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Permafrost Thickness and Distribution in Finnish Lapland — Results of Geoelectrical Soundings

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Summary: Geoelectrical soundings were carried out in 29 different places in order to find permafrost and to measure its thickness. In most places above timber line a permafrost thickness of 10—50 m was recorded. Permafrost was found at sites with thin snow cover during winter. Here, deflation phenomena on the summits of fjells indicate the occurence of permafrost. Vegetation type might be a good indicator of permafrost, too. It seems obvious that permafrost exists extensively on fjell summits of northern Finland.

Zusammenfassung: In verschiedenen Gebirgsräumen von Finnisch-Lappland sind — auf der Suche nach Permafrost — geoelektrische Sondierungen durchgeführt worden. Über der Waldgrenze ist dabei an den meisten Stellen Permafrost mit Mächtigkeiten zwischen 10 und mindestens 50 Metern angetroffen worden. Die Stellen sind im Winter schneefrei, und Deflationserscheinungen sowie der Vegetationstyp scheinen gute Permafrost-Indikatoren zu sein. Permafrost ist offensichtlich in Nordfinnland nicht nur in Palsa-Mooren, sondern auch auf Bergrücken weit verbreitet.

1. INTRODUCTION

Referring to northern Finland, one of the authors of this article wrote with full justification in 1979: "so far permafrost has been found only in mires in the cores of palsas" (SEPPÄLÄ 1982b). The other author has found large areas of thick permafrost in neighbouring northern Norway and Sweden (KING 1976, 1982, 1983, 1984, 1986a). Therefore it was tempting to carry out similar studies in Finnish Lapland, and this study aims to find out if there are other permafrost localities in Finnish Lapland in addition to just palsas. If permafrost were to be found, a second, more important, goal would be to measure its thickness, and to compare its existence with snow-depth observations, vegetation cover, the mean annual air temperature and other environmental parameters (KING 1986a). These comparisons should allow the prediction of possible permafrost localities in Finnish Lapland.

The distribution of palsas is fairly well known in northern Sweden (RAPP 1982), Norway (VORREN 1967; ÅHMAN 1977), and Finland (RUUHIJÄRVI 1960; OHLSON 1964; SEPPÄLÄ 1979, 1988). Palsas can be easily identified from aerial photographs, but this is not the case with permafrost in gravels or bedrock. The southern limit of the main palsa region follows the northern shore of Lake Inari towards eastern Enontekiö (south of Hietatievat, Fig. 1), and then extends west following about 68°25'N latitude to the border of Sweden. The area has been defined as discontinuous permafrost zone by PÉWÉ (1979).

2. STUDY REGION

2.1 *Topography and altitudes*

Northern Finland is flatter and lower in altitudes than neighbouring areas in Sweden and Norway, where the Kjölen mountains in the west rise above 2000 m (Fig. 1). In Finland, elevations higher than 1000 m are reached only in the NW corner (Kilpisjärvi and Halti) of the Caledonian mountains. Large areas of Finnish Lapland are less than 300 m above sea level (Atlas of Finland 1986, Folio 121—122). Many fjell summits are less than 500 m high. 700 m is a rare altitude and can be found at a few summits of eastern Saari-

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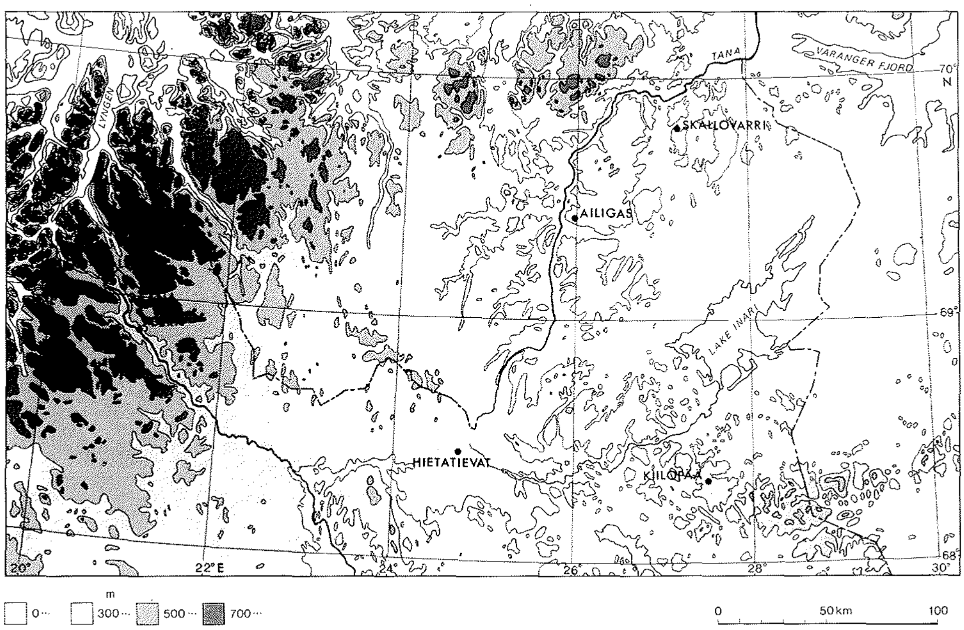

Fig. 1: Contour map of northern Fennoscandia and general location of sounding sites.

Abb. 1: Höhenlinienkarte von Lappland mit Lage der Untersuchungsgebiete.

selkä south of Lake Inari, and at the Ounas-Pallas fjells about 24 °E, and as already mentioned, in NW Finland west of 22 °E longitude (Fig. 1). In general, the topography is smooth and the fjells slope gently. The summits are very flat and large in area as is typical of old peneplain surfaces (SEPPÄLÄ & RASTAS 1980). The main part of Finland belongs of the Archaean shield area and the rather gentle mountains are the results of Tertiary uplifts as horsts; they surround, arc-like, the southern and western edge of the Lake Inari basin (TANNER 1938).

Typical topographic features are deep fault valleys cutting the mountains in blocks. The valleys are important for plant survival during the long and severe subarctic winter which dominates the fjell summits.

2.2 *Vegetation*

North of the southern limit of the palsa zone is the northern border of continuous pine forests (SEPPÄLÄ & RASTAS 1980). In the palsa zone pines do not grow on the mires, they remain on sand and gravel. The most frequent trees in the palsa zone are low birch (*Betula pubescens*). All the measuring sites of this study (except Kiilopää) are located north of the spruce forest zone which reaches its northernmost position (some 68 °30'N) close to the eastern border of Finland (AARIO 1960). The westernmost study sites are also outside of the pine forest zone. In the Hietatievat, Ailigas and Skallovarri areas pine and birch grow in the valleys as mixed forests.

In northernmost Finland, in the Tana River valley, the timberline on north facing slopes is just above 100 m a. s. l. In general, the forest limit is located between 300 and 400 m a. s. l. in the northern parts of the studied region, between 400 and 500 m a. s. l. in the western parts, and rising to 600 m a. s. l. altitude in Kilpisjärvi on the southwest facing slope of Saana mountain.

Heaths extends above timber line. The lower heathlands are dominated by shrubs such as *Betula nana, Vaccinium myrtillus* and *Empetrum hermaphroditum,* whereas in the fjell heaths at higher elevations *Sa-*

lix herbacea, Empetrum and alpine grasses with lichens and mosses occur. In the mountains of the NW *Cassiope tetragona* is abundant.

On the fjell summits blockfields and wind blown heaths with lichens and mosses as well as bare rock slabs are often found. Patterned ground (as stone polygons and stone stripes on slopes) occur regularly on fjell summits (SEPPÄLÄ 1982b).

Open mires with *Sphagnum, Eriophorum* and *Carex* growths are rather common in the valleys. They are normally very wet and their peat layer is less than 2 m thick (LAPPALAINEN 1972).

2.3 *Climate and seasonal frost*

According to KOLKKI (1965) the mean annual temperature in northernmost Finland ranges between +0.5 and —2° C (period 1931—60). The air temperatures are more moderate along the coast. The result is that the warmest area is the NE corner close to Varanger Fiord and the coldest area is the mountainous region in the NW corner. In the region where palsas occur, the mean annual temperature is —0,5° C or below. These temperatures represent the readings at few (about five) stations situated usually in valleys, and at a height of two metres above the ground surface. Local climatic conditions that are responsible for the permafrost formation might differ significantly (e.g. winter inversions).

The coldest months are January and February which are very similar. In the long term the monthly mean temperatures range from —11° C in the NE to —14° C to the S and W. During the coldest months, the minimum temperatures often fall below —40° C. Seasonal thaw starts in May when mean monthly temperatures rise above 0° C, but locally much snow still remains on the ground. Snow melt in the valleys continues throughout May and lakes at higher altitudes stay frozen until mid-June. Mean June temperatures in the study areas are between +7 and +10° C, July is the warmest month with mean monthly temperatures from +12° C to +14° C.

Mean dates of first soil frost formation are between 15th and 25th of October (SOVERI & VARJO 1977). In mineral soils in Utsjoki the depth of seasonal frost may reach 2 to 3.5 m (SEPPÄLÄ 1976); these measurements are made in valleys. In peatlands with normal snow cover the frost penetrates down to 40—60 cm (SEPPÄLÄ 1982a), seldom deeper in Utsjoki. If this happens, then there is not enough time for complete thawing during the preceding summer (SEPPÄLÄ 1986). In peatlands seasonal frost may still be encountered at the end of July, but usually thaws completely before the new freezing season starts (SEPPÄLÄ 1983). The frost season in northernmost Finland lasts up to 8 months in mineral soils and even 9 to 10 months in mires.

In the palsa region the annual precipitation is about 400 mm or less. During June-September more than 50% of the annual total precipitation occurs (HELIMÄKI 1966). The maximum thickness of snow cover is reached in March or April (60—80 cm). In the summit areas of fjells the snow cover is very thin (5 cm or less) and it may disappear completely even at the end of February (KALLIO et al. 1969). Birch forests have thicker snow cover than pine forests and by midwinter the low alpine heath possess only about 50% of the snow depth found in the birch forest (KÄRENLAMPI 1972; CLARK et al. 1985). The wind velocity strongly increases with higher elevations and this is of great importance for the thickness of snow cover (e.g. SOLANTIE 1974; KING 1986a).

A good correlation between snow depth and type of vegetation was found in Kilpisjärvi and Kevo region by CLARK et al. (1985). During the winter 1984/85 the snow depth ranged from 5 cm for medium altitude heath to 85 cm in birch forests. Plants which need a certain protection of snow cover do not survive without it, and this means that e.g. chionophilous plant communities (*Phyllodoce-Vaccinium myrtillus* heaths, meadow-like and heath like snowbeds) usually carry 80 cm snow at a maximum, while the wind swept heaths of the chionophobic communities have less than 20 cm snow (EUROLA et al. 1980). Thus,

Sounding number	Place name	Altitude (m a. s. l.)	Coordinates N E	L/2 in m	Date (1985)	Characteristics
1	Kaunispää	435	68°26'04'' 27°26'40''	380	27. 7.	Flat area with dry heath.
2	Skallovarri	360	69°49'43'' 27°08'24''	400	30. 7.	Flat area rather dry low alpine heath.
3	Skallovarri	360	69°50'00'' 27°08'24''	40	31. 7.	Deflation. Stone polygons, low alpine heath.
4	Skallovarri	360	69°49'58'' 27°08'21''	50	31. 7.	40 m E of site 3. Deflation surface. Low alpine heath.
5	Skallovarri	360	69°49'56'' 27°08'25''	50	31. 7.	Large vegetated stone polygons with diameter 8 m. Low alpine heath.
6	Skallovarri	360	69°49'52'' 27°08'28''	50	31. 7.	Hill with small deflation patches, small cairn, low heath.
7	Skallovarri	360	69°49'49'' 27°08'24''	40	31. 7.	Flat area, no deflation, larger cairn, about 80 m from site 6 Low alpine heath.
8	Skallovarri	320	69°49'20'' 27°09'30''	50	2. 8.	Hill with big boulder, glacial till, some deflation, low heath Some peat on the summit. For snow depth measurements s CLARK et al. 1985, Fig. 8.
9	Skallovarri	315	69°49'28'' 27°09'39''	50	2. 8.	Depression. *Betula nana* bushes.
10	Skallovarri	320	69°49'36'' 27°09'43''	50	2. 8.	Pronounced hill. Glacial till. Some deflation, similar as poi 8.
11	Skallovarri	320	69°49'42'' 27°09'52''	50	2. 8.	Large depression with boulders, patterned ground.
12	Skallovarri	320	69°49'47'' 27°09'56''	50	2. 8.	Large depression with wet patch. Low *Betula nana* and *Sal* bushes (Fig. 8).
13	Skallovarri	325	69°49'52'' 27°09'58''	50	2. 8.	5 to 6 m high with strong deflation. Coarse glaciofluvial gr (Fig. 9). Some peat on summit.
14	Skallovarri	305	69°48'39'' 27°10'00''	50	3. 8.	In birch forest, glacial till. Close to road.
15	Ailigas	535	69°25'52'' 25°58'45''	99	4. 8.	Saddle between the summits. Alpine heath with *Betula nan* and *Empetrum*.
16	Ailigas	540	69°25'54'' 25°58'17''	99	4. 8.	Summit of Skalonjuovttsa fjell. Alpine heath with *Empetru*
17	Ailigas	555	69°25'45'' 25°59'05''	0.54	4. 8.	Bedrock at Lanka fjell. Dry place. Schlumberger configura- tion.
18	Peldojoki	205	69°17'14'' 26°49'20''	50	5. 8.	Blow-out on Peldojoki glaciofluvial delta (Fig. 16). Barren sand. Temperature 2.5° C at the depth of 3.5 m (cf. SEPP LÄ 1971, Figs. 1 and 20). Pines are growing on the surface delta.
18a	Peldojoki	205	69°17'14'' 26°49'20''	37	5. 8.	Orthogonal to layout of sounding 18.
19	Hietatievat	355	68°26'38'' 24°43'08''	50	6. 8.	Large deflation basin. At the foot of esker among paraboli sand dunes.
19a	Hietatievat	355	68°26'38'' 24°43'08''	102	6. 8.	Orthogonal to layout of sounding 19.
20a	Perra	460	68°53'02'' 21°03'28''	0.6	9. 8.	On the top of a 6 m high palsa. Active layer 50 cm. On the southern side of the road.
20b	Perra	460	68°53'02'' 21°03'28''	48.6	9. 8.	As site 20a.
21	Saana	580	69°03'28'' 20°48'04''	50.1	10. 8.	Forest margin. 50 m N of path. Boulders. Marked with pla rod. For snow depths see CLARK et al. 1985, Tab. 11.
22	Saana	615	69°03'27'' 20°48'26''	50.1	10. 8.	N slope of Saana, mound with boulders. Marked with plas rod. Exposed to NNW. *Empetrum* and *Betula nana* heath.
22a	Saana	615	69°03'27'' 20°48'26''	300	10. 8.	Continuation of line 22.
23	Saana	830	69°02'59'' 20°49'20''	50	10. 8.	Medium altitude heath. *Betula nana, Empetrum*. 40 m abo two wooden crosses. 30 cm of fine till material on bedrock
24	Saana	890	69°02'49'' 20°49'53''	50	10. 8.	Medium altitude heath exposed to S. Slope: 13.5°.
25	Saana	880	69°02'52'' 20°49'49''	50	10. 8.	N slope, 25°. Strong solifluction. Medium altitude heath. (*siope tetragona, Salix herbacea*.
26	Pikku-Malla	600	69°03'54'' 20°44'02''	49.9	11. 8.	Above tree line. Low heath. Solifluction steps. 10—20 m tl till.
27	Pikku-Malla	680	69°03'40'' 20°44'33''	50	11. 8.	Low heath. 10 m below the summit. Very fresh rock surfa few cracks.
27a	Pikku-Malla	680	69°03'40'' 20°44'33''	0.133	11. 8.	As site 27. Bedrock conductivity measurement.
28	Pikku-Mala	710	69°03'33'' 20°44'53''	50	11. 8.	Big blocks on thin till cover, unsorted frost polygons. *Betu nana, Empetrum, Arctostaphylos alpina* and lichens.
29	Pikku-Malla	730	69°03'25'' 20°45'13''	50	11. 8.	10 m below the summit. Glacial till. Unsorted frost polygo Medium altitude heath. *B. nana, Empetrum, Arctostaphyl alpina, Diapensia lapponica*.

Tab. 1: Location of geoelectrical sounding sites (L/2 = electrode spread)

Tab. 1: Lage der geoelektrischen Sondierungsstellen (L/2 = Auslage) snow depth is a critical factor for the permafrost formation (KING 1986a) and this has been shown in experimental palsa studies, too (SEPPÄLÄ 1982a).

Topography has its effects on the air temperature: In advective weather situations there is the usual adiabatic gradient of about 0.6 °/100 m altitudinal difference. On the other hand, the relief is favourable for the formation of "cold air ponds" in the valleys with stagnant cold and heavy air. Then, the fjell tops can be up to 2 ° C warmer than the valley bottoms for long periods. Occasionally, it may even be 10 ° C warmer on the summits than in the valleys (HELIMÄKI 1974; HUOVILA 1974). This certainly does not mean that the permafrost formation on the fjell tops would be prevented because of lack of cold. Air temperatures there are still cold enough (e. g. —30 ° C instead of —40 ° C) and allow, because an isolating snow cover is often missing, a cooling of the ground and much deeper penetration of frost than in the snow covered valley bottoms.

Very special local climates exist in blow-outs of which two types are distinguished in Finnish Lapland. Edges of glaciofluvial deltas, eskers, hill summits and steep valley sides are exposed to the wind and often remain snow free during the winter. The second type is formed in sand dunes and on flat outwash plains and here, deflation hollows are mainly formed during the summer and are filled by thick snow in winter (SEPPÄLÄ 1974, 1984). The resulting ground temperature is therefore very different.

3. RESEARCH METHODS

The permafrost survey in Finnish Lapland covered very different areas and sites. As time, manpower and funds were limited for that purpose, the experience obtained in many mountain areas (Alps, Scandinavian mountains, Andes, Antarctica) suggested the application of DC-geoelectrical soundings as an efficient and very reliable method (KING 1982, 1984, manus.; KING et al. 1987). A Gga-30-equipment (Bodenseewerk Geosystem GmbH, Überlingen) was used.

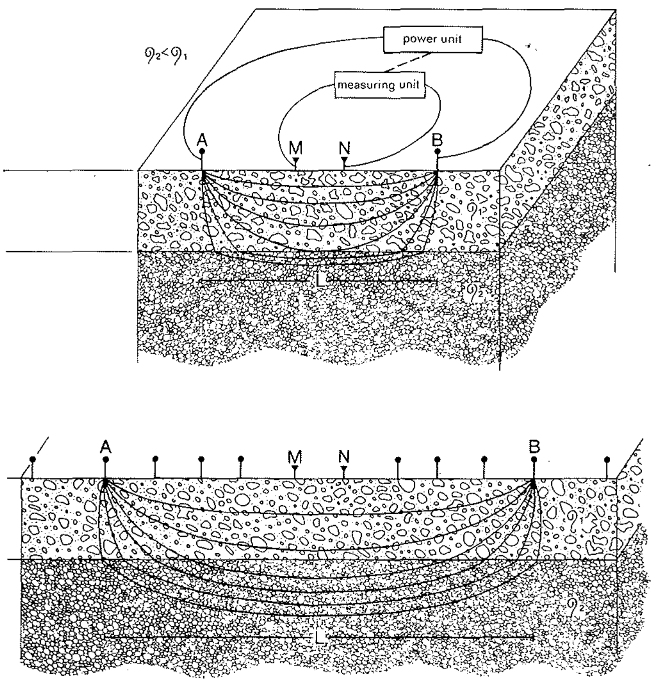

Fig. 2: Principle of a geoelectric sounding (two layer case). A direct current I is sent to the ground via two current electrodes, A and B. Two potential electrodes, M and N, are used to measure the resulting voltage U (equipotential lines are orthogonal to current flow lines shown on sketch). During a sounding the electrode separation AB (= distance L) is successively expanded and the calculated apparent resistivity is plotted versus the distance L/2 on bilogarithmic paper (cp. Figs. 4, 5, 9, 10, 13). The current flow is influenced by the specific resistivities of the surface and subsurface layers. Depth penetration increases with increasing distance L.

Abb. 2: Prinzip der geoelektrischen Sondierung für einen Zweischicht-Fall und zwei Meßpunkte mit unterschiedlicher Auslage L/2. Der Stromfluß zwischen den Elektroden A und B bzw. das an den Sonden M/N gemessene Potential wird durch die elektrische Leitfähigkeit auch des unter dem Oberflächenhorizont liegenden Materials beeinflußt. Der berechnete scheinbare Widerstand wird auf doppelt logarithmischem Papier gegen die Distanz L/2 aufgetragen (vgl. Abb. 4, 5, 9, 10, 13). Die Tiefenwirkung einer Sondierung steigt mit zunehmender Distanz L/2.

The geoelectrical sounding technique allows to measure apparent resistivities of surface and subsurface layers. The specific resistivities of unfrozen and frozen layers differ significantly (e. g. KELLER et al. 1966). Moreover, the resistivity of frozen rock increases with decreasing temperatures. These basic points are equally valuable for unconsolidated sediments and consolidated rock.

With geoelectric soundings, information on subsurface layers may be obtained in a relatively short time as the measurement is executed on the surface and does not need costly drilling or digging. Fig. 2 shows the general principles of the technique. But as with all other indirect geophysical soundings, difficulties with the interpretation of the sounding data may arise. For the exact calculation of the permafrost thickness, limitations and error sources exist due to (lateral) terrain effects and especially due to the fact, that for one sounding graph obtained in the field, several equivalent models may be calculated in the interpretation (KING 1982, 1984). In any case, a final decision for the right theoretical model always needs the results of a careful geomorphological survey. This is demonstrated at the beginning of the following chapter. For interpretation of multi-layer cases, other geophysical methods (e. g. ground temperature measurements, seismic or radio echo soundings) may support the final model (KING 1976; KING et al. 1987).

4. SOUNDING SITES AND RESULTS

4.1 *Skallovarri (Utsjoki, Kevo)*

In the Kevo region, Utsjoki, permafrost exists in many palsa mires (e. g. SEPPÄLÄ 1982a, 1983). The

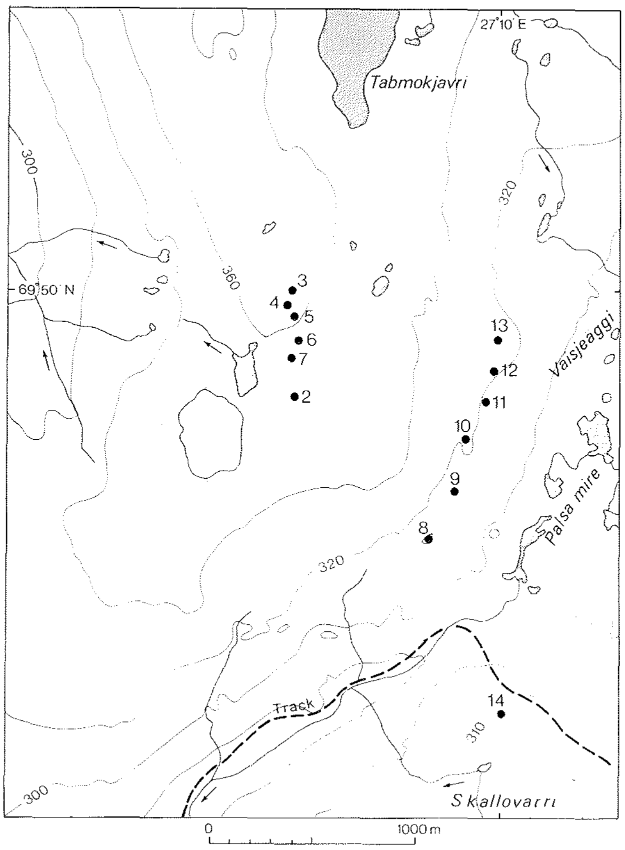

Fig. 3: Location of geoelectrical sounding sites in the Kevo area between Skallovarri and Puollamoaivi, Utsjoki (cp. Tab. 1). Drawn after topographic maps 393203 and 394101.

Abb. 3: Lage der Sondierungsstellen im Gebiet Kevo (vgl. dazu Tab. 1).

aim of our study in the Kevo area was to clarify whether permafrost occurrences exist also in the mountains that surround these mires. One of these mountains, Puollamoaivi (432 m high), is located some 13 km NE of Kevo Subarctic Research Station. Its southern continuation reaches to the immediate vicinity of the Skallovarri palsa mire (Fig. 3). Soundings 2 to 7 are located at an altitude of 360 m a. s. l. The sounding sites are located only 30—70 m higher than the surface of the palsa mire with an altitude of about 290 m a. s. l.

Typical field results are shown on Figs. 4 and 5. Tab. 2 displays the interpreted models of all our soundings. First is presented a general interpretation for the sounding results that all show a common basic trend. It is intended to show to the geographer, who may be in experienced in this technique, that an accurate geomorphological survey is indispensable for the right interpretation of geoelectrical field graphs. In a first approach, most field graphs can be treated as three layer curves of the double-descending type (MUNDRY et al. 1979). Their common property is that the curves start with very high specific resistivities (> 10.000 Ohm-m) and in some cases reach 60.000 Ohm-m (Tab. 2). The specific resistivities of the middle layer is between 10.000 and 2.500 Ohm-m. For the third layer values of 1.000 Ohm-m are obtained.

If we assume in Skallovarri the existence of a thick overburden e.g. dry boulders on bedrock, the soun-

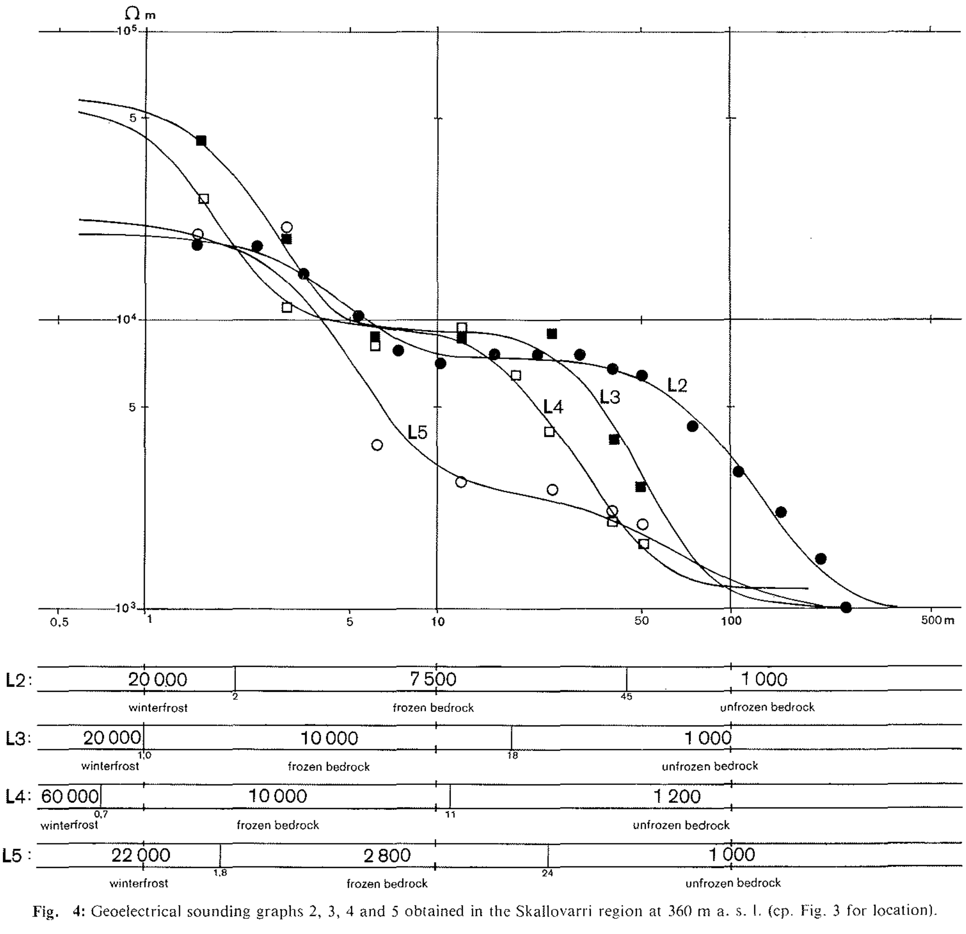

Fig. 4: Geoelectrical sounding graphs 2, 3, 4 and 5 obtained in the Skallovarri region at 360 m a. s. l. (cp. Fig. 3 for location).

Abb. 4: Ergebnisse der Sondierungen 2, 3, 4 und 5 im Skallovarri-Gebiet (Kevo) auf 360 m ü. d. M. (vgl. Lage auf Abb. 3).

ding graphs displayed in Fig. 4 could be interpreted as proof for permafrost-free terrain. The resistivity of the first layer would indicate seasonal frost, the second layer with values of or below 10.000 Ohm-m would be typical for permafrost-free sediments and $\varrho 3$ may be attributed to unfrozen bedrock. The value d2 would then indicate the depth of bedrock, e.g. 11 m for the site 4.

Geomorphological field evidence, however, shows that this interpretation cannot be true. Outcrops in the surrounding areas indicate that bedrock must be pretty close to the surface. An overburden of not more than 1 to 2 m is estimated for site 2. Under these circumstances (near surface bedrock) the curves of the double-decreasing type have to be interpreted differently. The specific resistivities $\varrho 1$ listed on Tab. 2 are again caused by ice-rich seasonal frost. Its thickness then corresponds more or less to the thickness of the overburden, and these values also correspond to the estimates obtained by geomorphological survey. Bedrock values display two very different specific resistivities. The relation between the values $\varrho 2$ to $\varrho 3$ is between 2.5:1 and 10:1 (Tab. 2). As the final resistivity of 1.000 Ohm-m must be caused by (unfrozen) bedrock, the resistivity $\varrho 2$ is definitely a clear and safe indication to frozen bedrock. The mentioned resistivity relation 4:1 or 10:1 is a reasonable value for frozen and unfrozen rock, respectively (see KING 1982).

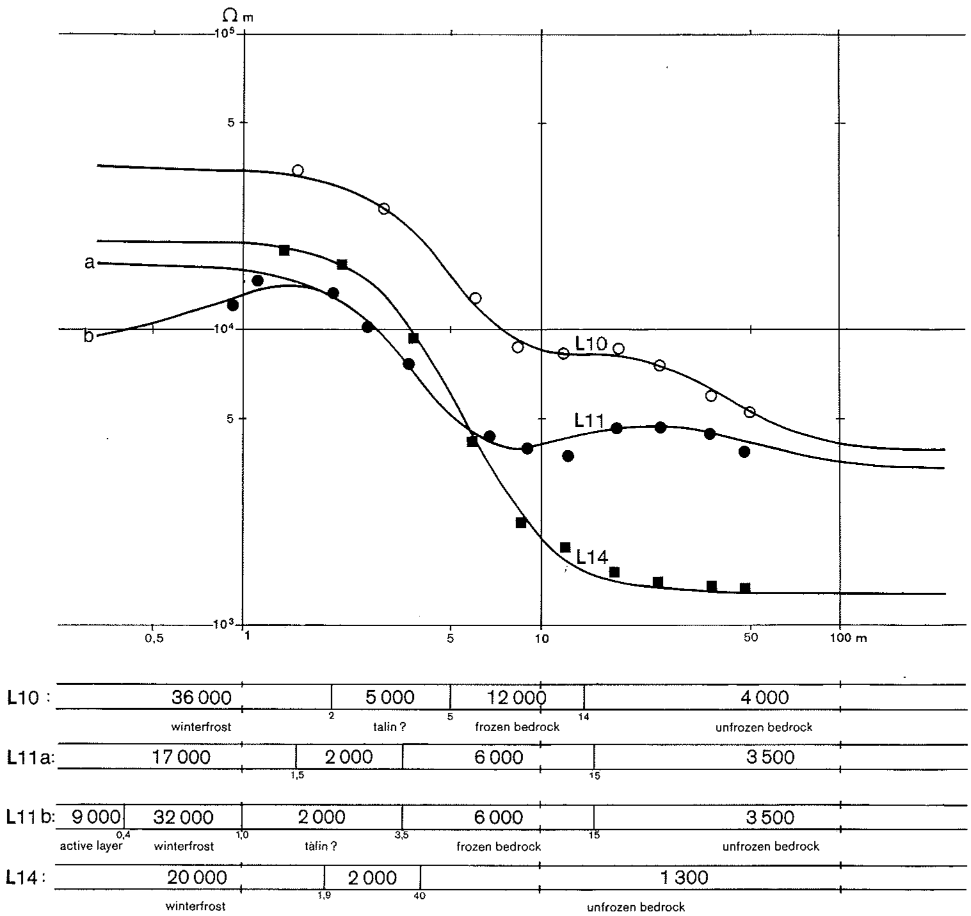

Fig. 5: Geoelectrical sounding graphs and calculated models 10, 11 and 14 from Skallovarri region at 320 m a. s. l. (cp. Fig. 3 for location).

Abb. 5: Ergebnisse der Sondierungen 10, 11 und 14 im Skallovarri-Gebiet (Kevo) auf 320 m ü. d. M. (vgl. Lage auf Abb. 3).

Sounding number	curve type (layers)	ϱ_1	(ϱ_m)	ϱ_2	ϱ_3	d_1	(d_m)	d_2
2	DD (3)	20 k	(4 k)	7.5 k	1 k	2.0	(3.0)	45
3	DD (3)	60 k	(4 k)	10 k	1 k	1.0	(1.6)	18
4	DD (3)	60 k	(4 k)	10 k	1.2 k	0.7	(1.0)	11
5	DD (3)	22 k	(1.2 k)	2.8 k	1 k	1.8	(3.0)	24
6	DD (3)	36 k	(2.5 k)	6 k	1 k	1.0	(1.6)	18
7	DD (3)	20 k	(1.2 k)	3 k	1 k	1.0	(1.6)	22
8	DD (4)	60 k	(4.0 k)	10 k	1.2 k	0.8	(1.2)	13
9	DD (3)	40 k	(2.8 k)	6.5 k	1 k	2.0	(3.2)	18
10	DD (3)	36 k	(5 k)	12 k	4 k	2.0	(5.0)	14
11	DD (4)	17 k	(2 k)	6 k	3.5 k	1.5	(3.5)	15
12	Mn (3)	5.5 k		1 k	3.0 k	1.7		6
13	DD (3)	50 k	(4 k)	10 k	1 k	1.0	(1.4)	7
14	D (2)	20 k	(2 k)	1.3 k	—	1.9	(4.0)	—

Abbreviations for curve type: D (2) = descending, 2 layers. DD (3) = double-descending type, 3 layers. DA (3) = double-ascending type, 3 layers. Mn (3) = minimum type, 3 layers. Mx (3) = maximum type, 3 layers; ϱ = specific resistivities, d_1 ... = depth of corresponding layer.

Tab. 2: Specific resistivities (in Ω-m) and depths (in m) of calculated models for the soundings in Kevo area (Skallovarri)

Tab. 2: Spezifische Widerstände (in Ω-m) und Tiefen (in Meter) der berechneten Modelle für das Kevo-Gebiet (Skallovarri)

Two further comments contribute to a better understanding of the graphs: First, the total thickness of permafrost (defined as subsurface material with a temperature below 0° C) is, and has to be, more than the result indicated by the geoelectrical sounding. The reason for this is: Permafrost with a temperature close to 0° C is hard to detect as the specific resistivity of this permafrost remains quite low due to unfrozen pore water. Second, the active layer in general is not displayed in our sounding graphs, because they start with a layout of L/2 = 1.5 m. However, detailed soundings show that the specific resistivities of the mentioned seasonal frost material drop rapidly for the values that are obtained with a layout L/2 of less than 1.5 m. An example is shown in sounding 11 (Fig. 5). These detailed measurements have usually been omitted in the field. The values have been put into parenthesis as $[\varrho_0]$ and $[d_0]$ for specific cases (Tab. 3).

After these introductory statements which are applicable for most field curves, the differences between the sounding graphs 2 to 7 are easy to interprete. The soundings 2, 3 and 4 show the similarities described above: three layers where the resistivity decreases with depth. However, Fig. 4 shows, that the decrease

Sounding number	curve type (layers)	ϱ_0	ϱ_1	ϱ_2	ϱ_3	(d_0)	d_1	d_2
21	Mx (3)	(<10 k)	60 k	2.5 k	—	(1.0)	2.2	—
22	Mx (3)	(<10 k)	60 k	3 k	—	(0.7)	1.4	—
23	Mx (3)		10-20 k	65 k	(4 k)		2	>50
24	Mx (3)		7-10 k	22 k	(4 k)		11	50
25	Mx (3)		10-15 k	33 k	(4 k)		11	>60
26	Mx (3)		5 k	8.5 k	(3.5 k)		1.5	(8)
27	Mx (4)		5 k	10 k	6 k	(0.7)	1.9	13
28	Mx (3-4)		12 k	55 k/15 k	4 k	(0.5 m)	1.6	40
29	Mx (3-5)		10 k	50 k 20 k 9 k	4 k	(1 m)	5/10	50

Tab. 3: Specific resistivities (in Ω-m) and depths (in m) of calculated models for the soundings in the Kilpisjärvi area (Saana and Pikku Malla). Unfrozen deep bedrock and unfrozen thin active layers have been assumed in some graphs (cf. text). For abbreviations cf. Tab. 2.

Tab. 3: Spezifische Widerstände (in Ω-m) und Tiefen (in m) der Modelle von Sondierungen im Kilpisjärvi-Gebiet. Geschätzte Werte für Auftauschicht und tiefliegenden nicht gefrorenen Fels in Klammern.

from $\varrho 2$ to $\varrho 3$ is located differently for the graphs 4, 3 and 2. The drop begins at L/2 = 14 m, 25 m and 40 m, respectively, and they indicate increasing permafrost thicknesses from sites 4 to 2. The corresponding models are displayed below the figures and show that permafrost reaches to depths of 11 m, 18 m and 45 m, respectively. These differences are not unusual for permafrost areas, as SEGUIN (1974: 347—350) could show in comparable studies in northern Quebec. Relict permafrost and differences in heat conductivity may be responsible. The graph for site 5 on Fig. 4 is in strong contrast to those of sites 2, 3 and 4. Its resistivity $\varrho 2$ is only 2.800 Ohm-m, a value that is certainly too low to be a sure indicator for frozen bedrock. It is only when the results of measurements 2, 3, 4 and 6 are considered together that $\varrho 2$ may be attributed to frozen bedrock. The low resistivity of 2.800 Ohm-m may be explained with small amounts of unfrozen pore water in the otherwise frozen bedrock with a temperature near 0° C.

Whether or not the permafrost in bedrock at sounding site 5 is active or relict cannot be answered with our sounding technique. Several possible models for the field values of site 5 exist. It can be demonstrated nicely that an unfrozen talik of even 1.2 m thickness and a resistivity of 1.200 Ohm-m does not show up clearly on the graph. This is another important limitation of the geoelectrical sounding technique: there has to be a minimum thickness for subsurface layers to be detectable; in our case, a minimum thickness for the $\varrho 2$-layer is the value of its depth d1 (cp. KING 1984: 49). This intermediate low resistivity layer ϱ_m and its depth d_m is shown in Tab. 2. Many other soundings show a low resistivity layer below the top high resistivity layer. This low resistivity layer ϱ_m may be due to a lower ice content or to a thin unfrozen talik below the seasonal frost layer. We omit any further comments on that phenomenon as our aim is to describe the general broad trends with simple theoretical models. More sophisticated models can easily be calculated for all sounding graphs, e. g. multi-layer models showing the developing active layer, a seasonal frost layer, taliks and multiple permafrost layers with different resistivities according to different ground temperatures. In this paper, we prefer to use the simple models.

It is concluded therefore that all sites on the crest of Skallovarri (Puollamoaivi) show the existence of permafrost, but its thickness seems to be different. The contribution of lateral effects to these differences

Fig. 6: Sounding site 12 in Skallovarri region shows patterned ground at a slight depression. Permafrost could not be found here. Photographed by M. Seppälä, August 2, 1985.

Abb. 6: Die Sondierungsstelle 12 (Skallovarri, Kevo) liegt in einer flachen Depression und weist Strukturbodenformen auf. Permafrost konnte hier nicht nachgewiesen werden.

may not totally be excluded. However, comparing our field notes on geomorphology it is quite striking that the sites with clear indication for permafrost show deflation (cp. Tab. 1), whereas signs of deflation are missing at sites 5 and 7. Sites 2, 6, 3 and 4 are windswept spots and show only thin snow cover in winter. For sites 7 and 5 a snow cover of several decimetres and maybe up to 1 m may exist, thus insulating the ground at least partly from winter cold. Geomorphology strongly influences the extent of permafrost, here.

Soundings 8 to 13, executed on the lower slope edge towards the palsa bog, have been done in order to check if permafrost exists not only on the windswept crests of mountains but also close to the palsas and in subsurface materials without the favourable thermal conditions of peat. Site 14 is situated in the birch forest of the valley floor. The results obtained are listed in Tab. 2 and displayed in Fig. 5. They are commented upon here only shortly.

The curves for the soundings 8 to 13 show similar trends to those already described from soundings 2 to 7. They mostly indicate that permafrost is also widespread in these lower and better protected sites. However, permafrost is missing at locations 12 and 14. The results in Tab. 2 and Fig. 5 may be summarized as shown below.

sounding site	remains of seasonal frost	permafrost	permafrost probably relict	no permafrost
8		x	x?	
9	x	x		
10	x	x	x	
11	x	x	x	
12				x
13	x	x	x	
14	x			x

Finally, it is useful to give data upon the palsa bogs in the areas of permafrost. The palsas that exist in the Kevo area are well developed with heights of about two metres and several tens of metres in diameter. These distinct features are typical for discontinuous permafrost (e. g. KING 1984) but not for sporadic

Fig. 7: Sounding site 13 in Skallovarri region is situated on a mound with pronounced signs of deflation. The existence of permafrost several meters thick may be assumed here according to our sounding results. Photographed by M. Seppälä, August 2, 1985.

Abb. 7: Die Sondierungsstelle 13 (Skallovarri, Kevo) befindet sich auf einer flachen Kuppe mit Anzeichen starker Deflation. Die Meßergebnisse deuten auf das Vorkommen von mehreren Meter mächtigem Permafrost an dieser auch im Winter schneefreien Stelle (vgl. dazu Abb. 6).

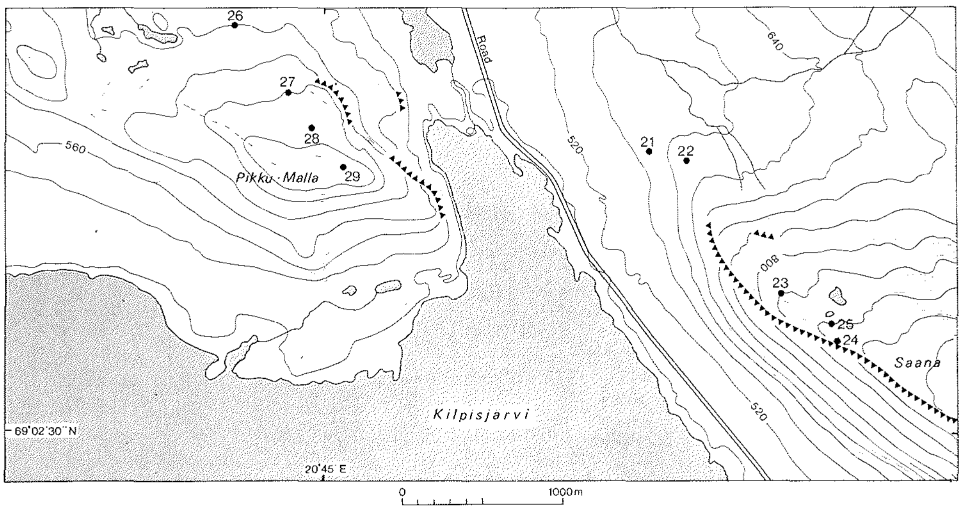

Fig. 8: Location of geoelectrical sounding sites in the Kilpisjärvi area (Saana and Pikku Malla). Drawn after topographic maps 182309, 182407 and 182312.

Abb. 8: Lage der Sondierungsstellen im Gebiet Kilpisjärvi (vgl. dazu Tab. 1).

permafrost where the mean annual air temperature is close to 0° C. In both zones palsas exist and may be unstable features, actively growing and decaying, thus leaving small ponds (HAMELIN & CAILLEUX 1969, KING 1979, SEPPÄLÄ 1971, 1979). Palsas that occur in sporadic permafrost are usually much smaller (a few decimeters high and a few meters in diameters) and less frequent. Examples for that type are given in KING (1984, Figs. 54 and 55) from the Dovre area, Norway (see also SOLLID & SØRBEL 1974).

4.2 *Saana and Pikku Malla (Kilpisjärvi)*

Kilpisjärvi is about 260 km WSW of Kevo, close to the point where the borders of Norway, Sweden and Finland meet. Nine soundings in this region indicate permafrost occurrences and their thickness. Of special interest to high altitude permafrost is the question of the lowermost sites. In order to compare sites with similar ecological conditions, windswept places at altitudes between 580 an 880 m a. s. l. have been selected.

The first set of soundings consist of measurements 21 to 25, located on the NW slope of Saana Fjell between 580 and 890 m a. s. l. (Fig. 8). Further comments on these sites and the applied configuration are mentioned on Tab. 1. The calculated models for the sounding graphs are listed in Tab. 3.

The results of the first two soundings (21 and 22) have been obtained at the lower Saana slope. As the curves are very similar, only measurement 22 is displayed in Fig. 9. The apparent resistivities decrease from the second to the third layer. The final resistivity of 3.000 Ohm-m undoubtedly corresponds to unfrozen bedrock. Geomorphological observations in the area indicate a debris thickness of several metres. This means, that the specific resistivities of the uppermost two layers originate from loose material. With a $\varrho2$-value of more than 10.000 Ohm-m, both soundings show that this material must be frozen and contains ice. However, with a thickness of only 1.4 and 2.2 m, respectively, no permafrost but only seasonal frost exists at these sites. Thickness and resistivity of the active layer have not been investigated in detail, but it may be added that models for the sounding 21 indicate a thickness between 70 cm (6.000 Ohm-m) and 100 cm (8.000 Ohm-m); for sounding 22 a thickness of 70 cm is calculated (10.000 Ohm-m).

In contrast to sites 21 and 22 the sounding graphs for sites 23, 24 and 25 display a continuously rising tendency. The graphs 22 and 25 are shown on Fig. 9 as typical examples. The resistivities start between 8.000 and 10.000 Ohm-m on the field graphs, but lower values for the active layer are very probable. The resistivity increase on the field graph 25 (and 23, 24) starts at L/2 = 10 m (9 m and 1 m, respectively). The sounding sites 25 (and 23) are located on slopes exposed to the north and show no clear flattening of the graph but a continuous increase of the apparent resistivity. This means that the specific resistivities at sites 23 and 25 rise to 30.000 Ohm-m or more, and the permafrost thickness is at least 50 m. A distinct flattening out of the graph can be observed at site 24 and allows one to conclude that a permafrost thickness of about 50 m exists with a mean specific resistivity of about 22.000 Ohm-m (Tab. 3). This site is at 890 m a. s. l. and the slope is exposed to the south.

Our conclusions to the mentioned permafrost thicknesses have been supported recently by ground temperature measurements taken by P.-P. JECKEL (oral communication). They show a mean annual ground temperature of 0° C and —1.5° C for altitudes of 890 m and 1000 m a. s. l. respectively. Further proof for thick permafrost occurrences comes from the data of BTS measurements done by P.-P. JECKEL (cf. HAEBERLI 1973, and KING 1984: 125—128 for method). They indicate the existence of discontinuous but patchy permafrost between 700 and 900 m a. s. l., and widespread discontinuous permafrost between 900 m a. s. l. and the summit at 1030 m a. s. l. (JECKEL, in prep.).

The sounding sites 26 to 29 are located on the northwestern slope of Pikku Malla (Fig. 8; HILTUNEN 1980). The altitudes between 600 an 730 m a. s. l. are between those of the Saana sites 22 and 23. Further

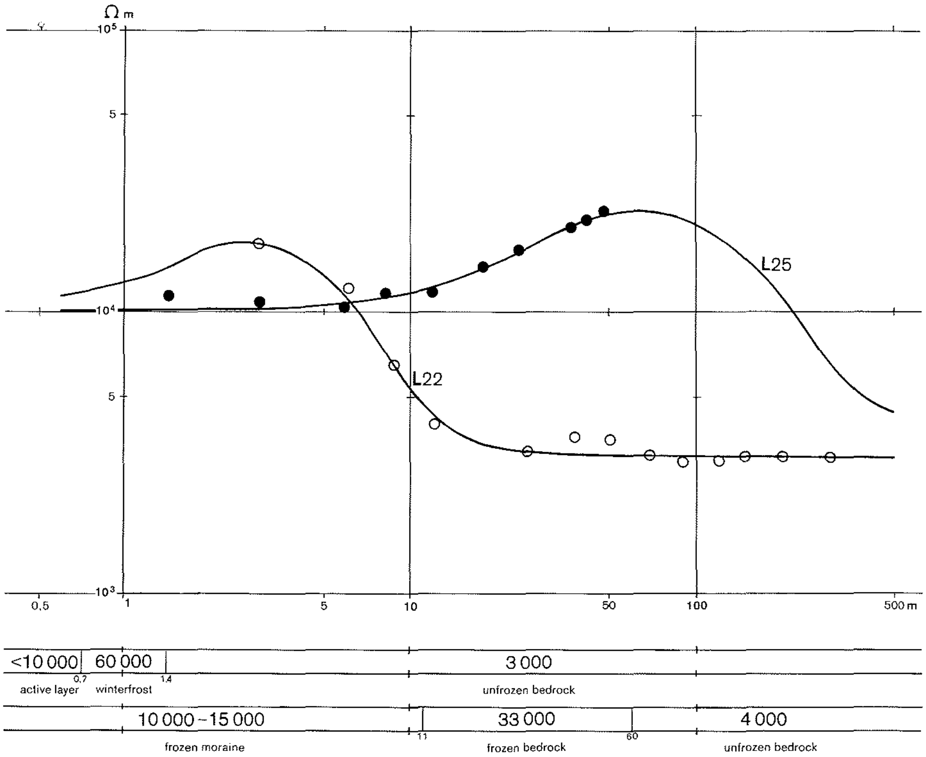

Fig. 9: Geoelectrical sounding graphs 22 and 25 from Saana (cp. Fig. 8 and Tab. 1 for details). For sounding 25 a minimum thickness of 50 m is assumed in the model curve.

Abb. 9: Ergebnisse der Sondierungen 22 und 25 von Saana (Lage auf Abb. 8). Für die Modellkurve 25 wird eine minimale Mächtigkeit von 50 m angenommen.

comments can be found on Tab. 1. Fig. 10 displays the field values and the model curves 26, 28 and 29, which are representative also for measurement 27.

In a first approach, all the four sounding graphs may be interpreted as three layer graphs, the main difference being the resistivity values: The apparent resistivities obtained at sites 26 and 27 are lower than 10.000 Ohm-m; those at sites 28 and 29 are higher than 10.000 Ohm-m. Again, a knowledge of the kind of subsurface material is indispensable for the right interpretation: Site 26 shows certainly a thick debris cover of morainic material (lee side of glacier flow) and depth to bedrock might be 10 or 20 m. A debris of two or several metres may be assumed also for sites 28 and 29, but it is probably less than 6 to 8 m. In contrast, site 27 is more or less devoid of loose material.

When these observations are taken into account, the conclusion is reached that permafrost at site 26 is not definite; the resistivity values of 8.500 Ohm-m are relatively low. The decrease from 8.500 to 3.500 Ohm-m at 8.0 m depth might hint at a "warm" permafrost occurrence, but it is also possible that this decrease is due to different material properties, maybe even to bedrock. An even smoother curve was obtained at site 27, but as loose material is missing the interpretation is different: The existence of permafrost is very plausible, although not absolutely safe. Permafrost probably reaches to a depth of 12 to 14.5 m, whereby the latter value was obtained with a model of 10.000 Ohm-m for $\varrho 2$.

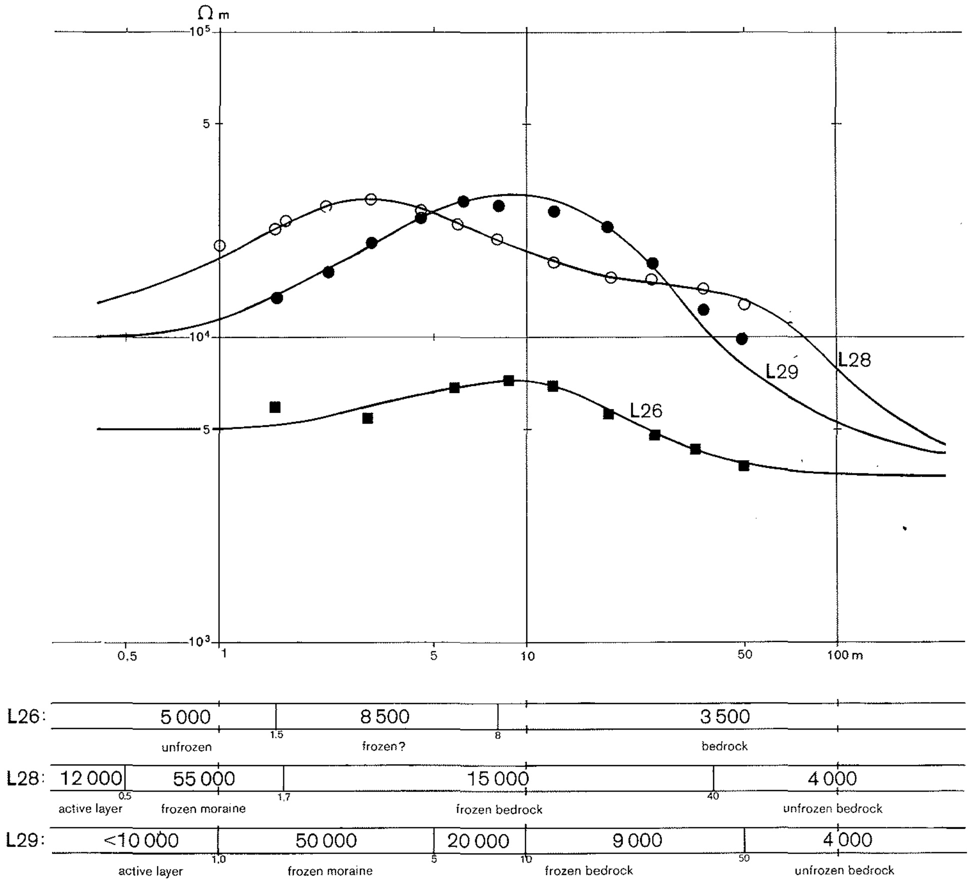

Fig. 10: Geoelectrical sounding graphs 26, 28 and 29 from Pikku Malla (cp. Fig. 8 and Tab. 1 for details).

Abb. 10: Ergebnisse der Sondierungen 26, 28 und 29 von Pikku Malla (Lage auf Abb. 8).

Fig. 11: View from Saana fjell over Lake Kilpisjärvi towards Pikku Malla. Photographed by M. Seppälä, August 10, 1985.

Abb. 11: Blick vom Saana über den Kilpisjärvi gegen den Pikku Malla.

Sites 28 and 29 prove the existence of permafrost by the considerably higher resistivities recorded (about 50.000 Ohm-m). A three-layer model for graph 29 points to a permafrost thickness of 20 m at least, a four layer model even aims at 50 m thickness (cf. Fig. 10). In curve 28, the permafrost thickness is certainly more than the depth to bedrock. If we assume a specific resistivity of 4.000 Ohm-m for unfrozen bedrock, the thickness is at least 40 m. An accurate permafrost thickness cannot be calculated due to the restricted layout of only 50 m.

4.3 *Ailigas and Kaunispää*

In the Ailigas area, soundings have been done at an altitude of about 540 m a. s. l. (Fig. 12). Sounding 15 is situated in a pass area and there might be a small snow drift here in winter. Site 16 is located on a windswept hill, whereas sounding 17 was measured on the bedrock of the Ailigas slope exposed to the west.

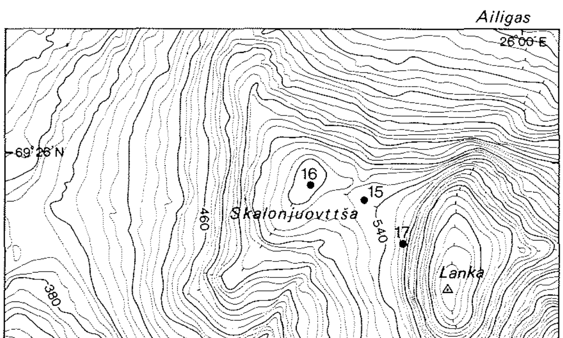

Fig. 12: Location of geoelectrical sounding sites in Karigasniemi area (Ailigas fjell). Contour intervals are 5 m (drawn after topographic maps 391110 and 301301).

Abb. 12: Lage der Sondierungsstellen im Gebiet Karigasniemi auf dem Ailigas (Äquidistanz = 5 m).

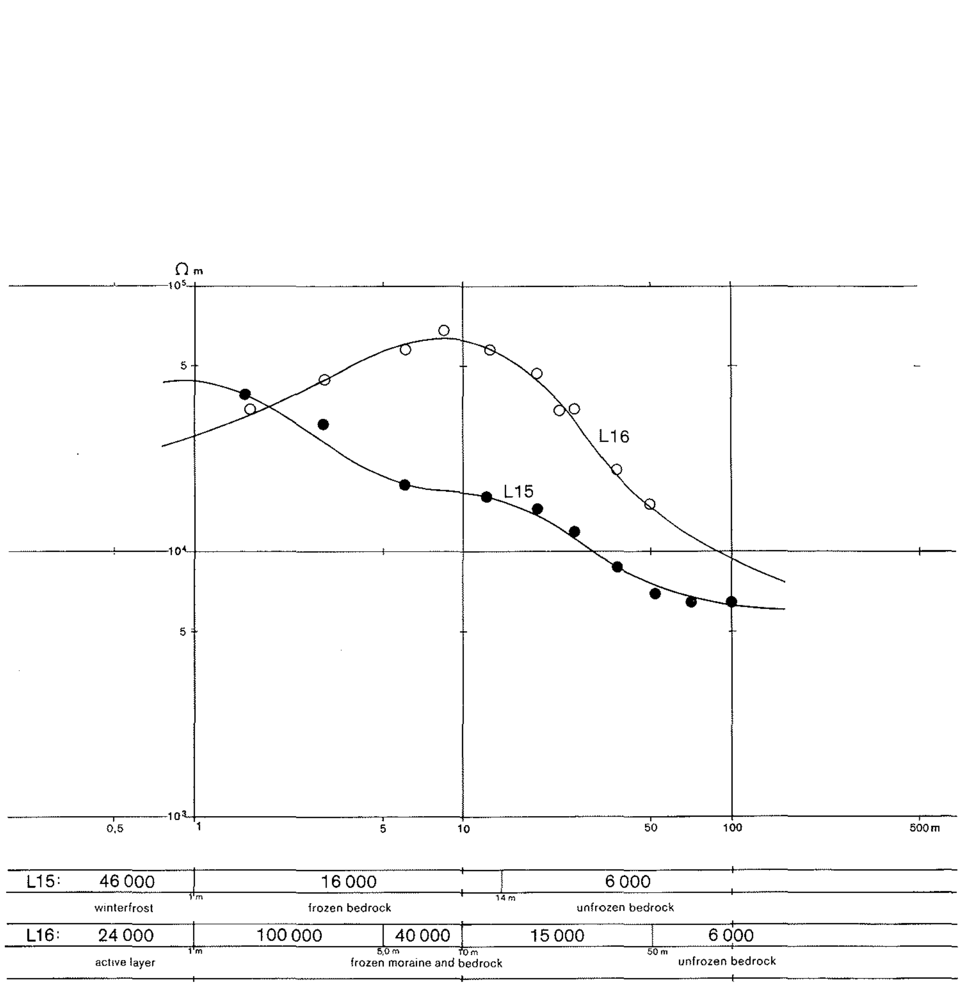

Fig. 13: Geoelectrical sounding graphs 15 and 16 from Ailigas (cp. Fig. 12 and Tab. 1 for details).

Abb. 13: Ergebnisse der Sondierungen 15 und 16 vom Ailigas (vgl. dazu Abb. 12 und Tab. 1).

Sounding 17 gives a good estimate for bedrock resistivity with 5.500 Ohm-m. The curve 15 is of the double descending type and is similar to the curves 3 and 4. The permafrost thickness of 14 m mentioned on Tab. 4 is again a minimum value and some permafrost with temperatures close to the freezing point must be added. Curve 16 hints to permafrost, too, but the values of the apparent resistivities become significantly higher with larger layouts, thus indicating thicker permafrost. The curve also indicates a thicker unfrozen surface layer than at site 15. This is reasonable, since there is probably no snow cover left in spring and the active layer can develop rapidly in summer. In contrast, in curve 16 the active layer does not show up, but as demonstrated at curve 11b (Fig. 5), a theoretical active layer of about 40 cm might be present here. The necessary soundings with short spacings have been omitted again as this is not of further interest for the determination of the permafrost thickness. On Ailigas, the two soundings and thicknesses obtained indicate, therefore, that permafrost is probably widespread at altitudes of 500 to 600 m.

Thirty kilometers south of Lake Inari, a first sounding has been done on Mt. Kaunispää in an altitude of about 435 m a. s. l. The windswept sounding site is near the summit. The sounding curve is of the four layer type and the model values are shown on Tab. 4. Permafrost may be present here. The aforementioned theoretical models can be interpreted as dry debris/wet debris / frozen bedrock/unfrozen bedrock, thus this simple model and the single sounding do not allow one to fix the exact limit to bedrock. If this interpretation is correct it would mean that there is a considerable permafrost thickness of about 70 m or more. This assumption, although astonishing at first, coincides reasonably well with a MAAT of —2.5 ° C. The indication of a quite thick active layer even hints to the possibility that this permafrost occurrence might be relict. This assumption seems to be reasonable because the formation of relict permafrost is possible according to the climatic history.

Sounding number	curve type (layers)	ϱ_1	ϱ_2	ϱ_3	d_1	d_2
15	DD (3)	46 k	16 k	6 k	1	14
16	Mx (5)	24 k	100 k 40 k 15 k	6 k	1	5 m 10 50 m
17	—	5.5 k	—	—	—	—
(18)	Mx (3)	100 k	>150 k	<2 k	0.7	>6
(19)	DD (3)	12 k	6—1 k	0.4 k	>1.2	10
(20)	Mx (3)	0.9 k	30 k	0.0.1 k	1.3	7.0
1	Mn, Mx (4)	10 k, 2.5 k	10 k	3 k	1.6/6.0	70

Tab. 4: Specific resistivities (in Ω-m) and depths (in m) of calculated models for the soundings at Karigasniemi (Ailigas), Hietatievat and Peera. For abbreviations cf. Table 2.

Tab. 4: Spezifische Widerstände (in Ω-m) und Tiefen (in m) der Modelle von Sondierungen in den Gebieten Ailigas, Hietatievat und Peera.

4.4 *Peldojoki, Hietatievat, Peera*

A number of further soundings have been done and are mentioned here as far as they are of interest to this study. About 30 km east of Karigasniemi, sounding 18 is located in the large Kiella-Peldojoki glaciofluvial delta. The measurements give extreme high apparent resistivities of more than 100.000 Ohm-m for the uppermost metres. Due to the resistivity decrease of the curve, a semi-quantitative evaluation is only possible and feasible model values are given on Tab. 4. As a frozen body may be undetectable in high resistivity sand, the extreme high values do not indicate permafrost. A grain size and mineral analysis was made in the laboratory, because these values are extremely high and have never been encountered during our soundings before.

Fig. 14: Sounding site at a large deflation surface on the edge of Peldojoki glaciofluvial delta. Steel probes M N are in the foreground, the electrode sticks may be recognized along the measuring tape. The recording instruments are located on a small terrace. Photographed by M. Seppälä, August 5, 1985.

Abb. 14: Sondierungsstelle auf Deflationsfläche auf dem glazifluvialen Delta des Peldojoki. Im Vordergrund die Sonden M/N, die Stromelektroden für verschiedene Längen L/2 stecken entlang dem Maßband. Das Meßgerät befindet sich etwas abseits der Sondierungsstelle auf einer kleinen Terrasse.

The surface sample consists of 98.2% sand, and a mineral analysis of the sand shows that about 90% are quartz, the remaining percentage consists mainly of feldspars.

The sounding 19 has been executed in the Hietatievat dune field, where SEPPÄLÄ (1974, 1984) did deflation measurements during many years. Deflation reaches 6 to 8 m, and the depression caused by deflation is about 200 by 100 m large.

The sounding graph gives continuously decreasing resistivity values from 12.000 Ohm-m to about 400 Ohm-m, and this final value hints to bedrock in about 10 m depth. A reliable indication of small permafrost bodies is not possible, but their existence is improbable due to climatic reasons. A grain size analysis shows that 97.2% consists of well sorted sand with 69% belonging to the fine sand fraction (63 to 200 μm). The remainder in the magnetic analysis is more than 83%, and it is estimated that two third consists of quartz, and about one third of feldspars.

The measurements in the Hietatievat dune field and on the Kiellajoki delta both show that the specific resistivity of unfrozen well sorted sand may rise to extreme high values that otherwise are typical for permafrost.

The soundings 20 a + b in the Peera palsa mire, Enontekiö show three layer curves of the maximum type. They allow only semiquantitative evaluations due to a very steep increase and decrease. The model shown in Tab. 4 therefore is one possible solution that gives a well fitting model curve. 900 Ohm-m is the resistivity of unfrozen and slightly frozen peat. An estimated resistivity of 30.000 Ohm-m for the ice-rich frozen peat gives then a lower limit of the permafrost of 7 m. It has to be stressed that other models exist, too, and that a detailed investigation of palsa bogs demands quite time consuming geoelectric mapping in order to get better ideas of the permafrost configuration in the bogs (cf. SEGUIN & CRÉPAULT 1979).

5. CONCLUSIONS AND DISCUSSION

Our study in the northernmost highlands of Finland suggests that permafrost is more extensive than was known before. The thickness of permafrost at many localities is at least 50 m. However, permafrost thicknesses in the higher summits (e. g. Halti 1328 m, top of Saana 1029 m a. s. l.) could reach at least 100 m. This assumption is also supported by recent ground temperature and BTS measurements (JECKEL, in prep.).

When selecting sites, the primary aim was not only to find permafrost but also to quantify the importance of snowcover and vegetation as critical factors in permafrost formation. The complex interdependence between permafrost and vegetation has already been summarized (e. g. TYRTIKOV 1978). Moreover vegetation is often a direct indicator for winter snow thickness, which is a primary reason for the occurrence or absence of permafrost (KING 1984: 62).

At most sites there were clear indicators for a thin snow cover and a good chance for the occurrence of permafrost. A thick winter snow cover was known from snow gauging at sites 14 and 21 and it would have been a great surprise to find permafrost there. Hietatievat esker region with its vast deflation areas among sand dunes is also covered by thick snow during winter. Only the sharp edges of blow-outs are free of snow but these are to small for permafrost formation. There are additional signs for a non-permafrost environment: Scattered pines are growing on the esker, and ground water draining from the esker edges forms wells which stay unfrozen through the winters. However, the groundwater temperature is very constant, just above freezing point, thus indicating a ground temperature near zero degree. Sand wedge polygons are exposed in some blowouts (SEPPÄLÄ 1966, 1982b), but they probably hint to colder conditions in the past and are, if at all, only weakly active. Another exception was the edge of Peldojoki glaciofluvial delta which is mostly wind-exposed and probably snow-free in winter. The absence of permafrost can

area	altitude (m a. s. l.)	MAAT (° C)	permafrost thickness
Kevo/Skallovarri	360 bzw. 320	—1.4°	10—25 (45; 0—7)
Kilpisjärvi/Saana	580 bzw. 615	—2.2°	0
	880 bzw. 840	—5.4°	50—60
Kilpisjärvi/Pikku Malla	600—620	—2.3°	8—13 (?)
	710—730	—3 °	45
Karigasniemi/Ailigas	540	—2.5°	15/50
Saariselkä/Kiilopää	435	—2.5°	70

Tab. 5: Permafrost thickness (in m) and estimated mean annual air temperature (in ° C)

Tab. 5: Permafrostmächtigkeiten (in m) und geschätzte mittlere jährliche Lufttemperaturen (in ° C)

be explained with its low altitude and its material (sand and gravel: SEPPÄLÄ 1971, samples 68—70) which makes the delta very water-permeable. Pines grow on the surface and this results in a thicker snow cover and hints also to the lack of permafrost.

Several conclusions relate to the general permafrost distribution in northern Finland. The lower limit of discontinuous permafrost changes its altitude and drops from the more maritime to the more continental and dry climates. This has been shown clearly by KING (1984, Figs. 67 and 69; KING 1986a, Figs. 5 and 6). The altitude as such (Fig. 1) doesn't hint therefore to permafrost. A connection of the lower limit of permafrost belts with the MAAT has been postulated. The lower limit of discontinuous permafrost is at about 300 m a. s. l. in the Utsjoki area and rises to values of about 500 m a. s. l. in the NW and the S of the study area (MAAT isotherms reduced to sea level are 0° C and + 1 ° C, respectively). But the number of weather stations in northernmost Finland is very limited and their location usually displays a rather special climate. Moreover, a maritime/continental contrast does not exist as clearly in northernmost Finland as in the Swedish and Norwegian mountains to the NW and W of our area (cp. isotherm in KING 1986b, Fig. 4).

Thus, the good correlation between snow depth/vegetation and permafrost distribution may help here more. This second approach has to be regionally (and climatically) limited. Encouraged by our sounding results, we forward the hypothesis, that permafrost regularly exists in the fjell summits of northern Finland. Here, the permafrost area is in general above timberline and indicated by low and medium heath vegetation. If this hypothesis is true, then the vegetation map of northernmost Finland (SEPPÄLÄ & RASTAS 1980) which indicates the distribution of barren fell tops (regio alpina) can be read as a map of permafrost. Similar interpretation can be given to the vegetation classification for the Kilpisjärvi region made with Landsat MSS data (CLARK et al. 1985, Fig. 5). It could be used not only as a snow depth surrogate map but also as permafrost map where parts of yellow, all orange (= light brown), brown and grey pixels on highlands then show the existence of permafrost. Certainly, further research work has to be done in order to prove this hypothesis. But our assumption is also encouraged by the regular permafrost distribution pattern which is comparable with that obtained by a large number of geoelectric, seismic, ground and snow temperature soundings in the neighbouring Kebnekaise area (KING 1983, 1984).

Whether permafrost is actually forming today is both important and difficult to answer. In some places, the active layer is thick and it might be possible that some permafrost is relict. However, to assume a glacial age would certainly be too far reaching. We know that during the climatic optimum 7000—5000 years ago, the pine tree line was hundreds of kilometres north of the present stage and on many fjell summits trees were growing, then (ERONEN 1979). At other localities we are quite convinced that severe winters followed by low summer temperatures may result in the formation of new permafrost. These latter sites are at least as favourable for permafrost formation as those where SEPPÄLÄ (1986) actually proved palsa growth. But to prove the growth of permafrost, continuous temperature measurements in deep bedrock and over many years are necessary.

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POSTSCRIPT

After submission of this manuscript to Polarforschung the Finnish newspaper Iltalehti (October 12, 1987) published the results obtained in a 114 m deep drill hole on the barren fjell summit area of Ylläs (67°34'N, 24°14'E; 718 m a. s. l.). In the well needed by Radio of Finland, water had frozen at 40 m depth below the surface. This means that an unexpected permafrost layer was penetrated during the construction work.