MAIN FEATURES OF THE GLACIAL AND POSTGLACIAL DEVELOPMENT OF PULMANKI VALLEY IN NORTHERNMOST FINLAND

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I. INTRODUCTION

Relative changes of sea level have had a great effect on the Quaternary formations of Finland. This is especially to be seen in the southern parts of the country, where some of the sea levels of the Baltic have covered the whole of South Finland except the highest hills. Although no part of the coast of the Arctic Ocean lies within the Finnish frontier to-day, it is probable that changes in the levels of that ocean have also directly influenced the Quaternary deposits of northernmost Finland (Fig. 1). The valley of the Teno River and its tributary Pulmankijoki is so low that a bay about 60 km long would be produced if the level of the ocean rose 20 m. One of the most prominent formations of Pulmanki Valley is a long and narrow lake called Pulmankijärvi. The special shape of this lake which differs from the shapes of other basins in the area and the horizontal and vertical proximity of the Arctic Ocean leads one to presume that perhaps the formations of the Pulmanki Valley as they are now are partly due to the ocean.

A series of questions arises from preceding hypothesis: Has the sea produced any changes in the area, and what characteristics are still left from this phase? When trying to solve these questions one is in the first place compelled to search for old shore lines on the slopes of the valley or any other indications that bear evidence that the area has been covered by the sea.

If it is found that the sea has reached far into the valley, it also has to be deduced when this occurred. Besides this, it must be known why the situation changed later on when Lake Pulmankijärvi was formed and under what conditions. If it is probable that the sea has had no part in the evolution of the valley, one must seek the cause for the particular shape of Pulmankijärvi and explore the various phases of development of the lake. Good objects of exploration are therefore the deltas of the rivers flowing into the lake, because being "livelier" than other objects on the shore, they react sensitively to any changes that occur.

On the basis of the above-mentioned questions, the main features of the

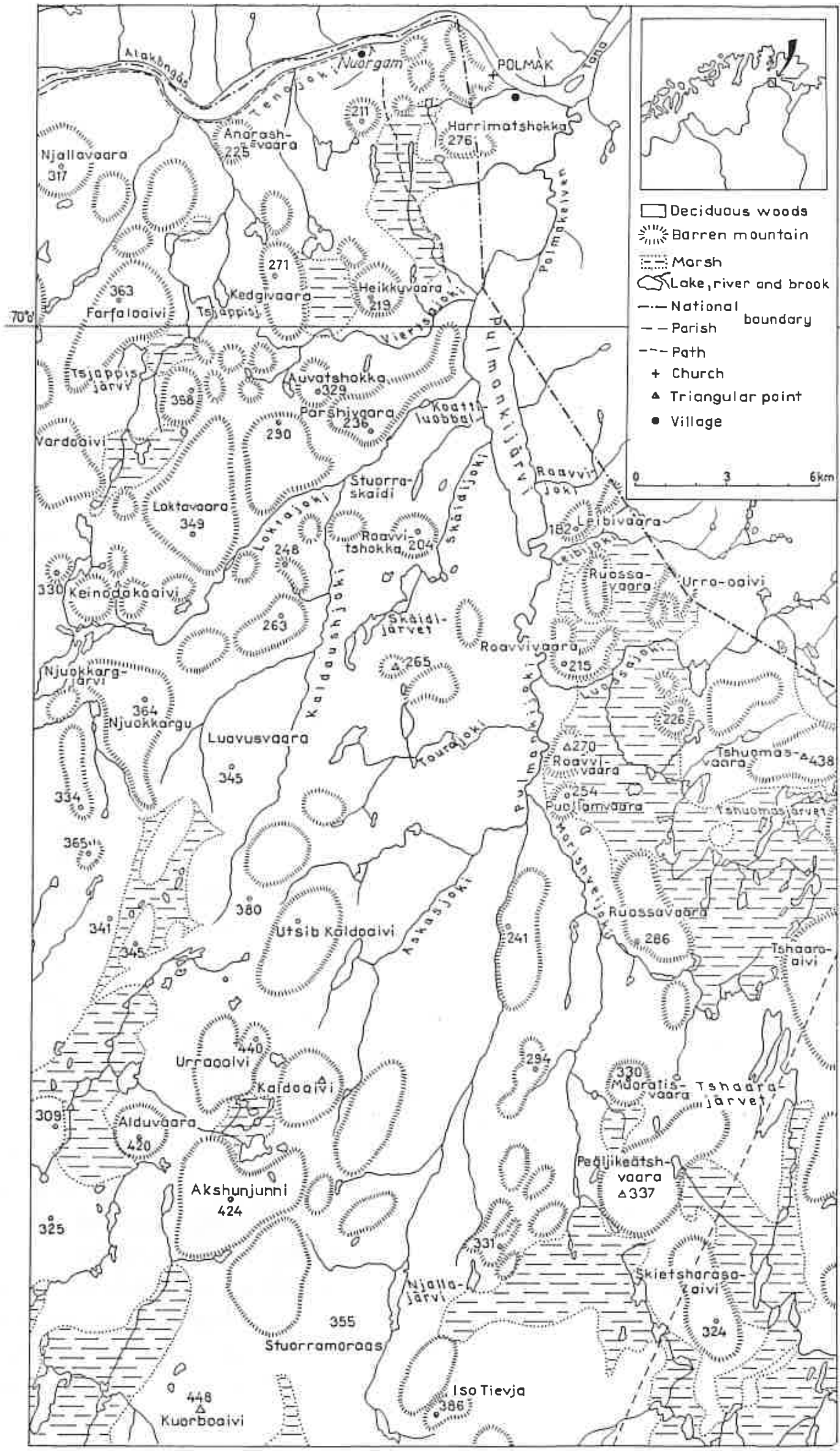

Fig. 1. Map of the Pulmanki Valley. Reduction of the Economic Map of Finland.

development of Pulmanki Valley are discussed in this paper. It has been necessary to pay the greatest attention to the part of the valley situated on the Finnish side and especially to the surroundings of Pulmankijärvi.

In the paper it has been necessary to deal with the postglacial period only because scarcely anything from the early periods has been preserved in its original form.

II. DESCRIPTION OF THE AREA

Lake Pulmankijärvi is situated on the border between Finland and Norway about 10 km south of the northernmost point of Finland (Fig. 1). The northern part of the lake (Polmakvatn in Norwegian) belonging to Norway represents one fourth of the whole basin. The 70th parallel passes through this wider, northern part of the lake. The lake itself, long and narrow (Fig. 2), with unbroken shores and no islands differs clearly from the lakes in its neighbourhood. A better impression of the clear-cut character of the lake is obtained by comparing it with basins of corresponding size in the Lake District of Finland. The length of Pulmankijärvi is about 10 km but the width only 1.0—1.5 km. According to PETÄJÄ (1964) the greatest depth of the lake is about 35 m.

Although the lake is not deeper, its bottom is almost 20 m below the surface of the Arctic Ocean. In the Economical Map of Finland (1:100000) the absolute elevation of the surface of the lake is only 17 m. These facts are interesting and unique in Northern Finland. The approximately 7 km long river called Polmakelven leading from Pulmankijärvi has eroded into glaciofluvial material here and there to a depth of 30—40 m forming many meanders. The gradient of the river is quite low, considering conditions in Lapland, as the fall of the river is only four metres and is divided evenly along its whole course. Owing to this, there are no rapids.

The Polmakelven River joins the Teno (Tana in Norwegian) River east of the Polmak village, 40 km from the mouth of the Tana. The level of the Teno River is only 13 m at the mouth of Polmakelven, so that also the lower course of this river slopes gently without rapids.

Pulmankijoki River which empties into the southern end of the lake is the biggest of the rivers flowing into Pulmankijärvi. Being about 35 km long, it extends into the district between the boundary of Utsjoki commune and a fjeld named Kuorboaivi. In this area the level of the lakes belonging to the water-course of the river is more than 250 m. Over a distance of 10 km the lower course of Pulmankijoki slopes gently without rapids, and has formed numerous meanders (Figs. 2 and 3). In this part the river has eroded 10—30 m into glaciofluvial material and reveals numerous old channels of the river at

Fig. 2. Lake Pulmankijärvi and Pulmankijoki River. The lake is long and narrow, with no islands. The river has eaten its way into glaciofluvial material forming many meanders.

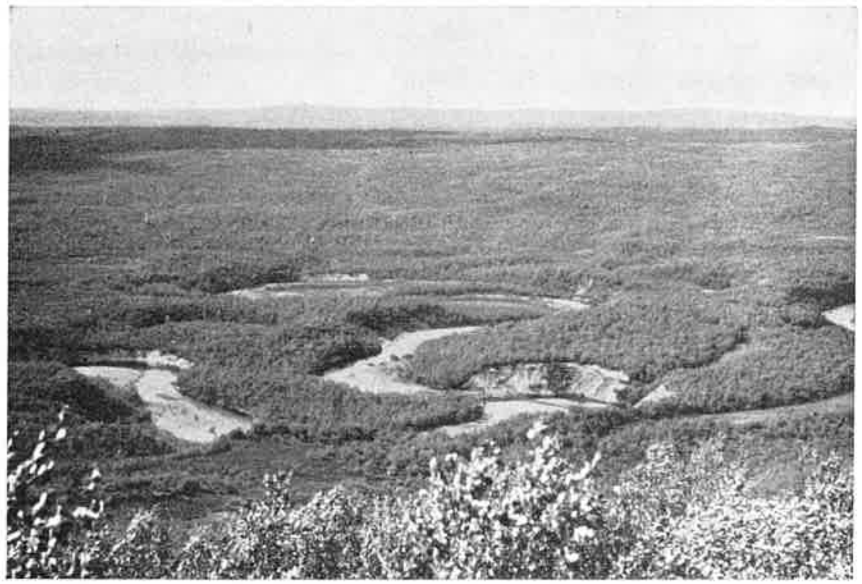

Fig. 3. The lower course of Pulmankijoki has eroded into glaciofluvial material, and forms many meanders. Some old channels of the river are also seen in the photo. The gradient of the river is quite small.

different levels. All the tributaries of the river are steep brooks full of rapids. The lengths of these small streamlets range from 10 to 15 km.

All the other rivers flowing into Pulmankijärvi obviously differ from Pulmankijoki. Every one of them is short, only from 5 to 20 km long and throughout their courses slope steeply and are full of rapids. Only at the mouths of the bigger rivers are small delta features seen. The glaciofluvial delta is most clearly evident at the mouth of the Kaldaushjoki River.

The area of the watercourse of Pulmankijärvi is quite low, considering conditions in Lapland because even the highest peaks are under 450 m. The general elevations are 200—300 m. To the east of the Pulmanki Valley there is a continuous chain of hills, where even the lowest levels are over 100 m and the peaks about 200 m on average. A similar chain forms the western side of the valley, but its highest crest is a little further from the bottom of the valley. The bottom of the Pulmanki Valley ranges from 13 to 25 m above sea level.

The annual changes in the level of the surface of Pulmankijärvi are quite noticeable, about 4 m. This is in the first place due to the great amounts of snow that melt in the spring; the drainage area of the rivers flowing into the lake is about 800 square kilometres. In the second place, the gradient of Polmakelven is only 0.5 m/km and it cannot bring down large amounts of water rapidly enough. The water is partly stored in Pulmankijärvi in the spring and the height of the surface of the lake decreases slowly up till August.

Studies of the bedrock of the area have not been completed and therefore accurate geological maps are lacking, but the main features are, however, known. According to the Atlas of Finland (1960) the rock of the area of the line Anarashvaara—Roavvitshokka—Puollamvaara—Finnish boundary is migmatite. In other parts of the Pulmanki Valley there are generally acid plutonic rocks.

The present writer has found that the types of rock have not influenced directly the shapes of the hills and the valley systems in the area. Faults in the bedrock had a greater effect on the relief than other structural features.

By far the most evident of the faults in the area runs on the line Pulmankijoki—Pulmankijärvi—Polmakelven— the lower course of the Teno River—Tana fjord. This line extends from the mouth of the Tana fjord about 140 km inland. Numerous smaller faults are united to this great fault, usually more or less transversely to the latter. The tributaries of the Pulmanki Valley flow along these faults.

In addition to the main fault there are a few other faults in an almost N-S direction in this area. The upper course of the Kaldaushjoki River lies in one of these fault-lines. The orientation of many lakes in the area is also connected with these faults although the direction of movement of the continental glacier has also had an influence on these basins.

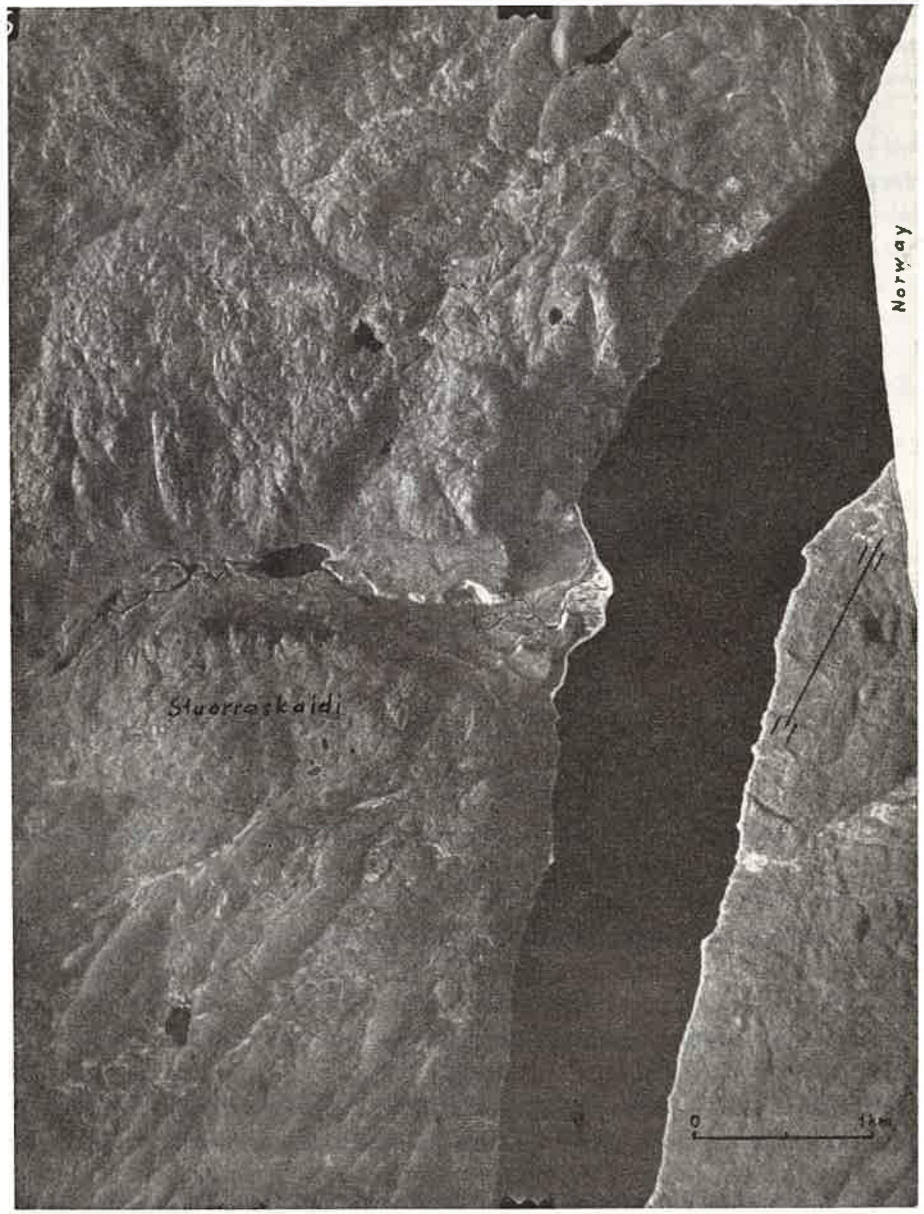

Fig. 4. Aerial photo of Pulmankijärvi. In the middle there is the glaciofluvial delta of Kaldaushjoki. Near the Stuorraskaidi hill some drumlins are seen.
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Fig. 5. Pulmankijärvi. In the foreground is a part of the delta of Kaldaushjoki. In the background, in Norway, there is glaciofluvial material at the bottom of the U-shaped valley.

III. THE PULMANKI VALLEY DURING THE ICE AGE

1. *Formations of the growing continental glacier*

The direction of movement of the continental glacier in general in the area around Pulmankijärvi is explained by the nature and distribution of drumlins. The most evident of these surround the hills Stuorraskaidi and Roavvitshokka (Fig. 4). According to the drumlins, the continental glacier has moved over the area in a direction deviating only about 10° from the S-N direction to the north-east. This is to be regarded as a general direction, because local formations have also influenced the course of the ice. In this case the most noticeable and influential features are the hardness and the faultlines of the bedrock. Because the bedrock in the area resists erosion quite well, the ice must have been directed partly along the faults. There are many examples of this.

It is obvious that much ice has moved powerfully in the direction of the main faultline mentioned, as this line was already low and above all corresponds exactly to the general flow direction of the ice. Thus the faultline has been formed by the ice like the fjords in Norway into a U-shaped valley. Owing to the smaller differences in altitude, the shape of the valley is not so distinct as that of Norwegian valleys (Fig. 5).

In other cases, e.g. in the valley of Kaldaushjoki, the ice has first passed along the general course and later has changed its direction to follow the SW—NE line of the fault. Thus the bend has turned northwards (compare Fig. 4, an aerial photo).

In addition to the U-shaped valleys the ice certainly made the hills of the area round and lower. Nowadays it cannot be decided how effective this work has been. Besides, it is difficult to say how much of the former loose material the ice had to make use of. Scientists have differing opinions about the thickness of the continental glacier in Northern Scandinavia. For example, according to TANNER (1930) the maximum thickness of the ice may have been about 3500 m. MARTHINUSSEN (HOLTEDAHL 1960 a) reports striation produced by the ice sheet at a height of more than 100 m a.s.l. on the low peninsula of Finnmark.

2. *Melting phase of the ice*

Of the scientists who have explored the glaciofluvial erosion and accumulation in Lapland TANNER (1915), MIKKOLA (1932), VIRKKALA (1955), HOLDAR (1957), HOPPE (1959), and PENTTILÄ (1963) may be mentioned.

As the continental glacier became thinner, the crust of the earth rose. How great the upwarping was is difficult to determine, because, e. g., eustatic changes in sea level have been rather great. Therefore in the following paragraphs the different phases of the uncovering of the continent will be explained as far as possible irrespective of whether they were due to the rising of the earth, lowering of the sea level, or to both simultaneously.

Terraces or other marks of the sea above 82 m have not been found on the slopes of the hills in the vicinity of Pulmankijärvi. This perhaps indicates that the surroundings of the lake have risen rapidly, especially in the early phases, above sea level and have been covered by the ice during the upward movement. The ice cover has prevented the appearance of marks produced by the sea.

When the marginal zone of ice moved gradually in a NNE—SSW direction, the peaks at the edge of ice were the first to lose their ice cover. Remnants of thick ice sheets were often left in the valleys. These strata of ice may have become detached from the rest of the ice-field and become dead ice. Secondly, the southern parts of the valleys lying in S—N and SW—NE directions contained still in this phase plenty of ice, whose melting waters carried blocks of ice and glaciofluvial material towards the Arctic Ocean. The valleys of the Pulmankijoki and Kaldaushjoki rivers were especially valleys of this type.

In this way the whole valley of Pulmanki got large amounts of loose material from the melting ice. The main part of this material was laid down in

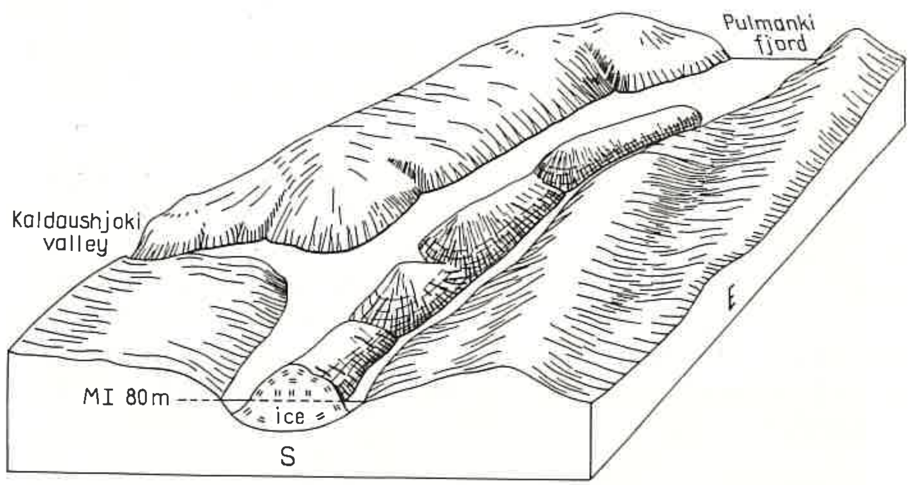

Fig. 6. Sketch of the dead ice in the Pulmanki Valley. A big block of ice prevented glaciofluvial deposits from accumulating on its site. The sea phase MI is here at a level of about 80 m and the greatest part of the valley is a fjord.

the southern and northern parts of the valley. From this arises an interesting question. Why has the central part of the valley received practically none of this material, so that the present deep lake has formed in the area? According to the opinion of the writer the only explanation seems to be that a big block of dead ice the size of the lake was left behind. This block prevented glaciofluvial deposits from accumulating there (Fig. 6) (cf. HOLTEDAHL 1960 b, Fig. 131).

The highest terrace that has been found until now in the area of Pulmankijärvi is at a level of 80 m. When the sea reached this height, the ice had almost disappeared so that the sea penetrated into the valley and made its own marks on the slopes of the valley. From the clear features of the terrace it is reasonable to conclude that the sea level remained at this level for a long period. The terraces mentioned are seen very clearly on the southeastern shore of the lake in the aerial photo 1:30000. For the sake of brevity, the mark M I is used in the following to signify this sea level.

It is obvious that during this long period the block of dead ice was situated in the valley so that ice rose in the middle of the valley while water flowed freely along its sides. The water flowed towards the sea taking along with it the finest elements of the material brought by the rivers. The strata in the vicinity of Polmakelven are therefore of fine sand or of coarse silt stratified easily and clearly into the water (Fig. 7). Coarser material brought by the rivers remained either directly behind the edge of the ice or sank immediately to the bottom after entering the slowly flowing water and formed large deltas

Fig. 7. Polmakelven River has eroded into the deposits of fine sand and coarse silt that have deposited in the water.

at the mouths of the rivers. The greatest of these are at the mouths of the Pulmankijoki and Kaldaushjoki rivers.

There are no marks of currents towards the sea on the shores of Pulmankijärvi at a level of 80 m. This can, however, be understood, because the water flowed slowly and took along only fine elements — the current had only weak erosive power. In the second place, this fine material was deposited above the ice and on the slopes of the valley. However, the material sank from the top of the ice after it melted to the bottom and the later sea and lake levels washed the slopes bare of the finest elements.

IV. POSTGLACIAL DEVELOPMENT

It is important to distinguish the latter part of the sea level MI from the glacial period, as it is probable that the level MI prevailed for some time after the ice had finally melted from the site of the present-day Pulmankijärvi. This is shown by the fact that when the central part of the valley was full of ice, the powers of the edges to cause shore lines were scarcely strong enough to produce clear terraces at a level 80 m.

During the MI phase the length of Tana fjord was quite considerable, about 120 km from its present mouth, Tana Horn. The fjord was very narrow

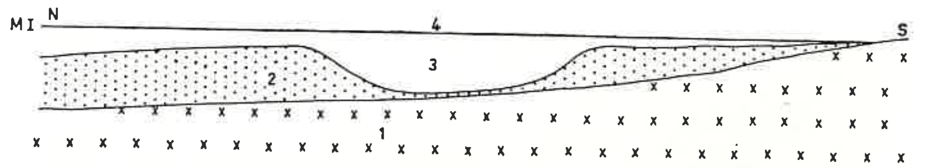

Fig. 8. Schematic longitudinal profile of Pulmanki fjord during the sea phase MI. In the southern part the depth of the fjord was at most 5—6 m, but increased to about 100 m at the site of the melted block of ice. North of this, the depth decreased again suddenly under 10 m and increased slowly towards the Arctic Ocean. 1) Bedrock 2) Glaciofluvial material 3) Basin of Pulmankijärvi 4) Sea level MI.

in places, e. g. in Pulmankijärvi only from 1.5 to 2.5 km and even less to the south. In the southern part, the depth of the fjord was at most 5—6 m over a distance of 6—7 km but naturally increased to over 100 m at the site of the lake. North of this place the depth decreased again suddenly to less than 10 m and then increased slowly towards the Arctic Ocean. The longitudinal profile of the bottom of the fjord thus had a special shape (Fig. 8).

After the MI phase the sea level fell evenly and quite rapidly relative to the mainland — this can be concluded from the fact that no terraces were formed immediately below the level of 80 m. Naturally, the consequence of this was that the lower course of Pulmankijoki was exposed rapidly and the river became of the length it is now. When the surface of the ocean fell still lower, a neck of land was formed on the northern side of lake Pulmankijärvi which gradually grew larger and was cut by the Polmakelven River which simultaneously grew longer.

In this way the Pulmanki basin separated from the Arctic Ocean. Since then the height of the surface of the lake has been indirectly dependent on the sea level of the ocean. Directly it is determined by the rapidity with which Polmakelven could eat its way through the threshold between the lake and the sea.

The lowering of the surface level of the lake was quite rapid from the beginning. This is because the highest terrace of the lake phase is only at a level of 60 m. Also the water of the basin became fresh rapidly as water was brought by the rivers. Changes in sea level and changes in longitudinal profile of Polmakelven have caused temporary pauses in the lowering of the lake level. Especially in the lower phases of the lake it is probable that the movements of the steepest part of the river bed have led to a rapid lowering of the surface of the lake (Fig. 9).

Taken all together, one can distinguish the following sea and lake phases and their altitudes in the Pulmanki Valley. The number of places where shore formations of each phase were found on different shores of the lake are given in column P in the table.

Sea phases	Level	P
MI	80 m	4
Lake phases		
I	60 m	2
II	54 m	3
III	42 m	4
IV	40 m	2
V	36 m	4
VI	34 m	2
VII	32 m	3
VIII	28 m	2
IX	27 m	4
X	25 m	1
XI	24 m	4

The present height of the lake is 17 m a.s.l.

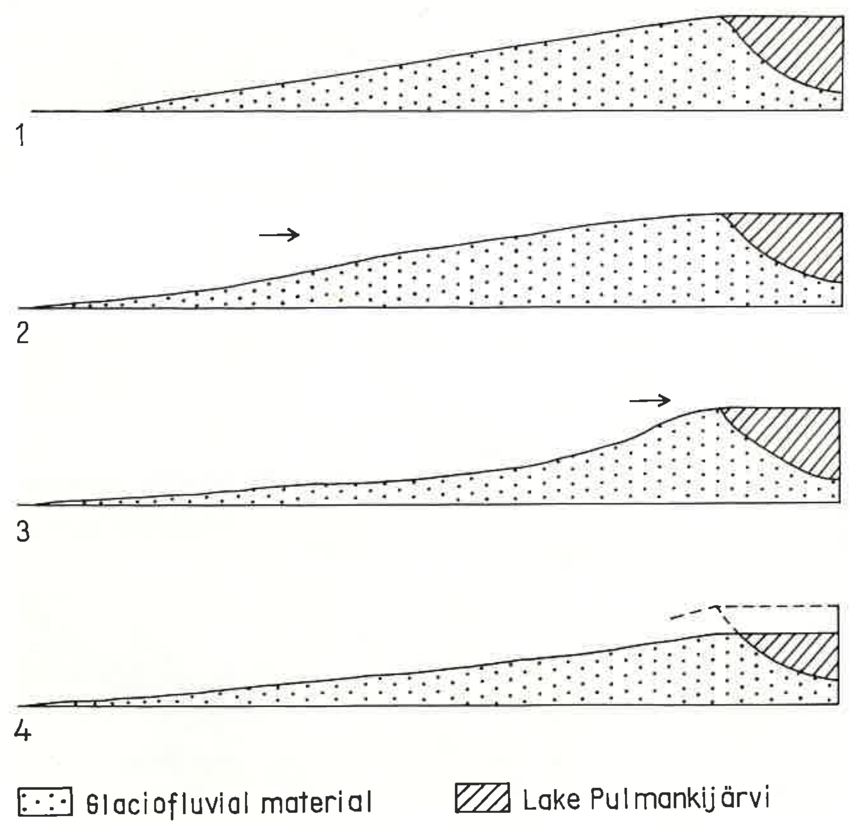

Fig. 9. Schematic diagram of the evolution of Polmakelven in longitudinal section. A rapid fall of the surface of Pulmankijärvi drawn in various stages. 1) Assumed beginning. Profile straight. 2) Steep part of the profile in the lower course, moving upwards . . . 3) . . . reaching Pulmankijärvi . . . 4) . . . suddenly lowering its surface.

Fig. 10. Kaldaushjoki River has eroded into the glaciofluvial delta to a depth of about 55 m and left many old channels and river terraces.

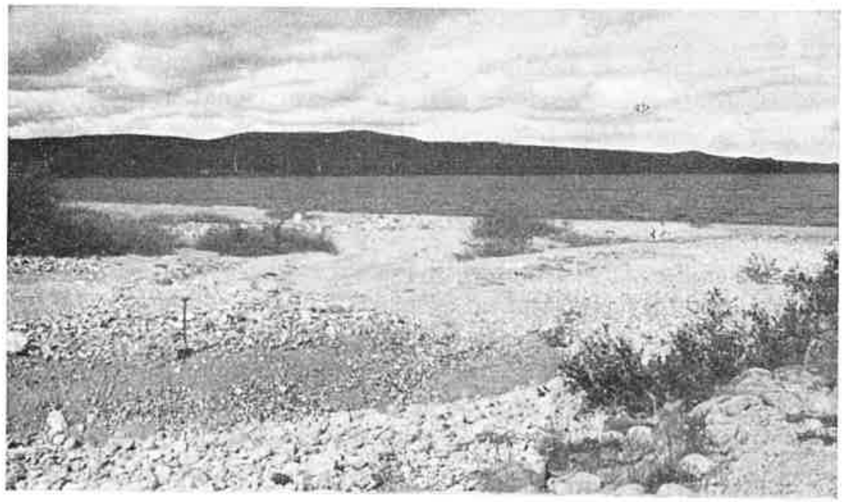

Fig. 11. The glaciofluvial material of the delta of Kaldushjoki is rather coarse, consisting of stones, gravel and coarse sand. In the youngest part of the delta one can see, for example, sand deposited on coarse gravel in the spring, during the alluvial time. The structure of the delta is not, therefore, very clear.

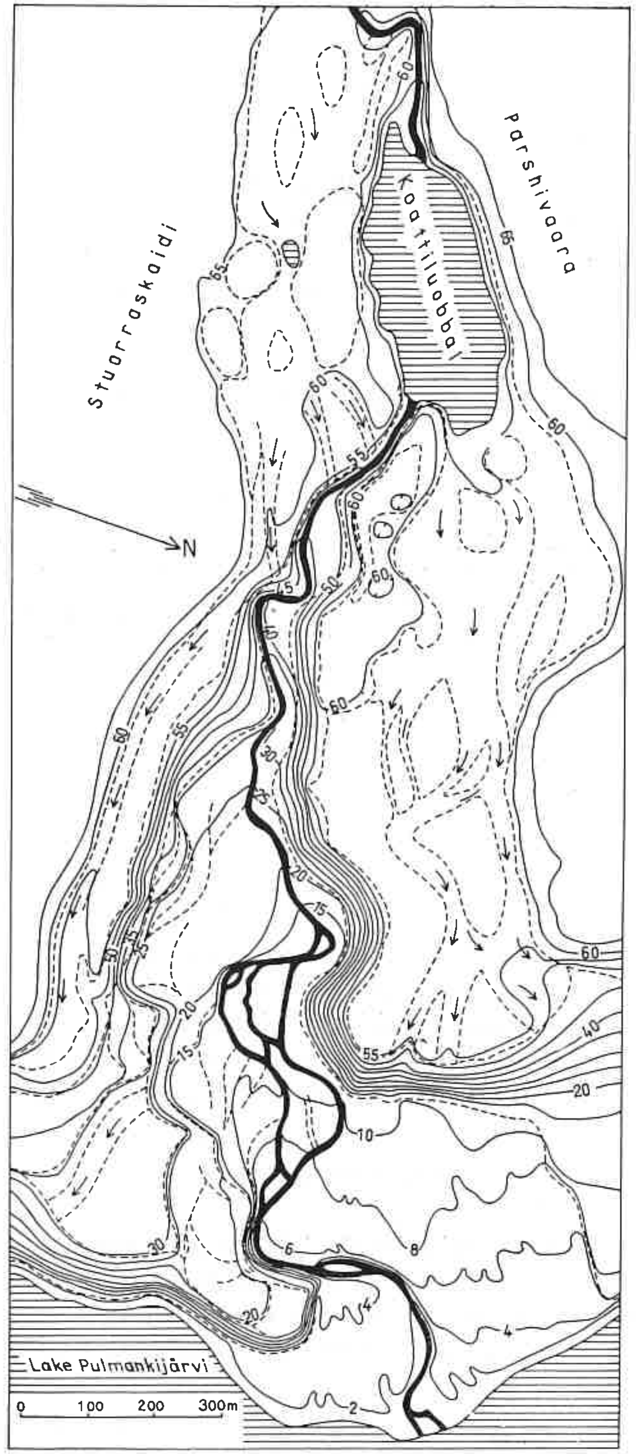

Fig. 12. **Delta of Kaldaushjoki. The altitude of the surface of Pulmankijärvi (17 m) is the O-level on the map. The contour interval is two metres from O to the level of 10 m and five metres higher up.**

In examining the various phases of Pulmankijärvi, the delta of Kaldushjoki has been an advantageous object of study. The river has eroded there to a depth of about 55 m into the galciofluvial delta and left signs of numerous old channels and river terraces (Figs. 10 and 11). A more detailed examination of the structure of the delta and of the movements of the river during the various lake phases is not possible here. From the aerial photo (Fig. 4) and the map (Fig. 12) the reader may, however, get some idea of the appearance of the delta.

V. THE SHORE LINES OF THE PULMANKI VALLEY COMPARED TO THE EXAMINATIONS OF THE SEA LEVEL IN NORTHERN NORWAY

Of the many scientists who have explored the sea phases in Northern Scandinavia TANNER (1915, 1930) should be especially mentioned. Yet, it is not out of place to compare the results of MARTHINUSSEN (1960) with the observations of the writer in Pulmanki Valley. When considering the isophases in MARTHINUSSEN's P 12 line, it is found out that the level of the shore line has been a little over 80 m in the northern part of Pulmankijärvi. On the basis of this it is quite probable that the MI phase is the same as P 12. (Slight differences in altitude are due to causes which it is impossible to consider here). After P 12 the sea did not influence directly the surroundings of Pulmankijärvi, not before the Tapes transgressions (MARTHINUSSEN). During the Tapes phases the sea suddenly started to rise somewhere from the lower level in the Pulmanki Valley up to the level of 31 m. This indicates that the Pulmanki basin that had been a lake before the transgression changed again into a fjord as a result of the rise of the sea level. When the sea level went down again, the basin changed into a lake, which phase is now going on.

The features explained above are only the main points of the relationships between the Arctic Ocean and the Pulmanki Valley.

VI. CONCLUSION

The Pulmanki Valley with its fjord-like shape is exceptional in Finland. During the glacial period this valley was eroded into a U-shaped valley. When the continental glacier receded, the water carried much glaciofluvial material through the main valley and its tributaries towards the Arctic Ocean. The sea was about 80 m above the present level after the last part had been uncovered from below the ice. The Pulmanki Valley thus formed an extension of Tana fjord, the total length of the fjord being about 120 km.

While the ice was melting a dead block of ice was left at the site of the present Lake Pulmankijärvi, where it prevented the glaciofluvial material from gathering on that spot. A large amount of this material accumulated south and north of the block of ice and partly on its sides, too. Later on, after the ice had melted and the sea level started to go down, the block was replaced by a fresh-water lake that was linked with the Arctic Ocean only by a river.

When the sea level rose during the Tapes transgressions, the lake was again changed into a fjord through its outlet. Later on, when the sea went down, the lake was formed again. The present-day Pulmankijärvi is thus the result of this "regeneration".

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