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by Pertti Lahermo

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THE GROUND WATER OF CENTRAL AND WEST LAPLAND INTERPRETED ON THE BASIS OF BLACK AND WHITE AERIAL PHOTOGRAPHS

BY

PERTTI LAHERMO

WITH 38 FIGURES AND TWO TABLES IN THE TEXT

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Ground water is formed most abundantly in glaciofluvial deposits such as eskers, kame fields, outwash plains, deltas and sandurs. Till deposits are usually weakly pervious. However, the intercalated lenses and beds composed of stratified drift act as underdrains for the ground water of the environment.

All over the investigation area the surface of the bedrock is broken up by ice wedging or preglacial weathering, so that even fairly shallow drilled wells yield appreciable amounts of ground water. The supply of ground water from very broken subsilicic bedrock is greater than that from deeper wells drilled in silicic bedrock areas.

Aerial photographic interpretation can be successfully used to localise the most significant surficial deposits containing ground water. Stereo examination of the level of the water table enables preliminary conclusions to be drawn concerning the directions of percolation and areas of discharge of the ground water. Springs and seeps and especially the direction of the flow of water on the surface of peat bogs can be established from aerial photographs, occasionally even more successfully than in the field. Photographic interpretation allows detailed inventories of springs to be compiled rapidly.

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INTRODUCTION

The primary aim of this investigation was to describe the modes of occurrence of ground water in different geological environments in Central and West Lapland (Fig. 1). Since it was not possible to carry out detailed field investigations over the whole of this extensive area, the stereoscopic interpretation of black and white aerial photographs was employed. The secondary aim was to establish the feasibility of aerial photographic interpretation in hydrogeology. North Finland and particularly Lapland provide excellent objects for this because of the sparsely timbered forests

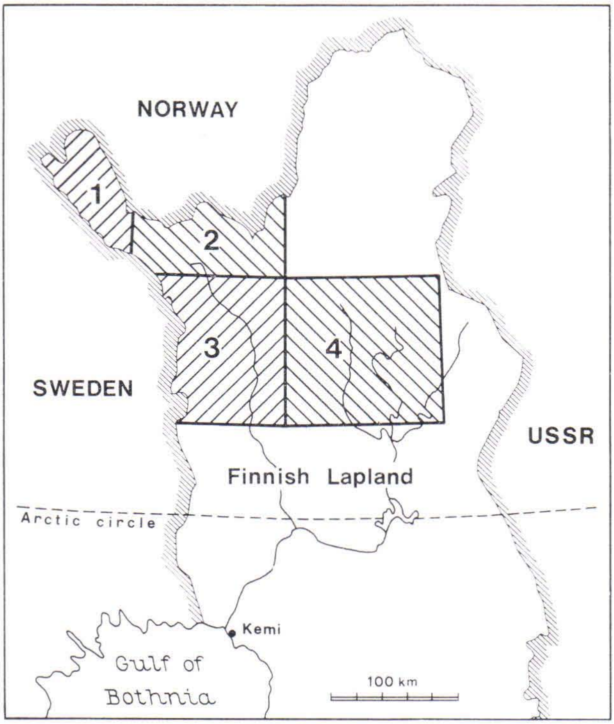

FIG. 1. The location of the investigation area in Finnish Central and West Lapland. The areas covered by the 1 : 400 000 map sheets of 1) Kilpisjärvi, 2) Enontekiö, 3) Kittilä and 4) Sodankylä (the corresponding map sheets of surficial deposits: Penttilä, Kujansuu 1964, Kujansuu 1966, 1967).

and ground vegetation. In addition, most of the study area belongs to the supra-aquatic zone (cf. Hyyppä 1966). This means that there has been no significant deformation of the surficial deposits by littoral forces and they are easily recognizable as primary.

In addition to the field work done for this study carried out from 1962 to 1972, almost 4 000 black and white aerial photographs were interpreted. All the interpretations were made from paper prints. The type areas selected on the basis of these photographs as being most representative of the occurrence of ground water are presented as hydrogeological maps. The surficial deposits and ground water conditions of each type area have been checked by field studies.

Although photogeology is increasing in popularity for ground water investigations, there have been no extensive studies on its applicability in Finland, where it has been discussed only in a few brief articles (Salmi 1971, Kujansuu 1971, Lahermo 1972). Elsewhere, the application of photogeology to ground water investigations has been treated at length (eg. Howe 1958, 1960; Meyer, Markovskiy 1962; Lattman, Parizek 1964; Lohman, Robinove 1964; Heath, Trainer 1968 and Newton 1971). However, the different geological conditions in Finland limit the application of these results in this country and in other glaciated regions with Precambrian bedrock.

Hydrogeological photo interpretation is applicable particularly to reconnaissance and regional ground water investigations. Thus, the more detailed, time-consuming and costly field studies can be directed towards those areas which appear most favourable for supplies of ground water. The greatest benefits from photo interpretation are gained in North Finland, in Lapland in particular, where field studies entail the covering of great distances over difficult terrain.

Aerial photo interpretation enables the conditions of the percolation and discharge of ground water and runoff to be established. This information aids the interpretation of the results of explorational geochemical investigations. The discharge of ground water is a contributory factor in the process of paludification. For this reason, the findings of this study may be applicable to forestry and botany as well as to peat investigations.

ON THE PHOTOGEOLOGICAL INTERPRETATION OF SURFICIAL DEPOSITS

The black and white aerial photographs taken for general survey are being successfully applied to investigations and mapping of surfical deposits in Lapland. The large-scale aerial photographs (1 : 20 000—30 000) can be used for detailed interpretations, and the small-scale photographs (1 : 40 000—60 000) for interpretations of large areas, particularly in studies on the genesis of surficial deposits. Prerequisites for successful photogeological interpretation are that the types of surficial deposits in the area be well known and that the results of the interpretation be checked with sufficient thoroughness in the field.

The differences in the topography of the terrain are greatly exaggerated in the stereo examination of aerial photographs, so that even the slightest morphological variations are revealed. Most glaciofluvial deposits, such as eskers, kame fields and outwash plains, can also be discerned by their characteristic morphology (cf. Bergström 1960, Penttilä 1961, Kujansuu 1967, Kihlbom 1970, 1971). With the exception of drumlin and hummocky moraine areas, till deposits have no characteristic shape. Usually those areas can be interpreted as till which have none of the features characteristic of other surficial deposits. The shadow thrown by the deposits in the aerial photographs also provides data concerning their morphology.

Indications of the types of deposits are also given by their location; eskers and outwash plains occur most typically in valleys, deltas and sandurs at the mouths of overflow drainage channels, and littoral deposits on the lower slopes of hills below the outwashed outcrops. If the highest marine level is known, the supra-aquatic and subaquatic surficial deposits can be distinguished from one another.

The advantage of aerial photo interpretation is that large geological units can be distinguished which in the field disintegrate into an irregular mosaic. By following the continuity of the patterns over a large area, it can be ascertained whether the object of interpretation is an esker or an outwash plain even though they do not occur coherently. Genetically diverse deposits can often be distinguished from one another on the bases of their difference in size, e.g. small dunes can be distinguished from extensive eskers.

A noticeable feature in the interpretation of aerial photographs is the sharpness of the borders. The sharp shore lines in watercourses indicate steep slopes and deep shores composed of coarse stratified drift, till deposits or bedrock. Transitional shore lines indicate gently sloping shallow shores often composed of fine-grained minerogenic or organic deposits.

Ecological indications come next to morphological indications in the interpretation of the quality of surficial deposits (see e.g. Tomlinson, Brown 1962, Moskalenko, Tagunova, Turmanina 1965). There is a close relationship between the grain size and moisture content of surficial deposits and vegetation. The ground water table in coarse-grained pervious sand and gravel is usually at a depth of several metres. Due to the dry soil the vegetation is meager. Pine is the main arboreal species and the ground is extensively covered with grey lichen which has a strong light-reflectance. A glaciofluvial field such as this shows up in a light grey tone on black and white aerial photographs (c.f. Fig. 8). In moist till terrain with a fine grain size, spruce and various deciduous trees predominate. The ground vegetation is more lush than in sand and gravel areas. Hence, on black and white aerial photographs, till is depicted by rather dark shades, depending on the type of vegetation (c.f. Fig. 18).

However, it is not always possible to distinguish stratified drift and till by their shade. The vegetation on dry, coarse-grained till is similar to that on sand and gravel ground. In addition, similar surficial deposits may be depicted by different shades depending on hydrogeological conditions. The coarse-grained till on the upper slopes of hills shows up lighter than the moist till of similar composition on the lower slopes. If an esker is covered by a till sheet, the primary glaciofluvial deposits can only be interpreted by morphology. In southern Finland the stratified drift and till deposits are not easily distinguishable on the basis of differenses in tones because of the lush ground vegetation and thick forest even in sand and gravel areas. There are also many other factors affecting the shade of the surficial deposits in aerial photographs, e.g. techniques and photographic material, the time when the photographs were taken, the seasons and the weather conditions.

Aerial photo interpretation allows the composition of surficial deposits to be estimated. The material of extensive gently sloping eskers is likely to be well-sorted sand and gravel, whereas in steep and narrow eskers it is coarser and more weakly sorted. The flat edges surrounding an esker usually consist of finer material than the ridge. The composition of the stratified drift in the different parts of glaciofluvial deltas and sandurs usually varies, the material on the proximal side being more coarse-grained than that on the distal side. The dunes at the edges and on the top of glaciofluvial deposits suggest silt- and sand-rich primary esker material.

Runoff* is slight on pervious sand and gravel deposits. Since most of the unevaporated rain water infiltrates into ground water there are only a few fairly straight streams from which forking is almost absent. On the other side, in even sand plains there are frequently meandering rivers and brooks. Sliding bare sand embarkments caused by fluvial erosion are seen light in aerial photographs. Observations on the drainage patterns of streams in the terrain also aid the identification of till deposits in some cases. Runoff is greater in till regions because the ground is less pervious. Hence, there is a close network of forking and meandering streams which form rapids in rocky till deposits. However, the fracture tectonics of the bedrock is usually the decisive factor in the formation of the drainage pattern.

Roads and paths are more abundant on flat sand and gravel deposits than on till because the former are more passable. Ditches are often unnecessary at the edges of the less important roads on sand and gravel deposits. Arable land occupies small areas in till terrain and the fields are often bordered by walls and heaps of stones. The forementioned factors all furnits indirect indications of the composition of the surficial deposits.

Aerial photo interpretation can sometimes be used for preliminary estimations of the thickness of the surficial deposits on the basis of their morphology and location (see e.g. Kihlbom 1970). The eskers and outwash plains in deep, steeply sloping valleys are probably of a considerable thickness. The frequency of outcrops and the slope of their walls in outwash plains often enable the thickness of the sand and gravel deposits in the immediate environment to be extrapolated. The depth of the dry glaciofluvial erosion channels and the present river beds also give indications as to the minimum thickness of the deposits. If the rivers flowing on outwash plains are rocky with many rapids, then probably the river basin has cut down through sand and gravel deposits to a stony till bed or to the bedrock.

* In this paper, runoff denotes both surface runoff and overland flow.

ON THE PHOTOGEOLOGICAL INTERPRETATION OF GROUND WATER CONDITIONS

The interpretation of aerial photographs has become an important method of investigation for ground water hydrologists. The varied possibilities offered by photogeological interpretation can be utilised in winter when field observations are not feasible. However, the hydrogeological interpretation of photographs will not succeed unless the mode of occurrence of the ground water is well-known. The interpretation can be facilitated by a thorough study of some limited and typical areas. This information can then be applied to new areas. The photographs are especially valuable as reconnaissance aids, both in the interpretation data already available and in the planning of further field investigations (Heath, Trainer 1968, p. 210).

Extensive glaciofluvial deposits containing abundant ground water can quickly be located and delimited with photographic interpretation (see e.g. Howe 1958, 1960, Meyer, Markovskiy 1962, Lahermo 1972). This is of particular significance in areas whose surficial deposits have not previously been mapped in detail. Preliminary conclusions can likewise be made as to the mechanical composition of the material and hence of its permeability (cf. p. 8).

Information concerning the ground water table can be obtained from aerial photographs by making observations on esker ponds, gravel pits with water at the bottom, springs, peat bogs and water bodies in the immediate environment. The morphology of the glaciofluvial deposits also provides indications of the location of the ground water table.

The establishment of ground water conditions from aerial photographs is mainly based on the mutual dependence which exists between vegetation and geological composition and the structure of the surficial deposits and bedrock, ie. on geobotany (cf. p. 7). In pervious sand and gravel deposits the variations in the vegetation can be used to roughly estimate the proximity of the ground water table. If there are deciduous trees and lush ground vegetation in the kettles and depressions of the eskers or outwash plains, the ground water table is near the surface. These areas show up darker on black and white photographs than do the drier areas in the vicinity. Also in hummocky moraine areas, on the lower slopes of hills and in the littoral zones of watercourses, the proximity of the ground water table appears as darker zones bordering on higher areas or as paludification.

The actual ground water table is not always well-developed in till rich in fines but rather the water content in the soil decreases upwards as a result of evaporation and transpiration. For this reason, the rough ground water table of till deposits with varying grain size may fluctuate considerably even over a short distance. There is often perched water on the more pervious till sheets overlying the weakly pervious till deposits, so that the hygrophytic, lush vegetation in the hollows high up on the slopes of the hills does not generally indicate the proximity of the ground water table. Where the altitudes of several adjacent ponds are markedly discordant, this discordance of water levels suggests that ponds are perched (Heat, Trainer 1968, p. 208). The shallow perched ponds in till areas often disappear altogether during dry seasons. In summary it can be stated that from aerial phtographs it is much more difficult to determine the true ground water table for till deposits than for permeable sand and gravel deposits.

The decrease of water-surface altitude in a series of lakes and ponds, consistently in one direction and along a credible gradient, suggests that the lakes are hydraulically connected with each other and that their levels mark the local position of the water table (Heath, Trainer 1968, p. 208). This inference is corroborated by the presence of pervious glaciofluvial material around the lakes. If the position of the water table in the different parts of the glaciofluvial or till deposits is known in this way, the directions of percolation can be determined and the dividers of the ground water localised. Hidden rock ridges dividing eskers into separate ground water basins can sometimes be localised on the basis of the structure of the bedrock in the environment (Salmi 1971).

Photo interpretation also enables the levels and areas of ground water discharge at the edges of glaciofluvial and till deposits to be established. In some places the discharge areas can be found more easily with aerial photographs than in the field. Using stereoscope magnification, the rivulets originating from springs and large seepage belts can be observed, particularly in the peat bogs surrounding eskers and till-covered hills (p. 28). Even though the springs cannot always be observed directly from aerial photographs, their location can often be predicted with the aid of the morphology of the deposits and the direction of percolation of the ground water. Photo interpretation is also a practical way of establishing the direction of runoff on hill slopes and peat bogs (p. 34, Lahermo 1972).

The quantity of the ground water discharging as springs at the foot of eskers and till-covered hills can be roughly estimated with photo interpretation. By establishing the possible discharge conditions of the ponds in the eskers and kame fields, the amounts of ground water can likewise be roughly estimated. Thus, field investigations concerning the rate of flow can be directed towards areas delineated in advance and some parts of the areas can be completely disregarded. The interpretation of ground water discharge and runoff is discussed in more detail on pp. 28—34.

The amount of infiltrated ground water can be roughly estimated for each area from aerial photographs on the basis of the extent, topography and local rainfall in the infiltration area. More ground water is infiltrated in outwash plains, kame fields and extensive gently sloping eskers composed of pervious material than in narrow, steep eskers whose material is less wellsorted. Under favourable conditions, as much as 50—80 % of the annual rainfall is infiltrated as ground water (see Lahermo 1971 b). The annual rainfall of the area under investigation is 400—600 mm. According to this, 6—14 litres of ground water per second could be obtained from one square kilometre under favourable conditions.

THE OCCURRENCE AND AERIAL PHOTOGRAPHIC INTERPRETATION OF GROUND WATER IN STRATIFIED DRIFT

Eskers and kame fields

Most of the eskers in the area under investigation were formed subglacially. They were deposited by the glaciofluvial melt waters of the Scandinavian ice sheet in either crevasses or tunnels (Kujansuu 1967). The eskers which were formed in these crevasses follow the gradient of the surface of the earth in the same way as running water. Conversely, the melt waters which flowed through glacier tunnels were possibly under high hydrostatic pressure, which would explain why some

FIG. 2. A typical steep-sloped esker composed of glaciofluvial sand, gravel and pebbles exposed in a road cut. On the right-hand side of the esker there is a pond, whose water surface indicates the ground water table of the esker. Raastajoki, to the North of the village of Palojärvi, Enontekiö.

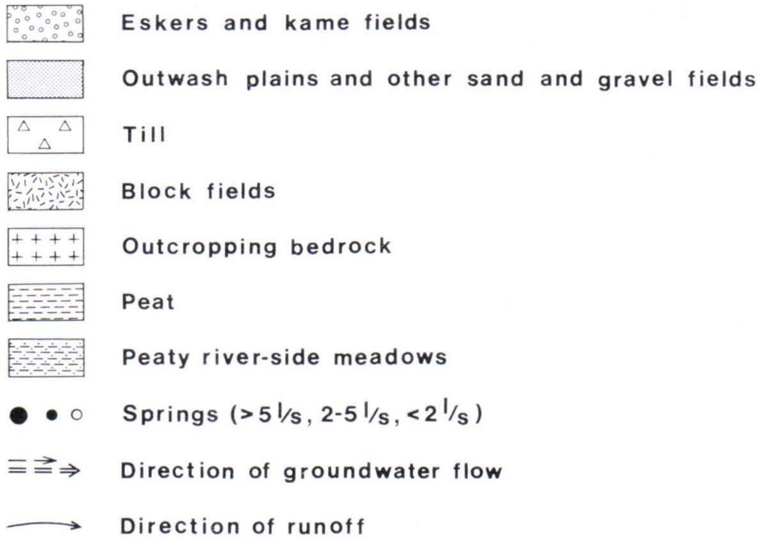

FIG. 3. Explanation of symbols used in the text maps.

eskers are located independently of the gradient. Deformed stratified structures show that in some rare cases the eskers were deposited by the flowing melt water englacially or supraglacially, either inside or on top of the ice sheet.

Here and there the eskers occur as several parallel ridges or as extensive esker enlargements. There are kame fields with characteristically varied topography consisting of mounds and roundish kettles formed by buried ice. It seems likely that some of the kame fields in the investigation area were formed supraglacially. The most common type of esker in the area under investigation is a steep and fairly narrow ridge composed mainly of glaciofluvial sand and gravel (Fig. 2, cf. Kujansuu 1967, Fig. 24). The amount of infiltrated ground water depends on the size, coherence and location of the esker, as well as on the permeability of its material. In some places the material is weakly sorted so that only small amounts of water are infiltrated. The eskers on high »dry» slopes of hills or fells are not able to store ground water to any appreciable amount.

The extensive and flattened eskers of the investigation area are usually composed of well-sorted sand and gravel (op.cit.). Therefore, they are most favourable as infiltration areas of ground water. The eskers in flat areas are surrounded by paludificated till terrain. An example of this is the esker on the southwestern side of Hietatievat in Enontekiö (Figs. 3, 4). The infiltrated water comes for the most part from the rain which falls on the esker ridge itself. The amount of ground water formed in this »direct infiltration» (cf. de Geer 1968, 1970) depends mainly on the extent and topography of the esker ridge as well as on the permeability of its material. Mälkki (1972)

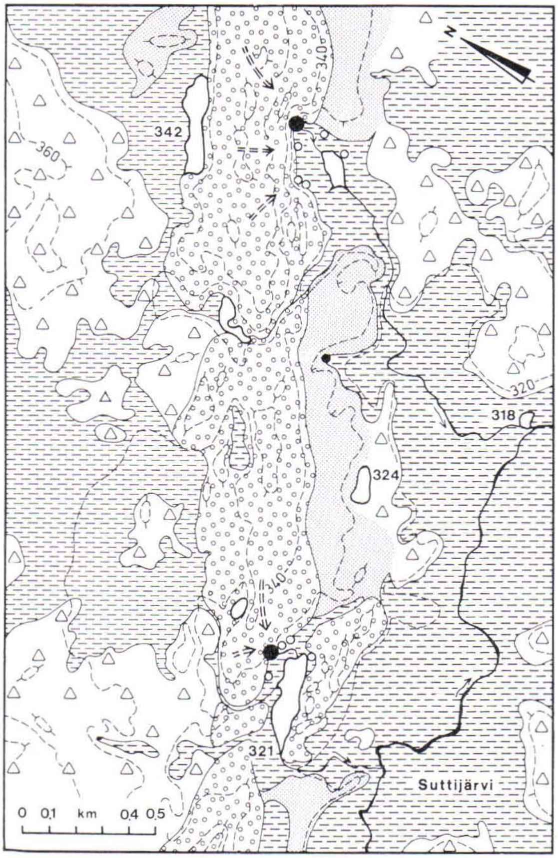

FIG. 4. An esker in a fairly flat paludificated area (cf. Fig. 5 a). The large spring in the northeastern part of the esker is depicted in Fig. 6. The mapping of the surficial deposits and the estimation of the direction of the ground water percolation were carried out by photographic interpretation. See text.

has given the name »anticlinic» to this type of esker ridge, on the basis of the mode of infiltration of the ground water (Fig. 5 a).

The ponds and peat bogs in the kettle holes on the esker and in its immediate environment show the approximate location of the ground water table. On the basis of stereo examination and the figures indicating the absolute elevation, it can be concluded that the ground water table is slightly higher on the northwestern side of the ridge. Hence, the percolation of the ground water is perpendicular to the direction of the esker sequence (Fig. 4, arrows) although some water may also come farther from the till area. The ground water discharges as large springs on the southeastern side of the esker. The discharge is greatest at the foot of the

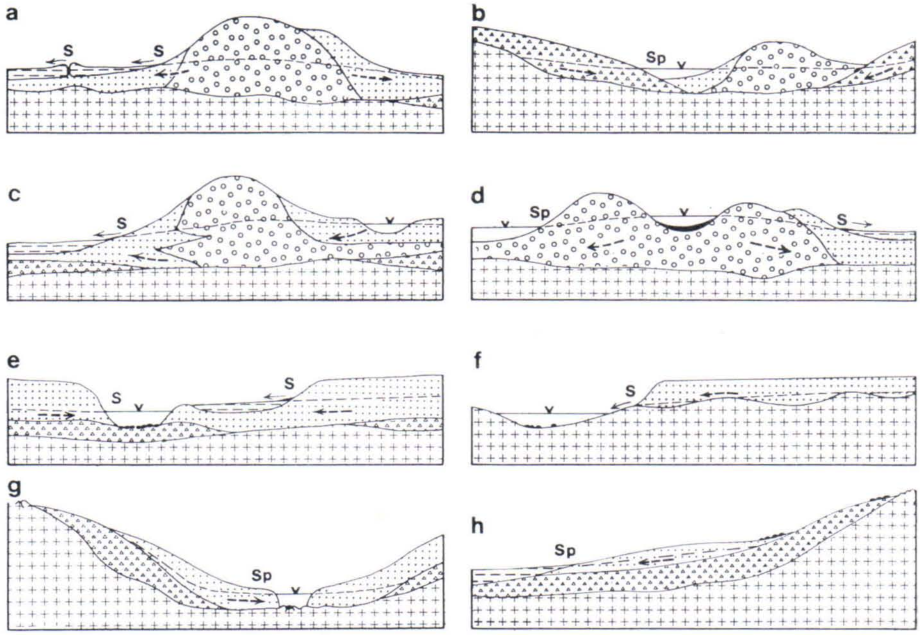

FIG. 5. Schematic profiles illustrating the percolation and discharge of ground water in deposits composed of stratified drift. S, spring, Sp, seepage belt or seep. In sections a—d the core of the esker and kame field composed of coarse material is marked with circles whereas the fines on the top and at the edges is indicated by dots. Other symbols are the same as in Fig. 3.
a: An »anticlinic» esker on flat terrain. The ground water is discharged into the environment. b: A »synclinic» esker in a valley collecting ground water from its surroundings. c: Natural recharge through the esker. d: The ground water in a kame field. Owing to the fine-grained material accumalated on the bottom of the kettles, the water table may be on a rather high level. e: An outwash plain in a river valley. Ground water discharges into the watercourse. f: An outwash plain deposited on bedrock higher than the water surface of the river. g: Outwash deposits partly underlain by till and sloping towards a river. h: Littoral sorted deposits on a lower slope of a till-covered hill. Most of the ground water is perched water. See text.

esker in the farthest corners of the small lakes and ponds where the ground water table is at its lowest level. The largest springs, which produce 10—15 litres per second, have formed sliding banks in easily eroding fine sand material on the steep slopes of the esker (Fig. 6). These bare slopes, which show up white on the aerial photographs, make the springs easier to distinguish.

Because of their origin, eskers occur most commonly on low-lying terrain, at the bottom of or on the lower slopes of elongated valleys. Hence, the large-scale fracture tectonics of the bedrock has had a decisive influence on the location of the eskers (Kujansuu 1967). Eskers of this type favour the infiltration of ground water because the flow is from the surrounding terrain towards the esker ridge. Hence, these eskers which act as collectors of ground water and whose water is

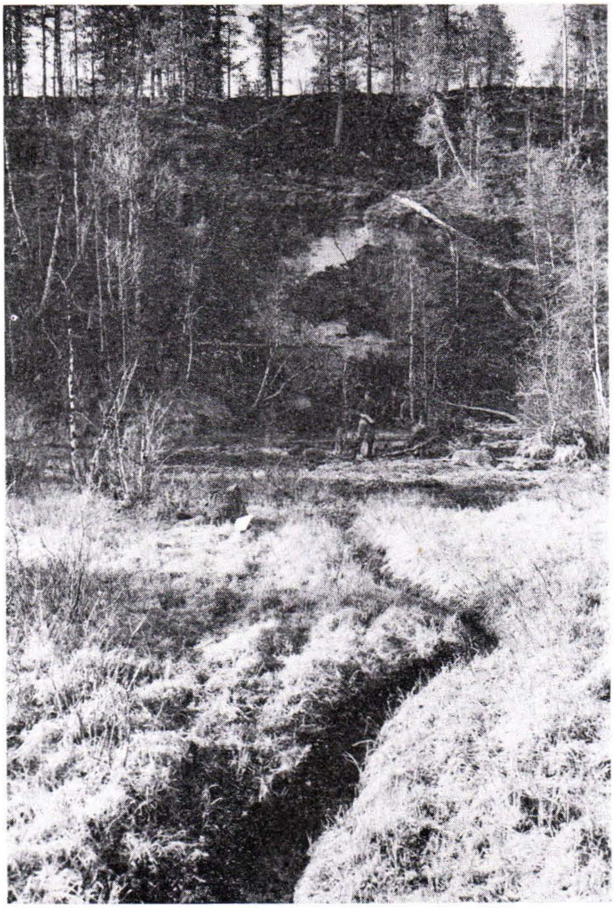

FIG. 6. Large springs from which a rivulet originates at the foot of the esker ridge. On the steep slope of the esker there are bare sliding fine sand and sand patches (light) caused by discharging ground water. The foreground is occupied by a sedge bog with subshrubs (primary Betula nana). The discharge is over ten litres per second. See text and Fig. 5 a.

mainly due to indirect infiltration may be called »draining eskers» (Fig. 5 b) (cf. de Geer 1968, 1970) or »syncline» eskers in accordance with Mälkki (1972).

The amount of ground water infiltrated depends not only on the extent and location of the esker and the permeability of the material, but also on the amount of water flowing from the till deposits and bedrock of the higher environment. The amount of ground water which comes in from outside the esker depends on geological conditions, the season, the altitude of the water table and possibly on the amount of ground water pumped out from the esker. A good example of a draining

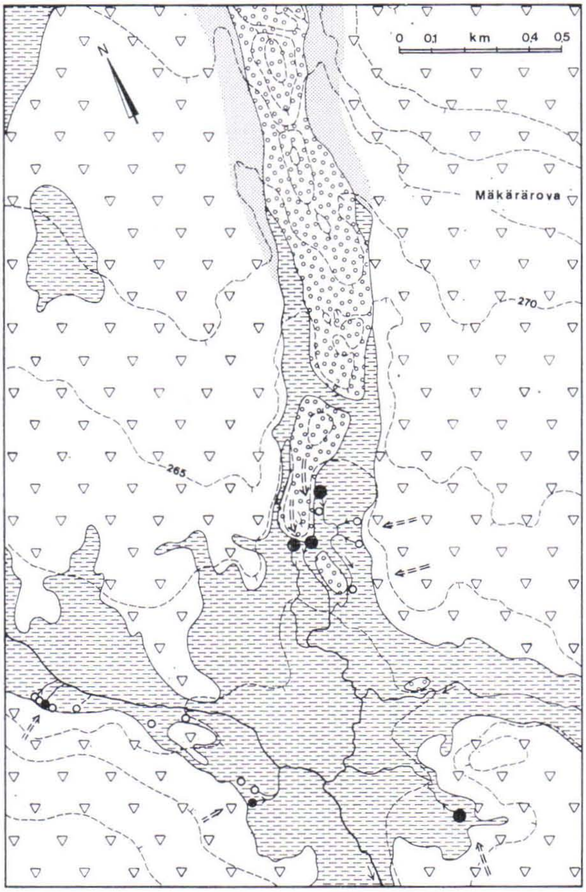

FIG. 7. A draining esker in a valley between till-covered hills (cf. Fig. 5 b). Most of the ground water percolates parallel to the ridge and is discharged at the end of the esker. Abundant ground water is also discharged in till areas. See text.

esker in a valley lying between till-covered hills is Mäkäränharju in the northern part of the commune of Sodankylä (Fig. 7). There is often more ground water from a draining esker than would seem likely from the actual size of the esker ridge. The ground water percolates mainly in the direction of the ridge. In Mäkäränharju the ground water discharges at the end of the esker through several springs, the largest of which produce over 5 litres per second. On till-covered hills, the ground water percolating towards the valley discharges in places as springs. Should an esker be located at the foot of a till-covered hill which has flat peat bogs on one side, the ground water only discharges on that side of the esker.

FIG. 8. Natural surface recharge from the River Käkkälöjoki through the esker (cf. Fig. 5 c). Abundant ground water which mainly originates from surface water is discharged in a large spring on the bottom of a gully, which is distinctly visible also in single aerial photograph owing to the shadow which it casts. Glaciofluvial material shows up light in sparsely timbered places. Peat bogs are seen as grey or black tones depending on the wetness and type of palustrial vegetation. By courtesy of Maanmittaushallitus (The National Board of Survey).

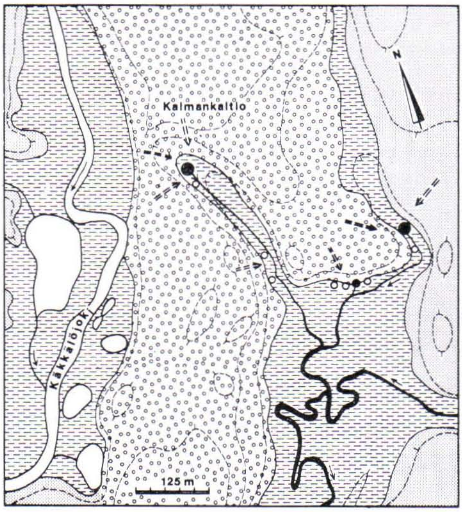

FIG. 9. Hydrogeologic interpretation based on the preceding aerial photograph. See text.

Because of their location, eskers in valleys generally have water bodies, such as elongated lakes and ponds, rivers and brooks, in their environment. The water table of the watercourses coincides with the ground water table of the esker (Fig. 5 b), so that they are in close association with one another. If the ground water table is lowered by pumping, the surface water is infiltrated into the esker and indirect infiltration takes place.

The esker ridges may block lakes and ponds as well as flowing watercourses, because in some places the esker material is weakly pervious or because there are deposits of fine-grained minerogenic and organic material on the bottom of the basins and channels. However, the surface water is always infiltrated to some extent into the esker, from which it discharges at a lower level on the opposite side of the ridge (Fig. 5 c). Natural surface recharge of this kind can be seen in the esker on the north-northeastern side of Hietatievat in Enontekiö (Figs. 8, 9). The River Käkkälöjoki on the western side of the esker supplies water to the glaciofluvial deposits. The ground water, partly coming from surface water, discharges several tens of litres

TABLE 1
The composition of surface and ground water in natural recharge
(see text and Figs. 8, 9).

	Käkkälöjoki (river)	Kalmankaltio (spring)
temperature (7. 7. 1972)	+21 — +23°C	+ 2.4
pH	7.1	6.7
specific conductance	42 μS	43
$KMnO_4$-consumption	19.9 mg/l	1.7
total hardness	0.6 dH°	0.8
HCO_3^-	15 mg/l	18
Ca^{++}	3.2 »	3.0
Na^+	1.3 »	1.4
K^+	0.5 »	0.6

per second through a spring known as Kalmankaltio. This lies at the bottom of an approx. 300 m long and over 10 m deep gully which is probably at least partly due to erosion caused by discharging ground water. The spring is about 10 m below the level of the River Käkkälöjoki which is at a distance of 130—150 meters so that the gradient of the ground water table is approx. 1 : 13—1 : 15. There is a distinct drop in the temperature of the surface water when it enters the soil (Table 1). The humus content and pH value also decrease, whereas the total amount of dissolved

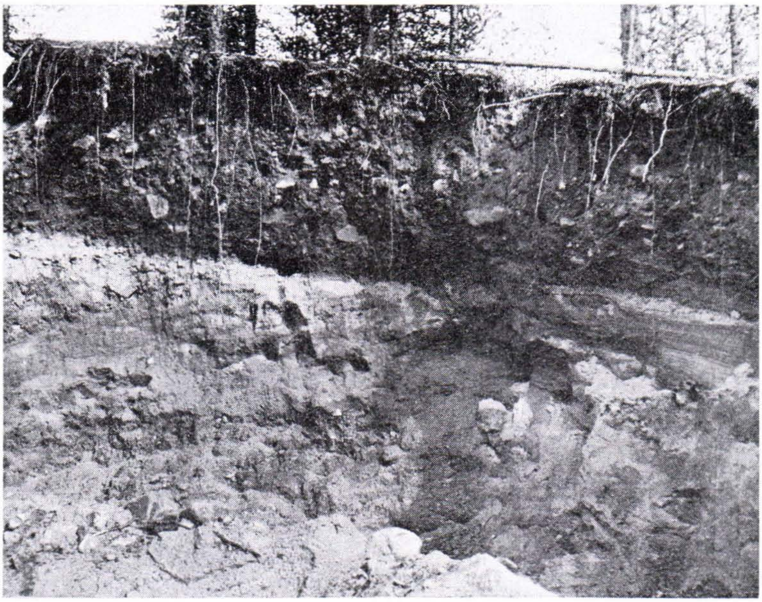

FIG. 10. Till bed rich in pebbles (dark layer) overlying stratified sand and gravel (light layer). The contact between till and glaciofluvial material is sharp. An esker cut in the village of Hingasvaara, Sodankylä.

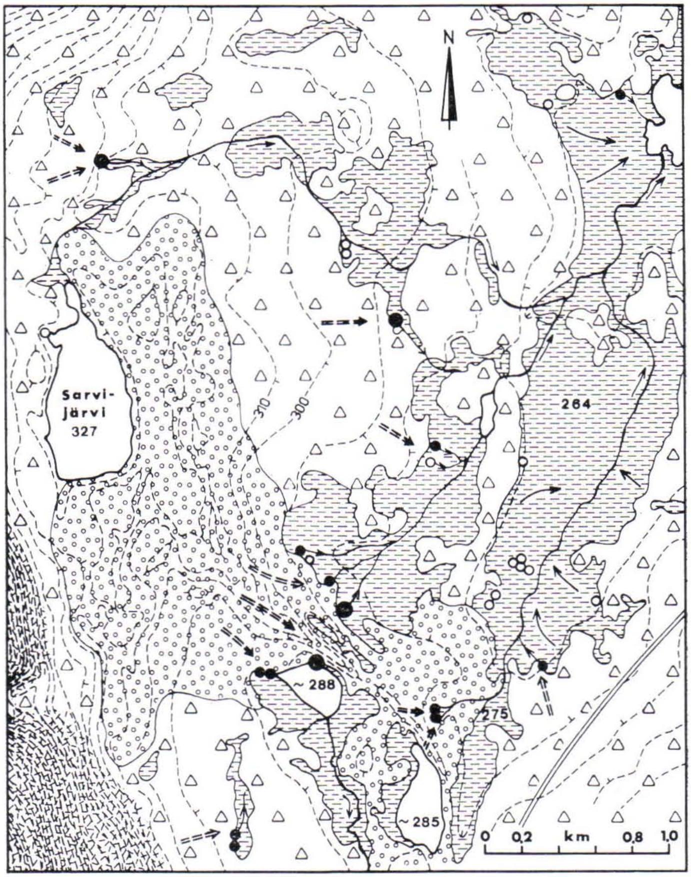

FIG. 11. An extensive kame field in association with an esker at the foot of Pallastunturi fell. Abundant ground water is percolated to southeast and discharged into peat bogs and the lake. See text.

electrolytes remains unaltered. Thus, there has been no marked leaching of dissolved inorganic matter from the glaciofluvial deposits. Instead humus is retained in soil, which fact is seen as a drop in the $KMnO_4$-consumption value.

Eskers are covered locally by the so-called »younger till sheet» (Fig. 10, cf. Mannerfelt 1945, Kujansuu 1967). This indicates that before the ice sheet finally melted it readvanced over the esker. Till-covered eskers have usually been flattened as rounded ridges while in some places they have disappeared almost completely. It is also possible that ablation till was deposited from both the inner and outer parts of the ice sheet as the final stage of melting was reached. In eskers covered by thick deposits of till there is no marked infiltration of ground water from the rain falling on the esker itself. However, eskers such as these may act as large underdrains

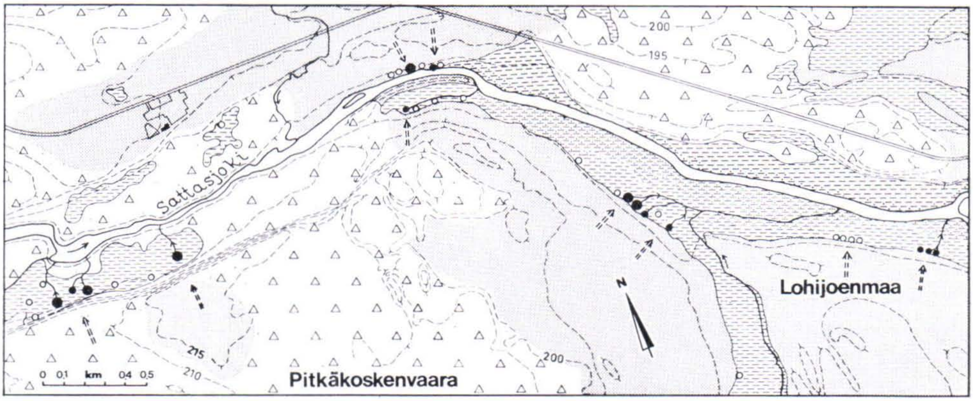

FIG. 12. Outwash plains in the valley of the River Sattasjoki. Ground water percolates towards the river and discharges as numerous springs. See text.

into whose lowest parts ground water may collect from the surrounding till deposits and the fractures of the bedrock.

The extensive kame fields composed of pervious glaciofluvial material have abundant ground water. Most of the unevaporated rain water infiltrates into the ground, since there is little runoff in the kames topography. The ground water in adjacent areas sometimes lies at different levels, which is indicated by pools and peat bogs on the bottom of the deeper kettle holes and by springs along the sides of the kame fields. In some cases the esker ponds are above the actual ground water table due to the minerogenic and organic fine-grained material deposited on the bottom and at the edges of the basins which reduce its permeability (Fig. 5 d).

The ground water in the kame fields originates chiefly from the rain which falls on the fields, but also frequently from water flowing down from a higher environment. An example of this is the extensive kame field of Sarvijärventievat on the eastern side of Pallastunturi fell in the commune of Kittilä (Fig. 11). It is remarkable for its variation in relative altitude. The ground water is percolated towards the southeast where it discharges through large springs at the edges of the peat bogs surrounding the kame field. The discharge is most intensive in the farthest corner of a small lake in the southeast of the kame field where there are numerous springs. This spring zone produces several tens of litres per second. Abundant ground water is also infiltrated in till areas, where it discharges through springs.

Outwash plains

The melt water of the continental ice sheet deposited flat sand and gravel fields either along the edge of the glacier or farther away from it in preglacial river valleys and fracture zones with gently sloping sides. Outwash plains such as these, successions

FIG. 13. A discharge area of ground water is bare of vegetation on the shore of the River Sattasjoki. The material of the outwash plain is pervious sand and gravel. Discharge 3—5 litres per second. See text.

of deltas or sandurs, are general in the investigation area, especially along the edges of the present rivers (cf. maps of surficial deposits: Penttilä, Kujansuu 1964, Kujansuu 1966). The proximal parts of the outwash plains are frequently associated with eskers indicating the direction of the melt water flow in the glacier.

The material of the outwash plains is usually well-sorted sand and gravel. The deposits may even be some tens of metres thick in the deepest parts of the valley, but become thinner towards the edges where the outwash grades into till often covered by peat.

The extensive flat outwash plains are the most significant ground water reservoirs in the investigation area (Fig. 5 e). Most of the ground water comes from the rain which falls on the outwash plain itself, because the runoff on the highly pervious material is slight. Ground water may also flow from the till deposits and bedrock in the higher environment to the outwash deposits lower down in the river valley (see Hausen 1948, Fig. 1). In many places steep and gradually sliding banks have been carved into the outwash deposits by the final melt water of the glacier and by present fluvial erosion (cf. Fig. 15). Steep banks eroded by glaciofluvial melt water are also to be seen in the thick till deposits bordering the river valleys (cf. Fig. 14).

To the north of Sodankylä in the valley of the River Sattasjoki there are extensive outwash deposits from which the ground water flows down to the river (Fig. 12).

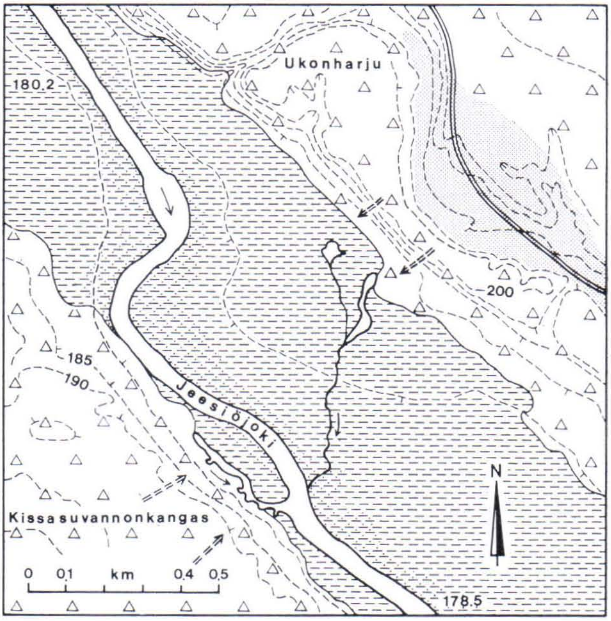

FIG. 14. Ground water discharging to the River Jeesiöjoki through the ponds. See text.

South of Sattasjoki the ground water discharges through the numerous springs in the alluvial bogs along the edges of the outwash plain and at the foot of the steep till bank. These bogs are partly a result of paludification caused by discharging ground water. The springs on the northern side of the Sattasjoki are at water level directly on the embankment (Fig. 13). Ground water probably discharges from these gravelly outwash deposits also below the water level of the river, although this cannot be demonstrated. The rate of discharge in the largest springs is 5 to 10 litres per second.

In the alluvial bogs alongside the rivers at the foot of the banks of outwash or till deposits there are many small ponds or long and narrow inlets from the river. Considerable quantities of ground water discharge from these into the Jeesiöjoki to the northwest of Sodankylä (Fig. 14). At the northern edge of the till-covered Kissasuvannonkangas hill ground water discharges to the Jeesiöjoki through a long inlet on the bottom of which there are numerous springs. The amount of discharging ground water cannot be estimated because the water table of the inlet is on the same level as that of the river. An estimated 10—15 litres per second of ground water discharges through two small ponds at the foot of a steep till bank to the south of Ukonharju. When the snow is melting in the spring the ponds are partly filled with flood water rich in humus.

FIG. 15. A sliding bank of an outwash plain on the shore of the River Kitinen. Ground water discharges into the river in the direction indicated by the arrow (notice the pools at the foot of the bank). The outcrop in the background close to the water line shows that the outwash deposits are locally above the surface of the water (cf. Fig. 5 f).

Here and there the outwash deposits are located on bedrock which is on a higher level than the water table of a river with the consequence that ground water is not stored (Figs. 5 f, 15). It percolates only in a thin layer on top of the bedrock and discharges at the foot of the bank as springs, or it sinks deeper into the joints in the bedrock. In some places in the river valleys the proglacial melt streams deposited thin sand and gravel layers sloping towards the river (Fig. 5 g). Along the edges they sometimes overlie till so that part of the ground water is perched water. The few »hanging» outwash deposits in elevated areas cannot store ground water to any marked degree. Here and there on the slopes of the extensive and deep river valleys in the northwestern part of the investigation area deposits of the kame terrace type occur which were formed by melt water flowing along the edges of glacier lobes in the river valleys (cf. Mansikkaniemi 1970). Due to their location, the kame terraces are insignificant as ground water reservoirs.

Some deltas and sandurs are located at the mouths of melt water overflow drainage channels (cf. Kujansuu 1967). Deltas are also common as enlargements of esker sequences. In general they are composed of well-sorted sand and gravel although there may be stoney material in the proximal part. The distal part often consists of fine sand or silt. The deposits at the centre attain thicknesses of 10—20 m but thin

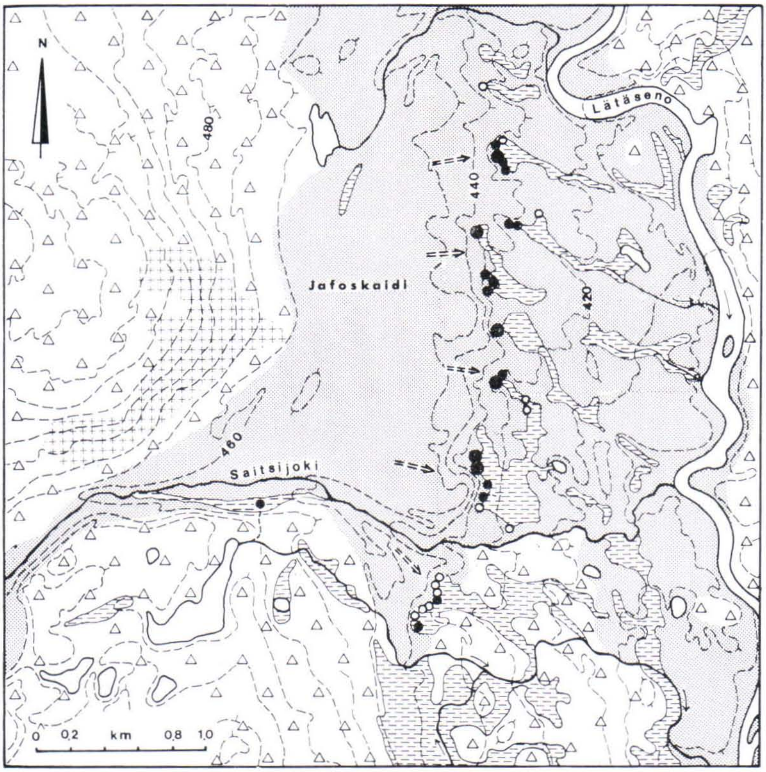

FIG. 16. The glaciofluvial delta at the mouth of the River Saitsijoki. Ground water is percolated towards the distal part which has abundant springs at the foot of the distal slope. See text.

out towards the edges. The surface of the delta is comparatively even with a distinct slope in the distal part. The material of the sandurs is often more weakly sorted and they vary in shape because the surface has been carved out by the last melt water streams.

Extensive deltas and sandurs contain large amounts of ground water, most of which is produced from the rainfall on the even surface. However, in the proximal part in particular, ground water may also flow from the till deposits and bedrock in the surrounding terrain. The flow of the ground water is primarily towards the distal part. An example of this is the extensive glasiofluvial delta at the mouth of the Saitsijoki valley in Enontekiö (Fig. 16, cf. Kujansuu 1967). The ground water discharges as numerous springs and seeping belts at the foot of the distal slope, which is probably attributable to an ice contact. Here the eroding action of discharging ground water has formed gullies several tens of metres long and 1—2 m deep. On the basis of the location of the gullies the ground water discharge may be predicted from aerial photographs although individual springs cannot be seen.

Littoral deposits

Here and there in the investigation area there are deposits which are usually small in size and composed of sorted drift and which cannot be classified as eskers, kame fields or outwash plains. The thin sand and gravel deposits on the lower slopes of the hills below the highest shore line are probably littoral deposits. It is possible that the highest marine phases may have extended as far as the river valleys in the southern part of the investigation area (cf. Hyyppä 1966). The largest littoral deposits exist to the south of this area where the marine phases were of longer duration.

On the whole, the littoral deposits are underlain by till so that the small amount of ground water is chiefly perched water (Fig. 5 h). It discharges as small springs which often dry up in the summer and winter.

THE OCCURRENCE AND AERIAL PHOTOGRAPHIC INTERPRETATION OF GROUND WATER IN TILL DEPOSITS

Till largely covered by peat is encountered over almost the whole of the investigation area. The till cover averages a few metres in thickness, but on the lower slopes of the hills the deposits may be as thick as 10—20 m. The lodgement till tends to level unevenness in the bedrock so that in fracture valleys the deposits may be even thicker. In the northern part of the investigation area there are till deposits with specific morphology of which the most common is hummocky moraine. They are either ablation or lodgement till in origin. Hence, in the latter case the topography probably represents the morphology of the glacier basement (Kujansuu 1967). The mean thickness of the deposits is probably greater in areas of hummocky moraine than in those of lodgement till.

The most abundant fractions in till are 0.02—0.2 mm and 0.2—0.6 mm in diameter. The clay content (under 0.002 mm) is usually less than 5—6 weight percent (Kujansuu 1967, Fig. 7, Lahermo 1970, Fig. 4). The abundance of pebbles and blocks varies from high to almost nil. The surface of the till deposits is usually loose, outwashed surficial till which facilitates the infiltration of the vadose water down to lower levels. Not only the mode of origin but also plant roots, frost action and weathering have influenced the composition and structure of the till deposits closest to the surface. Underlying this is more compact lodgement till with a higher content of fines in which the infiltration of the vadose water is most effective in stoney places, along root channels and along the lower part of the stoney and coarse-grained till layer overlying the bedrock (cf. Troedsson 1955).

Bedrock exposed on the tops of the hills has been shattered by postglacial frost wedging. This enables the vadose water to infiltrate into the fissures and fractures of the bedrock along which some of it reaches the till deposits on the lower slopes (Lahermo 1971 a). The preglacially weathered rock common in the central and

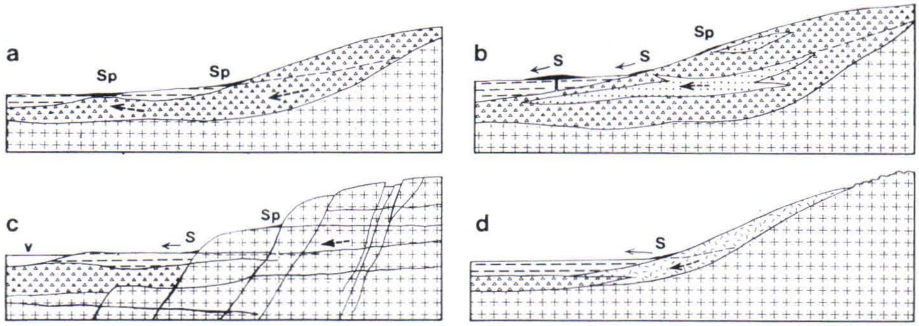

FIG. 17. Schematic cross-sections illustrating the percolation and discharge of ground water in different till deposits and bedrock. The symbols are the same as in Figs. 3 and 5.
a: The ground water in granulometrically homogeneous till deposits of a hill slope. b: The ground water in thick till deposits, in which there are intercalated sand and gravel lenses and sheets. c: The ground water in fractures of bedrock. d: The ground water in the block field of a hill slope. See text.

eastern parts of the investigation area grades into till without a clear boundary. Preglacial weathering mantles such as these occur most frequently in valleys but also on the slopes of hills and even on the tops of hills (see Kujansuu 1967). The weathered rock, which grades into fresh rock, is generally some tens of metres thick. The greatest observed thicknesses have been over 100 m (Virkkala 1955).

Small portions or lenses of stratified drift are common in the thick till deposits. There are also frequent occurrences of sand and gravel beds, some of which attain several metres in thickness. The extensive and continuous sand and gravel beds in till sheets probably represent deposits from glacial melt water formed on the older lodgement till. The stratified drift is overlain by younger till deposited by the re-advanced glacier. Thus, the sand and gravel layers separate two till sheets of different ages from each other (cf. p. 19, »younger till»). Such intercalated sand and gravel lenses in till beds are important sources of ground water because they act as »under-drains» beneath the ground water table. As aquifers they collect ground water from wide areas from the less pervious till in the environment.

On the till-covered hills some of the ground water discharges on the lower slopes and in the marginal zone of the surrounding peat bogs (Lahermo 1970, 1971 a). The till-covered hills and hummocks can be divided into two zones on the basis of the mode of occurrence of the ground water. One of these is the infiltration or recharge area of the ground water on the hill-tops and upper slopes where the water table is at a considerable depth. The inorganic material which is released by the weathering of the soil is washed downwards with the vadose water and is partly precipitated. The result is the formation of a ferrous-podsol profile (Tamm 1931, Aaltonen 1935, Mattson, Lönnemark 1939, Gustafsson 1968). The other zone is the discharge area on the lower slopes and in the marginal zone of the surrounding peat bogs where the water table is at or near the ground surface. There is only slight weathering in the soil saturated with ground water. Most of the weathering products

FIG. 18. A rivulet originating in three springs at the foot of a gently sloping till-covered hill. The timbered till areas are indicated in the aerial photographs by fairly dark shades. The lenticular peatlands between the hills show up as dark or light shades depending on the proximity of the ground water table and the type of palustrine vegetation. In the left hand corners of the picture the peat ridges are visible as light patterns against the dark wet bogs. See text. By the courtesy of Maanmittaus-hallitus (The National Board of Survey).

in the ground water and runoff are transported away and are not precipitated into the soil. Occasionally humus-podsol or blue-grey podsol without clear podsol profiles is formed in the top soil near the water table. The wet ground undergoes paludification and the water contains abundant humus.

If the permeability of the till remains constant in the whole sheet the ground water discharges over a large area as seepage belts or seeps both on the lower slopes of the hill and in the marginal zone of the surrounding peat bogs (Fig. 17 a). The predominant palustrine plants are Sphagnum, Bryales, sedge species and various subshrubs. A part of the ground water comes to the surface through springs, which chiefly occur where till beds poor in fines act as aquifers and where sand and gravel intercalates the till deposits and outcrop below the ground water table (Fig. 17 b). The discharge of the springs at the foot of the till-covered hills is usually some litres per second reaching in a few cases a maximum of 10—20 l/s.

FIG. 19. A typical spring and the rivulet originating from it at the foot of a till-covered hill. The peatland type is pine and birch bog with low hummocks. The light area in the background is open sedge bog. The discharge is approximately a couple of litres per second.

With stereoscopic magnification it is seen that the rivulets from the springs which show up as dark or black on aerial photographs usually start right at the edge of the bog (Figs. 18, 19). Sometimes the peat around the rivulet has increased in thickness so that the spring rivulets flow in gullies up to 2 m in depth. The spring rivulets themselves may not always be distinguishable on aerial photographs but their location is indicated by clusters of willow bushes which show up as darkish bands.

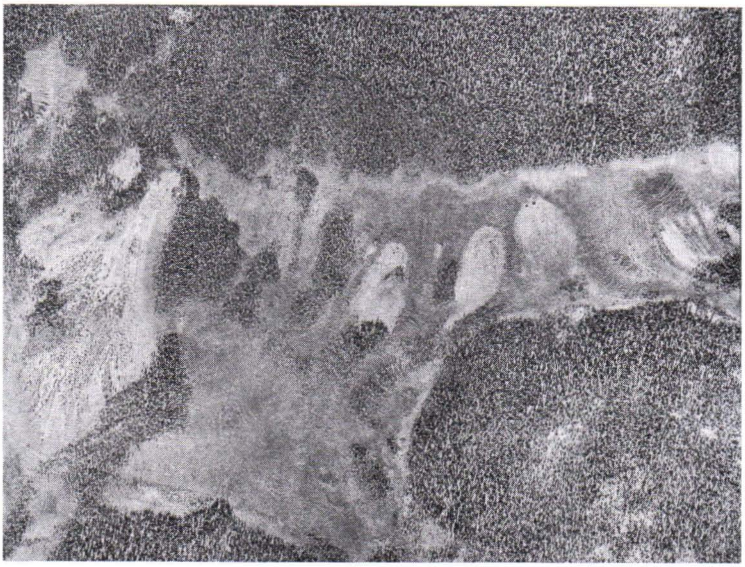

FIG. 20. In aerial photographs the seeps in a bog appear as lenticular light areas (in the centre and at the right hand side of the picture). In places ground water discharging from some seeps flows radially on the surface of the bog (in the left half of the picture). By courtesy of Maanmittaushallitus (The National Board of Survey).

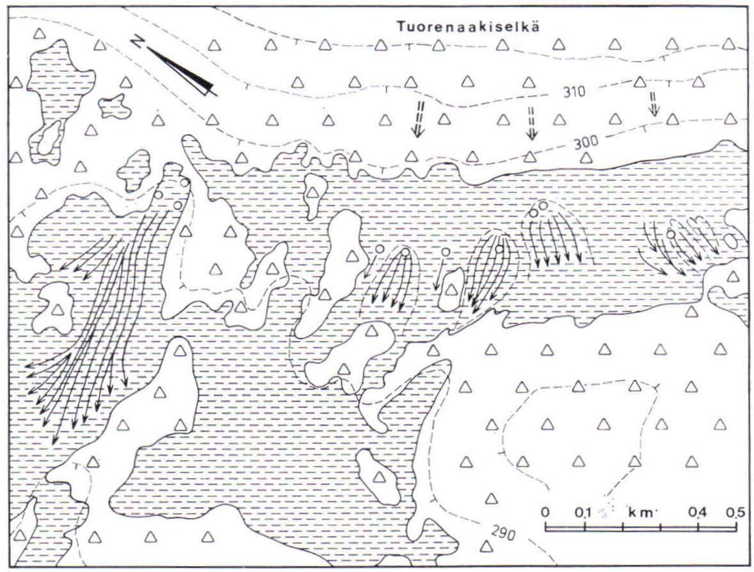

FIG. 21. Hydrogeologic interpretation based on the preceding aerial photograph. The spring to the west of number 300 (the black spot in the aerial photograph) is seen in the photograph in Fig. 22. See the symbols in Fig. 3 and text.

FIG. 22. A typical spring farther out in the bog. In the foreground around the spring a growth of low shrubs (Betula nana and willows) and spruces is visible. The palustrine vegetation of the edges of the spring basin consists of brown moss. The peatland type is open sedge bog with low hummocks. In the background there is the forested slope of a till-covered hill. See text and Figs. 20, 21

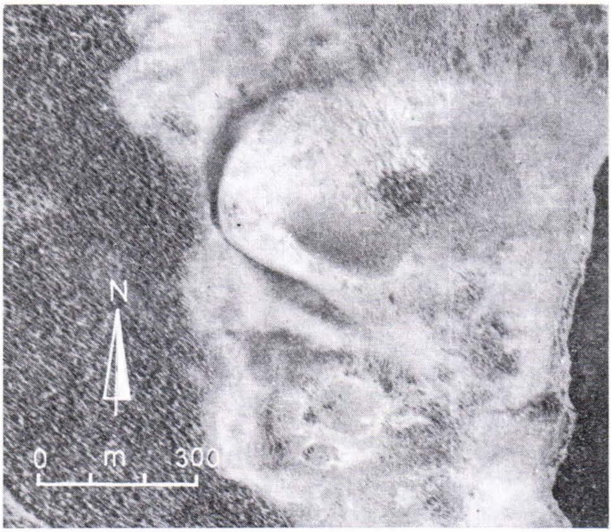

FIG. 23. Seeps in the peat bog at the foot of a till-covered timbered hill. Runoff on both sides of the largest spring (black dot to northeast of the letter N) appears as a dark curve. In the southern part of the bog there are some small seeps, which are seen as light irregular patches. See text. By courtesy of Maanmittaushallitus (The National Board of Survey).

FIG. 24. Three large spring basins in a peat bog surrounded by till-covered hills. See text. By courtesy of Topografikunta (The Army Map Service).

In the interpretation the spring rivulets may be confused with the surficial water streams flowing along the slopes. However, the latter usually flow in gullies with lush vegetation which show up on the aerial photographs as dark bands parallel to the slope. The vegetation on slopes above the spring rivulets is similar to that of the dry environment. If the discharging ground waters spread into wet, treeless sedge bogs, the direction of flow can only be determined approximately (see Fig. 33).

The ground water discharging from the till deposits contains more dissolved matter than does the rain water which collects directly on the extensive peatlands. For this reason the palustrine vegetation in the discharge areas is more pretentious than farther out in the peat bogs. The most common peatland type in the discharge area is sphagnum bog with a sparse growth of pines. It shows up lighter on the aerial photographs than the wet, treeless sedge bogs and fens beyond it.

The ground water flowing from the hills down to the till or sand and gravel deposits underlying the peat beds is under slight pressure. Since peat beds a few meters thick and saturated with water present an almost impermeable barrier, the springs and seepage belts are encountered far out in the bog. The springs occur chiefly in places where the peat bed is thin or where there are holes in it. The paludi-

FIG. 25. In paludificated valley the flow of ground water discharging from springs and seeps as well as that of the runoff is indicated on the bogs as light or dark streaks. By courtesy of Maanmittaushallitus (The National Board of Survey). See text.

fication of forest land on the gentle slopes above the spring also explains why springs are located several hundred metres away in the bog.

When the springs in the peat bogs are most characteristic of their type they rise clearly above their environment as low crater-like heaps of peat (Fig. 17 b). In the centre of these there are often one or more water basins up to several metres in diameter which reach the mineral soil under the peat beds. The ground water discharges from these either as small rivulets or more commonly as seepage. The water may discharge in one direction or radially over the edge of the crater-like spring.

The crater-like springs farther out in the bog show up on the aerial photographs as light areas which are frequently elongated in shape in the direction of flow (Figs. 20, 21). These light areas are open sedge bogs with more or less eutrophic or miner-

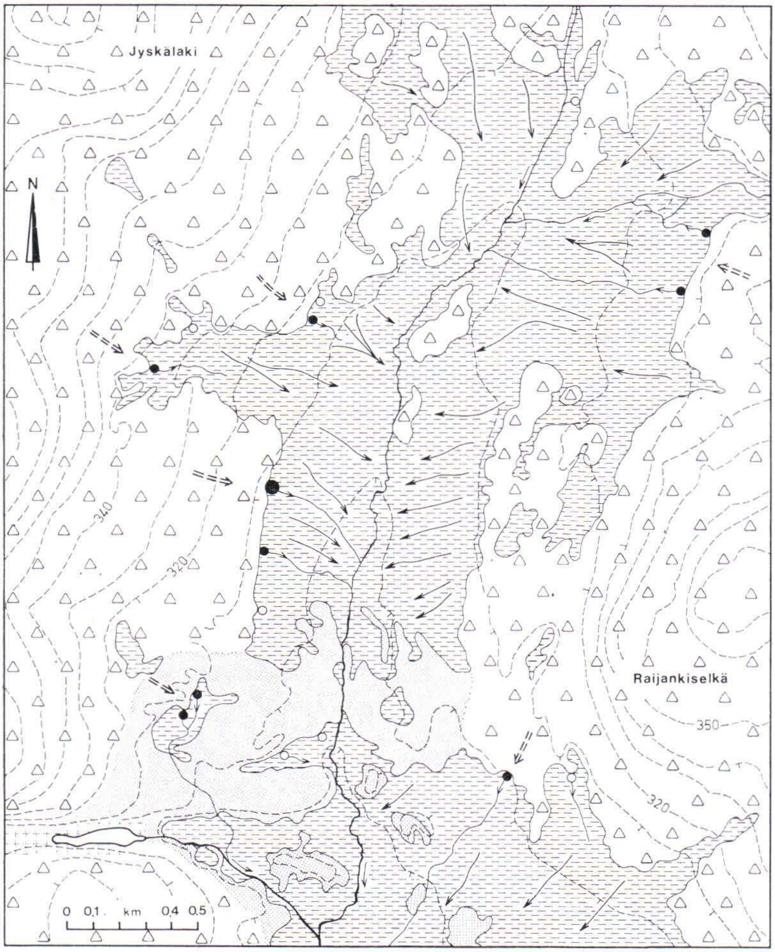

FIG. 26. Hydrogeologic interpretation of the preceding aerial photograph and its environment. The photointerpretation of surficial deposits by Kujansuu. See text.

ogenic vegetation, often with a sparse grouth of spruce and pine (Fig. 22). The darker environment in the aerial photograph is composed of wet treeless sedge bog with Sphagnum ridges. The small seeps in the bog are indicated by small light smudges of varying shape. The larger spring basins may be distinguished by black dots.

The occasional dark arch visible over the spring is a sign that the surface water flows on both sides of the crater-like spring. A good example is the spring to the west of Lake Säynäjärvi, near the village of Maunujärvi, Kittilä (Fig. 23). The flow

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from the spring (small black spot to the northeast of the letter N) on the bog is towards the lake in the east.

To the northeast of the village of Jeesiö in the commune of Sodankylä there are three long water basins with a floor of boulders and peat in the middle of a hill-encircled peat bog (Fig. 24). A total of several tens of litres of ground water per second infiltrated on the surrounding hills discharges from these basins, which join up with the River Pertamo-oja. In spring and during rainy spells abundant surface water rich in humus from the bogs is also included.

The lush vegatation in the discharge areas of ground water enables the direction of flow to be established by aerial photo interpretation. The directions of flow are depicted either as light streaks denoting lush vegetation or dark streaks denoting water. The ground water discharging on the hills and the runoff flow down and spread out into the creek or river in the valley in a featherlike pattern (Figs. 25, 26). The flow from hills completely encircled by bogs is radial. A glaciofluvial delta (dotted area) in the valley can be seen in the lower part of Fig. 26. The melt waters have flown through an outwashed gorge which is indicated by an elongated lake.

The sphagnum peat ridges on the surface of the bogs which are clearly visible on the aerial photographs, are of assistance when estimating the direction of the runoff. Like contour curves they are perpendicular to the direction of flow (Fig. 27, cf. Lappalainen 1970). If ground or surface water flow down from the slopes of the hills the peat ridges are parallel to the slope. Since the flow of water is towards the surface water bodies, the peat ridges also conform with the shores of lakes and rivers. In the middle of the bogs where the flow is sluggish because of the gentle gradient, the peat ridges are sparse but distinct (thin lines). On the sides of hills and in the littoral areas of water bodies where the flow is accelerated the peat ridges are small and close together (heavy lines). In the latter case they are not so pronounced nor readily distinguishable on aerial photographs.

Determination of the directions of flow of ground water and runoff based on aerial photo interpretation often gives better results than field observations because a better general picture of the variation in vegetation is obtained. The ground water discharging from the hills collects in the surface water bodies in valleys. If there are few bogs and lakes, the water in the brooks and rivers is mainly ground water during the dry seasons in summer and in winter. The close relationship between ground and surface water is also shown by their similar chemical composition (Lahermo 1970). The proportion of runoff is higher in flat highly paludificated areas than in areas of varying elevation and few bogs. During the floods which follow the melting of the snow and during rainy spells in summer and autumn most of the surface water is runoff from the hills and bogs.

The close relationship between streams and ground water can in some instances also be established by photo interpretation. This fact is illustrated by the River Joukhaisjoki which lies to the west of Sodankylä and empties into Lake Vaalajärvi (Fig. 28). It has numerous springs as its source which are visible on aerial photographs.

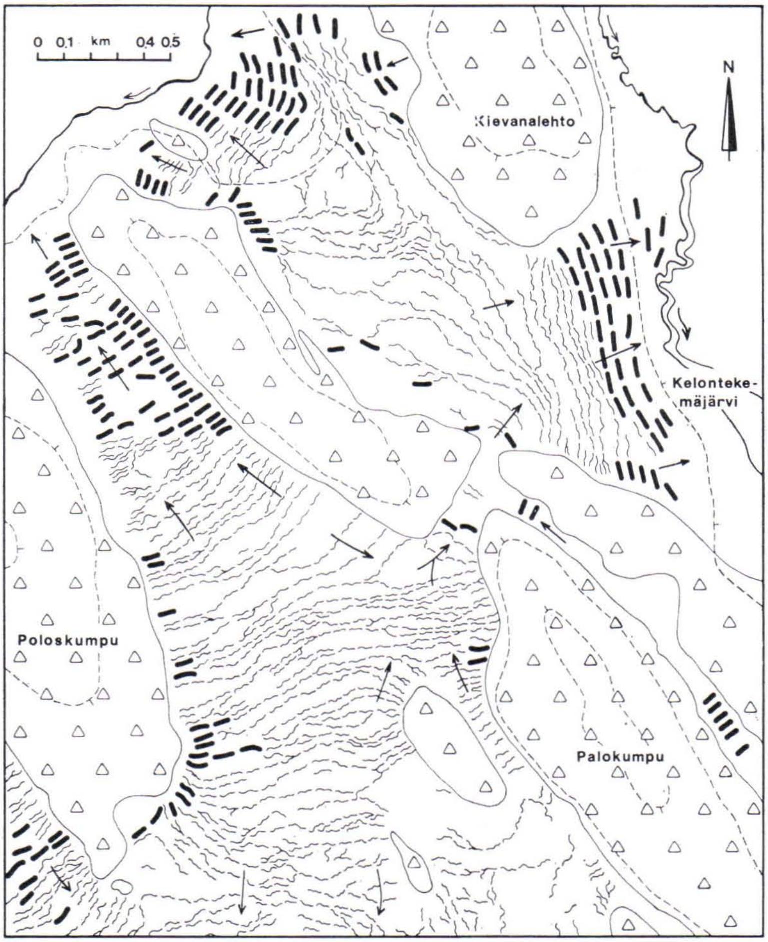

FIG. 27. Typical peat ridges in the bogs between the till-covered hills. Runoff is perpendicular to the peat ridges. The equidistance of contour lines is 10 meters. Thin lines, peat ridges far apart, heavy lines, peat ridges close to each other. See text.

Ponds and lakes represent the lowest level of the ground water table in their environment. Therefore, the ground water discharges into them either as springs or as seeps. No stream of any size empties into Lake Katajajärvi to the west of Sodankylä despite the fact that the lake has an outlet with abundant water (Fig. 29). During dry spells there is no runoff from the alluvial bogs surrounding the lake so that most of the water comes from ground water. There are indeed numerous springs in the bog and at the foot of the surrounding hills. The ground water also discharges into the lake below the level of the water close to the shore line.

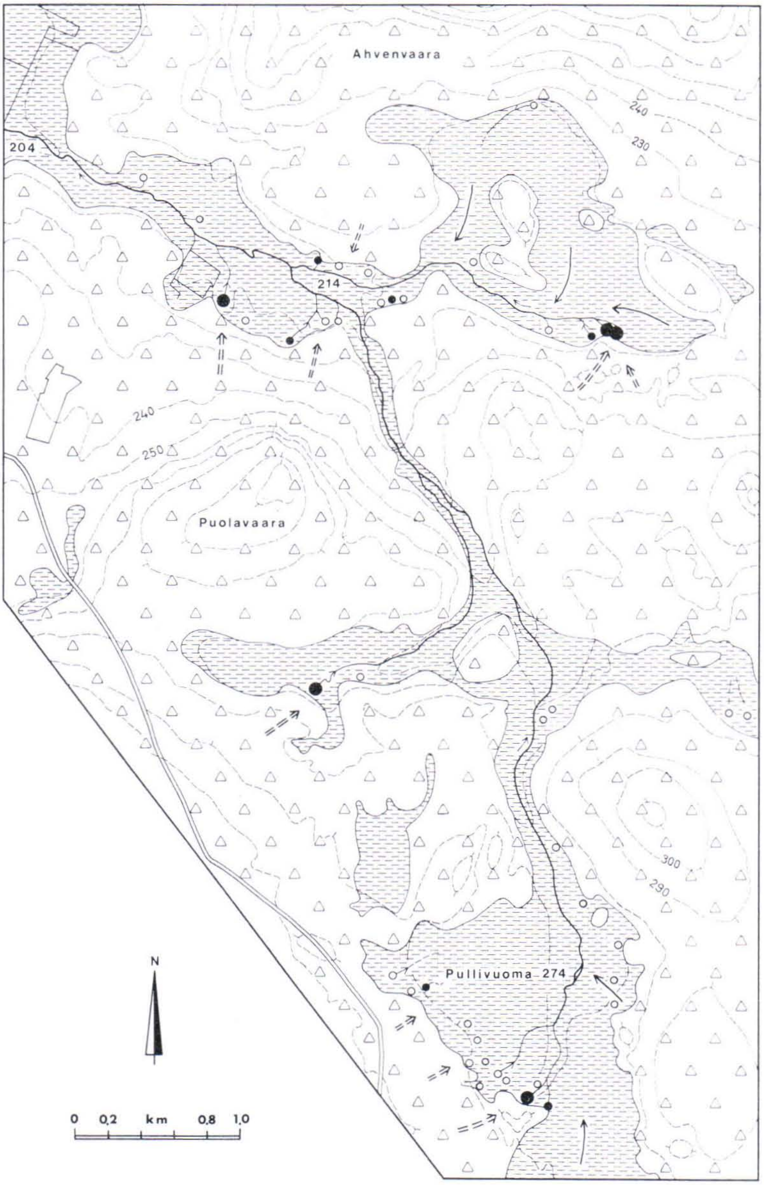

FIG. 28. The River Joukhaisjoki and the springs which are its source. See text.

The springs in the alluvial bogs encircling lakes and ponds are revealed on the aerial photographs either as rivulets originating from springs or as narrow inlets of the lake (Fig. 30). The large spring on the shore of Lake Suasjärvi in the north-eastern part of the commune of Kittilä is approximately at the site of a postglacial

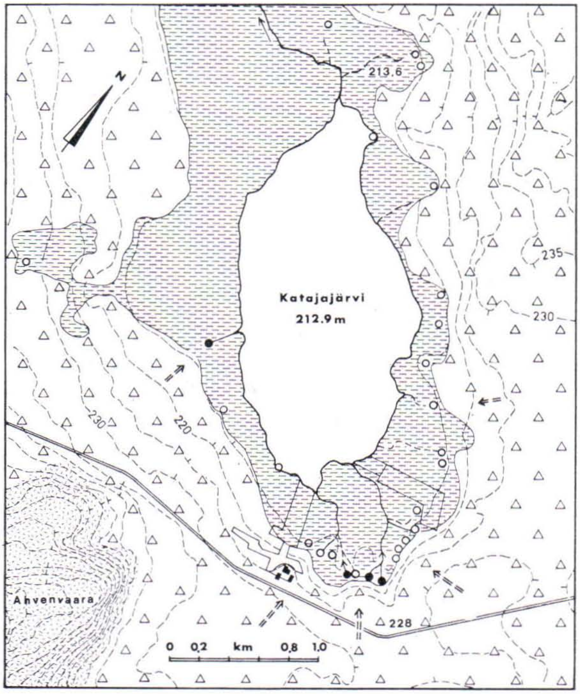

FIG. 29. A shallow lake with paludificated shores in a basin between till-covered hills. Ground water percolates towards the lake and discharges as springs at the foot of the hills, in alluvial bogs and on the shore line. See text.

fault along which a part of the ground water may come from quite a long distance (Fig. 31 c.f. Kujansuu 1964, Fig. 2). Ground water which discharges directly into a water course cannot usually be established from aerial photographs, although if the direction of percolation of the ground water and the geological conditions are known, preliminary conclusions can be drawn concerning the site of discharge.

In some places where the ground water discharges into shallow ponds and lakes, there are at the bottom deeper gullies parallel to the flow which show up as dark areas on the aerial photographs. Sometimes it is even possible to determine the direction of flow of surface waters through the lake as in Lake Sinermäjärvi, to the east of Sodankylä (Fig. 32). The flow of the stream is northwestwards both through the basin and parallel to the western shore. In the northeastern corner a small stream empties into the lake. The dark spots in the middle of the lake indicate the sites of discharge of ground water. Other sites are the till deposits on western shore.

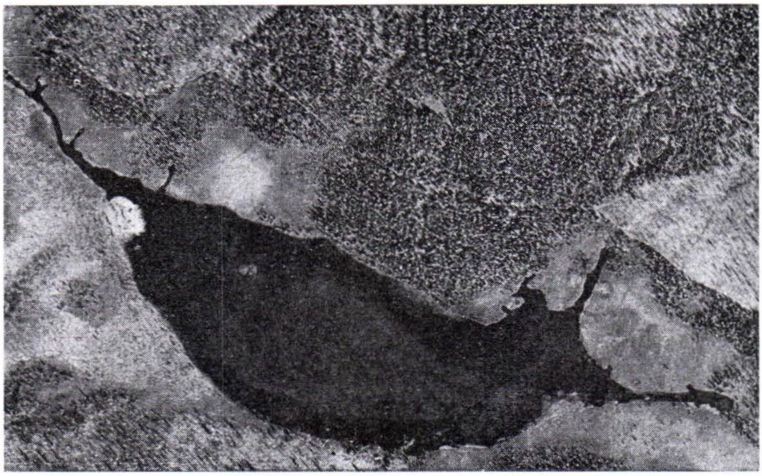

FIG. 30. Ground water discharges into Lake Suasjärvi through the inlets penetrating the alluvial bog and the springs at the foot of the hill. By courtesy of Maanmittaushallitus (The National Board of Survey).

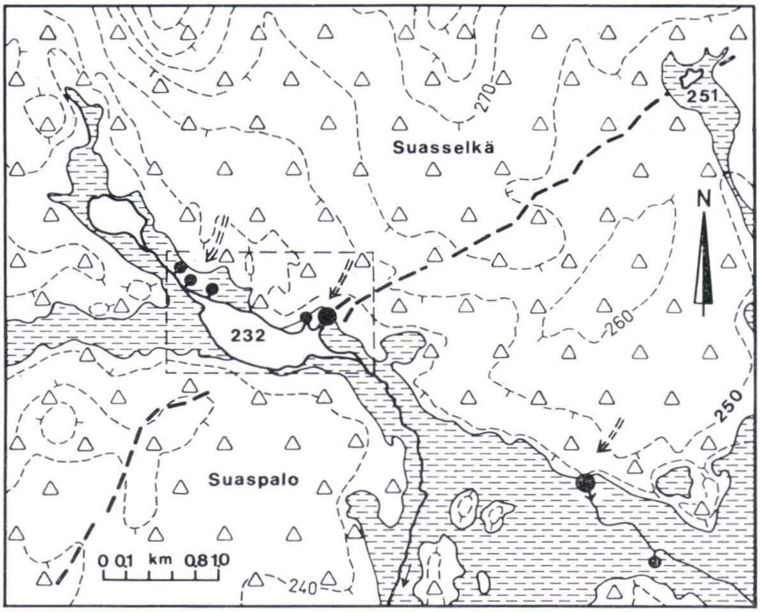

FIG. 31. Hydrogeologic interpretation of the area in the preceding aerial photograph and its environment. The location of the postglacial fracture zone is indicated by a heavy dotted line. See text.

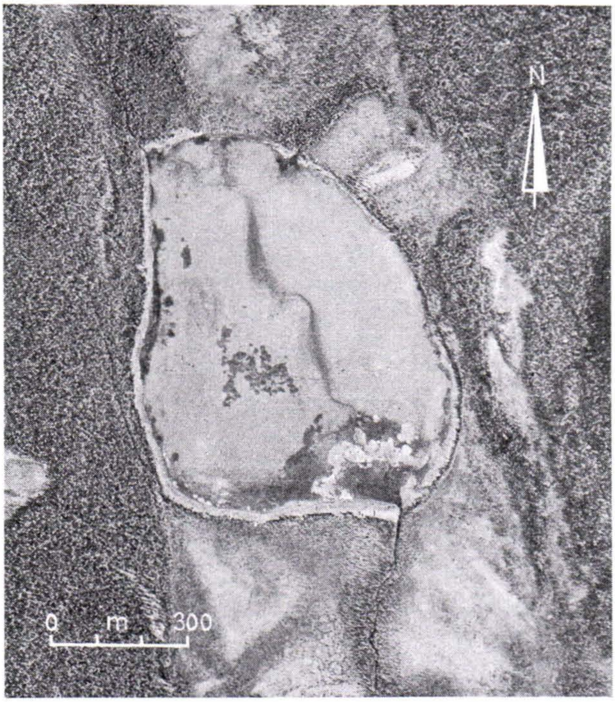

FIG. 32. A shallow lake bounded by bogs to the south and north and till deposits (forested areas) to the west and east. The direction of flow of the stream and the discharge of ground water is seen as darker lines and patshes at the bottom. See text. By courtesy of Maanmittaushallitus (The National Board of Survey).

THE OCCURRENCE AND AERIAL PHOTOGRAPHIC INTERPRETATION OF GROUND WATER IN BEDROCK

The numerous wells drilled in the investigation area are a source of information concerning the occurrence of ground water in the bedrock. The rates of production (in litres per hours) presented in Table 2 are only rough estimates since they are

TABLE 2

The mean depth and production of drilled wells in various bedrock areas in the study area and in the whole of Finland.

Area	Rock composition	Number of drilled wells	Mean depth, m	Mean rate of production, l/h
investigation area (Fig. 1)	all rocks	213	33	2 050
	silicic rocks	170	35	1 950
	subsilicic rocks	43	26	2 450
the whole of Finland (Laakso 1966)	all rocks	~ 1 100	68	2 450

FIG. 33. A slope of a hill covered by block fields and a thin till sheet. Ground water discharges into the bog through a large spring and a seeping belt. In the aerial photograph the block field can be distinguished from the more forested till deposits by its lighter shades. The smoothed tec tonic traces of the weathered bedrock, which are probably the bedding of quartzite (cf. heavy lines in Fig. 34), are distinctly visible in the aerial photograph. In the southwestern corner there are light peat ridges in wet bog. The latter shows up as dark patches. By courtesy of Topografikunta (The Army Map Service).

based on the recollections of the well-drillers and the owners of the wells. In addition, the test pumping was never of long enough duration to ensure that equilibrium was attained between the ground water flowing into the well and that being pumped out. In many cases the maximum capacity of the pump was too low. Accordingly, the actual mean production is probably somewhat higher than that presented in the table.

On the basis of data from over 200 drilled wells it can be seen that a fair amount of ground water is available from rather small depths (Table 2). This is due to the fact that the exposed bedrock is everywhere broken up by frost wedging. Locally, it is also weathered chemically to a great degree (cf. p. 25). The fractured surface furthers the infiltration of the vadose water down into deeper joints and fractures. The mean production for all the drilled wells in Finland is only slightly higher than for those of the investigation area although the mean depth of the former is twice that of the latter. The bedrock in southern Finland is probably less fractured so that deeper

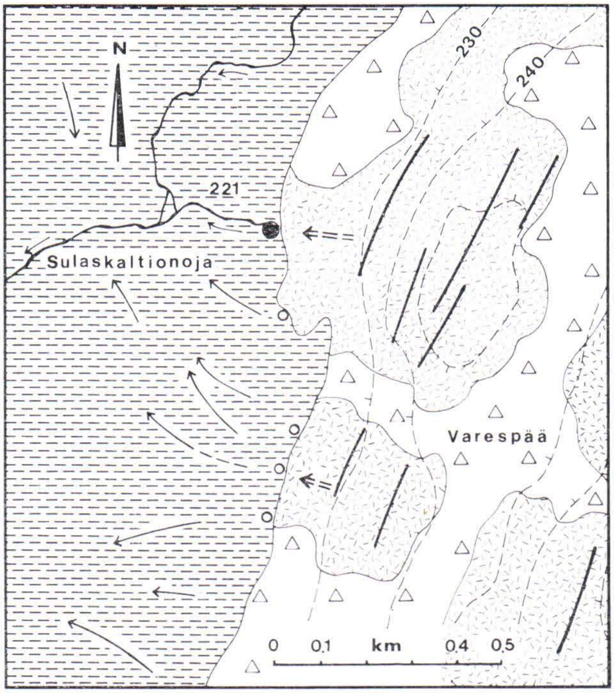

FIG. 34. Hydrogeologic interpretation based on the preceding aerial photograph. Black heavy lines indicate tectonic traces. See Fig. 3 and text.

wells had to be drilled to obtain adequate water. However, it has been established that there is no significant increase in ground water production even when the drilled wells are sunk below depths of 50—100 m (Lahermo 1971 b, p. 18).

The mean rate of production from drilled wells in regions of silicic bedrock (e.g. granites, gneisses, various light schists, mica schists, quartzites etc., cf. Mikkola 1936, 1937, Matisto 1959) is clearly lower than that in regions of subsilicic rocks (e.g. greenstones, dark schists, amphibolites, gabbros etc.). Ground water has been obtained in greater abundance from the considerably shallower wells in the subsilicic areas (Table 2), probably because of the extraordinarily intense fragmentation in greenstones and dark schists. In order to obtain the same amount of water in the country as a whole, the mean depth of wells must be three times that of what they are in the investigation area. It has been established on the basis of the data collected for the present study that there is no clear relationship between the depth and the rate of production of the drilled wells.

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Aerial photographic interpretation makes it possible to localise fracture traces with abundant ground water (e.g. Lattman, Parizek 1964). In many cases they can be established even when overlain by thick overburden. The supply of ground water can be assured by directing well sinking activities to such fracture zones. Photographic interpretation was not applied in this way in the investigation area.

The ground water flowing in the joints and fractures of the bedrock discharges locally as springs on steep slopes (Fig. 17 c). This is often perched water and run dry during dry spells.

Locally abundant ground water may discharge along the edge of the block fields at the foot of hills (Fig. 17 d). An example is the large spring of Sulaskaltio at the foot of Varespää hill in the western part of the commune of Sodankylä (Fig. 33). The rivulet whose source is the spring is seen as a dark band. To the south of the spring the ground water seeps out over a broad front at the foot of the hill (Fig. 34). The direction of flow of the ground water and runoff on the bog is depicted by wider dark bands in the aerial photograph.

A REGIONAL INVENTORY OF SPRINGS

In many cases the discharge areas of ground water or springs can be reliably localised from aerial photographs (cf. p. 28). The interpretation presumes a good knowledge of the geology of the area as well as of the mode of occurrence of the ground water. It is not feasible to map the springs merely on the basis of topographic and base maps (1 : 20 000) and it would take too long to make an inventory of the springs on the basis of field studies alone covered up a large area. Therefore, the only method of mapping springs which can be adapted to conditions over extensive stretches of northern Finland is photo interpretation. However, even in the best of cases, it is obvious that numerous springs covered by vegetation escape observation.

Successful spring inventory reguires that technically faultless aerial photographs be available. By increasing the scale of the photographs, the localization of the springs can be made more reliable. The most useful aerial photographs available are those with a scale of 1 : 22 000 or 1 : 30 000. High altitude photographs with a scale of 1 : 60 000 are not so suitable for interpretation because springs and areas with a slight discharge of ground water do not show up.

Photo interpretation also makes it feasible to draw preliminary conclusions concerning spring discharges on the basis of the width of the rivulets whose sources are springs (p. 10). Accordingly, the following classification was applied: 1) seeps and small springs (cross in Figs. 35—38), 2) medium-sized springs (open circle) and

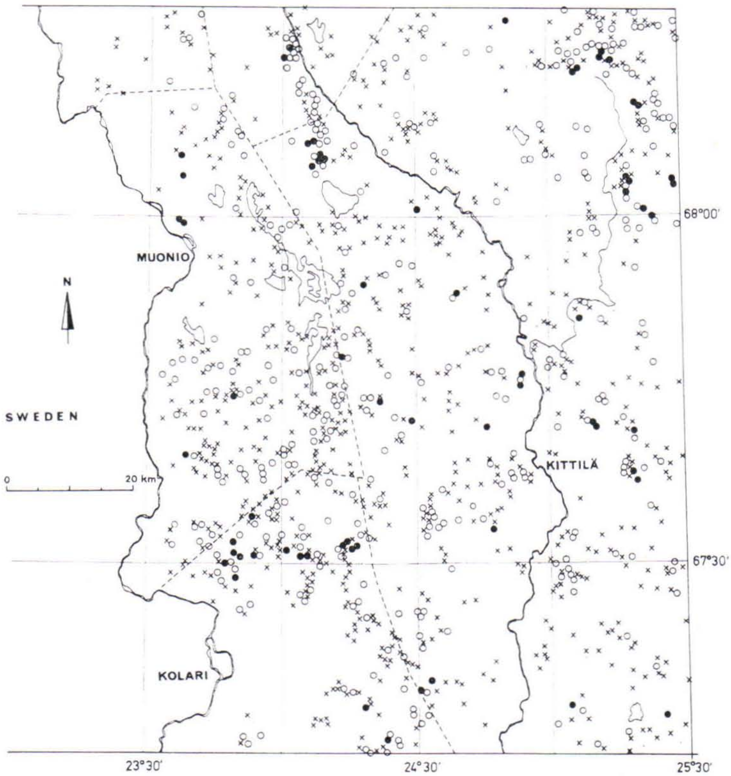

FIG. 35. The results of the spring inventory carried out in the area of the Kittilä 1 : 400 000 map sheet (cf. Fig. 1). Cross, seeps and small springs (< 2 l/s), open circles, medium-sized springs (2—5 l/s), black circles, large springs (> 5 l/s). See text.

3) large springs (black circle). The following values were used as a guide to the rates of discharge: less than 2 l/s, 2—5 l/s and more than 5 l/s.

The number of springs that could be interpreted was highest in the map sheet (1 : 400 000) areas of Kittilä and Sodankylä (Figs. 35, 36). It is easiest to reveal springs in areas of intensely varied topography where the peat bogs are clearly bounded by stratified drift and till deposits. Also, springs occur more abundantly at the foot of steep slopes because of the increased rate of percolation due to the steeper gradient of the water table. In flat areas the boundary between the bogs and the stratified drift and till is gradual so that observations on springs, and the streams rising from them, are hindered by trees and bushes. On the other hand, springs are rare in flat, extensively paludificated regions. In the interpretation of aerial photographs very similar abundances of springs were observed at the foot of till-covered hills and

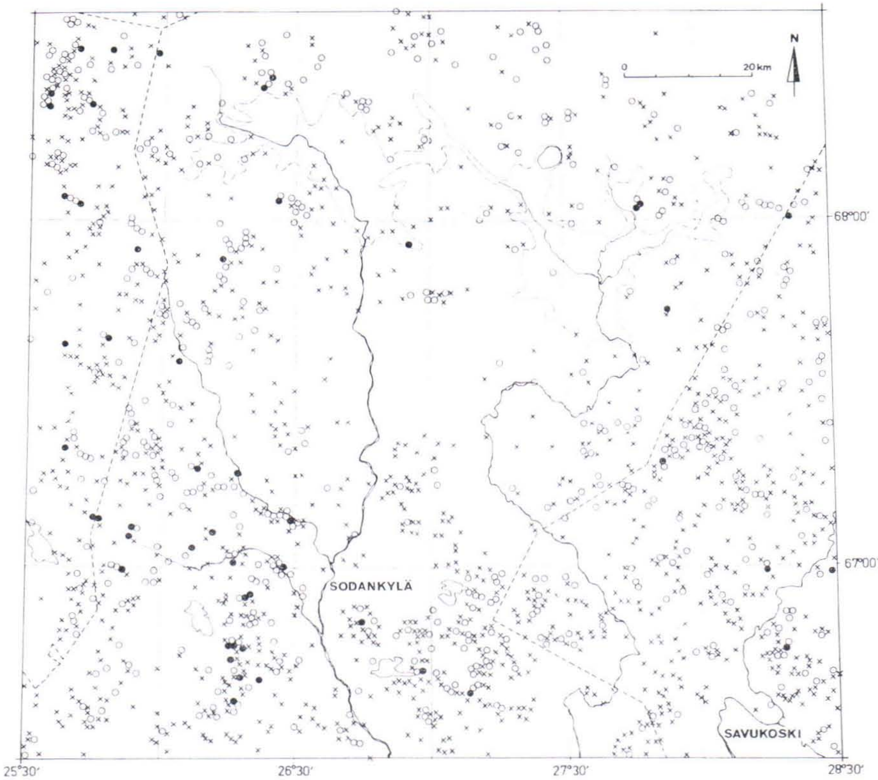

FIG. 36. The results of the spring inventory carried out in the area of the Sodankylä map sheet. On the upper half of the map the Lokka and Porttipahta reservoirs are marked with a dotted line.

on the sides of large glaciofluvial deposits. In the till and glaciofluvial areas the discharges of the springs are of the same order of magnitude. However, sporadic exceptionally large springs occur at the edges of extensive glaciofluvial deposits.

The interpretation of the springs in the hilliest northern and north-western parts of the investigation area from aerial photographs is difficult (Figs. 37, 38). There are block fields all over the lower slopes of these high hills and fells, many of which are north of the timber line. The bogs have a thin cover of peat and grade into till without any clear boundary. Therefore the runoff on the lower slopes of the hills often covered with thicket of bushes cannot usually be distinguished from discharging ground water. The springs which can be mapped most reliably by photo interpretation in these two map sheets are those skirting glaciofluvial deposits in the valleys, such as eskers, kame fields, deltas and sandurs.

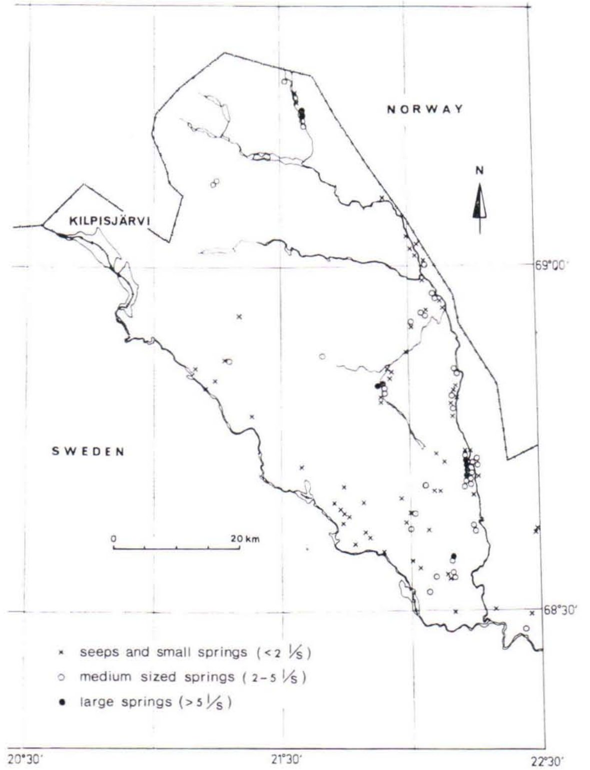

FIG. 37. The results of the spring inventory carried out in the area of the Kilpisjärvi map sheet.

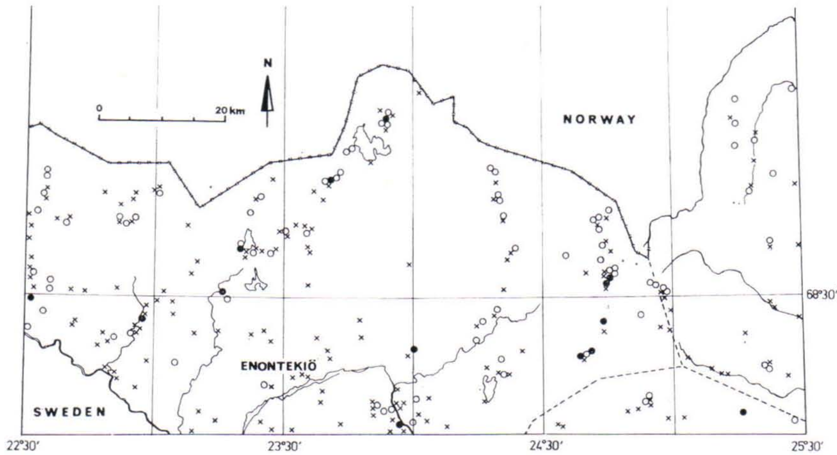

FIG. 38. The results of the spring inventory carried out in the area of the Enontekiö map sheet.

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