RETREAT OF THE CONTINENTAL ICE AND FLUVIOGLACIAL EROSION FEATURES ON THE TUOLBANJAUGOAIVI FJELD IN NORTHERNMOST FINLAND

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1. *Introduction*

During the last Ice Age Finland was completely covered by continental ice (see e.g. TANNER 1938 p. 431). When the climate became warmer the ice began to melt, first in southern Finland and then gradually northwards. In Lapland, however, the shores of the Arctic Ocean were first free of ice. The large amounts of water that melted left many erosion features and accumulations. These are most clearly seen in the northern regions of Finland which have always been highest above the sea level. In the following, the formations left by the melting water as the ice receded on a small fjeld named Tuolbanjaugoaivi in northern Lapland are discussed.

2. *Character of the Tuolbanjaugoaivi area*

Tuolbanjaugoaivi fjeld is located in the southwestern part of Utsjoki parish in Finnish Lapland in the drainage area of the Fiellu River that empties into the River Kevojoki. The fjeld is part of extensive granulite formations that extend from the Paistunturit fjelds in the north southeast to the Saariselkä fjelds. The bare rock is visible only in a few places near the summit of the fjeld. Elsewhere it is covered by a layer of moraine that is thin on the upper slopes, but may be over 10 metres thick in the adjoining valleys. The layer is evidently ground moraine. Its extension N 70—75° E shows that the glacial ice has spread to the area from the west-southwest, possibly from Norway. This direction differs from the usual southwest direction of the moraine layers elsewhere in northern Lapland (Fig. 1). On the northeast slope of Tuolbanjaugoaivi, opposite the Fiellugeädgeskaidi fjeld, the glacial ice has formed a table-like surface that slopes slightly toward the north and into which dry river beds have later been eroded.

The mean height of the peneplain in the area is roughly 350 metres above sea level. The highest summits rise to a height of nearly 500 metres above

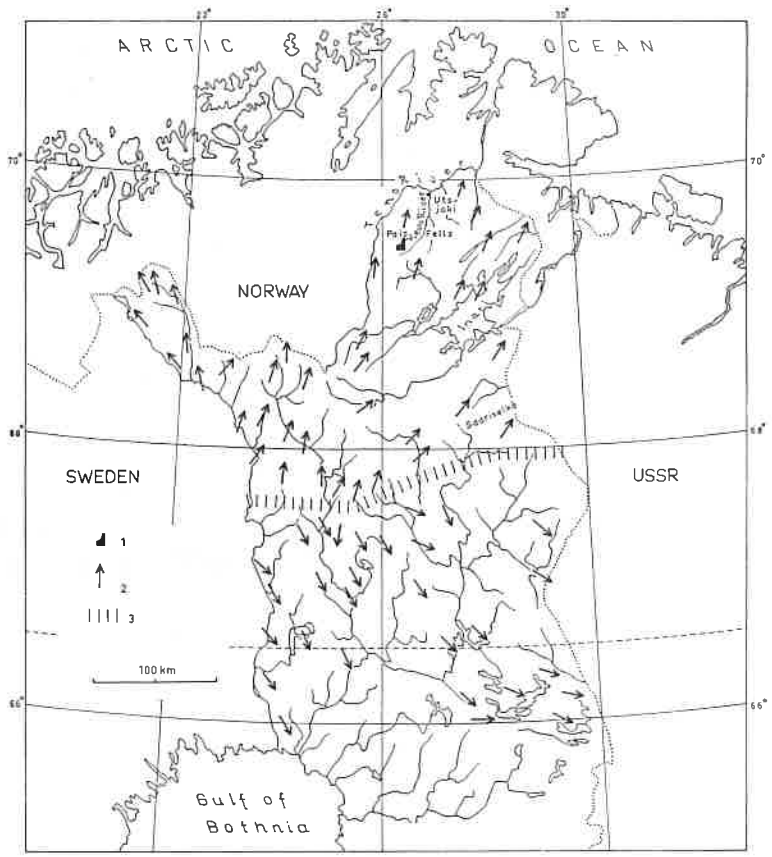

Fig. 1. Stages of deglaciation. 1 = Investigated area. 2 = General trend of ice movements. 3 = The ice divide of the last glaciation. (According to V. Okko, Atlas of Finland 1960, p. 4.)

sea level. These figures show that the vertical height differences are small. If the few steepfaced channels which eroded into the softer parts of the bedrock are disregarded, the sides of the fjeld slope gently and are rounded in form.

The examination of the erosion features on the fjeld is facilitated by the absence of forests and these features have been well preserved owing to the slight solifluction.

3. *Fluvioglacial erosion forms*

a. Overflow Channels

The archlike summit of Tuolbanjaugoaivi is traversed by three overflow channels (A, B and C in Fig. 2). The oldest of these channels, which crosses

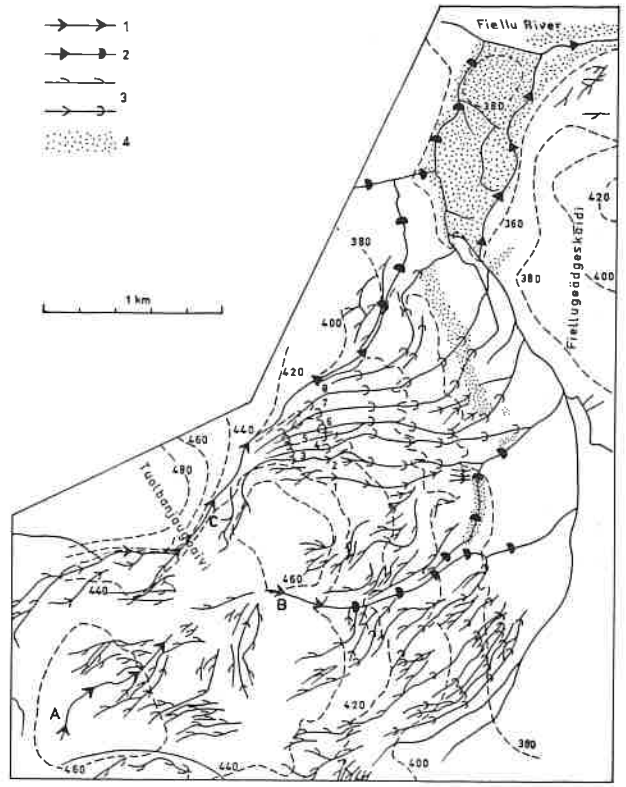

Fig. 2. Map of the drainage channel area on the Tuolbanjaugoaivi fjeld. 1 = Overflow channel. 2 = Subglacial drainage channel. 3 = Lateral drainage channel. 4 = Fluvioglacial accumulation.

the highest part of the fjeld from the southwest, is very typical and was evidently formed when the summit was freed of ice. The water from melting ice flowing from the southwest passed over a soft zone in the bedrock and eroded a channel some ten meters deep and some twenty metres wide at its upper edges. The water that flowed through channel A first encountered the ice margin and collected between the ice and the summit of the fjeld to form a lake, as a sign of which there is a shore bank in front of the channel. The waters of the lake escaped to the east and eroded a channel B which is much shorter and shallower than channel A and which continues lower down as a subglacial channel in the moraine. The water did not flow through this channel over a long period, but finally found a saddle in the fjeld where it eroded a third channel. This channel C is 40 metres deep in places, over 100 metres wide and about half a kilometre long. Water that later flowed from the west eroded a new channel in the upper part of channel C in a west-east direction.

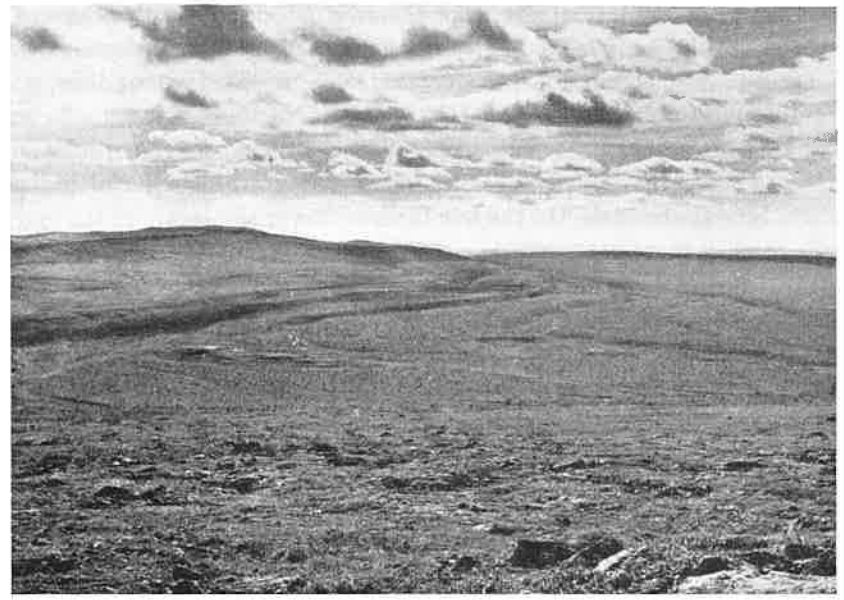

Fig. 3. View from the Fiellugeädgeskaidi fjeld southward. The formations of the drainage channel system on the slope of the Tuolbanjaugoaivi fjeld. In the middle background is the overflow channel C located.

These three channels, which are now dry, are formed in weak zones of the bedrock and follow the main faults in the granulite. Their directions are N 40—50° E (the lower ends of channel A and C) and N 70—80° W (the upper ends of channels B and C).

b. Lateral drainage channels

Lateral drainage channels are formed between the ice margin and the slope of the fjeld and as a consequence their cross section is asymmetrical. They do not follow the gradient of the slope and may be open at both ends. They frequently empty into subglacial channels, which proves that the latter have been produced before the former. The lateral drainage channels on Tuolbanjaugoaivi are on the upper slopes and are mostly shallow, less than one metre deep and usually vary from 100 to 200 metres in length. The largest channels are 2—3 metres deep and over half a kilometre long. The vertical distance separating them is over 2 metres on average, but may be as much as five metres on the steepest slopes and as little as one metre on the smaller inclines. The differences are somewhat larger than in the Laanila area (PENTTILÄ 1963, p. 37), where the average vertical distance is 1.6 m.

The slopes of the lateral drainage channels which reflect the slope of the ice margin are 2—3 : 100. Similar values have been found elsewhere (TANNER 1915, e.g. pp. 561, 568 and 606, PENTTILÄ 1963, p. 37). HOPPE (1950, p. 56) has found slightly smaller slopes, 1—2 : 100, in Norrbotten.

The lateral drainage channels in front of channel C form a special group (see Fig. 3). On the upper slopes there are five fairly small and indistinct one-sided lateral channels. On the less inclined lower slopes where the moraine layer is thicker there is a small two-sided channel (1 in Fig. 2), below which there are 7 larger drainage channels (2—8 in Fig. 2). The latter are indistinct at their upper ends. The slope has been eroded bare over a wide area, but there are isolated mounds of moraine several metres high as residues of a former uniform layer of moraine. The drainage channels have abrupt slopes and extend down to the bedrock near the summit, but lower down the slope they have less inclined slopes and the bedrock is exposed less often. They run first northeast, then north to the Fiellugeädgeskaidi slope, and turn to the northwest toward the Fiellu River. All but one of the channels, which is shallower, are 5—8 metres deep. Their widths vary from 30 to 80 metres. The vertical distance between them, 2—8 m, is greater than that between the lateral channels on the upper slopes. The slopes of the channels vary more (1—4 : 100) on the lower slopes of the fjeld.

These channels resemble both lateral and subglacial channels, the former in that their direction deviates from the incline of the slope, which is the same as that of the subglacial channel that is a prolongation of channel C, and the latter in that they are similar in form and meander and have shoals. It may hence be concluded that the water has first flowed along the ice margin for some distance in an area which has been completely eroded away by the water flowing through the upper sections of the channel, and has then penetrated under a thin ice layer but has still followed the ice margin and continued its flow along a moraine ridge that has loosely covered the ground.

The water has entered these drainage channels from channel C. If the drainage channels had not been subglacial, the water would have had to flow only from the ice margin along the slope of the fjeld. Every drainage channel belongs to a different period of melting ice. HOPPE (1950, pp. 41—45) has described a similar series of drainage channels which he found on the Kårsokielas fjeld in Norrbotten. He suggested that the main channels and the lateral drainage channels were formed by the flowing water at the same time. So much ice may have melted during a period of warm weather that all the water could not enter the subglacial channel at the lower end of the main channel, and the excess has spread laterally. MANNERFELT (1945, p. 17) concluded that the subglacial channel was blocked when the melting period began and the water was forced to flow along the ice margin. In summer and early autumn the water all flowed through the main channel. Also in this case the channels reflect the retreat of the ice. The lateral drainage channel system on Tuolbanjaugoaivi fjeld would hence have developed during the course of some ten years. According to MANNERFELT (1945, p. 49) observations of glaciers in Alaska have revealed that water from melting ice can erode very large channels during the course of one summer.

c. Subglacial drainage channels

Subglacial channels are usually connected to other channel types. Water flowing in lateral channels has often penetrated under the ice. The channels B and C on Tuolbanjaugoaivi have ended in subglacial channels, which obviously were at lower levels than the former. The channels that run between Tuolbanjaugoaivi and Fiellugeädgeskaidi and lead to the Fiellu River have at least initially formed under the ice. The thick moraine layer under the ice has gradually been eroded away and a basin has formed in which brooks now run in their own channels.

The erosion formations on Tuolbanjaugoaivi are limited to these three channel types and intermediate formations. Clear extramarginal channels are not found in the area.

4. *Accumulation forms*

Large accumulation formations are absent from the area unless the fluvioglacial delta near the Fiellu River is taken to be one. The water has, however, carried away large quantities of loose material from the fjeld slopes. Sedimentation has taken place to some extent along the Fiellu River, but the greater part of the displaced material has probably been transported to the Kevojoki River and even farther. The above-mentioned delta is most clearly visible quite close to the Fiellu River. Its twenty metres thick material is poorly sorted and is fairly coarse. The layer continues up the slope of Tuolbanjaugoaivi as an indistinct formation crossed by channels here and there. The material in the banks of these channels is similar to the material in the delta itself.

A ridge two hundred metres long and 5 metres high extends from the slope of Fiellugeädgeskaidi close to this fluvioglacial delta. The ridge is a subglacially engorged esker formed by water that has penetrated under the glacial ice.

At the ends of the moraine layers between the channels of the lateral drainage system (2—8) on Tuolbanjaugoaivi there lies a narrow area of sedi-

ment composed of finely divided material in which it is difficult to distinguish different layers. The change to moraine takes place so gradually that no boundary between the latter and the sedimented material can be distinguished. The level of the water in the basin in front of Fiellugeädgeskaidi must have been very high for these accumulations to have been formed. Although the flow has been vigorous, there may have been pools at the margins of the moraine layer where sedimentation may have taken place.

The deposited layers in the channels are insignificant. Only at the bottom of the channel running south from channel 2 is there a 1.5 metre-thick layer of sedimented very fine matter which winds have carried away here and there.

5. *Deglaciation*

Tuolbanjaugoaivi is one of the highest fjelds in the drainage area of the Fiellu River and hence its upper parts have been freed of ice at an early stage. As the summits in the vicinity became bare, dead ice remained in the valley and melted fairly rapidly. The last remnants of ice have been on the southeastern side of the fjeld and around the subglacial channel that was a continuation of channel C.

Water from melted ice has come also from areas west and southwest of Tuolbanjaugoaivi. This water evidently flowed through the channel long after the glacial ice on the eastern slope of the fjeld had disappeared. The flow continued by this route until the water found a new route over the lower ridges in the northwest part of the area.

The topography and the small size of the area did not favour the formation of large ice dammed lakes. The ridge between channels A and B is a remnant of a small lake dammed by ice over a short period. The water that produced the erosion formations came from the glacial ice during the melting period.

6. *Conclusions*

Favourable conditions such as the location of the area above the highest water level, the absence of forest vegetation and the weak solifluction after the Ice Age had the result that the formations in the area have been well preserved and are readily examined.

The formation of the unusual drainage channel system on the slopes of the Tuolbanjaugoaivi fjeld has been made possible by the thick, uniform and level moraine layer.

To judge from the vertical distance between the lateral drainage channels,

the ice has melted in the area much faster than in other areas in Lapland that have been studied.

The gradient of the glacial ice has been of the same order as elsewhere in Lapland, but the direction of recession has been slightly different.

Owing to the vigorous flow of water, fluvioglacial deposits are few in number, and where they occur in greater numbers the material is coarse and poorly sorted.

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