; 5. Contour lines (10 m intervals); 6. Springs and spring-fed streams.



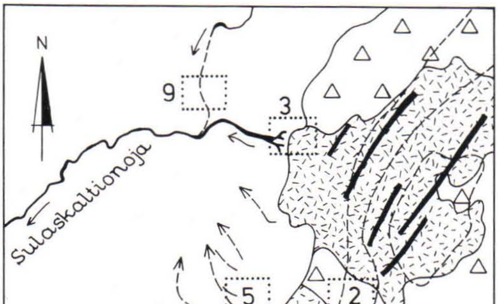


Plate II. Upper: Infra-red aerial photograph of the Sulaskaltionoja site about 10 km E of Kelontekemä, a village in the commune of Kittilä (topographic map 3712/07). By courtesy of the Army Map Service (Topografikunta).

Lower: The interpretation of the aerial photograph. The Sulaskaltionoja site comprises part of the NE slope of the till-covered hill Nopannenä, and the mire at the foot of it. Test areas 1—9 for vegetation analysis are indicated. Legend: 1. Spring and the stream originating from it; 2. Direction of flow of surface runoff and ground water seeping onto the mire; 3. Lineament caused by tectonic features. Other symbols as in Plate I.

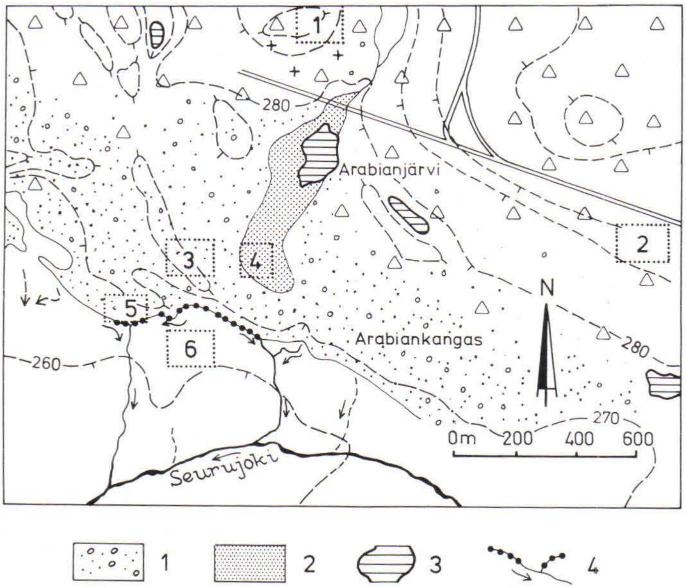
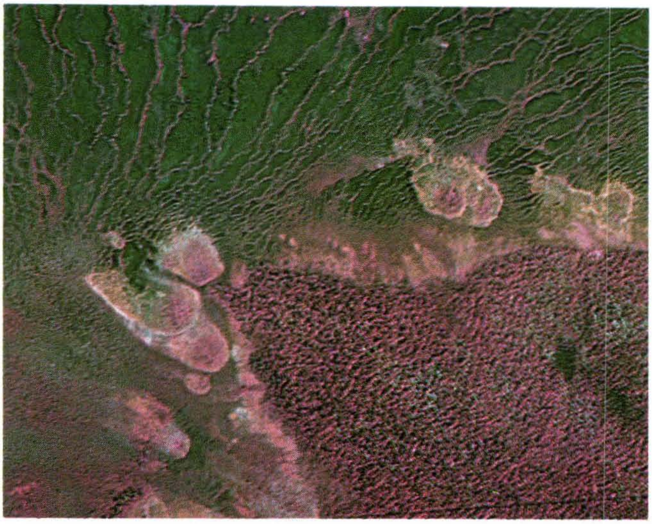


Plate III. Upper: Inra-red aerial photograph of the Arabiankangas site, about 14 km SSW of Pokka, a village in the commune of Kittilä (topographic map 3722/07). By courtesy of the Army Map Service (Topografikunta).

Lower: The interpretation of the aerial photograph. The Arabiankangas site comprises part of the slope of a till-covered hill, some sand and gravel deposits and the adjacent mire. Test areas 1—6 for vegetation analysis are indicated (Table 3). Legend: 1. Sand and gravel; 2. Medium sand; 3. Open water body; 4. Springs and streams originating from them in the border zone of the mire. Other symbols as in Plate I.



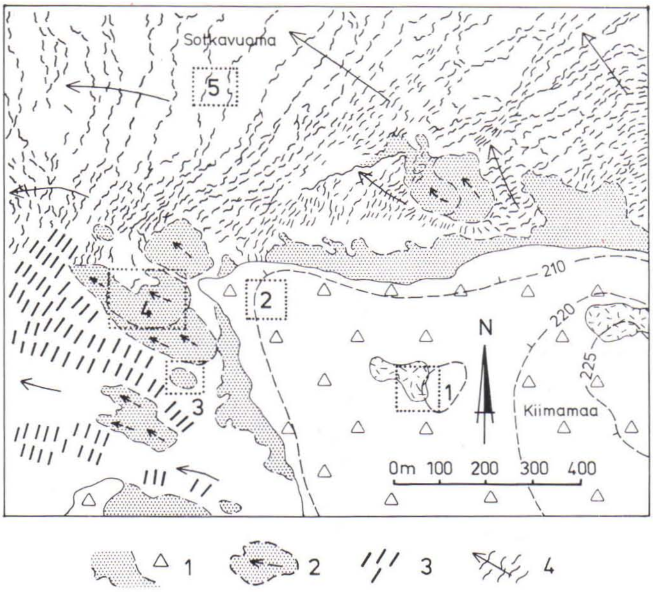


Plate IV. Upper: Infra-red aerial photograph of the Sotkavuoma site, about 5 km S of the village of Kelontekemä (topographic map of 3711/6). By courtesy of the Army Map Service (Topografikunta).

Lower: The interpretation of the aerial photopragh. The Sotkavuoma site comprises the NW slope of the low till-covered hill Kiimavaara, and the adjacent Sotkavuoma mire. Test areas 1—5 for vegetation analysis are indicated (Table 4). Legend: 1. The belt of pine bog bordering the hill; 2. Elongated patches of wooded rich fen around seeps with the direction of seepage; 3. Small closely spaced peat strings; 4. Larger peat ridges with the direction of runoff (see Fig. 6). Other symbols as in Plate I.

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