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GLACIER DAMMED LAKES
IN NORWAY

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GLACIER DAMMED LAKES
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BY

OLAV LIESTØL

Glacier dammed lakes may have their outflow over a bedrock threshold like other lakes, or they may flow on the surface or below the damming ice. In the former case the lake, over some considerable period, has a constant maximum level with marked shore lines corresponding to the threshold. But when the level is determined by the ice dam, the conditions are unstable. The level of the lake will then to a certain extent vary in step with the glacier, and never remain at a certain level for any length of time. The normal behaviour of such a lake will be a moderately fast rise of the water level, dependent upon the supply, until a certain critical level is reached, whereupon drainage is rapid. Such is also to some extent the case with the type of lake first mentioned, if the height of the pass is situated near to the critical level for drainage. This will establish a periodical process in the state of the lake, mainly determined by the relation between reservoir and supply. The water supply of a glacial lake will be concentrated in the summer months. If the afflux is large in relation to the reservoir, the lake will fill during the summer, in some instances repeatedly. Even if repletion of the lake takes more than a year, the chance for the water surface to attain the critical level will, because of the distribution of supply above mentioned, still be at a maximum in summer. Floods from glacial lakes will, therefore, occur in summer or early autumn. But there are exceptions. Mjølkedalsvatn which is later to be described, had, for instance, a number of outbreaks in the middle of winter and in early spring.

The mechanism of drainage of a glacial lake has been the subject of much discussion.

As yet we have too little information to form the foundation of satisfactory theories.

The simplest way imaginable for the drainage to start is when the rising water level of the lake overflows the ice barrier, and the water, provided with a sufficient surplus of heat, melts a canal down and through the ice barrier, and depletion of the lake will gradually take place. From Demmevatn which is to be dealt with later, the series of events is known, as well as from a number of lakes in Arctic regions. In the latter, the heat surplus will often be sufficient for the drainage only of some few metres during summer. Another theory proposed by Thorarinsson and a number of Norwegian scientists before him, suggests that the ice barrier will float when the water level has attained the critical level. This should occur when the level is $\frac{9}{10}$ of the ice height, and the water will then escape underneath the ice barrier. Theoretically this process will not lead to any depletion of the lake by itself, as there will instantly come a balance between the pressures of ice and water at the bottom. Thus only a water volume corresponding to the supply into the lake will be drained. J. W. Glen (1953) is of the opinion that drainage may start when the water opens a tunnel as a result of its pressure exceeding that of the ice. Experiences from artificial tunnels in Alpine glaciers seem to indicate that such a plastic widening will take place very slowly, at any rate at the moderate depths with which we are dealing. R. Haefeli and P. Kasser (1951) have, for instance, in a tunnel in Z'Muttgletscher measured a contraction of the order of magnitude of 1 % per 24 hours, where the overlying thickness of the ice was ca. 50 m. In order to obtain a corresponding overpressure and an extension of the same order of magnitude in a waterfilled tunnel, it is necessary to have an ice barrier of a thickness amounting to some hundred metres. Comparisons are, however, impossible because the ice plasticity will change according to the total pressure. When the water level is sinking, the overpressure of the water will also be cancelled, and the tunnel should gradually close up. Moreover, with most of the glacier dammed lakes in Norway the drainage starts before the critical levels is reached, that is when the water surface has reached $\frac{9}{10}$ of the height of the ice barrier. The fact is also that the tunnels stay open for a considerable time after the lakes are drained.

If, however, the water from the lake has in some way forced a small passage beneath the ice, it will, by melting, be able to extend and keep open a tunnel. To my knowledge there exist rather few temperature measurements from glacier dammed lakes. In Demmevatn daily observations of temperature were made in 1897, but no other

systematic measurements are known. In a glacier lake where the water masses often contact the ice as far down as the deepest layers, the temperature will theoretically not rise very much above zero. On warm sunny days the surface may, however, be locally warmed to several degrees above the freezing point. In 1897 the mean temperatures in Demmevatn varied between 1 and 1.5° C, but the depth for the measurements has not been stated. A relatively small heat surplus is needed, however, to open a tunnel in quite a short time. If, for instance, the temperature of the water is 1.0° C, and the quantity of water which in some way has started penetration of the ice barrier is 0.1 m³/sec., it will be able to melt:

$$V = \frac{1.0 \times 0.1}{80 \times 0.9} \text{ m}^3/\text{sec}$$

or well over 100 m³ in 24 hours. Now the relative widening of the tunnel is proportional to the penetrating water quantity:

$$\frac{dy}{dt} = ky$$

where y is the cross-section. Thus we have an accelerated widening of the tunnel. This appears to be in good agreement with water flow curves from the glacier lake of Østerdalsisen in the process of depletion. Even with a temperature of 0° C, as may be assumed in a number of the partly icefilled glacier lakes, melting of the drainage tunnel may take place. The potential energy available in the form of dammed water will mainly be transformed into heat by friction in the tunnel. With a height difference Hm , between the lake level and the entrance to the tunnel, the velocity without friction will be: $v = \sqrt{2gH}$. If, for instance, we put $H = 100$ m we obtain $v = 44.3$ m/sec. If the velocity is reduced to, say 5 m/sec, more than 98 % of the energy will still have been transformed to heat, and at 10 m/sec well over 90 %. Application of the latter will give as a result that the water running through the tunnel will give a quantity of heat:

$$Q = \frac{H \times W \times 0.9}{427} \text{ Kcal/sec}$$

Here W is the water flow in litres per sec. This quantity of heat will suffice for the melting of:

$$\frac{Q}{80} = 0.025 HW \text{ kg ice/sec}$$

If we put $H = 100$ and the water flow to $1 \text{ m}^3/\text{sec}$ we obtain a possible melting of 270 m^3 of ice in the course of 24 hours. The assumption is that the total heat surplus is applied for melting. As a matter of fact, however, some of the heat will certainly disappear together with the water out of the tunnel, especially when the tunnel is short and has a large cross-section. Another question is how the water at first succeeds in enforcing its way under the ice. Owing to the movement of the ice along an uneven basement, passages for the water will also easily form, as will be mentioned in the following (p. 145). The ordinary subglacial drainage system can certainly also play an important part.

Øvre Mjølkedalsvatn.

Øvre Mjølkedalsvatn is situated in Jotunheimen, at $61^\circ 27' \text{ N}$, $8^\circ 12' \text{ E}$. The lake is dammed by Mjølkedalsbreen (M. glacier) which flows down from the NW, filling Mjølkedalen (M. valley) to a length of some kilometres. When the lake is filled, outflow will occur northwards, over a low pass to Skogadalen. When the glacier had greater extension, the lake apparently had its natural outflow this way. Distinct traces from the water erosion are to be found in the couloir facing Skogadalen. When the lake empties under the glacier, the outflow will pass through Store Mjølkedalsvatn to Bygdin.

The first report about floods in Mjølkedalen dates from 1855, but a more detailed report is non-existent. Prof. E. Sars (1869) mentions a flood supposed to have occurred abt. 1865. The river then washed away all loose material at great breadth. This flood must evidently have been the most extensive until then. Later on the outbursts occurred at irregular intervals until 1937. From thence it looks as if the drainage tunnel has been kept open permanently.

In the 40 km^2 lake Bygdin, into which Mjølkedøla flows, water-level observations have been carried out since 1915. These give a picture of the extent of the flooding. Fig. 2 is a diagram prepared by H. Klæboe (1938), showing the extent and dates of the floods. Øvre Mjølkedalsvatn is, as will be apparent, drained by a highly varying reservoir, in contrast with most glacial lakes where the outbreaks occur when the water has reached a certain critical level. Hence one should have reason to believe that the opening of the drainage tunnel through Mjølkedalsbreen is of a more incidental character.

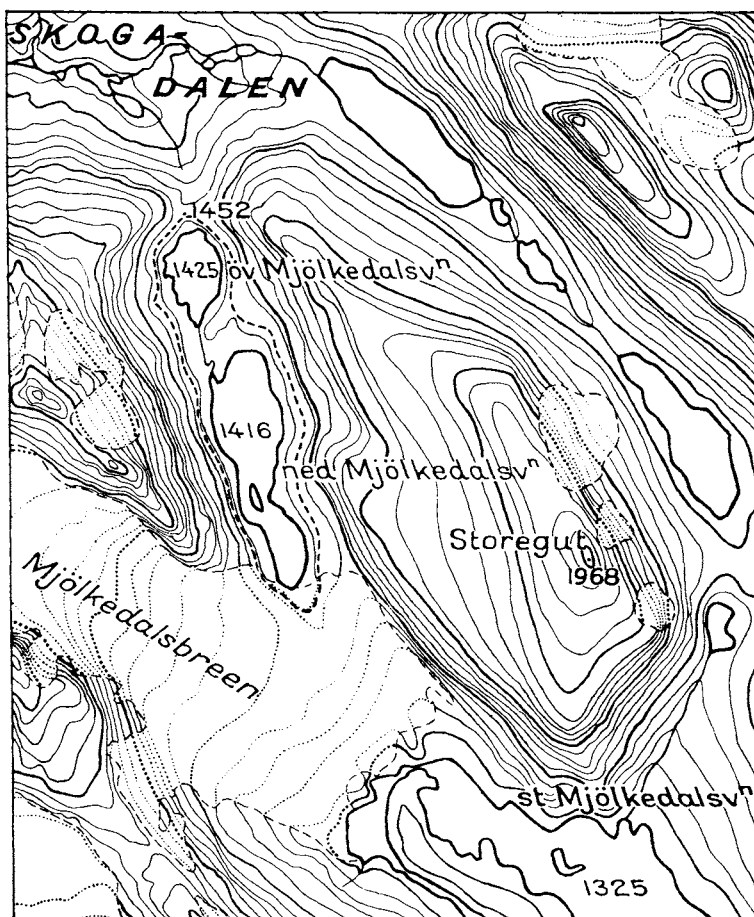


Fig. 1. Mjølkedalsvatn and surroundings. Upper shore line dotted. Contour intervals, 30 m.

In order to obtain a full reservoir, which for Øvre Mjølkedalsbreen is calculated to 34 mill. m^3 , no less than three years, or, to put it correctly, three summers are required. The greatest floods are, therefore, only to be expected at intervals of three years. Most outbreaks appear to have a duration of 48 hours, and the maximum flow amounts to more than $500 m^3/sec$.

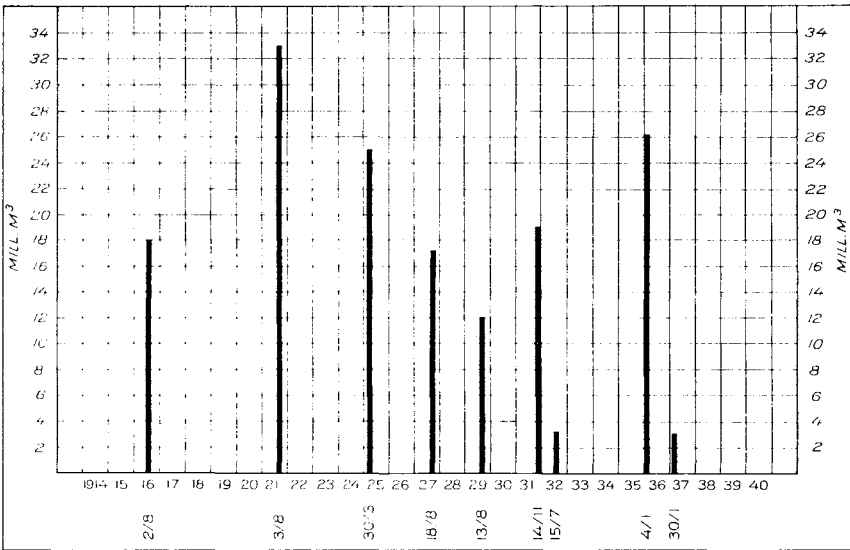


Fig. 2. Diagram showing the extent and dates of the floods in Øvre Mjølkedalsvatn.

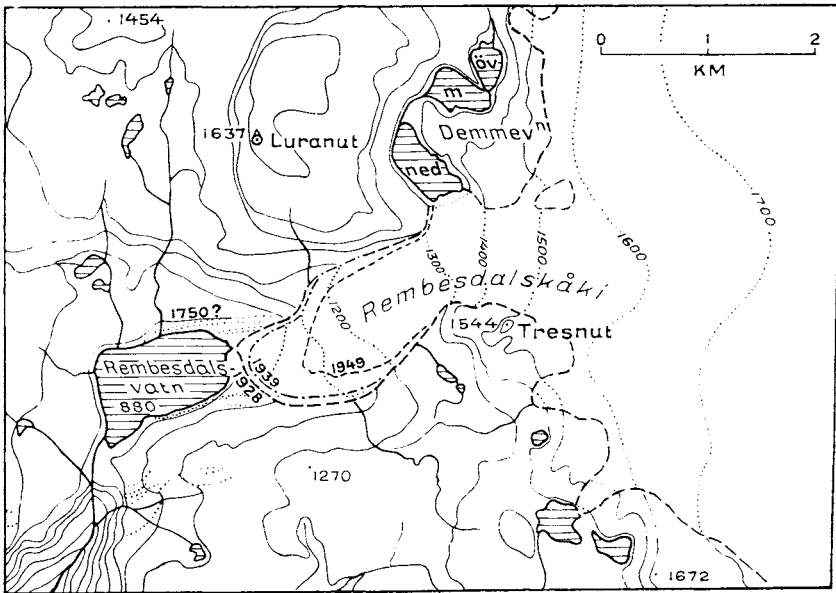


Fig. 3. Map, surveyed 1928, of Demmevatn and Rembedalskåki. Contour intervals, 100 m.

Demmevatn.

Demmevatn is dammed by Rembesdalskåki, an outlet glacier from Hardangerjøkelen. Due to the catastrophic outbursts from this lake this is the best known of the ice-dammed lakes in Norway.

As early as in 1842 P. A. Munch refers to the floods from Demmevatn. At that time, however, no flood had been recorded since 1813, but prior to that year floods had occurred at intervals of abt. 20 years. From 1861 we have a report of a great flood, but it was not until 1893 that the first really catastrophic flooding happened. It ravaged at large breadth the Simadal. The investigations made in connection with this last flooding revealed that within memory of man the population in Simadalen had observed minor floods every year, frequently at the end of August. The floods would have a duration of two—three weeks. In 1893, it expired after 24 hours.

As a precaution against further devastation a lowering of Demmevatn through a tunnel was proposed. In order to get a better understanding of the conditions at the lake, a series of observations and measurements were carried out in the years 1896—99. In 1897, for instance, it appeared that the inflow into the lake during the summer was quite regular, at ca. 4 m³/sec. On August 17 the water had attained such a high level that it began inundating the ice. A channel soon formed in the ice, gradually deepening and enlarging to a vast crevasse. The sides were overhanging, and from time to time large ice blocks dropped and partly blocked the outflow for some time. It proved impossible to undertake measurements in the crevasse, but obviously it gradually cut through to the very bottom, as the drainage of the lake advanced. This was evidently the normal course of drainage, and the cause of the moderate floods hitherto observed every year. In 1899 the tunnel was finished and it kept the water surface at a level corresponding to well over 20 m below the former one.

The tunnel served its purpose right up to 1937. Then, quite unexpectedly, an outburst occurred, causing heavier damage than ever before. The fact was that Rembesdalskåki in that period, like all glaciers in Norway, had retreated very rapidly, thus reducing the ice barrier considerably. This had also left more space for water in the lake. On this occasion the lake emptied in abt. 3.5 hours. At the bottom of the empty lake the opening of a large tunnel appeared, abt. 5 m diameter, running down beneath the glacier.

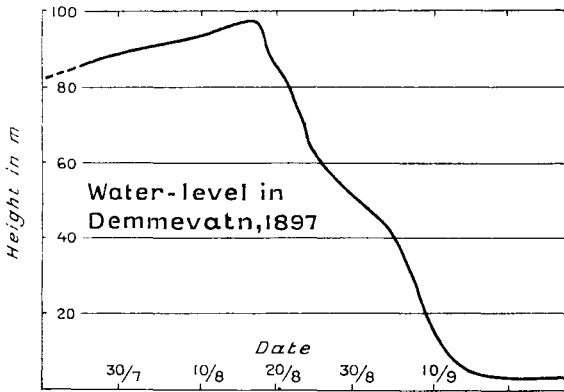


Fig. 4. Diagram showing water-level in Demmevatn during the flood in 1897. The water is here cutting its way through the damming ice from the ice surface to the bottom.

According to the calculations, the water volume passing through the tunnel on this occasion amounted to 11.5 mill. m³, corresponding to an average water flow of abt. 900 m³/sec. During the great flood in 1893 the reservoir was considerably larger, abt. 35 mill. m³, but the drainage was distributed over ca. 24 hours, corresponding to a flow of ca. 400 m³/sec. After the catastrophe in 1937 another tunnel was dug, ca. 50 m below the former one. The flood reoccurred in 1938, before the tunnel had been finished, but this time of lesser extent. The emptying which was observed by tunnel-workers, started at 6 a. m. on August 23. At 6.30 the water level had descended abt. 5 m, at 9.30 25 m, and at 1.20 p. m. the lake had emptied. From 6.30 a. m. to 9.30 a. m. the average water flow amounted to abt. 500 m³/sec., and from 9.30 a. m. to 1.20 p. m. abt. 360 m³/sec. The statement of the hour for the beginning of the drainage is not sufficiently accurate to enable a calculation of the outflow before 6.30. Considering a duration of half an hour for the first 5 metres lowering, the water flow will correspond to 830 m³/sec. In the course of the autumn the tunnel gradually closed, and on October 28 it had completely closed up. After 1938 no flood from Demmevatn has been reported.

The interesting trait about this glacial lake is that evidently two depletion processes are going on: one when the water comes through from above, another when the emptying is being rapidly completed

through a tunnel along the bottom. In the first case no upheaval of the ice takes place, in spite of the fact that the water builds up until its surface level reaches that of the glacier. The reason may be that the compact ice wall does not permit the water to force its way below the ice and cause upheaval. The ice has quite a considerable sloping, thus rendering upheaval possible only in a rather small area. The pressure in the ice will also be influenced and increased by the stowing of the glacial stream against the crag on the south side of the lake outflow. During the floods of 1893, 1937 and 1938 the water has in some way or other forced its way under the ice. The very rapid depletion might indicate an actual upheaval or a sudden opening of a tunnel, starting the flood. The temperature of the water, repeatedly measured in 1897 and 1898, was found to be from 1.0° to 1.5° C. Each cubic metre of water running through over the ice, will then theoretically be able to melt 0.013 to 0.018 m³ ice. That will suffice to explain the fact that the water cuts through from the surface of the glacial dam to the bottom. This temperature is, however, too low for a sufficiently rapid and wide opening of the tunnel, enabling depletion in as short a time as that in 1893 and 1937. One may suppose that the ground is rather sloping from the lake and down beneath the glacier. This will favour the opening of a tunnel, the hydrostatic pressure then being increased with the water pressing down under the glacier. The depletion tunnel need not be long because the main stream in the subglacial drainage system under Rembedalsskåki probably has its course very close to the lake.

Skadevatn.

Skadevatn is situated in the upper part of Vetlefjordsdalen in Fjærland in Sogn, south of Jostefonn. From bishop Neumann we have a written account of a great flood here in 1820. It ravaged farms and forests within its sweep down the valley. In 1848 another devastating flood occurred, according to De Seue. He was of the opinion that either has the river been dammed by an avalanche, or Vetlefjordsbreen (V. glacier) had blocked the outflow from a lake, and then a sudden outburst forced its way through the dam after some time. Later outbreaks are not known.

Vetlefjordsdalen has an abrupt termination abt. 10 km from the head of the fjord. In length wise continuation of the valley a steep

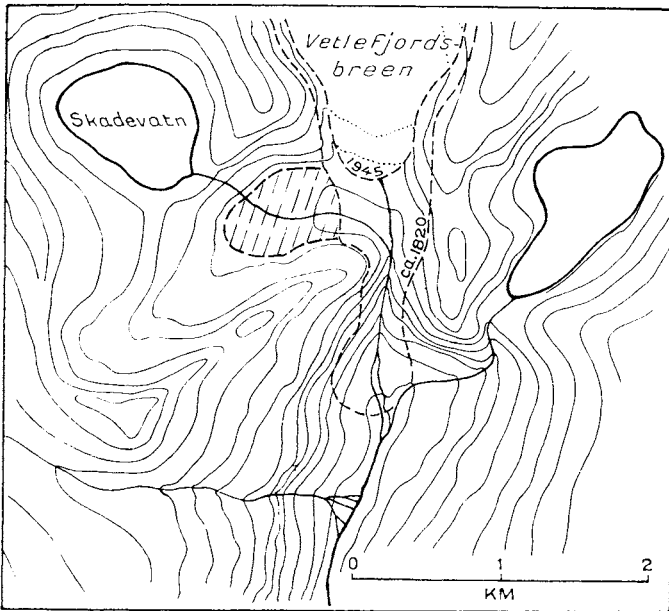


Fig. 5. Sketch map of Skadevatn and the lake (hatched) dammed by Vetlefjordsbreen.

gorge ascends towards the southernmost branch of Jostefonn, Vetlefjordsbreen. West of the upper part of the gap there are two deep corries, one above the other. In the upper part is situated the lake now called Skadevatn.

I doubt, however, that the Skadevatn itself has caused these floodings, but rather a dammed lake in the corrie below. When Vetlefjordsbreen had greater extension, it passed the corrie through the gorge and continued farther down. This created the foundation of an ice-dammed lake in the corrie west of the glacier. It must have had an appearance very much like that of Demmevatn.

Supposing that the damming has been abt. 50 metres, a height not unreasonable in relation to the possible extension of the glacier at the time of the reported outbursts, the volume of the glacial lake may be estimated at an order of magnitude of 10 mill. m³. This is a water volume approximating that drained from Demmevatn in 1937. The damage caused in Vetlefjordsdalen was possibly of a more serious

character than in Simadalen, because there is no basin below which serves as a regulating reservoir.

When De Seue visited the locality in 1868 the glacier barely reached the gorge below the corrie.

At present the tongue of the glacier has retreated several hundred metres past the mouth of the corrie. There is, therefore, no danger of an outburst from any ice-dammed lake in this area.

Brimkjelen.

This glacial lake is situated in a short corrieshaped branch valley named Store Brimkjelen, on the western side of Tunsbergdals glacier, the greatest outlet glacier from the Jostedal plateau. From the little glacier cap to the west an outlet glacier flows down into Brimkjelen. Formerly this glacier filled the whole corrie valley and joined Tunsbergdalsbreen. Later on it has decreased to a considerable extent, and much more rapidly than the main glacier. This caused a depression in the branch valley, originating a building up of water against Tunsbergdalsbreen. A great water reservoir was formed under the ice, causing the glacier to float. As the glacier continued decreasing, the ice cover gradually burst and was finally split into single ice floes. Photos from July 1937 (fig. 7) show the lake filled with floating ice floes. The glacier from the west now barely reaches the shores of the lake. During a visit to the locality in 1949 the author found that the glacier tongue had receded far up in the mountain side, and only a few ice bergs were lying near Tunsbergdalsbreen.

In 1896 the river Leirdøla which flows from Tunsbergdalsbreen, was observed to have a remarkably great water flow in relation to other glacial streams in the district. This was also the case in the three subsequent years. The first really ravaging flood, however, occurred August 1900, when the river swept away a bridge which had been in use for over a 100 years. In 1901 and 1902 the water flow was normal, but in 1903 the flood re-appeared. J. Rekstad examined the local conditions in 1900 as well as in 1903. The ice in Brimkjelen was then very much broken, reaching to a level 100 m below the main glacier. In 1926 a great flooding from Brimkjelen occurred anew, this time perhaps the largest one. O. Ingstad who examined the conditions that year, estimated the evaded water quantity to be between

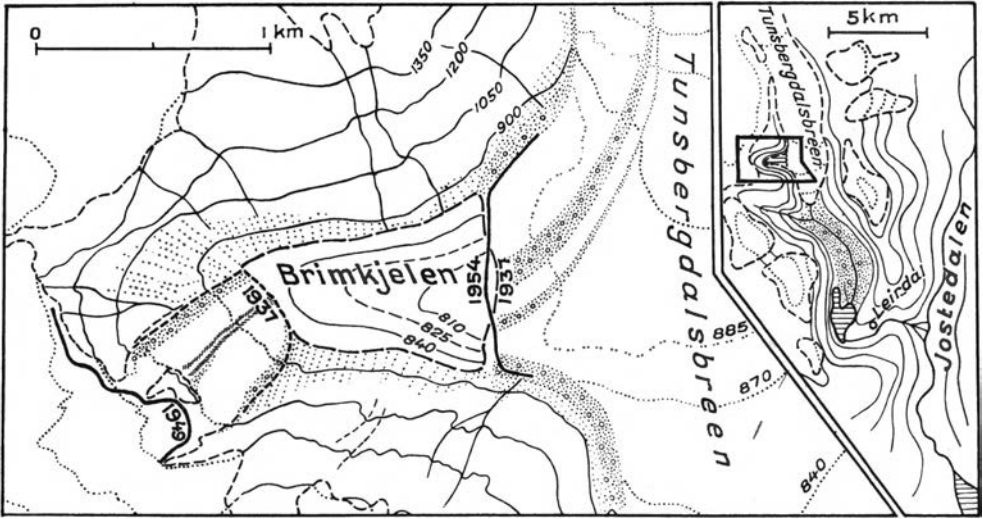


Fig. 6. Map of the glacier lake Brimkjelen dammed by Tunsbergdalsbreen.



Fig. 7. Brimkjelen 1937.



Fig. 8. Brimkjelen August 28th 1947. The bottom of the just emptied lake is filled with stranded ice bergs. Tunsbergdalsbreen in the foreground. Notice the difference in the glacier extension between 1937 and 1947. (Phot. Widerøe.)

25 and 30 mill. m³. The river carried off enormous quantities of gravel from Leirdal, and built up a large gravel cone across the bottom of Jostedalen. This caused a damming up of the Jostedals river and inundation of a number of farms. Later on the floods have re-appeared up to 1948. In 1949 traces were found from a little dam in the lowest basin near Tunsbergdalsbreen, but the water quantity must have been so small that no flood was observed farther down in the valley. In following years no floods from Brimkjelen have been recorded.

The drainage has normally been distributed over two-three weeks, with an accelerating growth towards a maximum. This relatively long depletion period must be due to the strong dam formed by Tunsberg-

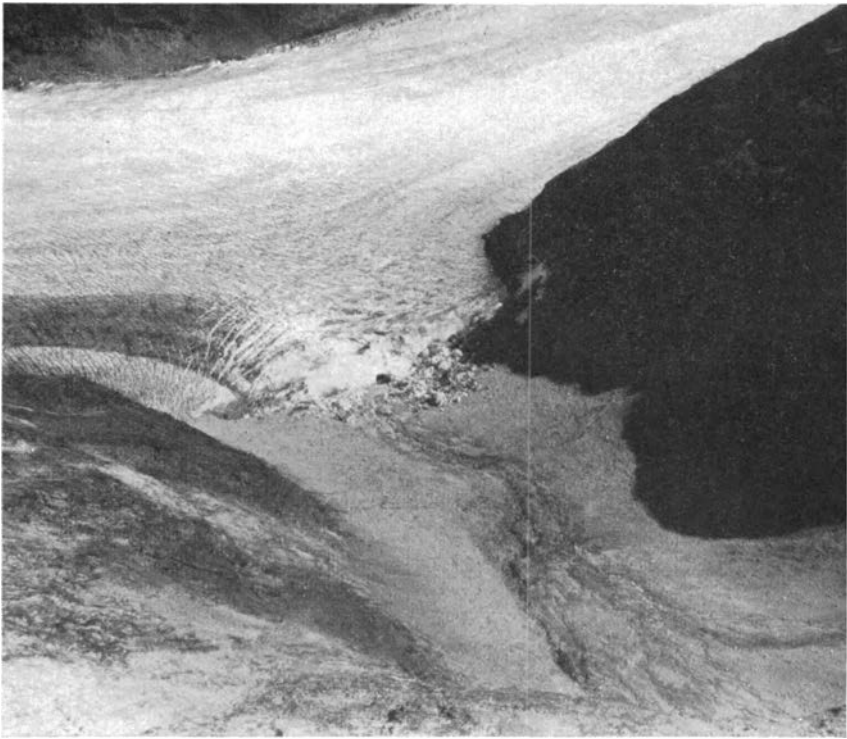


Fig. 9. Brimkjelen August 28th 1954. The opening of the tunnel where the water escapes is seen in the middle of the ice barrier. (Phot. Widerøe.)

dalsbreen itself. As will be seen from fig. 6 the water pressure at the bottom of the lake is by far equal to the pressure of the ice above the drainage tunnel. The Leirdal lake, situated above Leirdal, is a good regulating reservoir, reducing the damaging effects of the floodings.

From the above it will be evident in what manner an ice-dammed lake is being formed when the glacier is retreating. The thought then suggests itself: How were conditions when the glaciers were on the advance? There is reason to believe that the phenomena appeared analogously, only in the opposite sequence. The conditions are, however, not quite analogous because the glaciers were of a more active character, with far greater flow. A legal document from abt. 1700 may indicate the existence of an ice-dammed lake in Brimkjelen during the advancing stage of the glaciers.

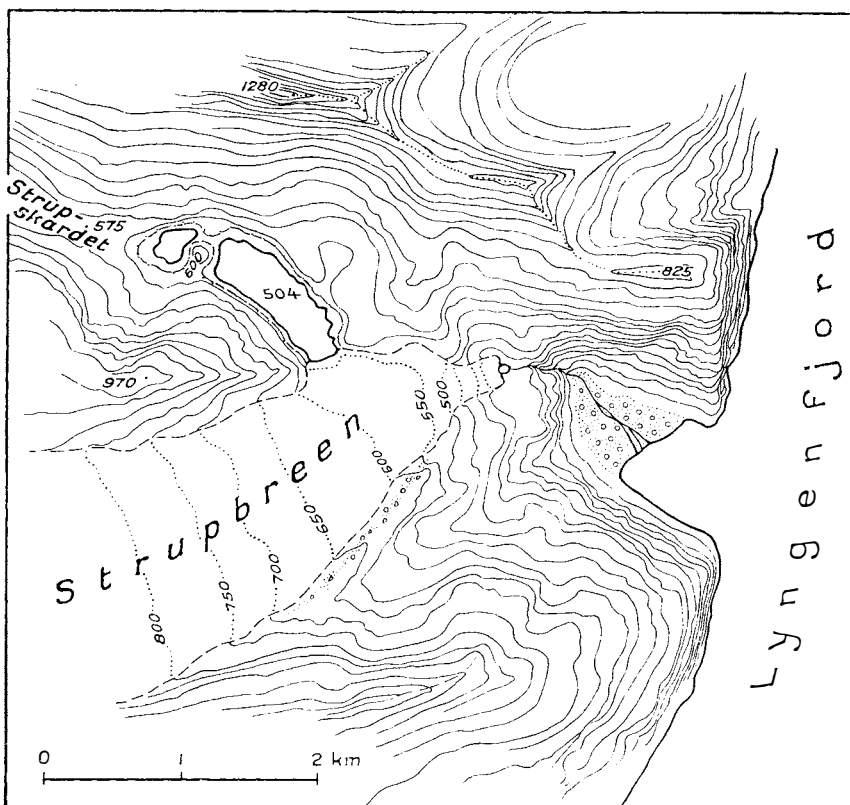


Fig. 10. Sketch map of Strupbreen and the glacier dammed lake in Strupskardet. Plotted from air photos taken on July 15th 1953.

The glacial lake in Strupskardet.

The northernmost glacial lake in Norway is situated in Strupskardet, a valley or a pass crossing the northern part of the Lyngen peninsula. It is dammed by Strupbreen (Strup glacier) which flows from the southwest towards the eastern part of the couloir. During its maximum extent, in the 18th century, the glacier probably stretched nearly down to the sea. At present the glacier front is found abt. 1 km from the shore, on a steep slope ca. 400 m above sea level. The sketch (fig. 10) has been prepared from an aerial photograph taken on July 15th, 1953. The lake was then probably nearly emptied, as the glacier stream did not appear exceptionally large compared with the other



Fig. 11. Strupbreen and the glacier dammed lake in Strupskardet.
(Phot. Widerøe.)

glacial streams of the area. The water level prior to the drainage is marked by a rim of ice ca. 28 m above the shore. This would correspond to a drained water volume of abt. 12 mill. m³. When the glacier was mightier, the lake was larger, but it is doubtful whether it ever stretched as far up as to a level corresponding to the highest point in Strupskardet. There are, at least, no visible traces of a western outflow or any shore line corresponding to this level.

As there are no people living in this district, there is but scarce information about the behaviour of the lake. The first report was delivered by the English glacier climbers M. M. G. Hastings and C. Slingsby, who in 1898 visited the district. They found a large lake filled with drifting ice blocks. But when they returned after a few days, the lake had drained, with only a little water left. From this it was evident that the depletion had taken place rather rapidly, as was the case with Demmevatn, with which lake there are also many other points of resemblance.

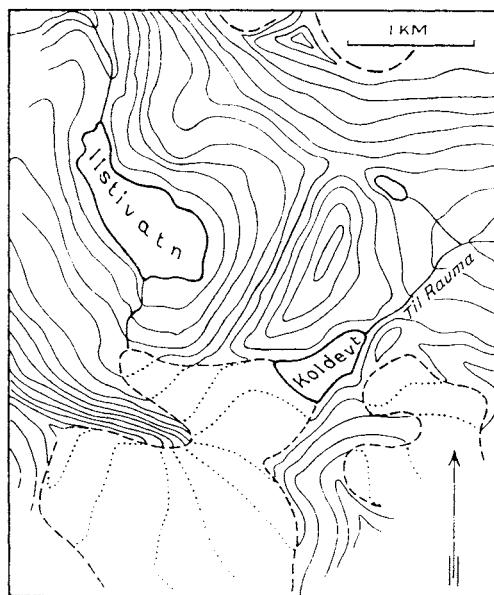


Fig. 12. Sketch map of Koldevatn and surroundings.

Koldevatn.

Koldevatn is situated above Muldal in Taffjord on Sunnmøre ($7^{\circ} 36' E$, $62^{\circ} 16' N$). The lake is dammed by a glacier terminating near the eastern part of Ilstivatnet, south of the watershed to Romsdal. At total damming, abt. 45 m, the outflow takes a northerly direction, passing a couloir, to Rauma.

There are conspicuous shore lines, in correspondance to the height of the pass. In the year 1932 the Norwegian State Department for Electricity and Water Resources (Vassdragsvesenet) computed the drained water mass at $3.6 \times 10^6 m^3$, and the water flow of the stream below during the flood maximum at $31 m^3/sec$, against the normal $3 m^3/sec$. The lake emptied in the course of 32 hours. At the outflow of Ilstivatnet, a narrow groove has now been forced, such that this lake, formerly a fitted regulating reservoir of the flood, has gained still further efficiency.

Blomsterskardvatnet.

Blomsterskardvatnet is situated to the south of Folgefonni, at the very edge of a precipice on Sandvikdalen. The lake had its original outflow in the northern part, but an outlet glacier flowing down from

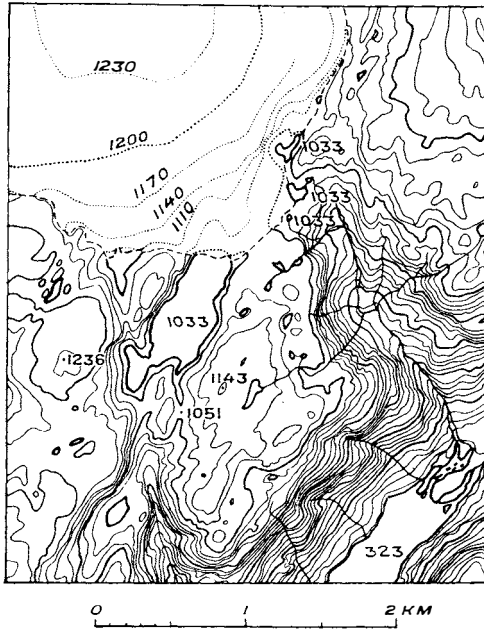


Fig. 13. Map of Blomsterskardvatnet and surroundings, 1954.
Contour intervals, 30 m.

NW is damming the northern part, giving the lake a southern outflow over a pass. The damming height is ca. 15 m, corresponding to a reservoir of abt. 3 mill. m³.

Three greater outbreaks are known from this lake. The first occurred on July 30., 1938, causing considerable damage in the little town of Mosnes, at Akerfjorden, where a number of houses were carried away. The outbreaks on August 19, 1944, and September 27, 1948, were of an equal extent, but caused less damage.

The glacial lake at Østerdalsisen.

This is the greatest ice-dammed lake from recent time in Norway. It is situated to the south of Svartisen, at one of its most important outlets, Østerdalsisen (66°3' N—14°03' E). The total area of this outlet amounts to 65 km². The glacier in its lower part joins Burfjellet, thus forcing the greatest part of the ice mass westwards, a minor part deflecting



Fig. 14. Air photo taken July 21st 1955 of Blomsterskardsvatnet and the southern part of the Folgefonn glacier cap. (Phot. B. Luncke, Norsk Polarinstitut.)

eastwards, in the direction of Svartisvatn. The glacial lake has formed during the later years in front of the western part. Normally, that is when the lake is filled to its maximum, it has a western outflow down to Glomdalen. The main drainage from the glacier also takes this course by the lake westwards. Only a small stream flows into the Svartisdal, with fairly clear water for a glacial stream. The main river, however, carries great quantities of mud. The lake is preferably extending by calving of the glacier tongue. During the later years the calving has occurred with a rapidity permitting only some few of the ice bergs to melt during summer. The glacial lake is, therefore, as will be evident from the photo fig. 15 filled with huge quantities of ice bergs.

Throughout the years the conditions at Østerdalsisen have been fairly well examined. As early as in 1873 De Seue carried out measurements of velocity on the eastern glacier outlet and took a number of photographs. Subsequently Rabot, Rekstad, Marstrander and Granlund visited the glacier, but they were principally interested in the eastern



Fig. 15. The emptied glacier dammed lake at Østerdalsisen August 1952.
(Phot. Widerøe.)

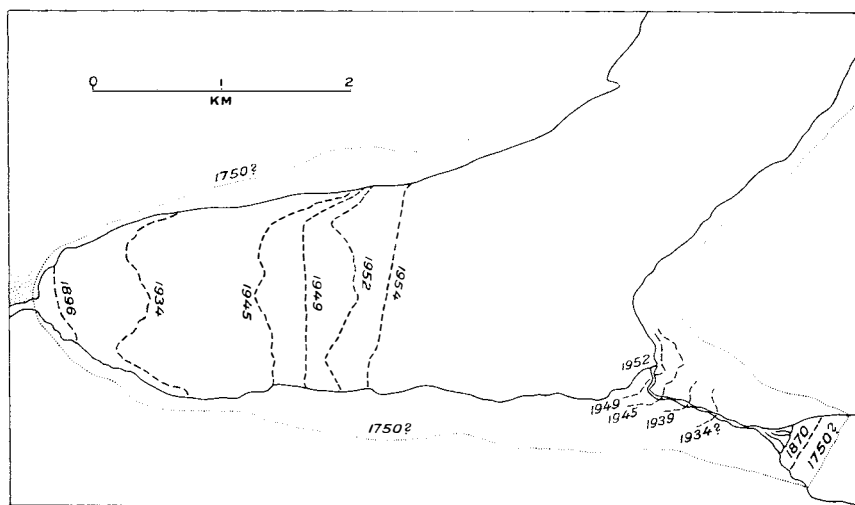


Fig. 16. Map of the different stages in the evolution of the Østerdalsisen glacier and the ice dammed lake.

branch towards Svartisdal. In the later years, after occurrence of the first outbreaks and ravaging floods from the glacier lake, the western part and the lake have been given more attention as well. G. Holmsen visited the lake in 1949 and in *Norsk Geografisk Tidsskrift* (vol. XII, no. 4, 1949) discussed the conditions at the glacier lake and the devastating effects of the outbreaks. Since the early beginning of the floods Norges Vassdrags- og Elektrisitetsvesen has carried out measurements of the water flow and the development of the lake and the glacier. On two occasions, in 1949 and 1954, the author made a glaciological examination and had a photogrammetrical map of the area prepared (Pl. 1).

As early as on the topographical map of 1897 is indicated a little lake in front of the glacier snout. From a photo taken by Gunnar Horn in 1934 the lake appears to have extended considerably, especially along the northern and southern shores. In the middle there is a large but low ice tongue, evidently floating. The normal melting has, so far, been the principal cause of extension, as there is not much calf ice to be seen. Later on the extension has accelerated, as already mentioned, mainly through ice breaking and melting. The map, fig. 16 and the table on page 143 show the extension of the lake up to 1954.

THE GLACIER DAMMED
LAKE AT ØSTERDALSISEN
AUG. 1954

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METER

NORSK POLARINSTITUTT

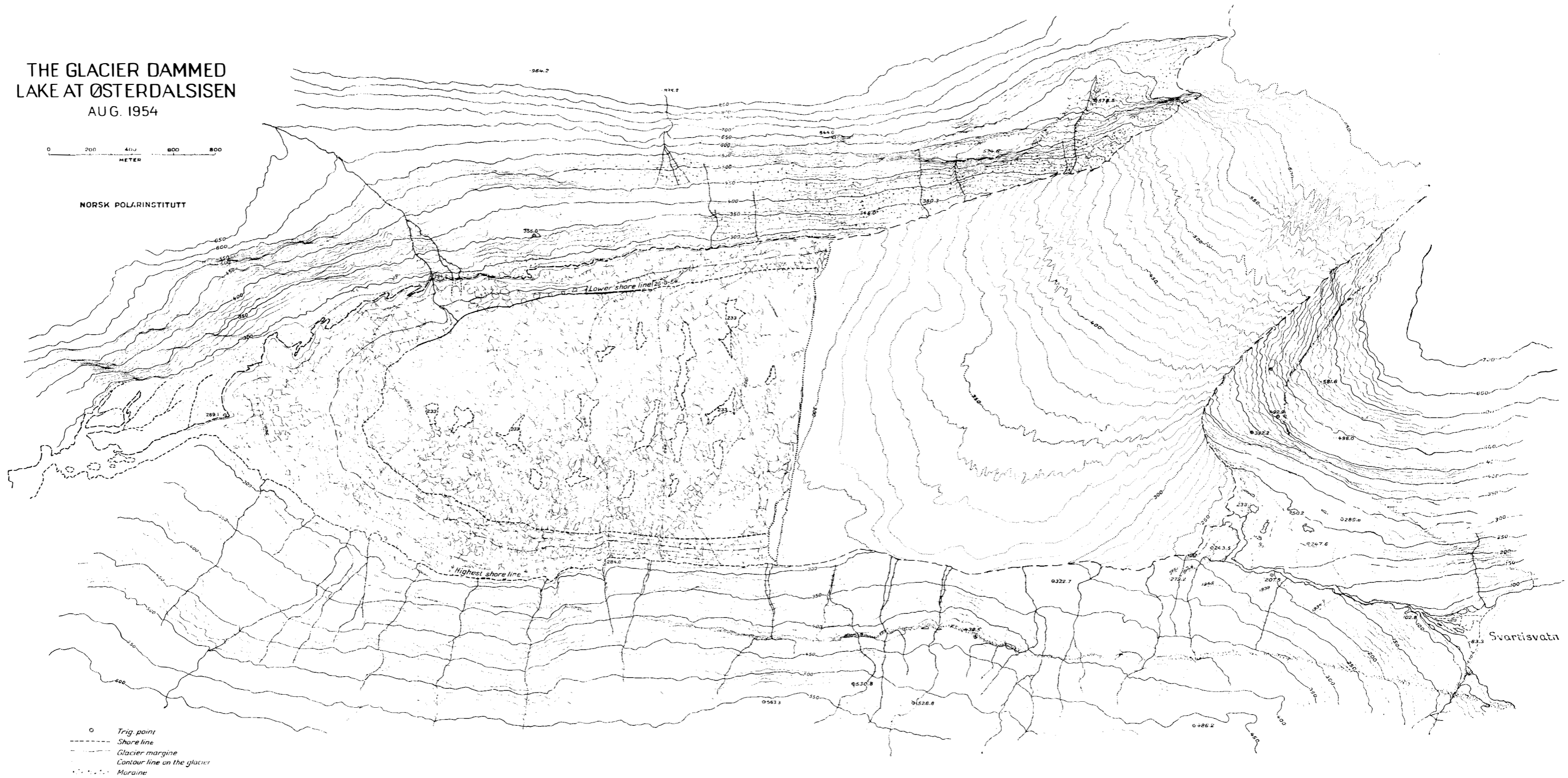


Plate 1.

Photogrammetric map of the glacier dammed lake at Østerdalsisen. Surveyed and plotted by O. Liestøl at the request of the Norwegian State Department for Electricity and Water Resources. Contour intervals, 10 m.

Year	Reservoir measured on the map	Drainage volume computed according to the water flow curve
1897	2 mill. m ³	- mill. m ³
1934	20 » »	-
1941	-	30 » »
1942	-	52 » »
1944	-	38 » »
1945	71 » »	45 » »
1946	-	56 » »
1947	-	82 » »
1948	-	92 » »
1949	93 » »	85 » »
1950	-	120 » »
1951	-	132 » »
1952	120	113 » »
1953	-	136 » »
1954	145 » »	150 » »

The lake had its first outbreak in 1941. Since then the flooding has occurred every year, except for 1943. The floods have started in July or in August, but in 1945 when of lesser extent than in the preceding years, it happened as late as in October. As yet the drainage has taken place with relatively moderate rapidity. At first there is obviously a steadily accelerating opening of the tunnel, causing the water flow to grow to a maximum after two-three weeks. The water flow will then diminish rather quickly, until a level corresponding to the natural afflux to the lake is reached. From the water flow curves on the water gauge at the outflow of Svartisvatn it appears that the tunnel remains open abt. two-three months after depletion of the lake. Systematical measurements of the water level in the glacier lake have never been carried out, but it is evident that the lake in all years has attained its original level at 285 m, and has its outflow in the westerly direction, before being emptied again. The lowest level observed amounts to 228 m (August, 1954). This corresponds to a drainage of 57 m. Fig. 17 shows a profile from Svartisvatn via the eastern glacier entrance to the former outflow from the lake. As the opening of the tunnel is situated at 222 m there is theoretically only 6 m left to continue the drainage downwards from the lowest level measured. It seems therefore reasonable that the bedrock threshold beneath the ice is situated at the easternmost part of the glacier, and that the lake may be drained with a maximum of ca. 60 m.

At the outflow of Svartisvatn a water gauge has, as before mentioned, been placed by Vassdragsvesenet, where measurements have been

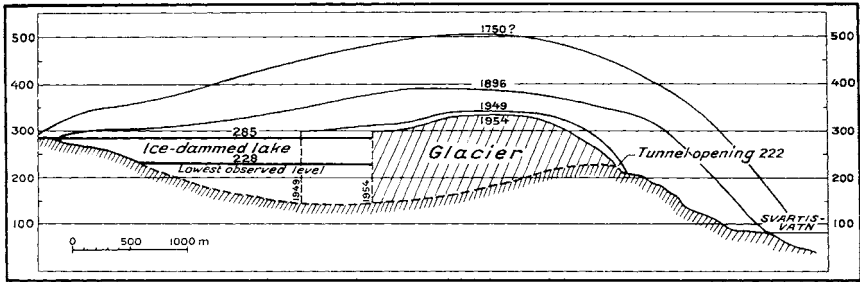


Fig. 17. Profile through the lower part of Østerdalsisen and the glacier dammed lake.

carried out since 1929. This will enable computation of the water volume which is being drained when the afflux to the lake is known. As an example, the water flow curve (fig. 18) for the summer of 1953 has been included. By integration of this curve we obtain the water quantity which passed the water gauge during the flood. The afflux to the lake is not to be measured directly, but a computation has been attempted by comparing with watercourse measurements in the vicinity. In subtracting the afflux we should obtain the volume drained from the glacier lake. Such computations have been made by Vassdragsvesenet during the flood years. From the appended map (plate 1) we are, however, able to compute directly the reservoir obtained in lowering the lake with 60 m. Fig. 19 shows the bathygraphical curve for the lake in 1954. The total volume represented by the unbroken line amounts to 165 mill. m³. This is, however, the total volume without taking the ice bergs into account. All ice bergs are floating when the lake is filled, but as they reach the bottom during the draining, the effect makes itself felt in the reservoir. The broken line represents the effective bathygraphical curve, that is, the one obtained when the effect of the ice bergs is considered. The two columns in the table on p. 143 represent the reservoir measured directly on the map and the drainage volume computed according to the water flow curve respectively. The discrepancy between the values in the two columns is due partly to the uncertain basis for the computations, partly to the fact that many years will elapse without total drainage of the lake.

The drainage from this lake requires considerable time and always takes place through a tunnel under the glacier. So far the depletion has not been caused by any upheaval or breaking up of the ice.

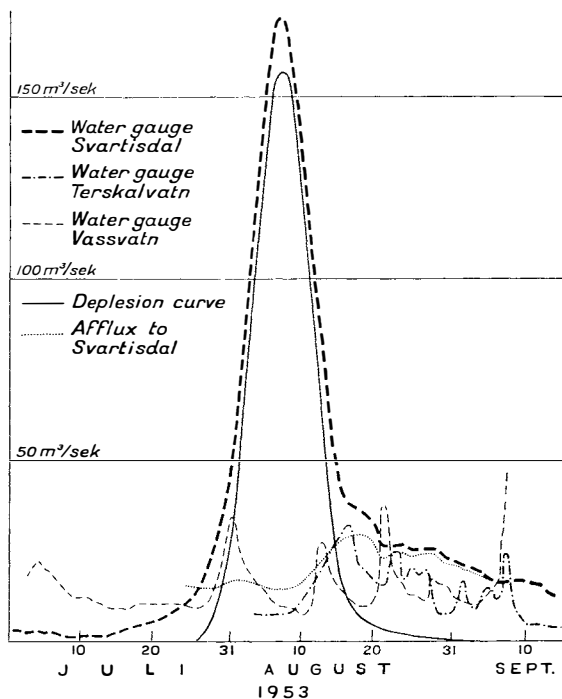


Fig. 18. Diagram showing run-off at the water gauge in Svartisdal during the flood in 1953.

It will be evident from the section that the glacier has been too high for that. The bed-rock beneath Østerdalsisen has, however, distinct east-west ridges perpendicular to the direction of the ice flow, to a great extent facilitating the formation of openings in a west-east direction. In a cavity under the ice, ca. 40 m from the edge, the flow of the ice along the rock basement was measured to 7 cm in 24 hours. (The surface flow at the same spot was abt. 10 cm in 24 hours.) Farther inwards one has to deal with faster flow at the bottom. The flow will then in the depths here dealt with, be too high and the ice not sufficiently plastic to make an adaption to the basement possible. When the ice is moving along this uneven stepformed basement, long cavities will, as mentioned above, easily form under the lee of the elevations. The subglacial drainage system will also be a possible important factor at the opening of the drainage tunnel. In August, 1949, temperatures of 3° to 12° C were measured in brooks flowing down the valley sides

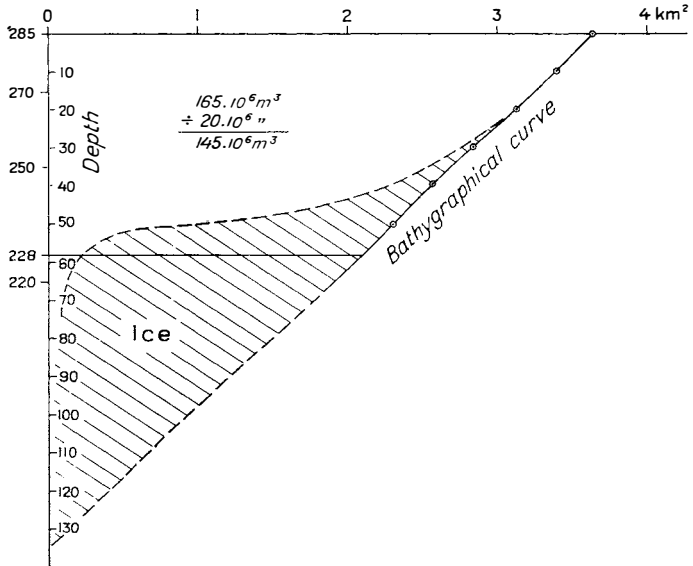


Fig. 19. Bathymographical curve of the glacier dammed lake at Østerdalsisen 1954.

and into the glacier. In one of them the water flow was estimated to ca. 20 l/sec, the temperature being 8.2° C. Theoretically this temperature would, therefore, enable melting of abt. 200 m^3 in 24 hours. As will appear from the preceding example, these affluents may form and keep open a large subglacial drainage system, and thereby facilitate the opening of the drainage tunnel. Owing to the large quantities of ice filling the lake, one has to deal with a water temperature around zero. The formation of a layer of more warm and heavy water at the bottom may, of course, be imagined when the lake is filled. Under all circumstances we have to take into consideration that the transformation of the potential energy of the water to heat will, in this instance, play a part in the opening of a drainage tunnel.

The section, fig. 17 will give a good illustration of the enormous decrease of this glacier during the last two centuries, causing the formation of the glacial lake. As above mentioned, we have from Southern Norway, observations indicating that the glaciers about 1600 were of an extension very much the same as that of the present time, although they were at that period on the advance. The suggestion then presents itself that a glacial lake also at that time was to be found

on the same spot. Examination of the shores of the river down from Svartisvatn shows clear evidences of a great flood. The loose material is swept away to, at an estimate, 5—6 m above normal water level, corresponding to a water flow of ca. 2 000 m³/sec. This can hardly be anything but a flood from an ancient glacial lake. With a water flow as suggested above emptying must have been completed in the course of 24 hours.

Glacier dammed lakes from the Glacial Period.

Glacier dammed lakes from the end of the last ice age are known from a number of localities in Scandinavia. The largest ones were the lakes dammed in the upper eastern valleys between the last remainder of ice and the watershed in west. Their total extension has not been fully determined, but lake sediments and partly beautiful shore lines indicate today the possible extension of these lakes. The shore lines can only have been formed during periods when the lakes had outflows over solid ground. At times when the height of the water level was determined by the damming ice, the conditions would have been too unstable for the development of a shore line.

In the literature is often suggested that a great catastrophe must have caused the final depletion of these lakes. There is, however, every reason to believe that these lakes, as well as the glacier dammed lakes of present time, have been periodically emptied. The lakes have probably existed until the ice became so thin that an outflow could be kept permanently open. That is, according to our experience from recent glacier dammed lakes, at a thickness of the ice of less than 50 m. The interval between each drainage will depend upon the relation between inflow and the lake volume. The ice dam was certainly quite broad. One has, therefore, to count with a considerable length of time for the opening of a drainage tunnel, and hence for the drainage itself.

Dealing with, for instance, the glacial lake which filled northern Østerdalen («Nedre Glåmsjø») and taking into consideration an inflow equalling that of present time, with addition of melt water from the remaining glacier area, this glacier lake could be filled in the course of ca. two years. Further, assuming that the drainage extended over one or two months, one might expect the river Glåma to receive a supplement to its water volume of the order of magnitude of 10 000 m³/sec.

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